ENGINEERING DESIGN STANDARD

EDS 08-4000

EHV NETWORK DESIGN

Network(s): EPN, LPN, SPN

Summary: This standard provides guidelines for the design and development of the 132kV, 66kV, 33kV and 22kV primary distribution networks to ensure they are safe, efficient and that they have due regard for the environment.

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Approver:	Paul Williams	**Date:**	22/04/2024

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Revision Record

Version	4.2	Review Date	06/11/2027
Date	15/04/2024	Author	Stephen Tucker

Reason for update: Introduction of new system earthing standard.

What has changed:

- Section 6.8 system earthing section replaced with reference to EDS 08-1111.
- Section 13 references updated.
- Legacy system earthing content in appendices moved to EDS 08-1111.

Version	4.1	Review Date	06/11/2027
Date	06/03/2023	Author	Stephen Tucker

Reason for update: System earthing clarification and minor corrections.

What has changed:

- Customer connection complexity requirement reinstated (Section 6.3).
- Neutral earthing requirements for 11/6.6kV transformers clarified (Section 6.8).
- 33kV underground transformer feeder diagram Figure 8-2 corrected (Section 8.1).
- Legacy system earthing included for reference.

Version	4.0	Review Date	06/11/2027
Date	06/12/2022	Author	Stephen Tucker

Reason for update: Interim update to address known issues pending a more comprehensive update with the associated protection standards.

What has changed:

- Structure aligned with EDS 08-3000.
- Statutory requirements summary added (Section 4).
- Complexity rules aligned to latest version of ENA EREC P18 (Section 6.3).
- Over-voltage protection included (Section 6.9).
- Single busbar banked transformer option added (Section 7.4).
- 33kV underground tee arrangement removed (Section 8.3).
- 33kV overhead tee arrangement removed (Section 8.4).
- 33kV overhead ring arrangement revised to include bus section circuit breaker (Section 8.6).
- 132kV and 33kV connections arrangements from EDS 08-4100 revised and included (Section 10).
- Disconnector removed from 132kV tee connection (Section 10.1.2).
- Cable, overhead lines, plant and equipment combined together in a new section (Section 11).
- Diagram key added (Appendix A).
- Document reviewed.

Version	3.0	Review Date	15/12/2022
Date	22/11/2017	Author	Stephen Cuddihey

Reason for update: Business review.

What has changed:

- Complexity rules for 33kV teed circuits clarified (Section 6.3).
- Voltage rationalisation from EDS 08-0116 incorporated (Section 6.4).
- Document renumbered from EDS 08-0145 and title amended.
- All connections related material now in separate document EDS 08-4100.

Version	2.0	**Review Date**	28/02/2017
Date	04/02/2014	**Author**	Marco da Fonseca
Section 11 updated to align with EDS 08-0051. Section 7 added. Section 8.3 modified to allow three options of 132kV cable terminations.			
Version	1.0	**Review Date**	
Date	01/03/2013	**Author**	Marco da Fonseca
Original.			

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1 Introduction

This standard provides guidelines for the design and development of the 132kV, 66kV, 33kV and 22kV primary distribution networks to ensure they are safe, efficient and that they have due regard for the environment.

Standard network configurations and substation layouts applicable across the EPN, LPN and SPN networks are not considered feasible, due to the historical development of the networks and the considerable differences in their geography, load density and the nature and expectation of their customers. Furthermore, it is likely that such an approach would lead to over engineering and over investment.

It is, however, desirable to reduce the number and complexity of arrangements to achieve an appropriate balance between cost and performance which is common and equitable to all customers. Rationalisation of the current design practices across EPN, LPN and SPN can, to a large extent, be achieved by standardisation of the specifications for lines, cables, plant, protection, automation, and earthing. These standards dictate the building blocks from which the system is constructed and are set externally to the design philosophy.

The purpose of this document is to provide a high-level standard for the design of primary distribution networks so that a consistent approach can be applied to all networks, whilst permitting designers/planners freedom to resolve each unique network problem with a bespoke solution, where required, which takes advantage of local circumstances.

The network design requirements detailed in this standard are based on:

- Statutory requirements (Section 4).
- The Distribution Code[1] requirements, in particular, to:
  - Permit the development, maintenance, and operation of an efficient, coordinated and economical system for the distribution of electricity.
  - Facilitate competition in electricity generation and supply.
  - Discharge the obligations on DNOs from their licence conditions and other European regulations.

2 Scope

This standard applies to the EPN, LPN and SPN EHV primary distribution networks including all voltages from 22kV up to and including 132kV.

The development of 20kV and 33kV distribution networks aimed at supplying large demand customers in the central area of London is outside the scope of this document (refer to EDS 08-4101 and EDS 08-3000). However, designs for the development of primary distribution networks in the areas where either 20-22kV or 33kV distribution networks exist should take account of these networks but their design and specification shall comply with standards that have been developed specifically for this purpose.

[1] The Distribution Code contains technical requirements relating to the connection to and use of electricity distribution systems, for existing and potential users. It sets out the procedures and principles that govern the DNO's relationship with all users of the distribution system.

3 Glossary and Abbreviations

Term	Definition
AIS	Air Insulated Switchgear
ASC	Arc Suppression Coil
BSP	Bulk Supply Point (point of supply from a transmission system to a distribution system)
CI	Customer Interruption. A measure of network security measured in customer interruptions/100 connected customers. This measure acts as a driver to reduce the occurrence of faults and to limit the impact of any one fault
CML	Customer Minutes Lost. A measure of network availability measured in customer minutes lost/connected customer. This measure acts as a driver to encourage fast restoration of un-faulted sections of network following a permanent fault
CHLDZ	The Central High Load Density Zone within the London network where the security of supply has developed with an enhanced level to the normal level
DNO	Distribution Network Owner
ENA	Energy Networks Association
End	For the purposes of ENA EREC P18 application, an item of switchgear connected to a circuit that may be used for making dead, providing protection clearance, or a point of isolation
EPR	Earth Potential Rise
EHV	Voltages above 11kV. These may be both transmission and distribution networks depending on location and requirement
FLC	Full Load Current
GIS	Gas Insulated Switchgear
GRP	Glass Reinforced Plastic
Grid Substation	A substation with an operating voltage of 132kV or 66kV and may include transformation to 33kV, 22/20kV, 11kV or 6.6kV
GSP	Grid Supply Point
HV	Voltages above 1000V; generally used to describe 11kV or 6.6kV distribution systems but may include higher or other legacy voltages
HILP	High Impact Low Probability
ICP	Independent Connection Provider
IDMT	Inverse Definite Minimum Time (Protection)
IDNO	Independent Distribution Network Owner
LV	Voltages up to 1000V; generally used to describe 230/400V or 230/460V distribution systems
n-1	First system outage
n-2	Second system outage
NER	Neutral Earthing Resistor
NEX	Neutral Earthing Reactor
NMS	Network Management System

Term	Definition
ONAN	Oil Natural, Air Natural
P18 Definitions	The definitions applicable to the application of ENA EREC P18 are detailed in Table 6-2
PoC	Point of Connection
Primary Substation	A substation with an operating voltage of 33kV and may include transformation to 11kV, 6.6kV or LV
RMU	Ring Main Unit
SCADA	System Control and Data Acquisition
SGT	Super Grid Transformer
Site	For the purposes of ENA EREC P18 application, one or more operational locations, which can have different postal addresses, located such that is it practicable to walk between them in a short period of time (approximately 10 minutes) thus allowing one person to reasonably carry out operations at both locations without causing undue delay
UK Power Networks	UK Power Networks (Operations) Ltd consists of three electricity distribution networks: • Eastern Power Networks plc (EPN). • London Power Network plc (LPN). • South Eastern Power Networks plc (SPN).
XLPE	Cross-linked Polyethylene

4 Statutory Requirements

Networks shall be designed with due regard to the statutory regulations detailed below:

- Electricity Act 1989 (Section 9).
- Electricity Safety, Quality and Continuity Regulations 2002.
- Health & Safety at Work Act 1974.
- Construction (Design and Management) Regulations 2015.

Networks shall comply with the requirements of the Distribution Licence Conditions for each area within UK Power Networks, specifically:

- Condition 5 (distribution system planning standard and quality of service).
- Condition 9 (compliance with the Distribution Code).
- The level of performance required by the Overall and Guaranteed standards agreed with OfGEM.

The following ENA Engineering Recommendations form the basis of network design:

- ENA EREC P2 – Security of supply.
- ENA EREC P28 – Planning Limits for Voltage Fluctuations Caused by Industrial, commercial and domestic equipment in the UK.
- ENA EREC P29 – Planning limits for voltage unbalance in the UK.
- ENA EREC G5 – Limits for harmonics in the United Kingdom electricity supply system.
- ENA EREC G99 – Requirements for the connection of generation equipment in parallel with public distribution networks on or after 27 April 2019.

5 Network Design

The principles detailed in this section shall be applied when additions or alterations are made to the EHV distribution network.

It is not intended that these principles are applied retrospectively to existing networks. However, when additions or alterations are to be made to an existing network that does not comply with this standard, opportunity should be taken to make the network compliant so far as is reasonable. In all cases, any changes should not increase the existing non-compliance.

A simple network is a safe network. In designing any additions or alterations, every endeavour should be undertaken not to increase the complexity of the network and to:

- Maximise the benefits of automation and remote control to reduce customer interruptions (CI) and customer minutes lost (CML).
- Support vulnerable customers who have a specific need or dependence on electricity.
- Support the increase in homeworking patterns.
- Support the electrification of transport and heating required to meet the 2050 net-zero targets.
- Support safety and operational requirements.

Due consideration shall be given to the network risk during the technical comparison of alternative schemes and standard risk assessment methodology should be employed to determine the probability and consequences of failure. The following factors should be considered as part of this process:

- Fault levels.
- Length of the circuits.
- Performance history of existing circuits.
- Number of customers supplied.
- Nature of load supplied.

If an acceptable risk rating is unachievable the scheme shall be discounted, and an alternative more robust solution shall be proposed.

Where reasonable and feasible, UK Power Networks shall maximise the use of the highest distribution voltage possible within an area and minimise the use of lower voltages to customer connections and low load density areas.

6 Network Design Requirements

6.1 Security of Supply (P2)

The primary distribution networks shall be designed to comply with the security of supply standards detailed in the latest version of ENA EREC P2.

EDS 08-1105 provides further guidance on the application of ENA EREC P2.

6.2 Circuit Length

6.2.1 Cable Lengths

The connection of cable tees to overhead lines shall be subject to a maximum length of cable given by the breaking capacity of the switchgear, though consideration shall also be given to the impact on fault levels, voltage drop, protection complexity and power quality.

Note: When replacing switchgear, they shall be rated at least to the former rating or higher.

The customer, prior to defining the cable route and installing it shall advise UK Power Networks of the maximum charging current of the total length of cable to be installed and any diversions from the initial route that may affect the total charging current. In the event of a generation site connection, the total site charging current contribution shall also be given.

Table 6-1 shows typical charging currents for 33kV, 66kV and 132kV underground cables in accordance with EAS 02-0061 and EAS 02-0030.

Table 6-1 – Typical Charging Currents (A/kM) at 33kV, 66kV and 132kV Cables

Cross-Sectional Area (mm^2)	**300**	**400**	**500**	**630**	**1000**	**1200**
33kV	1.443	-	1.574	1.915	2.328	2.693
66kV	2.514	2.753	-	-	-	-
132kV	3.831	-	-	4.788	5.507	5.746

6.2.2 Cable Capacitance Compensation Assessment

The maximum cable length and capacitance compensation assessment process is shown in Figure 6-1. The associated equations and an example are included below.

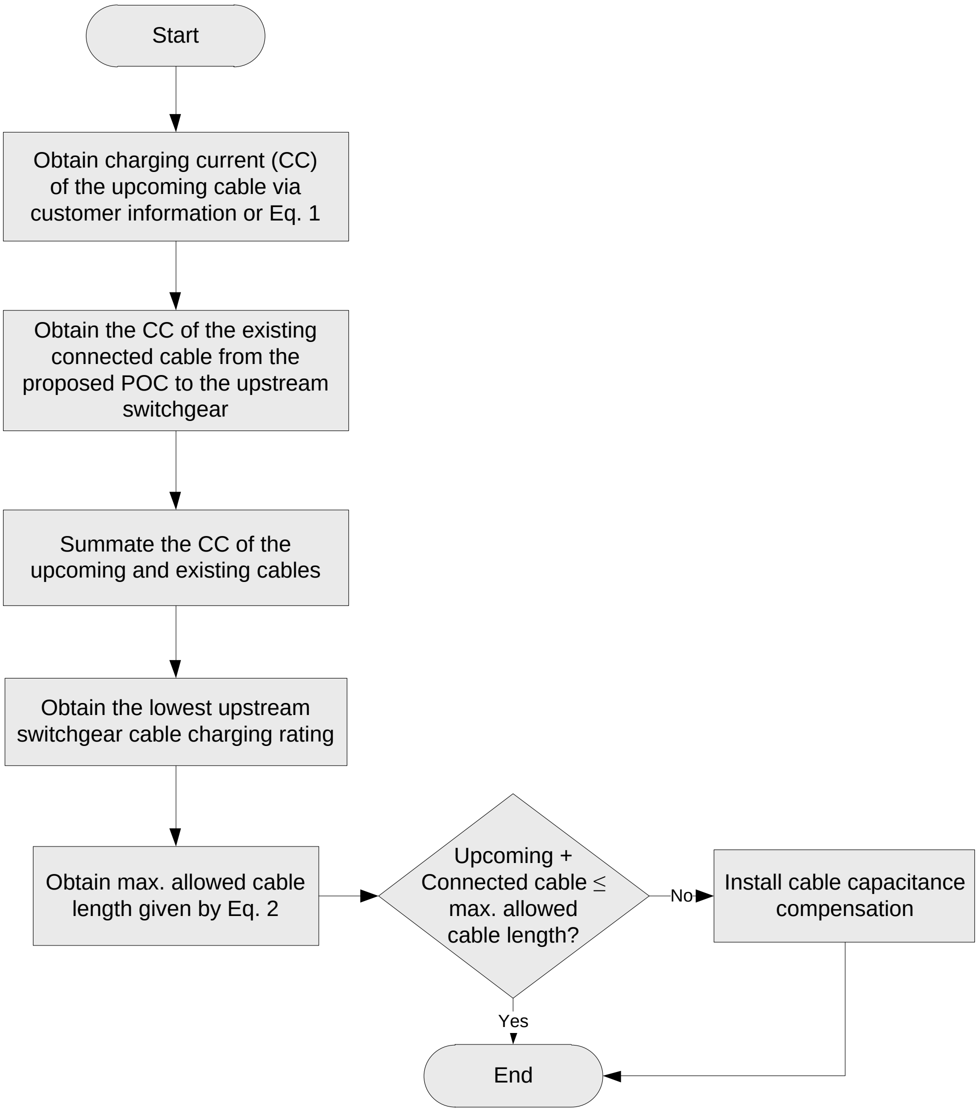


Figure 6-1 – Cable Capacitance Compensation Process

In cases where the charging current is not available, it shall be calculated using Equation 1. The capacitance shall be obtained from the conductor specification.

$$I_{charging} = \frac{2 \times \pi \times f \times C \times E}{1000000}, \qquad \text{Equation 1}$$

where f is the frequency of 50Hz, C the capacitance in μF/km and E the voltage phase-ground The following Equation 2 shall then be used to calculate the maximum cable length that can be connected. The lowest upstream switchgear cable charging rating shall be obtained from the relevant specifications.

$$\text{Maximum Allowed Cable Length} = \frac{0.9 \times I_{rating}}{I_{charging}} \qquad \text{Equation 2}$$

The 0.9 factor refers to a tolerance of 10%, which is added to account for any errors due to approximations and also overhead line capacitance contribution (usually negligible).

