ENGINEERING DESIGN STANDARD

EDS 08-4000

EHV NETWORK DESIGN

Network(s): EPN, LPN, SPN

Summary: This standard provides guidance on the design and operation of the 20kV to 132kV networks.

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Date: 29/11/2017

Approved By: Barry Hatton

Approved Date: 15/12/2017

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☒ Network Operations
☐ Procurement
☐ Strategy & Regulation
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☒ Contractors
☒ ICPs/IDNOs
☐ Meter Operators

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## Revision Record

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<td>Lee Strachan</td>
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<td>3.0</td>
<td>15/12/2022</td>
<td>Stephen Cuddihey</td>
</tr>
<tr>
<td>2.0</td>
<td>28/02/2017</td>
<td>Marco da Fonseca</td>
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<td>1.0</td>
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<td>Marco da Fonseca</td>
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**Reason for update:** Minor version update

**What has changed:** Reference to EDS 08-0119 changed to EDS 08-1105

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**Reason for update:** Business review

**What has changed:**
- Complexity rules for 33kV teed circuits clarified (Section 4.5).
- Voltage rationalisation from EDS 08-0116 incorporated (Section 8).
- Document renumbered from EDS 08-0145 and title amended.
- All connections related material now in separate document EDS 08-4100

**What has changed:**
- Section 11 updated to align with EDS 08-0051. Section 7 added. Section 8.3 modified to allow three options of 132kV cable terminations.
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1 Introduction

This standard provides guidance on the design and operation of the 132kV, 66kV, 33kV and 22kV networks. Standard network configurations and substation layouts which could be applied across the EPN, LPN and SPN networks are not considered feasible. This is due to the historical development of each network and the considerable differences in their geography, load density and the nature and expectation of their customers etc. Furthermore it is likely that such an approach would lead to over engineering and over investment.

Nevertheless, it is desirable to reduce the number and complexity of arrangements in order 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 networks so that a consistent approach can be applied to all networks, whilst permitting designers/planners freedom for original thinking to resolve each unique network problem with a bespoke solution which takes advantage of local circumstances.

All networks shall comply with the requirements of the Distribution Licence Conditions specifically condition 5 (distribution system planning standard and quality of service) and condition 9 (compliance with the Distribution Code).

Networks shall also be designed to provide the level of performance required by the overall and guaranteed standards agreed with the regulator.

2 Scope

This standard applies to the EPN, LPN and SPN EHV networks including all voltages from 33kV 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 08-0150 and EDS 08-0109). However designs for the development of primary EHV networks in the areas where either 20-22kV or 33kV distribution networks exist will need to take account of these networks but their design and specification will comply with standards that have been developed specifically for this purpose.
### Abbreviations and Definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>AIS</td>
<td>Air Insulated Switchgear</td>
</tr>
<tr>
<td>BSP</td>
<td>Bulk Supply Point (point of supply from a transmission system to a distribution system)</td>
</tr>
<tr>
<td>CHLDZ</td>
<td>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</td>
</tr>
<tr>
<td>DNO</td>
<td>Distribution Network Owner</td>
</tr>
<tr>
<td>ENA</td>
<td>Energy Networks Association</td>
</tr>
<tr>
<td>EPR</td>
<td>Earth Potential Rise</td>
</tr>
<tr>
<td>EHV</td>
<td>Voltages above 11kV. These may be both transmission and distribution networks depending on location and requirement</td>
</tr>
<tr>
<td>GIS</td>
<td>Gas Insulated Switchgear</td>
</tr>
<tr>
<td>GRP</td>
<td>Glass Reinforced Plastic</td>
</tr>
<tr>
<td>GSP</td>
<td>Grid Supply Point</td>
</tr>
<tr>
<td>HV</td>
<td>Voltages above 1000V; generally used to describe 11kV or 6.6kV distribution systems but may include higher or other legacy voltages</td>
</tr>
<tr>
<td>HILP</td>
<td>High Impact Low Probability</td>
</tr>
<tr>
<td>ICP</td>
<td>Independent Connection Provider</td>
</tr>
<tr>
<td>IDMT</td>
<td>Inverse Definite Minimum Time (Protection)</td>
</tr>
<tr>
<td>IDNO</td>
<td>Independent Distribution Network Owner</td>
</tr>
<tr>
<td>LV</td>
<td>Voltages up to 1000V; generally used to describe 230/400V or 230/460V distribution systems</td>
</tr>
<tr>
<td>n-1</td>
<td>First system outage</td>
</tr>
<tr>
<td>n-2</td>
<td>Second system outage</td>
</tr>
<tr>
<td>NMS</td>
<td>Network Management System</td>
</tr>
<tr>
<td>ONAN</td>
<td>Oil Natural, Air Natural</td>
</tr>
<tr>
<td>RMU</td>
<td>Ring Main Unit</td>
</tr>
<tr>
<td>SCADA</td>
<td>System Control and Data Acquisition</td>
</tr>
<tr>
<td>SGT</td>
<td>Super Grid Transformer</td>
</tr>
<tr>
<td>UK Power Networks</td>
<td>UK Power Networks (Operations) Ltd consists of three electricity distribution networks:</td>
</tr>
<tr>
<td></td>
<td>• Eastern Power Networks plc (EPN).</td>
</tr>
<tr>
<td></td>
<td>• London Power Network plc (LPN).</td>
</tr>
<tr>
<td></td>
<td>• South Eastern Power Networks plc (SPN).</td>
</tr>
<tr>
<td>XLPE</td>
<td>Cross-linked Polyethylene</td>
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4 Design Considerations

