Parliamentary Office of Science and Technology

Imperial College
OF SCIENCE, TECHNOLOGY AND MEDICINE

UK Electricity Networks

The nature of UK electricity transmission and distribution networks in an intermittent renewable and embedded electricity generation future

By

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in collaboration with
Parliamentary Office of Science and Technology (POST)

September 2001

IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE

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A report submitted in partial fulfilment of the requirements for the MSc and/or the DIC

September 2001

DECLARATION OF OWN WORK

I declare that this thesis…

UK Electricity Networks: the nature of UK electricity transmission and distribution networks in an intermittent renewable and embedded electricity generation future.

Is entirely my own work and that where any material could be construed as the work of others, it is fully cited and referenced, and/or with appropriate acknowledgement given

Signature: ______________________________________

Date: ____

Name of Student: _________________________________

Name of Supervisor: _______________________________

Abstract

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Electricity systems have developed during the last century on the basis of large central generating units. These feed into an interconnected high voltage transmission and lower voltage distribution network. Recent developments challenge this structure.

Electricity market liberalisation introduced in 1989 has had a profound impact on the nature of the UK Electricity Supply Industry (ESI). This, along with technological advances and increased environmental concerns, have fuelled interest in low-capital, small scale, low pollution technologies. The UK Government has also set a range of energy related targets that reflect environmental concerns – to increase the contribution of renewable electricity technologies and Combined Heat and Power (CHP), and reductions in greenhouse gas emissions (to which the electricity industry is a major contributor). This thesis argues that current regulatory and commercial frameworks require amending to fully reflect and to achieve these energy policy objectives.

CHP and other small-scale generating technologies are 'embedded' directly into the lower voltage distribution networks rather than connected to the transmission network. In a 'distributed' electricity system, embedded generators would meet localised demand. Any excess generation is fed into active distribution networks to meet demand elsewhere. As the number of different components in the network increase, so does the need for more 'active' management, and sophisticated control and monitoring at the distribution level.

The trend towards having a larger proportion of embedded and renewable generation will have implications for the whole of the UK ESI, in particular the configuration and operation of distribution and transmission networks. A number of strategic, technical, commercial and market issues are identified in this thesis. These include regulation and charging principles, the impacts of New Electricity Trading Arrangements (NETA) and the Utilities Act 2000, facilitation of competition in distribution networks, the variable output of certain renewable technologies, network integrity requirements and net-metering options. Failure to develop appropriate electricity networks will be a significant constraint to embedded and low carbon generation, and meeting Government energy targets.

This thesis argues that central to the development of flexible and active electricity networks is a clear vision of the 'Energy Future'. Market rules, regulations and incentives need to reflect social and environmental energy policy objectives. The basic aim of Government policy should be to construct an equitable regulatory and commercial framework that motivates network development, and within which embedded small-scale electricity generation can compete fairly with central large-scale electricity generation.

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Acknowledgements

A range of people deserve thanks for their advice, assistance and support over the last six months. My family, friends and colleagues at Imperial College and the Parliamentary Office of Science Technology have all contributed, providing encouragement when needed, and as importantly, entertainment and laughter.

I would like to acknowledge the contribution of the consultees and stakeholders who attended the ‘Group Review’. Their input provided focus and the necessary real world perspective. Special thanks go to Stewart Boyle and Lewis Dale.

I would also like to thank my thesis supervisor, Matthew Leach, for his discerning advice, and for reminding me of the distinction between a thesis and a report. Gary Kass deserves a mention for a number of reasons and has a been a constant source of support, insightful commentary and perceptive pwobing (sic). Thanks also to Sarah and Peter for the last minute advice and assistance in printing the final document

Special thanks are reserved for Faye, for amongst many things, managing to put up with me.

Acronyms, abbreviations and jargon

AC	Alternating Current
Alternating Current	Electric current that surges back and forth, in the UK at the frequency 50 times a second (50 hertz).
Current	Flow of electricity
CCGT	Combined Cycle Gas Turbine
CEGB	Central Electricity Generating Board
CHP	Combined Heat and Power – an embedded generation technology that simultaneously produces electricity and heat
CO_2	Carbon Dioxide – a greenhouse gas
Cogeneration	Simultaneous generation of electricity and heat (see CHP)
Direct Current	Electric current that flows in one direction
Dispatch	Instructing a generator to deliver or not deliver electricity into the system
Distribution	Transport and delivery of electric current to users at low voltage
DC	Direct Current
DEFRA	Department of Environment, Food and Rural Affairs – since June 2001 (see DETR)
DETR	Department of Environment, Transport and Regions – May 1997 to June 2001 (see DEFRA)
DNOs	Distribution Network Operators
DTI	Department of Trade and Industry
Embedded Generation	Generation connected to the distribution networks
EC	European Commission
EdF	Electricité de France
EGWG	Embedded Generation Working Group
ESI	Electricity Supply Industry
ETSU	Energy Technology Support Unit

EU	European Union
Frequency	Of alternating current – the number of times a second the current surges back and forth. Measured in hertz (Hz)
Grid	A network of high voltage transmission lines
Intermittency	Variable nature of output from certain renewable technologies, e.g. wind and solar
GW	Gigawatt – One billion watts
KV	Kilovolts – One thousand volts
KW	Kilowatt - One thousand watts
KWh	Kilowatt-hour – unit of electrical energy. One kilowatt consumed for one hour
Load	Technology that uses electricity and the amount of electricity it uses. Also referred to as demand
MW	Megawatt – one million watts
Mwe	Megawatt of electrical output
MWth	Megawatt of thermal/heat output
NETA	New Electricity Trading Arrangements
NFFO	Non-Fossil Fuel Obligation
NGC	National Grid Company – owners and operators of the high voltage transmission network in England and Wales
Ofgem	Office of Gas and Electricity Markets – regulator of the ESI in England, Scotland and Wales since 1999
Peak load	Maximum demand on the electricity system over a set period
Power	The amount of energy delivered in a unit of time – measured in watts
PIU	Cabinet Office Performance and Innovation Unit
POST	Parliamentary Office of Science and Technology
PV	Solar photovoltaic – a renewable generating technology
RCEP	Royal Commission on Environmental Pollution
RECs	Regional Electricity Companies

R & D	Research and Development
RO	Renewables Obligation
Synchronised	Surging back and forth in step
SYS	Seven Year Statement – a report, produced annually by NGC
Transmission	Transport of electric current at high voltages
TW	Terrawatt – a trillion watts
V	Volt – unit of electrical pressure which causes a current to flow
Voltage	Electrical pressure between different points in a circuit
W	Watt – unit of power which measures the work done when current is caused to flow in an electrical circuit

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1 Introduction

This thesis investigates the nature of electricity transmission and distribution networks in the UK that will be required for an electricity system that supports a greater proportion of intermittent renewable and embedded electricity generation. Government policy and the regulatory and commercial frameworks required to motivate the development of future transmission and distribution networks will be analysed.

Under the 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change, the UK has accepted a legally binding target to reduce greenhouse gas emissions by 12.5% by 2008 - 2012, as compared to 1990 levels. The UK government has targeted a reduction in its carbon dioxide (CO_2) emissions of 20% by 2010, as compared to 1990. As part of the Government's steps towards further reductions, it has drafted a 'Climate Change Programme'.

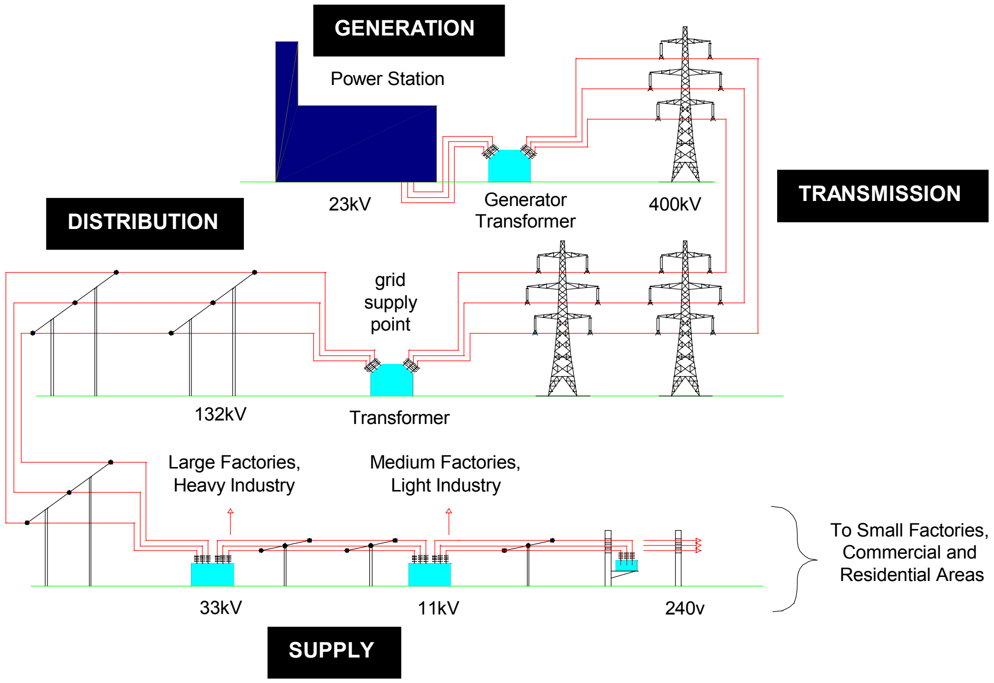
A key policy of this programme is the 'Renewables Obligation' aimed to produce 10% of the UK's electricity from renewable sources by 2010. Currently, renewables, including large-scale hydro generation accounted for 2.8% of total electricity generated in the UK in 1999. Generation from renewables other than large-scale hydro doubled from 1995 to 2000 (Electricity Association, 2001).

Another policy objective is to double the capacity of Combined Heat and Power (CHP) electricity generation to at least 10GWe by 2010. Presently, CHP is the prevalent form of embedded generation in the UK, contributing 4,239MW of electricity in 1999 (Digest of United Kingdom Energy Statistics, 2000). CHP is often referred to as cogeneration, a reflection of the technology's simultaneous production of electrical and heat energy. CHP plant tends to be located on industrial sites and to a lesser extent, commercial sites.

The key assumption lying behind this thesis is that the contribution of small-scale and renewable electricity generation will continue to increase, beyond 2010 targets. Indeed, in its statutory consultation on the Renewables Obligation, the Department of Trade and Industry (DTI) acknowledges the potential need to set more ambitious targets beyond 2010 (DTI, 2001).

The historical structure of the electricity generating industry tended towards large-scale generation plants and grid networks, state or private monopoly control, and the vertical integration of generation, transmission, distribution and supply functions. The transmission network transports electricity from generation units to distribution companies and a small number of large industrial customers. The distribution companies then deliver the electricity to the majority of customers through lower voltage networks. Figure 1 reflects this process of large-scale generation supplying individual consumers through an interconnected high voltage transmission network and local distribution system.

Figure 1: An Interconnected Electricity System

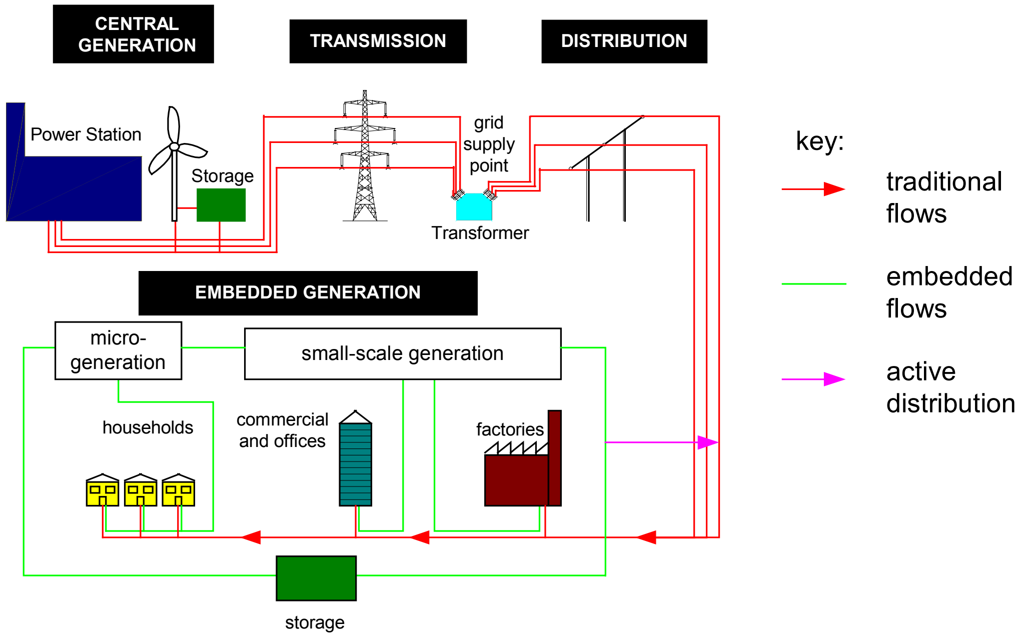


Source: National Grid Company, 2001

Since the late 1980s, the combined impact of the liberalisation of electricity markets, technological advances, tighter financial/lending constraints, and increased environmental concerns has fuelled interest in low-capital, small scale, fast revenue generating projects. This is demonstrated by the rapid proliferation of combined cycle gas turbines (CCGT) in the UK during the 1990s and the increase in CHP and other small-scale generating units being embedded into lower voltage distribution networks rather than connected to the high voltage transmission system.

A distributed electricity system is one in which small and micro generators are connected directly to factories, offices, households and to lower voltage distribution networks. Electricity not demanded by the directly connected customers is fed into the active distribution network to meet demand elsewhere. Electricity storage systems may be utilised to store any excess generation. Large power stations and large-scale renewables, e.g. offshore wind, remain connected to the high voltage transmission network providing national back up and ensure quality of supply. Again, storage may be utilised to accommodate the variable output of some forms of generation. Such a distributed electricity system is represented in Figure 2 below.

Figure 2: A Distributed Electricity System



A number of issues pertaining to the interactions between transmission and distribution networks will arise as the contribution of embedded and intermittent renewables increase. In the period to 2010 the current Government targets for renewables and CHP, if achieved or approached, will result in a considerable increase in embedded generation. Assuming that UK generating capacity in 2010 will be 70 GW, meeting the targets will result in an estimated total of ~7 GW of renewable capacity and 10 GW of CHP. But, not all this new capacity will be connected to distribution networks, e.g. large offshore wind.

ETSU (a sustainable energy consultancy) have estimated that, including existing embedded generation, meeting the targets will result in excess of 20-25GW (approximately one third) of total capacity connected to the distribution networks. ETSU arrived at this 20-25 GW figure through 6.8 GW of renewable, 10 GW of CHP and 4-7 GW of fossil fuelled non CHP, e.g. diesel and open cycle gas turbines. ETSU state that *"this 20-25GW embedded capacity cannot be accommodated on the currently configured networks without significant change"* (ETSU, 2001).

It is essential that debates regarding expanding renewable and embedded generation do not lose sight of associated network developments. High investment costs and long lead times for adapting and developing electricity networks must be fully acknowledged. Failure to develop appropriate electricity networks will be a significant constraint to embedded and low carbon generation, and meeting Government energy targets.

1.1 Aims

The key aim of this thesis is to assess - given the current industry, regulatory and technology environment – the development of a transmission and distribution network that reflects and can adapt to increased intermittent renewable and embedded electricity generation.

The development of electricity networks may take a number of paths. Three scenarios regarding the nature of future electricity transmission and distribution networks can be easily constructed.

- The transmission and distribution networks continue to function and be interconnected as now. (See Figure 1)
- The transmission system will serve as a conduit for transporting electricity and system balancing between more locally dependent and active distribution networks. (see Figure 2)
- Isolated distribution networks develop with high-voltage transmission having a limited role, transporting electricity from remote renewable resources, e.g. offshore wind and providing security of supply and other services. (See Figure 2 without the active distribution flows)

1.2 Objectives

A number of areas and issues require research to address the aims of the thesis. My objective is to:

- Provide a historical overview of UK Electricity Supply Industry
- Provide a historical overview of UK electricity transmission and distribution networks
- Analyse the impacts of liberalisation and regulation on national electricity networks
- Analyse the current and likely future impacts of New Electricity Trading Arrangements (NETA) on small-scale and intermittent renewable generation
- Define and assess embedded generation and intermittent renewable technologies
- Review new generating technologies (embedded generation, renewables and storage) and electricity networks
- Assess changing generation, transmission and distribution relationships
- Identify and analyse the key issues for electricity networks relating to increased embedded and renewable electricity generation
- Recommend future policy and regulatory structures and incentives to assist development of transmission and distribution networks

1.3 Collaboration

This thesis was produced in collaboration with the UK Parliamentary Office of Science and Technology (POST). POST is an office of the two Houses of Parliament (Commons and Lords), charged with providing balanced and independent analysis of science and technology based issues of public policy. POST carries out studies in areas such as defence, transport, environment, energy, food and health as well as science policy. Drawing on the talents, knowledge and expertise of the science and engineering community, POST acts as an independent and unbiased source of information. It is politically neutral, serves Parliament as a whole, and presents analyses and policy options tailored to the parliamentary process.

In addition to this thesis, a four page parliamentary briefing (POSTnote) will be produced and be distributed to over 600 parliamentarians, peers and other interested parties on the POST mailing list. Alongside the POSTnote, a modified version of this thesis will also be made available on the POST website **(**http://www.parliament.uk/post/home.htm**).**

The draft parliamentary briefing note will be issued for peer review by mid September 2001 and be published after parliament reconvenes following the summer recess. The POSTnote and web report will be launched at a parliamentary seminar in autumn 2001.

1.4 Method

Initial research was conducted by reviewing current literature and papers relating to decentralised electricity generation, cogeneration, renewable electricity generation, technical operation of large scale electricity transmission grids and regional distribution networks.

Also, the work and recommendations of the DTI/Ofgem Embedded Generation Working Group (EGWG) was reviewed. The EGWG comprised representatives from key stakeholders concerned with embedded generation and access to distribution networks. In addition, the views of the transmission network owner and operator, the National Grid Company (NGC), as presented to Parliamentary Select Committees and in their ‘Seven Year Statement’, were considered.

This research was used as a basis for the historical overview of the electricity industry and for analysing the evolution of, and rationale for the development of the current UK ESI structure. An initial critical review of key issues for electricity networks was also undertaken.

Preliminary discussions were held with a number of key stakeholders. These included the National Grid Company Plc (NGC), Ofgem, Cabinet Office Performance and Innovation Unit, Department of Trade and Industry, the then Department of Environment, Transport and Regions (DETR) now Department for Environment, Food and Rural Affairs (DEFRA) and the Institute of Public Policy Research (IPPR). Initial contact was in the form of informal interviews regarding the impacts of increased intermittent renewable and embedded electricity generation on existing transmission and distribution networks.

Key topics and areas for discussion were identified prior to the interviews (see above paragraph) and were used as the basis for more specific and probing questions. These interviews were used to gain a range of insights as to the specific issues of concern to the individual/association/organisation being interviewed. Freedom to explore areas of interest was provided, permitting a full exploration of ideas and issues (Macleod, 1997).

The lack of standard questions in the initial research stage raises concerns as to the reliability of the outputs. Associated difficulties include ensuring that biases are ruled out (Robson, 1993). However, it was felt that the unstructured informal interview offered the most appropriate opportunity to quickly gather rich and instructive background material to compare and contrast with the findings of the literature review. Annex One summarises the outputs of these informal interviews, which fed into the structured 'Group Review' process detailed below.

The outputs of these initial interviews - alongside findings from the literature review - were used as the foundation for analysing the structure, operation and function of electricity transmission and distribution networks in a intermittent renewable, embedded and decentralised generation future. A key issues consultation document was produced outlining key areas under the headings of technical; commercial and market; and policy and strategic (Annex Two).

The 'Key Issues' consultation document was used as the focus for a 'Group Review' held on 19 July 2001. Institutions that were represented at this review day were:

Combined Heat and Power Association

DEFRA – Sustainable Energy Policy Division

DTI – Energy Policy Directorate

Environment Agency

GPU Power

Greenpeace

Imperial College Centre for Energy Policy and Technology

National Grid Company Plc.

Ofgem

Parliamentary Office of Science and Technology

Parliamentary Renewable and Sustainable Energy Group

Scottish Power

TXU

United Utilities

The purpose of this group discussion and review was to assess issues identified in the consultation document, highlight issues that may have been overlooked or misrepresented, to discuss potential recommendations to address the key issues, and to identify areas for further research. Another purpose of the Group Review was to improve communication links and foster debate between key stakeholders in the UK ESI (Annex Three). After an introductory presentation, that outlined the purpose and objectives of the day, each participant was provided the opportunity to comment on the consultation document and to offer their opinion as to the issues at hand. These comments and opinions were noted. The plenary group was then broken up into three smaller groups. These three 'break-out' groups focussed on the major issues under one of the overarching technical, commercial and market, and policy and strategic concerns. The plenary group reconvened to receive feedback from the break-out groups and for further discussion.

The outputs of this review day (Annex Four) highlighting areas for further clarification and analysis thereby contributing to the next stage of research.

1.5 Structure of the Thesis

Following this introduction the thesis is structured as follows:

Chapter 2 examines the history of electricity from 1878. The impact of technological innovation, development of institutional structures and the economies of large-scale operation are outlined, providing a base of knowledge and understanding from which future industry developments will arise.

Chapter 3 analyses the UK electricity industry. This chapter provides an understanding of the restructuring process, the industry relationships that have established as a result, and the market structures and mechanisms that have been developed. From this follows a detailed assessment of likely future developments of UK electricity networks.

Chapter 4 examines the evolution of UK electricity networks. Analysing the historical development of this network, alongside the context and the rationale behind its operation and construction is essential to understanding the opportunities and barriers to its future evolution.

Chapter 5 defines the characteristics of embedded and intermittent generation and electricity storage technologies. The technical implications of the increased contribution of embedded and renewable generation to UK electricity supply are detailed and assessed.

Chapter 6 identifies and analyses the key issues for electricity networks related to increased embedded and intermittent generation. Synthesising research and outputs of consultations and the 'Group Review', this chapter highlights the range of issues pertaining to the interactions between transmission and distribution networks that will arise as the contribution of embedded and intermittent renewables increase. These implications and issues are examined under three broad headings – strategic, commercial and market, and technical.

Chapter 7 summarises the key issues related to the implications of increased embedded and intermittent renewable generation on transmission and distribution networks. Key conclusions and recommendations are highlighted.

2 The History of Electricity from 1878

Perhaps more than any other industry, the ESI illustrates the colossal impact of technological innovation and economies of large-scale operation on modern economic life. The purpose of this chapter is to serve as the base of knowledge and understanding from which future industry developments will arise. But, to quote two pessimistic views, *"nations and governments have never learned anything from history, or acted upon any lessons they might have drawn from it"* (Hegel, 1830) and "*history is more or less bunk*" (Henry Ford, 1916).

This chapter will review key moments in the history of electricity and the Electricity Supply Industry (ESI) from 1878, with focus on developments of particular importance to the UK. Reference to relevant international developments will be made throughout. It is appropriate to begin this historical overview in 1878, the year Thomas Edison formed his Electric Light Company, arguably the first electricity institution.

The market liberalisation introduced in 1989 has since had a profound impact on the nature of the UK ESI. This chapter overviews the reform of the electricity industry after 1989, analysing the rationale for reform, detailing the restructuring and liberalisation process and outlining the Electricity Pool and regulatory structure.

2.1 A Brief History of Electricity to 1989

Figure 3 outlines the key historical developments in electrical science, electricity generating technologies, practical applications of electricity, electricity demand and institutional structures. A more detailed history of electricity, including references, is attached to this thesis in Annex Five.

Figure 3: A Brief History of Electricity to 1989

Key	
ES	Electrical Science
PA	Practical Application
GT	Generating Technology
IS	Institutional Structures
ED	Electricity Demand

Year		A Brief History of Electricity
		The Birth of an Industry
1878	IS	The Edison Electric Light Company is formed to "own, manufacture, operate and license the use of various apparatus used in producing light, heat and power from electricity." Edison's vision is for a system that delivers electricity to individual homes from a central power station.

1879	ES PA	Thomas Edison in America and Joseph Swan in England simultaneously produce a carbon filament lamp that provides both brightness and longevity
1881	ES PA	The lead-acid accumulator (battery) is introduced, having the ability to be recharged by the newly developed DC generator, thus giving a supplementary supply of heavy currents.
1882	IS GT	Edison builds the first central electricity steam engine generating plant in to provide direct current (DC) electricity to one square mile of New York City and to an initial 52 customers. The investor-owned electricity utility is born.
1880s	IS	Direct current (DC) mini electricity grids establish across North America and Europe, financed and operated solely by town councils, private enterprise or a combination of the two
1880s	ES	Concerns over the suitability of DC current for long distance transmission due to losses
1883	ES GT	Nikola Tesla discovers the principle of alternating current (AC), that changes in opposite directions fifty times a second - 50 Hertz, and develops an alternating current generator and induction motor. AC current proves more suitable for electricity transmission over long distances.
1884	GT	Charles Parsons develops the steam driven turbine generator that significantly improves the efficiency and operation of coal fuelled generating plant. Further efficiency gains were made over the next few decades as the technology was further utilised and developed.
1885	IS	Westinghouse Electric Company buy the patent rights to Tesla's three-phase AC transmission system, and use the AC induction motor across North America.
1889	IS	The first public funded/municipal electricity project is developed in Bradford, Yorkshire.
1890s	GT	AC transmission allows the electricity system to cover larger geographical area, generation plant no longer needing be located close to sources of demand, bringing into play the possibility of electricity generation from more remote sources, e.g. hydroelectric power
1890s	IS	UK – autonomous central-station systems predominate and the mains networks begins to overlap geographically with obvious infrastructure inefficiencies. US – differing franchise rights offered by local municipalities keep the industry fragmented and ineffective.
1893	ES IS	The main technical dispute of grid integration is resolved by the introduction of the universal system in 1893 that accepts both AC and DC inputs with transmission strictly AC. The universal system allows the interconnection of existing systems and their power stations and drives the expansion of electricity supply over wider areas to more customers.
1890s	PA ED	Electricity applications expand from lighting to electric motors for street railways, trams and for stationary electric motors in factories.
Centralisation, Integration and Continued Growth		
1900s	IS	Germany – Local authorities facilitate integration of their electricity supply networks. US - Private companies merge to provide bulk supplies to municipalities in the US aided by the closely linked equipment manufacturers and supply companies. UK - Rivalry between private companies and local authorities obstructs integration.
1914 to 1918	ED	The impact of World War I upon the electricity industry is acute, world demand for electricity doubling and the electricity industry becoming a large global employer.
1918	IS	To highlight integration difficulties in the UK, by 1918 in London alone, there are 70 authorities, 50 different types of systems, 10 different frequencies and 24 different voltages.
1924	IS	The World Power Conference, now the World Energy Council, brings 1,700 delegates from 40 countries, the controllers of the electricity systems, together for the first time
1926	IS	The Electricity (Supply) Act, 1926 integrates the British electricity supply industry by establishing a 132,000V AC synchronous grid under the Central Electricity Board (CEB).
1930s	IS GT	Economies of Scale - Generating plant becomes ever larger, networks are extended and centralised, and electricity becomes ever more widely available and affordable. Interconnection of electricity systems has a levelling effect on demand cycles, provides improved security and back-up for plant malfunction, maintenance and rapid changes in demand through linking stored hydro and standard steam generation.

1930s	**PA** **ED**	Electricity is accepted as the energy of the future, an ever-growing number of appliances designed to be powered by electricity appear, such as washing machines and refrigerators.
1934	**ES**	The coil pearl lightbulb with which we are familiar with today is introduced.
1939 to 1945	**IS**	Damage to transmission and distribution structures during World War II limits the growth in electricity demand. National governments make the rebuilding of the grid and supply structures a priority, being increasingly seen as responsible for providing the public with power. The costs of financing the large-scale generation projects limit private sector enthusiasm.
	Centralisation and Nationalisation	
1945 onwards	**IS**	UK – Electricity Act 1947 nationalises the electricity supply industry, as much on the basis of social objectives for electrification for all as on potential economies. UK ESI is dominated by one large generating and transmission company, the Central Electricity Generating Board (CEGB), which sells electricity in bulk to 12 area distribution boards, each of which was obliged to serve a closed supply area or franchise. US - Persists with its majority private-owned centralised structure, imposing a similar structure on Germany and Japan in the immediate post-war years. USSR and Eastern Europe - ESI operated under the central planning system, large power stations being constructed by the state to drive industrialisation. Latin America, Africa and Asia - The post-colonial nations tend to adopt the centralised, nationalised structure.
1950s	**PA** **ED**	The US post-war consumerism boom is driven by the growth of electrical appliances available on the market, backed by an electricity supply industry geared towards sustained growth. Average power station size increase from 30MW to 300MW from 1950 to 1960.
1950s	**GT**	The predicted continued growth rates in electricity demand impact significantly on electricity system planning and on project finance. New power stations ,"the bigger the better", are constructed. Generating technologies develop to include the combustion of oil and natural gas, as well as coal in steam powered plants operating at fuel efficiencies of around 25% and outputs per unit of 500 MW. Lack of suitable or a publicly acceptable sites near to areas of demand contributes to the development of larger and more remote generating plant linked to the ever expanding high voltage transmission grid.
1956	**GT**	UK - Nuclear powered electricity generation begins with the opening of Calder Hall. Initial capital outlay is huge, much work needed to be done to bring them the capital costs in line with coal fired generation. By the 1960s, design improvements appear to have achieved such cost reductions, and across the world nuclear plant is ordered as a part of the portfolio to meet predicted increases in electricity demand.
1960s	**ED** **GT**	Annual demand growth rates in the region of 7% and large generating units (500 MW +) directly connected to high voltage transmission networks continue to be constructed to match ever-rising demand.
1970s	**ED** **IS** **GT**	US - The anticipated continuation of the high electricity demand growth patterns fails to materialise. Generating capacity growth outstrips demand increases, some utilities being left with excess capacity and damaged investor confidence. The OPEC oil embargoes of 1973-1974 and 1979 and subsequent sharp hikes in fossil fuel prices, alongside emerging concerns for the environmental impacts of electricity generation, lead to increased operating and construction costs of power plant projects across the world. Clean Air legislation has a significant impact on capital, fuel and operating costs, and energy conservation legislation encourages slower growth in electricity demand. Residential and industrial electricity prices begin to rise
1978	**GT** **IS**	US Public Utilities Regulatory Policies Act (PURPA) – Legislation is introduced to encourage Independent Power Producers and small-scale generation.
1979	**GT**	The faith in nuclear electricity generation as the panacea to concerns about security of fossil fuels diminishes as a result of near disaster at Three Mile Island, Pennsylvania in 1979.
1980s	**GT**	Environmental concerns regarding nuclear power and emissions from fossil-fuel generation continue to increase, aided by increased scientific knowledge and focussed NGO lobbying.

1982	**IS**	Chile – General Pinochet introduces legislation to liberalise the Chilean electricity industry.
1983	**IS**	UK – The Electricity Act 1983, similarly to PURPA, encourages the growth of independent power producers. The focus is on removing barriers to entry for non-utility generators and to provide independent producers of electricity open access to electricity networks, although its effects prove limited.
1986	**GT**	Chernobyl – the explosion at the nuclear power plant in the Ukraine raises worldwide concerns as the safety of nuclear generation.
1989	**IS**	UK Electricity Act 1989 – the UK ESI is privatised

2.2 The Reform of an Industry

Rationale and Motivation for Reform

In the late 1980s, the Conservative government viewed electricity as a tradable commodity whose supply and price should be determined by market forces. Diversity of generation sources would be at the behest of the market, the government's role reduced to that of ensuring fair competition, regulating natural monopoly and protecting the environment.

In the UK, the Electricity Act 1989 laid the foundations for the government's privatisation plans. Liberalisation was undertaken with the promise of increased efficiency, reduced consumer prices, the more general goal of widening share ownership in the UK and to raise revenues from the sell-off of government assets to finance tax reductions.

An additional motivation may have been the weakening of the then influential trade unions, particularly the National Union of Mineworkers (NUM) (Parker, 2000). The Conservative Government identified that a privatised electric utility industry would no longer be under an obligation to purchase British coal at its then high price. The privatised ESI would likely react by importing cheaper foreign coal or force UK price reductions. The scope for the NUM to take action without severely damaging the British coal industry would be removed.

Restructuring and Liberalisation

In liberalising the ESI, the Government decided to separate the natural monopoly constituents - transmission and distribution - from those to which competition would be introduced - generation and supply. In aiming to allow private participation, it was deemed necessary to 'unbundle' the vertically integrated ESI, create industry transparency and to break up long established industry relationships.

The Electricity Act 1989 laid the legislative foundations for the restructuring and liberalisation of the ESI, most of which was transferred to private hands through flotation on the stock market. More importantly, the Act introduced a competitive market into electricity generation and supply. It was considered impractical to duplicate the transmission and distribution networks and a system of independent regulation was introduced. The Electricity Act introduced a regulatory system headed by a Director General of Supply, responsible for ensuring an efficient and competitive electricity market and for protecting customer interests.

Structural change was rapid. By April 1990, the generation, transmission, distribution and supply elements of the UK electricity industry had been transformed. The new structure of the ESI allowed for competition in wholesale power generation. Prices were established through an 'Electricity Pool' (Box 1) and the monopoly transmission and distribution networks were subject to independent regulation.

Box 1 UK Electricity Pool – 1990 to 2001

The liberalisation process removed, not only the electricity generator's obligation to supply, but also the secure market for their output. The Electricity Pool of England and Wales was created in 1990 to balance electricity supply and demand, acting as a clearing house between generation and wholesale consumers of electricity. The National Grid Company (NGC) operated the 'Electricity Pool'. The primary wholesale consumers of electricity were the RECs. All electricity generators bid into the mandatory pool and all RECs were entitled to purchase their electricity from it.

The pool operated as a spot market, with 48 half-hourly blocks per day, each priced 24 hours in advance. The generation bids were entered in the National Grid Company 'Goal' program. Along with these bids forecast for demand were computed. From these inputs, the program derived the half-hourly marginal costs for the next day. The systems' manager ranked the bids in merit order from least to most expensive. The last unit needed to meet demand fixed the market clearing price (System Marginal Price). This last unit called, by the very nature of the clearing system, was the most expensive and thus many generators received payments higher than that which they had initially bid. Additional payments were on offer for ancillary services related to generation and quality of supply back up (Electricity Pool, 2001).

Simple economic theory dictates that a reduction in supply will force up price and many observers suggested that the electricity pool was open to manipulation by the large generators. They could together set the system marginal price for the bulk of the time through limiting available generating capacity. In addition, the electricity pool was more than often bypassed in favour of longer term bilateral contracts, known as Contract for Differences, that hedged the risk of the volatile pool prices. A review of the electricity pool led to its replacement in March 2001 by the New Electricity Trading Arrangements (NETA).

In England and Wales, generation was divided between two privately owned fossil-fuel generators, Powergen and National Power, and a nuclear generator, Nuclear Electric. Nuclear Electric was retained under public ownership, primarily due to its uneconomic nature. Ownership and operation of the high voltage transmission system was transferred to the newly created National Grid Company (NGC) with a specific remit to facilitate competition.

Fourteen Regional Electricity Companies (RECs) were set up to replace the area boards – twelve in England and Wales and two in Scotland. The RECs were the majority owners of the NGC until it's flotation in 1995. Each REC supplied to a franchise market in its area and oversaw the lower voltage distribution networks. Initially, customers with a demand in excess of 100kW were allowed to purchase electricity from alternative suppliers to their local REC, the threshold being phased out until its removal in May 1999. All electricity customers now have the freedom to choose their electricity supplier.

Vertical integration of the electricity industry was preserved in Scotland with the creation of ScottishPower and Scottish Hydro-Electric (now Scottish and Southern Energy). Nuclear generation was assigned to a separate company called Scottish Nuclear. The four generating stations in Northern Ireland were purchased by a number of competing generators in 1992. Northern Ireland Electricity became responsible for transmission, distribution and supply and was floated on the Stock Exchange in 1993.

Part privatisation of the two state-owned nuclear companies, Nuclear Electric and Scottish Nuclear, was undertaken in July 1996. They are now overseen by a holding company, British Energy.

Regulation

The Electricity Act 1989 created an independent regulatory system that covered England, Wales and Scotland, headed by the Director General of Electricity and Supply. The principal roles of the regulator were to ensure the effective introduction of competition into the ESI alongside adequate protection of consumer interests. The regulatory offices for electricity and gas were merged in 1999 to create the Office for Gas and Electricity Markets (Ofgem). Ofgem is governed by the Gas and Electricity Markets Authority and its powers are provided under the Gas Act 1986, the Electricity Act 1989 and the Utilities Act 2000. Ofgem, through advocating competition, is focussed on promoting and protecting the interests of gas and electricity customers and licensing and monitoring the gas and electricity companies, taking action where necessary to ensure compliance.

Ofgem’s main tasks are (Ofgem, 2001):

- Promoting competition in all parts of the gas and electricity industries by creating the conditions which allow companies to compete fairly and which enable customers to make an informed choice between suppliers.
- Regulating areas of the gas and electricity industries where competition is not effective by setting price controls and standards to ensure customers get value for money and a reliable service.

