Appendix D
Fault Levels
D.1

Short Circuit Currents

Three phase to earth and single phase to earth short circuit current analyses have been conducted by each Transmission Licensee (SHETL, SPT and NGET), in respect of their own Transmission Areas, in accordance with Engineering Recommendation G74 (ER G74). The series of tables presented in Appendix D, list the results of these analyses. To assist the reader in understanding the results, the next section of this chapter explains some of the salient points relating to the short circuit calculations including assumptions made and terminology used.

The listed currents should be regarded as indicative and therefore used as a general guide only. If customers require more detailed information relating to specific sites they may contact us as described in “Further Information” in Chapter 1.

Furthermore, although the short circuit duties at a node may at times exceed the rating of the installed switchgear, the switchgear may still not be overstressed for one or more of the following reasons:

- the topology of the substation is such that the switchgear is not subjected to the full fault current from all of the infeeds connected to that node. This is the case for feeder/transformer circuit breakers and mesh circuit breakers under normal operating conditions;
- switchgear is only subjected to excessive fault current when sections of busbar are unselected. This is the case for busbar coupler/section circuit breakers. On these occasions the substation can usually be temporarily re-switched or segregated to reduce the fault level; or
- re-certification of switchgear or modifications to it is already in hand that will remove the overstressing.

Finally, please also note that substation running arrangements are subject to variation. The running arrangements used for determining the short circuit currents presented in Appendix D may, in some cases, differ slightly from those presented elsewhere in this Statement.

Engineering Recommendation G74

International Standard IEC909, "Short-Circuit Current Calculation In Three Phase AC Systems" was issued in 1988 and has subsequently been published as British Standard BS7639. When IEC909 was issued the Electricity Supply Industry had no standard method or uniform methodology for fault level calculation. The hand calculation methodology detailed in IEC909 was considered conservative for the UK supply system and it was believed that its application could lead to excessive investment. In consideration of this potential excessive investment, an industry wide working group was established in 1990 to define "good industry practice" for the calculation of short circuit currents.

The resulting document, ER G74, defines a computer based method for calculation of short circuit currents which is more accurate than the methodology detailed in IEC909 and, as a consequence, potential capital investment is more accurately identified. ER G74 has been registered under the Restrictive Trade Practices Act (1976) by the ENA and the associated Statutory Instrument has been signed to this effect.

Short Circuit Current Calculation

Sophisticated computer programs are used for the purpose of conducting short circuit current analyses. Each analysis is based on an initial condition from an AC load flow and is carried out in accordance with ER G74. The broad calculation methodology is summarised in the following paragraphs.

When assessing the duties associated with busbars, bus section/coupler circuit breakers and elements of mesh infrastructure, it is assumed that all connected circuits contribute to the fault. When assessing the duties associated with individual feeder/transformer circuits it is assumed that the fault occurs on the circuit side of the circuit breaker with the remote ends of the circuit open. These represent the most onerous conditions in each case.

Short-circuit currents are calculated using a full representation of the NETS. Directly-connected and Large embedded generating units are also discretely represented with their electrical parameters based on data provided by the owner of the generating unit. Other Network Operators’ networks are represented by network equivalents at the interface between the NETS and the Network Operator's network. For example, a DNO network
connected to a 132kV busbar supplied by SGTs will usually be represented by a single network equivalent in the positive phase sequence (PPS) and zero phase sequence (ZPS) networks. The use of network equivalents allows short-circuit currents in the NETS to be calculated with acceptable accuracy and provides a good indication of the magnitude of the short-circuit currents at interface substations. Short-circuit currents quoted in Appendix D for interface substations are not, however, suitable for specifying short-circuit requirements for new switchgear at the interface substations. These will need to be agreed between the relevant Transmission Licensee and the Network Operator on a site specific basis.
The short circuit current is made up of an AC component with a relatively slow decay rate as shown in Figure D.1 and a DC component with a faster decay rate as shown in Figure D.2. These combine into the waveform shown in Figure D.3. The waveform in Figure D.3 represents worst case asymmetry and as such will be infrequently realised in practice.

**Figure D.1**

**AC Component of Short Circuit Current**

**Figure D.2**

**DC Component of Short Circuit Current**

**X/R Ratio**

The DC component decays exponentially according to a time constant which is a function of the X/R ratio. This is the ratio of reactance to resistances in the current paths feeding the fault. High X/R ratios mean that the DC component decays more slowly.

**DC Component**

The DC component of the peak make and peak break short-circuit currents are calculated from two equivalent system X/R ratios. An initial X/R ratio is used to calculate the peak make current, and a break X/R ratio is used to calculate the peak break current. Calculation of the initial and break X/R ratios is undertaken in accordance with IEC 60909-0 (2001-07) Method C (also known as the equivalent frequency method). We consider the equivalent frequency method to be the most appropriate general purpose method for calculating DC short-circuit currents in the NETS.

The DC component of short-circuit current is calculated on the basis that full asymmetry occurs on the faulted phase for a single phase to earth fault or on one of the phases for a three phase to earth fault.
Making Duties

The making duty on bus section/bus coupler breakers is that imposed when they are used to energise an unselected section of busbar which is either faulted or earthed for maintenance. Substation infrastructure such as busbars, supporting structures, flexible connections, conductors, current transformers, wall bushings and disconnectors must also be capable of withstanding this duty.