4.1 Overview

Notwithstanding the issues discussed in following sections, any of the arrangements shown therein may be adopted. However, due consideration shall be given to the network risk as part of the technical comparison process of alternative schemes. Standard risk assessment methodology should be employed where the probability and consequences of failure are plotted to determine a high, medium or low rating. Such factors considered should include the:

- 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.

4.2 Network Design Regarding Losses

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.

In addition for cable distances under 5km, the largest feasible cross section of conductor available shall be used regardless of load requirements.

4.3 Fault Levels

Refer to EDS 08-1110.

4.4 Maximum 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 disconnectors, though consideration shall be given to impacts on fault levels, voltage drop, protection complexity and power quality.

Note: When replacing disconnectors, 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 if diversions from the initial route were made 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 4-1 shows typical charging currents for 33kV, 66kV and 132kV underground cables in accordance with EAS 02-0061 and EAS 02-0030.
Table 4-1 - Typical Charging Currents (A/kM) at 33kV, 66kV and 132kV Cables

<table>
<thead>
<tr>
<th>Cross-Sectional Area (mm²)</th>
<th>300</th>
<th>400</th>
<th>500</th>
<th>630</th>
<th>1000</th>
<th>1200</th>
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<tr>
<td>33kV</td>
<td>1.443</td>
<td>-</td>
<td>1.574</td>
<td>1.915</td>
<td>2.328</td>
<td>2.693</td>
</tr>
<tr>
<td>66kV</td>
<td>2.514</td>
<td>2.753</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>132kV</td>
<td>3.831</td>
<td>-</td>
<td>-</td>
<td>4.788</td>
<td>5.507</td>
<td>5.746</td>
</tr>
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4.4.1 Cable Capacitance Compensation Assessment

The maximum cable length and capacitance compensation assessment process is shown in Figure 4-1. The associated equations and an example are included below.

Start

Obtain charging current (CC) of the upcoming cable via customer information or Eq. 1

Obtain the CC of the existing connected cable from the proposed POC to the upstream switchgear

Summate the CC of the upcoming and existing cables

Obtain the lowest upstream switchgear cable charging rating

Obtain max. allowed cable length given by Eq. 2

Upcoming + Connected cable ≤ max. allowed cable length?

Yes

Install cable capacitance compensation

No

End

Figure 4-1 – 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.

\[ I_{\text{charging}} = \frac{2\pi f C E}{1000000} \]  

Equation 1

where \( f \) is the frequency of 50Hz, \( C \) the capacitance in \( \mu \)F/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.

\[ \text{Maximum Allowed Cable Length} = \frac{0.9 \times I_{\text{rating}}}{I_{\text{charging}}} \]  

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 0.352\(\mu \)F/km, the charging current can be obtained using the previous equation:

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

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.
### 4.5 Network Complexity

The complexity of 132kV and 33kV circuits is based on ENA EREC P18 and shall adhere to the following requirements.

