DC Share

Final System Design Report

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1. Executive Summary

This report details the activities undertaken to progress the complete DC Share system design in readiness for procurement, manufacture and factory test. The activities detailed herein have essentially taken place since completion of the site selection process and during the time period March – December 2020.

As defined within the Full Submission Pro forma (FSP), the contents of this report shall cover the following subjects:

- Full description and specification of the trial installation
- Final system design and product specification *,
- System Functional Definition Document *,
- Detailed status of developments of hardware and software

And shall include all the main equipment “building blocks” for the complete DC Share project, summarised as being:

- Grid Tied Inverters (GTI)
- Electric Vehicle Charing Point (EVCP)
- Main Supervisory Controller
- Communications Network
- AC measurement System
- AC and DC Cabling
- DC Metering
- DC Isolation Devices

For all the above equipment, the designs have developed and concluded to the extent that procurement can proceed, and for the long-lead equipment items, this has already occurred.

During the next project period (essentially all of 2021), the remaining equipment components and systems will be procured, permitting the individual equipment builds to proceed and be factory tested, culminating in an “Integrated Factory Acceptance Test (FAT)”.

Upon successful conclusion of this Integrated FAT the entire design process can be considered closed and this shall be subject of the next Deliverable Report to Ofgem, due 18th December 2021.

* Note that these two items referenced within the FSP are combined into a single chapter within this report

2. Abbreviations

Full Wording	**Abbreviation**
Alternating Current	AC
Build of Materials	BOM
Business as Usual	BaU
Charge Point Operator	CPO
Design for Manufacture and Assembly	DFMA
Direct Current	DC
Distribution Network Operator	DNO
Dual Second Order Generalised Integrator Phase-Locked Loop	DSOGI-PLL
Electric Vehicle	EV
Electric Vehicle Charging Point	EVCP
Electricity North West	ENW
Full Submission Pro forma	FSP
Generic Object Oriented Substation Event	GOOSE
Grid Tied Inverter	GTI
Local Authority	LA
Low Voltage	LV
Mean Time Before Failure	MTBF
Mean Time To Repair	MTTR
Metal–Oxide–Semiconductor Field-Effect Transistor	MOSFET
National Innovation Competition	NIC
Of The Shelf	OTS
REpresentational State Transfer Application Programming Interface	RESTful API
Piecewise Linear Electrical Circuit Simulation	PLECS
Power Quality	PQ
Ricardo Energy & Environment	REE
Silicone Insulated-Gate Bipolar Transistor	Si IGBTs
Silicon Carbide Metal–Oxide–Semiconductor Field-Effect Transistor	SiC MOSFET
Soft Open Point	SOP
Silicon Carbide	SiC
Somerset West and Taunton Local Authority	SWT LA
Turbo Power Systems	TPS
Western Power Distribution	WPD

3. Brief Project Overview

DC Share is an innovation project funded by Ofgem's Network Innovation Competition (NIC), led by Ricardo Energy & Environment (REE) on behalf of Western Power Distribution (WPD). Electricity North West (ENW), Turbo Power Systems (TPS) and Vectos are project partners.

The aim of DC Share is to demonstrate an alternative method to traditional Alternating Current (AC) reinforcement for the provision of significant amounts of power to Electric Vehicle (EV) rapid charging hubs in urban locations. A Direct Current (DC) ring will be installed between four AC secondary substations to which three EV rapid charging hubs will be connected. The DC ring will allow the distribution of power between different AC substations and from AC substations to the DC rapid chargers. By sharing the rapid charging demand between AC substations with different load profiles, rapid charging hubs can be delivered without traditional reinforcement of the network. This will allow for rapid EV charging facilities to be developed in urban areas in a cost-effective manner and where there may be space constraints for additional AC substations. Additionally, this will provide equalisation between the existing AC substations leading to better utilisation of the capacity of existing assets leading to reduced costs (calculated to be 1,800MVA of capacity released up to 2050) and carbon emissions (calculated to be 26,000 tCO_2e of direct savings up to 2050).

DC Share will develop and trial a DC network to give a versatile and flexible solution for rapid EV charging using network equalisation. The system comprises four principal components:

1. Bi-directional power electronic converters connected between the 415 V AC network and ±800-900V DC distribution cable network;
2. A DC cable network with remote control sectionalising switches and connection hubs at strategic points;
3. A monitoring and control system to operate the charging and equalisation system, prioritising charge speeds and equalising the local distribution network;
4. Rapid EV charging equipment comprising DC hubs with smart chargers to enable managed utilisation of each DC hub whilst the cars are connected.

The project will be undertaken in Taunton town centre and Somerset West and Taunton Local Authority (SWT LA) are firmly engaged with the project team to assist project delivery.

We have secured the support and services of a reputable Charge Point Operator (CPO), namely Swarco, who are assisting the project team with the Electric Vehicle Charging Point (EVCP) design and will participate during the trial period to ensure data is captured and available for reporting purposes. Ultimately upon successful project closure, Swarco may benefit from assuming ownership of the EVCP's, subject to appropriate commercial considerations being reached between Swarco and SWT LA.

4. Description & Specification of the Trial Installation

4.1 DC Ring & Site Selection Design Update

Since issue of the Site Selection Report, the design of the DC Share network has had to be revised mainly due to SWT LA's revised requirements, summarised below. These revisions do, however, provide benefits over the initial design mainly in that a cabled river crossing is now no-longer required (and hence a significant project risk is removed) and the EVCP can now be situated across a greater number of SWT LA car parks, facilitating greater coverage and usage.

- SWT LA has now advised that the Firepool development will straddle both sides of the River Tone and their preference is now to provide EVCP on the Firepool development located on the southern side of the River Tone. This has removed the need for a river crossing and also has meant the substation we originally planned to use north of the river (Canal Street SStn) is now inappropriate due to its location.
- SWT LA has advised that only three (3) EVCP bays are available at Coal Orchard car park. Given that only 6 or 7 EVCP bays are available at Firepool car park we needed to incorporate a further SWT LA car park into the design to maintain 15 rapid EVCP positions. After discussion with SWT LA they have requested we integrate Canon Street car park, permitting greater coverage of rapid EVCP across the town centre. Each car park shall be connected to a different "quadrant" of the DC ring to reduce the possibility of overloading.

Since issue of the Site Selection Report, the Covid-19 travel restrictions gradually lifted enabling the project team to re-visit Taunton and undertake further detailed site surveys, enabling us to assess suitability of a wider choice of substations, especially important now that the DC ring is required to route a different way through Taunton due to the change in SWT LA car park locations.

The final agreed DC ring design, including choice of substations, SWT LA car parks, space availability for EVCP and the split of rapid charging types between car parks is therefore as shown within Appendix A.1.

In summary, the substations that will now be used to house the Grid Tied Inverter (GTI) equipment are:

- St Augustine Street,
- Eastgate Gardens,
- Hammet Street
- Works

and the three SWT LA car parks within which the EVCP will be located are:

- Coal Orchard
- Firepool
- Canon Street

In addition to the above we shall locate the main control point and its associated operator interface at Coal Orchard substation, which is a newly built substation contained within the Coal Orchard development. The Operator control point associated with the separate Lucy Gridkey system, required to extract the necessary substation AC measurement data, shall also be located here.

5. Final System Design, Functionality and Product Specification

5.1 DC Ring Basic Building Blocks

The following lists the main building blocks for the system and defines the Party responsible for their design and implementation. Each is then taken in turn and described in greater details within the following sections.

- Grid Tied Inverters (TPS)
- Electric Vehicle Charing Point (TPS)
- Main Supervisory Controller (Ricardo)
- Communications Network (Ricardo)
- AC measurement System (WPD)
- AC and DC Cabling (WPD)
- DC Metering (Ricardo)
- DC Isolation Devices (Ricardo)

The system architecture drawing summarising how the respective components are interconnected is as shown below in Figure 1.

Although each building bock is contractually assigned to a specified Party, the entire DC Share project team works seamlessly in order to identify, discuss and agree technical issues that either require team agreement and/or team integration and collaboration.

Technical conference calls are convened on a weekly basis to involve all Parties and, when necessary, specialists from within each respective Party are invited to participate in order to ensure correct and adequate coverage is given to any specific technical issue. The system architecture drawing summarising how the respective components are interconnected is as shown below in Figure 1. In terms of overall architecture, a Supervisory Controller will reside at a WPD substation and interface with two WANs that provide access to the data and equipment required by the Supervisory Controller to deliver its DC Share power network management function.

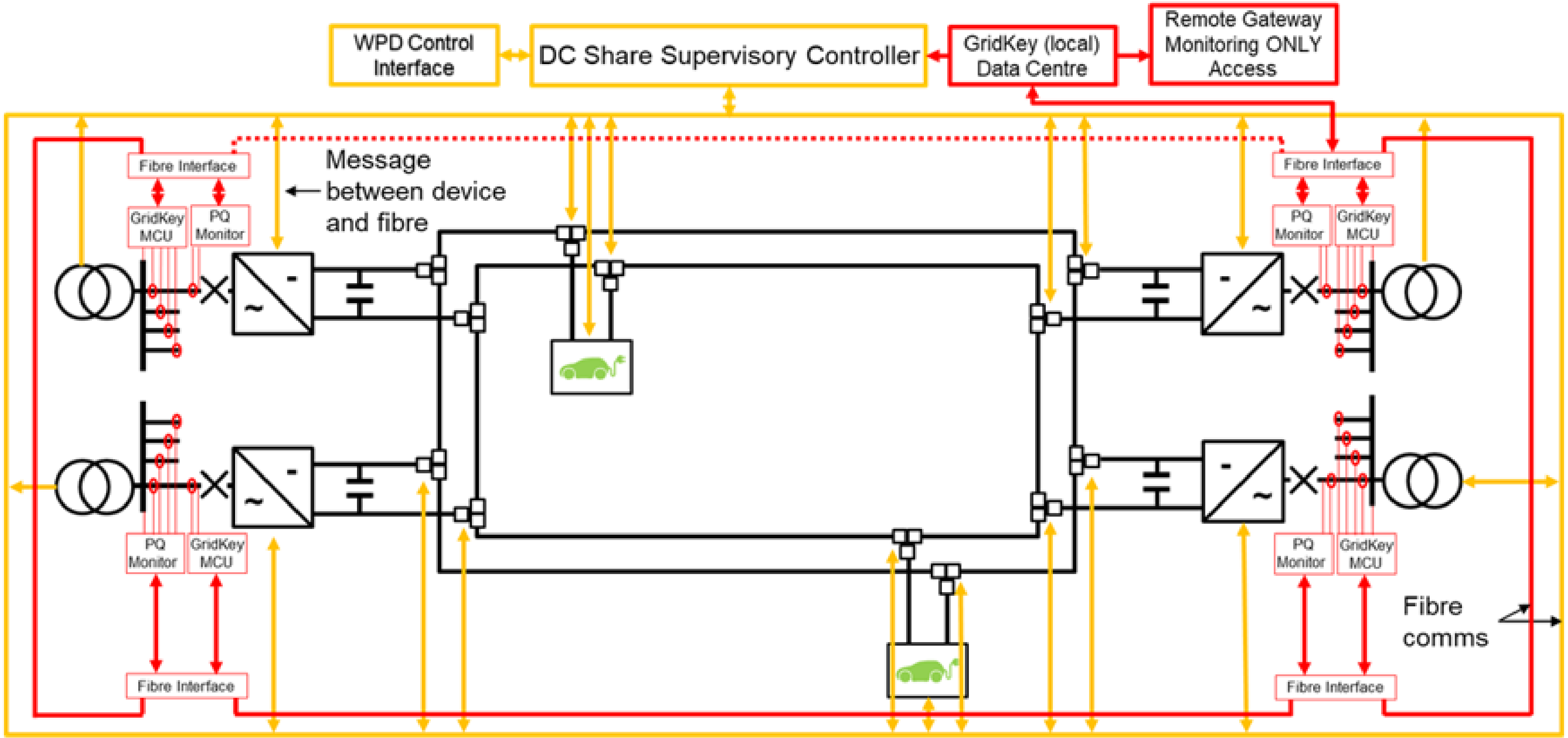
These two WAN's will operate as follows. Further details are provided in Section 5.

1) <u>DC Data</u>: Each GTI and the EVCP will be equipped with HSR nodes and all GTIs, EVCPs, and the Supervisory Controller will be linked in to a single HSR ring in accordance with the IEC standards 62439 3. The Supervisory Controller will be designed to interchange data with the GTIs and EVCPs via dedicated fibres in the HSR ring in accordance with IEC 61850 communications protocol.

2) <u>AC Data</u>: WPD will provide an AC Measurement System based on Lucy Gridkey Equipment, which shall link to a Local Control Centre via dedicated fibres using standard Ethernet IP.

Each of the individual components is described in more detail in section five of this report.

Figure 1: System Architecture Drawing (Overview)



5.2 System Protection

Naturally the subject of protection and how to design and provide suitable schemes to properly protect the DC Share equipment, WPD's existing assets as well as people has been central to many workshops and the following summarises the finalised solution.

To understand the rationale, we first need to understand the background and protection related design concepts for the main GTI equipment.

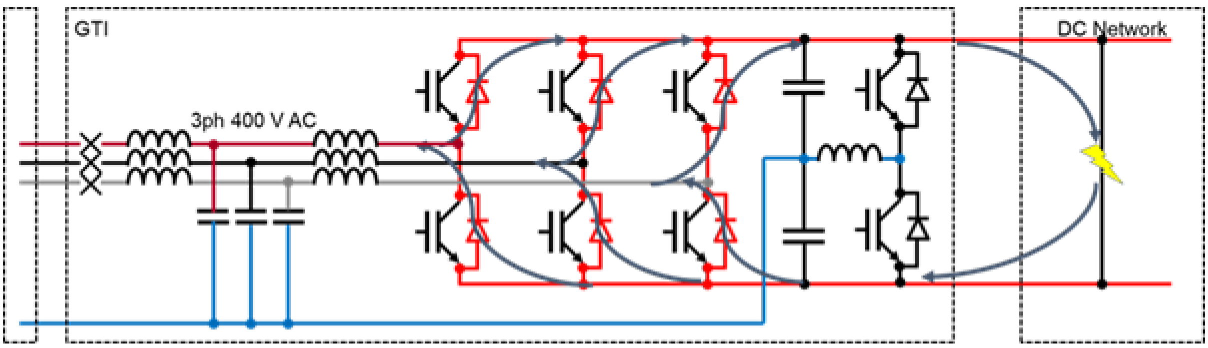
For DC Share, the GTI's are a product development from the "Soft Open Point" (SOP) equipment developed by TPS for the FUN-LV and Active Response innovation projects. This technology, although not developed by TPS, has also been used in WPD's Network Equilibrium project.

These SOP's are back-to-back power electronic converters, converting from AC to DC and back to AC all within an integrated cubicle. Through this conversion process, the control of power flow from one AC port to the other AC port is enabled.

The AC to DC conversions utilises either Si IGBTs (Silicone Insulated-Gate Bipolar Transistor) or SiC MOSFET (Silicone Carbide Metal–Oxide–Semiconductor Field-Effect Transistor) technology in a full bridge configuration. In these circuits, as shown in Figure 2, each IGBT (Insulated-Gate Bipolar Transistor) or MOSFET have reverse voltage diodes in parallel with the IGBT or MOSFET to provide a path for peak inductive load current (out of phase with the voltage) when the IGBT or MOSFET is switched off (not-conducting). Not including this component would cause the IGBT or MOSFET to fail when the current is out of phase with the voltage (inductive load).

The addition of the reverse diodes prevent an interruption of the current from an inductive load causing a voltage spike which could exceed the blocking capability of the IGBT or MOSFET or exceed the insulation level of the cable or converter components. They are necessary components to ensure the correct operation of the power electronic converter. The reverse diodes will conduct current from the AC side to the DC side when the voltage on the AC side is higher than the voltage on the DC side. The reverse diodes will not conduct current from the DC side to the AC side when the DC voltage is higher than the AC voltage. For protection this means that a DC fault will cause fault current to flow from the AC side to the DC side but an AC fault will not cause current to flow from the DC side to the AC side.

Figure 2: Fault current path in the GTI



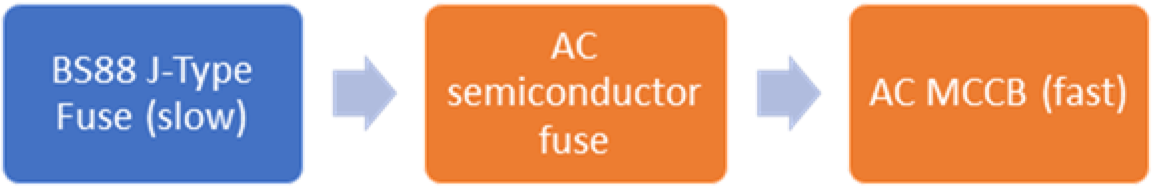
In the Soft Open Point (SOP) back-to-back converters, the DC bus is internal to these devices, very short and protected by the mechanical structure of the device. The risk of a DC fault is low so therefore no DC protection scheme was required and a circuit breaker on the input AC side can provide protection for the SOP device and the input AC circuit breaker is simply graded with the upstream AC protection.

However, for the DC Share project, the GTI's being developed are formed from only one half of a back-to-back SOP converter (eg only AC to DC) as described above and, as an extensive DC cabled ring is deployed linking the substations together, DC cable faults are possible and hence a suitable protection scheme needs to be designed accordingly.

A design decision at the beginning of the project was made to disconnect all GTIs from the network when a fault on the DC network is detected. This removed the requirement to install extra DC protection. A novel telecommunications-based protection scheme is being trialled by the project to facilitate this automatic/global disconnection. The GTIs will measure the DC current and DC voltage and, upon detection of a fault, the GTI will disconnect itself and broadcast an IEC61850 Generic Object Oriented Substation Event (GOOSE) message to the other GTIs to disconnect the DC Share Network. However, communication-based protection is not fail-safe, and it is therefore backed-up by a three-stage protection scheme as described below.

Each GTI will have an internal high speed semiconductor AC fuse and a MCCB using an electronic trip unit. A BS 88 J-type fuse will be used for the circuit feeding the GTI from the LVAC board as shown in Figure 3.

Figure 3: GTI Protection Scheme Design, Blue is WPDs Protection and Orange is the Protection Internal to the GTI



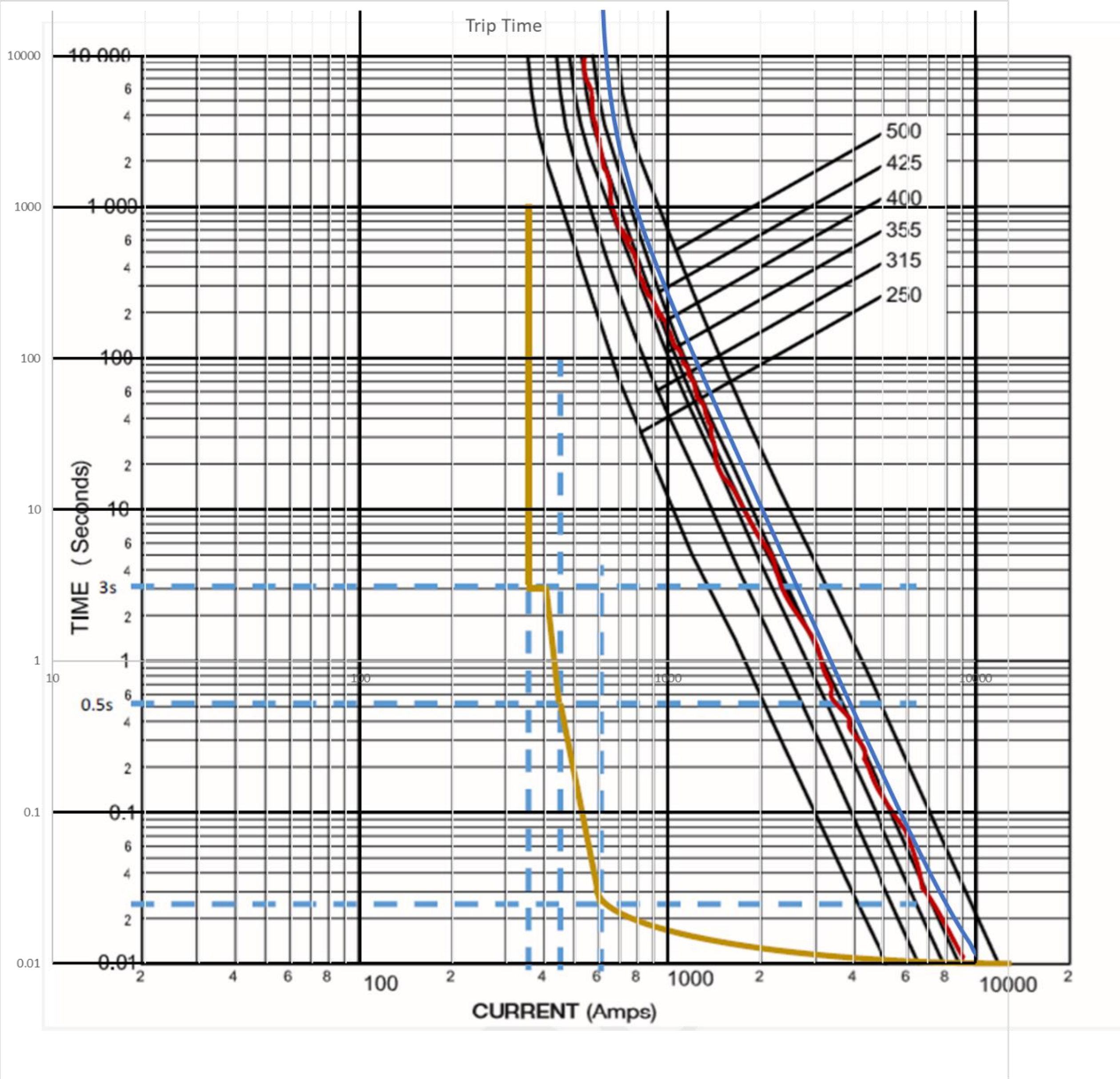
The discrimination between the BS 88 J-type fuse, the AC semiconductor fuse and the MCCB is shown in Figure 4. The graphs show that the MCCB should operate for the expected GTI or DC fault current. If the MCCB fails, it is backed up by the high-speed AC semiconductor fuse. The discrimination between the high-speed AC semiconductor fuse and the BS-88 type fuse is narrow and there is a risk the BS 88 J-type fuse also operates if the AC MCCB fails to operate. However, as no customers will be connected on the circuit between the LV board and the GTI then, should the fuse operate on the LV board, there will not be any impact to WPDs AC connected customers.

The operation time of this protection, the worst case fault current and I2t ratings were calculated. Understanding the worst case fault current and I2t values allowed a suitably rated DC cable to be specified and procured.

To undertake these fault current studies we have used the Piecewise Linear Electrical Circuit Simulation (PLEC) software platform to create a model of the DC Share network, using data and ratings for all equipment and distances between the equipment locations, upon which the simulations can be run.

