OFGEM

REPORT ON SUPPORT INVESTIGATIONS INTO RECENT BLACKOUTS IN LONDON AND WEST MIDLANDS

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1. EXECUTIVE SUMMARY

This report presents the findings of an investigation undertaken by independent consultants, PB Power, into two major loss of supply incidents in South London and the West Midlands on 28 August and 5 September 2003 respectively. Both supply failures occurred as a result of an incident on the transmission system of the National Grid Company (NGC) that caused a complete shutdown of electricity supplies in the respective areas.

The investigation was undertaken for Ofgem, the industry regulator, under the guidance of a steering committee including representatives from the Engineering Inspectorate of the Department of Trade and Industry. In the course of the investigation the Consultants met with key personnel of NGT and EDF Energy, the Distribution Network Operator (DNO) in South London and visited the two sites where the faults occurred. The Consultants also corresponded with the two DNOs (Aquila and East Midlands Electricity) involved in the West Midlands incident. Detailed questionnaires were sent to all parties and the responses to have been taken into account in the report.

A draft report on the investigation was issued by PB Power on 26 November 2003 and subsequent correspondence from NGT, EDF Energy, Aquila and East Midlands Electricity has been taken into account in the preparation of this Final Report. The analysis and conclusions presented in this report have been produced in response to the information made available to PB Power by NGT and the DNO's and closing, written exchanges on the final drafts. Throughout the investigation all four utilities co-operated fully with the investigation and PB Power appreciates the professional manner in which its inquiries, which were sometimes of a sensitive and difficult nature, were handled by the recipients. The report is presented in two volumes. The main body of the report is presented in this Volume 1, which addresses all aspects of the Scope of Work. Volume 2 is focused specifically on the detailed analysis of Protection Commissioning and Performance.

The scope of the investigation and the methodology used in the investigation is presented in Section 2 of this volume. The two incidents are then described in detail in Section 3 based on a detailed analysis of the evidence presented to us by the various parties. In Section 4 of this volume we summarise the findings of the investigation into protection issues. Section 5 examines the planning of the transmission outages in each area that were underway at the time the two incidents occurred and the assessment of the risk that these planned outages had on the security of supply. Section 6 reviews the evidence on communications between the various parties, stakeholders and the general public.

The conclusions reached from the investigation are presented in Section 7 and we recommend that the reader refers to Section 7 to view the conclusions in detail. However, we present here a summary of the key findings presented in both volumes of this report. These are that:

a) The losses of supply were caused by the unexpected operation of incorrectly applied protection relays at Wimbledon (London) and at Hams Hall (West Midlands).

b) For the South London incident, an incorrectly rated protection relay had been installed on the 275 kV Wimbledon – New Cross No. 2 circuit in May 2001. The system back-up overcurrent protection on the circuit should have had a 5 amp overcurrent relay installed, rather than a 1 amp relay. When the current through the Wimbledon - New Cross No. 2 circuit increased as a consequence of opening the Littlebrook – Hurst No.1 circuit to investigate an alarm associated with Hurst substation, it was sufficient to operate the back-up overcurrent protection on the Wimbledon – New Cross No. 2 circuit thereby disconnecting all of the demand supplied from Hurst and New Cross substations and also part of the Wimbledon substation demand. NGC has been unable to provide copies of sufficient documentation or correspondence to determine the reason for the installation of the incorrectly rated relay.

c) For the West Midlands incident, incorrect settings had been prescribed and applied to a multi-function relay that was used to provide Interlocked Overcurrent protection for the 400/132 kV, 240 MVA supergrid transformer SGT8 at Hams Hall substation, which was commissioned on 17 August 2003 The settings had been based on an inappropriate protection scheme design. The investigation has found that the relay also provided non-interlocked overcurrent and earth fault protection functions and that these should either have been disabled through relay configuration settings or else set to avoid incorrect transformer tripping. In the event, neither action had been taken, and when the current in SGT8 at Hams Hall increased as a result of SGT6, connected in parallel with SGT8, having to be unloaded to investigate a potentially serious problem with current transformer wiring, the relay operated to disconnect SGT8. The remaining transformer at Hams Hall, 275/132 kV 120 MVA transformer SGT3, then had the full substation load thrown onto it and its overcurrent protection correctly operated to trip the transformer's 132 kV circuit breaker and effectively disconnect Hams Hall 132 kV substation from the NGC transmission system.

d) The Wimbledon protection defect had lain hidden for over 2 years until unrelated emergency switching actions were instigated on 28 August 2003 and it may otherwise have remained hidden at least until the next scheduled protection maintenance tests. The Hams Hall defect had lain hidden for 19 days, after the new SGT8 transformer had been commissioned on 17 August 2003, until the emergency switching action was instigated on 5 September 2003. This particular defect would otherwise have soon been revealed as a consequence of increasing loading, and coincidentally records show that it came very close to causing SGT8 to be tripped at around noon on 28 August 2003.

e) ✂

f) ✂ At the time the incidents occurred, the system was operating within the requirements of NGC's Security and Quality of Supply Standard (SQSS). The investigation also concluded that the outage planning process was well founded and that all parties had participated in the programming of the outages and were aware of the planned outages well in advance.

g) Our investigation into the loss of supply incident in the West Midlands has focussed on protection commissioning issues ✂ that ultimately led to the total loss of supply at Hams Hall 132 kV substation and resulted in the disconnection of 200,000 customers, including some major customers such as Birmingham International Airport, car production plants and the NEC, and the loss of about 300 MW of demand. PB Power has examined other factors during its investigation, such as security of supply, the efficiency of the restoration process undertaken by NGC, Aquila and East Midlands Electricity, outage planning and communications and we consider that these were not major factors either in causing the incident or prolonging it.

h) The investigation of the London loss of supply incident, identified a number of factors, other than just protection commissioning problems, that were to some extent within NGC's control and which for one reason or another created the conditions under which the incorrectly applied protection relays operated and caused the loss of supply. The incident interrupted supplies to almost half a million electricity customers ✂ and disconnected over 700 MW of demand.

i) In South London at the time of the incident, two major 275 kV grid stations (i.e. Hurst and New Cross) supplying about 560 MW of demand were dependent upon two 275 kV cable circuits; one from Littlebrook and the other from Wimbledon. Normally four circuits supply these two substations, but planned maintenance work had caused two of these circuits to be out of service. It had been NGC's plan to phase these circuit outages such that they would run consecutively. However, a cable fault on EDF Energy's system in the local area prevented work on the Wimbledon – New Cross No. 1 circuit from proceeding to plan and it was therefore necessary to extend the duration of the outage on that circuit. This meant that the work overlapped with work scheduled for the Littlebrook – Hurst No. 2 circuit. Nevertheless, operation of the system in this way was still compliant with NGC's SQSS in that in the event of a fault on either of the two 275 kV cable circuits supplying Hurst and New Cross grid stations (on paper) adequate supply capacity would be provided by the remaining circuit.

j) Operation of the system with overlapping outages is not an uncommon occurrence and the slightly increased risk to security of supply from the overlap due a reduction in apparent circuit redundancy at that time, had been conveyed to EDF Energy. However, overlapping of the outages of the Wimbledon – New Cross No. 1 circuit and Littlebrook – Hurst No. 2 circuit was a contributory factor to the loss of supply incident in South London, simply because if they had not overlapped the loss of supply would not have occurred at that time.

k) The sequence of events that led to the London incident started when NGC's Electricity National Control Centre (ENCC) at Wokingham received a Buchholz gas alarm from shunt reactor SR3 connected to the tertiary of supergrid SGT3 at Hurst grid station. This is a serious alarm notifying the system controllers of a situation that could lead to catastrophic failure of a transformer or reactor. Due to a degree of ambiguity in the alarm message received at Wokingham, the control engineer interpreted the alarm as a gas accumulation in either SGT3 or its shunt reactor, SR3 and made the decision to isolate both pending a site investigation. NGC has accepted that the ✂ nomenclature of the alarm did not clearly indicate whether the transformer or the shunt reactor was the origin of the alarm. ENCC, following standard procedure, took immediate action to unload SGT3 and as part of that process opened the mesh corner at Hurst to which it was connected as a prelude to investigating the cause of the alarm. Due to the substation "mesh" arrangement, and hence the grouping together of incoming and outgoing circuits, this action also opened one of the two remaining circuits feeding Hurst and New Cross grid stations, hence leaving that part of the system operating on a single circuit risk. Operation on single circuit risk was intended to last only for the switching time , i.e. until SGT3 was disconnected and the Littlebrook – Hurst 275 kV cable circuit re-closed. Due to the switching referenced above, the combined load on Hurst and New Cross substations was transferred across to the Wimbledon – New Cross No. 2 circuit. As a consequence the current through that circuit increased sharply although it was still within the cable rating. Unfortunately the current was sufficient to operate the 1 amp relay that had been installed in error (the protection scheme was designed to use a 5 amp relay) and as a result the circuit was tripped and supplies lost across South London.

l) ✂ because of the ambiguity in the alarm message received at the Wokingham control desk, ENCC considered that the alarm may relate to SGT3 when it actually referred to the shunt reactor SR3 (connected to the tertiary winding of SGT3) and commenced the switching procedure to isolate SGT3 from the transmission system. In fact SR3 was not in service at the time and in reality no switching action was required to protect the alarmed equipment. This same piece of equipment had in fact experienced an identical Buchholz alarm on 26 June 2003. At that time the alarm was correctly identified by ENCC as a problem with the reactor alone, and as the reactor was, already out of service for operational reasons (as was the case on 28 August 2003) ENCC determined that no switching action was required.

m) However, with regard to item l) above, it should be noted that while the overlapping outages were in place, had it been necessary to open that mesh corner for any other reason, such as an actual gas alarm on SGT3 or a cable fault, then depending on the demand at the time, it is possible that the same unexpected protection operation at Wimbledon would have happened resulting in a loss of supply across South London.

n) Whilst receipt of a Buchholz alarm is a serious situation, NGT had known since March 2003 that the reactor SR3 had a serious oil leak (estimated to have lost 135 gallons of oil in the three months between March and June 2003 and had chosen to manage the leak by topping up the reactor with oil on a three monthly basis until the equipment could be taken out of service to effect a repair. ✂

o) Following the blackout, at an early stage in the supply restoration process, ENCC inadvertently energised EDFE Energy 's system at Bromley and Eltham when it omitted to confirm the status of its 132 kV circuit breaker on the LV side of SGT4 at Hurst. This also caused a "back-energisation" of NGC's own network, a potentially damaging condition that was only alleviated by the consequential, albeit unplanned operation of automatic protection equipments that inter-tripped an NGC circuit breaker at New Cross and the 132 kV and 33 kV circuit breakers connecting with EDF Energy's distribution system at Bromley.

p) Overall, the interruption of electricity supplies to the DNOs was relatively short with NGC able to restore supplies within about 40 minutes in each case. ✂

q) The investigation found that communications both during and after the incidents between NGC, the DNO's, the various stakeholders, the media and the general public was handled well and viewed to have followed good industry practice.

r) The report acknowledges the response of NGC, in setting up procedures to review a number of critical aspects of its operation, in line with commitments given in NGC's own reports on the two incidents. ✂

s) ✂

2. SCOPE OF INVESTIGATION AND METHODOLOGY

2.1 Summary of the loss of supply incidents

Supply failure in South London. At 18:20 hours on Thursday, 28 August 2003 an incident occurred on the National Grid Company's 275 kV transmission system in South London that led to a total loss of supply at Hurst and New Cross 275/132 kV grid stations and a partial loss of supply at Wimbledon grid station. The loss of supply impacted immediately on the distribution network of EDF Energy (EDFE), the Distribution Network Operator (DNO) for London and the South East, with the interruption of the electricity supply to 476,000 customers. A total demand of 724 MW was lost, amounting to about 20 percent of the total demand in London at that time.

✂ National Grid Company (NGC) was able to restore all supplies to EDFE by 19:01 hours ✂.

Supply failure in the West Midlands. A week later at 10:10 hours on Friday, 5 September 2003, an incident occurred at NGC's Hams Hall 400/275/132 kV grid station, near Birmingham, that led to a complete loss of supply from Hams Hall 132 kV substation. The substation supplies part of the distribution network of Aquila, the DNO for a substantial part of the Birmingham area and surrounding counties to the north, west and south of Birmingham. The electricity supply was lost to 143,000 Aquila customers, including a number of major consumers such as Network Rail, Birmingham International Airport, the National Exhibition Centre (NEC), two major car plants, Solihull and Sutton Coldfield town centres, shopping centres and a hospital. The supply failure also affected East Midlands Electricity (EME) which also takes a supply from Hams Hall with 58,000 customers, principally in the Tamworth area, suffering an interruption to their electricity supply.

By 10:21 hours EME restored supplies to all its affected customers by transferring the supply from Tamworth Grid (that had lost its supply from Hams Hall) to Drakelow via a 132 kV interconnector. By that time NGC had re-energised the Hams Hall 132 kV busbars and Aquila undertook a staged restoration of supply, with supplies restored quickly and efficiently in a manner agreed with NGC that was consistent with safety, operational requirements and the obvious need to ensure that further failures of NGC equipment were avoided. By 10:58 hours Aquila had restored supplies to all its customers.

The loss of supply in the West Midlands resulted in the disconnection of 213 MW of load on the Aquila distribution network and a further 88 MW on the EME distribution network. NGC were able to restore all supplies to the DNO's within 48 minutes; the first supplies being restored at 10:21 hours, 11 minutes after the loss of supply, and although the disruption to supplies was significant the impact on major consumers was reduced because of their own back-up generation on site. ✂

Initial feedback from the two incidents. The initial investigation by National Grid Transco (NGT), the parent company of NGC, into the two incidents identified that both were caused by the incorrect operation of automatic protection equipment. In each case this resulted in the unexpected tripping of critical circuits that blacked out large areas of London and the

West Midlands, the blackout in London was exacerbated by the effect it had on the local transport infrastructure. In both cases the protection relays in question were not faulty, but had simply been rated or set incorrectly on the NGC system.

There were other similar issues associated with the two incidents;

- both incidents occurred whilst the transmission network in the area was operating under planned outage conditions, as circuits were taken out of service as part of a major programme of planned maintenance and/or re-construction and
- in each case the protection equipment that "operated" was relatively new protection equipment.

The widespread disruption to commuters in South London and to electricity customers both in London and the West Midlands, coupled with concerns over security of supply, protection commissioning procedures, the planning of outages to allow scheduled maintenance of circuits and equipment to proceed, and the passage of information between NGC, the DNO's, major customers and the general public led Ofgem to initiate its own investigation into the two incidents.

Separate investigations are being undertaken by Ofgem, the industry regulator and the Department of Trade and Industry (DTI), through its Engineering Inspectorate. By its letter of 17 September 2003, Ofgem appointed PB Power to provide consultancy services to support Ofgem and DTI in assessing specific aspects of the blackouts in London and the West Midlands on the 28 August and 5 September respectively.

Both the Ofgem and DTI investigations will draw on the facts established by this PB Power report, with DTI required to report the outcome of its investigation to the Minister of State. Ofgem will utilise this information in forming its view as to whether a licence holder has breached any relevant licence condition.

2.2 Scope of investigation

The original scope of PB Power's support to Ofgem is presented in Appendix A of this report. The support investigation was designed to address three specific aspects of the investigation:

1. Protection Commissioning and Performance,

To review and critically evaluate the approach taken, the systems used, the processes followed and the management techniques adopted by NGC for selecting and commissioning protection equipment and deriving and implementing the associated protection settings.

2. Transmission Outages and Risk Management,

To review and critically evaluate the approach taken, the systems used, the processes followed and the communications strategies adopted by NGC and the relevant DNO for the programming and management of transmission outages.

3. Communications.

To review and critically evaluate the communications of NGC and the DNO's with consumers and other stakeholders both prior to, during and immediately following the incidents.

At the kick-off meeting with the Ofgem Steering Committee on 19 September, clarification on the scope was sought. It was agreed that as part of the scope PB Power was to gather and review evidence for Ofgem and to assist Ofgem and the DTI in their own investigations into the blackouts. A copy of the agreed notes of that meeting are presented in Appendix B of this report.

2.3 Methodology

Following the kick-off meeting a series of questionnaires were produced for NGT, EDFE, Aquila and EME based on an initial review of NGT's Investigation Reports[1] on the two incidents and the corresponding reports[2] from the relevant DNO's.

The initial questionnaire sent to NGT on 24 September addressed all three parts of the scope identified in Section 2.2 above. This was followed by four supplementary questionnaires that addressed various parts of the scope with the questionnaires reflecting specific concerns that arose as the investigation developed.

The information provided by NGT in response to the questionnaires generally fell into one or other of the following categories:

- Network single line diagrams
- Event records of each incident
- Standards and Procedures
- Tables of system voltages and power flows as the event evolved
- Formal written responses

Following receipt of the bulk of NGT's responses to the Initial Questionnaire and the 1st Supplementary Questionnaire, a meeting was held in London on 14 October with the NGT Project Directors, NGC Senior System Control Managers and PB Power's system control and system planning specialists to discuss the responses received up to that time and certain inconsistencies between the NGT report on the London incident and the information provided as evidence of the sequence of events. The meeting resolved a number of questions that were raised at that time. As the investigation continued, PB Power sent

[1] NGT's reports on the two incidents presented the results of internal Incident Investigations ✂.
[2] The EDF Energy report into the South London incident was produced by its Enquiry Team ✂. Incident reports were also produced by Aquila and East Midlands Electricity for the West Midlands incident for the Department of Trade and Industry, but these reports do not indicate whether an internal Panel of Inquiry was established.

additional supplementary questionnaires to NGT that addressed a number of the issues, including some of those previously discussed with NGT on 14 October. The NGT response to each question was considered and used as the basis of PB Power's report. A copy of the agreed notes of that meeting is also presented in Appendix B.

PB Power's protection specialists visited Wimbledon and Hams Hall substations on 16 and 17 October respectively to examine the physical evidence of the respective protection failures and to hold discussions with responsible NGC personnel at the two sites. Again the notes of the two site visits are presented in Appendix B.

✂

PB Power issued its draft report on the investigation to Ofgem on 26 November 2003. Ofgem reviewed the draft and then issued confidential versions of that report separately to NGT, EDF Energy, Aquila and East Midlands Electricity. The four utilities were then asked to provide comment relating to the factual accuracy of the report, which they did and these were received by PB Power on 15 December. PB Power then reviewed the responses. ✂ The response from NGT ✂ was in great depth and addressed all areas of the draft report. Thereafter PB Power responded to these comments in two parts on 24 December and 12 January 2004. In the meantime a second set of comments were received from NGT on 9 January commenting on PB Power's initial response and these were responded to by PB Power via Ofgem on 14 January. A third set of NGT comments responding to PB Power's comments of 12 and 14 January were received by PB Power on 15 January and responded to on 16 January. The correspondence between PB Power and NGT via Ofgem was a useful and important part of the investigation as it enabled the parties to resolve a number of the issues and concerns raised in the draft report.

This report is based on the evidence obtained in response to the various questionnaires, the review of the individual company reports on the incidents, the meetings with key company personnel, the site visits and the subsequent correspondence that followed the issue of our draft report on 26 November 2003.

3. SUPPLY FAILURES IN SOUTH LONDON AND WEST MIDLANDS

This section of the report describes the sequence of events associated with both loss of supply incidents. The sequence is based on the correlated evidence of the investigation reports issued by NGT and the respective distribution companies, and takes full cognisance of the sequence of events as catalogued by the companies' energy management systems, to the extent that the catalogued events sequence takes precedence.

3.1 Loss of supply in South London on 28 August 2003

3.1.1 Significant events during the pre-disturbance period

2001. The refurbishment of protection at Wimbledon 275 kV grid substation which included equipment associated with the two 275 kV Wimbledon – New Cross circuits was scheduled for completion in 2001. However, slippage in the progress of work on the Wimbledon – New Cross No. 2 circuit (associated with Mesh Corner 3) and a fault on a New Cross – Hurst circuit forced the cancellation of work on the Wimbledon – New Cross No. 1 circuit (associated with Mesh Corner 1) and its postponement until 2003.

In 2001 relay panels for the refurbishment of the two 275 kV Wimbledon - New Cross circuits were prepared, but only the panels for the Wimbledon – New Cross No. 2 circuit were commissioned. The partially refurbished panels for the Wimbledon – New Cross No. 1 circuit were put in storage until the 2003 outage could be arranged for the refurbished protection to be installed and commissioned. The Wimbledon – New Cross No. 1 outage was in force at the time of the London loss of supply incident on 28 August 2003.

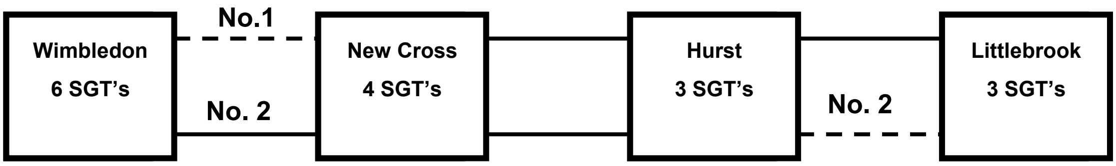
It is documented that the Contractor's original intention was to provide new over-current and earth fault protection based on a dual rated relay type DCD314, to replace the existing 5 Amp type MCGG42 over-current and 1 Amp type MCGG22 earth fault relays. However, at some stage, according to NGC's wish or agreement, this plan was dropped and it was decided to re-use the existing relays in the refurbished panel. For some reason, during the work on site in 2001, a new MCGG42 over-current relay was urgently ordered, applied and commissioned for the Wimbledon - New Cross No. 2 circuit, just prior to the feeder being re-commissioned, with the substitute relay being rated at 1 Amp instead of the 5 Amp rating of the relay that had been previously installed.

