WESTERN POWER DISTRIBUTION

INNOVATION

NEXT GENERATION NETWORKS

EDGE-FCLi

WPD_NIA_033

NIA MAJOR PROJECT PROGRESS REPORT

REPORTING PERIOD:

April 2019 - September 2019

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Contents

Glossary

Term	Definition
BAU	Business as usual
DG	Distributed Generation
DNO	Distribution Network Operator
EDGE	Embedded Distributed Generation Electronic
FCLi	Fault Current Limiting interrupter
GB	Great Britain
GRP	Glass Reinforced Plastic
HV	High Voltage
IPR	Intellectual Property Register
LCT	Low Carbon Technologies
LV	Low Voltage
NIA	Network Innovation Allowance
RMU	Ring Main Unit
UoW	University of Warwick
WPD	Western Power Distribution

1 Executive Summary

EDGE-FCLi project is funded through Ofgem's Network Innovation Allowance (NIA). EDGE-FCLi was registered in Sept 2018 and will be completed by November 2020.

EDGE-FCLi aims to upscale a newly developed solid-state Fault Current Limiting Interrupter (FCLi), targeted for cost effective connection of distributed generation, from prototype level to a commercial scale device, and trial it in one of WPD's generation customer's sites. GridON, the manufacturer, will be responsible for the FCLi design, build, testing, and installation and commissioning. The second project partner, RINA, will be responsible for the site design, project management, and data monitoring and technical consultancy.

This report details progress of the project, focusing on the last six months, from April 2019 to September 2019.

1.1 Business Case

The problem of high fault levels is more prominent in urban networks. An urban substation with 25 circuit breakers is assumed with 8 Ring Main Units (RMUs) per 11kV feeder (20 in total). Within the GB distribution network the majority of the old 11kV switchgear is rated at 13.1kA (250MVA). The typical reinforcement approach includes upgrading that with one rated at 25kA (476MVA). Close-up RMUs also need upgrading.

The typical cost of replacing an 11kV circuit breaker and all peripheral equipment is £50k. Similarly, the typical cost of replacing an 11kV RMU is £20k, while it is assumed that 25% of them will need replacing.

Base Cost= 11kV switchgear cost+ 11kV RMUs cost= (25*50)+(0.25*20*8*20)= £2050k

The fault level headroom enabled by the 25kA switchgear is 226 MVA and this can accommodate approximately six 5MW synchronous generators. Due to other technical constraints it is reasonable to assume that there will be a 33% reduction in allowed DG connections, hence allowing only four additional 5MW DGs.

The business as usual cost of an 11kV, 5MW FCLi is expected to be £275k, hence:
Method Cost= 4*275= £1100k **Saving= £950k**

1.2 Project Progress

The project has two main themes: 1) FCLi design, manufacturing, lab testing and live demonstration and 2) Demo site design and preparation. It was reported in the previous six monthly reports that a preliminary design of the FCLi was developed and issued by GridON, which went through a review and approval process by RINA and us. It was also informed that the University of Warwick has formally agreed to host the FCLi in series to their CHP generating units and after the initial data collection a set of preliminary site design documents were produced by RINA and reviewed by us.

In the last six months there was further significant progress in these two themes, which is summarised below:

- **FCLi Detailed Design**: Following the approval of the preliminary design GridON conducted further electrical simulations to refine and ascertain the design of individual phase modules as well as the total three phase system. A 2-stage multi-criteria fault detection system was designed and simulated in detail. The design also included a Built-in-Test (BIT) where the power modules periodically switch themselves OFF and ON again within 20µs, which enables the FCLi control to test the capability of the FCLi to interrupt current properly upon fault. A detailed failure analysis was also conducted on the power electronic systems (including IGBT switches, clamp and surge arrestor elements, individual modules etc.). Extensive thermal and mechanical/structural simulations were conducted to assure the IGBT temperature is well within its maximum specification at the worst case operating conditions. Corresponding cooling system is further investigated and thermal calculations were performed to prove that the proposed forced cooling system maintains the thermal integrity of the overall three phase system. The detailed design had gone through extensive review process by RINA initially and then us. The final design was approved at the beginning of July 2019.
- **FCLi Manufacturing**: At the time of writing this report the FCLi was still being manufactured, however, the majority (90%) of the work has already been completed. Assembling of all the 12 power modules (4 per phase) is nearing completion, which will be followed by their testing (individual module level). All but one PCBs are now manufactured and initial tests have been satisfactory. The Main Control Board which was just built is yet to be tested. The LV cabinet is being wired. The FCLi enclosure is nearly ready for bus-work installation. FCLi manufacturing/assembling is running slightly behind the schedule. There are multiple reasons, one of them being the delayed approval of the final design. However, GridON are doing some parallel functional testing to minimize the risk, and are confident that all the assembling and functional testing will be completed before the factory acceptance testing which is scheduled for the first week of November 2019.
- **Demo Site Design**:
    - Electrical design - The FCLi will be interfaced to our network through an HMI wall box panel. Based on FCLi' s interface signal list, produced by GridON, RINA produced HMI design and corresponding schematics. This design was reviewed in detail and approved by us. RINA has also produced an earthing design report. For the UoW' s internal 11kV network RINA produced a cable sizing and routing report.
    - GRP design - The FCLi will be placed inside a GRP enclosure at the demonstration site. Given the nature of the novel FCLi technology and corresponding ventilation and heat transfer requirement standard GRP design was slightly modified to meet the FCLi requirements. The GRP has been designed and is currently being manufactured by Envico.
    - Civil design – This mainly included the design of foundation/plinth (for placing FCLi and GRP) and cable ducts, trench etc. Based on FCLi and GRP weight and dimensions and also respecting the site specific locational and