Northern Ireland has its own regulatory body, the Office for the Regulation of Electricity and Gas (Ofreg). OFREG duties include promoting competition in the electricity industry, protecting electricity and gas consumers, and arbitrating in disputes between consumer and supplier.

2.3 Discussion

The history of the electricity supply industry is complex. Many factors have, and continue to, impact upon its development. The discoveries of the science of electricity, the development of generating technologies, designing practical applications of electricity and the formation of appropriate institutional structures to generate, transport and supply electricity have all combined to produce the ESI we know today. Different combinations of these factors in different countries, particularly institutional structures, have resulted in the development of a range of industry configurations at various times.

The nationalisation of the UK ESI in 1947 was undertaken as much to improve the efficiency and cost effectiveness of the ESI as to meet social objectives of the Government – to provide affordable and consistent electricity to all (Amin, 2000). Over estimation of demand growth and the oil crises in the 1970s resulted in generation over capacity and increased fuel costs. These developments prompted consideration and development of alternative generating technologies and energy storage, and the need to reconsider the suitability of industry structures for meeting energy policy objectives. Energy policy objectives were beginning to reflect the need for fuel diversity to ensure security of supply (a natural response to the oil crises) and to accept emerging concerns as to the environmental impacts associated with the electricity supply industry.

Since 1989, the UK ESI has undergone market liberalisation in order to increase efficiency and drive down costs. Worldwide, the trend towards market liberalisation is clearly evident. Predominately private ESIs exist in Belgium, Japan and Spain, with public-private ESIs operating in Germany, Denmark, Sweden, Finland and the US (IEA, 2001). The impacts of market liberalisation, as reflected in the UK ESI restructuring, are reviewed and analysed in the next chapter.

3 The UK Electricity Supply Industry

Following 40 years in the public sector, the ESI in the UK has experienced a radical restructuring programme since 1989. This was designed principally to create a competitive electricity market and ensure financial independence from Government.

A full understanding of the restructuring process, the industry relationships that have established as a result, and the market structures and mechanisms that have been developed is essential in assessing the future development of UK electricity networks

A summary of the UK ESI will be provided, detailing generation, transmission distribution and supply functions in England and Wales, Scotland and Northern Ireland. Recently introduced legislation - the Utilities Act 2000 and New Electricity Trading Arrangements - will be assessed, as will additional support offered for renewable and sustainable energy technologies. Following this will be an analysis of the impacts of the restructuring process on generation costs, generation technologies and electricity prices.

This chapter will close by detailing and considering stakeholders and activities that are of relevance to the nature of electricity transmission and distribution networks in an increased embedded and intermittent renewable electricity system.

3.1 Overview of UK ESI

England and Wales

Generation

The CEGB successor companies (Powergen and National Power) are no longer the only players in the wholesale electricity generating market. By 1999, 24 new generating companies had entered the generation market in England and Wales (Electricity Association, 2000). Box 2 details UK electricity generating companies.

Gas became the preferred fuel for new power generation plant in the UK. The 'Dash for Gas' took advantage of abundant North Sea gas supplies and cheap world gas prices and has had a significant impact on the mix of generation fuel sources in the UK. The expansion of gas was a significant factor in decline of coal generation from 70% in 1990/91 to 33% in 2000 (NGC SYS, 2001).

Box 2 UK Electricity Generating Companies

First Hydro, the operators of 1,800MW pumped storage facility in Dinorwig, Wales are owned by Mission Energy of the United States. Electricité de France, Enron and a growing number of new entrants are operating in the UK electricity generation market whilst a range of mergers and acquisitions have dramatically changed the make-up of electricity generating companies in the UK.

There are several large fossil fuel generating companies including Innogy (previously National Power), Powergen and TXU. The publicly owned British Nuclear Fuels (BNFL) own the older Magnox nuclear generating stations. The privately owned British Energy Generation (UK) Limited, an amalgamation of Scottish Nuclear and Nuclear Electric, operates the Advanced Gas-cooled Reactor (AGRs) and the Pressurised Water Reactor (PWR) nuclear power stations. Additional independent producers also contribute to electricity generation in the UK, utilising various technologies including CCGT, Combined Heat and Power (CHP), waste incineration, and onshore and offshore wind.

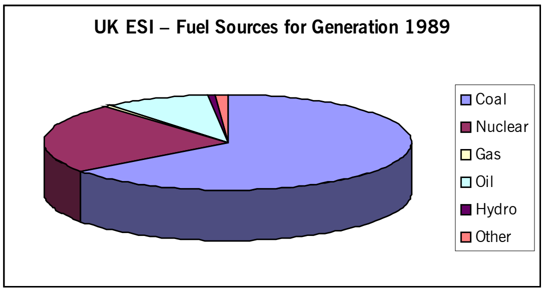
Primary Source source: Electricity Association, 2001

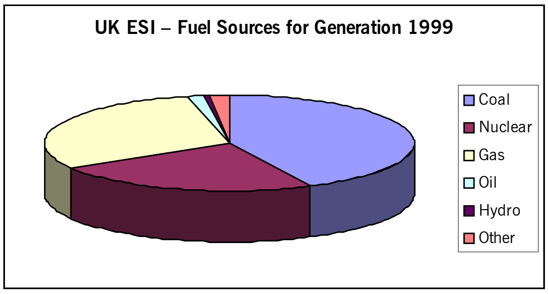
The advantages of CCGT were clear: low capital costs, short construction times, modular design, flexibility in location, improved efficiencies and lower emissions. From 1990 to 1999 18.6 GW of CCGT capacity was commissioned in England and Wales, with a further 4.2 GW under construction (Electricity Association, 2000). This new gas capacity has primarily replaced older oil and coal fired plant (Table 1).

Table 1: UK ESI – Fuel Sources for Generation, 1989 and 1999

Fuel use for generation	1989	1999
Coal	64.6%	38.6%
Nuclear	23.6%	31.1%
Gas	0.7%	27.1%
Oil	9.4%	1.1%
Hydro	0.5%	0.5%
Other	1.2%	1.6%

Source: Electricity Association (2000), The UK Electricity System





Concerns as to over reliance on gas and the continued demise of the UK coal industry motivated a Government review in 1998 as to energy sources for power generation and resulted in a temporary moratorium on the construction of new gas-fired plant. This moratorium was removed with the introduction of New Electricity Trading Arrangements (NETA) in March 2001 (Box 3).

Transmission

The high voltage (400kV and 275kV) transmission system, through which bulk electricity is transported from the electricity generators to the Regional Electricity Companies, is owned and operated by the National Grid Company plc (NGC). NGC is an independent company, floated on the stock market in 1995. NGC's statutory duties - provided under the Electricity Act 1989, the Utilities Act 2000 and their transmission licence - include developing and maintaining an efficient, co-ordinated and economic transmission system, facilitating competition in electricity generation and supply and the preservation of amenity and care for the environment (See Chapter 4).

Distribution and Supply

Distribution is the operation and maintenance of the assets which transport electricity from the grid supply points to individual customers. It incorporates a network of overhead lines, underground cabling, switches and transformers that operate at voltages from 132kv down to 240v.

Twelve Regional Electricity Companies (RECs) are in control of the local monopoly distribution networks in their franchise areas, e.g. SWALEC in South Wales. They are also responsible for electricity supply to the bulk of consumers within their franchise areas. The supply of electricity refers to the bulk purchase of electricity through the wholesale market and the sale of that electricity to customers. From 1999 the supply of electricity was fully liberalised and all consumers are now free to choose their supplier. For example, a customer living in Westminster can choose to purchase electricity from 'London Electricity', the REC, or from an alternative licensed provider such as 'nPower' or a renewable licensed provider such as 'Ecotricity'.

The direct successors to the Area Electricity Boards, the RECs licences set out a number of public service and other obligations including ensuring continuity and supply, non-discrimination, prohibition of cross-subsidies and price controls.

The licences required by suppliers who wish to sell to any customer attached to the distribution networks are referred to as 'second tier' licences. RECs can also obtain second tier licences to enable them to compete in distribution networks other than their own. Holders of second-tier licences include Innogy, Powergen and British Energy.

Scotland

Scottish Power and Scottish and Southern Hydro-Electric maintain responsibility for fossil fuel and hydro-power generation, transmission, distribution and supply. Scottish Nuclear generating plants are managed through the privatised British Energy. British Energy is connected to Scottish Power's transmission system and accounts for approximately one half of Scotland's electricity requirements (Electricity Association, 2000).

Although remaining vertically integrated, there is a requirement on Scottish Power and Scottish and Southern Energy to account separately for their generation, transmission, distribution and supply activities. This is in order to ensure that there are no cross-subsidies and that the companies are not earning excessive profits from use-of-system charges

The Scottish transmission and distribution network is connected to the England and Wales transmission system via an 'interconnector' (Box 7). Long term contracts with nuclear generating units and the excess capacity in Scotland has limited generation trading arrangements. But, generating plant in Scotland, irrespective of ownership, can sell to England and Wales. Ofgem have proposed the restructuring of Scottish wholesale electricity trading arrangements with the creation of a single British market by 2002 (Ofgem, 2001).

ScottishPower and Scottish and Southern Energy hold second tier licences and can supply customers across the UK electricity market, likewise any second tier licence holders can supply customers in Scotland. Alongside non-discriminatory third party access to transmission and distribution networks in Scotland, this provides for competition in the Scottish ESI.

Northern Ireland

In 1992, three private investors purchased the four electricity generating stations in Northern Ireland. Northern Ireland Electricity (NIE) became responsible for transmission, distribution and supply and was successfully floated on the Stock Exchange in 1993. 1998 saw further restructuring in Northern Ireland with the subsuming of NIE into a holding company, Viridian Group.

NIE acts as an Independent System Operator, purchasing electricity from the generating companies and operating the transmission and distribution networks. A separate supply business has been established within the company. In order to facilitate competition, second tier licences have been introduced. As in Scotland, there is no electricity pool in Northern Ireland. All generators are required to sell their electricity to the purchasing division of NIE who then sell it onto licenced suppliers.

3.2 The Utilities Act 2000 and the Wholesale Electricity Market

The Utilities Act 2000

The Utilities Act 2000 is the most significant piece of legislation for the UK ESI since the Electricity Act 1989, fundamentally amending the industry structure and the regulatory framework. The Utilities Act 2000 amended the Gas Act 1996, the Electricity Act 1989, and updated the regulatory regime. An overview of the Utilities Act 2000 is essential in understanding the legislative and regulatory environment in which the ESI is operating in at present, and into the near future.

The gas and electricity sectors have converged during the 1990s since industry restructuring, many companies now supplying both fuels to customers. Also, multi-utility groups have been established, providing a range of gas, electricity, water and telecommunication services.

The purpose of the Utilities Act is to advocate market development through integrated regulation of the gas and electricity markets, the separation of electricity supply and distribution, and the creation of the necessary framework to underpin the introduction of NETA (Box 3). The Act provides a principal objective to the Secretary of State and the Gas and Electricity Markets Authority to protect the interests of consumers, wherever possible through the promotion of competition. A number of the provisions within the Act seek improved regulation through transparency, consistency and predictability.

Combining and aligning the regulatory regimes for the gas and electricity industry is intended to ensure that regulation keeps apace with an increasingly convergent energy sector. A single regulatory body should improve the cost-effectiveness of regulation, allow for more integrated thinking and assist the development of collaborative and strategic relationships with the multi-utility corporations.

The Act introduced legislation for the separation of electricity distribution and supply, removing the concept of a ‘Public Electricity Supplier’ (PES). The concept of a PES was removed from April 2001, the duty to supply all customers being replaced by a statutory duty on the licensed Distribution Network Operators (DNOs) to connect and to maintain the connection. In order to ensure that at least one DNO is under such a duty to connect, geographic responsibilities along the lines of the existing PES areas have been attached.

The distinction between first and second tier suppliers was also removed. Previously, PESs were under a first tier licence that authorised them to supply electricity in their own area and a different second tier licence to supply electricity in other areas. The concept of a geographically exclusive area no longer applies.

From 2001, a licensed DNO is no longer permitted to hold a supply licence. Statutory duties have been placed on DNOs similar to those placed on the transmission network operator (NGC), requiring them to facilitate competition in generation and supply, to develop and maintain an efficient, co-ordinated and economical system of distribution and to be non-discriminatory in all practices. The Government intends that this duty will focus DNOs on the need for fair access to distribution networks for embedded generation.

New Electricity Trading Arrangements (NETA)

NETA is a new wholesale electricity market that went live on March 27 2001, comprising trading between generators and suppliers of electricity in England and Wales. The DTI has stated that along with other market reforms, NETA could help to reduce wholesale electricity costs by some 30% in real terms compared with 1998, worth some £2 billion a year (DTI, 2001).

The role of the NETA Programme is not to dictate how energy will be bought and sold on various exchanges or in bilateral contracts, but to provide mechanisms for the real time balancing of the actual amounts of electricity generated against the amounts contracted to be supplied (Box 3). NETA was designed to bring greater competition to the wholesale electricity market to ensure that wholesale prices reflect underlying market conditions, to the benefit of customers (Ofgem, 2001).

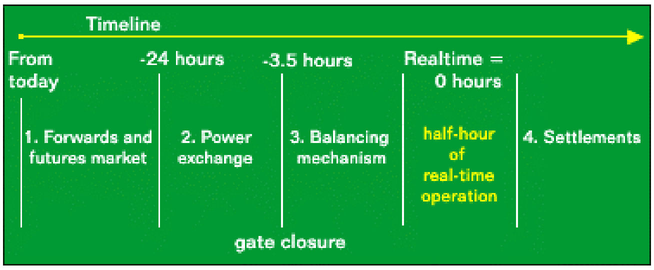
NETA has been constructed to deliver significant savings in wholesale electricity prices in England and Wales (Energy World, 2001). However, the Balancing and Settlement Code attaches high penalties on generators who produce less or more than contracted to. The impact of such penalties has been felt hardest by suppliers who utilise generation technologies that have more variable outputs, such as CHP and wind. The impacts on small generators were significant enough for Ofgem to announce a review of the initial impact of NETA on smaller generators on 9 April 2001, less than two weeks after its introduction. Outputs of this review are due to be published in August 2001.

3.3 Market support for Renewable and Sustainable Energy

A sustainable energy policy can be defined as a means of finding a balance between concerns for security of supply, economic efficiency, environmental protection and social considerations. While energy markets have been constructed to motivate economic efficiency, further mechanisms have been required to ensure security of supply, environmental protection and social considerations.

Box 3 New Electricity Trading Arrangements – March 2001 onwards

NETA is more akin to commodity markets and based on bilateral trading between generators, suppliers, traders and customers. Forwards and futures markets operate from 24 hours up to several years ahead alongside a short-term bilateral market that allows fine-tuning of positions. After closure of the short term bilateral market, a voluntary balancing market opens, with the NGC accepting bids for increments or decrements of generation or demand in order to balance total system generation and demand.



Source: Yorkshire Electricity, http://www.yeg.co.uk/business/industry_news/welcome.shtml

Forwards and Futures Market
Suppliers make estimates of their demand based upon contracted loads and sales expectations. They use this information to contract with generators to meet these basic requirements.

'Bi-lateral' trades take place in the forwards and futures markets. Contracts can be drawn up to cover requirements several years into the future.

Power Exchange (PX)
Suppliers fine-tune their positions from 24 hours before physical delivery. Suppliers are required to buy or sell electricity to cover any excess or shortfall between their actual position and that covered by the contracts in the Forwards and Futures market.

The importance for a supplier to be accurately informed about electricity demand is clear. Prices are likely to be volatile in the PX markets and the less a supplier is aware of their customer demand patterns, the greater the risk.

Suppliers declare their positions by making a Final Physical Notifications (FPN), up to 3.5 hours before physical delivery. The PX closes 3.5 hours before real-time operation, known as 'Gate Closure'. Settlements are undertaken on the basis of this FPN. Generators and suppliers can also make Balancing Mechanism Offers to help secure the system.

Balancing Mechanism
After offers have closed, the system operator (NGC) ensures that the system is balanced and secured, calling on the bids made in the Power Exchange to achieve this.

Settlements
This is effectively an accounting process whereby players in the Balancing Mechanism are subject to penalties if their positions were either over or under declared.

Primary source: Ofgem website, 2001

Renewable sources of energy currently exploited in the UK include hydro, wind, landfill gas, biomass, municipal and industrial waste, sewage gas and to a lesser extent, solar, wave and tidal. They have a critical role to play in contributing to the diversity, sustainability and security of UK energy supplies, their further contribution being central to meeting widely published Kyoto and Climate Change Programme targets.

Non-Fossil Fuel Obligation (NFFO)

The government noted that, at the time of market liberalisation, the costs of nuclear generation were too high to guarantee a market in the new structure. In 1989, the government introduced an obligation for the RECs to purchase specified amounts of 'non-fossil-fuel' electricity (Box 4), although the initial orders related to nuclear electricity only. These arrangements were extended to cover renewable electricity generation in 1990. Support for nuclear generation was removed in 1998.

Under NFFO, the government periodically (every 1-2 years) issued a call for bids to be submitted for a limited amount of funding support for new generation capacity. NFFO was structured on the basis of a number of technology bands - landfill gas, on-shore wind, small-scale hydro and waste-fired CHP - offering different kWh price support. Bids were accepted on the basis of the declared price and on financial durability of the project. Upon acceptance for NFFO support, the premium price was guaranteed for a number of years.

Box 4 Non Fossil Fuel Obligation

Funding for NFFO was provided the Fossil Fuel Levy incurred on licensed electricity suppliers. This levy was placed on the revenues earned by the electricity suppliers, who in turn passed on the cost of the levy to their customers. In 1989, the levy was 10%. But, reducing costs of electricity generation and the removal of support for nuclear plant has resulted in the levy reducing to 0.3% in England and Wales by October 1999 (Electricity Association, 2001). By the fifth NFFO rounds in England and Wales, the average price of electricity in successful bids halved, standing at 2.71p/kWh by NFFO 5 compared to the average pool selling price of 2.60pkWh (RCEP, 2000). To give a reflection of the funding provided through NFFO, renewables received £116 mill in 1997/98 (DTI, 2000).

The three dominant renewable technologies provided NFFO support were municipal and industrial waste, large wind farms and landfill gas projects. In the final bidding of NFFO these accounted for 41%, 29% and 21% respectively of the electricity contracted for (RCEP, 2000).

Up to 2000, there were five NFFO rounds in England and Wales, three in Scotland and two in Northern Ireland. Initial NFFO rounds offered support for five years only, but this was later expanded to a 15 year time horizon. As of 30 June 2000, 331 projects were contracted under NFFO, the Scottish Renewables Obligation and the Northern Ireland NFFO. Generating capacity totalled 834 MW (New Review, 2001).

Although initial completion rates of NFFO supported projects were encouraging (94% for NFFO 1), later rounds were not so successful. Statistics for NFFO 3 suggest a 40% completion rate, with later rounds being even less successful (New Review, 2001). Many of the successful NFFO projects were embedded technologies such as landfill gas and waste incineration.

A major criticism of NFFO was its disconnection from the planning system. Renewable electricity projects required guaranteed financial support before they could justifiably apply for planning permission. Although national policies to promote renewable energy were incorporated into the land use planning system through guidance issued in England, Scotland and Wales in PPG22, the lengthy and expensive planning permission process has delayed many NFFO supported renewable energy projects, some indefinitely. Major public opposition to onshore wind, primarily due to negative impacts on the landscape, has been another factor in limiting the success of NFFO projects.

Renewables Obligation

In order to align government support for renewables with newer market structures and trends, the Renewables Obligation was created under the Utilities Act 2000 with introduction intended for January 2002 (Box 5). All licensed electricity suppliers will be required to purchase a certain amount of renewable electricity, the obligation rising each year by 1% to 10% by 2010. The Act allows for the continuation of targets up to 2026, although the future obligations have yet to be defined. The Renewables Obligation is a key policy instrument for the Government meeting the national target of 10% renewable electricity contribution by 2010.

Box 5 Renewables Obligation

Renewable generators receive certificates (ROCs) which may be traded separately from physical electricity supply. It is also intended that these ROCs can be traded internationally should developments allow.

Suppliers have the option to buy out of their obligations, rather than meeting them, at an initial rate of 3p/kWh. Proceeds from this buy out will be recycled to suppliers who have met their obligation or who have purchased the appropriate ROCs.

Suppliers may also bank up to 50% or borrow 5% of their obligations against future years. Unlike NFFO, there are no separate bands of support for different technologies and large-scale hydro and conventional waste incineration are excluded from the initiative.

Additional support for offshore wind and energy crops will be provided in the form of capital grants. The Government, although “avoiding picking winners”, views these technologies as promising yet not quite market ready.

Ofgem will oversee the Renewables Obligation.

Primary source: DTI, 2001e

3.4 Impacts of Restructuring and Liberalisation

Generation Costs and Technologies

The nature of the Electricity Pool encouraged generating companies to drive the costs of generation down. Methods for reducing costs have varied and have included diversifying fuel sources, adopting new and more efficient technologies (CCGT), sourcing supplies of fuel on world markets and reductions in staffing. Such measures have resulted in major fossil-fired generators doubling productivity since market liberalisation in 1989 (Electricity Association, 2000).

As highlighted previously (Table 1), 18.6 GW of CCGT capacity was added from 1990 to 1999 (Electricity Association, 2000), new market entrants being responsible for half of this newly installed capacity (Hart et al, 2000). Total annual electricity supplied (effectively demand) in the corresponding period increased by 16%. Between 1988 to 1994, there was a 45 per cent reduction in generating costs per kWh in real terms due to fuel switching and increased efficiency, although only half of these savings were passed on to the consumers due to deficient competition in the new structure (Hart et al, 2000).

Table 2: UK ESI – Supply, Capacity and Demand, 1989 and 1999

	1989	1999
Electricity Supplied (net)	271.7 TWh	315.9 TWh
Net Capacity (major power producers)	70,300 MW	68,3000 MW
Maximum Demand	53,400 MW	56,300 MW

Source: Electricity Association (2000), The UK Electricity System

Competition for Customers and Electricity Prices

Due to the size of the market, and administrative and technical complexity, competition in the supply market was phased in over a number of years. Initial restructuring saw the 5,000 UK industrial sites with a maximum demand in excess of 1MW provided the opportunity to choose their electricity supplier. Those afforded the choice of electricity supplier was extended to 100kW and above in 1994, the threshold completely phased out in 1999.

One unit of electricity is essentially the same as any other. Thus, many large customers may view electricity as a commodity, purchasing decisions being largely governed by price. In 1997/98, Offer, the then regulator of the ESI, estimated that the competitive electricity supply market in Great Britain accounted for almost 50% of total electricity sales (146 TWh). 62% of the electricity purchased was from suppliers other than the appropriate RECs (Electricity Association, 2000).

In 1999, choice of supplier was offered to all 26 million electricity customers in the UK. Alongside the newly liberalised gas supply industry, many companies have offered 'dual-fuel' deals to customers, some now expanding into the telecommunications industry to become multi-utilities. By 15 July 2000, 5.15 million customers had moved from their former monopoly electricity supplier to a new supplier. This represents 18% of UK electricity customers and is equivalent to an average of 370,000 customers moving per month (Ofgem, 2001).

Electricity prices have fallen in real terms for all customer groups since 1990. For instance, the UK average annual domestic electricity bill has fallen in real terms from £281 in 1990 to £258 in 2000 (Electricity Association, 2000). Explanations given for such reductions have focussed on the impacts of greater competition in generation and supply, and tighter regulation of transmission and distribution networks (Electricity Association, 2000).

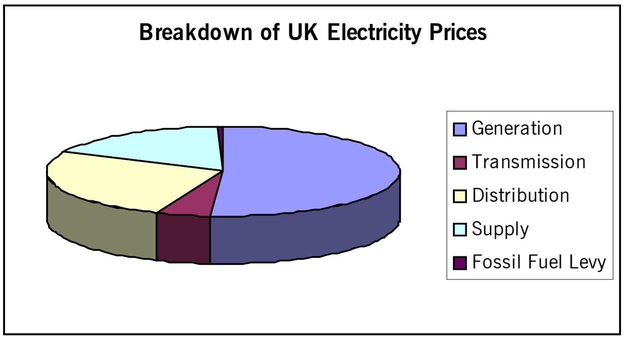
Breakdown of domestic electricity prices

One result of the restructuring of the UK ESI has been the increased transparency of costs within the industry. The price of electricity can be broken down across the key activities of generation, transmission, distribution and supply. Generation costs contribute significantly, although the combined costs of transmission and distribution account for over 30% of final electricity prices (Table 3).

Table 3: Breakdown of UK Electricity Prices by Function

Function	Percentage
Generation	51%
Transmission	5%
Distribution	26%
Supply	17.5%
Fossil Fuel Levy	0.5%

Source: Ofgem (2001) http://www.ofgem.gov.uk/customers/bills_electricity.htm



3.5 Other Stakeholders, Studies and Activities

It is essential to understand the context in which the industry may develop in the future. This section will outline the key stakeholders in the UK Electricity Supply Industry (ESI) and review recent studies, activities and political developments. A number of activities and developments highlighted in this section will be assessed and referred to in this thesis.

The European Union (EU)

The European Union's energy policy agenda focuses on four main areas, overarched by the continued development of the 'Single Market' and harmonisation of policies and practices. These four main areas are deregulation, environment, security of supply and issues relating to the accession countries. The Electricity Directive 1997 specifies a progressive opening up of electricity markets in EU member countries. Liberalisation of electricity markets and competition are viewed as *"the driving force for enhanced efficiency, better service and productivity gains to achieve lower electricity generation costs and reduced electricity prices for consumers"* (EC, 1999).

UK Government

The Government has recently announced a review of strategic issues regarding UK energy policy, set up in response to the recommendations made by the Royal Commission for Environmental Pollution (see below), and to take account of the UK's commitments to reduce CO_2 emissions. The review will be set within the context of meeting the challenge of global warming, while ensuring secure, diverse and reliable energy supplies at a competitive price and is planned to be completed by the end of 2001. (http://www.cabinet-office.gov.uk/innovation/2001/energy/energyscope.shtml)

Department of Trade and Industry (DTI)

The DTI is charged with working with others to meet UK government energy policy objectives. The DTI in its initial submission to the UK Energy Review highlighted that the UK energy strategy for the future needs to be pitched at the European, and in some cases, the global level (DTI, 2001).

Department of Environment, Food and Rural Affairs (DEFRA)

DEFRA take the lead on CHP and energy efficiency matters, and develop policy responses for climate change. DEFRA is a department that contributes to debates and policy formulation regarding sustainable, renewable and embedded electricity generation.

Parliament

Recent parliamentary inquiries include those by the House of Lords Select Committee (Electricity from Renewables), the House of Commons Select Committee on Science and Technology (Wave and Tidal Energy) and the House of Commons Environmental Audit Committee's publication of memoranda on renewable energy.

The Parliamentary Renewable and Sustainable Energy Group (PRASEG) is a cross party group for UK politicians that promotes sustainable energy issues in the UK Parliament. The Parliamentary Energy Group (PGES) is another all party parliamentary group concerned with energy policy, providing a link between MPs, Peers, MEPs of all parties and the ESI.

Reports and Studies

Embedded Generation Working Group (EGWG)

The joint Government/Industry Working Group on Embedded Generation Network Access Issues considered generating plant located in distribution networks contributing a larger proportion of total national generation. The backdrop to the EGWG was Government policy objectives for renewable plant and CHP, and the wish among developers to introduce various types of generating plant in distribution networks. EGWG produced a number of detailed recommendations that will be discussed throughout this thesis.

Royal Commission on Environmental Pollution (RCEP)

The Royal Commission on Environmental Pollution (RCEP), an independent body that advises the Queen, the Government, Parliament and the public on environmental issues, produced a report in June 2000 entitled 'Energy - The Changing Environment.' (RCEP, 2000). One of the key conclusions of the report was the need for the UK Government to plan for a 60% reduction in CO_2 emissions originating from the combustion of fossil fuels over the next 50 years. The RCEP concluded that this target can only be met with a large expansion of renewable electricity production well beyond the 10% target for 2010, significant and targeted improvements in industrial and domestic energy efficiency, and the wider use of CHP for industrial, commercial and domestic purposes.

The RCEP acknowledged that the limited size of CHP and most renewable generation units did not sit easily with existing transmission and distribution networks. These networks may likely require modification, in terms of technology and incentives, to accommodate the changing demands upon them.

Other Reports

A number of think tanks, consultancies, industry associations and others have produced reports focussed on sustainable energy futures. These include the Environment Agency's "Sustainable Energy Vision for the UK", the Fabian Society report "At the Energy Crossroads", the Forum for the Future report on "The UK's Transition to a Low-Carbon Economy" and The Institute for Public Policy Research "Low Carbon Initiatives" project.

3.6 Discussion

The impacts of the restructuring process that was initiated in 1989 on the UK ESI have been profound. The primary drive for the restructuring was economic, driving costs down through competition, reducing public sector costs and financing tax cuts for election campaigns. Much less attention was given to social and environmental objectives, and fuel diversity aspects of security of supply. The regulator has been charged to protect customer needs primarily through competition. Restructuring has resulted in a sea change in the generation mix, the 'dash for gas' significantly changing the nature of UK electricity generation, and resulting in a massive decline in coal generation.

The Utilities Act 2000 and NETA have further introduced competitive measures to the industry. The impacts of NETA on small-scale and renewable generators are of great concern, and although support through NFFO, now replaced by the more market orientated RO, has been provided, it seems at best that they are merely accommodating the negative impacts of the new market mechanisms. The 'unbundling of generation, transmission, distribution and supply has increased transparency of costs within the sector, highlighting, particularly, the significance of distribution activities to electricity prices.

As detailed above, there are a number of stakeholders influencing the development of the UK ESI, including the Government, Regulator, Parliament, industry, NGOs and others. Viewpoints and rationales of these stakeholders may often be in conflict. Government and industry desires for fully liberalised electricity markets must be weighed with the need to reduce and control electricity generation related CO_2 emissions. Reduction and control of CO_2 emissions will likely require some degree of government intervention, e.g. the Renewables Obligation and the Climate Change Levy.

The relationships of the stakeholders will be critical to future developments of the ESI. The complex interactions of government departments, government and industry forums (such as EGWG), and relationships between generation, transmission and distribution companies and others will all have a part to play in defining the route taken. In the near term, the widely stated 10% and 10GWe targets set by the Government may drive renewable and embedded generation expansion. The impacts of NETA and the outputs of the Energy Review may amend this progress. Nevertheless, the desire and need to reduce CO_2 emissions is likely to remain and as such, the UK ESI will have to adapt accordingly.

As stated in the Introduction, electricity networks need to develop in parallel with generating technologies if government policy and targets are to be met. This is the subject of the next chapter.

4 Evolution of UK Electricity Networks

The national electricity network was not simply built in situ, more it has evolved over the last 80 years from localised street networks to become the integrated national transmission and distribution network that exists today. Analysing the historical development of this network, the context and the rationale behind its operation and construction, and benefits of an interconnected transmission and distribution system is essential to understanding the opportunities and barriers to its future evolution.

This chapter opens with an overview of the origins and history of UK electricity networks. An assessment and analysis of the transmission network is provided, detailing the organisations, operation, interconnection projects, and access and charging structures. A similar overview and analysis is provided for the distribution networks. The chapter closes with an analysis of the benefits of the interconnected electricity network and the necessary methods for maintaining these benefits.

4.1 Origins and History of UK Electricity Networks

Figure 4 highlights key aspects in the development and evolution of UK transmission and distribution networks. A more detailed history is presented in Annex Six.

Figure 4: Origins and History of UK Electricity Networks

Period	Origins and History of UK Electricity Networks
1920s	
	• Independent electricity systems meet all the electricity requirements in their own area. • The sum of individual system reserve capacity equals 75% more generating plant throughout the country than needed to meet the peak demand (Cochrane, 1985). • The Electricity (Supply) Act 1926 creates the Central Electricity Board (CEB) to interconnect the most efficient electricity generating plant by a "national gridiron" of high voltage transmission lines. • Motivations for constructing the 'grid' include the economies of interconnection, rationalising national reserve capacity and security of supply. • The CEB purchases electricity output in bulk, selling this back to distribution and supply companies at cost plus appropriate grid construction and operating costs. • Construction of the 'national' grid begins in 1928.

1930s • The final pylon of the originally planned 'grid' is erected on the outskirts of the New Forest on 5 September 1933. • The 'national grid' of 4,800 km of 132kV transmission lines, 1,600km at lower voltages and 237 substations comes into full operation in 1935. • 'The grid' is series of networks based on the main industrial areas - Newcastle, Leeds, Manchester, Birmingham, Bristol, London and Glasgow – with limited capacity national tie-ins were factored into the system to allow transference between regions. • Of the existing 438 power stations, only 140 are deemed to be of a suitable size and efficiency for 'grid' connection (Hannah, 1979). • CEB gathers knowledge on cost effectiveness of power stations and on the social life and working routines of the population they serve. In the North West they learn to start up extra generators whenever Gracie Fields is due to sing on the radio (Hannah, 1979). • Demand estimates in the winter of 1938 highlight a potential shortfall in generation in the south of England. The transmission system is operated as one, co-ordinated from the South East, to take advantage of excess generation from the North. Although initially intended as a temporary measure until February 1939, the areas have remained connected ever since.
1940s • The 'national grid' comes to the fore during World War II, with the construction of 500 miles of transmission lines by 1942, adapting to changing patterns of demand due to the evacuation of urban areas. • *"During the blackest days of the war, the grid more than justified it's existence and played a large part in keeping the wheels of industry turning"* (Cochrane, 1985). • Post WWII hardship in Britain hits the ESI with reduced stocks of coal, the most significant fuel source for electricity generation at this time. • Clement Atlee's Labour Government responds by to nationalising the ESI in 1947, creating the British Electricity Authority (BEA) as the manufacturers and wholesalers of the ESI. BEA generate and transmit electricity via the 'grid' to twelve area distribution boards.
1950s • In line with Government objectives of taking advantage of available economies and providing electricity for all, the 'grid' is expanded and upgraded, construction beginning in 1950 on a 275kV supergrid with the ability to be upgraded to 400kV in the future. • The Electricity Act 1957 creates the Central Electricity Generation Board (CEGB), charged with providing *"an efficient, co-ordinated and economical supply of electricity in England & Wales… …with regard for the preservation of amenity, ranging from the natural beauty of the countryside to objects of architectural or historic interest"* (Cochrane, 1985). • The economic impacts of 275kV 'supergrid' are significant with reduced losses in higher voltage transmission making it cheaper to transport electricity than coal. In response, new generating stations were built closer to fuel sources (north and midlands) than to areas of demand (south east) – see bulk power transfers.
1960s onwards • The transmission capacity limits are met and the design and construction of 400kV grid begins in the 1970s, building on the existing 275kV network. • The original 132kV transmission lines are transferred to the area boards to be integrated into their distribution networks. • 1989 ESI liberalisation of the ESI results in the breaking up of the CEGB and the vertically integrated ESI, and the creation of separate transmission operators in England and Wales, Scotland and Northern Ireland. In England and Wales.

4.2 Transmission

As described in Chapter 3, there are four transmission systems in the UK, each separately operated and owned (Table 4). The largest system, in terms of line length and share of total transmission covers England and Wales and is owned and operated by the National

Grid Company (NGC). This consists of over 14,000 circuit km of 400kV and 275kV overhead lines and cables. In England and Wales, the 132kV network is primarily used for distribution whereas in Scotland it forms an integral part of the transmission network. In the north of Scotland, the network is operated by Scottish and Southern Energy, while the network in the south of Scotland is operated by ScottishPower. In Northern Ireland, the transmission and distribution systems are treated as a single system.

Table 4: Electricity Transmission Networks in the UK – 1999/00

	National Grid	Scottish & Southern	ScottishPower	N.Ireland Electricity
Line voltage				
400 kV	✔	-	✔	-
275kV	✔	✔	✔	✔
132kV	-	✔	✔	-
110kV	-	-	-	✔
Length in circuit km				
Overhead	13,608 km	4,750 km	3,851 km	1,268 km
Underground	614 km	58 km	247 km	45 km
Total	14,222 km	4,808 km	4,098 km	1,313 km
Demand and units transmitted				
Maximum demand	50,587 MW	1,639 MW	4,323 MW	1, 686 MW
Units transmitted	299.0 TWh	12.3 TWh	30.0 TWh	7.4 TWh
Percentage of TWh transmitted in the UK	85.7%	3.5	8.6	2.1

Data Source: Electricity Association (2001), Electricity Industry Review 5
* includes the distribution business

The National Grid Company plc (NGC)

NGC is an international organisation, created in the restructuring and liberalisation of the UK ESI in 1989 and floated on the stock market in 1995. NGC has operations and joint ventures in Latin and North America, Europe and Africa. In the UK, NGC's statutory duties include the development and maintenance of an efficient, co-ordinated and economic transmission system, facilitation of competition in electricity supply and generation and the preservation of amenity and care for the environment. In order to ensure a level playing field in relation to the daily operation of the system and access to the transmission network, the NGC is independent of generation and supply.

NGC also has a duty to provide transparent information on the charges for use of the network and its capability and characteristics, including opportunities for future use, and guidance to anyone who wishes to connect to the system.

