Report following railway power disruption on 9th August 2019

3rd January 2020

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1.0 Introduction

On Friday 9th August 2019 around 4:52pm, a number of electricity generators tripped off the power grid at approximately the same time. This is thought to have been caused by a lightning strike to an overhead transmission line. It resulted in disruption to power supply from National Grid, affecting the railway network causing widespread disruption.

The loss of generation caused the frequency of the power supply to the rail network to drop from its nominal value of 50.0Hz to below 49.0Hz for approximately 33 seconds, falling to a low of 48.8Hz. This is outside the normal range for power distribution to the rail network, but should have been manageable. The Railway Group Standard GL/RT1210 *AC Energy Subsystem and Interfaces to Rolling Stock Subsystem* and BS EN 50163:2004 *Railway applications —Supply voltages of traction systems,* specifies a lower frequency limit of 47.0Hz. The majority of rolling stock operated without any issues.

However, 31 trains were stranded as a result of the temporary drop in frequency. On the Class 700 and Class 717 rolling stock, protection systems operated within 200ms of the frequency falling to 49.0Hz causing a lock-out of 29 trains. 22 trains were permanently locked-out and could not be reset without a technician attending on site while 7 trains were restored through driver-reset. Two Class 387 trains were also trapped as a result of the lock-out experienced by the Class 700 and Class 717 trains. Passengers had to be evacuated from 30 trains to a place of safety (detrained). There were substantial knock-on delays following recovery of the vehicles.

During the time of the power disruption, two traction substations lost power at Tattenham and Chipstead. There was also loss of traction power on the Wirral line of MerseyRail, but in other areas, there was no report of traction power outage. Effects on non-traction power supplies included loss of eight signalling power supplies in rural locations. In addition, two Distribution Network Operator (DNO) supplies were lost at Chatham and Lewes.

This report summarises ORR's engagement with Ofgem, Network Rail, GTR and Siemens following the power disruption, concentrating on the impact the power disruption had on the rail network.

2.0 Impact Assessment

The power disruption affected various parts of the railway services directly and indirectly. Although loss of traction power was experienced at only one location as a result of the event, the quality of supplied power was affected, and it triggered other events which led to significant delays in railway services.

2.1 Impact on the quality of power supplied to the railway

The normal supply frequency as set out in the *Security and Quality of Supply Standards* (SQSS) and in the *Electricity Safety, Quality and Continuity Regulations 2002,* is 50Hz +/-0.5Hz.

During the power disruption, changes to the grid supply were transferred to Network Rail Infrastructure. The supplied power frequency dropped from a nominal 50.0Hz to a low level of 48.8Hz after 16 seconds. The frequency remained below 49.0Hz for approximately 33 seconds and was restored back to its nominal value of 50Hz 3 minutes and 36 seconds later.

Figure 1 below shows a frequency trace event published by Ofgem.