2002. In July 2002, as part of the normal outage planning process, discussions commenced with EDF Energy to plan the outage of the Wimbledon – New Cross No. 1 circuit to enable the new back-up protection to be applied and commissioned. The planning process proceeded as normal with regular meetings between NGC and EDFE taking place throughout 2002 and into 2003 that concluded in a formal agreement to release the 275 kV circuit, Wimbledon Mesh Corner 1 (MC1), New Cross Mesh Corner 3 (MC3) and associated transformers and reactors from service at appropriate times between 2 June 2003 and 8 August 2003.

The same process had been followed by NGC in agreeing the original outage period for the Littlebrook – Hurst 275 kV No. 2 circuit. This outage was planned to commence on

11 August 2003 and was required for insulator replacement on the overhead lines, for the installation of thermal monitoring equipment on the cable, for circuit breaker maintenance and other planned maintenance work at Littlebrook and on Mesh Corner 4 (MC4) at Hurst 275 kV grid station.

The planned outages of the Littlebrook – Hurst No. 2 circuit and Wimbledon – New Cross No. 1 circuit, two of the four infeeds from NGC's transmission system into the New Cross and Hurst substations supplying South London (see diagram below) through a total of seven supergrid transformers (SGT's) were scheduled to run consecutively, with a short gap between the two outages.



In September 2002 the Hurst supergrid transformer SGT3 underwent a programme of scheduled maintenance, involving a visual inspection of the equipment and operational checks on ancillary equipment.

2003. An oil leak developed on the Wimbledon – New Cross No. 2 cable circuit in the weeks prior to the scheduled start date for the planned outage of the parallel No. 1 circuit. This leak on the No. 2 circuit had to be repaired before the No. 1 circuit could be taken out of service as previously planned. EDFE similarly had experienced oil leakage problems on some of its distribution circuits and it was agreed to put back the start date for the Wimbledon – New Cross No. 2 outage until 1 July, with the completion date re-scheduled for the 28 September.

The identification by NGC of additional work required in the Littlebrook and Hurst areas led NGC to revise the start date for the Littlebrook – Hurst No. 2 circuit from 11 August to 26 August, with completion re-scheduled for 19 September.

The revisions to the planned outage dates meant that the Littlebrook – Hurst and the Wimbledon – New Cross circuit outages would now overlap from the 26 August to 19 September with two of the four 275 kV circuits that supply the demand between Littlebrook and Wimbledon scheduled to be out of service for a three-week period. However, although it was now intended for the outages to overlap, the planned supply arrangement between Wimbledon, New Cross, Hurst and Littlebrook still complied with NGC's Security and Quality of Supply Standard as is explained in more detail in Section 5 of the report.

In March 2003 the Hurst SR3 shunt reactor underwent a programme of scheduled intermediate maintenance, which includes proving of the operation of protective devices and testing of the operation of the ancillary equipment. In addition to this maintenance, routine inspections had been undertaken, which included a three-monthly check to monitor oil levels.

The NGC Intermediate Maintenance Record for the Hurst SR3 shunt reactor, dated 24 March 2003[3], clearly states that there was an oil leak on the lid of the cable box and that the equipment would need to be topped up within three months. On 19 June 2003 a routine inspection of the reactor was undertaken at Hurst and the inspection report states that the oil level was "ok", although there was an additional comment that "Shunt Reactor 3 cooler bank conservator low oil. Bund needs pumping out" included in the report. One week later on 26 June 2003, NGC's Electricity National Control Centre (ENCC) received a Buchholz gas alarm initiated by a low oil level on SR3 reactor. The ENCC events log shows that in this case the alarm was identified as relating to the SR3 reactor, which was out of service at the time and no switching action was undertaken. The oil level was then topped up on 27 June with 135 gallons of oil and during the period 1 July to 28 August NGC did not undertake any further maintenance on the Hurst Shunt Reactor 3 as none was considered necessary.

NGC had planned to start its work on the Wimbledon – New Cross circuit with the opening of Mesh Corner 1 (MC1) at Wimbledon, but a fault on an EDFE cable circuit on 28 June meant that MC1 had to remain in service and it was agreed that the work would be split so that work could commence at the New Cross end of the circuit4. In fact, although EDFE estimated that its cable would return to service in two weeks the cable did not return until 19 August.

On 1 July the planned outage of the Wimbledon – New Cross No. 1 circuit began with the opening of MC3 at New Cross to enable work to start on the protection change on that mesh corner and on the cable refurbishment work on the Wimbledon – New Cross No. 1 circuit. The 275 kV Wimbledon – Beddington No. 1 circuit connected to MC1 at Wimbledon was already out of service for a circuit breaker repair. With the opening of MC1 at New Cross, SGT3 and its associated shunt reactor were disconnected from the system.

The 275 kV grid station at Wimbledon provides a supply to EDFE's Wimbledon 132 kV grid substation (sections 3 and 4) via four 275/132 kV, 240 MVA supergrid transformers[5]. The normal configuration for the 132 kV substation is with SGT4 and SGT2 connected to reserve

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[3] The actual inspection took place at some time between 10 and 21 March 2003.

[4] The maintenance period for the Wimbledon – New Cross No. 1 circuit was originally scheduled to take eight weeks, with work running in parallel at Wimbledon and New Cross. However, as the start of work at Wimbledon was delayed the maintenance period had to be extended to thirteen weeks. This was done in order to allow key elements of the work to proceed, and to ensure system security was maintained the work programme and hence outage requirements were rearranged. The original plan had all of the "bundles" of relevant equipment (e.g. mesh corner, line etc.) out of service at the same time. Thus enabling work on the discrete bundles to progress at the same time and assist with certain work aspects such as end to end testing and maintenance of equipment (that would otherwise have been unavailable since they would have been required to serve as points of isolation on the system if the bundles were taken separately). This approach enables the overall outage requirements to be minimised. However, by releasing discrete bundles of equipment some work was allowed to proceed and still maintain system security, albeit increasing the overall duration of the work and hence outage required."

[5] Wimbledon 275 kV substation also supplies EDFE's Wimbledon 132 kV grid station (sections 1 and 2) via two 180 MVA supergrid transformers (SGT1B and SGT3B).

busbars 3 and 4, and SGT1A and SGT3A connected to main busbars 3 and 4 respectively. ✂ On 28 July, when it became clear that the EDFE cable circuit would not return to service until mid-August, NGC decided to take SGT1A out of service at Wimbledon in order to allow the refurbishment work there to begin. ✂

On 20 August, the day after the EDFE cable circuit was returned to service, MC1 at Wimbledon was opened and supergrid transformer SGT1B taken out of service.

The Littlebrook – Hurst No. 2 circuit was taken out of service on 26 August, as per the revised plans, to allow maintenance work to begin. The switching operation allowed MC4 at Hurst to remain energised and continue to supply EDFE via SGT4 with its shunt reactor SR4.

It is standard practice for NGC to control the voltage on its transmission system during summer nights, when demand is at a low, by switching in shunt reactors to limit the voltage rise caused by a predominately cable network. On the evening of 27 August shunt reactor SR3[6] associated with supergrid transformer SGT3 was switched into service as part of the control sequence to limit the rise in voltage during the night. At 09:12 hours on 28 August as the voltage started to fall in response to the growing daily demand, the 13 kV circuit breaker 3K0 was opened to disconnect the shunt reactor SR3 at Hurst from the system.

3.1.2 Sequence of events that led to the loss of supply

Figure 3.1 shows the system configuration on Thursday, 28 August at the start of the incident that led to the loss of supply.

Figure 3-1

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The key features of the supply arrangement at this time were:

a) The Littlebrook – Hurst No. 2 circuit was out of service for planned maintenance with the disconnector at the Hurst end open and the mesh substation at Hurst operating as a solid busbar.

b) The shunt reactor SR3 at Hurst (associated with the supergrid transformer SGT3) was out of service, although the transformer was in service.

c) The two New Cross – Hurst 275 kV circuits were in service.

d) Mesh Corner 3 at New Cross with supergrid SGT3 and its associated shunt reactor SR3 was out of service for planned maintenance.

[6] The 13 kV, 60 MVAr shunt reactor SR3 is connected to the tertiary winding of supergrid SGT3 and switched in and out of service by the 13 kV circuit breaker 3K0.

e) Mesh Corner 1 at Wimbledon with supergrid transformers SGT1A and SGT1B was out of service for planned maintenance.

f) The Wimbledon - New Cross No. 1 circuit was out of service for planned maintenance.

g) The Beddington – Wimbledon 275 kV circuit was out of service for circuit breaker maintenance.

h) The Kemsley/Beddington – Littlebrook 400 kV circuit was on open standby.

At 18:11 hours the Electricity National Control Centre (ENCC) in Wokingham received a Buchholz gas alarm indication from shunt reactor SR3 connected to the tertiary of supergrid SGT3 at Hurst substation. However, ENCC interpreted the alarm as a "grouped alarm" indicating a gas accumulation in either SGT3 or its shunt reactor, SR3, and made the decision to isolate both pending a site investigation. From our discussions with ENCC Managers and subsequent correspondence it was established that the mistaken interpretation of the alarm resulted from a degree of ambiguity in the alarm message received at the control desk[7].

The Buchholz alarm notifies the system controllers of a serious situation that could lead to catastrophic failure of high power electrical equipment, and ENCC, following standard procedure, took immediate action to unload SGT3 and as part of that process opened the mesh corner at Hurst.

NGC's post -incident investigation identified the low oil level in shunt reactor SR3 as the cause of the Buchholz alarm. In fact, SR3 was not in service at the time the alarm was triggered, it having been switched out at 09:12 hours that morning when it was no longer required for voltage control[8], and had ENCC correctly identified the alarm as referring to SR3, and seen that the reactor was not in service he would be expected to have taken no further action.

It should be borne in mind that ENCC are required to make decisive, timely and prudent decisions in a real-time environment. NGC claim that there have been many instances around the world where prevarication by control staff has resulted in serious incidents involving a complete loss of supply and that control staff must therefore be able to make decisions without the fear of being subjected to undue and detailed post event criticism, which will always have the benefit of hindsight. That said, it is understood that NGC have mechanisms in place, where system events are reviewed to identify learning points for future operation.

It is standard NGC procedure, as set down in section 8.17 of NGC Transmission Procedure TP105 "Operational Liaison and Practice", issue 1, dated September 2000, that in the event

[7] NGC has taken action to review the clarity of alarms on its system and this and other corrective action is listed in more detail later in this volume of the report.

[8] It was normal practice for the Hurst reactors to be in service daily from around midnight to 09:00 hours to control voltage on the 275 kV system.

of a Buchholz gas alarm it is essential to remove the alarmed equipment from service as quickly as possible to prevent a build up of gas in the transformer or reactor that could result in a catastrophic failure of the equipment, unless one or more of the following apply:

- An interruption to supplies will result.
- System stability or unacceptably high or low voltage conditions will result.
- Loading on the equipment can be reduced to such a level that gas is no longer produced.
- A responsible engineer requests that the equipment remains on load.

In these circumstances the procedure allows NGC time to unload the “alarmed” equipment by transferring load to an alternative supply.

ENCC having mistakenly interpreted the alarm as relating to supergrid SGT3, then followed procedure to remove SGT3 from service. ENCC reported the Buchholz alarm to EDFE at 18:17 hours[9] and asked EDFE to unload SGT3 by opening the 132 kV circuit breaker at Eltham Grid, at the remote end of the transformer circuit, on the basis that there was already sufficient transformer capacity available to secure the load in that area.

At 18:18 hours EDFE control informed ENCC that they had opened the 132 kV circuit breaker at Eltham Grid so that SGT3 at Hurst was now unloaded and could be disconnected. At 18:19 hours ENCC closed the 400 kV circuit breaker at Littlebrook on the 400 kV line from Beddington and Kemsley to secure the supply to Littlebrook, as the “second incomer” from Hurst would need to be temporarily opened.

At 18:20 hours ENCC initiated the switching sequence to remove the “alarmed” SGT3 transformer from service. The mesh substation arrangement at Hurst required the switching out of the Littlebrook – Hurst No.1 circuit through the opening of the 275 kV mesh circuit breakers S20 and S30 and the 400 kV circuit breaker at Littlebrook, before SGT3 could be disconnected from the Mesh Corner by opening disconnector H33, prior to returning the Littlebrook – Hurst No. 1 circuit to service. Circuit breakers S20 and S30 were opened at Hurst at 18:20 hours, to remove the connection between Littlebrook and Hurst substations thereby leaving the total demand at New Cross and Hurst substations supplied over the single Wimbledon – New Cross No. 2 circuit for switching time only. At this point, the Wimbledon automatic “back up” protection on the Wimbledon – New Cross No. 2 circuit operated and tripped the 275 kV circuit breakers S20 and S30 at Wimbledon and also the Wimbledon 132 kV circuit breakers 380A and 380B, controlling supergrid transformers SGT3A and SGT3B, to isolate Wimbledon MC3.

The unexpected disconnection of the Wimbledon – New Cross No. 2 circuit resulted in the separation of the New Cross and Hurst 275 kV substations from the NGC transmission system, thereby essentially interrupting supply to a total of six SGT’s at those locations. In addition, on Mesh Corner 3 (MC3) at Wimbledon, SGT3A and SGT3B that ✂ supply ✂ part

[9] The EDF Energy report on the incident records this as occurring at 18:15 hours.

of EDFE's South London ring[10] were also disconnected. The electricity supply to a large area of South London was therefore lost[11], with the complete loss of load connected to New Cross (359 MW) and Hurst (199 MW) plus some of the MC3 load at Wimbledon (166 MW), resulting in the loss of a total of 724 MW of EDFE's demand at the time of the incident.

EDFE reported the loss of supply to 31 main substations in London, six of which provided a supply to Network Rail and LUL sites, and also two primary substations(Petts Wood and Orpington) just outside the London area in South East England. The loss of supply affected 476,000 customers, a large section of the LUL rail network and part of the mainline rail service that runs through this area ✂.

3.1.3 Restoration of supplies by NGC

NGT's report on the incident[12] indicates that the control engineers at ENCC assessed the alarms received and concluded that the automatic protection on the Wimbledon- New Cross No. 2 circuit had "most likely" operated incorrectly. At the same time the EDFE Control Centre was in receipt of alarm annunciations from its 132 kV and 66 kV substations that were indicative of a major supply failure on the NGC transmission system.

At 18:21 hours, within one minute of the loss of supply occurring, EDFE and ENCC control engineers were in telephone contact during which ENCC confirmed that it had lost supply to Hurst and New Cross 275 kV substations and to MC3 at Wimbledon 275 kV substation.

At 18:22 hours NGC called out standby engineers to Wimbledon, New Cross and Hurst substations to investigate the situation and assist with the operation to restore supplies.

NGC made the decision not to return the Wimbledon – New Cross No. 2 circuit to service until the cause of the protection mal-operation had been identified, so that the restoration of supply had to come from Littlebrook, rather than Wimbledon.

NGC's first action at 18:25 was to re-establish the security of the wider system in West London. At Wimbledon L30 was opened to disconnect the Wimbledon – New Cross 2 circuit from Wimbledon MC3 and Wimbledon mesh circuit breaker S30 was then closed to re-energise MC3 (together with SGT3A and SGT3B) and prove its integrity. Wimbledon S20 was then closed, connecting Mesh Corners 2, 3 and 4 and re-establishing the 275 kV transmission system interconnection through Wimbledon. These actions further confirmed

[10] The EDFE South London Ring (SLR) system is run interconnected with Beddington, Chessington and Wimbledon supergrids. When Wimbledon SGT3B (which supplies part of the South London Ring) connected to 132 kV Section 1 & 2 tripped the other supergrids supplying SLR immediately absorbed the load supplied by Wimbledon SGT3B.
The New Cross 66 kV substation load interfaces with the SLR system via the local Chadwick Road 33 kV system, which in turn normally supplies Brixton 11 kV, Bengeworth Road 11kV and North Cross 11kV Substations, which were disconnected on the day.

[11] The south London area affected by the loss of supply extended from Bankside in the north, to Bexley in the east, Beckenham in the south and Kingston in the west.

[12] NGT's "Investigation Report into the Loss of Supply Incident affecting parts of South London at 18:20 on Thursday, 28 August 2003" dated 10 September 2003.

that the assumed suspect protection was associated with the Wimbledon - New Cross No 2 circuit.

At 18:26 hours ENCC began the switching sequence to restore supply to the network from Littlebrook. The planned maintenance work on the Littlebrook – Hurst No. 2 circuit was in progress and therefore NGC could not affect an immediate return to service of this circuit. It was NGC's view that it therefore had no option other than to re-energise Hurst substation via the Littlebrook – Hurst No. 1 circuit; namely the circuit that had been disconnected from Hurst by the opening of Hurst mesh circuit breakers S20 and S30 at 18:20 hours to allow the Buchholz alarm to be dealt with, that ENCC had taken to be associated with SGT3 supergrid transformer.

NGC advise that they were operating in an emergency situation and decided that restoration of supplies should be given utmost priority. Consequently, since SGT3 (that was thought to have set off the alarm) had been unloaded, and had remained energised without tripping, and would stay unloaded (though energised) during the restoration period, the risk of a continued build up of gas in SGT3 was considered to have been substantially reduced. NGC therefore considered that given the circumstances the Littlebrook – Hurst No.1 circuit could be re-closed to facilitate the restoration of supplies whilst accepting the now reduced risk to SGT3. To disconnect SGT3 prior to commencing restoration and to restore supplies to Hurst would have required the 400 kV circuit breaker at the Littlebrook end of the circuit to be opened, followed by opening of Hurst disconnector H33 then by re-closing of the 400 kV circuit breaker at Littlebrook. It was considered that these additional switching operations would prolong the restoration process. It was NGC's view that each operation introduced additional risk and could prolong the loss of supply or require NGC to either bring the Wimbledon – New Cross No. 2 circuit back into service (with the suspected protection problem assumed to having been identified and corrected) or return one of the other circuits that had been taken out of service for planned maintenance. The restoration strategy adopted was therefore to recover the transmission system in stages, taking account of the need to manage steady state voltages by switching out cable circuits at the appropriate stage.

However, before ENCC could re-energise Hurst substation and then New Cross substation it was necessary to ensure that no load had inadvertently been left connected to the system. ENCC therefore opened the 66 kV SGT circuit breakers at New Cross and also segregated MC4 at New Cross and MC2 at Hurst. At 18:30 hours ENCC closed mesh circuit breaker S30 at Hurst to re-energise MC4 and MC1 at Hurst, the Hurst – New Cross No. 1 circuit from Hurst (Mesh Corner 1), New Cross MC4 and New Cross SGT4. (Refer to Figure 3.2 below)

At this point in the restoration process ENCC failed to check the status of the 132 kV circuit breaker (2405) on the LV side of SGT4 at Hurst[13]. Circuit breaker 2405 should have been open to isolate the EDFE 132 kV system at Bromley and Eltham from the NGC system, but was left in a closed position. Consequently the supergrid transformers, SGT2 and SGT4, at Hurst remained connected to their respective 275 kV Mesh Corners and to the EDFE 132 kV system at Bromley and Eltham. The result was that upon energising Mesh Corners 1 and 4

[13] The 132 kV circuit breaker (2405) on the LV side of SGT4 was entirely under ENCC control.

at Hurst, the EDFE 132 kV network at Bromley and Eltham (plus the 33 kV network at Bromley) was inadvertently energised via Hurst SGT4. As Hurst SGT2 was still connected to EDFE at 132 kV and to Hurst MC2 at 275 kV, this action also "back energised" MC2 at Hurst. This resulted in "energisation" of the Hurst – New Cross No. 2 cable circuit and hence New Cross MC2 and its associated supergrid SGT2. At that time (in its pre-fault state) circuit breaker S10 at New Cross was still closed and the New Cross – Wimbledon No. 2 circuit was still connected to New Cross MC1. Therefore, this circuit was also energised together with New Cross Mesh Corner 1, the 100 MVAr (unswitched) shunt reactor and supergrid SGT1 connected to that mesh corner.

The "back energisation" of these two cable circuits (i.e. Hurst – New Cross No. 2 and New Cross – Wimbledon No. 2), via two series connected supergrid transformers could have resulted in overvoltages at 132 kV and 275 kV. NGC studies using a detailed system model estimated that the respective voltage magnitudes were limited to about 105% and 134% of nominal. In subsequent correspondence between NGC and PB Power it was agreed that the overvoltages had been limited by the effects of saturation of the 275 kV transformer cores. In the event, most probably due to the nature of the inrush currents drawn by the transformers, when subject to abnormally high voltage, automatic protection on these transformers may have mal-operated almost immediately (on closure of Hurst S30) to open S10 at New Cross and send an inter-trip signal to Hurst. This would also have operated the EDFE circuit breakers, disconnecting the EDFE network from Hurst SGT2. The 275kV disconnectors on New Cross SGT1 and SGT2 circuits also opened during this sequence. NGC have reported that at the time of the incident, there was no apparent damage to NGC equipment and subsequent investigations and tests have found no evidence of damage. There were also no reports from EDFE regarding equipment damage, or of any voltage related issues.

New Cross MC1 was segregated from the system by opening S10 and disconnecting supergrid transformers SGT1 and SGT2 from the 275 kV busbars. The Wimbledon – New Cross No. 2 circuit, that had unexpectedly tripped at 18:20 hours to shutdown the South London supply, was disconnected from the NGC system at 18:31 hours by opening the disconnector L10 at New Cross.

The New Cross – Hurst No. 2 circuit was then isolated from MC2 at New Cross by opening the switch L20. New Cross SGT2 was then connected onto MC2 at 18:39 hours by closing H23. The mesh circuit breakers S40 and S10 were then closed in turn at New Cross to energise MC1 and MC2 and also energise New Cross SGT2 to establish their integrity.