Prior to the introduction of NETA (Box 3), as the system operator, NGC had the role of despatching (calling to generate) all generation units over 100MW. There is approximately 63,000MW of such plant in England and Wales, more than 90 per cent of which is directly connected to the high voltage transmission network (NGC, 2001). This despatch role applied to generation directly connected to the high voltage transmission network or embedded in the distribution networks.

NETA represented a significant change for generators, electricity suppliers and the system operator alike. Generators and suppliers now enter into bilateral contracts, essentially self-despatching to meet the terms of these contracts. NGC now balances the system through accepting bids and offers for electricity from generators and suppliers through the NETA Balancing Mechanism, and ensures security and quality of electricity supply.

NGC fulfils two main roles. As the 'Transmission Asset Owner' (TO) it maintains and drives the long term development and investment in the transmission network. As the 'System Operator' (SO) NGC ensures the balancing of the system, matching generation with demand, maintaining frequency and voltage and overcoming transmission constraints. NGC provide 'ancillary services' (Box 6) that maintain the integrity of the transmission network. NGC also operate the interconnectors between France and Scotland (Box 7).

Box 6 Ancillary Services

The security and stability of the transmission system is dependent on the availability and provision, when necessary, of certain types of technical facility, known collectively as ancillary services. These services are economically contracted from a range of different providers and enable the maintenance of satisfactory voltage and frequency, as well as the restoration of power supplies after system failure.

The range of required ancillary services can be classified as mandatory, necessary and commercial. All large generators are obliged to provide the mandatory services central to the satisfactory operation of the system. Some generators are required to provide the necessary service of black start capability. Generators are also encouraged to enter into commercial Ancillary Service contracts, along with other large industrial users to provide complementary and additional services. This promotes competition and diversity in the ancillary service provision.

The National Grid Company (NGC) purchases ancillary services from generators and some consumers, the services purchased include:

- Frequency response - this is needed to maintain system frequency.
- Reactive power - this is needed to maintain voltage balance on the Transmission System.
- Reserve: scheduled (rapid response); standing (20 minute response); and contingency (5 to 24 hour response) - this is needed to counter the effects of generation failure /shortfall or demand forecast inaccuracy. The present stock of generators can be quicker at meeting instantaneous demand by inefficiently placing themselves on spinning reserve. Turbines are kept rotating without generating electricity to enable faster response but this is wasteful.
- Black start - this is the ability of a generating set to start up and provide electricity to the transmission system without an external power supply. It is fundamental that the network is prepared for the potential of a catastrophic failure and complete power loss. In certain situations, restarting the system may be impossible as most power plants require electricity to start up.

Source: NGC, 2001

Large generating units (registered capacity of greater than 100MW) tend to be directly connected to the 400/275kV transmission system operated by the NGC, although some are embedded within the lower voltage distribution networks. Medium (50MW–100MW) and small (less than 50MW) generating units are currently all embedded within the distribution networks. Embedded generation with capacity greater than 5MW is estimated at a total of 4872 MW for 2000/01, contributing approximately 6.5% of total UK electricity generation (NGC SYS, 2001).

Interconnection

Overhead lines connect England and Wales to Scotland with a nominal import capability of 1200MW (2001/02). A High Voltage Direct Current (HVDC) link with Electricité de France (EdF), connects into the UK network at Sellindge in Kent with an import capability of 1976MW. A further 4MW of interconnection capacity is proposed (Box 7), which would bring total capacity of existing and proposed interconnection links to approximately 6000MW - the equivalent to 8% of current UK generation capacity.

Box 7 Transmission Interconnection

Scotland - England and Wales interconnector
Overhead lines connect England and Wales with Scotland at 132kV, 275kV and 400kV with a nominal capacity of 1200MW. The average level of transfers into England and Wales is approximately 10.5TWh per annum and availability has exceeded 95% for the last three years (NGC, 2001). The Anglo-Scottish Interconnector is jointly owned by National Grid, Scottish Power and Scottish and Southern Energy. It is in the process of being upgraded to 2200MW to coincide with the completion of the second Yorkshire line.

France - England and Wales interconnector
A High Voltage Direct Current (HVDC) link with Electricité de France (EdF), connects into the 400kV system at Sellindge in Kent with an import capability of 1976MW and has been in operation since 1986. Ownership of the link is shared between National Grid and Réseau de Transport d'Electricité (RTE). The interconnector is approximately 70km in length with 45km of subsea cable. The average level of transfers into England an Wales is approximately 15TWh per annum and availability has exceeded 97% for the last three years (NGC, 2001)

Other proposed interconnections
In 2001, NGC signed a Joint Development Agreement with Statnett, the Norwegian grid operator, for the development of an £400m-£500m interconnection project between the east coast of **England** and the south-west coast of **Norway** (Financial Times, 21 May 2001). This North Sea Interconnector (NSI) will have a nominal capacity around 1200MW, and at 450 mile long is to be the longest DC subsea cable in the world. Subject to consents, approvals and commitments to capacity, NGC aim to begin construction in 2002 with completion envisaged by 2005/06.

A feasibility study of a 1,000MW nominal capacity subsea interconnector between **England** and the **Netherlands** has recently been concluded. Subject to consents, approvals and commitments to capacity, NGC aim to begin construction in 2003 with completion envisaged by 2005.

A study of the feasibility of a 500MW subsea interconnector between **Wales** and **Ireland** has also been undertaken, commencing in December 1999. This report is expected to conclude on the technical and commercial viability of the project in late 2001.

Funding for the feasibility stages of these projects was obtained from the European Commission under the Trans-European Networks (TENS) programme.

Primary Source: Personal Communication with NGC, 2001

Transmission Network Access

NGC is required to provide open access to the transmission network, although such a simple acknowledgement masks a number of technical requirements. Open access refers to allowing any generator to connect to, and any distributor to draw electricity from the transmission network. All distributors and generators seeking connection to the transmission system must meet appropriate technical standards classified in 'The Grid Code'. The 'Grid Code' addresses planning requirements, connection conditions, operational liaison and safety co-ordination, and is designed to ensure that technical difficulties are not caused for others already connected to the system. The terms for access are non-discriminatory, access being only deniable in clearly defined circumstances, such as those related to safety.

NGC must also facilitate access to the transmission system, statutory licence duties requiring that all requests for connection be responded to within three months. This three month period is used by the NGC to assess and investigate the design, planning, legal and economic aspects of the connection request. Should NGC respond with an offer of connection, the connection applicant has a further three month period to accept.

The provision of information to potential applicants for grid connection is an important aspect of introducing greater transparency into the ESI. NGC produces an extensive annual Seven Year Statement (SYS). The SYS includes information on demand, generation, spare capacity, the characteristics of the existing and planned transmission system, and its expected performance. The SYS is produced to enable NGC *"customers to evaluate opportunities for making new and/or further use of the transmission system"* (NGC SYS, 2001).

For embedded generating units larger than 100MW, NGC is required to offer terms for the use of the transmission network within 28 days. Should network reinforcement work be necessary to accommodate such a generator, NGC must state when the network will be ready and set out the appropriate use of system charges.

NGC tends not to levy charges for embedded generating units smaller than 100MW. This removes the requirement for connection and use of system agreements. However, NGC has expressed in the past its eagerness to be provided with information concerning any such embedded generators, concerned that such plant may have a material impact on the transmission system.

Transmission Network Charges

NGC levies three types of transmission charge to cover the investment, maintenance and operational costs of the transmission network: connection charges, transmission network use of system charges and balancing use of system charges (Box 8).

Connection charges are designed to reflect the cost of installing and maintaining the assets required for the connection of a generator or demand customers directly to the network. Transmission network use of system charges cover the regulated cost of the transmission network infrastructure assets and their maintenance and are shared between all transmission customers who use the system. Balancing use of system charges cover the costs of NGC incurred in its role as 'System Operator' in balancing the system and include the costs of ancillary services.

Box 8 Transmission Network Charges

Connection charges
Transmission connection charges are 'shallow', that is, they cover only those assets at or very near the connection site.

Customers may vary the design of their connections (subject to safeguards), choose whether they incur National Grid's regulated rate of return or some other form of financing, and can choose whether to arrange for the construction of these assets themselves or whether National Grid makes these arrangements.

Generators who connect to the distribution networks do not incur transmission connection charges but pay distribution connection charges to their host distribution company. Such generators may be of benefit to the host distribution company, reducing the demand on the transmission system, avoiding the need to reinforce grid supply points and hence reducing the transmission charges levied.

Transmission Network Use of System (TNUoS) charges
TNUoS charges are shared between all transmission customers who use the system in that year and are designed to reflect the marginal cost of reinforcement to meet increasing imports or exports from each area of the country.

Generators larger than 100MW incur payments to NGC in areas where reinforcements will be required to accommodate increased exports. Generators may receive payments from NGC in those areas of the country where generation offsets the need for transmission investment. Generators below 100MW are not subject to these charges. But, smaller generators may reduce the liability of electricity suppliers to pay the TNUoS demand charge. Thus, embedded generators may receive an 'embedded benefit' in all areas of the country. This benefit tends to be more significant in those areas where generation or demand reduction offsets the need for transmission investment.

Balancing Services Use of System (BSUoS) charges
BSUoS charges are levied on generators and electricity suppliers participating in the national electricity market. Generators larger than 100MW are required to participate in the national electricity market. Smaller generators have a choice to do so and have additional options available to them, allowing them to participate in the national market without incurring transmission charges. Small generators often aid electricity suppliers to avoid BSUoS charges and may be able to negotiate an embedded benefit.

Connection and Use of System Code
Ofgem and the DTI have noted that new transmission access, pricing and losses arrangements are necessary to complement NETA reforms and to ensure that the full benefits of NETA are fully realised by customers. This new Connection and Use of System Code (CUSC) was recently announced by the Secretary of State for Trade and Industry to come into force on 18 July 2001 (DTI Press Release, 2001). The CUSC provides flexible governance arrangements that are intended to allow for the introduction of new transmission access arrangements.

Primary Source: NGC SYS, 2001

4.3 Distribution

There are 12 licensed 'Distribution Network Operators' (DNOs) in England and Wales, two in Scotland and one in Northern Ireland. Key statistics for these DNOs, as are detailed below.

Table 5: UK Distribution Network Operators – 1999/00

Company	Distribution Network (circuit km) Underground	Overhead	Total	Distribution Customers (000s)
East Midlands Electricity	44,053	24,049	68,102	2,415
London Electricity	30,261	42	30,303	2,060
Manweb	23,974	21,447	45,421	1,432
Midlands Electric/GPU	24,078	35,759	59,837	2,275
Northern Electric	26,958	17,108	44,066	1,536
Norweb/United Utilities	44,852	13,925	58,750	2,239
SEEBOARD	32,700	12,300	45,000	2,122
Southern Electric	43,960	28,000	71,960	2,699
SWALEC	14,357	18,658	33,015	989
Western Power Distrib	55,168	35,116	90,284	3,261
TXU Europe	18,699	29,277	47,976	1,344
Yorkshire Electricity	40,590	15,785	56,375	2,061
Scottish and Southern	14,005	30,415	44,420	659
ScottishPower	40,337	24,448	67,785	2,059
NI Electricity	3,973	29,557	33,530	687

Source: Electricity Association (2001), Electricity Industry Review 5

As evident from the above table, the size of the network and the number of customers served differs greatly across the DNOs. Distribution networks are a function of their customer density and the size and nature of the region and terrain in which they have developed. Although risking stereotyping distribution networks, circuits tend to be buried in urban areas with high customer density, e.g. London and overhead in rural areas with low customer density, e.g. northern Scotland.

DNOs hold regional licences for the provision of distribution network services and are subject to regulatory control by Ofgem. Existing price controls provide incentives to each DNO to minimise its operating, capital and financial costs.

As discussed previously, the Utilities Act 2000 prohibits licensed DNOs from holding supply licences. The separation of distribution from supply must be complete by April 2002. Some RECs have already sold their supply businesses, including Norweb (now United Utilities), SWEB (now Western Power Distribution) and Midlands (now GPU Power Distribution).

Quality of Supply

In relation to electricity supplied to customers, quality of supply indicators include supply availability, minutes lost per customer (e.g. power cuts), security of supply, and supply interruptions per 100 customers. The design of the network – a function of population density and geography – and network operation and maintenance are key controllers of the quality of electricity supplied.

It is widely agreed that increased spend by DNOs on network reinforcement and replacement, improved overhead line repair methods, and the development of computer controlled network management systems have improved distribution reliability and availability of supplies during the 1990s (Electricity Association, 2001).

Performance Standards

Ofgem set overall standards of performance to provide additional incentives to DNOs to maintain availability and quality of supplies to individual customers. DNOs must pay certain penalties to customers related to restoring supplies after faults (within 18 hours of fault notification), giving notice of planned interruptions (5 days notice required) and investigation of voltage complaints (within 7 days). Three additional overall standards are monitored on the basis of predetermined minimum levels of service. Performance standards for the restoration of supplies within 18 hours and the correction of voltage faults within six months are set at 100%. The standard for the restoration of supplies within three hours is set at between 85% and 95% for different DNOs, primarily dependent on geographical access constraints.

The Utilities Act 2000 allows Ofgem to apply performance standards to all electricity suppliers and distributors. A new suite of standards has been designed by Ofgem to accommodate the separation of supply and distribution businesses of the RECs. These standards apply to all licensed DNOs and relate to the following:

- Restoration of supply following a fault
- Responding to failure of a supplier’s fuse
- Notification of planned interruptions
- Investigation and correction of voltage complaints
- Estimation of charges for connections or moving a meter
- Connection of premises to the distribution network
- Responding to customer correspondence and enquires’ and making and keeping of appointments

Distribution Network Connections

Customer Connections - The concept of a Public Electricity Supplier (PES) was removed in April 2001. The duty to supply all customers within a defined geographic area has been replaced by a statutory duty on the licensed DNOs to connect and to maintain the connection. In order to ensure that there is at least one DNO who is under a duty to connect, geographic responsibilities along the lines of the existing areas have been attached.

Supplier/Generator Connections - Statutory duties have been placed on DNOs similar to those placed on the transmission network operator (NGC), requiring them to facilitate competition in generation and supply, to develop and maintain an efficient, co-ordinated and economic system of distribution and to be non-discriminatory in all practices. Ofgem intend for this duty to focus DNOs on the need for fair access to distribution networks for embedded generation (Ofgem, 2001).

Distribution Network Charges
When establishing distribution network charges in 1989, the assumption was made that all electricity flows would be from the ‘Grid Supply Points’ to the customers. DNOs are provided with a revenue stream from demand customers via ‘Distribution Use of System Charges’ (DUoS) that cover the ongoing provision of the distribution network and factor the costs of connection over the long term. Charges were established in order to cover the costs of the price-regulated distribution activity (EGWG, 2001).

‘Embedded’ generation refers to generating capacity connected directly to the distribution networks. Although not always the case, it tends to be small-scale renewable or CHP plant. Embedded generators are not subject to DUoS charges, and therefore do not provide DNOs with constant revenue streams. The DNO response is to charge embedded generators the full cost of connection, despite a number of potential benefits that they may provide (see below). These ‘deep’ connection charges include all the associated costs of connection, including the protection of voltage control and the costs of equipment that may be required due to changes in fault level (Box 6). Such ‘deep’ connection charges can be considerable and can be a disincentive to embedded generation. Embedded generation is discussed in more detail in Chapter 5.

4.4 Benefits of an interconnected transmission and distribution system

As outlined in Figure 4, until the 1930s, largely isolated private and municipally owned utilities were responsible for electricity supply in England and Wales. The Electricity (Supply) Act 1926 sought to resolve the wasteful duplication of resources. Particular concern was given to each isolated authority installing enough generating plant to cover the breakdown and maintenance of its generation. To provide some idea of the size of the interconnected electricity network, the UK Electricity Transmission System is shown in

Figure 5 with significant generation plant included.

Interconnecting the separate distribution networks and utilities via a high voltage transmission system pooled both generation and demand. An interconnected transmission system also allowed for maintaining the quality of supply, e.g. frequency and voltage variations, across the system and offered economic and other benefits summarised below and detailed in Annex Seven:

Bulk power transfers

An interconnected transmission and distribution network allows for the bulk transmission of power from generation to demand centres. Many factors impact on the decision to construct a power station at a particular location including fuel availability, fuel transport costs, cooling water, land availability and network connection charges. Large generating units often have difficulty in gaining planning permission for location near to centres of demand due to environmental and social impact concerns. Certain renewable energy generation technologies such as wind or wave tend by their nature to be remotely located from centres of demand.

Figure 6 shows current average bulk power transfers in the UK, demonstarting the transmission of excess generation in the north and the midlands to the south.

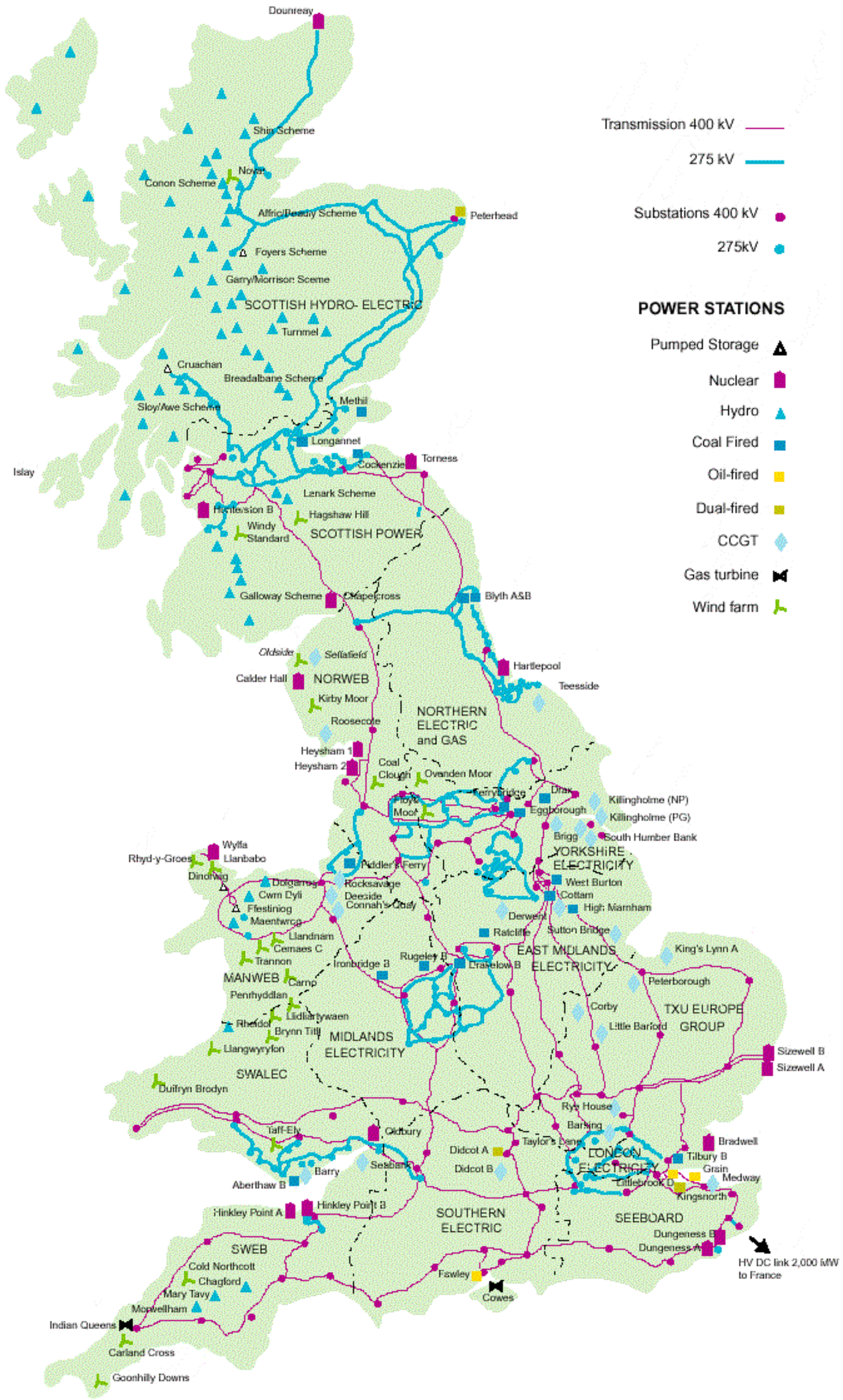
Economic Operation

The interconnected transmission system provides the main national electrical link between all participants (generation and demand). Connecting together all participants across the transmission system makes it feasible to select the cheapest generation available in the system - taking into account transmission losses and transmission capacity limits - irrespective of the location of the plant.

Customer security of supply

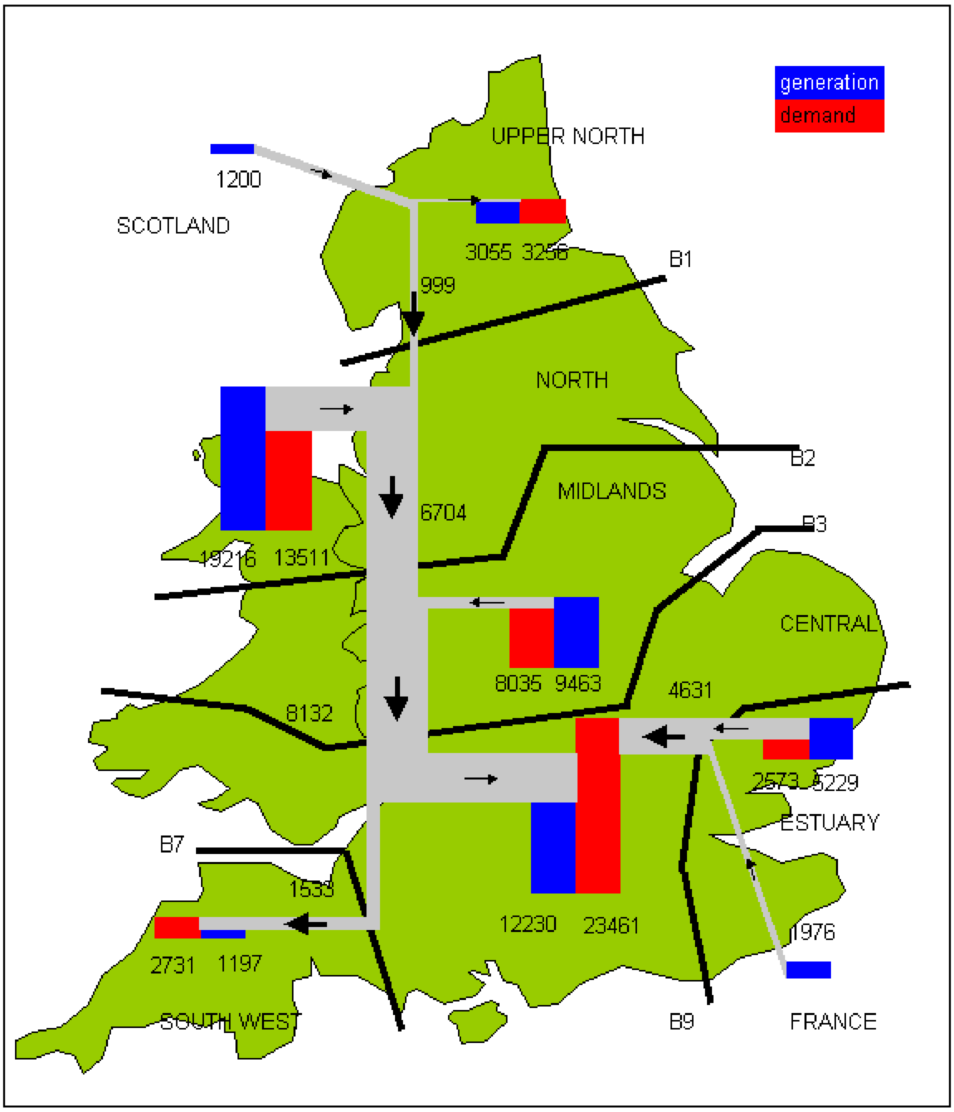
Customer security of supply refers to providing the customer with a continuous and uninterrupted electricity supply of the required quantity and of defined quality. This requires electricity networks to be adequately robust to maintain supplies should generation, transmission and/or distribution fail across varied demand patterns. Interconnected transmission and distribution networks allow exploitation of the diversity between individual generation sources and demand to maintain security of supply.

Figure 5: UK Electricity Transmission Network – April 1999



Source: The Electricity Association, http://www.electricity.org.uk/about_fr.html

Figure 6: Electricity Flow Pattern for 2001/02



Source: National Grid Company (2001) Seven Year Statement

Spare Generation Capacity

Additional generating capacity is needed to cover for generating plant becoming unavailable due plant breakdown, delay in commissioning of new units, weather variations, or understated demand forecasts. An integrated transmission and distribution system allows surplus generation capacity in one area to cover shortfalls elsewhere. This results in an overall reduction in the requirement of spare capacity across the interconnected network relative to the amount that would be required by each area individually. In the UK, the Central Electricity Generating Board (CEGB) traditionally adopted a spare capacity margin of 24% in excess of winter peak demand to provide security when planning the need for future installed generation capacity. Under NETA, the spare capacity margin is determined solely by the market.

Reduction in Frequency Response

System frequency varies continuously and is determined and controlled by a careful balance between demand and generation. If system demand is greater than system generation, frequency will fall. If generation is greater than demand, frequency rises. To avoid an unacceptable fall (Box 9) in frequency should generating plant fail, additional generation, electricity storage or reductions in demand need to be available that can be called upon at very short notice (Box 6 - Ancillary Services). This is referred to as 'frequency response'. Without an interconnected transmission system, each separate system would be required to carry its own frequency response. Interconnection allows the frequency response requirement to be established to cover the highest of the individual system requirements rather than to cover for the sum of them all.

Maintaining the benefits of an interconnected electricity network

Although an interconnected electricity network can provide a number of potential benefits (see above) maintaining these benefits requires a number of technical and administrative responses (Box 9). The implications of increasing embedded and renewable generation on maintaining these benefits are discussed in Chapter 6.

Box 9 Maintaining the benefits of an interconnected electricity network

Quality of Supply – Frequency and Voltage
An important factor in planning and operating the transmission and distribution networks is the need to ensure that the quality of electricity supply (frequency and voltage) is maintained within specified standards. In the UK, the Electricity Supply Regulations 1989 and the Grid Code specify that the frequency delivered to the consumer must not vary from the declared value by more than ±1%. Voltages below 132 kV must not vary by more than ±6% whereas voltages higher than 132 kV must not vary by more than ±10% (NGC SYS, 2001).

Frequency levels are sustained, all things being equal, by ensuring that generation is always in balance with demand plus losses in the transmission system. Reserve generation is held by the system operator, available instantly to cover against plant losses and/or surges in demand.

Voltage is affected by the nature of the network through which the electricity is transmitted. Its length, the level of electricity flow and demand (NGC SYS, 2001).

Two electrical characteristics of the transmission network are 'capacitance' and 'inductance'. They have opposite effects on the voltage, causing a rise or fall respectively, as electricity flows through the network. At low flow, the voltage along a transmission line rises from the sending to the receiving end. At high flow, the voltage will fall. The longer the transmission line, the greater the effect on voltage. At the 'natural loading' of the line, the inductive and capacitive effects cancel out and the voltage remains constant along the line.

Reactive Compensation
Voltage variations at the receiving end of transmission lines are corrected by special voltage compensation plant. This is known as reactive compensation. Capacitive reactive compensation increases the voltage level and is used for heavily loaded overhead lines. Inductive reactive compensation reduces the voltage level and is used for lightly loaded cables.

Reactive compensation plant need not be utilised at all the times. Reactive compensation units are often connected to the system in a floating mode, responding automatically or being switched in or out as changing system conditions dictate.

(continued over…)

Box 9 Maintaining the benefits of an interconnected electricity network (continued from previous)

Transmission system capability
In the UK, the ratios of generating capacity and demand vary in different areas across the country, traditionally the electricity flowing from North to South. From 1938, the transmission system has enabled generation surpluses in one part of the country to supply demand in other parts of the country. In assessing the ability of the system to achieve this, it is split into primarily importing or predominantly exporting areas. Connecting circuits linking such areas tend to represent the weakest links in the transmission system and thus indicate the ability of the system to accept bulk power transfers.

System losses
Electricity flow across the transmission system causes transmission power losses, primarily due to the heating of transmission lines, cables and transformers. Other losses include the unavoidable losses associated with overhead lines and transformers. These include fixed losses on overhead transmission lines, referred to as corona losses, which are a function of voltage levels and weather conditions. Fixed losses in a transformer are iron losses that vary with the frequency of the electricity flow.

Location of Generation and Impact on Transmission Network Reinforcement
The transmission system is planned to meet the Licence Standard that specifies that the transmission capability of any part of the system should exceed the maximum required flow. If the forecast maximum required flow exceeds the transmission capability, that part of the transmission network must be reinforced.

Maximum electricity flow in any part of the system is a function of the generation and demand in that part. The greater the difference between generation and demand, the greater the flow. The choice of site of new generating plant can therefore directly influence the need for major transmission reinforcements. For example, should a new generating plant be located in an area where generation exceeds demand (export area), the maximum electricity flow will increase. This increase in flow may exceed the transmission capacity of the existing system and give rise to the requirement for transmission reinforcement.

Locating new generating plant in an area where demand exceeds generation (import area) may be beneficial to the transmission system in relation to both security of supply and voltage control. All things being equal, it will reduce the flow over the transmission system, the associated need for additional reactive compensation, transmission losses, and the possible need for transmission system reinforcement.

In the UK, there is a large net flow from north to south. Locating new generating stations in the south would therefore appear to be beneficial to the transmission network.

Primary Source: NGC SYS, 2001

4.5 Discussion

Focussing on the rationale and motivations for the development of the interconnected electricity networks allows for interesting comparisons with the current decisions faced by the ESI. After the Second World War, expansion and interconnection appears to have been as much driven by social objectives of providing electricity for all as potential economic benefits. Such a situation is analogous with the desire to meet environmental objectives associated with the energy policy debate today.

The role of the transmission network operator has been amended considerably since 1989. From directly calling on generators to ensure that demand is met, NGC now provides the link between generators and suppliers by administering the NETA markets, balancing generation and demand, providing national security and quality of supply, and maintaining network integrity. In this way, as renewable energy sources expand (particularly larger scale remote renewables such as offshore wind), NGC's operation of the largest transmission network in the UK will remain significant (see Chapter 5).

Similarly distribution networks are critical to the expansion of embedded generation technologies. Although the size and nature of DNOs differ, access and charging principles remain the same. Quality of supply concerns are central to their operation. The Utilities Act 2000 has separated distribution and supply functions and charged DNOs to facilitate competition in generation and supply. Current access and charging arrangements for distribution networks appear to discourage embedded generation and require adaptation to fully meet the requirements of the Act.

It is important to recognise that a number of benefits are provided by an interconnected transmission and distribution network. These include providing bulk power transfers, ensuring utilisation of economic plant, providing cost effective spare capacity and maintaining quality of supply. However, these benefits are delivered through a series of technical and operational arrangements, many of which could be provided by embedded generation, given the opportunity.

The following chapter details and analyses embedded and intermittent generation technologies, highlighting associated implications for the operation of and interfaces between transmission and distribution networks.

5 Embedded and Intermittent Generation

Electricity systems have developed during the last century as represented in Figure 1. In essence, large central generating units feed into an interconnected high voltage transmission network. Electricity is transferred through this transmission system to feed lower voltage area distribution networks which deliver electricity to individual industrial and domestic customers.

Due to the policy, economic, technical and environmental trends indicated in Chapter 1, interest in connecting generation to distribution networks rather than transmission networks has increased over the last 10 years. New terminology has been developed to reflect this increased interest, namely 'embedded' and 'dispersed' generation.

This chapter defines embedded generation and details the drivers for expansion, and the technical implications of their increased contribution to UK electricity supply. The intermittent nature of certain generating technologies, particularly wind, will be analysed alongside implications for the operation of electricity networks.

Embedded and renewable generating technologies will be detailed and assessed, again the focus being the impacts of their generation characteristics on electricity networks. The chapter will close by analysing electricity storage technologies and applications, a potential support to embedded and intermittent renewable generation.

5.1 Embedded Generation

'Embedded' generation refers to generation connected to the distribution network rather than the transmission network. It is important to note that, as discussed previously, embedded generation is far from a new concept, having "been a feature of the electricity industry since it began more than a century ago" (EGWG, 2001). There is no universal definition of what constitutes embedded generation nor how it differs from conventional central generation. However, common attributes have been identified as (Jenkins et al, 2000):

- Not centrally planned
- Not centrally despatched
- Normally smaller than 50 to 100 MW
- Usually connected to the distribution system

Embedded generation technologies are either small in scale or can be produced economically in a range of sizes (ETSU, 2001). Such technologies are well matched to generating electricity where it is needed, therefore lending themselves to being embedded in the electricity distribution networks.

Drivers for the Expansion of Embedded Generation

The International Conference on Electricity Distribution Networks (CIRED) 1999 sought the views of representatives from 17 countries as to the policy drivers that encouraged the development of embedded generation. These drivers included:

- Reduction in gaseous emissions from electricity generation (mainly CO_2)
- Energy efficiency and rational use of energy
- Deregulation of competition policy
- Diversification of energy sources
- National power requirements

Other motivations for embedded generation include:

- Improved technological performance of modular generating plant and control technologies
- Increased difficulty – planning, public concerns, etc. – in locating large generating units
- Shorter construction times, lower capital costs, quicker payback periods of smaller units
- Location of generating plant nearer to the load thus reducing transmission charges
- Cultural drivers – political and cultural desires to develop low carbon energy technologies

The development of new technologies such as modular CCGT, micro and mini CHP, fuel cells and renewable energy, alongside the increasing awareness of the environmental impact of power generation has resulted in increasing commercial interest in their exploitation (ETSU, 2001).

Poor power quality and security of supply concerns, alongside the recognition of environmental benefits, have driven the recent growth of embedded generation technologies in the USA, e.g. California (Brooks and Butler, 2001). The principal drivers to date in Europe have been concerns over the environment and increased awareness of the newer technologies as market liberalisation progresses in the EU member states.

The DTI has stated that ensuring that the UK is in the forefront of the liberalisation of electricity markets and the advancement of embedded plant is of potential profit to UK plc. It will enhance industrial competitiveness and provide greater opportunities in overseas markets (DTI, 2001). Such opportunities may relate to the application of new technologies and the management of active distribution networks. With the move towards increased liberalisation of world electricity markets, UK companies could be well placed to exploit opportunities in establishing embedded generation projects and services.

A number of embedded generation technologies emit relatively low levels of CO_2 compared to large coal or gas fired plant. An increase in the contribution of such technologies to overall electricity supply could assist the UK in meeting greenhouse gas emissions reduction targets. The expansion of embedded generation can add to fuel diversity and UK energy security. Diverse forms of generation may be developed, including renewable technologies, such as wind, that are not reliant on imported sources of fuel.

Box 10 provides a case study of embedded generation in the Netherlands, highlighting a number of policy considerations, discussed below and in Chapter 6.

Box 10 Embedded Generation Case Study – The Netherlands

One of the responses in the Netherlands to the oil crises of the 1970s was to structure the ESI to provide incentives for the development of small-scale, decentralised generation. Local utilities with dense network infrastructures, built with of future capacity growth in mind.

A recent report produced by COGEN Europe looked at embedded generation in the Netherlands. Cogeneration has a 40% share of current installed capacity. A significant share of installed capacity is therefore decentralised. The Netherlands 1989 Electricity Act separated generation and distribution activities. But, distribution companies were allowed to continue their activities in generation plant under 25 MWe. This continued involvement of distributors has proved a key driver and motivation for them to address and resolve issues related to the increase in decentralised/embedded generation.

The Dutch experience has shown it is possible for decentralised generation to develop without major difficulties, although strong political will to achieve this is a key element. The development of active distribution networks was achieved through formulating adequate technical regulations and measures that did not entail prohibitive costs. A survey of Dutch utilities concluded that the main issues for the grid in case of a growth of cogeneration capacity are not technical, rather organisational and commercial/contractual (COGEN Europe, 2001).

Overview of Technical Implications of Embedded Generation

As discussed previously, distribution networks have been constructed to accept bulk power transfers from the transmission system for distribution to customers. A significant increase in embedded generation may result in a reversal of electricity flows, subject to generation and demand levels at certain periods. This would require distribution networks to adapt their passive nature to become ‘active’, having the ability to accept bi-directional electricity flows. The major technical implications of increased embedded generation include (Jenkins et al, 2000):

Network voltage changes

DNOs are required to supply customers at a voltage within specified standards (Box 9, Chapter 4). This requirement has often determined the design of distribution networks, and techniques to maximise the use of distribution circuits while maintaining voltage levels have been developed over the years (Jenkins et al, 2000). Network voltage is in part determined by the level of electricity flow, and embedded generation and subsequent changes in electricity flows must be taken account of.

Network fault levels

Embedded generation increases the distribution network fault levels – the voltage that trips the network. In urban areas, it is common for distribution networks to be operating near to the existing fault level, therefore providing an obstacle to embedded generation (Jenkins et al, 2000). Connected embedded generation may require upgrading of the distribution network, an expensive undertaking currently borne by embedded generators under existing charging principles in the UK.

