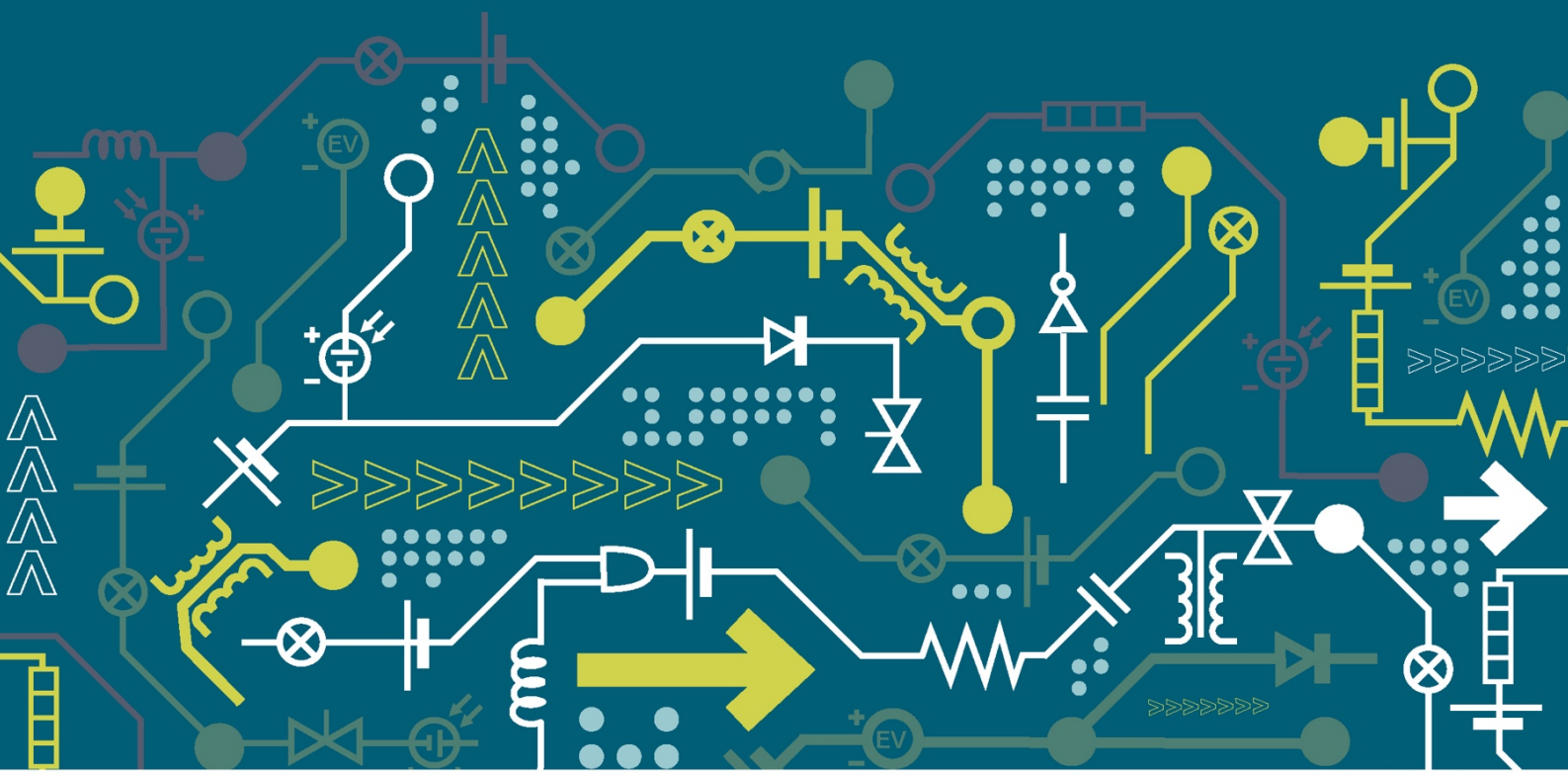
WPD INNOVATION

EDGE-FCLi

6 Monthly Report

April 2020 – September 2020



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Name	Role
Daniel Hardman	Author
Neil Murdoch	Reviewer
Yiango Mavrocostanti	Approver

Contact Details

Email
wpdinnovation@westernpower.co.uk

Postal
Innovation Team
Western Power Distribution
Pegasus Business Park
Herald Way
Castle Donington
Derbyshire
DE74 2TU

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1 Executive summary

The Embedded Distributed Generation Electronic Fault Current Limiting interrupter (EDGE-FCLi) project is funded through Ofgem's Network Innovation Allowance (NIA). EDGE-FCLi was registered in September 2018 and is due for completion by March 2022.

EDGE-FCLi aims to develop a prototype solid-state fault current limiter into a commercial scale device. The device is manufactured by GridON, Israel and has been designed to connect in series with Distributed Generators (DG) on the 11kV network with a maximum 5MW rated output. The device can quickly disconnect the generation from the network upon detection of a fault condition. The FCLi has the capability to limit the fault current contribution from DG and therefore overcome fault level issues that can limit network capacity and prevent future DG connections.

The project is being delivered collaboratively between WPD and UKPN to ensure that a device is developed that is safe to connect to the 11kV network and is also replicable so that it can be deployed throughout GB. Both WPD and UKPN plan to install and trial an FCLi device on their respective 11kV networks with significant coordination of the FCLi design, factory and laboratory testing to ensure that the devices are suitable for longer-term testing and trials in the field.

This report details project progress from April 2020 to September 2020.

1.1 Business case

The growth of connected DG has caused an increase fault level across the 11kV network. This is particularly an issue in urban areas, where the fault level is more likely to exceed the capability of the switchgear to safely disconnect a network fault. The following section describes the business case for the FCLi device.

A typical 33/11kV urban primary substation can be assumed to contain 25 no. circuit breakers in total, with on average 20 no. 11kV feeders per substation. It has been assumed that there is eight Ring Main Units (RMUs) per 11kV feeder.

Within the GB distribution network, the majority of the existing 11kV switchgear is rated at 13.1kA (250MVA). The typical reinforcement approach includes upgrading the switchgear to 25kA (476MVA) units. In addition, RMUs close to the primary would also need to be upgraded.

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. It is assumed that 25% of RMUs will need to be replaced if the fault level at the site increases above the existing limits. Therefore:

Base Case Cost= 11kV switchgear cost + 11kV RMU cost = (25 x £50k) + 0.25 x (20 x 8 x £20k) = £2,050k

The fault level headroom enabled by the 25kA switchgear is 226 MVA per site and this can accommodate approximately six no. 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 x £275k = £1,100k

There is therefore a saving of £950k per installation (Base Case Cost – Method Cost).

