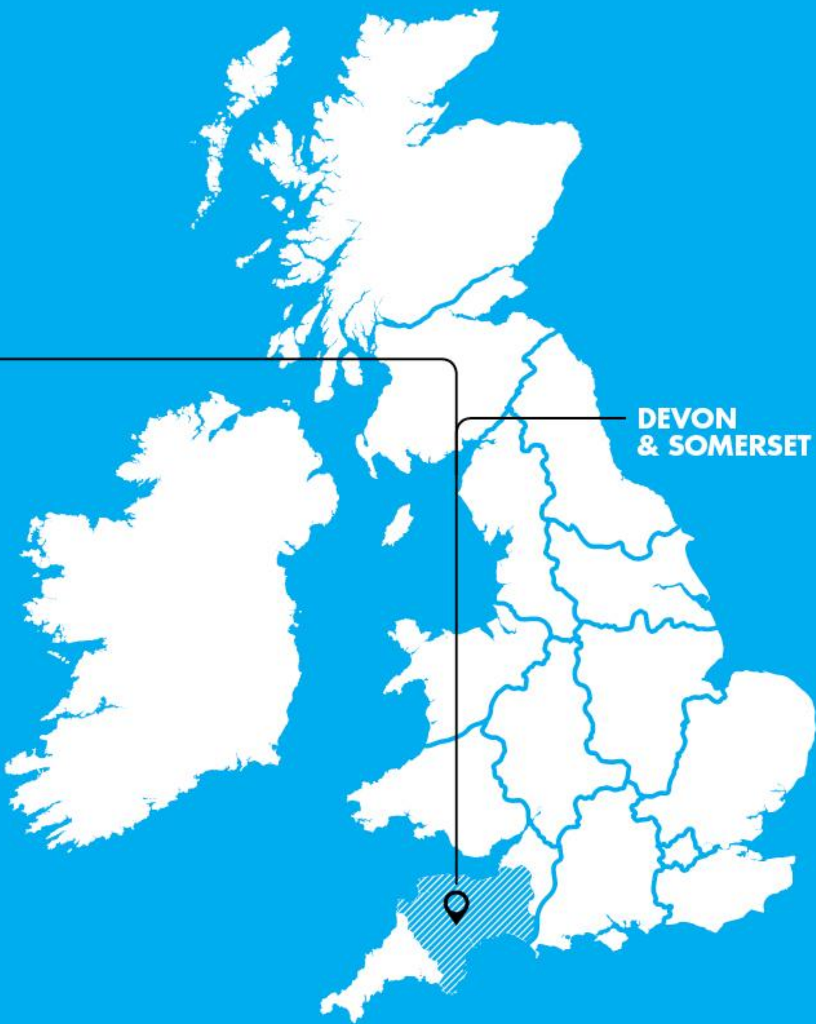
WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND



SDRC-3
Detailed Design of the FPL Method

LCN Fund
Low Carbon Networks

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Contents

Glossary

Term	Definition
AC	Alternating Current
AIS	Air Insulated Switchgear
BSP	Bulk Supply Point
CT	Current Transformer
DC	Direct Current
DNO	Distribution Network Operator
EHV	Extra High Voltage
EMF	Electro-Magnetic Field
ENA	Energy Networks Association
EVA	Enhanced Voltage Assessment
FPL	Flexible Power Link
GSP	Grid Supply Point
HSOC	High Set Over Current
HV	High Voltage
HVDC	High Voltage Direct Current
IDMT	Indefinite Mean Time
kV	Kilo Volt
LCNF	Low Carbon Networks Fund
LCT	Low Carbon Technology
LOM	Loss of Mains
LV	Low Voltage
MVA	Mega Volt Ampere
MVAr	Mega Volt Ampere Reactive
MW	Mega Watt
NG	National Grid
NOP	Normal Open Point
OCEF	Overcurrent Earth Fault
OHL	Overhead Line
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
SDRC	Successful Delivery Reward Criteria
SOP	Soft Open Point
SVO	System Voltage Optimisation
UPS	Uninterruptable Power Supply
VT	Voltage Transformer
WPD	Western Power Distribution

1 Introduction

1.1 Network Equilibrium

Network Equilibrium is a Tier 2 Low Carbon Networks Fund (LCNF) project which aims to demonstrate how novel voltage and power flow management can release network capacity. This release in capacity shall allow the connection of new customers, including Low Carbon Technologies (LCTs), to the distribution network during both normal and abnormal conditions.

The trial location for Network Equilibrium encompasses the 33kV and 11kV distribution networks in Western Power Distribution's (WPD) South West area across the counties of Somerset and Devon.

1.2 Methods

Network Equilibrium will use the latest advances in power, communication and computing systems to release network capacity. The project has been split into three technical methods as follows:

- The Enhanced Voltage Assessment (EVA) Method;
- The System Voltage Optimisation (SVO) Method; and
- The Flexible Power Link (FPL) Method.

This report focuses on the FPL method and will form the Successful Delivery Reward Criteria (SDRC) 3: "Detailed Design of the FPL Method".

1.3 FPL Method

Where possible it is advantageous to operate power networks in large groups whereby the load or generation on a system can be equally shared across the group. Distribution Networks are typically operated in separate, smaller, network groups defined by connections to Grid Supply Points (GSPs) from National Grid (NG). The main reason for this is that paralleling or connecting network groups between different GSPs is likely to result in:

i. Abnormal power flows due to differences in network impedance between the two sources;
ii. Phase angle issues; and
iii. Higher fault levels due to the combined sources from the GSPs.

WPD's network in the South West typically comprises multiple 132/33kV Bulk Supply Points (BSPs) fed from a 400/275/132kV GSP. In turn, the BSPs then connect with a number of 33/11kV substations through an interconnected 33kV network. A typical arrangement is shown in Figure 1-1 below.

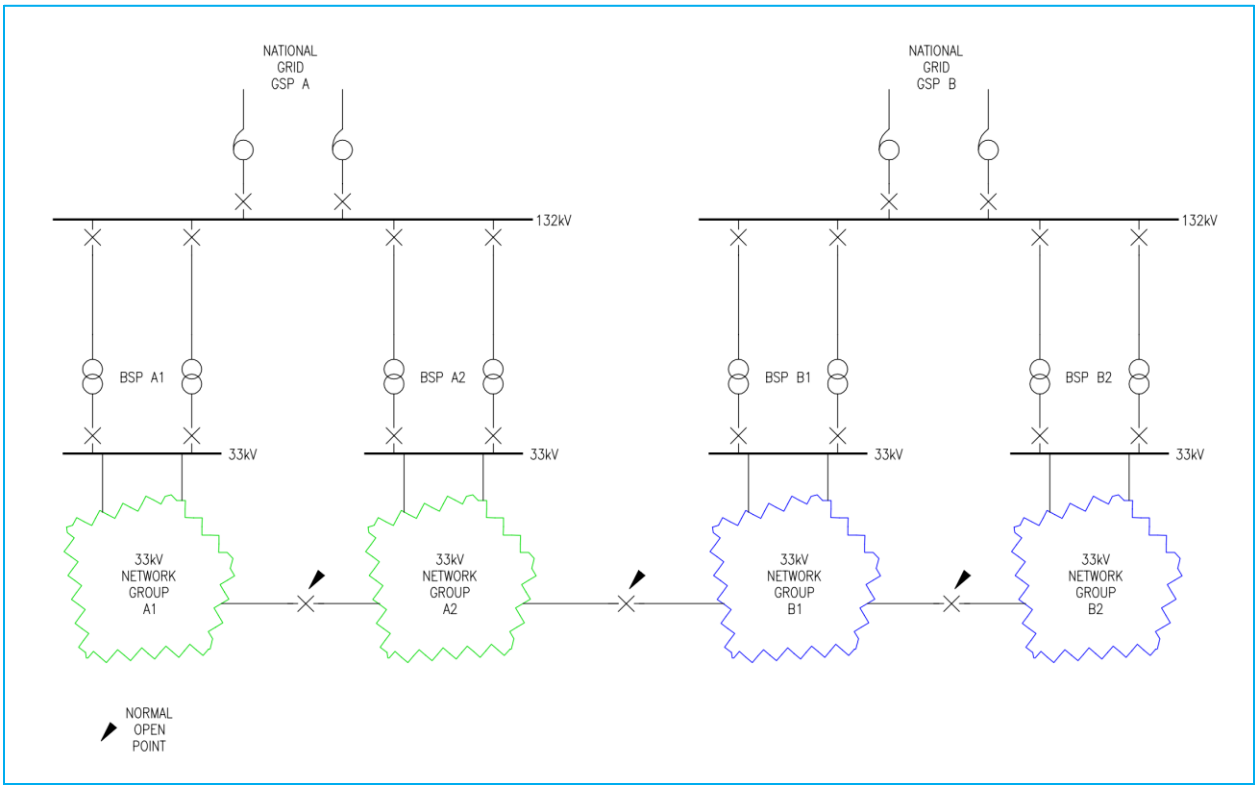


Figure 1-1: Typical Arrangement of a DNO Network

33kV networks are often run as an interconnected system in rural areas such as WPD's South West area. The interconnected network will generally be fed from a single BSP to ensure that power flow and voltage are not adversely affected should an adjacent BSP transformer trip or another network fault occur.

In general, paralleling the 33kV or 11kV networks within the same network group is achievable assuming power flow, voltage and fault levels are within limits. However, placing two separate network groups in parallel through the 33kV or 11kV network is not advised due to the issues explained above.

With the increase in embedded generation and LCTs over recent years, some BSPs have seen a high penetration of generation whilst a neighbouring BSP has experienced a growth in demand. The significant increase of either load or generation on a BSP will cause both voltage and thermal constraints on the 33kV network. This scenario can lead to significant network reinforcement required to support the additional load and generation growth on the two BSPs.

The FPL method aims to solve these voltage and thermal issues by enabling the parallel operation of two BSPs (from separate GSPs), and therefore the ability to share their network capacity, through the utilisation of two back-to-back AC-DC converters. The FPL will enable real and reactive power flows, at what was previously a Normal Open Point (NOP) between two network groups, to be independently controlled to optimise the power flow of the existing network assets. The device will allow the connection of the two previously distinct networks without any of the negative impacts that would occur if the parallel connection occurred without the FPL installed.

The method will improve the flexibility of the network by transferring excess power from a group with high levels of generation to a group with high demand. This will release additional capacity in the network allowing additional generation or load to be connected to congested networks without the need for major reinforcement works.

1.4 SDRC Summary

This report forms one of the eight deliverables as part of Network Equilibrium. SDRC-3, “Detailed Design of the Flexible Power Link Method”, delivering a report on the detailed design of the FPL Method.

2 FPL Device

2.1 Operation Overview

The FPL as part of Network Equilibrium will be connected across two previously unconnected electricity distribution networks (BSPs) to enable active power (P) transfer between them and provide independent reactive power (Q) on both sides.

The active power flow operation of the FPL is shown in Figure 2-1, where active power is transferred from a generation dominated network in Grid Group 1 to a demand dominated network in Grid Group 2. This enables a greater utilisation of the complete system, whereby previously the Grid Group 1 would have reached its capacity of generation acceptance (due to reverse power flow constraints) and significant network reinforcement would be required. Similarly this would be the case for an increase in load on the Grid Group 2 (causing firm capacity limits to be exceeded) that could be transferred to Grid Group 1 to mitigate reinforcement requirements.

The reactive power (Q) operation of the FPL will be utilised to appropriately manage each BSP voltage, through separate Q control at each side of the FPL. This will ensure that the change in power flows between the two BSPs does not cause the 33kV network to exceed the ±6% voltage statutory limit.

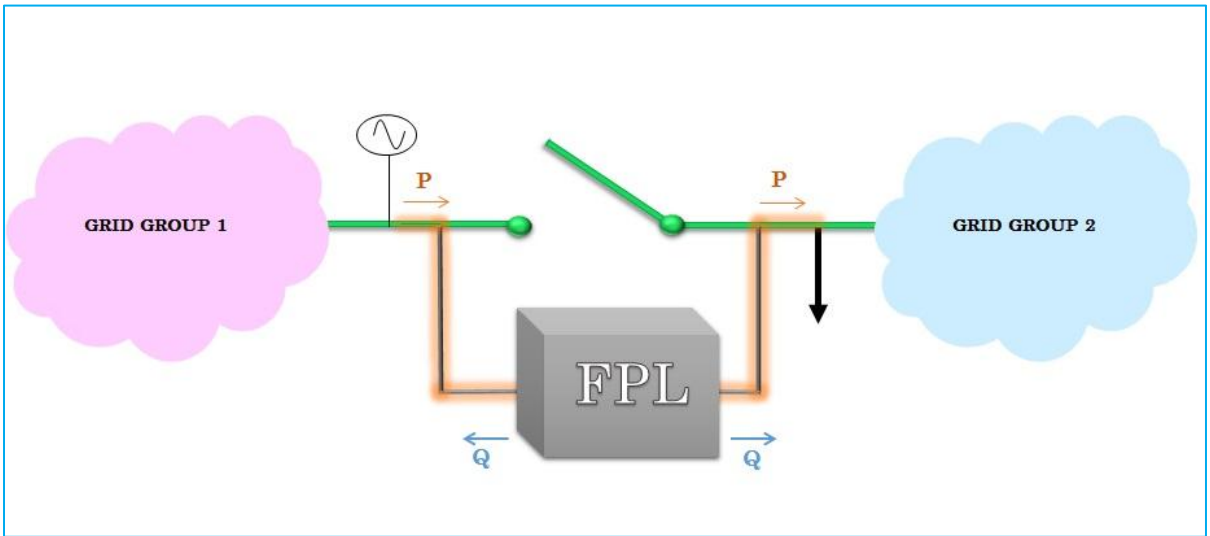


Figure 2-1: FPL Operation

The methodology for the control of the P and Q parameters will be to ensure that the two BSPs, Grid Group 1 and 2 in Figure 2-1, do not encounter any network violations. The possible network violations to be considered are:

- Maximum firm capacity operation on BSPs (Load);
- Maximum reverse power flow capacity operation on BSPs (Generation);
- Minimum BSP network voltage (Load); and
- Maximum BSP network voltage (Generation).

A key consideration is to also ensure that the interconnector feeder's thermal ratings are not exceeded, whereby this is considered to be the immediate connection point of the FPL back to both BSPs.

The FPL will be controlled through real-time analysis of the voltage and current at both BSPs along with consideration being given to the thermal rating of the FPL interconnector. Through the use of real-time system monitoring the minimum P and Q values will be calculated to ensure that, at all times, the network is operating within its operational limits. This functionality is included within the project's SVO method, whereby the minimal P and Q values will be calculated and communicated to the FPL through WPD's existing network management system (NMS).

2.2 Technology Overview

The FPL is a power electronic device that consists of two back-to-back AC to DC voltage source converters connected together via a DC busbar link. At both 33kV interface points of the FPL there is a step down transformer that transforms the network voltage down to a voltage suitable for the converters.

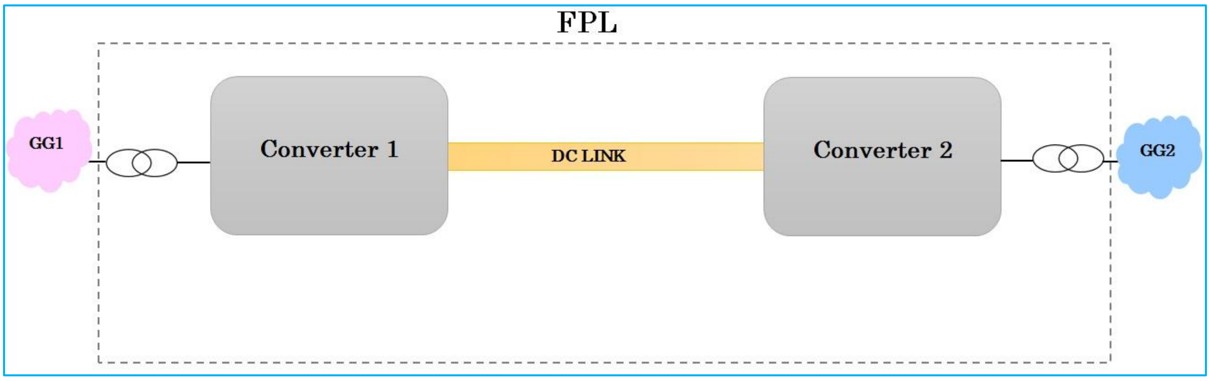


Figure 2-2: FPL Components

Each converter comprises a number of power electronic high-frequency switching modules that turn rapidly on or off in a controllable, coordinated, manner to convert from AC to DC and back. The switching sequence of the internal modules determine how much active power is transferred between the two sides, the direction of the active power and also how much reactive power is exported or imported at each side.

2.3 Tender Specification

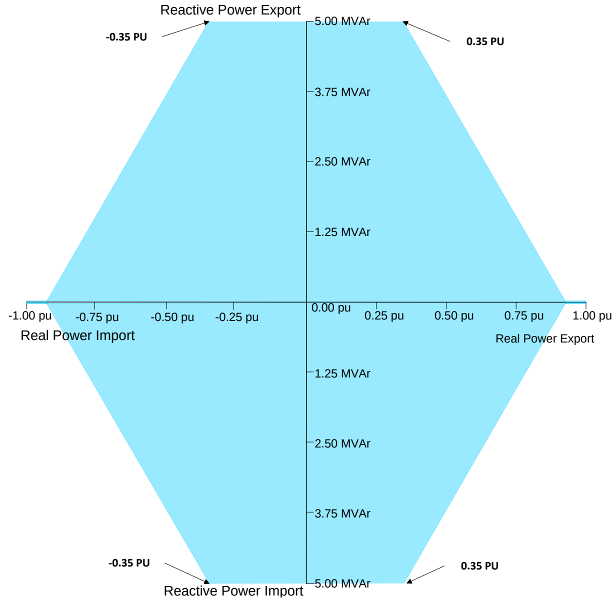
Table 2-1 below details the key information provided to potential FPL suppliers as part of the tender process.

The critical elements of the specification are the requirements for the device to meet the standard voltage and insulation requirements expected of any device connecting to the 33kV network along with the operating range for both real and reactive power.

The real power operating range has been selected to be ±20MVA and the reactive power operating range has been selected to be ±5MVAr. These values were selected as the average 33kV overhead line network in the project area is rated at 20MVA and the 5MVAr of reactive power enables a 2.5% voltage change at a BSP when the FPL is considered to be installed at the mid-point between two BSPs in the project area.

Other elements considered in the technical specification are any exclusion zone requirements, sound levels and environmental conditions. The exclusion zone has been determined to be 1.5m from the device with an electro-magnetic field (EMF) of 500µT (5G). This is driven by the limit of EMF exposure for someone with an electronic medical implant. Both noise and environmental limits are selected from WPD's standard outdoor installed EHV transformer specification.

