

Guidance Document

G0111 DC Protection and Commissioning

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1 Purpose

- 1.1** The purpose of this Guidance is to provide guidance on each clause of the Standard S1111 together with informative attachments on particular protection systems. This document is structured such that each clause of the Standard is given followed by guidance. The clause numbering replicates the numbering used within the Standard for ease of cross-reference.
- 1.2** The purpose of this Standard is to define the requirements for the determination of protection settings and for the commissioning of d.c. protection systems to ensure that protection systems will function correctly for the conditions specified in this Standard.

Guidance:

DC protection is vital to the safe operation of the LU system, Engineering Standard S1111 sets requirements for the determination and verification of d.c. protection settings and ensures that management control systems and procedures are employed and detailed records are maintained.

7 gives guidance of the process in the form of a flow chart.

2 Scope

- 2.1** This Guidance applies to all 630V d.c. and 750V d.c. circuits derived from traction sub-stations. The d.c. Traction Supply system nominal voltage shall be 630V or 750V as defined in LU Standard 1-122 for the various Underground Lines, which includes the range of operating voltages to be expected. For the purposes of this standard, 'd.c. circuits' and 'd.c. protection' systems refer to these nominal voltages throughout this standard.

Guidance:

The majority of d.c. circuits are traction current sections fed by positive and negative circuit breakers located in traction sub-stations at each end of the section. Feeds to depots may be fed by dedicated circuit breakers or may be a subsidiary circuit from a traction current section.

There are some d.c. circuits presently used for non-traction purposes (e.g. escalators) and these circuits have much lower load current demand than traction circuits. These circuits must be protected from pole-to-pole faults by inverse definite minimum time and direct acting high setting instantaneous protection (Engineering Standard S1110 refers).

- 2.2** Excluded from the scope of this Standard is the calibration and maintenance of protection equipment.

Guidance:

The Standard is not intended to specify protection equipment for a.c. systems.

The Standard also is not intended to cover which protection system should be used in a particular application but this Manual provides guidance on how to provide the required protection on existing d.c. circuits should the installed protection prove insufficient.

Traction earth fault detection systems are outside the scope of the Standard and are therefore not covered. The requirements for pole-to-earth fault protection in final



depot circuits and double-pole-to-earth fault protection are covered and more guidance is provided against the relevant clauses.

- 2.3** This Standard applies to all new installations in its entirety and to existing installations where the necessary hardware exists to enable full compliance.

Guidance:

The Standard is mandated for all changes to any d.c. circuit from the date of implementation. Each affected d.c. circuit should be reviewed against the requirements of the Standard and the protection set and verified accordingly.

The review of existing d.c. circuit protection, where the necessary hardware exists, should be approached such that priority is given to those d.c. circuits which comply least with the Standard. It is expected that LU and/or LU Suppliers may apply for appropriate concessions to the Standard, which may be granted subject to a programme to achieve full compliance within reasonable timeframes.

- 2.4** This standard replaces G-111 A1.

3 Guidance

3.1 General

- 3.1.1** This Standard shall be used to determine and verify d.c. protection settings. This Standard shall be applied when:

- a) new or alterations to existing d.c. protection or equipment is proposed;
- b) alterations to feeding or operational configuration are proposed;
- c) d.c. protection equipment is to be replaced or refurbished;
- d) significant ETE replacement or alterations to the circuit are proposed;
- e) the train service or traction rolling stock is altered.

Guidance:

The requirements of the Standard are to be applied when any of the listed system changes [(a) to (e)] occur even if short term or temporary. If the user is in any doubt regarding the applicability of the Standard, the LU Technical Authority should be consulted for further guidance.

The following listings provide examples of each of the listed items:

- a) additional or modified circuit breakers;
additional or modified protection equipment;
subsidiary protection provided (e.g. within a depot);
- b) track layout alterations (including temporary changes);
temporary sub division of a CRS for engineering or other works (e.g. opening of normally closed TIS);
permanent way changes;
sub-station equipment replacement (e.g. d.c. switchgear or rectifiers).
- c) refurbishment of DAOL protection;
additional protection provided (e.g. inverse overcurrent, undervoltage / inter-tripping).
- d) replacement conductor rail for all or part of a section;
renewal or re-routing of track feeder cables.