1.2 Project progress

During the period from April 2020 to September 2020, the FCLi that is intended for trials on WPD's network has successfully passed both the Factory Acceptance Testing (FAT) and Short Circuit Testing. The FAT was carried out at GridON's facilities in Israel and concluded on 1 June 2020. The Short Circuit Testing

was carried out at the KEMA third party laboratory in Prague, Czech Republic on 29-30 June 2020. After the Short Circuit Testing the FCLi was shipped directly to the UK and is now located in a WPD storage facility awaiting deployment for the Long Duration Performance Test (LDPT) (or 'soak test').

The original scope was to carry out the LDPT at a third-party laboratory and pass rated current through the FCLi for an extended duration of time. However, the project team has instead decided to proceed with an alternative plan to carry out the LDPT at its final installation location, the University of Warwick (UoW) 33/11kV primary substation. The requirement for an LDPT at a third-party laboratory was originally proposed due to the uncertainty regarding the thermal performance of the FCLi when installed in a Glass Reinforced Plastic (GRP) housing at site. However, the project team worked with GridON to develop a robust testing specification and were able to perform additional temperature rise tests during the FAT. The results from the temperature rise tests demonstrated that the cooling system of the FCLi performed well and remained stable, thus alleviating concerns associated with the thermal modelling and negating the need to perform further tests at a third party laboratory. Furthermore, testing the device at the final site location allows the project to make cost efficiencies and avoids the logistical challenges associated with installation at a third-party laboratory.

During this reporting period there have been significant challenges to the project delivery because of the COVID-19 pandemic. In particular the FAT and Short Circuit Testing were both witnessed by WPD engineers remotely over videoconference. This represents a major departure from the usual policy of witnessing testing in person and therefore a dedicated discussion has been given to this in Section 5.1. Overall, the remote witness testing proved to be successful and provided valuable learning for future projects.

The COVID-19 lockdown in the UK meant that the planning for the LDPT could not be done in parallel with the preparation for the device testing as making the necessary arrangements with third parties was severely restricted. This led to the decision to place the device into one of our storage facilities while the planning for the LDPT could take place. Whilst this has led to some minor delays, it allowed time for the project team to explore the alternative LDPT plan, which will lead to significant cost savings for the project as described above.

Whilst there have been minor delays due to the COVID-19 pandemic, delays to the overall re-baselined programme have been avoided. Throughout the reporting period we have continued to communicate regularly with UKPN to share progress information and to understand the respective impact of COVID-19 on each of our project programmes. This will continue going forwards to ensure that the projects are delivered safely and effectively.

1.3 Project delivery structure

The EDGE-FCLi Project Review Group (PRG) meets on a bi-annual basis. The role of the PRG is to:

- Ensure the project is aligned with organisational strategy;
- Ensure the project makes good use of assets;
- Assist with resolving strategic level issues and risks;
- Approve or reject changes to the project with a high impact on timelines and budget;
- Assess project progress and report on project to senior management and higher authorities;
- Provide advice and guidance on business issues facing the project;
- Use influence and authority to assist the project in achieving its outcomes;
- Review and approve final project deliverables; and
- Perform reviews at agreed stage boundaries.

1.4 Project resource

Table 1-1 provides an overview of the project resources for the project.

Table 1-1 Project resources

Project Partner	Name	Role
WPD	Yiango Mavrocostanti	Innovation Team Manager
GHD	Daniel Hardman	Project Manager
UKPN	Jack McKellar	Project Manager
GridON	Yoram Valent	CEO
	Roy Iscovitsch	President & Co-Founder
	Uri Garbi	Project Manager
	Alex Oren	Senior Engineer
	Dvir Landwir	Senior Engineer

1.5 Procurement

Table 1-2 provides a summary of the status of the procurement activities for the project.

Table 1-2 Procurement status

Provider	Services/Goods	Project Area	Status/Due Date
GridON	Detailed Design	Design	Complete
GridON	FCLi	Build	Complete
GridON	FAT	Testing	Complete
GridON	Short circuit testing	Testing	Complete
EMS	Sub.net monitoring system	Trial	Delivered
Envico	GRP housing	Installation	Under manufacture
Control Engineering Ltd	HMI wall box panel	Installation	Delivered
Nexans	Surge Arrestors	Installation	Delivered
Nexans	T-connectors	Installation	TBD

1.6 Project risks

A proactive role has been taken to effectively manage risk in the delivery of the EDGE-FCLi project. Processes have been put in place to review the applicability of existing risks; identify and record new risks that have arisen; and update the impact, likelihood and proximity of risks that have developed. A summary of the updates to the most significant risks in the previous six monthly reporting period are provided in Section 7.2.

1.7 Project learning and dissemination

The project learning is captured throughout the project lifecycle by ongoing engagement with the project partners and stakeholders. The learning is regularly recorded and updated through our reporting processes and disseminated through various media. Table 1-3 gives a summary of the dissemination activities that have already taken place. The project learning for the current reporting period is given in Section 5.

Table 1-3 Project dissemination

Event	Date	Attendance	Location
Low Carbon Network Fund Conference	16 October 2018	N. Pogaku*	Telford, UK
Electricity Innovation Forum on New Technology and Commercial Evolution, ENA	28 September 2018	N. Pogaku* S. Ebdon*	London, UK

*Note – These staff members are RINA employees that were responsible for project management prior to the re-baselining activities in late 2019. RINA no longer have an active involvement in the development and deployment of the WPD FCLi; however, they are providing support to UKPN's programme delivery.

2 Project Manager's report

2.1 Project background

The project aims to design, build, test, install and trial a solid state FCLi on the 11kV distribution network. The FCLi is designed to connect in series with DG and quickly disconnect the generation upon the detection of a network fault. The FCLi is therefore able to reduce the fault current contribution from generation fitted with the device, thus allowing the cost-effective connection of DG to networks that are fault level constrained.

2.1.1 Project re-baseline

The FCLi project was re-baselined in December 2019 to allow for greater collaboration with UKPN to ensure that the device is replicable and deployable throughout GB. The collaboration will consist of working jointly on the design of the FCLi device, factory and laboratory testing to ensure that it is suitable for longer-term testing and site trials. A further addition has been the inclusion of a LDPT into the programme to understand how the device behaves in a controlled environment over a long period of rated current operation. This will give further assurances that the FCLi is safe to connect to the 11kV network.

The project work packages have been adjusted accordingly to meet the new project requirements. Table 2-1 gives the new work package structure along with an indication of the status of each of these work packages.

An updated NIA Project Registration and Project Eligibility Assessment (PEA) document was subsequently submitted to the ENA on 3 January 2020 after agreement was made with UKPN on their more integrated role in the project.