The results from running the simulation software are provided within Appendix A.7.

Figure 4: GTI Protection Coordination. Red is the AC Semiconductor Fuse and Placed on Top are the Trip Characteristics from the MCCB (yellow) and BS 88 J-Type Fuse (blue).



5.3 Grid Tied Inverters

The GTI device will be installed indoor within a secondary substation. The LV networks of four neighbouring substations will be connected via a new DC network. The DC network will be formed by a DC cable creating a ring main between the four substations.

The purpose of the four connected GTI's is to act as a Soft Open Point (SOP) between four adjacent low voltage substations. The GTI's will facilitate a controlled transfer of power between the substations bringing flexibility to the low voltage network and improving the utilisation of the existing infrastructure; at the same time making DC power available via the DC ring-main for fifteen electric vehicle rapid chargers.

The GTI's use the new Silicon Carbide (SiC) semiconductor devices that have very low losses at high frequency. High frequency operation results in low audible noise with potential reduction in LCL filter component size. The inverters are designed to be able to import or export power from each GTI terminal via the common DC link. This will allow the GTI's to perform the required functions:

- Real power transfer between substations and to the rapid EV Chargers.
- Reactive power support if required.
- Voltage support.
- Power factor correction and improvement.
- Phase imbalance improvement.
- Loss reduction.
- Harmonic content improvement (Difficult to detect due to low impedance at the GTIs terminals)
- Fault ride through.
- Creation of a controlled DC micro network.

The GTI is arranged as two conjoined cabinets: the first housing the Grid Tied Inverter and the second a neutral leg converter to facilitate imbalanced grid side operation. The power electronics components are force air cooled with usage high reliability fans. The lifetime of fan is higher than 30khrs, but thanks to changeable speed the lifetime is higher than nominal. The system is made up from three "phase leg" modules plus one "neutral leg" module.

GTIs allow import/export of balance/unbalanced active and reactive power and 3rd, 5th, and 7th harmonic compensation. The GTI modes of operation can be split into two main areas: DC microgrid voltage control and AC grid support.

5.3.1 DC Microgrid Voltage Control

The DC Microgrid voltage control consists of three modes: DC Link Control, Droop Control and Constant Power Control.

5.3.1.1 DC Link Control Mode

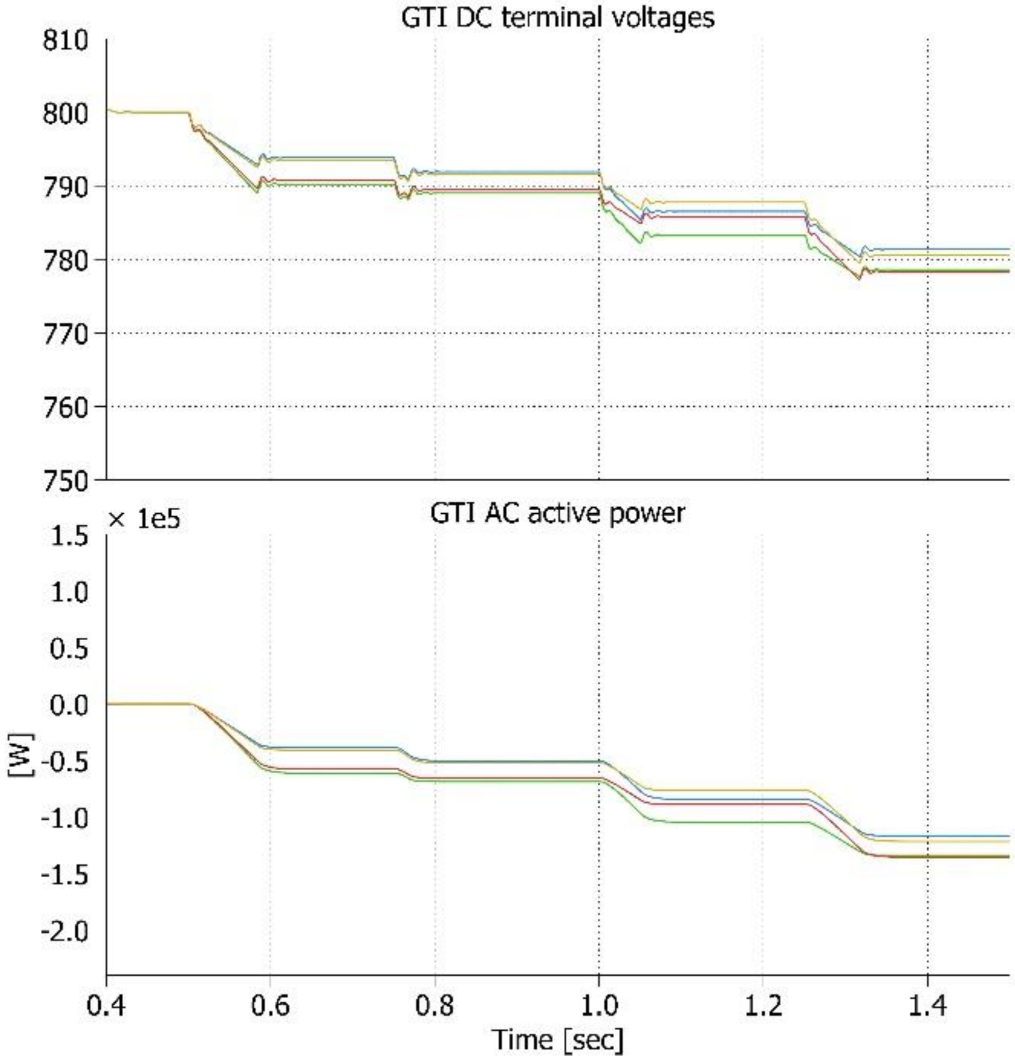
DC link control mode will be used only during system start-up. One of the four GTI's will be responsible for DC link voltage control. The DC microgrid is initially pre-charged by external circuits to approx. 550-650V. Once the DC microgrid is pre-charged, the GTI [in DC link control mode] Moulded Case Circuit Breaker (MCCB) is closed. The GTI metal–oxide–semiconductor field-effect transistor (MOSFET) remain disabled and the dual second order generalised integrator phase-locked loop (DSOGI-PLL) is synchronized to AC grid. Once synchronized, GTI MOSFETs can be enabled. The microgrid voltage is ramped up to 800V. Once DC link voltage is established, the remaining GTIs can connect to adjacent AC grids. After initial start-up, all GTIs will work in one of the below two remaining modes.

5.3.1.2 Droop Control Mode

In droop control mode, active power reference is calculated by local droop controller, based on DC link voltage measurement. The droop control characteristic can be optimized using measurement from remaining GTIs or by supervisory controller. Figure 2 shows the GTIs DC terminal voltages and AC active powers while all four GTIs sharing DC ring load in the droop control mode.

In droop control mode, the overloaded transformer can be supported by flattening the droop characteristic. The droop control will be limited to power import from AC grid to DC microgrid. In case that one of the transformers needs to be further supported (power export from DC ring to AC grid) also the constant power mode can be used.

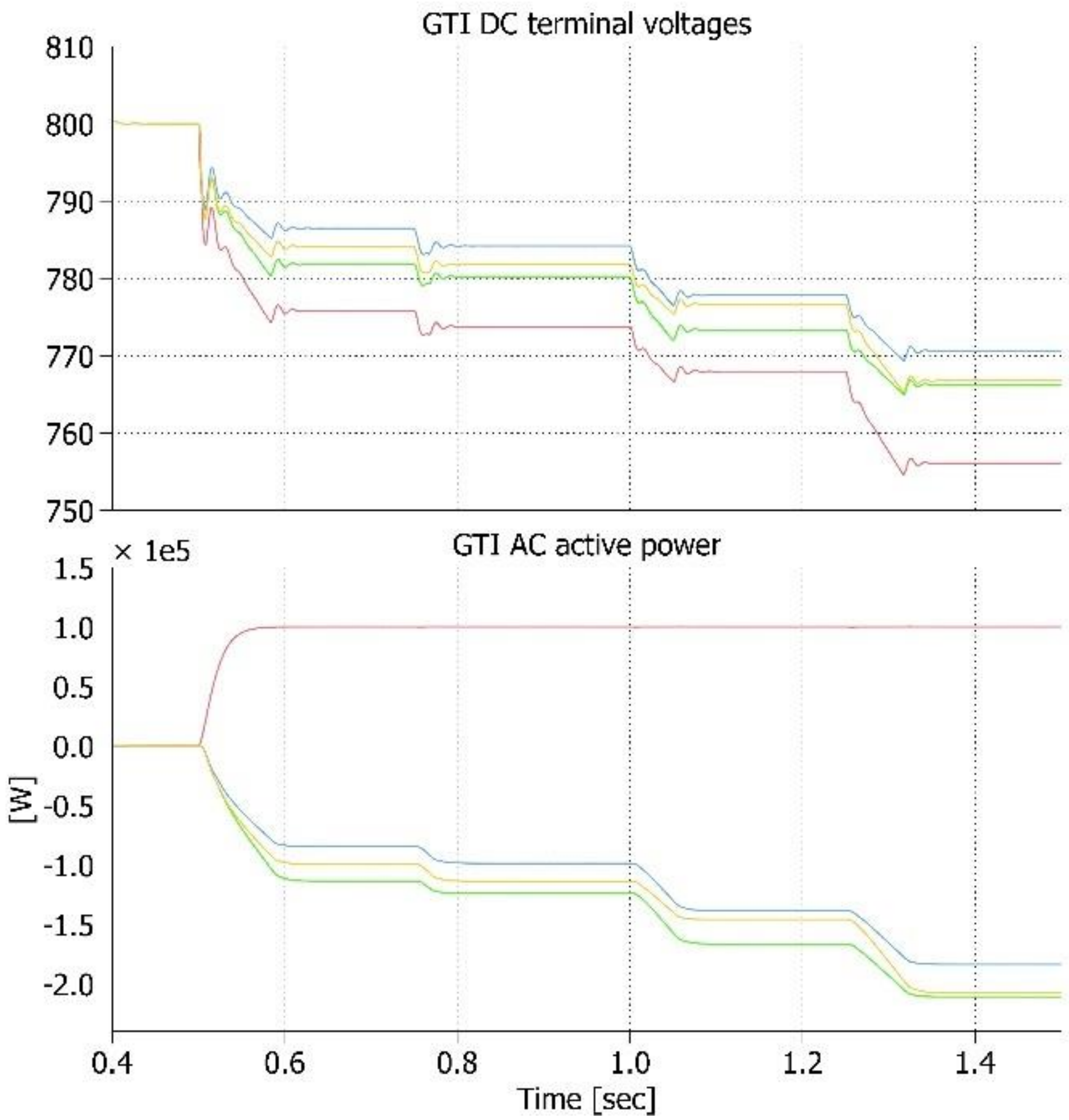
Figure 2: All four GTIs working in the DC ring droop control mode



5.3.1.3 Constant Power Mode (Follow Set-Point Mode)

This mode is allocated for active power AC grid support. In constant power mode (or follow set-point mode), active power reference is provided by supervisory controller rather than calculated by droop controller. Number of GTIs in constant power mode would be limited to maintain stability of the DC network, hence remaining GTIs will stay in droop control mode. Figure 3 shows GTIs DC terminal voltages and AC active powers while three GTIs working in DC ring droop control mode and one (GTI B) in constant power mode. DC ring load conditions are same to example shown in Figure 2, where all four GTIs are in droop mode.

Figure 3. Three GTIs working in the DC ring droop control mode and one (GTI B) in constant power mode



5.3.2 AC Grid Support

As GTI allows import/export of balance/unbalanced active and reactive power different modes of operation can be implemented (Power Factor correction, Loss reduction, Voltage support, Overloaded transformer support etc.). Below sections describe how active and reactive power flow is controlled. Phase imbalance improvement and harmonic compensation are described separately.

5.3.2.1 Active Power Flow Control

The active power AC grid import/export is controlled by one of the above DC Ring voltage control modes.

In droop control mode for example, the overloaded transformer can be supported by changing slope of the droop characteristic. The droop control is however limited to active power import from AC grid to DC microgrid. Thus, if active power needs to be exported from DC microgrid to the AC grid, the constant power mode can be used. In constant power mode (or follow set-point mode), active power reference is provided by supervisory controller rather than calculated by droop controller. Number of GTIs in constant power mode needs to be limited to maintain stability of the DC network.

5.3.2.2 Reactive Power Flow Control

The reactive power is controlled independently from active power. By controlling reactive power, the GTI can improve the Power Factor of the AC feeder or transformer. The GTI can inject or absorb reactive power to compensate any inductive or capacitive load. Power Factor support only needs to operate, when there is enough active power flowing in the cable. Feeders with low loads may have a low power factor but do not need compensating.

The reactive power can also be used to maintain GTI's terminal voltage within mandatory limits.

By default, reactive power reference is set to zero, thus no reactive power flow between GTI and AC grid. The reactive power is directly controlled by supervisor controller.

5.3.2.3 Phase Imbalance Improvement

The PED reduces the phase imbalance of the AC feeder or transformer. In the past it was trialled using the voltage at the terminal of the GTI to detect the unbalance in the feeder. The thought was that any unbalanced load would cause an unbalanced voltage that could be detected by the GTI. This method had limited effect to reduce the imbalance. Therefore, we now propose to measure the power for each phase at the distribution substation. The PED would then export an unbalanced power to compensate the unbalanced loads connected to the feeder.

In droop control mode, the unbalanced power will be added to balanced part (per phase) calculated by droop controller. Depends on unbalanced power direction, the balanced power may be increased/decreased to provide total power required by DC microgrid (droop controller). In constant power mode, the GTI will simply follow supervisor active power demand.

The reactive power required for phase imbalance improvement is independent on active power reference and GTI will follow supervisor reactive power demand.

5.3.2.4 Harmonic Improvement

The GTI can reduce the harmonic current in the feeder or transformer by injecting an anti-phase harmonic current.

NOTE harmonic improvement will be difficult to detect and control based on GTI terminal voltage due to low input impedance from being close to the transformer.

5.3.3 Faults, Trips, and Lockouts

The DSP control card will provide the following functions for the processing of any defined fault:

- A fault flag.
- A fault counter.
- A decrement timer.
- A lockout flag.

Fault information will be stored in non-volatile memory, so that fault counter and flags are not lost in case of loss of mains.

When a fault occurs the fault flag is set and the fault counter will be incremented by 1.

A fault flag will usually cause the state machine to enter the tripped state. Current and voltage measurements are performed continuously to determine a “healthy state” and indicate that a fault is cleared following a “fault state”. When a fault is cleared, the state machine will exit the fault state and the decrement timer will be started.

When the decrement timer reaches a configurable time limit the fault counter will be decremented by 1. The decrement timer will be restarted and will continue to operate until the fault counter has reached 0. The GTI will continue its normal operation as before the fault.

Should the fault counter exceed a configurable limit, then a lockout flag is set.

A lockout flag will cause the state machine to enter the Locked-Out state and open MCCB. Only a reset command will allow exit from this state to a normal operating state. A reset command can be performed locally or remotely. If a Lock-out can be identified as been caused by a PED internal failure (e.g. Component Failure) the reset shall only be allowed locally. This would normally be after an on-site inspection to identify and rectify the fault.

Detailed table with all software protection is given in Appendix A.2.

5.3.4 Mechanical Arrangement

The GTI is a modular design comprising of two enclosures:

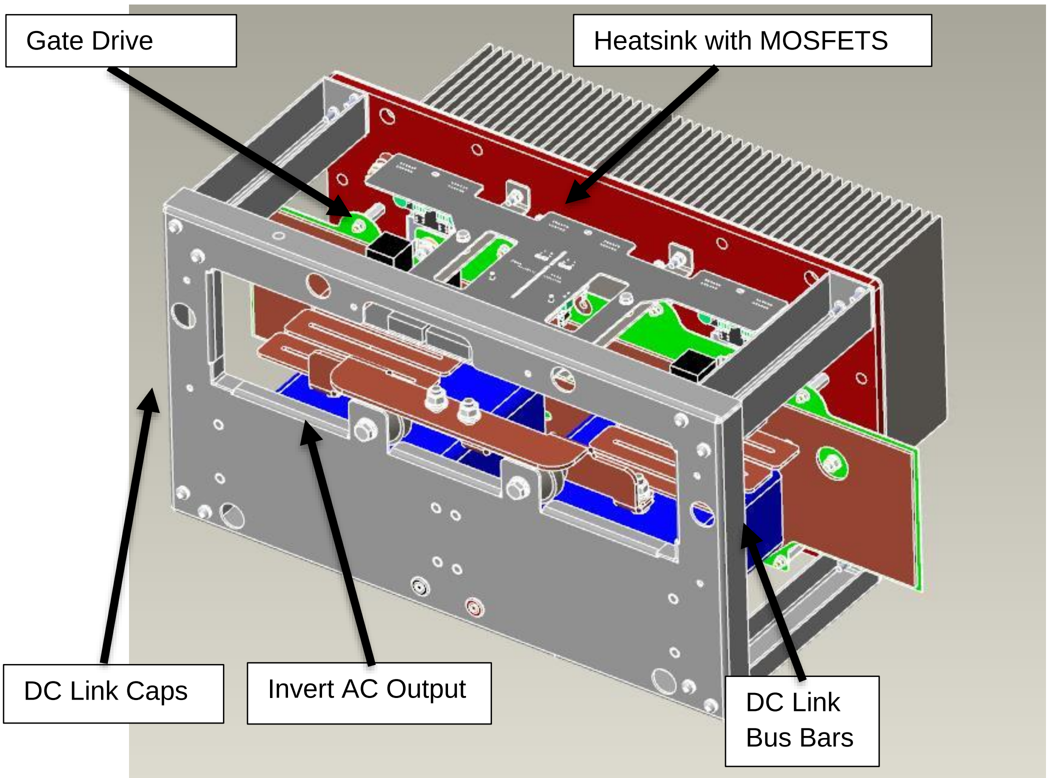
- 3-phase grid-tied inverter enclosure
- Neutral leg converter enclosure

5.3.4.1 Inverter Leg Module

The inverter, as detailed within Figure 4, is formed from three identical inverter leg modules. The inverter leg modules incorporate the following parts:

- Heatsink and mounting frame
- Over temperature thermal protection sensor
- SiC power switching devices (two in parallel)
- DC link capacitors
- Gate drive card
- DC Link discharge resistor

Figure 4. Inverter Leg Module



The inverter leg heat sink can cool three MOSFET modules (CREE CAS300M12BM2) connected in parallel. When three modules are formed into a 3-phase inverter it is capable of handling 400kVA.

For DC-Share, a 250kVA inverter is required so with one MOSFET removed the design still has plenty of margin in reserve for overload and fault handling.

5.3.4.2 MOSFET Characteristics

The MOSFET chosen for this application is the CREE CAS300M12BM2, as shown in Figure 5. This device is operated at a frequency ~20kHz to ensure low acoustic noise from the unit in operation.

Main Features

- Ultra-Low Loss
- High-Frequency Operation
- Zero Reverse Recovery Current from Diode
- Zero Turn-off Tail Current from MOSFET
- Normally-off, Fail-safe Device Operation
- Ease of Paralleling
- Copper Baseplate and Aluminium Nitride Insulator

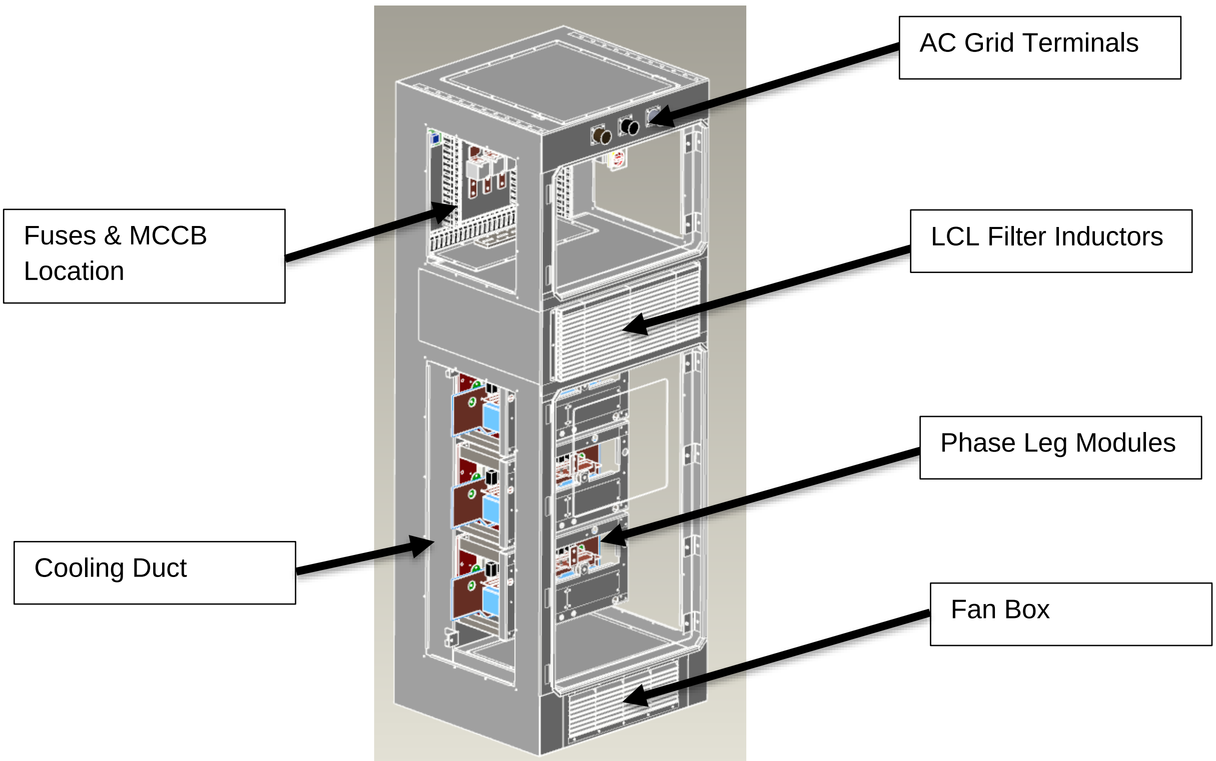
Figure 5 Cree MOSFET Device data

Voltage drain to source	1.2kV
On resistance	5mOhm
Continuous drain current	402A @25°C
Pulsed drain current	1500A @25°C
Maximum junction temp	150°C
Switching rise time	68ns
Switching fall time	43ns

5.3.4.3 GTI Enclosure

The enclosure, as shown in Figure 6, is a bespoke design manufactured from mild steel and is power coated to eliminate corrosion. The enclosure prime requirement is to manage the air cooling of the leg modules. A duct system is formed where the inverter leg modules bolt in to. The duct is positioned above a fan box that houses the single cooling fan. The fan is chosen to be quiet, electrically efficient, and have a long life. The fan is speed controlled and monitored by the inverter control card.

