LV Engine

LVDC Trial Site

LVDC Protection Strategy Summary

1 Purpose

This document aims to summarise the protection arrangement that is currently in place at the new LV Engine substation which supplies a single 150kW EV charger at a ±475V DC. This is a unique installation providing an LVDC supply directly to customer fixed equipment.

There are more detailed studies and product reports/catalogues that can be available on request from the project team, nonetheless some of those supporting documents are included in the Appendix.

2 Introduction

At the LV Engine trial site, a 500kVA Unified Power Flow Controller (UPFC) which is capable of supplying both LVAC and LVDC has been deployed. The main purpose of this trial is to demonstrate the first UK DNO DC supply. A single DC-fed 150kW ultra rapid EV charger is supplied by the UPFC which is rated at 158kW continuous DC supply.

The UPFC is connected to an LVDC switchboard within the substation by three single core cables (a positive pole at +475V, a negative pole at -475V, and a mid-point 0V). A DC system mid-point can be considered equivalent to a neutral in an AC system. The complete schematic is shown in Figure 1 (for better quality see the Appendix) where points of isolation are also numbered in red.

The boundary between SPEN and the customer is the outgoing cable terminations of the LVDC switchboard located within substation. The LVDC cable and the EV charger are owned and operated by the customer.

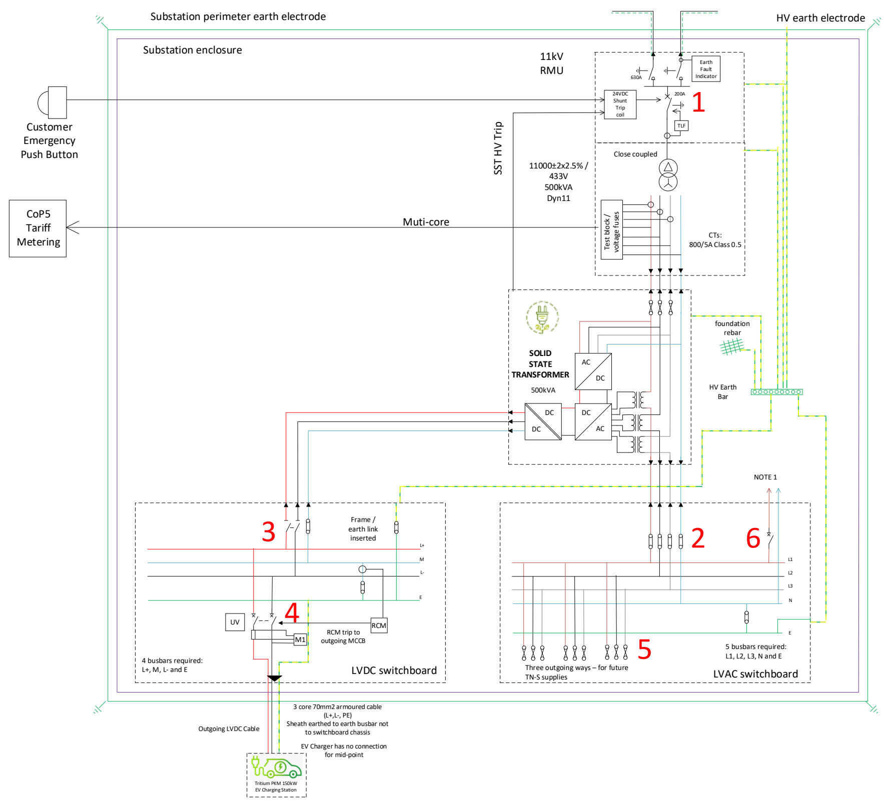


Figure 1 –substation schematic diagram

3 Protection Arrangement

Due to the use of power electronic based rectification, the UPFC DC output cannot provide sustained fault current in excess of its rating (158kW or 166A). Therefore, typical LV AC protection schemes based on overcurrent devices such as fuses or thermo-magnetic devices in moulded case circuit breakers (MCCBs) are not suitable for this application. However, the UPFC automatically switches off the DC supply if it experiences any current beyond its rating (see the appendix on UPFC DC fault management).

The customer's cable (EV charger) is connected to SPEN's LVDC switchboard where a DC MCCB[1] provides point of isolation between customer's cable and LVDC switchboard. The LVDC switchboard supplies the customer's EV charger by a three-core cable which carries the supply positive (+475V), negative (-475V) and earth. The EV charger does not have a mid-point connection, although the DC system mid-point is solidly bonded to earth in the substation.