The installation and trial of our device at the selected trial site location is now dependent on successful completion of the LDPT and successful operation of the UKPN device on their 11kV network for a period of six months. This approach allows the project to maximise the learning generated whilst also ensuring customers receive continuing value for money.

Table 2-1 Adjusted work packages following project re-baseline

Work Package No.	Work Package Description	Status
1	Device specifications	Completed
2	Preliminary FCLi design and review	Completed
3	Detailed FCLi design and review	Completed
4	FCLi device manufacture	Completed
5	Performance testing (FAT & Short Circuit Testing)	Completed
6a*	LDPT (conditional on successful completion of WP 1-5)	Planning in Progress
6b*	Installation and operation of the UKPN FCLi on their 11kV network	Not started
7*	Trial of the WPD FCLi on 11kV network (conditional on successful completion of WP 6a and 6b for six months)	Not started
Asterisk (*) indicates the updated/new work packages		

2.1.2 Project progress in the last six months

Factory acceptance testing

The FCLi underwent FAT between 26 May 2020 and 1 June 2020 at GridON's testing facilities in Israel. The FCLi successfully passed the FAT according to the approved test specification. Figure 2-1 shows the FCLi device during the tests in the factory and Figure 2-2 shows the device being packed for onward shipment to the KEMA laboratory in Prague, Czech Republic for the Short Circuit Testing.

Figure 2-1 FCLi during FAT test in Israel

Figure 2-2 FCLi being packed after successful FAT

The FAT was originally due to be witnessed in person by WPD in Israel on 17-18 March 2020, however, it was eventually postponed in response to the COVID-19 pandemic that was escalating during this period and causing severe restrictions on international and domestic travel. After the situation stabilised in Israel, GridON were able to propose the option to allow WPD engineers to witness the testing remotely over videoconference. This is a significant departure from WPD policy where witness testing of this nature is normally attended in person. However, in this exceptional case it was agreed to proceed with the remote witnessing given that assurances were made by GridON that WPD's test requirements would be satisfied and also to avoid significant delays to the programme due to the COVID-19 restrictions.

The remote witnessing of the tests proved successful with GridON providing WPD witnessing engineers with the appropriate viewpoints and detailed walkthroughs of the test equipment and procedures. Figure 2-3 and Figure 2-4 below show some screenshots of the FAT from the viewpoint of the WPD witnessing engineers. GridON used Zoom to provide the videoconferencing system. The learning generated from the remote witnessing is documented and described in more detail in Section 5.1.

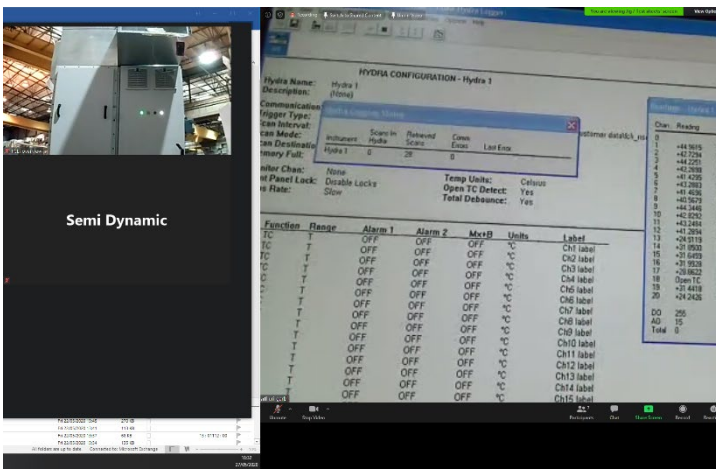


Figure 2-3 Screenshot from Zoom videoconference showing results from the temperature rise test

Figure 2-4 Screenshot from Zoom videoconference showing FAT setup

The FCLi performed well during the FAT. Most notably, the device passed the 95kV Lightning Impulse (LI) tests as well as the temperature rise test. It was observed that the forced air-cooling system was able to keep the Insulated-gate Bipolar Transistor (IGBT) heat sink temperatures well below the maximum levels at the rated load current (328A). Further detail on the learning generated from the FAT is provided in Section 5.1.

Short circuit testing

GridON made arrangements to ship the FCLi immediately after the FAT and the device underwent Short Circuit Testing between 29 and 30 June 2020 at KEMA's testing facilities in Prague, Czech Republic. The FCLi successfully passed the Short Circuit Testing according to the approved test specification. Figure 2-5 shows the FCLi device located in the test bay at the KEMA lab and Figure 2-6 shows the device being packed for onward shipment to the UK where it was placed into WPD storage facilities.

Figure 2-5 FCLi with HV connections in the KEMA test bay

Figure 2-6 FCLi being packed for onward shipment to the UK after Short Circuit Testing

The Short Circuit Testing was originally due to be witnessed in Prague on 23-24 April 2020, however, as described in the previous section, it was postponed in response to the COVID-19 pandemic. GridON rearranged the KEMA test booking to June 2020 in anticipation that restrictions would ease, allowing the witnessing engineers to travel to the Czech Republic. However, this was not the case and restrictions remained in place. In particular, the Czech government closed its borders to non-Czech nationals, except for citizens from certain EU countries. With restrictions and guidance changing on a daily basis WPD performed a risk assessment and suggested postponing the testing, however, GridON were confident that the testing could be completed and decided to continue with the plan to ship and test the device at KEMA. Unfortunately, the team that performed the FAT were unable to travel to KEMA due to the restrictions and GridON had to send two senior management staff to perform the set-up and tests. Ultimately, our project team agreed to remotely witness the tests in the same way that we did for the FAT.

The remote witnessing of the tests proved to be successful with GridON engineers providing remote guidance to their testing team in the Czech Republic, and providing WPD witnessing engineers with the appropriate camera viewpoints and detailed walkthroughs of the test equipment and procedures as

previously carried out for the FAT. The learning generated from the remote witnessing is documented and described in more detail in Section 5.1.

The FCLi performed well during the Short Circuit Testing. The device was able to detect and interrupt short circuit current very rapidly and meet all the acceptance criteria documented in the test specification. Further detail on the learning generated from the Short Circuit Testing is provided in Section 5.2.

Long duration performance test

The LDPT is a new project work package incorporated into the updated Project Registration and PEA document that was submitted at the end of 2019. The FCLi is a novel device that uses power electronics to quickly interrupt fault current from customer connected generation; it is therefore a critical requirement that the device is tested robustly before connection to the operational 11kV network. After project team discussions during the re-baselining activities, it was decided to include the LDPT to give additional reassurance that the device can operate for longer time periods at its rated current before being connected to the operational 11kV network.