Example:

Take a conductor with a nominal cross-sectional area of 630mm^2 at 33kV which has a maximum capacitance of 0.352μF/km, the charging current can be obtained using the previous equation:

$$I_{charging} = \frac{2 \times \pi \times 50 \times 0.352 \times \frac{33000}{\sqrt{3}}}{1000000} = 2.107\text{A/km}$$

The lowest cable charging rating of the upstream switchgear can be obtained from the switchgear specification. In this example, it is the ABSD with a cable charging rating of 20A.

$$\text{Maximum Allowed Cable Length} = \frac{0.9 \times 20}{2.107} = 8.5\text{km}$$

If the future cable length is higher than the maximum allowed, cable capacitance compensation is required and may be provided by a shunt reactor or any other form. Apart from reducing stress in the network, it will also provide power factor correction.

6.3 Network Complexity (P18)

6.3.1 Overview

The complexity of all circuits covered by this standard is based on ENA EREC P18 and includes the following requirements.

- Making dead for operation purposes.
- Protection clearance.
- Transformer banking.
- Isolation.

A summary of the P18 requirements is given in the following sections using the P18 definition sin Table 6-2.

For further information and examples, refer to the latest version of ENA EREC P18.

Table 6-2 – ENA EREC P18 Definitions

Term	Definition
Circuit	Part of an electricity system between two or more items of switchgear relevant to the EREC P18 restriction being considered. It may include transformers, reactors, cables and overhead lines. Busbars are not considered as Circuits and are to be considered on their merits
Dead	At or about zero voltage and disconnected from any live system
End	An item of switchgear connected to a circuit that may be used for making dead, providing protection clearance, or a point of isolation
Isolation	A function to disconnect, for reasons of safety, the supply from every source of electrical energy for a circuit, a discrete section of a circuit or item of switchgear. This can be achieved by isolating equipment that is secured to avoid accidental or inadvertent re-energisation
Protection Clearance	The automatic operation of switchgear to remove all sources of electrical energy to a circuit or section of circuit that has faulted
Site	One or more operational locations, which can have different postal addresses, located such that is it practicable to walk between them in a short period of time (approximately 10 minutes) thus allowing one person to reasonably carry out operations at both locations without causing undue delay

6.3.2 Making Dead and Protection Clearance

The normal operating procedure for making a circuit dead (by a suitably authorised person) or the protection clearance (due to a fault) shall not require the opening of more than seven ends.

For making dead the ends can be circuit breakers and/or appropriately rated switches. For protection clearance the ends shall be circuit breakers.

The ends shall not be located on more than four different sites.

- Two circuit breakers and/or appropriately rated switches on a mesh type substation of the same voltage in the mesh controlling a circuit, shall count as one end.
- Where a circuit is controlled by two circuit breakers and/or appropriately rated switches which select between main and reserve busbars, they shall count as one end.
- Circuit breakers and/or appropriately rated switches that are normally operated open and are not required to operate to make the circuit dead or clear a fault, should not be counted as an end unless there is a need to include the circuit breaker in the protection scheme, in which case that circuit breaker shall be counted as an end.
- Circuit breakers and/or appropriately rated switches that are not required to operate to make dead the circuit dead or clear a fault, should not be counted as an end.
- Circuit breakers and/or appropriately rated switches that are operated as part of an operational procedure to make the circuit dead, shall be counted as an end.
- Circuit breakers that are not required to operate to clear a fault on the relevant circuit but are required to operate to disconnect networks that would otherwise become unearthed, inadequately protected or to manage voltage, shall be counted as an end.
  Where a customer is connected to a circuit via a single exit-point circuit breaker, that circuit breaker shall be counted as an end, even where fault clearance would actually be achieved by the operation of one or more customer-owned circuit breakers (for example those associated with the customers loss-of-mains protection) within the customer's installation.

6.3.3 Transformer Banking

The normal operating procedure for making dead or protection clearance shall not interrupt supplies to more than three transformers at any one site.

- A transformer with two lower voltage windings counts as one transformer.

6.3.4 Isolation

The normal operating procedure for isolating a circuit or item of switchgear that has been made dead shall not require the opening of more than seven ends. For the purposes of this restriction, an end is a device providing Isolation. The ends shall not be located on more than four different sites.

- For the purpose of providing Isolation, ancillary equipment (e.g. voltage transformer fuses) are not to be counted as an additional end if they are located on the same Site as a relevant end.
- Where the normal operating procedure for isolating an item of switchgear directly connected to a busbar does not require the opening of ends at more than four Sites this restriction does not apply.

6.3.5 Customers

The maximum number of customer connections that may be interrupted by isolating a single circuit shall be two.

6.4 Fault Levels

Design fault level shall be in accordance with EDS 08-1110.

For general information on fault levels refer to EDS 08-1110**.**

6.5 Protection, Control and Monitoring

For further information on protection, control and SCADA refer to EDS 05-0001, EDS 05-0002 and EDS 05-4100.

6.5.1 Protection Systems

The impact on existing protection systems shall be considered during new connections, network reinforcement, network reconfiguration or switchgear replacement. Consideration shall be given to protection settings, sensitivity and zone reach, and schemes shall be re-designed and replaced as necessary.

Remote end legacy protection systems shall be replaced to support standardisation of new equipment being installed; e.g., if a new 132kV tee connection is being installed then the remote end protection shall be replaced to match the new 132kV tee connection equipment to the latest standard. This is due to legacy equipment approaching end-of-life and to take full advantage of modern equipment benefits to support transition to net zero.

Protection systems shall be designed in accordance with EDS 05-0001, EDS 06-0002 and EDS 05-4100 as appropriate. More complex schemes will require a protection philosophy to be developed in conjunction with the network design to ensure adequate protection.

6.5.2 Voltage Control

The impact on the existing grid or primary substation voltage control scheme shall be considered during new connections, network reinforcement, network reconfiguration or switchgear replacement.

In particular, the proposed connection of a generation scheme may affect the correct operation of the voltage control scheme at a grid or primary substation, where:

- The grid or primary transformers are subjected to reverse power flow due to the generation connection.
- The generator provides a significant proportion of the site maximum demand, and the voltage control scheme relies on line/load drop compensation.

The voltage control scheme shall be assessed and, where required, it shall re-designed and upgraded or replaced as necessary to ensure it will continue to operate correctly.

Additionally, the reverse power capability rating of the tap changer at the grid or primary substation shall be checked to ensure it is not compromised. Where necessary, any replacement, modifications or servicing recommended by the manufacturer shall be carried out as a part of the works. Refer to the voltage control standards for further details

6.5.3 Remote Source Circuit Breaker Intertrip

Where transformer high voltage windings are not controlled by a local circuit breaker and the preferred option of installing one has been carefully considered and discounted, intertripping shall be provided to open the remote source circuit breaker using one of the following options:

- Pilot cable or other means over which intertrip send and receive signals are passed. For 132kV systems, this may take the form of an overall transformer feeder protection scheme where the circuits are short and comprised entirely of underground cable.

- Fibre optic with unit protection, providing that all 33kV feeder main protection can be converted to unit protection.

- As a last resort, a fault throwing switch. The transformer protection operates a switch which places an earth fault on one phase of the incoming circuit which is detected as a feeder fault by the source protection, refer to ETS 03-6414.

The earth fault currents on resistance/reactance earthed 66kV and 33kV primary networks are restricted and the operation of a fault thrower imposes no significant risk to the network. The 132kV systems use solid earthing and produce high earth fault currents which could cause considerable danger or damage. Therefore, fault throwers shall therefore no longer be used for new 132kV installations and circuit breakers shall be used to provide local control of the transformers as shown in Figure 6-2 and Figure 6-3.

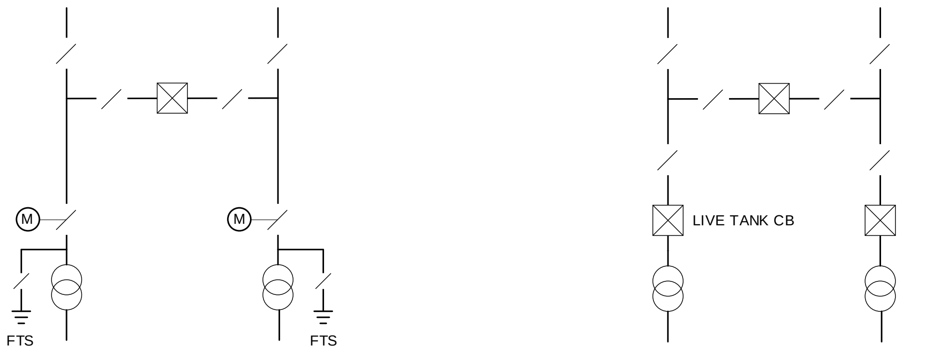


Figure 6-2 – 132kV Legacy and Modified Single-switch Layout

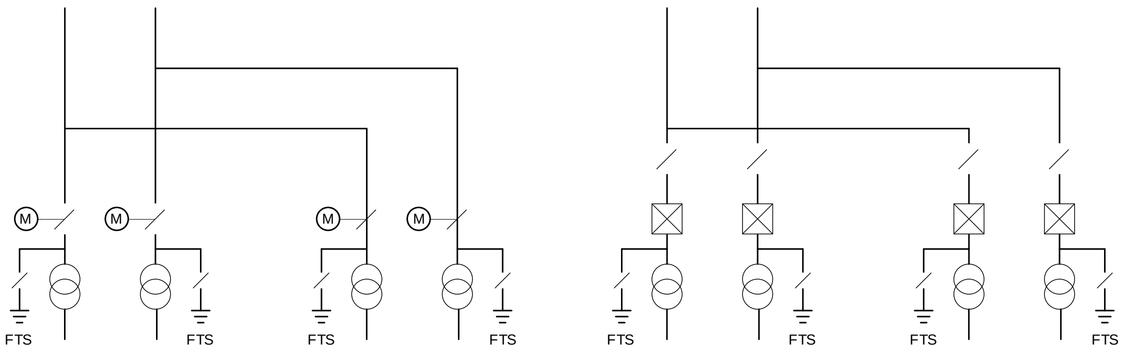


Figure 6-3 – 132kV Legacy and Modified Teed Transformer Feeder Layout

6.6 Voltage Rationalisation

6.6.1 General

The EHV system in the LPN region utilises a range of voltages that have existed since the time when there was significant generation capacity within London itself. The generation capacity has progressively been replaced by grid connection points and the EHV system has been developed by taking a holistic approach that addresses voltage rationalisation, removal of older assets and the installation of significantly more transformer capacity.

Within the Central London area to accommodate the high load densities new substations based on 132kV incoming circuits and 66MVA three-winding transformers have become the standard. Whilst this design has been predominantly applied to Central London it is equally applicable to the other high load density parts of LPN, EPN and SPN, particularly where 132kV distribution is already available.

The current infrastructure strategy for Central London involves significant reinforcement of the 132kV system which will establish 132kV as the predominant EHV voltage within the central area. Any proposals to invest in systems operating at the legacy voltages of 66kV, 33kV or 22kV shall be considered in the context of whether they will deliver efficient longer-term investment and the extent to which they are compatible with any future migration to 132kV.

6.6.2 66kV Systems

Some 66kV systems remain in the LPN region which provide significant capacity and supply sensitive areas of Central London and there is little possibility of this voltage level being entirely replaced by 132kV in the short to medium term. However, there should be a general presumption against extending the 66kV system or replacing the assets and opportunities for standardisation to 132kV should be addressed when they arise. The presence of a significant length of 66kV fluid-filled cable represents a further reason to reduce this asset where possible.

The need to replace 66kV assets because of poor condition may become necessary. Significant expenditure on such replacements should ideally be avoided by considering the removal of the asset as part of a voltage rationalisation scheme. However, any such scheme shall be economically justified and where this cannot be demonstrated ‘like for like’ asset replacement may be the only option.

Where 66kV assets are to be replaced, reinforced or extended 132kV rated switchgear and cables should be used. Each case will ultimately be considered on its merits and the marginal additional costs involved will be subject to formal approval as part of the capital authorisation procedure. Similarly, there will be cases where extending the 66kV network provides the only economic solution to a network reinforcement or new connection requirement. Transformers shall have dual ratio primary windings, e.g. 132/66/11kV to facilitate future uprating or re-use elsewhere. While a 132kV solution is preferable, each case shall be individually justified.

In summary, there should be a general presumption against extending the 66kV system or replacing the assets except where there is a need urgently to address network risk.

