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Engineering Recommendation P25

Issue 2 2017

The short-circuit characteristics of single-phase and three-phase low voltage distribution networks.

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Amendments since publication

Issue	Date	Amendment
Issue 2	2017	Major revision of Issue 1 to address the following points. • Content from P25 Issue 1 and P26 Issue 1 amalgamated in a single document. • References to normative Standards updated. • Update terms in document, for example 'PES' now described as 'DNO'. • Re-calculation of fault levels for range of service lengths. The principal technical changes are described below. Title: Document title changed from '*The Short-Circuit Characteristics of Public Electricity Suppliers' Low Voltage Distribution Networks and the Co-ordination of Overcurrent Protective Devices on 230V Single Phase Supplies up to 100A'* to '*The short-circuit characteristics of single-phase and three-phase low voltage distribution networks'* on account of the amalgamation of P25 Issue 1 and P26 Issue 1. Foreword: new clause added to provide publishing information and description of who the document is intended for. Some of the content has been taken from P25 Issue 1 Clause 1 and Clause 7 (Responsibility). Introduction: the content from P25 Issue 1 and P26 Issue 1 has been consolidated and references updated (ESQCR replaces Electricity Supply Regulations 1988). Reference to ER P23 has been included.

		Scope: new clause added to define the supply types which are covered in the document. Some of the wording has been taken from the ‘Introduction’ in P25 Issue 1 and P26 Issue 1. Wording has been amended to clarify that both ‘existing’ and ‘planned’ supplies are covered. A new capacity limit for poly-phase LV supplies is set at 400 A per phase. A paragraph has been inserted to explain that the guidance in the EREC may not be full appropriate for interconnected-LV networks. Clause 2, Normative references: new clause added to capture all normative references. Previous references described in P25 Issue 1 Annex A have been updated and/or removed as appropriate. Clause 3, Terms and definitions: new clause added to capture all terms and definitions used in the document. Previous terms in P25 Issue 1 Annex A have been repeated. A considerable number of new definitions have been inserted which are now used in the document. Clause 4, The incoming service arrangements: New sub-clause 4.1: added to introduce the responsibilities of the customer, DNO and meter operator. Sub-clause 4.2 (P25 Issue 1, Clause 2): description of ‘looped’ service has been deleted, references and terms updated and description of BS 7671 Regulation 473.1.4 has been deleted and replaced with reference to Clause 7 of the document. A new Figure 1 replaces the description of a typical supply arrangement. A note has been inserted beneath Figure 1 highlighting the differing sizes of cut-out fuse-link which may be in use. The purpose of the cut-out fuse-link has also been clarified. Sub-clause 4.3 (P26 Issue 1, Clause 2): re-written to include a description of typical three-phase connection arrangements, a) and b). A new Figure 2 has been inserted to depict a typical supply arrangement. Clause 5, The PSCC on the DNO’s LV distribution network: Sub-clause 5.1 (P25 Issue 1 Clause 3 and P26 Issue 1 Clause 3): common aspects for both single-phase and three-phase are detailed, any duplicated content between the two previous documents has been deleted and editorial amendments completed. An explanation of how network capacity is related to PSCC value has been added. Sub-clause 5.2: new sub-clause inserted to introduce the theory of short-circuit currents and associated terminology. The content has been developed from BS EN 60909-0. Sub-clause 5.3: new sub-clause inserted to describe the parameters used to determine the PSCC values on the DNO’s LV network, and the basic formulae to calculate PSCC values. Sub-clause 5.4: the single-phase PSCC value of 16 kA as described in P25 Issue 1 Clause 3 has been changed to 19.6 kA as determined by latest calculation. A paragraph explaining the requirements for interconnected-LV networks has been added. Sub-clause 5.5: the three-phase PSCC value of 25 kA described in P26 Issue 1 Clause 3 has been changed to 25.9 kA. Reference to the previous 18 kA has been deleted. ‘415 V’ has been changed to ‘400 V’ to align with 230 V phase-to-earth. A paragraph explaining the requirements for interconnected-LV networks has been added. Clause 6, Contribution to PSCC from LV generation or motors: New clause and associated sub-clauses inserted to provide background and guidance on LV generation and LV motors which may be found on DNO LV networks.

		Clause 7, Estimation of the PSCC at the supply terminals: Sub-clause 7.1: new sub-clause inserted to introduce the concept of attenuation. A paragraph describing the significance of power factor has been repeated, previously described in P26 Issue 1, with the exception that ‘power factor’ has been changed to ‘X/R ratio’. Sub-clause 7.2: the content from P25 Issue 1 Clause 4 and Clause 5 has largely been repeated in this sub-clause with the following exceptions: ‘16 kA (p.f. 0.44)’ has been changed to ‘19.6 kA (X/R = 2.5)’ and a new sentence explaining the assumed ‘tee-off point’ has been added. Table 1: all values previously published in P25 Issue 1 Table 1 have been deleted and replaced with newly calculated values. PSCC values for service line lengths greater than 20 m have been removed. Sub-clause 7.3: the content from P26 Issue 1 Clause 4 and Clause 5 has largely been repeated in this sub-clause with the following exceptions: the previous paragraph relating to ‘18 kA’ and the associated Table 2 from P26 Issue 1 have been deleted, P26 Issue 1 Table 1 values have been deleted and replaced with newly calculated values. Sub-clause 7.4, Estimation of LV generation/motor contribution: new sub-clause inserted to provide guidance on the treatment of generation/motor short-circuit current contribution on LV networks. Clause 8, Selection of protective devices: Sub-clause 8.1: new sub-clause added to clarify general requirements for protection device selection. Previous content in P25 Issue 1 Clause 6 has been updated with new references to BS 7671 and ECA publication – *Guide to the Wiring Regulations*, and an explanation of the importance of X/R ratio when verifying a device rating has been added. Sub-clause 8.2 (P25 Issue 1 Clause 6): references have been updated as necessary. Bibliography: new clause added to capture information references. Details of all other technical, general and editorial amendments are included in the associated Document Amendment Summary for this Issue (available on request from the Operations Directorate of ENA).