The LDPT was originally intended to be performed in a third-party laboratory following successful completion of the FAT and Short Circuit Testing. A series of negotiations were held with the Power Networks Demonstration Centre (PNDC) during the early part of 2020, culminating in a detailed quotation for the works on 7 Feb 2020. Unfortunately, the COVID-19 pandemic caused the postponement of the FAT and Short Circuit Testing and therefore the final confirmation of the test scope and contractual terms and conditions were unable to be finalised with PNDC. The UK then went into full lockdown in March and this continued into May and early June 2020, with a gradual easing of measures in July 2020. This meant that the project team was unable to finalise the LDPT preparations in parallel with the rescheduled FAT and Short Circuit Testing owing to the severe restrictions in place.

The LDPT planning was restarted after the device had passed the Short Circuit Testing in early June and shipped to the UK. By this time, lockdown restrictions were easing in the UK allowing greater certainty for planning. As discussed in previous sections, the device performed well in the temperature rise test that was carried out as part of the FAT. In fact, the testing went ahead of the planned schedule allowing GridON to complete a second temperature rise test to validate that the cooling system design worked effectively with a lower fan speed setting. This test was also passed successfully and gave our project team confidence that the device would be able to cope with the demands of a full rated current LDPT.

An alternative plan was then investigated for carrying out the LDPT at the UoW primary substation instead of a third-party laboratory. This would involve connecting the device to the local substation Low Voltage Alternating Current (LVAC) supply and a downstream resistive load bank so that a nominal current could be driven through the FCLi. The alternative plan has the benefit of significant cost savings as it removes the requirement for a third-party lab. In addition, the plan avoids the challenges and risks associated with transporting the device, GRP and testing equipment to the third-party lab and back again to the site. Research into the existing equipment at UoW found that the site could supply a suitable LV current for the test and so it was decided to proceed with the alternative plan.

The project team is currently developing the design documentation to facilitate the connection of the FCLi to the LVAC supply at the UoW site.

IAC test review report

In this reporting period the project team has produced a report that documents the technical review of observations from the Internal Arc Classification (IAC) Test carried out on a dummy FCLi device at KEMA's laboratory in Prague, Czech Republic on 16 December 2019. In particular, the report investigated the health and safety risk posed to operatives and members of the public should an internal arc fault occur in the device when it is in service at the UoW primary substation.

It is to be noted that the IAC Test carried out on the FCLi dummy unit on 16 December 2019 is only applicable to the UKPN FCLi design. WPD witnessed the IAC Test as a neutral observer with the

responsibility of documenting the test process and results for future reference. The WPD FCLi is not specified as IAC compliant in the equipment contract signed with GridON. Instead, the WPD design adopted the following measures to mitigate the need for internal arc compliance:

- The WPD FCLi is housed in a self-contained GRP housing separate from the main substation building; and
- The FCLi uses a mechanical interlocking mechanism to restrict access to the GRP housing. Site personnel will only be allowed access the FCLi when the device is isolated from the HV circuits and each of its feeder circuit breakers is closed to earth.

Notwithstanding the above, the report was produced to identify and assess the risk posed by the device at its final installation location. It was concluded that the existing FCLi design and the proposed installation location is acceptable, and no remedial/mitigating measures are necessary following review of the ramifications of the IAC test results. However, it was advised that the performance of the FCLi is reviewed on an ongoing basis after it is connected to the 11kV network and the conclusions of the report reassessed should the performance of the device change for any reason.

COVID-19 impact

The COVID-19 pandemic has had a significant impact on the EDGE-FCLi project. The sections above related to the FAT, Short Circuit Testing and LDPT, have all detailed the specific impact on the progress on these activities.

Table 2-3 presents a summary of the overall impact to the project and a summary of the actions being taken in response to the event.

Table 2-2 Summary of COVID-19 impact

Work Package No.	Work Package Description	Affected?	Comment
5	FAT & Short Circuit Testing	Yes	This work package is now complete. In the re-baselined programme, the FAT & Short Circuit Testing was due for 17-18 March 2020 and 23-24 April 2020, respectively. They were then postponed to 1 June 2020 and 29-30 June 2020 respectively
6a	Long Duration Performance Test (LDPT)	Yes	Work is now underway with the preparation for this work package after successful FAT & Short Circuit Testing
6b	Installation and operation of the UKPN FCLi on their 11kV network	Possibly	Could be delayed due to UKPN programme being adversely impacted. This situation is being monitored carefully through regular teleconferences with UKPN, however, there are no indications at this time that there will be delays due to COVID-19
7	Trial of the WPD FCLi on 11kV network	Possibly	This activity is dependent on successful completion of the preceding work packages and is susceptible due to knock-on delays. There may be the need to modify the project scope and timeline because of our communications with UKPN

3 Progress against budget

Table 3-1 summarises the details of the progress that has been made with respect to the project budget.

Table 3-1 Project finances

Budget Item No.	Budget Item	Budget (£k)	Expected Spend to Date (£k)	Actual Spend to date (£k)	Variance to Expected (£k)	Variance to Expected (%)
1	GridON EDGE-FCLi Unit	1,250.0	1,045.0	1,044.7	-0.3	-0.0
2	Contractor Costs	367.6	360.5	360.5	0.0	0.0
3	WPD Project Management	122.1	67.8	67.1	-0.7	-1.0
4	Equipment and Labour	258.9	184.1	184.1	0.0	0.0
5	Schneider Switchgear	105.2	105.2	105.2	0.0	0.0
6	Long Term Performance Test	108.0	0.0	0.0	0.0	0.0
-	**Totals**	**2,211.8**	**1,761.9**	**1,761.6**	**-0.3**	**-0.0**

Comments around variance

No comment is required on the variances as shown in Table 3-1.

4 Progress towards success criteria

Table 4-1 presents the progress towards the success criteria documented in the EDGE-FCLi Project Registration and PEA document.