access restrictions a foundation design was produced by RINA and approved by WPD.

- Data monitoring system – RINA has agreed with WPD to deploy a Sub.net monitoring device to monitor the field data during demonstration period. This has now been procured and will be installed during phase 2 site works in January 2020.

- **Demo Site Preparation**: Phase 1 works, which included installation of a new 4 panel extension board, FCLi foundation, and cable works have all been completed. After a slight delay in installing the metering panels the UoW CHP generating units are transferred onto the 11 kV bars via the new 4 panel extension board. Phase 2 works which is mainly about installation and commissioning of FCLi will be undertaken in January 2020.

1.3 Project Delivery Structure

1.3.1 Project Resource

Project Partner	Resource	Detail
Western Power Distribution	Faithful Chanda	Project Manager, WPD
GridON	Yoram Valent	CEO, GridON
	Uri Garbi	R&D Manager, GridON
	Alex Oren	Senior Engineer
	Dvir Landwir	Senior Engineer
RINA	Nagaraju Pogaku	Project Manager & Senior Tech. Consultant, RINA
	Simon Ebdon	Head of Power Systems, RINA
	Sayyed Zulqarnain	Principal Consultant, electrical, RINA
	Enrico Rossi	Civil Engineering Manager, RINA

1.4 Procurement

The following table details the current status of procurement for this project.

Provider	Services/goods	Area of project applicable to	Anticipated Delivery Dates
GridON	Components ordering	Device build	Long lead items were ordered from different suppliers and have already been delivered
Ardan Electrical Engineering Ltd	Device manufacturer/ subcontractor	Device build and type test	November 2019
KEMA Prague	Short circuit testing	Device short circuit test	December 2019
EMS	Sub.net monitoring system	FCLi data monitoring	Already delivered
4-Panel board	Schneider	Switchgear	Installed
Envico	GRP	FCLi housing	Dec 2019
Michael Smith Switchgear Ltd	Mechanically Interlocked Isolation Switch	Mechanical Interlock	Dec 2019
Control Engineering Ltd	HMI Wall box panel	FCLi and Grid control interfacing	Dec 2019
Nexans	Surge Arrestors	FCLi lightning protection	Already delivered
Nexans	T-Connectors	FCLi and grid interface	October 2019

Table 1-1: Procurement Details

1.5 Project Risks

A proactive role in ensuring effective risk management for EDGE-FCLi is taken. This ensures that processes have been put in place to review whether risks still exist, whether new risks have arisen, whether the likelihood and impact of risks have changed, reporting of significant changes that will affect risk priorities and deliver assurance of the effectiveness of control.

Contained within Section 7.1 of this report are the current top risks associated with successfully delivering EDGE-FCLi as captured in our Risk Register. Section 7.2 provides an update on the most prominent risks identified at the project bid phase.

1.6 Project Learning and Dissemination

Project lessons learned and what worked well are captured throughout the project lifecycle. These are captured through a series of on-going reviews with stakeholders and project team members, and will be shared in lessons learned workshops at the end of the project. These are reported in Section 5 of this report.

Event	Date	Attended by/ To be attended by	Location
Balancing Act conference	20th June 2019	Faithful/Uri	London

2 Project Manager's Report

2.1 Project Background

WPD, GridON & RINA put together an innovation proposal to upscale a newly developed solid-state Fault Current Limiting Interrupter (FCLi) by GridON. The FCLi enables cost effective connection of distributed generators to networks which are already fault level constrained.