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Foreword

This Engineering Recommendation (EREC) is published by the Energy Networks Association (ENA) and comes into effect from the date of publishing. It has been prepared under the authority of the ENA Engineering Policy and Standards Manager and has been approved for publication by the ENA Electricity Networks and Futures Group (ENFG). The approved abbreviated title of this engineering document is “EREC P25”, which replaces the previously used abbreviation “ER P25”.

Guidance relating to 230 V single-phase supplies and 400 V three-phase supplies, previously provided in ER P25 Issue 1 and ER P26 Issue 1, is now superseded by this Engineering Recommendation (EREC). ER P26 has been withdrawn.

The guidance in this EREC will be of interest to designers of customer low voltage (LV) installations and it is expected that such persons are conversant with the requirements of BS 7671 (IET Wiring Regulations).

This EREC provides guidance on the estimation of maximum prospective short-circuit current (PSCC) on the DNO LV network and at the supply terminals.

This EREC also provides commentary on the selection of protective devices based on the estimated PSCC.

The guidance contained in this EREC is given to the best of the authors’ knowledge, based on information available. No guarantee can be given however that the information will not change in the future. The DNO cannot be held responsible for costs incurred due to inaccuracies contained in this document or subsequent changes to the network. Where the reader of this EREC is in doubt regarding the guidance provided, they should consult the relevant DNO.

The term “should” is used in this document to express a recommendation. The term “may” is used to express permission.

NOTE: Commentary, explanation and general informative material is presented in smaller type, and does not constitute a normative element.

Introduction

The Electricity Safety, Quality and Continuity Regulations (ESQCR) 2002 (as amended) [N1] enforces statutory requirements for DNOs. ESQCR Regulation 28 requires the DNO to state the ‘maximum prospective short-circuit current at the supply terminals’.

ESQCR [N1] also places a responsibility on the customer to provide and maintain a safe electrical installation. Electrical installations which are designed to the requirements of BS 7671 are deemed to comply with the safety requirements in ESQCR [N1].

Regulation 612.11 of BS 7671 requires that the prospective fault current, under both short-circuit and earth fault conditions, be measured, calculated or determined by another method, at the supply terminals. This information may then be used in the selection of equipment in conjunction with appropriate Standards or manufacturer's information.

NOTE: ESQCR Regulation 28 also requires the DNO to state ‘the maximum earth loop impedance of the earth fault path outside the installation’. This is covered by ENA ER P23 [N3].

1 Scope

This Engineering Recommendation (EREC) provides guidance on the estimation of maximum prospective short-circuit current (PSCC) at the supply terminals of existing and planned electrical installations which are connected to DNO LV networks via a single-phase service rated up to 100 A or a poly-phase service rated up to 400 A per phase.

For three-phase supplies, where the arrangement consists of more than one separately protected three-phase service, direct from the DNO’s LV busbar in the substation, individual guidance should be given on application to the DNO.

The guidance in this EREC may not be fully appropriate for interconnected-LV networks which are prevalent in certain regions of the UK; for example in London, Merseyside, Wirral, and North Wales. Suitable guidance should be obtained direct from DNOs operating in such regions.

2 Normative references

The following referenced documents, in whole or part, are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Standards publications

BS HD 60269-3, BS 88-3, *Low-voltage fuses. Supplementary requirements for fuses for use by unskilled persons (fuses mainly for household and similar applications). Examples of standardized systems of fuses A to F*

BS EN 60909-0, *Short-circuit currents in three-phase a.c. systems. Calculation of currents*

BS EN 61439-3, *Low-voltage switchgear and controlgear assemblies. Distribution boards intended to be operated by ordinary persons (DBO)*

BS 7671:2008+A3:2015, *Requirements for Electrical Installations. IET Wiring Regulations*

Other publications

[N1] Statutory Instrument 2002 No. 2665, *The Electricity Safety, Quality and Continuity Regulations 2002 (as amended)*[1]

[N2] Meter Operator Code of Practice Agreement, www.mocopa.org.uk

[N3] ENA EREC P23, *Guidance on Earth Fault Loop Impedance at Customers' Intake Supply Terminals*

[N4] ENA EREC G81, *Framework for new low voltage housing development installations Parts 1-6*.

[N5] ENA TS 35-1 Part 1, *Distribution transformers. Part 1 Common clauses*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply

3.1
customer
person supplied or entitled to be supplied with electricity at any premises

NOTE: Customers will include both domestic and commercial/industrial supplies.

3.2
Distribution Network Operator (DNO)
person or legal entity named in the distribution licence to operate an electricity network

NOTE: Where an independent distribution network operator (IDNO) is present, it should be treated as a DNO for the purposes of this EREC.

3.3
LV
voltage not exceeding 1 000 V a.c. r.m.s.

3.4
HV
voltage above LV but less than or equal to 20 000 V a.c. r.m.s.

3.5
interconnected-LV network
LV network which operates with distribution substations interconnected via LV circuits

NOTE 1: Interconnected-LV networks generally exhibit higher short-circuit currents in comparison to radial LV networks.

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[1] S.I. 2012 No.381, *Electricity Safety, Quality and Continuity Regulations (Northern Ireland) 2012 (as amended)*, applies in Northern Ireland.

NOTE 2: Interconnected-LV networks are known to exist in London, Merseyside, Wirral, and North Wales.

NOTE 3: Radial LV networks serving high load density areas of major city centres may warrant the same treatment as interconnected-LV networks.

3.6
meter operator

registered authority under the Meter Operator Code of Practice Agreement (MOCoPA), installing and maintaining electricity meters

3.7
power factor (p.f.)

ratio of the real power, flowing to the load or from the generation plant, to the apparent power in the circuit

3.8
point of supply

point at which the customer installation is connected to the supply, following passage of the supply through the meter

3.9
rated breaking capacity

maximum value of current at which the device is capable of complying with a prescribed test duty cycle at the prescribed voltage and X/R ratio

3.10
root mean square (r.m.s.)

square root of the mean square of a set of values

NOTE 1: For a pure sine wave, as in a.c. waveforms – peak-to-peak = $2\sqrt{2}$ * r.m.s.