Table 4-1 Progress towards success criteria

Criterion No.	Success Criterion	Progress
1	The FCLi limits and reduces the fault current contribution of the generator to zero before the first current peak	The FCLi underwent Short Circuit Testing on 29-30 June 2020. The device successfully detected and interrupted all short circuit conditions before the first current peak of the prospective short circuit current. Refer to further detail on the findings from the testing in Section 2.1.2 and 5.2
2	The FCLi introduces minimal disturbance to the network and the generator during normal operation	This criterion can only be assessed following the outcome of the LDPT and final connection to the UoW site. Refer to Section 2.1.2 for further detail on the LDPT
3	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.	The FCLi underwent Short Circuit Testing on 29-30 June 2020. The device successfully detected and interrupted all prospective fault currents greater than the fault detection settings. The device did not trigger for currents below the settings value and remained in its conduction mode. Refer to further detail on the findings from the testing in Section 2.1.2 and 5.2. The FCLi will now be connected to the 11kV network subject to successful completion of the LDPT. The trial will then determine the success of this criterion over a prolonged period of operation on the live 11kV network

5 Learning outcomes

The following learning outcomes resulted from activities during this reporting period:

5.1 Factory acceptance testing

The device performed well in the FAT. Most notably, the temperature rise test passed successfully with the forced air-cooling system able to keep the IGBT heat sink temperatures well below the maximum levels at the rated load current (328A). The most onerous temperature rise test involved operating the device at its rated current with an N-1 cooling fan condition i.e. 11 out of the total 12 fans operational and with simulated clogging of the air intake filters. The temperature of the IGBT heatsinks stabilised quickly (approximately after 20 minutes) owing to the small thermal mass of the IGBT module design. The maximum measured IGBT heatsink temperature was 55°C (Phase L1, Heatsink 1) at a laboratory ambient temperature of 31°C. This corresponds to a semiconductor junction temperature (Tj) of 90°C, which is well below the maximum allowable value that is calculated by the IGBT manufacturer (Tj below 125°C for 40°C ambient).

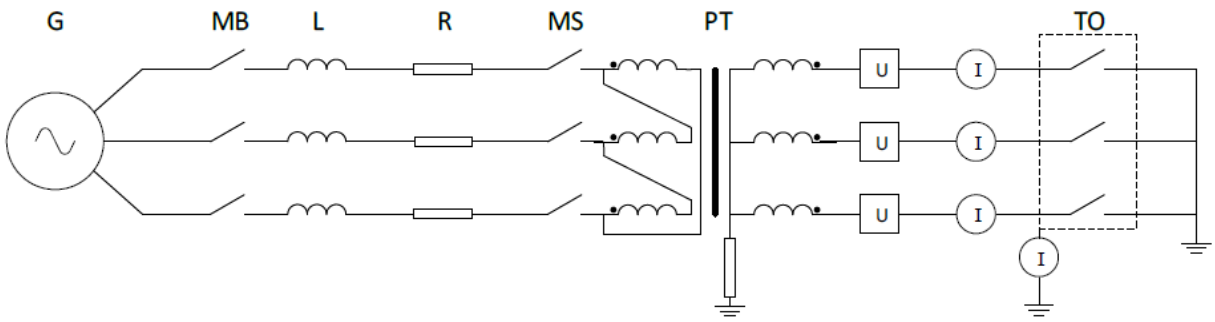
As described in Section 2.1.2, the FAT was witnessed remotely over video conference due to the COVID-19 pandemic. This proved to be an effective way of progressing the project programme under the severe restrictions on international travel. However, there were some learning points that the project team captured that would be helpful to guide future remote witness testing. They are as follows:

- Ensure the cameras that are used are modern and are capable of high definition video. This will help the engineers to have a clear view of the equipment under test. In addition, it is advised that all cameras are fitted with a tripod support (or equivalent) to minimise jitter;
- It is useful to request a plan/trial prior to the testing that documents the number of cameras and their positioning relative to the test object. This will allow the witnessing engineer(s) to review whether they are able to view all relevant parts of the device/setup;
- It was also useful to have a fixed camera setup to show the alarms/trips at the device interface to confirm that the device performed correctly for each test;
- It is advisable to have two witnessing engineers present on the video conference so that the tasks associated with viewing the more complex tests (such as functional tests), where multiple views are required, can be shared between the witnessing engineers; and
- It would be advisable to have the capability to screen share on all PC terminals where test results are captured to improve the efficiency of the tests i.e. this would avoid the use of a camera to view a PC monitor to check measurements (which can be difficult to view in this way).

5.2 Short circuit testing

The FCLi performed well in the Short Circuit Testing and passed all stipulated performance tests in the test specification. The following paragraphs present the results from the testing in more detail.

The FCLi was tested at KEMA's third party laboratory in Prague, Czech Republic. To perform the testing, the device was placed in series with one of their generator sets as shown in Figure 5-1. The prospective (or calibration current) is set by manually adjusting the inductance and resistance in the circuit with the FCLi disconnected from the circuit. After the prospective current is set correctly, the FCLi is switched into the circuit and the test is performed.



G	= Generator	TO	= Test Object	U	= Voltage Measurement to earth
MB	= Master Breaker	L	= Reactor	I	= Current Measurement
MS	= Make Switch	R	= Resistor		
PT	= Power Transformer	C	= Capacitor		

Figure 5-1 Test circuit in place during short circuit testing at KEMA

The testing applied several different short circuit prospective/calibration currents to the device to simulate specific network fault conditions that would be expected at the trial site. These were documented in the testing specification and are briefly summarised in Table 5-1.

Table 5-1 Summary of short circuit prospective/calibration currents applied to the FCLi

Test ID	Fault Type	Prospective Current (RMS kA)	X/R Ratio for Prospective Current	Notes
1	3-phase	0.46	14	Full asymmetry in one of the phases to be greater than 1.1kA peak. Simulates a remote fault on the network i.e. at the end of an adjacent 11kV feeder that yield low fault current infeed from the generator
2	3-phase	0.33	14	Full asymmetry in one of the phases to produce 840A peak. Simulates the worst-case transient event i.e. a prospective current just below the fault detection setting of the FCLi (the FCLi should not interrupt)
3	3-phase	2.10	14	Full asymmetry in each of the phases in turn to be greater than 5.3kA peak. Simulates a medium sized three phase fault i.e. located midway down an adjacent 11kV feeder
4	3-phase	25.0	14	Full asymmetry in one of the phases to be greater than 62.5kA peak. Simulates the maximum expected fault current i.e. a fault at the generator terminals
5	Phase-to-phase	21.7	14	Full asymmetry in one of the phases to be greater than 55.1kA peak
6	Single phase-to-ground	1.00	14	Maximum asymmetry in the tested phase greater than 2.54kA peak

The FCLi is configured with fault current detection settings that have been specifically chosen for the UoW site during the design phase of the project. These fault detection criteria are programmed into the FCLi by default.

As part of the test specification, WPD requested that GridON change to a different set of fault detection criteria for some of the prospective current tests to validate that the device could be reprogrammed and correctly interrupt fault current at the new setting.

Figure 5-2 shows the FCLi interrupting the 460A RMS prospective current. The current interruption can be seen in the green line. Figure 5-3 shows the FCLi interrupting the 460A RMS prospective current with the non-default setting. The current interruption can also be seen in the green line. Throughout the testing the FCLi correctly interrupted the short circuit current at both fault detection settings.