The proposed project runs for 2 years and 3 months and is divided into six work packages

1. Device specifications – Specifications will be defined to cover all the device requirements

2. Preliminary FCLi design and review- This includes the identification of key components, high level electrical, thermal and control design, and detailed test plan preparation. Implications on site design will also be derived.

3. Detailed FCLi design and review – This involves full design of all parts including power modules, insulation, control system and operator interface, fault detection system, enclosures, thermal and ventilation detailed design. Long lead time components will be ordered

4. Site design, review and preparation – Civil and electrical site design, and design review, followed by site preparation works to accommodate the integration of the FCLi

5. FCLi manufacturing and testing – the FCLi will be manufactured and undergo factory and external lab testing

6. Installation, commissioning energisation and field operation – The FCLi will be installed, commissioned, and energised. Subsequently it will be operated in the network, its behaviour will be monitored and its performance will be analysed for a 9-month period.

2.2 A Summary of the Previous Six Months Report

Following the registration process with Ofgem the project formally started in September 2018. The technical specifications, which were already agreed during the contract and registration stage, formed the basis for the FCLi design. There were two main activities in the early stages of the project: (i) conceptual/preliminary design of the FCLi and (ii) demo site identification.

GridON introduced a high level concept of the FCLi in their conceptual design document that covered the power circuit and control system architecture. This was followed by

preliminary design activities covering mechanical, thermal, electrical design and initial electrical performance simulations. These designs were reviewed by both RINA and our own teams. After a successful review process the preliminary design was approved in February 2019.

Another milestone was achieved when the University of Warwick (UoW) agreed to host the FCLi live demonstration after we successfully engaged with UoW facilities team. It was agreed to connect the FCLi in series to UoW' s CHP units (three units of total size 4.2 MW). Site visits then followed to initiate the site electrical and civil design activities. Other activities involved the interface design (between FCLi and our network control) through a dedicated HMI panel, and to support the design of modifications to the UoW internal network.

2.3 Project Progress in the Last Six months

2.3.1 FCLi Detailed Design, Review and Approval

Following the approval of the preliminary design GridON continued with detailed design of the FCLi. Further electrical simulations were carried out to refine and ascertain the design of individual phase modules as well as the total three phase system Figure 1 shows the three phase arrangement and corresponding auxiliary equipment.

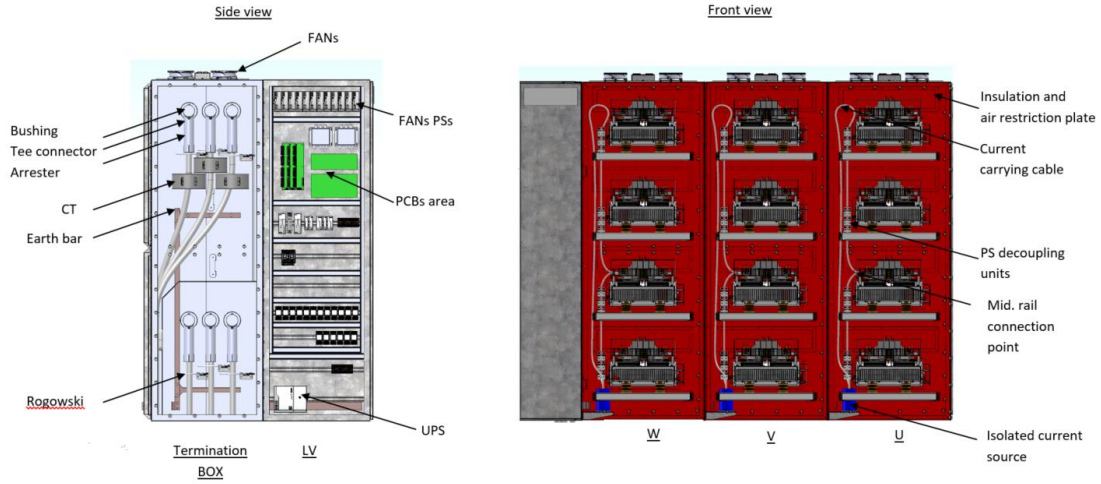

Figure 1: Three phase module arrangement

A 2-stage multi-criteria fault detection system (

Figure 2) was designed and simulated in detail. The design also included a Built-in-Test (BIT) where the power modules periodically switch themselves OFF and ON again within 20µs. This test enables the FCLi control to test the capability of the FCLi to interrupt current properly upon fault. A detailed failure analysis was also conducted on the power electronic systems (including IGBT switches, clamp and surge arrestor elements, individual modules etc.).