- e) altered service frequency;
new rolling stock or changes in rolling stock performance;
regenerative braking introduced;
altered number of coaches.

- 3.1.2 LU and/or LU suppliers shall have processes and appropriate safety management and quality management systems which must be in place to ensure that the technical deliverables and requirements as set out in this Standard are adhered to at all times.

Guidance:

This clause is included to reinforce the general requirements for safety and quality management, which should already be in place for all LU and/or LU Suppliers. Some detailed formalised processes may need to be set out and put in place by LU and/or LU Suppliers in order to comply fully with the requirements of the Standard.

- 3.1.3 LU and/or LU suppliers are required to create, edit and maintain comprehensive and detailed records and archived material sufficient to satisfy the requirements of this Standard.

- 3.1.4 An auditable trail of documented evidence shall be provided for all d.c. protection systems and their settings.

Guidance:

Part of the assurance process is normally for LU and/or LU Suppliers to provide “data packs” which detail the changes to the system to the LU Technical Authority. It is recommended that this approach is used to satisfy the requirements of clause 3.1.2. Pro-forma type data packs, accepted by the LU Technical Authority, would provide consistent levels of information in a format recognised and understood by all parties aiding a quick turnaround of applications for change. The QICC process is also used to formalise the applications.

- 3.1.5 No changes shall be made to a d.c. circuit until the requirements of this Standard have been fully complied with.

- 3.1.6 Written evidence of compliance shall be submitted to, and written confirmation received from the LU Technical Authority before any changes are implemented.

Note: Written confirmation is not required for emergency changes or where essential changes are identified at very short notice but should be sought within one week of implementation of such a change.

Guidance:

The LU Technical Authority needs to be assured that the processes and personnel involved in carrying out protection calculations meet with the requirements of the Standard. The procedures and personnel used in determining the settings and those used for verification of the settings are subject to audit.

It is expected that submission of proposed changes using standard pro-forma applications will allow changes to be reviewed, accepted and implemented quickly and may assist full understanding of the requirements for each d.c. circuit application. For the more significant and project based changes, the QICC process is used to formalise the applications in conjunction with d.c protection change procedures.

It is understood that in some circumstances (for instance emergency works) it may not be possible for the LU Technical Authority to provide acceptance of the change.

Allowing emergency changes would ensure that equipment can be returned to service and would not be held up awaiting LU acceptance. LU would expect such changes to be notified as soon as practicable and full assurance documentation submitted within a week to formally implement the change.

It should be noted that when the LU Technical Authority does not hold design authority for protection studies or for the resultant protection settings, the LU Technical Authority requires assurance that changes to the system are technically correct and managed by competent persons.

- 3.1.7 The calculation and verification of d.c. protection settings shall be carried out by competent and accredited persons using approved processes and procedures.

Guidance:

LU and/or LU Suppliers should provide the necessary processes and procedures and would be responsible for their approval. LU and/or LU Suppliers should also determine and keep records of those persons who are approved as competent. The LU Technical Authority will audit and accept the processes and will accredit competent persons.

- 3.1.8 The determination of circuit parameters and verification techniques by measurement and or test shall be carried out using approved processes and procedures issued by the body responsible for the activity.

Guidance:

Assessment of competence for personnel carrying out protection studies is vital due to the safety implications. Protection settings determined by competent persons using agreed procedures will provide assurance to the LU Technical Authority of the consistency and accuracy of settings. LU and/or LU Suppliers should provide, approve and maintain the processes and procedures necessary to provide assurance to the LU Technical Authority.

- 3.1.9 LU and/or LU suppliers proposing a change to a d.c. circuit or protection system shall obtain written acceptance of the change from all LU Suppliers with responsibility for the circuit, its operation, performance or maintenance.

