29th September 2005

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Dear Dr Rands,
Royal Society of Edinburgh
Inquiry : Issues for Scotland's Energy Supply: Submission by Alan Shaw

Submission by Alan Shaw, Retired Chartered Engineer

"Kelvin to Weir, and on to GB SYS 2005"

Map of Grid (G.B.SYS. Figure A.1.1)

1. Introduction

Born, educated and initially trained as a professional engineer in Edinburgh I am delighted to contribute to the above Inquiry. I will limit my submission to aspects, including those in Scotland, of GB Supergrid 2005, and of renewable energy and nuclear power.

I am glad that RSE has restricted contributions to organisations and individuals with relevant experience. The growing governmental tendency to set up open public consultations on such complex matters tends to muddy the waters and delay decision making.

Timely is the comment by Professor Maxwell Irvine that "energy is an emotive subject and too important to become a party political issue". It is a matter of concern among chartered engineers, at all levels, that in the UK it has become so, and too often debated by individuals, including government ministers, manifestly with no technical knowledge of the subject whatsoever and disinclined to take professional advice.

I have read the consultation questions with a sense of *deja vu.* Fifty years ago I was invited to join one of the industrial consortia set up to implement urgently the UK White Paper Programme of Atomic Energy. In addition to our enjoyably strenuous "day jobs" midnight oil had often to be burned to submit collective thoughts to the broadsheet press and technical journals about the future of nuclear versus other forms of power generation.

Our mother company owned a leading fundamental research laboratory studying fusion power. In those far off days the time scale for economic take off of fusion power seemed to be about thirty years. Nothing has changed - it is still thirty years! But the problem is akin to putting a piece of the sun safely into an invisible magnetic bottle and safely making a reliable profit out of it for a further thirty years. That does not come cheaply - or quickly.

For the RSE Inquiry the most valuable predictions and advice will obviously come from bodies and individuals with long term financial, commercial and operational interests in energy matters. Fifteen years, rather than fortyfive, seem to me a more credible range for projections.

Leading sources of information in the electricity field are the three transmission companies, National Grid plc, Scottish Power plc and Scottish and Southern Energy plc/ Scottish Hydro plc

Under the terms of their transmission licences they have each for several years produced a rolling annual Seven Year Statement of their plans and operations. From 1st April 2005 this task has become unified by the appointment of National Grid plc as GB System Operator and producer, with the collaboration of the two Scottish companies, of the new GB Seven Year Statement, GB SYS 2005.

Already seamlessly on the Internet, this is a dynamic textbook of the planning and operation of one of the largest and most compact electricity systems in the world, to which Scotland has greatly contributed from the very beginning of the national grid.

The Great Britain basis has apparently arisen because the UK public electric supply industry is under two separate Regulators- OFGEM for mainland Great Britain and OFREG for Northern Ireland. The Northern Ireland electricity system is almost identical in annual maximum demand (c.1600MW) to that of Scottish Hydro plc. Although it also is a 50 cycle AC system it is not synchronised with the GB system because the 500MW Scotland - Northern Ireland Moyle submarine Interconnector is HV DC.

The National Grid plc submission to this RSE Inquiry is limited to one page. But that page points to three documents which are required reading for such an Inquiry. They are the Ten Year Statement (TYS) in gas, the Seven Year Statement (SYS) in electricity, and a paper "Transporting Britain's energy" (gas to 2014/15).

For those interested in the evolution of the UK grid system I offer a few historical notes. Engineering is the application of science to human need. Much political lip service is paid to reduction of costs and the increase of efficiency. The national grid was formed to make those objectives continuously attainable in the fields of generation, transmission and distribution.

2. Public lighting by electricity

The initial public interest in electricity in the nineteenth century focussed on the possibility of lighting superior to the whale oil lamp or the flaring "fishtail" gas burner.

From 1856 for about thirty years four UK lighthouses in south east England were illuminated experimentally by Professor F H Holmes's invention of carbon-arc lamps powered by primitive steam driven alternators. For domestic use the intense light of carbon arc electrodes was too brilliant and too costly for domestic use. Increased safety at sea justified the high cost. There the brilliance was welcomed.

in 1876 P. Jablochkoff, a Russian officer working in Paris, invented his famous "electric candle"- the first carbon arc lamp cheap enough to be used on a large scale and using AC for equal consumption of the two carbon rods. Experimental public lighting installations appeared in both Paris and London in 1877. Large football matches were occasionally played under this brilliant glare.

1880 saw Sir Joseph Swan's residence in Low Fell, Gateshead as the first house in Britain, possibly in the world, to be lit by incandescent electric bulbs, giving the softer illumination and lower cost required.

In 1884 Dr John Hopkinson of London showed mathematically that, contrary to general opinion, alternators could be run connected in parallel. This set the scene worldwide for the centralising of alternators in power stations.

3. The steam turbine and economies of scale

The same year, 1884, brought the filing of two patents on the steam turbine and the commissioning in the same year of the world's first turbo-generating set (of 7.5kW/DC) all by the Hon Charles Parsons of Newcastle-upon-Tyne.

Until then electricity generators had been driven by large and noisy reciprocating steam engines, they could not run on superheated steam without costly cylinder lubrication systems.

The steam turbine ran quietly and without vibration. Most importantly, it offered, with advances in metallurgy over time, huge economies of scale, with substantial reductions in capital cost per Megawatt (MW) for each doubling of designed MW capacity. The reciprocating engine was now obsolete and individual turbine-alternator sets increased in designed output from 1MW in 1900 to the world's largest (Germany) of 1,300 MW by 1976. The size of the electricity network places an upper limit on the largest turbo-alternator which can be installed. In the UK the largest standard sets are each 660 MW gross output.

4. Thermodynamic efficiency (including notes on CHP).

For thermal plant, overall thermal efficiency is governed by a law of thermodynamics stating that the higher the turbine inlet steam temperature and pressure and lower the exhaust steam temperature and pressure the higher the overall thermal efficiency.

Steadily improving metallurgy has allowed thermal efficiency of power station generation gradually to be increased, from around 22 per cent in 1939 to about 42 per cent. With such improvements made possible by increased steam pressures and temperatures the inlet steam pipes of large modern turbines glow cherry red, but invisibly under thermal lagging and planished steel outer casings.

In recent years UK political interest in efficiency of electricity generation has focussed on "Combined Heat and Power" (CHP) in the belief that this is a high efficiency (80 per cent) way of generating electricity. It is an already well known extension of the law of thermodynamics mentioned above. But it is an application peculiar to the economic production of low pressure, low temperature steam as a process heat source in many and various manufacturing processes.