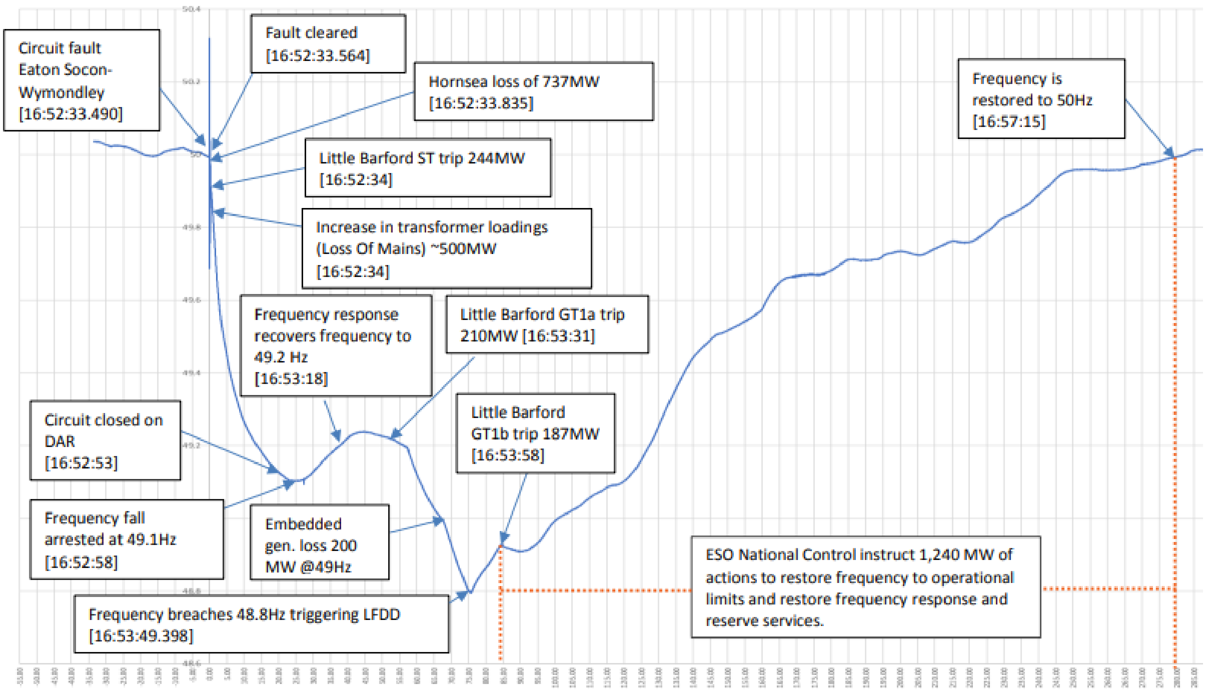

Figure 1 – Annotated Frequency Trace of Event [extracted from National Grid Technical Report on the events of 9 August 2019 published 06/08/2019]

The majority of the rolling stock on the network at the time operated without notable issues, but a fleet of Class 700 and Class 717 trains operated by Govia Thameslink Railway (GTR) shut down within 200ms of the frequency dropping below 49.0Hz. The Railway Group Standard GL/RT1210 *AC Energy Subsystem and Interfaces to Rolling Stock Subsystem* and BS EN 50163:2004 *Railway applications — Supply voltages of traction systems* specify that a traction power supply may have a lower frequency limit of 47.0Hz.

However, an advisory note to the standard defines a narrower range of 49.0Hz to 51.0Hz within which the train is required to operate normally. Outside this range, it is permitted to reduce performance or to disconnect the vehicle drives.

2.2 Effect on GTR's Class 700 and Class 717 fleet

Within 200ms of the power supply frequency dropping below 49.0Hz, 29 trains comprising Class 700 and Class 717, operated by Govia Thameslink Railway, shut down and were locked-out by on-board safety systems. Initial attempts made by drivers to bring the trains back into operation proved abortive and required the intervention of Fleet Control to advise drivers on the next action.

According to a technical review carried out by GTR, '*all Desiro City Class 700 and 717 units operating on AC Voltage suffered a Protective Shutdown where the converter, known as the 4QC (Four Quadrant Chopper) shut down.'* When the 4QC shuts down, the train is isolated from the traction power supply. Available power is restricted to the limited on-board battery supply, which only supplies certain key on-board systems and does not provide power for traction.

Following the diagnosis of the shutdown by Fleet Control, a GSM-R (Global System for Mobile Communications – Railway) call was broadcast to instruct drivers of affected trains to carry out the Battery Reset Process. The process led to the recovery of 7 of the affected units. 22 trains could not be reset and required the attendance of a technician to recover them.

At the time of the event, the technicians available were too few compared to the number of stranded trains. 18 Technicians with laptops were sent to restore the trains immediately, and within the next hour more technicians were mobilised.

2.3 Effects on timetable

The geographical locations of some of the trains meant they were not easily accessible, making the entire train recovery process time-consuming. Passengers were safely detrained at stations and on track from 30 stranded trains. There were significant train delays, cancellations and part-cancellations of train journeys. However, full service was restored within 24 hours. Table 1 shows a list of affected routes.