Quality of Supply

Embedded generation can produce voltage variations on distribution networks, although variations can be minimised through careful design of embedded plant and the correct synchronisation of generators (Jenkins et al, 2000).

Protection

Embedded generation requires additional controls and monitoring to protect the generating equipment itself, and to protect the distribution network from fault level currents and issues associated with 'islanded' operation (see below).

Other technical issues related to embedded generation are assessed in more detail in Chapter 6 and include:

- 'Islanded' operation - embedded generators operating disconnected from the distribution network and supporting local supplies in the event of network failure
- Ancillary services – embedded generators providing reserve and frequency response
- Bulk power transfers - reduced electricity flows from the transmission to distribution networks as a result of increased penetration of embedded generation development will not necessarily result in a corresponding reduction in the bulk transfers
- Network modelling, management and control - need for network modelling to assess the technical issues will arise in a decentralised network
- Net-metering and smart-metering - allowing customers to offset their electricity consumption from distribution network by selling their own embedded generated electricity to the network
- Domestic and micro-generation – 'plug and play' technologies

5.2 Intermittency

Several of the embedded and renewable energy technologies, e.g. wind and solar, raise issues relating to the intermittent and variable nature of their output. This characteristic suggests that electricity from such sources can not be guaranteed. But, intermittency should not be confused with unpredictability, e.g. tidal electricity generation may be intermittent but is very predictable.

The greater the contribution of intermittent generation sources to total supply, the greater the effects of intermittency will be. However, a minority share of intermittent and variable generation should not be a significant technical constraint (Anderson and Leach, 2001).

In providing evidence to the House of Lords Select Committee on 'Electricity from Renewables' in 1999, NGC outlined the criteria that would likely trigger extra operational costs, one of which was generation subject to fluctuating greater than 20% of peak system demand. Using this criteria, 7,500MW of wind capacity could be accommodated within the system (Millborrow, 2001). However, the overall output of wind generation rarely changes enough to cause a problem for a system which must be able to cope with sudden and substantial losses of power (Hartnell, 2000). Denmark is a country where wind contributes significantly to total electricity supply and demonstrates the ability to accept significant wind generation on electricity networks (Box 11).

Box 11 Intermittent Generation Case Study – Denmark

In Denmark, the capacity of installed wind generation is 2,380 MW, the overall contribution to total electricity generation being 13%. (James & James, 2001). The contribution of wind in certain districts is as high as 80% (Hartnell, 2000). Accurate prediction systems for wind generation were identified as essential to allow electric utilities to plan for likely fossil-fuelled generation required. Prediction systems have been developed using Danish Meteorological Institute data, and have proved sufficiently accurate (Hartnell, 2000).

Variation in the location of plant is another important factor. A large network of geographically diverse wind turbines, e.g. 10 MW of capacity, would dramatically improve the predictability and reliability of output. Estimates suggest that a separation of between 5km and 10km for two wind turbines is enough for their output to be treated as independent (Grubb, 1991). However, some concerns remain as to the instances of totally calm days affecting large areas of the UK

Intermittent and variable output must also be considered in relation to the role the generation source is providing. Intermittent and variable generation sources may not be best suited as base-load plant, contributing more to ancillary services, peak demand and seasonal variations, e.g. higher demand for electricity in the winter when the wind speed tends to be higher. Alternatively, the right mix and location of intermittent and variable output, alongside appropriate aggregation, may provide opportunities for the provision of base-load output. Certain renewable energy sources show a degree of inverse correlation that may help flatten and ease the predictability of output, e.g. low winds on sunny days and high winds on overcast days. By using combinations of different variable source, hydro, storage and/or trade (interconnectors), there seems no technical reason why large systems should not derive well over half their power from variable sources (Grubb, 1997).

At high levels of intermittent contribution to overall supply (perhaps over 20%), the effects of intermittency will be more prominent. Back-up facilities and/or electricity storage have been highlighted as potential technologically and economically necessary responses to such effects (Anderson and Leach, 2001). But, although increased generation from variable renewable sources may increase the value of storage and vice versa, storage is in no sense the only answer (Grubb, 1997). Electricity storage is analysed in more detail in Section 5.4.

5.3 Embedded Generation Technologies

Some conventional generating technologies can be used at a scale appropriate to embedded and decentralised generation e.g. CCGT. But, a number of newer technologies using a variety of fuel sources are beginning to enter the fray. Embedded generation plant ranges from established technologies such as diesel generators to more recent technologies such as fuel cells. It is necessary at this juncture to analyse the important embedded generation technologies. *"Understanding the interaction of embedded generation with the power system requires an appreciation of the technology… … the characteristics of the energy sources and… … the conditions in which the embedded generation plant is operated"* (Jenkins et al, 2000).

The output of embedded generators can be classified under two, not necessarily mutually exclusive, categories. Certain embedded plant's output is intended for use on-site and tends to be in the form of combined heat and power. The other category of embedded plant generates output for the supply of third parties and is often renewable in nature, e.g. biomass or wind.

CHP and wind generation technologies are discussed in detail, a reflection of their likely major contribution in the near term to Government targets. Characteristics of other embedded and renewable technologies are overviewed in Box 12.

Combined Heat and Power (CHP)

CHP is the most significant form of embedded generation in the UK contributing 4,239 MW of electricity and 15,093 MW of thermal capacity from 1,313 sites in 1999 (Digest of United Kingdom Energy Statistics, 2000). CHP is often referred to as cogeneration, a reflection of the technology's simultaneous production of electrical and heat energy. CHP plant tends to be located on industrial sites. For example, in the UK, the chemical industry has constructed CHP plant that generates 1,180MW of electricity and 5,970MW of heat. The electricity produced is consumed by the host of the CHP plant, any surplus or deficit sold to or purchased from the local DNO. The generated heat may be utilised for industrial purposes on-site, for on-site space heating and/or linked to a local district-heating scheme.

CHP schemes are fuelled either exclusively or by a combination of gas, coal and bio-fuels such a wood chip and sewage gas. CHP expansion has appeared to avoid the locational bias evident in the previous geographical pattern of generation location. In England and Wales, the installed capacity of CHP schemes has an approximate distribution of 53% in the North and Midlands and 47% in the South (NGC SYS, 2001). Figure 6 indicates that over 80% of total generation in England and Wales is located in the North and the Midlands

The location of embedded CHP plant is defined by the location of the heat demand. CHP schemes are conventionally designed to meet the electricity and heat requirements of the host sites or defined district-heating scheme. That said, this convention is a commercial choice rather than a necessity. Should policy and economic incentives allow, CHP plant is capable of being designed to provide electricity and associated ancillary service to the distribution and transmission networks to which they are connected.

CHP efficiencies reach as high as 80%, this high efficiency rating contributing to a reduction in greenhouse gas emissions relative to traditional fossil-fuelled generating units. The UK Government has set targets for at least 10,000MWe of CHP by 2010. The potential for industrial, commercial, domestic and household CHP may be as high as 27,000MWe, more than 40% of UK supply (DETR, 1997)

Wind

The utilisation of wind energy is not new, documents suggesting that wind powered irrigation schemes were common in China as far back as 2,000 years ago (Waugh, 1994). However, it was not until the late 1970s that work began on the development of wind power to contribute large amounts of electricity to the interconnected electricity networks. Wind power, both on and offshore, is among the more developed and promising renewable energy technologies and contributed 9% of UK's renewable electricity generation in 1998 (Electricity Association, 2000). However, this still represents less than 0.2% of total generation. ETSU have estimated that onshore and offshore wind could supply 150 TWh of cost effective electricity (less than 4p/kWh) to UK electricity by 2010, over 40% of total UK electricity consumption in 2000 (ETSU, 2001).

Expansion of the industry, from the first mass production of a wind turbine in Denmark in May 1980, has been rapid. From 1993 to 2000, the market for wind turbines in Europe grew by an average of 40% per annum, total worldwide installed capacity meeting the equivalent of the electricity demands of 10.6 million households by January 2001 (James & James, 2001).

Box 12 Embedded and Renewable Energy Technologies

Fuel Cells
A fuel cell converts chemical energy in a fuel source directly to electrical energy. Although originally invented in 1839, fuel cell technology development has been slow, the main source of funding and research being the space industry. Multinational companies, including GE, Alstom and Siemens-Westinghouse are developing a variety of fuel cell technologies. Efficiencies can reach over 50%, twice that of the equivalent internal combustion device (Hart et al, 2000). They are a clean technology relative to the emissions from traditional fossil fuel generation units. Potential fuel sources included natural gas, biomass and hydrogen. They are modular by nature, outputs ranging from 5kW to 1MW per unit, being well suited to embedded and distributed generation. They allow generation to be located near to demand and can operate persistently at high capacities and efficiencies.

Renewable Technologies
Renewable energy is derived from renewable sources, i.e. the use of which does not deplete the resource. Such sources include the sun, wind, rivers, waves, tides, heat from inside the earth and the sustainable growth of crops. In the UK, Government includes landfill gas and municipal and industrial wastes in its classification of renewable sources eligible for financial support. The location and potential output of renewable electricity plant is primarily determined by the availability of the renewable resource, one of the most lucid examples being the choice of location for hydro-electric plant. Some of the key renewable energy technologies include:

Hydro-electric power
This is the most widely utilised source of renewable electricity in the world, in 1998 contributing 17.9% of the world's electricity generation and 2.3% of the world's total energy supply (IEA, 2001). 1.38% of UK electricity supply is generated from hydro-power, the majority of which is in Scotland (Digest of United Kingdom Energy Statistics, 2001).

Hydro electric schemes often involve the construction of large dams across valleys and the flooding of vast areas of land, villages and towns. This has led to widespread criticism of such large schemes from both an environmental and social perspective, best highlighted by the ongoing debate concerning the Ilisu dam project in Turkey. Lack of remaining suitable sites limits the potential in the UK. There may remain some potential for the development of small-scale hydro projects and river run-off schemes with generating capacities under 5 MW.

Solar
Solar photovoltaics (PVs) convert solar radiation into electricity. Costs remain high, but may fall alongside increased R & D, increased production and associated economies. Building integrated PV systems, e.g. building facades and solar roofs, have been identified as a key commercial application of PVs in the developed world (Hart et al, 2000).

ETSU have suggested that nearly 80% of the UK's energy needs could be met by PVs. Even on cloudy days, solar panels are capable of generating power. The cost of PVs dropped fivefold over the last 15 years and is set to fall further once a mass market is established for it (TXU Europe, 2001). Although UK solar programmes have traditionally been much smaller than other countries, some growth is anticipated from DTI's market incentives and reduced VAT. (continued over...)

Box 12 Embedded and Renewable Energy Technologies (continued from previous)

Biomass
Biomass is biological matter such as trees, grasses and agricultural crops which can, primarily through combustion, be used as fuel for the production of energy. Biomass can also be used with coal in conventional power plant. Co-firing is the most economical near-term option for introducing new biomass power generation, and lowers the air emissions from coal-fired plants (Hart et al, 2000). ETSU estimates the potential resource for energy crops and agricultural and forestry wastes is 20 TWh and 15 TWh respectively by 2010. Energy crops have also been mooted as an area of great potential for the troubled UK agricultural industry.

Wave and tidal
The UK is blessed with some of the largest wave and tidal power resources in the world. A recent report by the House of Commons Select Committee acknowledged the high capital costs and need for further R & D and highlighted that energy from waves and tides was predictable and reliable.

Micropower
Some of the most radical developments in electricity generation technologies are in the area of heat and power systems for hotels, offices, small businesses and homes (Fabian Society, 2001). Multinational companies such as ABB, BG, BP Amoco, Shell, Turbec and Capstone are investing, researching and developing fuel cells, solar photvoltaics and microturbines. Stirling engines are being developed for small-scale generation and domestic CHP systems. Capstone and BG are offering power plant down to the 10 to 100 kW level (Hart et al, 2000).

5.4 Electricity Storage

The primary use of stored energy in the central energy supply system has been for load levelling, managing the diurnal and seasonal variability of the electricity supply and demand cycles (Yehia and Karkkainen, 1988). Decentralised storage systems may also reduce losses, reduce the need for reinforcements of the transmission and distribution system, and facilitate voltage control (Anderson and Leach, 2001). Available storage technologies are detailed in Box 13.

Energy storage applications

Electricity storage can perform a number of functions from load levelling to postponement of transmission system upgrades. Electricity storage applications of particular relevance to this thesis are summarised below:

Reduction in transmission congestion

An essential element of network operation is to ensure that it is capable of transmitting power from source to use. Bottlenecks may exist at specific points on the network at which large generation sources and large demand areas are linked, and through which only a certain amount of electricity can flow at any given time period (Gandy, 2000). Storage closer to high demand areas, positioned beyond such a bottleneck and with comparatively low cost may improve flexibility and efficiency of the network.

Reliability, predictability and flexibility

These are key elements for electricity generation. The generating characteristics of wind, solar, wave and tidal tend to have few of these capabilities as detailed below:

- Wind - Gusty or calm days are inadequate for power production.
- Solar - Cloudy days and darkness at night result in a fall in output.
- Wave - Another power source dependent on changeable weather conditions.
- Tidal - Twice a day, turning of the tide leads to a reduced output.

Box 13 Electricity Storage Technologies

Pumped Hydro
Utilises the potential energy of a body of water at a relatively high elevation by linking of an upper and lower reservoir. Electrical energy is generated when the water is released to flow through turbines, the process continuously recycled when the water is pumped back up and recharges the upper reservoir. Pumped hydro storage is a mature technology characterised by long life and large capacity. The need for suitable sites is a key feature and means further construction is unlikely in the UK.

Regenesys
A new regenerative modular fuel cell technology developed by Innogy and encompassing an electro-chemical reaction involving two salt solutions (liquid electrolytes). The reversible process converts electrical energy into chemical potential energy.

Flywheels
Kinetic energy is stored in the rotational inertia of a spinning flywheel, electrical energy being generated during spin-down. Recent developments have involved using magnetic bearings and vacuum containment to minimise frictional losses and noise.

Hydrogen
The visionary no emissions end point of the low carbon economy. Output from renewable and embedded generators may be used to create hydrogen for use in fuel cells as back up to the individual generator or for transportation through pipelines for central back-up and/or for transport demands.

Batteries
Electrochemical storage by creating electrically charged ions in cells, the chemical energy being converted back into electrical energy in direct current form.

Superconducting Magnetism
DC current is circulated through a superconducting coil with energy stored in a magnetic field.

Compressed Air
Power is used to compress air that is stored underground, commonly in a rock or salt cavern. The air is released either directly through a turbine to generate electricity or more efficiently into a combustion chamber with fuel, where it is ignited and expanded through a turbine.

Capacitors
Often used to store a relatively small amount of electrical energy in electronic circuitry. More high-powered capacitors have been developed increasing potential uses in power electronics.

Source: Aplin, Butler and Turner, 2001

Storage can be used to counteract the inherent intermittent nature of electricity generation by renewable sources. Attachment of energy storage to renewable energy sources can result in a more reliable, predictable and flexible supply

Store when cheap, sell when high

An issue with renewable energy is the current comparative expensive cost of generation. Storage may be used to take advantage of price and cost differences by charging up with surplus electricity at low cost times and discharging in peak cost periods. The process of storing electricity when demand and costs are low and selling when the price of electricity matches the cost of renewable sources of power could make projects more commercially attractive.

However, storage could defer investment in new generation by allowing polluting power stations to store electricity and sell when the price is high. Thus, energy storage may slow the progression to high efficiency technology and renewable energy, as new power generator construction is deferred.

Storage for combined heat and power systems (CHP)
CHP systems generate heat and power concurrently. Both may not necessarily be needed at the same time and there may be periods whereby there is excess heat or power production. Excess is a waste of valuable resources and impacts on the overall cost of energy production.

Incorporating thermal and energy storage into CHP systems separates the generation and utilisation of heat and power. This would have the impact of raising the energy service efficiency of CHP to even greater levels. High efficiency storage systems should ultimately lower the cost of supply.

5.5 Discussion

Although there is no clear definition of what constitutes embedded generation, a number of key characteristics can be identified. These include connection to the distribution network, low output capacities up to 100MW and lack of central planning. Some existing electricity generating technologies can be scaled down to the embedded level. However, in line with environmental and social policy objectives and trends, the newer technologies such as small-scale gas fired CHP, fuel cells, micro-turbines and renewables are the focus of much attention and research.

The inherent intermittent nature of many of the renewable technologies has been of great concern. Many studies have focussed on wind technologies - seen as the most cost effective renewable technology in the near to medium term (eg. Fabian Society, 2001). The capabilities of the existing networks to accept intermittent wind generation, impacts of diversity of location, and predicting outputs on the basis of meteorological data have all been assessed. Outputs of these studies suggest that the UK networks are capable of accepting up to at least 10% contribution to UK electricity supply from wind, all other things being equal.

Integrating wind capacity beyond 10% appears to be dependent on a number of factors including the array of technologies utilised, abilities to predict outputs from intermittent sources, the progress of electricity storage technologies and the development of actively managed transmission and distribution networks. As the number of different components in the network increase, so does the need for more sophisticated control and monitoring at the distribution level.

The next chapter identifies and analyses the key issues that will need to be addressed for electricity transmission and distribution to support a greater proportion of intermittent renewable and embedded electricity generation. The chapter will highlight and discuss the role of government policy, the regulatory and commercial frameworks, and technical requirements in moving to a ‘distributed energy future’.

6 Identification and Analysis of Key Issues

Chapters 2, 3 and 4 considered the historical development of the UK electricity supply industry and the evolution of transmission and distribution networks. Chapter 5 examined embedded and intermittent generation, electricity storage technologies, and discussed the impacts of these technologies on existing transmission and distribution network operation.

Looking to the future, this chapter identifies and analyses the key issues that electricity networks will need to address as a result of increased intermittent renewable and embedded electricity generation. These issues were first identified in the literature review, initial consultations (Annex One) and through the 'Group Review' held on 19 July 2001 (Annex Four). Further analysis and synthesis was then conducted.

A number of issues pertaining to the interactions between transmission and distribution networks will arise as the contribution of embedded and intermittent renewables increase. In the period to 2010 the current Government targets for renewables and CHP, if achieved or approached, may result in excess of 20-25GW of total capacity connected to the distribution networks. This level of capacity cannot be accommodated on the currently configured networks without significant change. (ETSU, 2001)

It is therefore important that the impacts of increased embedded generation on transmission and distribution networks in the UK are not viewed in isolation. Much of new renewable energy and CHP plant needed to meet the Government's targets may be of small capacity, and find it most cost-effective to connect to lower voltage distribution networks. The trend towards having a larger proportion of embedded and renewable generation will therefore have implications for the whole of the UK ESI, in particular the configuration and operation of distribution and transmission networks. These implications will be examined under three broad headings:

- **Strategic Issues** – Vision, Regulation and Charging, and Skills and Innovation
- **Commercial and Market Issues** - Facilitation of Competition; and Costs and Benefits of Embedded Generation
- **Technical Issues** - System Integrity Requirements, System Integrity Methods, and Distribution

6.1 Strategic Issues

Vision

The 'Group Review' highlighted that businesses within the UK ESI are concerned that there is no clear direction for the future development of their industry (Annex Four). As detailed in this thesis, many commentators and analysts expect an increased contribution from small scale, decentralised, low carbon generating technologies and an expansion of some larger scale renewables such as offshore wind and biomass. If this long-term vision is to be realised, there is a need to supplement the current perspective of five to seven years, and to allow longer time horizons for strategic planning.

Over the next few decades, certain technology trends may bring geographical generation and demand patterns into balance. For instance, as detailed in Chapter 5, embedded generation tends to be more or less evenly distributed across the country. Thus, a high market penetration for fuel cells, micro-CHP and CHP district-heating systems would bring electricity generation adjacent to where it is consumed in all areas of the country through the transmission of their fuel source by the existing natural gas pipeline infrastructure.

However, other technologies may maintain or even increase the need for bulk electricity transfers. Renewable energy resources, such as wind and wave power, are most abundant in the north and west of the country while demand is highest in the south and east. Rural agricultural or forestry fuel sources are required for biomass power stations. Proposed interconnection expansion may allow access to new hydro, wind and geothermal resources (ETSU, 2001).

Electricity network issues could be made more explicit in Government energy policy considerations, e.g. security of supply concerns. There are real issues that need addressing and the ESI stakeholders need to recognise the reality of obstacles, challenges, problems and each others positions. Sharing and pooling resources across the industry to address key issues is an essential response to the demands and issues evident in the liberalised ESI.

There remains a tension between free market principles and the desire for long term planning and co-ordination. Market based governance systems are emerging in a variety of forms, but all require that individuals play a greater role, and that governments relinquish actions to markets where feasible (Weinberg, 2001). Any long-term vision must take account of dichotomy between central planning and liberalised markets.

Government and policy makers need to develop a vision of the long term (2050), define desired outcomes and to construct the regulatory and financial incentives required to achieve them. The management of transmission and distribution networks involves 30-40 year investment and infrastructure decisions, set against short-term transitional electricity generation markets. The difficulty in aligning the two is apparent. The current Energy Review, due to report by the end of 2001, provides the opportunity to develop a vision of what electricity networks will do and be like in the future and how users may be charged for access to them. The development of a coherent structure and forum across industry and government to facilitate such a transition is therefore important (EGWG, 2001).

Regulation and Charging

Long term transmission and distribution network planning and investments run counter to the shorter term generation investments. Certainty of the regulatory regime is another critical factor influencing investor decisions. Reviewing industry price controls every five years provide a short-term outlook for long-term asset and investment decisions. The Group Review agreed that a five-year regulatory framework is not appropriate for 30-40 year assets (Annex Four). That said, one of the projected characteristics of decentralised, small-scale generation technologies electricity is that they do not require such long term planning nor involve large capital investments. The question remains, however, how to regulate without knowing what your end goal is?

One approach to delivering joined-up policy goals and addressing uncertainty as to future policy and regulatory changes is to move to 'Performance Based Regulation' (PBR). Beyond simply setting performance standards (see Section 4.3) and penalising for non-compliance, this would provide a positive incentive for DNOs by linking revenues to performance measures - customer value through fewer interruptions, stable voltages, speedy response to queries or requests for work or connection, low accident rates etc - rather than the size of the capital asset base.

Many have observed, including EGWG, that the regulatory regime based on asset value is inappropriate for meeting environmental and social objectives (EGWG, 2001). *"The primary drive within the restructured England and Wales electricity system has been for economic efficiency (through competition); with much less concern being placed on the social obligations of equity and security of supply"* (Amin, 2000). PBR would remove the DNO guarantee of a return on capital investments, and provide incentives for them to reach high levels of performance at lowest cost. This may therefore encourage novel forms of system support, including embedded generation, provided such alternatives were cheaper than infrastructure investments.

Presently, 2% of DNO's income is based on performance criteria. It is thought that a move beyond 20% is needed to ensure that the incentives for embedded generation are in place (Fabian Society, 2001). PBR could be introduced at the next Distribution Price Control

Review in 2005. EGWG and others have suggested that there appears sufficient justification to start the ball rolling and to consider introducing appropriate measures as soon as is possible prior to the full review in 2005 (EGWG, 2001).

While networks need to develop to allow flexibility, present distribution networks are on the whole, simple and passive. The need for clearer price structures and signals to drive change is evident. One of the key regulatory issues identified by EGWG is how embedded generators are charged for access and use of the distribution and transmission networks is a very complex area. Although discussed in more detail later in this chapter, at this point it is important to note that consistent and long term charging structures need to be established. Issues must be prioritised, focussing initially on how DNOs charge for services. Incentives and profits of DNOs must also be considered.

Skills and Innovation

Skill shortages were highlighted in the 'Group Review' (Annex Four) as being of great concern with only four British universities offering power engineering courses. The decentralised electricity system would increasingly demand such skills and the Government, industry and academia must develop appropriate incentives and information provision to bridge this potential skills shortage

Research and Development (R & D) has been noted as another area for concern (Group Review, 2001 and RCEP, 2000). DNOs are the major group who must define R & D requirements yet appear reluctant to pursue embedded generation as an option. ETSU concluded that the requirements for R & D have been clouded by the commercial and regulatory frameworks. Companies in the UK have technology under development that could enable embedded generation to play a more significant role in helping the DNOs operate a safe and cost effective network. However, without clear indications of interest from DNOs these technology providers are reluctant to invest in developing potential solutions (ETSU, 2001). Some government funded R & D is available through the Engineering and Physical Science Research Council 'New and Renewable Energy Programme' which includes elements related to electricity networks.

6.2 Commercial and Market Issues

Facilitation of Competition

The Utilities Act 2000 requires DNOs to facilitate competition in electricity generation and supply. Effective information flows, clear market entry processes, and equitable transparent terms for connection and use of the distribution system are central to such a requirement.

The existing regulatory framework does not easily allow the financial and operational benefits of embedded generation to DNOs to be recognised. Indeed, embedded generation often results in additional costs to DNOs rather than providing business development opportunities. The regulatory environment could be re-structured to allow DNOs to develop their business through increased load connections and collect revenue through Use of System charges. DNOs will do what is asked, provided the correct incentives are in place to motivate them (Group Review, 2001).

New Electricity Trading Arrangements (NETA)

The immediate impacts of the introduction of NETA on embedded and renewable generation have been widely debated, and will be central to a report to be produced by Ofgem and DTI in August 2001. To summarise the debate, NETA's Balancing and Settlement Code places penalties on suppliers for failing to match their contracted levels of output, either above or below. Generators that are 'out of balance' are required to 'top-up' or 'spill' via the Balancing Mechanism and are subject to penalty charges. This clearly impacts on generators who might have difficulty in accurately controlling and predicting output, such as some renewable and embedded generators.

NETA has moved the goalposts to reflect more the economic benefits of certain types of generation. The Group Review concurred with the concern regarding the impacts of NETA on technologies with variable outputs. It also acknowledged that, despite Government and Ofgem objectives and responsibilities, NETA does not attempt to address the social or environmental aspects of energy policy (Annex Four). NETA may continue to remain defective for smaller market players with less reliable outputs, who will continue to be exposed to the Balancing and Settlement Code. Large generators with access to diverse forms of generation should be able to bear the risk of the variable output of renewable and other plant.

In relation to the transmission network, the role of the NGC is more focussed on security of supply within their system balancing responsibilities. The role of transmission is very much changed in the liberalised market, now more a facilitator than a constructor or maintainer of the network.

The current market appears unlikely to be conducive to meeting renewable and CHP targets, so meeting these targets may require Government intervention. One option would be to pull CHP and renewable generators out of NETA. CHP and renewable technologies are likely to need more than the oft used 'level playing field' to meet the targets and for DNOs to become renewable and embedded friendly. Another option may be facilitating the development of aggregation (see below) and supporting energy storage technologies to smooth the variable outputs of some technologies (see Chapter 5). It is important to note that tweaking the market by government is much more transparent in the liberalised market and will require clear justification.

Aggregation

The concept of 'aggregation' or brokerage has been raised in the debates concerning the recent California energy crisis (Brooks and Butler, 2001). Electricity supply problems in California have been of great concern to industry, particular for the hi-tech, high-energy users located in the state. Many of these industrial users responded to past fears of supply security by purchasing on-site, off-grid back-up generation capability, often in the form of diesel generators. Such generation is restricted through permits and has tended to lay idle for much of the year, actual utilisation falling well under that permitted. Companies have begun to establish a niche in the market through aggregating this unused capacity from a number of sources and making it available to the grid. The DNOs could take this aggregator role in the UK, taking excess output from CHP and other small-scale generating technologies. Other potential 'aggregators' include third party 'Trading Co-operatives'.

Such developments are advantageous to owners of embedded generation, as long as their security of supply is guaranteed, as it offers them access to another income stream without too much administrative time and cost. Such developments could make embedded and distributed energy a much more viable and attractive proposition. Policies designed to ease aggregator access to electricity networks will have a significant impact on such developments. Indeed, some have suggested that aggregation and generation co-operatives might be a market response by renewable and CHP generators.

Providing Incentives to Distribution Network Operators

Provided with suitable incentives, DNOs will invest in their network to augment the potential for embedded generation connection. They could strengthen the network to maintain acceptable fault levels and increase the scope for connecting new generation. Amending the network's configuration may allow more flexible operation of embedded generation under fault conditions. New technology such as super-conducting fault level limiters, energy storage technologies and household technologies such as energy efficient lighting and appliances, PV, fuel cell, Stirling Engine, etc could all be encouraged by DNOs through links with Government Departments, the Energy Savings Trust, and the Energy Efficiency Commitments of electricity supply companies.

DNOs are ideally placed to play a significant role in developing the commercial and technological shift required to encourage the expansion of renewable and embedded generation, in partnership with other agencies. The right commercial and regulatory frameworks need to be in place to facilitate this.

Minimising Red Tape on Embedded Generation Projects

Small-scale generators seek as simple contractual arrangements as possible. The existing arrangements often require embedded generators to enter into contractual relationships with both the NGC and DNOs. The EGWG report highlighted the need for NGC to adapt their contractual agreements with DNOs so that embedded generators may choose to have a single point of contact with their host DNO, and choose whether to enter into agreement with NGC.

Licence conditions would need to be developed for DNOs to link to NGC. One point of contact for embedded generators concerning connection would be provided, the DNO undertaking all liaisons with NGC. Such developments could facilitate DNOs taking on the aggregator role discussed above, and measures to stimulate aggregation require consideration.

Provision of Information

The EGWG report highlighted the importance of information and transparency in facilitating the development of embedded generation. Information regarding connection points and the effect of location on likely connection charges is central to decisions on the location of embedded plant. Developers of embedded generation have been concerned that the information made available to them is erratic, inadequate and overly complex (EGWG, 2001). Effective information flows, accessible processes for market entry and transparent terms for connection and use of networks are all key factors.

The Utilities Act 2000 requires DNOs to publish network development statements, intended to inform the market place, enable developers to identify potential business opportunities, and provide transparent costs for network connections.

EGWG acknowledged that an appropriate balance between the value and costs of providing the information must be established (EGWG, 2001). Comparisons are readily made with the information provided in NGC's Seven Year Statement (SYS) which provides information on system opportunities, policies on connection and use of system charging, and general approaches to facilitating new market entrants. These were cited by the EGWG as good practice and worthy of consideration for addressing the issues that are emerging at the distribution level with respect to embedded generation. (EGWG, 2001)

However, acknowledgement must be given to the relatively increased complexity of distribution systems, their extensive length, varied voltage levels, dynamic demand profiles and variety.

At the very least, however, a consistent approach across DNOs to the provision of information and the connection application process would assist embedded generation development. General connection guidelines for embedded generation that clarify the roles of developers and DNOs and set standards, both for the quality of information submitted by developers and the quality of the response from DNOs, would be another encouraging development.

Cost and Benefits of Embedded Generation

Distribution Charging Principles

At present, generator customers incur 'deep' connection charges. Such charges include the costs of the direct connection and any associated costs of reinforcing the distribution network as far as the local grid supply point. In comparison, demand customers pay relatively shallow ('shallowish') connection charges along with Distribution Use of System (DUoS) charges.

The current arrangements present a significant financial barrier to the connection of new generation. A generator may only need a portion of the minimum reinforcement for which it must pay. This produces clear inequities between first and subsequent generator connections. EGWG suggested that a move towards sharing more of the benefits with others, such as existing and future customers and future embedded generators is required.

Therefore, the duty on DNOs to facilitate competition in generation may require significant amendments to be made to the way in which DNOs charge for the connection to and use of distribution networks. A number of charging options exist and include:

- 'Shallow' charges, whereby the generator pays only for the connection to the distribution network at the nearest suitable point. Such charges are similar to connection charges applied to generators connecting to the transmission network.
- 'Shallowish' charges, whereby the generator pays for connection as above plus any reinforcement triggered by the connection to the distribution network at the same voltage as the connection and one voltage level above that of the connection. This structure is analogous to the connection charges applied to load customers connecting to distribution networks.

The introduction of 'shallow' and 'shallowish' charges would reduce the capital cost incurred and encourage additional connections of embedded plant. EGWG acknowledged that ‘shallow’ charges would likely to be more effective than ‘shallowish’ charges in this respect.

An important consideration is the potential weakening of locational signals that are present in the existing ’deep’ charging structure. ‘Shallow’ charging provides no locational signal whereas ’shallowish’ charges may place significant costs on other users. But, varied charges between locations could provide incentives and disincentives to plant location. Discussions in the Group Review reflected on the option of introducing a rationed or auctioned subsidy to fund reinforcement, thereby lessening connection charges, retaining a locational signal in the price, and building infrastructure so that the first-comer doesn’t pay for the second-comer’s “free ride” (Annex Four).

The above charging options may require that reinforcement costs be met through other charges. Demand customers could pay all reinforcement costs through increased Demand Use of System charges, although significant embedded generation would result in significant additional costs and raise inequity concerns. Generation customers could pay all reinforcement costs for generators through a new generator entry charge. Alternatively, load and generation customers could pay reinforcement costs through entry and exit charges. Such an option is equitable while providing significant encouragement overall to the connection of new embedded generation. It could also provide the locational signals to generators and customers lost through a move to a new charging regime.

EGWG highlighted that, regardless of any amendments made to the charging regime, analysis and assessment of the potential short and long term impacts of options for changes is required (EGWG, 2001). Such analysis should encompass existing embedded generators that have already paid deep connection charges.

Recognising the Benefits of Embedded Generation

Embedded generation can provide benefits to customers through increased reliability, uninterruptible service, energy cost savings and onsite efficiencies (NREL, 2000). Similarly, there are a number of potential benefits to the distribution network in terms of lower transmission and distribution losses and reduced capital requirements.

For instance, the Transmission Network Use of System charging procedures provide locational signals as to the most economic areas for development from a transmission system point of view. Embedded generators may also receive the benefit of the avoided demand charges when meeting demand of local suppliers, such benefits being of higher value in the south of the country. The potential for improving the economic efficiency of locational signals is currently being undertaken as part of a wider review of transmission access arrangements currently led by Ofgem.

However, it is not enough simply to recognise the true value of embedded generation. The regulatory framework must reward this value (see charging structures).

6.3 Technical Issues

System Integrity Requirements

Security of Supply

Security of supply is a key element of Government energy policy. Indeed, committees in the House of Commons and House of Lords have recently announced their intention to examine energy security. The current transmission system contributes to security of supply by ensuring that demand in a specific part of the country is not solely dependent on the availability of generating plant located within that area. This allows for the opportunity for any available generation, regardless of location, to be utilised to meet demand.

Therefore, the transmission system therefore will be likely to continue to play an integral role in the future electricity system, even with higher penetration of renewables, CHP and embedded generation. But there are examples of embedded generation being used to provide generation reserve to a large interconnected system. In France, EdF can call on 610 MW of distributed diesel generators for such a role (Jenkins et al, 2000).

Existing methods for connecting embedded generation ensure maintenance of the security of the overall network. But this is at a significant cost to developers. Managing the network differently may offer opportunities for amending the methods and recognising that operation of embedded generation in ‘island mode’ could bring security benefits under outage conditions. ‘Islanded’ operation refers to embedded generators operating disconnected from the distribution and transmission networks, supporting local supplies in the event of network failure. Such an arrangement, albeit on a localised basis, could significantly reduce frequencies and extent of ’power-cuts’. The maintenance of voltage, frequency and network safety under such operating conditions would likely remain with the DNOs and requires consideration.

EGWG recommended that, in the short term, measures under the existing standards require clarification to allow recognition of the contribution of embedded generation to network security and performance, attaching a target date of January 2003 to such a review (EGWG, 2001). Similarly, EGWG recommended a Health and Safety Executive and

DTI review of the implications of connecting widespread embedded generation for the safety of distribution network operation. With a potentially vast number of generators being connected to the system, safeguards are needed to ensure DNOs can be confident that a particular part of distribution network is 'dead' in the event of circuit outages.

Embedded and Renewable Generation and Ancillary Services

Facilitating and encouraging the development of open ancillary service markets that maintain the integrity of the transmission network (Box 6) may be essential in addressing longer-term technical issues that may arise from a larger proportion of wind and other intermittent renewables. The NGC have established arrangements that allow small and decentralised generators to provide reserve and frequency response through the use of aggregating agents. The EGWG suggestion that DNOs should facilitate local ancillary service markets is an important development.

Encouragement should be given to the most cost-effective provision of co-ordinating and controlling the network and ensuring national standards for quality of supply. It follows that this should ensure additional requirements can be provided in respect of reserve and response that may be made necessary to accommodate large amounts of intermittent wind generation. They may also allow the displacement of some of the large grid-connected power stations that currently provide these services without any impact on system security. Local ancillary markets would also provide embedded generation with additional income streams.

It is essential that the continuing availability of ancillary services in the longer-term be ensured as embedded generators progressively displace present providers. The same aggregator agents as discussed above could assist smaller participants to provide such services to the required capacity and levels of dependability. As identified by EGWG, DNOs may in future perform this aggregating role as the facilitator of markets to obtain services directly for the distribution network or to sell on to the transmission network.

Intermittent Generation

The electricity system in the UK consists of diverse generating plants linked by an interconnected network. This interconnected network is capable of integrating a substantial amount of intermittent renewable generation without adapting operational procedures. For instance, the reliability of existing plant, particularly older generating units, may be more prone to breakdown and delays in start up. The psuedo-intermittent nature of such plant is already factored into the integrated system.