To raise large quantities of steam of such low thermodynamic quality with a dedicated steam boiler and pass it straight to the process would be very expensive indeed. This cost is enormously reduced by raising steam at power station levels of pressure and temperature, passing it through a steam turbine driving an alternator and exhausting the steam directly to the process at the pressure and temperature required.

Under this system the combined energy produced as electricity and as heat in process steam is as much as 80 per cent of the energy in the steam raising boiler fuel. The point apparently missed by government in setting an annual CHP target far above the original national level is that the electricity produced is a by-product totally subservient in rate of production to the varying process heat rate required.
The market in which to sell the idea of CHP is therefore only of financial interest to large process heat users able to sell-on any surplus electricity produced.

If, as may often be the case, the variations in process steam demand and therefore by-product electricity produced, do not match the daily pattern of demand by the grid locally then surplus electricity can become a liability not an asset, as there is normally no means of storing it.

DTI July 2005 annual figures show that, in the four years commencing 2000, CHP installed capacity (expressed as MWe = megawatts electric = maximum continuous rating of the alternator, not electricity produced in the year.) were at a uniform level of about 4,750 MWe. In 2004 the level rose to about 5,300 MW/e. The government target is still 10,000 MWe.

5. AC or DC? - The "battle of the systems"

From 1886 to 1900 there was a "battle of the systems" with Lord Kelvin, Thomas Edison and others fighting a rearguard action on behalf of direct current (DC) against progressives such as Sebastian V.Z.de Ferranti and George Westinghouse, promoting alternating current (AC). This offered cheap voltage transformation for reduction of transmission line losses and the universal use of cheap, simple and reliable asynchronous induction motors.

In USA this competition was red in tooth and claw. Edison designed the world's first electric chair for the execution of criminals and sold it to the prison authorities specifying that it should be operated using "Westinghouse current" i.e. AC, promoted by his rival!

In 1887 a French metal syndicate cornered much of the world's copper supplies, forcing up prices and highlighting the main advantage of A.C - cheap voltage transformation. (Today power electronics allow DC to compete with AC in this feature on high voltage power lines.)

6. Thermal losses in electrical conductors.

In an electrical circuit power in watts equals volts times amperes. Thermal losses in conductors equal the square of the current in amperes, times volts. Therefore transmission losses can be reduced by raising voltage, thereby minimising current for a given power.

The optimum voltage is decided by balancing savings due to thermal loss reduction against increase in capital cost of insulation of conductors e.g. longer insulator strings and taller towers.

Underground high voltage transmission cables can be twenty times as costly as overhead lines and maintenance more difficult and time consuming

7. Tesla's polyphase electricity system

By 1900 the UK the electricity supply industry had taken off economically. That year saw the first public supply of *three phase current* (from the new Neptune Bank power station, Tyneside, designed by Charles Merz,)

This system was invented by the Serbian Nikola Tesla who emigrated to America to work for George Westinghouse. In it, the stator of an alternator is wound with the equivalent of three separate alternators in one machine but physically separated at an angle of 120 degrees to each other. One end of each of the three windings is bonded to the other two to form an earthed "star point".

Vectorial mathematics show that the combined alternator output now requires, not six power lines but only three, accompanied by a small wire to take out of balance currents and to run along the top of transmission towers for earthing and lightning protection. Thus the Tesla three phase system economises enormously in copper, and throughout the entire electricity system.

8. Statement by Lord Kelvin of Largs

In his inaugural address at the official opening of Neptune Bank in 1901 the great scientist/ engineer of the nineteenth century, Lord Kelvin of Largs (William Thomson), famously said: "I don't know what electricity is, and cannot define it- I have spent my life on it. I do not know the limit of electricity, but it will go beyond the limit of anything we conceive of today."

This charmingly frank Scottish polymath had, en passant, by inventing and patenting a wide range of electrical equipment, by being a consultant on the transatlantic cable and a partner in two engineering consulting firms, become a wealthy man who could afford a 126 foot yacht (“Lalla Rookh") and a baronial estate. His advice was valued in gold.

He had also dominated by the sheer power of his intellect the fields not only of electricity and magnetism but also of thermodynamics, hydrodynamics, geophysics, tides, the shape of the earth, its rotation and geomagnetism. He also opposed Charles Darwin's theory of evolution, remaining "on the side of the angels". He died in 1907 and was buried in Westminster Abbey.

9. Enter, the 132kV grid.

Meanwhile the UK electricity supply industry continued to develop, as disparate municipal electricity undertakings and a few large private companies. ***There was no coordinating body*** and little or no electrical interconnection. Some were on DC, some on AC and the latter ran on various frequencies from a flickering 25 cycles per second to cycles.

By 1925, the government had become alarmed by the chaotic existence of this huge electrical ragbag of private enterprise based on 500 mainly municipal power stations, tiny by today's standards and including 80 per cent spare capacity for security of supply.

Fortunately, possibly mindful of Kelvin's statement, Stanley Baldwin's administration delegated the solution to a dynamic Glasgow engineering industrialist, Lord Weir. He, with leading consulting engineers such as Charles Merz, quickly drew up a recommended framework for the whole UK electricity supply industry.

The Electricity (Supply) Act 1926 embodied into law the Weir Committee's proposals, establishing the Central Electricity Board which was empowered to design and construct a 132kV national grid and force the replacement of all existing stations as fast as a few very large, thermally efficient "selected" power stations could be built to take their place.

Implementation took place with astonishing speed. The first grid tower in the UK was erected in 1928 near Edinburgh The first of the large "selected " stations was Portobello, Edinburgh, from which on 30th April 1930 the first section of the new 132 kV UK national grid, the Central Scotland Electricity Scheme, was switched on by Herbert Morrison, the Minister of Transport.

The UK grid was largely completed by 1935, reducing by 1938 the proportion of spare plant necessary from the former 80 per cent to about 15 per cent. The resulting capital saving amounted to 75 per cent of the cost of building the grid and generating costs fell by 24 per cent.

10. Putting the "national" into "grid"!

The 132 kV grid was originally intended to be operated as a number of normally independent regional grids. Each could be connected to a neighbouring regional grid if and when required. The approach of World War required the setting up, in London, of a bomb-proof national grid control centre. With some trepidation the inter-regional isolating switches were closed and as nothing untoward happened they were never re-opened except in emergency. The grid was truly national from there on and made an enormous contribution to the war effort.

The nationwide interconnection of the grid forced upon the Central Electricity Board by war emergency conditions introduced the possibility of long distance bulk transmission. This became increasingly valuable in the immediate postwar period when rising electricity demands raced new power station construction.