Routes	**Cancelled**	**Part-Cancelled**	**Delay Minutes**
Sussex	38	22	2051

Routes	Cancelled	Part-Cancelled	Delay Minutes
Wessex	0	2	716
Kent	36	43	1727
Western	0	0	658
LNE-York	86	44	5569
LNE-EM	197	79	2780
LNW-N	14	24	428
Wales	0	6	499
TOTAL	**371**	**220**	**14428**

Table 1 – Affected routes, cancellations and delays
Source: Network Rail's National Daily Report 09/08/2019

2.4 Possible impact on railway substation and signal power supply

During the power outage the grid frequency dropped from a nominal 50Hz to 48.8 Hz, which was transferred to the OLE (Overhead Line Equipment). 48.8 Hz is one of the low frequency demand disconnection (LFDD) bands where the Distribution Network Operator (DNO) sheds load to stabilise the system and to protect essential services such as the rail traction supply. However, it is the duty holder's responsibility to ensure backup systems are in place to maintain functionality where loss of power may lead to emergency situations. Backup systems could include generators, uninterruptable power supplies (UPS) or specific contracts with DNO.

Due to the activation of LFDD in response to the loss of generation, some DNOs supplies had to be temporarily disconnected. There was traction power outage on the Wirral line of the MerseyRail after rectifiers tripped when domestic supply was lost to LFDD. This resulted in 428 minutes delay.

The substations at Tattenham and Chipstead also experienced power quality issues, which caused the protective devices for the traction rectifiers to operate, temporarily switching the power off. The rectifiers were however quickly reinstated. The resilience of the system meant that traction power supply was maintained during this time.

During the time of the power disruption there was also a loss of two DNO supply points at Chatham and Lewes. This is still under investigation and may have been caused by LFDD.

Also, at the time of the disruption, eight signalling power supplies were lost in rural locations.

The affected locations were fed by local DNO networks which may have been affected by the LFDD implementation. Affected locations were:

- Wye, Kent
- Southease, Sussex
- Norwood Fork, London
- Trowbridge, Wiltshire
- Magor, Wales
- Bangor, Wales
- Croes Newydd, Wales
- Kirby Thore, Cumbria

Investigations are still ongoing to understand, if the power disruption led to the loss of signal supplies in the affected eight locations.

2.5 Possible impact on compensation

Passengers using most railway operators, including GTR, are entitled to compensation for train delays. For a 30 to 59 minutes delay they are entitled to a refund of 50% of the cost of a single ticket or 50% of the cost of the relevant portion of a return ticket. For 60 to 119 minutes they are entitled to 100% of the cost of a single ticket or 100% of the cost of the relevant portion of a return ticket. If their delay exceeds 120 minutes then they are entitled to a full refund. In all cases they are entitled to complete their journey.

There was an increase in delay compensation claims received by train operators in period 5 (21st July to 18th Aug) to the highest level since May 2018 timetable disruption with a particular peak for GTR. Although this cannot be directly attributable to the power disruption, it is likely to have been a factor. There was no corresponding peak in complaints during this time and this remained on trend. This would suggest the train operating companies' process worked.

3.0 Review of Investigations

ORR engaged with Network Rail, GTR and Siemens, to understand the extent of the impact of the power disruption and why it significantly affected the railway services despite not losing traction power. Network Rail owns and manages the railway infrastructure. GTR is a train operating company operating the affected trains and carrying out some of the maintenance. Siemens as the train manufacturer designed the software on the affected trains and also maintains some of the trains. Key railway stakeholders who were impacted by the power disruption are conducting investigations to establish lessons learned so as to drive improvement.

3.1 Permanent versus temporary lock-out

Traditionally, on-train electrical equipment were protected by fuses, circuit breakers and other hard-wired devices to monitor the status of the equipment. With the evolution of on-board monitoring systems, software has taken on some of the protection role; monitoring the status of inputs and outputs and where necessary restricting or isolating the equipment. This report refers to a "lock-out" as a situation where a component's operation has been stopped by a software-based protection system.