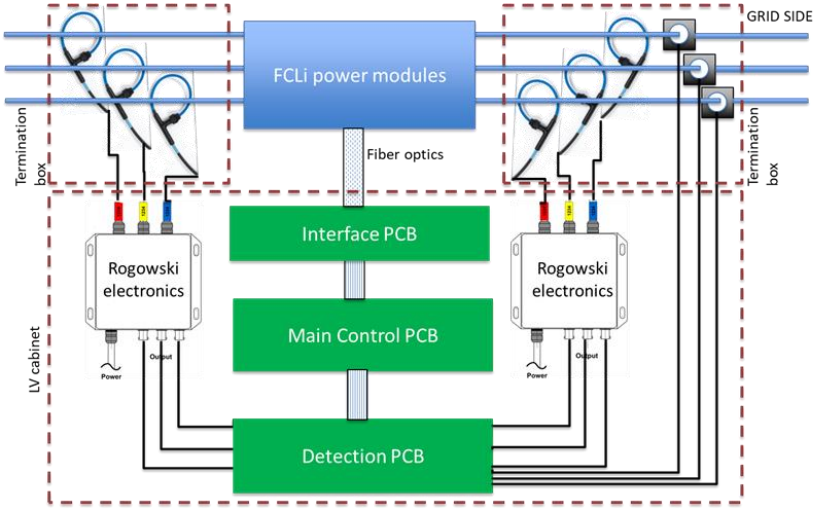

Figure 2: Fault Detection System

Extensive thermal and mechanical/structural simulations were conducted to assure the IGBT temperature is well within IGBT temperature is well within its maximum specification at the worst case operating conditions. Corresponding conditions. Corresponding cooling system is further investigated and thermal calculations were performed to prove that were performed to prove that the proposed forced cooling system maintains the thermal integrity of the overall three integrity of the overall three phase system. Sensitivity analysis under N-1 case (outage of one fan or clogged filters etc.) one fan or clogged filters etc.) was also carried out.

Figure 3 shows the temperatures at some strategic points in the typical cross section of the device during its worst case operation conditions and N-1 (40°C ambient temperature/11 out of 12 fans).

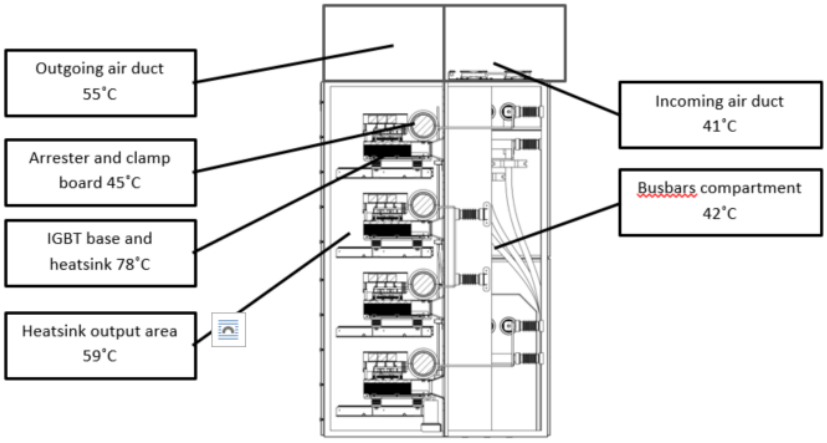

Figure 3: Temperature Compliance of Key Components

The FCLi detailed design was reviewed by RINA and our wider teams. Multiple review meetings were held with GridON to discuss the design concerns and to agree further analysis and evidence. The revised design along with review comments and responses were eventually accepted after multiple iteration of submissions; the final design was approved at the beginning of July 2019.

2.3.2 FCLi Manufacturing

After completion of the final design GridON started manufacturing the FCLi. Procurement of long lead items such as IGBTs early in the project enabled quicker assembling of the key systems such as power modules. At the time of writing this report the FCLi was still being manufactured, however, a majority of the work has been completed. Assembling of all 12 power modules (4 per phase) is nearing completion, which will be followed by their testing at individual module level. All but one PCBs are now manufactured and initial tests have been satisfactory. The Main Control Board was just built but was yet to be tested. The LV cabinet is being wired. The FCLi enclosure nearly ready for bus-work installation.