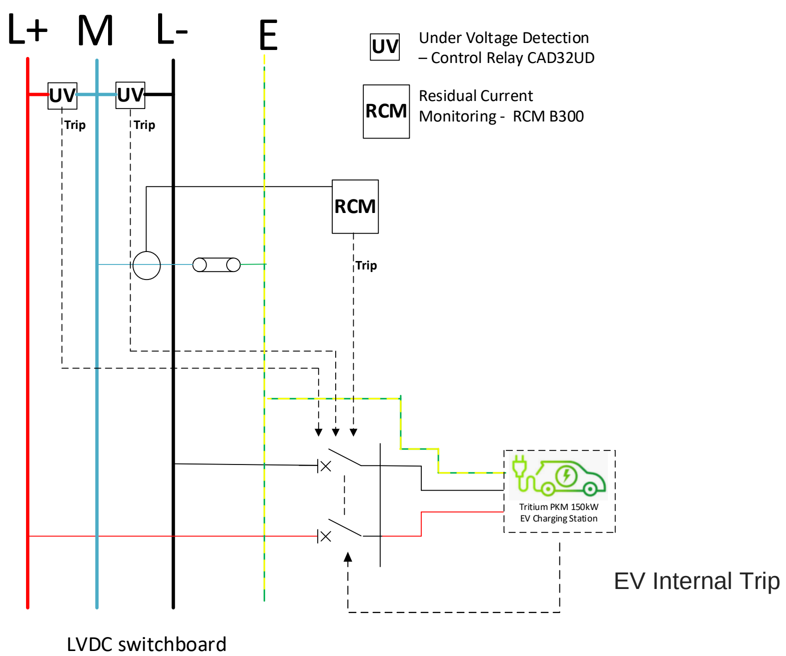
The MCCB is fitted with a shunt trip release that may triggered by one of the following conditions (shown diagrammatically in Figure 2):

- Undervoltage on the positive pole, triggered by a control relay in case of loss of voltage i.e. DC supply switches off

- Undervoltage on the negative pole, triggered by a control relay in case of loss of voltage i.e. DC supply switches off

- Earth current leakage detection by a Residual Current Monitor (RCM), in case there is any current flowing between the DC mid-point and Earth.

- An inter-trip issued by the EV charger based on their internal protection logic e.g. someone opens the EV charger door. Figure 3 shows the tripping arrangement within the DC charger.



[1] Moulded Case Circuit Breaker

Figure 2 – LVDC Switchboard protection arrangement

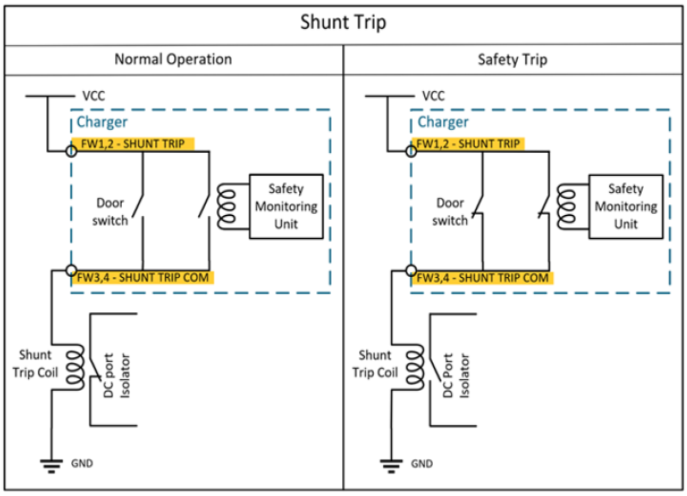


Figure 3 – Tripping arrangement within the EV charger

A summary of the protection strategy is as follows:

1- If any fault occurs between the UPFC LVDC terminals and the EV charger, the UPFC switches off in less than 1.0 ms if the fault current is greater than 166A or an imbalance load of more than 20A between the positive and negative pole is detected. This will result in an under-voltage on either the positive pole, the negative pole or both. This will be detected by one or both under-voltage release coils, which will trip the MCCB.

2- After a period of time (20s configurable), the UPFC will attempt to re-start and energise its DC terminals.

   a. If the UPFC sees a fault current greater than 166A or an imbalance load between the positive and negative pole of more than 20A, the fault is upstream of the MCCB, so the UPFC will send a trip signal to the 11kV Ring Main Unit's (RMU) shunt trip coil. This condition suggests that fault is within the substation hence the reason for isolating the supply to the 11kV/LV transformer and UPFC.

   b. If no current is seen during the UPFC DC restoration, then the DC will be ramped up to its nominal voltage (±475V), and the LVDC switchboard will be re-energised. As the MCCB is open (it requires manual intervention to re-close it), this would suggest that the fault is downstream of the LVDC switchboard i.e. on the customer's LVDC cable or EV charger.