Permanent lock-outs are in place to protect against on-board risks with high severity such as fire and electrocution, which could occur when damaged components get reenergised. A permanent lock-out requires a technician with a laptop to physically connect to the train and reset the lock-out.

Temporary lock-outs are in place to protect against risks with low severity following a short-lived system fault or mal-operation. In such cases the train either resets itself as soon as the fault is cleared, or the train driver resets the software system using a Battery Reset Process.

During the 9 August power supply disruption, the Class 700 and Class 717 rolling stock were immobilised by safety system interventions. All Class 700 and 717 trains had been programmed by Siemens to operate from a power supply of a nominal 50.0Hz, with a minimum frequency of 49.0Hz. When the software detected that the frequency had dropped below this level, it operated as designed, disconnecting the traction drive within 200ms.

Individual trains within the fleets had different software levels installed, as a software change was being implemented progressively across the fleets. On detecting the frequency drop, the units with software version 3.25.x went into a temporary lock-out while the units with version 3.27.x went into permanent lock-out. The drivers were able to reset units with a temporary lock-out by carrying out a battery reset, while the units with a permanent lockout required a technician to attend to perform a reset.

3.2 Implementation of Permanent Lock-out

The two software versions reacted differently as the later version 3.27.x software was intended to address what had been identified as a safety risk linked to the earlier software version 3.25.x. Siemens identified that there could be circumstances where the Train Control Management System (TCMS) locked out a train system in response to a serious fault or out-of-specification condition that could lead to a safety incident, only for the driver to perform a battery reset. This cleared the lockout and allowed power to be restored to the fault which could make the incident worse. This could readily occur because there are many scenarios that are cleared by a battery reset, only some of which actually link to a safety-related fault or out-of-specification condition. The driver may be unaware of what type of fault caused the TCMS to operate and use a battery reset as a means of regaining control of the train in order to keep the railway service operating. This could re-establish potentially damaging fault conditions, worsening the situation and potentially creating safety risks.

In order to prevent the situation arising where a driver is unaware of a safety-related fault or out-of-specification condition and carries out a battery reset with the potential to worsen the situation, Siemens decided to implement a “permanent lock-out” in software version 3.27.x that could not be cleared by a battery reset. Such a permanent lock-out would require a technician to attend the train and perform an analysis of the causes of the lock-out before clearing it. Siemens identified a range of trigger conditions for the permanent lock-out, intended to be those conditions that could be made worse by clearing a lock-out that had been imposed. Among the conditions selected was the detection of a low power supply frequency.

3.3 Implications of permanent lock-out

The imposition of a lock-out when the supply frequency is outside of specified limits is understood to be a protection against the generation by the 4QC of electromagnetic interference in a range that can affect signalling circuits. Such protection is only required when the power supply is not in the specified frequency range, and therefore the lock-out could be permitted to automatically reset when the supply frequency returns to its nominal value. This appears likely to result in the minimum of disruption without increasing safety risks. However, power supply frequency excursion of the magnitude experienced are unusual, so the service-disrupting implications of imposing a lock-out requiring a driver or – as in this case – a technician to reset appear not to have been given weight when developing the protection parameters for the on-train software.

Most permanent lock-outs are triggered by events relating to the train itself, which are unlikely to arise simultaneously on multiple trains. Variations in the power supply frequency, however, affect many trains at the same time and result in the same response from all trains that have the same software. It appears therefore that the collective response of the Class 700 and 717 trains to the out-of-specification supply frequency was in accordance with the software design, but was not an explicit intention. Siemens accepts that the temporary reduction in frequency should not have been considered a situation that requires a permanent lock-out.

3.4 Applicable standards

The trains were introduced using the interoperability process imposed by the Railways (Interoperability) Regulations 2011, which requires compliance with Technical Specifications for Interoperability (TSI). Standard BS EN 50163:2004 is mandated by the Energy TSI. Although it allows a frequency range down to 47Hz, it also goes on to note, *"Note 2: In practice, the variation of frequency is more closely controlled in Europe than stated above. Vehicles will operate only within frequency tolerances 25kV/50Hz range from 49Hz to 51Hz. If the frequency is out of this range, the vehicles performance may be reduced or the vehicle drives shall be disconnected*" [BS EN 50163:2004+A1:2007 Clause4.2 Note 2].