6.6.3 33kV Systems

For the purposes of providing guidelines in respect of the 33kV system it is necessary to differentiate between the new 33kV distribution network that has been developed within the Central London area encompassing Finsbury Market, Wellclose Square and Back Hill (refer to EDS 08-4101) and the more extensive 33kV system that is in place in the outer areas of London and within EPN and SPN.

For the most part, the 33kV system in the outer areas will remain as a standard sub-transmission voltage unless there are local factors that favour the introduction of 132kV. In the Central London 33kV is the preferred connection voltage for single customers with demands of 5MVA as detailed in EDS 08-0150.

6.6.4 22kV Systems

In referring to the 22kV system it is important to distinguish the old sub-transmission system from the newer 20kV distribution network that has been established around Bankside.

The old 22kV sub-transmission systems are relatively small in extent, although an appreciable length of 22kV cable remains, offer very low capacity for modern EHV distribution and have a transformer age profile that places the bulk of the assets in the early to mid-1950s. There is no merit in extending this system and every endeavour should be made to remove these assets as part of any major reinforcement scheme that either involves the assets directly or offers the potential to decommission them as part of an associated scheme. However, the need to replace 22kV assets because of poor condition may become urgent and some investment may be unavoidable.

20kV systems exist mainly in south London (Bankside) for distribution purposes and are not in the scope for this standard.

6.7 Central London Network Design

For further information on the Central High Load Density Zone (CHLDZ) and High Impact Low Probability (HILP) sites refer to EDS 08-1104 and EDS 08-1105.

6.8 System Earthing

System neutral point earthing, including the use of arc suppression coils, shall be applied in accordance EDS 08-1111.

EDS 08-1111 provides an overview of neutral point earthing methods and their application at all voltages. It also includes a summary of the legacy system earthing used on each distribution network.

6.9 Over-voltage Protection

Insulation coordination shall be considered during the design stage, where applicable an insulation co-ordination study shall be carried out in accordance with BS EN IEC 60071-1/2 to determine suitable over-voltage protection.

Surge arrestors shall be installed on all 132kV overhead line to underground transitions.

Further information on lightning protection is available in ENA ETR 134.

7 132kV Network Configurations

7.1 Grid Supply Points

More than one DNO, or DNOs and generators may share a GSP connection point. At shared sites it is the convention that the transmission operator owns the 132kV busbar and the DNO owns the equipment in their circuit bay up to the busbar isolator, busbar clamps (or gas barrier for GIS switchgear).

At GSPs connecting a single DNO it is the convention for the DNO to own the 132kV busbar and the transmission operator to own the transformer bays up to the busbar isolator busbar clamps (or gas barrier for GIS switchgear). Operational and planning arrangements between the DNO and the Transmission Network Operator are defined in the Grid Code.

The preferred arrangement is for the 132kV busbars to run solid where fault level constraints permit and for all SGTs to run in parallel. A typical arrangement is shown in the figure below. This configuration applies both to AIS and GIS switchgear designs which shall be determined by the availability of land, physical constraints etc. at the specific location.

Typically, a double busbar arrangement is employed providing ‘main’ and ‘reserve’ busbars which each have a bus section circuit breaker thereby providing four discrete sections of busbar to which an SGT is connected. The main and reserve busbars are coupled by means of bus coupling circuit breakers. Two bus-couplers are shown in Figure 7-1 although historically a single bus-coupler may have been employed.

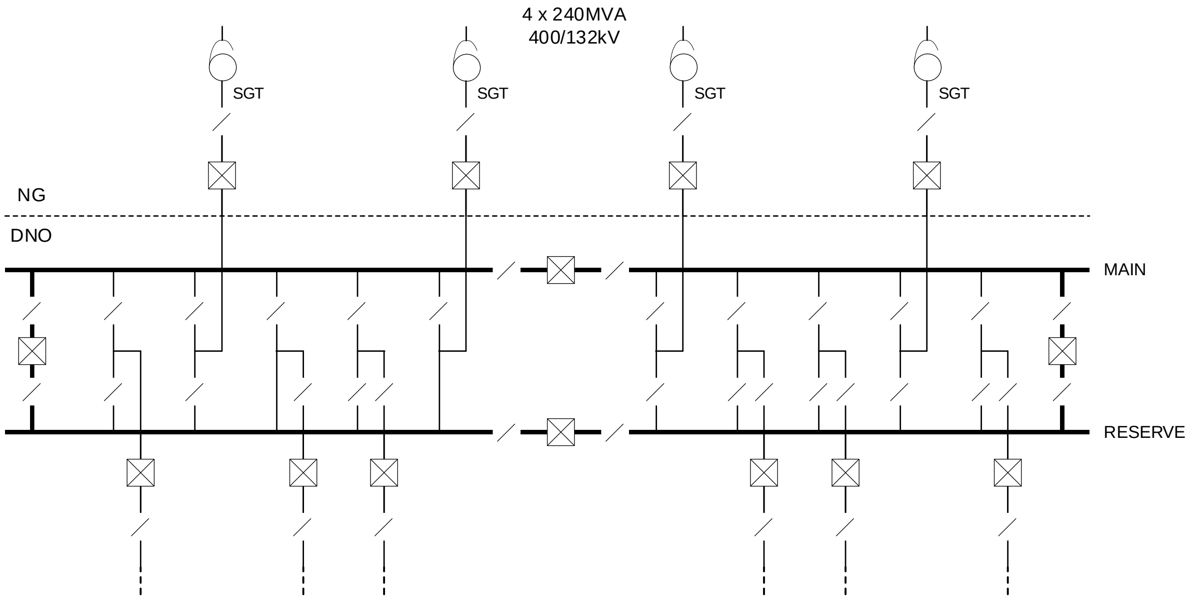


Figure 7-1 – GSP Arrangement

7.2 Transformer Feeder Networks

At the 132/66kV, 132/33kV or 132/11kV substation there is minimal requirement for 132kV switchgear. Substations supplied from overhead lines shall normally comprise of a transformer disconnector and integral earth switches only to provide isolation of the transformer and earthing of the line and transformer circuits.

New 132kV transformer feeder substations supplied by means of underground cable shall have no 132kV switchgear. The 132kV cables shall be terminated as follows in order of preference:

a) Via cable sealing ends with a remotely controlled disconnector with earth switches, provided enough space is available on site.

b) If the previous option is not considered viable, the 132kV cables shall be terminated via cable sealing ends with an earth switch and a removable busbar copper end connecting the sealing ends to the transformer.

c) As a last option, the 132kV cables shall be terminated via cable sealing ends with a removable busbar section.

Intertripping shall be provided by means of multi-core or fibre optic pilot cables.

Teed transformer feeder arrangements shall have disconnectors and/or switches to control each transformer such that under prearranged or fault outages the healthy transformer can be kept in service.

The use of 132kV fault throwers for intertripping of transformer faults is not permitted. New and re-equipped 132kV substations shall employ approved circuit breakers as an alternative to the use of fault throwers if there is no reliable communications channel available for intertripping.

The resilience of transformer feeder arrangements which are supplied by long overhead lines typically longer than 20km shall be enhanced by the provision of a 132kV bus section. This shall in the event of a transformer failure concurrent with a circuit outage enable the remaining healthy transformer to be supplied from the healthy circuit. These arrangements should also be laid out to provide for a future third transformer as shown in Figure 7-2.

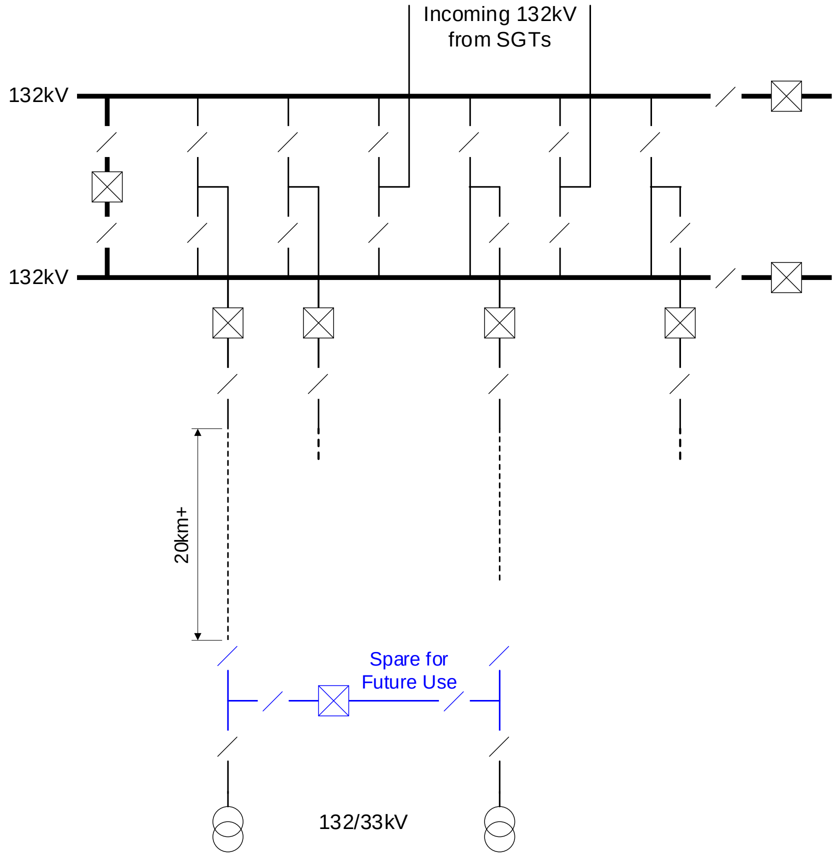


Figure 7-2 – 132kV Transformer Feeder Arrangement

7.3 Teed Transformer Networks

Historically the 132kV networks have been developed to the minimum level of security to satisfy ENA EREC P2. Investment has been prioritised on the need to develop and maintain an efficient, co-ordinated, and economical system of electricity supply. Teed 132kV networks have developed due to their cost effectiveness and are still commonplace but have the disadvantage of having little resilience to second circuit outage conditions which can result in major outages.

Solid 132kV tee points shall be avoided; all tee points shall be equipped with remote controlled isolation as a minimum.

When the need arises for a new BSP to be commissioned, the resilience of the existing network should be addressed, and options should be considered to improve the connectivity of the network.

7.4 Banked Transformers

Banked transformer arrangements are generally used at BSPs where there is a requirement for two secondary voltages e.g., 132/33kV and 132/11kV as shown in Figure 7-3.

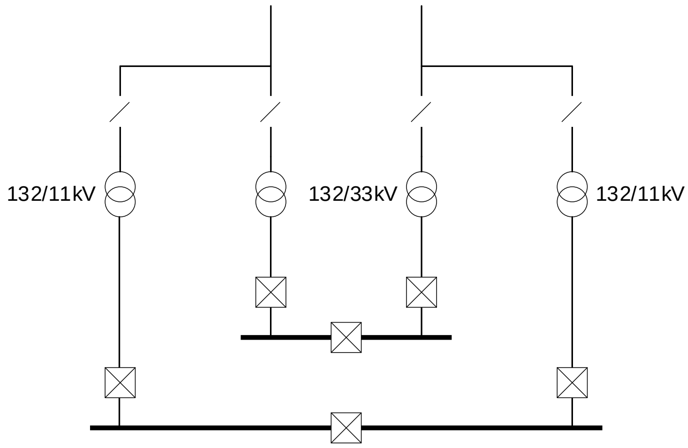


Figure 7-3 – Secondary Voltage Banked Transformer Arrangement

Disconnectors with integral earth switches are provided for each transformer but there is no requirement for 132kV line disconnectors.

As seen in Figure 7-4, banked transformer arrangements may also be used for transformer reinforcement options where it would be impossible to install a 2-switch 132kV bus section to connect a third transformer or the existing transformers are already of the maximum rating. The provision of an auto-switching scheme including source auto reclose shall be installed to enable a healthy transformer to be reinstated if one transformer faults in a banked pair.

Note: Generally, existing busbar arrangements should not be replaced on a like-for-like basis, bus sections and couplers should be installed to provide maximum flexibility.

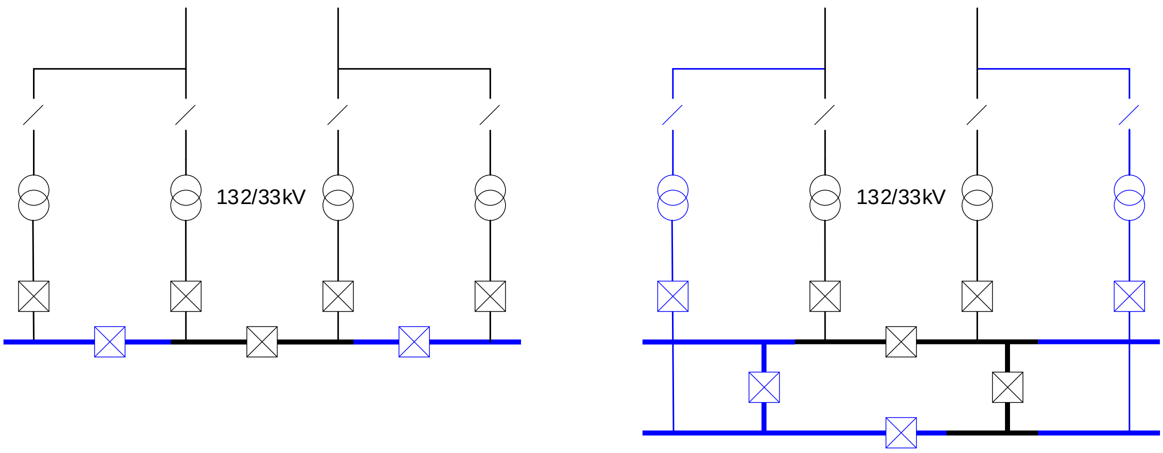


Figure 7-4 – 132kV Banked Transformer Arrangement Reinforcement Options

7.5 Banked Distribution Circuits

The use of banking for distribution circuits should be avoided wherever possible on the EHV distribution network due to the reduction of system flexibility, therefore other options shall be considered prior to accepting banked circuits.

However, where it can be demonstrated that banking is either unavoidable due to physical or operational constraints, or a necessity due to prevailing network conditions, banking may be accepted. Full load outage support shall be required for any banked circuits.