FCLi manufacturing/assembling is running slightly behind the schedule. There are multiple reasons for this, one of them being the delayed approval of the final design. However, GridON are doing some parallel functional testing to minimize the risk, and are confident that all the assembling and functional testing will be completed before the factory acceptance testing which is scheduled for the first week of November 2019.

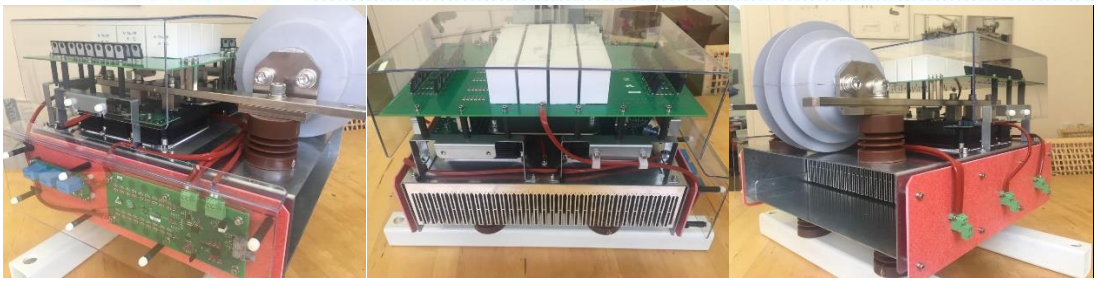

Figure 4: Power Module

Figure 5: Enclosure (left) and LV (central) and HV (right) Modules in Progress

2.3.3 Demo Site Detailed Design

2.3.3.1 Electrical Design

The FCLi will be interfaced to our network through an HMI wall box panel. Based on FCLi' s interface signal list, produced by GridON, the HMI design and corresponding schematics were produced. This design was reviewed in detail and approved. We also received the earthing design report from RINA for the primary substation. For the UoW's internal 11kV network RINA produced a cable sizing and routing report.

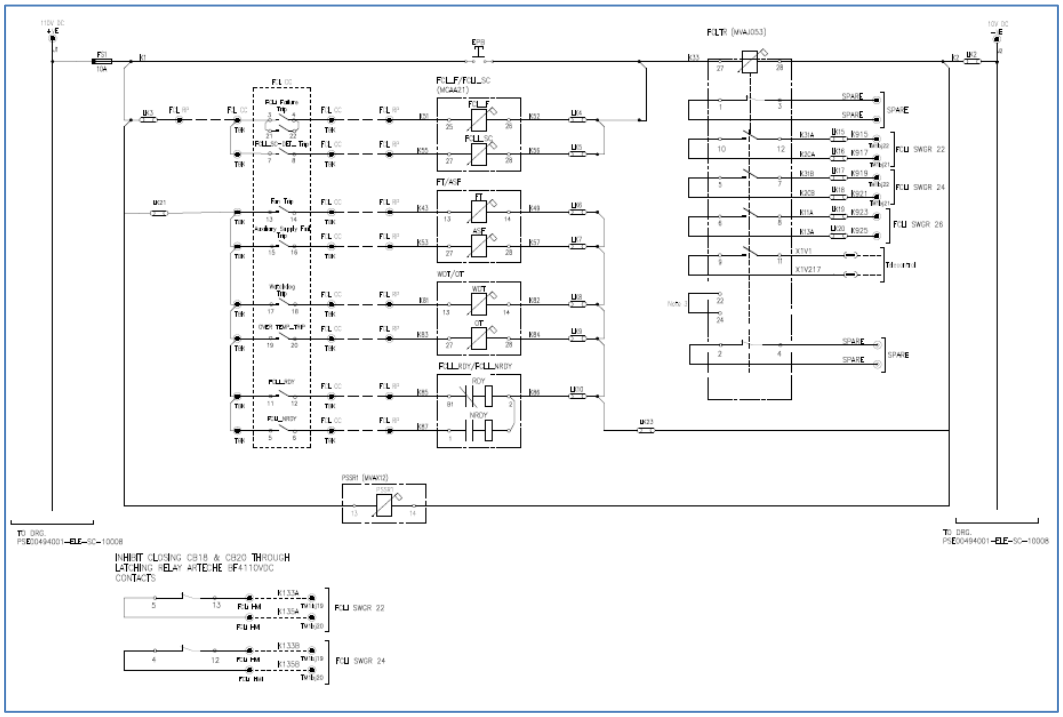

Figure 6: HMI Panel DC Schematic Snapshot

2.3.3.2 GRP Design

The FCLi will be placed inside a GRP enclosure at the demonstration site. Given the nature of the novel FCLi technology and corresponding ventilation and heat transfer requirement, standard GRP design was slightly modified to meet the FCLi requirements. The GRP has been designed and is currently being manufactured by Envico.