11. How the grid improved power station economics.

The UK was still almost entirely coal based, and in 2004 were still using 50 million tons of coal per annum. From north to south were groups of coalfields, the Scottish Central Belt, Northumberland-Durham with the Cumberland field to the west, a huge group in the Midlands, then the South Wales- Forest of Dean- Bristol group and in the distant south east, the small Kent coalfield.

By about 1960 nearly all coal was machine mined and 70 per cent of production was of "smalls" -unsuitable for domestic and many other uses. It was virtually a by-product of machine mining and ideal for large power stations with coal mills reducing it to a fine dust and blowing it into cathedrals of flame.

This was the cheapest of coals and its cost ranged from between £5 and £6 per ton in the older coalfields to as little as £3.50 on the East Midlands coalfield. The cost of electricity sent out from the new super power stations was typically 0.5 p per kWh, made up as to annual capital charges (on £50 per kW) of 0.10p, operation and maintenance 0.05p and coal price (at £3.50 per ton) 0.35 per ton.

To transport coal by rail in the UK then cost £1 per ton per 100 miles = 0.10p per kWh for a base load station. The grid could carry all the coal required as electricity at a fraction of the rail transportation costs. The oil equivalent of small coal was residual fuel oil after the refinery had distilled around a thousand more volatile products from the imported crude petroleum. The grid enabled power stations to be built near refineries (e.g.Stanlow and Fawley) and the residual fuel oil converted into electricity at the cheapest price and transported away to distant centres of demand cheaply by the grid .

12. The grid and hydro-electric power

Hydro-electric power, which in the UK is already virtually fully developed, is generated in the mountainous regions of the country; in northern Scotland (the former North of Scotland Hydro-Electric Board}, in the Clyde valley, in south western Scotland (Galloway) and also in Wales. The national grid is connected to them all and takes away, as required, to centres of demand all over the UK the output of these beautiful parts of the UK. The centre of gravity of UK electricity demand is well south of a line drawn from the Bristol Channel to the Wash. There is therefore a steady flow of electricity from Scotland and northern England to the south

The grid is also similarly connected to large pumped storage stations (Cruachan 400MW, and Foyers 300MW) in the Highlands of Scotland and Dinorwig (1,728 MW) and Ffestiniog, (360 MW) in North Wales. These, using night time off peak electricity from adjacent (in grid terms) base load nuclear power stations to pump water uphill, meet the daily peak loads of the main centres of population in central Scotland and the Liverpool region respectively by letting down water as hydro electric power during such times

None of these pumped storage stations are generating "primary" electricity from rainfall. They are extraordinarily useful devices for lopping day time peaks off regional demands. One of the reasons they are so useful both for this and for meeting unexpected voids in intermittent production from e.g. wind turbines, is the unique ability of hydro turbines to pick up full load from standstill, in a minute or so.. However, nothing in engineering is free! About one quarter of the kWh generated is used to pump the water uphill again. But it is a much valued operational facility and has pulled the grid out of overload situations many times

13. The grid and nuclear power.

When, in February 1955, the government published its White Paper "A programme for nuclear power", the existence of the UK national grid made it easy to site the new commercial nuclear electricity stations in remote locations.

Their turbines receive non- radioactive steam from the nuclear reactor heat exchangers and exhaust it, as from fossil fuelled power stations, into condensers. The steam, condensed on the outer surfaces of sea water cooled metal tubes, gravitates into the condenser sump and is immediately pumped back into the nuclear heat exchangers as boiler feedwater in a completely closed cycle.

The North Wales 400 kV grid has an interesting configuration embracing in its ring a number of natural flow and pumped storage hydro stations with a spur line to Anglesey's Wylfa (1,081MW) nuclear power station, thus minimising the transmission line losses when using nuclear base load generation to pump water up to the high level reservoirs of Dinorwig (1,728 MW) and Ffestiniog (360 MW) Another spur connects the ring to the Liverpool and West Midlands regions of the grid for peak loppng.

The Supergrid grid connects installations as far apart as the Dounreay nuclear site on the north coast of Scotland and the two Dungeness nuclear power stations on the English Channel coast 530 miles south, as well as Hunterson B and Torness in the Scottish central belt and the other nuclear power stations south of the Border.

Nuclear power stations as compared to coal and oil fired power stations are characteristically of high capital cost per kilowatt but low running cost per kilowatt hour. For optimum overall system economy they are run continuously at as near full load as possible, normally only being withdrawn for routine annual maintenance, as for other types of plant. The system base load is their natural habitat.

It is therefore costly to run them as standby for any form of unpredictable intermittent energy connected to the system. Also due to their massive construction their response time to outages of volatile intermittent plant are too slow. They can however be used to cover slower variations in system load.

In France , in the nationalised Electricite de France grid, because of absence of indigenous fuel resources, over 75 per cent of the total electricity demand in MWh is met by 58 pressurised water reactors similar to but not identical to our Sizewell B power station in Suffolk. Their combined capacity of over 62,000 MWe
is equivalent to the present GB annual maximum instantaneous demand.

14. Commercial secrecy.

In Section 9 above ("Enter, the 132 kV Grid) Portobello power station, Edinburgh, was mentioned as being the first "selected" station connected to the UK grid under the 1926 Electricity (Supply Act. It had been formally opened by King George V in 1923. The third and final stage, bringing its output up to just over 146MW, was opened in the summer of 1939 by the Rt Hon Sir Thomas Mackay Cooper MP, Lord Advocate of Scotland.

An interesting feature of the Portobello 1939 Commemorative Brochure is that it lists in great detail the capital costs, the generation costs for 1937-38 and the electricity output figures for 1937 and 1938. Such figures are difficult if not impossible to obtain for new stations today. Yet in other countries it has been possible for visiting foreign engineers to have frank discussions with power companies about project and other costs. Few or no inhibitions about exchanging such figures have been encountered. The UK appears still to have a reputation for secrecy in discussion of costs and "commercially sensitive" information

In 1949 a delegation from the British Electricity Authority (predecessor of the CEGB) sent a delegation to the United States and Canada led by Sir John Hacking. It reported in particular on the latest practices adopted by U.S. utility companies in the design, construction, maintenance and operation of generating plant, transmission developments, costs of production and tariffs.

About three or four years later a senior engineer who had been one of the delegates described frequently going from one company to another who were in fact in competition.

He asked an American host why it was that they, the American companies, were able to be so free with their information knowing that the delegation was moving on to their competitors within hours.