The New Cross – Hurst No. 2 circuit was then isolated from MC2 at Hurst at 18:43 hours by opening switch L20. Following discussion with EDFE, and action by them to ensure that their system was correctly configured for restoration, the mesh circuit breaker S20 at Hurst was closed to connect all four Mesh Corners in an open mesh and to energise Hurst SGT2, making it available for loading by EDFE.

At 18:48 hours the mesh circuit breakers at New Cross, S10 and S40, were opened to de-energise New Cross MC1 and MC2 so that SGT1 could be re-connected to MC1 by closing H13. S40 was then closed to re-energise MC1 and New Cross SGT1.

At 18:38, ENCC had offered to restore supplies to Wimbledon 132 kV busbars, but EDFE requested ENCC to hold off, then at 18:48, EDFE requested restoration of demand at Wimbledon. By 18:52 hours the Wimbledon 132 kV circuit breakers 380A and 380B controlling supergrid transformers SGT3A and SGT3B were re-closed to connect the transformers to the Wimbledon 132 kV busbars at bus sections 3 and 4, and bus sections 1 and 2 respectively and restore load.

At 18.51 hrs another Buchholz alarm message was received by ENCC that protection had operated to trip SR3, but since STR3 was out of service no indication of circuit breaker operation was received.

At 18:52, ENCC offered New Cross SGT1 and SGT4 to EDFE, who requested ENCC to wait[14]. At 18:57 hours, following a request from EDFE, the New Cross circuit breakers 1T0 and 4T0 were closed to energise the 66 kV busbars and restore EDFE load at New Cross from Mesh Corners 1 and 4 of the 275 kV substation. By 19:01 hours EDFE had restored supplies across its network via NGC's supergrid transformers, that were available again at Hurst, New Cross and Wimbledon.

Figure 3.2

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It was not until 23:00 hours that the Wimbledon – New Cross No.2 circuit which had unexpectedly tripped was re-connected, but with the back-up protection now disabled. The circuit was restored only after NGC had undertaken extensive checks at the substation so that the integrity of the remaining protections was positively verified. At 00:19 hours on Friday 29 August the Hurst – New Cross No. 2 circuit was re-connected to return the system between Littlebrook and Wimbledon to the supply arrangement that existed before the Buchholz alarm was received.

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3.2 Loss of supply in the West Midlands on 5 September 2003

3.2.1 Background

NGC is about halfway through a five-year investment programme to upgrade the transmission system in the West Midlands in response to changes in the energy market and future demand growth. A significant part of that investment is associated with major construction and asset replacement works being undertaken at Hams Hall, an established NGC site between Birmingham and Coventry.

The Hams Hall site currently accommodates three substations at 400 kV, 275 kV and 132 kV. The substations are each owned by NGC. The 132 kV substation provides a

[14] SGT2 was not available due to a temporary air system problem, which prevented closure of New Cross S10 at this stage

supply to two DNO's, namely Aquila and East Midlands Electricity. The demand at Hams Hall immediately prior to the incident was estimated by NGC at around 250 MW[15].

The construction and asset replacement work at Hams Hall when completed will see the retirement of the 275 kV substation and the upgrading of the existing 275 kV circuits to 400 kV. This work is due to take place over a 10-year period. The current works are the first stage of the scheme, which sees the 400 kV Substation's capacity increased with the addition of two new 400/132 kV 240 MVA Transformers, i.e. to 4 x 240 MVA. The three 275/132 kV 120 MVA Transformers in the 275 kV substation will then be decommissioned. The completion date for these works was December 2003. The 132 kV substation is being replaced by a new GIS indoor substation. The completion date for the 132 kV works is 2005.

To facilitate the next stage of construction work NGC had agreed with Aquila and EME to commence the following set of planned outages on 5 September 2003:

a) Outage of MC3 at Hams Hall 275 kV substation and SGT2 to enable SGT2 to be de-commissioned.

b) Outage of MC4 at Hams Hall 275 kV substation and SGT1 to enable SGT1 to be de-commissioned.

c) Outage of section 4 of the main busbar at Hams Hall 132 kV substation to allow SGT2 to be disconnected to facilitate the ongoing construction work.

These outages had been planned well in advance with the full co-operation of NGC, Aquila and EME.

3.2.2 Events leading up to the Blackout

A new supergrid transformer, SGT8, was commissioned at Hams Hall on 17 August 2003 and had operated satisfactorily after first being loaded on 20 August. On 4 September, the day before the West Midlands blackout, the supply to the 132 kV load at Hams Hall was shared between the new 400/132 kV 240 MVA supergrid transformer SGT8, the 275/132 kV 120 MVA supergrid transformer SGT3 and two other 275/132 kV 120 MVA supergrid transformers (SGT1 and SGT2).

During the evening of 4 September, an existing 400/132 kV 240 MVA supergrid transformer SGT6 was re-commissioned and put back on load. This followed a 132 kV bay change and some secondary system changes at the 400 kV substation, associated with the removal of the old METRO SCADA system that was being replaced by a new numerical Substation Control System (SCS). After SGT6 had been on load overnight, the two 275/132 kV transformers SGT1 and SGT2 were switched out at 06:12 hours on 5 September, in preparation for their de-commissioning. The load was then being supplied by SGT8

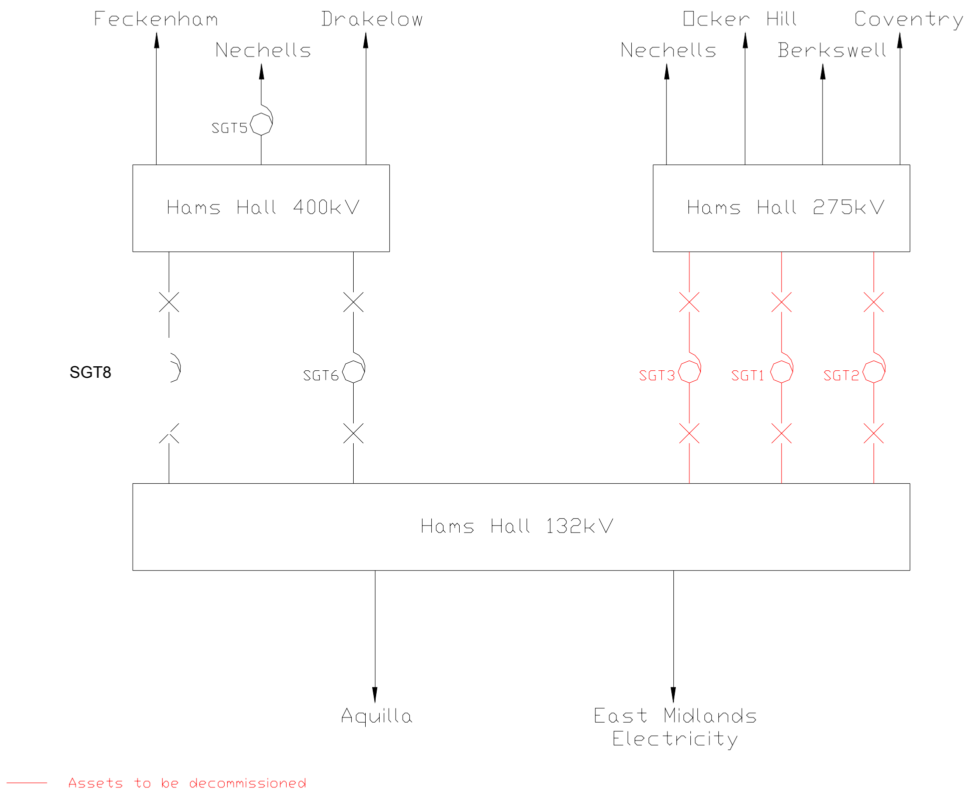
[15] Although NGT estimated the loss of supply at around 250 MW, the individual DNO estimates of lost load, when combined, put the lost load at around 300 MW.

(240 MVA), SGT3 (120 MVA) and the newly re-commissioned SGT6 (240 MVA). Figure 3.3 shows the supply arrangement at Hams Hall following the disconnection of SGT1 and SGT2.

At around 10:00 hours on 5 September, during a general inspection of the SGT6 400 kV relay room, NGC engineers smelt burning and a closer inspection of a suspect cubicle showed smoke issuing from its gland plate. At 10:03 hours an NGC site engineer contacted the Electricity National Control Centre (ENCC) at Wokingham to inform them that there was a problem with SGT6 at Hams Hall.

ENCC assessed the situation and were satisfied that SGT6 could be unloaded without affecting the security of the system, since there was still 360 MVA of transformer capacity in service to meet the 301 MW of demand on the 132 kV substation at the time. ENCC checked the status of SGT1 and SGT2, both taken out of service at 06:12 hours that morning, and requested that the work on SGT1 and SGT2, which had just started, be halted. The transformers could then be returned to service to provide additional capacity while the problem with SGT6 was addressed.

Figure 3.3: Layout of Hams Hall 400/275/132 kV substation prior to incident



Charred cables and localised sparking within the secondary wiring were observed in the cubicle and identified as being associated with wiring of some 132 kV Current Transformer (CT) circuits for SGT6. At this point, (10:09 hours) the site engineer contacted ENCC and requested permission to temporarily unload SGT6 and its 132 kV CT's by locally tripping the SGT6 132 kV circuit breaker. Permission was granted and the circuit breaker was opened at 10:10 hours.

In effect the removal of SGT6 diverted load to the remaining transformers SGT8 and SGT3. The load on SGT3 increased instantly from 33 MW to 84 MW, which was still within the rating of the 120 MVA transformer. The load on SGT8 also increased instantly from 138 MW to 217 MW (i.e. 223 MVA), but was still within its rating of 240 MVA. However, the increased current flowing through SGT8 was sufficient to cause the "unwanted" non-interlocked protection elements to operate within the multi-function relay that had been used to provide the 132 kV protection for SGT8 transformer circuit and trip the transformer. With SGT8 disconnected, the full load (i.e. 320 MVA) on the 132 kV substation was carried by the remaining 120 MVA transformer, SGT3, and as a result the overcurrent protection on SGT3 operated correctly to trip the transformer's 132 kV circuit breaker and the supply to Hams Hall 132 kV substation and with it the supply to Aquila and East Midlands Electricity (EME) customers.

The loss of supply affected 143,000 Aquila customers and 58,000 EME customers with pre-incident demands of 213 MW and 88 MW respectively.

It was later established that the 132 kV CT wiring problem had arisen as a result of equipment having been removed from one of the SGT6 132 kV CT circuits, through some confusion that had arisen in connection with the METRO replacement work. The CT circuit had been accidentally left open after a transducer had been removed without a wire link being inserted to close the circuit. Leaving an operational CT circuit open when the CT is passing primary load current will result in high voltages being developed across the CT secondary windings and wiring. It is a hazardous condition, in terms of the risk of fire, or injury to engineering staff and one which might result in damage to the CT winding. Such a fault obviously needs to be rectified with some urgency. Once the condition had been identified, NGC and the Contractor's staff on site realised that it could be safely dealt with by taking SGT6 and its 132 kV CT's off load for a short period, which was the course of action taken.

3.2.3 Restoration of supplies

From an examination of the alarms received it was evident to NGC engineers that the SGT3 transformer, that had correctly tripped on overload, could be returned to service immediately. At 10:10 hours, ENCC contacted both affected DNO's to advise them of the circumstances and it was confirmed that SGT3 could be returned to service. To accomplish this ENCC requested Aquila to split its demand so that power could be restored in stages.

In the meantime NGC instigated site checks on the SGT8 protection and the SGT6 CT wiring problems. NGC then informed EME's Network Management Centre that it had lost supplies to Hams Hall ✂.

At 10:21 hours SGT3 was returned to service to energise the 132 kV busbars at Hams Hall substation. The load on SGT3 was increased in stages between 10:21 and 10:25 hours, until SGT3 was approaching full load. By 10:31 hours SGT2 was made ready to come back into service.

Concurrent with the restoration process, investigations on site into the SGT6 wiring problems had identified the cause and following remedial action to rewire the CT circuitry and undertake an on-site check, transformer SGT6 was made available for service at 10:36 hours. With SGT3, SGT2 and SGT6 operational again, giving a total installed capacity of 480 MVA, this provided adequate capacity to restore supplies to all of the lost demand and the supply to Aquila was fully restored by 10:52 hours.

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3.3 Summary of the key elements of the two incidents

The examination of the sequence of events associated with the two incidents as detailed in subsections 3.1 and 3.2 has highlighted a number of important issues that are summarised below. These issues are then considered in greater detail in later sections of this report and in volume 2, where the protection issues are examined in much greater detail.

The analysis of the sequence of events has confirmed the following:

a) Both incidents occurred because of the incorrect operation of automatic protection equipment, which caused the unexpected tripping of a key circuit element (i.e. the Wimbledon – New Cross No. 2 circuit, in the London incident and supergrid transformer SGT8 at Hams Hall in the West Midlands incident). The loss of these circuits resulted in the loss of supply to over 700 MW of load in London and up to 300 MW of load in the West Midlands.

b) Both incidents occurred when the NGC transmission system was operating under planned outage conditions, but within the requirements of NGC's Security and Quality of Supply Standard.

c) Both unexpected operations of the protection equipment were incorrect operations, which occurred because of errors made during the delivery of new protection and the failure to identify the errors in each case through the commissioning procedures that were applied.

d) For Wimbledon, the latent protection system defect had remained hidden for over 2 years. Had circumstances not prevailed to substantially increase the load current through the circuit, that then caused the protection to incorrectly operate, it is possible that the error may have lain dormant on the network at least until the next planned maintenance tests. For Hams Hall, the defect had lain hidden for 19 days, but it would soon have been revealed with full loading of the transformer or during clearance of a local network short circuit. Analysis of records shows that the defect came close to being revealed after just 11 days.

e) In the London incident a number of factors combined to set up the conditions that eventually triggered off the loss of supply. These are summarised as:

- Planned outages that were forced to overlap, because of circumstances outside of NGC's control, although overlapping outages are not uncommon and as stated did not breach security standards,

- The occurrence of a Buchholz gas alarm on equipment associated with one of the two remaining 275 kV circuits supplying NGC grid stations in South London,

- The ambiguous nature of the alarm message received by the control engineer at the ENCC and the subsequent mistaken interpretation that led to the decision to open the Littlebrook – Hurst No. 1 circuit to investigate the cause of the Buchholz alarm that was taken to be on SGT3 at Hurst, when it was actually associated with the shunt reactor SR3, that in fact was not in service at the time.

- Finally, the installation of an inadequately rated overcurrent and earth fault relay to protect the surviving Wimbledon – New Cross No. 2 circuit that was left supplying the whole of South London.

f) It should be pointed out here, that had the incident with the Buchholz alarm not occurred and the sequence of events that it triggered not happened it was still possible that the supplies to South London could have been lost whilst the overlapping outages were in place with the protection problem unidentified. Had a Buchholz alarm actually occurred on SGT3, (or for that matter had a fault occurred on the Littlebrook – Hurst No. 1 circuit, or on any equipment connected to the same mesh corner at Hurst) during the period when the two 275 kV circuit outages overlapped, that required the same mesh corner at Hurst to be opened, then providing the load current was sufficiently high, the same 1 amp relay would have operated unexpectedly to trip the remaining Wimbledon – New Cross circuit with the same result. Although the extent of the disruption would depend on the time that it occurred and the level of load in the area.

g) The NGC restoration process returned supplies to all EDFE substations within 37 minutes ✂. However, there was potentially a problem during the initial stage of restoration when ENCC neglected to check the status of a circuit breaker at Hurst that was closed and should have been opened. Consequently when NGC started the restoration process it inadvertently energised EDFE's system and "back-energised" its own system. Fortunately protection operated almost instantaneously to disconnect EDFE and the "back-energised" part of NGC's network to avoid any damage caused by overvoltages.

h) In the West Midlands incident the problems were basically caused by failings in the protection commissioning process. These basically led to the CT wiring problems on supergrid transformer SGT6 at Hams Hall that required SGT6 to be taken out of service. This increased the load on SGT8, which then unexpectedly operated the “unwanted” non-interlocked facility in the multi-function relay that provided the 132 kV protection for SGT8 and which had not been set correctly. When SGT8 tripped, the total load (approximately 300 MW) was then left on SGT3, the surviving 120 MVA transformer, that tripped out on overcurrent.

i) ✂

In the following sections we look more closely at the three distinct parts of the investigation as defined in the Scope of Work.

4. PROTECTION COMMISSIONING AND PERFORMANCE

4.1 General

In section 3 the report described in factual terms the course of events associated with the two loss of supply incidents. An analysis of the events, including pre-event and post-event activities, is presented in Sections 4 to 6 of this report. The analysis identifies the key factors that created the conditions that put the transmission system security of supply at risk, reviews the effectiveness of the supply restoration procedures, identifies the cause of each event and recommends remedial action to eliminate the cause of the supply failures in the future.

The report has indicated in Section 3 that whilst the action taken by NGCC to open mesh corner 3 at Hurst 275 kV substation as a first stage in a sequence of emergency switching operations to isolate SGT3 and its associated shunt reactor SR3 triggered the events that led almost instantaneously to the loss of supply in South London, the loss of supply was itself brought about by the incorrect operation of the “System Back-Up” protection for the Wimbledon – New Cross No. 2 circuit at Wimbledon Substation.

The loss of supply incident at Hams Hall near Birmingham was triggered by the emergency switching action to unload SGT6 a few hours after it had been re-commissioned following some weeks of substation modification work. This was to allow the investigation of a potential safety and fire hazard that had developed within its 132kV instrument CT secondary wiring within the 400kV relay room. The switching procedure was carried out successfully, but when the SGT6 load was transferred to the remaining transformers SGT8 and SGT3 supplying Hams Hall 132 kV substation the increased current in SGT8 caused an incorrect operation of the 132 kV “Interlocked Overcurrent” protection scheme for SGT8, which tripped the transformer and brought about the loss of supply.

The investigation into protection commissioning and protection related matters is therefore a key element of the overall investigation. Many of the issues are complex and of a detailed nature and require specialist knowledge to fully appreciate the arguments presented. Consequently the full analysis of the review into Protection Commissioning and Protection Performance is presented as Volume 2 of this report. The analysis and conclusions presented in Volume 2 are summarised here as Section 4.

4.2 Focus of investigation

The London Blackout was caused by the incorrect operation of the ”System Back-Up Overcurrent” protection for the New Cross 275 kV No.2 circuit at Wimbledon, after the load current on the circuit increased, following emergency network switching operations to disconnect plant with an apparent problem at Hurst substation. The increased load current was well within the expected capability of the circuit and it should not have tripped.

The protection relay that initiated tripping was a conventional electronic unit, of type reference MCGG42. The relay actually operated correctly, but the incorrect protection system operation occurred because its primary current threshold for operation was five times lower than it should have been. This was due to the fact that a relay with secondary current inputs rated at 1 Amp had been installed in error, during protection system refurbishment work in May 2001, rather than a relay with the required 5 Amp rated inputs.

The relay rating error should have been detected during standard commissioning tests and procedures laid down by NGC, but it was not. The result was that the protection system was commissioned with a latent defect that remained hidden for over 2 years, until the system emergency that arose on 28 August 2003. The latent protection system defect prevented the Wimbledon to New Cross No. 2 circuit from being used to its full capability during an emergency.

The West Midlands Blackout was caused by the incorrect operation of the "Interlocked Overcurrent" protection [scheme] for the 132 kV side of the new 400 kV/132 kV step-down transformer SGT8 at Hams Hall. The incorrect protection system operation occurred when the load current on SGT8 increased, following an emergency network switching operation to unload the parallel transformer SGT6. This was to urgently deal with a serious secondary system problem that had been discovered for SGT6, some hours after it had been re-commissioned, following some weeks of substation modification work. The increased load current was well within the expected capability of SGT8 and it should not have tripped.

The protection relay that initiated tripping was a multi-function, numerical relay, of type reference KCGG142. The relay actually operated correctly, but the incorrect protection system operation occurred because non-interlocked protection functions had been unintentionally left enabled within the multi-function relay, due to errors and omissions in the settings that had been prescribed for the relay. A contributory factor was that non-interlocked overcurrent and earth fault protection had been provided as part of the contractor's protection scheme design in addition to interlocked overcurrent protection, which was inappropriate. The non-interlocked protection was not required and it had not been requested by NGC. The non-interlocked protection functionality should have either been completely disabled, through relay configuration settings, or its parameters should have been set such that there would have been no danger of it issuing an unwanted trip during clearance of a transmission network short circuit or during a system emergency.

The setting errors and omissions for the new protection relay for SGT8 were not detected during commissioning. For the numerical, multi-function relay in question, the nature of the errors and omissions was such that they would not necessarily have been detected, even if the standard NGC commissioning tests and procedures had been fully applied. The result was that the protection system was commissioned with a latent defect that remained hidden for 19 days after SGT8 had been commissioned, until the system emergency that arose on 5 September 2003. The latent protection system defect prevented the new SGT8 from being used to its full capability during an emergency.

The NGC-approved Settings Engineer had obviously appreciated that there was some non-interlocked protection functionality included within the protection scheme supplied by the Contractor, since the NGC settings summary sheet (MARS) that the Engineer had prepared for the multi-function KCGG142 protection relay had indicated that the non-interlocked overcurrent protection functionality of the protection was not to be used. However, there was an omission to detail how the unwanted protection should have been set out of service and some of the output configuration settings that had been prescribed were erroneous, but they were in line with configuration setting indications on the scheme diagram that had been supplied by the Contractor, which were inappropriate for the NGC application.

Unlike the Wimbledon defect, the Hams Hall defect was of a type (non-delayed tripping) that would have been revealed within days or weeks, rather than years – possibly without causing any loss of supply. This would have been during full loading of SGT8 or during clearance of a local system short circuit. In fact, PB Power has noted that the defect came very close to being revealed during SGT8 loading at around noon on 28 August, when an unwanted tripping of the SGT8 would probably not have caused any loss of supply. It was the fact that the SGT8 defect was revealed during a system emergency involving another transformer at the same substation, that the unwanted tripping resulted in the loss of supply.