2.3.3.3 Civil Design

The civil design mainly included the design of foundation/plinth (for placing switchgear, FCLi and GRP) and cable ducts, trench etc. Based on FCLi and GRP weight and dimensions and also respecting the site specific locational and access restrictions a foundation design was produced by RINA and was reviewed and approved by us.

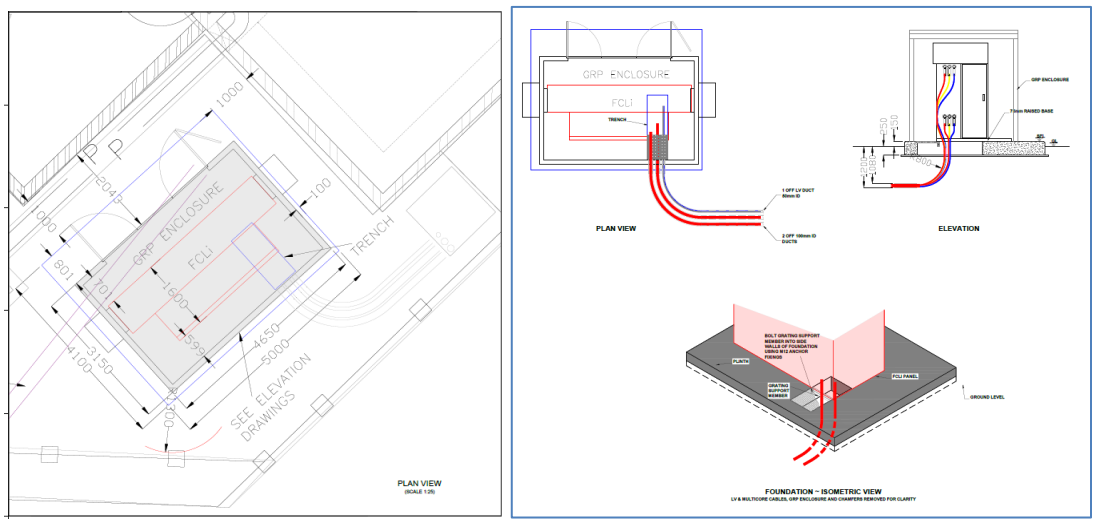

Figure 7: FCLi & GRP Positioning at UoW Primary (left) and Foundation Details (right)

2.3.4 Demo Site Preparation

There was plenty of activity at the UoW primary throughout the summer. Works commenced on the 29th of July. Tenders for the site works were awarded to Morrison Utility Services for the electrical works and RM Builders for the civil works. HV Power were contracted to carry out the changes on the university's network. The four new panels are installed and cold commissioned. All the cabling works at the primary substation and university network are completed. The FCLi foundation works are also completed. After a slight delay in installing the metering panels the UoW CHP generating units are transferred onto the 11 kV bars via the new four panel extension board. The second phase of the works, which is mainly about installation and energisation of FCLi, is planned for January 2020.

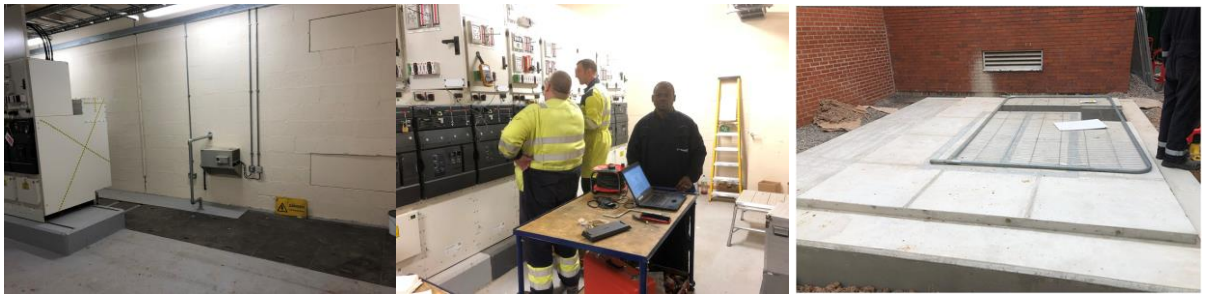

Figure 8: 11kV Switchroom at UoW Primary before installing new panels (left), after installation of new panels (middle) and completed FCLi foundation (right)