Table 2-1: FPL Technical Specification

Requirement	Rating
Nominal operational voltage	33kV
Nominal operational frequency	50 Hz
Insulation requirements [ENA TS 41-36]	Rated voltage: 36kV Lightning impulse withstand voltage: 170kV Power and Frequency voltage withstand: 70kV
Exclusion zone (Not to be greater than)	1.5 m @ 500µT (5G)
Real Power Operating Range [ENA TS 35-3]	-20MW to 20MW
Reactive Power Operating Range [ENA TS 35-3]	-5MVAr to 5MVAr
Complete Power Operating Range [ENA TS 35-3]	
Short circuit current withstand capability [ENA TS 41-36 / 35-3]	Peak: 62.5kA Symmetrical rms: 25kA Asymmetrical rms: 31.3kA Short term fault duration: 3 seconds
Reliability (after commissioning)	99.9%
Availability (after commissioning)	98.6%
Environmental considerations (e.g. indoor or outdoor location) and ingress protection (IP)	Outdoor, with normal service conditions as per IEC 60076-1 and IEC 60529 Minimum IP55
Maximum sound power level when carrying rated load current	80dBA ONAF at 1M
Failure mode of device	Fail-safe in all circumstances

Other key considerations for the FPL device to successfully integrate and operate on the system are the device's losses and the physical dimensions of the device.

The device constitutes two types of losses:

- Heat loss generated by the device through the process of converting from AC to DC and back to AC.
- Cooling to remove the heat generated by the device (through an LV metered supply).

2.4 FPL Performance Metrics

Throughout the project, the performance of the FPL will be understood by measuring its operation in respect to:

- Real Power Output (P);
- Reactive Power Output (Q);
- Harmonic effect;
- Voltage fluctuations; and
- Speed of operation.

These metrics will be measured throughout the project on an individual level (as described below); however, the key learning will be driven by understanding the device's ability to successfully perform all the individual metrics simultaneously.

2.4.1 Real Power Output (P)

This will be monitored to understand the FPL's ability to ensure that principally there are no thermal capacity violations on either of the two interconnected BSP networks. This will be assessed through appropriate trials where pseudo firm capacity and reverse power flow capacity limits are set at each BSP to ensure the device can correctly function for different distinct network operating requirements.

2.4.2 Reactive Power Output (Q)

The primary function of the reactive power output, Q, is to ensure that both the BSP voltages and the voltages along the FPL feeders are kept within the 33kV statutory limits. Throughout the trial element of the project this will be constantly monitored and assessed. To ensure that the device operates effectively throughout the project a variety of voltage limits at each BSP and at the FPL point of connection will be specified to measure the device's ability to successfully regulate the voltage to a required value.

2.4.3 Harmonic Effect

Throughout the project the harmonic content of the FPL at the point of connection and its effects on the remote points of the network are to be measured. It will be monitored to ensure that as well as not breaching G5/4-1 planning limits it also allows an adequate amount of harmonic headroom availability for harmonic contributing loads or generation connections to be added to the existing system.

2.4.4 Voltage Fluctuations

The variation of P and Q on the system will, as described in the document, have an effect on voltage. The immediate step change effect on the voltage, throughout the project, will be monitored to ensure that it does not exceed the P28 planning standards.

2.4.5 Speed of Operation

The performance of the FPL relies on its speed of operation to understand that a change in value, for either thermal or voltage limits, is moving towards the violation value and reacts in an appropriate time to ensure the violation doesn't occur. This will be monitored to ensure that the device operates to enable the system to be fully optimised in terms of maximising the available capacity of the existing system.

3 FPL System Integration

3.1 Overview

The following section describes the various options for integrating an FPL into a DNO's electrical network.

It is imperative that any new equipment installed as part of an Innovation Project must not adversely impact the continuity of supply or operation of the existing network. Therefore, the options considered for integration of the FPL technology will ensure that the FPL can be electrically disconnected and the network returned to the current operational arrangement as and when required. In addition, it is important to ensure that the FPL remains in continuous service by having reliable protection schemes and auxiliary supplies.

3.2 Integration Options

The FPL for Network Equilibrium is designed to be connected between two previously unconnected network groups at 33kV. Connecting two network groups could be achieved by installing new cable or overhead line circuits between two substations. However, this would result in additional risk of delay and excessive expenditure for trialling the FPL technology. Instead, it is proposed that existing infrastructure between two network groups will be used. This is generally a 33kV NOP at a primary substation or switching station which forms a connection point between network groups.

All the substations and switching stations considered for Network Equilibrium contain only 33kV Air Insulated Switchgear (AIS). The following three options have been identified for integrating the FPL at 33kV either at a primary substation or switching station.

3.2.1 Option 1 – Within a Normally Open 33kV Interconnector

The first option entails connecting the FPL within a 33kV normally open interconnector at a substation between two network groups. The typical existing network arrangement for this option is shown in Figure 3-1.

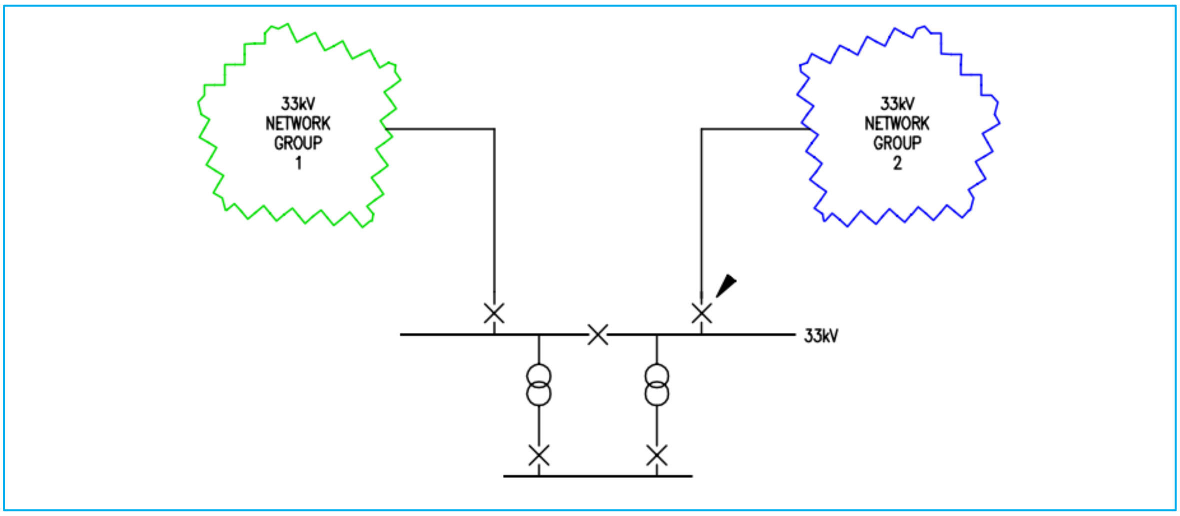


Figure 3-1: Option 1 - Existing Network Arrangement

The FPL would be integrated into the 33kV network using a five panel switchboard. Two circuit breakers would be used for the FPL connection, two for the incoming / outgoing 33kV circuits to the substation and a bus-section to allow for disconnection and restoration of the network for maintenance purposes. With two network groups running in parallel, the NOP would be placed on the bus-section of the new five panel switchboard. The proposed arrangement showing the network modifications in red are shown in Figure 3-2 below.

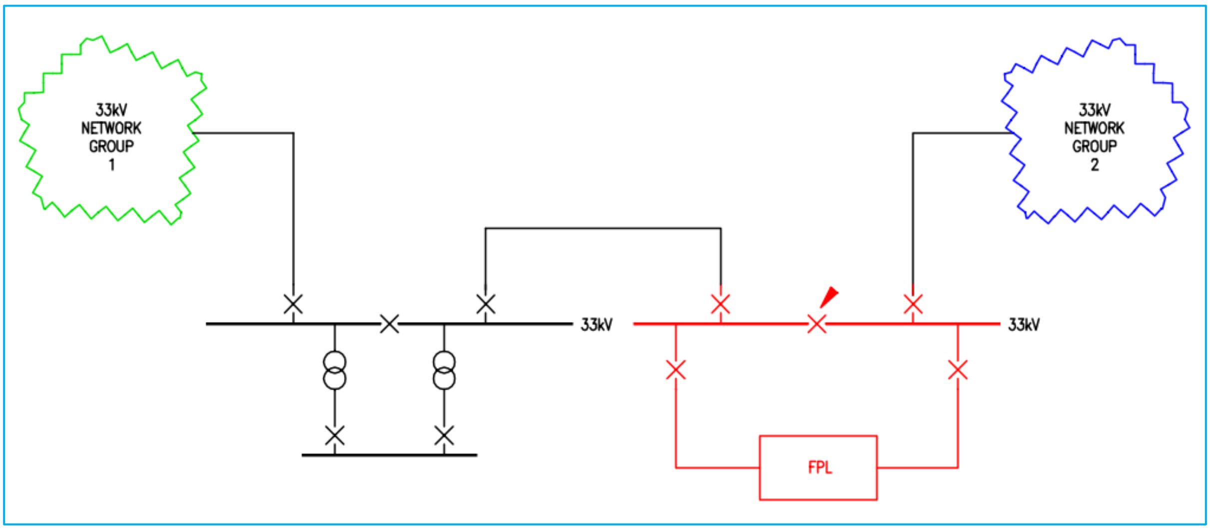


Figure 3-2: Option 1 - Proposed Network Arrangement

3.2.2 Option 2 – Across a Bus-Section

Option 2 considers a switching station that has an existing bus-section circuit breaker separating two 33kV network groups as shown in Figure 3-3.

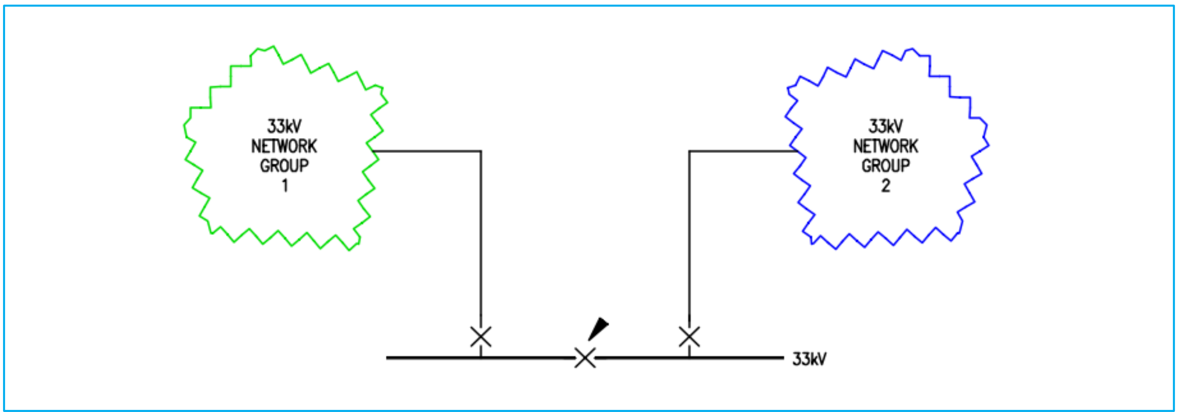


Figure 3-3: Option 2 - Existing Network Arrangement

Connection of the FPL would comprise installing two new 33kV circuit breaker bays for the FPL either side of the bus-section. The existing 33kV bus-section circuit breaker would be used as the "by-pass circuit breaker" for the FPL. The configuration showing the proposed arrangement is shown in Figure 3-4 below.

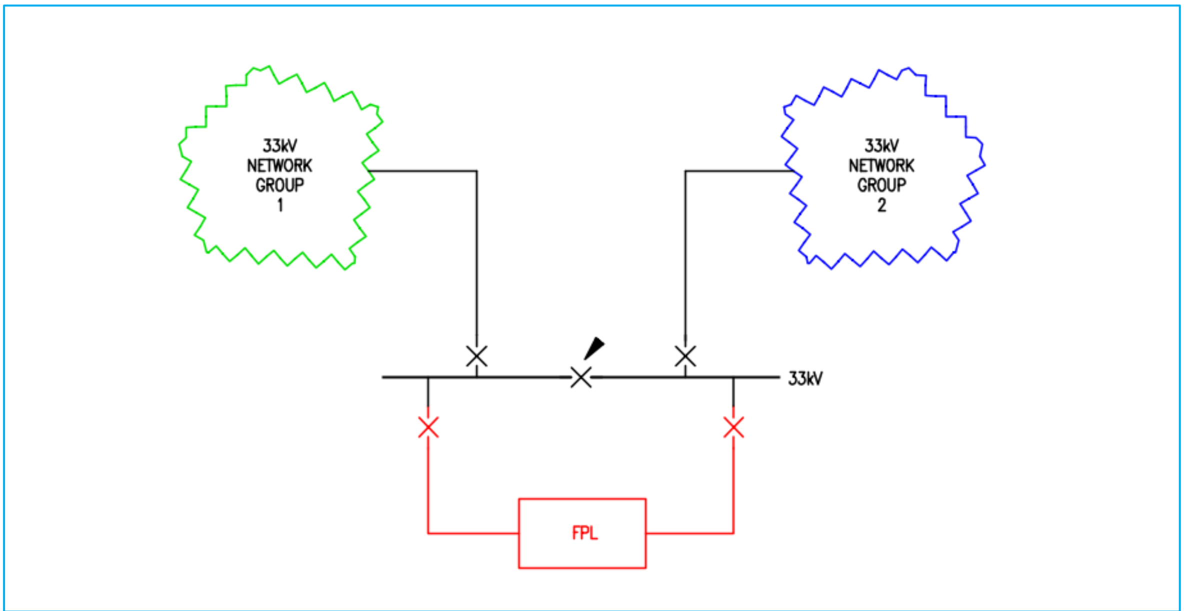


Figure 3-4: Option 2 – Across Existing Bus-Section Circuit Breaker

The arrangement for Option 2 is shown for extension of an existing AIS switchyard. An alternative solution for sites with space constraints could involve replacing all outdoor equipment with new indoor equipment housed in a new switchroom.

3.2.3 Option 3 – Network Mesh

The final network integration option considers a switching station that connects three network groups as shown in Figure 3-5.

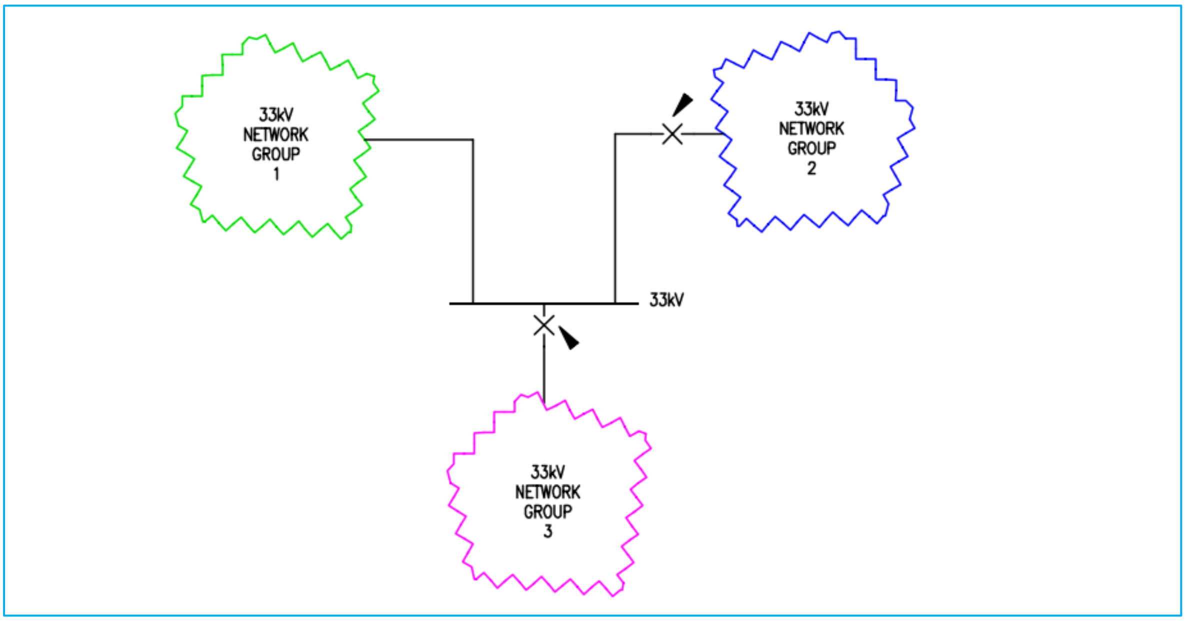


Figure 3-5: Option 3 - Existing Network Arrangement

In this arrangement an FPL can be integrated so that each separate network group can be connected together. By installing a new 33kV seven panel, three section switchboard, the FPL can be configured to transfer power across all the combinations of network groups. Figure 3-6 shows the configuration of the FPL to allow power transfer across Network Group 1 and Network Group 2.

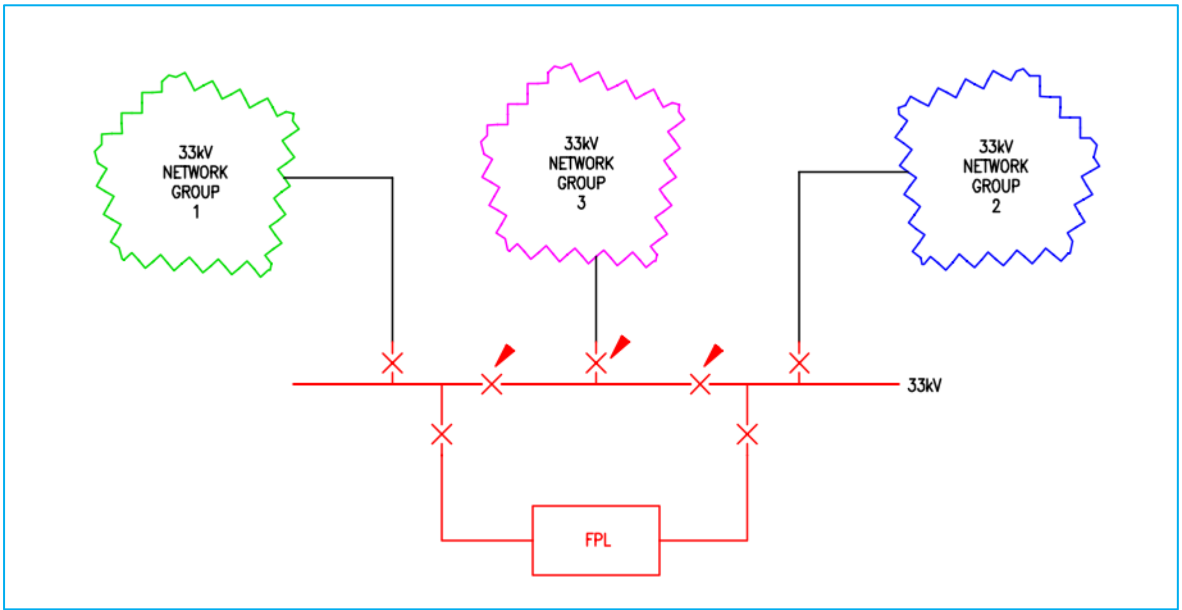


Figure 3-6: Option 3 - Proposed Network Arrangement

3.3 FPL Protection Options

The FPL will be equipped with internal protection installed by the manufacturer to provide alarms and trips for device faults. In order to effectively protect the network from any fault within the FPL a new protection scheme will be installed on the WPD circuit breakers connected to the FPL.