NOTE 2: 230 V a.c. is an r.m.s. value. Peak voltage (amplitude) is 230 V * $\sqrt{2}$ = 325.3 V.

3.11
short-circuit current

3.11.1
prospective short-circuit current (PSCC), I_{PSCC}

maximum current that would flow in a circuit, in the event of a short-circuit of zero impedance at the point of fault

NOTE 1: PSCC is measured as the r.m.s. value of the short-circuit current.

NOTE 2: The actual short-circuit current will be less if the protective device has a current limiting feature or an appreciable impedance.

NOTE 3: Referred to as ‘prospective fault current’ in BS 7671.

3.11.2
initial symmetrical short-circuit current, I''_k

RMS value of the a.c. symmetrical component of the short-circuit current at the instant of the fault

NOTE: Initial symmetrical short-circuit current is interpreted as the PSCC for the purposes of this EREC.

3.11.3
peak short-circuit current, i_p
instantaneous value of a short-circuit current, occurring at the first a.c. peak after fault inception

3.11.4
symmetrical short-circuit breaking current, I_B,
RMS value of the a.c. symmetrical component of the short-circuit current at the instant of contact separation of the first pole to open of a switching device

3.12
short-circuit location

3.12.1
far-from-generator
LV network location which has minimal or no contribution to the PSCC from LV generation and/or LV motors

NOTE 1: At a far-from-generator location, the magnitude of the symmetrical a.c. component of the prospective short-circuit current remains essentially constant

NOTE 2: Clause 6.2 and 6.4 of this EREC describes the criteria for assessing contribution from LV generation and LV motors.

3.12.2
near-to-generator
LV network location which has a contribution to the PSCC from LV generation and/or LV motors

NOTE: Clause 6.2 and 6.4 of this EREC describes criteria for assessing contribution from LV generation and LV motors.

3.13
supply terminals
ends of the electric lines situated upon any customer's premises at which a supply is delivered and, unless otherwise agreed in writing, where a meter is employed to register the quantity of the supply and is directly connected to those lines

NOTE 1: Referred to as ‘origin of an installation’ in BS 7671.

NOTE 2: The supply terminals are located ahead (towards the DNO LV network) of the point of supply.

3.14
X/R ratio
ratio of reactance to resistance, from the point of fault to the source

NOTE: The X/R ratio determines the peak short-circuit current and the rate of decay of the d.c. component.

4 The incoming service arrangements

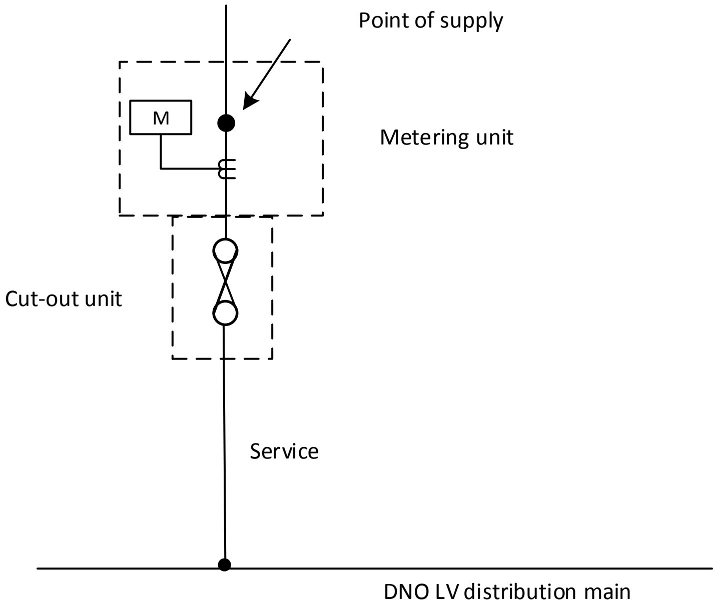
4.1 General

The user of this EREC should ensure they are familiar with the responsibilities of the customer, DNO and the meter operator. For the meter operator, the MOCoPA [N2] defines responsibilities.

4.2 Single-phase supplies

The DNO LV distribution main is overhead or underground and installed along the public pathway or road either at the front of the property or on the far side of the road. In new open plan housing estate developments the LV distribution main would normally be located in the public footpath at the front of the house. The service to individual customers is either overhead or underground and generally connected to the nearest point of the LV distribution main.

A single-phase service consists of a cut-out unit, as depicted in Figure 1 and is typically used for domestic and small commercial properties.



NOTE: New domestic supplies typically have an 80 A or 100 A cut-out fuse-link fitted. Older domestic supplies may have an 80 A or 60 A cut-out fuse-link fitted.

Figure 1 — Typical single-phase supply

The DNO cut-out fuse-link is installed to meet the requirements of ESQCR Regulation 24. The cut-out fuse-link protects the DNO's service from overcurrent but also provides protection against overcurrent in the zone between the output terminals of the cut-out and the supply terminals (point of supply). This zone includes the electricity meter(s) and any control devices installed for tariff purposes. Under the terms of the MOCoPA [N2], the responsibility for the connection between the cut-out and the meter rests with the meter operator.

The connections and equipment on the load side of the supply terminals (e.g. in the consumer unit) are the property and responsibility of the customer. Refer to Clause 8 for guidance on selection of protection device.

The DNO cut-out fuse-link may not clear faults on the customer's installation and the DNO cannot accept responsibility for consequential damage to the customer's installation. The DNO has the right to charge the customer the cost of supplying and fitting a replacement cut-out fuse-link in this event.

Author Note: The above paragraph is taken from the previous issue of P25. A suggestion is to remove as it may not be appropriate for this document. Do reviewers wish to retain it?