It is inevitable that errors and omissions can be made by any party involved in the specification, engineering, installation, setting and commissioning of protection systems for power networks. ✂ In recognition of this fact and of the potentially serious consequences of such errors and omissions, it is necessary for any Transmission Network Operator (TNO) to have processes, procedures and associated supervision in place that will identify and correct any errors that have been made, before a protection system is signed off as being fit for service, at the end of the commissioning process.

The focus of this investigation report was to determine the reasons why two protection system defects had not been identified before they caused wide-area power failures.

Since the unwanted protection operations on 28 August in South London and on 5 September in the West Midlands were evidently incorrect, there must either have been a ✂ lapse in the application of NGC's established processes, procedures or associated supervision for the delivery of new protection systems, or that they had a ✂ flaw or inadequacy. In the event of any flaw or inadequacy it was important to establish

(a) whether this had always been the case

(b) whether the situation had arisen as a result of equipment technology changes

(c) whether the situation was due to any changes in the way in which established and necessary processes, procedures or supervision are being applied.

The Consultants have reviewed NGC's established processes and procedures to facilitate the investigation of how they may have failed at Wimbledon and Hams Hall.

4.3 Review of London incident

4.3.1 Background

The protection that operated incorrectly at Wimbledon on 28 August was part of a refurbished protection scheme that was commissioned in 2001. Following an NGC Tender Enquiry, for Protection Refurbishment work at various sites, a Contractor was appointed in

2000 to refurbish the protection and control systems for the 275 kV Mesh Corners 1 and 3 at Wimbledon Substation. The refurbishment required the existing primary plant circuit breakers, voltage transformers and current transformers to be retained, but included refurbishment of the Main Back-Up protection systems for the Beddington 1 and New Cross 1 Feeder, associated with Mesh Corner 1 and for the New Cross 2 Feeder, associated with Mesh Corner 3.

In accordance with the Design Intent Document (DID) that was issued to NGC by the Contractor on 15 August 2000 (actually entitled Detailed Design Specification), the proposed refurbishment work involved the engineering of new protection panels with the provision of some new protection relays, to replace existing relays close to life expiry, and with the re-use of some existing relays. Any protection equipment not being re-used was to be offered to NGC for their retention (maybe for re-use elsewhere or for spares), or it was to be disposed of.

All the new protection panels for the refurbishment work at Wimbledon were manufactured in 2000-2001 and outages had been planned to facilitate the installation and commissioning of the refurbished protection schemes for all three feeders in 2001. It transpired, however, that only the Mesh Corner 3 commissioning work could be completed in that year, which covered only the New Cross 2 Feeder. The Mesh Corner 1 work, including the New Cross 1 and Beddington 1 Feeders, had to wait until outages became possible in 2003. These outages were in place at the time of the incident of 28 August 2003. The refurbished protection schemes associated with Mesh Corner 1 were stored from 2001 until their installation and commissioning commenced in 2003.

4.3.2 Summary of the incident

The blackout occurred when the New Cross 2 Back-Up overcurrent protection incorrectly tripped Mesh Corner 3 and the New Cross 2 Feeder at Wimbledon. This was after the feeder load current increased to approximately 1460 Amps following remote opening of the Hurst end of the Hurst - Littlebrook 1 No. 1 circuit by ENCC, to address an apparent plant problem at Hurst. The operation of the overcurrent protection was incorrect, since its intended primary operating threshold had been 5,100 Amps, equivalent to about 3.5 times the actual current experienced.

It was eventually established by NGC that the actual primary operating threshold of the protection was 1020 Amps, due to the fact that a protection relay with a 1 Amp secondary current rating had been installed and commissioned instead of a relay with a 5 Amp rating. With the increased load current that was seen after the Littlebrook – Hurst circuit had been opened at the Hurst end, and with the settings that were applied to the 1 Amp rated relay, it would have taken approximately 6 seconds for the relay to trip the circuit.

From NGC's load profile of the New Cross No.2 circuit since the refurbished protection system had been commissioned in 2001, it appears that the maximum demand placed on the circuit in the period had been 340 MVA, during July 2001. This would have been equivalent to approximately 714 Amps, so the operating threshold of the defective Back-Up Overcurrent protection had not been exceeded until the incident of 28 August 2003.

According to NGC Transmission Plant Specification TPS 2.24.3, for Protection Settings Policy, the required Back-Up overcurrent protection threshold setting for the 275 kV New Cross No.2 circuit would indeed have been between 5,100 and 5,200 Amps.

4.3.3 Summary of the incorrect protection installation

The detailed investigation of the installation of incorrect protection of the Wimbledon – New Cross No.2 circuit has revealed a number of facts that are summarised below:

1. Less than one month prior to the delayed re-commissioning date of the New Cross 2 Feeder and its refurbished protection scheme, a substitute MCGG42 overcurrent relay was ordered by the Contractor, from the relay manufacturer. This was to be a replacement for the planned re-use of the 5 Amp rated MCGG42 of 1997 vintage, that had been retained from the original protection scheme. The order effectively requested urgent delivery and the manufacturer obliged.

   The replacement relay that was ordered, delivered, fitted and commissioned was a 1 Amp relay. It is not known why it was necessary to order a "last-minute" replacement relay or why a 1 Amp relay was ordered to replace the 5 Amp original. ✂ NGC's analysis of the available information suggested that a decision was taken to substitute a contemporary variant of the MCGG42 unit, procurable from the manufacturer, rather than retain the existing relay. However, no such replacement was made for the New Cross No. 1 circuit protection refurbishment. ✂

2. The relay manufacturer appears to have despatched the relay that had been ordered in May 2001 in well under their normal manufacturing lead-time. It is understood that the relay that was actually delivered to site had been manufactured in 2000 and so the manufacturer appears to have taken an unusual step to provide urgent assistance to the Contractor.

3. The commissioning tests for the replacement 1 Amp relay were performed in accordance with the Contractor's test procedure laid down in the document PTS299, rather than the available NGC procedure SCT 20.5.3. The NGC procedure required a check to be made as to the correct current rating of the relay to be tested, for it to be tested with its service settings applied and for the definitive NGC MARS setting summary sheet to be attached to the completed test document.

   The Contractor's procedure was based on testing virtually all the relay settings, but not the service settings.

4. The record of back-up protection tests for New Cross 2, along with many other test records, was signed off on 1 June 2001, after the Feeder had been re-commissioned on 26 May. There is no record of the actual date of relay testing. There is also no evidence of tests having been conducted with the required service settings applied.

5. The NGC MARS sheet, which displays the serial number of the relay that was tested, has the relay rating clearly listed as 5 Amps, which differs from the 1 Amp rating that was clearly recorded in the Contractor's commissioning test record. If the MARS

sheet had been available at the time of commissioning and if it had been carefully referred to, there would have been a good chance that the relay rating error would have been spotted. The MARS sheet appears to have been prepared before the date of commissioning and so it would have been available, but no documentary evidence has been provided to confirm that the MARS sheet was in the possession of the Contractor's Commissioning Engineer at the unrecorded time of the Commissioning tests.

6. The required New Cross 2 overcurrent protection threshold setting for service, which had been calculated for a 5 Amp rated relay (In = 5 Amps), was 0.85 x In. It was also possible to apply this setting to the incorrectly installed 1 Amp relay (In = 1 Amp) and so the action of applying the service settings to the relay would not have highlighted the relay rating error.

7. ✂

8. The proposed use of the Contractor's own test procedure for the Back-Up Overcurrent and Earth Fault protection, rather than the appropriate NGC procedure, was detailed in the Contractor's Commissioning Report Quality Plan, which had been approved by the NGC Commissioning Panel on 23 March 2003. The approved plan also required that the tests were to be 100% witnessed by NGC. In the copies of the Plan and the completed test procedure documents provided to PB Power for review, the NGC witness signatures are missing.

9. NGC has since stated that their Commissioning Engineer for Wimbledon has confirmed that a collective decision was taken to selectively witness the secondary injection tests associated with the New Cross No.2 circuit. Tests relevant to the back-up protection were deemed to be within the scope of the supplier and were therefore not witnessed by NGC. The Commissioning Report Quality Plan does not appear to have been revised and no other documentary evidence has been provided to confirm this change of plan.

10. There had been slippage in the planned progress of work for the Wimbledon refurbishment project, with the Mesh Corner 3/New Cross 2 start date having been delayed by a distribution system fault. ✂ The planned subsequent work for Mesh Corner 1 eventually had to be put on hold until 2003, due to the impact of an NGC feeder fault between Hurst and New Cross. The Mesh Corner 1 refurbishment equipment had to be held in storage for 2 years.

4.3.4 Conclusions regarding the London incident

The following conclusions are drawn with regard to the incorrect trip of the New Cross No.2 circuit on 28 August 2003:

1. It was due to the erroneous substitution of an overcurrent relay of incorrect rating just prior to commissioning, for reasons unknown.

2. There was apparently a collective commissioning management failing of both NGC and the Contractor, as members of the Commissioning Panel chaired by NGC, to ensure that the Back-Up protection was commissioned according to NGC's established standard procedures, supported by dated documentary evidence of the required service settings having been tested and of the tests having been witnessed, as planned.

3. If the definitive NGC MARS setting sheet for the protection had been in the possession of the Contractor's Commissioning Engineer at the time of commissioning and if careful reference had been made to it, there would have been a good chance that a qualified and experienced Commissioning Engineer would have spotted the relay rating error. The MARS sheet had been created before the protection could have been tested and the particular Engineer would undoubtedly have been vetted and approved by the NGC Commissioning Panel that had been created for the project, but there is an absence of any documentary evidence that he was actually in possession of the MARS sheet during tests and there is no record of the date on which the tests actually took place.

4. The established NGC commissioning procedures are considered to be within the realms of best international practice and they are considered to have been adequate for the type of Back-Up protection that had to be tested, had they been fully applied. However, the addition of a formal test procedure to prove that the required circuit "loadability" is not constrained by any protection system, would make NGC's procedures more robust for all types of protection, with it probably becoming a necessity where the latest types of multi-function numerical protection relays are applied.

4.4 Review of the West Midlands incident

4.4.1 Background

The protection that operated at Hams Hall on 5 September 2003 was part of a new protection scheme for the 132 kV side of a new 400 kV/132 kV supergrid transformer (SGT8). The provision of the new transformer and protection scheme was part of an extensive transmission system reinforcement programme that is under way for the West Midlands. As part of the scope of work for Hams Hall, the existing 132 kV Substation is being re-engineered to become a replacement substation, on the same site, which will be named "Lea Marston" in its final form. Details of the scope of work for the Hams Hall 400 kV substation and the new Lea Marston 132 kV Substation were provided in NGC Tender Documents C/XT019 and C/XT022, respectively.

The re-engineering of Hams Hall substation, while it continues in operation, involved a complex set of intermediate and final connection arrangements for the incoming transformer circuits, with complex 132 kV bay "swap-overs" taking place at various stages, which affected both primary and secondary substation systems.

Both the NGC tender documents for the 400 kV and 132 kV Hams Hall work solicited turnkey type contracts and both were released to a single Contractor. The scope of the Contractor's responsibility for the ongoing work covers "the design, detailed design, procurement, delivery to site(s), erection, testing, commissioning, setting to work" of equipment. With particular reference to the protection responsibilities of the Contractor, it is a requirement that "the settings to be applied to protection systems shall be specified by the Contractor and calculations shall be submitted to NGC for assessment and agreement, **not less than six months** prior to the commencement of any testing or associated commissioning activities on site."

The tender document statement regarding the responsibility for providing protection settings requires some clarification, in line with the Consultant's understanding of what had been NGC's policy and in response to NGC's confirmation, through subsequent correspondence discussion, via Ofgem. The NGC practice had been to make the Contractor responsible for providing settings for "unit" protection systems, where co-ordination with other protection, outside the scope of work of the Contractor, was not required and where the contractor would have access to all information required to propose settings for dependable and secure protection performance. The proposed settings would then be checked by NGC. All other protection settings would be determined by an approved NGC Settings Engineer. For SGT8 at Hams Hall, the Contractor was responsible for proposing the "unit" protection settings, such as the Transformer Differential and HV Connections differential protection, but NGC assigned the responsibility for producing settings for the "non-unit" protection, including the 132 kV protection that operated incorrectly, to an approved NGC Settings Engineer who was a sub-contracted Consultant.

4.4.2 Summary of the incident

The day before the blackout that took place on 5 September, the 132 kV load at Hams Hall had been supplied by the new 400 kV/132 kV Transformer SGT8 (240 MVA), the 275 kV/132 kV Transformer SGT3 (120 MVA) and by two other 275 kV/132 kV transformers SGT1 and SGT2 (2 x 120 MVA) which were due to be de-commissioned. In the evening of 4 September an existing 400 kV/132 kV Transformer SGT6 (240 MVA) was re-commissioned and put back on load, following a 132 kV bay change and some secondary system changes at the 400 kV substation associated with the removal of the old METRO SCADA system that was being replaced by a new numerical Substation Control System (SCS). After SGT6 had spent one night on load, the two transformers SGT1 and SGT2 were taken out of service at 06:12hours on 5 September, in preparation for their de-commissioning. The Hams Hall 132 kV load was then being supplied by SGT8, SGT3 and the newly re-commissioned SGT6.

At around 10:00 hours on 5 September, NGC Engineers discovered smoking, burning and sparking of secondary wiring within a cubicle located in the SGT6 building at the 400 kV substation. They identified that the wiring was associated with some 132 kV Current Transformer (CT) circuits for the newly re-commissioned SGT6 and they requested permission from ENCC to temporarily unload SGT6 and its 132 kV CT's by locally tripping the SGT6 132 kV circuit breaker. Permission was granted and the circuit breaker was opened. This action triggered the incorrect SGT8 protection operation that caused the blackout.

It was later established that the 132 kV CT wiring problem had developed as a result of equipment having been removed from one of the SGT6 132 kV CT circuits, through some confusion that had arisen in connection with the METRO replacement work. A CT circuit had been accidentally cut and left open, after a transducer had been removed, without a wire link having been inserted to re-make the circuit. Leaving an operational CT circuit open when the CT is passing load current will result in high voltages being developed across the break and across the CT windings. It is a hazardous condition, in terms of the risk of fire, or injury to engineering staff, and one which might result in costly damage to a CT winding. The occurrence of such a fault would certainly require urgent attention. Once the fault had been identified, NGC and the Contractor's staff on site judged that it could be safely dealt with by taking SGT6 and its 132 kV CT's off-load for a short period, which was the course of action they instigated.

The Hams Hall 132 kV protection scheme includes interlocked overcurrent protection (ILOC) and this functionality was provided by the use of a multi-functional protection relay. The interlocked overcurrent protection (ILOC) protection must be interlocked with 132 kV busbar protection trip relay operation. The protection should not be armed unless the busbar protection trips. In this case, there was no operation of the busbar protection or any of its trip relays and so the ILOC protection relay should therefore not have tripped.

It has now been established that it was the <u>non-interlocked</u> overcurrent protection functionality of the multi-function relay used to provide ILOC protection that had caused the trip. This had unintentionally been left in service, on its default current settings, within the multi-functional protection relay that had been deployed to provide the required 132 kV ILOC protection for SGT8. With the applied CT ratio setting, the default current setting for the non-interlocked protection had been 1000 Amps primary. It has also been established that the time delay setting for the non-interlocked protection had been set to zero, which was a departure from the default setting. When SGT6 was taken out of service, the 132 kV load current for SGT8 increased from approximately 630 Amps to around 1000 Amps, which caused the non-interlocked overcurrent protection to operate.

The relay tripped the 400 kV and 132 kV circuit breakers of SGT8 just 20 seconds after the 132 kV circuit breaker of the parallel transformer SGT6 had been manually opened, under local control, with permission from the ENCC. This action was required to address the serious secondary system problem that had been observed by NGC staff with the recently re-commissioned SGT6. After SGT8 was incorrectly tripped by protection, the 275 kV/132 kV Transformer SGT3 was left supporting the Hams Hall 132 kV load in isolation. The load on SGT3 reportedly rose to 319 MVA, but its rating is only 120 MVA. At 266% of rated load and with NGC transformer back-up protection typically set to pick up at 145% of rated load current, it was certain that the first-stage of the SGT3 Back-Up Overcurrent protection would soon operate to trip the SGT3 132 kV circuit breaker. This correct protection operation occurred approximately 15 seconds after the incorrect SGT8 trip, with the result that all load was lost at Hams Hall 132 kV substation.

The load profile of SGT8 since it had first been loaded on 20 August 2003, 3 days after it had been commissioned indicates that the maximum demand on the new transformer before the incident on 5 September had been 233 MVA at around noon on 28 August (coincidentally 6 hours before the London incident). This would have been equivalent to approximately 1019 Amps. For the non-interlocked overcurrent protection function of the relay in question, the actual pick-up current was calibrated to 105% of the current setting, with a tolerance of $\pm$5%. The actual primary pick-up current of the protection function in question would have been centred on 1050 Amps, with a possible pick-up of somewhere between 1000 – 1100 Amps. It would seem therefore that SGT8 had only marginally avoided being tripped on 28 August 2003[16] through the operation of this function, although an isolated trip of SGT8 on that day would not have resulted in any loss of load. It appears that the trip on 5 September had also been marginal, since it took approximately 20 seconds for the protection to trip after SGT6 had been taken off load, even though the non-interlocked protection in question had been set with a zero time delay.

4.4.3 Summary of the SGT6 open circuit current transformer (CT) incident

1. As part of the work to replace the old METRO SCADA system at the 400 kV substation, work was in progress to interface the new SCS system to existing instrumentation CT's and VT's and to remove wiring and equipment that had been identified on drawings as being redundant.

2. A Contractor's Wireman, opened a general services cubicle in the SGT6 400 kV relay room to commence SCS interfacing work, but he found that there was wiring and a transducer present that was not shown on the marked-up copy of the master drawing that he was working to. He flagged up the matter with his supervisor and the Contractor's Commissioning Engineer.

3. NGC's account is that the Contractors reviewed the situation on site with NGC staff. Their wireman was subsequently advised to remove some of the redundant wiring and equipment that was not shown on the drawing, to make room for the new SCS wiring. This was apparently on the understanding that the wiring to be removed was not associated with any CT circuits. Due to the complexity of the operation, the Contractor's Commissioning Engineer, who is regarded by NGC as being capable and experienced and who had been approved by the project Commissioning Panel, carried out the removal of the redundant wiring himself. It was during his work that the wiring of a 132kV CT circuit was cut.

4. Whenever a Contractor undertakes work on an NGC site, the Contractor is responsible for marking up and creating new site master drawings according to changes that have been made. It is not uncommon, however, for some lag to exist between changed equipment status and site drawing status. In this case, it appeared that the Contractor for some previous work had created a drawing somewhat ahead of work completed on site to remove redundant wiring and equipment and some deletions were made to a drawing that had not actually occurred in practice.

[16] The same day, incidentally, as the South London incident.

5. As the Contractor's Commissioning Engineer disconnected the apparent redundant wiring to allow new wiring to be connected, he cut the Yellow phase 132 kV CT circuit wiring to remove a current transducer from the cubicle. The Commissioning Engineer would have been very much aware of the necessity to link the break in the CT circuit, but for some reason he was either not aware that a CT circuit had been cut or he forgot to arrange for the circuit to be remade via a link ✂.

6. After having performed any modification work on CT secondary circuits, tests should be conducted to prove the circuits afterwards. Tests may have been omitted in this case due to that fact that the work to remove equipment not shown on a drawing was, in fact, unplanned work or that there was no knowledge of a CT circuit having been interfered with.

7. ✂

8. After SGT6 was commissioned in the evening of 4 September, it was not until the load on the transformer increased to a substantial level, during the morning of 5 September, that the break in the CT circuit came to be noticed by NGC staff, through the burning of insulation caused by sparking across the open CT circuit.

9. The authorised unloading of SGT6, by opening its 132 kV Circuit Breaker, made it possible for a link to be safely made in the open CT circuit, such that the transformer could be quickly put back on load. In the intervening period, however, the unloading of SGT6 and the increased loading of SGT8 caused the defective SGT8 132 kV protection scheme to operate incorrectly, which caused the blackout.

10. NGC has stated that, due to the circumstances at Hams Hall on 5 September 2003, the CT and associated wiring was not checked before it was returned to service on 5 September 2003. However, a week later, SGT6 was taken out of service and the CT was tested to SCT sheet 20.1 – Current Transformers Magnetisation Tests and the secondary wiring was subjected to Insulation Resistance tests in accordance with SCT sheet 20.4.1. All tests proved satisfactory.

4.4.4 Summary of the incorrect SGT8 ILOC protection application

1. Despite NGC's reasonably clear specification, especially in terms of the protection schematic diagram that accompanied the tender document, it appears that the Contractor had been confused as to the actual requirements for SGT 132 kV protection at the Hams Hall/Lea Marston substation.

2. The NGC specification required only Interlocked Overcurrent protection at the 132 kV substation, but the contractor had engineered and supplied a scheme, based on a multi-function numerical relay, which provided both System Back-Up (non-interlocked) Overcurrent and Earth Fault protection and supplementary Interlocked Overcurrent protection (ILOC).

3. The title of the Contractors' scheme drawing number T1/42/152119, which had been submitted to NGC, was "Circuit Diagram 3 Phase Overcurrent and Earth Fault

Protection”. There was no specific reference on the diagram to Interlocked Overcurrent protection which was the principal reason for providing this equipment. This should have been picked up by NGC’s Commissioning Panel and by the approved NGC Settings Engineer as an issue that required some investigation/clarification against the Contractor’s reviewed Design Intent Document before commissioning commenced.