3- In case of an earth fault for which the short circuit may not exceed 166A nominal current, the RCM back protection is in place to detect any current above 150mA in the mid-point to earth link in the LVDC switchboard. This results in sending a trip signal to the MCCB.

Figure 3 shows the time sequence of various events when any LVDC fault occurs between UPFC LVDC terminal and EV charger.

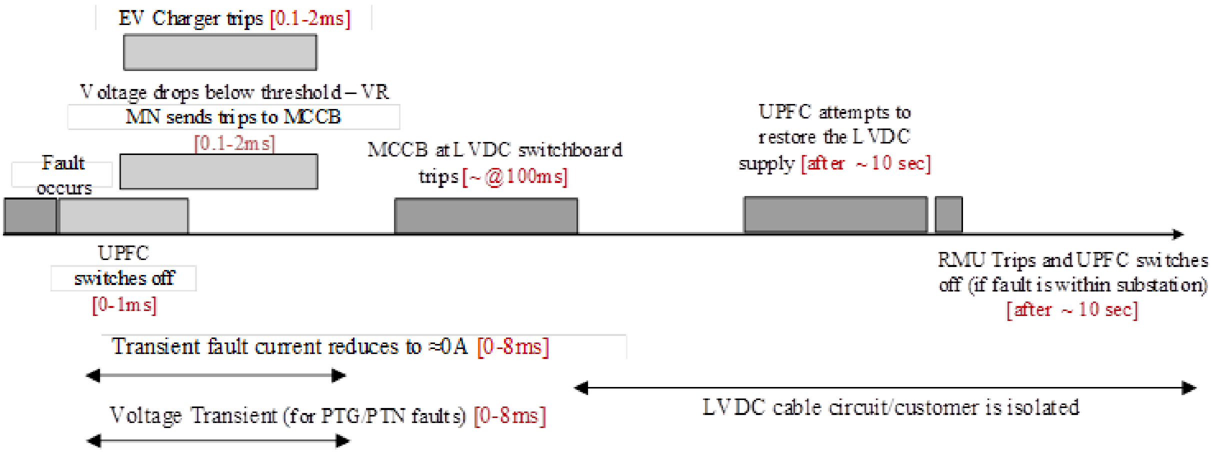


Figure 3 - Time sequence of various events from fault inception

4 Earthing arrangement

Following extensive consultations, a TN-S earthing arrangement was approved for the LVDC supply to the EV charger. For any future LVAC supply, the earthing arrangement shall be studied and consulted based on the nature of that AC supply. It should be noted that substation is a low earth potential rise (EPR) substation according to studies and site measurements.

The earth connection to the EV charger is provided by two circuit protective conductors (CPCs) from the substation:

1- One core of the 3-core cable is allocated as a CPC and connected to the earth bar in the substation at one end and to the earth terminal at the EV charger at the other end, Figure 4.
2- The armour of the 3-core cable is earthed at the substation end and also connected to the EV charger chassis from the other end, see Figure 5.

Figure 4 – CPC connection to earth terminal

Figure 5 - Cable armour earthed connection to the chassis

5 Site measurements

SPEN commissioned Electrical Investigation Ltd to carry out a site survey on the installation. The measurements collected from the site are summarised in the table below.