4.3 Three-phase supplies

Three-phase LV supplies are provided by an underground or overhead circuit and designed depending on the size and type of connection, and in accordance with the DNO's requirements. A number of possible arrangements are described below.

a) Three-phase cut-out unit and service, connected to the DNO LV distribution main (similar to Figure 1).

b) Three-phase cut-out and service, connected to the LV busbar at the DNO's substation, as depicted in Figure 2.

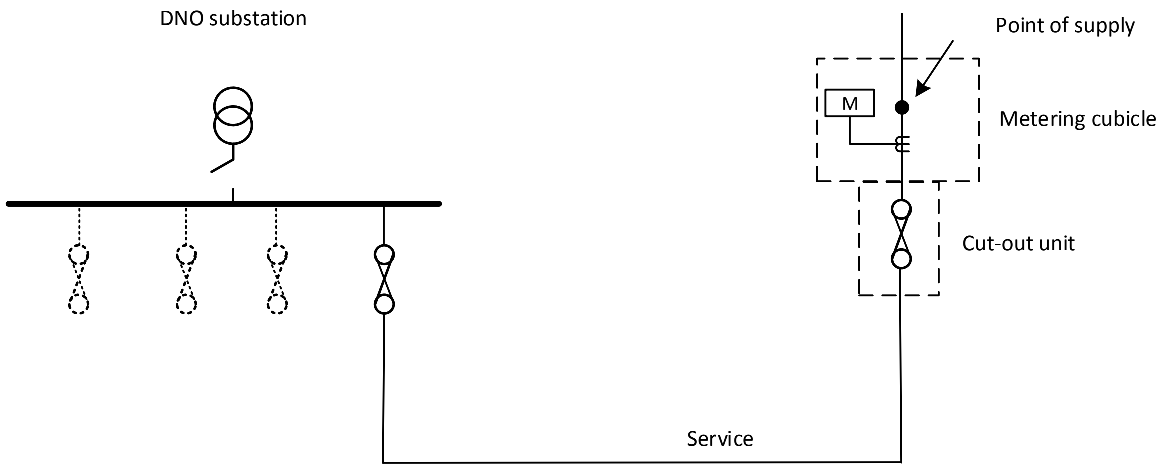


Figure 2 — Typical three-phase supply connected directly to the DNO substation

The requirements for three-phase supplies are generally the same as for single-phase supplies governed by ESQCR [N1] and defined in BS 7671 and the DNO's documentation.

5 The PSCC on the DNO’s LV distribution network

5.1 General

The PSCC at any point of the DNO’s LV network, including the customer's supply terminals, is governed largely by the network capacity, since this influences the rating of plant and equipment and the length of circuits which, in turn, affects the network impedance.

The PSCC can increase in the course of time, due to:

- increasing LV demand leading to additional capacity being created in the DNO network;
- connection of distributed generation to the DNO network;
- changes on the HV network (network reconfiguration or equipment replacement).

To avoid the need for repeated changes in the protective equipment and the consequent costs, DNOs normally design their LV network to a maximum PSCC and select the equipment for their network accordingly. This equipment includes the DNO’s switchgear, for example, the cut-out unit and fuse-link.

It is strongly recommended that designers of customer installations use the same philosophy when selecting equipment and ensure the short-circuit rating of equipment exceeds the maximum possible PSCC, particularly where it will be required to operate close up to the supply terminals.

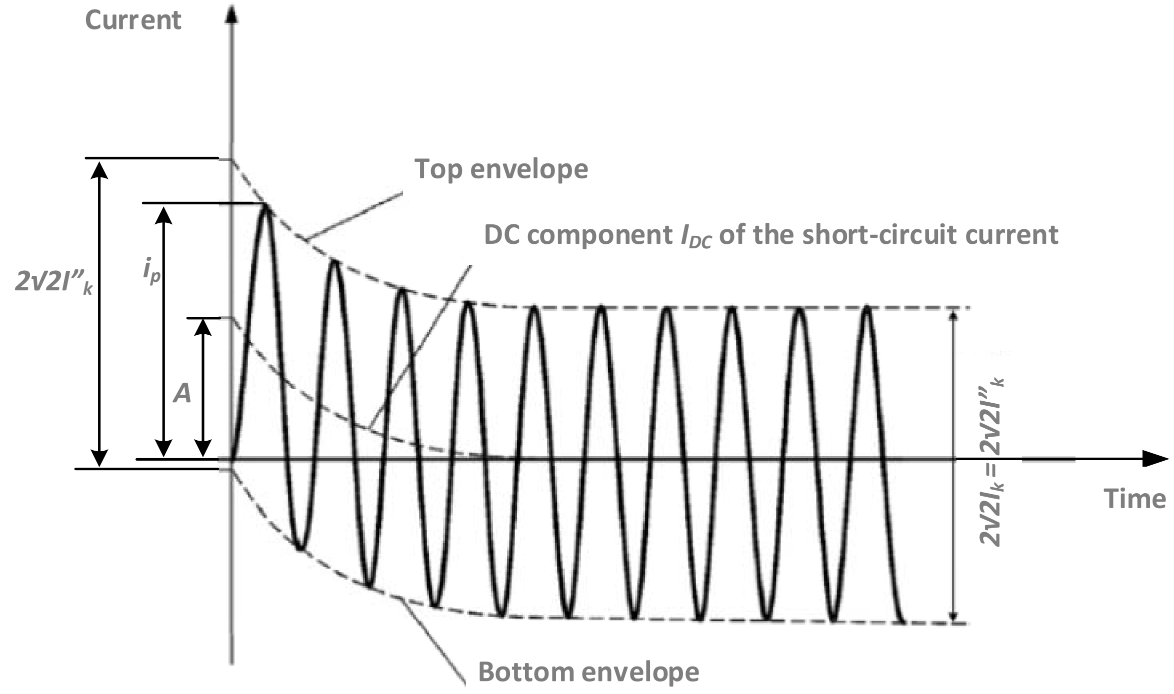
5.2 Short-circuit terminology

A thorough and complete calculation of short-circuit current will determine the currents as a function of time at the short-circuit location, from the start of the fault until it ends. In most cases, particularly for LV networks, a determination like this is not necessary. For LV faults, Ohm’s law can be used to calculate the short-circuit current – using the sum of the impedances from the source to the fault location – with sufficient accuracy. Nonetheless, it is useful to understand the terminology used in calculations and to appreciate the components of the current.