Figure 6 Inverter Enclosure Internal View

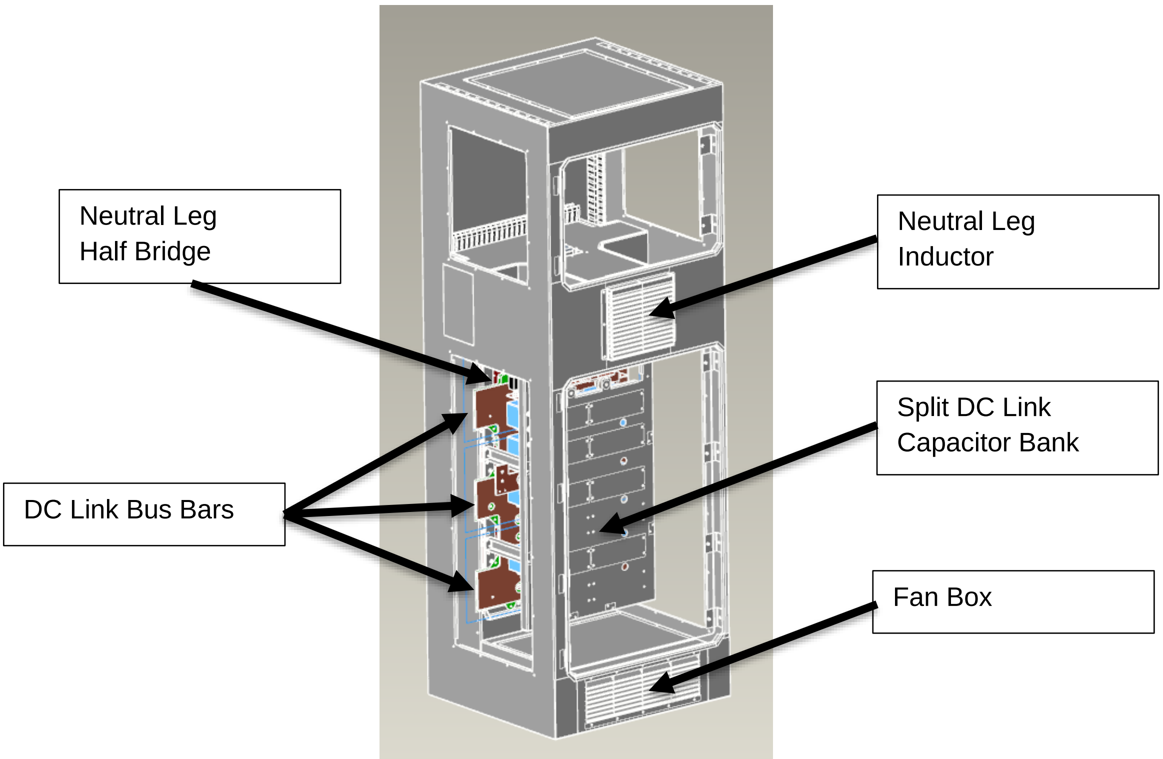


The view in Figure 6 shows the enclosure with the front cover fitted. The sides of the enclosure are open for the DC link bus bar (and other signal power wiring) to connect through to the other enclosures. The bolted together combined enclosure ends top and bottom openings will be closed off with external covers to protect against live terminals.

5.3.4.4 Neutral Leg Enclosure

The neutral leg module, as shown in Figure 7, is required to deal with the neutral current generated when the GTI is running in the phase rebalancing mode. The neutral current would cause voltage ripple on the DC Link if it were not for the neutral leg converter. The neutral leg converter comprises of a split bank of capacitors connected by a laminar bus bar with an additional half-bridge leg integrated as a module. The half-bridge leg drives an inductor connected to the capacitor bank centre connection. By controlling the half-bridge current to match the neutral current the voltage ripple on the DC link can be significantly reduced.

Figure 7 Neutral Leg Enclosure Internal View

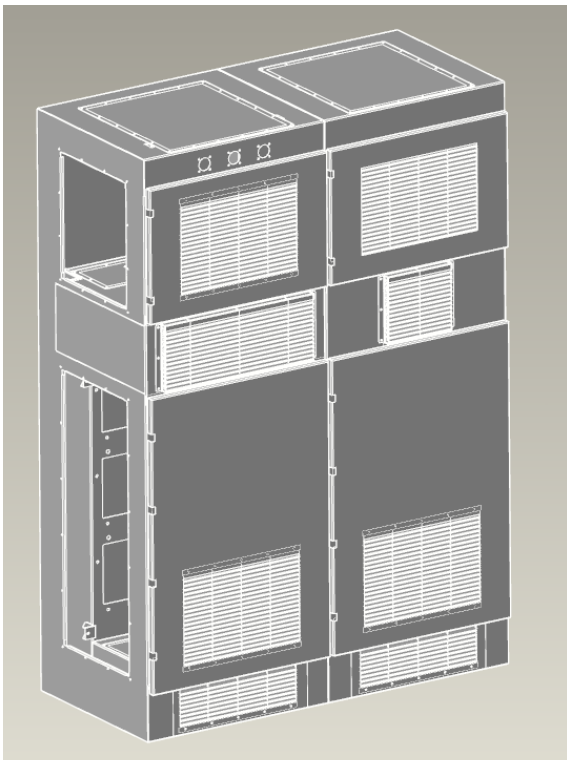


The enclosures can be supplied individually to ease installation or bolted together as a fully tested system.

5.3.4.5 Complete Enclosure

Figure 8 details the complete GTI System cubicle design

Figure 8 Complete GTI System View with Front Covers Fitted



The view in Figure 8 will have blanking-off panel fitted to each end to ensure safety from live parts, and to protect the internal equipment from dust, moisture, and vermin.

5.3.4.6 Enclosure Lifting Points

The enclosure is fitted with four lifting eyes positioned on the top corners to enable lifting for transport and installation.

5.3.4.7 Floor Mounting Arrangement

Adjustable mounting feet will be provided to enable the enclosures to sit level on uneven ground. Additional fixing down method will need consideration when the installation location is finalised.

5.4 Electric Vehicle Charging Points

Mass charging of EVs will require significant upgrades to the LV distribution networks in the future. Installing fast chargers will require new feeders, new transformers and if connecting at LV, could cause voltage flicker issues. There is significant uncertainty around EV adoption rates and AC network upgrades required to match anticipated charging demand.

DC-Share is designed to overcome these issues by connecting EV through power electronics to defer network reinforcement through smarter management of power flows. Moreover, using a DC connection gives a geographical flexibility by enabling the network to span larger distances.

DC-Share enables EV Charger load management to occur to ensure capacity is not exceeded, and additional capacity can be released from the connected substations that will have complementary load profiles.

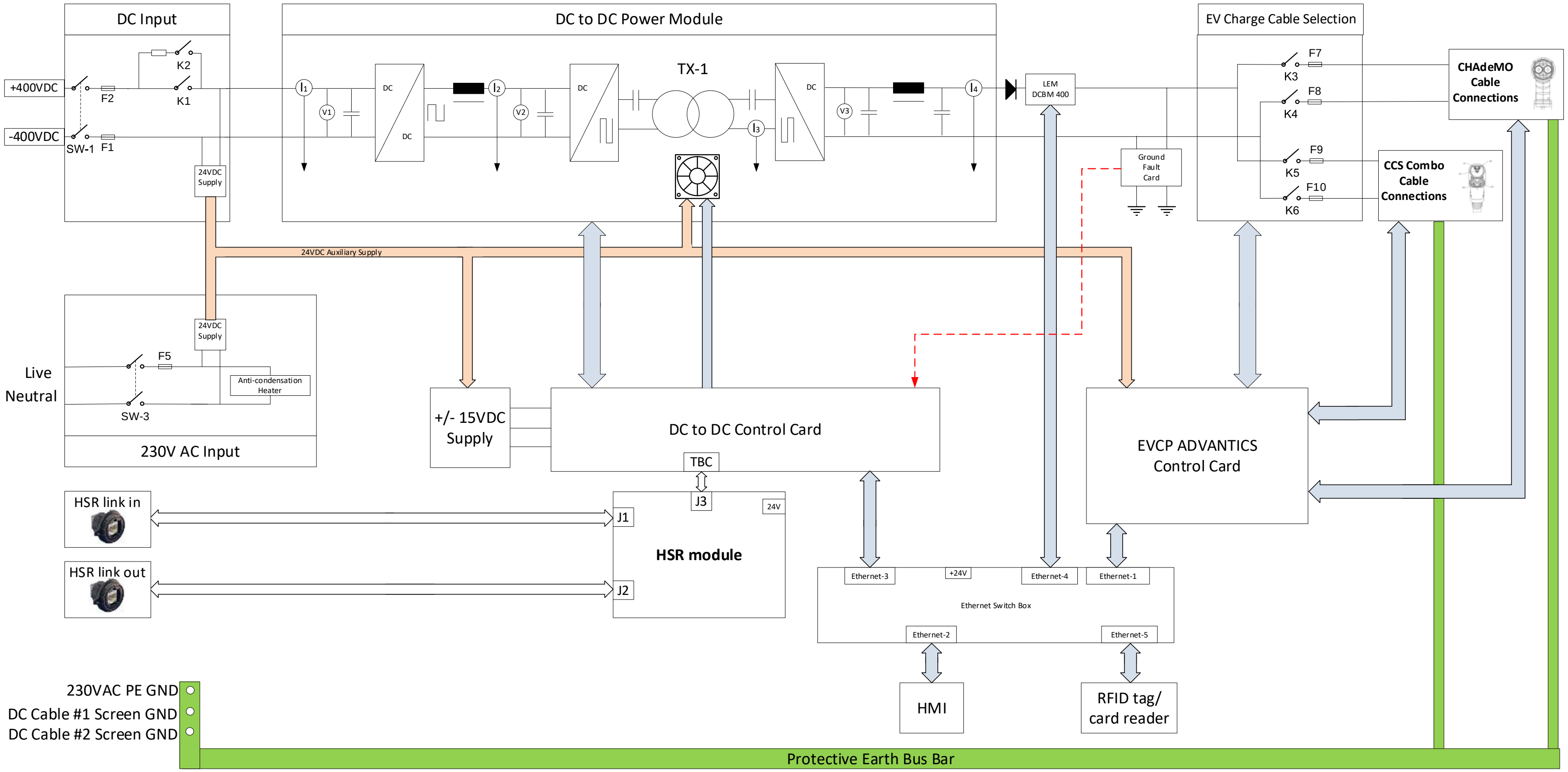
Refer to Appendix A.3 for EVCP specifics.

5.4.1 Electrical Design

5.4.1.1 EV Charger Block Diagram

The system is controlled and optimised for efficiency and enabling services to the wider network system. Figure 9 provides the block diagram/design.

Figure 9 EV charger block diagram



5.4.1.2 DC Input Circuit

The DC power on TB5-1, TB5-2, TB5-3, TB5-4 are from the external DC ring main. The supply is centre earthed resulting in +/-400VDC. The input DC power can be isolated by switches SW1. DC supply protection is by DC fuses F1 and F2.

To reduce capacitor inrush current when input voltage is applied contactors K1 and K2 are open at start up. Once K2 is instructed to close the internal DC link capacitors charge via a resistor. When the DC link is fully charged K1 is closed and K2 is opened. Full transfer power transfer can now be undertaken by the EV charger circuit.

5.4.1.3 AC Input Circuit

The DC power on TB6-1, TB6-2, TB6-3 are from the external single phase 230VAC supply. The 230VAC supply ensures the EVCP control equipment continues working when the main DC Ring Main supply is missing.

5.4.1.4 Internal Auxiliary Power Supply Arrangement

The PSU1 and PSU2 are paralleled on their outputs to supply the internal +24VDC control equipment (internal auxiliary load is estimated at <150W).

PSU1 is powered from the +/-400VDC ring main, the second supply PSU2 is powered from the single phase 230Vac supply. This arrangement ensures the charger control circuits always remains intelligent. PSU-3 fed from the combined 24VDC powers DC to DC Control Card.

5.4.1.5 Power Supply Monitoring

The DC to DC control card monitors the following supplies continuously:

- +/-400VDC
- 230VAC
- +24VDC
- +/-15VDC

When the supplies are within limits the control card state machine will ensure safe orderly start up when requested. Consequently, if the supplies are out of limits the state machine ensures the EVCP shutdown in a safe orderly manner.

5.4.1.6 DC to DC Power Module (Battery Charger)

The DC to DC battery charger converter is from an internal development program information on this part can be supplied separately. Its task is to convert the input DC supply from the ring-main to a controlled voltage and current suitable for safe rapid charging of electric vehicle battery (TPS part number 800-317).

5.4.1.7 Ground Fault Monitor

To ensure charging of the vehicle is conducted safely, it is a requirement that the charger output to the vehicle has a ground fault monitor card.

The charger shall detect the ground fault between the output circuit and enclosure of the charger and between the charging circuit and the vehicle chassis.

The charger shall stop charging and shall not be allowed to charge until the ground fault has been cleared. The insulation monitoring device on the vehicle shall not interfere with the operation of the ground fault detector in the charger while the charging connector is connected to the vehicle. Failure detection of ground fault detection circuit requires a self-diagnostic function.

The charger shall check the integrity of its ground fault detection circuit before turning on. The charger shall shift to error stop process in case a failure in the ground fault detection circuit is detected.

5.4.1.8 EV Charger Interface to Vehicle Circuits

The CHAdeMO circuit charger output to the vehicles is via main isolation contactors K3, K4. Output protection given by F7, and F8.

The CCS Circuit charger output to the vehicles is via main isolation contactors K6, K7. Output protection given by F9, and F10.

5.4.1.9 Series Diode

A series diode included in the output of the power module feeding the vehicle battery is included to stop inrush current welding contacts together of the isolation contactors (K3, K4 or K5, K6) when initiating vehicle charging sequence.

5.4.1.10 LEM Direct Billing Meter DCBM 400

DCBM 400 energy meter is dedicated to measure DC Energy fed to the vehicle battery. DCBM 400 can measure up to 400 kW. DCBM The module uses a 4-wire measurement system, that can be programmed for, cable loss compensation, live measurement, and signed data through its Ethernet interface.

5.4.1.11 Ground Fault Monitor Card

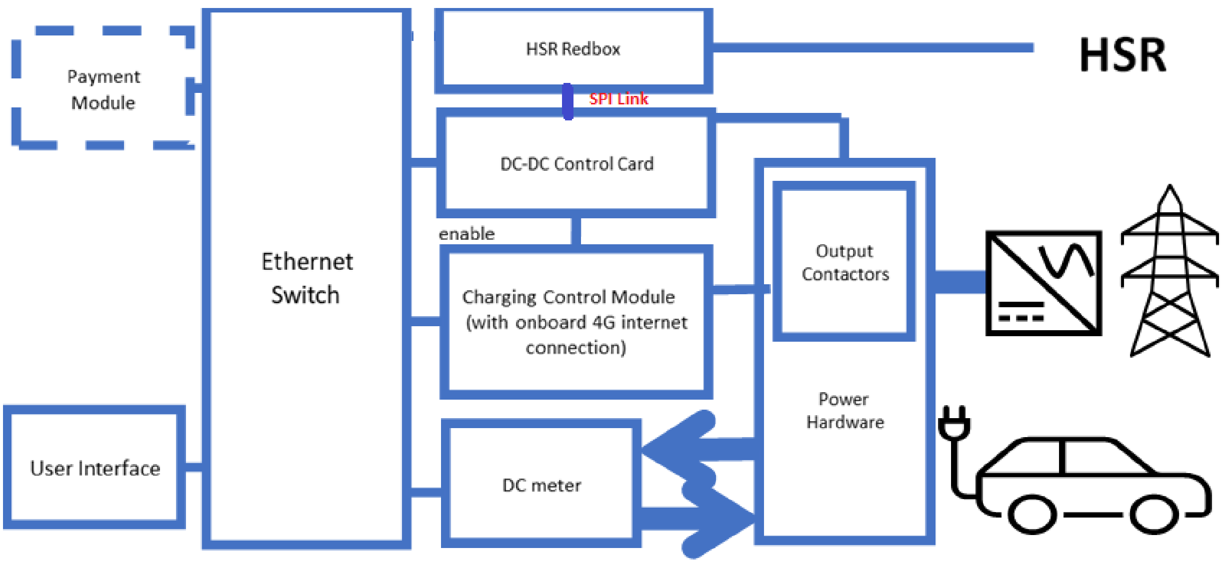
The SIM100MOD detects not only resistive leakages but also capacitively stored energy that could be harmful to human operators. The module can detect all sources of leakage, including multiple, simultaneous symmetrical and asymmetrical faults, as well as resistive paths between the chassis and points in the battery with the same potential as the chassis it is capable of operating correctly even when the battery is active and experiencing large voltage variations.

5.4.1.12 EVCP Control Module (ADVANTICS)

The EVCP control module, interfaces with the back-office systems of the charge point operator and the vehicle its charging and other EV charger subsystems to allow compatible vehicles to be rapid charged.

Figure 10 illustrates how the charging control module is likely to interface with the other EV charger subsystems. It is anticipated than most inter module communications will be made using ethernet. Note that implementation details are shown for illustration purposes and are subject to change.

Figure 10 - Charging Control Module Context



The charging system is to be realised through implementation of the following functionality:

1. Provision of the following vehicle interfaces – in conjunction with the other EV charger subsystems

    a) Combined Charging System (CCS) (Basic as defined in Combined Charging System Definition and Scope version 1.2.9)
    b) CHAdeMO 1.2 or higher (as a minimum the mandatory requirements)

2. Allowing communication and control of the charger via the Open Charge Point Protocol (OCPP 1.6J). The following minimum features will be included:

    a) Authorize
    b) BootNotification
    c) ChangeAvailability
    d) ClearCache
    e) GetConfiguration
    f) Heartbeat
    g) MeterValues
    h) RemoteStartTransaction
    i) RemoteStopTransaction
    j) StartTransaction
    k) StatusNotification
    l) StopTransaction

3. Coordinating with connected vehicles to enable charging in line with the appropriate vehicle interface standard including:

   a) Detecting when a vehicle is connected
   b) Interpreting data transmitted by the vehicle (e.g. required voltage and current)
   c) Providing data requested by the vehicle (e.g. charger rated voltage and current)
   d) Managing the cable lock
   e) Determining when it is safe and permitted (by the vehicle interface) to start charging
   f) Determining when it is necessary to stop charging

4. Controlling the relevant EV charger contactors to safely charge the vehicle in line with the vehicle interface standards including:

   a) Performing the appropriate cable pre-charge procedure
   b) Connecting the active vehicle interface to the DC-DC converter
   c) Disconnecting the outputs from the DC-DC converter

5. Communicating with the DC-DC control card to:

   a) allow charging in line with the appropriate vehicle interface standard including:
      - Retrieving the electrical parameters required by the vehicle charging interfaces (e.g. maximum output voltage, maximum current)
      - Adjusting the current/voltage setpoints and limits of the DC-DC converter to match the requirements of the vehicle charging interface
      - Enable/disable the output of the DC-DC converter
   b) Reset the DC-DC control software when requested via OCPP

6. Action the following signals from the system supervisor controller

   a) Power Limit Request - The output power the EV charger will attempt to maintain while complying with the relevant vehicle interface standard.
   b) Power Limit Demand – The output power the EV charger should not exceed.

7. The system supervisor signals will be processed as follows:

   a) The maximum power level for a new charging session will not exceed the lesser of Power Limit Request and Power Limit Demand.
   b) During an active charging session
      - The EV charger will respond to current & voltage set points from the connected EV provided that the requested set point does not exceed
         - ➢ The present Power Limit Demand level
         - ➢ The maximum power level for the session
      - Adjusting the Power Limit Request level will, where possible, cause the EV charger to request that the maximum power level for the session is adjusted accordingly. The requested value will not exceed the present Power Limit Demand level (i.e. even if where Power Limit Request > Power Limit Demand).
      - Lowering Power Limit Demand to a value less than the chargers present output power will result in the output power being is promptly reduced to the new value of Power Limit Demand.
      - Lowering the Power Limit Demand may cause a vehicle error and/or cause the charging session to be terminated by the vehicle.

8. Anticipated use of Power Limit Request and Power Limit Demand by the system supervisor:

a) Power Limit Demand should always be >= Power Limit Request
b) During an active charging session
  - The normal mechanism for managing power use by the EV chargers is Power Limit Request
  - Power Limit Demand will normally be used as a last resort (i.e. to prevent a system level error)

9. Communicate with the connected DC power meter to retrieve the data required by the user interface and back office systems.

10. Communicate with the user interface to:

a) Indicate charger status
b) Display data required to enable charging
c) Action user input as required
d) Display the amount of energy transferred in the current charging session in kWh

5.4.2 Mechanical Design

The enclosure will comprise of two main parts, firstly the Plinth that is fixed into the carpark surface, and secondly the EV-Charger itself.

5.4.2.1 Plinth Design

The plinth will be constructed from stainless steel to ensure a long life in the ground.

The plinth is specifically designed to:

- Firmly anchor the EV-Charger in position
- Provide a point for cable entry up into the EV-Charger enclosure
- Raise the EV-Charger above ground level to prevent water ingress
- Ensure the EV-Charger enclosure is vermin proof

The plinth can be installed first with a temporary cover plate to protect the cables before the EV-Charger is installed.

The civil works associated with the foundation requirements for the EVCP plinth shall be designed and provided by WPD at a later stage.

5.4.2.2 Charging, plugs and cables

The EV charger will charge either a vehicle with CCS or CHAdeMO plug connection, but not both together.

- PHOENIX CONTACT Chademo charging cable, SEVD-02E Series, SEVS14-004D, 125A
- Sumitomo Electric Industries LTD, CCS charging cable, EV-T2M4CC-DC200A-3,5M50ESBK11 – 1107040, 200A

5.4.2.3 EV-Charger Main Design Points

The EV-Charger enclosure will be manufactured from stainless steel powder epoxy coated. The construction will consider the following points:

- Enclosure designed to meet IP55
- Vandal resistant by using high security door locks with additional security fixings (IK10)
- Tilt sensor in case of vehicle impact
- Additional safety by use of door interlocks and fixed insulated panels with danger labels
- Forced cooling system maintains safe surface temperatures of enclosure for the public
- Ventilation louvre designed to reduce intake of debris and powdered snow
- EMC shielding
- Equipotential bonding
- Acoustic noise suppression
- Flexible design for positioning of vehicle charging cables

5.4.2.4 EV Charger Design

The following snapshots from the mechanical design department show the basic concept. We are considering front access only with small front to back dimension.

5.4.2.5 DC to DC Power Block Assemble

The DC to DC power block is shown in Figure 11 it will comprise of all the components required to form the power module. The power module will take in the 800VDC supply to produce an isolated supply suitable to charge the EV battery.