In an interim email to ORR, Siemens stated, "*The original design of the class 700 is for the 4QCs to stop pulsing when the line frequency is out of range and automatically restart when the frequency come back in range. This does not require driver action. With the hysteresis implemented, the 4QCs lock when line frequency drops below 49Hz and they restart when the frequency rises above 49.5Hz*."

4.0 Conclusion

Although the power disruption of 9th August 2019 led to severe delays to the rail network, in many ways the network responded well. The vast majority of the rolling stock was unaffected and there was minimal disruption to the signalling system. Considering the geographic area over which the power supply disruption took place, its impact on railway services can be considered to have been much less than a more localised day-to-day operational incident such as a dewirement.

23 trains were evacuated without incident. Passengers delayed appeared to accept the situation was out of the control of Network Rail and were able to claim compensation. As a result, compensation payments claimed by the public increased but complaints did not.

Network Rail’s electrical system reacted well although some resilience issues were identified. Network Rail have begun work to ensure, where necessary, adequate back up supplies are available for non-traction essential supplies and are working with the DNO to improve resilience.

The significant delays encountered by most passengers could be attributed to the permanent lock-out of some of the Class 700 and Class 717 trains. Findings so far revealed that TCMS software classed the reduction in frequency as a scenario which required a permanent lock-out.

The permanent lock-out resulted in 30 trains running the upgraded software to be effectively stranded on the network and therefore requiring a technician reset. This resulted in significant delays for the entire network and significant knock on effects that lasted beyond the initial incident. However, full service was restored within 24hours.

So far, ORR has not been able to establish any non-compliance with *The Railways (Interoperability) Regulations 2011*, as amended, that could warrant an enforcement action. The findings are lessons learned that will be fed back for awareness and improvement.

5.0 Actions and Recommendations

- Siemens to implement a software patch which will be installed on all the Class 700 and Class 717 trains to stop them going into permanent lock-out in the event of frequency drop.

- Siemens to check software to ensure all scenarios leading to permanent lock-out are appropriate

- All TOCs are to be notified of the risk of the train protection system resulting in an unintended reaction. Adequate check needs to be carried out, and corrective actions where necessary, to prevent reoccurrence.

- Network Rail to engage with DNOs to verify the impact of LFDD on low voltage power supplies on the wider railway, particularly in areas suspected to have been affected, and take actions to improve resilience where necessary.

- Network Rail to review resilience of traction power supplies in the area affected by LFDD and take improvement actions.

List of Acronyms

4QC 4 Quadrant Chopper

BEIS Department for Business, Energy and Industrial Strategy

DNO Distribution Network Operator

ESO Electricity System Operator

GTR Govia Thameslink Railway

LFDD Low Frequency Demand Disconnection

Ofgem Office of Gas and Electricity Market

OLE Overhead Line Equipment

ORR Office of Rail and Road

SQSS Security and Quality of Supply Standards

TCMS Train Control Management System

TSI Technical Specification for Interoperability

Glossary of Terms

4QC	Four Quadrant Chopper – for converting a fixed DC input to a variable DC output. It is connected to the train control and communication network for specific operations.
Converter	Converts an alternating current to direct current
DNO	Distribution network operators licenced to distribute electricity which is transmitted to them by National Grid
Frequency	Frequency of oscillations of alternating current (AC) in an electric power grid transmitted from a power station to the end user
GSM-R	Global System for Mobile Communications – Railway or GSM-Railway is an international wireless communications standard for railway communication and applications.
Hz	Hertz - the SI unit of frequency
OLE	Overhead Line Equipment - supplies electrical power to trains
Rectifier	An electrical device which converts an alternating current into a direct one by allowing a current to flow through it in one direction only
TCMS	Train Control & Management System (TCMS) is a train-borne standard control, communication and train management system