4. In a settings calculation sheet, the approved NGC Settings Engineer, who was a sub-contracted Consultant, had calculated appropriate generic settings for the ILOC functionality of the Contractor’s protection scheme, but the settings were not clearly linked to the particular parameters of the KCGG142 protection relay.

5. In the production of the definitive MARS setting sheet for the KCGG142 relay, it is clear that there was a failure by the approved NGC Settings Engineer to prescribe settings that would prevent the unwanted non-interlocked overcurrent and earth fault protection functionality of the Contractor’s scheme from interfering with system operation and normal system fault clearance.

6. On the definitive NGC MARS summary sheet, the non-interlocked overcurrent and earth fault protection elements of the relay had actually been assigned to operate trip output and alarm relay contacts, so the “unwanted” protection was effectively enabled. The setting parameters for the non-interlocked protection functions had been annotated as “not used”, but such settings do not exist. As a result, the non-interlocked overcurrent protection was left at its factory default current setting, which was equivalent to 1000 Amps primary. The prescribed time setting had been changed from the default definite time setting of 60 seconds to zero seconds. The non-interlocked earth fault protection settings parameters were not even listed on the MARS sheet, so it is assumed that they were left at the default settings equivalent to 200 Amps primary with a definite time delay of 100 seconds.

7. NGC has confirmed that the complete ILOC protection scheme information had been provided to the approved NGC Settings Engineer. Furthermore, NGC stated that discussions had taken place between the scheme supplier and the Settings Engineer to understand the relay logic proposed by the supplier. It is not clear, therefore, why the MARS sheet errors and omissions were made or why the Settings Engineer did not highlight the fact that the proposed scheme was not entirely appropriate.

8. ✂

9. It might be argued that the Contractor’s Commissioning Engineer should have queried the use of the “not used” terms on the MARS sheet when applying settings to the relay, rather than leaving the particular settings at their default values, but a Commissioning Engineer could understandably have assumed that the terms indicated that the settings for the particular parameters were the equivalent of “not relevant”, with the assumption that the Settings Engineer had rendered the associated element ineffective through other settings.

10. As a result of the settings actually applied to the protection relay, any external fault fed by the transformer, or any heavy load current above 1000 Amps at 132 kV (229 MVA), would result in instantaneous protection tripping of the SGT8 400 kV and 132 kV Circuit Breakers.

11. The ✂ incorrect SGT8 load trip came on 5 September 2003, which was 16 days after SGT8 had first been loaded. From NGC loading records for SGT8, it appears that it had also been extremely close to tripping incorrectly at around noon on 28 August2003.

12. ✂ Although the protection relay in question was Type Registered with NGC, there was no formally approved Site Commissioning Test (SCT) document template for the ILOC scheme. NGC subsequently stated its view that the use of the manufacturer's own commissioning test sheet, being derived from the service manual of the Type Registered relay, was adequate to check the general functionality of the relay type. However, NGC recognised that the sheet does fall short for testing particular applications of the relay, such as an Interlocked Overcurrent protection function. The sheet had not been formally registered by NGC as an SCT document for the relay type.

13. Under TP106 requirements, the Contractor's test procedure was to cover Stage-1 testing. The complete test record was signed by the Contractor's Commissioning Engineer only. Under TP106, at the discretion of the Commissioning Panel, it may not be necessary for Stage-1 tests to be witnessed. Such agreements would be documented in the Commissioning Plan, but this key document, which is required under NGC Transmission Procedure TP106 does not appear to exist, since no copy has been provided.

14. Even if adequate ILOC test procedures had been applied, it is unlikely that the erroneous enabling of non-interlocked overcurrent protection within the multi-function KCGG142 relay and its undue restriction on SGT8 loadability would have been highlighted unless a loadability test had been applied to the protection scheme to confirm that the transformer could be loaded up to its emergency rating without any protection element issuing an unwanted trip. Such testing is not yet widely applied by other TNO's worldwide, but the Consultants recommend some testing of this form for the future, when commissioning multi-function relays.

15. The Contractor had incorrectly engineered SGT intertripping arrangements from the 132 kV substation to the 400 kV substation, whereby operation of the 132 kV busbar protection would intertrip the 400 kV SGT Circuit Breaker. This unwanted arrangement actually negated the need for ILOC protection. Having subsequently identified what appeared to be an error, the Contractor brought it to NGC's attention on 29 August 2003, after SGT8 had been on load for 9 days.

16. ✂

17. NGC has indicated that it monitors the working hours of the Contactor's staff and its own staff and that no one is permitted to exceed the rules of the EU Working

Directive. Examination of the Contractor's timesheets shows that three of the four commissioning engineers had worked on average between 50 to 60 hours per week (with the fourth engineer averaging just over 40 hours per week) over the five weeks prior to the Hams Hall incident. Given the nature of commissioning work, the Consultants do not regard this as excessive given the very nature of commissioning work, where the adoption of flexible working hours is essential to get the job done, and at certain stages in the commissioning programme it may be necessary for the engineers to work in well in excess of the 48 hours per week average laid down in the EU directive. ✂ In NGC's response to questions and comments on this topic it has emphasised that the commissioning process is one of intense activity, interspersed with periods of waiting for appropriate system conditions to allow work to proceed directly on the transmission system. NGC has also indicated in its response on this topic that site staff are supported by a range of specialist engineers who spend significant time on site during the commissioning period. We do accept NGC's statement that it takes its responsibilities for a safe and healthy workplace seriously and that it is normal practice for commissioning staff to follow significant periods of work with periods of recuperation, as is the case at Hams Hall. ✂

4.4.5 Conclusions regarding the West Midlands incident

The following conclusions are drawn with regard to the incorrect trip of SGT8 on 5 September 2003:

1. The Contractor did not appear to have understood that only Interlocked Overcurrent protection was required for the 132 kV protection of SGT8.

2. The Contractor had engineered and delivered a protection scheme, based on a multi-functional numerical relay, which provided unwanted non-interlocked, System Back-Up, Overcurrent and Earth Fault protection as well as ILOC protection, through its proposed configuration settings and scheme wiring.

3. The NGC Commissioning Panel and the NGT-approved Settings Engineer failed to identify the Contractor's confusion before commissioning took place, concerning their commitment to provide the specified ILOC protection and the inappropriate protection scheme design that they had supplied.

4. The approved NGC Settings Engineer, who prepared settings for the ILOC functionality of the protection scheme and who completed the definitive NGC MARS setting sheet, failed to prescribe settings that would effectively prevent the unwanted, non-interlocked, overcurrent and earth fault protection functionality of the Contractor's scheme from interfering with system operation and normal system fault clearance.

5. The commissioning test procedure used by the Contractor for the SGT8 132 kV ILOC protection was inadequate and there was no NGC approved Site Commissioning Test (SCT) procedure for the ILOC protection scheme that had been supplied.

6. A Commissioning Programme document, as required under Transmission Procedure TP106, does not appear to have been issued, since no copy has been provided for review, in response to requests.

7. There was apparently a collective commissioning management failing of both NGC and the Contractor, as members of the Commissioning Panel chaired by NGC, to ensure that the SGT8 ILOC protection scheme was commissioned according to NGC's established standard procedures, supported by the documentation required under NGC's Transmission Procedure TP106, for Equipment Commissioning and Decommissioning.

8. Even if appropriate ILOC test procedures had been applied, it is unlikely that the erroneous enabling of non-interlocked overcurrent protection by settings errors and its undue restriction on SGT8 loadability would have been highlighted. Only the blind application of a loadability test to the protection scheme would have confirmed that the transformer could be loaded up to its emergency rating without any protection element issuing an unwanted trip. ✂

9. A high volume of complex work is being undertaken in operational substations at Hams Hall.

The open circuit CT for SGT6, which precipitated the incident of 5 September, resulted from the following factors:

1. A master drawing issued by a Contractor from previous work was ahead of the actual status of equipment on site.

2. Items had been deleted from the master drawing that had not actually been removed on site.

3. An omission by the Contractor's and NGC's staff to have the site drawing discrepancy properly researched before the Contractors were conditionally instructed to remove non-documented wiring and equipment.

4. ✂

4.5 Proving Transmission Circuit Loadability

Proving the 'loadability'[17] of a transmission feeder or transformer is vital for transmission system security. The highest load current that is likely to be carried by a circuit will generally occur following a forced outage of another feeder or transformer, at a time when the transmission system may already be operating under planned outage conditions. If the circuit protection then operates incorrectly, there may well be a major loss of load. That is

[17] The "Loadability" of a circuit, or item of plant, is defined as the maximum level of load current that it is able to carry before the current will be interrupted by the operation of any item of automatic protection

precisely the wrong time to discover that the protection is imposing some unforeseen loadability limit.

Whilst NGC's established procedures would probably have resulted in the incorrect relay rating being identified during commissioning tests at Wimbledon, if they had been fully applied, NGC has since recognised, in its remedial actions report of 15 October 2003, a need to introduce some form additional primary operating current check procedure to make their existing procedures more robust and the Consultants support this view.

Now that multi-function numerical protection relays are being widely deployed as part of NGC's protection asset replacement programme, and especially where many of NGC's previous in-house activities are being devolved to Contractors, there is an increased need for additional loadability testing, as discussed in Section 4.8 of Volume 2. Even if NGC's established procedures had been fully applied during commissioning of the SGT8 ILOC protection at Hams Hall, which was based on a multi-function relay, and even if a formal back-calculation procedure for primary operating current had been applied, the particular protection defect, caused by configuration settings errors, would probably not have been identified during commissioning.

Irrespective of any existing NGC Site Commissioning Test (SCT) procedures, which may or may not be available for the particular types of protection that can be applied to a transmission circuit, PB Power recommends that supplementary circuit Loadability Tests should be devised and conducted once all the service settings have been applied to the circuit protection systems. Such tests should prove that none of the protection systems will restrict the loadability of the circuit, by incorrectly operating at below the level expected by system planners and operators. To allow for the responses of any voltage-dependent protection functions, as well as current-dependent functions, it is suggested that loadability tests should include the simulated application of a prescribed level of system voltage (e.g. 90%) and the simulated application of forward and reverse load flow at a prescribed load angle (e.g. 30^0 lagging).

In the Consultant's experience, the type of loadability testing being suggested is not yet common practice for other TNO's worldwide and so NGC is not outside best international practice by not specifically requiring such tests. However, as with NGC, other TNO's are experiencing increasing supply interruptions caused by protection setting errors, where the complexity of new multi-functional relays is a contributory factor and where the errors are not being picked up by established commissioning tests and procedures.

4.6 General conclusions

As well as the particular conclusions regarding the London and West Midlands blackout incidents there are a number of other observations that can be drawn from the investigation that are of a more generic nature. These are summarised here:

1. Human error, related to the delivery of new protection systems, was responsible for both the London and West Midlands Blackout incidents

2. With one noted exception, related to new types of protection equipment, NGC has a sound set of defined practices and procedures laid down for the delivery of protection schemes for use on its transmission network, which cover their design, design approval, procurement, manufacture, setting and installation/integration.

3. The exception, in the opinion of the Consultants, is where multi-function numerical relays are deployed, such as the type involved in the West Midlands incident, where there is the lack of a formalised procedure for verifying that such protection schemes will not interfere with the required loadability of transmission circuits and plant through the inadvertent enabling of unwanted protection elements. Whilst NGC's existing procedures are in line with typical international practice, they tend to dwell on proving that the protection will behave as intended by the scheme Design Engineers and the Settings Engineers. It is the Consultants' experience, that there is growing international recognition that more general procedures will be required to determine that protection systems are fit for service, due to the increasing incidents related to multi-functional numerical protection relays and with the devolution of many activities by TNO's to Contractors. ✂

4. NGC has laid down suitable guidelines and procedures for the assessment and authorisation of its own staff and for Contractor's staff who might be involved with the delivery of protection schemes for use on its transmission network. This stemmed from a recognition by NGC, in a presentation to major suppliers on 6 December 2002, that the number of protection incidents arising from deficient commissioning practice had risen to an unacceptable level.

5. In common with other Transmission Network Operators world-wide, multi-function numerical relays are proving to be a new source of human error ✂.

6. From the evidence gathered and made available, it appears there were collective commissioning management failings of both NGC and the Contractor, as members of the Commissioning Panels chaired by NGC, to ensure that NGC's established practices and procedures were fully adhered to during the delivery of the new protection schemes for the New Cross 2 Feeder at Wimbledon in 2001 and for the SGT8 132 kV protection at Hams Hall in 2003. Both the Contractors and NGC appear to have made mistakes in the delivery of the schemes and the fact that NGC practices and procedures do not appear to have been rigidly enforced, contributed to certain errors passing unnoticed until they resulted in incorrect protection operations during increased loading of circuits, following emergency switching operations with the transmission networks under planned outage conditions.

7. ✂

8. ✂

9. From NGC's protection performance statistics, which are attached as APPENDIX B of Vol.2, it was noted that there had been a significant decline in the protection security index in the financial year 2002/2003. The Consultants' review of NGC's

submitted incident reports confirmed that all the incidents had been rooted in protection settings errors.

10. The Consultants' review of all NGC's submitted protection incident reports related to losses of supply for the last 10 years has highlighted that all the incidents were as the result of human error concerning the determination or application of protection settings or during protection testing. Most errors had occurred while the transmission system was already under planned outage conditions, due to maintenance / extension / refurbishment work.

11. After reviewing NGC's submitted summary of reported Back-Up protection operations for the last 10 years, where only 9 out of the total of 38 operations resulted in losses of supply, the consultants noted that 7 of the incorrect operations had been for Overcurrent or earth-fault protection and 5 were due to incorrect protection settings.

12. The Consultants have commented on NGC's stated reasons for the application of Back-Up protection and on the reasons offered for its application in a 1988 CEGB report. NGC has reported that the application of such protection was reviewed in 1998 and again in 2002. On both occasions NGC did not identify any policy changes as being necessary, although the Consultants had noted that NGC rules for setting distance Zone-3 back-up protection were changed in 2002. The Consultants concur with NGC that the application of the particular protection functions that incorrectly operated at Wimbledon and Hams Hall was justified.

13. NGC now places great emphasis on outsourcing, through its new contract strategy and service agreements with suppliers. As with all organisations associated with the UK Electricity supply industry, NGC admits that it is becoming increasingly difficult to recruit and retain graduate engineers. NGC reports that for power engineering, in particular, it has seen a reduction in the number of universities and academic institutions that have power engineering as a mainstream course. It has taken a number of initiatives to ensure that it is able to consistently recruit the number of graduates that are needed to support its programmes across its business. To date, NGC states that it has been successful, but this has required a whole series of initiatives and the formation of strong relationships with universities. NGC states that it is an issue that needs to be closely monitored because power engineering has become less fashionable than perhaps it was a few years ago. ✂

5. TRANSMISSION OUTAGES AND RISK MANAGEMENT

The loss of supply incidents in South London and the West Midlands in each case occurred essentially as a result of a protection maloperation that caused supplies to be disconnected to a large area, affecting almost 700,000 customers in total, including major transport systems, industrial plants, civil amenities and town centres.

However, in both incidents the transmission system was operating at the time under planned outage conditions to enable scheduled maintenance or construction work to be carried out.

In this section the report considers whether the incidents amounted to a breach of system security and whether the outages were a significant factor in either causing the problem or escalating its severity. The approach taken by NGC for the programming of transmission outages and the level of co-ordination achieved with the DNO's is reviewed. The systems that NGC and the DNO's follow in setting up and managing the planning and implementation of the transmission outages are also identified and evaluated in this section of the report.

Finally a brief appraisal is given of the communications strategies adopted by NGC and the DNO's to inform stakeholders of potential risks associated with system operation when transmission outages are being planned.

5.1 Approach to planning of system outages

NGC and the DNO's are constrained by the annual load profile as to when they can programme outages on their respective transmission and distribution systems. In the United Kingdom, the overall system demand is traditionally low in summer and high in winter, although in large commercial areas, such as the City of London, where there is a concentration of electricity demand from high-rise office blocks with electrically driven air conditioning plant, the peak demand in summer can approach that in winter.

Annual daily maximum load profiles for the demand at Wimbledon, Hurst, New Cross and the South London ring are presented in Appendix E. They show that with the exception of the Christmas period, demand is at it lowest from May through to September, which creates a window of opportunity for the transmission or distribution company to schedule planned maintenance in this period.

In scheduling outages in a limited period, NGC and the DNO's endeavour to programme maintenance work such that outages can be bundled together, where it is feasible and will not place the system at risk. This will reduce downtimes and in the long run prove a cost effective solution to system maintenance. This is particularly the case in South London, where there are a number of mesh substations with multiple items of equipment connected to each mesh corner, so that when a mesh corner is taken out of service for scheduled maintenance[18], the associated transformers, reactors, switchgear and other equipment connected to the mesh corner can be included in the work.

NGC follows an established process in planning outages for construction and maintenance work. The process is based on a sound analytical exercise that is undertaken to demonstrate that the transmission system will operate satisfactorily during the outage period for the range of credible contingencies as defined in the operational planning standards that are now incorporated into NGC's Security and Quality of Supply Standard (SQSS).

NGC commence the planning exercise for each individual outage well in advance of when the outage is required. The planning is an interactive exercise involving the respective DNO and although in the early stages the communications between NGC and the DNO are regular, if not on a continuous basis, the contacts and information exchange between NGC and the DNO is gradually stepped up over the twelve month period leading up to the scheduled outage. In the last quarter before the outage is scheduled to proceed, contact is maintained on a weekly and sometimes daily basis as the outage date gets closer. This allows the parties to re-schedule outage dates if certain works are required to overrun and impact on the proposed programme, as was the case in South London when two 275 kV circuit outages were forced to overlap.

The communication channels established between NGC and the DNO's enable NGC to keep the DNO's informed of planned outages well in advance and this includes the identification of any risk to supplies. The DNO should then be able to take the necessary action to manage the risk to its distribution system or else request NGC to adjust the timing of planned works.

The approach followed by NGC in planning system outages is well established, takes account of practical issues, incorporates power system analysis to predict system performance under credible contingencies, involves the DNO's in the planning process on an interactive basis well in advance and provides direct communication facilities to assist the distribution company in its management of risk.

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5.2 General process for the planning of transmission outages

The principle requirement of outage planning is to ensure that whilst equipment is out of service for planned maintenance work the transmission system will continue to operate safely and securely, and within defined technical performance limits as set down in both planning and operational standards.

NGC plans and operates the transmission system in accordance with its own Security and Quality of Supply Standard (SQSS). This Standard forms part of NGC's licence conditions

[18] NGT Engineering Services Planning (Current Year) use a Work Management System (MIMS), which provides times for maintenance packages specific to individual items and types of equipment. Reasonably NGT has stated that there is no standard time for work on a mesh corner outage, as the outage duration depends on what equipment is being maintained.

and has the approval of Ofgem, the industry regulator. Table 4.1 of the Standard identifies the minimum planning supply capacity on the system for a first and second outage contingency for a range of group demands. The requirements are identical to Classes C to E as set out in Engineering Recommendation P2/5, that establish the Security of Supply requirements that the DNO's are required to meet.

The SQSS requires NGC to ensure that the transmission system, will satisfy a number of basic conditions. In particular, irrespective of whether it is operating as a fully intact system or with an outage condition, the system must continue to operate under any one of a range of credible worst case unplanned outages, without causing the system to suffer:

- loss of supply (above pre-defined power levels);
- unacceptable overloading of transmission equipment;
- unacceptable voltage conditions; or
- system instability.

For wholly cabled circuits, like those between Hurst and Wimbledon, the system has to be secured against the credible loss of a single cabled circuit. Other credible loss cases include a single circuit overhead line or a double circuit overhead line (when both circuits are strung on the same tower), the loss of a mesh corner or a supergrid transformer.

To ensure that the SQSS is satisfied under outage conditions a comprehensive process is followed prior to the release of a circuit for maintenance work.

NGC planning engineers assess from a system security viewpoint the viability of all transmission outages using well established procedures. As part of the transmission outage planning process network analysis studies are undertaken using a suite of network analysis tools. These tools are used to model the transmission system and its electrical characteristics including network topology, assumed generation disposition and despatch, connections to the distribution network and the response of the electrical equipment. From this analysis the information on system behaviour is obtained for the range of credible operating conditions in accordance with the requirements set out in the SQSS, including those when a forced outage occurs whilst planned outages are in progress. All outages are assessed against expected demands and line loading and checked that they are fully compliant with the SQSS.

Detailed planning of transmission outages begins at the year ahead stage, when the initial assessment of outages takes place. At this stage NGC's outage planning database (TOPAM) is populated. TOPAM contains all pertinent information on transmission outages (times, dates, work involved & emergency restoration times).

Then in week 39 of the year ahead stage all NGC customers receive a copy of the TOPAM print out detailing transmission outages that are to affect them in the following year.

During the year NGC maintains regular liaison with the DNO's and any large private customer connected directly to its transmission system regarding transmission outages that will affect them. The timescales vary, reflecting the historic requests of customers, but during the current year phase of the planning process customers will receive hard copies of the TOPAM database on the following basis:

- Every week covering outage planning for the next 12 to 16 weeks.
- Every day covering any changes to the plan made by NGC.

In addition to this information NGC holds regular liaison and update meetings with the DNO's to discuss the transmission outage plan in detail. These are held monthly in the case of EDF Energy, Aquila and EME.

During the planning process regular telephone and email contact takes place to agree detailed arrangements for changes to transmission outages.

Within the current year timescales[19] at the 13 week ahead stage, NGC starts looking in detail at the transmission outage plan for a particular week. The plan is continually being optimised by trained, authorised and experienced engineers using NGT's power system analysis package.

