National Grid Transco

NATIONAL GRID COMPANY PLC

(A wholly owned subsidiary of National Grid Transco plc)

Investigation Report into the Loss of Supply Incident affecting parts of South London at 18:20 on Thursday, 28 August 2003

This report has been produced by National Grid Company plc (National Grid) to record the investigation findings concerning the loss of supply in south London on 28 August 2003. The purpose of the investigation is to enable National Grid to identify the cause or causes of the incident so it may seek to prevent a recurrence. The purpose of the report is not, however, to identify legal liability; therefore the data and information within it have not been compiled in accordance with rules of evidence and cannot be treated as determining either National Grid's nor any individual's legal liability.

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Investigation Report into the Loss of Supply Incident affecting parts of South London at 18:20 on Thursday, 28 August 2003.

Executive Summary

Introduction

1 A combination of events led to an electricity power supply failure in south London that occurred at 18.20 on 28 August. Restoration began at 18.26 and power supplies from National Grid were fully restored at 18.57. This report describes the circumstances leading to the loss of supply, the steps taken to restore supplies and the measures in hand to minimise the risk of a recurrence.

Transmission System in South London

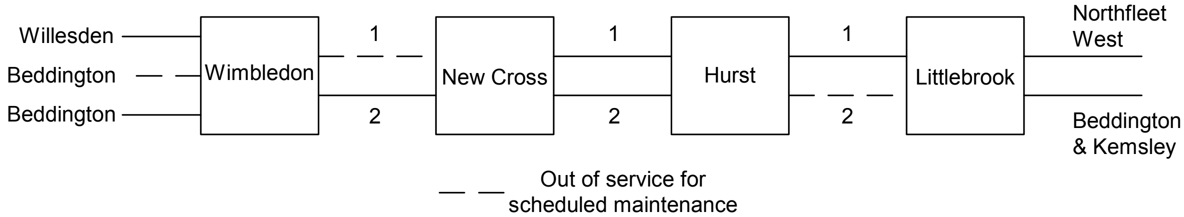
2 The transmission system in south London consists of four substations at Littlebrook, Hurst, New Cross and Wimbledon. Normal demands of around 1,100MW are drawn by EDF Energy to supply domestic customers and London Underground, together with supplies for other large users including NetworkRail. Following the incident supplies were lost from Hurst, New Cross and part of Wimbledon.

Maintenance Activity in the Area

3 On 28 August 2003, scheduled maintenance was underway on one circuit from Wimbledon to New Cross and one from Littlebrook to Hurst. This level of maintenance is usual during the summer months, when demand for electricity is generally lower.

4 In line with normal practice, the arrangement of the transmission system to accommodate the maintenance had been agreed with the operator of the distribution system for the London region, EDF Energy, well in advance, during July 2002. Routine weekly communication between EDF Energy and National Grid resulted in the planned outage at Wimbledon proceeding on 1 July 2003. EDF Energy confirmed that it could arrange its distribution system to accommodate this outage securely for the maintenance period.

Figure 1: Schematic of the south London transmission system



The First Fault

5 The sequence of events started at 18:11. Engineers at the Electricity National Control Centre (National Control) received an alarm indicating that a transformer, or its associated shunt reactor, at Hurst substation was in distress and could fail, potentially with significant safety and environmental impacts. This “Buchholz alarm”, told National Control that gas had accumulated within the oil inside the equipment, which can lead to a major failure. National Grid has approximately 1,000 transformers with associated equipment connected to its transmission system and on average only 13 Buchholz alarms are received each year.

6 National Control contacted EDF Energy to discuss the Buchholz alarm and asked EDF Energy to disconnect the distribution system from the transformer. Then, as is normal practice in this situation, National Control initiated a switching sequence to disconnect the transformer from the transmission system. This switching sequence temporarily left supplies dependent on a single transmission circuit from Wimbledon that feeds New Cross and Hurst substations. Under National Grid operating procedures a Buchholz alarm is sufficiently serious to warrant the isolation of equipment and reduced security is acceptable for “switching time”. This is a period of time, normally around five to ten minutes, during which the transmission system is rearranged, by connecting and disconnecting circuits, so that the affected equipment can be taken out of service.

7 The switching sequence to remove the transformer began at 18:20, disconnecting Hurst substation from Littlebrook substation. This enabled a safe shutdown of the transformer which had suffered the alarm, but left Hurst supplied only from Wimbledon via New Cross.

The Second Fault

8 Unexpectedly, a few seconds after the switching, the automatic protection equipment on the number two circuit from Wimbledon to New Cross operated, interpreting the change of power flows, due to the switching, as a fault.

9 The transmission system is extensively fitted with many levels of automatic protection equipment, aimed at isolating faults and preventing damage to equipment or even a complete shutdown of the transmission system. They measure system characteristics, such as voltage and current and, in the event of a fault, will automatically disconnect affected equipment. On the National Grid transmission system there are approximately 43,000 such pieces of equipment, each with its individual settings to meet local requirements.

10 The automatic protection relay disconnected the circuit from Wimbledon to New Cross. This disconnected New Cross, Hurst and part of Wimbledon from the rest of the transmission system, causing the loss of supply. 724MW of supplies were lost, amounting to around 20% of total London supplies at that time. This affected around 410,000 of EDF Energy’s customers, with supplies being lost to parts of London Underground and NetworkRail.

Restoration

11 Restoration actions began at 18:26, re-energising the Hurst substation from Littlebrook and then isolating the Wimbledon to New Cross circuit, that had automatically disconnected itself, to prevent a recurrence.

12 At 18:38 National Control offered to restore supplies to Wimbledon for EDF Energy. EDF Energy requested restoration of that supply at 18:48 and restoration was completed at 18:51. From this point onwards, London Underground could restore electricity to the underground network, when they considered it was safe to do so.

13 At 18:41 EDF Energy restored supplies via National Grid's Hurst substation to approximately one third of the consumers.

14 Some 30 switching actions enabled National Grid to restore overall supplies to all substations concluding with New Cross at 18:57 which restored the remaining supplies for NetworkRail. The substations remained connected to the rest of the transmission system via a single circuit until 23:00, the time at which the automatic protection equipment that had operated at Wimbledon was successfully isolated. The number two circuit from Wimbledon to New Cross was then safely returned to service and normal levels of security were restored. A rapid check was made to similar automatic protection equipment.

Communication

15 During the incident there was significant operational communication between National Grid and EDF Energy. Communications were initiated at 18:17, following the Buchholz alarm being reported, and EDF Energy were requested to remove the demand from the transformer. At 18:21 EDF Energy called National Grid to confirm that there was a problem on the transmission system.

16 Such operational communications continued throughout the restoration, with continuous telephone conversations between control engineers at National Grid and EDF Energy's control centre, working together to reconnect the affected area. Some 17 minutes later National Grid offered to restore supplies to Wimbledon and New Cross.

17 At 18:51 National Grid was called by New Scotland Yard and National Control informed them that this was a system incident with no third party involvement.

18 The complex and rapidly changing chain of events affected a large number of organisations. In the wider communication exercise through Thursday night and Friday, in addition to briefing the media, National Grid was in contact with the emergency services, the DTI, Ofgem, the London Mayor, energywatch and others.

Investigation

19 The planning of maintenance works had been carried out in accordance with National Grid's policies and that the maintenance work could not be regarded as a cause of the incident. The investigation confirmed that the transmission system arrangement and the communication with the distribution system operator regarding this maintenance complied with the relevant National Grid planning standards and operating procedures.

20 All actions in configuring and switching the transmission system complied with National Grid's planning standards and operating procedures and that the restoration process was carried out quickly and professionally without further incident. The response by control engineers to re-secure the network and restore the balance of generation and demand ensured that the disturbance was contained within the affected substations.

21 The reason that the second fault occurred was that an incorrect protection relay was installed when old equipment was replaced in 2001. This incorrect installation was not discovered despite extensive quality control and commissioning procedures followed by both supplier's and National Grid's specialist staff. This piece of equipment has been replaced. Once the cause was known an extensive survey of similar equipment was immediately initiated. To date 20% (9,000 items) of this type of equipment on the National Grid system has been surveyed and there have been no similar cases. The remaining equipment will be surveyed within four weeks.

22 The engineers involved in the commissioning of the automatic protection equipment had the appropriate training, authorisation, experience and skills to undertake the task. There is evidence that the detailed commissioning procedures were followed correctly at all stages and that no part of the process had been omitted. However, the rating of the automatic protection equipment that is included on the documentation used for commissioning could have been more clearly visible to the commissioning engineers.

23 The actions to remove the Hurst transformer did not directly contribute to the cause of the incident. The consequential increase in flows on the Wimbledon to New Cross circuit, which were within operational limits, initiated the operation of the protection relay at Wimbledon. National Grid engineers would not expect their actions to remove the equipment would have caused the loss of supply.

24 The impact of the incident on the areas of south London was exacerbated by the loss of supplies to underground and railway transport services.

25 From the 20 July, EDF Energy's distribution system was arranged such that a significant supply to London Underground was dependent on a single transmission circuit. This meant that in the event of a fault occurring on one of National Grid's transformers at Wimbledon the distribution system configuration would result in a loss of supply. However, National Grid understands that EDF Energy had contingency arrangements for immediate restoration of supplies to London Underground in such an eventuality.

26 Following normal practice, during the incident there was extensive communication between National Control and the EDF Energy Control Centre, with both control rooms working effectively together during the incident.

Actions being pursued

27 This is the largest loss of supply from National Grid for over ten years and the company has expressed its deep regret. This incident involved a number of other parties and National Grid will be working closely with them in the coming weeks to examine the consequences and identify improvements in systems or procedures. National Grid has reviewed its part in the incident and is committed to the following steps:

- **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.**

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

- **National Grid is urgently surveying all installations as a further check on the integrity of the automatic protection equipment.**

- **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.**

- **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.**

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INTRODUCTION

28 National Grid Company plc (National Grid), a wholly owned subsidiary of National Grid Transco plc, transports electricity and balances the system on a second by second basis. National Grid delivers electricity from generators and interconnectors to 12 distribution network operators for local distribution to over 24 million consumers and directly to a small number of large industrial users. National Grid is the sole holder of an electricity transmission licence for England and Wales and has a statutory duty under the Electricity Act 1989 (as amended by the Utilities Act 2000) to develop and maintain an efficient, coordinated and economical system of electricity transmission and to facilitate competition in the supply and generation of electricity.