Figure 11 EVCP power module showing internal components

EVCP power module will include:

- DSP control card
- Input Buck chopper inductor and power MOSFET circuit
- Input Mosfet power Bridge
- 100kW isolation transformer
- Output active rectifier power Bridge
- Output LC filter

- Control VT's and CT's
- DC filter capacitors
- Gate drive cards
- Heatsink and cooling ducting
- Module chassis

The power module will be manufactured and tested separately and has its own part number. The module is designed for quick easy change out for maintenance on site.

5.4.2.6 EVCP Enclosure Design

The concept is to minimise the front to back dimensions with front access only, this suit a carpark location where back-to-back placement of charger points is required. Without the need for rear access placement against a wall is also possible.

The latest enclosure model is shown in Figure 5-2 it is definitely "work in progress" but gives an impression of our design thoughts.

The model in Figure 12 has the HMI panel missing, the HMI touch screen module will be designed to:

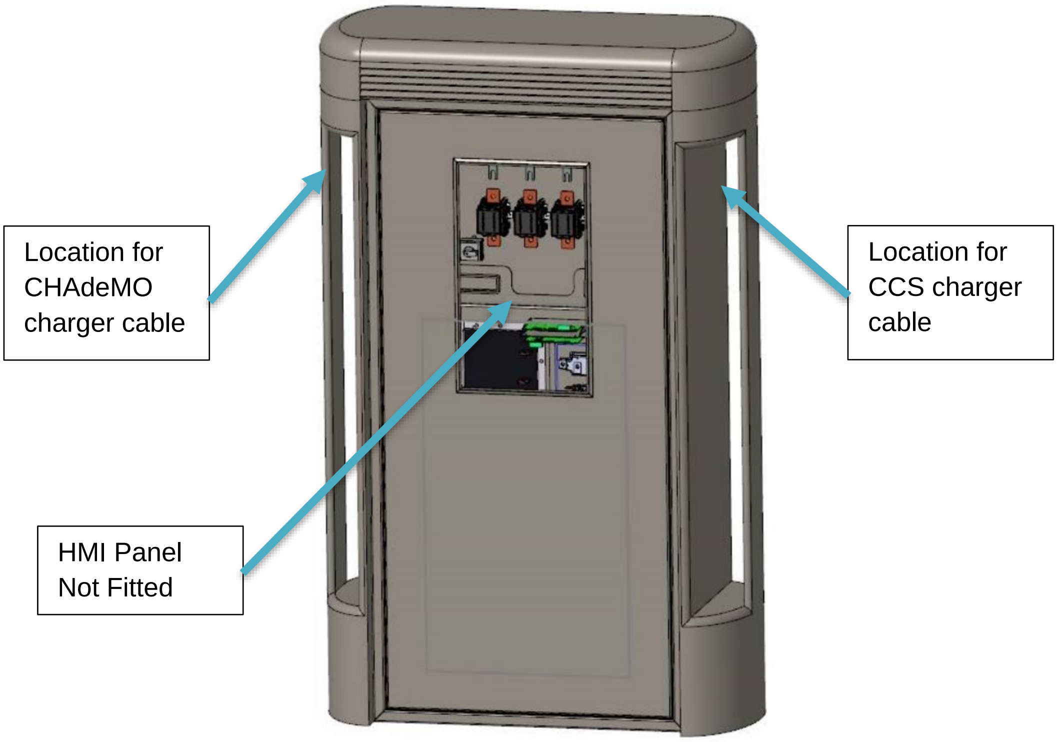
- Withstand harsh environments
- Start and stop the charge cycle
- Customer interface
- Charge payment module

The charging cables will be positioned at each side of the enclosure in the protected slots indicated in Figure 12. The cable assemblies are proprietary items that come fully certified for the voltage and current the charger will supply to the vehicle.

When the cable is not in use a cradle will be included to keep it safe and protected from the environment (we may consider locking it in position using the normal latch function when not in use).

EVCP input dc supply has cables enter in the base of the enclosure. The cables come thought a split gland plate. Cable entry design including gland plate and cable type will be specified in the EVCP ICD Document 327-02-005.

Figure 12: Front View of EVCP with HMI Panel Removed



The charger enclosure will be fixed down to the preinstalled base (not shown at present) using M10 stainless steel bolts or similar.

5.4.3 Internal Cooling

The cooling fan will be positioned below the DC to DC power module in a removable fan box.

A large input grill (although not shown at present) on the front of the unit ensures low velocity air is pulled in avoiding intake grill blockage. The cooling air at 5m/s will share between the heat sink duct and the duct that the transformer and inductors are located. The warm air is then ducted to the top of the enclosure to expel from the vents at the top of the enclosure. The vent design at the top ensures the warm air is deflected upwards away from the public. The fan windings are fully encapsulated, and it has an integrated speed control function.

The fan is the same used to cool the GTI inverter stacks, fan: R3G225-RD05-03. Parameters of fan are described in Table 1 below.

Table 1: Fan Parameters

Parameters	Unit	Value
Nominal Voltage	[VDC]	24
Nominal AC Current	[A]	3.4
Power consumption	[W]	82
Nominal speed	[1/min]	2200
Control speed	[-]	Yes: PWM / 0÷10V
IP	[-]	IP54

Size	[mm]	225
Working temperature	[°C]	-25 ÷ 65
Noise (LpA_{in})	[dB(A)]	<62

Note: Fan type could change if thermal analysis does not confirm it is suitable for the application.

5.4.4 Sendyne Isolation Monitor for Unearthed DC Power Systems

The Sendyne SIM100MOD is a insulation monitoring device for Electric Vehicles (EV/HEVs) capable of operating correctly even when the battery is active and experiencing large voltage variations. The SIM100MOD continuously monitors the isolation resistance between a vehicle's IT (Isolated Terra) power system and chassis for deterioration of insulation and potentially dangerous levels of leakage current. Based on the SIM100 IC, which utilizes an advanced algorithm developed by Sendyne that is compatible with all relevant standards for charging stations.

The SIM100MOD detects not only resistive leakages but also capacitive stored energy that could be harmful to human operators. The module can detect all sources of leakage, including multiple, simultaneous symmetrical and asymmetrical faults, as well as resistive paths between the chassis and points in the battery with the same potential as the chassis. Communications are achieved via an isolated CAN 2.0B interface (500 kbit/s or 250 kbit/s), with an input voltage range of 5 V to 53 V, and a wide temperature range of –40 °C to +105 °C. The module was designed to ISO 6469-3:2011-12 / FMVSS 305.

Further consideration is to be given to fit an additional RCD detection relay to give extra protection against earth faults.

5.4.5 LEM Direct Billing Meter DCBM 400

DCBM Series are static energy meters dedicated to DC Energy metering and billing. Figure 13 shows the details for the DC meter procured for the project. DCBM Series provide a reliable energy metering solution in the field of DC applications, adapted to cover the complete range of Electric Vehicle DC chargers up to 600 kW (Ultra-fast Charging station). DCBM Series include 4-wire measurement system, cable loss compensation, live measurement, and signed data through Ethernet interface.

Figure 13 LEM DCBM 400 Hardware

Features

- Range of operation 150 VDC to 1000 VDC
- Imax 400A and 600A
- Accuracy Class B
- Compatible with 4 wire measurement
- Cable loss compensation
- Ethernet communication with HTTPS/REST protocol
- Signed data readouts in OCMF / LEM protocol
- Transaction mechanisms with start & stop tags
- Wide auxiliary power supply range +12 ... +48 V DC
- DIN rail 35mm and screw mounting
- Meter Unit operating temperature range: -25°C to 70°C
- Sensor Unit operating temperature range: -40°C to 85°C
- Integrated display with backlight
- Reinforced insulation at 1000 VDC, OVC II
- Physical security seals

Standards

- EN 50470-1:2006
- EN 50470-3:2006
- PTB 50.7
- CISPR32 Class-B emission
- EN 62052-31:2015
- IEC 62052-11:2003
- IEC 61000-6-2:2016
- IEC 61000-6-3:2016
- UL94-V0
- Designed according to VDE-AR-E-2418-3-100

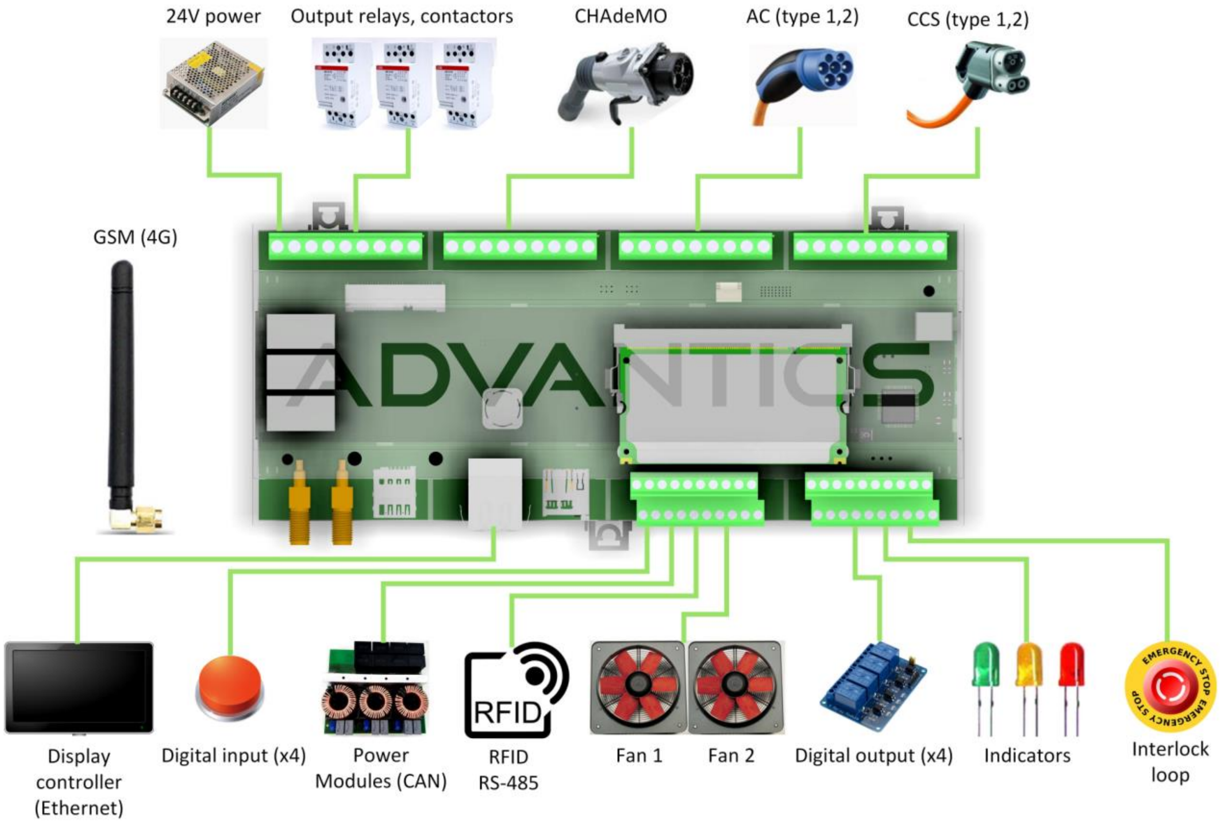
5.4.6 ADVANTICS EVCP Controller

The ADM-CS-SECC is a charge controller for electric vehicle charging stations. The main features, as shown in Figure 14 below, include:

- Linux system, running on iMX7 ARM platform
- CCS (Combined Charging System) – DIN SPEC 70121 and ISO 15118
- CHAdeMO interface (1.x)
- AC charging interface (IEC 61851-1, J1772)
- Ethernet (RJ45)
- Extension slot with 4G modem, GPS, Wi-Fi (optional)
- RS-485 (user managed)

- Relays for output contactor control
- CAN bus (for power modules control)
- OCPP interface
- SD card

Figure 14: ADVANTICS EVCP Controller



5.4.7 Cellular Antenna

To enable the Advantics module to communicate using GSM (4G) an external antenna is required. Typical low-profile antenna that will mount on the top of the EVCP enclosure.

5.4.8 HSR Module

The HSR hardware proposed is from Texas Instruments Part No AM335x ICE EVM Rev2.2.

On page-3 of EV Charger Draft Schematic 800327-EV-SCH Rev-C, J1 and J2 of the HSR module are RJ45 Ethernet sockets. The RJ45 cables will be terminated within the EVCP at an appropriate interface connector (their location to be defined). The HSR module Unit-3 connects to the DSP control card Unit-1's SPI bus, the cards need to be mounted as close together as possible. J3 is a 0.1" header with a short jumper cable to the control card.

5.4.9 230VAC Auxiliary Power Budget Estimate

In normal operation both 24VDC/200W power supplies PSU1 and PSU2 are powered and share the auxiliary load (<100W taken from each power supply). When PSU1 is not powered (when the +/-

400VDC is missing) the EVCP will go into standby mode. In standby mode PSU2 maintains power to control functions and to communication equipment (<100W taken from PSU2).

5.5 Supervisory Controller

5.5.1 Overview of System Design

The supervisory controller will be provided by a specialist Contractor with appropriate experience and capability in this field. A separate procurement activity against a suite of tendering documents which specify the necessary functional and performance criteria for the hardware, software, interfaces and general requirements (such as testing, documentation etc) has already been initiated.

In essence, the supervisory controller shall consist of the following main hardware items:

- A central processing platform (the “controller”);
- Human Machine Interface (HMI)
- Time synchronisation via Global Positioning Satellite (GPS)
- Connectivity equipment as necessary to permit seamless interfacing with all other project hardware
- Power supplies

and provide the following functionality:

- Monitor and control the entire installation both under normal operating and network fault conditions in a safe, efficient and reliable manner. It shall be capable of operating fully automatically using intelligence gained from the received data. At any time, operator control may also be activated, locally or remotely and under this case automatic control shall be disabled.
- Provide a local operator interface plus a remote web-based log-in facility
- Manage the charging and equalisation system, prioritising charge speeds and equalising the local distribution network via a suite of software algorithms.

The main software required shall be as follows:

- Operating System Software. This shall be real-time, multi-user, multi-tasking operating system which shall provide a suitable environment for executing the software intended to be run, especially for real-time (and “near-real-time”) programs.
- Applications Software. This shall be based upon a bespoke suite of software modules which together shall enable the functionality as described within a series of “Use Cases” to be implemented. Please refer to the summary details contained within Appendix A.4.
- System Operation and Management Software.

Facilities shall be provided within the system operation and management software to provide basic functionality such as:

- Use access and control
- Data processing

- Alarm and event processing
- User interface management
- Provision of trend displays
- Accommodate non-telemetered data points and facility to permit operator manual dressing of the same
- Display tagging for attaching notes to network elements upon the displays
- Operator Log-Book for recording any and all comments that may be pertinent to the operation and management of the system.
- Print output to a file
- Management (creation/edit etc) of the database and displays

Facilities for data archiving and subsequent retrieval of archived data into prepared report templates shall be provided.

The availability for the supervisory control system has been specified to be at least 99.9% assuming a Mean Time To Repair (MTTR) of 8 hours.

Under all credible loading scenarios, field data presented in user defined displays has been specified to be updated within 2 seconds of receipt of the incoming message by the central processing platform and, in addition, the user displays presenting values in the real-time database have been specified to be displayed within 2 seconds of being requested by a user.

5.5.2 Procurement Activities

Prior to floating the tendering documentation, we initiated a Pre-Qualification exercise in August 2020 in order to gauge industry interest in the project and assess capability of suppliers to undertake the necessary works.

The PQ document was issued to twelve (12) reputable engineering companies and four (4) companies responded.

These suppliers were as follows (in alphabetical order):

- ABB
- Capula
- Lucy Electric
- Schneider

After review of the returned PQ documentation it was considered that all four companies were suitable for inclusion in any following tendering activity.

The full tendering documentation package for the supervisory control and communications network was concluded during October 2020 and, after discussion between all project Parties to conclude agreements on specific issues such as interfaces, floated to each PQ company during November 2020.

Current date for bid submission is set for 31st Dec 2020, subject to any request for extension being received from suppliers and approved.

Upon completion of the procurement and award of Contract to the successful bidder, one of the Contractors first activities will be to develop detailed Functional Design Specifications which should comply with the functional and performance criteria specified within the tendering document.

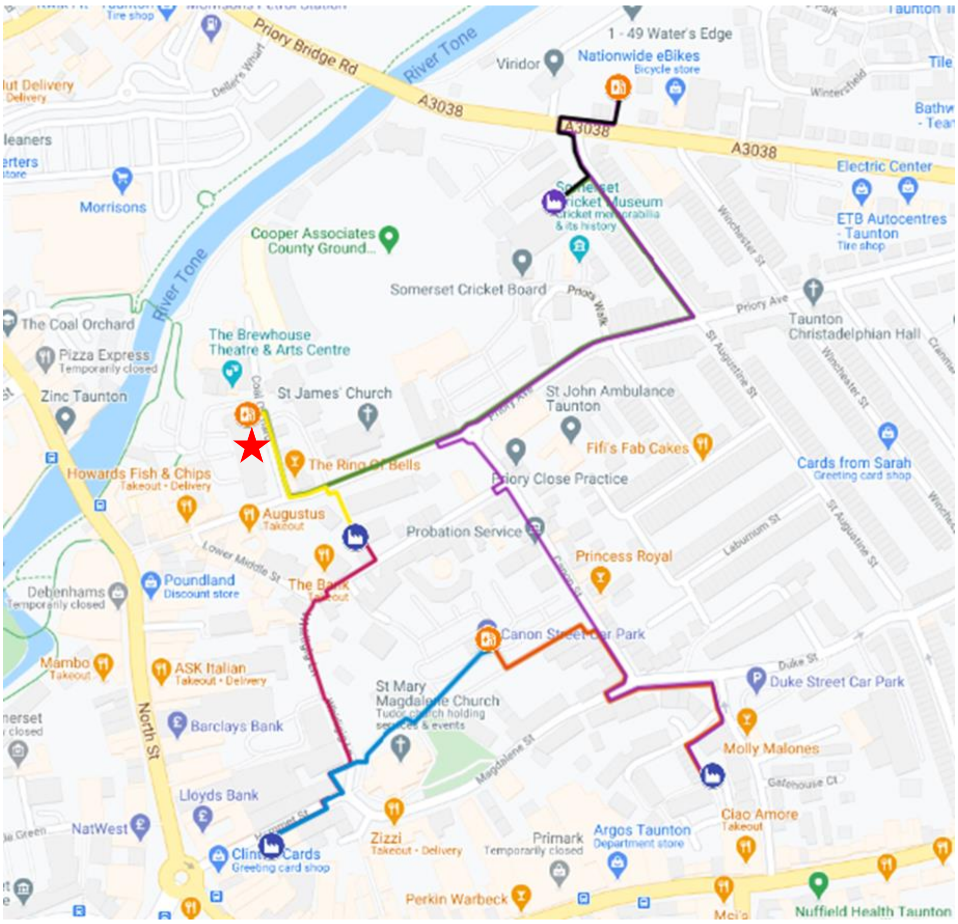
This will then naturally progress through to a detailed design stage where the architecture, hardware, software and interface requirements will all be developed and finalised.

5.6 Telecommunications

The overall telecommunications infrastructure shall be provided by a mixture of Parties, notably:

- WPD – providing the FO and Ethernet cabling, connectors and termination/splice boxes, along with the interface equipment required by the Lucy Gridkey system
- TPS – providing the communication interface equipment required within their GTI and EVCP equipment builds

A redundant Fibre Optic (FO) network (“backbone”) shall be installed around the DC ring connecting all main operational components. Figure 15 below shows the DC ring, of which the FO ring will also be laid in the same trench, ensuring that suitable distances are maintained, to connect every GTI and EVCP on the network. Note the Coal Orchard substation on the map denoted by the red star, this site will house all of the control system hardware and the User Interface as it is dry and there is ample room to hold the equipment securely. There will not be any DC equipment within this substation.



Armoured FO cable shall be procured through WPD business as usual processes and installed in trenches along with the DC ring cable. WPD Telecoms will be providing suitable ducting for the project.

The entire “dig and lay” process shall be undertaken by WPD contractors during 2021 and all such works will comply with their internal policies and procedures, under Business as Usual.

. The fibre optic cables used within Western Power Distribution are Single Mode, Non Dispersion Shifted Fibre manufactured to BSEN 60793-2-50, containing 24 fibres Data sheet for the FO cable that shall be provided by WPD is included in Appendix A.5.

The cable will be installed inside of a FO Cable Duct which is multilayer D90 96.5mm CT Duct made to specification EN50086, with an outside diameter of 96.5mm, (Class 2) 3mm wall thickness, green PVC ducting. Marker tape manufactured to ENA TS 12-23, with a minimum dimension of 1000mm long bearing the words “CAUTION WPD TELECOMS FIBRE OPTIC CABLES BELOW Tel 0330 123 5510” shall be installed above all Telecoms Ducts on all routes at 75mm above the ductwork. All duct laying shall be performed in accordance with WPD Standard Technique TC3A. The installation of the duct will meet the below criteria:

- The line for all ducts being laid shall be as straight as possible.
- All ducts leading into buildings shall be both gastight and watertight.
- A minimum clearance of 150mm shall be provided with the ducting at the base of lamp standards, light rail and trolley wire standards, traffic signal posts and other similar plant.
- High voltage cables for electricity supplies, electric railway or tramway systems exceeding 1000 Volts shall have a minimum clearance of 50mm with the ducting with no exceptions.

The full ducting specification has been appended to this report in A-10.

The FO cabling shall be terminated within each substation and car park distribution box within a 24 core capacity termination box, which will be suitable for the environment including IP ratings. An example of which is provided in Appendix A.5. As we shall only utilise four fibres within the current project implementation (two for the main supervisory controller ring and two for the Lucy Gridkey system), the remaining fibres shall be capped and terminated within each enclosure.

Items of equipment at the remote ends of the network (eg the EVCP) that are not required to be connected directly to the FO backbone shall be connected via OTS media converters accommodating standard electrical Ethernet cabling. Appendix A.5 provides examples of this.

5.6.1 Equipment and Protocols Architecture, Equipment and Protocols

To minimise the risk of network failure we have specified that a secure High Availability Seamless Redundancy (HSR) FO ring utilising IEC61850 telecommunications protocol, utilising Generic Object Oriented Substation Event (GOOSE) signalling for protective actions and Manufacturing Message Specification (MMS) for data exchanges is required.

This shall be designed and implemented by the supervisory controller Contractor in association with TPS.

It is expected that to implement this design will require some equipment object modelling design work plus extensive integrated testing within the factory to demonstrate correct functionality is achieved.

5.7 AC Measurement System

In order for the main supervisory controller to function correctly and compute the necessary control actions, it will require receipt of the substation loading (AC) measured data. Such data (currents and voltages) shall be obtained from each outgoing LV way and summated to provide a “total load” for the substation.

WPD already utilise equipment from Lucy Electric Gridkey for this purpose and shall be deploying identical equipment for the DC Share project. This equipment is already deployed as BaU implementations and no additional design or development works are foreseen for DC Share.