Guidance:

Refer to guidance under clause 3.1.11 below.

- 3.1.10 LU and/or LU suppliers, in accordance with approved procedures, shall exchange approved technical information with LU and/or LU suppliers as necessary to support this Standard.

Guidance:

Some d.c. circuits have sub-systems, some with separate protection, and some with protection provided at source. Wherever there is a division of responsibility on a circuit, both responsible parties should ensure that sufficient information is exchanged to allow the protection to be correctly set and for the protection systems to overlap as stipulated in the Standard.

7.5 provides guidance for responsibilities of circuits.

- 3.1.11 Protection settings shall be re-determined where any protection device, circuit, sub-station characteristic, operational feeding arrangement, train service or traction rolling stock change beyond the parameters used to determine the settings.

Guidance:

This clause covers changes such as:

- a) conductor rail wear affecting resistance and inductance;
- b) replacement or increase of rectifiers affecting fault levels, source impedance;
- c) alteration to the operational feeding of the circuit affecting circuit impedance;
- d) introduction of regenerative braking affecting the effective fault level;
- e) increase of train service pattern affecting the load on the circuit.

It is noted that protection settings may be set to include for the train service up to the line limit in terms of signalling capacity which therefore would include alterations to the train service unless the signalling system is altered. Similarly, train bunching, which may increase the train load on the protection, could be accounted for by setting protection to the "line limit";

- f) change to rolling stock type affecting load and transient characteristics.

3.1.12 Where sub-distribution equipment exists in a circuit, the extent and boundaries of d.c. protection shall be determined, recorded and accepted by all LU Suppliers with responsibility for any part of the d.c. circuit.

3.1.13 The protection settings and the co-ordination of the protection for the entire d.c. circuit shall be agreed by LU and all LU suppliers involved.

Guidance:

See the guidance given for 3.1.10 and 3.1.11.

3.2 Protection system records

3.2.1 Comprehensive records shall be produced and maintained by LU and all LU suppliers. Records shall include:

- a) declaration of compliance with the requirements of this and other relevant standards by appropriate design submissions;
- b) descriptions of the change proposals with a safety and operational risk assessment;
- c) circuit description, location, designation, operational constraints and approved design drawings of the circuit arrangement;
- d) the protection equipment, its characteristics and tolerances;
- e) the circuit characteristics and tolerances;
- f) details of the competent personnel used;
- g) the approved calculated protection settings and relevant technical studies;
- h) tests carried out and the test configurations used;
- i) records to verify the protection settings applied on site are to the approved design settings;
- j) records shall be kept of test fault traces and other key test records. Short circuit test data shall be electronically recorded in a digital format suitable for processing in spreadsheet applications;



- k) all change control decisions and supporting justification for deviation from approved design settings taken at any stage in the test and implementation process.

Guidance:

The listing provided above should be recorded in a structured and logical format and should be clearly legible. Many protection settings apply for significant periods of time the information should be clear and unambiguous to personnel not involved in the original protection studies.

Specific care and attention should be paid to ensure that the settings recorded are as those applied on site following the verification activities. LU and/or LU Suppliers should be able to demonstrate that they have suitably robust processes in place to ensure that final changes made on site, for whatever reason, remain within the requirements of the Standard and are correctly reflected in their records. This area may be subject to specific audit by the LU Technical Authority.

- 3.2.2 A register of protection equipment and settings shall be maintained for each 630V d.c. circuit. The LU Technical Authority shall be the custodian of these records
- 3.2.3 Where more than one party has responsibility for the protection of a d.c. circuit, each party shall maintain a register to demonstrate the discrimination and overlap of the protection systems involved.

Guidance:

This register is in effect a summary of the full protection record and should be cross-referenced such that changes to the protection are recorded in the register. It is expected that the register should contain:

- a) the circuit designation;
- b) the protective device types;
- c) the settings of each device;
- d) the protection calculation cross-reference;
- e) any subsystem protective device, its settings and asset custodian.