Measurement / Test	Test Result	Comment
Fall-of-potential (FOP) test at Tritium charger (earth disconnected)	1.31kΩ	This is the 'fortuitous' earth resistance of the foundation and bolts to earth, there is minimal contact through the foundation slab. If the CPC becomes disconnected this is the only return path for earth-fault at the Tritium charger.
Earth clamp meter test at Tritium charger (earth disconnected)	>1.5kΩ	This is at the limits of accuracy of the test clamp and confirms the local electrode contribution at the Tritium charger is a high resistance. The FOP test above shows 1.31kΩ is a more accurate value.
FOP at Tritium Charger (earth connected)	~0.3Ω	This is the approximate earth resistance of the charger with a dominant electrode contribution from the substation and HV network. The measurement is approximate as the traverse used was insufficient for an accurate reading of a large network; indicative only. This confirms that a low resistance connection to the network / substation has been achieved.
~~**Cable insulation test (carried out by SPEN); Tritium charger switched off and isolated.**~~ swzx	Earth to Grey 2.5MΩ Earth to Brown 2.5MΩ increasing Between cores (Grey to Brown) 3.5MΩ	Values measured by the SAP from the substation and noted by Jordan Electrical for inclusion on test certificate. CPC (black core with G/Y tape) and armour combined at substation. Armour cut (unterminated) at charger.
Cable continuity test (after correction for test lead resistance)	Earth to Brown 0.06Ω E to Grey 0.08Ω Grey to Brown 0.08Ω Armour to Black <0.3Ω	Short applied at substation end. Measured by Jordan Electrical at Tritium Charger
Voltage and polarity	Brown to chassis 475V Grey to chassis -476V Black to chassis: 0V (continuous – bolted) Black to armour: 0V (also continuous – connected at substation)	OK – no load
Earth fault loop impedance (EFLI)	Not measured – Jordan Electrical test equipment not rated for EFLI on 950V DC system. It can (in theory) be measured by loading the system and recording voltage drop, this will indicate the source impedance. A load test was not possible at time of visit, but is not strictly necessary, see comment.	The earth fault loop impedance (Zs) can be found by adding conductor resistances (both cores) to the external loop impedance Ze declared by SPEN. Zs is required on test certificates as it influences protection operation time / calculations for conventional systems. It is NOT directly relevant to a DC rectifier output when this provides a current limit, since effectively the Ze value will increase / voltage will collapse at the moment of the fault. Protection tests carried out by SPEN will be more relevant to demonstrate satisfactory fault clearance times. It is acceptable to omit Zs in this case, for reasons given above.

6 Commissioning tests

The following tests carried out on site confirm all the tripping signals to the outgoing MCCB.

Trip test	Description	Result
Undervoltage trip	Step 1 - EV charger was energised, and DC was in normal operating condition. Step 2 - DC switched off manually through the UPFC HMI	MCCB tripped. LVDC MCCB trip LED turned RED on display panel
RCM trip	Step 1 - EV charger was energised, and DC was in normal operating condition Step 2 - The RCM was simulated by disconnecting the 24V supply from the RCM, this bring the leakage normally open contact to close. This same situation occurs if a leakage is detected.	MCCB tripped. LVDC MCCB trip LED turned RED on substation display panel. Leakage Alarm and Warning LEDs turned RED on substation display panel.
EV charger trip	Step 1 - EV charger was energised, and DC was in normal operating condition. Step 2 - EV charger door was opened by Tritium staff	MCCB tripped

7 Risk assessment

Scenario	Result	Possible Consequence	Likelihood of injury
Cable damage – primary protection	Overcurrent will exceed DC output from the UPFC causing voltage collapse.	UPFC output electronically switched, undervoltage relay triggered, MCCB open	Low – fault cleared in ~ 0.1 seconds
Cable damage – secondary protection	Earth fault current will flow.	RCM detects any earth current above 150mA and trips MCCB, this is backed up with any imbalance current above 20 A that results in loss of DC supply and MCCB trip	Low – fault cleared in ~ 0.1 seconds
Failure of UPFC to detect a short-circuit	Following a fault, the DC rectifier does not switch off even when it is overloaded. This may be due to significant internal cascading failures within the UPFC. . It should be noted that this scenario means several control and hardware protection failures would need to coincide. See Appendix 1 : DC Fault Management for UPFC	Residual Current Monitoring will detect the fault current instead as a back-up protection and trips the MCCB.	Low – fault cleared in ~ 0.1 seconds
Severed CPC and cable armour	Broken CPC and cable armour can leave the charger unearthed.	If three fault conditions occur concurrently there would be an earth potential rise on the EV charger. These three conditions would be: CPC severed, cable armour severed and pole to earth fault at the charger. This would be an extremely unlikely scenario. For a bolted fault at the EV charger the earth current that would be in the order of 475V/1.31kΩ=365mA. This earth fault current would flow through the soil in between the EV charger and the substation. This would trigger the earth leakage protection on the RCM at the	Low

		substation. More saturated soil conditions would cause higher current flows and a higher probability that the RCM would trip. If the soil were drier leading to higher soil resistivity the touch voltage at the EV charger would be low enough not to cause concern.	

Appendix– Additional documents

Name of document	Source
LVDC Switchboard Schematic	PDF Adobe Acrobat Document
EVCP SLD	PDF Falkirk Electric Schematic Diagram.¦
DC charger user manual	PDF TRI155.INS.1797_PK M150CS User Unit Ir
UPFC DC fault management	PDF DC Fault Management for UP

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