The potential benefits of storage (regenysys, hydrogen, etc.) to intermittency has been discussed previously in Chapter 5. However, some commentators suggest that there is no technical nor economic need for dedicated electricity storage linked to intermittent renewable capacity because fluctuations of energy output are lower than often assumed (Hartnell, 2000).

For instance, if the wind is not blowing in one location, it is likely to be blowing elsewhere. Thus, geographically dispersed wind generation may resolve overall concerns over intermittency. But, such impacts may be limited in an individual contract market such as NETA whereby individual generators face the problems of intermittent generation of individual wind farms. The development of wind co-operatives could be a response to such market exposure. The geographical distribution of intermittent generation may result in more localised impacts on transmission and distribution networks. For example, large off-shore wind capacity in the north of Scotland would have a significant impact on the nature and available capacity of local transmission and distribution networks.

As stated previously, intermittency should not be confused with unpredictability. Studies have been undertaken into predicting wind generation output. Research has shown 95% predictability for output 24 hours ahead, with suggested further gains to come (ISET, 2001).

NGC have examined the interaction of renewables, CHP and other embedded generation with the transmission network and system operation activities. NGC have expressed confidence that transmission related issues will not become a barrier to accommodating the amount of renewables or CHP generation necessary to meet the Government's 2010 targets (HoC Environmental Audit Committee, 2001). They further conclude that, depending on the location and type of technology, the transmission network might be able to accommodate a greater proportion of renewables, CHP or other embedded generation than that specified in the 2010 targets. NGC do not perceive potential problems with a 10% contribution from wind generation nor insurmountable problems with increased levels (Annex Four).

System Integrity Methods

Flows between the Transmission and Distribution Networks

If the expectation is for an increasing proportion of embedded generation, electricity flows from the transmission to the distribution networks will likely be reduced. This may delay the need for transmission network reinforcement, although this is unlikely to remove the need for the substations/grid supply points at these transmission-distribution interfaces.

Such interfaces may still be required to balance the fluctuation between generation and demand in specific parts of the distribution network from minute to minute.

There is the potential for embedded generation to contribute to such a level that distribution networks may be in a position to export electricity to the transmission system. Grid reinforcement would only be necessary at appropriate interfaces should exports to the transmission system exceed the existing transmission capacity or compromise quality of supply.

Bulk Power Transfers

Reduced electricity flows from the transmission to distribution networks as a result of increased penetration of embedded generation development will not necessarily result in a corresponding reduction in the bulk transfers across the transmission network. Bulk transfers are more dependent on the relationship between the location of generation and demand, including base and peak demand patterns.

As discussed in Section 4.4 and shown in Figure 7, existing patterns of generation and demand produce a net north to south power transfer across the transmission network of up to 10,000MW (NGC, 2001). This pattern represents the excess generation capacity located in the north (near coal and gas fuel supplies) relative to demand in that area. Thus, this excess capacity is exported to meet demand in the south. Such bulk transfer patterns are evident throughout the year. As demand falls from its winter peak, it tends to be the output of the more expensive generation units in the south that are switched off first, thus maintaining bulk transfer patterns.

These bulk transfer patterns indicate that new embedded generation units in the north may only serve to displace higher cost generation in the south. This would result in increased bulk system transfers in the same way as new transmission system connected generation in the north. New embedded generation in the south may likely displace older and expensive southern generation leaving north to south bulk power flows unchanged.

NGC suggest that for these reasons, bulk transfers on the transmission system are likely to continue. This situation will remain until such a time that there is a significant shift towards an improved regional balance between demand and generation, whether embedded or directly connected to the transmission network. Taking the existing situation, such a shift would require a significant increase in generation in the south.

Charges for use of the transmission system have been structured to provide incentives for generation, using the transmission system to locate in the south of the country. Despite such incentives, generation continues to locate in the north. Embedded generators are not liable for these charges and have not received a direct incentive to locate in the south. But, embedded generators may enable suppliers to avoid payments of transmission demand-related use of system charges. Such charges are higher in the south than in the north, thus offering an indirect incentive for embedded generators to locate in the south.

In addition, the remote and low demand locations of many of the existing renewable energy technologies, e.g. biomass in the countryside, offshore and onshore wind in Northern Scotland, etc., will maintain the need for bulk transfers at high voltages. Indeed, the NGC are already in discussions with wind developers about arrangements for transmission connections and charges.

Network Modelling, Management and Control

An increasingly active network with multi-generator connections will require complex modelling and simulation tools to allow accurate evaluation. ETSU has identified the need for network modelling to assess the number of technical issues that will arise in a decentralised network (ETSU, 2001).

ETSU suggested that in the first instance, effort should focus on integrating embedded plant through the automation. With better modelling to understand the impacts on network operation, intelligent and automated management and control equipment would facilitate the development of embedded technologies. (ETSU, 2001). Automatic adjustments could be made to the network to maintain the system within the required limits, including the dispatch of embedded plant.

Distribution

Development of Active Distribution Networks

The Group review concluded that in the short to medium term, one of the biggest technical issues facing DNOs relates to the development of active, rather than passive distribution networks (Annex Four). Traditionally, DNOs have focussed on passively serving demand, building and maintaining adequate infrastructure in order to receive power from the transmission network for delivery to customers. The passive nature of distribution networks has been formalised and encouraged through design codes, price controls, incentives and the regulatory environment. The role of the responsive and active management and matching of demand and generation has been taken by the transmission network operator.

However, increased embedded generation would require active management of distribution networks involving a stepped introduction to adapt to new management, technological and administrative demands. Monitoring and control systems would require development to ensure effective communication and control of fault levels, quality of supply, security of supply and safety aspects. The impacts of a shift from uni-directional to bi-directional electricity flow have raised safety concerns and are new territory for many DNOs.

Central to the evolution of active distribution networks remains the market mechanisms and regulatory environment in which DNOs operate. At the distribution level, connection agreements and contractual frameworks need to ensure equitable treatment of embedded generation and central generation alike, truly recognising the cost and benefits of both.

In the near future, as networks are designed with a view to increasingly integrating embedded generation, so the degree and benefits of active management will increase. However, to date the DNOs may have stressed the costs and technological limitations of the shift towards active distribution networks, ahead of the potential benefits.

Developing active distribution systems would require Ofgem and Government support. For instance, investment will be needed to reconfigure the distribution network. But there is some debate over the time-scale for the required investment (ETSU, 2001 and Annex Four). Should embedded and intermittent generation expand rapidly, large scale investment will be needed quickly, whereas incremental investment could be sufficient for a gradual transition.

Net-metering and Smart-metering

'Net-metering' can be defined as using electricity networks as a kind of battery with fair prices in both directions to improve the economics of small plant (Financial Times, 10 August 2000). Net-metering allows customers to offset their electricity consumption originating from the transmission and distribution network by selling their own generated electricity to the network. Box 14 provides details of a net-metering case study involving TXU Europe and Greenpeace.

Small-scale generators can sell back to the distribution network. The payment they receive should reflect the costs of operating the distribution network, distribution losses, information management, co-ordinating supply and ensuring quality of supply, and the benefits, e.g. removal of need for network reinforcement, provision of local ancillary services. The potential costs associated with the metering and charging alternatives need to be established. These include installation, meter reading, developing and implementing new demand profiles for domestic and micro-scale generation, bi-directional metering, implementing half-hourly metering, and addressing the stranded costs of existing metering assets.

Box 14 Net-metering Case Study – TXU Europe and Greenpeace

A children's adventure playground in East London, powered by solar photovoltaics, has entered into a groundbreaking deal put together by Eastern Energy, a TXU company, with the support of Greenpeace.

The Eastern Energy agreement means that the playground can be paid the same price for the surplus electricity they 'export' to the national grid during daylight hours as they pay for any conventional electricity they 'import'. The playground will be paid 5.51p a unit for the electricity it exports via Eastern Energy and received £250 in compensation, as it did not receive any payment from its old electricity supplier for power previously exported.

Net metering works by the customers' standard electricity meter being modified to record the number of exported units. When the meter is read, imported units are charged for, and a rebate is paid to the customer for units that are exported, at the same unit price.

The solar net contract is open to the first 1000 domestic customer applicants who either have existing solar panels or who wish to install them. Through the contract, TXU agrees to pay the customer the same unit price for the exported electricity as that charged per the tariff type and payment method used to purchase electricity from Eastern Energy. This price match will initially be offered for a five-year period to April 2005.

Source: TXU Europe, 2001

Metering should be economic to install and be linked to tariff arrangements that allow all the parties concerned to measure or estimate with confidence the information they need. The tariff level is an important factor for domestic feeds into grid. Although there are a number of potential methods, it is essential to ensure that domestic generators get paid.

Metering options include (EGWG, 2001):

- The retention of one way meters linked to tariffs based on demand profiles that estimate typical flows in both directions. Although this would minimise installation costs, administration costs may be high and profiling may not encourage reductions in energy consumption once the profile has been established
- Bi-directional meters that operate with a net energy tariff or a profiled tariff which could estimate typical energy flows in both directions
- Import-export meters that provide measurable information on power flows in both directions thereby reducing the reliance on estimated demand profiles.

Some have suggested that not including legislation to encourage net or dual metering in the Utilities Act 2000 was a missed opportunity to encourage the development of domestic micro-generation technologies (Fabians, 2001). Nevertheless, the TXU case study (Box 10) shows the construction of net-metering arrangements is possible in the current commercial and regulatory frameworks.

Domestic and Micro-Generation and 'Plug and Play'

The development and application of technologies such as photovoltaics, fuel cells, micro turbines and Stirling engines is expected to lead to a significant growth in domestic and commercial generation. Such domestic or micro generation could meet most of a typical household demand.

The impact of widespread micro CHP or PV systems on the demand and generation profiles of distribution networks would be significant. A distribution network may have no net electricity flow over certain times of the day, its role reduced to balancing the networks and providing the appropriate level of backup capacity and security. Such a development would have implications, not only for DNOs, but also for suppliers, generators of all sizes, and the transmission operator.

That said, the development of domestic and micro generation is not without its pitfalls and complications. A number of technical and financial decisions will need to be addressed. For instance, simpler and transparent connection and payment structures need to be established in a manner that is appropriate to micro-scale generation technology. Payment mechanisms, via metering, profiles and fixed charges, for use of the distribution system, selling exports and buying imported electricity must be developed (see above).

Most forms of micro-generation must comply with strict engineering standards that were designed for larger generation plant. Work needs to be initiated to construct and apply appropriate yet simpler engineering standards for micro-generation (3rd I-P M, 2001). Such standards would need to be suitable for mass produced equipment and take fully into account important security and safety issues. Producing such standards would aid the development of what have been termed 'plug and play' small-scale generation units.

6.4 UK ESI Strengths and Weaknesses

Work undertaken by ETSU has identified a number of strengths of the UK ESI relevant to the development of embedded generation, many of which are equally relevant to renewable generation technologies (Box 15). However, as identified within this thesis and by ETSU, there are a number of weaknesses across the UK ESI that, if not addressed, may seriously limit options for the development of embedded and renewable generation technologies. These weaknesses may also limit the ability of the UK ESI to take advantage of the considerable UK and overseas business opportunities.

Box 15 Embedded Generation and UK ESI Strengths and Weaknesses

Strengths

- Strong expertise in small gas turbine and generation technologies
- Strong science & technology and consultancy base
- Internationally recognised university departments in power engineering
- Internationally recognised consultancy in commercial and technical issues associated with embedded generation
- A large number of experienced project developers

Weaknesses

- Limited number of UK manufacturers of network hardware
- Limited ESI research capability in the UK (Section 6.1)
- Unhelpful regulation and lack of incentives on Distribution Network Operators to do other than invest in distribution assets
- New trading arrangements that do not explicitly consider embedded generation
- The risk averse character of many utilities
- Lack of support for demonstration and deployment of new technologies
- Slow rate of renewables development
- Ageing distribution infrastructure
- Lack of industry forums to debate issues and agree methods of approach

Source: ETSU, 2001

Chapter 7 will outline the key issues related to the implications of increased embedded and intermittent renewable generation on transmission and distribution networks and highlight recommendations for actions to address these issues. The broad headings used in this chapter will be retained in this chapter.

7 Discussion and Conclusions

This chapter will outline the key issues related to the implications of increased embedded and intermittent renewable generation on transmission and distribution networks. The broad headings used in Chapter 6 are retained. Key conclusions and recommendations are highlighted in bold text.

7.1 Strategic Issues

Central to the development of flexible and active electricity networks is a clear vision of the 'Energy Future'. UK Energy Policy responsibilities are split across a wide range of departments. As evident from the 'Group Review', key stakeholders within the UK ESI are concerned about the lack of focus and direction as to the future nature of their industry (Annex Four). Thus, **there is a clear need for the Government and the ESI to establish its vision of electricity systems in the future and to put in place the appropriate regulatory and commercial frameworks to achieve this.** The Government should move away from the short-term perspective and consider the 2010 targets and beyond.

Such an opportunity should not be missed by the Energy Review that is currently taking place. The fear of 'picking winners' is justified and public money should not unnecessarily be diverted towards technologies that will not be successful. *" Policy makers wishing to promote these technologies need to recognise the importance of supporting the industry during these fledgling years for the sake of longer term development of the industry"* (Amin, 2000). Establishing a vision does not necessarily entail 'picking winners'. **If the vision is for a low carbon, decentralised energy future operating in a liberalised market, the key to success is putting in place appropriate and flexible regulatory and commercial frameworks. The market can decide which technologies may be successful.**

Running alongside the fear of 'picking winners' is the concept of developing a 'level playing field' through the regulatory and commercial structures. This level playing field is an equitable regulatory and commercial framework within which transmission and distribution connected generation can compete fairly and that is flexible to allow for future developments in the generation mix. Although liberalised in 1989, the current UK ESI structure still represents over 40 years of public investment and Government support. **A truly level-playing field would factor in the historical support provided to the ESI by offering funding and support for newer technologies that may prove beneficial in developing the transmission, distribution and generation elements of the 'Energy Future'.**

The lack of focus and direction in UK Energy Policy is not aided by the split in responsibilities and priorities across Government departments. Some have called for the creation of a Sustainable Energy Agency linked to the Energy Minister and focussed on driving cross-departmental agendas related to CO_2 emissions reductions, fuel poverty strategies, UK business development and so on (Fabian Society, 2001). **A Sustainable Energy Agency would be central to the development of a coherent structure across industry and government to facilitate the transition.**

Transmission and distribution networks need to develop to allow flexibility, yet present distribution networks are on the whole, simple and passive. The need for clearer price structures and signals to drive change is evident. Long term transmission and distribution network planning and investments run counter to the short-term generation transitions. Certainty of the regulatory regime is another critical factor. **Regulation must be designed and structured to deliver joined-up policy goals and address uncertainty as to future policy and regulatory changes.**

The introduction of performance based regulation would remove the DNO guarantee of a return on capital investments and provide incentives for them to reach high levels of performance at lowest cost. This may therefore encourage novel forms of system support, including embedded generation, provided such alternatives were cheaper than infrastructure investments. **Government, Ofgem and industry support must be established to allow an increasing proportion of DNO revenues to be set on the basis of performance based regulation.**

Charging structures need to be constructed to address the structural problems that have been made apparent since ESI liberalisation in 1989. Issues must be prioritised, focussing initially on how DNOs charge for services. Incentives and profits of DNOs must also be considered. **Consistent and long term charging structures need to be established.**

Potential skill shortages that would be increasingly demanded in a decentralised electricity system have been highlighted. Again, **Government, industry and academia must collaborate to develop appropriate incentives and information provision to bridge the skills gap.**

7.2 Commercial and Market Issues

As required by the Utilities Act 2000, **effective information flows, clear market entry processes, and equitable transparent terms for connection and use of the distribution system are central to DNOs facilitating competition in generation and supply**. Such a requirement. Provided with suitable incentives, DNOs will invest in their network to augment the potential for embedded generation connection. DNOs are ideally placed to manage the commercial and technological shift required to encourage the expansion of renewable and embedded generation. The right commercial and regulatory frameworks need to be in place to facilitate this. **Policies designed to ease aggregator access to the grid and to encourage such a role to be taken in the UK by the DNOs or Energy Trading Co-operatives may have a significant impact on the developments of embedded generation and active networks.**

NETA does not attempt to address the social or environmental aspects of energy policy, despite the stated desire in government policy to bring economic, environmental and social issues together under the 'sustainable development' moniker. However, NETA has not been favourable to embedded and renewable generators, penalising those have difficulty in accurately controlling and predicting output – CHP and intermittent renewable generators. Larger generators with access to diverse forms of generation should be able to adapt internally to cover for the variable output of renewable and other plant. **Smaller generators will have to work (via storage, aggregation or co-operatives) to make their electricity output more predictable and secure.**

The current market appears unlikely to be capable of meeting renewable and CHP targets and the Government may have to intervene. Options include pulling CHP and renewable generators out of NETA, facilitating the development of aggregation and supporting energy storage technologies to smooth the variable outputs of some technologies (see Chapter 5). Any government intervention would be more transparent in the liberalised market and require justification.

Improved information and market transparency will facilitate the development of embedded generation. Effective information flows, accessible processes for market entry and transparent terms for connection and use of networks are all key factors. An appropriate balance between the value and costs of providing the information must be established, to **develop a consistent approach across DNOs towards providing information and the connection application process.**

DNOs are ideally placed to play a significant role in developing the commercial and technological shift required to encourage the expansion of renewable and embedded generation, in partnership with other agencies. **Provided with suitable incentives and the right commercial and regulatory frameworks, DNOs will invest in their network to augment the potential for embedded generation connection.**

The current 'deep' charging arrangements present a significant financial barrier to the connection of new generation. The duty on DNOs to facilitate competition in generation may require significant amendments to be made to the way in which DNOs charge for the connection to and use of distribution networks. **Consideration must be given to 'shallow' and 'shallowish' charging structures that would reduce the capital cost incurred and encourage additional connections of embedded plant.** As advocated by EGWG, a full analysis and assessment of the potential short and long term impacts of options for change is required.

Recognising and rewarding the potential benefits of embedded generation to the distribution network in terms of lower transmission and distribution losses and reduced capital requirements is another key development. **Simpler connection arrangements for embedded generators are needed** and could facilitate DNOs taking on the aggregator role.

7.3 Technical Issues

Security of supply is a key element of energy policy, the current transmission system contributes to this by ensuring that demand in a specific part of the country is not solely dependent on the availability of generating plant located within that area. **The transmission system will be likely to continue to play an integral role in the future electricity system**, even with higher penetration of renewables, CHP and embedded generation.

Managing the network differently may offer opportunities for recognising that operation of embedded generation in 'island mode' could bring security benefits under outage conditions. '**Islanded' operation, albeit on a localised basis, could contribute to security of supply and significantly reduce frequencies and extent of 'power-cuts'.**

In order to maintain the integrity of the transmission network in addressing longer-term technical issues that may arise from a larger proportion of wind and other intermittent renewables, wider ancillary service markets should be encouraged. Local ancillary markets would also provide embedded generation with additional income streams. **Facilitating and encouraging the development of open ancillary service markets, accessible to embedded and renewable generation would be a positive step.**

The psuedo-intermittent nature of existing plant, particularly older generating units, is already factored into the integrated system. **The interconnected electricity network is capable of integrating a substantial amount of intermittent renewable generation without adapting operational procedures.**

Some commentators suggest that there is no technical nor economic need for dedicated electricity storage linked to intermittent renewables. However, **the potential benefits of electricity storage technologies should be further researched.**

Research into predicting wind generation output has shown 95% predictability for output 24 hours ahead. Therefore, **intermittency should not be confused with unpredictability.**

Depending on the location and type of technology, the transmission network might be able to accommodate a greater proportion of renewables, CHP or other embedded generation than that specified in the 2010 targets. In examining the impact of renewables, CHP and other embedded generation, NGC have expressed confidence that **transmission related issues will not become a barrier to accommodating the amount of renewables or CHP generation necessary to meet the Government's 2010 targets.**

If the expectation is for an increasing proportion of embedded generation, electricity flows from the transmission to the distribution networks may be reduced. That said, bulk transfer patterns are dependent on the relationship between the location of generation and demand. The remote and low demand locations of many of the existing renewable energy technologies suggest that **bulk transfer patterns appear fairly persistent.**

To help facilitate the development of embedded and intermittent renewable technologies, **an increasingly active network with multi-generator connections will require complex modelling and simulation tools.**

The passive nature of distribution networks has been formalised and encouraged through design codes, price controls, incentives and the regulatory environment. The role of the responsive and active management and matching of demand and generation has been taken by the transmission network operator. **Increased embedded generation would require active management of distribution networks involving a stepped introduction to adapt to new management, technological and administrative demands.**

Central to the evolution of active distribution networks remains the market mechanisms and regulatory environment in which DNOs operate. **At the distribution level, connection agreements and contractual frameworks need to ensure equitable treatment of embedded generation and central generation alike, truly recognising the cost and benefits of both.**

Net-metering allows customers to offset their electricity consumption originating from the transmission and distribution network by selling their own generated electricity to the network. **The potential costs associated with net-metering and charging alternatives need to be established.**

The development and application of technologies such as photovoltaics, fuel cells, micro turbines and Stirling engines is expected to lead to a significant growth in domestic and commercial generation. The impact of widespread micro CHP or PV systems on the demand and generation profiles of distribution networks would be significant. **Simpler engineering standards and transparent connection and payment structures need to be established in a manner that is appropriate to micro-scale generation technology.**

7.4 Discussion

Expanding and incorporating small and intermittent electricity generating units on a transmission and distribution network that has been constructed around centralised generation and bulk transfers requires innovative approaches to managing and operating the system. Alongside this, regulatory deficiencies and uncertainty obstructs the uptake of new technologies and practices. The various arrangements have not yet been revised to recognise the changing electricity market place that will be driven by the development of cost effective modular generation plant that can be sited close to sites of demand and the increasing awareness of the environmental impact of power generation (ETSU, 2001).

EGWG suggested that significant amendment to incentives and other indicators was required, otherwise the targeted expansion of CHP and renewable generation would be restricted (EGWG, 2001). Alignment of the incentives for all the key stakeholders is required to create the right commercial environment in which embedded generation can contribute to a stable and secure network whilst ensuring a diversity of fuel supplies in a more environmentally sustainable manner. Commitment by all the parties to a co-ordinated programme of work is essential. In particular, clear statements of intent by Government and Ofgem are critical to the success of the programme and for providing incentives for DNO action. Only then can the full potential for embedded generation be realised (EGWG, 2001).

In the meantime, however commentators express concerns that *"reducing energy prices and increasing competition have been the main political drivers for liberalising energy markets in the past decade. In contrast, sustainability and climate-change have been paid only lip-service during most of this period"* (Fabian Society, 2001). The impact of recent policy interventions to encourage embedded and renewable generation, such as the

Renewables Obligation and the Climate Change Levy, have been severely limited by the negative impacts of NETA on small scale and renewable generators.

The DTI, in its initial submission to the UK Energy Review, highlighted that post 2010 CO_2 emissions may start to rise as nuclear plant comes to end of life, subject to which technologies replace this generation capacity. If the Government is serious about meeting its Kyoto, Renewable and CHP targets by 2010, and continuing progress beyond, the focus of policy and regulation must clearly be adapted.

In the same submission, the DTI reflected that policies that imply higher energy prices must take into account the social costs and impacts on schools, hospitals and, business and address the overall fuel poverty strategy. Recent trends indicate a degree of synergy between the core energy policy objectives of competitiveness, social objectives, energy security and environment. For example, the dash for gas from secure supplies from UK fields has reduced electricity prices and emissions. But will these synergies continue?

ETSU has acknowledged the longer term potential of embedded generation to reduce overall costs to the consumer by providing a more efficient electricity system that generates and delivers power close to the point of use (ETSU, 2001). However, the adaptation of transmission and distribution networks to encourage and operate with significant quantities of embedded generation will be an issue in delivering any long term cost reductions.

The decision whether to facilitate the development of embedded generation by establishing a level playing field through regulation or by imposing measures to meet Government targets is an important one. Revising regulation will impact upon the design and management of distribution networks. But, it may not be enough in itself to meet current Government targets for embedded generation within the timescales set.

There are a number of potential scenarios and possibilities for creating the right business environment to encourage new approaches to embedded generation and demand management. The two extremes are the open market environment, and the rigid regulatory environment that requires the connection of additional embedded generation capacity.

Key characteristics of an open market environment might include: increased certainty of the minimal performance based regulatory system, local ancillary and security services markets, opportunities for increased DNO revenue, and an amended the generator and demand management connection charging mechanism.

Key characteristics of a rigid regulatory environment might include: reward schemes for each MW of renewable or good quality CHP generation connected; electricity generated or consumption saved.

A market environment that lies between these two extremes is the most likely outcome. Dialogue between DNOs and Ofgem is key to developing proposals and constructing market mechanisms that will facilitate increased connection of embedded generation.

In addressing such issues, EGWG recommended that Ofgem need to ensure that the regulatory regime supports and provides incentives to DNOs to meet their obligations to facilitate competition in supply and generation (EGWG, 2001). Certain aspects dominate DNO business:

- regulation and incentives;
- generation connection charging principles;
- and commercial mechanisms to support technical innovation.

Ofgem should focus initial efforts on these dominant aspects.

7.5 Final Comments

The DTI recently announced on 31 July 2001 the creation of a new body focussed on small and low carbon generators, following up the recommendations of EGWG. Their press release acknowledged that the *"failure to address the barriers to small generation could compromise the Government's renewable and CHP targets for 2010"* (DTI, 2001). This announcement is a positive step.

The early steps along the road to a more sustainable energy future are crucial. They must smooth the likely transitions rather than lay barriers in the way. The failure to expand embedded and renewable generation technologies and to adapt transmission and distribution networks may result from regulatory deficiencies rather than technology constraints.

With a privatised energy industry and foreign ownership of many companies, the development of embedded and renewable energy technologies will have to be guided through modifications to the market rules, regulations and incentives. This includes clear direction by the Government to its energy regulator through its Social and Environmental Guidelines. Ofgem published their Environmental Action Plan on 20 August 2001, setting out the "*guiding principles which will determine how Ofgem will approach environmental issues"* (Ofgem, 2001). The Action Plan includes direct reference to reviewing the treatment of embedded generation (as recommended by EGWG) and administering the Government's policy to increase the contribution of renewables. Whether such actions will include amending NETA to reflect more the environmental and social aspects of the energy policy agenda remains to be seen.

The need for the Government to establish a strategic and co-ordinated approach across all stakeholders is clear. The creation of a Sustainable Energy Vision and an associated agency would assist in developing such an approach. Such an agency would need to:

- produce long term recommendations for further action
- assess the potential contribution of technologies to the Government's targets
- appraise the impact on stakeholder businesses.

The expansion of the 'national grid' after the Second World War appears to have been driven as much by the social objective of electricity for all as by economic efficiency. A full appreciation of the potential social and environmental benefits of embedded and renewable generation could trigger comparable policy decisions.

The basic aim of Government policy should be to construct an equitable regulatory and commercial framework within which transmission and distribution-connected generation can compete fairly and which allows for future changes in the generation mix. The key challenge is to seize the opportunity offered by the current Energy Review to create a new electricity system that supports and stimulates, not stifles embedded and renewable electricity generation.

Critique of the Method and Areas for Further Research

As with all Masters theses, there are limitations inherent with time, resource and other constraints. These affect the methods available and the scope of the thesis.

Methods

Identification of the key stakeholders was undertaken by a combination of internet searches, a review of reports and research in related areas, and consultation across the industry. A 'snowball' method was used, whereby experts were interviewed and asked to suggest other relevant stakeholders. This proved successful in identifying the key stakeholders, as demonstrated by the attendees of the 'Group Review' (Annex Four) who represented a wide range of interested parties across government, industry and other sectors.

The rationale for using informal interviews in the first stage of contact has been discussed previously. It was felt that, given time constraints, constructing a considered structured questionnaire or interview was in appropriate. The informal interview provided the opportunity to quickly gather the relevant information. The outputs of these informal interviews contributed to the production of a 'Key Issues Consultation Document' that was used as the focus of the 'Group Review'. The fact that the 'Group Review' considered that this document was a good and thorough reflection of the key issues at hand confirms that the informal interviews were a useful and critical part of the review process.

Wider consultation and peer review at all stages of the research would have been welcome. Time-constraints limited such opportunities, particularly the ability to hold a second review day. However, the 'Group Review' confirmed the relevance of the issues covered in the consultation document. This has been further confirmed by positive feedback from a narrower consultation of the final thesis.

Collaborating with POST proved useful, providing ready access to people, documents, resources and advice. The independent nature of POST helped to address stakeholder concerns any concerns as to potential bias in the final report. Also, bringing together the review group was a useful exercise in itself, enabling the key stakeholders to interact and discuss matters that, as highlighted in this thesis, require further discourse.

Scope

Alongside recommendations in Chapters 6 and 7, a number of areas outside the scope of this thesis that require further research and evaluation can be identified. These include:

- Energy efficiency and electricity demand management strategies are essential elements of energy policy. Activities in these areas will operate concurrently with the future development of electricity networks.
- Comparisons between UK and overseas networks in relation to operation, regulation, etc.
- Modelling the operation and economics of distributed electricity networks.
- Detailed analysis of various electricity industry regulatory structures (actual and theoretical). The introduction of performance based regulation is advocated in this thesis. These analyses could take into account the regulatory experiences of other privatised utility sectors such as gas and telecommunications.
- Customer perceptions. For instance, rre customers willing to pay more for sustainable electricity? What is the potential uptake of domestic generation technologies, should commercial and regulatory frameworks be amenable? What are public perceptions as to the appropriate amount of public money that should be used to fund the development of new technologies and networks?

Further consideration of the factors above is necessary to establish the detail of any new measures introduced in the UK to guide electricity network development. In addition, the conclusions and recommendations of this thesis may need further consideration in light of the findings of the UK Energy Review, expected in December 2001.

In summary, it is my opinion that this thesis provides a thorough overview of key issues that need to be addressed to ensure that electricity networks develop to allow the expansion of embedded and renewable electricity technologies. It coherently brings together the relevant technical and policy issues and highlights the importance of electricity networks in meeting Government CHP and renewable targets. It is hoped that this thesis will stimulate further debate and research in this area.

Bibliography and References

Amin A-L (2000) *The Power of Networks: Renewable Electricity in India and South Africa*, SPRU – Science and Technology Research, University of Sussex

Anderson D and Leach M (2001) *Intermittency of Generation within Large Energy Systems*, Imperial College of Science, Technology and Medicine, UK

Aplin M, Butler S and Turner N (2001) *Electrical energy storage: An assessment of pumped hydro, flywheel and Regenesys technologies*, MSc Environmental Technology – Technology Assessment, Imperial College of Science, Technology and Medicine, UK

Archard D (2001) *A Sustainable Energy Vision for the UK – A Discussion Paper*, Environment Agency Sustainable Development Unit

Audience Dialogue, http://www.audiencedialogue.org/kya10.html, accessed on 27/04/01

Awel Aman Tawe Windfarm – Wales, http://www.awelamantawe.co.uk/contents.html, accessed on 27/04/01

Bornemann HJ (1997) Conceptual Design of a 5 MWH/100 MW Superconducting Flywheel Energy Storage Plant for Power Utility Applications, *IEEE Transactions on Applied Superconductivity: Volume 7, Number 2, pages 398- 401*

Boyle G (1996) *Renewable Energy: Power for a Sustainable Future,* OUP, Oxford, UK

Brooks T and Butler S (2001) *The California Energy Crisis: A Lesson in How Not to Liberalise?* MSc Environmental Technology – Policy Assessment, Imperial College of Science, Technology and Medicine, UK

Bryden IG and Macfarlane DM (2000) The Utilisation of Short Term Energy Storage with Tidal Current Generation Systems, *Energy 2000,Volume 25, pages 893-907*

Business.com,
http://www.business.com/directory/energy_and_environment/electric_power_utilities/transmission_and_distribution/national_grid_group/profile/, accessed on 25/05/01

Cabinet Office PIU (2001) *Energy Policy Review*, http://www.cabinet-office.gov.uk/innovation/2001/energy/energyscope.shtml

Cochrane, R. (1985) *Power to the people: The story of the national grid*, Central Electricity Generating Board, Newnes Books, ISBN: 0600358755

COGEN Europe (2001) *Briefing 16 - Growth of decentralised power production: A challenge for the electrical grid? The Dutch experience*, The European Association for the Promotion of Cogeneration

Department of Environment, Transport and the Regions (1997) *Assessment of CHP Potential*, A report produced by ETSU.

Department of Trade and Industry (2000) *UK Energy Sector Indicators 2000*, DTI, London, UK

Department of Trade and Industry (2001a) *Consultative document on electricity network management issues*, http://www.dti.gov.uk/energy/egwg/condoc.pdf

Department of Trade and Industry (2001b) *Embedded Generation Working Group Report into Network Access Issues*, http://www.dti.gov.uk/energy/egwg/e_gen_report.pdf

Department of Trade and Industry (2001c) *Initial Contribution to PIU Energy Policy Review*, http://www.cabinet-office.gov.uk/innovation/2001/energy/energyscope.shtml, accessed on 05/08/01

Department of Trade and Industry (2001d) *New Review*, http://www.dti.gov.uk/NewReview/html, accessed on 24/05/01

Department of Trade and Industry (2001e) *The Renewables Obligation Statutory Consultation*, New & Renewable Energy: Prospects for the 21st Century

Department of Trade and Industry (2001f) *Wilson works with Ofgem to shine a green spotlight on small generators*, Press Release, 31 July 2001

Department of Trade and Industry (2001g) *New Electricity Market Goes Live*, Press Release, 27 March 2001

Department of Trade and Industry website (2001), http://www.dti.gov.uk/index.htm, accessed continuously

Digest of United Kingdom Energy Statistics 2000, Department of Trade and Industry, http://www.dti.gov.uk/epa/dukes.htm/, accessed on 24/05/01

Digest of United Kingdom Energy Statistics 2001, Department of Trade and Industry, http://www.dti.gov.uk/epa/dukes.htm/, accessed on 24/05/01

Edison Electric Institute (EEI) homepage, http://www.eei.org/resources/, accessed on 10/05/01

Electricity Association (2000), *The UK Electricity System*, Electricity Association Services Limited

Electricity Association (2001), *Electricity Industry Review 5*, Electricity Association Services Limited

Electricity Association, http://www.electricity.org.uk/, accessed on 23/05/01

Electricity Pool, http://www.elecpool.com/index.html, accessed on 08/06/01

Electricty Association (2000) *Renewable Electricity in the UK*, Environmental Briefing Number 7 – August 2000, Electricity Association Services Limited

Embedded Generation Working Group (2001), http://www.dti.gov.uk/energy/egwg/index.htm, accessed on 24/05/01

Encyclopedia.com, http://www.encyclopedia.com/, accessed on 10/05/01

Energy Efficiency & Renewable Resources in Electric Industry Restructuring, Public online group, http://eerr.notes.org/, accessed on 23/05/01

Energy Information Administration (EIA) - Electricity Reform Abroad and U.S. Investment (1997), http://www.eia.doe.gov/emeu/pgem/electric/contents.html, accessed on 24/05/01

Energy Information Administration (EIA) - Official energy statistics from the US government, http://www.eia.doe.gov, accessed on 14/05/01

ETSU (2001) *Technology Status Report: Embedded Generation and Electricity Studies*, A report by ETSU as part of the DTI's New and Renewable Energy Programme, http://www.dti.gov.uk/renewable/embedded.htm

European Commission (1999) *Opening Up to Choice: The Single Electricity Market*, http://europa.eu.int/comm/energy/en/elec_single_market/elecbro.pdf

European Commission (2000) *Towards a European Strategy for the Security of Energy Supply*, Green Paper, European Commission, November 2000

Fabian Society (2001) *At the Energy Crossroads: Policies for a Low Carbon Economy*, authors - Gareth Thomas MP & Stewart T Boyle.