Note: Operational constraints exist regarding the use of banking for example:

- 132kV GIS switchgear does not have test points to access the cable ends, therefore the cable end box shall be de-gassed for testing.
- For cable faults on one GIS switch, a double teed outage is required as the switchgear needs to be de-gassed.
- Switchboard extensions require the last live circuit at the end of the board to be de-gassed.

7.6 Mesh Networks

Mesh designs, a group of two or more feeders running in parallel, are preferred for 132kV urban underground systems because they:

- Provide economic and efficient designs.
- Provide high levels of utilisation of network capacity.
- Reduce the number of feeders emanating from GSPs.
- Eliminate the need for banking connections.
- Provide greater network resilience via interconnection between grid supply groups.

However, in inner city areas where land availability is an issue and land values are high the switchgear at 132/11kV substations will invariably need to be of indoor GIS design and the added cost of switchgear will need to be considered in comparison with transformer feeder arrangements where no switchgear is required.

7.7 Overhead Lines Double-Circuit Optimum Phasing

A magnetic field is created for each of the circuits in a double-circuit overhead line. The field characteristics are determined by the order of the three phases that constitute the circuits and the direction of power flow. The resultant magnetic field is comprised of the summation of both fields.

Within UK Power Networks all new double-circuit overhead lines shall be in an optimum phasing arrangement either being of untransposed or transposed construction as shown in Figure 7-5.

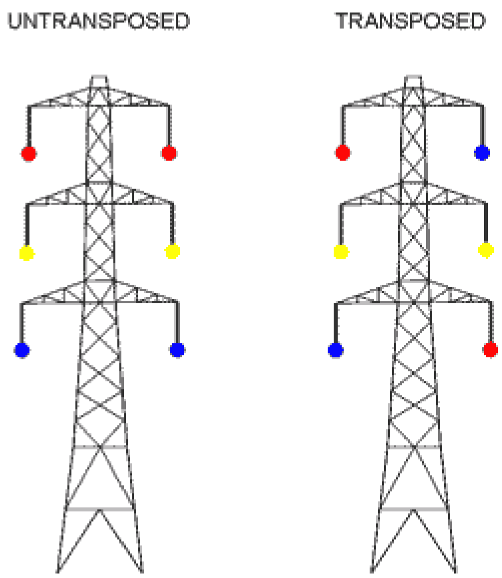


Figure 7-5 – Optimum Phasing – Construction Arrangement

Where it is not possible to identify an optimum phasing, the existing phasing should be retained for existing circuits. The circuit shall be identified, and optimum phasing adopted at the earliest opportunity.

8 33kV Network Configurations

The following section defines feeding arrangements for different EHV network configurations. 11kV busbar arrangements are defined in Section 9.

Note: In the following diagrams, feeder and transformer circuit breakers are distributed between all busbar sections as required for the local network configuration dependent upon loading, protection, and fault level criteria. This will also determine which bus section / coupler circuit breakers are normally open and if auto switching is required.

8.1 Underground Transformer Feeder Networks

The simplest and perhaps most reliable network configuration is that of the duplicate transformer feeder shown in Figure 8-1 since it is readily understood, easy to operate and does not involve complicated protection systems. Such systems are commonplace in medium load density urban areas comprising mixed residential and commercial loads. At the primary substations there is no requirement for 33kV switchgear as the 33kV circuit can terminate directly onto the transformer providing appropriate intertripping is in place.

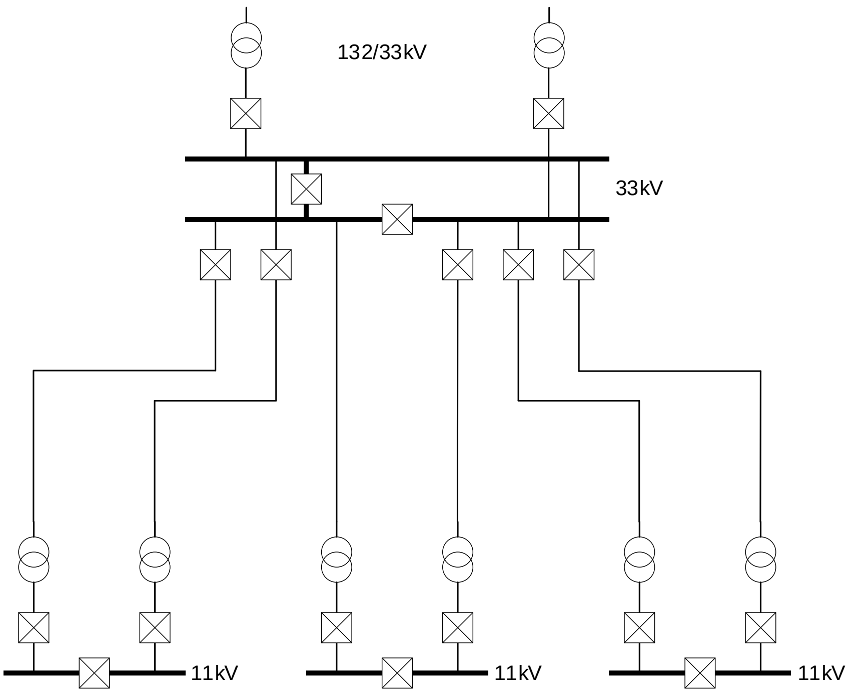


Figure 8-1 – Underground Transformer Feeder Network

Generally, with underground networks the intertripping of primary transformer faults is achieved by multi-core or fibre optic pilot cables laid with the 33kV cables.

Transformer sizes may vary in relation to the primary substation demand with the normal maximum capacity being provided by 2 x 20/40 MVA continuous emergency rating transformers which integrate with the 2000/2500A 11kV switchgear.

All supplies remain secure for n-1 outage conditions but under n-2 conditions both circuits supplying an individual primary substation supplies are lost. However, the secondary networks emanating from each substation should be designed to interconnect thus providing limited back feeds under the double outage condition.

Demands of less than 100MW require only to be restored in repair time under n-2 outage conditions to be compliant with the ENA EREC P2 standard. However, where a primary substation supplies a secondary network which is 'islanded' or has limited interconnection the risk to customer supplies should be assessed and, where practical, steps should be taken to mitigate the risk.

Transformer feeder networks are unlikely to provide the most economic system due to the high capital cost of the 33kV cables and the fact that the assets are restricted to 50% utilisation. Both utilisation and security are enhanced where three and four feeder arrangements are employed as shown in Figure 8-2 and Figure 8-3.

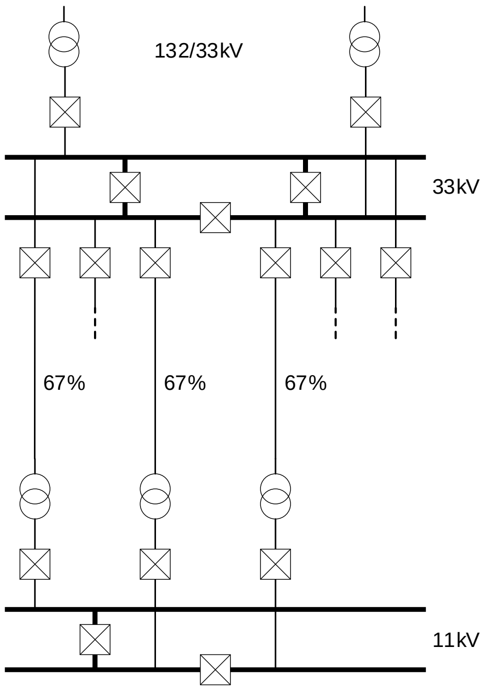


Figure 8-2 – Underground 3 x Transformer Feeder

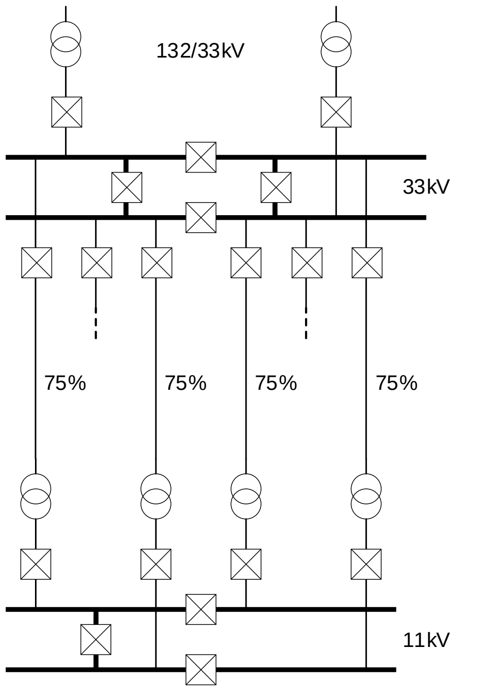


Figure 8-3 – Underground 4 x Transformer Feeder

In the three-feeder arrangement shown in Figure 8-2, each circuit can run normally at 67% of rating on the basis that under outage conditions the load on the faulted feeder divides equally between the remaining healthy feeders such that they are loaded at 100% of rating.

The three-feeder arrangement also provides greater resilience as under both n-1 and n-2 outage conditions some of the demand can be maintained. Planned outages are restricted to periods when the network is secured for an n-2 condition.

If the transformers are of the ONAN type, of nameplate rating of 15MVA and 12-hour overload rating of 1.3 pu (19MVA) (commonly used in LPN), the firm capacity, n-1 condition is:

- F_C = 19MVA × 2 = 38MVA, therefore each transformer would be running at 12.66MVA maximum pre-fault load (84% utilization of nameplate rating or 67% utilization of 12 hour overload rating).

For an n-2 condition, the firm capacity is:

- F_C = 0.67 (summer or weekend load in CHLDZ maximum demand) × 38MVA = 25.5MVA. As the remaining transformer rated at 19MVA overload condition is insufficient, 6.5MVA would need to be transferred away for an n-2 condition.

In the four-feeder arrangement in Figure 8-3 utilisations of 75% can be achieved and the network has even greater resilience. Taking the same transformers as before, the firm capacity n-1 condition is:

- F_C = 19MVA × 3 = 57MVA, thus each transformer would be running at 14.25MVA maximum pre-fault load (95% utilization of nameplate rating or 75% of 12 hour overload rating).

For an n-2 condition, the firm capacity is:

- F_C = 0.67 (summer or weekend load in CHLDZ maximum demand) × 57MVA = 38MVA.

There would be no need to transfer load away as the remaining two transformers, rated at 19MVA would be able to hold 38MVA.

A four-transformer substation has, therefore, the advantage of not having to transfer load away on an n-2 condition; system assets are highly utilized; HV interconnectivity is more secured and is more resilient for n-2 situation; on the planning load estimates, an n-1 loading of 57MVA is breached in the same year mathematically that n-2 loading of 38MVA is breached.

For further information on security of supply refer to EDS 08-1105.

8.2 Overhead Transformer Feeder Networks

The arrangement of an overhead transformer feeder network is shown in Figure 8-4.

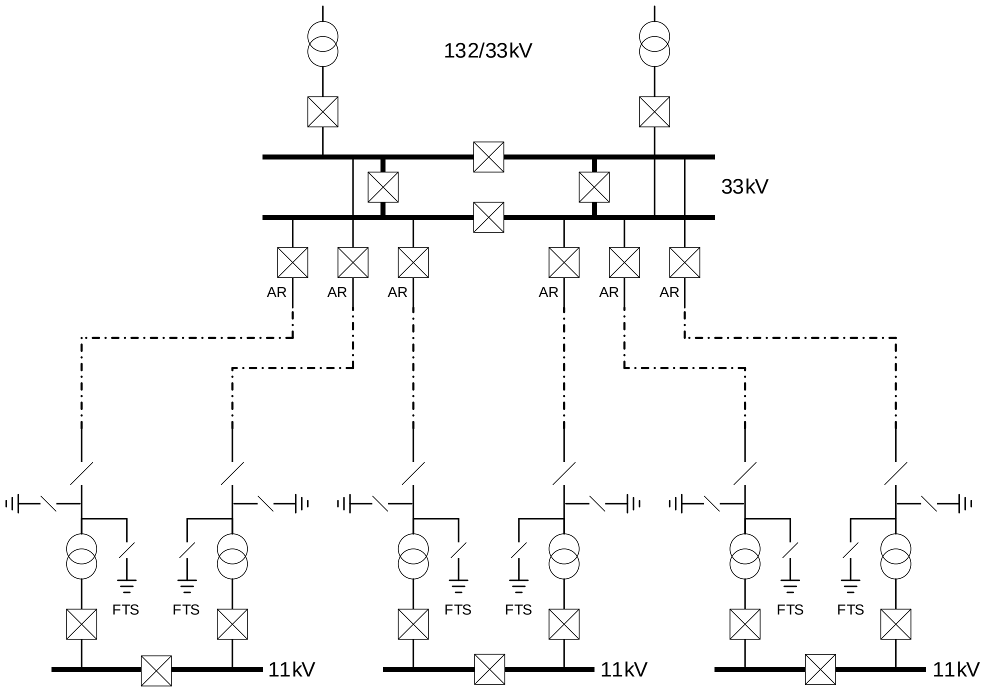


Figure 8-4 – Overhead Transformer Feeder Network

The arrangement is similar to that of the underground network and will be appropriate to rural areas where typically a primary substation may be established in a small town or load centre and supply surrounding villages. Generally, the primary substation will comprise two transformers having a maximum rating of 12/24MVA.

For remote source circuit breaker operation, refer to Section 6.5.3.

A transformer isolator shall be fitted with an earth switch on the line side of the isolator to protect operators against induced voltage. A circuit main earth is thus possible when maintenance work is to be carried out on a transformer.

8.3 Underground Teed Transformer Networks

Arrangement removed due to the lack of a 33kV approved RMU. Consider the underground ring arrangement detailed in Section 8.5, or consult the author for alternative options.

8.4 Overhead Teed Transformer Networks

Arrangement removed due to the lack of a suitable protection solution. Consider the overhead ring arrangement detailed in Section 8.6, or consult the author for alternative options.

8.5 Underground Ring Networks

Figure 8-5 shows an underground ring network supplying three primary substations but in practice such an arrangement would have limited applications.