The normal operating procedure or protection operation for isolation of 132kV and 33kV circuits shall require no more than seven circuit-breaker operations at a maximum of four sites subject to the following interpretation:

- All circuit-breakers connecting the circuit to another part of system shall be counted.
- In a mesh, or similar type substation, two circuit-breakers of the same voltage in the mesh shall be counted as one circuit-breaker.
- Where a circuit is controlled by two circuit-breakers which select between main and reserve busbars they shall be counted as one circuit-breaker.
- Switching isolators shall not be counted as circuit-breakers.
- Multiple operations carried out at the same site in one visit shall only count as one operation.

No more than three transformers shall be banked together on the HV side. **Note:** A transformer with two lower voltage windings counts as one transformer.

No item of equipment shall have isolating facilities at more than four sites subject to the following interpretation.

- Isolating facilities shall normally be provided by means of circuit-breakers and their associated isolators.
- Points of isolation at adjacent sites (as determined by UK Power Networks) to permit the efficient and effective use of one authorised person at those points during the isolation and restoration of the circuit shall be counted as one site.
- Isolators with a ‘fault make, load break’ capability shall count as circuit-breakers.

The maximum number of customer connections that may be interrupted by isolating a single circuit shall be two.
5 132kV Network Configurations

5.1 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 a SGT is connected. The main and reserve busbars are coupled by means of bus coupling circuit-breakers. Two bus-couplers are shown in Figure 5-1 although historically a single bus-coupler may have been employed.

![Figure 5-1 – GSP Arrangement](image-url)
5.2 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 by the Planner/Designer, the 132kV cables shall be terminated instead via cable sealing ends with an earth switch and a disconnectable 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 inter-tripping 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 inter-tripping.

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 cross-bay. 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 5-2.
5.3 Teed Transformer Networks

Historically the 132kV networks have been developed to the minimum level of security to satisfy ENA EREC P2/6. 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.
5.4 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 5-3.

![Banked Transformer Arrangement](image1)

Figure 5-3 - 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 5-4, banked transformer arrangements may also be used for transformer reinforcement options where it would be impossible to install a 2-switch 132kV cross-bay in order 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 in the event that one transformer in a banked pair faults.

![Banked Transformer Arrangement Reinforcement](image2)

Figure 5-4 – 132kV Banked Transformer Arrangement Reinforcement
5.5 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 has to 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.

5.6 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 taken into account in comparison with transformer feeder arrangements where no switchgear is required.

5.7 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 5-5.
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.

5.8 **CHLDZ and HILP Network Design**

Refer to EDS 08-1105.

5.9 **132kV 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 LPN region but may be considered for use elsewhere if required. New substations in high load density areas are designed to provide the maximum possible capacity and 132kV incoming circuits with 132/11/11kV three-winding transformers have become the standard for use in the central LPN region. 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 are also critical when addressing the required rating of a transformer.
5.10 132kV Switchgear

For the use of outdoor open terminal equipment refer to ETS 03-6600.

For the use of GIS switchgear refer to EDS 03-6650.

5.11 132kV Overhead Lines

Lines are to 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.

5.12 132kV Underground Cables

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

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 C55/4, 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 (Value taken from C55/4) 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.

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

5.13 Protection Systems

Protection systems shall be designed in accordance with EDS 05-0001. More complex schemes will require a protection design philosophy to be developed in conjunction with the network design to ensure it can be adequately protected.
6 33kV Network Configurations

The following section defines feeding arrangements for different EHV network configurations. 11kV busbar arrangements are defined in Section 6.9.

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.

6.1 Underground Transformer Feeder Networks

The simplest and perhaps most reliable network configuration is that of the duplicate transformer feeder shown in Figure 6-1 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.

Generally with underground networks the inter-tripping 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 backfeeds 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 P2/6 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 6-2 and Figure 6-3.