The answer was that their technical development was so rapid that by the time a competitor had been able to verify the detailed information he might have obtained, and had been able to take advantage of it, the data would have become obsolete. This healthy attitude to freedom of information is badly needed in this country.

15. Nationalisation and centralised control.

The Electricity Act 1947 brought fully centralised control of design, construction and operation for all UK generation, transmission and distribution plant and equipment. Due to the almost complete lack of new power station construction during the1939-45 war the newly nationalised industry faced rapidly increasing electricity demand from both domestic and industrial consumers.

At first, in 1947, to speed manufacture and construction of new plant, turbo-alternator outputs were standardised by governmental order at 30 MW and 60MW and so were their steam conditions (temperature and pressure)/.

This restriction was lifted in August 1950, enabling development of turbines of ever increasing individual output. New steam turbine outputs rose from 60 MW to 600MW by 1970 and later to 660MW.

In 1949 the first 60 MW UK alternator with hydrogen cooling was commissioned at Littlebrook B power station. Better cooling had reduced the size of the set for a given output resulting in lower capital costs and easier transportation to site

In 1956, at the Bold A power station, a prototype 30 MW alternator using water cooling through the stator bars was the first in the world to do so. These and other technical developments were aimed at reduction of both capital and running costs.
In each national electricity network there is a practical upper limit of generator unit size. For many years now the UK limit has been around 660MW. But larger networks such as in Germany and Russia are able to accept even larger units. In 1976 a 1,300MW single shaft turbo-alternator, the world's largest was commissioned at the Biblis PWR nuclear power station of RWE Germany. The alternator was water cooled. In 1980 a 1,200MW single shaft turbo-alternator was commissioned at the 4,800 Kostroma (Russia) coal fired power station.

Meanwhile during the postwar period of system expansion the original 132kV transmission network required reinforcing at higher voltage levels. In July 1949 275 kV was adopted by the British Electricity Authority (forerunner of the CEGB) as the standard voltage for a new transmission network superimposed on the existing 132 kV grid and construction commenced shortly afterwards.

In 1965 the first 400kV line was inaugurated, running for 150 mies from Sundon, Bedfordshire to West Burton in the Midlands. The two new 275 kV and 400kV systems running in parallel with each other became known as the Supergrid. In northern Scotland the 275 kV and 132 kV networks act as the Supergrid. Again the whole object of their being is to reduce transmission losses and the capital costs of construction per MW. From the 1926 beginning of the national grid onward every effort was made to minimise visual impact on the environment, avoiding skyline intrusions wherever possible.

During the first 24 years of complete nationalisation the dominant engineer to emerge was Sir Stanley Brown. He became Chief Engineer (Construction) of the newly formed British Electricity Authority in 1949, later Chief Engineer. When the Central Electricity Generating Board formed in 1957 he became Chief Engineer and in 1965 Chairman. This was an organisation twice the size of the next biggest producer in the world, the Tennessee Valley Authority.)

He immediately began a campaign to rush, in England and Wales, £100 million of new power station plant of ever increasing turbine size into commission. The first 300 MW sets were commissioned around this time on both sides of the Border (CEGB's West Thurrock and SSEB's Cockenzie). Fortyseven 500 MW units were ordered at a cost of £500 million (just over £20 per kilowatt). There were considerable teething troubles but Sir Stanley never faltered and went on to order 600 MW, later, 660 MW sets, with 1,000MW sets in prospect. Offered the Chairmanship of the Electricity Council in 1971 he chose to retire, aged 61.

In retirement he frequently wrote to the Financial Times. In 1977, lamenting once again the lack of political will which had prevented Britain's nuclear industry getting underway in 1970, he said

"Make no mistake, the large scale development of nuclear power is both necessary and desirable. It is in fact inevitable unless either civilisation cracks or the world is prepared to carry on cooking over cow-dung fires and reading by candlelight. Nuclear power is ushering in a second Industrial Revolution and this country contracts out of it at its peril."

16. Nuclear power - its future as seen September 2005

Since the first commercial "magnox" nuclear power stations of the February 1955 White Paper "A programme for nuclear power" were commissioned in 1961, the Magnox and AGR nuclear fleets, together with the 1,100MW pressurised water reactor at Sizewell B have supplied 2,000 TWh of electricity to the UK grid. Today they are still safely generating electricity at the rate of over 80 TWh per annum, 23 per cent of total UK annual requirements of c. 350 TWh.

The last of the AGR stations was Torness. which achieved a world record for the longest continuous operational period by a nuclear reactor and turbine - around fifteen months.

The Sizewell "B" pressurised water reactor, was intended to be the first of a series. The Sizewell "B" Public Local Inquiry commenced its main hearing on 11th January 1983. The hearings were completed in 11th March 1985, the longest public inquiry ever held.

The station was not commissioned until 1995. The question arises as to who should bear the enormous cost of such public consultations. If as protracted as the Sizewell Inquiry the engineering firms contracting to build the power station face heavy costs in maintaining reserves of technical staff , labour and mater to be ready to start construction if and when the Inquiry authorises construction.

It is clear that the public chiefly require assurance of the safe long term storage of all levels of radioactive nuclear waste arising from both from both "legacy" and "new build" power stations. Included in the same concerns must be radioactive arisings from medical and industrial applications of radioactive materials used for diagnostic and non-destructive testing methods used throughout the country.

Revitalisation and dynamic reorganisation of national nuclear waste processing and storage facilities are unlikely to materialise as long as the government fails to enlist the support of their numbers of now ageing MPs still nostalgically reminiscing about their good old days as student campaigners for nuclear disarmament and their refusal to differentiate between atomic bombs and civilian nuclear power stations.

According to A.Rahman, (Ref 12) "The French nuclear industry is very active and contributes significantly to the French national economy. It receives full support from the French government and it meets its obligations fully by producing energy for national requirements. As France has no natural energy resources of any significance, it is viewed in France that maintenance of its nuclear power capability at a substantial level is vital. (As noted above French nuclear capacity in MW exceeds the entire present GB annual maximum MW demand.)

The French public is also quite sympathetic to the nuclear option. In order to maintain and sustain public support, France has undertaken a very substantive programme of R & D to resolve outstanding issues important to the nuclear industry. The lead given by the French government by issuing the Law No. 91-1381 is an indication of its farsightedness."

17. Privatisation in 1990 of the UK electricity supply industry

The Conservative government justifications for the 1990 privatisation are tabulated below: -

The UK Electricity System

Prior to 1990	***After 1990***
Monopolistic	**Competitive**
Cost-plus tariffs	**Downward pressure on prices**
Engineering led	**Market led**
Centrally planned	**Encourages diversity**
Closed to new entrants	**Open to new entrants**

(Electricity Association 1999)

The main result was that both short and long term planning of new power station design and construction and construction were to be left to market forces.