Foreign & Commonwealth Office (2001) *UK Statement in Response to G8 Renewable Energy Task Force Report*, Press Release, 30 July 2001

Franklin Institute Online, http://sln.fi.edu/franklin/scientst/scientst.html, accessed on 09/05/01

FT Energy (2001) *Power Markets in Europe: The Solution to Understanding Europe's Changing Power Markets – Executive summary*, © Copyright Financial Times Energy 2001, http://www.ftenergy.com/samples/PMiE_ExSum.pdf, accessed on 25/05/01

Gandy S (2000) *A guide to the range and suitability of electrical energy storage systems for various applications and an assessment of possible policy effects*, MSc Environmental Technology Thesis, Imperial College of Science, Technology and Medicine, UK

Grubb M (1991) The Integration of Renewable Energy Sources, *Energy Policy*, September, 670:688

Grubb M with Vigotti R (1997) *Renewable Energy Strategies for Europe Volume II: Electricity Systems and Primary Electricity Sources*, The Royal Institute of International Affairs Energy and Environmental Programme, Earthscan Publications Ltd, London

Hannah, L. (1979) *Electricity before Nationalisation*, The Electricity Council, Macmillan Press Ltd, ISBN: 0333220862

Harden F, Bleijs JAM, Jones R, Bromley P and Ruddell AJ (1999) Application of a Power-Controlled Flywheel Drive for Wind Power Conditioning in a Wind/Diesel Power System, *Ninth International Conference on Electrical Machines and Drives, conference* *publication no 468,* IEEE

Hart, D. Bauen, A. Leach, M. & Papathanasiou, D. (2000) *Decentralised Electricity*, Financial Times Energy, ISBN: 1840833696

Hartnell, G (2000) *Wind on the System – Grid integration of Wind Power*, Renewable Energy World, James & James (Science Publishers) Ltd, March – April 2000

HC 291 - House of Commons Science and Technology Committee (2000-2001) *HC 291 Seventh Report – Wave and tidal energy*, The Stationery Office Ltd, ISBN: 0102301018

HC334 - House of Commons Environmental Audit Committee (2000-2001) *HC334 Memoranda – Renewable Energy*, The Stationery Office Ltd, ISBN: 010230601X

Hockney RL, Driscoll CA (1997) Powering of Standby Power Supplies Using Flywheel Energy Storage, *INTELEC, pages 105-109*

Inenco Group, http://www.inencogroup.com/, accessed on 20/07/01

INNOGY (2001) http://www.innogytech.com/, accessed on 27/05/01

Institut für Solare Energieversorgungstechnik (ISET), http://www.iset.uni-kassel.de/, accessed on 30/05/01

Institute of Energy (2001) *Energy World: The magazine of the Institute of Energy*, http://www.instenergy.org.uk/

Institution of Electrical Engineers, http://www.iee.org.uk/publish/faraday/faraday1.html, accessed on 09/05/01

International Conference on Electricity Distribution Networks (1999) *CIRED Preliminary Report of Working Group 4*, CIRED Conference in Nice – June 1999

International Energy Agency - IEA (2001), *Electricity Market Reform: An IEA Handbook*, http://www.iea.org/pubs/studies/files/elemar/table2.pdf

International Energy Agency (2001) *Key World Energy Statistics*, http://www.iea.org/statist/keyworld/keystats.htm, accessed on 25/06/01

3rd Inter-Parliamentary Meeting (2001) *Renewable Energy Sources in the EU*, http://www.eufores.org/gotland_conclusions.htm

James & James (2001) *Guide to Renewable Energy Companies 2001*, James & James (Science Publishers) Ltd, ISBN: 1902916263

Jenkins, N. Allan, R. Crossley, P. Kirschen, D & Strbac, G. (2000) *Embedded Generation*, The Institute of Engineers, Power and Energy Series 31, ISBN: 0852967748

Lancaster University, Department of Sociology, http://www.comp.lancs.ac.uk/sociology/PeterLinks/Survey/sld001.htm, accessed on 27/04/01

Macleod, C (1997) *Learning Paper 5: Interview Studies*, The Robert Gordon University Aberdeen, School of Public Administration and Law, http://umi.eee.rgu.ac.uk/modules/research/internal/resmeth/rmeth5_1.htm

Millborrow, D (2001) *Operation of the UK electricity system with wind energy*, unpublished consulation document??

Model T Ford Club (2001) http://www.modelt.org/tquotes.html, accessed on 21/08/01

National Assembly for Wales (2001) *Strategic Study of Renewable Energy Resources in Wales – Draft Report*, http://www.wales.gov.uk/subitradeindustry/content/consultations/renewableresources-e.htm, accessed on 24/05/01

National Grid Company plc (2001) *Seven Year Statement*, http://www.nationalgrid.com/uk/

National Grid Company plc (2001) *Ancillary Services*, http://www.nationalgrid.com/uk/activities/mn_ancillary.html, accessed on 22/07/01

National Renewable Energy Laboratory – NREL (2000) *Making Connections: Case Studies of Interconnection Barriers and their Impact on Distributed Power Projects*, http://www.nrel.gov/docs/fy00osti/28053.pdf

Northern Ireland Electricity (NIE), http://www.nie.co.uk/, accessed on 08/06/01

OFGEM (2001) *Ofgem's Response to the Embedded Generation Working Group Report on Network Access Issues*, http://www.ofgem.gov.uk/docs2001/embeddedresponse.pdf, accessed on 18/05/01

OFGEM (2001) *Review of the initial impact of NETA on Smaller Generators - Conclusions Report on Terms of Reference*, http://www.ofgem.gov.uk/docs2001/netainitialimpact.pdf, accessed on 18/05/01

OFGEM (2001) *Transmission Access and Losses under NETA - A Consultation Document*, http://www.ofgem.gov.uk/docs2001/37_trans.pdf, accessed on 24/05/01

OFREG (2001) http://ofreg.nics.gov.uk/, accessed on 18/06/01

Parker, M. (2000) *Thatcherism and the Fall of Coal: Politics and Economics of UK Coal 1979 – 2000*, Oxford University Press, ISBN: 0197300251

Patterson, W. (1999) *Transforming Electricity: The coming generation of change*, The Royal Institute of International Affairs, Earthscan Publications Ltd, ISBN: 185383341X

Ramage, J. (1997) *Energy – A Guidebook: 2nd edition*, Oxford University Press, Oxford

Robson, C. (1993) *Real World Research*, Blackwell Publishers Ltd, ISBN: 0631176896

Royal Commission on Environmental Pollution 22nd Report (2000) *Energy: the changing climate*, Schoenung, SM et al (1996) Energy storage for a competitive market, *Annual Review of Energy and the Environment, Volume 21*

Scholz Electrical Company, http://www.scholzelectrical.com.au/default.htm, accessed on 09/05/01

Science and Public Policy: Journal of the International Science Policy Foundation (2000), Volume 27, Number 3, June 2000

The Education Site, http://www.the-education-site.com/menu.html, accessed on 09/05/01

Thomas Edison's homepage, http://www.thomasedison.com/, accessed on 10/05/01

TXU Europe website, http://www.txu.com/eu/, accessed on 25/06/01

United Nations Food and Agriculture Organization - UN FAO (1990) *The community's toolbox: The idea, methods and tools for participatory assessment, monitoring and evaluation in community forestry*, http://www.fao.org/docrep/x5307e/x5307e00.htm#Contents, accessed on 27/04/01

University of British Colombia , The School of Library, Archival and Information Studies, http://www.slais.ubc.ca/resources/research_methods/interviews.htm, accessed on 10/05/01

US Department of Energy – Distributed Power Program, http://www.eren.doe.gov/distributedpower/, accessed on 25/06/01

US Department of Energy (2000) *Strategic Plan for Distributed Energy Resources*, http://www.eren.doe.gov/der/pdfs/derplanfinal.pdf

Waugh D (1994) *The Wider World*, Thomas Nelson & Sons Ltd

Weinberg C.J (2001) Keeping the Lights On: Sustainable Scenarios for the Future, *Renewable Energy World*, July to August 2001, James & James (Science Publishers) Ltd

World Energy Council, http://www.worldenergy.org/wec-geis/, accessed on 24/05/01

Yehia E and Karkkainen S (1988) *Energy Storage Systems in Developing Countries,* Cassell, London, UK

Yorkshire Electricity Group, http://www.yeg.co.uk/welcome01.shtml, accessed on 20/07/01

PERSONAL INTERVIEWS

See Annex One for notes of the meetings detailed below.

Tim Green, Electrical Engineering, Imperial College of Science, Technology and Medicine, 17 May 2001

Catherine Pearce, Parliamentary Renewable and Sustainable Energy Group (PRASEG), 30

May 2001

Chris Hewett, Institute of Public Policy Research (IPPR) – Senior Research Fellow Sustainability Team, 7 June 2001

Robert Gross, Cabinet Office Performance and Innovation Unit, 8 June 2001

Catherine Mitchell, Cabinet Office Performance and Innovation Unit, 8 June 2001

Arthur Cook, Ofgem – Embedded Generation Co-ordinator, 12 June 2001

Amanda Mcintyre, Ofgem – Head of Renewables and CHP, 12 June 2001

John Scott, Ofgem – Technical Director, 12 June 2001

Stewart Boyle, writer and energy consultant, 13 June 2001

Dr Amal-Lee Amin, DETR/DEFRA – Sustainable Energy Policy Division, 14 June 2001

Anthony White, Schroder Salomon Smith Barney – Managing Director European Utilities, 14 June 2001

Lewis Dale, National Grid Company Plc – Regional Strategy Manager, 15 June 2001

Philip Baker, DTI – Head of Electricity Technology, 19 June 2001

Graham Bryce, DTI Energy Policy Directorate – Deputy Director International Energy Markets, 19 June 2001

Steve Jacobs, DTI Energy Policy Directorate, 19 June 2001

GROUP REVIEW

The following list details those that attended the Group Review on 19 July 2001 (see Annexes Three and Four)

Stewart Boyle	Writer and Energy Consultant
Graham Meeks	Combined Heat and Power Association
Dr Amal-Lee Amin	DEFRA – Sustainable Energy Policy Division
Graham Bryce	DTI – Energy Policy Directorate
Phillip Baker	DTI – Head of Electricity Technology
Dan Archard	Environment Agency – Policy Development Officer
Chris Wakeman	GPU Power – DNO
Doug Parr	Greenpeace

Mathew Leach	Imperial College Centre for Energy Policy and Technology (ICCEPT)
Lewis Dale	National Grid Company Plc.
John Benson	Ofgem
David Cope	Parliamentary Office of Science and Technology (POST)
Gary Kass	POST
Sarah Pearce	POST
Cathie Hill	Scottish Power
Rob Shackleton	TXU Europe
Mike Kay	United Utilities

Annex One Summary of Initial Meetings

KEY POINTS FROM PRASEG MEETING ON 8 MAY 2001 – MICHAEL MEACHER

- £260 million expanded support programme for renewables and £100million to be allocated in the Autumn.
- NETA – needs to be monitored as it appears that it is favouring the larger and vertically integrated players. Need for a sub-market for green and renewable producers to keep them wasy from the harshness and volatility of NETA?
- Alan Jones – Woking – Embedded generation is a totally different market than that which NETA serves.

MEETING WITH TIM GREEN – ELECTRICAL ENGINEERING @ IC – 17 MAY 2001

- Short to medium term – biggest impact on distribution system relates to the fact that it was never constructed and envisaged to have generation within it and for power to come out of it.
- Very little control of generation within distribution systems.
- Modest impact on the national grid – potentially helpful in clearing up blockages.
- NGC – all about security of supply – particularly under NETA within balancing responsibilities.
- National Grid as little more than a reserve facility???
- NG – monitoring approx 50 main generating sites and 50 bulk supplies to distribution.
- Impact of technology – decision support.
- NG – inability to despatch is a big issue – ability to mange balance and reserve has been eroded.

CABINET OFFICE PIU MEETING – CATHERINE MITCHELL AND ROB GROSS – 8 JUNE 2001

- PIU – Resource productivity and renewables; energy efficiency and productivity
- Timeframe to 2050 – what would the low carbon future look like.
- Are 2010 targets going to be met, if not, why not? Etc.
- What is the rationale for providing support to renewables when they are not the most cost effective for reducing carbon emissions?
- Concepts regarding the positive externalities of innovation
- Foresight scenarios used as basis for assessments.
- DNO view on move to active distributed energy systems– too hard and too costly while others say that it is easy and not too expensive.
- Potential big policy concern to MPs – Curbing carbon emissions and climate change while keeping the lights on.

OFGEM – ARTHUR COOK, JOHN SCOTT, AMANDA MCINTYRE – 12 JUNE 2001

- AC – Embedded Generation Co-ordinator - incentives and price controls, connection charging mechanisms.
- JS – Technical Director – interested in embedded generation and sees big issues as information and incentives, quality of supply – voltage, freq, harm and impacts on industrial processes, distribution and transmission impacts.
- Amanda McIntyre – Head of Renewables and CHP – adminsters CCL and compliance with RO,

other duties relating to Ofgems Enviro Action Plan.
- Ofgem – long term development strategies and consultation with DNOs regarding pseudo SYS.
- Overall management of the power system is a key issue made more difficult in an island context.
- Synchronisation of generation often taken for granted but needs to be managed by somebody, even in an islanded network.
- Variability is an important issue.
- Safety concerns more a distribution issue – currently uni-directional flow BUT two way flow required to be accommodated.
- Transmission network (expensive, only where justified) not as prevelant as distribution networks.
- What would be the ultimate decentralised scenario and how would we introduce measures to counteract problems, demands, etc?

STEWART BOYLE – WRITER AND ENERGY CONSULTANT – 13 JUNE 2001

- Lots of interesting stuff BUT informal chat so didn't write much down BUT initial feedback on draft likely to be very useful and gave good contacts.
- Offshore wind is essential component for reaching targets BUT intermittency and transmission issues. Work has been undertaken into predicting wind from meteorological data. From 18 months work already down to 95% predictable for 24 hours ahead THUS how intermittent is intermittent???
- Contact for above: Peter Zacharias – Tel: +49 5617294242; email pzacharias@iset.uni-kassel.de
- BG have identified potential market for 100,000 replacement boilers per annum and are looking at domestci micro-chp – plug and play systems BUT need easier planning regs, aggregation and net-metering???
- "Net metering" – allowing customers to offset their electricity consumption originating from the grid by selling their own generated electricity to the grid for the same price.
- Dan Reicher – previous US assistant secretary of state for energy "small-scale energy systems need policy support right now to get fair access to the market at affordable prices" (FT, 10 August 2000).
- June 2000 – ABB launched Alternative Energy Solutions, selling its large scale power plant business and concentrating on systems smaller than 10MW. This business strategy – aiming for annual sales of $1bn by 2005 and $2.5bn by 2010 – assumes a move away from the centralised large scale plant and national grids to a small-scale, local virtual utility system linking small industrial and domestic electric and heat plant.
- Net metering – "using the grid as a kind of battery with fair prices in both directions improves the economics of small plant" (FT, 10 August 2000).
- Small scale generators selling back to grid + a fee that reflects the costs of the grid, transmission losses, information management, co-ordinating supply and ensuring quality of supply????

DETR/DEFRA – DR AMAL-LEE AMIN – 14 JUNE 2001

- Look at Sacramento Municipal Utility District – an interesting case study for decentralised and islanded system.
- Asset based regulation "v" performance based regulation
- DETR/DEFRA concerns: Sustainable Energy Policy, lead on CHP and energy efficiency, embedded generation and longer term efficiency issues, 2010 and beyond.
- Renewables obligation is through to 2026.

SCHRODER SALOMON SMITH BARNEY – ANTHONY WHITE – 14 JUNE 2000

- Previous jobs – CEGB and Head of Strategy at NGC.
- The role of transmission is very much changed in a liberalised market – now a facilitator instead of a constructor and maintainer.
- Uplift costs – introduced into grid in 1994 and brought massive change as to how the business was run.
- Need to change the regulation to performance based rather than asset based.
- Big problem with profits being related to assets.
- Need to stop the disincentive to DNOs to connect embedded generation.
- The future role of the grid may not be bulk transfer BUT system stability.
- NGC may become smaller in asset and larger in systems control – operating the networks.
- Price signals at domestic levels – metering – providing the market place.
- DC systems for local active networks – would it be better???
- Net metering up to a certain stage but how useful in the long term?

NATIONAL GRID COMPANY – LEWIS DALE – 15 JUNE 2001

- Lewis Dale, Market Analysis – load forecasting, technical impact of renewables, representation at EGWG NOW Regulatory Strategy Manager
- Charles Davies – Commercial Director at NGC
- Ofgem – information and incentives project – 2% of DNO income tied to performance – consultation on capacity/access auctions for transmission, balancing services mechanism scheme.
- NGC internalise the external costs through operating network that would otherwise be passed on to consumers.
- Big thrust on the transmission side is operational efficiency.
- NG already discussing with large offshore wind in North West.
- Is it better to upgrade 132kV of just link to 400kV system?
- More connections = more income BUT only a relatively small percent of NGC income
- NG income – connection + infrastructure + balancing
- NG income £800 mill pre-vesting = RPI – X
  £100 mill postvesting – reasonable return
- RCEP offered that “NGC were not aware of the challenges facing them” BUT NGC acknowledge that the industry and market do need developing and that feel that they are aware of what is going on.
- EGs feel that the NGC are going to be defensive due to no connection income and use of transmission charges BUT this is a misinterpretation.
- 95% of generation is connected to the high voltage transmission network.
- NGC can see a changing role BUT don’t see EG or CHP as a particular threat.
- Long term continuing role, need for local markets, traded service nationally and locally.
- Active distribution networks central to the early history of electricity.
- Technology wise, everything is pretty much there.
- National and local markets exist – EG can choose to play in their GSP/REC area only.
- Locational constraint issues.
- The bigger the % the more likely the problems – although not insurmountable.
- NGC report on wind and intermittency due very soon. At least room on the grid for 20%??
- The market value of diversity – immediate response – value of the grid?
- 10,000MW needed in the South to balance the systems BUT new units are not replacing

existing Southern plant.
- Bulk transfer patterns appear resilient.
- If only concerned with diversity – local low voltage transmission may be OK
- NGC – "a long term role with new opportunities"
- Meeting on 4 July between NGC and RCEP to flesh out 2050 scenarios
- NGC issues for the future: will there be nuclear?
- Large gas fired plant or micro- CHP, Fuel cell, etc.?
- Massive renewables development?
- April 2006 – New price control review on Transmission Access – a critical juncture?
- 4 technical impacts: intermittency
  interfaces – fault levels and controls
  potential bulk-transfer reinforcement
  technological change (if not grid connected plant controlling frequency then whom???)
- More underground cabling in UK for amenity reasons than anywhere else in Europe.
- Big potential for improving existing lines – 400kV currently 300% more efficient than at time of initial construction.
- The geographical nature and trends for demand are very important to grid reinforcement.
- Forecasts suggest that surplus capacity will widen over the next few years – BUT NETA??
- Biggest rise in capacity expected in northern england, while increased demand in the south is expected to outstrip rises in local generation capacity – bulk power transfers remain.
- Extent of over capacity – reduced long and medium term electricity prices?? – slower development of new plant.

SYS forecasts
- Peak winter demand increasing by 1.4% annually over next seven years (9.8%) from 53.1GW to 58.6GW
- Capacity to rise by 18.8% over next seven years from 67.7GW to 86.5GW
- Potential surplus increases from 26.1% to 45% by 2007-08 (24% in 1990 at restructuring)

DTI ENERGY POLICY DIRECTORATE – GRAHAM BRYCE, PHILLIP BAKER AND STEVE JACOBS - 19 JUNE 2001

- Finland system operator – VVR have done a lot of work into intermittency and transmission.
- Neta and the balancing mechanism are unique – only other system with self-dispatch is Nordpool.
- Before means Electricity pool – NETA IS THE NEW GOD
- Going back to the future – system previously had more regional control.
- Big jump from merit-order despatch to self-despatching system.
- There is no capacity encouragement in NETA
- Must be very careful and clear with definitions – what is the national grid??
- Scottish and Southern matters – a very different tpe and way of operating their network.
- Frequency balancing – look at Europe with automatic frequency control. Very different in the UK – impact of intermittency on freq control.
- The move to NETA more important than the shift to the pool.
- Even under NETA, the NGC has retained the right to force generation should circumstances dictate BUT not for embedded plant. DNOS may need similar powers.
- 1970s – 25% of generating plant was connected to distribution networks.
- Development of active systems requires Ofgem and Govt support to reach any degree of significance in the near to medium term.
- Security of supply is a big political and technical issue – already of concernto NGC on a bad

winters night.

- DNOs love OCGT due to it's highly controllable nature – CHP less so.
- Renewables Obligation – level of buy out price may well decide whether targets will be met.
- Suppliers deal with uncertainty as well as generators.
- Key stakeholders – Network operators – generators – suppliers – consumers
- Net metering – a misnomer often used by people who don't understand. The tariff level is the most important factor for domestic feeds into grid. Although a number of potential methods, must ensure that domestic generators get paid – a big debate in itself hidden behind a simplifies term.

Annex Two Consultation Document (19 July 2001)

As sent to invitees to the 'Group Review'

UK ELECTRICITY NETWORKS

Electricity transmission and distribution in the UK in an intermittent renewable and embedded electricity generation system

Key Issues for UK Electricity Networks – consultation document

This consultation document is intended to set out the key issues that electricity networks will need to address as a result of increased intermittent renewable and embedded electricity generation and examine the interactions between the transmission and distribution networks.

The document will provide some of the background information for the group discussion, alongside the knowledge and expertise of the participants. A prioritisation exercise will further focus discussions on the day.

Summary Table of Key Issues

Technical Issues
Intermittency, variability and predictability of output
Bulk power transfers
Security of Supply
Flows at Interfaces between the Transmission and Distribution Networks
Development of Active Distribution Networks
Technical and Operational Developments – Fault levels, Voltage control, Electricity flows, etc.
Commercial and Market Issues
New Electricity Trading Arrangements (NETA)
Recognising the Benefits of Embedded Generation and Co-ordinating Developments
Minimising Red Tape on Small Embedded Generation Projects
Network Access Arrangements and Processes
Facilitation of Competition
Charging Principles
Provision of Information
Policy and Strategic Issues
The Transmission Network, Renewables and Embedded Generation
Actions to Address Longer-Term Transmission Issues Associated with Renewables
Actions to Address Longer-Term Transmission Issues Associated with Embedded Generation
Longer-Term Network Requirements
The Contribution of Embedded Generation to Network Performance
Domestic and Micro Generation
Net-metering
Stakeholder Behaviour
Performance 'v' Asset Based Regulation
Distribution Network Operators
Transmission Network Issues
Future Network Design, Management and Business Environment

The views of the transmission network owner and operator, the National Grid Company (NGC), as presented to Parliamentary Select Committees and in their 'Seven Year Statement' will be highlighted. Also, the work and recommendations of the DTI/Ofgem Embedded Generation Working Group (EGWG) will be reviewed. EGWG comprised representatives from key stakeholders concerned with embedded generation and access to distribution networks and included embedded generators, DNOs, NGC, suppliers, small and large consumers, the Energy Savings Trust, Ofgem, DETR and the DTI.

The key issues will then be regarded in relation to technical, commercial and market, and policy and strategic concerns.

Interactions between the transmission and distribution networks

A number of issues pertaining to the interactions between transmission and distribution networks will arise as the contribution of embedded and intermittent renewables increase. It is thus important that the impacts of increased embedded generation on transmission and distribution networks in the UK are not viewed in isolation.

The bulk of new renewable energy and CHP plant needed to meet the Government's targets will likely be of small capacity. Although such generating plant may find it most cost-effective to connect to lower voltage distribution networks, the trend towards having a larger proportion of embedded generation will interact with the high voltage transmission network in a number of respects. The link between transmission, distribution and embedded generation is exemplified by the NGC treating new embedded generation capacity as negative demand on the transmission system for network planning purposes (NGC SYS, 2001).

The Transmission Network and the National Grid Company's (NGC) Perspective

In the near term, the 10% renewables and 10 GWe CHP targets set by the Government for 2010 appear likely to have a modest impact on the transmission network. Indeed, in some instances these targets may prove to be beneficial, e.g. by locating embedded generation plant beyond a transmission-distribution interface nearing full capacity. In evidence to the House of Commons Environmental Audit Committee, NGC stated that "for transmission, we do not foresee any specific issues that would impose a barrier to meeting the government's 2010 targets for renewable generation" (HC344).

NGC have contributed to the embedded and renewable electricity generation debate through representation on a number of working groups and advisory panels, including EGWG. NGC has also presented evidence over the last couple of years to the House of Lords Select Committee on European Communities report into "Electricity from Renewables", the House of Commons Select Committee on Science and Technology report into "Wave and Tidal Energy" and to the House of Commons Environmental Audit Committee. Furthermore, embedded and renewable electricity generation issues are reported in the National Grid's annual 'Seven Year Statement'.

NGC have also highlighted four major technical impacts of current electricity trends and policy: (Personal Consultation, 2001)

- Intermittency of renewable and emebedded generation
- interfaces – fault levels and controls
- potential bulk-transfer reinforcement
- technological change (if not grid connected plant controlling frequency then whom?)

Distribution Networks and The Embedded Generation Working Group Report

The joint Government/Industry Working Group on Embedded Generation Network Access Issues was convened in March 2000 and had a very specific remit to consider:

- Ways of assessing the degree to which distribution network operators (DNOs) facilitate competition in generation as well as supply;
- Ensuring that design and operation processes take fully into account the contribution made by embedded plant to the operation of the network;
- The charging regimes employed towards the connection and operation of such plant;
- The information provided both with respect to the structure of charges applied to embedded generators (including micro generators and the use of dual or net metering) and to the opportunities geographically to developers to connect plant; and
- The scope in the longer term to design and operate networks with much higher concentration of embedded plant.

For the Government's targets of 10GWe by CHP and 10% contribution to total electricity generation by renewable plant by 2010 to be achieved, distribution networks will have to accommodate far more embedded plant than is currently the case. Additionally, under the Utilities Act 2000, there is a new duty on DNOs to facilitate competition in generation and supply. The group concluded that current regulatory framework, financial incentives and network design approaches are not geared to meeting such objectives.

The group suggested that significant amendment to incentives and other indicators was required, otherwise the targeted expansion of CHP and renewable generation would be restricted. Alignment of the incentives for all the key stakeholders is required to create the right commercial environment in which embedded generation can contribute to a stable and secure network whilst ensuring a diversity of fuel supplies in a more environmentally sustainable manner. Only then can the full potential for embedded generation be realised.

EGWG identified an extensive range of design, operational, charging and information issues requiring amendment, highlighting that short-term action was a real possibility. The group also acknowledged that other amendments may require more long-term revisions of the regulatory regime, design and operational codes and procedures, and in some cases, the legislation. Work needs to start immediately in view of the next distribution price control review in 2005. Commitment by all the parties to a co-ordinated programme of work is essential. In particular, clear statements of intent by Government and Ofgem are critical to the success of the programme and for incentivising DNO action.

The group stated that "many recommendations will require significant changes in approach from DNOs, Ofgem and embedded generators themselves" (DTI-EGWG, 2000). It also acknowledged that the quick implementation of changes may result in extra costs. "The implications of this for companies and customers will have to be balanced against the benefits of embedded generation" (DTI – EGWG, 2001).

The EGWG report detailed two main recommendations:

Recommendation 1

"Ofgem should review the structure of regulatory incentives on DNOs in the light of the new statutory duty on DNOs to facilitate competition, - in particular to assess the effect this new framework will have on all the stakeholders including DNOs, Generators, Customers and Suppliers" (EGWG, 2001)

EGWG acknowledged that such a fundamental review would only be practicable at the next price control review in 2005. But, it suggested that some changes were feasible within the framework of the present price control structure and a co-ordinated and managed programme of work needed to begin immediately under Ofgem leadership to:

- Construct a charging regime for embedded generators that fully reflects the DNOs duty to facilitate competition in generation as well as in supply. Ofgem, DNOs and embedded generators need to address the financial implications of adopting shallower charges for connection of embedded plant in advance of the next price control review.
- Review and prepare guidance to allow DNOs to interpret design and operational codes to fully account for the contribution of embedded generation to network performance. Such guidance needs to be closely followed by a more thorough review of the codes and of the governance arrangements for distribution networks.
- Establish more consistent provision of information by DNOs to developers of embedded generation and demand.

Recommendation 2

"A Group should be established under Government leadership to co-ordinate and take forward the implementation of the present Group's recommendations for the longer term" (DTI-EGWG, 2001).

The EGWG highlighted that their recommendations needed to be initiated immediately because "without the changes recommended in this report, it is unlikely that the level of embedded generation envisaged by the Government will be accommodated on distribution networks" (DTI-EGWG, 2001). The final caveat of the EGWG was that it was essential that solutions be equitable to all players, not imposing excessive costs on customers and preserving security of supply.

Key Issues – Technical

Intermittent, Variable and Predictable Output

Several of the promising embedded and renewable energy technologies, e.g. wind and solar, raise issues relating to the intermittent and variable nature of their output, suggesting that electricity from such sources can not be guaranteed.

The greater the contribution of intermittent generation sources to total supply, the greater the effects of intermittency will be. A minority share of intermittent and variable generation should not be a significant technical constraint. The problems provided by high levels of intermittent contribution may be counteracted by the introduction of reserve generation and/or electricity storage.

Variation in the location of plant is another important factor. A large network of geographically diverse wind turbines, e.g. 10 MW of capacity, would dramatically improve the predictability and reliability of output. Estimates suggest that a separation of between 5km and 10km for two wind turbines is enough for their output to be treated as independent (Grubb, 1991).

Intermittency should not be confused with unpredictability. For example, tidal electricity generation may be intermittent but is very predictable. Wind is a likely essential component for reaching both renewables and CO2 reduction targets, yet is an intermittent source of electricity. Studies using meteorological data have been undertaken into predicting wind generation output. After 18 months research, 95% predictability for output 24 hours ahead has been reported with suggested further gains to come (ISET, 2001). An imminent NGC report on wind generation and intermittency has concluded that, subject to the variety in location of turbines, there is room on transmission system for 20% contribution by wind without significant technical impact. This may challange the view of wind electricity generation being beset by intermittent output problems.

Intermittent and variable output must also be considered in relation to the role the generation source is providing. Intermittent and variable generation sources may not be best suited as base-load plant, contributing more to ancillary services, peak demand and seasonal variations, e.g. higher demand for electricity in the winter when the wind speed tends to be higher. Alternatively, the right mix and location of intermittent and variable output, alongside appropriate aggregation, may provide opportunities for the provision of base-load output. Certain renewable energy sources show a degree of inverse correlation that may help flatten and ease the predictability of output, e.g. low winds on sunny days and high winds on overcast days.

Studies as to the ability of the existing UK networks to accommodate variable wind generation suggests that up to a one third contribution is achievable (Grubb, 1991).

reliability of existing plant – psuedo-intermittency already factored into the system.

Bulk Power Transfers

Reduced electricity flows from the transmission to distribution networks as a result of increased penetration of embedded generation development will not necessarily result in a corresponding reduction in the bulk transfers across the transmission network. Bulk transfers are more dependent on the relationship between geographical location of generation and geographic patterns of demand.

Existing patterns of generation and demand produce a north to south power transfer across the transmission network of up to 10,000MW (NGC, 2001). This pattern represents the excess generation capacity located in the north (near coal and gas fuel supplies) relative to demand in that area. Thus, this excess capacity is exported to meet demand in the south. Such bulk transfer patterns are evident throughout the year. As demand reduces against the annual peak, it tends to be the output of the more expensive generation units in the south that are switched off first.

These bulk transfer patterns indicate that new embedded generation units in the north may only serve to displace higher cost generation in the south. This would result in increased bulk system transfers in the same way as new transmission system connected generation in the north. New embedded generation in the south may likely displace older and expensive southern generation leaving north to south bulk power flows unchanged.

NGC suggest for these reasons, bulk transfers on the transmission system are likely to continue. This situation will remain until such a time that there is a significant shift towards an improved regional balance between demand and generation, whether embedded or directly connected to the transmission network. Taking the existing situation, such a shift will require a significant increase in generation in the south.

Charges for use of the transmission system have been structured to provide incentives for generation using the transmission system to locate in the south of the country. Embedded generators are not liable for these charges and have not received a direct incentive to locate in the south. But, embedded generators may enable suppliers to avoid payments of transmission demand-related use of system charges. Such charges are higher in the south than in the north, thus offering an indirect incentive for embedded generators to locate in the south. Despite such incentives, generation continues to locate in the north.

In addition, the remote and low demand locations of many of the existing renewable energy technologies, e.g. biomass in the countryside, offshore and onshore wind in Northern Scotland, etc., will maintain the need for bulk transfers at high voltages. Indeed, the NGC are already in discussions with wind developers as to arrangements for transmission connections and charges.

Security of Supply

The current transmission system contributes to security of supply by ensuring that demand in a specific part of the country is not solely dependent on the availability of generating plant located within that area. This allows for the opportunity for any available generation, regardless of location, to be utilised to meet demand. The transmission system therefore may continue to play an integral role in the future electricity system, even with higher penetration of renewables, CHP and embedded generation.

Flows at Interfaces between the Transmission and Distribution Networks

If the expectation is for an increasing proportion of embedded generation, electricity flows from the transmission to the distribution networks will likely be reduced. This may impact on the transmission network through delaying the need for network reinforcement, although this is unlikely to remove the need for the substations/Grid Supply Points at these transmission-distribution interfaces. Such interfaces may still be required to balance the fluctuation between generation and demand in specific parts of the distribution network from minute to minute.

There is the potential for embedded generation to contribute to such a level that distribution networks may be in a position to export electricity to the transmission system. Grid reinforcement would only be necessary at appropriate interfaces should the level of exports to the transmission system be at a level that exceeded the existing transmission capacity.

Development of Active Distribution Networks

In the short to medium term, one of the biggest technical issues facing DNOs relates to the development of active, rather than passive distribution networks. As steam-based embedded generation has been de-commissioned over the last 25 years, distribution networks have tended to focus on passively serving demand. DNOs have built and maintained adequate infrastructure in order to receive power form the transmission network for delivery to customers. The passive nature of distribution networks has been formalised and encouraged through design codes, price controls, incentives and the regulatory environment. The role of the responsive and active management and matching of demand and generation has been taken by the transmission network operator.

Increased embedded generation would require the active management of distribution networks involving a stepped introduction to adapt to new management, technological and administrative demands. Monitoring and control systems would require development to ensure effective communication and control of fault levels, quality of supply, security of supply and safety aspects. The impacts of shift from uni-directional to bi-directional electricity flow has raised safety concerns and is new territory for many DNOs.

Central to the evolution of active distribution networks remains the market mechanisms and regulatory environment in which DNOs operate. At the distribution level, connection agreements and contractual frameworks need to ensure equitable treatment of embedded generation and central generation alike.

As networks are designed with a view to increasingly integrating embedded generation, so the degree and benefits of active management will increase. The DNOs approaches to addressing the shift towards active distribution networks have tended to play up the costs and technological limitations. In the 1970s, a significant amount (approximately 25% compared to 5% in 2000) of generating capacity was connected to distribution networks. However, the recent history of interlinked active distribution networks appears to have been easily forgotten. A shift to active distribution systems would be more back to the future than a new age, but their development would likely require Ofgem and Government support to reach any degree of significance in the near to medium term.

Technical and Operational Developments
The increased presence of embedded generation in distribution networks has technical implications in four key areas:

- Fault levels – Connecting embedded generation in urban areas may increase existing fault levels above plant capabilities.
- Voltage control – Connecting embedded generation to rural 11kV circuits may increase voltages above statutory limits.
- Electricity flows – Connecting inappropriately sized generation may cause flows to exceed plant capabilities and/or adversely affect network losses.
- Network security - Existing methods for connecting embedded generation ensure maintenance of the security of the overall network. But, this is at a significant cost to developers. Managing the network differently may offer opportunities for amending the methods and recognise that operation of embedded generation in island mode could bring security benefits under outage conditions.

Key Issues – Commercial and Market

New Electricity Trading Arrangements (NETA)
The immediate impacts of the introduction of NETA on embedded and renewable generation have been widely debated and will be central to a report to be produced by Ofgem and DTI in August 2001. To summarise the debate, NETA's Balancing and Settlement Code places penalties on suppliers for failing to match their contracted levels of output, either above or below. Generators that are 'out of balance' are required to 'top-up' or 'spill' via the Balancing Mechanism and are subject to penalty charges. This clearly impacts on generators who might have difficulty in accurately controlling and predicting output, such as renewable and embedded generators.

In relation to the transmission network, the role of the NGC is more focussed on security of supply within their system balancing responsibilities. The role of transmission is very much changed in the liberalised market, now more a facilitator than a constructor or maintainer of the network.

Recognising the Benefits of Embedded Generation and Co-ordinating Developments
The Transmission Network Use of System charging procedures provide locational signals as to the most economic areas for development from a transmission system point of view. Embedded generators may also receive the benefit of the avoided demand charges when meeting demand of local suppliers, such benefits being of higher value in the south of the country.

The potential for improving the economic efficiency of locational signals is currently being undertaken as part of a wider review of transmission access arrangements currently led by Ofgem.

Minimising Red Tape on Small Embedded Generation Projects
Embedded generators seek as simple contractual arrangements as possible. The existing arrangements often require embedded generators to enter into contractual relationships with both the NGC and DNOs. The EGWG report highlighted the need for NGC to adapt their contractual agreements with DNOs so that embedded generators may choose to have a single point of contact

with their host DNO, any choose whether to enter into agreement with NGC.

Network Access Arrangements and Processes
The EGWG report highlighted the importance of information and transparency in facilitating the development of embedded generation. Effective information flows, accessible processes for market entry and transparent terms for connection and use of networks are all key factors. NGC's responses to such issues include the provision of information on system opportunities through its annual Seven Year Statement, policies on connection and use of system charging, and general approaches to facilitating new market entrants. These were cited by the EGWG as good practice and worthy of consideration for addressing the issues that are emerging at the distribution level with respect to embedded generation.

Facilitation of Competition
The Utilities Act 2000 requires DNOs to facilitate competition in electricity generation and supply. Effective information flows, clear market entry processes, and equitable transparent terms for connection and use of the distribution system are central to such a requirement.

The existing regulatory framework does not provide financial or operational benefits to DNOs from embedded generation. Indeed, embedded generation often results in additional costs to DNOs rather than providing business development opportunities. The regulatory environment could be re-structured to allow DNOs to develop their business through increased load connections and collect revenue through Use of System charges. EGWG recommended that Ofgem should consider what regulatory changes are needed to provide such incentives by January 2002.