OVERVIEW OF THE INCIDENT

29 On 28 August 2003, two events occurred on the National Grid electricity transmission system in south London, resulting in an electricity supply failure on the transmission system from 18.20 until 18.57.

30 The loss of supply occurred following a switching operation to remove a transformer at Hurst 275kV substation from the transmission system in response to an indication that a serious alarm had been activated on the transformer or its associated shunt reactor. Actions were taken to remove the transformer from the system which required a controlled disconnection of the circuit between Littlebrook and Hurst. For a short period of 5 to 10 minutes (switching time) this resulted in the supply at New Cross, Hurst and parts of Wimbledon being dependent on a single transmission circuit. Within seconds of this operation the circuit between Wimbledon and New Cross substations automatically disconnected itself. The combination of these two events was to isolate Hurst, New Cross and a part of Wimbledon 275kV substations from the main transmission system, disconnecting 724MW of supplies to EDF Energy's distribution network.

31 The loss of supply affected 410,000 of EDF Energy's customers in an area of south London approximately bounded by Bexley in the east, Kingston in the west, Bankside in the north and Beckenham in the south, and led to significant disruption to London Underground and NetworkRail. Supplies from the transmission system to EDF Energy were restored within 37 minutes.

32 Roger Urwin, National Grid Transco's Chief Executive Officer initiated a incident investigation chaired by Nick Winser, Group Director Transmission and Chief Executive of National Grid Company plc.

33 This is the outcome of the incident investigation into the events of the 28 August 2003.

BACKGROUND

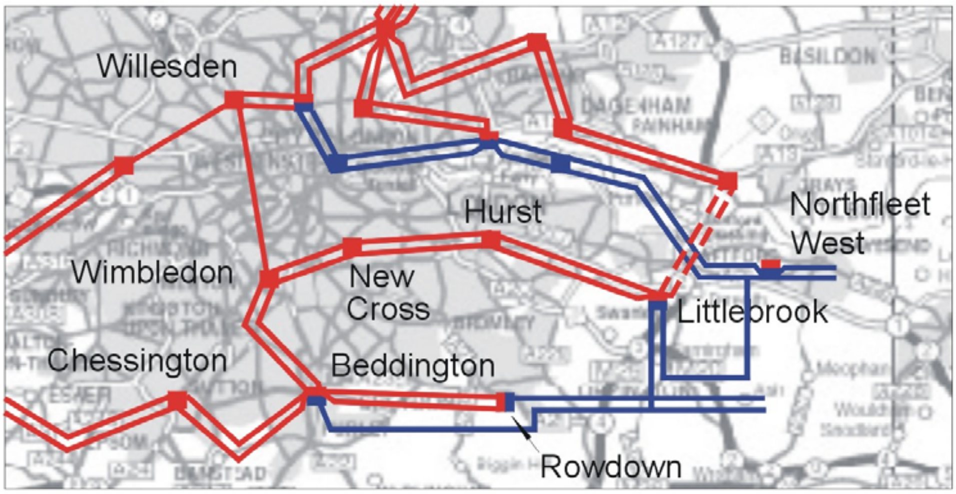
The transmission system in south London

34 The National Grid transmission system provides an integrated network for the bulk transfer of power across England and Wales. The transmission system, which is operated at 400,000 volts and 275,000 volts, connects major power stations and delivers electricity to the regional distribution networks. The peak demand on the England and Wales transmission system is around 54,400MW. The demand for electricity in the Greater London area represents about 20% of the total transmission system demand in England and Wales.

35 The transmission system has been designed and built for an expected life of between 15 years and 80 years, depending on the type of asset.

36 There are no large generation stations connected directly to the transmission system in the Central London area, although large power stations exist close to London at Barking, Grain, Littlebrook and Kingsnorth. The transmission system facilitates the transmission of power from these and more remote generating stations to London.

Figure 2: Transmission system in south London



37 The south London 275kV network between Wimbledon and Littlebrook is shown in the above figure. The network is made up of substations, which include switchgear, transformers, shunt reactors and protection and control equipment. These are connected by circuits comprising overhead lines and cables. A description of the assets that make up the south London network is provided in appendix 1.

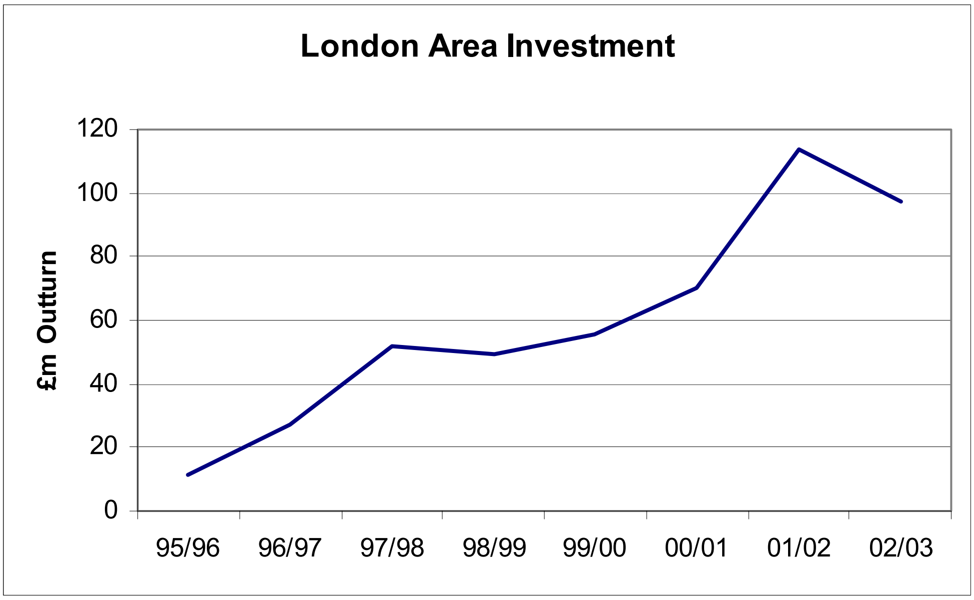
Investment Programme in the Area

38 Since 1990, around £3,600m has been invested in the National Grid transmission system. Of this, approximately £700m has been invested in the transmission system in the Greater London area.

39 Major elements of this work include connection works for new generation at Barking and Kingsnorth, construction of two new substations at West Ham and St Johns Wood, and major infrastructure reinforcement including the new 20km cable between Elstree and St Johns Wood.

40 Since 1995/96 investment in the London area has been increasing and has been around £100m per year for the last 2 years as the new Elstree-St Johns Wood tunnel and cable circuit has been constructed.

Figure 3: Investment in the London area



41 Of the investment in the London area, around £75m has been invested in the Littlebrook to Wimbledon 275kV system and the adjacent network in south London. Specific projects have included:

- Supply point reinforcement works at Littlebrook and New Cross
- 275kV cable works on the circuits between between Hurst, New Cross and Wimbledon over the period 1995 to 2002
- Works to provide a new tunnel under the River Thames at Dartford and new 275kV cables for the Littlebrook to West Thurrock 275kV circuits
- Switchgear replacement
- Automatic protection and control system replacement.
- Environmental improvement works at several sites, such as enhancing oil containment works.

42 As part of National Grid's planned asset replacement programme, future work in the Littlebrook to Wimbledon 275kV system and the adjacent network in south London

includes the replacement of shunt reactors, replacement of the Beddington-Rowdown 275kV cable, the extension of the supply point at New Cross and improvements to cable cooling systems and joint bays.

43 The average expenditure in the London area is planned to be over £50m per year over the next 5 years.

44 **There has been a considerable investment programme in the transmission system in and around London since 1990, and this programme is set to continue at a high level in future years.**

Key Policies and Procedures Relevant to the Incident

45 As part of National Grid's responsibility to operate a safe, secure and reliable transmission system it has a responsibility to ensure that the asset related safety, environmental and operational risks are managed and acceptable. In addition, the company has an obligation to carry out this duty in an efficient manner. To this end National Grid has developed an asset management approach which uses a combination of maintenance, refurbishment and replacement strategies. The procedures, which provide a framework for the delivery of this approach, are well established and defined and subject to external audit as part of National Grid's ISO 9001 accreditation. Details on National Grid's maintenance, asset replacement and commissioning policy are included in appendix 2.

FINDINGS

Operating Arrangements on the day

46 On the evening of Thursday 28 August 2003, the transmission system in the south of London was secure and was operating in accordance with the relevant National Grid planning standards and operating procedures (Appendix 3 provides details). The substations were all configured in a secure manner supplying normal demands of around 1,100MW.

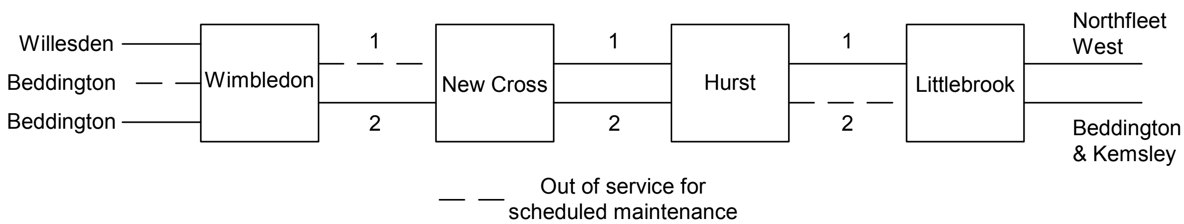
47 The transmission system in the area was arranged with a number of circuits out of service for scheduled maintenance.