The traditional method for protection of AC devices, such as primary transformers, connected to the HV network is a unit protection scheme. This monitors the current flow in and out of the device, checking that any difference is within a set tolerance and tripping if not. However, the design and operation of the FPL with back-to-back AC-DC converters with different power flows either side mean that traditional AC protection methods are no longer viable.

The following sections describe the options available for protecting the FPL.

3.3.1 Option 1 – Overcurrent and Earth Fault

An overcurrent and earth fault (OCEF) protection scheme would provide Inverse Definite Minimum Time (IDMT) characteristic to disconnect the FPL. The operation time of the protection scheme would be determined by the value of fault current flowing, with higher fault currents corresponding to faster trip times.
As normal load current can flow both ways through the FPL, there is no advantage to include a directional element within the OCEF relay to try to enable faster operation times. The operation of OCEF on either FPL CB 1 or FPL CB 2 would be wired to initiate a trip to both FPL circuit breakers to ensure that the device was completely removed from service.

3.3.2 Option 2 – High Set Overcurrent

A High Set Overcurrent (HSOC) characteristic can be implemented to provide faster operation times compared with an IDMT characteristic. The HSOC is set to operate instantaneously when fault current is seen over the set threshold.

The HSOC characteristic can be provided within most modern OCEF numerical relays to provide a combination of both functions using only one set of 5P10 or 5P20 CTs. The operation of the HSOC, as with the OCEF, would operate both 33kV FPL circuit breakers.

Applying HSOC to the FPL circuit breakers would ensure rapid tripping of the FPL for fault currents that are more than 125% to 150% of the rated continuous current of the FPL.

3.3.3 Option 3 – Loss of Mains Protection

To disconnect the FPL for faults which are not directly associated with overcurrent a loss of mains (LOM) scheme can be implemented. This scheme monitors CT and VT inputs to establish if the network surrounding the device has healthy voltage and frequency. Should a drop in voltage or rate of change of frequency occur, the LOM scheme will initiate a trip of FPL circuit breakers 1 and 2.

3.4 Network Protection Options

Typically, circuits between substations on overhead 33kV networks are protected using a distance scheme. Distance protection operates by using voltage and current measurements to calculate impedance and if it is lower than the setting in the relay it is assumed the fault is located within the relay's protected zone.

The ability of the FPL to operate in both load and generation modes at leading and lagging power factors will result in the "seen" impedance changing. The following section describes the options for providing protection of the network around the FPL.

3.4.1 Option 1 – Distance with Back-Up OCEF

The existing distance protection scheme could be modified by reconfiguring the existing settings to ensure that the relay does not over or under reach during operation of the FPL. The distance protection relays would be configured with a directional element to prevent the relay looking into the FPL. The relay would be set to look along the outgoing circuit based on the FPL operating at 80% normal output.

3.4.2 Option 2 – Current Differential Unit Protection with Back-Up OCEF

An alternative for the main protection of the surrounding 33kV network would be to provide a current differential scheme on each feeder connecting to the FPL site. The circuit breaker at each end of the feeder (and any network tees) would need to be equipped with a current differential relay. In addition, a fibre optic link would need to be installed between each site to allow the relays to communicate. If an existing communication link is not available significant costs would be incurred. However, this option would provide extremely reliable discrimination of faults within the protected zone. Overcurrent and earth fault would be provided as back-up to the main protection scheme should it fail.

3.5 Auxiliary Supplies

The FPL requires a 3-phase LV supply to power the control systems and auxiliary systems including cooling. It is a requirement that a back-up uninterruptable power supply (UPS) is installed within the FPL to ensure that the control system and critical components remain operational at all times or until such time so that the FPL can be disconnected safely. There are three options for provision of the LV supply.

3.5.1 Option 1 – Single Supply

A single LV supply can be provided from an existing or new distribution transformer from a nearby 11kV circuit. The single supply would provide a cheaper connection than other options and could be implemented quicker. However, this would be a non-firm connection and as such may be subject to longer outage periods.

3.5.2 Option 2 – Two separate 11/0.415kV Supplies

The second option is to provide two LV supplies from separate 11kV sources incorporating an auto switchover scheme should either of the two supplies fail. This scheme would provide a firm supply, however it may be difficult to get two independent supplies from different sources in rural areas such as the Network Equilibrium Project area.

3.5.3 Option 3 – 33/0.415kV Auxiliary Supply

Finally, a 33/0.415kV transformer could be installed and connected to the same 33kV switchboard as the FPL. This would not require a connection to the 11kV network with the LV supplies provided on site next to the FPL. The disadvantage of this option is that the costs are much higher than both 11kV connection options due to procurement of an extra 33kV circuit breaker and a larger transformer.

3.6 SCADA Integration

The FPL will require integration into the existing supervisory control and data acquisition (SCADA) system for remote monitoring and control by WPD. The FPL and associated equipment is expected to have a large number of inputs and outputs for control, status and analogs. There are two options for integrating the FPL into the SCADA system.

3.6.1 Option 1 – Connection to existing Remote Terminal Unit

In order to provide and interface control, status and analog information for the FPL device a connection to the existing WPD Remote Terminal Unit (RTU) could be provided. To achieve this, the existing RTU would require available space for the new signals and have the correct functionality to allow the exchange of information required for the FPL.

3.6.2 Option 2 – New D20 Remote Terminal Unit

The second option would involve installing a new RTU dedicated for the FPL and the associated equipment. The new RTU would be designed to WPD’s current standard (D20 GE Grid Solutions RTU) and sized according to the requirements of the FPL.

4 Key Considerations when Incorporating FPLs within 33kV Networks

4.1 Harmonics

The AC-DC and DC-AC conversion process of the FPL is performed by two converters each containing multiple power electronic switching modules. In order to carry out both conversions, the sequential operation of the power electronic switching modules in each convertor at high frequency is required. This operation leads to harmonic content being produced on the incoming AC network and also inserted into the output AC current waveform.

The planning limit for network harmonic content is defined in the Energy Networks Association's (ENA) Engineering Recommendation G5/4-1. To keep harmonic contributions to a minimum and within the defined planning limits, filters can be installed at the devices point of connection. The filters can be designed to target and reduce specific harmonic orders.

Detailed background network harmonic data has been collected and analysed for the Network Equilibrium project area. A key consideration when tendering the FPL device was its impact on the network harmonic content. Analysis carried out to date has shown that filters will be required on both sides of the FPL device to keep the harmonic content within planning limits.

4.2 Voltage Step Change

The operation of the FPL will transfer active power between two different networks and supply or absorb reactive power at each of its two sides. The direction of power flow will determine whether the voltage will be increased or decreased in the 33kV network. Fluctuations in the power transfer of the FPL under normal operation will cause changes in the network voltage.

Planning limits for the maximum allowable change in voltage due to power fluctuations is defined in the ENA's Engineering Recommendation P28. It states that for general operation the maximum magnitude change in voltage is 3% over 600 seconds and 10% for infrequent events.

The control system for the FPL will be set such that the ramp rate of the device will be limited by the voltage change at its connection point. The ability of the FPL to control the reactive power input and output means that it is able to limit its impact on the voltage to remain within planning limits for any active power flow.

5 Substation Selection Criteria

5.1 Overview

The South West region of WPD's network currently contains 11 NOPs between BSPs that would connect different National Grid Groups on the 33kV network if closed. Of these, six are within Network Equilibrium's designated project area. As the FPL device can be installed anywhere along the BSP interconnector, to provide the facility of removing the NOP, a further two sites were considered for FPL integration selection. This facilitated eight sites in total, with Quartley Switching Station providing two possible FPL connection options. Each possible FPL integration site and the BSPs that would be connected are detailed in Table 5-1 below.

Table 5-1: Initial FPL Site Locations

BSPs	Current Normal Open Point	Proposed FPL Location
Barnstaple – Taunton	South Molton	South Molton
		Exebridge
		Quartley Switching Station
Bridgwater – Woodcote	ABSD middle of Feeder	ABSD middle of Feeder
Tiverton – Taunton	Tiverton Moorhayes	Quartley Switching Station
		Tiverton Moorhayes
	Burlescombe	Burlescombe
Exeter City – Tawton	Winslakefoot Switching Station	Winslakefoot Switching Station
Exeter City – Barnstaple	Lapford	Lapford

5.2 Initial selection

As part of the process for the selection for the installation location of the FPL, the network was analysed to determine the maximum power transfer available between the BSP pairs. Table 5-2 shows the power transfer capability at each location.

Table 5-2: FPL Location Power Transfer Capability

FPL Location	BSPs	Power Transfer
ABSD middle of Feeder	Bridgewater - Woodcote	4 MW
Lapford	Exeter City - Barnstaple	8 MW
Burlescombe	Tiverton - Taunton	10 MW
Exebridge	Barnstaple - Taunton	11 MW
South Molton	Barnstaple - Taunton	14 MW
Winslakefoot Switching Station	Exeter City – Tawton	14 MW
Quartley Switching Station	Tiverton - Taunton	16 MW
Tiverton Moorhayes	Tiverton - Taunton	16 MW
Quartley Switching Station	Barnstaple - Taunton	17 MW

At this stage a desktop study was carried out which investigated the power transfer capability of the BSP interconnection and the physical size at each substation considered for

FPL integration. Based on the low power transfer capability the Bridgewater – Woodcote and Exeter – Barnstaple connections were discounted. Investigation of available substation space for the integration of the FPL then ruled out Burlescombe and South Molton.

Table 5-3 below lists the four sites that remained viable and were investigated further for potential FPL integration.

Table 5-3: Final FPL Site Locations

Site	BSPs to be Connected
Exebridge Substation	Barnstaple – Taunton
Quartley Switching Station	Barnstaple – Taunton; or Tiverton – Taunton
Tiverton Moorhayes Substation	Tiverton – Taunton
Winslakefoot Switching Station	Exeter City – Tawton

5.3 Criteria

Following the desktop studies for each site, a number of additional criteria were considered to inform the selection of the location for inclusion of an FPL device. These criteria were:

- Availability of Space: What space is currently available and what space could be made available via changes to the existing equipment arrangement;
- Network Connection: How can the connection of the FPL be realised? Can the existing equipment be utilised and if not, how extensive are the works;
- Substation Access: Is there suitable access and space within the substation for manoeuvring and offloading of equipment? Are there any obstructions on potential delivery routes;
- Customer Impact: What customers may have supply connection changed by the closure the normally open point?

A weighting was assigned to each of the above factors to determine an overall individual score for each location. These are shown in Table 5-4 below. The practical aspects of each site are the primary criteria considered, namely the availability of space and suitable connection to the network while maintaining ability to revert to the current operational philosophy.

Table 5-4: Site Selection Weightings

Area	Weighting
Availability of space	50%
Network Connection	30%
Substation Access	10%
Customer Impact	10%

Appendix A shows the selection matrix detailing the hierarchy of substation selections with Appendix B showing detailed site investigation reports.

6 FPL – Installation Design

Exebridge 33/11kV substation was selected for installation of the FPL device following assessment of each substation. Further information can be found in Appendix A. Figure 6-1 provides an overview of the 33kV network surrounding Exebridge.

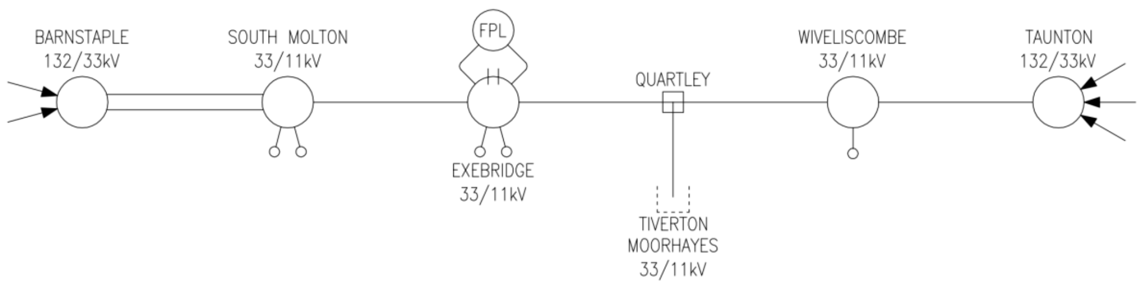


Figure 6-1: Overview of 33kV Network at Exebridge

The following section provides details on the works that will be required at the substation to accommodate the chosen FPL technology.

6.1 Enabling Works

6.1.1 Surveys

Surveys are to be carried out at the Exebridge site prior to the works to install the FPL. This will include the following:

- Service location: A survey will be completed to locate all existing underground services, including HV/LV cables, drainage and buried structures.
- Ground investigation: A ground survey will be completed to confirm the soil content and load bearing capacity at various depths. This will determine the methodology for delivery and offloading of the FPL, potentially via a crane. In addition, this information will also be used to determine the structural requirements of the new switch house and FPL foundations.

6.1.2 Overhead Line Modifications

Both the existing 33kV incoming overhead line (OHL) from Quartley/Taunton and the outgoing OHL to South Molton/Barnstaple terminate within the boundary of the substation on the South East and North West corners respectively. In order to facilitate access to the chosen FPL location, the terminal pole of the Taunton OHL needs to be removed. A new terminal pole will be constructed outside the substation boundary to transfer the OHL circuit onto a cable.

6.2 New 33kV Switchboard

The existing 33kV equipment at Exebridge is installed in an outdoor 33kV compound. In order to create suitable space for the FPL installation, a new 33kV switch house with an indoor switchboard is required. This will be positioned in the North East corner of the existing site and positioned in such a way that the existing substation remains operational during the construction process.

6.2.1 33kV Switchgear

Due to Exebridge currently having a primary substation with supplies from either side of the existing bus section, the FPL had to be located on the OHL circuit from Exebridge to South Molton. Therefore option 1 “Within a normally open 33kV interconnector” was chosen for connection of the FPL.

In order to provide suitable protection to the Primary Substation and the wider network following the FPL installation, it is necessary to install new 33kV circuit breakers for both primary substation feeders and the OHL Circuit from Exebridge to Taunton.

The new 33kV switchboard will consist of eight panels as per Figure 6-2 below. The bus section between the two FPL feeders will be operated normally open with the FPL in service.

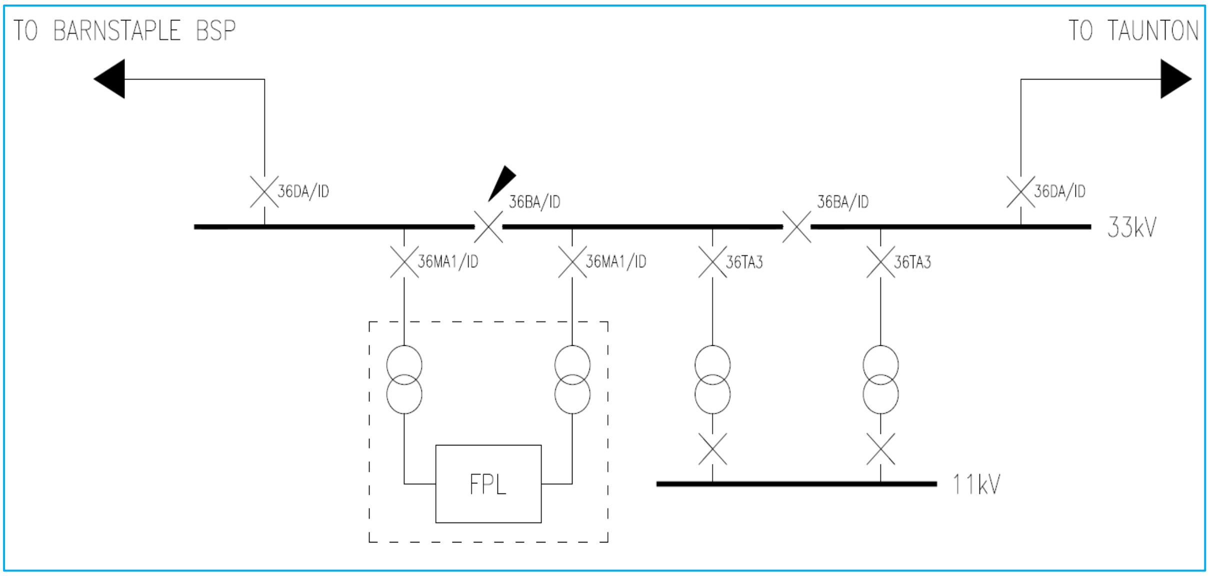


Figure 6-2: Exebridge 33/11kV Single Line Diagram following FPL Installation

The requirements for the new circuit breakers are listed in Table 6-1 below:

Table 6-1: New circuit breaker requirements

CB Type	36DA/ID	36TA3	36BA/ID	36MA1/ID
Number of Panels	2	2	2	2
Function	Primary substation outgoing feeder with distance protection	Primary substation outgoing T/F feeder with local intertripping	Primary substation bus section	Primary substation outgoing metering circuit breaker for FPL connection
Rated Voltage	36kV	36kV	36kV	36kV
Number of Phases	3	3	3	3
CB Rating (cont.)	1250A	1250A	1250A	1250A
Rated short-time withstand	25kA	25kA	25kA	25kA
Cable box	3 x 1c (up to 400mm^2) & 3 x 1ph surge arresters	3 x 1c (up to 400mm^2) & 3 x 1ph surge arresters	3 x 1c (up to 400mm^2) & 3 x 1ph surge arresters	3 x 1c (up to 400mm^2) & 3 x 1ph surge arresters
Cable entry	Bottom	Bottom	-	Bottom

6.2.2 Protection

Protection on all panels except the FPL feeders will be as per standard WPD protection philosophy. This is currently distance protection on the two OHL feeders, HV restricted earth fault protection on the two transformer feeders and overcurrent on the bus section breakers. The new 33kV switchboard will also come equipped with high impedance busbar protection as per current WPD standards.