When the dust of this re-organisation had settled, putting it in military terms, the huge army of 150,000 people in the UK supply industry, with an annual productivity of about £70,000 per head, had lost both its General and its General Staff officers. Its Intelligence Corps - the CEGB Research Division - had also disappeared. Also, it's assets had been sold off to private industry, including American, French and German companies. It now appeared to be a headless chicken, completely at the mercy of blind market forces.

By 2002/3, the total number of employees had fallen to 55,000 and productivity had doubled, to about £140,000 per head. The lights had still not gone out and nothing had changed -or had it? What had changed was that in 1997 there had been a General Election and a radical change of government. In the same year, after the General Election, there had also been the UN Kyoto Climate Change Conference in which the new UK government had pledged itself to serious cuts in greenhouse gas emissions. (GHG)

Had the government set about implementing this reduction in GHG emissions even-handedly among the factual generators of greenhouse gas emissions (including multi engined jet aircraft and rapidly increasing road transport) the subsequent impact on the landscape, especially the `Scottish landscape, might have been greatly reduced.

But instead of walking to work at Westminster, or switching from 4 x 4 cars to minis, the government saw that the sitting duck., the headless chicken was at their mercy -- the statistically transparent electricity supply industry, already showed a self started record of significant greenhouse gas reduction.

The idea of replacing or even increasing the non- GHG emitting nuclear generation fleet and simultaneously encouraging and supporting the re-organisation of the UK nuclear waste disposal organisation in harmony , as in France, never seems to have occurred. Yet the government were elected to run the country efficiently, not to bow to the perceived voting potential of emotional green pressure groups.

So GHG reduction by renewable energy was now to be by cheap(?) electricity generating windmills, thousands of them , and mostly in Scotland and Wales. To a government south of Watford it was a "done deal”. But of course there was more to it than that. The UK national grid and its generators , which for fortytwo nationalised years had focussed on economy but also security of supply, without any competition, had been thrown to the market force wolves and non GHG emitting British Energy had nearly had to let the lights go out.

A growing electricity system subordinate entirely to market forces can not develop on the basis of short term "catch as catch can" investment. A secure source of long term investment is also essential. Market confidence depends on, et al, a government energy policy which can be seen to have been well thought out technically and once announced, seen to have been placed in competent and enduring hands.

18. Climate change problems.

After the 1990 privatisation there followed eight years during which the industry was radically reorganised and sold to private companies, many of them of foreign nationality.

Then came a radical change of UK and government and the 1997 United Nations Kyoto Conference on Climate Change. in agreement with the internationally desired reduction of greenhouse gas emissions the new UK government launched a vigorous expansion of electricity production based on renewable energy and especially wind power. following existing Danish and German leads.
With forty years uneventful operational experience of large commercial nuclear power stations, over 20% of UK electricity continuously being supplied under base load conditions and free of greenhouse gas emissions, vigorous further development of nuclear power was seen by engineers as the logical and in the long term cheapest solution. By 1997 the jointly owned National Grid /Electricity de France cross Channel 2,000MW interconnector had been importing French electricity at nearly 100 per cent load factor for four years. Because France has few natural fuel resources of any significance (Ref:12) 75 per cent of French electricity is nuclear generated and greenhouse gas free.

Instead of instituting, as the French had done, an R &D programme to update and reinforce nuclear waste disposal in support of nuclear power expansion, it repeatedly over many years declared the "nuclear option" still open but did nothing to maintain it despite obtaining a second term in office.. Instead under the UK Renewable Energy Programmes of 2,000 and 2,003 a huge programme of renewable energy, based mainly on wind power, was put in place.

19. Wind power and the pattern of UK electricity demand.

Throughout the 1987 Edition "Chronology of the UK Electricity Industry" (Ref: 1) every event historically relevant to its development for around 100 years, amounting to some 4,500 items , has been indexed.

Only nineteen, less than half of one per cent, are under the heading "Wind Generators"and these installations in include those in Denmark, Germany, Sweden , UK and USA.Some were as large as we see today, In 1941 a 1,250 kW Putnam wind turbine ran on public electricity supply in USA until 1945

Until 1997 climate change and greenhouse gas emissions were not regarded by engineers as an issue. Wind generators were set up from time to time experimentally. The CEGB installed a 200kW wind turbine at their test station at Carmarthen Bay, upgraded it later to 300kW and planned a MW sized machine for Richborough power station if a suitable design had been available. Sweden installed a 3 MW machine in Gotland at about that time but neither appear to have been taken forward.

At that time the UK electricity grid was powered by fully controllable prime movers. Steam turbines, hydro-electric and a dozen or so gas turbine stations from 1940 onward. All could be run up to synchronism and connected or disconnected to or from the national grid in a fully planned manner at will. Intermittent, uncontrollable wind turbines would not have been welcomed, especially as they were not seen to compete economically with existing conventional plant. The present programme is being heavily subsidised as part of the considerable price being currently paid for non-green house gas emitting generation. .

Public electricity supply in the UK from the national grid has always allowed domestic, industrial or other commercial consumers to switch on and off at will, 24 hours a day, 365 days a year. The resultant aggregate national demand has long displayed consistent and familiar patterns identifiable by day, by season or by important public events. National grid control rooms have decades of experience in anticipating the forthcoming load for every hour of every day. The slightest imbalance of supply with demand is corrected by plant on standby or "balancing" duty. Fine tuning by ultra responsive pumped storage turbines is one technique.

The range of variations in demand, daily, weekly, seasonally and annually, is demonstrated by the following recently published graphs as follows:-

<u>Figure 1- GB Summer and Winter Daily Demand Profiles in 2004/05</u>

Here the vertical axis is (System) Demand MW and the horizontal axis half hourly for 24 hours. There are four typical daily seasonal curves. Reading from the lowest curve - (red) "Summer Minimum (Sunday 13/6/ 04)'" from left to right, demand sinks slowly from midnight until at about 0600 hrs it has fallen to the annual minimum "Base Load" level. It then climbs slowly until plateauing at about 1230 hrs. Then follows another slow decline until , with a "blip" at 2230 hrs. midnight is again reached.