Short-circuit current may be considered as formed by two components:

- AC component;
- DC component, which decays exponentially at a rate dependant on the X/R ratio in the fault current path.

The variation of short-circuit current as a function of time is characterised by whether the short-circuit location is far-from-generator or near-to-generator, as explained in BS EN 60909-0. In general, short-circuits on LV networks are normally far-from-generator[2], and hence, the magnitude of the symmetrical a.c. component of the PSCC remains constant, as depicted in Figure 3. At locations near-to-generator, the magnitude of the symmetrical a.c. component of the PSCC decreases with time (relativity long compared to d.c. component decay).



Key

I''_k	initial symmetrical short-circuit current
i_p	peak short-circuit current
I_k	steady-state short-circuit current
i_{DC}	DC component of short-circuit current
A	initial value of the DC component i_{DC}

[BS EN 60909-0, Figure 1]

Figure 3 — Short-circuit current of a far-from-generator location with constant a.c. component.

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[2] BS EN 60909-0 Clause 7.1.1 requires short-circuit calculations to distinguish between far-from-generator and near-to-generator short-circuit. The IET publication, ‘Short-circuit Currents’ [3], presents the assumption that short-circuits in LV radial systems may be treated as far-from-generator short-circuits.

The initial symmetrical short-circuit current, I''_k, is an r.m.s. value of short-circuit current and can be interpreted as – PSCC, defined in this EREC.

The peak short-circuit current, i_p, is an instantaneous value of the short-circuit current and occurs at the first a.c. peak after fault inception. It is derived, using a formula, from the initial symmetrical short-circuit current and the X/R ratio. The value of i_p determines the peak make current for a circuit breaker.

The symmetrical short-circuit breaking current, $I_{B,}$ is the r.m.s. value of the short-circuit current at the instant of contact separation of the first pole to open of a switching device. This effectively determines the required rated breaking capacity of the switching device. In the case of most LV networks which are categorised as far-from-generator, then the value of I_B is identical to the value of the initial symmetrical short-circuit I''_k.

When the short-circuit location is near-to-generator, then the machine (generator or motor) will contribute to the current and hence, to the magnitude of quantities I''_k, i_p and I_B. Also, the magnitude of the initial a.c. component of PSCC decays with time for near-to-generator faults and so the current variation with time will appear different to that in Figure 3.

Clause 6 of this document describes how to categorise and treat LV networks which may be near-to-generator.

5.3 Basis of calculation of the maximum PSCC

Short-circuit calculations on the DNO's HV network are generally carried out using a software model, in accordance with ENA ER G74 [2]. However, for the DNO's LV network, the PSCC is generally determined by hand calculation using information about the DNO's network, such as: HV network fault level; the distribution transformer impedance; and the voltage at the secondary side of the distribution transformer.

The following values form the basis of the calculation of the maximum PSCC value.

a) DNO HV network fault level: 250 MVA (X/R ratio = 10).

b) Distribution transformer: three-phase transformer with maximum rating of 1 000 kVA, secondary phase-to-phase voltage of 433 V[3], and impedance of 4.75% (distribution transformer specification is covered by ENA TS 35-1 Part 1 [N5]).

Using the above values and also taking account of the size and length (impedance) of the LV distribution main and service cables connected to the transformer secondary, a maximum PSCC value is calculated.

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[3] 433 V is the no-load secondary voltage on the LV winding of a standard DNO distribution transformer. The nominal voltage of a DNO LV network is 400/230 V.

PSCC for a three-phase fault:

$$I_{PSCC} = \frac{E}{Z_1} or \frac{E}{Z_{SC}}$$

Where,

E = phase-to-neutral voltage

Z_1 = positive sequence impedance

Z_{SC} = phase impedance

NOTE: Z_1 is equivalent to Z_{SC}, which is the quadratic sum of reactances and resistances, upstream from the fault i.e. $\sqrt{R^2 + X^2}$

PSCC for a single-phase (phase-earth) fault:

$$I_{PSCC} = \frac{3E}{Z_1 + Z_2 + Z_0} or \frac{E}{Z_{EFLI}}$$

E = phase-to-phase voltage

Z_1, Z_2, Z_0, = Positive-, negative-, and zero-sequence impedances, respectively

Z_{EFLI} = earth fault loop impedance

NOTE: $(Z_1 + Z_2 + Z_0)/3$ is equivalent to Z_{EFLI}.

5.4 PSCC on the DNO’s LV distribution main

The maximum design value of the PSCC for single-phase 230 V supplies should be taken as 19.6 kA at the connection of the service to the LV distribution main.

For interconnected-LV networks, the PSCC value should be obtained from the relevant DNO. Such information is normally readily available from the DNO’s online library facility in respect of ENA EREC G81 [N4].

5.5 PSCC for three-phase LV supplies

The maximum design value of PSCC for three-phase 400 V supplies in situations where the service is connected direct to the LV busbar of the DNO's substation, should be taken as 25.9 kA.

In cases where the service is connected to DNO's LV distribution main, the maximum design value for the PSCC will be lower than 25.9 kA: the reduction being dependent on the length of LV distribution main and length of service.

For interconnected-LV networks, the PSCC value should be obtained from the relevant DNO. Such information is normally readily available from the DNO’s online library facility in respect of ENA EREC G81 [N4].

6 Contribution to PSCC from LV generation or motors

6.1 General

Generators and motors connected to an electrical network have the potential to contribute to the short-circuit current during a fault.