Where a sub-system or systems exist under different responsible parties the information exchanged between the responsible parties is normally expected to be limited to the first protective device in the subsystem and vice versa (i.e. a one up, one down principle). This information will enable the correct overlap, co-ordination of the entire d.c. circuit and exchange of information as required by clause 3.1.11 of the Standard. There may, however, be instances where the sub system can be protected by the upstream protection and in these cases the exchange of information will need to be extended to cover the parameters of the downstream circuit. Good liaison and co-operation between suppliers will ensure all d.c. circuits are provided with the best possible protection.

3.3 Protection system criteria

- 3.3.1** The purpose of the d.c. protection is to permit the maximum load the existing infrastructure can withstand whilst at the same time protecting against any hazards such as fires caused by overloading or faults.
- 3.3.2** The electrical protection shall operate for all pole-to-pole faults. This shall include all current and/or voltage conditions which are not the result of the operation of the train service.

Note: Circuit breakers will incorporate protection systems in accordance with class H or V of BS EN 50123-1.

Guidance:

Electrical protection shall operate for all pole-to-pole faults.

- 3.3.3** New protection relays shall as a minimum be provided with the following elements in order to be able to comply with this purpose.
- i) Instantaneous/time delayed protection having a range of settings greater than the direct acting overload device in the circuit breaker.
 - ii) At least two independent inverse characteristic elements each of which can choose at least the very inverse and extremely inverse of the IEC inverse curves.
 - iii) The facility to be able to switch off or set out of range for other elements including thermal and rate of rise protection.

Guidance:

Pole-to-pole faults would ideally be protected by a fast acting protection element which would detect all faults whilst allowing uninterrupted operation of the train service under all operating conditions. In practice this is not achievable with instantaneous protection elements alone and in most cases additional protective elements are required to meet the requirements of the Standard.

7.7 provides details of fast acting protection, its required reach, and how it is supplemented by additional protection to achieve full cover.

- 3.3.4** Protection systems shall provide fault protection for pole-to-earth faults for Depot Shed final d.c. circuits.

With regard to new overhead trolley lead systems, where switchable trolley leads are used, earth fault protection shall be installed in each switchable overhead trolley lead to provide protection of the train lead and connected final circuit (train) and trip the trolley contactor system.

This principle should apply to similar d.c. systems where a final circuit exists and an automatic point of isolation can be created by the action of a suitable contactor / motorised switch or circuit breaker at the furthest extent of the electrical system from its source.

This requirement would apply also to load isolating equipment in shed pedestals and that used in the control of supplies to low level conductor rails for individual wash roads.

The intention is to maximise power system availability and to minimise disruption to other services and operations in the shed. This is in line with industry good practice for all protection systems.

Guidance:

This protection will include low level conductor rail sections (e.g. wash roads) and overhead trolley systems. Sidings do not require this protection. In some instances pole-to-earth fault protection has been provided to supplement the subsystem overload protection. This protection must be set to operate at a current level below that of the current which will flow through the bleed resistors. In a practical sense, schemes providing this protection need to indicate the presence of the earth fault to aid fault clearance and avoid lengthy circuit outages. Often "pre-close" earth fault schemes are used together with "post close" earth fault protection in order to avoid closing onto an earth fault.

The definition of the final circuit in the above clause of the Standard is the point in the electrical system where the final protection / isolation device is situated for a depot shed shore supply radial circuit.

7.10 provides details of this type of protection.

3.3.5 Detection and clearance of faults shall be achieved within the minimum practicable time.

3.3.6 The following parameters shall not be exceeded in any case:

- a) the equipment rated withstand capability;
- b) the maximum let through I^2t of $1.22 \times 10^9 \text{ A}^2\text{s}$ for the detection and clearance of any fault;

Guidance:

Fault current limitation to the minimum practicable is best practice for protection. The limitations of (a) & (b) above are maximum levels which must not be exceeded but generally it is expected that protection will operate well within these limits.