The FPL switchgear panels will utilise all three protection options specified in Section 3:

1. High set overcurrent;
2. Loss of mains protection; and
3. Backup overcurrent earth fault protection.

The proposed CT and VT requirements for the new circuit breakers are listed in the Table 6-2 below:

Table 6-2: Proposed CT and VT requirements

Panel	36DA/ID	36TA3	36BA/ID	36MA1/ID
Description	Outgoing feeder with distance protection	outgoing T/F feeder	Bus section	Outgoing metering (Feeder CB to FPL)
Busbar Protection	1200/1 Class PX	1200/1 Class PX	2 no. sets of 1200/1 Class PX	1200/1 Class PX
OCEF	800/1 7.5VA 5P20 (1250A continuous rating)	800/1 7.5VA 5P20 (1250A continuous rating)	800/1 7.5VA 5P20 (1250A continuous rating)	800/1 7.5VA 5P20 (1250A continuous rating)
Current Differential	-	2000/1 Class PX[1]	-	2000/1 Class PX[1]
Distance Protection	800/1 Class PX	-	-	-
SBEF	-	-	-	-
Voltage Transformer	25VA Class 0.5	-	-	25VA Class 0.5
Note 1: CTs to be shorted when not in use				

The relays to provide the protection functionality will be selected from the WPD approved protection relay list. The range of relays for each protection application is shown in Table 6-3.

Table 6-3: Protection relays

Protection Type		
Busbar Protection	Distance	OCEF
Micom P122 Micom P142 Micom P145 Micom P445 7SA522 7SR1103-3 (Argus C)	Micom P445 Micom P543 7SA522	Micom P122 Micom P142 Micom P145 Micom P445 7SA522 7SR1103-3 (Argus C) 7SR2103-1 (Argus M)

There is an existing distance protection scheme in place at each of the 33kV OHL remote ends (incoming feed from Quartley/Taunton and the outgoing feed to South Molton/Barnstaple). The remote end distance protection settings will be modified to accommodate the FPL installation.

Modifications to the standard WPD specification are required to ensure suitable backup systems are in place for safe operation of the FPL device. These modifications will be provided as part of the next phase of the project.

6.3 New Switchboard Connections

The cables to/from the new switchboard will be 3 x 1c 400mm^2 Cu XLPE. New cable containment will be installed for routing the cables to/from the new switchboard. The cable screens will be earthed at both ends.

6.4 Auxiliary Systems

6.4.1 New Switchgear

The new switch house will require new LVAC, 110V DC and 48V DC supplies. The LVAC supply will be provided from two new ground mounted 11kV/415V transformers within the substation boundary. The single line diagram showing the connections required to provide the new LVAC supply is shown in Figure 6-3. The new LVAC distribution board will be located in the new switch house and will have auto changeover functionality between LV Supply 1 and 2 identified in Figure 6-3.

The new LVAC will supply new 110V and 48V battery chargers which will be located in the new switch house. Standing and momentary 110V and 48V DC loads on the new switchgear (including protection) will be determined by the switchgear manufacturer.

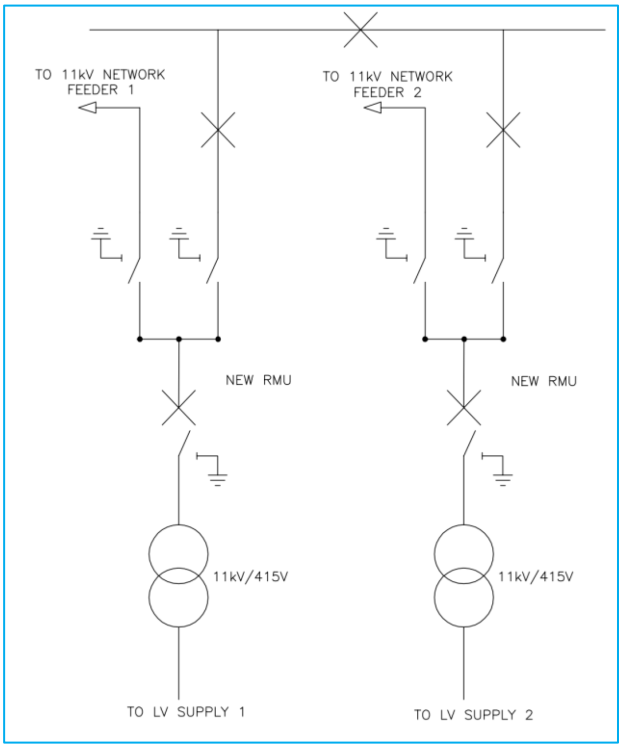


Figure 6-3: Proposed LVAC Supply

The LVAC supplies will be metered as per existing WPD standards for primary substation sites and equipment. The metering panel will be installed adjacent to the new 33kV switch house. This will facilitate a mechanism to understand the operating costs of the FPL, which were a key consideration in the procurement process of the device.

6.4.2 Earthing

The new switchgear, FPL and other associated plant and equipment will be integrated into the existing earth grid at Exebridge. The design of the extensions and connections will be in accordance with manufacturer specifications and WPD Engineering Specification *EE Spec: 89/2 Fixed Earthing Systems for Major Substations*.

6.5 Telecommunication

All control and indication signals from the new equipment will be integrated into a new D20 RTU to be installed in the new switch house as per option 2. This is to ensure that there is enough capacity in the system to provide the I/O requirements of the FPL and the new 33kV switchgear, however, it employs the standard WPD communications methodology already pleasant on site.

A full I/O list and multi-core schedule shall be developed to include:

- Standard I/O and telecontrol for 33kV switchgear and protection relays;
- Standard I/O for auxiliary systems (LVAC, 110V DC and 48V DC); and
- FPL specific I/O and telecontrol (manufacturer to advise).

Surf Telecom will be responsible for integration of the new equipment into the existing SCADA system.

6.6 33kV Compound Modifications

With the construction of the 33kV switch house and installation of the 33kV switchgear, the existing 33kV AIS busbars and circuit breaker will be de-commissioned. This will be staged in such a way to ensure that supplies are maintained to the primary substation at all times. Firstly the OHL to South Molton and the 33/11kV Transformer No.2 feeders will be transferred to the new switchboard followed by the OHL from Taunton and 33/11kV Transformer No.1 circuits.

With the new board fully commissioned with all existing circuits connected, the old 33kV equipment will be removed from site and the compound modified for installation of the FPL. This will involve the creation of new foundation structures and cable trenches for both power and communication cables. The compound will also be extended in order to maintain required safety clearances. The existing and proposed layouts for Exebridge Substation are shown in Figure 6-4 and Figure 6-5 respectively.

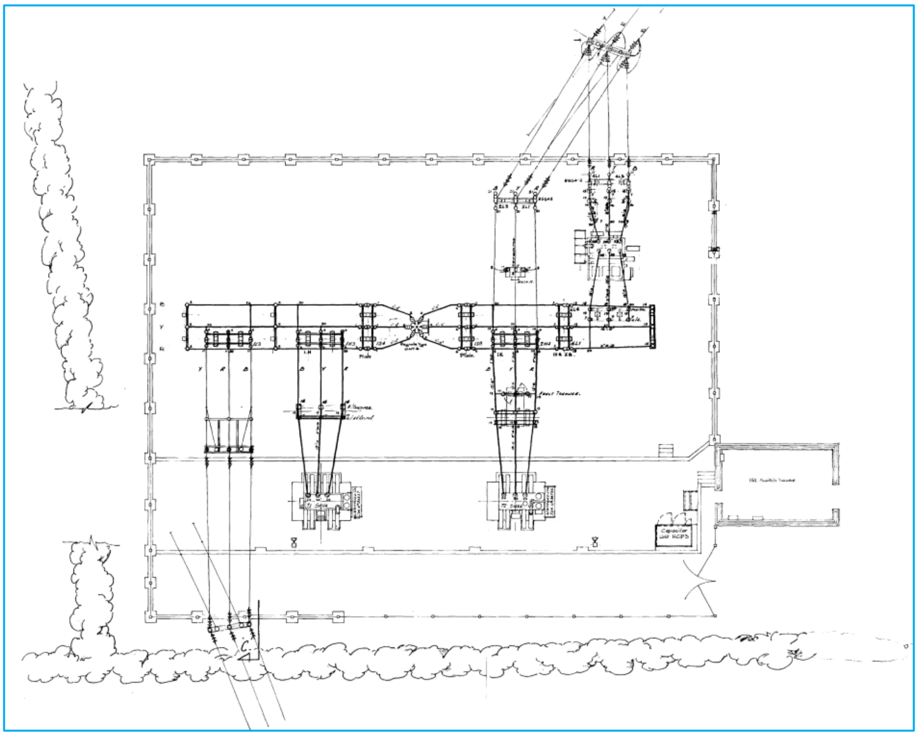


Figure 6-4: Existing Exebridge Site Layout

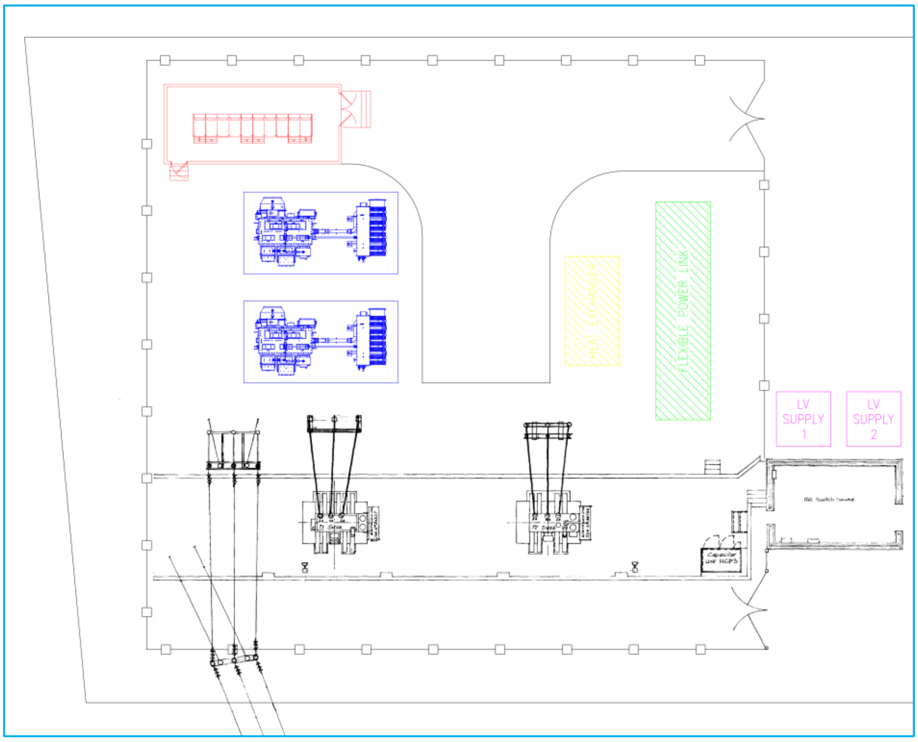


Figure 6-5: Proposed FPL and Switch House Layout for Exebridge

6.7 Civil Works

6.7.1 New 33kV Switch House

The new switch house will be a containerised solution manufactured off site and delivered as a complete unit including all switchgear and auxiliary equipment pre-installed prior to delivery and offloading to site. The containerised switch house will be installed on helical piles to raise the building above ground level. This will allow access for EHV cable routing under the building and to any damp issues. The new helical pile supporting structure will be designed against the relevant dead and dynamic loads to be provided by the building manufacturer. The evaluation of loads other than those specified for the manufacturers equipment shall be in accordance with appropriate British Standards for the assessment of dead and dynamic loads.

6.7.2 FPL

The two transformers associated with the FPL will be installed on individual concrete plinths. The plinth dimensions and concrete specification will be designed based on the transformer dead and dynamic loads provided by the manufacturer.

The FPL will be installed inside a bespoke enclosure. The enclosure will be installed on helical piles to raise it above ground level. The new helical pile supporting structure will be designed against the relevant dead and dynamic loads to be provided by the FPL manufacturer.

7 Risk Register

Table 7-1: Risk Register

Risk	Effect	Action
Delay in FPL Tender and/or delivery	Civil arrangements cannot be finalised Delay to project completion date	FPL ITT approved and issued in time. Effective programming and management of FPL manufacturer
Supplier unable to progress technology through from proto-type status to network ready status	Unable to procure relevant technology Delay to project completion date May not be able realise the full benefit of the FPL.	Detailed tender assessment on technical aspects of the technology. Ensure risks are captured during tender assessments with requests for detail of progress on proto-type units
Working in live 33/11kV substation	Potential harm to persons	All works shall comply with the Distribution Safety Rules
Access roads and bridges on transport routes inadequate for vehicles	Unable to deliver technology to site	Undertake a transport survey to determine adequacy of route prior to technology delivery
Handling of contaminated materials during excavation, dismantling and construction	Potential harm to persons / Lost Time Incident	Contamination survey (COSHH) to be carried out. Identify any contaminated oil and spoil. Provide suitable handling, transport and storage facilities for contaminated spoil and waste. Disposal of spoil and equipment to be carried out by approved suppliers using licensed and approved disposal facilities

8 11kV FPL Integration

Whilst the detailed design of the FPL integration has focussed on the 33kV device, knowledge and learning has been captured for the integration of an FPL into an 11kV network.

8.1 FPL Technology

The 33kV FPL is based on learning generated from transmission level High Voltage Direct Current (HVDC) systems. Due to the voltage level, 33kV, the system can be scaled down from a large, complex system due to the protection and operational requirements associated with an EHV network. However, for the 11kV network, a simpler protection and operation philosophy are employed. This means that for the installation of an FPL on the 11kV network significant learning from UK Power Networks FUN-LV project, which employs Soft Open Points (SOP) on the LV network, could be utilised.

8.2 Key Considerations when Incorporating FPLs within 11kV Networks

As described in Section 4 the key considerations for the 33kV integration of the FPL are harmonic and voltage step change. This is also the case for the 11kV network; however, customer impact and standard network design are also key considerations.

Due to the numbers of 11kV connected customers on the network it makes the protection and operation of an FPL more complex. 33kV networks are generally point-to-point connections with very few, if any customer connections. However, 11kV networks have a significant level of direct customer connections. This means that for any serially connected device, such as an FPL, the risk of wide scale tripping of customers is significantly increased.

Another key consideration is the fact that historic 11kV networks, due the radial nature of design, taper towards the end of the feeder. This is to say that, generally, the cross-sectional area of the overhead or underground 11kV system is smaller the further from the primary substation. This must be considered in detail due to the fact that in most cases the FPL will be connected between the ends of two radial 11kV feeders. This will significantly limit the transfer capability of the FPL unless supporting network reinforcement is carried out.

9 Appendices

Appendix A – Substation Selection Matrix

Appendix B – Substation Survey Reports

Appendix A – Substation Selection Matrix

Network Equilibrium - Primary Matrix

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Ranking	1	2	3	4
Criteria	Exebridge Substation	Tiverton Moorhayes Substation	Winslakefoot Switching Station	Quartley Switching Station
Availability of Space	No space restrictions	Minor space restrictions	Major space restrictions	Major space restrictions
	Ample space available for construction of new switchhouse and FPL with removal of existing 33kV AIS switchgear	Site area large enough for installation. However, there are potential staging issues and difficulty in modifying existing OHL terminal poles.	FPL and switchroom just within site while maintaining safety distances. Minimal room available for FPL delivery and offloading.	FPL and switchroom just within site while maintaining safety distances. Minimal room available for FPL delivery and offloading.
Network Connection	Modifications internal to the site boundary only	Major modifications internal and external to site boundary	Minor Modifications internal and external to site boundary	Major modifications internal and external to site boundary
	All works can take place within existing site boundary	Difficult to re-terminate existing OHLs due to dual carriage way. Un used 11kV switchhouse requires demolition before any works can start on site.	Two new terminal poles can be placed on site boundary. All remaining works will take place within	Three new terminal poles required outside existing site boundary. Issues with existing wayleaves makes this would make this difficult to complete. Lack of space for equipment delivery
Substation Access	Minor restrictions	Minor restrictions	Major restrictions	Major restrictions
	Narrow roads and small weight restricted bridge to cross	Close to main carriage way. Route through town centre with tight roundabouts.	Main access to site via an unmade road unsuitable fro goods vehicles. Rest of route narrow with houses either side.	Extremely narrow road bordered by houses
Connected Customer Impact	Minimal impact	No impact	No impact	Major impact
	Single Embedded generation customer connected to alternative BSP with FPL in service	Existing NOP. No impact on existing customers	Existing NOP. No impact on existing customers	Potential for a complete Primary substation and an embedded generation customer to be switched to an alternative BSP with FPL in service
Score	86.7	62.5	55	40.8

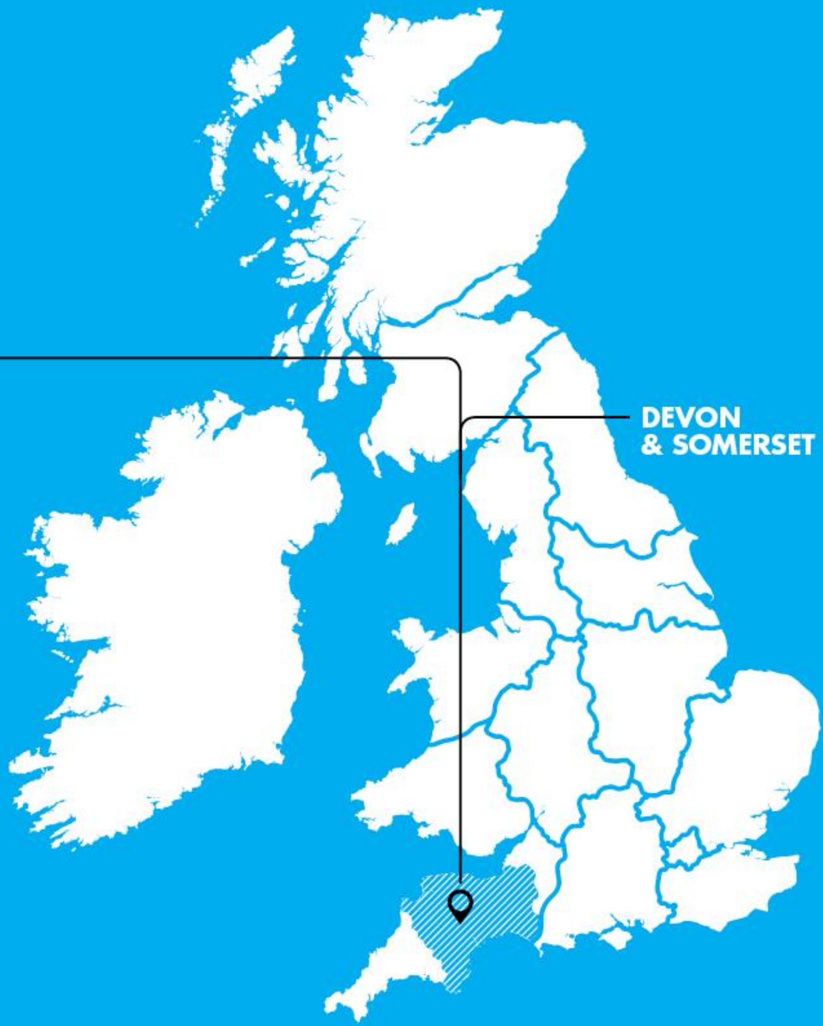
Appendix B – Substation Survey Reports

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND

FPL Substation Investigation
Exebridge 33/11kV



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Contents

1 Introduction

This report will determine the requirements for installing a Flexible Power Link (FPL) on the 33kV network at Exebridge 33/11kV Substation. The report will detail the existing site arrangement and outline the potential layout and connection options of the FPL at the substation including any enabling works. Site specific risks associated with the installation and operation of the FPL will also be described.