Circuit	Reason	Dates
Number two circuit from Littlebrook to Hurst	Installation of thermal monitoring on cables, maintenance of circuit breakers and other planned maintenance at Hurst and Littlebrook	26 August to 19 September
Number one circuit from Wimbledon to New Cross	Major refurbishment of the cables and installation of new protection and control systems	1 July to 28 September

48 The Wimbledon, New Cross and Hurst substations, that were to be affected by the incident, were connected to the rest of the transmission system by two circuits, ensuring that a single transmission fault would not result in a loss of supply.

49 A simple diagram of the transmission network in this area of London is illustrated in the figure below.

Figure 4: Schematic of the Transmission System in South London



50 If a fault did occur and left supplies dependent on a single transmission circuit, in most cases, National Grid was able to restore security of supply within switching time or by returning one of the circuits that was out on maintenance.

51 To maintain an efficient transmission system it is necessary to undertake planned maintenance. The disconnection of circuits and network configuration is planned and agreed following a rigorous process that involves studies to both optimise the coordination of outages with parties connected to the system and to ensure the network configuration is secure against all credible faults that may occur.

52 The planning process to agree these outages and the configuration of the system began in July 2002. As part of the process regular liaison meetings were held and exchanges of information undertaken with EDF Energy (on a daily basis in the last two months). These discussions concluded in a formal agreement for the release of

the circuits before the work was due to commence. As is normal, the maintenance schedules of both EDF Energy and National Grid were subject to change during the early part of the summer. EDF Energy were fully engaged in this process and fully aware of the configuration of the transmission system and its impact on its system. As part of this process the contingency plans for EDF Energy's 132kV Wimbledon substation were discussed, as the planned outage would entail a reduction in the number of feeds from the National Grid transmission system from four to three. National Grid understood that due to limitations on the EDF Energy's system, some distribution supplies from Wimbledon would be dependent on a single transmission circuit. National Grid understands that in the event of the loss of this transformer EDF Energy's post fault action would be to immediately switch its Wimbledon Grid 132kV substation to reinstate supplies, from the remaining two National Grid transformers.

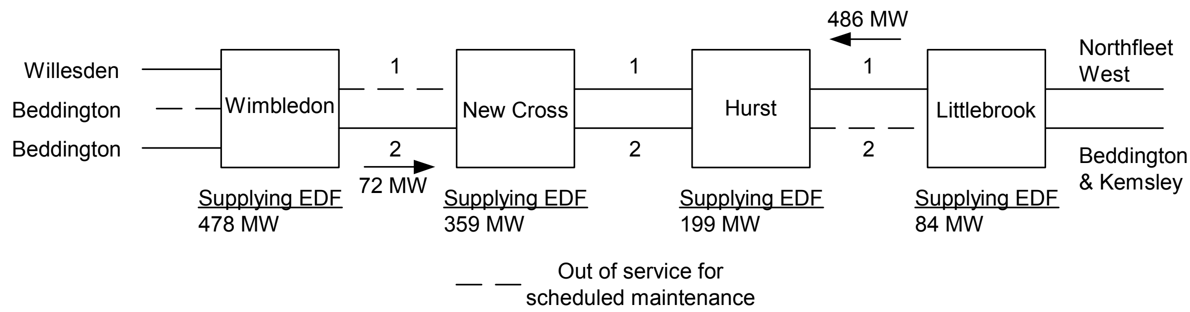
53 If the circuits that were out for maintenance had been available, clearly there would have been no loss of supply. However maintenance is an essential part of sustaining an efficient transmission system and to increase security above the current standards would require a huge investment in new transmission assets.

54 **The investigation confirmed that the configuration of the transmission system was not a contributory factor to the loss of supply.**

Sequence of Events

55 The sequence of events commenced on Thursday 28 August at 18:11 when an alarm was received at the Electricity National Control Centre (National Control) at Wokingham. The system configuration at the start of the incident and the power flows are illustrated below.

Figure 5: Transmission system configuration and power flows



56 The sequence of events during the incident is described below. The detailed switch operations is attached in appendix 4.

57 At 18:11 staff at the National Control received an indication that a transformer or shunt reactor at Hurst substation was in distress and could fail, with potentially significant safety and environmental impacts. The indication, called a "Buchholz alarm", told National Control that gas had accumulated within the oil inside the transformer or shunt reactor, which can lead to equipment failure.

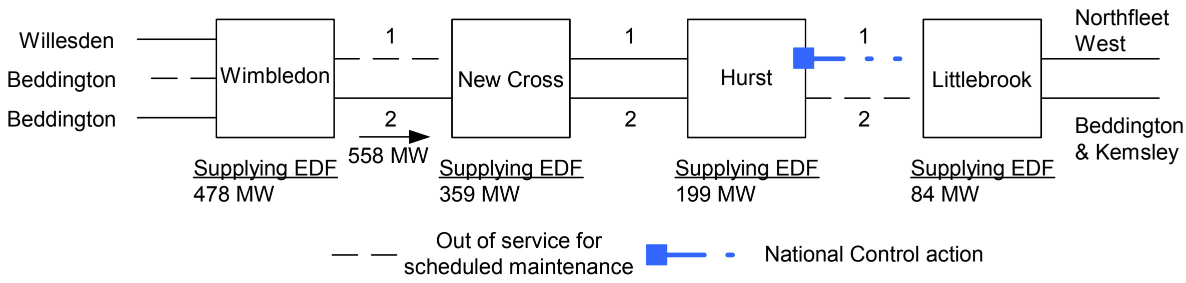
58 At 18:17 discussions were held with EDF Energy regarding the Hurst transformer or shunt reactor. National Control informed EDF Energy that the transformer was to be switched out of service. To achieve this the transmission system had to be rearranged by switching equipment and circuits in and out, so the affected equipment could be safely and securely taken out of service. During switching time (typically 5 – 10 minutes) one circuit would supply New Cross and Hurst substations.

59 EDF Energy confirmed that they had disconnected the transformer from the distribution system. There was no impact on supplies to EDF Energy as these remained connected to Hurst substation via two other transformers.

60 The immediate priority was security of supplies. At 18:19 the circuit from Littlebrook to Beddington and Kemsley was switched in. This reconfiguration of the network ensured power flows at Littlebrook substation would be secure once the number one circuit from Hurst to Littlebrook was switched to take the Hurst transformer and associated Hurst shunt reactor three out of service.

61 At 18:20 two circuit breakers were opened at Hurst to remove the transformer or shunt reactor from service. At this point, the Hurst and New Cross substations were supplied from Wimbledon 275kV substation and were dependent on the single, number two circuit, from Wimbledon to New Cross.

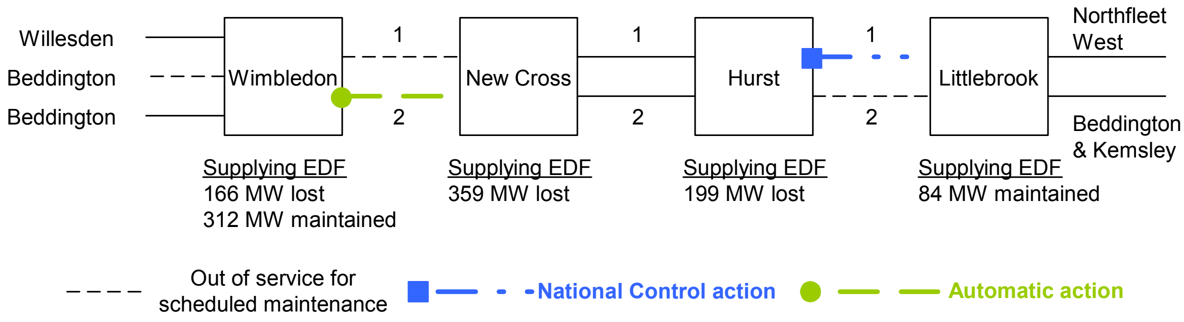
Figure 6: Transmission system at 18.20



62 Immediately following the opening of the two circuit breakers at Hurst, the automatic protection relay operated on the number two circuit from Wimbledon to New Cross automatically opening two circuit breakers at Wimbledon and removing the number two circuit from Wimbledon to New Cross from service. This isolated New Cross, Hurst and part of Wimbledon substations from the rest of the system. All supplies were lost at Hurst and New Cross substations and 35% of the supplies were also lost to EDF Energy's Wimbledon Grid 132kV substation. Two transformers at Wimbledon continued to supply Wimbledon Grid 132kV substation.

63 The transmission network was now configured as in the diagram below.

Figure 7: Transmission system immediately following the incident



64 Following the event EDF Energy transferred 72MW of demand supplied by Wimbledon Grid 132kV substation to another supply point by reconfiguring the distribution network.

65 Assessing the alarms received, National Control concluded that the automatic protection equipment on the number two circuit from Wimbledon to New Cross had most likely operated incorrectly.

66 At 18:21 National Control and EDF Energy discussed the loss of supply and the substations affected.

67 At 18:22 standby engineers were called out to Wimbledon, New Cross and Hurst substations to investigate and help restore supplies.

68 At 18:23 National Control commenced the sequence of operations to restore security for the remaining transmission system and restore supplies. It was decided to keep the number two circuit from Wimbledon to New Cross out of service until the cause of the operation of the automatic protection relay was established, as it was highly probable that if switched into service the automatic disconnection would recur.

69 At 18:25 the network was reconfigured to isolate the number two circuit from Wimbledon to New Cross, while Wimbledon substation was fully energised by closing the two circuit breakers which had automatically opened following the earlier operation of the automatic protection equipment. These actions re-secured the transmission system against further faults, minimising the chance of further losses of supply. Due to uncertainty over the cause of the protection operation, the re-energised transformer feeding Wimbledon Grid 132kV substation was not immediately made available to EDF Energy, although two transformers at Wimbledon capable of carrying the entire demand remained in service throughout the incident.

70 Having re-secured the system at 18:25 the restoration strategy was to configure the network for a phased re-energisation starting at Littlebrook. A complex switching sequence was required to prepare the transmission and distribution network and ensure that the risk of further faults was minimised by carefully switching cable circuits to control the voltage.

71 By 18:30 further reconfiguration of the network had taken place and the first sections of Hurst and New Cross substations had been re-energised.