For example DAOL protection is high speed and will clear faults within 25ms of detection. Longer clearance times are experienced when employing protection such as undervoltage with inter-tripping where clearance is reliant on the remote inter-tripping which may take significantly longer than near instantaneous or DAOL.

It should be noted that equipment, as stated in (a) above, relates to all component parts of the d.c. circuit.

The limitation of b) above is set by the withstand of the approved LU magnetic short circuit bar and is recognised as the weakest link in many d.c. circuits but should only be used as an upper limit.

In some cases (e.g. depot sheds), equipment and cable withstand levels may be significantly less than the I^2t limit stated in b), hence the overriding requirement will be as stated in (a).

3.3.7 Electrical Protection Systems shall be provided such that injury and danger occurring as a result of faults are minimised.

3.3.8 Electrical protection systems shall not limit the ability of LU's distribution system to deliver power up to its full capacity except where necessary to prevent injury or danger or damage to equipment.

3.3.9 Where suitable inverse time protective elements are provided, the protection shall be configured so as not to exceed the equipment rated withstand capability.



Note: Overload protection in addition to fault protection is a requirement although it is accepted that this is difficult to achieve using existing technology. In the majority of cases inverse overcurrent elements do not provide suitable overload protection without causing nuisance tripping and existing thermal protection elements are not acceptable as detailed in the Guidance document G0111. Inverse overcurrent elements can however be used to protect against sustained overloads considering the very variable nature of the traction load seen at the substation. For sidings and depots which are subject to variable configurations with continuous auxiliary loads from the stabled trains overload protection is required to protect the infrastructure.

Guidance:

It is recognised that providing protection against all current that is not a result of load is difficult to achieve especially with the high traction loads experienced on d.c. systems. LU currently employs two types of protection designed to limit energy levels to the equipment rating.

The first is a basic system which trips following a set period above a set current (this is based on definite minimum time) and is referred to as Timed Overcurrent Trip (TOT) but its basic nature provides only limited protection in most cases. Although TOT exists on the system it is noted that TOT protection is prohibited for new works and only elements described in 3.3.3 shall be used.

The second is of the Inverse Definite Minimum Time (IDMT) type which can be more accurately set to operate before the equipment withstand level is reached.

Protection against overloads may require extended detection time periods to ensure correct operation. It is therefore accepted that the 3 second limit usually applied to a.c. protection may be exceeded but the equipment withstand limits must not be exceeded.

- 3.3.10** d.c. circuits fitted with a protection system consisting of several protection elements shall provide fault protection at any point on the circuit with a minimum overlap of 5% between protection elements.

Guidance:

In accordance with clauses 3.3.14 and 3.3.17 c) the 5% overlap must be achieved even when taking into account abnormal feeding arrangements, n-1 and circuit and device tolerances.

It should be noted that some d.c. circuits, particularly in depots have part of the circuit protected by a second (or second and third etc.) protective device (e.g. fuse) situated physically remote from the sub-station protection. In these cases the 5% minimum overlap from the first protective device must encompass the second device (the second encompass the third and so on) such that a fault occurring on the downstream side of the second protective device within the overlap zone will cause both first and second protective devices to detect the fault and one device to trip. The tripping sequence should be such that the device closest to the fault will operate first, providing the correct discrimination.

Meeting the requirements above will satisfy the minimum requirements of the Standard and in some cases this may be the best achievable for a circuit. However, in many cases it may be possible to increase the "overlap" such that the first protective device provides partial or total backup protection for a second downstream device. Backup protection by this method should be provided wherever possible.

- 3.3.11** The characteristics of the protection device shall be determined from manufacturer's data and shall include tolerances. Tolerances can be checked on a sample basis for new installations.

Guidance:

Protection equipment has accuracy levels given by manufacturers and these should be used. If manufacturer's data is unavailable, the tolerances must be determined by test.

- 3.3.12** The circuit parameters shall be determined from manufacturer's data, approved records, or by measurement and test.