In addition to the above, Power-Quality (PQ) meters shall be deployed on the LVAC ways to assess network harmonics frequency and temperature which shall be used exclusively for WPD system operational purposes and are not required to be integrated with the main supervisory controller.

All the above referenced measurements and data shall be transferred via dedicated fibres within the fibre optic ring to the Lucy Electric Gridkey (local) Data Centre which shall be located at Coal Orchard substation.

These dedicated fibres shall be configured as a traditional Ethernet LAN and be separated from the fibre optic HSR ring provided for the main DC Share project implementation.

Figure 1 depicts the above design and architecture, with the Lucy Electric Gridkey equipment shown in red. Appendix A.6 provides a selection of data sheets associated with this equipment.

The Lucy Electric Gridkey (local) Data Centre shall process the received data and calculate 1 minute averaged values of the voltage and current on each LV way and summate to provide averaged values for the substation as a whole. It shall also calculate average active and reactive powers from the data received.

The main supervisory controller shall then poll the Lucy Electric Gridkey (local) Data Centre every minute in order to extract this averaged data for use within its use-case algorithms.

REpresentational State Transfer Application Programming Interface (RESTful API) shall be used to facilitate this transfer of data.

In terms of “design”, the only new issue to be considered is the connectivity method between the Lucy Electric Gridkey (local) Data Centre and the main supervisory controller and this shall be determined by the supervisory controller contractor after consultation with Lucy Electric during detailed design phase. However, it is expected that such connection can be achieved either directly or via LAN cards and switches.

The Lucy Electric Gridkey (local) Data Centre shall also have connection to a centralised/remote monitoring platform accessed via a secure gateway, provision of which will be provided directly by WPD as a BaU implementation.

In addition to the AC measurement devices from Lucy Gridkey, WPD shall also be installing Power Quality (PQ) devices at each substation, connected to the LAVC distribution board, to measure system harmonics for their internal monitoring and use. Data sheet for an example PQ meter is provided within Appendix A.6.

5.8 AC and DC Cabling

5.8.1 Introduction

Specifically with regards the design for the DC ring cabling, we have first undertaken an assessment of the calculated power flows around any portion of the ring at any time and under any operating condition (normal or fault) in order to determine the requirements for current carrying capacity.

This assessment concluded the following:

- When operating under normal conditions at 800V, the DC cable is expected to be capable of carrying approx. 360A continuously. This equates to approx. 290kW, excluding network/cable losses. Therefore, any ring design/operating condition which permits power & current flows not exceeding these values is deemed to be acceptable.
- With the given ring design, it can be shown that under the two opposing network conditions (full EV charging with no network equalisation and zero EV charging with full network equalisation), the power and current flows are acceptable at all times for continuous operation.
- It is accepted that there may be instances whereby larger power/current may flow for an extended period of time and the maximum design limit is agreed to be 400kW/500A for 60 minutes.
- For power/current flows above the normal operating condition but below the maximum design limit, a longer period of operation may be permitted, for example 350kW for up to 90 minutes. Final decision to be agreed after trial operation.
- Should the power/current flows not reduce to normal operating conditions (290kW/360A max) within these time periods then the supervisory controller should act to reduce export and/or reduce EV charging capacity so that normal operating conditions are resumed.
- Design intent is to minimise "unnecessary cycling" of the DC network when power/current flows exceed the normal operating conditions.
- Should the DC ring operate above its normal operating condition for a long period of time then a period of "reduced operation" (below 290kW/360A) may be required to allow the cable to cool adequately.

In addition to the above, the DC ring network has been simulated in PLECS (Piecewise Linear Electrical Circuit Simulation) in order to determine worst-case values for parameters such as short-circuit values.

Appendix A.7 provides summary details of the above analysis work.

Results from the above design analysis have therefore provided a set of parameters that the DC cable must comply with, as referenced below.

5.8.2 DC Cabling - Specifics

The DC cabling is required to form the actual DC ring and also to connect the EVCP's to the DC ring.

Given that bespoke DC cabling shall be procured, the same cable shall be used for all the above.

The cable shall be 300 mm2 SAC, XLPE insulated, copper wire screen, PVC sheath – with the two cables +VE and -VE supplied pre-twisted as a 'duplex'.

WPD are currently in discussions with cable vendors to conclude commercial arrangements and manufacturing lead times and the final DC cable thus chosen shall be determined during 2021.

5.8.3 AC Cabling Specifics

The AC cabling is required to connect the GTI's to a spare way on the LVAC board.

Tri-rated cable that is suitable for installing in confined areas, permits installation flexibility (eg can bend with a small radius) and is capable of carrying the peak current requirement (360A) at all times shall be used.

WPD shall procure such cable from TRATOS (*or equivalent*) and 150mm^2 cable capable of carrying up to 440A has been chosen.

Appendix A.8 provides the cable data sheet.

5.9 DC Metering

DC Meters are required to be installed within the EVCP's to provide tariff metering so that users of the EVCP's can be accurately billed.

To date, there doesn't exist a UK certified DC meter for this application. CPO's instead typically use an AC meter and accept that the losses incurred will not be accountable or billable and hence revenue will be lost.

After extensive market research we have determined that a DC meter designed and manufactured by LEM (European based) may be the most suitable meter to use, especially as it has recently successfully completed a series of PTB accredited certification trials for EVCP applications.

We have therefore chosen LEM DC meter DCBM400 which is capable of operating with DC currents upto 400A.

A single unit has been procured and is currently with TPS for trial, to verify how best to integrate into their overall EVCP design and communicate with it.

LEM remain keen to work with the DC Share team to assist during this trial as they naturally view this activity as being important to demonstrate the suitability of their products within the UK EVCP industry.

Assuming the trial proceeds as expected then the remaining units will be procured.

Appendix A.9 provides a summary of the technical details of this DC meter along with the PTB certification certificate.

Full details may be obtained from the LEM website here.

5.10 DC Isolation Devices

In order to permit WPD staff to work safely on the DC network, we have introduced DC Isolation devices into the overall DC ring design.

These devices shall be located at each substation and at each car park "EVCP hub" where they shall be used to enable physical isolation of the connected equipment to the DC ring to be achieved.

In order to ascertain market interest and capability for providing DC isolation devices a Pre-Qualification exercise was undertaken which specified the following functional requirements:

- Support in the location of a fault by providing measurement information to the DC Share Supervisory Controller and SCADA or having the ability to locate a fault by sending a pulse down the faulted cable and measuring the reflection.
- Reconfigure the DC network during normal operation

- Reconfigure the DC network to isolate a faulted section of cable after protection has operated to clear a DC cable fault. The DC isolators are not required to break the DC fault current, but they must be able to withstand the DC fault current.
- Provide points of isolation for maintaining the EV chargers or a section of DC cable.
- Provide a mechanism for de-energising the DC cable which could remain charged after a disconnection due to the use of low leakage DC cables.
- Allow for the connection of a cable fault locating devices.

The PQ document was issued to twelve (12) reputable engineering companies in July 2020.

Only two (2) responses were received back and neither response provided a solution which was fully compliant with the specified functionality. The main issue preventing companies from responding in a compliant manner related to the issue of automating the DC isolation devices.

Upon further dialogues with responding companies, it became apparent that whilst this could be achieved, it was not something that had been undertaken before and hence there was uncertainty as to whether-or-not it could be accomplished and, even if developed, would require additional cubicles which would present a challenge for implementation within the constrained confines of a typical distribution substation. Cost was also an issue as the budgetary funds for “Miscellaneous Equipment” within the Contract, for which this DC Isolation equipment needs to be procured from, was limited and could not support such development or equipment.

It was therefore decided to remove the requirement for automation of the DC isolation devices and instead simplify the requirement to only provide ability to manually isolate equipment connected at the various DC ring connection points.

These manual DC isolation devices shall be based upon standard BaU devices deployed by WPD within their existing LV networks.

6. Detailed Status of Developments of Hardware and Software

6.1 Introduction

For the DC Share project, the main equipment items that have required hardware and/or software development are the GTI, EVCP, control system and DC isolation equipment

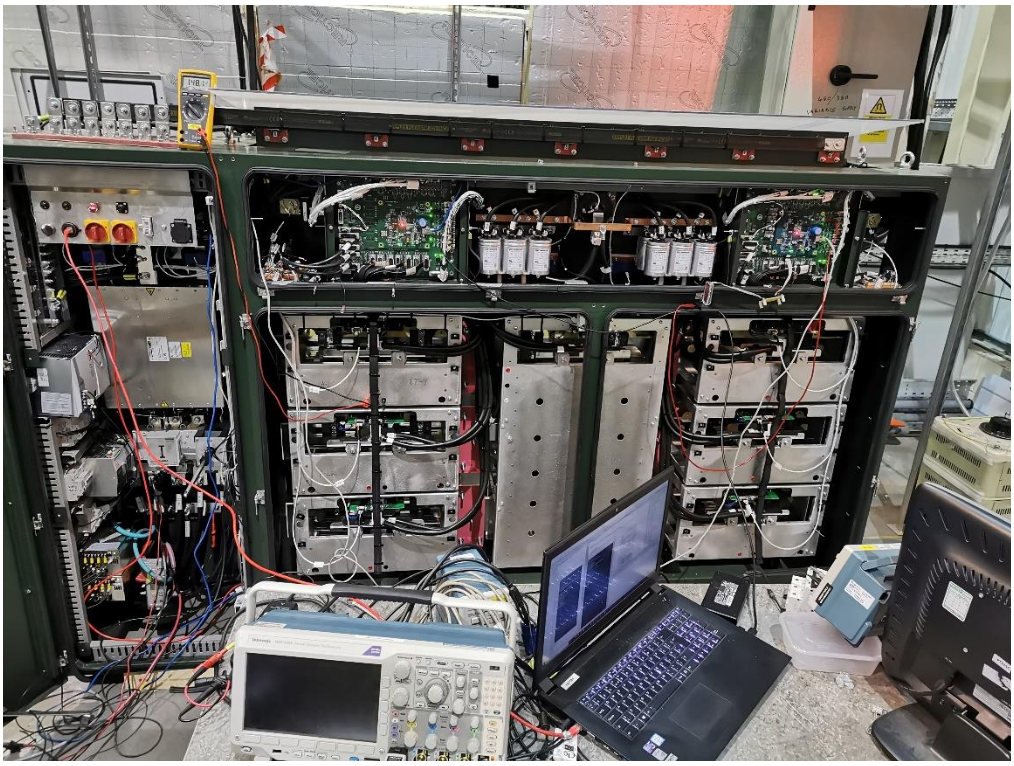
For each, the following sections describe the type and extent of development works undertaken.

6.2 GTI

GTI is based on two former projects called 2T and 3T SOP. Both projects are Soft Operation Points. The 2T project is a two-terminal converter with a power 250kVA which allows on energy exchange between two connected substations. The 3T project is similar but connects three substations and has a power of 400kVA. The 2T was made as a street furniture. 3T was made as an indoor device.

Currently both above mentioned projects are in commissioning phase at TPS factory. Figure 15 shows a 2T SOP undergoing factory commissioning.

Figure 16: 2T SOP Factory Commissioning



GTI is a connection of both projects. Power modules are from 2T and they are placed in 3T cubicle. As a result, we have 250KVA converter designed as an indoor device.

Because both previous projects were very similar to GTI, there was not required so many changes. On the base of Design for Manufacture and Assembly (DFMA) analysis, system simulations and reviews.

GTI has been equipped with additional protection limiting short circuit current and protecting SiC modules. Furthermore, additional droop control mode has been added to provide possibilities of equal current sharing between 4 GTI's working on the same DC bus. GTI has been equipped with electrical wired HSR communication with implemented IEC 61850 comms protocol.

6.3 EVCP

The development projects undertaken by TPS were to develop the know-how on galvanically isolated DC-DC power converter (eg devices which permit passage of signals between circuits but block stray currents) for use in rail auxiliary power supplies and future energy projects such as EV chargers. The converter was initially targeted at the rail market however the technology once developed and de-risked can be applied in other sectors where galvanic isolation is required.

Figures 16 shows a prototype example of this equipment whilst Figure 17 shows a later product development stage.

The development project was to extend the TPS know-how on the use of high power 1200V and 1700V Silicon Carbide devices. The resulting building blocks or reference designs can then be used to support up-coming programs such as DC-Share.

The DC-DC converter provides galvanic isolation between the power source (750VDC third rail supply) and the equipment mounted within the rail vehicle. The same goes for electric vehicles where maximum safety can be achieved by designing the EV and the CP with fully isolated systems, so the car body stays at earth potential at all time. Before and during the charging process a ground fault monitoring system ensures galvanic isolation is present and maintained. The vehicle will be disconnected from the charge point before it becomes a danger to the vehicle owner.

Galvanic isolation is not a new requirement, but conventional solution was to use a low frequency transformer. This method is no longer acceptable as low frequency transformers are:

- Heavy
- Noise
- Large
- Costly
- Give low Efficiency

The alternative is a high frequency transformer (>20kHz) that solves the above problems.

The base DC-DC development was to produce a viable building block to support galvanic isolation of systems up to 100kW at 500 Vdc output capability. The future for EVCP is inevitably higher power faster charging systems. Therefore, we will no doubt see charging systems go beyond 350kW and 1000Vdc.

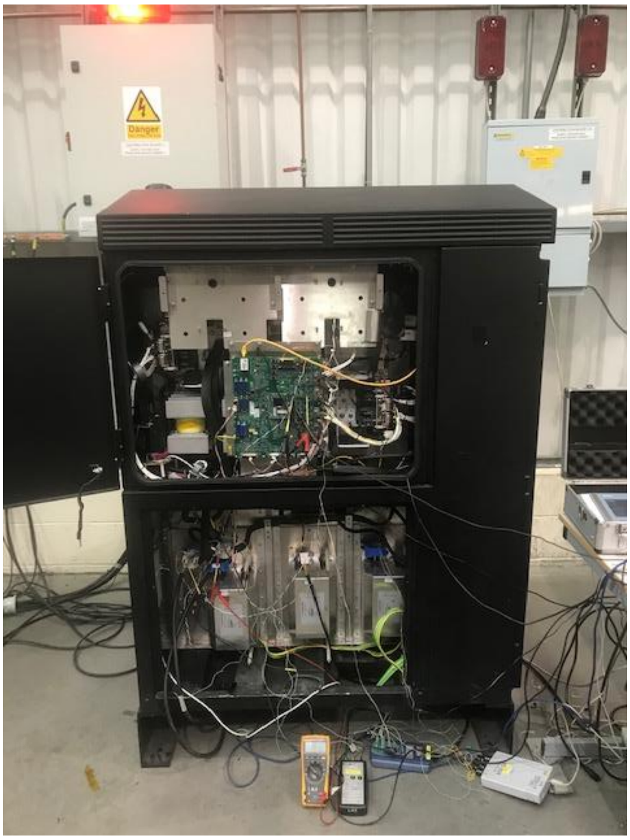
The internal DC-DC development program produced the following benefits:

- Developed and validate reference topology and architecture for use in future projects for EV voltages of up to 500 Vdc.
- Develop and validate a control algorithm and simulation model.
- Identify critical parameters of main power electronics components.
- Test and develop gate drive cards capable of meeting the SiC drives requirement
- Identify low inductance circuit layouts to achieve the expected high efficiency when switching at high frequency

- Develop a reference Build of Materials (BOM) identifying fixed and scalable components.
- Design approach and converter topology to support up-coming applications.
- A functionally tested prototype.
- A Mean Time Before Failure (MTBF) figure for the building block.
- SiC gate drive design
- Control card requirements for HF frequency converters

Figure 17: Original DC-DC Converter From 2014 (rail converter prototype)

Figure 18: Resonant DC-DC Converter 2020 (utilising FUN-LV GTI)



6.4 Control System

6.4.1 Summary of Design & Development Issues (Hardware)

The control system is required to correctly interface with a variety of equipment provided by TPS and also WPD, notably the GTI, EVCP and the Lucy Gridkey AC measurement system.

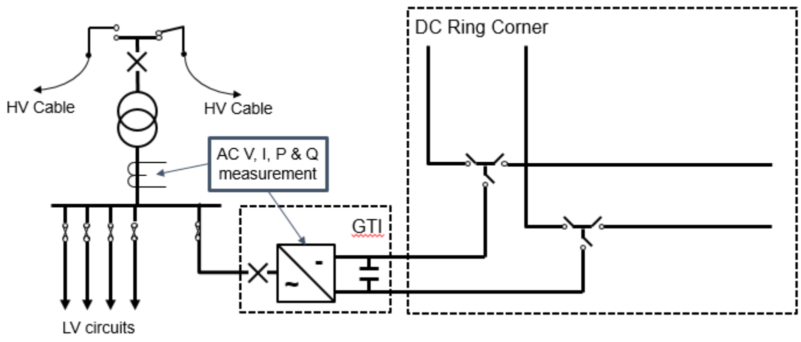
The actual control system hardware will be based upon standard "OTS" computing technology such as PC, HMI etc so no particular design and development issues are foreseen with regards the basic supply.

However, the main aspect that has required some hardware design and development considerations relates to the hardware interfacing requirements between the control system and the other main project equipment plus any special telecommunication arrangements and these are summarised below.

1) Control System Interfacing to the GTI's

   The control system shall extract all necessary analogue data from both the AC and DC networks either side of the GTI as shown in Figure 18 below.

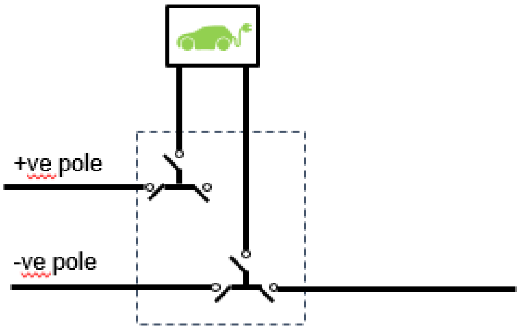
Figure 19: GTI Interfacing



2) Control System Interfacing to the EVCP's

   The control system shall extract all necessary analogue data from both the AC and DC networks either side of the GTI as shown in Figure 19 below.

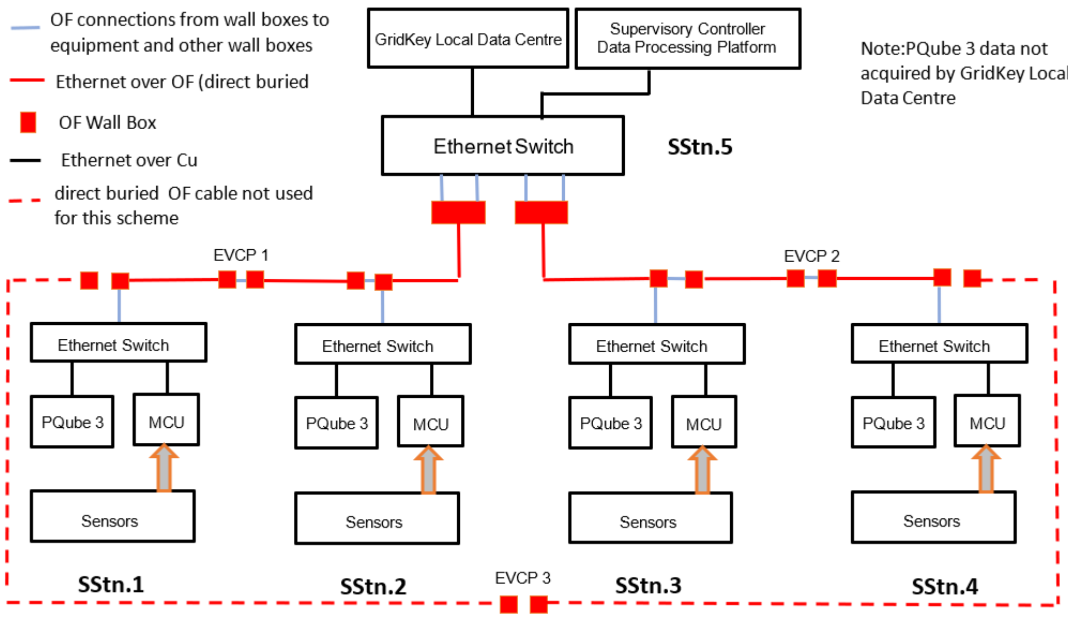
Figure 20: EVCP Interfacing



3) <u>Control System Interfacing to the Lucy Gridkey AC Measurement System</u>

The Lucy Gridkey system will operate via its own separate FO network. The data it receives shall be provided to the Supervisory Controller via standard Ethernet connectivity. Figure 20 below shows the proposed telecommunications infrastructure required for this system.

Figure 21 : Lucy Gridkey Communications Architecture



6.4.2 Summary of Design & Development Issues (Software)

The control system is required to supervise (manage, monitor and control) the entire system.

It achieves this by receiving data, processing it and determining which actions, if any, to take.

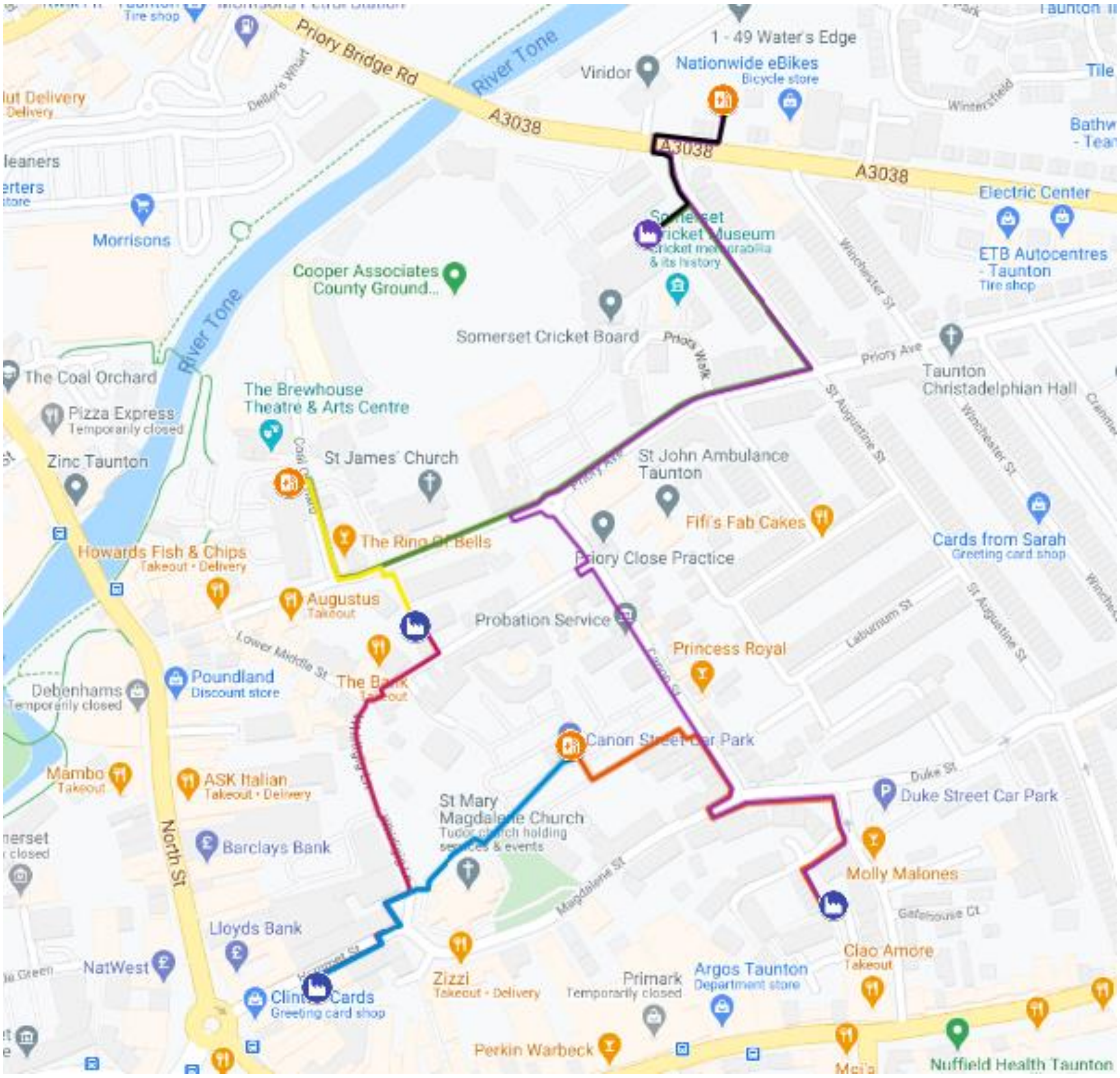
The actions available to the control system are defined within a set of "use cases" which have been developed by Ricardo and discussed/approved by the project team.