The type and rating of the generator or motors determines how much contribution there will be to the short-circuit current and whether the short-circuit is categorised as near-to-generator or far-from-generator.

Due to the design constraints on the DNO LV network, the rating of generator or motor that can be connected is much smaller than at the high voltage networks. Hence, it is common for short-circuits on the DNO LV network to be treated as far-from-generator.

The following types of generator and motor may be present on a DNO LV network.

a) A generator which is directly coupled to the DNO LV network.

b) A generator which is coupled via power electronics to the DNO LV network.

c) An induction motor is directly connected (coupled) to the DNO LV network.

6.2 LV direct coupled generation

There are generally two types of generator which could be directly coupled to the supply and may be present on the DNO LV network.

i. Synchronous generators.

   These machines rotate at a speed which is synchronised with the LV network frequency (50 Hz) and require a separate excitation power supply. If a short-circuit is applied to the terminals of a synchronous machine, the current will start out very high and decay to a steady-state value. Synchronous generators generally deliver six times rated current before decaying.

ii. Asynchronous generators, also known as induction generators.

   These machines rotate faster than synchronous speed and draw excitation power from the LV network. For short-circuits, an induction generator should be treated the same as an induction motor (see 6.3)

Synchronous generators may be present on the DNO LV network as part of a local power production process, e.g. biofuel generation, diesel generation etc. The DNO should be contacted for details of generation on the LV network.

In accordance with BS EN 60909-0, a near-to-generator short-circuit can be assumed if at least one synchronous generator contributes an initial short-circuit current which is more than twice the machine's rated current – which generally covers all synchronous generators.

6.3 LV generation coupled via power electronics

Power electronics are used with a variety of generation sources to create or convert voltage and current waveforms. The most common power electronics systems are inverters and converters and Figure 4 depicts a block diagram of typical systems connected to DNO LV networks.

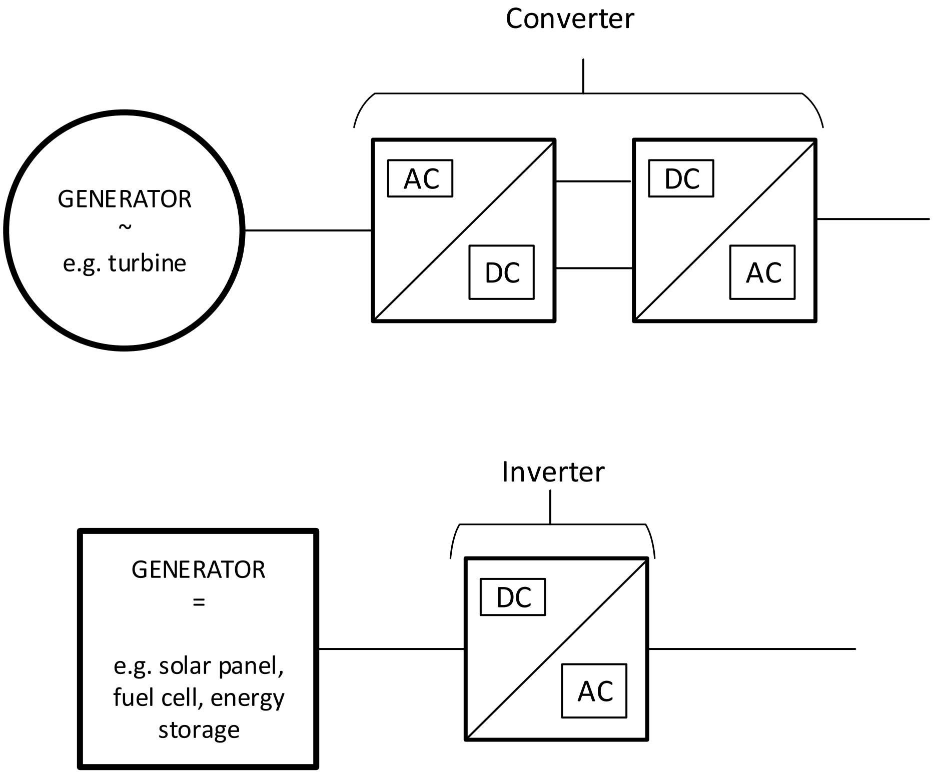

Figure 4 — Generators with power electronic interfaces

Inverters or converters do not behave the same as synchronous or induction machines. They do not have a rotating mass component; therefore, they do not develop inertia and have a much faster decaying envelope for fault currents.

For LV networks, the accepted engineering practice is to assess the short-circuit contribution of a power electronic connected generator at 1.2 times its rated current. Based on this assumption, power electronic connected generation provides insignificant or minimal contribution to the short-circuit current. However, if the current limitation of the unit is unknown or is greater than 1.2 times rated current, and there is a high density of such units on the LV network, the contribution to short-circuit current should not be assumed to be insignificant.

6.4 LV motors

For most applications, LV motors are asynchronous machines, otherwise known as induction motors.

If a short-circuit is applied to the terminals of an induction motor, the initial current will begin very high before decaying completely. The rate of decay is such than that induction machines do not normally contribute to the symmetrical short-circuit breaking current.

Induction motors generally deliver four to five times rated current before decaying. LV induction motors rated larger than 30 kW may be assumed to deliver five times rated current to the short-circuit and those rated smaller than 30 kW may be assumed to deliver four times rated current.

On the DNO LV network, there may a selection of machines present. It may be a very tedious exercise to determine the contribution of each individual induction motor. Hence, for simplification of short-circuit calculations and in accordance with BS EN 60909-0, groups of induction motors may be combined to a single equivalent motor.

In accordance with BS EN 60909-0, a near-to-generator short-circuit can be assumed if an induction motor contributes more than 5% of the initial symmetrical short-circuit current without the motors connected.

NOTE: The IET publication 'Short-circuit currents' [3] provides further background reading on asynchronous short-circuit contribution.