72 At 18:31 National Control confirmed those developments to EDF Energy Control and informed them that it would contact them soon to start restoring supplies.

73 At 18:38 National Control informed EDF Energy Control that supplies could be restored to Wimbledon Grid 132kV substation. During the same conversation National Control also informed EDF Energy Control that supplies at New Cross could be restored. At this time EDF Energy Control requested time to assess the distribution network and agreed to call back.

74 By 18:40 further reconfiguration of the network had taken place energising further sections at New Cross and Hurst.

75 At 18:40 National Control contacted EDF Energy Control to offer restoration of supplies at Hurst. EDF Energy reconfigured the distribution network and EDF Energy's Bromley supplies were restored at 18:44. This restored approximately a third of the 410,000 customers lost at 18:20.

76 Between 18:44 and 18:50 further reconfiguration of the transmission system took place.

77 At 18:48 EDF Energy Control contacted National Control to complete restoration of supplies to the Wimbledon Grid 132kV substation. At 18:52 all remaining supplies to Wimbledon Grid 132kV substation were restored.

78 At 18:51 a further Buchholz alarm was received relating to the transformer or shunt reactor at Hurst. No indications were received that the transformer had been disconnected by automatic protection, indicating that the shunt reactor was the faulty equipment.

79 At 18:51 New Scotland Yard contacted the National Grid control room and it was confirmed that the loss of supply was a system incident, with no third party involvement.

80 At 18:52 National Control contacted EDF Energy Control to restore supplies at New Cross. EDF Energy Control requested time to assess the distribution network prior to restoring supplies and agreed to call back.

81 At this stage 29 switching operations had been planned and successfully executed in 26 minutes.

82 At 18:56 EDF Energy Control called National Control back and EDF Energy supplies to New Cross were restored at 18:57. At this point all supplies from the transmission system were available to the distribution network.

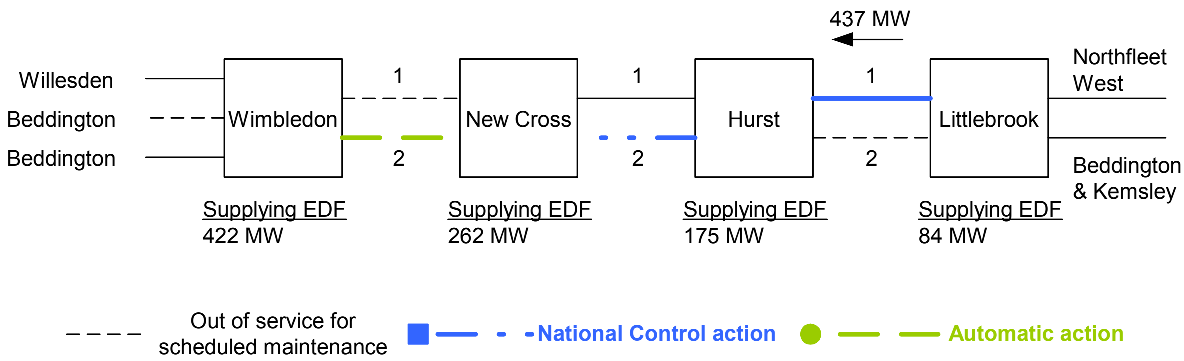
83 At 19:10 EDF Energy Control contacted National Control and asked for the Hurst transformer to be returned to increase security on the distribution network. The original Buchholz alarm was attributable to the shunt reactor at Hurst which was isolated and the transformer was made available to EDF Energy Control.

84 At 19:14 EDF Energy Control confirmed all supplies to consumers had been restored.

85 During the period 19.00 to 19.45 standby site engineers arrived at the three sites. On arrival each standby engineer checked protection relay indications and alarm logs and confirmed the situation with National Control. To support the restoration process and initial investigation, two further engineers were also called to attend site.

86 The network was now configured as follows:

Figure 8: Transmission system after restoration



87 At 20:02 restoration of all supplies was confirmed with New Scotland Yard.

88 At 20:55 EDF Energy Control requested a formal report on the incident.

89 After assessment by engineers on site at Wimbledon, it was confirmed the automatic protection relay had been taken out of service and the number two Wimbledon to New Cross circuit was returned to service at 23:00. This action further enhanced security at Wimbledon and Hurst. No further switching was carried out to allow the system to be re-assessed and minimise the risk of any further faults. Full security was completed by reconfiguring the network overnight, with full security re-established at 01:05 on 29 August.

90 The Standby engineers called to site remained on each site until restoration was complete.

91 **Following the initial loss of supply National Control engineers correctly assessed the risks and restored transmission supplies within 37 minutes.**

Communication during the incident

92 Throughout the incident close communication was maintained between National Control and EDF Energy. Communications relating to this incident commenced at 18:17 following receipt of the initial alarm and were maintained throughout the incident and well into the night. In addition, National Control received a call from New Scotland Yard, and confirmed that this was a system incident.

93 The incident generated substantial media interest, with National Grid handling some 300 media calls on Thursday evening.

94 A verbal statement was given to journalists within 25 minutes of the incident. Written media statements were issued at 21.25 on Thursday evening and 13.30 on Friday afternoon.

95 During a major incident, National Grid would normally communicate with bodies such as Ofgem, DTI, energywatch and others with a direct interest, depending on the incident. Contact was made with Ofgem, DTI and other parties as soon as possible during the incident and communication continued through the evening and the following days.

96 Following the event there were high-level contacts with Ofgem, the Energy Minister, DTI officials, the Mayor of London, EDF Energy and energywatch, among others.

Response to the Buchholz Alarm

97 National Control actions were in line with National Grid procedures for responding to an indication that a Buchholz alarm had been activated on a transformer or shunt reactor at Hurst 275kV substation.

98 The causes and implications of a Buchholz alarm are set out in appendix 5, but in summary, the alarm provides a warning of potential problems in the transformer or its associated shunt reactor that could result in a major failure. Hence, due to the nature of the consequences of such a failure, National Grid procedures specify the equipment is to be disconnected from the transmission system, except in a limited number of circumstances. These exceptions include any action that would result in a loss of supply.

99 As is normal in the design of control room systems, to avoid “alarm flooding” in the event of major system incidents, alarms are combined to reduce the total number displayed in the control room. The investigation noted that the grouping and nomenclature of the alarms for the transformer and shunt reactor did not clearly indicate whether the transformer or the associated shunt reactor was the origin of the gas alarm.

100 When the alarm was received, National Control took immediate action to begin the process to remove the transformer by asking EDF Energy to disconnect it from the distribution system.

Disconnection of the Transformer

101 National Control undertook further switching actions in order to disconnect the transformer from the transmission system. The specific design of the substation, called a “mesh”, required the disconnection of the circuit from Littlebrook to Hurst. The switching plan undertaken was in accordance with National Grid procedures on operating mesh substations which, for the five to ten minutes taken to switch, left the electricity supply at New Cross and Hurst substations dependent on a single circuit.

102 The disconnection of the Littlebrook to Hurst circuit re-routed power and as expected increased the power flows on the number two circuit from Wimbledon to New Cross from 72MW (213MVA) to 558MW (695 MVA). This is comfortably within the design ratings of 815 MVA for the circuit.

103 The investigation confirmed that the operational decision to switch out the Littlebrook to Hurst circuit and supply Hurst and New Cross from a single circuit from Wimbledon, for the five to ten minutes required to complete the switching, was in accordance with operating procedures and took account of the need to remove the safety risk of a major failure of a transformer.

104 The investigation has also confirmed that the configuration and capability of the system was in accordance with National Grid’s standards and procedures, and that National Grid undertakes an average of 2,700 annual switching operations at mesh corners without incident.

105 **The investigation has found that National Grid engineers would not expect their actions in removing the equipment to have caused a loss of supply.**

Unexpected Operation of the Protection

106 At National Grid’s Wimbledon substation, the automatic protection equipment associated with the number two circuit from Wimbledon to New Cross, detected the change in power flows as a result of the switching at Hurst, as a fault. The protection equipment disconnected the circuit to prevent damage to other equipment and/or the propagation of the fault through the transmission system.

107 In this case the protection relay that operated was being used for backup protection. Backup protection is fitted to the transmission network, in conjunction with the main protection and is designed to disconnect faults not cleared by the main protection equipment.

108 The protection equipment that operated was an Inverse Definite Minimum Time (IDMT) relay, a commonly used type. It does not operate immediately, but starts to operate when the electric current on the circuit exceeds a certain threshold. The speed of operation depends on how far the measured current is above the threshold level.

109 The protection relay had been correctly specified during the design process and the settings sheet had been correctly produced. However the relay that had been physically supplied and installed at Wimbledon was a 1 ampere rated relay, not the 5

ampere relay specified on the settings sheet. In all other respects the settings on the relay were correct and were confirmed during several check points in the construction and commissioning process.

110 The effect of installing a 1 ampere relay instead of a 5 ampere, meant that the current flow at which the protection would operate was five times lower than the correct rating and below the rating of the circuit itself.

111 The 1 ampere protection relay was set to operate at a current of 1,020 amperes on the transmission circuit and was triggered on the day by a current of 1,460 amperes. This is significantly below the operating capability of the cable, at 4,450 amperes and the original specification of the protection relay, at 5,100 amperes (see appendix 6).

112 The protection relay was commissioned in June 2001 as part of a replacement scheme. Following a survey conducted as a result of the incident, all the automatic protection equipment in the area was surveyed and found to be correctly installed. A full survey of similar equipment at all substations in England and Wales has been initiated, and to date, having completed 20% of the total, no further cases have been revealed.

113 The incident investigation found that despite rigorous processes for commissioning protection equipment, the wrong protection relay was installed and commissioned at Wimbledon substation and this caused the number two circuit from Wimbledon to New Cross to automatically disconnect unexpectedly, and caused the loss of supply.