These use cases form an integral part of the control and communications tendering document and it is expected that the successful bidder will design bespoke application software based upon the functionality specified within the use cases in readiness for robust factory acceptance testing.

Examples of some use cases are provided within Appendix A.4.

Appendices

A.1.1 Finalised DC Ring Design



Location	Number of 50kw Chargers	Number of 100kw Chargers	Total Number of Chargers
Coal Orchard	2	1	3
Cannon Street	4	2	6
Firepool	4	2	6
Total	10	5	15

A.1.2 Grid Tied Inverter Specifics

The GTI's will facilitate a controlled transfer of power between the substations bringing flexibility to the low voltage network and improving the utilisation of the existing infrastructure; at the same time making DC power available via the DC ring-main for fifteen electric vehicle rapid chargers.

A2.1 GTI Main Specification

Parameter	**Value**
AC Connection Voltage	400V +10%, -6%
AC Connection Frequency	49.5 Hz – 50.5 Hz
AC Connection Power Factor	-0.9 to +0.9, nominal operation at unity power factor
AC Connection number of phases	3
AC Connection neutral connection	Solidly earthed
Continuous rating	250kVA
Dielectric voltage withstands	1.8kV rms, 1 minute
Nominal DC output voltage	800V
EMC	According to IEC61000-2-2
Switching Frequency	20kHz
Heat output	Maximum 7.5 kW (3%)
Ambient temperature operating conditions	-20 to + 40 degrees Celsius
Maximum Noise level	Target: (convertor and cooling system) 56dB(A) at 5m. Measured as per IEC 60076-10:2016
IP rating	41
Dimensions	2004mm (without plinth) x 1450mm x 690mm (H x W x D)
Weight	~700kg

A2.2 GTI Software Safety Functions

The following table summarises the settings of the software-initiated trips.

The protection function will be linked to a lockout function which will count the number of occurrences of the fault within a finite time. In cases where the number of faults, within the time period, is above a predefined level the inverter will be placed in a locked-out state.

Lockouts are classified as Minor or Major where a Minor lockout puts one inverter (e.g. 1 out of 4 GTI's) in lockout but still allowing the other converter(s) to operate. A Major lockout puts the entire system (all four GTI's) in lockout and stops power flow on all GTI's.

Trip	Measurement	Trip level 250kVA	Time to Trip	Hysteresis	Time to Reset	Trips to Lockout	Decrement period	Type of Lockout
DC Link Overvoltage								
DC Link Over Voltage	DC	880	10ms	10	5s	10	2 min	Major
Half DC Link Over Voltage	DC	475	10ms	0	5s	10	2 min	Major
DC Link Undervoltage								
DC Link Under Voltage	DC	680	10ms	10	5s	10	2 min	Major
Half DC Link Under Voltage	DC	175	10ms	0	5s	10	2 min	Major
DC Link Overcurrent								
DC link over current (Long)	DC	345	10ms	0	5s	10	2 min	Major
DC link over current (Short)	DC	390	5ms	0	5s	10	2 min	Major
Half DC Link Over Current	RMS	200	10ms	0	5s	10	2 min	Major
AC Grid Overcurrent								
Grid Over Current (Long)	RMS	400	10ms	0	10s	3	2 min	Minor
Grid Overcurrent (Short)	RMS	450	5ms	0	10s	3	2 min	Minor
AC Grid Overvoltage								
Grid Overvoltage (Long)	RMS	256	1s	0	10s	N/A	N/A	N/A
Grid Overvoltage (Short)	RMS	276	10ms	0	10s	N/A	N/A	N/A
AC Grid Undervoltage								
Grid Undervoltage (Long)	Amplitude	205	10s	10	10s	N/A	N/A	N/A
Grid Undervoltage (Short)	Amplitude	184	500ms	10	10s			
Grid Undervoltage (Immediate)	Amplitude	160	20ms	10	10s			
AC Grid Frequency								
Over Frequency High (Band 2)	Hz	52	10ms	1	5s	N/A	N/A	N/A
Over Frequency Low (Band 1)	Hz	50.5	60s	0	5s			
Under Frequency High (Band 1)	Hz	49.5	60s	0	5s			
Under Frequency Low (Band 2)	Hz	47.5	10ms	1	5s			
Components (Software Based)								
MOSFET Fault*	Logic	1	1ms	N/A	10s	10	2 min	Minor
Temperature Fault (Immediate)	Celsius	70	0	30	N/A	5	30 min	Minor
Components (Interrupt Based Protections)**								
MOSFET Fault Ph	Logic	1	0	N/A	10s	10	2 min	Minor
MOSFET Fault N	Logic	1	0	N/A	10s	10	2 min	Major***
Inductor Ph OC (instantaneous)	peak	+/-650A	0	N/A	10s	N/A	N/A	Major
Inductor N OC (instantaneous)	peak	+/-650A	0	N/A	10s	N/A	N/A	Major

A.1.3 Electric Vehicle Charge Point Specifics

A3.1 DC to DC Power Module Data Sheet (100kW, 500V)

General

The power module (TPS part No 151-322) is a compact, 100kW power supply with an input of 800Vdc. There is a single output with an adjustable range of 50 to 500Vdc up to 200Adc. It is highly suitable as a building block for modular DC Fast Charger for Electric Vehicles.

The main features of the module are:

- Input over/under voltage protection
- Output over current protection
- Output over voltage protection
- Output short circuit protection
- Over temperature protection
- Alarm function

DC to DC Power Module Main Specification

Rated Power kW	Input Voltage Range Vdc	Output Voltage Range Vdc	Output Current Range Adc	Ripple (p-p) Rated Load (%)
100	650 to 850Vdc	50 to 500Vdc	0 to 200Adc	<+/-1%Vo

DC to DC Power Module Environmental Conditions

No	Item	Technical Specification	Unit	Remarks
1	Operating Temperature	-20 to +40	°C	
2	Storage Temperature	-20 to +50	°C	
3	Relative Humidity	≤90	%	
4	Altitude	≤1000	m	
5	Cooling	Forced cooling, TBD has temperature-sensing timing function.		

DC to DC Power Module Electrical Characteristics

No	Item	Technical Specification	Unit	Remarks
6	Rated Input voltage	650 to 850	**Vdc**	
7	Max input current	170	Adc	
8	Max Inrush current	<1	Adc	Pre-charge circuit
9	Output voltage range	50 to 500	Vdc	

10	Rated output range	500	Vdc	At rated input
11	Output current	200	Adc	Output voltage 500Vdc at 200Adc
12	Output power rating	100	kW	
13	Efficiency	≥95	%	At full load
14	Start-up delay	TBC	S	Output voltage up to 500Vdc At rated input voltage
15	Turn on/off overshoot amplitude	≤±5	%	
16	Load regulation	≤±1	%	
17	Input current harmonic	≤5	%	Rated input, rated load
18	Temperature coefficient	TBC	%/℃	

DC to DC Power Module Protection Characteristics

No				
19	Input under voltage protection point	≥(TBC)	Vdc	Will auto recover
20	Input under voltage recovery point	≥(TBC)	Vdc	
21	Input over voltage protection	≥(TBC)	Vdc	Will auto recover
22	Input over voltage recovery	≥(TBC)	Vdc	
23	Output over voltage protection point	≥(TBC)	Vdc	Programable
24	Output over current protection point	≥(TBC)	Adc	
25	Short circuit protection	Can endure circuit without damage Will lockout if short circuit persists		Short circuit detected due to low voltage present
26	Over temperature protection	Heat sink and main magnetics monitored to determine over temperature. Lockout i over temperature persists.		

DC to DC Power Module Safety

No	**Item**	**Technical Specification**	**Remarks**
27	Dialectical strength	3535Vdc/30mA/ 1min	No flashover, no breakdown.

	Input-output		
28	Dialectical strength Input-ground	3535Vdc/30mA/ 1min	
29	Dialectical strength Output-ground	2121Vdc/30mA/ 1min	
30	Isolation resistance Input-output	≥10MΩ@500Vdc	Under STP humidity 90%,
31	Isolation resistance Input-ground	≥10MΩ@500Vdc	
32	Isolation resistance Output-ground	≥10MΩ@500Vdc	
33	ground resistance	＜0.01Ω	Tested at 50A/4min
34	Touch current (Input-ground)	TBC (≤3.5mA)	Review required

DC to DC Power Module EMC

No	**Item**		**Technical Specification**	**Remarks**
35	EMC	CE	CLASS A	
		RE	CLASS A	
		EFT	LEVEL 3 criteria B	IEC61000-4-4
		SURGE	LEVEL 4 criteria C Input meet difference mode ±2KV, common mode ±4KV	IEC61000-4-5
		DIP	Drop to 70%UT, duration 10ms, at angle of 0°,45°,90°,135°,180°,225°,270°,315°, meeting class B. Drop to 40%UT, duration 100ms, at angle of 0°,45°,90°,135°,180°,225°,270°,315°, meeting class C. Drop to 0%UT, duration 5000ms, at angle of 0°,45°,90°,135°,180°,225°,270°,315°, meeting class C. IEC61000-4-11 ESD	IEC61000-4-11
		ESD	For the shell which would be touched by human in the normal operation: contact discharge +/-6KV ; air discharge+/-8KV standard B.	IEC61000-4-2
		ESD	For the shell which would be touched by human in the normal operation, contact discharge+/-8KV ; air contact +/-15KV standard R.	
		CS	LEVEL 3 criteria A	IEC61000-4-6
		RS	LEVEL 3 criteria A	IEC61000-4-3

		Voltage fluctuation and flicker	Pst≤1.0 P1t≤0.65； dc≤3%； dmax≤4%； The time of d (t) ≥ 3% is no more than 200mS.	IEC61000-3-3
		Current harmonic	CLASS A	IEC 61000-3-2 [6]
		Anti Lightning	The AC input terminal can endure surge current wave of 5kA、8/20μS , 5 times each for positive and negative， time cycle 1 minute.（refer to standard：YD 5098-2001）.	

A3.2 EVCP Data Sheet

General

Item	Technical Specification
DC Power Supply	+Ve pole / 0V / -Ve pole
DC Voltage	+400Vdc, 0V, -400Vdc
Nominal DC Voltage Range (pole to pole)	800Vdc
Efficiency	95% at full load
Input Protection	Semiconductor protection fuse in each pole
Output Safety Protection	• Sendyne isolation monitor for unearthed (IT) DC power systems • Backed up with RCD Type B
Network Connection	Ethernet 10/100BaseTX
Interface protocol	OCPP 1.6J
Compliance	• CE / Combo-2, (DIN 70121; ISO15118), IEC 61851-1; IEC 61851-23, IEC 61851-21-2 • CHAdeMO compatible
Enclosure Rating	Designed to meet IP57 / IK10
Enclosure Material	Stainless steel
Operating temperature	-20 ºC to +40 ºC
Ambient temperature storage	-20 ºC to +60 ºC
Operating humidity	5 % to 95 % Non-condensing
Socket protection	TBC (Locking System)
RFID system	TBC (ISO / IEC14443-1/2/3 MIFARE Classic)
Display HMI	TBC (8” colour antivandal touch screen)
Power limit control	DC by software
DC cable length CCS	TBC (3 meters)

DC cable length CHAdeMO	TBC (3 meters)
Lights for status indication	TBC (RGB colour indicator)
Dimensions (D x W x H)	TBC Width, 900mm Height, 1800mm (excluding plinth) Depth, 400mm
Weight	TBC
Cooling system	Air cooling fans
Operational noise level	TBC (< 55 dBA)
DC Power Meter	LEM DCBM400
Wireless Communication EU	4G LTE/WiFi Hotspot/GPRS/GSM
Contactless payment	TBC (Integrated credit card payment terminal)

EVCP CHAdeMO Output Rating (50kW)

Item	Technical Specification
Maximum DC input current	66 ADC
Required power supply capacity	52.5 kW
Maximum output power	50kW
Output voltage range	50 – 500 VDC
Maximum output current	125 ADC
Connection	CHAdeMO / JEVS G 105

EVCP CHAdeMO Output Rating (100kW)

Item	Technical Specification
Maximum DC input current	132 ADC
Required power supply capacity	105 kW
Maximum output power	100kW
Output voltage range	50 – 500 VDC
Maximum output current	200 ADC
Connection	CHAdeMO / JEVS G 105

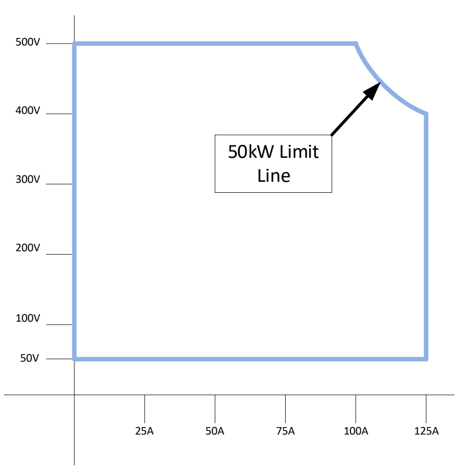
EVCP CCS Output Rating (50kW)

Item	Technical Specification
Maximum DC input current	66 ADC
Required power supply capacity	52.5 kW
Maximum output power	50kW
Output voltage range	50 – 500 VDC
Maximum output current	125 ADC
Connection	CCS Combo Type 2

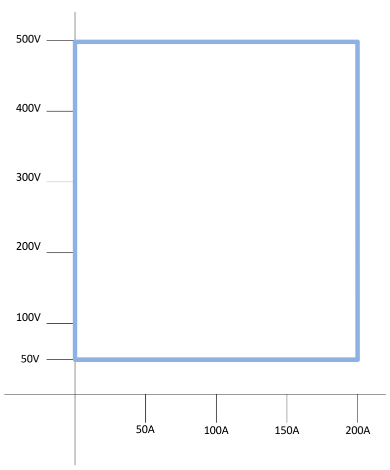
EVCP CCS Output Rating (100kW)

Item	Technical Specification
Maximum DC input current	132 ADC
Required power supply capacity	105 kW
Maximum output power	100kW
Output voltage range	50 – 500 VDC
Maximum output current	200 ADC
Connection	CCS Combo Type 2

50kW CHAdeMO and CCS Power Graph



100kW CHAdeMO and CCS Power Graph



A.1.4 Supervisory Controller Use Cases

Bespoke software shall be developed and implemented to provide the functionality defined within the set of use cases specified below.

Under Normal Operation

- N1: Pre charge the DC cable in normal operation
- N2: Enabling a GTI when the DC cable is charged in normal operating conditions
- N3: GTI enters standby due to no EV charging or power transfer through the DC network in normal operating conditions
- N4: Discharge the DC cable in normal operation
- N5: Interface for charging EV with communications
- N6: Interface for charging EV when communications fails
- N7: Calculating if Limits are Exceeded
- N8: Responding to limits at the AC substation or DC network
- N9: Decreasing EVCP charging demand
- N10: Increasing the maximum charging demand at an EVCP
- N11: Disabling the EVCP
- N12: EV charging load shared equally among GTIs
- N13: EV charging shared depending on AC substation utilisation
- N14: Equalising the AC substation and EVCP load through the DC network
- N15: Minimising DC Cable Losses for EVCP load
- N16: Number of GTIs enabled depends on EVCP loading
- N17: Phase balancing at an AC substation
- N18: Power factor control at an AC substation (reactive power)

Under Fault Conditions

- F1: Pre charge the DC cable with a DC fault
- F2: DC cable fault
- F3: Identifying the faulted section of DC cable

- F4: GTI fault
- F5: EVCP fault
- F6: Loss of mains at an AC substation
- F7: GTI emergency stop pressed
- F8: GTI Pre-charge failure

Supervisory Control Interactions

- 1. S1: Manual start-up of the DC Share network through the DC Share Visualisation and Control
- 2. S2: Manual adjustment of the DC Share network thought the DC Share Visualisation and Control
- 3. S3: Shutdown of the DC Share network through the DC Share Visualisation and Control
- 4. S4: Reporting of the measurement data to the DC Share Visualisation and Control
- 5. S5: User access to the measurement data from the DC Share Visualisation and Control

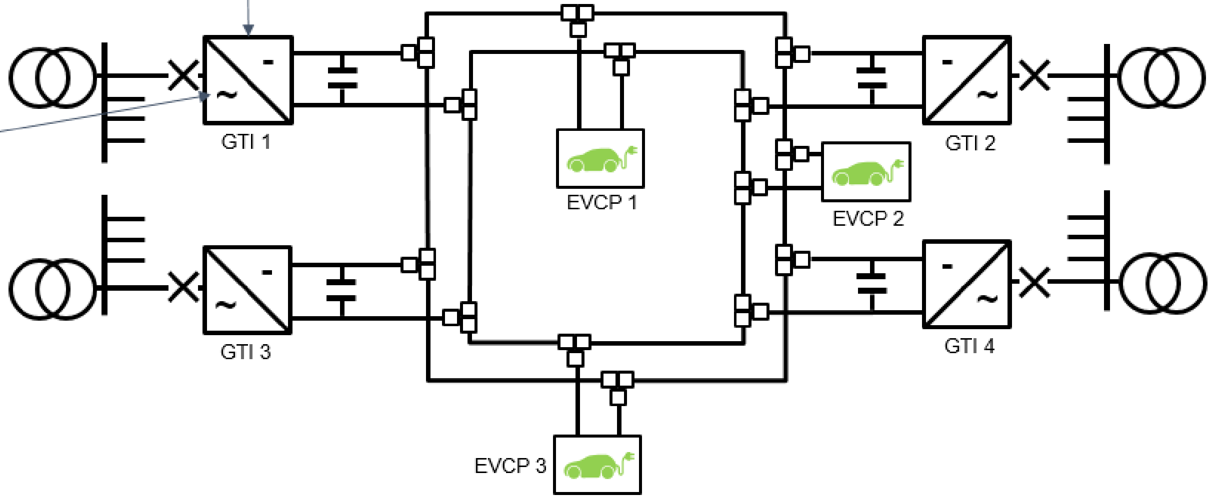
Examples relating to the information contained within each type of use case is provided below.