7 Estimation of the PSCC at the supply terminals

7.1 General

The maximum PSCC values described in Clauses 5.3 and 5.4 will be subject to attenuation by the service which should be accounted for to estimate the maximum PSCC at the customer's supply terminal.

An indication of the X/R ratio is provided in the following sub-clauses, which is of interest when selecting protective equipment (see Clause 7). The X/R ratio indicated is calculated for fault conditions and does not relate to the X/R ratio of the installation under normal load conditions.

7.2 Single-phase supplies

Table 1 shows the maximum PSCC and associated X/R ratio, for a range of service lengths, based on a PSCC of 19.6 kA (X/R = 2.5) at the tee-off point, for a single 100 A service. The tee-off point is assumed to be at 15 m along a 300 mm^2 cable[4], which is connected to the LV busbar at the DNO's substation. Two sets of values are given in Table 1 to account for the range and sizes of cables and overhead lines in use by the DNOs.

The service length may be measured or estimated from site plans as the shortest distance from the edge of the footpath nearest the installation to the service cut-out. Even if the position of the LV distribution main is known to be on the far side of the road, this additional length should not be included since it is not uncommon to increase the capacity of the LV distribution network by installing additional LV distribution mains.

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[4] Cable resistance (phase and neutral): R = 0.1242 Ω/km. Cable reactance (phase and neutral): X = 0.067 Ω/km.

For the majority of installations covered by this EREC, the customer’s switchgear will be positioned within a metre of the DNO cut-out unit. Where this is not the case, for example in some forms of multiple-occupancy building, the designer may wish to allow for the additional attenuation in PSCC due to the length of DNO cable between the cut-out and the customer's switchgear. The designer may find it convenient to add the service length estimated to the length of the DNO cable within the installation and read the PSCC from Table 1. Alternatively the PSCC estimated at the cut-out may be used as a basis for calculating additional attenuation.

Table 1 — Estimated maximum PSCC at the DNO cut-out based on declared level of 19.6 kA (X/R = 2.5) at the connection of the service to the LV distribution main

Length of service (m)	Up to 25 mm^2 Al or 16 mm^2 Cu Service cable or Overhead line		Up to 35 mm^2 Al or 25 mm^2 Cu Service cable or Overhead line	
	PSCC (kA)	**X/R**	**PSCC (kA)**	**X/R**
0	19.6	2.5	19.6	2.5
1	17.0	2.0	17.9	2.0
2	14.8	1.7	16.2	1.7
3	13.2	1.5	14.7	1.4
4	11.8	1.3	13.4	1.3
5	10.6	1.2	12.3	1.1
6	9.7	1.1	11.4	1.0
7	8.8	1.0	10.5	0.9
8	8.2	1.0	9.8	0.9
9	7.6	0.9	9.1	0.8
10	7.1	0.9	8.5	0.7
11	6.6	0.8	8.0	0.7
12	6.2	0.8	7.6	0.7
13	5.8	0.8	7.1	0.6
14	5.5	0.7	6.8	0.6
15	5.2	0.7	6.4	0.6
16	5.0	0.7	6.1	0.5
17	4.8	0.7	5.9	0.5
18	4.5	0.6	5.6	0.5
19	4.3	0.6	5.4	0.5
20	4.2	0.6	5.2	0.5

7.3 Three-phase supplies

Table 2 shows the maximum PSCC and associated X/R ratio, at the service entry position for services connected direct to the LV busbar in the DNO's substation. A range of PSCC values are provided for different service sizes, and lengths up to 50 m.

To use the Table 2 it is necessary to ascertain the length and cross-sectional area of the service phase conductors which should normally be available from the DNO.

In the case where the supply terminals are a cut-out arrangement and the customer's switchgear is positioned more than one metre electrically from the cut-out, the designer may wish to allow for additional attenuation in the PSCC due to the length of cable between the cut-out unit and the customer's switchgear. The designer may find it convenient to add the service length estimated to the length of cable within the installation and read the PSCC from Tables 2. Alternatively, the PSCC estimated at the cut-out may be used as a basis for calculating the additional attenuation.

Tables 2 values are based on standard aluminium cables in metric sizes. Table 3 gives approximate equivalent sizes of copper conductor in metric and imperial units and of aluminium conductor in imperial units.

Table 2 — Estimated maximum PSCC at the DNO cut-out based on declared level of 25.9 kA (X/R = 4.1) at the connection of the service to the LV busbar in the DNO's substation.

Length of service (m)	Service cross-sectional area									
	95 mm² Al		120 mm² Al		185 mm² Al		240 mm² Al		300 mm² Al	
	PSCC (kA)	X/R	PSCC (kA)	X/R	PSCC (kA)	X/R	PSCC (kA)	X/R	PSCC (kA)	X/R
0	25.9	4.1	25.9	4.1	25.9	4.1	25.9	4.1	25.9	4.1
5	23.6	2.3	23.9	2.5	24.4	3.0	24.6	3.2	24.7	3.3
10	21.1	1.6	21.9	1.9	22.9	2.3	23.2	2.6	23.5	2.9
15	18.8	1.3	20.0	1.5	21.4	2.0	22.0	2.3	22.4	2.5
20	16.8	1.1	18.2	1.3	20.1	1.7	20.8	2.0	21.3	2.3
25	15.1	0.9	16.7	1.1	18.8	1.5	19.7	1.8	20.3	2.1
30	13.7	0.8	15.3	1.0	17.7	1.4	18.7	1.6	19.4	1.9
35	12.5	0.7	14.1	0.9	16.6	1.3	17.8	1.5	18.6	1.8
40	11.4	0.7	13.1	0.8	15.7	1.2	16.9	1.4	17.8	1.7
45	10.5	0.6	12.1	0.8	14.8	1.1	16.1	1.3	17.0	1.6
50	9.8	0.6	11.3	0.7	14.0	1.0	15.4	1.3	16.4	1.5

Table 3 — Approximate equivalent cable sizes for use with Table 2.