2 Substation Overview

Exebridge 33/11kV substation is fed from Taunton Main BSP and is a part of the Bridgewater-Seabank-Taunton interconnected 33kV network group. The 33kV network at Exebridge is normally supplied from Taunton via Quartley switching station. The alternative 33kV supply to Exebridge is from Barnstaple BSP. This alternative connection can be energised by closing the Normal Open Point (NOP) at South Molton 33/11kV substation. Figure 2-1 below shows the network configuration at Exebridge 33/11kV.

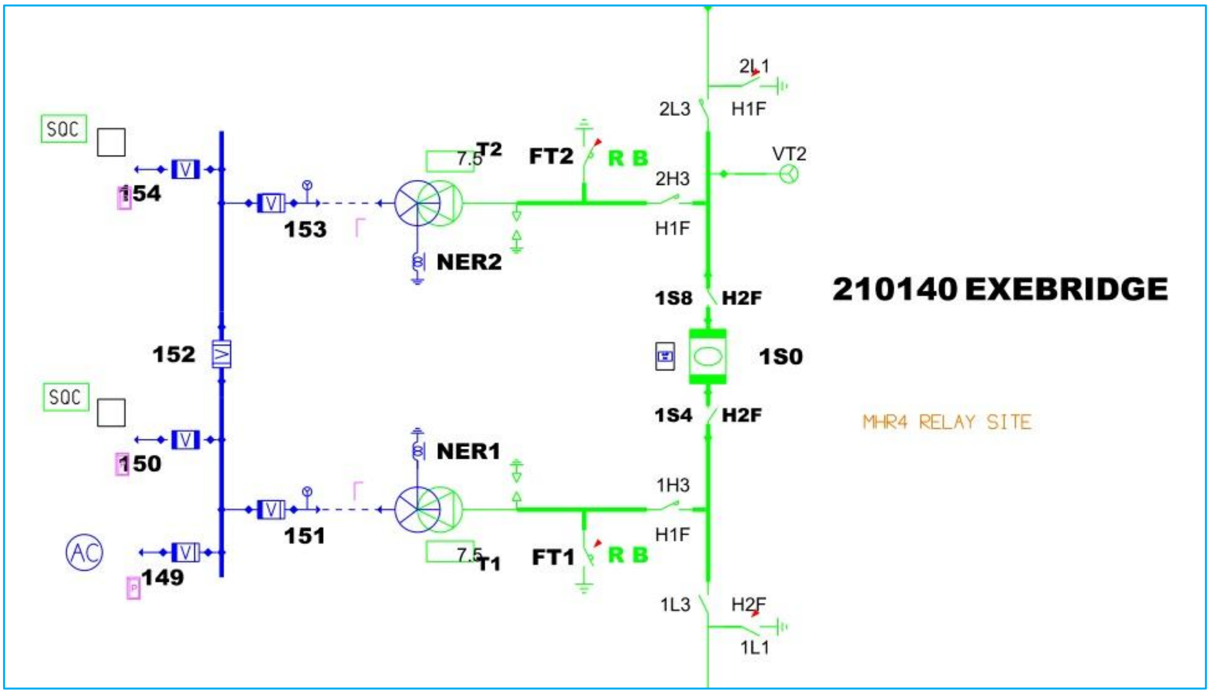


Figure 2-1: Existing Single Line Diagram for Exebridge

Exebridge Substation comprises a 33kV AIS compound, 2 no. 7.5MVA 33/11kV transformers and a 6 panel 11kV switchboard. The incoming 33kV overhead line from Quartley connects to busbar section 1. The 33kV overhead line from South Molton is connected to busbar section 2. The only 33kV circuit breaker at the substation is the bus-section separating busbar sections 1 and 2. The HV protection on the 33/11kV transformers operates fault throwers to trip the remote ends and provide fault clearance.

Table 2-1 below shows the Peak Demand and 33kV Generation for the two BSPs that can supply Exebridge 33/11kV.

Table 2-1: BSP Peak Demand and 33kV Generation

	Peak Demand (MVA)	33kV Generation (MW)
Taunton Main	87.22	30.75
Barnstaple	55.18	30.07

Exebridge substation is accessed directly from the main road that passes the substation. The site access is sufficient for small vehicles; however, it is highly likely that the opposite side of the main road would be disrupted when larger vehicles need to access the site. The entrance to the substation could be widened by removing the foliage and surrounding shrubbery around the access gate.

3 Existing Equipment

3.1 33kV Compound

The 33kV compound is made up of a six bay Air Insulated Switchboard (AIS) with a single 33kV bus-section circuit breaker. Of the six bays, two are utilised by the incoming 33kV overhead line supplies and two by connections to 33/11kV Primary Transformers. The remaining bays are currently spare.

The two 33kV overhead line supplies come in on poles located outside of the compound but within the site boundary. The overhead lines then drops down to a terminal point inside the compound fence before being connected to a bay.

In addition to the overhead lines a WPD Surf communications line follows the same route as the overhead line up to the terminal poles located within the site boundary. As it enters the compound it is diverted around the north and eastern faces of the compound between the two terminal poles via an underground fibre optic cable.

The size of the 33kV fenced compound is 28 x 34m. On the eastern side of the site the fence it may be extended by 11m, if required, up to the site boundary. Extension to the south would require further consideration as this could impinge on the existing site entrance. In the south east corner of the substation plot there is an 11 x 22m area which does not infringe on the entrance and could be used for future extension. Figure 3-1 below shows the existing site arrangement.

Figure 3-1: Existing Site Layout at Exebridge

3.2 33kV Protection Schemes

The 33kV networks feeding Exebridge utilise distance protection relays with back up over current / earth fault relays on both sides of the bus section circuit breaker. Fault throwers are installed on the 33kV side of each transformer to clear faults detected within the HV zone of the transformer.

3.3 Other

The 11kV switchroom is situated in the south west corner of the 33kV compound near to the main site entrance. Feeder cables from the 11kV switchboard run alongside the compound fence and out the east side of the site.

There is an existing fibre optic communication circuit that enters the site on the overhead line from Taunton and then leaves the site on the overhead line towards South Molton.

4 FPL Installation

4.1 Electrical connection

To create a suitable space within the substation for the FPL installation, the existing 33kV AIS arrangement would need to be replaced with an indoor installation. The indoor installation would provide the same operational arrangement but in a much smaller foot print. A new 8 panel 33kV indoor switchboard would be required to connect the existing circuits and provide the FPL connection and by-pass facility. Figure 4-1 below shows the proposed 33kV single line diagram.

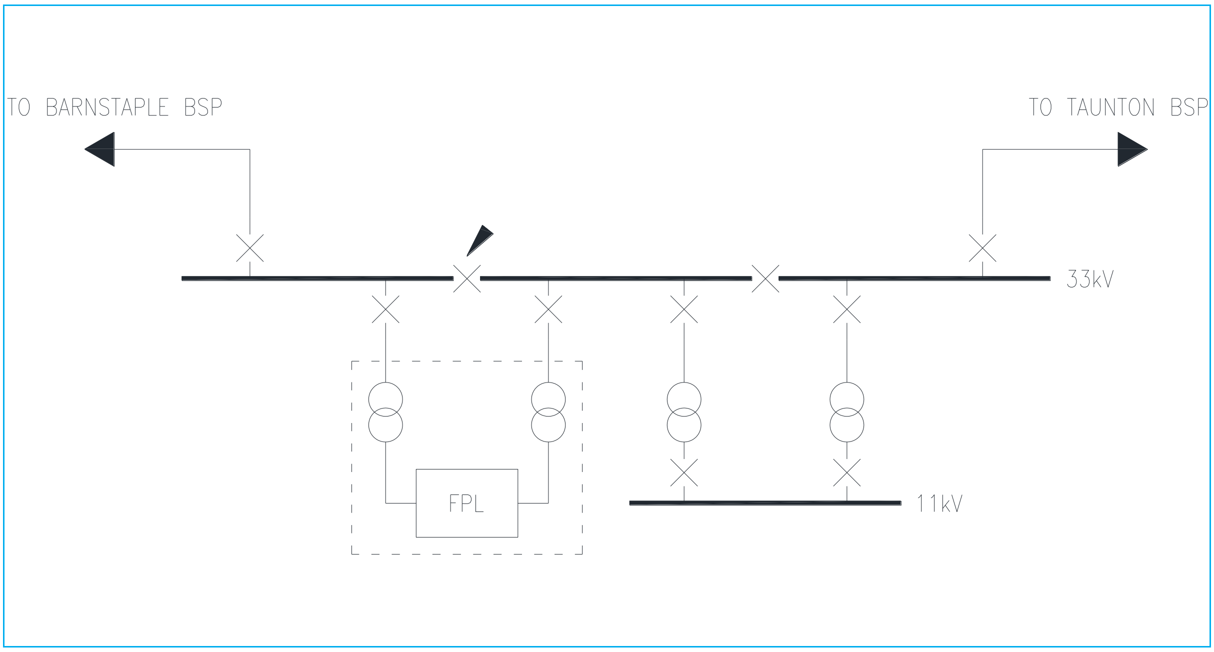


Figure 4-1: Proposed Exebridge 33/11kV Single Line Diagram Following the FPL Installation

After connection of the FPL, the NOP currently at South Molton would be moved to the 33kV by-pass circuit breaker at Exebridge. For operational reasons, if the FPL is taken out of service the network must be reverted back to the current operating arrangement with the NOP at South Molton.

4.2 Protection

The main protection on the two 33kV circuit breakers supplying overhead line feeders would be distance protection. Overcurrent and earth fault protection would be incorporated as back-up protection for the main protection scheme.

It is envisaged that the FPL circuit breakers would be protected using a combination of High Set Overcurrent (HSOC) with back-up overcurrent and earth fault protection schemes. However, further discussions with the chosen FPL manufacturer would need to take place to determine the optimum protection scheme.

The new 33kV transformer feeders would be supplied with WPD's standard protection scheme. The new scheme would be integrated with the existing protection to remove the need for the fault throwers.

The new 33kV switchboard would come equipped with high impedance busbar protection as per WPD standards. The bus section breakers would be protected as per current WPD policy.

4.3 FPL Layout

The arrangement of the FPL is manufacturer specific, however, it is expected that the main components of the FPL will comprise:

- 40ft container housing the switching modules and control elements;
- Two step down transformers; and
- Coolers for the switching modules.

As described previously, the installation of the new 33kV switchboard and FPL will require the outdoor 33kV switchgear to be removed. To create addition space in the compound it is recommended that the overhead line section pole in the south east corner of the site is relocated.

Figure 4-2 below shows the proposed FPL and switchhouse layout at Exebridge.

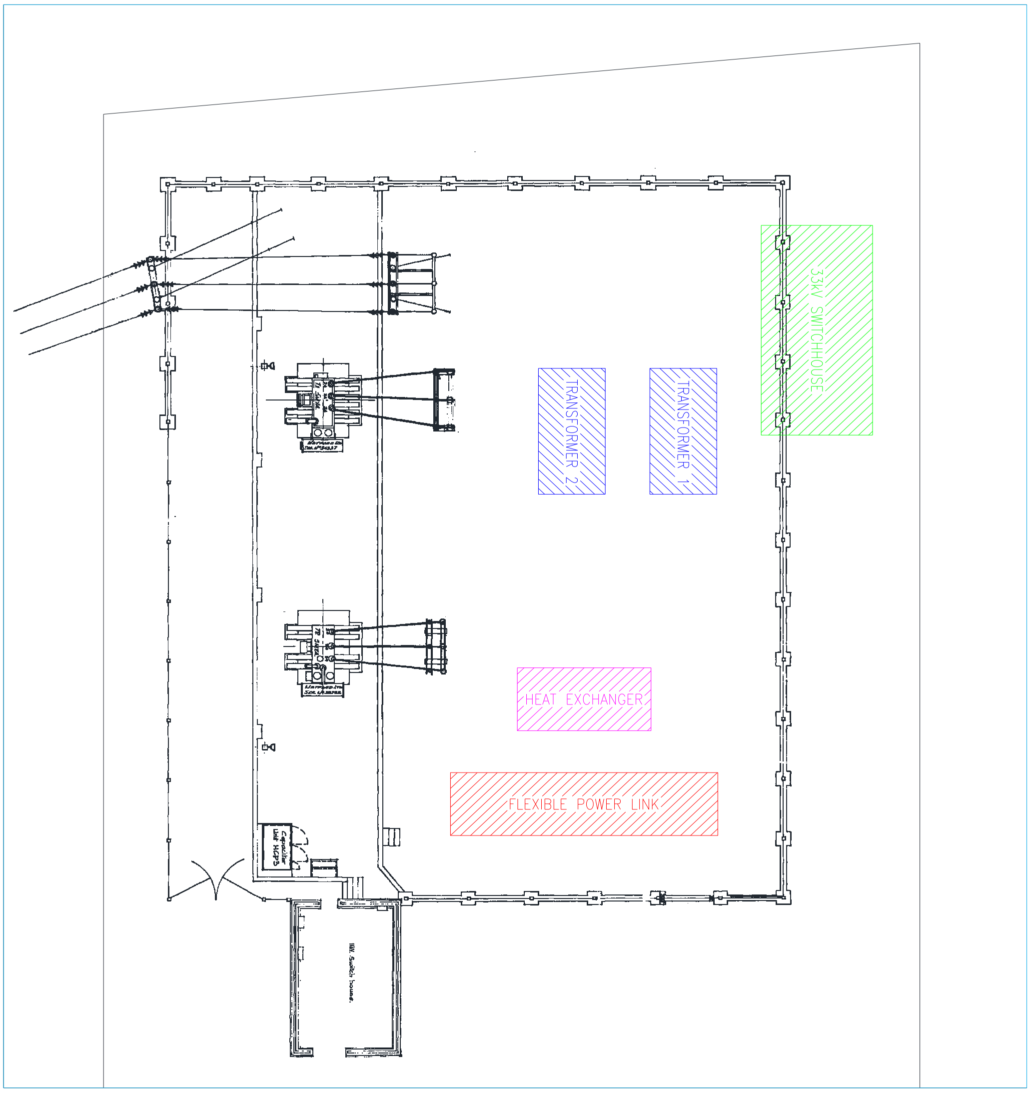


Figure 4-2: Proposed FPL and 33kV Switchhouse Layout at Exebridge

4.4 Staging

The FPL installation works would need to be staged so that the existing substation remains operational throughout the works and minimises the outage time. The first stage of the installation would involve construction of the new building for housing the indoor 33kV switchgear. Following installation and cold commissioning, the switchboard would be energised by diverting the 33kV feeder from South Molton on to the new switchboard.

Once energised, T1 would be transferred over allowing Exebridge to be temporarily supplied via South Molton until T2 and the 33kV feeder from Quartley were transferred to the new switchboard. The 33kV compound will then have the AIS switchgear removed to create suitable space for the FPL installation.

4.5 Delivery

As described in section 2, access will be via the A396. The additional major obstacles will be a bridge which needs to be passed over if the site is accessed from the north. Approaching from the south there are areas of the road with hanging trees on both sides which may impose a height restriction.

5 Health and Safety

5.1 Overview

Safe operation and continuity of supply shall be the main considerations for WPD, nominated working parties and manufacturers involved with any works to install FPL equipment at Exebridge. The *Health and Safety at Work Act 1974* and *Electricity at Work Regulations 1989* shall be fully implemented with a view to making the equipment safe to install, operate and maintain.

5.2 CDM

The works at Exebridge will fall under the *Construction Design and Management Regulations 2015*. WPD will be the Principal Contractor during all phases of the works.

5.3 Risk Register

Table 5-1: Site specific risk register

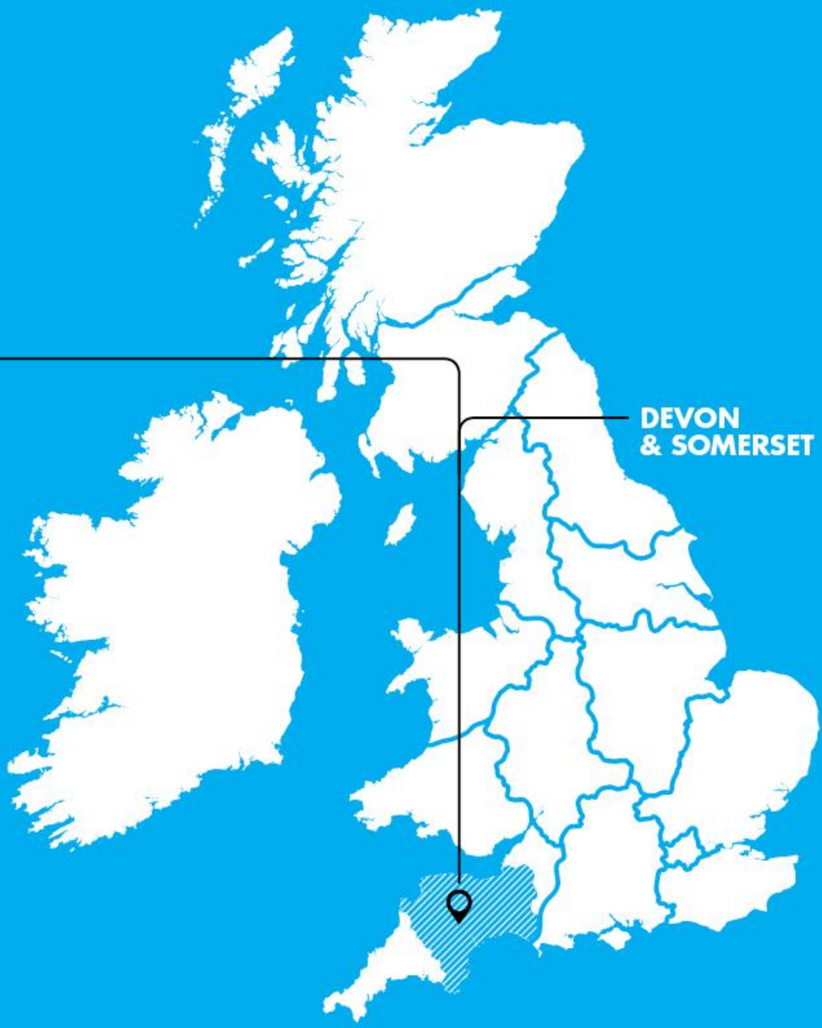
Risk	Effect	Action
Delay in FPL Tender and/or delivery	Civil arrangements cannot be finalised Delay to project completion date	FPL ITT approved and issued in time. Effective programming and management of FPL manufacturer
Supplier unable to progress technology through from proto-type status to network ready status	Unable to procure relevant technology Delay to project completion date May not be able realise the full benefit of the FPL.	Detailed tender assessment on technical aspects of the technology. Ensure risks are captured during tender assessments with requests for detail of progress on proto-type units
Working in live 33/11kV substation	Potential harm to persons	All works shall comply with the Distribution Safety Rules
Access roads and bridges on transport routes inadequate for vehicles	Unable to deliver technology to site	Undertake a transport survey to determine adequacy of route prior to Technology delivery
Handling of contaminated materials during excavation, dismantling and construction	Potential harm to persons / Lost Time Incident	Contamination survey (COSSH) to be carried out. Identify any contaminated oil and spoil. Provide suitable handling, transport and storage facilities for contaminated spoil and waste. Disposal of spoil and equipment to be carried out by approved suppliers using licensed and approved disposal facilities

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND

FPL Substation Investigation
Tiverton Moorhayes 33/11kV



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Contents

1 Introduction

This report will determine the requirements for installing a Flexible Power Link (FPL) on the 33kV network at Tiverton Moorhayes 33/11kV Substation. The report will detail the existing site arrangement and outline the potential layout and connection options of the FPL at the substation including any enabling works. Site specific risks associated with the installation and operation of the FPL will also be described.