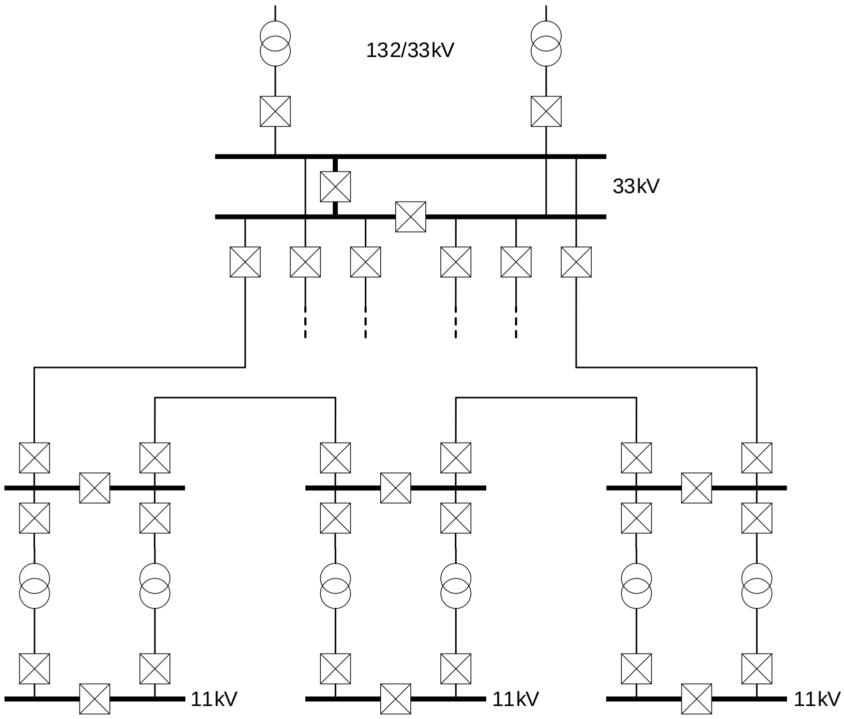


Figure 8-5 – Underground Ring Network

The aggregate demand of the three primary substations could not exceed the rating of the first legs of the ring emanating from the 132/33kV grid substation and on the basis of a single core XLPE cable design comprising three 630mm^2 copper conductors the rating would be approximately 50MVA.

Whether or not the overall 33kV circuit length and thus capital cost would be less than the transformer feeder arrangement would depend upon the geographic relationship of the primary substations.

Extensible indoor metalclad circuit breaker equipment would be required at each primary substation and each 33kV circuit shall preferably be protected by a unit protection system.

Although compliant with ENA EREC P2 standard for security of supply, under n-2 conditions all supplies to the network would be lost. From a security standpoint the ring network is, therefore, inferior to the transformer feeder arrangement.

A ring system employing two primary substations would, however, be technically acceptable and is likely to provide an economic arrangement. However, as with the transformer feeder arrangement only 50% utilisation is achieved.

8.6 Overhead Ring Networks

Overhead ring networks as shown in Figure 8-6 are commonplace in sparsely populated rural areas where the primary substations may be at some considerable distance from the 132/33kV grid substation. Where ring systems cannot be avoided (extending a ring overhead network is acceptable) suitable means of automatic isolation shall be employed (distance protection, auto reclose or SCADA automation scripts).

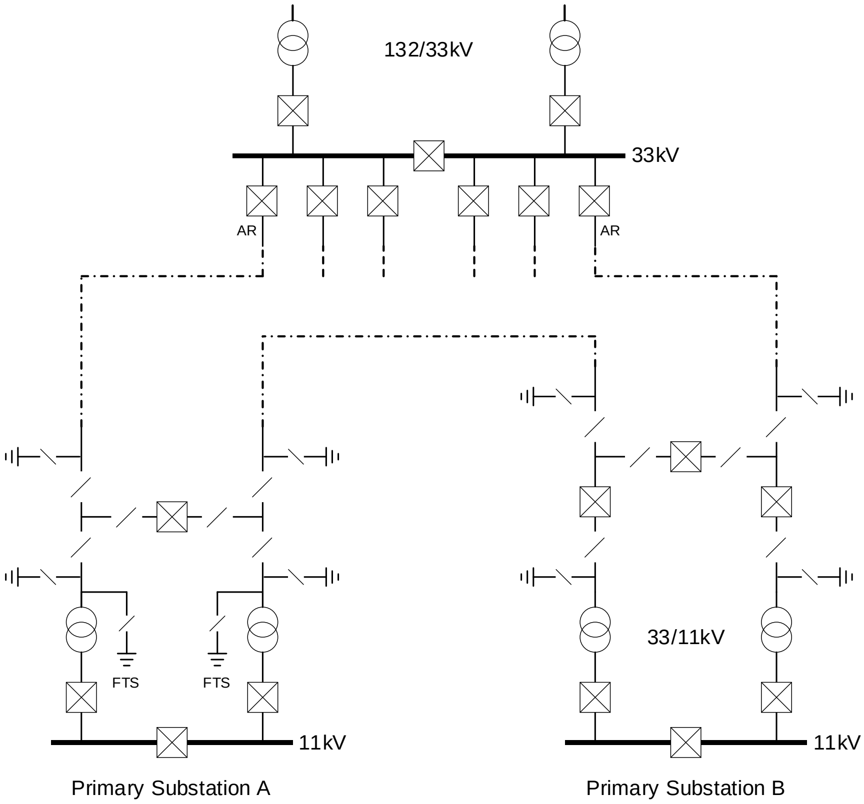


Figure 8-6 – Overhead Ring Network

Generally small rural substations use outdoor open terminal equipment subject to environmental constraints and particularly where the lines enter the substation site directly. Where the entry to the substation site is by means of underground cable extensible indoor metalclad switchgear may be cost effective.

Primary substation A in Figure 8-6 is no longer a viable option for future developments as UK Power Networks considers fault thrower switches as a form of remote circuit breaker operation to be a last resort, however fault throwers may be replaced at existing sites following failure. The design uses the 'single switch' principle employing a single bus section circuit breaker. The transformer protection opens both the 11kV circuit breaker and the 33kV bus section circuit breaker in addition to closing the fault throwing switch. Following closure of the fault throwing switch and after a predetermined interval during which the source protection operates and the source circuit breaker opens, the faulted primary transformer auto disconnects. After a further interval the 33kV bus section closes to restore the ring. If the transformers at each primary substation are operated in parallel customers experience no loss of supply.

Primary substation B employs both bus section and transformer circuit breakers and although more costly this arrangement is considerably more robust and transformer faults cause less disturbance to the network than the single switch arrangement.

8.7 Underground Mesh Networks

Mesh networks provide a robust infrastructure and are employed mainly in high load density areas requiring a high level of security. A typical arrangement is shown in Figure 8-7.

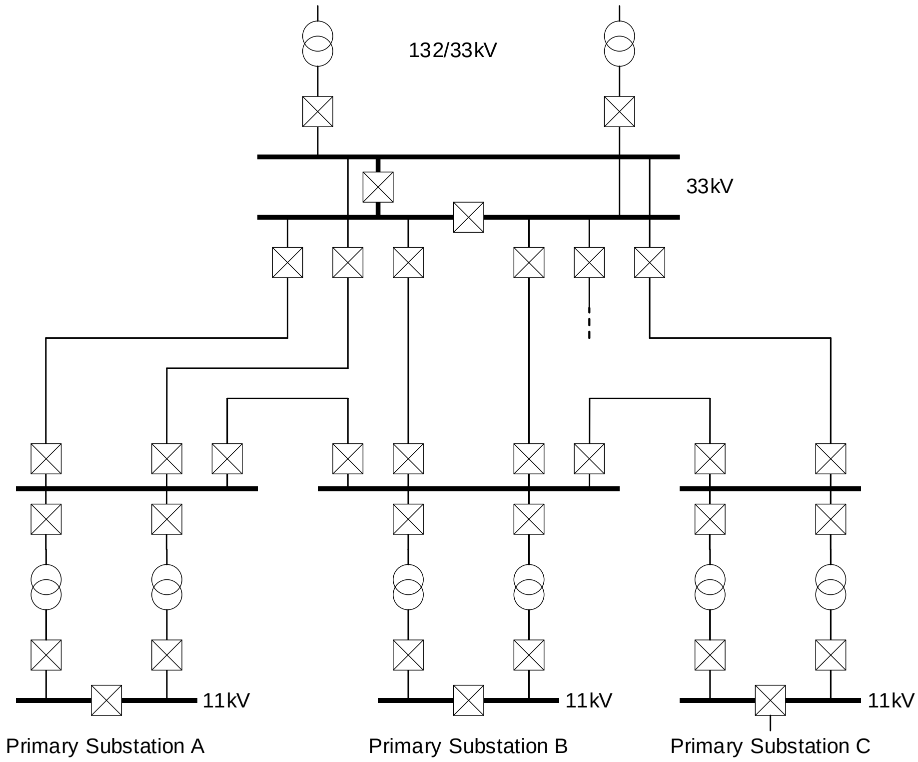


Figure 8-7 – Underground Mesh Networks

Such networks employ extensible metalclad indoor switchgear and unit protection schemes are required because the number of grading steps and alternative running arrangements could not be catered for with IDMT over-current and earth fault or distance protection systems.

As with the three and four transformer feeder arrangements above, mesh networks also permit higher utilisation of the circuit assets and hence reduce circuit costs. However, it may not be possible to achieve the theoretical utilisation as the load flows in each circuit will be proportionate to its respective impedance.

Mesh networks also have greater resilience, as the risk of total loss of supplies resulting from the n-2 outage conditions are reduced when compared to simple ring or two transformer feeder arrangements.

Mesh networks also provide a cost-effective solution when network reinforcement is required or where it is not possible to acquire new circuits and the utilisation of the existing assets needs to be increased. In the reinforcement option shown in Figure 8-8 the proposed reinforcement allows a maximum of 75% utilisation to be achieved when under loss of an individual circuit the load is equally shared between the remaining three circuits.

Furthermore, under the n-2 circuit outage scenario, supplies to both substations can be maintained albeit only partial restoration at an individual substation may be possible at times of system maximum demand. Loss of both circuits to a substation supplied by two transformer feeders inevitably results in loss of supplies although there may be limited interconnection at the lower voltage.

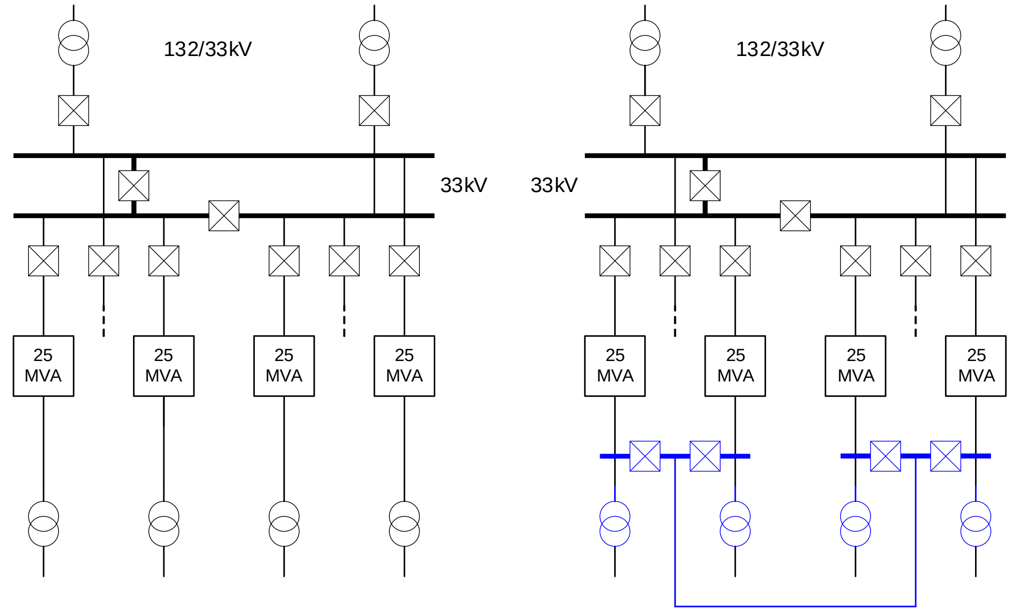


Figure 8-8 – Reinforcement Option by Improving Network Utilisation

In LPN, where substations are closer to each other when compared to EPN and SPN, reinforcement options using existing plant are possible, thus increasing load transfer capability, reliability, security and improving the utilisation of all assets. Take the arrangement in Figure 8-9. By having two, two transformer substations connected with an auto close (couplers remain open and sections closed) the site has a higher resilience, utilizes all four transformers at nearly their full capacity, HV interconnectivity is more secured and is more resilient for an n-2 situation.

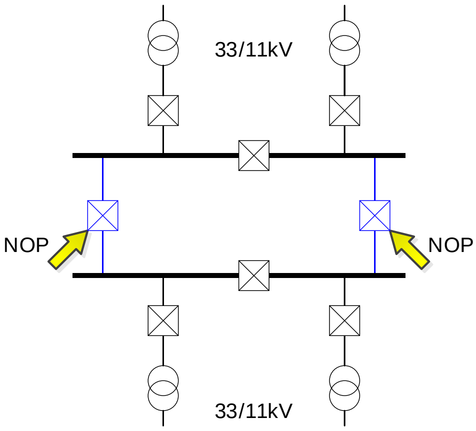


Figure 8-9 – Dual 2 Transformer Substations Reinforcement via Interconnection

With a firm capacity (during n-1) of 57MVA (19MVA x 3), under pre-fault conditions, each transformer is operating at 14MVA with each busbar at 28.5MVA.

For an n-2 situation, transfer capability is not needed as the substation would be able to hold the load of 38MVA (19MVA x 2) for 12hours. Besides being resilient for an n-2 situation, it also contributes with 19MVA to transfer availability during n-1 (57MVA-38MVA=19MVA).

8.8 Overhead Mesh Networks

Given the large geographic area supplied by some rural overhead networks it would be both impractical and uneconomical in many cases for all primary substations to be connected as transformer feeders. Wayleaves and consents may also be an issue given the number of circuits that would be required.