Charging Principles
At present, generator customers incur 'deep' connection charges. Such charges include the costs of the direct connection and any associated costs of reinforcing the distribution network as far as the local grid supply point. In comparison, demand customers pay relatively shallow ('shallowish') connection charges along with Distribution Use of System (DUoS) charges.

The current arrangements may present a significant financial barrier to the connection of new generation. A generator may only need a portion of the capability of the minimum reinforcement for which it must pay. This produces clear inequities between primary and secondary generator connections. EGWG suggested that a move towards sharing more of the benefits with others, such as existing and future customers and future embedded generators is required.

The duty on DNOs to facilitate competition in generation may require move away from the current charging arrangements; significant amendments may be needed to the way in which DNOs charge for the connection to and use of distribution networks. A number of charging options exist and include:

- 'Shallow' charges, whereby the generator pays only for the connection to the distribution network at the nearest suitable point at an appropriate . Such charges are similar to connection charges applied to generators connecting to the transmission network.
- 'Shallowish' charges, whereby the generator pays connection as above plus any reinforcement triggered by the connection to the distribution network at the same voltage as the connection and one voltage level above that of the connection. This structure is analogous to the connection charges applied to load customers connecting to distribution networks.

The introduction of 'shallow' and 'shallowish' charges would reduce the capital cost incurred and encourage additional connections of embedded plant. EGWG acknowledged that 'shallow' charges would likely to be more effective than 'shallowish' charges in this respect.

An important consideration is the potential weakening of locational signals that are present in the existing 'deep' charging structure. 'Shallow' charging provides no locational signal whereas 'shallowish' charges may place significant costs on other users. But, various charges between locations could provide incentives and disincentives to plant location.

The above charging options may require that reinforcement costs be met through other charges. Demand customers could pay all reinforcement costs through increased DuoS charges, although significant embedded generation would result in significant additional costs and raise inequity concerns. Generation customers could pay all reinforcement costs for generators through a new generator entry charge. Alternatively, load and generation customers could pay reinforcement costs through entry and exit charges. Such an option is equitable while providing significant encouragement overall to the connection of new embedded generation. It could also provide the locational signals to generators and customers lost through a move to a new charging regime.

EGWG highlighted that it was "for Ofgem to consider, in the light of wider Government policy objectives, to what degree embedded generation should be encouraged through connection charging policies" (DTI – EGWG, 2001). Regardless of any amendments made to the charging regime, analysis and assessment of the potential short and long term impacts of options for changes is required. Such analysis should encompass existing embedded generators that have already paid deep connection charges.

Provision of Information

Information regarding connection points and the effect of location on likely connection charges is central to decisions on the location of embedded plant. Developers of embedded generation have been concerned that the information made available to them is erratic, inadequate and overly complex.

The Utilities Act 2000 and proposed licence conditions requires DNOs to publish network development statements. NGC's Seven Year Statement is considered to be a valuable source of information about generation opportunities. EGWG identified the critical information required by generation developers, analysed cost effective ways of providing such information and established minimum standards to which all DNOs might be expected to work in future.

In order to meet the proposed licence requirement on DNOs to publish a network development statement, certain network information needs to be made available. Such a development statement should inform the market-place, enable developers to identify potential business opportunities, and provide transparent costs for network connections.

EGWG acknowledged that an appropriate balance between the value and costs of providing the information must be established. Comparisons are readily made with the information provided in NGC's SYS. But, acknowledgement must be given to the relative increased complexity of distribution systems, their extensive length, varied voltage levels, dynamic demand profiles and variety of networks.

A consistent approach across DNOs as to the provision of information and the connection application process would assist embedded generation development. General connection guidelines for embedded generation that clarify the roles of developers and DNOs and set standards, both for the quality of information submitted by developers and the quality of the response from DNOs, would be another encouraging development.

Key Issues - Policy and Strategic

The Transmission Network, Renewables and Embedded Generation
In developing their approach to renewables, CHP and other embedded generation, NGC have examined their likely interaction with the transmission network and system operation activities, identifying areas where NGC activities may affect development of such projects. NGC, as part of the EGWG, expressed their willingness to actively work to ensure NGC approaches fit with the actions and options identified by the group for ensuring that renewables and CHP are treated on an equitable basis relative to other users of distribution and transmission networks.

EGWG identified a number of transmission issues in its report. NGC have expressed in evidence provided to the House of Common Environmental Audit Select Committee in May 2001 their confidence that transmission related issues will not become a barrier to accommodating the amount of renewables or combined heat and power generation necessary to meet the Government's targets. They further added that, depending on the location and type of technology that penetrates the market, the transmission network may be able to accommodate a greater proportion of renewables, CHP or other embedded generation than that specified in the 2010 targets.

Actions to Address Longer-Term Transmission Issues Associated with Renewables
Facilitating and encouraging the development of open ancillary service markets may be essential in addressing longer-term technical issues that may arise from a larger proportion of wind and other intermittent renewables. The NGC have established arrangements that allow small and decentralised generators to provide reserve and frequency response through the use of aggregating agents. The EGWG suggestion that DNOs should facilitate local ancillary service markets is an important development.

Encouragement should be given to the most cost-effective provision of national frequency control and reserve demand. It follows that this should ensure that additional requirements can be provided in respect of reserve and response that may be made necessary to accommodate large amounts of intermittent wind generation. They may also allow the displacement of some of the large grid-connected power stations that currently provide these services without any impact on system security. Local ancillary markets would also provide embedded generation with additional income streams.

Actions to Address Longer-Term Transmission Issues Associated with Embedded Generation
It is essential that the continuing availability of ancillary services in the longer-term is ensured as embedded generators progressively displace present providers. The same aggregator agents as discussed above could assist smaller participants to provide such services to the required capacity and levels of dependability. As identified by EGWG, this aggregating role may in future be performed by DNOs as the facilitator of markets to obtain services directly for the distribution network or to sell on to transmission network.

Longer-Term Network Requirements
Certain technology trends may bring geographical generation and demand patterns into balance. For instance, high market penetration levels for fuel cells, micro-CHP and CHP district heating systems would bring electricity generation adjacent to where it is consumed in all areas of the country through the transmission of their fuel source by the existing by gas pipeline infrastructure.

But, other technologies may maintain or even increase the need for bulk electricity transfers. Renewable energy resources, such as wind and wave power, are most abundant in the north and west of the country. Rural agricultural or forestry fuel sources will likely be required for biomass power stations. Proposed interconnection expansion may allow access to new hydro, wind and geothermal resources.

The Contribution of Embedded Generation to Network Performance
EGWG identified three main areas that required further assessment through a co-ordinated programme of work needed to be put in place by Ofgem. Such a programme should include a clear timetable for delivery. The three main areas are:

- Design codes - The contribution to network security from embedded generation and the potential effects on system performance as experienced by customers need further analysis. In the short term, measures under the existing standards require clarification to allow recognition of the contribution of embedded generation to network security and performance. EGWG attached a target date of January 2003 to such a review.
- Ancillary services – The ability of embedded generators to provide services to the network, other than security, also require review by Ofgem. Such a review should focus on services such as voltage support; provision or absorption of reactive power, frequency response; reserve and black start. This would provide a differentiation between services that could be traded with the NGC or with others and the local security and system performance concerns of DNOs. Aggregation of ancillary services provided by small independent embedded generation by DNOs or others could ease appropriate trading arrangements with the NGC. EGWG attached a target date of January 2003 to such a review.
- Islanded operation - A review of the benefits and disadvantages of allowing embedded generators to operate in islanded mode and supporting local supplies in the event of network failure is required. Such an arrangement, albeit on a localised basis, can significantly lower the number of customer minutes lost. The maintenance of voltage, frequency and network safety under such operating conditions would likely remain with the DNOs and requires consideration. The group recommended a Health and Safety Executive and DTI review of the implications of connecting widespread embedded generation for the safety of distribution network operation. With a potential vast number of generators being connected to the system, safeguards are needed to ensure DNOs can be confident that a particular part of distribution network is 'dead' in the event of circuit outages.

EGWG offered that Ofgem need to ensure that incentives for DNOs to action the above are in place, assessing the costs and benefits of the changes proposed with a view to making any necessary licence changes.

Domestic and Micro Generation
Micro generation technology such as Stirling Engine or Fuel Cell based central heating systems and Photovoltaic (PV) roof systems may have significant implications for the future operation of distribution networks. Domestic or micro generation could meet most of a typical household demand (average of less than 1 kW but can have a peak of around 10 kW). The impact of widespread micro CHP or PV systems on the demand and generation profiles of distribution networks would be significant.

A distribution network may likely have no net electricity flow over certain times of the day, its role reduced to balancing the networks and providing the appropriate level of backup capacity and security. Such a development would have implications, not only for DNOs, but for suppliers, generators of all sizes, and the transmission operator.

That said, the development of domestic and micro generation is not without its pitfalls and complications. A number of technical and financial decisions will need to be addressed:

- Connection charges - simpler and transparent connection and payment structures need to be considered for smaller generators. Distributor charging options would need to be established in a manner that is appropriate to micro-scale generation technology.

- Payment mechanisms, via metering, profiles and fixed charges, for use of the distribution system, selling exports and buying imported electricity – There is a key requirement to establish potential costs associated with the metering and charging alternatives including those related to installation costs;meter reading cost; developing and implementing new demand profiles for domestic and micro-scale generation; costs and effects of bi-directional metering (often known as net metering) solutions; costs of implementing half-hourly metering; and the stranded costs of existing metering assets.

Technical requirements for connection to the distribution network that enable parallel operation - Most forms of micro-generation must comply with complex engineering recommendations. Work needs to be initiated to construct and apply appropriate yet simpler engineering standards. Such standards would need to be suitable for mass produced equipment and take fully into account important security and safety issues.

Metering arrangements for measuring the generation output, export to and import from the network - Metering should be economic to install and be linked to tariff arrangements that allow all the parties concerned to measure or estimate with confidence the information they need. Options include :

- The retention of one way meters linked to demand profile based tariffs that estimates typical flows in both directions. Although this would minimise installation costs, administration costs may be high;
- Bi-directional meters that operate with a net energy tariff or a profiled tariff which could estimate typical energy flows in both directions;.
- Import-export meters that provide measurable information on power flows in both directions thereby reducing the reliance on estimated demand profiles. Such a meter, alongside supportive legislation, could allow householder generators to benefit from Renewable Obligation Certificates.

Net-metering

"Net metering" – allowing customers to offset their electricity consumption originating from the transmission and distribution network by selling their own generated electricity to the network for the same price.

The tariff level is the most important factor for domestic feeds into grid. Although a number of potential methods, must ensure that domestic generators get paid – a big debate in itself hidden behind a simplified term of 'net-metering'.

Net metering – "using the grid as a kind of battery with fair prices in both directions improves the economics of small plant" (FT, 10 August 2000).

Small scale generators selling back to grid + a fee that reflects the costs of the grid, transmission losses, information management, co-ordinating supply and ensuring quality of supply????

Price signals at domestic levels – metering – providing the market place.

Net metering up to a certain stage but how useful in the long term?

Stakeholder Behaviour
If Government climate change and energy targets are to be met, the role of embedded generation and demand side management need to be recognised as an integral part of the electricity network design and operation. The potential for varied changes to stakeholder behaviour must be acknowledged. Such stakeholder behaviour may include:

- Amending the present incentives system to one that is neutral towards assets employed or operating costs and that rewards DNOs on the basis of improved performance. Current DNO incentives focus on the value of capital assets.
- The development, by embedded generators and other stakeholders, of more controllable generation, capable of providing integrated voltage control, security, etc.
- The development of tariff and metering arrangements that facilitate active demand and generation management.
- NGC adapting its agreements with DNOs to manage the impacts on the transmission system from the connection of a new embedded generator. This would allow an embedded generator to benefit from having only a single point of contact with its host network operator.

Performance 'v' Asset Based Regulation
Requirement to change the regulation to performance based rather than asset based?

Linking DNO revenues to performance measures, (customer value through fewer interruptions, stable voltages, speedy response to queries or requests for work or connection, low accident rates etc) rather than the size of the capital asset base. This would remove the DNO guarantee of a return on capital investments and incentivise them to reach high levels of performance at lowest cost. This may therefore encourage novel forms of system support, including embedded generation provided such alternatives were cheaper than infrastructure investments.

Distribution Network Operators
Provided with suitable incentives, DNOs may invest in their network to augment the potential for embedded generation connection. They could strengthen the network to maintain acceptable fault levels and increase the scope for connecting new generation. Amending the network's configuration may allow more flexible operation of embedded generation under fault conditions. New technology such as super conducting fault level limiters, energy storage technologies and household technologies such as energy efficient lighting and appliances, PV, fuel cell, Stirling Engine, etc could all be encourage by DNOs.

DNOs are ideally placed to manage the commercial and technological shift required to encourage the expansion of renewable and embedded generation. That said, the right commercial and regulatory frameworks need to be in place to facilitate this.

Transmission Network Issues
The future role of the grid may not be bulk transfer BUT system stability?

NGC may become smaller in asset and larger in systems control – operating the networks.

NG income – connection + infrastructure + balancing

NG income   £800 mill pre-vesting = RPI – X

                 £100 mill postvesting – reasonable return

The market value of diversity – immediate response – value of the grid?

Future Network Design, Management and Business Environment

When considering the implications of introducing embedded generation into distribution networks, the key issues that arise are :

- Possible future changes to regulatory process and incentives
- Future treatment of DNO business costs
- Lack of incentives to establish a local 'ancillary' services market
- Treatment of connection charges

The decision whether to facilitate the development of embedded generation by establishing a level playing field through regulation or by imposing measures to meet Government targets is an important one. Revising regulation will impact upon the design and management of distribution networks. But, it may not be enough in itself to meet current Government targets for embedded generation within the timescales set.

There are a number of potential scenarios and possibilities for creating the right business environment to encourage new approaches to embedded generation and demand management. The two extremes are the open market environment and the rigid regulatory environment that requires the connection of additional embedded generation capacity.

Key characteristics of an open market environment might include: increased certainty of the minimal performance based regulatory system; local ancillary and security services markets; opportunities for increased DNO revenue; and an amended the generator and demand management connection charging mechanism.

Key characteristics of a rigid regulatory environment might include: reward schemes for each MW of renewable or good quality CHP generation connected; electricity generated or consumption saved.

A market environment that lies between these two extremes is the most likely outcome. DNO and Ofgem consultation to develop proposals and construct market mechanisms that will facilitate increased connection of embedded generation is key to market development.

In addressing such issues, EGWG recommended that Ofgem need to ensure that the regulatory regime supports and incentivises DNOs to meet their obligations to facilitate competition in supply and generation. Certain aspects dominate DNO business: regulation and incentives; generation connection charging principles; and commercial mechanisms to support technical innovation. Ofgem should focus initial efforts on these dominate aspects.

The need for the Government to establish a strategic and co-ordinated approach across all stakeholders to research and development seems clear. Such a group needs to produce long term recommendations for further action and to assess their potential contribution to the government's targets and impact on stakeholder businesses.

Annex Three Invitation, Attendees List and Presentation

Invitation to Group Discussion and Review

UK ELECTRICITY NETWORKS

Electricity transmission and distribution in the UK in an intermittent renewable and embedded electricity generation system

Date: Thursday 19 July 2001
Time: 1:45pm to 5pm
Venue: Atlee Suite, Portcullis House, Embankment, Westminster

POST is an office of the two Houses of Parliament (Commons and Lords), charged with providing balanced and objective analysis of science and technology based issues of relevance to Parliament. POST carries out studies in areas such as defence, transport, environment and health as well as science policy. Drawing on the talents, knowledge and expertise of the science and engineering community, POST acts as an independent and unbiased source of information. It is politically neutral, serves Parliament as a whole and presents analyses and policy options tailored to the parliamentary process.

The purpose of this group discussion and review is to assess the initial draft of the *key issues* chapter of POST's report concerning electricity transmission and distribution in the UK in an intermittent renewable and embedded electricity generation system.

The review meeting is also intended to discuss potential recommendations to address the key issues and to identify areas for further research. The ultimate output of this consultation process will be a 4 page parliamentary briefing (distributed to 600+ parliamentarians) and a more detailed report to be made available on the POST website (http://www.parliament.uk/post/home.htm).

Proposed Timetable

Facilitation will be provided by Stewart Boyle, a writer and energy consultant.

Time	Activity
	Welcome and introductions
2:00pm to 2:25pm	Welcome, background and introductory presentation
	Review of draft chapter detailing key issues
2:25pm to 2:45pm	Scope of issues, major omissions, additional concerns not covered, etc.
	Focussed review of key issues – technical, market and strategic
2:45pm to 3:00pm	Prioritisation Exercise
3:00pm to 3:40pm	Break into groups for focussed discussions
3:40pm to 4:00pm	Tea and coffee break (continue break-out group discussion?)
4:00pm to 4:20pm	Continuation of smaller group discussions
4:20pm to 4:40pm	Mini presentations from the review groups
4:40pm to 4:55pm	Drawing together of key themes and debates
4:55pm to 5:00pm	Next steps and closing remarks

Attendees list

Facilitator: Stewart Boyle

Name	Organisation	Confirmed	Actual
~~David Millborrow~~	~~British Wind Energy Association~~	✕	✕
~~Catherine Mitchell~~	~~Cabinet Office – PIU~~	✕	✕
Graham Meeks	Combined Heat and Power Association	?	✓
Dr Amal-Lee Amin	DEFRA – Sustainable Energy Policy Division	✓	✓
Graham Bryce	DTI – Energy Policy Directorate	✓	✓
Phillip Baker	DTI – Head of Electricity Technology	✓	✓
~~Steve Jacobs~~	~~DTI – Energy Policy Directorate~~	?	✕
Dan Archard	Environment Agency – Policy Development Officer	✓	✓
Chris Wakeman	GPU Power – DNO	✓	✓
Doug Parr	Greenpeace	✓	✓
~~Tim Green~~	~~Imperial College – Electrical Engineering~~	?	✕
Mathew Leach	ICCEPT	✓	✓
~~David Tolley~~	~~Innogy~~	✕	✕
~~Chris Hewett~~	~~Institute for Public Policy Research (IPPR)~~	✕	✕
Lewis Dale	National Grid Company Plc.	✓	✓
John Benson	Ofgem	✓	✓
~~Dr Ashok Kumar MP~~	~~Parliamentary Group for Energy Studies~~	✓	✕
David Cope	Parliamentary Office of Science and Technology	✓	✓
Gary Kass	Parliamentary Office of Science and Technology	✓	✓
Sarah Pearce	Parliamentary Office of Science and Technology	✓	✓
Scott Butler	Parliamentary Office of Science and Technology	✓	✓
~~Gareth Thomas MP~~	~~PRASEG~~	✓	✕
~~Keith Allott~~	~~Royal Commission on Environmental Pollution~~	?	✕
~~Anthony White~~	~~Schroder Salomon Smith Barney~~	✕	✕
Cathie Hill	Scottish Power	✓	✓
~~Martin Cotterel~~	~~Sundog Energy~~	✕	✕
Rob Shackleton	TXU – Regulation	✓	✓
Mike Kay	United Utilities	✓	✓

Groups for break-out discussions

Strategic	Technical	Market
David Cope – POST	Gary Kass – POST	Scott Butler – POST
Sarah Pearce – POST	Phillip Baker – DTI	**Graham Bryce – DTI**
~~Steve Jacobs – DTI~~	Graham Meeks - CHPA	John Benson - Ofgem
Matthew Leach – Imperial College	Dr Amal-Lee Amin - DEFRA	~~Gareth Thomas MP – PRASEG~~
Chris Wakeman – GPU	~~Tim Green – Imperial College~~	Mike Kay – United Utilities
Dan Archard – Environment Agency	**Lewis Dale - NGC**	~~Keith Allott – RCEP~~
Doug Parr – Greenpeace	Cathie Hill – Scottish Power	Rob Shackelton - TXU
~~Dr Ashok Kumar MP – PGES~~		

Names in bold indicate the chairpersons of the break-out groups.

Presentation

Parliamentary Office of Science and Technology

UK Electricity Networks

Group Discussion and Review
19 July 2001
Portcullis House, Westminster

Slide 1 Outline of Presentation
Context of the Report
Publication and timetable
Purpose of the day
Timetable of events
Outputs of the day

Slide 2 Context of the Report
Govt set targets of 10% renewables and 10 GWe CHP by 2010 and further targets beyond?
Other UK responses to global climate change concerns, e.g the Climate Change Levy and the Renewables Obligation.
Impact of liberalised electricity markets, technological advance, tighter financial/lending constraints, and increased environmental concerns
Expansion of interest in low-capital, small scale, fast revenue generating projects.

Slide 3 Context of the Report cont...
How will electricity transmission and distribution networks adapt to these changing circumstances?
Will the transmission and distribution networks continue to function as before?
Will the transmission system serve as a conduit for transporting electricity between more locally dependent regional grids?
Will high-voltage transmission have a role at all?

Slide 4 Publication and timetable
4 page Parliamentary Briefing (POST Note) to 600+ interested parties
Detailed Report made available on internet
Published in Autumn 2001
Formal launch in Autumn 2001

Slide 5 Activities

Scope of issues, major omissions, additional concerns not covered, etc.
Prioritisation exercise (Stewart Boyle)
Focussed Group Discussions
Presentation of Group Discussion Outputs
Drawing together of key themes/debates
Next steps and closing remarks

Slide 6 Outputs of the Day

Highlight factual errors and omissions from the consultation documents
Encourage open debate concerning key issues
Generate a consensus as to critical areas/issues that need addressing
Focus further research
Foster ongoing collaborative relationships

Annex Four Outputs from Group Discussion and Review

UK ELECTRICITY NETWORKS

Electricity transmission and distribution in the UK in an intermittent renewable and embedded electricity generation system

GROUP DISCUSSION AND REVIEW

Date: Thursday 19 July 2001
Time: 1:45pm to 5pm
Venue: Atlee Suite, Portcullis House, Embankment, Westminster

INITIAL POINTS - ROUND TABLE

- General feeling around the table that the identification of key issues captured most of the salient points.
- Must be aware of the target audience, particularly in respect of the longer document.
- Long term of decentralised energy – need to move away from the short-term perspective to really looking at 2010 and beyond.
- The move towards a decentralised and disaggregated energy system appears inevitable.
- 2010 targets may mean up to 16GW of embedded generation – the interfaces between transmission and distribution, aggregation of generation and micro-generation are very important
- Regulatory incentives are the key – liberalisation broke the momentum of the large-scale centrally planned industry and increased the transparency of the ESI, thus highlighting structural problems
- Decentralised electricity systems are central to the sustainable energy vision.
- Clear need to prioritise issues –how do DNOs charge for services? Distribution network charging structures are critical
- What will networks do and be like in the future and how do we charge for it?
- Investment and skills implications – regulation needs to reflect this and DNOs need a way out of the RPI-X straightjacket.
- First steps are very important in order to smooth the transition rather than laying a number of barriers that required to be breached.

PRIORITISATION EXERCISE

In expanding initial discussions, the group highlighted the following as being priorities for action:

Market

- Need to recognise the true value of embedded generation (renewable and CHP) and regulation must reward this value.
- Renewable and embedded generation targets can not be met by edict alone, and require appropriate support, incentives and regulatory frameworks.
- The current market appears unlikely to be capable of meeting renewable and CHP targets. Thus, there is a need to intervene in the market to encourage generation, transmission and distribution. Likely to need more than just a level playing field to meet the targets and to get DNOs renewable and embedded friendly.
- Impacts of NETA on small generators is of great concern.
- Distributed energy will never be properly valued unless the value of the power being provided is truly charged to the customer.

Technical

- Dispersed wind may resolve intermittency BUT what impact in a decentralised market – Need for wind co-operative?
- Human Resources issues – appropriate staffing levels and available technical skills
- The microprocessor as the driver for a sophisticated decentralised control system.

Strategic

- There is a need for industry and government to accept that there are diffuse arrangements of decision making. At present distribution networks are on the whole, simple and passive. The need for clearer price structures and signals to drive change is evident. In the short to medium term, embedded generation may be viewed as negative load on the networks.
- Certainty of regulatory regime is critical. The price control every 5 years gives a short-term outlook for long-term asset/investment decisions. Long term network designs "v" short term generation transitions. One of the characteristics of decentralisation electricity s that it doesn't require long term planning and have the attached worries of sinking big assets.
- Transmission and distribution networks = 60 year investment/infrastructure decisions "v" short term transitional generation markets – How do you match the two????
- Need for sharing/pooling of resources across the industry to address key issues
- Who decides what needs to be done? – particularly at a technical level. Central control required to a certain degree – setting of standards, etc.
- How do you regulate without knowing what your end goal is – need for a vision taking account of dichotomy between central planning and liberalised market
- Controls of the system – central "v" distributed – virtual networks.
- Customer behaviour and protection is very important and must ensure that the lights are kept on.

BREAK-OUT GROUP DISCUSSIONS

The attendees broke up into smaller discussion groups to focus on key issues under the broad headings of market, technical and strategic. The break-out groups presented their discussions to the full group. Summaries of these presentations are provided below:

Market Issues

NETA AND MARKET MECHANISMS

- Has moved the goalposts to reflect more the economic benefits of certain types of generation.
- NETA does not attempt to address the social and environmental aspects of energy policy
- If NETA settles down, it may remain bad for small players but could be good for diverse large suppliers.
- Tweaking the market by government is much more transparent in the liberalised market and requires or justification.

RECOGNISING THE BENEFITS

- Crucial to recognise the benefits of embedded generation to the distribution network in terms of losses and reduced capital requirements.

RED TAPE

- Licence conditions for DNOs to link to NGC, e.g. one point of contact for connection with DNO-NGC liaison being taken by the DNO.
- Could facilitate the aggregator role to be played by DNOs.·
- Always need someone to facilitate supply
- Need for measures to stimulate aggregation

CHARGING

- Very complex area but needs to be established and consistent
- Congestion charging in Active Distribution Networks – matching of the transmission and distribution networks to the generation market

NET METERING

- Profiling "v" Half hourly metering

INCREASED CONNECTION OF EMBEDDED PLANT

- DNOs will do what is asked, provided the correct incentives are in place to motivate.

CERTAINTY AND PROVISION OF INFO

- Development of standard framework of charges for connections of less than 50 MW
- Provision of information may be less of an issue under a better charging structure.

Technical Issues

INTERMITTENCY

- NGC has no issue with 10% wind – can't verify 20% but do not perceive insurmountable problems with increased levels of wind.
- Predictability as an issue – market responses to lower reliability/capacity security?
- Impact of storage – pumped storage, regenerative fuel cells (on generators and aggregators)
- The mechanical and electrical inertia of the system will change as intermittent generation increases.
- Intermittency as an element of active management – local ancillary markets, bootstrapping needs planning.
- Geographical distribution of intermittent generation and impacts on local transmission and distribution network.

BULK TRANSFERS

- Mismatch between location of supply (source "v" acceptability) and demand
- Balance best resource location and demand location
- Impact of the size of generation
- Capture all costs – economic, environmental and social
- Strategic issues: planning process/community involvement
- Potential of increasing the capacity of transmission and distribution networks without new lines

ACTIVE NETWORKS

- Relevance of 25% embedded in 1970s? – networks themselves are very different now
- Technology gap in using the current network in active mode
- Market views self despatch as important
- Active management of a distribution network is not necessarily the same as active management of a transmission network (e.g. Islanding – local and regional)
- Investment is needed for the distribution network – via an incremental path NOT a major cash injection
- Who has the incentive to do anything at the moment?
- Valuing ancillary services within distribution markets

PLUG AND PLAY

- Needs greater emphasis in the report
- Standardisation – PV, MicroCHP, etc.
- Smarter metering – customer interests, equity/inclusiveness, ESCOs

Strategic Issues

VISION

- Develop a coherent structure across industry and government to facilitate development
- Need to look at the long term (2050) outcomes and regulatory/financial incentives to achieve them
- How can networks develop to allow flexibility?
- At what level /scale would the network start to restrict expansion of embedded generation and renewables?

DIALOGUE

- Develop a coherent structure across industry and government to facilitate development
- Need to bring network issues into Government policy considerations
- Mistrust – everyone should recognise that there are real issues to address
- Need to recognise the reality of obstacles, challenges, problems and each others positions

SKILLS AND INNOVATION

- Skill shortgaes of great concern
- Only 3 or 4 Universities offer power engineering courses
- A new system will demand these skills
- R&D on networks considerably reduced after privatisation – limited research capacity
- How do you provide incentives for technical developments?

REGULATION – CHARGING

- Must be designed and structure in order to deliver joined-up policy goals
- Uncertainty over future policy/regulatory changes
- A 5 year regulatory framework is not appropriate for 40-50 year assets.
- Legislation to allow net or dual metering – not in the Utilities Act
- Virtual utilities and aggregation (assists competition) + ancillary service provision
- Offsetting costs by Network Operator?
- Maintaining return on assets within a new regulatory framework?

FINAL COMMENTS OF GROUP

- The ESI was restructured to become saleable assets BUT the priorities today seem somewhat different.
- The assets have been sweated BUT what now?
- Sea change – Ten year transitions of the ESI?
- Big tension between free market principles and the desire for long term planning and co-ordination
- Technical – short term is OK and the lights can be kept on – Long term issues/problems can be resolved BUT at a cost
- Incentives and profits – is RPI – X an appropriate regime for meeting environmental and social objectives?
- The failure to expand embedded generation and renewables may likely be as a result of regulatory failure NOT technical failure
- Applied R&D concerns
- Need for real leadership.

Annex Five History of Electricity up to 1989

This annex will review key moments in the history of electricity and the Electricity Supply Industry (ESI) up to 1989. The period post 1989 will be considered in more detail in Chapter 2 and Annex Six. The work of the electricity pioneers will be examined and the evolution of the ESI will be overviewed across appropriate time periods. Although the focus will be on the UK, references to relevant international developments will be made throughout. Perhaps more than any other industry, the ESI illustrates the colossal impact of technological innovation and economies of large scale operation on modern economic life. The purpose of this chapter, through summarising the history of the ESI, is to attempt to serve as the base of knowledge and understanding from which future developments will arise. However, to quote a pessimistic view, “nations and governments have never learned anything from history, or acted upon any lessons they might have drawn from it” (Hegel, 1830).

ANCIENT ORIGINS

Ancient Greece and Thales of Miletus - 7th to 4th century BC

Electrical storms played a significant part in the creation of life on Earth and electricity has been around as long as the Earth itself. Magnetic and electrical phenomena have been familiar concepts for centuries. Myth has it that that the word magnet originates from Magnus, the name of a shepherd boy in ancient Greece whom placed the tip of his staff on a rock while tending his flock on Mount Ida. The rock exerted such a pull on his staff that he couldn't free it (The Education Site, 2001). However, it is more likely to originate from Magnesia, rocks found in Asia Minor, that are natural magnets and formed from an iron ore now known as Magnetite. Magnesia were believed to have great powers, ranging from curing many ailments to attracting lovers.

In the seventh century BC, Thales of Miletus, the Greek philosopher and mathematician, noted that rubbing the stone amber on cloth would attract light objects, concluding that the amber had become magnetic. However, he remained troubled by the fact that his rubbed amber could not pick up metals whereas Magnetite would attract iron without having to be rubbed.

The Chinese and the Arabs - 4th century BC to 1600

Around 376 BC, Haung Ti, a Chinese general, was made aware that, when suspended from a piece of thread, a piece of Magnetite would align with the direction of the Earth's North and South (Scholz Electric, 2001). This knowledge was quickly employed to aid his soldiers in finding their way over the long distances they travelled. The compass was in effect born, although it took until the thirteenth century for the Chinese to employ the Magnetite compass on board their ships, after which it was soon adopted by the Arab sailors. Through them, the compass was brought to Europe.

1600 TO 1830 - THE ORIGINAL ELECTRICITY PIONEERS

William Gilbert, Otto Von Guericke and Francis Hauksbee

By 1600, the compass was in common use. William Gilbert, the Physician to Queen Elizabeth I, explored the behaviour of static electricity. Continuing the work and deliberations of Thales, he realised that a force was created when a piece of amber was rubbed with wool and attracted light objects. He became aware that Thales had not been able to separate the difference between static electricity on the amber and magnetism in the Magnetite. He derived the word 'electrica' to refer to substances that acted like amber from the Latin term electricus, meaning to "produce from amber by friction." This term has its roots in the Greek term elektor, which means beaming sun (Education Site, 2001).

After Gilbert's discovery that a force of electric charge is created by friction of different materials, a number of further studies were undertaken. In 1660, Otto Von Guericke built the first static electricity generator. A glass ball was turned by hand and rubbed against a cloth, creating sparks of static electricity. He also showed that electricity could be transmitted by using a wet string to conduct electricity several feet.

Research by Francis Hauksbee at the Royal Society in London resulted in the discovery in 1709 of the effects of putting a small amount of Mercury in the glass of Von Guericke's generator and evacuating the air from it. When a charge was built up on the ball and then a hand placed onto it, the glass ball would glow at a brightness sufficient to read by. This effect was similar to the strange glow seen around ships in electrical storms known as St. Elmo's Fire. Unbeknownst to himself, Hauksbee had created the Neon Light (Encyclopedia.com, 2001)

Benjamin Franklin

Benjamin Franklin further developed the work of Gilbert and announced in 1747 that this electric charge exists of two types of electric forces, an attractive force and a repulsive force. He gave the charges names and symbols, positive (+) and negative (-), to identify the two forces. Franklin suspected correctly that lightning was an electric current in nature, and that a lightning bolt was really a spark of electricity. His famous stormy kite flight in June of 1752 led him to develop many of the terms that we still use today when we discuss electricity - battery, conductor, condenser, charge, discharge, uncharged, negative, minus, plus, electric shock, and electrician (Franklin Institute, 2000).

Alessandro Volta

In 1786, Luigi Galvani, an Italian professor of medicine, found that the leg of a dead frog twitched violently when touched by a metal knife. Galvani proposed that this meant that the muscles of the frog must contain electricity. By 1792, another Italian scientist, Alessandro Volta, demonstrated that the main factors in Galvani's discovery were in fact the two different metals - the steel knife and the tin plate upon which the frog was lying. Volta showed that electricity is created when moisture comes between two different metals. This led him to invent the first electric battery or primary cell, the voltaic pile, which he made from thin sheets of copper and zinc separated by paper soaked in salt water.

A new kind of electricity was discovered. Electricity that flowed steadily like a current of water instead of discharging itself in a single spark or shock. Volta demonstrated that electricity could be made to travel from one place to another by wire, thereby making an important contribution to the science of electricity. The unit of electrical potential, the Volt, is named after Volta (Scholz Electric, 2001).

Hans Christian Oersted and Andre Marie Ampere

Volta's discovery enabled more experiments to be carried out with a reasonably controllable and sustained flow of electricity. During one experiment in 1820, a Danish Scientist, Hans Christian Oersted, noticed that a current of electricity would cause a deflection on a compass needle. Oersted deduced that this was a consequence of the wire's electric current producing magnetism and introduced the world to electromagnetism.

Oersted's discovery quickly led to many different ideas and theories about the relationship between electricity and magnetism. In the same year, a French physicist, Andre Marie Ampere, showed that two parallel conductors carrying currents travelling in the same direction attract each other and, if travelling in opposite directions, repel each other. He formulated the laws that govern the interaction of currents with magnetic fields in a circuit. As a result, the unit of electric current, the amp, was derived from his name.

Georg Simon Ohm

In 1827, the German physicist, Georg Simon Ohm, discovered one of the most fundamental laws of current electricity. Ohm closely examined Volta's principle of the electric battery and Ampere's work on the relationship of currents in a circuit. He was able to demonstrate from his experiments the simple relationship between resistance, current and voltage, Ohm's famous law, stating that the flow of current is directly proportional to voltage and inversely proportional to resistance, allowed scientists for the first time to work out the amounts of current, voltage and resistance in electric currents, and the variations of one through changes in the others. Altering circuit components such as resistances enabled the design of circuits to perform specific functions. This new unit of electrical resistance, the ohm, was named after him.

1830 to 1880 - THE BIG BREAKTHROUGHS

Michael Faraday

The English scientist, Michael Faraday, was enthused by the invention of the electromagnet and wondered if electricity could produce magnetism, then why couldn't magnetism produce electricity? In 1831, Faraday found the solution and demonstrated the continual production of electric current from mechanical induction. Electricity was produced through magnetism by motion, a magnet moving inside a coil of copper wire creating a tiny electric current to flow through the wire (IEE, 2001). Faraday founded the science of electromagnetism and his discoveries form the basis of the electrical industry today (IEE, 2001).

Developments occurred at a rapid rate after Faraday's experiments. As a new source of energy, electricity’s full potential was not realised and the race to develop generators that could be of industrial use was on.

Primary and secondary cells

Continuing the work undertaken by Volta, in 1836, the Daniell Cell became the first moderately efficient cell (battery). This was followed by the Leclanche cell in 1866, said to be the forerunner of the modern dry battery that is used in portable radios today. 1881 saw the introduction of the lead-acid accumulator (battery) that had the ability to be recharged by the newly developed DC generator, thus giving a supplementary supply of heavy currents. With this progress the primary batteries became less important, although remained in use for limited purposes, such as telegraphy. The lead-acid battery or the secondary cell is still used comprehensively today, for example in motor vehicles (Scholz Electric, 2001).