2 Location

Tiverton Moorhayes 33/11kV substation is fed from Tiverton BSP and is a part of the Abham-Exeter-Landulph interconnected 33kV network group. The 33kV network at Tiverton Moorhayes is normally supplied from Tiverton BSP. The alternative supply is from Taunton BSP via Quartley switching station. This alternative connection can be energised by closing the Normal Open Point (NOP) at Tiverton Moorhayes 33/11kV substation. Figure 2-1 below shows the network configuration at Tiverton Moorhayes 33/11kV.

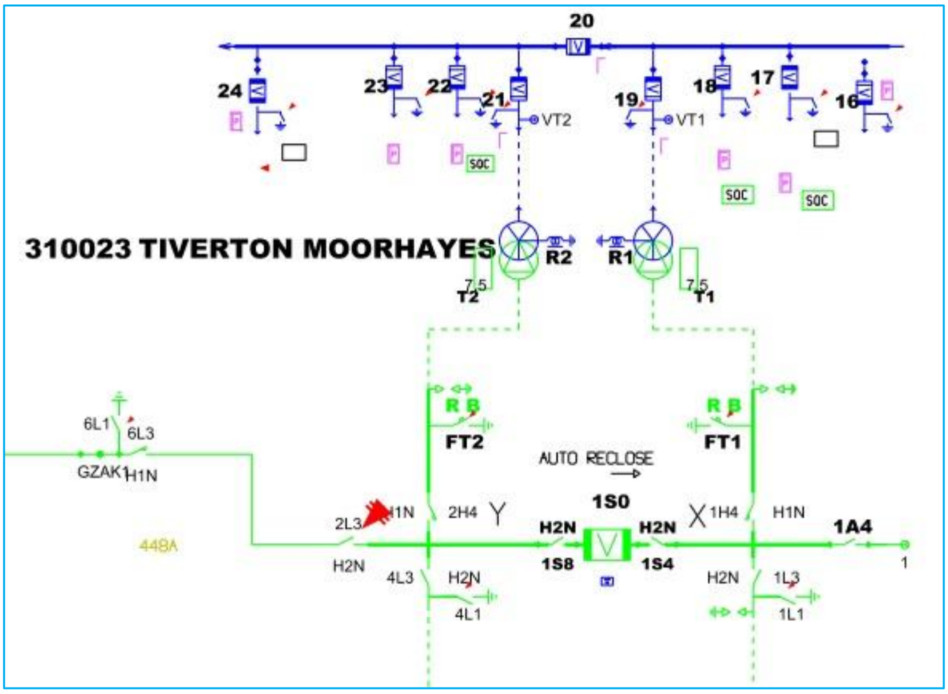


Figure 2-1: Existing Single Line Diagram

Tiverton Moorhayes Substation comprises 33kV AIS compound, two 33/11kV transformers, an 11kV switchhouse and a local distribution substation. The incoming underground cable supply from Tiverton BSP is connected to busbar section 1. The 33kV overhead line to Quartley is connected to busbar section 2 via a normal open disconnector along with an underground cable circuit from Tiverton Junction 33/11kV substation. The only 33kV circuit breaker at the substation is the bus-section separating busbar sections 1 and 2. The HV protection on the 33/11kV transformers operates fault throwers to trip the remote ends and provide fault clearance.

Table 2-1 below shows the Peak Demand and 33kV Generation for the two BSPs that can supply Tiverton Moorhayes 33/11kV.

Table 2-1: BSP Peak Demand and 33kV Generation

	Peak Demand (MVA)	33kV Generation (MW)
Taunton Main	87.22	30.75
Tiverton	56.91	4.55

Access to the site is via Bolham Lane which can either be approached by crossing a bridge over the A361 or by turning off the A361 and going through Tiverton. The site entrance has sufficient space for access.

3 Existing Equipment

3.1 33kV Compound

The 33kV compound is made up of a six bay Air Insulated Switchboard (AIS) with a single 33kV bus-section circuit breaker. Of the six bays, two are utilised by the incoming 33kV cable supplies, one by an incoming OHL connection, and two for connections to the 33/11kV Primary Transformers.

The 33kV overhead line comes in on a tower located outside of the compound but within the site boundary. The overhead lines then drops down to a terminal point inside the compound fence before being connected to a bay. There is an additional 11kV overhead line pole located next to the 11kV switchhouse towards the west side of the compound.

The size of the 33kV fenced compound is 29 x 33m. The fence is already extended to the edge of the site boundary and therefore cannot be extended further. Figure 3-1below shows the existing site arrangement.

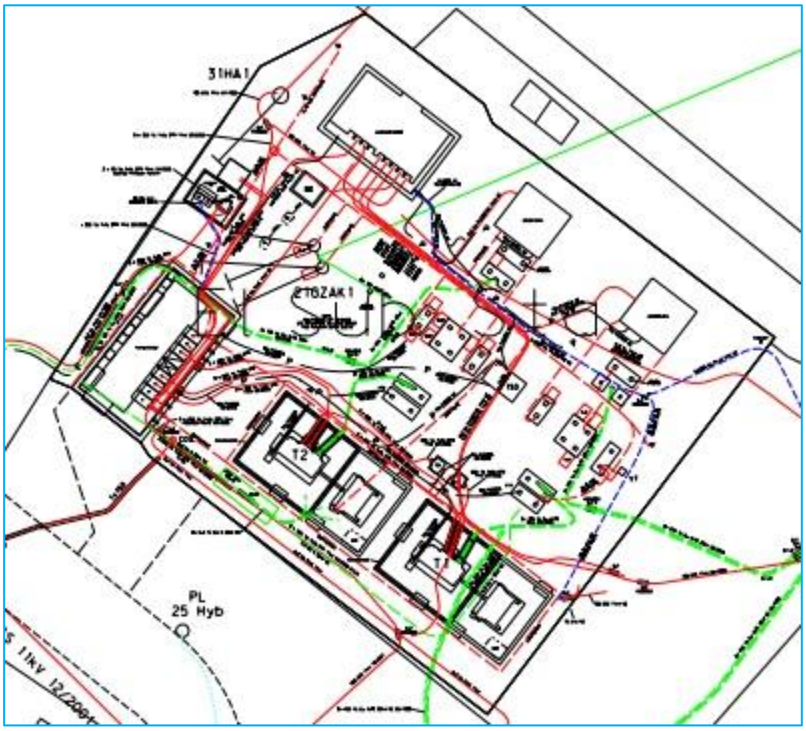


Figure 3-1: Existing Site Arrangement

3.2 33kV Protection Schemes

The 33kV networks feeding Tiverton Moorhayes utilise distance protection relays with back up over current / earth fault relays on both sides of the bus section circuit breaker. Fault throwers are installed on the 33kV side of each transformer to clear faults detected within the HV zone of the transformer.

3.3 Other

An 11kV switchroom is situated inside the south west corner of the main compound constructed in 2006. The previous, now unused, 11kV building is located in the North West corner of the substation along with two concrete plinths for the original Primary transformers. The compound also contains an 11/0.433kV packaged substation on the western edge providing local LV supplies.

4 FPL Installation

4.1 Electrical connection

To create a suitable space with in the substation for the FPL installation the existing 33kV AIS installation requires replacement with an indoor installation that can provide the same operational arrangement in a much smaller foot print. In order to connect the FPL, two feeder breakers and a bus section breaker will be installed between the new breakers for the OHL circuit to Quartley and the Primary substation transformer feeder. Figure 4-1below shows the proposed 33kV single line diagram.

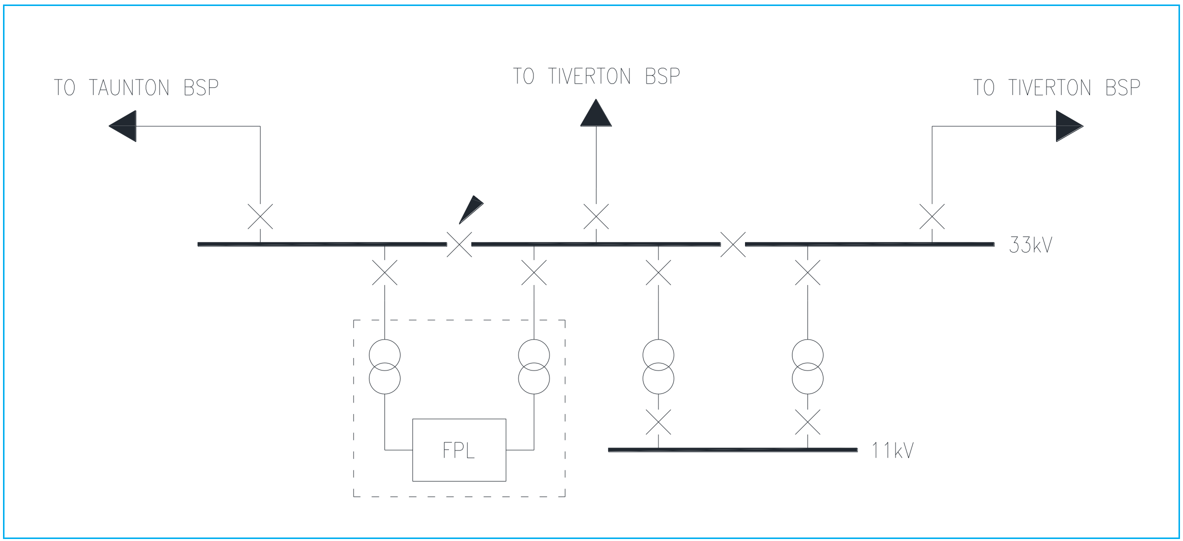


Figure 4-1: Proposed Tiverton Moorhayes Single Line Diagram following the FPL Installation

4.2 Protection

The main protection on the three 33kV circuit breakers supplying the overhead line and cable feeders would be distance protection. Overcurrent and earth fault protection would be incorporated as back-up protection for the main protection scheme.

It is envisaged that the FPL circuit breakers would be protected using a combination of High Set Overcurrent (HSOC) with back-up overcurrent and earth fault protection schemes. However, further discussions with the chosen FPL manufacturer would need to take place to determine the optimum protection scheme.

The new 33kV transformer feeders would be supplied with WPD's standard protection scheme. The new scheme would be integrated with the existing protection to remove the need for the fault throwers.

The new 33kV switchboard would come equipped with high impedance busbar protection as per WPD standards. The bus section breakers would be protected as per current WPD policy.

4.3 FPL Layout

The arrangement of the FPL is manufacturer specific, however, it is expected that the main components of the FPL will comprise:

- 40ft container housing the switching modules and control elements;
- Two step down transformers; and
- Coolers for the switching modules.

As described previously, the installation of the new 33kV switchboard and FPL will require the outdoor 33kV switchgear to be removed. All overhead line poles within the compound area will also require removal to create enough space for the FPL installation.

Figure 4-2 below shows a potential layout of the FPL at Tiverton Moorhayes.

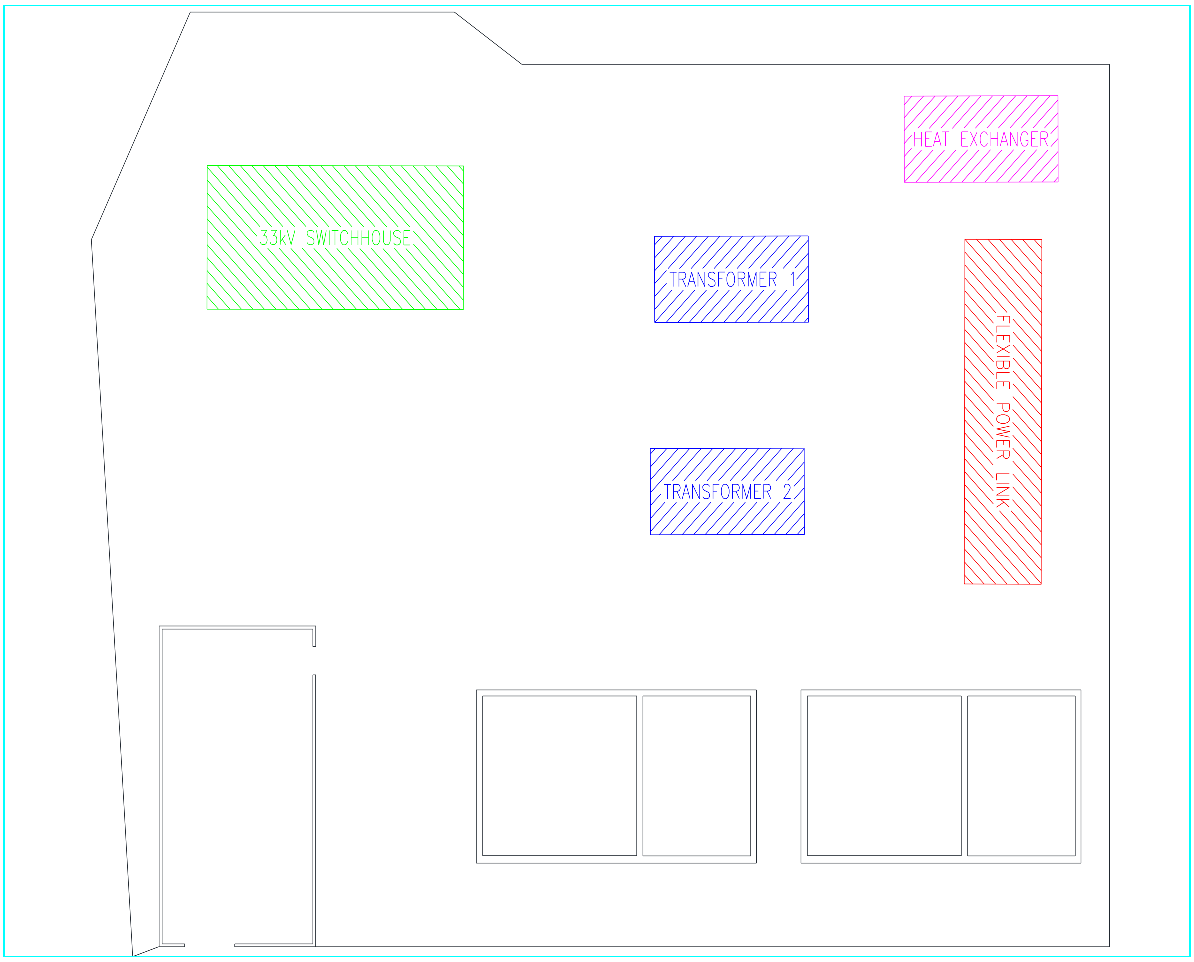


Figure 4-2: Proposed FPL and 33kV Switchhouse Layout at Tiverton Moorhayes

4.4 Staging

The FPL installation works would need to be staged so that the existing substation remains operational throughout the works and minimises the outage time. The first stage of the installation would involve construction of the new building for housing the indoor 33kV switchgear. Following installation and cold commissioning, the switchboard would be energised by diverting the 33kV feeder from Tiverton BSP on to the new switchboard.

Once energised, T1 would be transferred over with Tiverton Moorhayes temporarily supplied via Tiverton Junction until T2 and the 33kV feeder from Tiverton Junction were transferred to the new switchboard. Finally the overhead line circuit to Quartley would be transferred. The 33kV compound will then have the AIS switchgear removed to create suitable space for the FPL installation.

4.5 Delivery

As described in section 2, access will be via the A361. The site can then be accessed from the north via Bolham Lane or from the south through Tiverton town. Access to large vehicles is likely to be restricted.

5 Health and Safety

5.1 Overview

Safe operation and continuity of supply shall be the main considerations for WPD, nominated working parties and manufacturers involved with any works to install FPL equipment at Tiverton Moorhayes. The *Health and Safety at Work Act 1974* and *Electricity at Work Regulations 1989* shall be fully implemented with a view to making the equipment safe to install, operate and maintain.

5.2 CDM

The works at Tiverton Moorhayes will fall under the *Construction Design and Management Regulations 2015*. WPD will be the Principal Contractor during all phases of the works.