114 The commissioning of the automatic protection equipment involved a number of stages as set out in appendix 2. The investigation has found evidence to support that the relay settings had been correctly calculated. The setting sheets were correctly produced and signed by both the engineer who calculated the settings and the engineer who confirmed the application of those settings to the protection equipment. Furthermore the investigation confirmed the protection equipment had been tested by the manufacturer in accordance with industry practice, and that pre-energisation inspection tests were carried out. There is evidence that the rating of the automatic protection equipment that is included on the documentation used for commissioning could have been more clearly set out and hence visible to the commissioning engineers. The investigation found no evidence that any part of the commissioning process had been omitted.

115 **The investigation has found that the direct cause of the loss of supply was the incorrect operation of a backup protection relay on the number two circuit from Wimbledon to New Cross.**

Maintenance of Assets

116 National Grid has an established maintenance policy and the assets involved in the incident have all been maintained according to that policy.

117 The following table summarises the maintenance undertaken on the assets involved in the incident at Wimbledon and Hurst.

Item Description	Last Maintenance undertaken	Next scheduled maintenance
Number two circuit from Wimbledon to New Cross, backup protection	Commissioned 2001	2007
Hurst Transformer 3	September 02	2006
Hurst Transformer 3 Shunt Reactor	March 03	2009

118 **The investigation found that an appropriate level of maintenance had been carried out on the assets and poor asset condition was not a contributing factor to this incident.**

Other Factors

119 The investigation has determined that together with the above factors that are directly attributable to the operation of the transmission system, there were a number of other factors, external to the transmission system, that may have contributed to the duration or scale of the incident.

Configuration of EDF Energy's Wimbledon Grid 132kV Substation

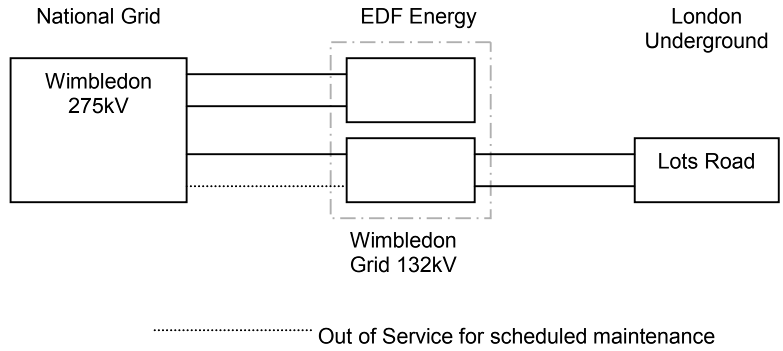
120 EDF Energy own and operate the 132kV substation at Wimbledon, which is physically located on different site to National Grid's substation. Maintenance outages were agreed between National Grid and EDF Energy as part of a well defined process and significant information was exchanged on network configuration and contingency plans for faults.

121 Four transformers from National Grid's 275kV substation at Wimbledon supply EDF Energy's 132kV substation. Normally all four transformers are connected ensuring that supplies can be maintained for the loss of any one transformer. National Grid understands that EDF Energy splits its Wimbledon substation into two parts to reduce fault currents and prevent over-stressing the equipment. Normally, with two transformers supplying each part.

122 When National Grid requires one of the transformers to be taken out of service for maintenance, EDF Energy configures its network with one transformer on one part and two on the second (figure 9). Two transformers supply the majority of demand for Wimbledon and Wandsworth. The remaining transformer supplies the remaining demand at Wimbledon and Wandsworth, together with demand at Lots Road for London Underground.

123 If one transformer is out of service for maintenance the Lots Road circuits will always be dependent on a single transmission circuit, because they can only be connected to the single transformer.

Figure 9: Configuration of EDF Energy's distribution system



124 The configuration of Wimbledon Grid 132kV substation on 28 August 2003 is illustrated in the diagram above. National Grid maintained supplies to the section connected to transformers two and four throughout the incident.

125 National Grid understands that when one of its transformers is out of service and in the event of a fault on the remaining transformer, the normal arrangement would be for EDF Energy to connect the two parts of the Wimbledon Grid 132kV substation. However, National Grid does not know whether, in these particular circumstances, EDF Energy would have been able to take such post-fault action.

126 **The investigation found that the configuration of the EDF Energy's distribution system was not a contributory factor to the initiation of the incident. However, a more rapid implementation of post-fault actions or an alternative configuration could have mitigated the overall impact of the incident, reducing the duration and perhaps the scale of the loss of supply.**

Communications

127 Following normal practice, during the incident there was extensive communication between National Control and the EDF Energy Control Centre. Communications were initiated at 18:17, when the initial Buchholz alarm was reported, and EDF Energy were requested to remove the demand from the transformer. At 18:21 EDF Energy called National Control to confirm that there was a problem on the network, and 17 minutes later National Control called back offering to restore supplies to Wimbledon and New Cross.

128 Such operational communications continued throughout the restoration, with numerous telephone conversations between National Control engineers and EDF Energy's control engineer, working together to reconnect the affected area.

129 Following the restoration of supply, communications with the control rooms continued as further reconfiguration of the systems took place to ensure full security was restored.

130 During the incident National Control managers were confident that this was a system incident and this was confirmed to New Scotland Yard at 18.51.

131 From Thursday evening and over the next day, National Grid gave working level and senior level briefings to DTI (including the Energy Minister), Ofgem, the Mayor of London, energywatch and many others with a direct interest.

132 National Grid began responding to the very large number of media calls within 25 minutes of the start of the incident through its communication procedures. Senior executives from the company were available for media interview between late Thursday evening and early Saturday morning.

133 The investigation has found a crucial factor in communications during the incident was that, although National Grid was able to restore supplies to its network within 30 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 National Grid, but some of its customers could only be restored a short time afterwards. Disruption to rail services continued after power was restored due to timetables being disrupted and the evacuation of trains.

134 The prime route for communications with the public is generally through the standard channels of the providers of these services. For instance it would be through the customer call centre of EDF Energy and through the railway companies' passenger information units. This was appropriate, as only these service providers could let the public know how the incident had affected their operations.

135 The providers of key services to the public, such as the underground and railway network operators, typically draw their electricity supplies from the local distribution network. During an incident involving loss of electricity supplies, including on the National Grid system, that would typically expect to communicate with the distribution company.

136 **The investigation has found that further work is required as to whether enhanced communication between National Grid and the various organisations providing key services to the public during such a major incident would help them in making decisions on how to respond to the incident and communicate about their services with the public.**

Investigation

137 The planning of maintenance works had been carried out in accordance with National Grid's policies and that the maintenance work could not be regarded as a cause of the incident. The investigation confirmed that the transmission system arrangement and the communication with the distribution system operator regarding this maintenance complied with the relevant National Grid planning standards and operating procedures.

138 All actions in configuring and switching the transmission system complied with National Grid's planning standards and operating procedures and that the restoration process was carried out quickly and professionally without further incident. The response by control engineers to re-secure the network and restore the balance of

generation and demand ensured that the disturbance was contained within the affected substations.

139 The reason that the second fault occurred was that an incorrect protection relay was installed when old equipment was replaced in 2001. This incorrect installation was not discovered despite extensive quality control and commissioning procedures followed by both supplier's and National Grid's specialist staff. This piece of equipment has been replaced. Once the cause was known an extensive survey of similar equipment was immediately initiated. To date 20% (9,000 items) of this type of equipment on the National Grid system has been surveyed and there have been no similar cases. The remaining equipment will be surveyed within four weeks.

140 The engineers involved in the commissioning of the automatic protection equipment had the appropriate training, authorisation, experience and skills to undertake the task. There is evidence that the detailed commissioning procedures were followed correctly at all stages and that no part of the process had been omitted. However, the rating of the automatic protection equipment that is included on the documentation used for commissioning could have been more clearly visible to the commissioning engineers.

141 The actions to remove the Hurst transformer did not directly contribute to the cause of the incident. The consequential increase in flows on the Wimbledon to New Cross circuit, which were within operational limits, initiated the operation of the protection relay at Wimbledon. National Grid engineers would not expect their actions to remove the equipment would have caused the loss of supply.

142 The impact of the incident on the areas of south London was exacerbated by the loss of supplies to underground and railway transport services.

143 From the 20 July, EDF Energy's distribution system was arranged such that a significant supply to London Underground was dependent on a single transmission circuit. This meant that in the event of a fault occurring on one of National Grid's transformers at Wimbledon the distribution system configuration would result in a loss of supply. However, National Grid understands that EDF Energy had contingency arrangements for immediate restoration of supplies to London Underground in such an eventuality.

144 Following normal practice, during the incident there was extensive communication between National Control and the EDF Energy Control Centre, with both control rooms working effectively together during the incident.

Actions being pursued

145 This is the largest loss of supply from National Grid for over ten years and the company has expressed its deep regret. This incident involved a number of other parties and National Grid will be working closely with them in the coming weeks to examine the consequences and identify improvements in systems or procedures. National Grid has reviewed its part in the incident and is committed to the following steps:

- **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.**

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

- **National Grid is urgently surveying all installations as a further check on the integrity of the automatic protection equipment.**

- **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.**

- **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.**

Appendix 1: Asset Condition and Replacement Planning

Substations

146 Hurst, New Cross and Wimbledon substations were commissioned in 1970, 1969 and 1967 respectively.

147 Experience has shown that a technical life of 45 years can be reasonably expected for an outdoor substation, of design similar to Hurst, sited in a non-aggressive environment. Therefore replacement prior to 2015 is likely to be required (subject to confirmation by condition assessment). Investment is currently planned for 2011.

148 Wimbledon and New Cross are both indoor substations, and therefore the majority of the equipment is subject to a much lower level of environmental attack, consequently a longer technical life can be generally expected of these assets.

149 With the exception of the circuit breaker S40 at New Cross 275kV substation which is SF6, all the mesh breakers are air-blast circuit breakers as originally installed. The average age of the original circuit breakers is 34 years.

150 During the 1980's SF6 switch disconnectors have been installed on four of the 275kV shunt reactor circuits, while two 13kV shunt reactors at Hurst are connected via original air blast circuit breakers. A summary of the relevant circuit breakers is included in table 1.