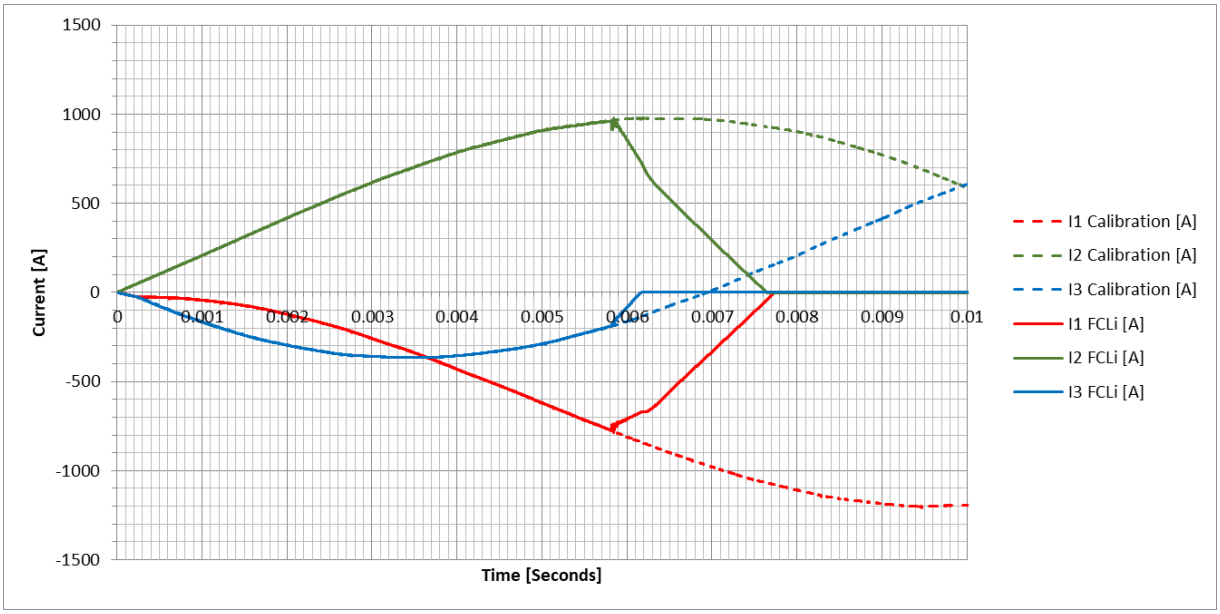


Figure 5-2 3ph 460A RMS prospective current – detection thresholds setting 1

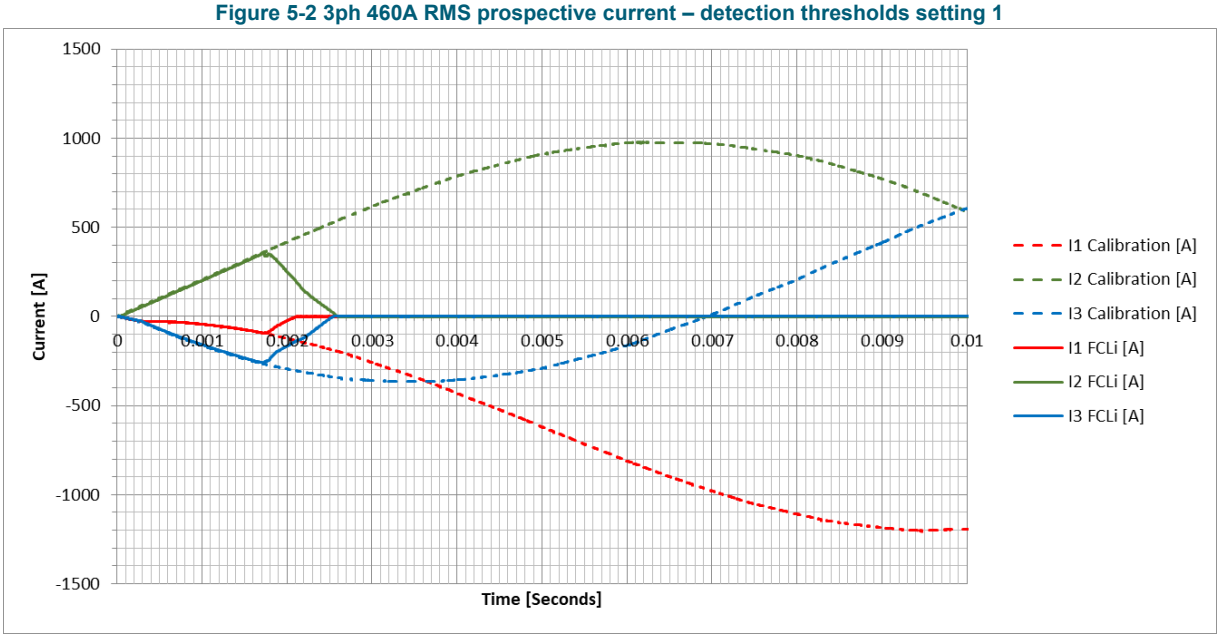


Figure 5-3 3ph 460A RMS prospective current – detection thresholds setting 2

The FCLi operates very rapidly under very close-in faults i.e. a fault at the generator terminals. Figure 5-4 shows the device undergoing a 25kA RMS prospective current test. The device operated in less than 200µs from the initiation of the short circuit current.