5.3 Risk register

Table 5-1: Site specific risk register

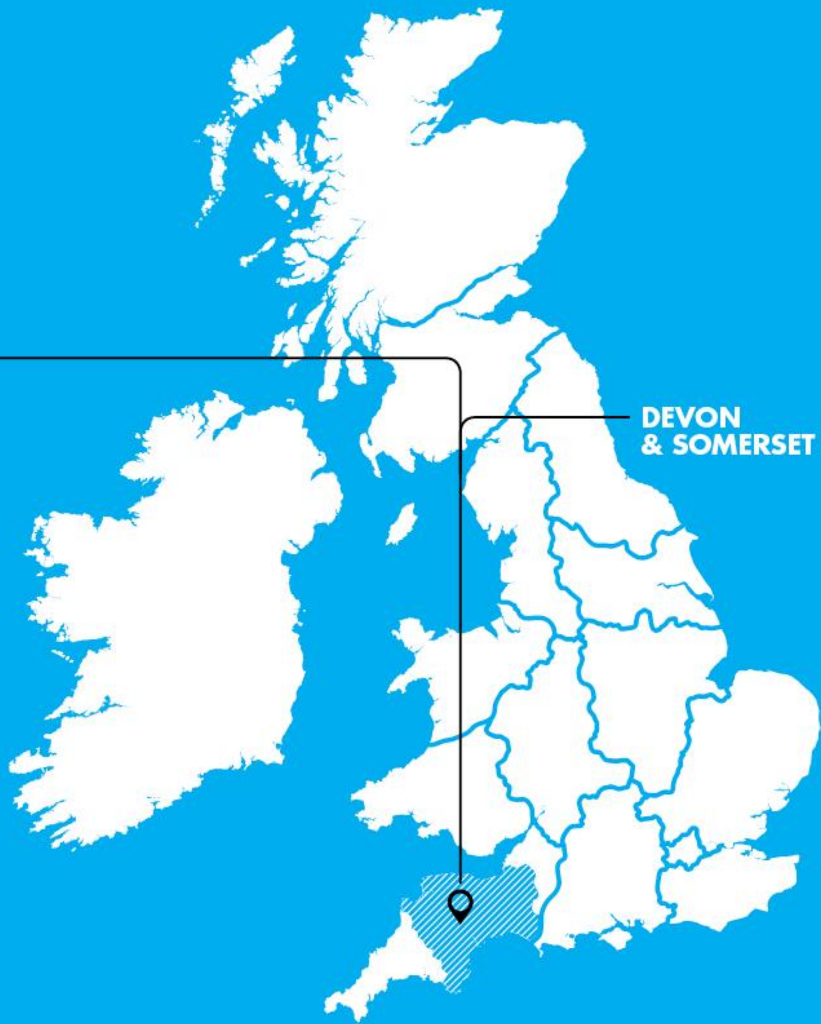
Risk	Effect	Action
A trip occurs whilst connecting to the new switchgear.	Loss of supply to customers. Fines could be incurred.	Stage any replacement works such that if any trips occur, the out of service equipment can be quickly re energised.
The access roads are too small to deliver the equipment to the site.	Deliveries can't be made. If the crane can't be delivered it will be difficult to carry out some of the works.	Carry out deliveries during times of low traffic to minimise disruption on narrow roads. Find an alternative method of lifting.
A new protection scheme is used for the FPL that is untested at large scales.	Chance of failure or malfunction may be higher.	Test the protection scheme before installing. Have protection and monitoring of the protection equipment.
Underground obstructions encountered when laying the foundations.	Foundations become more expensive. Work is delayed.	Do a ground survey before carrying out the civil works. Ensure any underground utilities and obstructions are known before carrying out work. The layout needs to be changed depending on the ground conditions.
The 33kV compound will still be live when constructing the new switchgear.	Electrocution could occur Restrictions will be in place on where work can be carried out on site.	Clearly define no go areas whilst work is underway. Ensure the site team has a health and safety briefing before starting work on site.
The overhead line could obstruct the crane operation.	Overhead line could be damaged. Equipment could be damaged if dropped.	Only carry out crane work during clear visibility to help ensure that no accidents occur. Earth the lifting vehicles to protect he operator from electric shocks.
Hitting underground cables when digging the foundations.	Loss of supply to customers. Fines could be incurred.	Ensure the local of all underground cabling is known and design foundations such that there is enough distance from the cables.

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND

FPL Substation Investigation
Winslakefoot 33kV Switching Station



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Reviewed by:	Yiango Mavrocostanti	10.03.2016
Approved (WPD):	Jonathan Berry	11.03.2016

Revision History

Date	Issue	Status
11.03.2016	1	Final

Contents

1 Introduction

This report will determine the requirements for installing a Flexible Power Link (FPL) on the 33kV network at Winslakefoot 33kV Switching Station. The report will detail the existing site arrangement and outline the potential layout and connection options of the FPL at the switching station including any enabling works. Site specific risks associated with the installation and operation of the FPL will also be described.

2 Substation Overview

Winslakefoot Switching Station is a Normal Open Point (NOP) on the 33kV network between Exeter City and North Tawton BSP.

One 33kV incoming circuit supplied by Exeter City BSP is tee'd with a connection to Folly Bridge 33/11kV substation. The outgoing 33kV circuit is connected to North Tawton BSP with tee'd connections to Whiddon Down and Moretonhampstead 33/11kV substations. Figure 2-1 below shows the network configuration at Winslakefoot switching station.

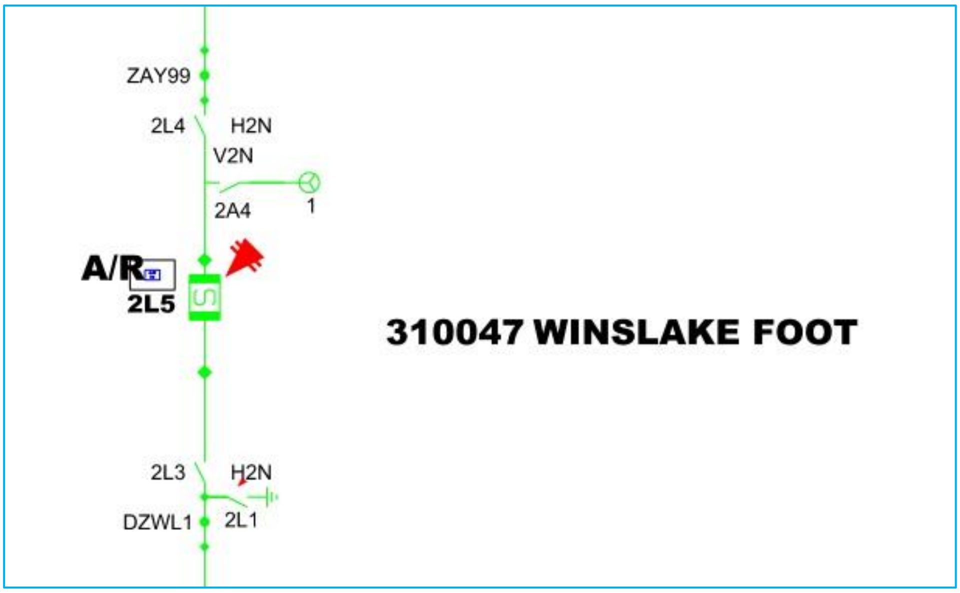


Figure 2-1: Existing Single Line Diagram

Table 2-1 below shows the Peak Demand and 33kV Generation for the two BSPs that would be connected following installation of the FPL at this site.

Table 2-1: BSP Peak Demand and 33kV Generation

	Peak Demand (MVA)	33kV Connected Generation
Exeter City	97.07	0
North Tawton	22.42	71.54[1]

[1] Please note the generation figure covers both North Tawton and Pyworthy

3 Existing Equipment

3.1 33kV Compound

Winslakefoot switching station comprises a 33kV outdoor compound with a small access road from Tedbury St Mary. The compound contains two overhead line terminal poles, a 33kV circuit breaker and a control room. The total site boundary is 22 x 14.5m with the 33kV compound positioned in the North East corner of the site measuring 14.5 x 10m. Figure 3-1 below shows the existing site arrangement.

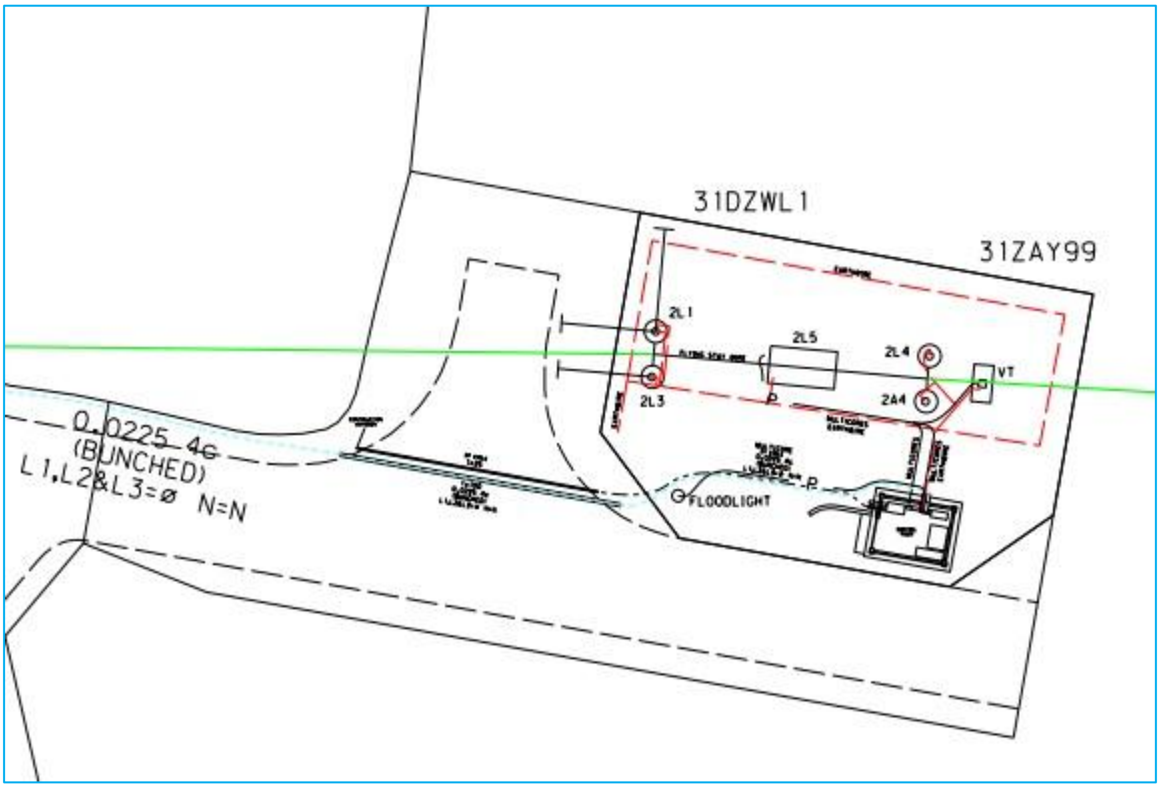


Figure 3-1: Existing Site Arrangement

3.2 Protection Schemes

Both of the overhead lines feeding Winslakefoot are protected via distance protection relays with back up overcurrent and earth fault relays applied to the 33kV circuit breaker.

4 FPL Installation

4.1 Electrical connection

In order to provide a suitable connection point at the substation for the FPL, a new 33kV indoor switchboard would need to be installed. This will require the construction of a new building to contain the switchgear and control equipment. The switchboard would comprise five panels; two outgoing feeder panels to North Tawton and Exeter City, two FPL feeder panels and a single bus section panel. Figure 4-1 below shows the proposed 33kV single line diagram.

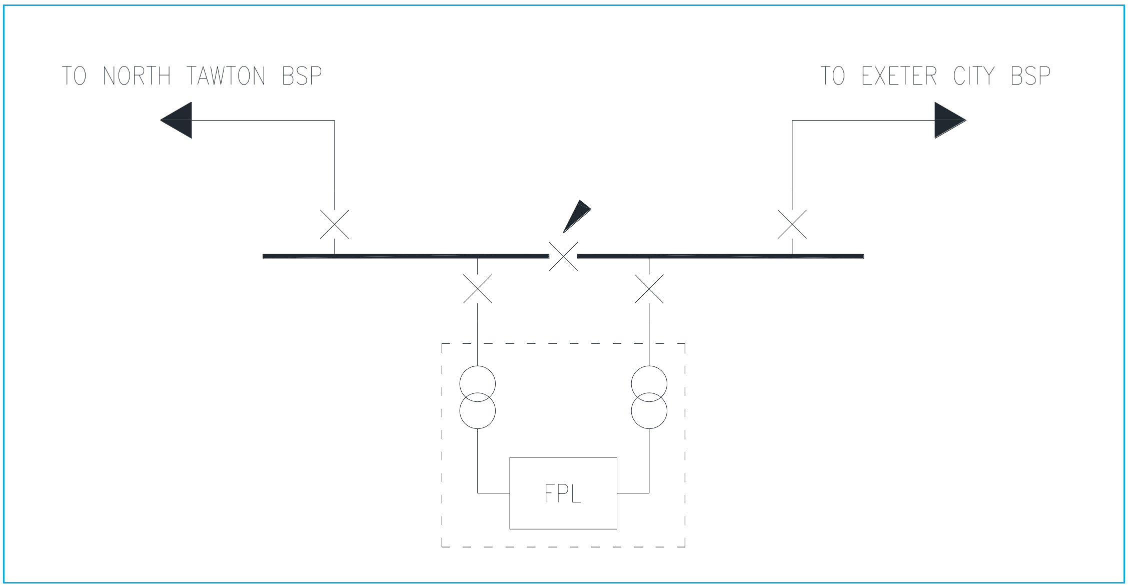


Figure 4-1: Proposed Winslakefoot Single Line Diagram following the FPL Installation

The existing NOP on the breaker at Winslakefoot will be transferred to the bus section breaker following installation of the FPL. If for operational reasons the FPL is taken out of service, no additional switching will be required to return the network to its current state.

4.2 Protection

The two overhead line feeders and bus section circuit breakers will be specified as per current WPD policy. The main protection on the outgoing feeder circuits provided by distance protection relays.

It is envisaged that the FPL circuit breakers would be protected using a combination of High Set Overcurrent with back-up overcurrent and earth fault protection schemes. However, further discussions with the chosen FPL manufacturer would need to take place to determine the optimum protection scheme.

The new 33kV switchboard would come equipped with high impedance busbar protection as per WPD standards. The bus section breakers would be protected as per current WPD policy.

4.3 FPL Layout

The FPL will be positioned to enable safe delivery, installation and maintenance of the equipment. The existing site is currently not large enough to safely install, operate and maintain the FPL device, therefore additional land adjacent to the switching station would need to be acquired. Figure 4-2 below provides an overview of substation layout following the FPL installation.

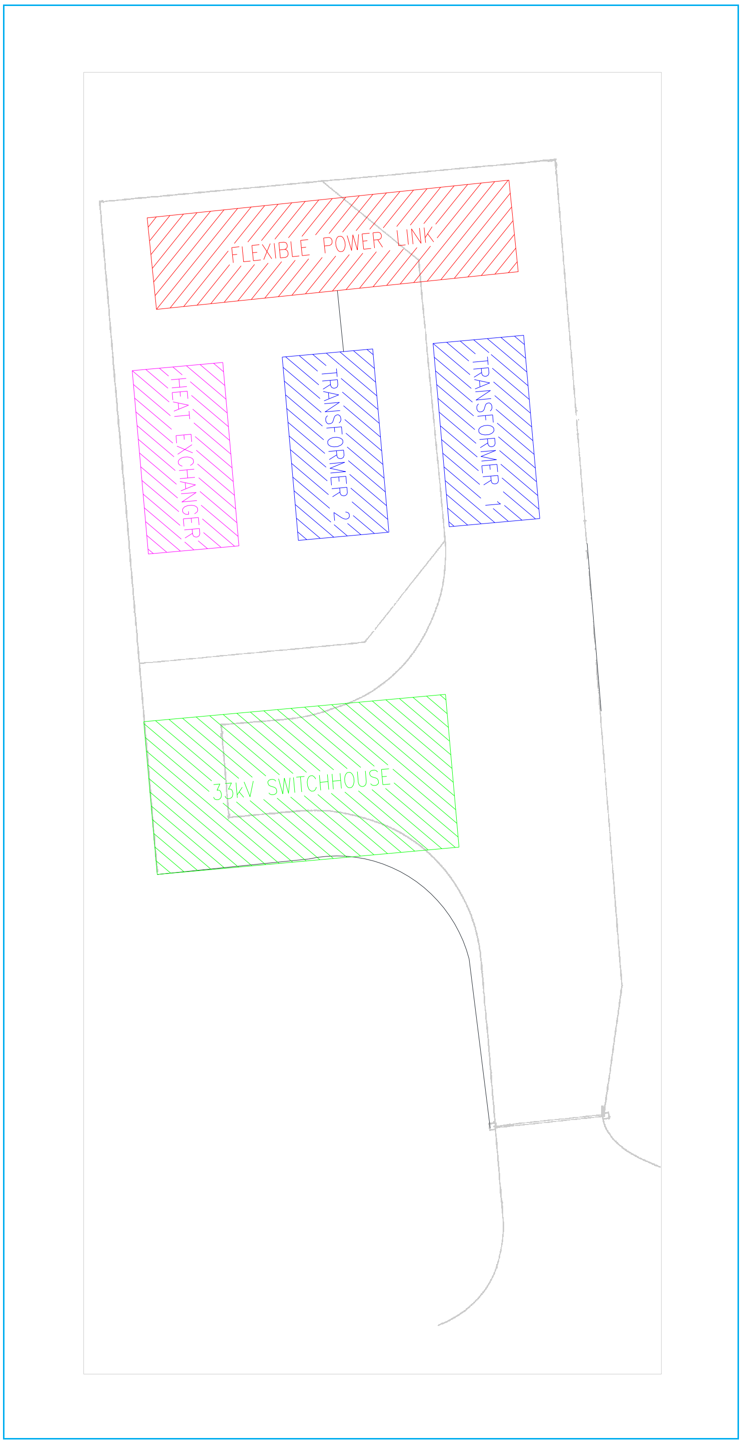


Figure 4-2: Proposed FPL and 33kV Switchhouse Layout at Winslakefoot

4.4 Staging

The FPL installation works will be staged to maximise the availability of the existing switching station by minimising any outage times. The 33kV switchroom will be constructed and commissioned first followed by the transfer of the two existing circuits onto the new switchboard. During each circuit transfer, the terminal poles within the site will be removed and new terminal poles erected outside the site boundary.

Once all circuits have been transferred, the remainder of the existing 33kV compound will be cleared and the new FPL compound constructed.

4.5 Delivery

Immediate access to the switching station is via a single track unpaved road that is currently unsuitable for the large vehicles.

5 Health and Safety

5.1 Overview

Safe operation and continuity of supply shall be the main considerations for WPD, nominated working parties and manufacturers involved with any works to install FPL equipment at Winslakefoot. The *Health and Safety at Work Act 1974* and *Electricity at Work Regulations 1989* shall be fully implemented with a view to making the equipment safe to install, operate and maintain.

5.2 CDM

The works at Winslakefoot will fall under the *Construction Design and Management Regulations 2015*. WPD will be the Principal Contractor during all phases of the works.

5.3 Risk Register

Table 5-1 below highlights the site specific risks when carrying out the proposed modifications to the substation.