The green curve next above (Wednesday 16/6/04), being for a working day, is more vigorous, plateauing at 0930 hrs and starting the evening decline at 1700 hrs. The upmost, (black) curve is the day of Winter Maximum (Monday 13/12/04) plateauing sharply at 0830 hrs, starting to peak at 1530 hrs, peaking at 1730 hrs and then declining fairly steeply away until midnight. That 1730 hrs was the GB annual peak 2004. To meet it required the Megawatt power equivalent of one hundred 600 MW turbines running at full load. In order to follow the subsequent evening decline in demand load 20,000 MW had to be shed fully controllably in six hours - an average of 3,333 MW per hour.

Figure 2 shows week by week over the year maximum and minimum MW demand curves. Figure 3 shows duration of load at various levels throughout the year. The right hand "tail" of the red ALDC curve defines the MW height of the base load area and agrees with the annual minimum load MW shown in Figures 1 and 2.

Returning to our Figure 1 discussion of the Annual Winter Peak, the 60,000MW of steam gas and hydro turbines among which the annual peak demand is shared are connected directly to the 400kV/275 kV SuperGrid (275kV/132kV in Scotland) and directly brought on line and controlled by GB System Operator via a system of firm bids the previous day from generating companies plus a service from one or two dedicated power stations on "fine balancing" duty.

Wind turbines are not connected to the Supergrid but into the 33kV and lower voltage distribution networks as "Embedded Generation". Their output is not "seen" by the grid control except as part of a national or regional electricity increase or decrease in demand which must immediately be 'balanced" to prevent a rise or fall of system frequency from the standard 50 cycles per second.

Just how much wind power can be installed on the national grid without risking destabilisation and blackouts is still open to question. A debate in the House of Lords (Ref 14) concluded that expert opinions agreed that up to 10 per cent of wind generated MWh could be accommodated, but that there is some lack of agreement about the range 10 to 20 per cent and above.

20. Tidal power

The pattern of demand for electricity coupled with the huge scale of the industry makes it essential that proposals for large scale adoption of each kind of natural energy resources be preceded by thorough research into how their natural variations can be accommodated within the grid system due to the patterns of consumer demand.

As explained in Ref 9 (27.3.1) tidal power is governed by sea level which varies approximately with a 12.4 hour period, the diurnal ebb and flow cycle, superimposed upon a longer sinusoid with a period of 353 hours, the springs-neap cycle. The largest tidal barrage in operation is the Rance estuary scheme in France. The tides follow a two week cycle throughout the year. The output is computer controlled and optimised to match the needs of the French grid. The nominal average output of this 240 MW project is between 50 and 65 MW and is thus not the maximum that could be obtained, but it contributes maximum savings to the grid. While La Rance electricity is the cheapest electricity on the French national grid Electricity de France say that it would be too expensive to build any further power stations.

Studies have shown that the method of operation that results in the lowest unit cost of energy is either simple ebb generation, or ebb generation with pumping at high tide. As the generation period is about an hour later each day the generation (and pumping if used) needs to be planned in advance to integrate with the demand and supply of the grid.

21. Storage of electricity.

The key to successful integration of natural energy sources with a rhythm incompatible with the patterns of consumer demand is of course storage of electricity. The only established large scale method at present is that of pumping water uphill. But this is only a specialised form of hydro-electric engineering, which tends to be very capital cost intensive. To visit the four pumped storage schemes in the UK viz. Dinorwig and Ffestiniog in North Wales and Cruachan and Foyers in the Scottish Highlands is to be impressed by their visual size.

But these four schemes total 2,788 MW - only 4.7 per cent of the GB 2004 annual maximum demand and, in a good year, yield for peak lopping duty about 2,800 GWh of hydro generation, less than one per cent of GB MWh total annual generation. To pump this water back uphill to the reservoirs requires expenditure of 970 GWh. Obviously any supplementary natural source of energy offering an annual increase of ten per cent would need the existing national pumped storage fleet to be multiplied by a factor of 5 in GWh terms..

22. Matching supply to demand (Ref: Section 18 above)

In section 18 above Figures 1 and 2 show, respectively, diurnal and annual (divided into week by week) consumer MW demand curves. The area lying vertically below each of these curves is the product of the MW average for each curve times its hours duration along the graph's horizontal axis viz 24 hours for Figure 1 and 8,760 hours for Figure 2. i.e. each area represents the amount of electricity in MWh demanded by that curve.

The mixed generation fleet in the system must continuously match the variations in MW (and therefore in MWh) of the demand curve 24 hours per day. If the average rate of supply (MW) falls short of the average rate of demand (MW) in any given period, the central grid control room is presented with a fall in system frequency for which it must immediately compensate.

This it does by increasing total *generation* MW above the total *demanded* MW sufficiently to cause system frequency to rise *above* the statutory average of 50 cycles per second *long enough to restore that average frequency over the period*. In such a situation voltage can also be affected but each alternator on line will normally have automatic voltage regulation.

This frequency control can only be exercised by the grid control room having at its complete disposal one or more dedicated "balancing" stations whose output is both completely variable and sufficiently responsive. In order of characteristic speed of response to load change we have hydro (pumped storage or natural flow), CCGT and coal fired stations. Two units of the Dinorwig pumped storage power station are customarily set aside for such duty.

It cannot be reiterated too often that the fundamental problem with large-scale introduction of wind energy, and other naturally based energy sources, is the incompatibility of their natural generation patterns with the daily, weekly and monthly patterns of domestic, industrial and commercial consumer demand.

Figure 3 (see also Section 19), the annual load duration curve (ALDC), shows the complete annual demand pattern by load duration and discloses the respective sizes of the base load (see right hand vertical axis) and load following components required to be met by the generation fleet.

Figure 4 shows how this is done by filling in the area below the red ALDC with power stations grouped by fuel type in horizontal "layer cake" formation.