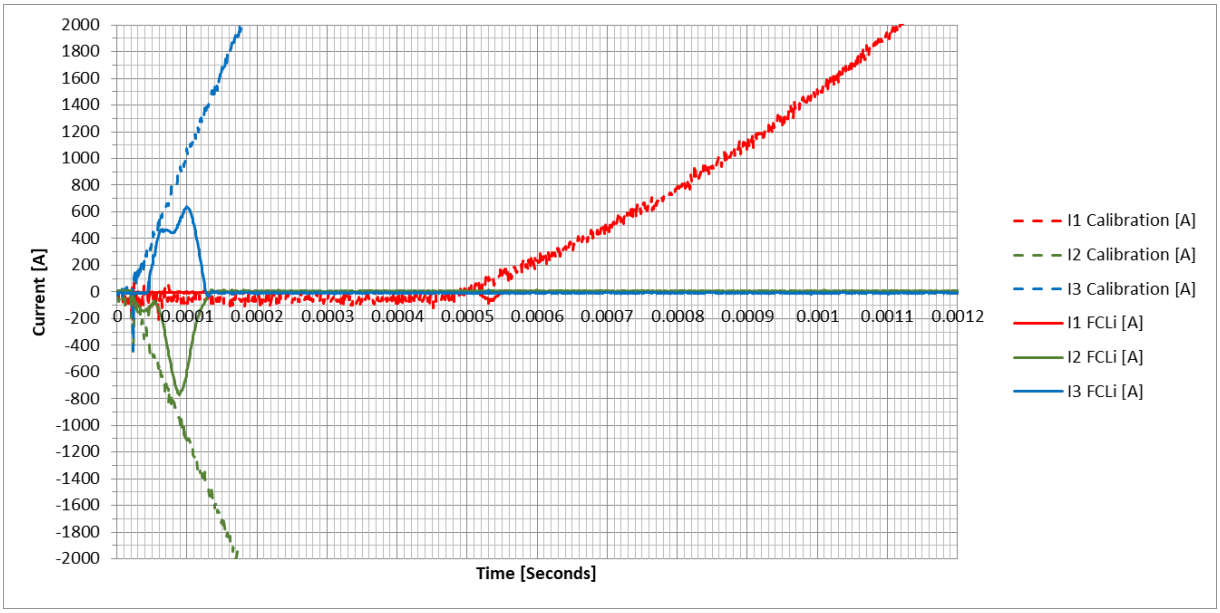


Figure 5-4 3ph 25kA RMS prospective current – detection thresholds setting 1 (zoomed in on x-axis)

The device behaved correctly for all simulated fault conditions, including those that simulate remote faults (i.e. a lower prospective current applied to the device). The device also interrupted the prospective short circuit currents before the first peak of the waveform in all relevant tests.

The device also successfully suppressed the overvoltages induced during the short circuit current interruption. The largest overvoltage was observed during the 460A RMS prospective current test and was limited to approximately 24kV. Figure 5-5 shows the current and voltage waveform recordings for the 460A RMS test. The figure shows the overvoltage reaching its maximum value in phase L2 (U2).

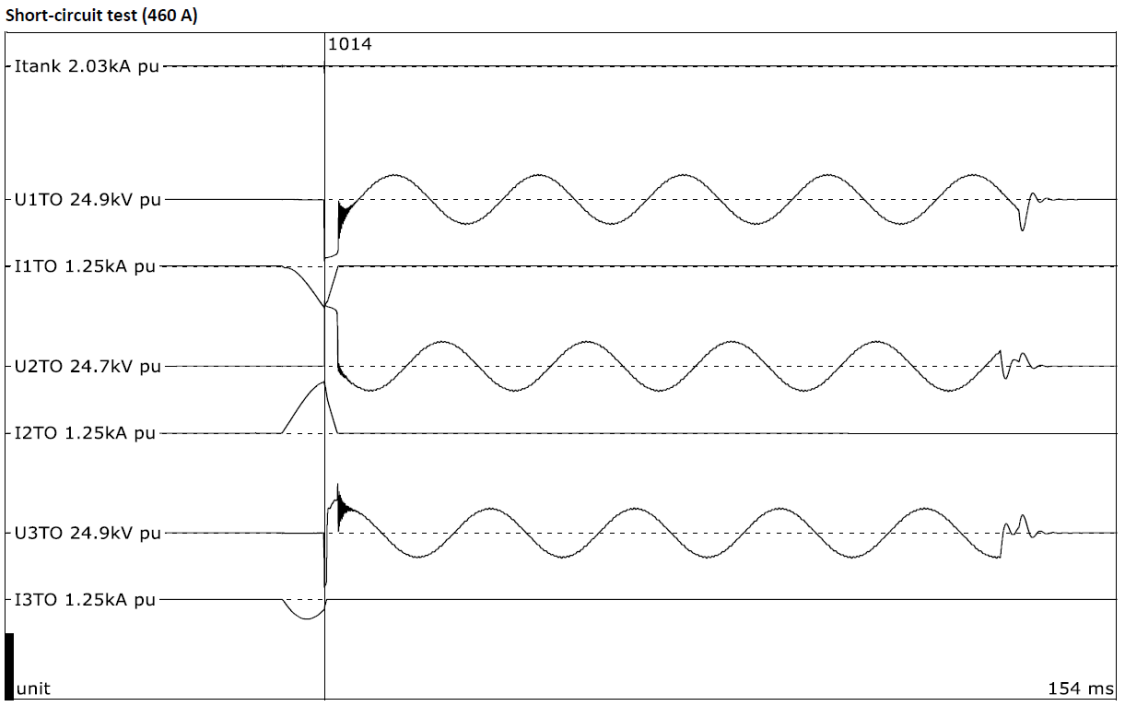


Figure 5-5 3ph 460A RMS prospective current – V, I waveforms – detection thresholds setting 1

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:

1. Patent application “DC Power Supply Arrangement” - filed on 24 January 2017
2. Patent application “AC Switching Arrangement” - filed on 21 March 2017

7 Risk management

7.1 General

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 WPD's 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.

7.2 Current risks

The EDGE-FCLi risk register is a live document and is updated regularly. There are currently nine live project related risks, which has reduced from 12 in the last six-monthly report. This is due to the successful completion of the FAT and Short Circuit Testing combined with a reduced impact from COVID-19 as restrictions have been eased. The risk register includes mitigation action plans for each identified risk and appropriate steps then taken to ensure risks do not become issues wherever possible.

In Table 7-1 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.

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

Risk	Risk Rating	Mitigation Action Plan	Progress
The COVID-19 pandemic continues for a long period of time creating extended delays to the NIA project programme	Major	The action to be taken is to monitor the situation closely and identify risks early so that they can be mitigated	Regular progress calls are continuing with UKPN to assess COVID-19 risks. At the moment there is no indication of any issues resulting from this communication

Risk	Risk Rating	Mitigation Action Plan	Progress
FCLi fails the LDPT	Major	A robust test specification and test criteria are required to ensure that there is no ambiguity in the results of the test Ensure both parties know the procedure to be taken if the device trips	A design pack has been produced for the LDPT and is now under internal review by the project team
UoW request changes to their current network feeding arrangement	Major	Regular updates with the Primary Systems Design (PSD) team in charge of the budget quotation. Research the proposed UoW scheme to see the impact of the changes	The project team have been in communication with the PSD team and are awaiting further details from UoW
GRP needs a crane for offload onto plinth at UoW	Moderate	A clear site layout is communicated to the GRP manufacturer to allow them to perform a second site/route survey and confirm if a crane is indeed required	Site layout has been sent to the survey subcontractor
Delays in UKPN's programme translate to delays in WPD's FCLi installation and energisation dates	Moderate	Regular progress calls with UKPN to discuss their test and install schedule and identify delays early	Situation is being monitored closely but is not expected to be an issue as UKPN programme is largely independent of WPD's

Figure 7-1 provides a graphical summary of the project risk register to give an ongoing understanding of the project risks.