Aluminium metric cable (mm^2)	Copper metric cable (mm^2)	Copper imperial cable (in^2)	Aluminium imperial cable (in^2)
70	35	0.06	0.1
95	-	-	-
120	70	0.1	0.15
150	95	-	0.2
185	-	0.15	0.25
240	120	0.20	0.3
300	185	0.25	0.4

7.4 Estimation of LV generation/motor contribution

7.4.1 Synchronous machines

Where a synchronous LV generator is connected to the DNO LV network, it should be accounted for in the short-circuit current calculation. It is preferable to undertake a short-circuit calculation in accordance with BS EN 60909-0, using an appropriate network modelling tool or mathematical spreadsheet calculation. Details of the DNO substation transformer, synchronous generator(s) and relevant cable/overhead circuits (resistance and reactance values per km), should be obtained from the DNO.

The synchronous generator(s) will contribute to the PSCC at the DNO LV busbars and the values in Table 4 may be useful when undertaking calculations.

Table 4 — Synchronous generators, typical contributions to PSCC at DNO LV busbars

Three-phase synchronous generator rated power (kVA)	Contribution to PSCC at DNO LV busbars (kA)
100	0.45
200	0.9
300	1.8
400	2.7

Notes:

1. The synchronous generators in this table are assumed to deliver six times rated current to the initial symmetrical short-circuit current.
2. It is assumed that the synchronous generators are directly connected to the DNO LV busbar on a cable of negligible impedance.
3. The contribution values are applicable for a 3-phase fault.
4. The contribution values have been determined with only one generator running.

5 The PSCC at the DNO LV busbars will be subject to attenuation on the LV distribution main and/or service, as described in Clause 7.2 and Clause 7.3.

7.4.2 Asynchronous (induction) machines

For a PSCC value of 25.9 kA at the DNO LV busbars, the minimum size of induction machine that should be considered during short-circuit calculations is an equivalent three-phase 200 kVA unit or aggregated units exceeding 200 kVA. This assumes that the machine is capable of delivering five times its rated current to the initial symmetrical short-circuit current.

The designer should aggregate the sizes of all known induction machines on the LV network. Three-phase induction generators and motors should aggregated. Identical single-phase units can be considered by combining in groups of three to represent one three-phase unit.

Heat pumps are common in parts of the UK as a source of domestic heating. Such units normally contain an induction motor (compressor) which may be driven via power electronics or directly from the supply.

A heat pump which incorporates a directly coupled motor may require consideration during short-circuit calculation. If it is assumed that the induction motor is single-phase with a full load current of 16 A, three such units would be equivalent to a three-phase 12 kVA induction motor. Fifty-four such units would be equivalent to a three-phase 216 kVA induction motor. Hence, if there is a high density of heat pumps on an LV network, and more than fifty single units, these should be considered during the short-circuit calculations.

Only induction machines which are running at the time of the fault will contribute to short-circuit current. A worst case scenario would be to assume that all induction machines are running prior to the occurrence of a fault.

As an estimate, an equivalent three-phase 200 kVA induction machine will contribute 1.1 kA to the PSCC at the LV busbars i.e. increasing the value to 27 kA.

8 Selection of protective devices

8.1 General

It is the designer’s responsibility to select protective devices for protection of the customer installation against fault current in accordance with Regulation 434 of BS 7671.

If the rated breaking capacity of the proposed device is equal to or greater than the maximum PSCC as stipulated in Clause 5 or as estimated in Clause 7, no further consideration may be necessary.

In accordance with Regulation 434.3 of BS 7671, a protective device at the supply terminals may not be needed if, the DNO “installs one or more devices providing protection against fault current and agrees that such a device affords protection to the part of the installation between the origin and the main distribution point of the installation where further protection against fault current is provided”. It should be noted that in practice, an agreement with the DNO does not normally exist.

When performing short-circuit calculations, it is important to consider the X/R ratio. The higher the X/R ratio, the greater the degree of magnetic energy stored in the system and so the greater is the energy of the arc (higher the fault current) which the protection has to control. Therefore, when verifying the ratings of electrical equipment, both rated breaking capacity and the X/R ratio should be taken into consideration.

NOTE: The reader may be aware of the publication by the Electrical Contractors’ Association (ECA) – Guide to the Wiring Regulations [1]. This publication provides guidance on selection of circuit-breakers which may prove informative. However, the designer should take responsibility when ascertaining the required rating of protective devices.

8.2 Single-phase supplies

For single-phase supplies, when the rated breaking capacity of the protection equipment is less than the maximum PSCC it is possible to allow at the design stage for the limitation in fault energy let through by the DNO cut-out fuse (see BS 7671 Clause 435.5.1). If this option is used, the designer should assume that the cut-out will contain a 100 A fuse-link to BS HD 60269-3, BS 88-3. The designer should also take into account the requirements in BS 7671 to avoid danger and minimise inconvenience in the event of faults (Regulation 314.1).

In order to assist designers in selecting protective devices in conjunction with the limitation in energy let-through of the DNO cut-out fuse-link, the conditional testing procedure has been established in Annex ZB of BS EN 61439-3. Whenever devices are selected on the basis of the conditional test the designer should ensure that the conditions that pertain within the installation are not more onerous than those required by BS EN 61439-3.

8.3 Three-phase supplies

Installations supplied by a three-phase service which consist only of separated single-phase equipment, so that there is no possibility of a phase-to-phase fault within the installation, may be regarded so far as the selection of protective equipment is concerned, as single-phase installations. In such cases for service line sizes up to 35 mm^2 the guidance given for single-phase supplies in this EREC may be applied.

Bibliography

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

[1] Electrical Contractors' Association (ECA) *Guide to the Wiring Regulations 17th Edition IEE Wiring Regulations (BS 7671: 2008)*

[2] ENA ER G74, *Procedure to meet the requirements on IEC 60909 for the calculation of short-circuit currents in three-phase AC power systems*

[3] IET Power and Energy Series 51, *Short-circuit Currents*, J. Schlabbach, 2005, ISBN 978-0-86341-514-2

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