The making duty on individual circuits is that imposed when they are used to energise a circuit which is either faulted or earthed for maintenance. This encompasses the persistent fault condition associated with Delayed Auto-Reclose (DAR) operation.

Breaking Duties

Bus section/coupler breakers are required to break the fault current associated with infeeds from all connected circuits if a fault occurs on an uncommitted section of busbar. Circuit breakers associated with a feeder/transformer or a mesh corner are required to break the fault current on the basis that the circuit breaker is the last circuit breaker to open clearing the fault.

Circuit breakers associated with faulted circuits are required to interrupt fault current in order to safeguard system stability, prevent damage to plant and maintain security and quality of supply.

Initial Peak Current

In Figure D.3, both the AC and DC components are decaying and the first peak will be the largest and occurs at about 10ms after the fault occurrence. This is the short circuit current that circuit breakers must be able to close onto in the event that they are used to energise a fault; hence this duty is known as the Peak Make. However, this name is slightly misleading because this peak also occurs during spontaneous faults. All equipment in the fault current path will be subjected to the Peak Make duty during faults and should therefore be rated to withstand this current. The Peak Make duty is an instantaneous value.

Figure D.3
Combined AC and DC Components of Short Circuit Current

RMS Break Current

This is the RMS value of the AC component of the short circuit current at the time the circuit breaker contacts separate (see Figure D.1), and does not include the effect of the DC component of the short circuit current.

DC Break Current

This is the value of the DC component of the short-circuit current at the time the circuit breaker contacts separate (see Figure D.2).
Peak Break

As both the AC and DC components are decaying, the first peak after contact separation will be the largest during the arcing period. This is the highest instantaneous short circuit current that the circuit breaker has to extinguish, hence this duty is known as the Peak Break. This duty will be considerably higher than the RMS Break because, like the Peak Make duty, it is an instantaneous value (therefore multiplied by the square-root of 2) and also includes the DC component.

Choice of Break Time

The RMS Break and Peak Break will of course be dependent on the break time. The slower the protection, the later the break time and the more the AC and DC components will have decayed. For the purposes of this Statement a uniform break time of 50ms has been applied at all sites. For the majority of our circuit breakers, this is a fair or pessimistic assumption. In this context it should be noted that the break time of 50ms is the time to the first major peak in the arcing period, rather than the time to arc extinction.
Generator Infeed Data

All generating units of directly connected large power stations are individually modelled together with the associated generator transformers. Units are represented in terms of their Positive Phase Sequence (PPS) sub transient and transient reactances (submitted under the provision of Grid Code), as well as the DC stator resistances and Negative Phase Sequence (NPS) reactances (neither of these data items are submitted under the Grid Code but the stator resistance value is currently derived or assumed from historic records and the NPS reactance is calculated as the average of the relevant PPS sub transient reactance \((X_{d}'' + X_{q}'')/2\). Fault level studies for planning purposes are carried out under maximum plant conditions (i.e. with all Large power stations included whether contributory or not) to simulate the most onerous possible scenario for a future generation pattern.

Auxiliary System Infeed Data

The induction motor fault infeed from the station board is modelled at the busbar associated with the station transformer connection. Where sufficient information is not available, it has been assumed that Auxiliary Gas Turbines are connected to the station boards as well as to the main generating units in order to simulate the most onerous condition. Where the X/R Ratio has not been provided, a value of 10 has been assumed.

Where the information is available, the fault infeed from the unit board, due to induction motors and auxiliary gas turbines, is modelled as an adjustment to the main generator sub-transient reactance. A more detailed model of the power station system may have to be used to assess fault levels when station and unit boards are interconnected.

GSP Infeed Data

Infeed data for induction motors and synchronous machines at GSPs is submitted by Users under the provision of the Grid Code. Infeeds from induction motors and synchronous machines are modelled as equivalent lumped impedances at the GSP.

Where the information is not available, 1MVA of fault infeed per MVA of substation demand, with an X/R ratio of 2.76 is assumed for all induction motors in the absence of more detailed data. This is in line with the requirements of ER G74.

Where more detailed fault level studies are required at 132kV or below, the associated system should be modelled in detail down to individual Bulk Supply Points (BSP’s). Induction motor infeeds should then be modelled at these BSP busbars.

LV System Modelling

Where interconnections exist between GSPs, these equivalents take the form of PPS impedances between those GSPs. The ZPS networks take the form of minimum ZPS values modelled as shunts at the GSP busbars.

Where interconnections to other GSPs do not exist, the equivalents take the form of equivalent LV susceptances modelled as shunts at the GSP busbar. The ZPS networks are modelled as shunt minimum ZPS values at the GSP busbars.

The values of PPS impedances between GSPs shunt LV susceptances and shunt ZPS minimum impedances are as submitted by the Users under the provision of the Grid Code.
The Fault Levels of a system provides a good indication of the strength of the network. It is important that it is calculated accurately to make sure that all electrical components are rated to withstand the Fault Current. Fault Level information in Great Britain for the most onerous system conditions – winter peak demand – can be viewed using the accompanying spreadsheet. The Fault Levels calculated here are based on the Gone Green Scenario covering SHE Transmission, SPT and NGET each year from 2013/14 to 2022/23 excluding 2020/21 and 2021/22.