The design of overhead networks will, therefore, comprise a mixture of transformer feeders, ring and mesh networks and the configuration proposed under any investment strategy shall be based on cost, taking account of the geography of the area, the disposition of load and the existing network characteristics.

9 11kV Switchgear Configurations (at Grid and Primary Substations)

The configuration of the 11kV switchboards at grid and primary substations is complementary to the primary layout in maximising the available capacity and security of the overall arrangement.

Both single and double busbar designs may be specified with busbar ratings up to 2500A. Bus section, bus-coupler, bus inter-connector and transformer incomer circuit breakers may also be rated at 2500A to match the busbars.

Dependent upon the secondary network configuration feeder circuit breakers rated at 630A, 800A, 1250A, 2000A, or 2500A may be used. Commonly feeder circuit breakers are rated at 630A as this matches the rating of a 300mm aluminium triplex 11kV circuit.

At single busbar substations, feeders should be arranged across the switchboard such that each separate feeder of a group or simple ring is connected to a discrete section of busbar. This will provide security to the 11kV network and in addition facilitate the off-loading of busbars for planned busbar outages.

In considering the switchgear arrangement at a specific site the following issues should be addressed:

- The merits of single versus double busbar designs.
- Integration of transformer and 11kV switchgear ratings.
- The likelihood of future transformer reinforcement.
- Parallel groups of feeders on the 11kV network.
- Physical layout and fire segregation between busbar sections.
- Parallel operation of incoming transformers vs. automatic restoration.
- Fault level constraints.

Note: In the following diagrams, feeder and transformer circuit breakers are distributed between all busbar sections as required for the local network configuration dependent upon loading, protection and fault level criteria. This will also determine which bus section / coupler circuit breakers are normally open and if auto switching is required.

9.1 Busbar Loading Principles

The loading on busbars connected to the dual secondary windings of transformers should be as even as possible, to within 5MVA to allow the common EHV winding tapchanger to control the voltage in a reliable manner when the secondary windings are operated interleaved and to obtain the maximum loading capability for the substation under first outage conditions.

Where HV feeders supply an interconnected LV network, or form a unit protected HV ring, then all HV feeders supplying the interconnected LV group, or the unit protected HV ring should normally be connected to the same busbar section. Existing arrangements may be considered for retention provided that any bus section or bus coupler circuit breakers between HV feeders, at main substations, supplying interconnected LV groups or unit protected rings are not operated automatically by protection or sequence switching arrangements.

Any future proposals for connections of HV feeders supplying interconnected LV networks or unit protected rings across busbar sections of primary substations should be avoided in principle. If any cases arise where it is considered that there is a benefit from such an arrangement it must first be discussed with UK Power Networks Asset Management and agreement obtained before implementation.

The general method of load assessment on busbars is to:

a) Under normal running conditions, check that the currents through any section of busbars, cables interconnecting busbars, bus section and bus-coupler circuit breakers and related current transformers do not exceed the equipment's rating.

b) Repeat studies for outage conditions, including HV feeder outages, envisaged in the Security of Supply standard assuming that any auto-switching scheme or telecontrol action operates correctly.

The initial assessment shall be done using aggregated loadings provided in the HV feeder load files. Diversity should be considered if equipment ratings are seen to be exceeded by the aggregate loads before action is taken.

The above studies should be repeated prior to the adoption of any subsequent change in running arrangements.

9.2 2 x 60MVA 132/11/11kV Substations

The 11kV switchgear at substations comprising two 60MVA; 132/11/11kV double wound secondary transformers shall always be of double busbar design and a typical configuration is given in Figure 9-1.

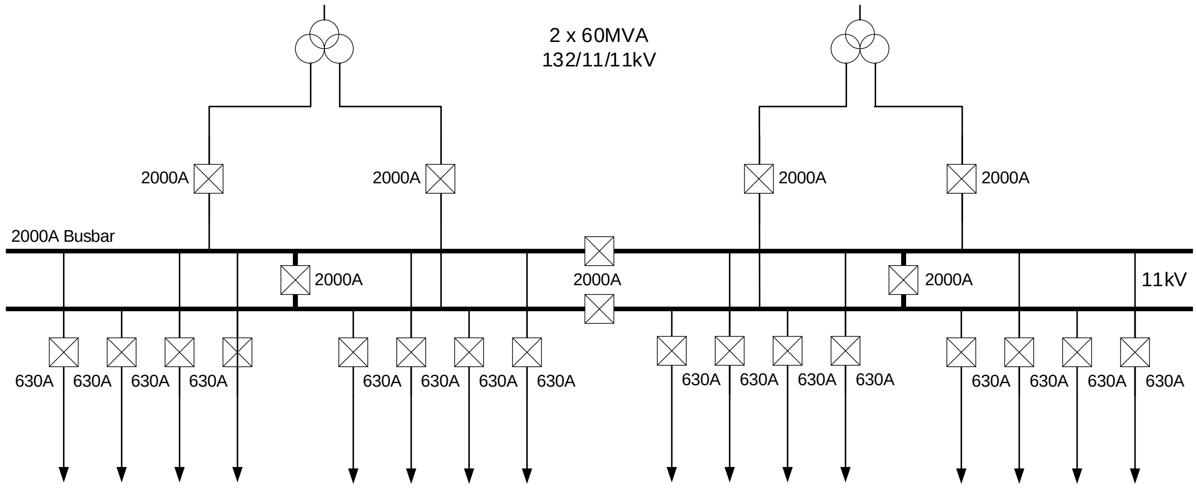


Figure 9-1 – 2 x 60MVA Double Busbar Feeder Substation

Two bus section circuit breakers and two bus-coupler circuit breakers are required to achieve the desired level of security and operational flexibility. The switchgear shall be divided into two sections interconnected by cables or busbar system and located within separate switchrooms to provide full segregation against fire and smoke.

9.3 3 x 66MVA 132/11kV Substations

The configuration shown in Figure 9-2 is typically used in the LPN Region, in high load density areas, where a large number of outgoing 11kV feeders is required. Typically, the outgoing circuits would be unit protected for parallel operation and would supply groups of load in specific areas.

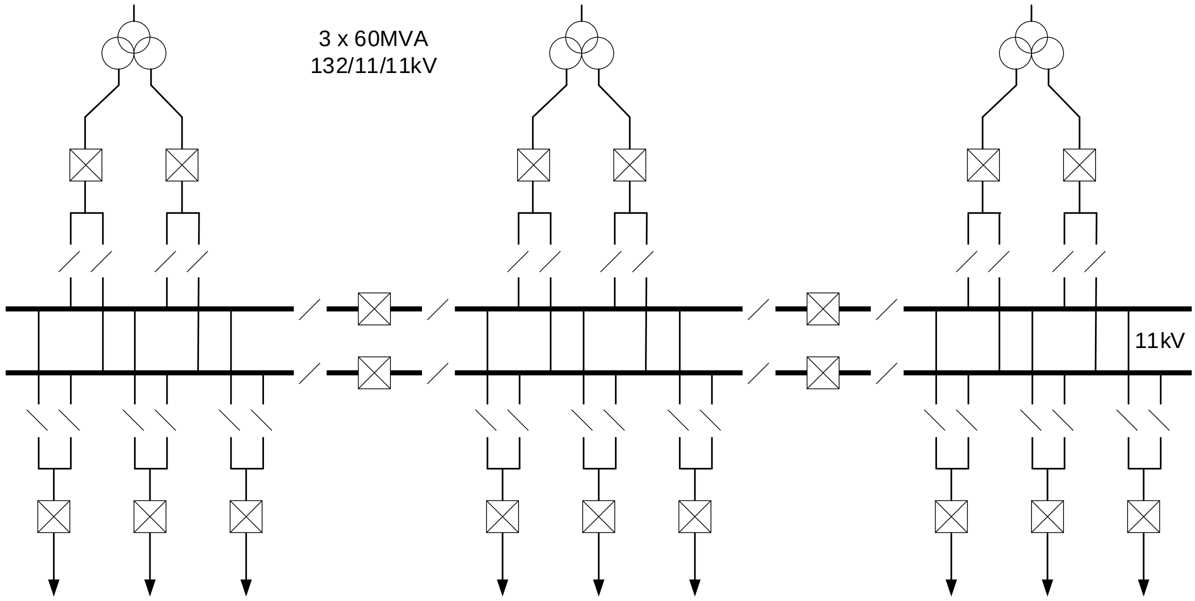


Figure 9-2 – 3 x 66MVA 11kV Switchgear Configuration

9.4 2 x 12/24MVA 33/11kV Substations

33/11kV substations comprising two transformers up to 12/24MVA ratings shall generally be of single busbar design as shown in Figure 9-3. It is acceptable for both sections of switchgear to be accommodated in a single switchroom and no provision shall be made for segregation in the event of explosion or fire and smoke damage.

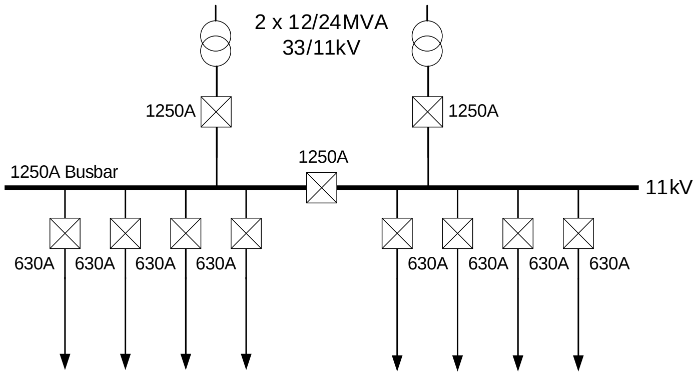


Figure 9-3 – 2 x 12/24MVA 11kV Switchgear Configuration

The maximum transformer rating of 24MVA at 11kV is equivalent to 1250A and a switchboard comprising 1250A incomers, busbars and bus section provides the ideal arrangement. Transformer incomers shall be installed directly either side of the bus section circuit breaker such that under transformer outage conditions the busbar loadings are equalised by feeders to the left and right of the healthy incomer.

Where the network comprises, parallel feeders supplying a single customer or a mesh group the feeders cannot be connected to the same section of busbar since in the event of a busbar outage under fault or pre-planned outage conditions customer supplies would be lost.

Where transformers run in parallel it may be possible to arrange feeders of a mesh group to either side of the bus section as shown in Figure 9-4.

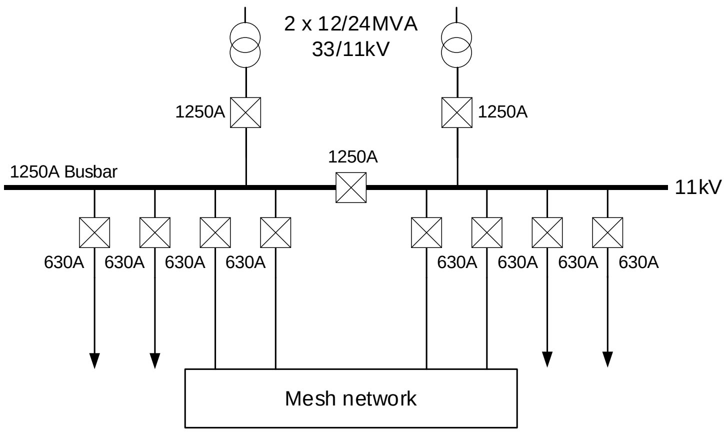


Figure 9-4 – 2 x 12/24MVA 11kV Mesh Network Switchgear Configuration

This arrangement may, however, have undesirable consequences in the event of a busbar or 33kV network fault since the fault could be ‘back energised’ via the 11kV network. This may also be an issue with a single customer whose supply is provided by two or more parallel circuits. Where mesh distribution or customer supply networks are required with single busbar 11kV switchgear configured with a single bus section switch it will however be necessary to run primary transformers in parallel as a normal arrangement.

A second option to overcome the busbar security issue is shown in Figure 9-5.

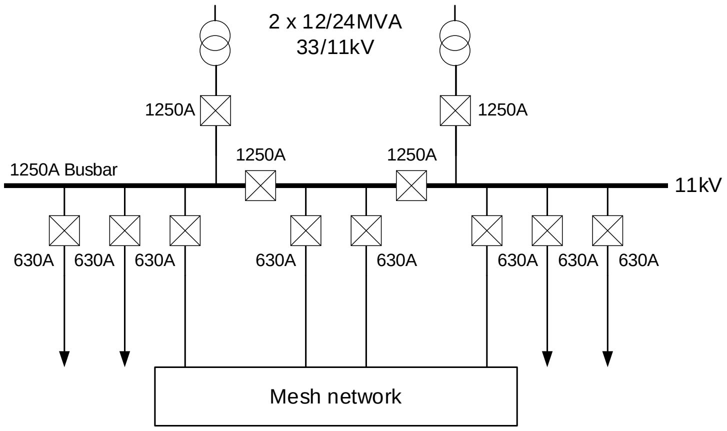


Figure 9-5 – 2 x 12/24MVA 11kV Secured Mesh Network Switchgear Configuration

An additional bus section circuit breaker is employed with feeder circuit breakers either side. In the event of a busbar fault or planned outage the network is supported by the feeders which are connected to the healthy busbar. However, the possibility remains that the customer demand cannot be supported on the remaining feeders and a more robust solution employing double busbar switchgear would be required.

9.5 2 x 20/40MVA 33/11kV Substations

The 11kV switchgear configuration at a substation comprising either two 20/40MVA 33/11kV or two 30MVA 132/11kV transformers is shown in Figure 9-6.