Substation	Circuit Breaker	Design type	Voltage (kV)	Year Commissioned
WIMB2	S10	Air-blast circuit breaker	275	1967
WIMB2	S20	Air-blast circuit breaker	275	1967
WIMB2	S30	Air-blast circuit breaker	275	1967
WIMB2	S40	Air-blast circuit breaker	275	1967
WIMB2	K45	SF6 switch disconnector	275	1989
WIMB2	L30	SF6 switch disconnector	275	1986
WIMB2	L55	SF6 circuit breaker	275	1989
HURS2	S10	Air-blast circuit breaker	275	1970
HURS2	S20	Air-blast circuit breaker	275	1971
HURS2	S30	Air-blast circuit breaker	275	1970
HURS2	S40	Air-blast circuit breaker	275	1970
HURS2	K15	SF6 switch disconnector	275	1988
HURS2	K25A	SF6 switch disconnector	275	1986
HURS2	L20	SF6 switch disconnector	275	1986
HURS2	K20B	SF6 circuit breaker	275	2001
HURS2	2K0	Air-blast circuit breaker	13	1971
HURS2	3K0	Air-blast circuit breaker	13	1971
NEWX2	S10	Air-blast circuit breaker	275	1969
NEWX2	S20	Air-blast circuit breaker	275	1969
NEWX2	S30	Air-blast circuit breaker	275	1969
NEWX2	S40	SF6 circuit breaker	275	1986
NEWX2	L10	SF6 switch disconnector	275	1986
NEWX2	L20	SF6 switch disconnector	275	1986
NEWX2	K35	SF6 switch disconnector	275	1988

Table 1: Circuit breakers and switch disconnectors at Hurst, New Cross and Wimbledon substations

Transformers

151 National Grid has conducted considerable research into the deterioration modes and life-limiting processes associated with power transformers. As a result of this improved understanding, transformers are generally expected to have an asset life in excess of the associated substation assets, unless they belong to a design group with a known defect.

152 Together at Hurst, New Cross and Wimbledon there are a total of 13 transformers supplying the 132kV and 66kV distribution networks from the 275kV transmission system. These 13 transformers are drawn from 9 different design groups and from 8 different manufacturers, giving high diversity and resilience against linked or common mode failures.

153 The average age of these transformers is 33.5 years in the range 17 to 38 years, all considerably below the age where replacement would be required under normal circumstances.

154 A summary of the transformer designs and installation dates at these sites is given in the table below:

SGT Circuit	Ref Number	Year Commissioned	High Voltage (kV)	Low Voltage (kV)	MVA
HURS2 SGT2	T5437	1971	275	132	240
HURS2 SGT3	T5438	1971	275	132	240
HURS2 SGT4	T5770	1970	275	132	240
WIMB2 SGT1A	T4219	1967	275	132	240
WIMB2 SGT1B	T3583	1965	275	132	180
WIMB2 SGT2	T4220	1967	275	132	240
WIMB2 SGT3A	T4725	1967	275	132	240
WIMB2 SGT3B	T3487	1976	275	132	180
WIMB2 SGT4	T4726	1968	275	132	240
NEWX2 SGT1	T6758	1986	275	66	180
NEWX2 SGT2	T4264	1970	275	66	180
NEWX2 SGT3	T4263	1970	275	66	180
NEWX2 SGT4	T6616	1978	275	66	180

Table 2: Summary of transformers

155 National Grid monitors the condition of all transformers through dissolved gas analysis. In addition National Grid maintains a history of family performance, defects, faults and design weaknesses to aid replacement planning. Routine monitoring gives no cause for immediate concern with any of the above assets and none of the 13 belong to a family with a known design weakness. There are a number of transformers where oil quality is an issue, National Grid prioritises oil replacement and reclamation nationally and these transformers will be picked up when appropriate by this programme.

Shunt Reactors

156 There are a total of 9 shunt reactors installed at Hurst, Littlebrook and Wimbledon substations. Details are provided in table 3.

157 Some shunt reactors have been targeted for replacement due to a known overheating problem. A proactive replacement programme has installed new units at Wimbledon and New Cross substations. More recently, condition monitoring of some 275kV shunt reactors has indicated the need to replace a number of units, including those indicated at Wimbledon and Hurst substation.

158 The nature of shunt reactor failures is such that the safety and environmental risks of failure are not as great for those of transformers.

Circuit	Reference Number	Year of Commissioned	Voltage (kV)	MVAr
HURS2 Sh Reac 1	R031	1970	275	100
HURS2 Sh Reac 2	R081	1999	275	100
HURS2 Sh Reac 4	R172	1964	275	100
HURS2 SGT2 13kV Sh Reac	R084	1966	13	60
HURS2 SGT3 13kV Sh Reac	R084	1970	13	60
WIMB2 Sh Reac 2	R153	2002	275	100
WIMB2 Sh Reac 4	R108	1970	275	100
NEWX2 Sh Reac 1	T148	2000	275	100
NEWX2 Sh Reac 3	R149	2000	275	100

Table 3: summary of shunt reactors

Overhead Line Routes

159 The anticipated technical lives of overhead line conductor systems have been defined by design and operating environment. Using historic information and developed knowledge of deterioration mechanisms, National Grid anticipates a reliable service life of 45-50 years. Sub-components of overhead line systems have a shorter technical life and may require replacement at an earlier interval. This is addressed through a combination of planned refurbishment (based on condition assessment) and inspection based maintenance. The design and current status of overhead lines in the south London area is summarised below.

Route name	Circuit	Constructed	Line type
ZBG	Littlebrook- Barking	1965	L2
4TP	Kemsley-Littlebrook- Rowdown	1976	L6
TP	Littlebrook- Beddington	1961	L2/L8
VN	Hurst-Littlebrook	1966	L2
ZBA	Barking-Littlebrook	1962	L2
ZZT	Littlebrook – Rowdown / Beddington – Littlebrook	1964	L2
PM	Hurst – Eltham	1955	PL1

Table 4 : Summary of overhead line routes

Cable Routes

160 Technical lives for underground transmission cables are generally in excess of 50 years. Notable exceptions pertinent to the recent incident in London are gas filled or gas compression cables where shorter asset lives are appropriate. In addition to this design, National Grid has also experienced tape-corrosion problems on certain cable designs which, left unchecked, result in reducing availability, increased oil leak rate and the requirement to replace them. Of the major cable routes of interest in this report (detailed in table 5), the Hurst-Littlebrook circuit had been identified as "at risk" and a combination of replacement and pressure reduction work was completed in 1999 as a mitigation measure.

161 In order to ensure cable circuits achieve the anticipated life, a mid-life refurbishment of routes is required to ensure the serviceability of ancillary systems, including cooling, bonding and oil ancillary systems. To reduce the risk of an environmental incident as a result of a cable oil leak, an on-going programme of joint bay refurbishment is in place, which targets joints by environmental sensitivity of the installed location.

Circuit Name	Location	Voltage (kV)	Cable Type	Length (km)	Year Commissioned
Littlebrook - West Thurrock 1	Dartford Tunnel	275	PLGCC	1.653	1966
Littlebrook - West Thurrock 2	Dartford Tunnel	275	PLGCC	1.639	1966
Hurst - Littlebrook 1	Hurst - Littlebrook	275	OF S/C	2.625	1967
Hurst - Littlebrook 2	Hurst - Littlebrook	275	OF S/C	2.495	1967
Hurst - New Cross 1	Hurst - New Cross	275	OF S/C	21.404	1967
Hurst - New Cross 2	Hurst - New Cross	275	OF S/C	21.752	1967
New Cross - Wimbledon 1	New Cross - Wimbledon	275	OF S/C	13.415	1967
New Cross - Wimbledon 2	New Cross - Wimbledon	275	OF S/C	13.479	1967
Wimbledon - Willesden	Wimbledon - Willesden	275	OF S/C	20.793	1967
Beddington - Wimbledon 1	Wimbledon	275	OF S/C	0.172	1988
Beddington - Wimbledon 1	Beddington	275	OF S/C	0.372	1988
Beddington - Wimbledon 2	Beddington	275	OF S/C	0.484	1978
Beddington - Wimbledon 2	Wimbledon	275	OF S/C	0.213	1978

Table 5: Summary of cable routes

Feeder Protection Systems

162 The majority of the automatic protection systems at Wimbledon, Hurst and New Cross are modern electronic relays that have replaced older electro-mechanical devices. Most of the relays have been replaced since the mid 1990s and those that have not are programmed for replacement over the next two years.

163 This equipment provides greater functionality than those that they replaced and also contain a comprehensive self-supervision system. As a result, they ensure correct clearance of system faults and minimise the risk of protection systems operating incorrectly.