In the three feeder arrangement shown in Figure 6-2, 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:

\[ F_C = 19MVA \times 2 = 38MVA \]

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

\[ F_C = 0.67 \times 38MVA = 25.5MVA \]

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 6-3 utilisation 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:
\[
F_C = 19 \text{MVA} \times 3 = 57 \text{MVA}, \text{ thus each transformer would be running at 14.25MVA maximum pre-fault load (95% utilization of nameplate rating or 75% of 12 hour overload rating).}
\]

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

\[
F_C = 0.67 \text{ (summer or weekend load in CHLDZ maximum demand)} \times 57 \text{MVA} = 38 \text{MVA}.
\]

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

A 4 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 of security of supply, refer to EDS 08-1105.

### 6.2 Overhead Transformer Feeder Networks

The arrangement of an overhead transformer feeder network is shown in Figure 6-4.

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 10.1.

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.
6.3 Underground Teed Transformer Networks

Dependent upon the geography of a particular location it may be expedient to supply two new substations from the same feeders or to establish an additional primary substation by extending from an existing site using the arrangement shown in Figure 6-5. In these cases suitable means of remote isolation shall be employed such as RMUs. The use of a teed transformer feeder network shall as a minimum include transformer isolation.

![Figure 6-5 – Underground Teed Transformer Feeder Network](image)

The application of this arrangement may be limited due to restricted ratings of the 33kV cables emanating from the 132/33kV grid substation. Such arrangements may only be possible where large cross section cables have been laid to a development area in the anticipation of future growth, where load at a substation did not meet expectation or has contracted due to loss of a major industrial or commercial load.

This may require that the banking connections have to be performed either at the 132/33kV grid substation or within a primary/switching substation.

Solid or ‘crutch joint’ 33kV tee points shall be avoided; all tee points shall be equipped with remote controlled isolation as a minimum.
6.4 Overhead Teed Transformer Networks

Due to the distances involved and the diverse geographic location of the load centres, teed overhead networks as shown in Figure 6-6 are commonplace in rural areas. In these cases suitable means of remote isolation should be employed such as a pole mounted remote controlled switch/circuit-breaker.

![Figure 6-6 – Teed Overhead Transformer Feeder Network](image)

The provision of local transformer isolation at the primary substations is an operational requirement and shall be fitted to provide a visible means of isolation and the earth switch enables a circuit main earth to be applied whilst working on the transformer. Teed arrangement isolation has the added benefit that it is only necessary to disconnect one transformer of the pair supplied by each circuit thereby minimising the risk of customer outages.

Solid 33kV tee points shall be avoided; all tee points shall be equipped with remote controlled isolation as a minimum.

For remote source circuit-breaker operation, refer to Section 10.1. For fault throwing switches refer to Section 6.5.
6.5 Underground Ring Networks

Figure 6-7 shows an underground ring network supplying three primary substations but in practice such an arrangement would have limited applications.

![Figure 6-7 – Underground Ring Network](image)

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 630mm² 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 P2/6 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.
6.6 Overhead Ring Networks

Overhead ring networks as shown in Figure 6-8 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).

Generally small rural substations will employ 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. A number of 33kV switchgear arrangements may be employed.

Primary substation ‘A’ in Figure 6-8 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 for existing sites following failure. It is designed on 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 line 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.
6.7 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 6-9.

![Figure 6-9 – Underground Mesh Networks](image)

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 6-10 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.
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 6-11. 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.

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 12 hours. Besides being resilient for an n-2 situation, it also contributes with 19MVA to transfer availability during n-1 (57MVA-38MVA=19MVA).
6.8 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.

6.9 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.

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

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 are as follows:

- 1 or 2 circuit-breakers,
- retrofit,
- defect rectification etc;

However it is acceptable for the Planner/Designer to use engineering judgement.

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.
6.10 33kV Overhead Lines

All new 33kV overhead lines shall be of single circuit wood pole unearthed design and comply with the UK Power Networks Overhead Line Construction Manual. All lines shall be designed and constructed for a maximum conductor working temperature of 75 °C. Refer to EAS 02-0000 for approved cables.

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.

6.11 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. 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.

Refer to EDS 02-0034 which contains cable ratings for common installation conditions and ECS 02-0019.

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 C55/4, 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 (Value taken from C55/4) 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.