END

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Yours sincerely,

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G.B. SYS. FIGURE A.1.1
2005/06 TRANSMISSION SYSTEM
WITH LARGE POWER STATIONS
AS AT 1st DECEMBER 2004
THE SHETLAND ISLANDS
Plant Type
Existing
NUCLEAR
COAL
OIL & OCGT
CCGT/CHP
HYDRO/PUMPED STORAGE
WIND
OTHER
SUBSTATIONS:
SCOTTISH HYDRO-ELECTRIC TRANSMISSION
SP TRANSMISSION LTD.
NGC
Peterhead
Torness
Lynemouth
Hartlepool
Teesside
Heysham
Wylfa
Dinorwig
Ffestiniog
Ironbridge
Rugeley
Didcot
Hinkley Point
Oldbury
Aberthaw
Dungeness
Sizewell
Great Yarmouth
Kings Lynn
Little Barford
Peterborough
Corby
Spalding
Sutton Bridge
West Burton
Cottam
Brigg
Salt End
Saltend
Staythorpe
Ratcliffe
Derwent
Fiddlers Ferry
Rocksavage
Deeside
Connahs Quay
Shotton Paper
Ferrybridge
Drax
Fellside Power
Roosecote
Baglan Bay
Seabank
Shoreham
Cowes
Barking
Taylors Lane
Rye House
Brimsdown
Grain
Medway
Littlebrook
Tongland
Auchencrosh
Girvan Distillery
Black Law
Hagshawhill
Dun Law
Crystal Rig
Fife Power
Baldovie
Tullo
Errochty
Clunie
Rannoch
Fort William
Foyers
Fort Augustus
Farr
Paul's Hill
Stoneywood
Inverurie
Boyndie
Glens of Foundland
Burgar Hill
Spurness
Marine Energy Test Centre
Great Yarmouth
Brigg
Barking
Corby
Dungeness
E de F

Figure 1 - GB Summer and Winter Daily Demand Profiles in 2004/05 (National Grid 2005 GB Seven Year Statement)

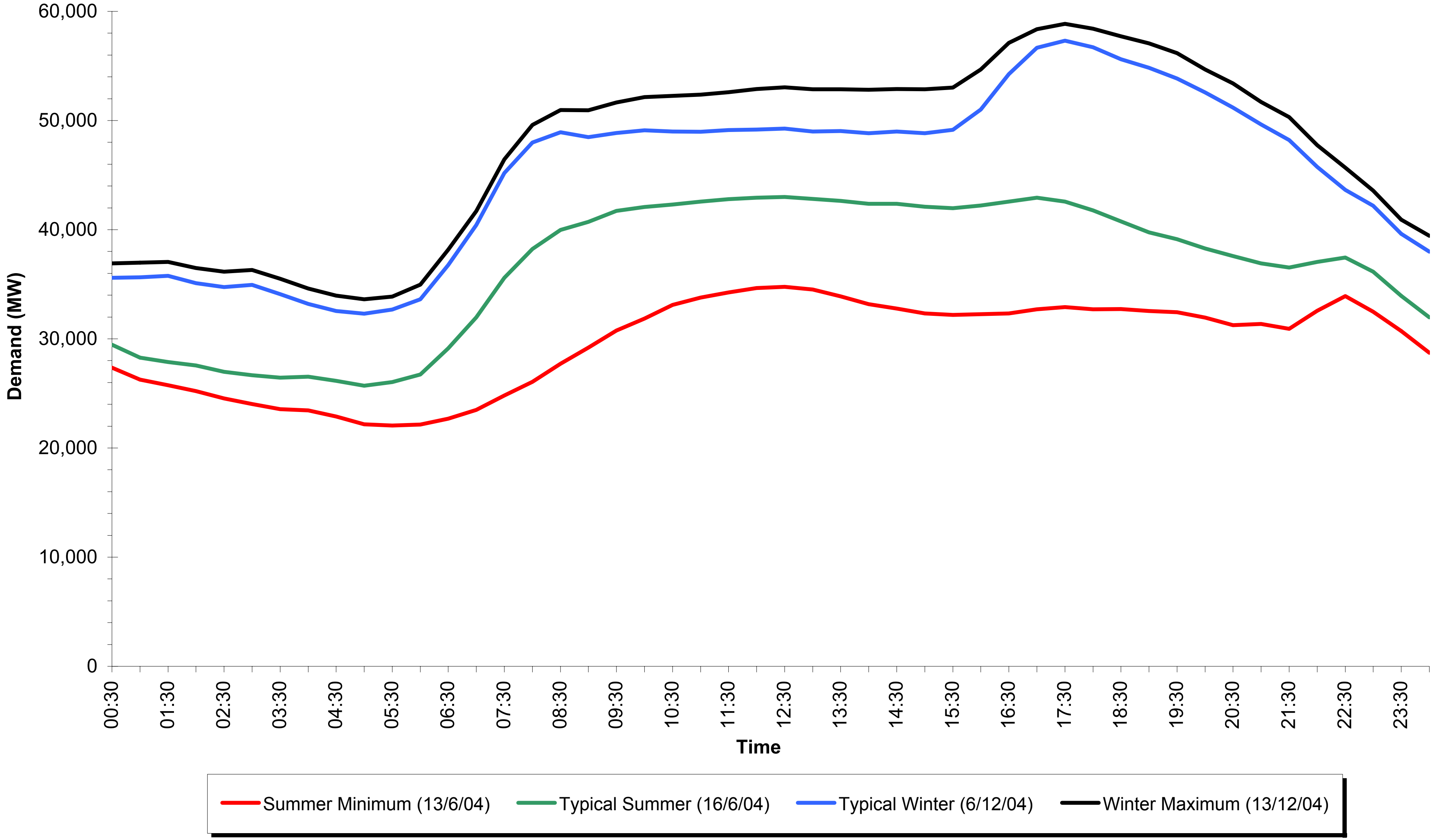

Figure 2 - Weekly Maximum and Minimum Demands in 2004 (National Grid 2005 GB Seven Year Statement)