Circuit	Type of Protection	Equipment at given substation	Equipment at given substation	Year Commissioned
New Cross – Wimbledon 1		New Cross	Wimbledon 1	
	1st Main Feeder Protection	Solkor – R	Solkor – R	Replacement due in 2003
	2nd Main Feeder Protection	Microphase FM	Microphase FM	1997
	Back-up overcurrent	MCGG22	MCGG22	1997
New Cross – Wimbledon 2		New Cross	Wimbledon 2	
	1st Main Feeder Protection	LFCB 192	LFCB 192	2001
	2nd Main Feeder Protection	Microphase FM	Microphase FM	1996
	Back-up overcurrent	MCGG22	DCD314A	2001
New Cross – Hurst 1		New Cross	Hurst 1	
	1st Main Feeder Protection	LFCB 192	LFCB 192	2002
	2nd Main Feeder Protection	Microphase FM	Microphase FM	1996
	Back-up overcurrent	MCGG62	MCGG62	1996
New Cross - Hurst 2		New Cross	Hurst 2	
	1st Main Feeder Protection	LFCB 192	LFCB 192	2001
	2nd Main Feeder Protection	Microphase FM	Microphase FM	1995
	Back-up overcurrent	MCGG62	MCGG62	1995
Wimbledon – Beddington 1		Wimbledon	Beddington 1	
	1st Main Feeder Protection	Microphase FM	Microphase FM	1997
	2nd Main Feeder Protection	SHNB	SHNB	Replacement due in 2003
	Back-up overcurrent	DCD114	CDG36	Replacement due in 2004
Wimbledon – Beddington 2		Wimbledon	Beddington 2	
	1st Main Feeder Protection	THR	THR	1999
	2nd Main Feeder Protection	Microphase FM	Microphase FM	1999
	Back-up overcurrent	DCD314	DCD314	1999
Wimbledon – Willesden		Wimbledon	Willesden	
	1st Main Feeder Protection	Solkor – R	Solkor – R	Replacement due in 2005
	2nd Main Feeder Protection	Solkor – R	Solkor – R	Replacement due in 2005
	Back-up overcurrent	MCGG22	TJM10	Replacement due in 2005

Circuit	Type of Protection	Equipment at given substation	Equipment at given substation	Year Commissioned
Hurst – Littlebrook 1		Hurst	Littlebrook 1	
	1st Main Feeder Protection	Translay S	Translay S	1999
	2nd Main Feeder Protection	LFZR (Plain)	LFZR (Plain)	1999
	Back-up overcurrent	MCGG22	MCGG22	1999
Hurst – Littlebrook 2		Hurst	Littlebrook 2	
	1st Main Feeder Protection	Microphase FM	Microphase FM	2000
	2nd Main Feeder Protection	LFZR111	LFZR111	2002
	Back-up overcurrent	MCGG22	TJM10	2000

Table 6: Summary of Feeder Protections

Control Systems

164 The Substation Control Systems (SCS) facilitate remote operation of substation equipment from both National Control and the local substation. The SCS also provides remote monitoring, operational metering, event logging and alarm handling facilities. Substation automation functions (eg auto-reclose, automatic voltage control or synchronisation) may be embedded in the SCS or facilitated by stand-alone units linked to the SCS.

Substation	Control System	Year Commissioned
Hurst	METRO	Replacement due 2005
Wimbledon	METRO	2003
New Cross	INSTEM	1999

Table 7: Substation control systems

Appendix 2: Details of National Grid's Key Policies Relevant to the Incident

Maintenance Policy

165 National Grid operates a preventative maintenance policy that is based on the inspection and maintenance of assets before they are expected to fail or experience significant defects.

166 Effective delivery of inspection and maintenance is achieved through a single national policy, national planning and a national workforce to deliver this. In addition to ensuring compliance with legislation, the maintenance regime is designed to manage safety, risks to the environment and the performance of all assets from commissioning to replacement.

167 Inspection and maintenance policy is primarily based on routine maintenance at specified intervals. In some cases duty based maintenance is undertaken. For example transformer tap changers are maintained at a specified interval but this would be brought forward if they experience a specified number of operations.

168 Manufacturers' recommendations are the basis for maintenance policy, however this is enhanced by feedback derived through normal operation and maintenance activities and following incident investigations.

169 There is flexibility in the maintenance intervals to allow assets associated with the same circuit to be maintained at the same time. This "bundling" of work improves system availability by optimising the amount of time circuits are out of service for maintenance and construction works.

170 Maintenance and inspection is centrally planned and scheduled using a work management system. Records are held to confirm completion of the maintenance, and condition information and any abnormalities found on inspection are recorded and repairs are scheduled where necessary. Information from each time equipment is maintained is used to inform the maintenance policy.

Asset Replacement Policy

171 It is National Grid's policy to use condition assessment and diagnostic techniques to identify and replace assets in a timely manner before failure in service occurs. In establishing an asset replacement programme the aim is to deliver a safe, secure and economic transmission system, thereby meeting the statutory and licence duties. Widespread failures in service are unacceptable and a sustainable asset replacement programme is therefore necessary for assets that have long replacement and repair times. National Grid uses a risk management approach to determine the most appropriate asset replacement programme.

172 Knowledge of equipment deterioration mechanisms combined with operational history and environmental exposure is used to develop an anticipated replacement programme for each equipment design group. These programmes are used to aid replacement planning.

173 To ensure the replacement of assets at the most appropriate point within the declared asset life range, condition assessment is undertaken. The condition assessment processes take into account the operating environment, operational duty, fault and defect history, various condition testing techniques, visual condition assessment and engineering knowledge of site and specialist staff.

174 In establishing the asset replacement programme consideration is given to avoiding outage congestion and thereby maintaining access to the transmission system allocating internal resources effectively and optimising the management of our suppliers.

Commissioning Policy on Automatic Protection Equipment

175 Prior to any assets being used operationally on the transmission system, National Grid undertakes an extensive and rigorous commissioning process. This process comprises of on-site inspections and tests to verify that the equipment is correctly installed and performs as specified. Tests are carried out in two stages. First, prior to the equipment being connected to the power system, operational conditions are simulated, and checks undertaken to confirm the equipment operates as designed. Secondly, with the equipment connected to the power system, its performance under actual operational conditions is confirmed. It is only when both stages have been completed successfully that the assets will be commissioned onto the system.

176 To ensure that the commissioning process is carried out to a high professional standard, National Grid's policy sets out both the need for a very clear process framework, and the need to develop engineers with the requisite knowledge and skills.

177 The process framework comprises:

a) Automatic protection relay settings must be calculated in accordance with industry standards and manufacturers' recommendations.

b) A protection relay settings sheet must be prepared which specifies both the relay and its setting and this must be jointly signed by the engineer who calculates the settings, and the engineer who confirms that the setting has been correctly applied to the relay.

c) Commissioning tests must be carried out in accordance with an approved test document which verifies that the setting applied to the protection relay is the setting specified on the protection relay settings sheet.

d) Formal inspections of the settings must be carried out both immediately before and after the in service commissioning tests, to confirm that the setting applied to the protection relay accords with the setting specified on the protection relay settings sheet.

178 The development of the requisite knowledge and skills is defined in a commissioning authorisation programme. This requires the tutoring and assessing of those with defined commissioning responsibilities, leading to a certificate of authorisation. Confirmation of skills retention and development is through annual re-evaluation which, if satisfactory, leads to certificate re-authorisation.

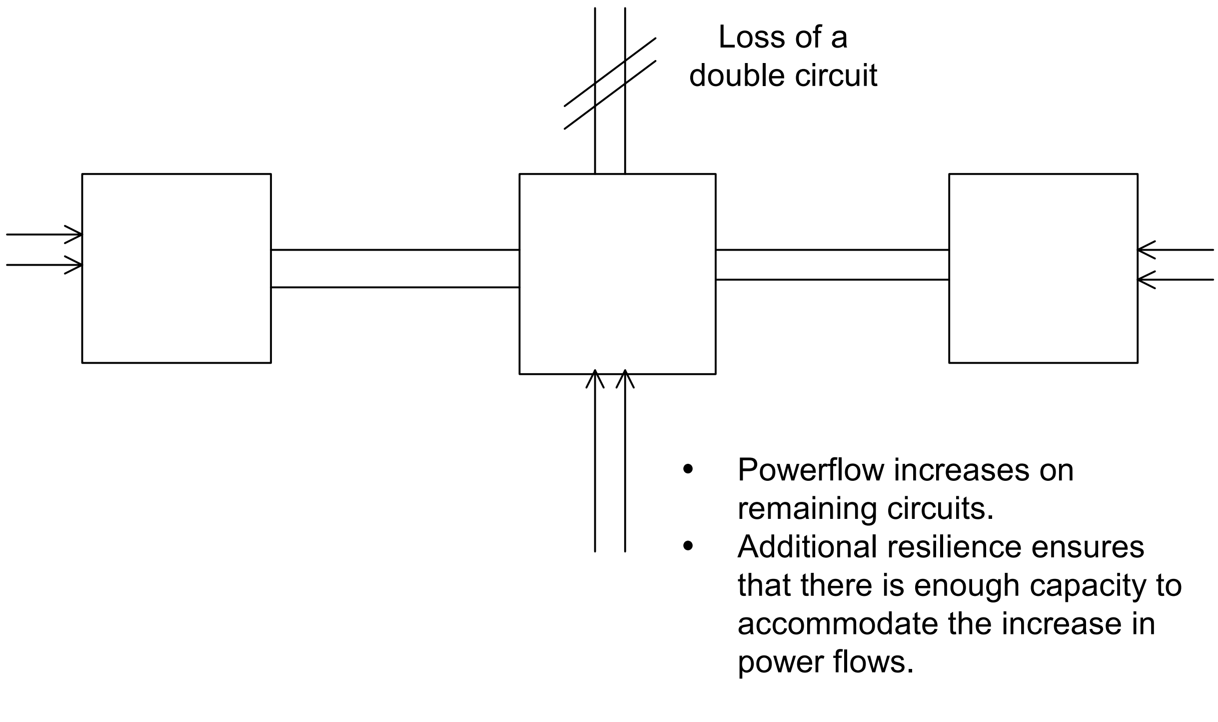
Appendix 3: How National Grid plans and operates the transmission system

179 National Grid plans and operates the transmission system in accordance with the Security and Quality of Supply Standard (SQSS), which is a requirement of the Transmission Licence.

180 National Grid's system performance against the SQSS is reported annually to Ofgem in accordance with the Transmission Licence and is publicly available. Overall, an improved level of system performance has been achieved since privatisation. Performance is reported in terms of availability, system security and quality of service. Average annual system availability and winter peak availability rose significantly until 1999 and have remained at a high level. The annualised number of losses of supply and unsupplied energy varies on a year by year basis with no performance degradation. Quality of supply is reported to Ofgem each year in terms of compliance with statutory limits and shows only five voltage and eleven frequency excursions since 1990, with no frequency excursions for the last seven years.

181 In essence, the SQSS determines the degree of additional resilience that must be built in to the transmission system so that the system is robust against credible equipment failures and the need to maintain the assets. Typically, the main system must be able to withstand the unplanned loss of a double circuit (two overhead lines hanging on the same transmission towers), although smaller demand groups are permitted to be dependent on a single circuit when circuit outages are required.

182 This is illustrated in the diagram below. When the double circuit is lost, the flow of electricity on the remaining circuits will increase to compensate for the loss. The transmission system is designed and operated to be able to accommodate these additional flows.