2.3.5 FCLi Testing

External HV lab slots for Factory Acceptance Tests (FATs) and Short circuit tests are now confirmed:

- FAT : 5th-7th November 2019 (Ardan Electrical Eng. Ltd, Tel Aviv)
- Short circuit testing: 3rd - 4th December 2019 (KEMA, Prague)

3 Progress Against Budget

Spend Area	Budget (£k)	Expected Spend to Date (£k)	Actual Spend to Date (£k)	Variance to expected (£k)	Variance to expected %
WPD Project Management	74.147	51.959	51.959	22.188	30
Project Partner Project Management - RINA	340.4	187.220	187.220	153.180	45
Equipment & Labour	148.951	33.902	33.902	115.049	77
Schneider Switchgear	105.220	99.100	99.100	6.12	6
GRIDON	1250	630	630	620	50
TOTAL	**1918.718**	**1002.181**	**1002.181**	**916.537**	**48**

Comments Around Variance

Spend is below the expected value as the project is delivering in accordance to the project plan - on time and on budget. Project partner costs are paid in line with the agreed schedule, and so are the project management fees.

4 Progress towards Success Criteria

Expected success	How this is being achieved
The FCLi limits and reduces down to zero before the first peak the fault current contribution of the generator during a network fault	This is the fundamental aspect of the FCLi design. The FCLi is made of IGBT switches. These switches open within a few milliseconds (before first peak) when the fault current exceeds a pre-set threshold. There are surge arrestors in parallel and clamping circuit. The surge arrester absorbs the vast majority of the grid stored energy during current interruption. It is selected such that it has a significant energy margin over the maximum anticipated grid energy. The clamping circuit provides reduction of transient voltage originating from parasitic inductances in the FCLi circuit. Detailed electrical, thermal and mechanical/structural simulations have been conducted which showed good agreement with the desired behaviour.
The FCLi introduces minimal disturbance to the network and the generator during normal operation	The FCLi is specified and being designed such that there is minimum disturbance to the network. High performance components were chosen along with appropriate redundancy. Detailed simulation results showed 0.23% voltage drop at rated current whereas the specification is <0.5%. Similarly, an almost negligible harmonic content (0.06%) was observed in the grid voltage at rated current.
The FCLi remains in normal conduction mode for transient non-fault related events and for faults outside the 11kV network on to which it is connected	Fault detection thresholds are chosen such that FCLi is insensitive to spurious and remote faults.
Any device failures are minor and do not render the plant unavailable for more than a few hours	Sufficient design margins are maintained in the design to minimise the risks.

5 Learning Outcomes

The technology that was demonstrated in a small-scale single phase prototype has been scaled up and a full 3 phase product went through preliminary design and final design.

FCLi operational sequences were discussed with project partners and documented.

Grid interface aspects were investigated in length and a signal list has been produced and agreed with WPD.

6 Intellectual Property Rights

A complete list of all background IPR from all project partners has been compiled. The IP register is reviewed on a quarterly basis.

GridON entered this project with two relevant background IPR patent applications:

a. Patent application "DC Power Supply Arrangement" - filed on 24-Jan-2017
b. Patent application "AC Switching Arrangement" - filed on 21-Mar-2017

7 Risk Management

Our risk management objectives are to:

- Ensure that risk management is clearly and consistently integrated into the project management activities and evidenced through the project documentation;
- Comply with WPDs risk management processes and any governance requirements as specified by Ofgem; and
- Anticipate and respond to changing project requirements.

These objectives will be achieved by:

- ✓ Defining the roles, responsibilities and reporting lines within the Project Delivery Team for risk management;
- ✓ Including risk management issues when writing reports and considering decisions;
- ✓ Maintaining a risk register;
- ✓ Communicating risks and ensuring suitable training and supervision is provided;
- ✓ Preparing mitigation action plans;
- ✓ Preparing contingency action plans; and
- ✓ Monitoring and updating of risks and the risk controls.

7.1 Current Risks

The EDGE-FCLi risk register is a live document and is updated regularly. There are currently 22 live project related risks. Mitigation action plans are identified when raising a risk and the appropriate steps then taken to ensure risks do not become issues wherever possible. In Table 7-1**Error! Reference source not found.**, we give details of our top five current risks by category. For each of these risks, a mitigation action plan has been identified and the progress of these are tracked and reported.