Any issues with the planned outages, such as arrangements with customers and NGC field staff, expected demands, running arrangement diagrams for substations or any other information that the control staff should be aware of is detailed in a set of operational notes to the ENCC which are submitted on a weekly basis and updated via a bulletin that is issued every working day to system control staff.

5.3 Generic planning and operational guidance for planned outages

Guidance on planning outages in specific areas of the NGC system is available to NGC planning and control engineers in a number of formats:

- A Transmission Planning and Information Database (TPID)
- Historic operational notes and running arrangements
- A generic 'archive of experience' which covers all NGC substations and gives general guidance on planning and control issues.

The generic planning guidance for Hams Hall and South London has been extracted from NGC internal procedures and is attached in Appendix F.

[19] Within one year of the scheduled outage period.

5.4 Bundling of work and transmission outages

NGC undertakes the majority of its outages during the summer months, when there is expected to be a larger margin between transmission capacity and expected demand. The work undertaken during these outages covers maintenance, construction (in order to carry out system reinforcement or asset replacement) and defect rectification. Failure to undertake this type of work can result in plant failure.

NGC mitigates the risk of plant failure by ensuring that work is undertaken in a timely fashion. However, the bundling of work sometimes occurs within some outages in order to minimise any future discrete outage requirements. This bundling of work improves system availability by optimising the time that circuits are out of service.

On occasions, as was the case in the London incident, the overlap of transmission outages in the same geographical area becomes necessary, possibly as a result of factors that are outside of NGC's control. However, all outages are assessed by NGC against the SQSS and taken only with the agreement of the affected customer. As part of the planning process, consideration is given to the Emergency Return To Service (ERTS) time of outages in similar geographic areas to ensure that simultaneous outages are not all subject to long ERTS times.

In the specific case of South London both the original placements and the final placements for the outages were fully assessed against the expected demands and line loadings and according to NGC were fully compliant with the SQSS and this appears, indeed, to be the case. From our discussions with NGT and EDFE we are satisfied that the distribution network operator was fully informed of the position regarding the overlap and agreed the outage placement dates.

5.5 Risk management

Overlapping outages. At the year ahead stage the outages on the Wimbledon - New Cross No. 1 circuit and the Littlebrook - Hurst No. 2 circuit[20] were planned to run consecutively. However, due to the volume of work planned on these circuits it was always a possibility that the first outage would overrun and that for a period both circuits would be out of service at the same time. PB Power is satisfied that there were no economic factors involved in the overlap of these outages; the work was planned to take place when resource was available, work plans were in place and system conditions were acceptable.

NGC state that the possibility that these circuit outages could overlap was actively studied against the SQSS from June 2003 onwards and that at no time were any additional risks identified with the above outage combination.

Compliance with the Security Standards. The first stage, in assessing the need for risk mitigation measures to ensure that system performance will not be seriously affected by

[20]The outage of the Wimbledon - Beddington No. 1 circuit was also included in this group and according to NGT also originally programmed as a consecutive outage.

faults that may occur during a planned outage, is to confirm that outages are compliant with the SQSS. In both the South London and West Midlands incidents the planned outages were assessed to be compliant with the SQSS.

Security of supply with mesh substations. The effects of circuit outages on overall network availability and reliability are a particular characteristic of mesh substation arrangements. As can be seen from Figure 3.1, with the arrangements adopted in South London, the planned outage of a mesh corner will result in a number of items of plant being unavailable for service. This same issuearises when it is necessary to temporarily open a mesh corner to allow equipment to be taken out of service, as was the case with SGT3 at Hurst.

Issues relating to the complexity of operation, and hence associated increased risk were identified in 1989 in two documents produced by NGC's forerunner, the CEGB National Grid Division (NGD)[21]. These two documents stated that

"Now that we have reliable and compact gas-insulated substation designs at our disposal, it will be operationally advantageous to replace several mesh substation designs by their double busbar[22] equivalents particularly in the London area."

NGC has advised PB Power during the course of the investigation that it had undertaken a review of network complexity in 1996 and concluded that there was no economic justification for the large scale investment that would be required to move from a mesh design to a double busbar design in order to reduce complexity. However, when considering system modifications and asset replacement works it is our understanding that NGC does consider the potential for increasing flexibility at these sites. Whilst this may be so, the complexity and inflexibility associated with switching operations and arranged outages on the mesh substations at Wimbledon, New Cross and Hurst was, like the overlapping outages, a contributory factor in initiating the chain of events that led to the loss of supply in South London.

ERTS strategy. Other risk mitigation measures considered by NGC included the adoption of an Emergency Return To Service (ERTS) strategy consistent with NGC's policy for the application of ERTS as outlined in NGC's Operational Procedure DP883 – "Application of Security and Quality of Supply Standard in Operational Timescales".

A summary of the ERTS strategy that was applicable with the two incidents is given below:

> ***South London.*** The ERTS time for the Wimbledon MC1 outages was 6 weeks (day and night) working, and the ERTS time for the Littlebrook – Hurst outage was 36 hours (day and night). As both of these outages had been assessed as being fully compliant with the SQSS these ERTS times did not give NGC any additional

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[21] Asset Replacement Strategy of the National Grid Company, 20 July 1989, and also Asset Lives and Capital Investment Programme, NGCAB 22, 27 July 1989.

[22] It should be noted that traditional double busbar substations generally require only one switching operation to isolate an item of plant, with other items of plant being unaffected, compared with a mesh substation which requires a number of switching operations before an item of plant can be isolated.

concern. The ERTS times were discussed and agreed with EDF Energy during regular liaison meetings.

Hams Hall (West Midlands). Both supergrid transformers SGT1 and SGT2 were scheduled for asset replacement and were in the process of being decommissioned to allow new higher capacity SGTs to be installed. As such, Emergency Restoration Times were not applicable for these outages. However, the outage plan for Hams Hall had been assessed as being fully compliant with the SQSS and the decommissioning of these transformers did not give NGC any cause for concern. Other ERTS times were discussed and agreed with Aquila and EME at regular liaison meetings.

Summarising, the outages in South London and at Hams Hall were both considered against NGC's SQSS and P2/5 and agreed with the affected DNOs. No security standard violations were identified and therefore none of the affected sites were planned to be operating at an unacceptable risk during the outage programme.

Manning of substations. NGC does have a policy for manning substations at times of increased system risk, for example during adverse weather conditions. However, since there was no indication of an increased risk and the weather was fine and because much of the South London network is underground anyway (and therefore hardly affected by adverse weather) NGC did not consider it necessary to man the South London substations.

Enhanced ratings and load transfers. Due to high air conditioning loads the summer loading at some sites in Central London (an area that is partly supplied from New Cross) can be similar to the winter peak loading. Consequently, there can be reduced windows of opportunity to take transformer outages in this area during the summer outage season. This restriction is not exclusive to mesh corner outages, but can affect any site with a large air conditioning load. To facilitate transformer maintenance at places with high summer loadings, measures are taken to acquire enhanced ratings on the remaining supergrid transformers and to arrange load transfers away from the site to ensure security of supply is maintained. NGC say that it is also not uncommon for short duration work to take place at the weekend or overnight when the demand is lower.

NGC has indicated that the capability to secure demand post-fault during outage periods was adequate at Hurst, Wimbledon MC3 and on the South London Ring, which comprises Chessington SGT2 and SGT4B, Beddington SGT1A and SGT2A and Wimbledon SGT1B and SGT3B. However, the demand profile at New Cross is higher than the SGT capability available post-fault during an SGT outage. NGC state that enhanced ratings are acquired on the remaining transformers and load transfers agreed with the DNO to ensure that there is sufficient capacity to secure demand at New Cross post-fault.

A detailed summary of the planning history of Wimbledon MC1 and Hurst – Littlebrook 2 outages is presented in Appendix G.

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5.6 Conclusions

The evidence provided by NGC in response to a range of questions on the procedures followed in planning the outages in South London and at Hams Hall in the West Midlands has been reviewed and compared with corresponding evidence provided by the DNO's, i.e. EDF Energy, Aquila and East Midlands Electricity.

As a result we can state that:

a) NGC's outage planning process follows a rigorous procedure designed to ensure that the outage will not place the transmission system at risk with respect to the requirements laid down in the Security and Quality of Supply Standards.

b) The outage planning process is commenced well in advance of the scheduled outage period and encourages the interactive involvement of the local DNO(s) to ensure that the DNO is fully aware of the outage plans and of any particular risk to the security of supply.

c) The communication routes between NGC and the respective DNO's for outage planning are well established and were followed throughout the outage planning process for the South London and Hams Hall outages.

d) Notification of the overlap of outages in South London was conveyed by NGC to EDF Energy as part of the normal passage of information between the two parties. The overlap, however, did not place the NGC system at any undue risk of supply failure as set down in the Security and Quality of Supply Standards.

e) At Hams Hall, the supergrid transformer outages were not a significant factor in the loss of supply incident since the supply to the 132 kV busbars was secure even after the loss of the transformer SGT6.

f) Whilst the outages in South London and at Hams Hall did mean that the system was operating under planned outage conditions, there was sufficient capacity available to supply the load on a secure basis according to the guidelines laid down in the Security and Quality of Supply Standards.

Overall, our review of security of supply confirms that NGC was in both cases compliant with the security requirements as laid down in the Security and Quality of Supply Standards and as such was not in breach of its transmission licence in this respect. ✂

6. COMMUNICATIONS DURING AND AFTER THE INCIDENT

6.1 NGC COMMUNICATIONS

The NGC response to questions posed by PB Power on communications issues during and after the London and West Midlands incidents is summarised below.

6.1.1 Incident response plans

Operational. The Electricity National Control Centre (ENCC) at Wokingham is used to provide the first line of response to major incidents such as losses of supply. The prime function of the ENCC is to manage the power system and to implement actions to restore supplies. The ENCC is also responsible for mobilising staff and contingency plans together with initiating the communications process.

The ENCC is supported on a 24-hour basis by the Duty Officer Rota, which comprises senior Operations and Trading personnel and the Duty Rota for the UK Communications team. In addition Senior Managers in National Grid Transco (NGT) are contactable on a continuous basis.

NGC have in force Transmission Procedure TP 118 "System Event Response" and Business Procedure BP1504 "System Incident Network" that set out the response mechanism for major incidents and for the establishment and operation of a System Incident Centre. Copies of these procedures have been provided to the Consultants for this investigation.

Non-operational. NGT, NGC's parent company, maintains a continuous, 24-hour press response team. In the case of the London incident, initial enquiries from the media were to the out-of-hours duty press-officer. In the case of the West Midlands incident, these were dealt with by the office press team, since the supply failure occurred within normal working hours.

6.1.2 London incident

Operational. NGC state that for the London incident the ENCC at Wokingham directed all operational communications with EDF Energy (the affected DNO) and also dealt with Police enquiries from a senior level plus a limited number of public and media enquiries. These telephone-based communications were automatically recorded and NGC has provided a transcript that details the calling parties, the time of the call and a précis of the message.

In addition, contact with the DTI and Ofgem was established at senior level at an early stage during the incident and NGC has provided details of the calling parties and the date and time of the calls.

The reports issued by NGC and EDFE on the London incident appear to indicate that in the main, good communications was maintained between their respective control rooms throughout the incident.

It is acknowledged by NGC that part of the EDFE distribution system was inadvertently energised when S30 circuit breaker at Hurst was closed to energise supergrid SGT4 at an early stage in the restoration process. However, the incident occurred because ENCC did not check the status of its own 132 kV circuit breaker at Hurst that controlled the interface between NGC and EDFE.

This incident should not therefore be interpreted as a communications failure between NGC and EDFE since there was no intention to energise the EDFE system and as such the switching operations should have had no impact on EDFE's system.

Evidence has also been supplied to confirm that ENCC established full communication with EDFE Control during the initial incident and at all stages of the restoration process, prior to the re-energising and subsequent loading of SGT's to return supplies to all EDFE customers.

Non-operational. NGT has confirmed that communications originated from its headquarters in Warwick and that this was beneficial on the evening of Thursday 28 August as it only took 30 minutes to mobilise the press team in the office for an incident that happened outside normal working hours. A team of seven was assembled by 19:30 hours and, prior to that, calls were being handled by the duty press-officer and several colleagues who co-ordinated a response by telephone. The London incident was classified as a "serious incident" and the crisis communications procedure was invoked.

The number of calls to NGT on Thursday 28 August was around 300 and these were handled by the emergency press team. As part of the crisis arrangements, the Chief Operating Officer was called in to provide a senior level spokesperson. A series of interviews was completed on the evening and the following morning. After this further interviews were arranged with the CEO for Transmission through broadcast studios in Millbank, London. A media teleconference was set up for all national correspondents, at 15:00 hours on Friday 29 August. During the course of the London incident two media statements were issued in addition to the verbal responses given to journalists, one on the Thursday evening and another on Friday morning which went into more detail on the sequence of events. The NGT press team was also in contact with DTI and Ofgem on the Thursday evening. In a wider communications exercise during the following day, in addition to briefing the media, NGT contacted the DTI, Ofgem, Energywatch and the affected distribution companies. A record of contacts made has been provided by NGT.

NGT consider that a crucial factor in communications during the incident was that, although it was able to restore supplies to its network within 40 minutes, the various services to the public returned to normal in different timescales and in different ways. For example, after re-configuring the distribution network EDF Energy was able to restore supplies to some of its customers before supplies were restored by NGC. However other customers could not be restored until NGC was able to restore supplies to its network. ✂

NGT worked in conjunction with the press offices of EDF Energy throughout the incident. While NGT was able to confirm the problems on the transmission system, it understandably considers that the impact of the incidents upon consumers was better explained by the DNOs as they had their own specific customer information. NGT also considers that the prime route for communications with the public is through the normal channels of the providers of these services, such as the customer call centre of EDF Energy ✂. NGT understandably considers this appropriate, as only these service providers could let the public know how the incident had affected their own operations.

NGT has confirmed that stakeholder communication with Energywatch, DTI and others was mainly from its London office. The prime focus for media contact moved from Warwick to the London Group HQ during the course of the morning of Friday 29 August onwards. This was because broadcast interviews were organised with senior executives at Millbank TV studios from Friday lunchtime. A press teleconference for print media was organised at 15:00 hours on Friday with the London-based senior executives. A final radio interview on the BBC’s Radio 4 Today programme was given on Saturday morning, 30 August.

NGT has pointed out that in the case of the London incident, where supplies were restored in a relatively short time, a System Incident Centre was not set up and that it moved rapidly into the post-event non-operational communications phase.

6.1.3 West Midlands incident

Operational. NGT state that for the West Midlands incident the ENCC at Wokingham directed all operational communications with Aquila and East Midlands Electricity (the affected DNOs) and also received one enquiry from a Distribution Network customer. These telephone based communications were automatically recorded and NGT has provided a transcript that details the calling parties, the time of the call and a précis of the message.

In addition, contact with DTI and Ofgem was established at a senior level at an early stage during the incident and NGT has provided details of the calling parties and the date and time of the call.

Non-operational. Throughout the incident NGT worked in conjunction with the press offices of Aquila and EME. While NGT confirmed the problems on the transmission system, NGT considered that the impact of the incident upon consumers was better explained by the DNOs as they had their own specific customer information.

The West Midlands incident occurred during normal office hours and the press team was therefore already on hand and they confirmed to the media that a problem had occurred on the NGC system at 10:10 hours. Three media statements were issued over the course of the incident. The second confirmed more detail and the third summarised the incident soon after restoration was complete. Media interest in this incident was only regional and lasted for an hour or so after power was restored.

NGT point out that in the case of the West Midlands incident, where supplies were restored in a relatively short time, a System Incident Centre was not set up and NGT moved rapidly into the post-event non-operational communications phase.

6.1.4 Summary and conclusions

1. NGC and NGT have formal procedures in place to deal with Operational and Non-Operational Communications for major incidents that occur during normal office hours and for those that occur during out-of-office hours. These procedures are considered to be in accordance with Good Industry Practice.

2. The procedures in (1) were invoked during the two incidents and we are satisfied that there was no delay in the dissemination of information to key stakeholders and to the general public.

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7. CONCLUSIONS AND RECOMMENDATIONS

For ease of presentation and discussion, this section is structured such that the London incident is considered first, then the West Midlands incident and then some general observations are given in relation to protection issues that were ultimately to blame for the supply failures. This section also includes comment on the investigation reporting and finally itemises a list of remedial measures that NGC is implementing since the incidents, as a result of its own investigations, to minimise the risk that similar events will occur in future. The conclusions presented in this section of the report also summarise the more detailed conclusions presented earlier in this volume and also in Volume 2 which specifically focuses on protection-related issues.

7.1 The London incident

The main conclusions reached as a result of our investigation into the loss of supply incident that affected large parts of south London on 28 August 2003 are summarised below:

a) The loss of supply occurred because of the operation of incorrectly applied System Back-Up Overcurrent protection associated with the 275 kV Wimbledon – New Cross No. 2 circuit. This circuit had been left as the sole source of supply to the demand on NGC's New Cross and Hurst 275 kV grid stations, following the opening of mesh corner 3 at Hurst to investigate a potentially serious problem that had set off a Buchholz gas alarm associated with an item of equipment that was connected to that mesh corner. The opening of mesh corner 3 also opened, albeit on a temporary basis, the Littlebrook – Hurst No. 1 circuit which had with the Wimbledon – New Cross No. 2 circuit supported the load supplied from New Cross and Hurst substations.

b) The System Back-Up protection operation occurred because of a latent defect that had not been revealed during the commissioning processes that had been applied, following refurbishment of the protection, in 2001.

c) The System Back-Up protection was defective in that an overcurrent relay with a 1 Amp secondary current rating had been substituted just prior to commissioning in May 2001, when a relay of 5 Amp rating was actually required.

d) The incorrectly rated relay operated when the current through the remaining 275 kV transmission circuit that supplied Hurst and New Cross grid stations increased suddenly when the Littlebrook – Hurst No. 1 circuit was opened. Although the resultant current of 1460 amps was well within the circuit's rating and below the intended protection setting of 5,100 Amps, it was above the actual protection setting of 1,020 Amps, due to the use of the incorrectly rated relay. As a consequence, the Wimbledon – New Cross No. 2 circuit was tripped with the result that over 700 MW of load was disconnected across South London, interrupting supplies to 476,000 customers, including some major customers such as London Underground and Network Rail.

e) Although the loss of supply was severe and much greater than any that had been experienced in recent years, the supply failure did not occur as a result of a failure by National Grid Company to meet its obligations with respect to system security as set down in its Transmission Licence through the Security and Quality of Supply Standard. Whilst there were two major outages in place to allow planned maintenance work to proceed on the NGC system in the South London area , with two of the four 275 kV circuits that normally supply Hurst and New Cross substations out of service, the network was still compliant with the operational security standard. Initially the outage programme had been planned for the two outages to run consecutively, but circumstances outside NGC's control caused the outages to overlap. Indeed it is not uncommon for such planned outages to overlap without any problems being experienced on the system.

f) The investigation found that the process followed by NGC in planning the South London outages was based on sound practice and involved EDF Energy at all stages and that good communications were maintained throughout the outage planning process.

g) The loss of supply occurred when the current through the Wimbledon – New Cross No.2 circuit increased suddenly when the circuit was left to supply the full demand on two South London grid stations. Had circumstances not prevailed to leave this circuit as the sole source of supply into South London then the protection problem may have lain dormant without causing a loss of supply, at least until the next scheduled routine testing of the protection systems for the feeder,. On the other hand whilst the system was operating with the overlapping outages in place, any fault on the Littlebrook – Hurst No. 1 circuit, or equipment connected to mesh corner 3 at Hurst, or even a requirement to disconnect plant from that mesh corner would have left Hurst and New Cross totally dependent on the Wimbledon – New Cross No. 2 circuit and this could equally have caused a supply failure across South London, although the severity of its impact on the area would depend on the load and the time the supply failure occurred.

h) With regard to the actual incident itself, it is clear now that the incident was triggered when the Buchholz gas alarm from shunt reactor SR3 at Hurst was interpreted by the control engineer(s) at NGC's Electricity National Control Centre (ENCC) as relating to a grouped alarm associated with either the supergrid transformer SGT3 at Hurst or its associated shunt reactor, SR3. . NGC has acknowledged that the mistaken interpretation occurred because the message received at the ENCC control desk was ambiguous. NGC has taken action since the incident to address this problem and review the whole question of alarm ambiguities. Having mistakenly identified SGT3 as the likely source of the alarm, ENCC then followed procedure to unload the transformer and opened mesh corner 3 at Hurst for this purpose and in doing so caused the Wimbledon – New Cross circuit to trip resulting in the widespread loss of supply across South London.

i) The reactor SR3 at Hurst that alarmed was, in fact, out of service at the time, and had been since earlier that day as part of the normal voltage control process that NGC follow daily. It is likely therefore that had the control engineer correctly identified that SR3 was the cause of the alarm and noted that the reactor was out of service at the time he would not have taken action to open mesh corner 3.

j) It is known that NGC had operated the Hurst SR3 reactor with an oil leak since March 2003 and had decided to manage the situation by topping up the reactor with oil on at 3-monthly intervals. ✂

k) NGC was able to restore supplies to all EDF Energy substations within 37 minutes of the loss of supply. The supply interruption was therefore much less dramatic and severe than those experienced recently in the USA and in Europe. Given the complexity of the transmission system in south London it can be argued that ENCC performed its duties ably in restoring supplies within such a short period of time. However, the investigation did identify an error during the restoration process that could have had more serious consequences. NGC have acknowledged that at an early stage in the process the ENCC failed to check the status of the 132 kV circuit breaker at Hurst on the LV side of SGT4 which controls the interface with EDFE. The circuit breaker should have been in an open position when NGC energised SGT4 at the start of the restoration process. In fact the circuit breaker was left closed and when SGT4 was energised the action inadvertently energised the EDFE system at Bromley and Eltham and also “back-energised” NGC’s own system between Hurst and New Cross and also through to the open disconnector at the Wimbledon end of the Wimbledon – New Cross No. 2 circuit. In the event, protection associated with the supergrid transformers operated almost instantaneously (for as yet undetermined reasons, though most probably due to the nature of the inrush currents drawn by the transformers, when subject to abnormally high voltage) to disconnect the “back-energised” part of NGC’s network, thereby limiting the exposure of NGC’s equipment to the consequences of the “back-energisation” and any associated adverse effects, e.g. overvoltages and over-fluxing of transformer cores.

l) The investigation found that on the evidence provided by the companies, the communications procedures adopted by NGC ✂ both during and in the immediate post-incident period were in accordance with good industry practice.

m) There appears to have been a collective commissioning management failing of both NGC and the Contractor, as members of the Commissioning Panel, chaired by NGC, to ensure that the Back-Up protection was commissioned according to NGC’s established standard procedures, supported by dated documentary evidence of the required service settings having been tested and of the tests having been witnessed, as planned..

n) The investigation of the protection commissioning issues that arose as part of the investigation into the London incident are covered in more detail in Volume 2, however, it should be noted here that NGC has undertaken its own investigation into the protection issues and produced its own report identifying remedial actions needed to prevent similar problems occurring again in the future.

o) ✂

With specific regard to the incorrect operation of the protection equipment on the Wimbledon – New Cross No. 2 circuit this may be attributed to a combination of events, namely;

- The erroneous substitution of an over-current relay of incorrect rating just prior to commissioning, for reasons unknown.
- An apparent, collective commissioning management failing, of both NGC and the Contractor, as members of the Commissioning Panel, chaired by NGC, to have the relay commissioned according to NGC's prescribed standard procedures, with its service settings being applied and with reference to the MARS sheet.
- The decision by NGC not to have the tests witnessed, as had originally been planned.