6.12 33kV Protection Systems

Protection systems shall be designed in accordance with EDS 05-0001.
7 11kV Switchgear Configurations at Primary and Grid Substations

The configuration of the 11kV switchboards at primary and grid 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.

7.1 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.
7.1.1 Assessment of Load Distribution on Busbars

The general method of assessment 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 taken into account 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.

7.2 11kV Switchgear Configuration – 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 7-1. 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.

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 7-2.

![Figure 7-2 – 2 x 12/24MVA 11kV Mesh Network Switchgear Configuration](image)

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 7-3.

![Figure 7-3 – 2 x 12/24MVA 11kV Secured Mesh Network Switchgear Configuration](image)

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.
7.3 11kV Switchgear Configuration – 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 7-4.

![Figure 7-4 – 2 x 20/40MVA 11kV Switchgear Configuration](image)

7.4 11kV Switchgear Configuration – 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 7-5.

![Figure 7-5– 4 x 12/24MVA Double Busbar Feeder Substation](image)
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.

7.5 11kV Switchgear Configuration – 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 7-6.

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.
7.6 11kV Switchgear Configuration – 3 x 66MVA 132/11kV Substations

The configuration shown in Figure 7-7 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.

![Diagram of 3 x 66MVA 11kV Switchgear Configuration](image)

Figure 7-7 – 3 x 66MVA 11kV Switchgear Configuration

7.7 Switchboard Segregation

Substations designed for a firm capacity over a value described on EDS 07-0003 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 will be sited in separate rooms with fire segregation barriers and will be interconnected by means of cable or busbar system.

Refer to EDS 08-4100 regarding customer and UK Power Networks EHV switchgear segregation.
7.8 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.
8 Legacy Voltages – Voltage Rationalisation

8.1 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.

8.2 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.
8.3 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 08-0150) 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.

8.4 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.
9 System Earthing

9.1 132kV Network

The neutral point of 400/132kV or 275/132kV transformer windings is solidly earthed (zero impedance) at the GSP. The benefit of this arrangement is that during phase to earth faults the healthy phases remain at a relatively constant nominal system phase to earth voltage thus reducing insulation costs. However, earth fault currents at the busbars are relatively high typically 20% higher than for phase to phase faults. The magnitude of earth fault currents will attenuate more rapidly down the feeders.

The 132kV windings of all transformers at BSPs are star connected and have their neutral points solidly bonded to earth. As a result a network phase to earth fault will result in current flow through the neutral to earth connections of all transformer primary windings connected into that GSP network.

High phase to earth fault currents have the potential to create excessively high EPR at substation sites requiring particular attention when designing substation earthing systems. It is desirable to provide a continuous earth conductor on all 132kV circuits between substations. The earth conductor is connected to the main earthing system (metallic earth bonding system) at each substation and provides a return path for fault currents reducing the current flow to earth and hence reducing the EPR. For steel tower overhead lines the earthing conductor provides a means of bonding support steelwork to earth at each tower position.

132kV overhead line systems are available using wood pole supports with no earth conductor. Any design utilising this type of construction shall include a risk assessment stating:

- The effects on the BSP substation EPR when energised from a circuit with no continuous earth conductor between that BSP and the source GSP.
- How the EPR is maintained within limits for network phase to earth faults on any cable sheath or metallic structure forming part of that circuit.

9.2 66kV and 33kV Windings

The secondary windings of 132/66kV and 132/33kV transformers supplying the 66kV and 33kV networks are delta connected and a neutral connection point is not, therefore, available. To enable earth fault detection a neutral point is provided by a separate earthing/auxiliary transformer in which the primary winding is star connected.

The 66kV side of a 132/66kV transformer may be a star winding with its neutral point earthed via external neutral impedance.

Phase to earth fault current is limited by series impedance in the fault path and can be provided as zero sequence impedance in the earthing/auxiliary transformer primary winding or as an external impedance connected between the earthing transformer primary winding neutral point and the substation earth.
The position of the zero sequence impedance affects network voltages during earth faults.

- With an external neutral earthing resistor or reactor and a zero impedance fault the faulted phase is at earth potential with minimal volt drop in the transformer winding, causing the healthy phases to rise in voltage to line voltage levels relative to earth potential.