Use Case N1: Pre charge the DC cable in normal operation

All DC Switches are manual

1. Supervisory Controller sends signal for external pre-charge circuit to switch on and pre-charge(~550 Vdc) DC network

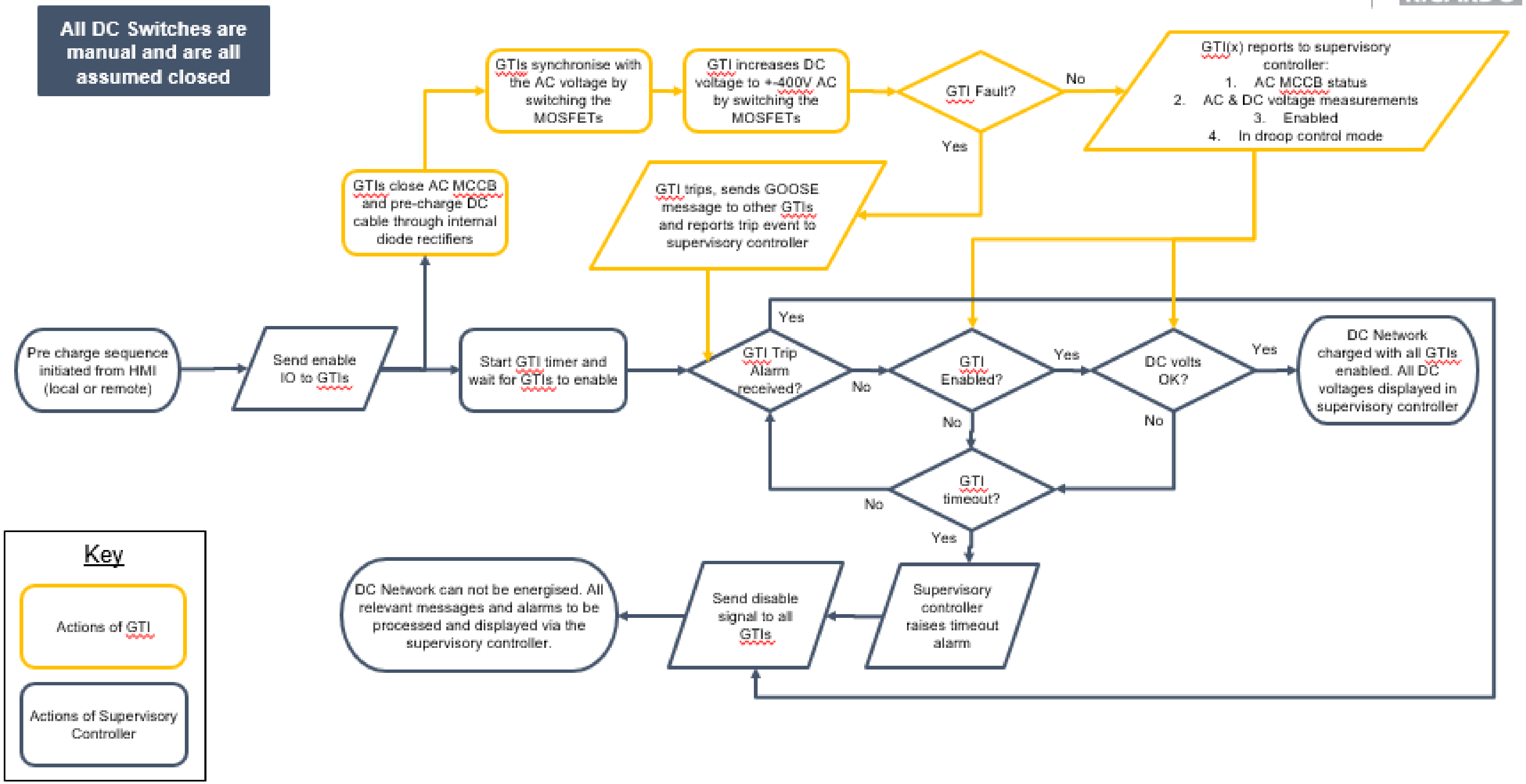
2. Pre-charge circuit reports the DC network is charged and sends measurements back to the supervisory controller



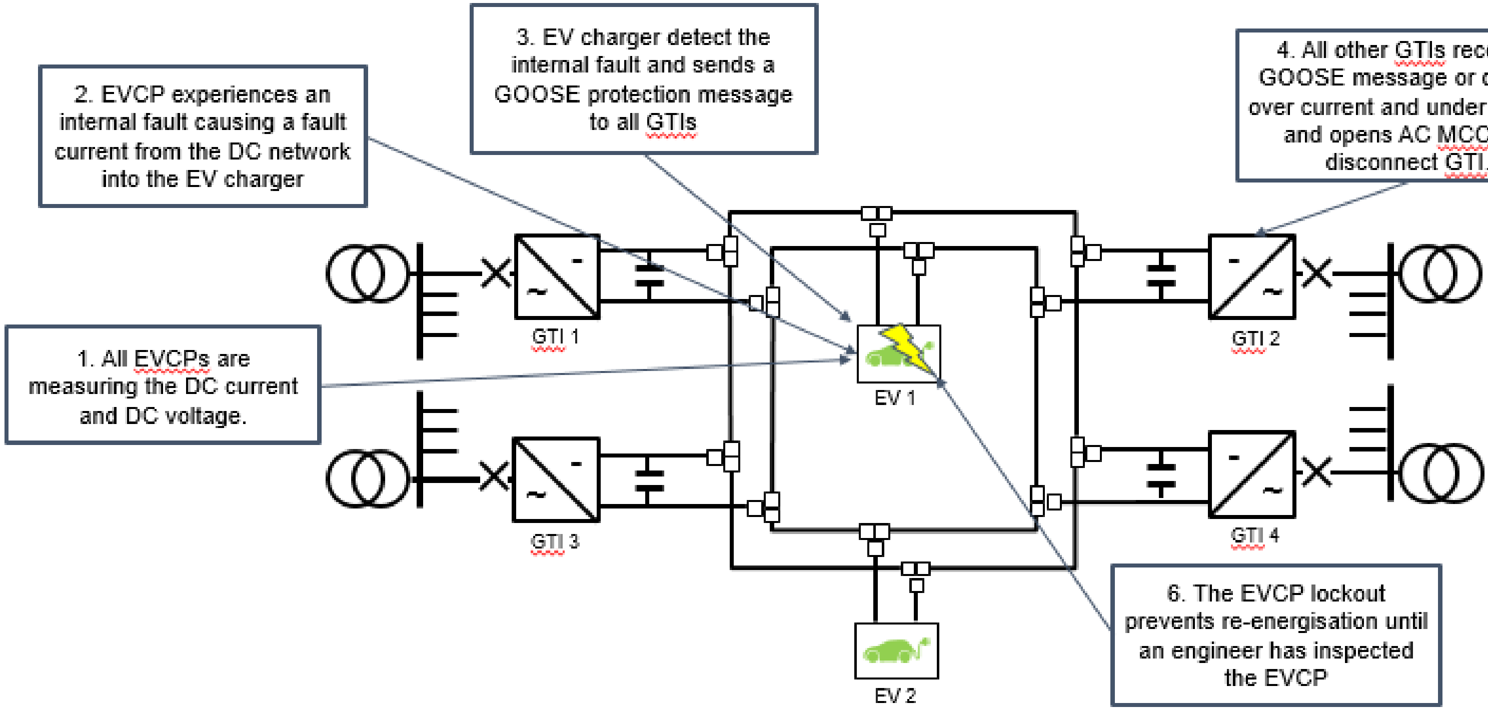
Prerequisites
1. There are no faulty sections of network.
2. All DC isolators are closed. If any DC isolators are open, refer to use case F1 before executing this use case.
3. The DC network is de energised and AC MCCB are open.

- Sequence starts with all GTIs disconnected from the AC supply and all DC isolators closed (from previous manual operation).
- An external pre-charge circuit is instructed to charge the DC cable by sending a pre-charge signal. Failure to pre-charge the DC cable, or if one GTI experiences a fault during pre-charge, will result in the GTI disconnecting (Use Case F8). Once the DC network is pre-charged, the GTIs can be enabled (Use Case F2).
- There is an external pre-charge circuit at every GTI responsible for pre-charging the DC cable.

Use Case N1: Pre charge the DC cable in normal operation flowchart



Use Case F5: EV charger fault

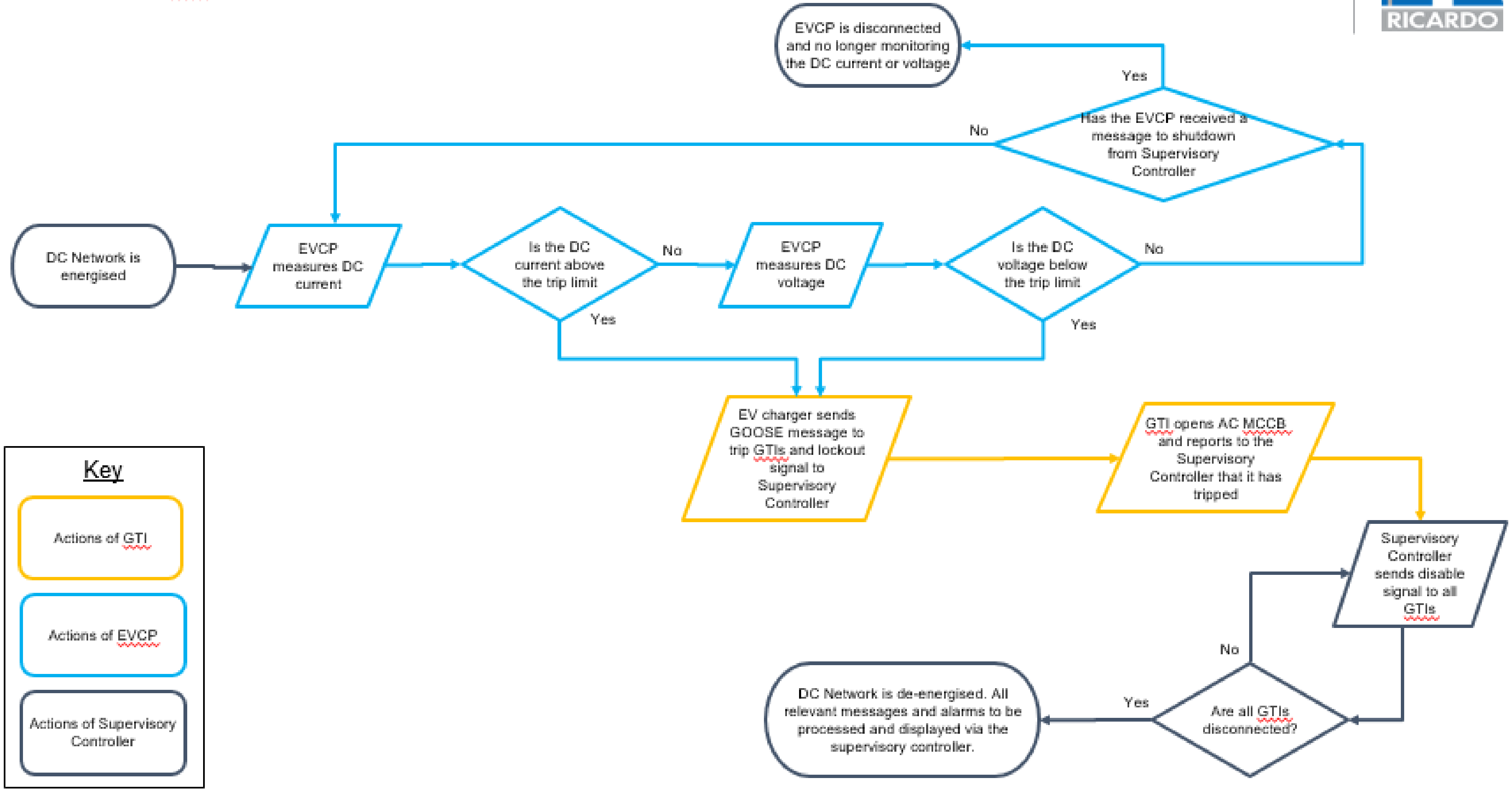


Prerequisites

1. The DC Share network is energised
2. The communications network is functioning correctly.
3. The GTIs are able to broadcast and receive GOOSE messages.
4. The GTIs shutdown on receipt of the shutdown GOOSE message.

- When a fault occurs at the EV charger, the EV charger should detect it has an internal fault and send a GOOSE message to the GTIs. On receipt of the GOOSE message, all GTIs should shut down. If unable to issue GOOSE then the remaining GTI's should automatically detect and disconnect regardless.
- The GTIs may also detect the fault and open their AC MCCB based on their DC current and voltage measurements. This would be the same process as a DC cable fault (Use Case F2).
- The DC Network should lockout preventing re-energisation until the faulted EVCP has been isolated from the DC cable network.

Use Case F5: EV charger flowchart



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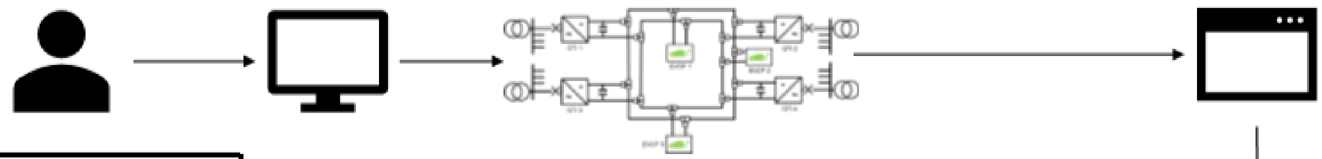
Use Case S1: Manual start-up of the DC Share network through the DC Share Visualisation and Control



Prerequisites
1. The communications network is functioning correctly.
2. All equipment in the DC Share network is able to send measurement information and receive control commands.
3. The User has sufficient training to operate the HMI.

GTI Visualisation
- GTI1, DC: V & I, AC: V, I, P & Q
- GTI2, DC: V & I, AC: V, I, P & Q
- GTI3, DC: V & I, AC: V, I, P & Q
- GTI4 DC: V & I, AC: V, I, P & Q

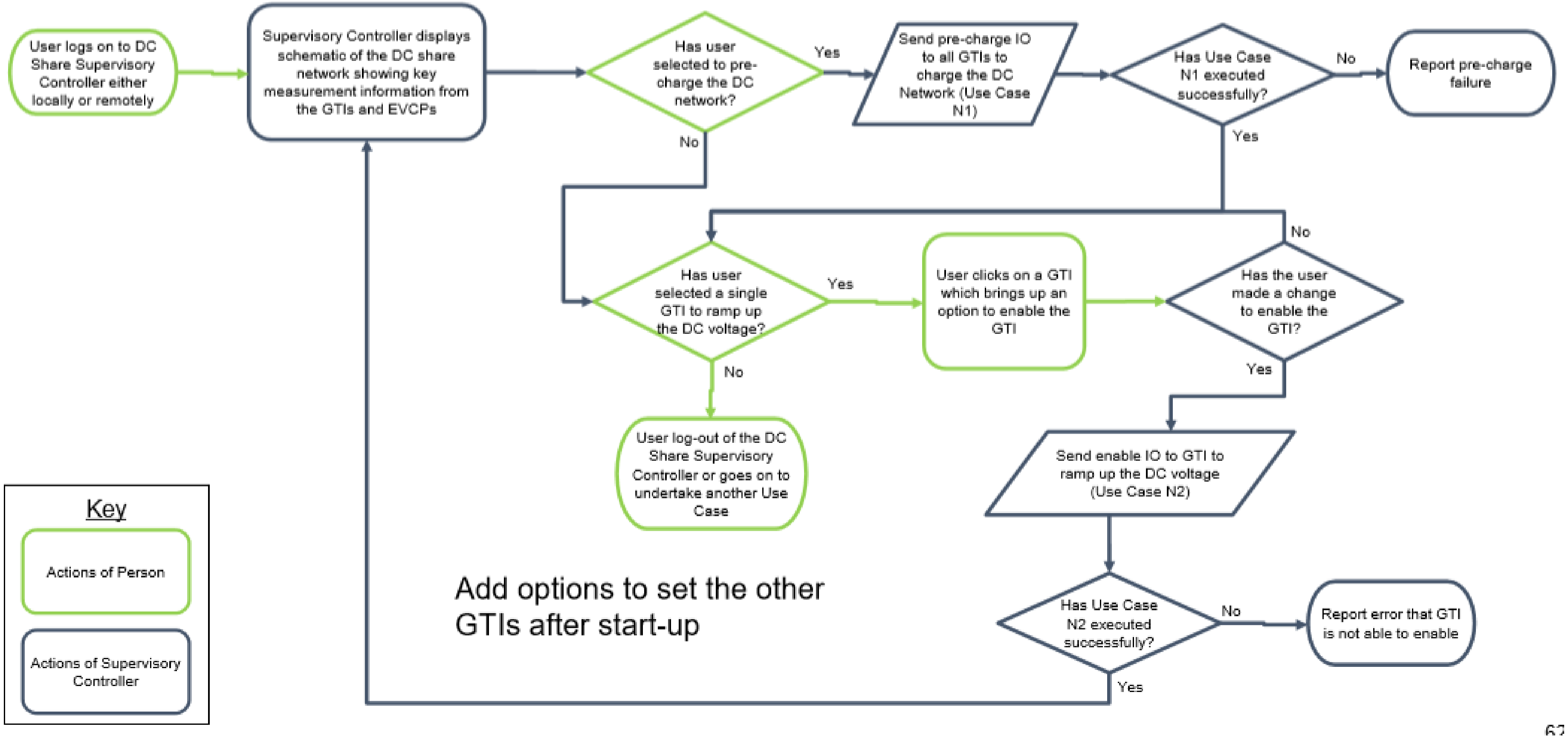
DC Visualisation
- DC: V, I & P

AC Substation Visualisation
- AC: V, I, P & Q

GTI Control
- Enable All GTIs
- Enable GTI1
- Enable GTI2
- Enable GTI3
- Enable GTI4

- This use cases describes the actions of the user to start the DC Share network using the HMI from the supervisory visualisation and control interface.
- The HMI reports the status of all measurements in the AC and DC network. User choses how to start up the network based on Use Case N1 or Use Case N2. The user is able to enable the GTIs and observe the charging of the DC network.
- Each GTI may need to be individually started when looking for a GTI fault in the network.

Use Case S1: Manual start-up of the DC Share network through the DC Share Visualisation and Control flowchart



A.1.5 Communications Cabling and Equipment

Fibre Optic (FO) cabling shall be subject to WPD Telecomms Department Provision but shall be based upon the following cable:

EMTELLE

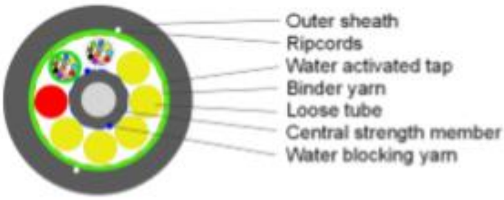
Cable Proposal CP2651-WPD

Issue 2 24th October 2016 Page 1 of 1

FibreFlow™

24F Duct Cable

Western Power Distribution



Application

All dielectric optical fibre cable designed for blowing or pulling into ducting.

Features and Benefits

Sheath:	High density polyethylene with carbon black, UV-stable
Water Blocking:	Gel-filled loose tube, water blocking elements
Strain Relief	FRP central strength member
Standard fibre type:	Single mode to G652D (ITU-T)
Specification	complies with the requirements of WPD Engineering Specification EE SPEC: 63/1
Fibre Attenuation (20°C):	0.33 dB/km max at 1310 nm and 1383 nm 0.21 dB/km max at 1550 nm 0.23 dB/km max at 1625 nm
Cable mass	152 g/m nominal
Cable outer diameter	12.2 mm nominal
Bending radius	20 x cable diameter minimum during installation 10 x cable diameter minimum in service
Working load	2.6kN (0.05 dB/km max increase, fibre strain minimal)
Breaking load	10kN minimum

FIBRE IDENTIFICATION

12 Fibres per tube

Fibres coloured as

(1) blue; (2) orange; (3 green; (4) brown; (5) Grey; (6) white;
(7) red; (8 black; (9) yellow; (10) violet; (11) pink; (12) aqua

SHEATH MARKING

Marked every 1m with

Surf Telecoms SPEC 63/1 - Fibre Count – Emtelle – Year– Meter Mark

Example of FO Termination Box (Subject to WPD Telecomms Department Provision)

24 Core Capacity Fiber Optic Termination Distribution Termination Box Gray Color

Large Image : 24 Core Capacity Fiber Optic Termination Distribution Termination Box Gray Color

Product Details:

Place of Origin:	China
Brand Name:	YUHUI
Certification:	ISO,RHOS,UL,CE
Model Number:	YH-1220-24

Payment & Shipping Terms:

Minimum Order Quantity:	200pieces
Price:	Negotiation
Packaging Details:	1piece/box
Delivery Time:	15days
Payment Terms:	TT,LC,West Union
Supply Ability:	5000pieces/month

Contact Now

Example of Media Convertor (Subject to WPD Telecomms Department Provision

Ethernet Media Converters

Product/Art. no	Description
MCW-211 3645-0xxx 	**Industrial Ethernet Media Converter** 1 x 10/100 Mbit/s, Ethernet TX 1 x 100 Mbit/s, Ethernet FX Operating voltage: 10-60 VDC Operating temperature: -25 to +70 °C (-10 to +158 °F)
MCW-211-F1G-T1G 3645-2001 	**Industrial Ethernet Gigabit Media Converter** 1 x 100/1000 Mbit/s, Ethernet TX, RJ-45 1 x 100/1000 Mbit/s, Ethernet FX, SFP Operating voltage: 9.6-57.6 VDC Operating temperature: –40 to +74 °C (–40 to +165 °F)

A.1.6 Lucy Gridkey & Power Quality Measurement Equipment

GRIDKEY

Why choose the GridKey MCU318?

GridKey is a custom designed continuous monitoring solution for low voltage (LV) networks. It consists of a number of current sensors on each feeder together with voltage taps, connected to a Metrology and Communications Unit (MCU) which processes the sensor data and generates and logs substation loading and condition parameters.

This information is relayed to a cloud based data centre where the data is securely stored, analysed and displayed. Substation performance and feeder cable condition can be analysed via our customer web portal.

The GridKey MCU318 LV monitoring system is designed specifically to offer a flexible and highly configurable information system with the following benefits:

- Safe and easy retrofit solution for installations indoors and out – lightweight and compact with no interruption of customer supply
- Built to be weather resistant – IP54 rated; meeting relevant electrical standards for external and internal substation use
- When used with SlimSensor modified Rogowski sensors the system provides class 2 metering accuracy – on three phases of up to 6 feeders
- Comprehensive reporting of substation feeder and calculated busbar parameters, giving better information to drive evidence based decision making for grid management
- Compact design allows the system to be fitted internally within LV cabinets reducing the risk of theft or vandalism. A built-in GPRS modem and antenna provides reliable communications
- A secure Wi-Fi connection to the unit is provided to allow configuration and testing whilst installing
- GridKey are able to supply a cost effective roaming SIM card, which forms a secure data link with the GridKey data centre. These can be soldered directly onto the PCB to improve security and reliability.

The customer can choose to configure and generate alert messages that would be sent via the data network system for multiple grid measurement states, for example to provide indications and warnings of any over or under voltage currents.

The information and alerts provided enable network managers to make evidence based decisions and plan effectively for future preventive maintenance and capital expenditure.

Page 1

Lucy Electric

Specifications

Metrology

Measurement Standards	Class 2 in accordance with EN 62053-21 when used with Slimsensor current sensors
Electrical safety standards	EN 61010-1: 2010, with corrigendum May 2011 EN 61010-2-030: 2010
Over voltage	300 V rms category IV. pollution degree 3
Current measurement range	Accurate up to 720 A AC per feeder phase No damage at any over-current condition
Operating voltage and measurement range	230V AC + 15%, -20% rms phase to neutral
Line frequency	50Hz (nominal)

Protection, Environmental & Compatibility

IP Rating	IP54
Electromagnetic compatibility	EN 61000-6-2 immunity EN 61000-6-4 emissions
Surge protection	IEC61000 6kV
Operating temperature range	- 20ºC to 55ºC (<93% RH, non-condensing)
Storage temperature range	- 25ºC to 70ºC
Altitude	Up to 2000m

Mechanical

Size (h x w x d)	300mm x 245mm x 80mm
Weight	1.35 kg
IP category	IP54 IEC 60529
Impact	EN 62262 IK06
Power	Power from single phase only, 6W typical, 11W maximum (GPRS enabled)
Communications interfaces	GSM/GPRS quad band 850/900/1800/1900 MHz Any network SIM can be provided by customer

GridKey is a collaboration between Sentec, the smart grid and metering specialists and Lucy Electric, experts in the design, development, manufacture and integration of a wide range of sensor and data exploitation systems.

For more information about GridKey please contact us:
Website: www.gridkey.co.uk
Email: info@gridkey.co.uk

Phone: +44 (0)1268 850000

GKSS0818

DATA SHEET

pqube3.com

PQube® 3 Power Analyzer

OVERVIEW

This compact instrument is simply the best power monitor and real-time sensor you can buy.

It records every type of AC power disturbance—including 4 MHz sampling of impulses—Class A certified, ultra-precise revenue-grade energy meter. Monitor up to two 3-phase loads, or eight single-phase loads with a single instrument.

It goes beyond AC power too. Records environmental data—such as temperature, humidity and barometric pressure, vibration, 3-axis acceleration—as well as process parameters, for example: torque, RPM, fuel level, water flow, and more.

Easy to install, easy to use.

Delivers ultra-precise results immediately to your inbox.