It is highly likely that the erroneous relay substitution would have been detected had the established NGC procedures been fully applied.

Finally had the circumstances of the 28 August 2003 not occurred, it is possible that the latent protection system defect would have continued to lie dormant in the network, at least until the protection was subjected to its next periodic maintenance testing.

7.2 The West Midlands incident

The investigation into the loss of supply incident in the West Midlands on 5 September has shown that outage planning was not an issue, neither was security of supply. The investigation has confirmed that the incident was related to errors made in determining settings for a multi-function protection relay for a new transformer at Hams Hall and failures in the applied protection commissioning procedures, which resulted in the errors not having been detected. The inappropriate design of the protection scheme, based on a multi-function protection relay, was a contributory factor. The incident was triggered by the need to address a serious secondary system fault associated with another transformer, which had been re-commissioned some hours earlier after some weeks of substation modification work. The problem with this transformer stemmed from an error made during the installation of a new Substation Control System. The defective protection system ultimately caused the shutdown of the 132 kV substation and the interruption of supplies to Aquila and East Midlands Electricity, the DNO's that take supplies from Hams Hall 132 kV substation.

The West Midlands incident began when NGC site engineers discovered a problem with the secondary system wiring for SGT6 transformer that had been re-commissioned the previous day. The problem was a potential fire hazard associated with an open circuit of the 132 kV CT wiring in the 400 kV relay room. There was sufficient transformer capacity available to allow SGT6 to be unloaded to tackle the problem, without requiring another supergrid transformer to be energised first. As a precaution, the Emergency Return to Service was requested for two old transformers (SGT1 and SGT2), for which decommissioning work was just about to commence. There were no other transformers immediately available for service. When SGT6 was taken out of service its load was transferred to SGT 8 and SGT3 transformers. At this point the 132 kV "interlocked overcurrent" protection scheme for SGT8 incorrectly operated to trip the transformer which then transferred all the load on Hams Hall, which was in excess of 300 MW to SGT3, the remaining transformer which was only rated at 120 MVA. The SGT3 132 kV circuit breaker was then naturally tripped by Stage-1 overcurrent protection, due to the severe overloading, to effectively disconnect Hams Hall from the NGC transmission system. The loss of supply affected 143,000 Aquila customers and 58,000 EME customers (i.e. a total of 201,000 customers) with pre-incident demands of 213 MW and 88 MW respectively. The West Midlands incident began when NGC site engineers discovered a problem with the secondary system wiring on SGT6 transformer that had been re-commissioned the previous day. The problem was a potential fire hazard associated with an open circuit of the CT wiring in the 132 kV relay room. There was sufficient transformer capacity available to allow SGT6 to be removed from service without requiring another supergrid transformer to be energised first. However, when SGT6 was taken out of service its load was transferred to SGT 8 and SGT3 transformers. At this point the "interlocked overcurrent" protection [scheme] on SGT8 incorrectly operated to trip the transformer which transferred all the load on Hams Hall, which was in excess of 300 MW to SGT3, the remaining transformer which was only rated at 120 MVA. SGT3 then tripped to effectively disconnect Hams Hall from the NGC transmission system. The loss of supply affected 143,000 Aquila customers and 58,000 EME customers (i.e. a total of 201,000 customers) with pre-incident demands of 213 MW and 88 MW respectively

The high volume of complex work that is being undertaken in an operational substation, such as that which is taking place at Hams Hall, requires NGC and the Contractor's site staff alike to adhere strictly to procedures that are designed to minimise risk to the safety of personnel and equipment, to system integrity, and to security of supply. The failure to follow these procedures contributed significantly to the events that led to the loss of supply.

Detailed conclusions on the shortcomings of the protection commissioning process and the cause of the loss of supply are presented in Section 4 of this volume and in greater detail in Volume 2 of the report. However, the key conclusions are summarised below:

7.2.1 SGT6 secondary wiring problems

a) The open circuited CT wiring on SGT6, which precipitated the incident, resulted from a combination of factors related to the adequacy and currency of the master drawing used for installation work associated with the provision of a new Substation Control System.

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b) The marked-up, as-built wiring diagram for a general services cubicle did not show some redundant equipment and wiring that had been left over from some previous site modification work. ✂

7.2.2 Incorrect operation of SGT8 protection equipment

The incorrect trip of SGT8 which caused the loss of supply in the West Midlands resulted from a combination of factors related to protection commissioning, but also factors related to equipment design and the quality of work by the approved NGC Settings Engineer. Of particular concern is that:

a) The Contractor did not appear to have understood that only Interlocked Overcurrent protection was required for the 132 kV protection of SGT8. The Contractor had engineered and delivered a protection scheme, based on a multi-functional numerical relay, which provided unwanted, non-interlocked, System Back-Up, Overcurrent and Earth Fault protection as well as ILOC protection.

b) The NGT Commissioning Panel and the NGT approved Settings Engineer failed to identify the Contractor's confusion before commissioning took place, concerning their commitment to provide the specified ILOC protection and the inappropriate protection scheme design that they had supplied.

c) The approved NGC Settings Engineer failed to prescribe settings that would effectively prevent the unwanted, non-interlocked, overcurrent and earth fault protection functionality of the Contractor's scheme from interfering with system operation and normal system fault clearance.

   Through a mixture of default and prescribed settings for the non-interlocked protection, the relay was set up to trip with zero time delay if the SGT8 load went above 229 MVA or if it passed current to an external fault.

d) The commissioning test procedure used by the Contractor for the SGT8 132 kV ILOC protection was inadequate and there was no NGC approved Site Commissioning Test (SCT) procedure for the ILOC protection scheme that had been supplied.

e) A Commissioning Programme document, as required under Transmission Procedure TP106, does not appear to have been issued.

f) There was apparently a collective commissioning management failing of both NGC and the Contractor, as members of the Commissioning Panel, chaired by NGC, to ensure that the SGT8 ILOC protection scheme was commissioned according to NGC's established standard procedures, supported by the documentation required under NGC's Transmission Procedure TP106, for Equipment Commissioning and Decommissioning.

g) Even if appropriate ILOC test procedures had been applied, it is unlikely that the erroneous enabling of non-interlocked overcurrent protection by settings errors and its undue restriction on SGT8 loadability would have been highlighted. Only the blind application of a loadability test to the protection scheme would have confirmed that the transformer could be loaded up to its emergency rating without any protection element issuing an unwanted trip. Such testing is not yet widely applied by other TNO's worldwide, but some testing of this form is recommended by the Consultants for the future, when commissioning multi-function relays.

7.2.3 Communications

From the evidence presented it would appear that ✂ NGT ✂ handled the communications issues in accordance with "good industry practice" and made every effort to keep their stakeholders, and the general public well informed of the situation both during the incident and in the period following restoration of supply.

7.3 General observations on protection issues

As well as the particular conclusions regarding the London and West Midlands blackout incidents there are a number of other observations that can be drawn from the investigation that are of a more generic nature. These are detailed in section 4.6 of the report with the most significant summarised here:

1. Human error, related to the delivery of new protection systems, was responsible for both the South London and West Midlands blackout incidents.

2. With one possible noted exception, related to new types of protection equipment, NGC has a sound set of defined practices and procedures laid down for the delivery of protection schemes for use on its transmission network, which cover their design, design approval, procurement, manufacture, setting and installation/integration. NGT has also laid down suitable guidelines and procedures for the assessment and authorisation of its own staff and for Contractor's staff who might be involved with the delivery of protection schemes for use on its transmission network.

   The exception in the opinion of the Consultants, is where multi-function numerical relays are deployed, such as the type involved in the West Midlands incident, where there is the lack of a formalised procedure for verifying that such protection schemes will not interfere with the required loadability of transmission circuits and plant, through the inadvertent enabling of unwanted protection elements. Whilst NGC's existing procedures are in line with typical international practice, they tend to dwell on proving that the protection will behave as intended by the scheme Design Engineers and the Settings Engineers. It is the Consultants' experience, that there is growing international recognition that more general procedures will be required to determine that protection systems are fit for service, due to the increasing incidents related to multi-functional numerical protection relays and with the devolution of many activities by TNO's to Contractors. ✂

3. In common with other Transmission Network Operators world-wide, multi-function numerical relays are proving to be a new source of human error ✂.

4. From the evidence gathered and made available, it appears there were collective commissioning management failings of both NGC and the Contractors, as members of the Commissioning Panel, chaired by NGC, to ensure that NGC's established practices and procedures were fully adhered to during the delivery of the new

protection schemes for the New Cross 2 Feeder at Wimbledon in 2001 and for the SGT8 132 kV protection at Hams Hall in 2003. Both the Contractors and NGC appear to have made mistakes in the delivery of the schemes and the fact that NGC practices and procedures do not appear to have been rigidly enforced, contributed to certain errors passing unnoticed until they resulted in incorrect protection operations, during increased loading of circuits, following emergency switching operations, with the transmission networks under planned outage conditions.

5. ✂

6. ✂

7. From NGT's submitted protection performance statistics for the last 10 years, it was noted that there had been a significant decline in the protection security index in the financial year 2002/2003. A review of NGT's submitted incident reports confirmed that all the incidents had been rooted in protection settings errors. A review of NGC's submitted protection incident reports related to losses of supply for the last 10 years has highlighted that all the incidents were as the result of human error, concerning the determination or application of protection settings, or during protection testing and most errors had occurred while the transmission system was already under planned outage conditions, due for maintenance / extension / refurbishment work.

8. NGT now places great emphasis on outsourcing, through its new contract strategy and service agreements with suppliers. As with all organisations associated with the UK Electricity supply industry, NGC admits that it is becoming increasingly difficult to recruit and retain graduate engineers. NGC must ensure that it will have adequate internal human resources for the future- especially to interface with and to supervise the work of contractors. NGC reports that for power engineering, in particular, it has seen a reduction in the number of universities and academic institutions that have power engineering as a mainstream course. It has taken a number of initiatives to ensure that it is able to consistently recruit the number of graduates that are needed to support its programmes across its business. To date, NGC states that it has been successful, but this has required a whole series of initiatives and the formation of strong relationships with universities. NGC states that it is an issue that needs to be closely monitored because power engineering has become less fashionable than perhaps it was a few years ago. NGT verbally confirmed that it would be retaining its existing in-house training establishment and that its expansion into gas as well as electricity activities had strengthened the need for such a facility. ✂

7.4 Reporting issues

In response to the two loss of supply incidents, NGT, NGC's parent company, EDF Energy, Aquila and East Midlands Electricity, all produced their own investigation reports which were intended for both internal and external consumption. ✂

With regard to the reports issued by the four companies involved in the incident the NGT report is by far the more detailed, and justifiably so since the supply failures were on NGC's system. However, there were issues associated with the incident that, whilst not the direct cause of the loss of supply, came to light during our investigation and which had not been reported on in NGC's own report on the incident. In particular we refer to:

a) association of the Buchholz alarm (that started the sequence of events that eventually resulted in the loss of supply) with the Hurst SR3 reactor rather than SGT3 and the fact that NGC had been "managing" the oil leak for some time,

b) the ambiguity of the alarm message and the consequent misinterpretation by the ENCC control engineer,

c) the "back energisation" of NGC's system when Hurst SGT4 transformer was energised after ENCC omitted to check the status of its 132 kV circuit breaker that controlled the interface with EDFE at Hurst.

NGC has stated its view that each of these points were not in themselves the cause of the supply failure ✂. Furthermore NGC's has stated that its report on the incident which was produced within two weeks of the incident occurring was produced for a wide, generally non-technical audience, and that it therefore had to tailor the material it presented in the report to the audience. ✂ NGC has made significant efforts internally to investigate the two incidents and design and implement programmes to action a range of remedial measures covering a number of topics. These are listed under material presented in subsection 7.5.

7.5 Remedial action taken by NGC since the incidents

NGC has indicated in correspondence with PB Power following the issue of our draft report that since the London and West Midlands incidents occurred in August and September 2003 it has implemented a range of improvements and initiatives to minimise the risk of similar supply failures in the future.

NGT stated in its Investigation Report on the London incident that it was committed to a number of actions, which are repeated below:

1) NGC will work closely with other network operators to identify any improvements in co-ordination to enhance the overall security of electricity supplies, particularly to city centres and transport systems

2) NGC will work closely with EDF Energy, the Mayor, London Underground, Network Rail and other London emergency and public service agencies to establish improved and more responsive communications in the event of major loss of supply.

3) NGC is urgently surveying all installations as a further check on the integrity of the automatic protection equipment.

4) NGC will carry out a further comprehensive investigation examining all aspects of the management of the protection systems so as to eliminate, as far as

possible, the risk of incorrect installation or operation of automatic protection equipment.

5) NGC will work to review operational procedures, and control room systems, including alarm presentation, in close consultation with Ofgem, DTI and other associated parties, to ensure that there is the right balance between safety risks and supply security.

Appendix H of this Volume presents a copy of NGC's table identifying detailed actions to be taken arising from the (NGC) Investigation Report recommendations. The table addresses each of the five commitments listed above. It breaks down the various areas of improvements and initiatives into individual tasks. These would seem to cover a large scope of activities addressing key issues such as protection commissioning, security of supply, communications, alarm ambiguities, DNO interfaces, reliability of supply to key sites and risks of leaving plant in service.

NGC has stated that the responsibility for addressing each of the recommendations has been given to a senior manager within NGT, an arrangement put in place following the incidents. NGT say that having recognised that their reports on the two incidents were less detailed than their usual approach they included in the reports broad recommendations for further work then established workstreams to examine the two incidents. The workstreams are all said to be active at present and the personnel involved are individually responsible for implementing the lessons learnt in their respective areas.

This demonstrates NGC's commitment to learning lessons from the two incidents. It is encouraging that all of the issues that have been identified in our investigation are being followed up by NGC ✂.

APPENDIX A

ORIGINAL SCOPE OF WORK

London and West Midlands Blackouts

Scope of Work for Consultants

Scope

The Consultant will support Ofgem and DTI in assessing specific aspects of the Blackout experienced by South London on 28 August 2003 and east Birmingham on 5 September 2003.

1 - Review and critical evaluation of the approach, systems, processes, and management techniques adopted by NGC for selecting and commissioning protection equipment and deriving and implementing the associated protection settings.

2 Review and critical evaluation of the approach, systems, processes, and communication strategies adopted by NGC and the relevant DNO for programming and management of transmission outages.

3 Review and critical evaluation of the communications with consumers and other stakeholders during and immediately following the incident.

Part 1
Protection commissioning and performance

A- Equipment selection

- Review and evaluate the rationale for selecting the particular protection equipment that led to these blackouts. This will include review the exchange of design information covering:
  - As-installed drawings records prior to commissioning of new protection
  - Design Criteria
  - Calculation of setting ranges and system expected current levels used in the calculation of settings
  - Specification documentation
  - Procurement

- Site delivery checks and audit trail

B- Commissioning

- Review and evaluate the procedures and quality control arrangements for commissioning the protection equipment
- This will include the roles and processes adopted by both NGC and their contractors, the adequacy of the skills, experience and competences of the staff entrusted with these tasks.
- The Consultant will identify any areas where improvements may be possible, including specific recommendations, where appropriate.

C- Performance and previous lessons learnt

- Review and evaluate the historic performance of NGC protection over the last 5 years (specifically incidences of protection maloperation). Assess any trends and/or causes. Establish whether NGC have held formal investigations into any protection related events during the last five years and if so to assess whether the recommendations were implemented and remain currently applied or have been adapted in the light of organisational changes.

Part 2
Transmission Outages and risk management

A- Critical evaluation

- Review and critical evaluation of the approach, systems, processes, and communication strategies adopted by NGC and the relevant DNO for programming and management of the relevant transmission outages
- This will examine the process from year ahead planning through to outturn, evaluating and assessing the reasons for programme changes.
- Specifically this review will establish whether the relevant operational security standards were satisfied.
- The review will also evaluate whether the risks associated with specific outages and outage combinations were understood, formally assessed and communicated. This will include whether the pros and cons of bundled outages were examined.

- The review will also evaluate whether potential mitigation actions and contingency plans were identified and how these were to be applied. This will include possible re-programming of the outage or the works to be undertaken within the outage (e.g. deferment or accelerated working), manual or automatic post-fault action or load transfer for the duration of the outage.
- The review will assess whether the resultant levels of risk were adequately communicated to all interested parties (including key customers)
- Specifically, the consultant will compare the need to adopt a 2+1 arrangement at Wimbledon 132kV substation during maintenance of a mesh corner, with other similar UK substations. This will include comparison of the risk mitigation measures adopted at those comparable substations.
- Consultants to review the process involved with the bundling of multiple outages associated with the Wimbledon construction outage and the recommissioning process.

Part 3
Communications during and after the incident.

A- Critical evaluation

- Review and critical evaluation of the communications with consumers and other stakeholders during and immediately following the incident
- This will include customer call handling and identify any constraints on the company systems or the telecommunications channels that serve them.

Deliverables

- Prepare an initial questionnaire to elicit written answers from the companies, prior to clarification during site visits. Note the consultants will inform the companies that any information provided may be published unless they indicate any good reason for keeping this confidential.
- Prepare a record of any site visits, providing copies for Ofgem and the DTI.
- Provide weekly progress update via e-mail to the Project Manager
- Prepare draft report, explaining the methods employed and the results.
- The report will outline the processes used (with flowcharts etc as appropriate) and identify the strengths and weaknesses associated with the various systems, processes, assumptions and data being used to commission the protection.
- The report should specifically comment on the robustness, quality and accuracy of NGC's protection commissioning processes (including risk management techniques)
- This report will in particular examine the robustness and appropriateness of NGC and the relevant DNO transmission outage planning processes. This will include specific compliance with operational standards, plus the approach adopted for the management , mitigation and communication of associated risks.
- The consultant will recommend possible enhancements to these procedures.
- The companies consulted will be afforded an opportunity to correct factual errors in this draft report.
- Incorporate comments provided by the Project Manager and issue final report to Ofgem and DTI.
- Electronic copies of the report in a form suitable for publication on Ofgem's website.

D- Miscellaneous

- In addition the consultant shall support Ofgem and DTI in interpreting the results and in associated discussions with NGC or other parties.
- If necessary, the consultant will also assist Ofgem and DTI if necessary in defending this work.