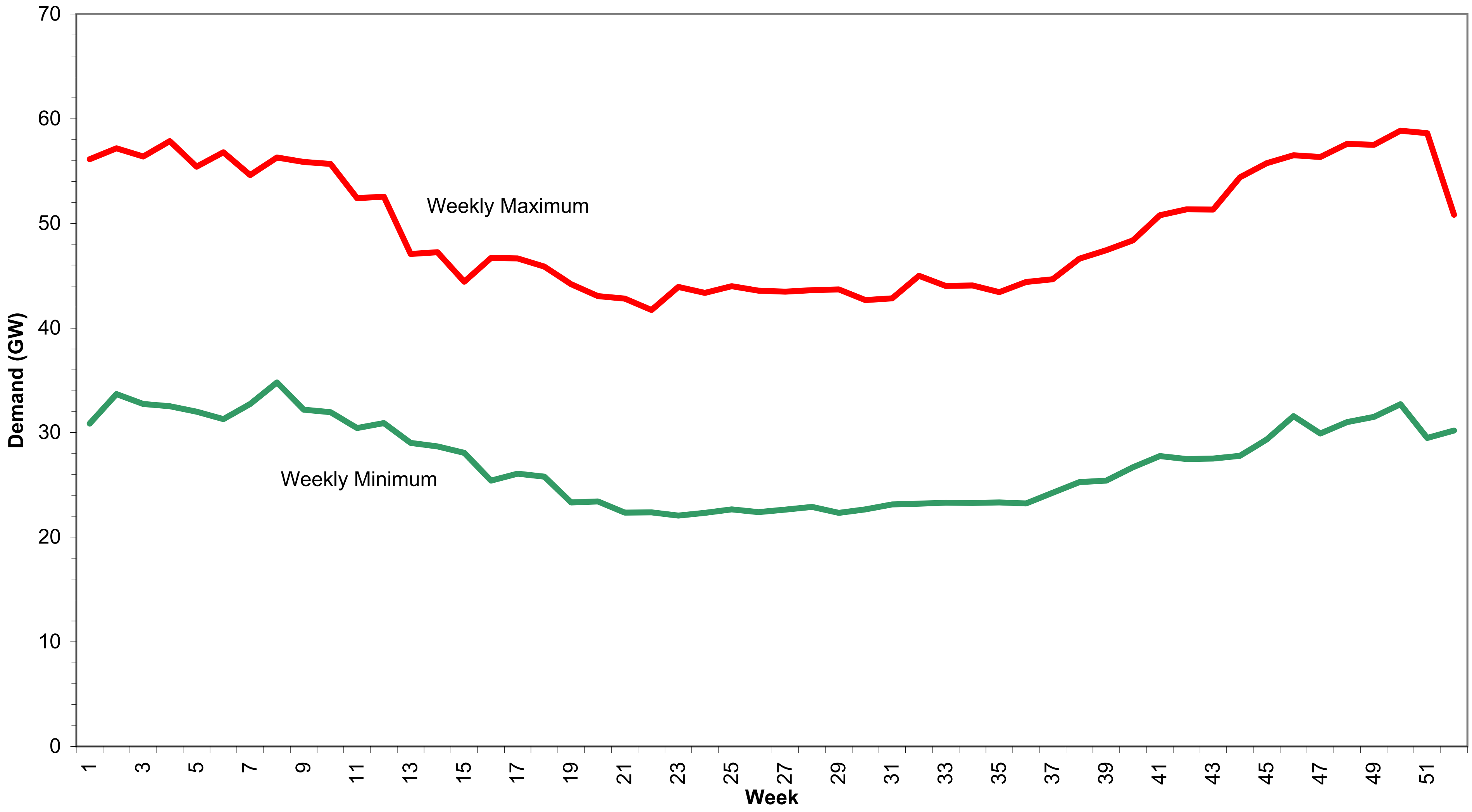

Figure 3 - Annual Load Duration Curve for 2004 (National Grid 2005 GB Seven Year Statement)

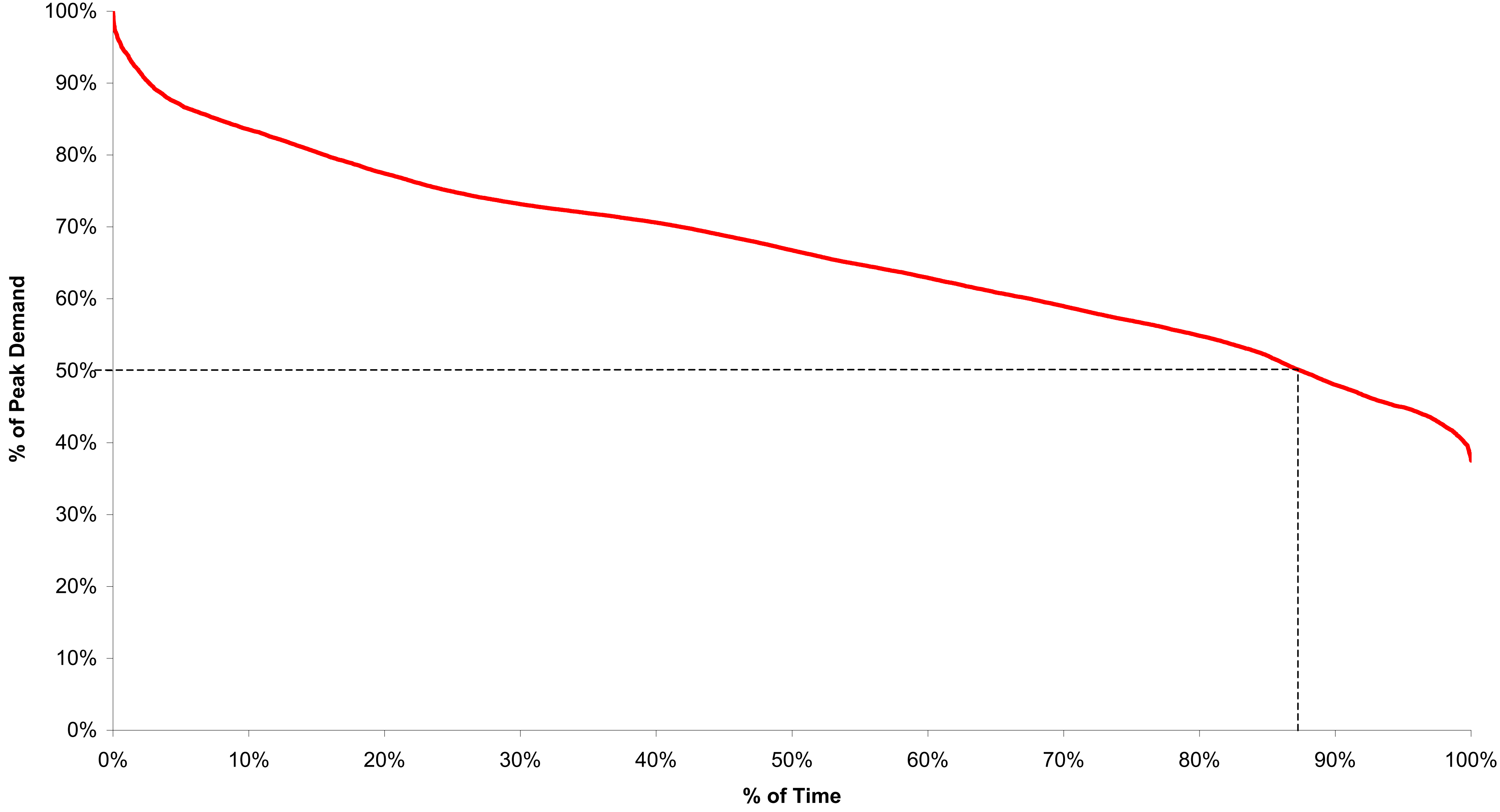

Figure 4 - Load Duration Curve showing responsive plant requirement net of demand management and firm contracts 2004/05 (National Grid 2004 Seven Year Statement)