FEATURES

- Installs easily with an ultra-compact footprint
- Connects directly to voltages up to 690 V
- Certified for Class A power quality according to IEC 61000-4-30 Ed3
- Computes 4-quadrant ANSI Class 0.2 revenue-grade energy on eight single-phase channels
- Monitors DC power and process parameters with four additional AC/DC analog channels
- Detects and records high-frequency impulses at 4 MHz
- Measures in real time and records 2 kHz ~ 150 kHz emissions
- Auto-detects the mains frequency, wiring configuration and nominal voltage
- Holds years of data and thousands of events via 32 GB of internal flash memory

RESULTS

- Real-time readings via protocols: Modbus and SNMP
- Events recordings and graphs: CSV, GIF, and PQDIF
- Daily, weekly, monthly trends and graphs: CSV, GIF, and PQDIF

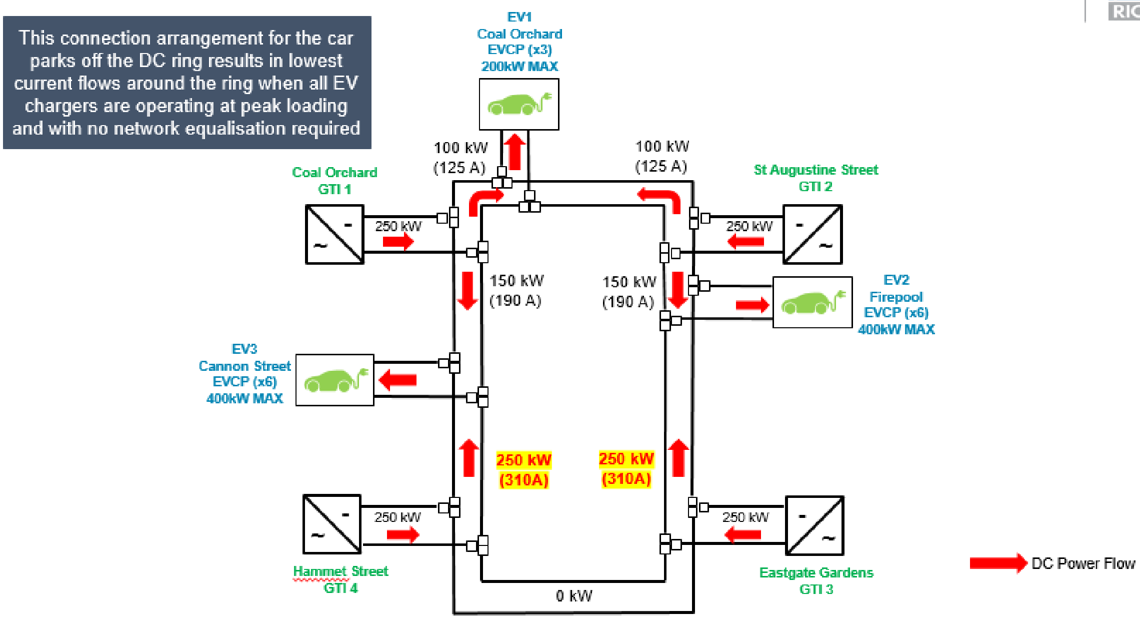
Above & Beyond Power Quality

www.powerstandards.com

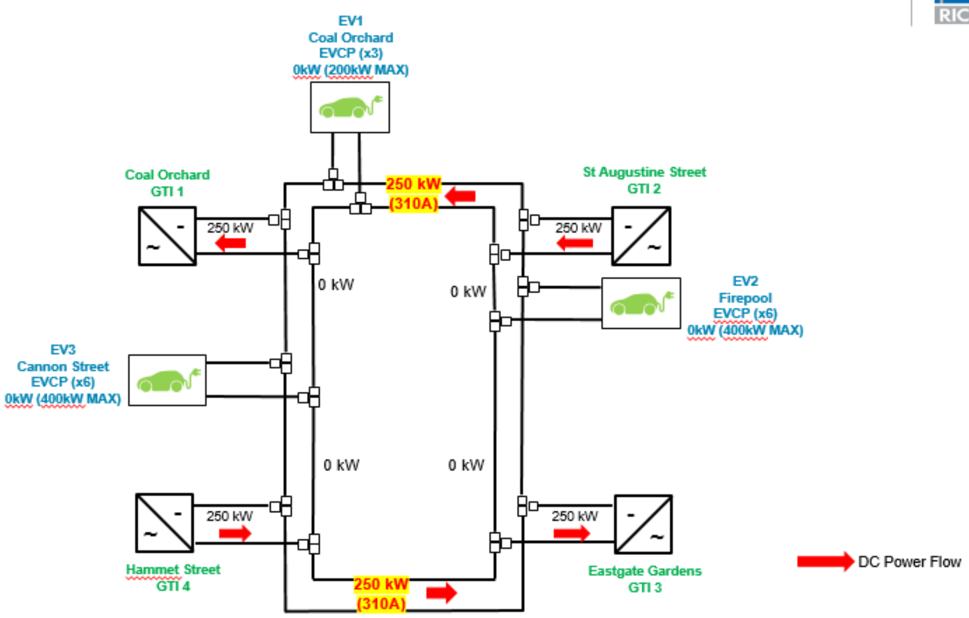
A.1.7 DC Ring (Power Flow) Design & PLECS Simulation

A selection of slides from the complete DC Ring (Power Flow) analysis datapack is provided below along with the results sheet after running the PLECS simulation model.

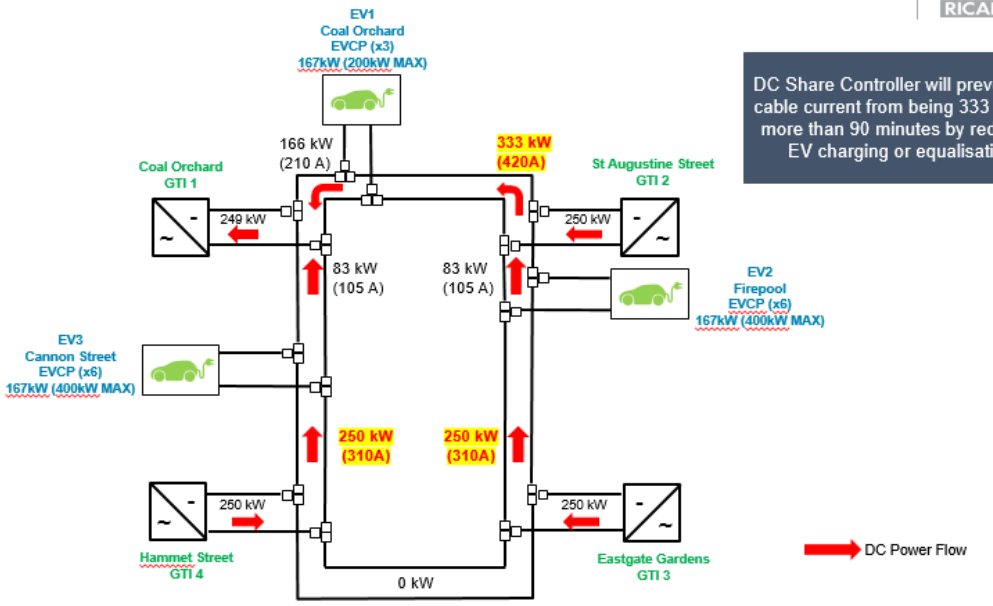
DC Network 100% EV Charging @ 1MW



DC Network Balancing Example #2: GTI 2 Direct to GTI 1 and GTI 4 Direct to GTI 3

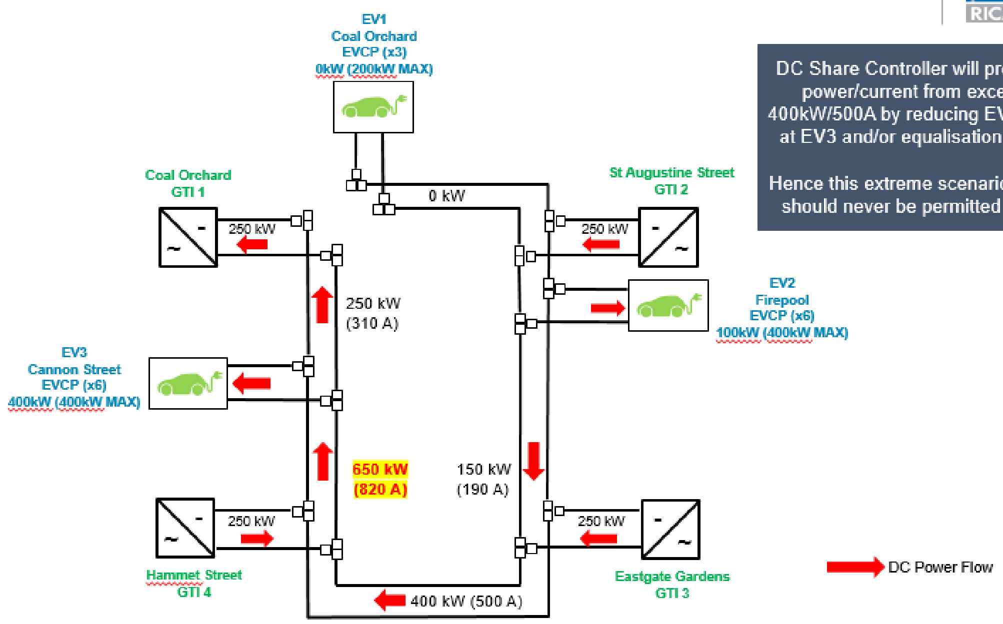


DC Network Supporting Balanced EV Charging Whilst Fully Exporting at GTI1



DC Share Controller will prevent the cable current from being 333 kW for more than 90 minutes by reducing EV charging or equalisation

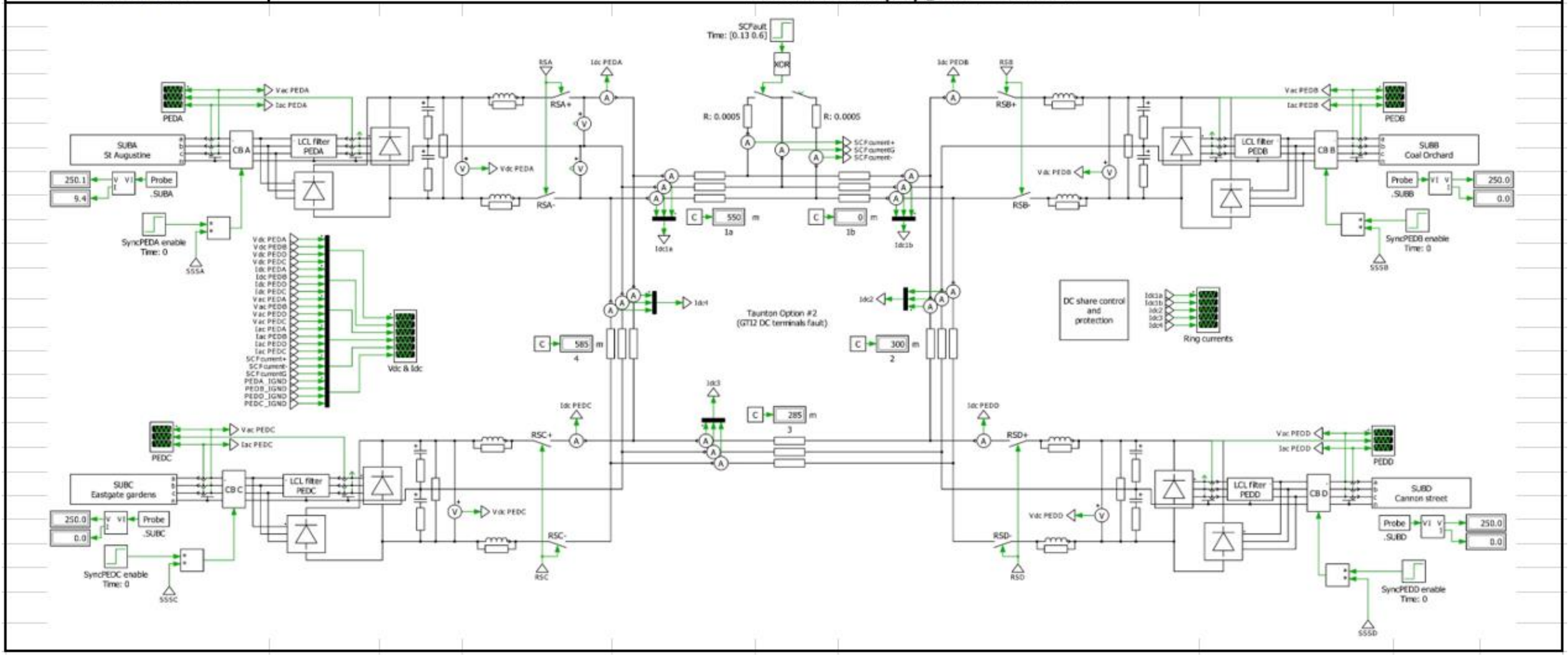
DC Network Supporting EV Charging and Exporting at One Substation with a Cable Outage



DC Share Controller will prevent the power/current from exceeding 400kW/500A by reducing EV charging at EV3 and/or equalisation at GTI 1

Hence this extreme scenario (650kW) should never be permitted to occur

DC Share Fault Simulation Network	
Fault Location	**DC terminal fault (0m) @ GTI2 DC terminals**



Summary

Two fault studies have been presented one where the fault is located at the at the terminals of GTI2 and the second where the fault is located in the middle of the cable between GTI1 and GTI4

The results from the fault studies are summarised as follows:

Peak AC fault current drawn by the GTIs	16.5411	kA
Peak DC fault current exported by the GTIs	37.852	kA
Peak fault current in the DC cables	42.5508	kA
Peak fault current at the location of the fault	45.4225	kA
Maximum fault clearance time	0.075	s
Required I^2t withstand of the DC cables	1.453133	MA^2s

A.1.8 AC Cabling Data Sheet

AC Cable

Jun 2013

TRATOS

Flexible cables

TRATOS® C-TRI-RATED - Superflexible

PVC Tri-rated appliance wire 0.6 / 1kV 105 °C single core single insulated. Suitable for all fixed wiring switchboard / control panel applications. Significant reduction in wiring installation time due to flexibility and ease of handling; Smaller and more compact panel construction feasible due to bending radius and flexibility; Very fine untinned copper wire ensures high flexibility; Special 105 °C PVC insulation provides outstanding flexibility and mechanical strength; Self extinguishing - does not sustain combustion;
All cables are metre-marked and product coded.

TRATOS® C-TRI-RATED

CONSTRUCTION & FEATURES

- **Copper:** plain annealed
- **Insulation:** Flexible PVC 105 °C
- **Insulation colours:** red, blue, black, white and earth in all sizes. Orange, grey, pink, purple and brown also available 0.75mm2 to 2.5mm2. Other colours available on request.

TECHNICAL INFORMATION

- **Minimum operating temperature:** 0 °C
- **Maximum operating temperature:** 105 °C
- **Voltage rating:** 0.6 / 1kV
- **Min. Bending radius:** 3 x Ø
- **Standards:** BS 6231, UL 83, CSA C22.2, UL Flame test UL 1581/ VW1 FT1 FT2
- UL / CSA approved

TRATOS C-TRI-RATED®

Nominal Cross Sectional Area mm²	Diameter of wires in conductor (max.) mm	Nominal Insulation mm	Overall Diameter (max.) mm	Weight (approx.) kg/100m	Size AWG	Current Rating Max. A
0.50	-	-	-	-	22	11
0.75	0.21	0.8	2.8	1.5	20	14
1.0	0.21	0.8	2.9	1.8	18	17
1.5	0.21	0.8	3.2	2.4	16	21
2.5	0.21	0.9	3.8	3.7	14	30
4	0.21	1.0	4.5	5.6	12	41
6	0.21	1.0	5.2	8	10	53
10	0.21	1.3	6.7	13	8	75
16	0.21	1.5	8.4	21	6	100
25	0.21	1.5	9.7	30	4	136
35	0.21	1.6	11.2	41	2	167
50	0.21	2.0	13.4	58	1	204
70	0.21	2.0	15.3	77	2/0	259
95	0.21	2.0	17.2	103	3/0	321
120	0.21	2.3	19.4	130	-	374
150	0.21	2.4	21.4	162	-	440
185	0.21	2.4	24.1	196	-	485
240	0.21	2.4	26.9	252	-	595
300	0.21	2.8	30.1	314	-	680

* 150mm, 185mm, 240mm and 300mm are only available in bi-rated
** 0.75mm up to 6mm cables are only available on 100m reels

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A.1.9 DC Meter Data Sheet & PTB Certification

Direct Current Billing Meter DCBM Series

Ref: DCBM 400, DCBM 600 series

DCBM Series are static energy meters dedicated to DC Energy metering and billing. DCBM Series provide a reliable energy metering solution in the field of DC applications, adapted to cover the complete range of Electric Vehicle DC chargers up to 600 kW (Ultra-fast Charging station).
DCBM Series include 4-wire measurement system, cable loss compensation, live measurement, and signed data through Ethernet interface.

Features

- Range of operation 150 VDC to 1000 VDC
- Two sizes: Imax 400A and 600A
- Bi-directional metering for Vehicle to Grid (V2G)
- Accuracy Class B
- Compatible with 4 wire measurement
- Cable loss compensation
- Ethernet communication with HTTPS/REST protocol
- Signed data readouts in OCMF / LEM protocol
- Transaction mechanisms with start & stop tags
- Wide power supply range +12 ... +48 V DC
- DIN rail 35mm and screw mounting
- Meter Unit operating temperature range: -25°C to 70°C
- Sensor Unit operating temperature range: -40°C to 85°C
- Integrated display with backlight
- Reinforced insulation at 1000 VDC, OVC II
- Physical security seals

Advantages

- Split meter concept easy to integrate into systems
- Flexible integration with busbars or wires
- OCMF readouts compliant with S.A.F.E
- Compliant for energy billing or parking time billing
- System monitoring: Current, Voltage, Power, Temperature

Applications

- Electric Vehicle Charging infrastructures
- Data centers
- DC grids & Energy Monitoring

Standards

- EN 50470-1:2006
- EN 50470-3:2006
- PTB 50.7
- CISPR32 Class-B emission
- EN 62052-31:2015
- IEC 62052-11:2003
- IEC 61000-6-2:2016
- IEC 61000-6-3:2016
- UL94-V0
- Designed according to VDE-AR-E-2418-3-100

N° 92.47.10.153.0 Page 1/11

L18005ASDA/version 0

LEM reserves the right to carry out modifications on its transducers, in order to improve them, without prior notice

LEM International SA
Chemin des Aulx 8
1228 PLAN-LES-OUATES Switzerland
www.lem.com

PTB
Physikalisch-Technische Bundesanstalt
Nationales Metrologieinstitut

KBS
Konformitätsbewertungsstelle

Baumusterprüfbescheinigung

Type-examination Certificate

Ausgestellt für: *Issued to:*	LEM International SA Chemin des Aulx 8 1228 Plan-les-Ouates SCHWEIZ
gemäß: *In accordance with:*	Anlage 4 Modul B der Mess- und Eichverordnung vom 11.12.2014 (BGBl. I S. 2010) *Annex 4 Modul B of the Measures and Verification Ordinance dated 11.12.2014 (Federal Law Gazette I, p. 2010)*
Geräteart: *Type of instrument:*	Gleichstromzähler (elektronisches Messwerk) mit abgesetzten Strom- und Spannungssensor
Typbezeichnung: *Type designation:*	DCBM...
Nr. der Bescheinigung: *Certificate No.:*	DE-20-M-PTB-0075
Gültig bis: *Valid until:*	05.10.2030
Anzahl der Seiten: *Number of pages:*	45
Geschäftszeichen: *Reference No.:*	PTB-2.3-4095087
Nr. der Stelle: *Body No.:*	0102

Zertifizierung: *Certification:*	Braunschweig, 06.10.2020	Bewertung: *Evaluation:*
Im Auftrag *On behalf of PTB*	Siegel *Seal*	Im Auftrag *On behalf of PTB*

Dr. Christoph Leicht *Dr. Michael Blaz*

A.1.10 Fibre Optic Ducting Specification

Product Specification

PVC DUCT GENERIC SPECIFICATION EN CLASSES (TELECOMMUNICATIONS DUCTING)

1.0 General

1.1 Emtelle uPVC duct is a solid wall pipe manufactured in accordance with relevant, internationally recognised quality standards under an ISO 9000/2000 quality system.

1.2 The application area covered, within this document are telecommunications.

1.3 Size ranges from 54mm to 160mm OD and includes plain ended and interference fit socket joints

1.4 PVC ducts are supplied on non-returnable wooden U-frames. The pipe pallets are designed to be stored on even, stable ground, they must not be stored more than 3 pallets high.

1.5 The finished product shall be free from surface defects which are material to the pipes physical performance and colour is light stable in UK and Ireland for 6 months external storage unless otherwise agreed by customer specification

1.6 The finished product shall be printed or labelled according to customer requirements and traceable to Emtelle's ISO 9000: 2000 quality system.

2.0 Raw Material

2.1 Raw Materials are uPVC resin and other additives suitable for the required properties of the finished product.

3.0 Dimensions

OD SIZE nominal mm	I.D. Nominal / mm	WALL THICKNESS nominal/ mm	EN 50086 2-4 Compression Strength Classification in Newtons	EN 50086 2-4 Impact Strength Classification in Joules
54	51	1.75	250	
54	50	2.1	450	15
54	49	2.5	750	
88.9	84	2.4	250	
88.9	83	2.95	450	20
88.9	82	3.5	750	
96.5	91	2.55	250	
96.5	90	3.1	450	28
96.5	89	3.7	750	
105	100	2.7	250	
105	98	3.3	450	28
105	97	3.9	750	
110	104	2.8	250	
110	103	3.37	450	28
110	102	4	750	
125	119	3	250	
125	118	3.7	450	28
125	116	4.35	750	
160	153	3.6	250	
160	151	4.35	450	40
160	150	5.13	750	

3.1 The duct shall have dimensions (mm) as per table above, all testing is conducted at +20 degrees C.

3.2 Compression strength and impact strength test s procedures are as specified in BS EN 50086-2-4.

4.0 Product Performance

Unless otherwise specified

4.1 Telecommunication ducting systems comply with BS EN 50086/2/4, 250N, 450N or 750N Classifications.

4.2 The key physical measurements have equal importance across application area.

Application	Telecoms	Specification	Pass criteria
Compression	M	BS EN 50086-2-4	<5% deflection
Impact	M	BS EN 50086-2-4	>9 from 12 pass
Gellation (Acetone)	O	BS 509 Pt1 1987	No effect other than swelling
Tensile	O	BS 2782 Pt3 method 320A 1976	>44.1N/mm" and >80%
Static friction coefficient	O	EATS 12-24 1989	<0.27
Colour fastness, 6 months	O	500kJ/cm²/Year uv climate zone	Maintains colour 6 months above ground
Colour range	M	BS4800, BS 5252 or RAL charts	Within customer range
UV Stability, 6 months	O	As specified performance	Maintains performance above ground
Heat Reversion	O	BS 1401 to method B of EN 743 air	<5% Reversion no blistering

Colour fastness and UV stability are based on application being in the UK and Ireland only.
Colour Fastness Ref:- apx Trainee – Basic and Problem Solutions for PVC-Extrusion (Germany)

5.0 Marking

Duct systems will be marked with the relevant specification to give durable detail and traceability after installation.