183 The SQSS was subject to a review in the mid 1990's, and a revised standard was approved by Ofgem following extensive consultation with the industry and customers. The provisions of the SQSS bear comparison with standards applied elsewhere in the world and are equivalent to those that existed before privatisation of the industry.

184 The level of additional resilience built in to the transmission system is a balance of risk between cost and security. The existing standard has delivered an extremely high level of security and reliability by international standards. It would require a very high level of additional cost and investment to increase the current level of security across the entire system.

185 Application of the security standard, supported by a sustained high level of investment, has delivered an extremely low level of customer demand lost, as a result of events on the transmission system. The average level of unsupplied energy over the past five years has been 0.0001% of the total supplied. For comparison this is 27 times lower than the average reported through a benchmarking exercise involving 16 major transmission system operators in 1999/2000 and 2000/2001.

186 During winter months the system is usually operated with all circuits in service. Where this is not possible, for example due to extensive construction works or equipment failure, there is sufficient flexibility to ensure the security standard is met. During the summer months, when demand for electricity is lower, circuits are taken out of service for maintenance and construction works. These circuit outages are carefully co-ordinated with each other, with distribution network operator outages, generation outages, and with demand profiles to ensure that the system remains compliant with the security standards.

187 As indicated above, the transmission system includes additional resilience to allow for the unplanned loss of equipment. When such losses occur, remedial action is taken as soon as possible to restore the level of security. In some circumstances, it is necessary to switch circuits out of service for up to 5 to 10 minutes whilst other equipment is being taken out of service for maintenance or repair. During these switching operations a reduced level of security may apply, however the probability of a second equipment failure during this time is extremely small.

Appendix 4: Switching Operations

	Time	Location	Equipment	Status
Initial event	18:11:37	Hurst	Hurst SGT3 SR3	Buchholz Alarm Received
Manual response to alarm	18:18:00	Hurst	SGT3 LV Breaker	Opened
	18:19:40	Littlebrook	X605	Closed
	18:20:17	Hurst	S20	Opened
	18:20:28	Hurst	S30	Opened
Mesh Corner 3 Backup Protection	18:20:36	Wimbledon	380B	Opened
	18:20:36	Wimbledon	380A	Opened
	18:20:37	Wimbledon	S20	Opened
	18:20:38	Wimbledon	S30	Opened
Restoring Security	18:23:47	Wimbledon	L30	Opened
	18:25:06	Wimbledon	S30	Closed
	18:25:46	Wimbledon	S20	Closed
Restoration Strategy	18:26:46	New Cross	2TO	Opened
	18:26:53	New Cross	1TO	Opened
	18:27:02	New Cross	4TO	Opened
	18:28:23	New Cross	S40	Opened
	18:29:25	Hurst	S10	Opened
	18:30:23	Hurst	S30	Closed
	18:30:24	New Cross	S10	Opened
	18:30:40	New Cross	H13	Opened
	18:30:40	New Cross	H23	Opened
	18:31:24	New Cross	L10	Opened
	18:33:41	New Cross	H13	Closed
	18:36:42	New Cross	H13	Opened
	18:39:02	New Cross	L20	Opened
	18:39:22	New Cross	H23	Closed
	18:40:14	New Cross	S40	Closed
	18:40:34	New Cross	S10	Closed
	18:43:56	Hurst	L20	Opened
	18:44:58	Hurst	S20	Closed
	18:48:15	New Cross	S10	Opened
	18:48:28	New Cross	S40	Opened
	18:48:58	New Cross	H13	Closed
	18:50:07	New Cross	S40	Closed
Demand restoration	18:50:59	Wimbledon	380A	Closed
	18:52:13	Wimbledon	380B	Closed
	18:57:03	New Cross	1TO	Closed
	18:57:21	New Cross	4TO	Closed
Restoring Security	19:24:46	New Cross	S10	Closed
	19:30:10	New Cross	2TO	Closed
	22:59:41	Wimbledon	L30	Closed
	23:00:04	New Cross	L10	Closed
	00:18:58	New Cross	L20	Closed
	00:19:19	Hurst	L20	Closed
	01:05:15	Hurst	S10	Closed

These times relate to times received on control systems at National Control

Appendix 5: Background on Buchholz Alarms and Potential Consequences of Transformer Failure

188 The Buchholz relay is a protection device that has an alarm function for abnormal gas levels or low oil in an oil filled transformer or shunt reactor. The device also automatically initiates the disconnection of the equipment if the oil level falls further or a major internal failure occurs.

189 All faults within a transformer tank result in localised heating and breakdown of the oil. When the fault is of a very minor type, such as a hot joint, gas is released slowly, but a major fault involving severe arcing causes rapid release of large volumes of gas as well as oil vapour. This action can be violent with the gas and vapour not having time to escape but instead building up pressure and displacing the oil.

190 A Buchholz alarm is a dependable indication of an active fault within the transformer. The consequences of such a fault developing to failure are sufficiently severe to warrant disconnection. While the majority of transformers are removed from service before a major failure occurs, on occasions no warning is available. Approximately 20% of transformer failures result in a breach of the main tank. As shown below, the potential safety and environmental consequences of failure are clear.

Figure 10: Failed Transformer

191 In view of the potentially serious consequences of a transformer failure, it is National Grid's policy that National Control will immediately take transformers out of service when a Buchholz alarm is received. This policy takes into account the very low probability of a second circuit fault during the 5 to 10 minutes it would take to perform the switching operation, estimated to be less than 1:40,000. The exception to this is when the removal of the transformer would lead to a direct loss of supply, in which case the balance of risk favours a delay whilst further investigations take place.

Appendix 6: Purpose of Automatic Protection Equipment and Operation of the Backup Protection Relay

192 During normal operation the power system supplies load current. At times of peak demand a 275kV circuit may be subject to load current which is as high as 5,200 amperes. However, when the 275kV power system is subject to a fault (short circuit) the current increases significantly, and could rise as high as 40,000 amperes. These very high fault currents are disruptive and potentially damaging to the power system and must be quickly removed.

193 The purpose of 'protection' is to detect a fault on the power system and then instruct the appropriate circuit breakers to automatically disconnect the faulty item of equipment from the power system. This process needs to be accomplished as fast as possible to prevent:

(a) unnecessary damage to faulty equipment
(b) potential damage to healthy equipment – that is required to carry the high fault current until the fault is removed
(c) unstable operation of generating equipment – leading to loss of generation
(d) loss of supply to customers

194 Two types of protection are applied to the transmission system: main protection which protects a specified item of equipment, e.g. a transformer, an overhead line circuit, or a cable circuit; and backup protection which provides backup when the main protection fails.

195 Main protection will not operate for either load current or fault current (other than a fault on the equipment it is protecting). The same is not true for backup protection. It will operate for any current, either load or fault current, that is above its setting.

196 The Inverse Definite Minimum Time (IDMT) relay used on the number 2 circuit from Wimbledon to New Cross has two settings – an operate current setting (i.e. the current at which the relay commences to operate) and a time delay setting – the latter is known as the time multiplier (TM). Once the current flowing into the relay exceeds the operate current settings of the relay, it commences to operate. For example, if the operate current setting of the relay is equal to 1 ampere and the current flow into the relay is below 1 ampere, the relay will not operate – but once the current flow into the relay exceeds 1 ampere, it will commence to operate. The speed of operation is dependent upon both how many times the current flowing into the relay is greater than the operate setting current, and the setting of the TM. However, for the purposes of the investigation it is only necessary to focus on the operate current setting.

197 The operate current setting, I_S, of the relay is related to its Rating, alternatively called the Nominal Current, I_n. Relay ratings are usually 1 ampere or 5 ampere but others are available. The relays are equipped with current setting multipliers, CS, which are applied to I_n, to give a range of operate current settings so that

$$I_S = CS * I_n$$

198 On the relay installed on the number two circuit from Wimbledon to New Cross, CS could be selected from 0.05 to 2.4 in increments of 0.05 and was, in fact, selected to 0.85, so

(a) with a 1 ampere Rating relay, I_S = 0.85 x 1 ampere = 0.85 ampere

or

(b) with a 5 ampere Rating relay, I_S = 0.85 x 5 ampere = 4.25 ampere

199 The current in the high voltage (HV) circuit is converted to the current into the relay by a current transformer. On the number 2 circuit from Wimbledon to New Cross the ratio of the current transformer was 1,200/1. This means that for every 1,200 amperes that flow in the high voltage circuit, 1 ampere will flow into the relay.

200 So with reference to (a) above, if the relay has a Rating of 1 ampere then a relay current of 0.85 ampere will cause the relay to operate, and this corresponds to a high voltage circuit current of 0.85 x 1,200 = 1,020 amperes. Alternatively, if a relay of Rating 5 ampere was selected, a relay current of 4.25 ampere will cause the relay to operate and this corresponds to a high voltage circuit current of 4.25 x 1,200 = 5,100 amperes.

201 To summarise:

A relay with a Rating of 1 ampere requires 1,020 amperes on the HV circuit to cause operation
A relay with a Rating of 5 amperes requires 5,100 amperes on the HV circuit to cause operation

202 At the time of the incident the HV circuit current on number two circuit from Wimbledon to New Cross was 1,460 amperes and this caused the 1 ampere Rating relay to operate. If the correct relay with a 5 ampere Rating had been installed then operation would not have occurred.

203 Relay ratings are selected to accommodate the current rating of the HV circuit to which the relay is connected. The number two circuit from Wimbledon to New Cross has a current rating of 4,450 amperes. Consequently, a 5 ampere relay rating, allows a HV circuit current of 5,100 amperes before operation.

Appendix 7: References

Transmission Security and Quality of Supply Standard:
http://www.nationalgrid.com/uk/library/documents/mn_license_standard.html

Grid Code
http://www.nationalgrid.com/uk/indinfo/grid_code/index.html

System Performance Report 2002/03
http://www.nationalgrid.com/uk/library/documents/pdfs/System_performance_Report_2002_03.pdf

Transmission Licence
http://www.nationalgrid.com/uk/library/documents/mn_transmission_licence.html