The Electric Telegraph and the telephone

The main characteristic of the primary cells, i.e. the provision of a constant source of significant amounts of electric power at reasonably low voltage, made them an essential component of the early communications system. Alongside the invention of a practical electromagnet, they opened the way for development of the electric telegraph and later the telephone. The idea of an electric telegraph was conceived by an American, Samuel Morse, in 1831. It proved practical in 1837, when Morse was able to make use of a supply of electricity from batteries alongside the electromagnet to complete his invention. It was based on the sending of coded messages over wires by means of electrical impulses. These impulses were identified as means of communication as dots and dashes and referred to as “Morse Code”. This electric telegraph was the first system of electrical communication.

By 1875, the Scot Alexander Graham Bell realised that electricity may be utilised for other forms of communication than Morse Code over telegraph wires. He focussed on acoustics and sound, based on the principle that if Morse Code created electrical impulses in an electrical circuit, some means of sound causing vibration in the air could also create electrical impulses in a circuit (Scholz Electric, 2001). On 7 March 1876, his invention was officially patented and a successful demonstration was made at an Exhibition Hall in Philadelphia. Although others were working on similar inventions, including Elisha Gray and Thomas Edison, Bell won the day and the honour of inventing the “electrical speech machine”, more commonly referred to as the telephone.

Electric motors and lighting

Much development work focussed on electric motors and lighting against the strong competition of the well established steam engines and gas lighting. Claims were made as to the harmful effects of using electricity; causing headaches, skin disorders and the onset of allergies, much of this negative feeling originating from the threatened gas and steam industries.

Electric carbon arc lighting had been exhibited in experimental form in 1808 by Sir Humphry Davey, the British scientist, who demonstrated how electricity can jump across two carbon roads. Davey used a large battery to provide the heavy current required by the arc lights for his demonstration as no means of mechanically generating electricity had as yet been developed.

Arc lights worked on the principle that when two carbon rods in a circuit are brought together, an arc is created. This arc gives off a brilliant incandescence and can be maintained as long as the rods are just separated and kept mechanically fed. The arc lights took a heavy current from their battery sources and it was not until around 1860, when adequate generating sources were available, that practical use was made of them. Arc lights were used mainly for street lighting and in picture theatres and continued to be used until the early 1900s but were eventually superseded by the incandescent light.

Private companies, such as Siemens in Germany and Cromptons in Britain, began to be established to provide electric lighting for streets, theatres and galleries, and to the more avant-garde and wealthy homes.

The incandescent bulb

Progress continued apace, and after arc lights were put to practical use, efforts were geared towards further developing lighting technology. Such experiments centred on the development of a universal light for use in the home or office, rather than just for street lighting. Initially platinum was used for a filament and enclosed it in a glass bulb. But, it soon burnt out and it was not until 1879 that an adequate lamp was produced.

In 1879, Thomas Edison in America and Joseph Swan in England simultaneously produced a carbon filament lamp that provided both brightness and longevity. Edison replaced platinum with a filament of carbonised bamboo fibre and Swan used a carbon filament, from parchmentised cotton thread. Edison wanted to bring light into every home and factory and proclaimed the news of this achievement to the world, patenting his invention on 21 December 1879 (Thomas Edison’s Homepage, 2001). The impact of the electric lightbulb was substantial, creating the first extensive demand for electricity half a century after current had first been observed.

And so the electric light and power industry was born. Continued experiments focussing on the optimal material for the filament further increased the efficiency of the incandescent lamp. Tungsten wire was used In 1911, followed by the development of the gas filled lamp in 1913. By 1934, the coiled coil pearl lamp with which we are familiar with today was introduced..

The DC Generator

After the work of Edison and Swan, the DC generator became one of the essential components of a constant lighting system, as commercial and residential lighting became practical. After Oersted's discovery in 1820 that an electric current produces magnetic fields, the DC motor was developed. It was initially thought that magnetism could not produce electricity, such as by a DC generator. The work of Faraday in discovering the principle of electromagnetic induction in 1831 altered this perception (IEE, 2001).

The electric motor and the electric generator are based on this principle, yet it took until 1871 for the electric generator to be used commercially. Zénobe Théophile Gramme, a Belgian electrical engineer, continued the work of Antonio Pacinotti, an Italian physicist who had produced a direct current dynamo, and in 1869 constructed a dynamo of his own that proved practical in applications such as electric illumination (Scholz Electric, 2001). By reversing the principle of his dynamo, Gramme invented the electric engine. By 1872, Siemens and Halske of Berlin had improved on Gramme's generator by producing the drum armature and further by the slotted armature in 1880.

1880 to 1915 – THE BIRTH OF AN INDUSTRY

Closed-circuit electric lighting systems became showcases for wealthy individuals and major public buildings, often powered by a variety of different generators (Hart et al, 2000). Edison had his eyes on the bigger picture and formed the Edison Electric Light Company in 1878 to "own, manufacture, operate and license the use of various apparatus used in producing light, heat and power from electricity." Edison envisaged a system that would deliver electrical energy to individual households from a central power station, taking advantage of economies of scale and bringing the unit cost of electricity in line with the competition, namely gas lighting (Hart et al, 2000). Edison built the first central electricity steam engine generating plant in Lower Manhattan, New York, in 1882. It provided direct current (DC) electricity to one square mile in New York City, including offices on Wall Street and those of the New York Times, although on the first day of operation only 52 customers wanted electricity. The investor-owned electricity utility was born (Thomas Edision Homepage, 2001).

The commercial response was swift. A wave of central generation electricity systems were installed, not only be Edison's companies and licensees, but also by electrical engineers such as Werner Von Siemens in Germany and Charles Merz of England. Offering electricity from public-supply mains avoided the high costs of installing individual generators on individual premises, and the first electricity mini-grids began to develop.

Such projects remained expensive and few people could afford the service, typified by the initial slow growth rate of privately-run central power stations. Funding from the public purse seemed to offer the greatest potential, 1889 seeing the first municipal electricity development in Britain at Bradford (Hart et al, 2000). Industry growth was stimulated by reductions in the overall costs of production and supply as the scale and number of projects grew.

Transmission and mini-grids

Through the 1880s, mini-grids were established across North America and Europe. These developments were financed and operated solely by town councils, solely be private enterprise or by a mixture of the two (Hart etal, 2000). The US model tended towards private ownership and Germany towards a public and private partnership. Meanwhile, in the UK the constant clashes of the private sector, local government and Parliament limited initial progress, as fears of the creation of tyrannical and monopolistic electric lighting companies came to the fore.

Research continued and offered that DC/one way current had it's limitations in relation to transmission over long distances. As a DC system expanded with wires extended ever further, the cost of losses from the wires became prohibitive, likewise the restorative response of using heavier transmission wires (IEE, 2001). Alternating current (AC) generation, current that surges rapidly back and forth in the circuit, was the alternative. A device known as a transformer could raise or lower the voltage of AC electricity as required. As defined in Ohms Law, "in an electric wire carrying a given amount of power, the higher the voltage the lower the current and therefore the lower the losses in the wire" (Patterson, 1999). A transformer allows AC voltage to be stepped up, thus lowering current prior to transmission over the wires. A transformer at the other end of the system can be used to lower voltage before delivery to end users. In this manner, transmission losses were significantly reduced, allowing for remote-sited electricity generation, e.g. hydropower.

Although opposed by Edison, one of his employees, Nikola Tesla, an inventor from Croatia, was working on developing an alternating current induction motor. Tesla discovered the rotating magnetic field in 1883, the principle of alternating current, that changed in opposite directions fifty times a second, referred to as 50 Hertz. The alternating current generator has a rotating magnetic field. Tesla then developed plans for an induction motor, that would become his first step towards the successful utilisation of alternating current (Scholz Electric, 2000).

In 1885, George Westinghouse, head of the Westinghouse Electric Company and one of Edison's main competitors, bought the patent rights to Tesla's three-phase system of alternating current. In 1886, the first alternating current power station was placed in operation. Tesla set up his own laboratory and announced his invention of the AC motor in 1888. Westinghouse then hired Tesla to sell AC transmission using the AC induction motor across North America. All, bar Edison, agreed that AC was superior to DC (Thomas Edison Homepage, 2001). Even Edison's Electric Company, now named General Electric, switched to AC, ousting their founder in the process. All modern day electric motors such as fans, air conditioners, and refrigerators run on principles established by Tesla.

The comparable reduction in losses due to the change from DC to AC allowed the electricity system to cover larger geographical areas. Generation plant need no longer be located close to sources of demand, bringing into play the possibility of electricity generation from more remote sources, e.g. hydroelectric power stations., and transportation to clustered demand points. This high voltage transport of electricity was called “transmission” so as to differentiate it from the lower voltage “distribution” of electricity direct to users (Patterson, 1999).

Concept of load diversity

Samuel Insull, a contemporary of Edisons, chose not to join the revloution at the General Elctric Company, rather he decided to focus his attention to utility operations. Insull began to shape and define important economic concepts that still govern modern utility planning and pricing today.

Insull noted that generating plant had high fixed costs, initial high investment for plant and distribution, and low operating costs. He offered that having more customers connected to the system would increased revenues, therby spreading the fixed costs across a wider customer base (Hart et al, 2000). This would bring costs down, and thus encourage more customers. The development of the demand meter made it possible for Insull to more accurately price electricty, setting rates to cover the fixed and variable costs of generation and distribution.

Insull also noted that separate companies often provided electricty for specific purposes only, e.g. residential lighting, for trams, etc. Demand patterns were clearly identifiable, such as demand for lighting at night. Generating plant was often idle for significant parts of the day. Simple economic analysis identified that higher profits were available the longer the plant was in use (Hart et al, 2000). A lower average kWh cost was also possible. Electricity, with the exception of batteries and pumped hydro and newer technologies such as flywheels and regenysys, cannot be readily stored. Insull recognised that the key was to find the right mix of customers to utilise the plant for as much of the day as possible. In order to maximise plants to their fullest, one might factor for the early morning and late afternoon tram demand peaks, the daytime business demand load and the evening residential lighting demand patterns, all of which could be provided at cheaper costs by one continuous generating plant (Hat et al, 2000).

The universal system

Those wishing to develop electricity systems now had a choice between DC or AC generation. In the UK, central-station systems were autonomous and the mains networks began to overlap geographically with obvious infrastructure inefficiencies. While in the US, differing franchise rights offered by local municipalities kept the industry fragmented and ineffective. As demand for electricity increased throughout the 1890s and 1900s, de facto monopolies began to be established as rival companies competed over unserviced areas rather that duplicating existing systems (Patterson, 1999). But, industry competition developed as a growing number of companies fought over the ever-shrinking unserviced areas. A patchwork of different systems across North America and Europe arose, varying in ownership, financing and technology.

The call for integration between mini-grids became undeniable, the economies of scale for power generation dictating that fewer and larger power plants would drive down unit costs and make electricity affordable to increased domestic and industrial users alike. The main technical dispute was resolved by the introduction of the universal system in 1893 that used AC-DC converters and transformers. The universal system accepted both AC and DC inputs, transmission was strictly AC, and delivery to users at either AC or DC as demanded. “The universal system made possible the interconnection of existing systems and their power stations, permitting amalgamation and steady expansion of electricity supply over ever wider areas to more and more customers, not only for lighting but also for electric motors for street railways or trams, and in due course also for stationary electric motors in factories.” (Patterson, 1999)

As high voltage AC transmission became the norm, hydroelectricity came to the fore and was tapped wherever possible. Steam powered generation often required the regular delivery of bulk supplies of coal and emitted smoke, soot and ash over the local environment. Early 20th century steam powered generators were operating at fuel efficiencies of under 10 per cent (Patterson, 1999). However, the major industrial areas of the UK, Germany, Russia and the USA tended to have little hydroelectric potential close enough to areas of demand whereas coal was plentiful. England in the 1880's was the centre of the industrialised world and was powered by large, noisy and inefficient reciprocating steam engines that had captured the energy of coal and transformed Britain.

In 1884, Charles Parsons developed the steam driven turbine generator that significantly improved the efficiency and operation of coal fuelled generating plant. Although comparatively simple in it’s conception relative to current technology and practices, the fundamentals remain the same. In steam driven turbine generation, heat is generated by burning fuel such as coal, peat, oil or gas. This heat is used to convert water to high pressure steam. The steam is then heated again to increase it's temperature and pressure and is then fed into the turbine. Further efficiency gains were harvested over the next few decades as the technology was further utilised and developed.

Countries proceeded to integrate their electricity supply networks. Local authorities facilitated integration in Germany, while private companies merged to provide bulk supplies to municipalities in the US, such developments aided by the closely linked equipment manufacturers and supply companies (Patterson, 1999). The picture in Britain was somewhat different, the rivalry between private companies and local authorities obstructing integration.

1915 to 1945 – CENTRALISATION, INTEGRATION AND CONTINUED GROWTH

The impact of World War I (1914-1918) upon the electricity industry was acute, world demand for electricity doubling and the electricity industry becoming a large global employer (IEE, 2001). British legislators responded by ensuring that the 600 plus separate electricity departments and companies that had developed by the end of the War needed to be brought under control. “By 1918, in London alone there were 70 authorities, 50 different types of systems, 10 different frequencies and 24 different voltages.” (Cochrane, 1985) The Electricity (Supply) Act, 1926 integrated the British electricity supply industry by establishing a 132,000V AC synchronous grid under the Central Electricity Board (CEB).

Under the doctrine of economies of scale, generating plant continued to be ever larger, networks were extended and centralised electricity became ever more widely available and affordable. The interconnection of electricity systems offered many technical and economic advantages. Interconnection can have a levelling effect on demand cycles, provide improved security and back-up for plant malfunction, maintenance and rapid changes in demand through linking stored hydro and standard steam generation. Interconnection also enabled a reduction in the amount of “spinning reserve” required as back-up, thus reducing system costs.

In 1924, the World Power Conference, now called the World Energy Council brought 1,700 delegates from 40 countries, the controllers of the electricity systems, together for the first time (WEC, 2001). The scale may have been becoming ever larger but the basics remained pretty much the same. Steam or water turbine generators fed AC into a network of high voltage transmission and low voltage distribution wires, this synchronised AC system operating to all intent and purposes as a single machine (Patterson, 1999).

Electricity was accepted as the energy of the future. An ever growing number of appliances were powered by electricity, such as washing machines and refrigerators. Electricity demand continued its inextricable rise, particularly during World War II (1939-1945), although damage to transmission and distribution structures limited growth somewhat. National governments made the rebuilding of the grid and supply structures a priority and were increasingly seen as responsible for providing the public with power (Hannah, 1979). The costs of financing the large scale generation projects often limited private sector ability and enthusiasm.

1945 TO 1985 – CENTRALISATION AND NATIONALISATION

Energy policy agenda

Energy policy can be defined as a means of finding a balance between concerns for security of supply, economic efficiency, environmental protection and social considerations. Such concern may often be in conflict and relative views as to the most important may differ with government, economic cycles and other factors.

Governments took the opportunity to amend administrative and technological systems and to strengthen the centralised structure of the industry, many going as far as full nationalisation. Electricity had become a public service, the post-war years seeing the creation of Electricite de France and Enel of Italy, amongst others (Hart et al, 2000).

In the UK in 1947 and 1948, Clement Atlee's Labour government under the Electricity Act, nationalised the electricity supply industry. Prior to this nationalisation, there existed 300 electricity supply companies with average generating plant capacity of 10 MW. The main goals were the provision of electricity to all parts of the country and the removal of variations in voltages and price tariffs. *"In England Wales, the drive for equity became particularly prominent following World War II. Subsequently, socially driven regulation led to the extension of the national grid to rural areas with little concern of the economic viability of these decisions"* (Amin, 2000). The structure of the nationalised industry in England and Wales was dominated by one large generating and transmission company, the Central Electricity Generating Board (CEGB), which sold electricity in bulk to 12 area distribution boards, each of which was obligated to serve a closed supply area or franchise (Cochrane, 1985). A co-ordinating body, the Electricity Council, dealt with overall policy matters. In Scotland and Northern Ireland there were vertically integrated boards which also exercised regional monopolies. This monopolistic system was characterised by centrally planned investment, an engineering-led approach and a cost-plus pricing mechanism.

The US persisted with its majority private-owned centralised structure, imposing a similar structure on Germany and Japan in the immediate post-war years. The Soviet Union and Eastern Europe electricity structures were operated under the central planning system. large power stations being constructed by the state to drive industrialisation. The post-colonial nations of Latin America, Africa and Asia tended to adopt the centralised, nationalised structure (Patterson, 1999).

The US post-war consumerism boom has been attached largely to the growth of electrical appliances available on the market backed by an electricity supply industry geared towards sustained growth. The period from 1950 to 1960 saw average power station size increase from 30MW to 300MW, the cost of generation and price per unit falling accordingly (Hart et al, 2000). Central generated electricity had become part of everyday life.

The predicted continued growth rates in electricity demand impacted significantly on electricity system planning and on project finance. With an ever increasing obligation to supply, new power stations were clearly required and according to the mantra of the day, “the bigger the better.” Generating technology had developed to include the combustion of oil and natural gas, as well as coal in steam powered plants operating at fuel efficiencies of around 40 per cent and outputs per unit of 500 MW. Lack of suitable or a publicly acceptable sites near to areas of demand contributed to the development of larger and more remote generating plant linked to the ever expanding high voltage transmission grid.

Nuclear powered electricity generation had also entered the equation, Queen Elizabeth II opening the world’s first nuclear power station at Calder Hall (now Sellafield) in 1954. Although the early proponents of nuclear suggested that it would be too cheap to even meter, the initial capital outlay was huge and much work was needed to be done to bring them the capital costs in line with coal fired generation. By the 1960s, design improvements appeared to have achieved such cost reductions and across the world nuclear plant was ordered as a part of the portfolio to meet the predicted increases in demand (Patterson, 1999).

Excess capacity and the oil crisis

In the US, the impact of prolonged economic growth was increasing inflation and higher interest rates. The anticipated continuation of the high electricity demand growth patterns of the 1960s failed to materialise. Generating capacity growth began to outstrip demand increases, some utilities being left with excess capacity and damaged investor confidence. The consequence was an increase in residential and industrial electricity prices. In the US, between 1975 and 1985, residential and industrial electricity prices rose by 13% and 28% in real terms respectively (EIA, 2001).

The OPEC oil embargo of 1973-1974 and subsequent sharp hikes in fossil fuel process, alongside growing concerns for the environmental impacts of electricity generation led to increased operating and construction costs of power plant projects across the world. Clean Air legislation had significant impact on capital, fuel and operating costs and energy conservation legislation encouraged slower growth in electricity demand (Patterson, 1999). As the security of fossil fuels became a key concern, many countries responded by undertaking orders to expand the contribution of nuclear generation. But, the faith in nuclear electricity generation soon diminished as a result of near disaster at Three Mile Island, Pennsylvania in 1979.

The ESI was having to look at itself in a new light. Its purpose was no longer to simply continue to provide ever increasing amounts of electricity of cheaper prices. The world beyond the customers electricity meter was no longer an untouchable and uninspiring domain. Demand-side management through conservation, advice and better technology, e.g. energy efficient light bulbs, became essential, particularly in the US for maintaining revenues and profitability (Brooks & Butler, 2001).

In response to the oil crises of 1974 and 1979, energy policy in the 1970s was driven by perceived fossil fuel shortages, the common response in most developed countries being increased state intervention. For example, the introduction in the US of the Public Utilities Regulatory Policies Act (PURPA) in 1978 encouraged the development of smaller, non utility power producers through the elimination of many prohibitive procedural and planning regulations. Many of these independent power producers initially used renewable energy sources, often wind, although later used natural gas.

UK - Electricity Act 1983

One of the first acts of electricity reform by the Conservative government elected in 1979 was the Electricity Act 1983. Similar to legislation passed in the US, the Electricity Act of 1983 was designed to encourage the growth of independent power producers. It was focussed on removing barriers to entry to non-utility generators and to provide independent producers of electricity open access to the national grid., the Act requiring the CEGB to purchase electricity from private producers at avoided costs, that is, at a price equal to the costs the board would have incurred to produce the same quantity of electricity itself. Its effects were limited due to the low rates of return that the CEGB allowed incumbent power producers discouraging new entrants and the failure to fully remove the unfair access to the grid that incumbent power producers had over new entrants.

The period post 1989 is detailed in Section 2.2 and Annex Six.

Annex Six A History of UK Electricity Networks

Introduction

This appendix will review the origins and history of UK electricity networks from 1920 to the present day. The technological, legislative and market developments over this period are highlighted throughout.

1920s – The Weir Report and the Electricity (Supply) Act 1926

In the 1920s, most electricity systems operated independently, meeting all the electricity requirements in their own area. Operating the system with sufficient capacity to meet the worst case scenario likely to arise was essential. Each area provider needed to factor in enough reserve plant to provide electricity during maintenance or plant breakdown, leading to 75% more generating plant throughout the country than was needed to meet the peak demand (Cochrane, 1985).

The government report headed by Lord Weir published in 1925 led to the drafting of the Electricity (Supply) Act, 1926. The Central Electricity Board (CEB) was created and given the job of interconnecting the most efficient electricity generating plant by a “national gridiron” of high voltage transmission lines. Once this transmission network was constructed, the CEB would specify levels of generation to achieve lowest overall costs. The CEB would then purchase electricity output in bulk and sell this back to distribution and supply companies at cost plus appropriate grid construction and operating costs (Hannah, 1979).

The CEB was also charged with co-ordinating annual overhaul programmes in order to maintain the best possible availability of generating units and transmission capacity. The inevitable short-term problems related to plant breakdown and transmission faults were factored into the decision making process.

The fundamental philosophy behind the grid was, not that long distance transmission was economic, but rather that intra-regional interconnection of the generating stations in each area would bring significant economies (Cochrane, 1985). Another rationale for the development of a linked transmission network was concerned with security of supply. If anything were to go wrong at a local power station, the grid would be able to provide supplies from somewhere else. Many critics labelled the Weir report and the Act as an unprecedented experiment that was likely to have highly detrimental effects on electricity supply, and would prove cumbersome and unworkable (Cochrane, 1985).

Such criticisms were somewhat dismissed by the government, although the dream of electricity for all in England, Scotland and Wales did not start to be realised until the middle of 1928 when construction on a national grid system began. The job of building the national grid was immense, through the design of a complex and resilient electrical system, negotiation of suitable routes, location of generating plant and other factors. Although more expensive than the 33kV or 66kV transmission options on the table, the decision to transmit at 132kV was justified by cheaper line costs per unit of power transmitted and by lower losses in transmission at higher voltages (Hannah, 1979).

The initial vision of Weir report of a national gridiron was scaled down to a series of networks, each with grid and operational control and based on the main industrial areas. Limited capacity national tie-ins were factored into the system to allow transference between regions. The six grid areas in England and Wales were Newcastle, Leeds, Manchester, Birmingham, Bristol and London, while in

Scotland the grid was focussed on the Glasgow area (Cochrane, 1985). Of the existing 438 power stations, only 140 were deemed to be of a suitable size and efficiency for grid connection (Hannah, 1979). By despatching load at grid control centres, in addition to knowing which power stations had the lowest costs, the CEB developed a wealth of knowledge on the social life and working routines of the population they served. In the North West, for example, they learned to start up extra generators whenever Gracie Fields was due to sing on the radio (Hannah, 1979).

1930 to 1945 – Completion of the National Grid and the Integrated Single Network
The development of the 132kV transmission system and the construction of associated transformers, switch gear, metering and control apparatus of a type needed to deal with high voltages required much innovation and technological development. The CEB reported that the construction and design of the national grid spurred technological development and the development of the export business of the UK electrical manufacturing industry (Cochrane, 1985).

The final pylon of the originally planned grid was erected on the outskirts of the New Forest on 5 September 1933. The national grid consisted of 4,800 km of 132kV transmission lines, 1,600km at lower voltages and 237 substations and came into full operation in 1935. The savings impacts were almost immediate. By 1938, £3,25 million was saved on generating costs and reserve plant was down from 75% to 15%, saving a further £22 million (Cochrane, 1985). The mid-thirties also saw the introduction of larger capacity generating stations, such as Battersea in London, with ratings of 60MW to 100MW.

The next stage of development for the national grid was based on the premise that if savings were being accrued with the grid working as seven independent networks, what savings might be available if the system was unified? On 29 October 1937, a grid control engineer decided to test whether the transmission system could operate as an integrated single system, seemingly without the permission of the appropriate authorities. The integrated system operated perfectly adequately.

Demand estimates in the harsh winter of 1938 highlighted a potential shortfall in generation in the south of England. This triggered the decision to run the transmission system as one, co-ordinated from the South East, to take advantage of excess generation from the North. If the measure of efficient spare capacity planning is that when everything seems to be going wrong supplies can be maintained, the CEB and the grid had passed the crucial test (Hannah, 1979). Although initially intended as a temporary measure until February 1939, the areas have remained connected ever since.

The national grid came to the fore during World War II. People were evacuated from urban areas and the impact on geographical patterns of demand were significant. The CEB responded through the construction of over 500 miles of transmission lines by 1942 to transfer electricity from the evacuated urban areas. The national grid enabled the electricity to keep flowing, regardless of damage to individual plant in different areas. “During the blackest days of the war, the grid more than justified its existence and played a large part in keeping the wheels of industry turning” (Cochrane, 1985).

Post World War II years – Nationalisation of the Electricity Supply Industry
The immediate post WWII years may be best summed up by the words of the then UK Prime Minister, Clement Atlee. “You cant fight a war and scrape the bottom of the barrel, throwing in everything you’ve got, and then start up again as if nothing has happened.” The ESI was far from immune to the hardships of post-war Britain, particularly affected by reduced stocks of coal, the most significant fuel source for electricity generation at the time.

Atlee's Labour Government response was to nationalise the ESI in 1947. The British Electricity Authority (BEA) was created, effectively becoming the manufacturers and wholesalers of the ESI in generating and transmitting electricity via the grid to large substations/bulk supply points. Twelve area distribution boards were the retailers of the ESI, purchasing in bulk from the BEA for distribution to the homes, shops, factories and other electricity users (Hannah, 1979).

1950s – Grid expansion, the CEGB and Interconnection

The grid network was expanded, construction beginning in 1950 on a 275kV supergrid with the ability to be upgraded to 400kV in the future. The new pylons were twice the size of the existing 132kV ones. There can be few people who think that a series of large metal structures supporting a network of cables actually improves the landscape, and from the very start of the grid's construction the impact of the thousand of miles of obtrusive transmission lines has been the subject of public disquiet and environmental concern. The proposed expansion triggered much protest from groups concerned with environment and landscape protection. More restrictive Town & Country Planning Regulations and the development of National Parks, Areas of National Beauty and Sites of Specific Scientific Interest also complicated the routing of new transmission lines.

The Electricity Act (1957) created the Central Electricity Generating Board (CEGB). The CEGB's often contradictory charge was to provide "an efficient, co-ordinated and economical supply of electricity in England & Wales… …with regard for the preservation of amenity, ranging from the natural beauty of the countryside to objects of architectural or historic interest" (Cochrane, 1985).

The economic impacts of 275kV supergrid were significant. Reduced losses in higher voltage transmission meant that it had become cheaper to transport electricity than coal. New generating stations, rather than being built close to areas of demand, began to be constructed near to fuel sources. Coal powered units with capacities of 2000MW and above were constructed in the Midlands and North East England to serve the growing demand in the South. 1985 figures show that there was an 8,000MW to 9,000MW average daily feed from the coal fired generating units in the Midlands and North East into the south, effectively transporting 'coal by wire' (Cochrane, 1985). Transmission capacity limits were soon reached and in the 1970s the design and construction of 400kV grid began, building on the existing 275kV network. Most of the original 132kV transmission lines were transferred to the area boards to be integrated into their distribution networks.

Discussions began as early as 1949 between the BEA and Electricitie de France (EdF) about the viability of constructing a cross-channel electricity transmission link between the UK and France. Agreement was reached in 1957. DC submarine cables were laid on sea-bed with a transmission capacity of 160 MW. Although successful when in operation, the cables suffered consistent damage due to trawler fishing and other activities on one of the busiest stretches of water in the world.

1980s to present day– DC interconnection with France and ESI Liberalisation

The 1970s saw plans for the construction of a 2,000MW DC UK-France interconnector. The cabling was buried in the seabed to avoid the damage experienced by the previous development. The UK-France interconnector has been operating on a fully commercial basis since 1986.

1989 saw the liberalisation of the ESI in the UK that resulted in the breaking up of the CEGB and the creation of separate transmission operators in England and Wales, Scotland and Northern Ireland. In England and Wales, the National Grid Company was created, originally owned by the Regional Electricity Companies but later becoming a plc in 1995

Annex Seven Benefits of Interconnected Networks

Introduction
Until the 1930s, largely isolated private and municipally owned utilities were responsible for electricity supply in England and Wales. The Electricity (Supply) Act 1926 sought to resolve the wasteful duplication of resources. Particular concern was given to each isolated authority installing enough generating plant to cover the breakdown and maintenance of its generation.

Interconnecting separate utilities with a high voltage transmission system pooled both generation and demand. An interconnected transmission system also allowed for maintaining the quality of supply - in terms of frequency variations, voltage level, voltage waveforms, voltage fluctuations and harmonic levels - across the system and may provide economic and other benefits detailed below:

The following detail is primarily based on Appendix C to the National Grid Company's Seven Year Statement, 2001 (http://www.nationalgrid.com/uk/)

Bulk power transfers
Many factors impact on the decision to construct a power station at a particular location. These include fuel availability, fuel transport costs, cooling water, land availability and the grid connection charges. In the case of CHP stations a local market for the heat output is also be a major factor.

Large generating units often have difficulty in gaining planning permission for location near to centres of demand due to environmental and social impact concerns. Renewable energy generation technologies such as wind or wave tend by their nature to be remotely located away from centres of demand. An interconnected transmission system allows for the bulk transmission of power from generation to demand centres.

Economic Operation
The interconnected transmission system provides the main national electrical link between all participants (generation and demand). Connecting together all participants across the transmission system makes it feasible to select the cheapest generation available in the system. This provides market participants with the opportunity to trade with the most competitive players. The network operator can accept the most attractive bids and offers via a balancing mechanism to meet the demand, irrespective of the location of the generating plant.

Customer security of supply
In this context, security refers to providing the demand customer with a continuous and uninterrupted electricity supply of the required quantity and of defined quality. This requires that the generation, transmission and distribution systems to be adequately robust to maintain supplies under conditions of plant breakdown or weather-induced malfunctions across varied demand patterns.

Interruption to electricity supply may occur due to insufficient or unavailable generation, transmission or distribution capacity. In the UK, the system operator manages the transmission system in accordance with strict standards laid down in the Transmission Licence.

Security of supply may not ne maximised when the sources of electricity are close to the demand they supply. Transmission circuits have tended to be more reliable than individual generating units (NGC SYS, 2001), enhanced security seemingly delivered by providing sufficient transmission capability between customers and the national reserve of generation. The transmission system allows the network operator to exploit the diversity between individual generation sources and demand.

Reduction in Plant Margin
The ideal would be a system where total installed generation capacity meets forecast maximum demand. But, additional capacity is required for security to cover the reality of generating plant becoming unavailable due to breakdown, delay in commissioning of new units, climatic variations – a particularly cold spell increasing demand, understated demand forecasts and other factors.

An integrated transmission and distribution system permits the use of surplus generation capacity in one area to cover shortfalls elsewhere. The need for additional installed generation capacity across an integrated system is smaller than the sum of individual area requirements.

In the UK, the CEGB traditionally adopted a planning margin of 24% to provide security when planning the need for future installed generation capacity. Under the pre-NETA Electricity Pool arrangements, capacity payments in respect of available generation capacity were incorporated. Such capacity payments were a function of Loss of Load Probability (LOLP) and the Value of Lost Load (VOLL) and were intended to provide a signal of capacity requirements. Under NETA the plant margin is determined by market forces.

Reduction in Frequency Response
In the UK, NGC has a statutory obligation to maintain frequency between certain specified limits. System frequency varies continuously and is determined and controlled by a careful balance between demand and generation. A situation whereby demand is greater than generation results in a fall in frequency whereas, if generation is greater than demand, frequency rises.

With the exception of pumped-storage and new technologies such as fuel cells and regenysys, electricity cannot be stored in substantial quantities. To avoid an unacceptable fall in frequency should generating plant fail, additional generation needs to be available that can be called upon at very short notice. This is referred to as frequency response.

Without an interconnected transmission system, each separate system would be required to carry its own frequency response. Interconnection allows the net frequency response requirement to be established equal to highest of the individual system requirements in order to cover for the largest potential loss of generation rather than the sum of them all.

Frequency and voltage
An important factor in planning and operating the transmission system to provide secure and economic supplies of electricity is ensuring that the quality of the supply - frequency and voltage - are maintained at a satisfactory level. In the UK, the Electricity Supply Regulations 1989 and the Grid Code specify the frequency and voltage delivered to the consumer must not vary from the declared value by more than ±1% (frequency) and ±6% (voltages below 132kV) and ±10% (voltages at 132kV and above) respectively (NGC SYS, 2001).

Frequency
The speed at which generating units operate defines frequency. Satisfactory levels are sustained through ensuring that the MW generated is always in balance with the MW demand plus the MW lost in the transmission system. Frequency remains the same at all points on the transmission system regardless of the distance from the generation source. As discussed previously, should demand exceed generation then frequency will fall and vice versa. Adjustments made to both

generation and demand ensure transmission system frequency does not vary beyond the required limits around the nominal value (50Hz). The system operator holds reserve generation at all times, available instantly to cover against plant losses and/or surges in demand.

Voltage

The control of voltage, albeit more complex, is also defined by the generating unit. Voltage is modified by the nature of the network through which the power is transmitted. Its length, the level of power flow and the electrical characteristics of the customers' demand all have an effect (NGC SYS, 2001).

Two electrical characteristics of the transmission network are capacitance and inductance. They have reverse effects on the voltage, causing a rise or fall respectively, as power flows through the network. At low power flow the capacitive effect is dominant, the voltage along a transmission line rising from the sending to the receiving end. At high power flow, the inductive effect is dominant and the voltage will fall. The longer the transmission line, the greater the effect on voltage. At what is called the 'natural loading' of the line, the inductive and capacitive effects cancel out and the voltage remains constant along the line.

Reactive Compensation

A low voltage at the receiving end of a long and heavily loaded transmission line, rather than rectified through adjustment of the generation at the remote sending end, is corrected locally by a special voltage compensation plant. This is known as reactive compensation.

Capacitive reactive compensation increases the voltage level and is used for heavily loaded overhead lines. Inductive reactive compensation reduces the voltage level and is used for lightly loaded cables.

Reactive compensation plant need not be utilised at all the times. It is more common for reactive compensation units to be connected to the system in a floating mode, responding automatically or being switched in or out as changing system conditions dictate. Such scenarios include as the demand level changes and maintenance of acceptable voltage levels following a system fault.

Transmission system capability

In the UK, there is a variety of ratios of generating capacity and demand in different areas across the country, traditionally the electricity flowing from North to South. From 1938, the transmission system has enabled generation surpluses in one part of the country to supply load in other parts of the country. In assessing the ability of the system to achieve this brief, the system is split into primarily importing or predominantly exporting areas. Connecting circuits linking such areas tend to represent the weakest links in the transmission system and thus indicate the ability of the system to accept bulk power transfers. The circuits which link areas together are the system boundaries.

System losses

Power flow across the transmission system causes transmission power losses. The bulk of these losses are a function of the square of the current flowing through the circuit or transformer windings (I2R) causing heating of transmission lines, cables and transformers. Such losses, by their very nature, are often referred to as variable power loss.

Other losses include the unavoidable losses associated with overhead lines and transformers. Although termed fixed losses, although stable relative to the variable losses and fairly constant, they can and do vary.

Fixed losses on overhead transmission lines are referred to as corona losses which are a function of voltage levels and weather conditions. Fixed losses in a transformer are iron losses, occuring in the iron core of the transformer when subjected to an alternating magnetic field. Iron losses vary with the frequency of the power flow producing the alternating magnetic field.

Impact on Transmission of Generation Plant Location

The transmission system is planned to meet the Licence Standard, thus ensuring that the firm transmission capability of any part of the system exceeds the maximum required power flow. If the forecast maximum required power flow exceeds the firm transmission capability, then that part of the transmission system must be reinforced.

The maximum power flow in any part of the system is a function of the generation and demand in that part. The greater the difference between generation and demand, the greater the power flow. The choice of site of new generating plant can therefore directly influence the need for major transmission reinforcements. For example, should a new generating plant be located in an exporting area (generation exceeds demand), the maximum power flow will increase. This increase in power flow may exceed the firm transmission capacity of the existing system and give rise to the requirement for transmission reinforcement.

Positioning new generating plant in an importing area may be preferable for the transmission system compared to a more distant site in relation to both security of supply and voltage control. All things being equal, it will reduce the imports over the transmission system, the associated need for additional reactive compensation, transmission losses, and the possible need for transmission system reinforcement. In the UK, the transmission system currently carries heavy power flows from North to South. Locating new generating stations in the South would therefore be generally beneficial to the transmission network.