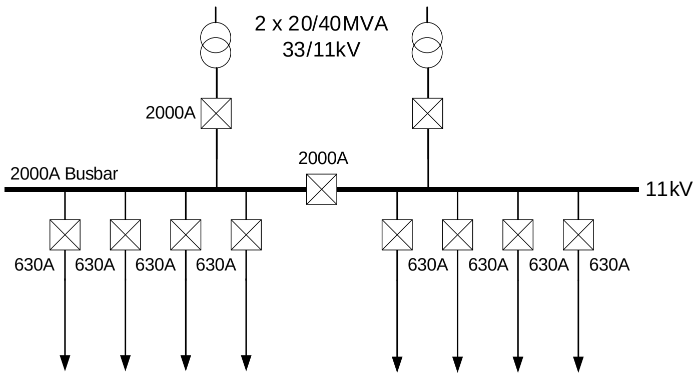


Figure 9-6 – 2 x 20/40MVA 11kV Switchgear Configuration

9.6 4 x 12/24MVA 33/11kV Substations

Many existing substations are designed on the principle of four transformer feeders which can terminate with 12/24MVA transformers. When the 11kV switchgear reaches the end of its useful life and replacement is required, a point is reached where it is necessary to decide whether to retain the existing infrastructure or alternatively overlay the existing feeders with cables of greater capacity such that a two transformer arrangement can be adopted.

Dependent upon the age of the 33kV cables, whether they are of solid or gas/oil assisted design and their condition and performance history it may be expedient to maintain the status quo and replace the switchgear on a 'like for like' basis.

A typical configuration of a four transformer feeder substation is given in Figure 9-7.

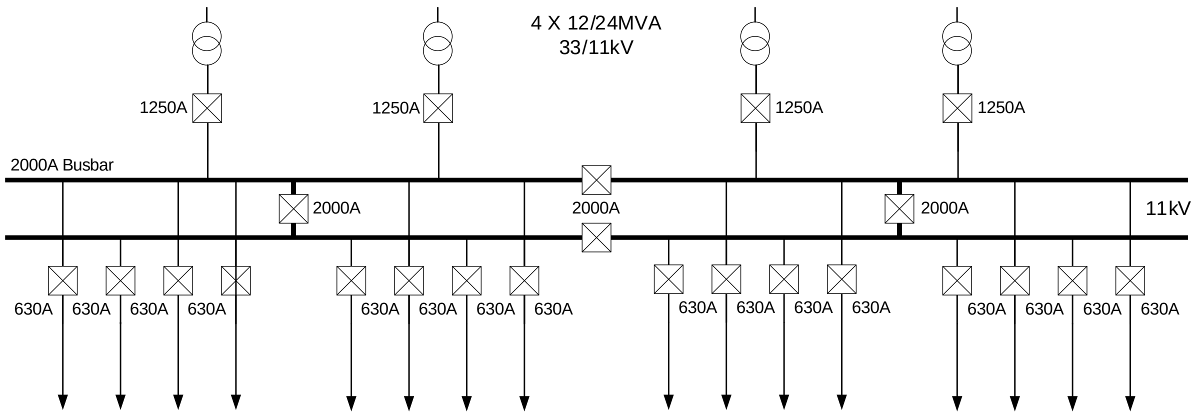


Figure 9-7– 4 x 12/24MVA Double Busbar Feeder Substation

A double busbar arrangement is required to provide operational flexibility and to ensure that under outage conditions of a single transformer the load on the remaining transformers can be shared equally. Two bus section switches and two bus-coupler switches are required to provide flexible running conditions. The number and rating of the feeder circuit breakers will be tailored to meet the network requirements.

9.7 Fault Level Considerations

When planning the network, in order to ensure the correct IDMT protection system operates, under normal and reasonable abnormal conditions, the network shall be planned and arranged so that:

$$\frac{\text{minimum 3 phase fault current}}{\text{maximum balanced load}} \geq 2.2 \quad \text{and} \quad \frac{\text{minimum earth fault current}}{\text{maximum load imbalance}} \geq 2.2$$

In special circumstances, where specialist protection functions such as voltage controlled overcurrent and other specialist protection are used, this factor could be reduced to 1.4.

For interconnected systems, extra care shall be taken as the protection sequence of events is more complex.

Where fault level exceeds the secondary switchgear rating at a specific site with primary transformers running solid the following actions should be considered:

- Open the bus section and add an auto-close scheme.
- Consider fault current limiter.
- Replace switchboard.

If the switchboard is due to be replaced in the near future, consideration should be given in bringing that investment forward.

10 132kV and 33kV Connection Arrangements

10.1 132kV Connections

10.1.1 Overview

Customer 132kV connections shall be provided via an overhead line tee connection (Section 10.1.2) or loop connection (Section 10.1.3) where possible. A direct connection from a substation (Section 10.1.4) may be provided as a last resort.

All 132kV connections shall be designed in accordance Section 7.

In the following sections, consideration shall be given to protection settings, sensitivity and zone reach, impedance increase, fault levels and implications to the voltage control scheme. Schemes shall be replaced as necessary.

It may be inappropriate to provide connection from the 33kV or 66kV primary networks for one or more of the following reasons:

- No primary infrastructure in the vicinity of the development.
- The development is adjacent to an existing 132kV circuit.
- The generator output or MPR cannot be accepted on the primary network by virtue of excessive fault level, voltage rise, reverse power flow or inadequate thermal capacity.

Where it is demonstrably economic to provide the connection at 132kV such an arrangement shall be offered irrespective of the agreed capacity requested. UK Power Networks owned 132kV switchgear and equipment shall generally be of open terminal outdoor design subject to compliance with environmental safety standards.

In areas where the infrastructure is predominantly of direct 132/11kV transformation and no lower voltage primary networks exist, customer connections of greater than 15MW will invariably be provided with 132kV points of connection. However, where due to physical or technical constraints it is impractical or uneconomical for a 132kV supply to be provided to the generator site a 132/11kV transformer may be provided at an existing UK Power Networks 132kV site.

10.1.2 132kV Tee Connection

A 132kV tee connection is shown in Figure 10-1 and is likely to provide the optimum technical and economic solution where a proposed site is traversed by an existing 132kV overhead line.

Tee connections from 132kV networks shall only be provided if the network satisfies the requirements of Section 6 and 7, and a satisfactory protection system can be achieved. If the existing 132kV circuit is protected by a unit protection scheme, the protection shall either be modified to provide a 'three ended' scheme or a 132kV loop connection shall be considered in accordance Section 10.1.3.

A tee connection from an existing 132kV underground cable circuit is unlikely to be feasible and therefore, a loop connection in accordance with Section 10.1.3 is the preferred method of providing a connection from a 132kV cable circuit.

The protection and control requirements for 132kV tee connections are detailed in EDS 05-0002. Refer to drawings EDS 05-0002-307 to 309 for the PoC and EDS 05-0002-302 to 306 for the customer end.

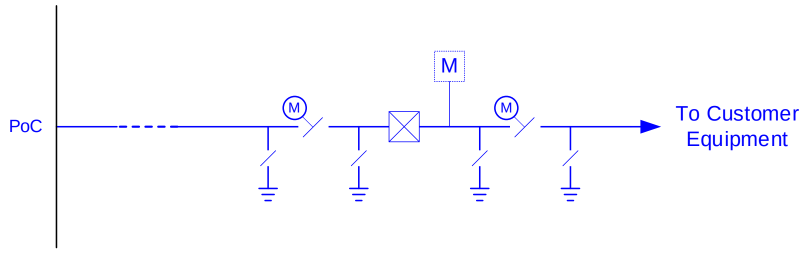


Figure 10-1 – Tee Connection from 132kV Overhead Line

10.1.3 132kV Loop Connection

A 132kV loop connection is likely, subject to the configuration of the network, to provide additional security for the customer. A loop connection may be provided from either and overhead line or underground cable circuit as shown in Figure 10-2.

The protection and control requirements for 132kV loop connections are detailed in EDS 05-0002. Refer to drawings EDS 05-0002-310 to 311 for the PoC and EDS 05-0002-302 to 306 for the customer end.

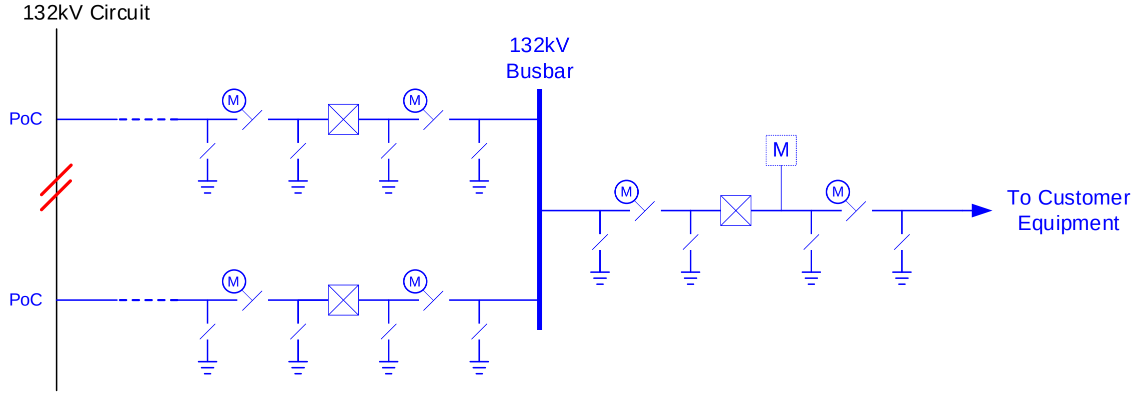


Figure 10-2 – Loop Connection from 132kV Overhead Line

10.1.4 132kV Substation Connection

Connections may also be provided directly from an existing 132kV substation. This may be from a 400kV or 275kV GSP by means of extension to an existing double-busbar arrangement as shown in Figure 10-3 or, subject to satisfying protection, complexity and operational constraints, banked with an existing circuit as shown in Figure 10-4.

Where the customer site is not in proximity of a GSP, a 132kV connection may be provided from a 132/33kV or 132/11kV grid substation as shown in Figure 10-5. The connection arrangement will depend upon the customer's requirements for security and available space at the substation.

The protection and control requirements for 132kV substation connections are detailed in EDS 05-0001.

The protection and control requirements for the customer end are detailed in EDS 05-0002, refer to drawings EDS 05-0002-302 to 306.

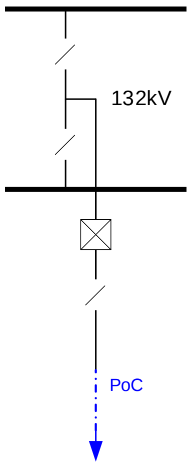


Figure 10-3 – New 132kV Circuit from a GSP

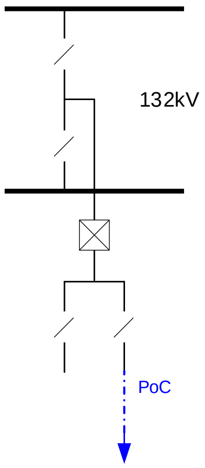


Figure 10-4 – New 132kV Banked Circuit from a GSP

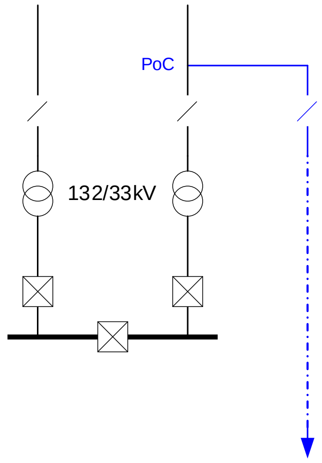


Figure 10-5 – New Circuit from 132kV Substation

10.2 33kV Connections

10.2.1 Overview

Customer 33kV connections shall be provided via an overhead line tee connection (Section 10.2.2) or an underground cable loop connection (Section 10.2.3).

All 33kV connections shall be designed in accordance Section 8.

10.2.2 33kV Tee Connection

An underground cable connection may be provided from a 33kV overhead line via a tee with an isolation as shown in Figure 10-6. The device controlling the connection to the main line shall be either a suitably rated disconnector or a circuit breaker.

Note: It is not feasible to provide a tee connection from a 33kV underground cable as the tee connection requires isolation. A loop connection shall be provided in accordance with Section 10.2.3.

In instances where the 33kV circuit to which the connection is to be made is protected by unit or distance protection or operates as a transformer feeder circuit with overall protection, additional 33kV circuit breakers are required, and shall be provided as part of the scheme. This arrangement may also be required where the 33kV circuit is part of a mesh network or where the circuit complexity is such that a tee connection would not be permitted.

Where wayleaves and consents are readily available the connection from the tee point to the customer site may be by means of an overhead line circuit with appropriate isolation at the tee point.

The protection and control requirements for 33kV connections are detailed in EDS 05-0002, refer to drawings EDS 05-0002-201 / 203.

Customers shall be made aware that a tee connection cannot be maintained during network outages, whether a fault or maintenance driven.

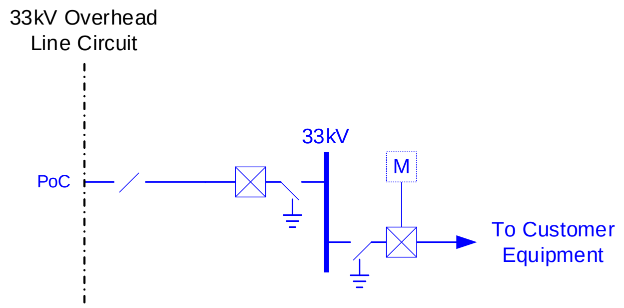


Figure 10-6 – Tee Connection from an Existing 33kV Radial Overhead Circuit

10.2.3 33kV Loop Connection

A connection from a 33kV underground cable shall be provided via a loop connection as shown in Figure 10-7.

The protection and control requirements for 33kV connections are detailed in EDS 05-0002, refer to drawings EDS 05-0002-202 / 204.

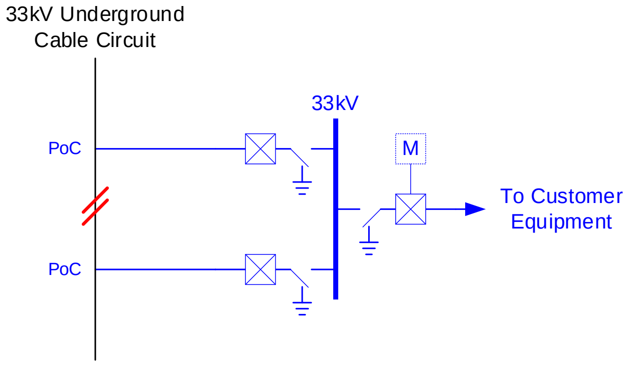


Figure 10-7 – Loop Connection from an Existing 33kV Underground Cable

10.2.4 33kV Increased Security of Supply Connections

Some customers may not wish to be constrained by network outages due to economics or contractual obligations, and the risk of a ‘single leg’ connection may be unacceptable. The network security arrangements shall be discussed with the customer at an early stage to determine the required network availability and the acceptable level of risk for the point of connection.