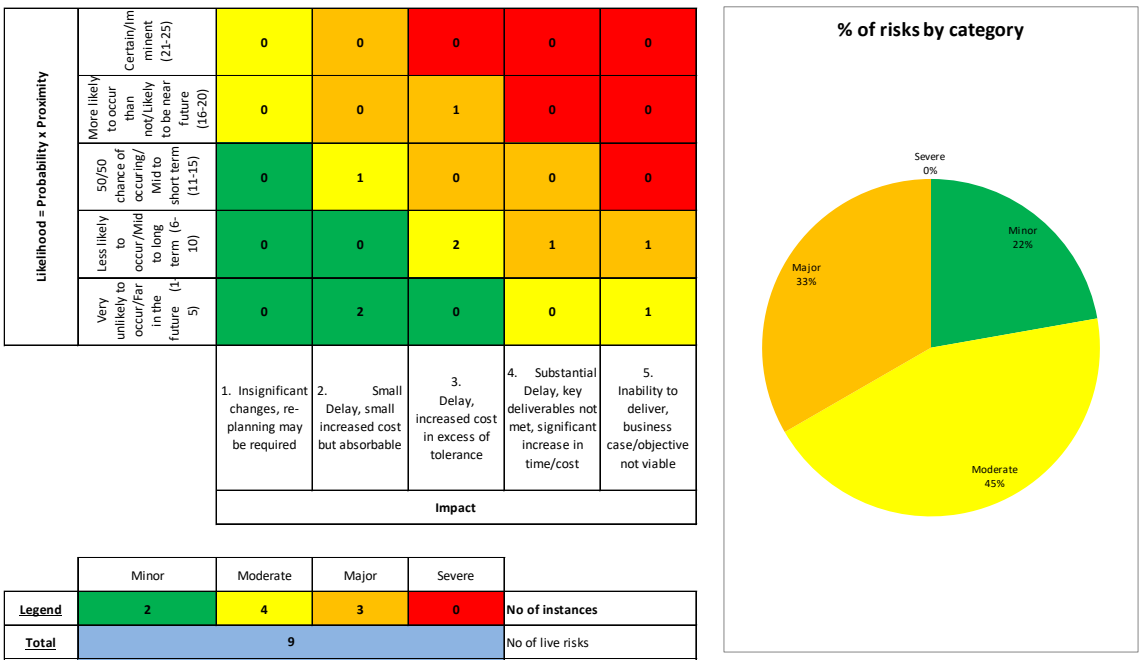


Figure 7-1 Graphical view of project risks

7.3 Update for risks previously identified

Descriptions of the most significant risks, identified in the previous six monthly progress report are provided in Table 7-2 with updates on their current risk status.

Table 7-2 Risks identified in the previous reporting period

Risk	Previous Risk Rating	Risk Rating	Mitigation Action Plan	Progress
Delays in high voltage/high power lab tests	Severe	Closed	Continual review of COVID-19 situation to ascertain when testing can be rescheduled. In the meantime, robust review of the updated design pack	The FAT and Short Circuit Testing has been completed successfully so risk has been closed
The COVID-19 pandemic continues for a long period of time creating extended delays to the NIA project programme	Major	Major	The action to be taken is to monitor the situation closely and identify risks early so that they can be mitigated	Regular progress calls are continuing with UKPN to assess COVID-19 risks. At the moment there is no indication of any issues resulting from this communication
Delays in UKPN's programme translate to delays in WPD's FCLi installation and energisation dates	Major	Moderate	Regular progress calls with UKPN to discuss their test and install schedule	Risk has reduced to moderate because COVID-19 isn't having a large impact on UKPN's programme
WPD unable to approve the changes to the device captured in the design pack submitted after preliminary testing	Moderate	Closed	Thorough review of the documentation and robust commenting to GridON	Device has been manufactured
Design upscale from single phase prototype to three phase fully operational device may not be realised as expected	Major	Closed	WPD are to thoroughly review the updated design pack prior to FAT. The FAT and short circuit tests are to be robustly monitored during witnessing	The FAT and Short Circuit Testing has been completed successfully so risk has been closed

8 Consistency with project registration document

During the last reporting period, the Project Registration and PEA document were updated as part of a wider re-baselining process to integrate greater UKPN collaboration in the development, testing and trial of the FCLi device. The aim of the re-baseline is to increase the replicability of the technology across GB, ensure the device is safe to connect to the 11kV network and maintains continued value for money for network customers.

A copy of the latest Project Registration and PEA document can be found here.

At this point in time the project is consistent with the re-baselined project budget and programme. The COVID-19 pandemic is also not causing delays to the overall re-baselined WPD and UKPN programmes. However, the situation is being reviewed carefully and it may be necessary to revisit the registration document in the future to adapt the project scope or timescales to consider COVID-19 related delays. Further details of the impact the COVID-19 pandemic on the project are given at the end of Section 2.1.2.

9 Accuracy assurance statement

This report has been prepared by the EDGE-FCLi Project Manager (Daniel Hardman), reviewed and approved by the Innovation Team Manager (Yiango Mavrocostanti).

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.

Glossary

Acronym	Definition
AC	Alternating Current
BIT	Built-In-Test
CEO	Chief Executive Officer
COVID	Coronavirus disease 2019
DC	Direct Current
DG	Distributed Generation
DNO	Distribution Network Operator
EDGE-FCLi	Embedded Distributed Generation Electronic Fault Current Limiting interrupter
ENA	Energy Networks Association
EU	European Union
FAT	Factory Acceptance Testing
GB	Great Britain
GHD	Gutteridge, Haskins & Davey Limited
GRP	Glass Reinforced Plastic
HMI	Human Machine Interface
HV	High Voltage
IAC	Internal Arc Classification
IGBT	Insulated-gate Bipolar Transistor
IP	Intellectual Property
IPR	Intellectual Property Rights
KEMA	Keuring van Elektrotechnische Materialen te Arnhem
LDPT	Long Duration Performance Test
LI	Lightning Impulse
LVAC	Low Voltage Alternating Current
MVA	Mega Volt-Amperes
NIA	Network Innovation Allowance
PEA	Project Eligibility Assessment
PNDC	Power Networks Demonstration Centre
PRG	Project Review Group
PSD	Primary Systems Design
RMS	Root Mean Square
RMU	Ring Main Unit
UKPN	UK Power Networks
WP	Work Package
WPD	Western Power Distribution

Western Power Distribution (East Midlands) plc, No2366923
Western Power Distribution (West Midlands) plc, No3600574
Western Power Distribution (South West) plc, No2366894
Western Power Distribution (South Wales) plc, No2366985
Registered in England and Wales
Registered Office: Avonbank, Feeder Road, Bristol BS2 0TB

wpdinnovation@westernpower.co.uk
www.westernpower.co.uk/innovation

@wpduk