- With earth fault current limited by the zero sequence impedance of the earthing /auxiliary transformer primary winding, its neutral point solidly earthed and a zero impedance fault, the faulted phase will be at earth potential. However, the internal volt drop in the transformer winding will be relatively high compared with the main transformer (i.e. its terminal volts will decrease significantly) resulting in minimal neutral to earth voltage displacement, hence the non-faulted phases have a minimal phase to earth voltage increase.

9.3 11kV or 6.6kV Windings

The secondary windings of 132/11kV, 66/11kV and 33/11kV transformers supplying the 11kV network are either star or delta connected depending on the vector group of that network. The earthing arrangements are as described in Section 9.2 and may be earthed solidly or via an impedance.

9.4 Arc Suppression Coils

HV neutral earthing using an arc suppression coil is used in some areas to earth the star point of primary transformers and allow single phase earth faults to be held on the 11kV or 6.6kV distribution network without causing the operation of protection devices. This has the probable effect of clearing transient faults without causing permanent damage and of reducing the number of CIs and CMLs associated with rural networks.

9.5 Surge Arrestors

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

9.6 Dual Cable, Single Circuit

Where a second cable is installed in a single circuit to increase thermal capacity of that circuit, protection and earthing shall be considered for both cables, not only for the single circuit.
10 General Requirements

10.1 Remote Source Circuit-breaker Operation

Where primary 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, some form of inter-tripping is required in order to open the remote circuit-breaker. This may be by means of:

- Inter-tripping channels provided by pilot cable or other means over which inter-trip 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.

- Installing fibre optic and using 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 or EPR. The 132kV systems however being solidly earthed produce earth fault currents of significant magnitude which could cause considerable danger or damage. Fault throwers therefore shall no longer be used for new 132kV installations and live tank circuit-breakers shall be used for local control of transformers as shown in Figure 10-1 and in Figure 10-2 for a teed transformer feeder.

![Figure 10-1 – 132kV Standard and Modified Single-switch Layout](image-url)
10.2 **SCADA and Network Automation**

Refer to EDS 05-0001 for further information on protection, control and SCADA.

10.3 **Substation Earthing**

All grid and primary substation earthing shall be in accordance with the following standards:

- EDS 06-0013 – Grid and Primary Substation Earthing Design.
- ECS 06-0022 – Grid and Primary Substation Earthing Construction.

10.4 **Substation Accommodation**

All grid and primary substation shall be constructed in accordance with the relevant civil design standards EDS 07-0105 and EDS 07-0003.

Refer to EDS 08-4100 for further information on substation accommodation, layouts and land requirements for customer connections.
11 References

11.1 UK Power Networks Standards

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11.2 Legislation

- Construction Design and Management Regulations 2007
- Electricity Act 1989
- Electricity Safety. Quality and Continuity Regulations 2002
- Guaranteed Standards: OFGEM Guidance and Proposals on Best Practice – Electricity Distribution
- Health & Safety at Work Act 1974
11.3 Industry Standards

ENA EREC C55-4  Insulated Sheath Power Cable Systems
ENA EREC G59  Engineering Recommendation G59 Connection of Embedded Generation to Public Electricity Networks
ENA EREC G54  Limits for Harmonics in the United Kingdom Electricity Supply System
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 ETR 130  Engineering Technical Report 130 – Application Guide for Assessing the Capacity of Networks Containing Distributed Generation
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
National Grid  Grid Code for Great Britain
OFGEM  Distribution Code for Great Britain

12 Dependent Documents

The documents below are dependent on the content of this document and may be affected by any changes.

EDS 02-0034  33kV Single Core XLPE Cables
EDS 05-0001  132kV Grid and Primary System Protection and Control Schemes
EDS 06-0019  Customer EHV and HV Connections (including Generation) Earthing Design and Construction Guidelines
EDS 08-0147  Guidance on the Use of Arc Suppression Coil Earthing
EDS 08-0148  Appendices to ENA ER G81
EDS 08-0149  Customer Interface Systems
EDS 08-3000  HV Network Design
EDS 08-4100  EHV Customer Demand and Generation Supplies
EDS 08-5010  Energy Storage
EDS 08-5040  Guidelines for the Provision of System Monitoring