Details of the Risk	Risk Rating	Mitigation Action Plan	Progress
Design upscale from single phase prototype to three phase fully operational device may not be realised as expected	Major	Preliminary and detailed design simulations and analysis and then lab testing once the manufacturing is done	Detailed design is now completed and no significant issues were found. Lab tests after the FCLi is manufactured will give more confidence.
FCLi fails during high voltage/high power tests	Major	During the early stages of the project extensive simulations and design verifications will be done to make sure the final design meets the specifications.	Detailed design is now completed and no significant issues were found.
FCLi fails to interrupt faults during demonstration, resulting in damages to customer and/or DNO equipment	Major	Following successful prototype testing, the design of the full FCLi will be carefully verified through simulations and testing. It may be possible to select a demonstration site where site fault levels do not exceed the switchgear ratings even if FCLi fails to interrupt the fault current.	Detailed design is now completed and no significant issues were found. Lab tests after the FCLi is manufactured will go more confidence.
Delays in FCLi manufacturing	Moderate	Long lead items were ordered early in the project.	Power modules are being assembled. Printed circuit boards manufacturing and testing is in progress. System enclosure is being assembled
Delays in high voltage/high power lab tests	Moderate	Efforts will be made to engage with a high power lab (likely KEMA) as early as possible into the project	Test labs are already booked. However, this risk is also connected with delays in FCLi manufacturing.

Table 7-1: Top five current risks (by rating)

Table 7-2 provides a snapshot of the risk register, detailed graphically, to provide an on-going understanding of the projects' risks.

Likelihood = Probability x Proximity	1. Insignificant changes, re-planning may be required	2. Small Delay, small increased cost but absorbable	3. Delay, increased cost in excess of tolerance	4. Substantial Delay, key deliverables not met, significant increase in time/cost	5. Inability to deliver, business case/objective not viable
Certain/Imminent (21-25)	0	0	0	0	0
More likely to occur than not/Likely to be near future (16-20)	0	0	0	0	0
50/50 chance of occuring/Mid to short term (11-15)	0	0	0	0	0
Less likely to occur/Mid to long term (6-10)	0	3	5	0	2
Very unlikely to occur/Far in the future (1-5)	0	0	4	5	1
	Impact				

	Minor	Moderate	Major	Severe	
Legend	7	11	2	0	No of instances
Total	20				No of live risks

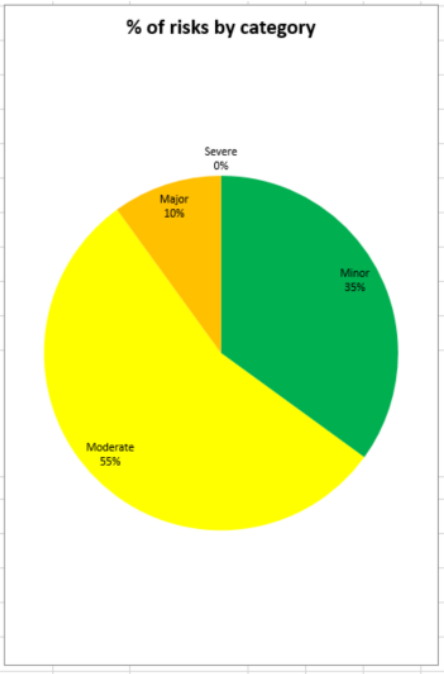

Table 7-2: Graphical view of Risk Register

7.2 Update for Risks Previously Identified

Descriptions of the most significant risks, identified in the previous six monthly progress report are provided in Table 7-3 with updates on their current risk status.

Details of the Risk	Previous Risk Rating	Current Risk Rating	Mitigation Action Plan	Progress
Timely completion of system assembly and FAT		moderate	Very close follow up on many parallel tasks – both internally and with our subcontractors.	Making all efforts to complete on time

Table 7-3: Risks identified in the previous progress report

8 Consistency with Project Registration Document

The scale, cost and timeframe of the project has remained consistent with the registration document, a copy of which can be found here:
https://www.westernpower.co.uk/projects/edge-fcli

However, the schedule of some activities have been brought forward to meet the generator customer requirement (University of Warwick) to conduct the site preparations works in summer vacation period (July 2019-Sept 2019) instead of originally planned Sept 2019 to Nov-2019 period. The positive aspect of this accelerated plan is that the trial period increases by nearly three months and hence the network can potentially present more network faults to FCLi to interrupt and hence prove its functionality.

9 Accuracy Assurance Statement

This report has been prepared by the EDGE-FCLi Project Manager Faithful Chanda reviewed and approved by the Innovation Team Manager (Jon Berry).

All efforts have been made to ensure that the information contained within this report is accurate. WPD confirms that this report has been produced, reviewed and approved following our quality assurance process for external documents and reports.