Table 5-1: Site specific risk register

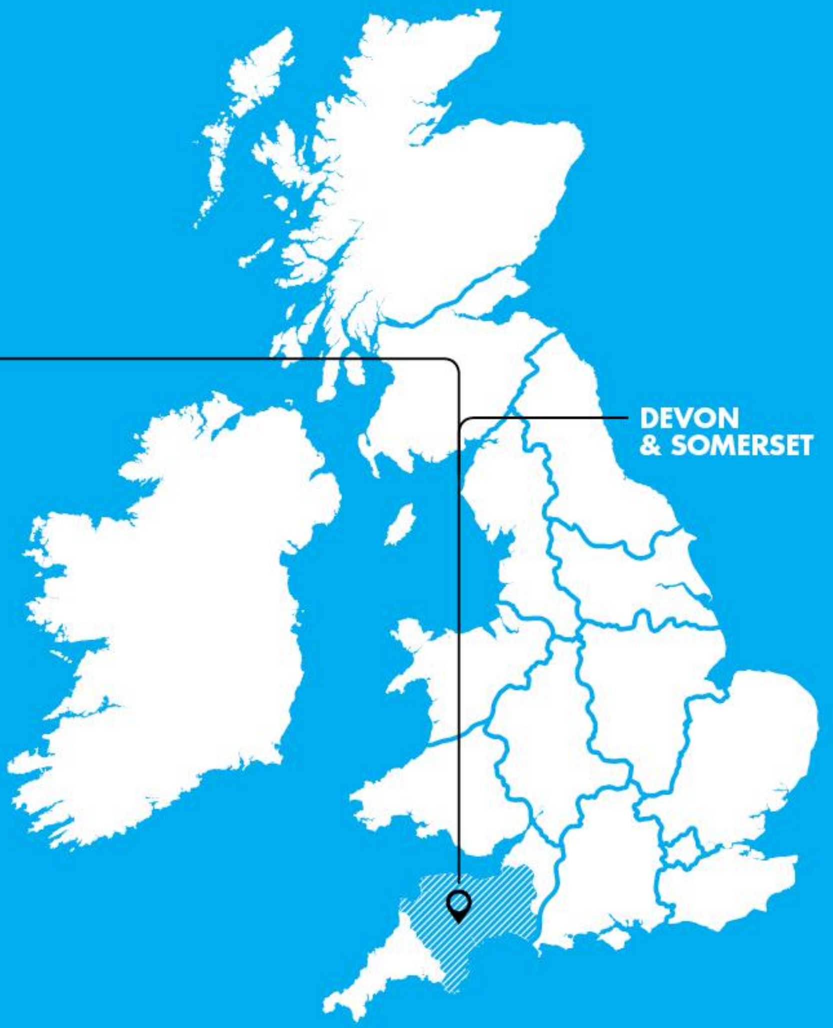
Risk	Effect	Action
The access road and entrance is too small to deliver the equipment to the site.	Deliveries can't be made. If the crane can't reach the site it will be difficult to carry out some of the works.	Modify the road junctions to be more suitable. Acquire or rent land for laydown to enable crane to fit on site. Find an alternative method of lifting.
A trip occurs whilst connecting to the new switchgear.	Loss of supply to customers. Fines could be incurred.	Stage any replacement works such that if any trips occur, the out of service equipment can be quickly re energised.
A new protection scheme is used for the FPL that is untested at large scales.	Chance of failure or malfunction may be higher.	Test the protection scheme before installing. Have protection and monitoring of the protection equipment.
Underground obstructions encountered when laying the foundations.	Foundations become more expensive. Work is delayed.	Perform a ground survey before carrying out the civil works. Ensure any underground utilities and obstructions are known before carrying out work. The layout needs to be changed depending on the ground conditions.
The 33kV overhead line will still be live during parts of the construction period.	Electrocution could occur. Restrictions will be in place on where work can be carried out on site.	Clearly demark areas whilst work is underway. Ensure the site team has a health and safety briefing before starting work on site.
The overhead line could obstruct the crane operation.	Overhead line could be damaged. Equipment could be damaged if dropped.	Only carry out crane work during clear visibility to help ensure that no accidents occur. Relocate the towers for the overhead line.

WESTERN POWER DISTRIBUTION

NETWORK EQUILIBRIUM

BALANCING GENERATION AND DEMAND

FPL Substation Investigation
Quartley 33kV Switching Station



LCN Fund
Low Carbon Networks

Report Title	:	Quartley 33kV Switching Station FPL Investigation Report
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Approved (WPD):	Jonathan Berry	11.03.2016

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Contents

1 Introduction

This report will determine the requirements for installing a Flexible Power Link (FPL) on the 33kV network at Quartley Switching Station. The report will detail the existing site arrangement and outline the potential layout and connection options of the FPL at the switching station including any enabling works. Site specific risks associated with the installation and operation of the FPL will also be described.

2 Location

Quartley Switching Station is fed from Taunton Main BSP and is a part of the Bridgwater-Seabank-Taunton interconnected 33kV network group. Quartley Switching Station is supplied from Taunton via Wivelliscombe. There are two alternative supplies to Quartley; from Barnstaple via Exebridge by the closure of the Normal Open Point (NOP) at South Molton 33/11kV substation or from Tiverton by closure of the NOP at Tiverton Moorhayes. FIGURE XX below shows the network configuration at Quartley Switching Station.

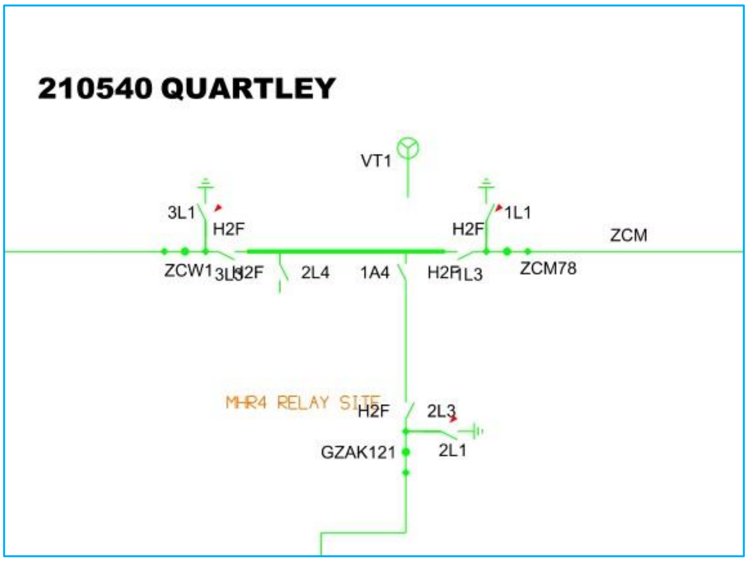

Figure 2-1: Existing Single Line Diagram for Quartley

Quartley comprises a 33kV compound containing three overhead line poles and a control room. There was previously a single circuit breaker connected to the circuit to Tiverton Moorhayes that operated as the NOP before being removed from network due to reliability issues.

Table 2-1 below shows the Peak Demand and 33kV Generation for the three BSPs that can supply power through Quartley.

Table 2-1: BSP Peak Demand and 33kV Generation

	Peak Demand (MVA)	33kV Connected Generation
Taunton Main	87.22	30.75
Barnstaple	55.18	30.07
Tiverton	56.91	4.55

3 Existing Equipment

3.1 33kV Compound

The site is currently made up of a single 33kV compound containing three OHL poles, an out of service circuit breaker and a 33kV control room. In addition to the overhead lines, a WPD Surf communications line follows the overhead line into the site from Taunton, entering the control room, before leaving site on the overhead line to Exebridge and Barnstaple.

Figure 3-1 below shows the existing site arrangement.

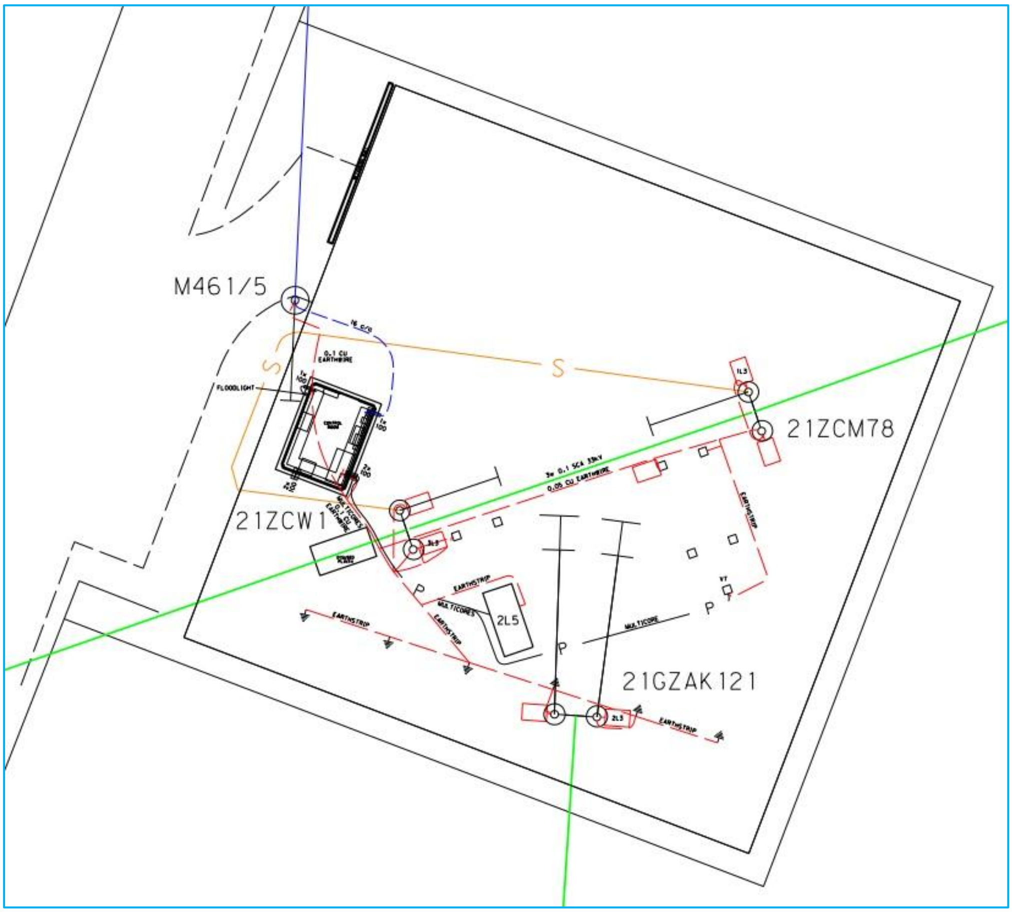

Figure 3-1: Existing Site Arrangement

The total site boundary is 26 x 22m with fields on three sides. However, there are current wayleaves issues with the adjacent land owner meaning any extension to the compound would prove difficult.

3.2 33kV Protection Schemes

There is currently no protection schemes applied at Quartley Switching Station with all network protection installed at the feeder remote ends. The protection applied to the remote end circuit breakers is distance protection.

4 FPL Installation

4.1 Electrical connection

In order to provide a suitable connection point at the substation for the FPL, a new switchboard will need to be installed, requiring the construction of a new switchhouse and removal of all existing equipment from within the compound area. Due to ability at Quartley to close two normal open points between different grid groups, the proposed switchboard will allow the FPL to be moved between the two. Figure 4-1 below shows the proposed Single Line Diagram for the FPL connection.

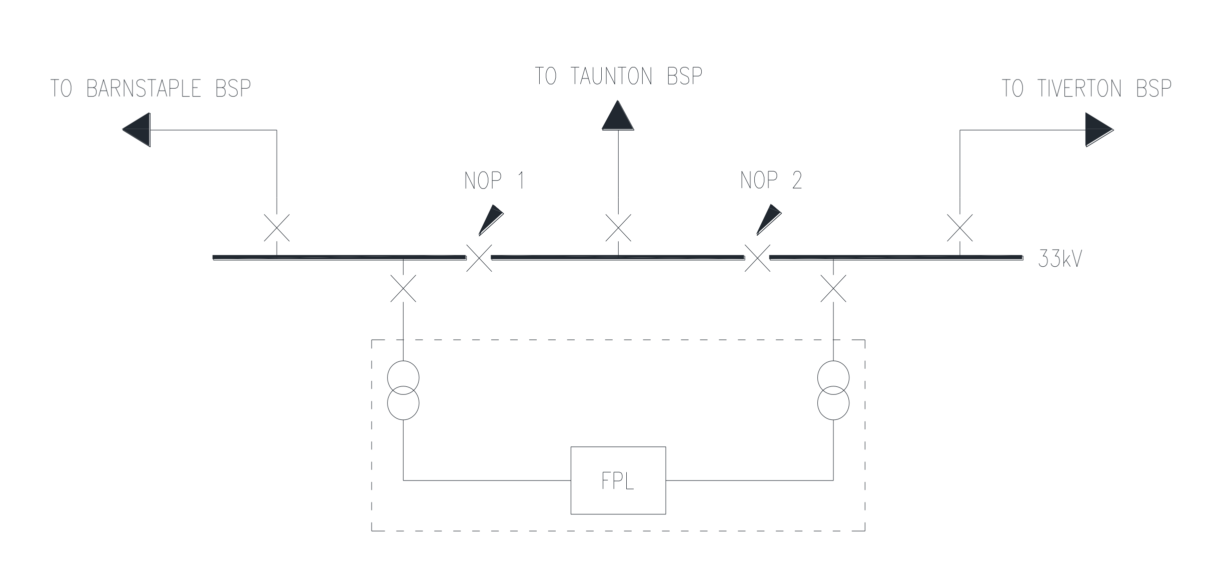

Figure 4-1: Proposed Quartley Single Line Diagram following the FPL Installation

The opening of circuit breaker 1 and the closure of circuit breaker 2 will allow the FPL to connect Taunton Main and Barnstaple BSPs. Under this configuration, if the FPL is taken out of service, the existing normal open point at South Molton must be reopened and circuit breaker 1 closed.

Conversely, by opening circuit breaker 2 and closing circuit breaker 1, Taunton Main and Tiverton BSPs can be connected together. If the FPL is taken out of service there is no requirement to revert the normal open point back to Tiverton Moorhayes.

4.2 Protection

The main protection on the three circuit breakers supplying overhead line feeders would be distance protection. Overcurrent and earth fault protection would be incorporated as back-up protection for the main protection scheme.

It is envisaged that the FPL circuit breakers would be protected using a combination of High Set Overcurrent (HSOC) with back-up overcurrent and earth fault protection schemes.

However, further discussions with the chosen FPL manufacturer would need to take place to determine the optimum protection scheme.

The new 33kV switchboard would come equipped with high impedance busbar protection as per WPD standards. The bus section breakers would be protected as per current WPD policy.

4.3 FPL Layout

The arrangement of the FPL is manufacturer specific, however, it is expected that the main components of the FPL will comprise:

- 40ft container housing the switching modules and control elements;
- Two step down transformers; and
- Coolers for the switching modules.

As described previously, the installation of the new 33kV switchboard and FPL will require all existing equipment within the 33kV compound to be removed. This will require the erection of new poles with cable sealing ends outside the site boundary.

Figure 4-2 below provides an overview of the substation layout following the FPL installation with the new 33kV switchhouse incorporated into the site boundary.

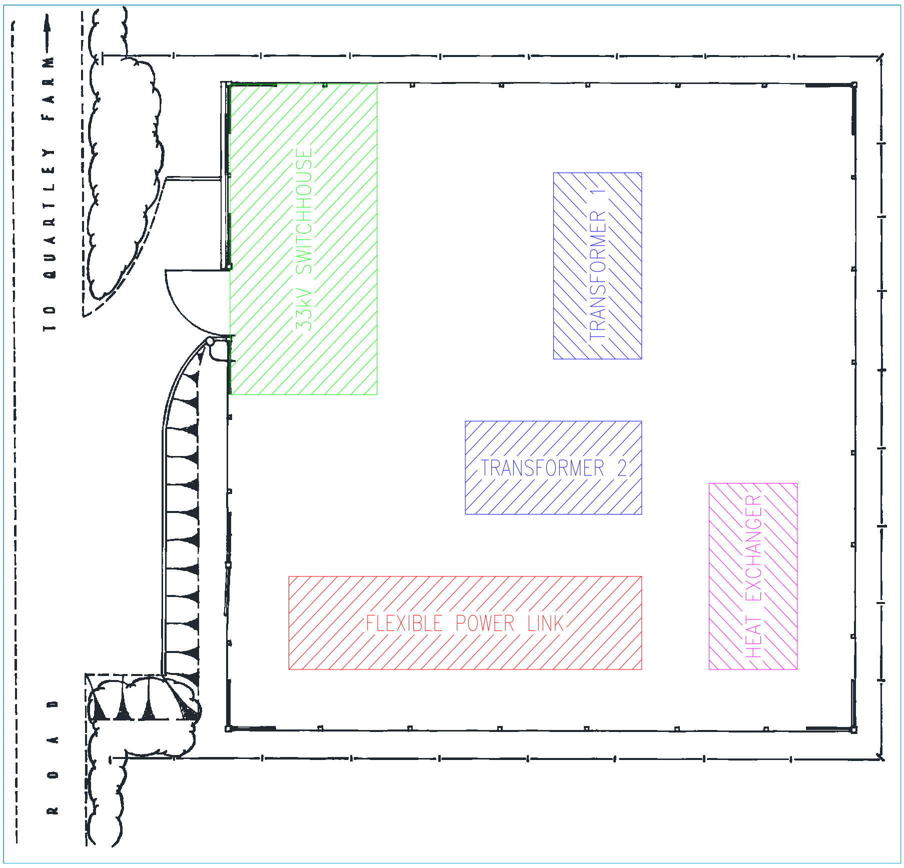

Figure 4-2: Proposed FPL and 33kV Switchhouse Layout at Quartley

4.4 Staging

The FPL installation works would need to be staged so that the existing substation remains operational throughout the works and minimise outage time. Firstly the 33kV switchroom will be constructed and cold commissioned, followed by the removal of each OHL pole and the transfer of each circuit to the new switchboard.

4.5 Delivery

The site is accessed from a narrow lane that is unsuitable for the size of vehicle it is expected will be required for delivery of the FPL. There are no other access restrictions currently identified on any proposed delivery routes.

5 Health and Safety

5.1 Overview

Safe operation and continuity of supply shall be the main considerations for WPD, nominated working parties and manufacturers involved with any works to install FPL equipment at Quartley. The *Health and Safety at Work Act 1974* and *Electricity at Work Regulations 1989* shall be fully implemented with a view to making the equipment safe to install, operate and maintain.

5.2 CDM

The works at Quartley will fall under the *Construction Design and Management Regulations 2015*. WPD will be the Principal Contractor during all phases of the works.

5.3 Risk Register

Table 5-1: Site specific risk register

Risk	Effect	Action
The access road and entrance are too small to deliver the equipment to the site.	Deliveries can't be made. If the crane can't be delivered it will be difficult to carry out some of the works.	Modify the road junctions to be more suitable. Acquire or rent land for laydown to enable crane to fit on site. Find an alternative method of lifting.
A trip occurs whilst connecting to the new switchgear.	Loss of supply to customers. Fines could be incurred.	Stage any replacement works such that if any trips occur, the out of service equipment can be quickly re energised.
A new protection scheme is used for the FPL that is untested at large scales.	Chance of failure or malfunction may be higher.	Test the protection scheme before installing. Have protection and monitoring of the protection equipment.
Underground obstructions encountered when laying the foundations.	Foundations become more expensive. Work is delayed.	Do a ground survey before carrying out the civil works. Ensure any underground utilities and obstructions are known before carrying out work. The layout needs to be changed depending on the ground conditions.
The 33kV line will still be live when constructing the new switchgear.	Electrocution could occur Restrictions will be in place on where work can be carried out on site.	Clearly define no go areas whilst work is underway. Ensure the site team has a health and safety briefing before starting work on site.
The overhead lines could obstruct the crane operation.	Overhead line could be damaged. Equipment could be damaged if dropped.	Only carry out crane work during clear visibility to help ensure that no accidents occur. Relocate the towers for the overhead line.