If a generator is proposed adjacent to an existing 33kV dual circuit overhead line or where two lines are in close proximity, both circuits may be teed.

In the absence of 33kV network in the proximity of a proposed generator, or where network analysis shows that load flow, fault level or voltage rise constraints cannot be achieved; a duplicate connection shall be provided from the nearest 132/33kV grid or primary substation.

To achieve the required network configuration or flexibility, two discrete connections using circuit breakers are required; each connection shall be designed around the arrangements shown in Figure 10-6 and Figure 10-7. However, due to the configuration of the customer installation, it may be necessary to terminate all circuits on a single switchboard with a bus section circuit breaker to facilitate busbar maintenance or to cater for a busbar fault. This arrangement also offers greater security to the customer.

The 33kV switchgear arrangement at the customer’s premises may be of either outdoor open terminal or indoor switchgear subject to site constraints.

Connections involving more than two 33kV circuits should generally not be considered as it is unlikely that the level of generation requiring such a connection could be accepted on the 33kV network and neither is it likely to be the most economical solution.

11 Cable, Plant and Equipment Requirements

11.1 Substations

11.1.1 General

All grid and primary substations shall be constructed in accordance with the relevant civil design standards refer to EDS 07-4000.

For further information on substation accommodation and land requirements for customer connections refer to EDS 08-3100.

11.1.2 Switchboard Segregation

Substations should also be designed to provide added security to prevent total loss of supplies in the event of a fire or explosion. Generally, the sections of switchgear should be sited in separate rooms with fire segregation barriers and be interconnected by means of cable or busbar system.

Refer to EDS 08-3100 regarding customer and UK Power Networks EHV switchgear segregation.

11.1.3 Substation Earthing

Grid and primary substation earthing shall be designed in accordance with EDS 06-0013 and constructed in accordance with ECS 06-0022.

11.2 Cables

11.2.1 132kV Underground Cables

For approved 132kV cables refer to EAS 02-0000. Cable core size and material will depend upon installation conditions and required rating and take account of possible future network development plans.

Cables shall be installed in accordance with ECS 02-0019.

11.2.2 33kV Underground Cables

All new 33kV cable circuits shall be of single core cable design, refer to EAS 02-0000.

The cables shall be installed in ducts where necessary for future access or additional mechanical protection. The cable shall be selected based on the required rating and installation conditions. In assessing the required cable size, due consideration should be given to the load cycle and nature of the load (refer to Section 6.2.1). The load cycle of cables connecting embedded generation or supplying commercial or industrial loads where the peak demand is sustained for eight hours or longer shall be assumed to be continuous.

Cable ratings for common installation conditions are detailed in EDS 02-0034.

Cables shall be installed in accordance with ECS 02-0019.

11.2.3 Cable Bonding

The power losses in a cable circuit are proportional to the currents flowing in the metallic sheaths of the cables. Therefore, by reducing or eliminating the metallic sheath currents through different methods of bonding, it is possible to increase the cable rating. Refer to ENA EREC C55, which defines the technical requirements for cable bonding arrangements. Three methods are generally applied:

- Both ends bonded – under this arrangement the cable sheaths provide path for circulating currents which create losses in the screen and reduce the cable rating.

- Single point bonded – under this arrangement the cable sheaths are bonded at one end only which prevents circulating current but a voltage is induced between the screens of adjacent phases and between the screen and earth. If the cable length is so that the standing voltage in the open end is less than 65V (from ENA EREC C55) there are no safety implications. Otherwise, it can lead to safety issues.

- Cross bonded – under this arrangement the circuit provides electrically continuous sheath runs from earthed termination to earthed termination but with the sheaths so sectionalized and cross-connected using link boxes as to limit the sheath circulating currents. This arrangement is generally used on long circuits where the circuit rating would be considerably impaired by bonding at both ends.

Whilst due regard should be given to these options it is generally preferred that all cable circuits shall be bonded at both ends and only where this would lead to unacceptable sheath losses and thus reduced rating should single point or cross-bonded options be considered.

11.3 Overhead Lines

11.3.1 132kV Overhead Lines

132kV overhead lines shall be constructed in accordance with ENA TS 43-1 to 43-9 for steel tower lines and ENA TS 43-50 for wood pole lines.

11.3.2 33kV Overhead Lines

All new 33kV overhead lines shall be single circuit wood pole unearthed design and comply with the overhead line construction manual. All lines shall be designed and constructed for a maximum conductor working temperature of 75˚C. For approved materials refer to EAS 01-0000.

Construction of 33kV dual circuit wood pole overhead lines may be required under some circumstances, but outage and common mode failure constraints should be considered before using this type of construction. Single circuit construction should be used wherever possible.

Overhead line ratings shall be based upon ENA EREC P27.

11.4 Switchgear

11.4.1 132kV Switchgear

132kV outdoor open terminal shall be in accordance with ETS 03-6600.

132kV GIS switchgear shall be in accordance with EDS 03-6650.

11.4.2 33kV Switchgear

33kV Switchgear shall be in accordance with ETS 03-6510

Single and double busbar indoor metal clad options are available. Use of double busbar switchgear shall generally be restricted to 132/33kV BSP substations but may occasionally be necessary at major ‘bussing’ points on the 33kV network.

Standard busbar ratings shall be 2000/2500A with circuit breaker ratings of 800A, 2000A, 2500A.

Outdoor open terminal 33kV switchgear shall generally not be considered for 132/33kV BSPs either for new installations or where existing assets are to be replaced. The cost differential between indoor and outdoor alternatives is now such that generally, open terminal outdoor arrangements no longer offer an economic solution particularly when life time costs are taken into account. However, the cost differential is less marked when all outgoing circuits could otherwise be landed by overhead fan down connections without the introduction of short cable sections.

Outdoor layouts have the added risk of failure due to environmental and/or vandalism causes and have a considerably greater impact on environmental and visual amenity. Furthermore, the land requirement for open terminal arrangements is considerably greater than that of indoor switchgear and this has a considerable bearing on costs where land values are at a premium.

When replacing switchgear at outdoor open terminal sites it is often possible to construct a new switchroom and erect the new indoor switchgear off-line to minimise the risk of loss of customer supplies whilst carrying out the replacement. The surplus land which becomes available may also attract a good sale price.

The same arguments will invariably apply also to all 33/11kV or 33/6.6kV substations and 33kV switching points supplied from urban 33kV underground systems where circuit entries to the substations are by means of underground cable. Where transformer feeder arrangements are employed (unless connected to a teed circuit and then means of isolation will be required) 33kV switchgear is not required as the 33kV cables should terminate directly within the cable box of the 33/11kV or 33/6.6kV transformer.

The choice of indoor switchgear versus outdoor open terminal arrangements at remote rural locations where the connection is provided by 33kV overhead lines is less clear cut and minor new developments, replacements or extensions utilising open terminal equipment may provide solutions which are acceptable both from a technical, economic and operational standpoint. Examples of such situations are as follows:

- New substations connected by overhead lines where the transformer(s) have bushing connections and are controlled by disconnector only.

- Replacement of switchgear at substations connected by overhead lines where the existing transformers have 33kV bushings.
- Replacement of circuit breaker at single switch site connected by overhead line or cable where all structures and disconnectors are in good condition.
- Where single switch substation layouts are required and alternative indoor switchgear configurations cannot be achieved economically.

Examples of minor developments include 1 or 2 circuit breakers, retrofit, defect rectification etc.

Generally, where substations are connected by cable sections, the preferred option is for indoor switchgear even though the network may be predominantly of overhead line construction and particularly if transformer replacement is also required.

Where the existing transformers are to be retained the connection to the transformers will be by use of a simple heat shrink termination structure.

However, the advantages of indoor layout shall not prevent the Planner/Designer from assessing sites on a case-by-case basis taking into account environmental factors, location, potential ESQC issues and others. Where the use of new outdoor open terminal switchgear is unavoidable, it shall comply with EDS 03-6520, or EDS 03-6501.

The use of pole mounted type 33kV high speed auto reclosing devices should also be considered as an economic means of providing control and protection on rural 33kV overhead networks. These may provide an economic option for control of transformers particularly where fault throwing switches are impractical or undesirable. Where teed networks are installed the use of automatic and telecontrolled sectionalising switches should also be considered.

11.5 Transformers

Only approved primary transformers shall be used on the EHV distribution network.

The use of 120MVA 132/33kV transformers is not recommended as the network risk under outage conditions is unacceptable. At 132/33kV BSPs with estimated demands greater than the firm capacity of two 90MVA transformers (117MVA) alternative arrangements employing three 60MVA or three 90MVA units should be considered.

The use of 66MVA 132/11/11kV double wound secondary transformer shall be restricted to high load density areas which would mostly be in the London region but may be considered for use elsewhere if required. New substations in high load density areas shall be designed to provide the maximum possible capacity and 132kV incoming circuits with 132/11/11kV three-winding transformers are the standard approach in the central London. Transformers with a rating of 66MVA have a cyclic 86.6MVA load capability and shall be used with 2500A 11kV switchgear.

When specifying transformer ratings, due regard should be paid to the location and environment in which the transformer is to be installed since this has a considerable impact on the efficiency of cooling systems.

The nature of the demand and daily load cycle shall also be considered when determining the required rating of a transformer.

12 General Requirements

12.1 Legal Consents

UK Power Network shall acquire new consents in accordance with AST 05 002 Property & Consent Acquisition Policy. Any termination received on the network should be referred to the Property & Consent Department in the first instance.

13 References

13.1 UK Power Networks Standards

EAS 01-0000	Approved Equipment List – Overhead Lines
EAS 02-0000	Approved Equipment List - Cables and Joints
EAS 02-0030	66kV and 132kV Single Core XLPE Cables
EAS 02-0061	33kV Single Core XLPE Cables
ECS 02-0019	Installation of Underground Cables - LV to 132kV
ECS 06-0022	Grid and Primary Earthing Construction
EDS 02-0034	33kV Single Core XLPE Cables
EDS 03-6501	Specification for Pole Mounted Air Break Switch Disconnectors for Operating Voltages Up To and Including 33kV
EDS 03-6520	Open Terminal Switchgear for Main Substations 36kV (Internal Use Only)
EDS 03-6650	Gas Insulated Switchgear - 72.5kV and 145kV
EDS 05-0001	132kV Grid and Primary System Protection and Control Schemes
EDS 05-0002	Protection and Control Schemes for Customer Demand and Generation Connections
EDS 05-4100	11(6.6)kV Primary Substation Protection Control Application
EDS 06-0013	Grid and Primary Substation Earthing Design
EDS 07-4000	Grid and Primary Civil Design Standards
EDS 08-1104	HILP Assessment Process
EDS 08-1105	Guidance for the Application of ENA EREC P2 Security of Supply
EDS 08-1110	Fault Levels
EDS 08-3000	11/6.6kV Secondary Distribution Network Design
EDS 08-3100	EHV and HV Customer Demand and Generation Supplies
EDS 08-4101	London 33kV Distribution Network Design and Customer Supplies
ETS 03-6414	Specification for 36kV Outdoor Fault Throwing Switch
ETS 03-6510	Specification for Indoor 12kV,24kV and 36kV Metal-enclosed Switchgear for Grid and Primary Substations
ETS 03-6600	Specification for Open Terminal Switchgear - 72.5kV & 145kV

13.2 Legislation

Electricity Act 1989

Health & Safety at Work Act 1974

Electricity Safety. Quality and Continuity Regulations 2002

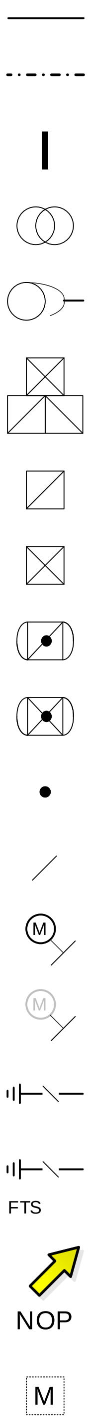
Construction Design and Management Regulations 2007

13.3 National and International Standards

Distribution Code	The Distribution Code of Licensed Distribution Network Operates of Great Britain (http://www.dcode.org.uk/)
Grid Code	Grid Code for Great Britain
ENA EREC C55	Insulated Sheath Power Cable Systems
ENA EREC G5	Harmonic Voltage Distortion and the Connection of Harmonic Sources and/or Resonant Plant to Transmission Systems and Distribution Networks in the United Kingdom
ENA EREC G99	Requirements for the Connection of Generation Equipment in Parallel with Public Distribution Networks on or after 27 April 2019
ENA EREC P2	Security of Supply
ENA EREC P27	HV OHL Current Ratings
ENA EREC P28	Planning Limits for Voltage Fluctuations Caused by Industrial, Commercial and Domestic Equipment in the UK
ENA EREC P29	Planning Limits for Voltage Unbalance in the UK
ENA TS 43-1 to 43-9	132kV Tower Line Profiling/Lattice Towers/Tower Foundations/Tower Steelwork/Tower Line Construction/3 L4(m) Steel Tower Lines/Issue 3 OHL Clearances/2 L7(m) Steel Tower Lines
ENA TS 43-50	132kV Wood Pole Lines
ENA ETR 134	Lightning Protection for Networks up to 132kV
BS EN IEC 60071-1:2019	Insulation co-ordination. Definitions, principles and rules
BS EN IEC 60071-2:2018	Insulation co-ordination. Application guidelines

Appendix A – Diagram Key

The symbols below are used in the network diagrams throughout this document.



Underground cable

Overhead line

Busbar

Transformer

SuperGrid Transformer

Ring Main Unit (RMU)

Switch

Circuit breaker

Pole-mounted Switch (remote control)

Pole-mounted Recloser (remote control)

Remote control Switch or Circuit Breaker

Disconnector

Disconnector Motorised

Disconnector Motorised Optional

Earth Switch

Fault Throwing Switch

Normal Open point

Metering