APPENDIX B

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APPENDIX C

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APPENDIX D

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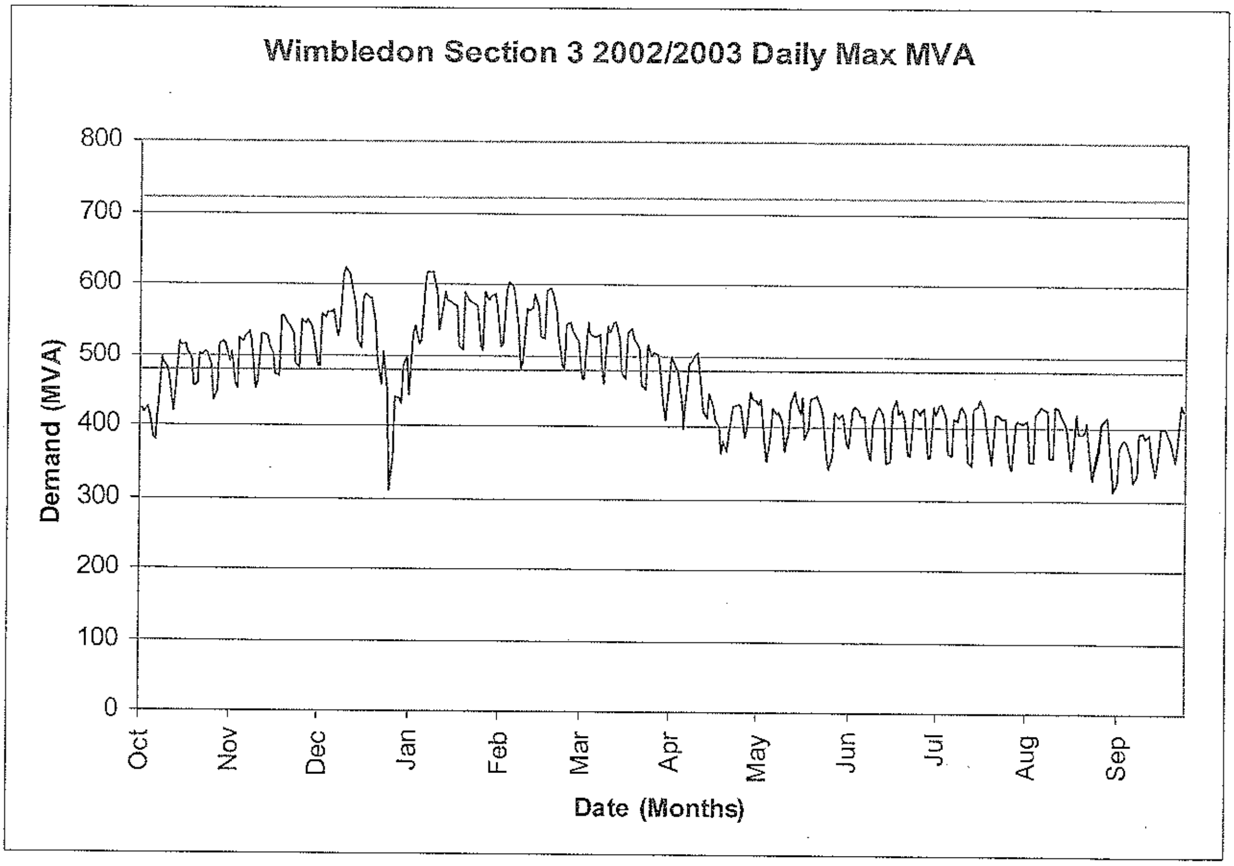
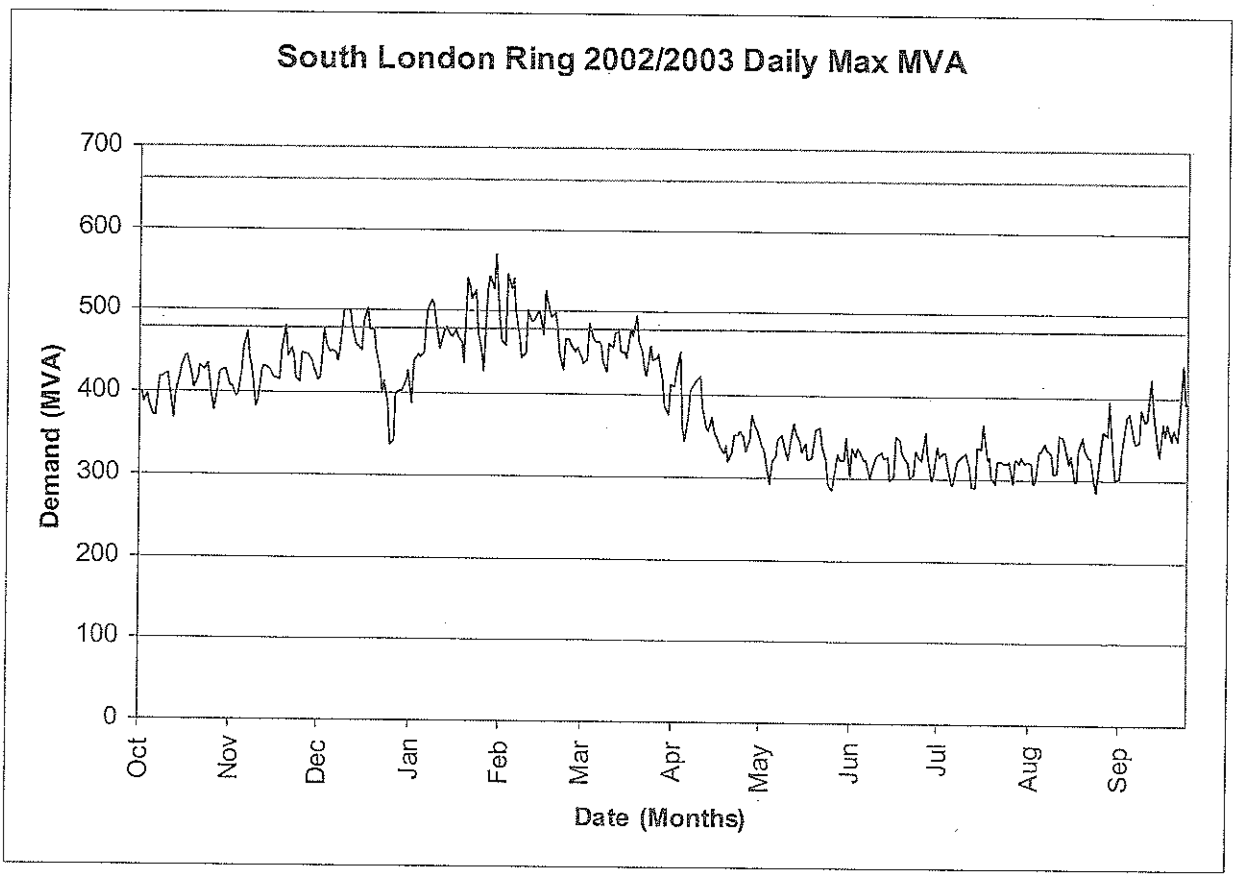
APPENDIX E

ANNUAL LOAD PROFILES OF SOUTH LONDON SUBSTATIONS


Wimbledon Section 3 2002/2003 Daily Max MVA
Demand (MVA)
0
100
200
300
400
500
600
700
800
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Date (Months)


South London Ring 2002/2003 Daily Max MVA
Demand (MVA)
0
100
200
300
400
500
600
700
Oct
Nov
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Feb
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Apr
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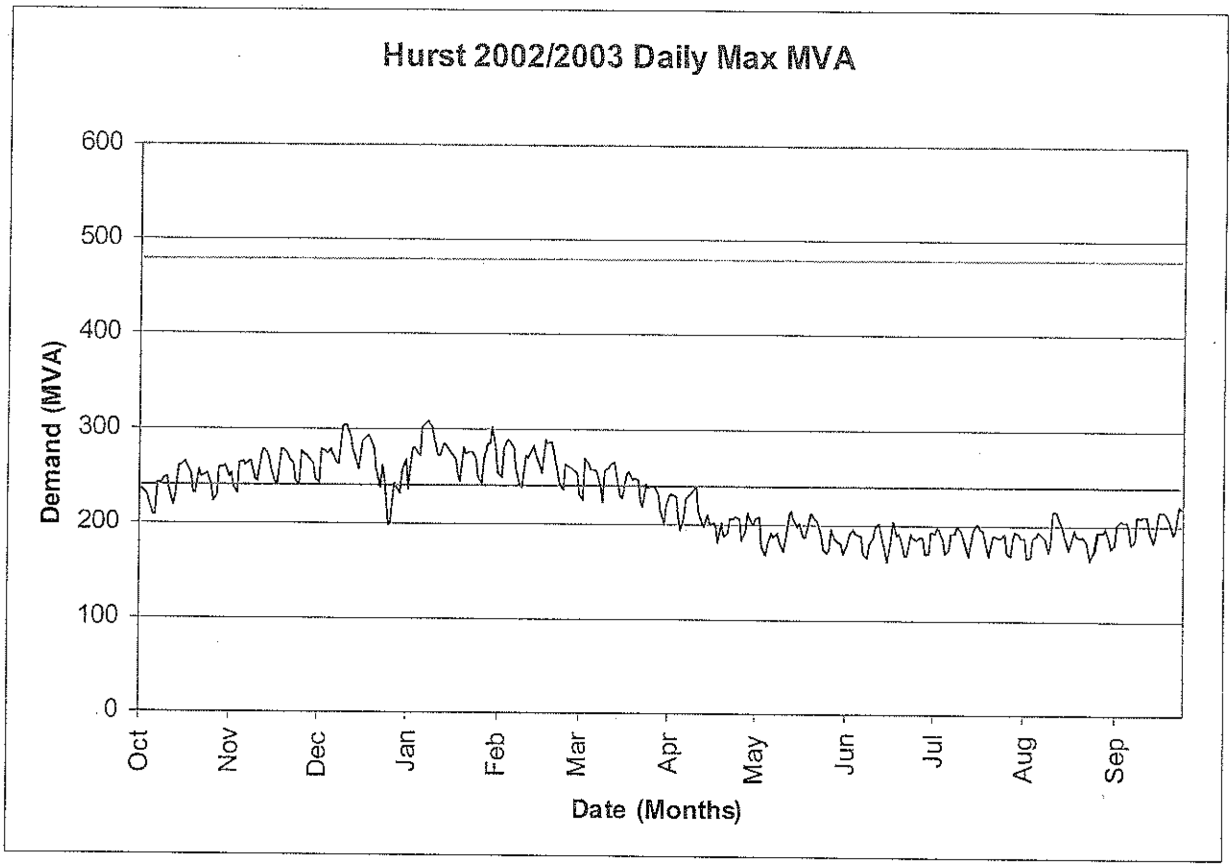
Jun
Jul
Aug
Sep
Date (Months)


Hurst 2002/2003 Daily Max MVA
Demand (MVA)
0
100
200
300
400
500
600
Oct
Nov
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Mar
Apr
May
Jun
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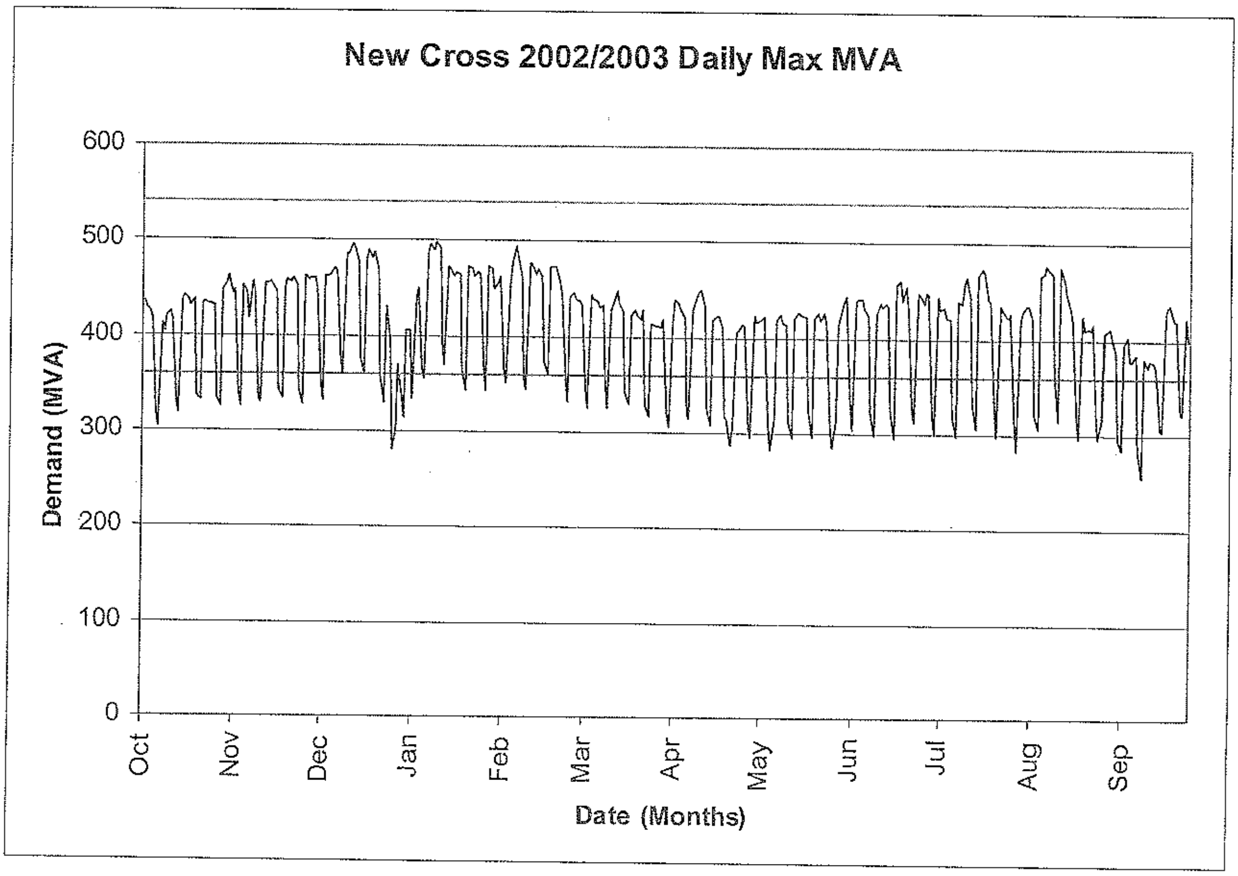
Date (Months)


New Cross 2002/2003 Daily Max MVA
Demand (MVA)
0
100
200
300
400
500
600
Oct
Nov
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May
Jun
Jul
Aug
Sep
Date (Months)

APPENDIX F

✂

APPENDIX G

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APPENDIX H

SUMMARY OF NGC DETAILED ACTIONS ARISING FROM INVESTIGATION REPORT RECOMMENDATIONS

Appendix 1: Detailed Actions arising from the Investigation Report Recommendations

1) National Grid will work closely with other network operators to identify any improvements in co-ordination to enhance the overall security of electricity supplies, particularly to city centres and transport systems.

WP1	Review of co-ordination processes in investment timescales with a view to enhance reliability, in particular to key sites.	1.1	Establish a list of "critical customers" where failure of supply detrimentally impacts societal welfare. Determine the identification, location and strategic needs of such critical customers eg Network Rail, BAA, London Underground. Review with the DNO any options and alternatives to reduce risk supply failure, especially to critical customers
		1.2	Review application of SQSS and P2/5 under outage conditions
		1.3	Review co-ordination with DNO's to ensure adequate exit capacity from design to operational stage, especially where security of supply is impacted
		1.4	Review whether the current Spares strategies are appropriate at key sites.

2) National Grid will work closely with EDF Energy, the Mayor, London Underground, Network Rail and other London emergency and public service agencies to establish improved and more responsive communications in the event of major loss of supply.

WP1	Review of existing mechanisms	1.1	NGT /Industry Emergency Procedures a. ESEC currently under industry review tested under recent exercise Krakatoa and judged fit for purpose. b. Fuel Security code – currently awaiting new proposals from DTI c. OC6 Emergency Demand measures and system warnings tested as part of Krakatoa and judged fit for purpose
		1.2	Communications a. Database consolidation of gas and electricity industry contacts. This will include Directory of Emergency Aid. Issue of wider availability in NGT currently under discussion e.g. reduce number of databases in use b. Wider industry communications subject of industry –wide working group (formally ESECRG) c. Roles and Responsibilities for managing non-industry communications to be confirmed. Needs to be read in conjunction with WP4. d. Engineering Services have drafted new Staff allocation procedure in an emergency
		1.3	Discussion with London Stakeholders - Take proposals back to respondents in London to check if meets needs - in conjunction with 3.2 & 4.2.
WP2	Review of [best] practice.	2.1	Develop best practice strategy for responsive communications in the event of a loss of supply
		2.2	Develop practical measures & steps to facilitate implementation
		2.3	Develop key features of a successful communications strategy for all timescales
WP3	Review of London/UK Emergency/ Contingency Planning Groups.	3.1	a. Review the potential list of contacts b. Discuss with DTI c. Develop policy paper on proposed NGT response to dealing with RR needs. d. Finalise Strategy e. Draft Executive paper f. Plan for NGT regional contacts.
		3.2	Create regional NGT resilience network a. One- two one meetings with regional resilience teams to confirm arrangements b. Check with London parties that this meets their needs - see 1.3 & 4.2 c. Establish our-reach programme comprising regional forums
WP4	Introduce improved and more responsive communications in the event of a loss of supply.	4.1	Taking account of work package 1 & 2, develop proposals
		4.2	Present to relevant London Resilience forum/sub groups - in conjunction with 1.3 & 3.2
		4.3	Implement and review effectiveness

3) National Grid is urgently surveying all installations as a further check on the integrity of the automatic protection equipment; and
4) National Grid will carry out a further comprehensive investigation examining all aspects of the management of the protection systems so as to eliminate, as far as possible, the risk of incorrect installation or operation of automatic protection equipment.
These recommendations and those the relevant aspects that arise from the Investigation into the Hams Hall incident will be covered by the following work packages

WP1	Design Review	1.1	Scheme Design Review of Hams Hall project
		1.2	Assessment of all future commissioning works
		1.3	Design Review of protection schemes subject to their assessment in action 1.2
		1.4	Specify Design Change Procedure at inaugural commissioning panel meeting
		1.5	Ensure written confirmation that site records align with existing equipment is received prior to new construction work commencing
		1.6	Rating of all protection relays and associated CT to be defined in the Design Intent Documentation (DID)
		1.7	Implement Design Compliance Audits reviewing all design issues identified in the DID. A sample of circuit diagrams will be checked with a bias towards tripping functions
		1.8	For schemes in delivery, full and detailed design reviews to be carried out.
WP2	Procurement Review	2.1	Obtain equipment setting policy on all relays previously type registered and on all future relays
		2.2	Request suppliers provide standard application diagrams for all type registered relays
WP3	Installation & Commissioning	3.1	Undertake a protection relay setting survey
		3.2	Review protection relay survey results and address all discrepancies.
		3.3	Survey Multi-Functional Relays Implicated in the West Midlands Incident
		3.4	Review West Midlands type Multi Function Relay original survey results and address discrepancies.
		3.5	Survey Other Multifunctional Relays associated with tripping functions at SGT sites
		3.6	Review other Multi Function Relay survey results and address discrepancies.
		3.7	Increased supervision and checking at specified projects
		3.8	Establish process to ensure that all unwanted relay functionality is disabled
		3.9	Improve confirmation of relay settings sheet data - Tick all correct settings on setting sheet when confirmed on site.
		3.10	Implement Trip and Alarm Testing prior to stage 2 commissioning for all Projects in Delivery
		3.11	Implement mandatory independent pre & post commissioning checks
		3.12	Recalculate back-up protection relay settings
		3.13	Confirm Primary Operating Current (POC) - Commissioning engineer to calculate from relay secondary injection and compare with settings sheet.
		3.14	Extend commissioning authorisation to all contractor staff involved in stage 1 commissioning
		3.15	Communicate Learning Points and actions taken to NG Commissioning Staff
		3.16	Communicate Learning Points and actions taken to Suppliers

5) National Grid will work to review operational procedures, and control room systems, including alarm presentation, in close consultation with Ofgem, DTI and other associated parties, to ensure that there is the right balance between safety risks and supply security.

WP1	Response to Plant Integrity Alarms	1.1	a) List relevant documentation. b) Extract and summarise relevant sections of this documentation. c) Provide 'walk-through' of procedures for responding to Plant Integrity Alarms (see first deliverable bullet below)

		1.2	a) Identify how alarms are specified for new plant and existing plant (retrofitting). b) Make recommendations for changes as appropriate (eg to create a policy if none exists, or modify an existing one if necessary). c) Deliver first draft of new/revised policy. d) Obtain approval for new/revised policy. d) Initiate retrofitting where justified.
		1.3	a) Survey of Bucholz history, based on PB Power response. b) Survey of 'loss of insulating media' alarms (subject to discussion)
		1.4	a) Analysis of risks of leaving plant in service (first draft) b) Final version of the above
		1.5	Analysis of risks of taking plant out of service a) List known risks & control measures (eg those covered in 'more cautious' operating practices, ES pre-winter checks, plus any others we are aware of). b) Where possible, provide background material of incidence of different types of risk. c) Recommend any new control measures required.
WP2	Outage Placement and Security Standards	2.1	a) List relevant documentation. b) Extract and summarise relevant sections of this documentation. (MAF to cover TPs and O&T procedures)
		2.2	MB to arrange a meeting as soon as practical to discuss these first four issues (consistency of application of standards, communication between departments, handling of DNO changes, impact of rising fault levels) (and also WP2.9) a) Summarise current business processes around these issues. b) Make recommendations for any improvements required.
		2.3	a) Summarise current business processes for handling long-term TLRs. b) Make recommendations for any improvements required.
		2.4	a) Identify and cost investment required to raise security standard in London b) Comment on how representative this is likely to be for other sensitive areas.
		2.6	Statement of options for defining sensitive sites
		2.8	a) Summary statement of impact of permanent 'more cautious' operation b) Full statement of impact.
		2.9	a) List relevant documentation and summarise key points b) Make recommendations for any improvements required.
		2.14	Review the process and procedures that validates and monitors Emergency Return To Service (ERTS) data.
WP3	Alarm Presentation	3.1	a) List relevant documentation. b) Extract and summarise relevant sections of this documentation.
		3.2	a) Review policy on nomenclature and grouping of alarms, and consistency with ops diagrams and control nomenclature (initial thoughts) b) Recommendations for revised policy and delivery of consistency. c) First draft of revised documentation, if appropriate
		3.3	a) Identification and clarification of responsibilities for all stages of the alarm 'life-cycle' (initial thoughts) b) Recommendations for revised responsibilities if necessary. c) Production of new/revised TP if appropriate (first draft)
		3.4	a) Initial thoughts on testing and review of alarms b) Recommendations for revised procedures if necessary.
		3.5	Assessment of the resources required for a full audit of alarms
		3.6	Training for control staff re changes in policy or practice.
WP4	Operation across NGC/EDFE (and possibly other) interfaces under	4.1	A desk-top review of our procedures and training for the handling of system incidents.
		4.2	Developing best practice for guidance in switching under abnormal network conditions.

	interfaces under emergency conditions	4.3	Analyse the management of the London failure and restoration sequence and its control using our Network Training Simulator
		4.3	Working with other network operators to improve understanding and communications under abnormal system conditions.
		4.4	Using our team briefing and team development processes to promulgate lessons learnt and best practices with control teams.