- 3.3.13** Where approved records are not available, the circuit shall be surveyed to obtain the necessary information. This information shall be agreed with the appropriate responsible LU sections and/or suppliers and the LU Technical Authority.

Guidance:

To determine the level of current which will flow in the event of a pole-to-pole fault or double-pole-to-earth fault, the characteristics of the traction current section to be protected must be known. Instantaneous or DAOI and inverse overcurrent all rely on the flow of traction current which is determined from the resistance of the track components and from the driving voltage.

Fault current is restricted by the impedance of the source which must be included in the calculations. The transformer / rectifier no load voltage and resistance at each sub-station are required together with the equipment configuration.

LU's power system consists of traction sub-stations with multiple rectifiers. For the purpose of determining the fault levels, the system is considered with only one rectifier operational at each sub-station. This provides the minimum practical source fault level to be used in setting protection.

The voltage used for protection calculations should be the light load voltage. This light load voltage should be determined taking cognisance of the h.v. system voltage which feeds the sub-stations across the network. It is expected that LU and/or LU Suppliers use for calculations the h.v. system normal operating voltage with suitable justification to support the value used. This voltage should be reviewed periodically to ensure that the appropriate d.c. voltage is applied.

7.2 provides guidance on rectifier voltage regulation.

- 3.3.14** The protection system shall operate correctly for agreed normal, maximum and n-1 feeding as a minimum for operational conditions, and feeding configurations. It is acceptable to allow for a risk based approach dealing with compound assumptions.

Guidance:

The level of rectifier capacity, as detailed in 3.3.10 above is an example of operational conditions which may alter from day to day affecting the fault levels and therefore the protection settings. In some instances (e.g. in depots), the feeding may be regularly altered by use of track isolating switches, and this needs to be taken into account when determining the protection.

Conversely, maximum fault levels must be considered to ensure equipment withstand levels are not exceeded.

- 3.3.15** Circuit parameters used in calculations shall remain valid for the duration the protection will remain operational.

- 3.3.16** Where any changes in parameters cannot be predicted (e.g. conductor rail wear), re-determination of settings shall be required at intervals sufficient to ensure fault detection.

Guidance:

Generally the parameter which will alter over time is the conductor rail. Wear, electrical and mechanical, will affect its electrical properties such as resistance and inductance. These factors need to be considered and included in the calculations where appropriate. There is some evidence that rail wear is in the order of 0.1% per annum for steel conductor rail, but substantiation would be required to use this figure.

- 3.3.17** It shall be demonstrated that correct protection is provided while meeting the following criteria:

- a) stability for load conditions including traffic “bunching”;

Guidance:

Protection should be set to a level which ensures stability under all traction load conditions. Experience and system studies have determined suitable settings for rolling stock types, train service patterns and loading under abnormal conditions. This includes traffic bunching to the limit of the signalling system which occurs due to service abnormalities or other such problems). These loadings should be taken as a minimum level for the protection settings.

- b) the effects of regenerative rolling stock have been taken into account in the calculations to avoid ‘current masking’ phenomena. It is acceptable to take a risk based approach when dealing with current masking.

Guidance:

Regenerative train current can reduce the amount of current supplied to a short circuit from the sub-station. This may affect overcurrent protective devices and in some circumstances sustain track voltage following a circuit breaker trip impeding the operation of undervoltage protection.

For lines utilising trains with regenerative capability, it must be established the most likely worst case scenario for the simultaneous number of trains, regenerative current and voltage levels produced on the circuit as a result.

These currents must then be introduced to the fault circuit to ascertain the impact on the protection system.

Details of regenerative train current effects on the protection are given in 7.8.

- c) all device and circuit tolerances have been included in the calculations;

Guidance:

Device tolerances should generally be available from the manufacturers of equipment or from records. In the absence of this information it is expected that the data will come from tests carried out to determine the tolerance as required by clause 3.3.12.

- d) for pole-to-pole faults which may occur at any point on a d.c. circuit, the fault path between positive and negative poles shall include a resistance equivalent to an arc with a voltage of 50V.

Guidance: