Notes on Completion: Please refer to the appropriate NIA Governance Document to assist in the completion of this form. The full completed submission should not exceed 6 pages in total.

Network Licensees must publish the required Project Progress information on the Smarter Networks Portal by 31st July 2014 and each year thereafter. The Network Licensee(s) must publish Project Progress information for each NIA Project that has developed new learning in the preceding relevant year.

NIA Project Close Down Report Document

Date of Submission

Jun 2022

Project Reference

NIA_WPD_033

Project Progress

Project Title

EDGE-FCLi (Embedded Distributed Generation Electronic Fault Current Limiting interrupter)

Project Reference

NIA_WPD_033

Funding Licensee(s)

WPD - Western Power Distribution (East Midlands) Plc

Project Start Date

September 2018

Project Duration

3 years and 7 months

Nominated Project Contact(s)

Yiango Mavrocostanti - Western Power Distribution, Jack McKellar - UK Power Networks

Scope

The project will consist of the following 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.
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.
4. FCLi device manufacture.
5. Testing – The FCLi will undergo a number of rigorous tests including: Factory Testing, Laboratory/Type Testing and Internal Arc Testing.
6. At this point, if all elements (1-5) have been successful then the following will take place: a. WPD – long term ‘soak’ testing of the device to ensure stability of operation of the device and wider system b. UKPN – register separate NIA project to trial the installation and operation of the FCLi within the 11kV network.
7. Trial of the FCLi within WPD’s 11kV network where 6a is successful

Objectives

- Design an 11kV FCLi for a <=5MW generator.

- Manufacture the FCLi.
- Perform detailed testing on the manufactured FCLi including Factory Acceptance Testing, external lab testing and 'soak' testing.
- Complete Internal Arc Testing of a prototype device.
- Provide learning and recommendations for the suitability of such a device for implementation in the distribution network.

Success Criteria

The project will be deemed successful if during the trial period:

- The FCLi limits and reduces down to zero before the first peak the fault current contribution of the generator during a network fault.
- The FCLi introduces minimal disturbance to the network and the generator during normal operation.
- 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.
- Any device failures are minor and do not render the plant unavailable for more than a few hours.

Performance Compared to the Original Project Aims, Objectives and Success Criteria

The performance compared to the original objectives are detailed as:

- Design an 11kV EDGE-FCLi for a <=5MW generator.
o Complete. The final detailed design was approved
- Manufacture the EDGE-FCLi.
o Complete. The device was fully manufactured to approved detailed design
- Perform detailed testing on the manufactured EDGE-FCLi including FAT, external lab testing and 'soak' testing.
o Complete. The device has successfully undergone the FAT, short circuit testing at KEMA, Prague and the Long Duration Performance Test (LDPT) or 'soak' testing at the University of Warwick (UoW) trial site
- Complete Internal Arc Testing of a prototype device.
o Complete. UKPN have completed an Internal Arc Test (IAC) on their prototype unit

Provide learning and recommendations for the suitability of such a device for implementation in the distribution network.
o Complete. The project is now closed, and all learning and recommendations have been captured in the EDGE-FCLi performance report and the project closedown report.

The performance compared to the success criteria are detailed as:

- The EDGE-FCLi limits and reduces the fault current contribution of the generator to zero before the first peak during a network fault.
o Complete. The WPD EDGE-FCLi successfully passed all short circuit tests carried out at the KEMA third party laboratory Prague, Czech Republic on 29-30 June 2020
- The EDGE-FCLi introduces minimal disturbance to the network and the generator during normal operation.
o Complete. The WPD EDGE-FCLi was installed with a bypass circuit breaker for the field trial. This ensured that the generator could be reconnected to the network without the EDGE-FCLi in the circuit, thus avoiding prolonged outages of the CHP generators
- The EDGE-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.
o Complete. The WPD EDGE-FCLi successfully passed all short circuit tests carried out at the KEMA third party laboratory Prague, Czech Republic on 29-30 June 2020. These tests also included short circuit prospective currents that were below the detection thresholds.
- Any device failures are minor and do not render the plant unavailable for more than a few hours.
o Complete. The WPD EDGE-FCLi was installed with a bypass circuit breaker for the field trial. This ensured that the generator could be reconnected to the network without the EDGE-FCLi in the circuit, thus avoiding prolonged outages of the CHP generators

Required Modifications to the Planned Approach During the Course of the Project

The project is now closed, and a full description of all modifications can be found in the associated project closedown report. A summary of the required modifications are given below:

Project Re-baseline

The EDGE-FCLi project plan was re-baselined in December 2019 to allow for greater collaboration with UKPN, and to further ensure that the device is replicable and deployable throughout GB. The adapted plan facilitated a more integrated and joined up approach to the design, factory testing, and laboratory testing of the EDGE-FCLi to ensure that it was suitable for longer-term testing and site trials. The re-baselined plan included greater testing requirements to ensure the device was safe to connect and operate on the 11kV network. This involved UKPN carrying out an Internal Arc Classification (IAC) test and WPD completing the LDPT, a long term 'soak'test.
The project work packages in the NIA Project Registration and Project Eligibility Assessment (PEA) were subsequently adjusted

tomeet the new project requirements. An updated PEA was subsequently submitted to the ENA on 3 January 2020 after agreement wasmade with UKPN on their more integrated role in the project.

UKPN Status

In the last reporting period UKPN were due to create a separate NIA project to carry out the remainder of their EDGE-FCLi programme. However, UKPN have encountered significant difficulty coming to agreement with the customer at their trial site after the onset of COVID-19. This was further compounded by reliability concerns related to UKPN trialling the EDGE-FCLi at a hospital, due to the spurious trips experienced in the field trial that have caused some outages of the EDGE-FCLi at the WPD trial site.
After continuing discussions with UKPN, we understand UKPN have been evaluating the merits of different options for continuing with a separate NIA project, including selecting a different trial site for EDGE-FCLi. However, at the time of this process is still underway and a separate NIA project has not yet been developed.

Project Direction Refinement
The delays to the UKPN installation meant that a further refinement of the project direction had to take place to ensure that the project could continue and provide learning to the wider industry. The WPD installation was initially conditional on a successful six-month trial of the EDGE-FCLi device at UKPN's trial site, however, this dependency could not be achieved due to the COVID-19 delays previously mentioned. Therefore, to maintain progress and project learning, the WPD EDGE-FCLi was connected independently of UKPN. The project work packages in the PEA were modified accordingly and submitted to the ENA on 20 January 2022.

The internal WPD internal change request management procedures were followed at all time in the project

Lessons Learnt for Future Projects

The following learning relates to the last 12 months of the project. The project is now closed, and a full record of all project learning is available in the six monthly reports and associated closedown report.

HV cable VLF 'pressure' testing

A routine requirement prior to the connection of a new piece of equipment is to carry out a Very Low Frequency (VLF) 'pressure' test on the HV cables after they are installed, but before they are terminated. For polymeric insulated 11kV cables this involves applying 10.8kV 0.1Hz sinewave between the conductor and earth for each cable. The purpose is to check that the integrity of the insulation is not compromised before final connection.
The HV cables had been terminated at the EDGE-FCLi but left unterminated at the switchgear cable box at the UoW site. It was therefore proposed to carry out the VLF test with the EDGE-FCLi in the circuit to avoid having to disconnect the terminations at the EDGE-FCLi. However, the manufacturer advised that this was not to be done to avoid any damage to the internal power electronic circuitry. As a result, the site project team carried out the VLF with the EDGE-FCLi in the circuit and reconnected the HV terminations after the test was successfully completed. This issue did not impact the overall connection and energisation activities.

Alarm screen configuration
A key element in connecting innovation equipment is consideration of how the alarm and trip signals from the device interface with the central control system. Our control engineers have two main alarm screens. The primary screen displays all alarms that are set to be 'acknowledgeable' i.e., the engineer needs to manually accept the alarm remove it from the page.
The primary screen is typically used for high priority alarms that require control actions from the engineer. The second screen displays manual or auto-acknowledged alarms. It is used as an event viewer. Auto-acknowledge alarms are typically low priority alarms that go straight to the secondary screen to avoid presenting a burden of alarms to the engineer. The project team worked closely with the control systems team to ensure that the alarm priorities were correctly defined in the control system configuration prior to the final commissioning and energisation of the EDGE-FCLi.

Control polarity during hot commissioning

There was a key learning point on site during the hot commissioning of the EDGE-FCLi prior to the energisation onto the 11kV network at UoW. When carrying out the functional testing of the control commands from our control centre, it was observed that the Idle and Recovery commands were reversed i.e., the IDLE command would trigger a Recovery action and vice versa. This was tracked to

a wiring issue in the HMI panel that marshals all the signal wiring between the EDGE-FCLi and the substation equipment. This was quickly resolved during the commissioning and caused only minor delays; however, the point reinforces the need for robust testing and commissioning processes at site to identify issues and rectify them before final energisation. We recommend that the post-FAT or pre-commissioning procedures are updated to check and confirm that any subsequent wiring modifications have been carried out correctly.

BIT Trip 1

The EDGE-FCli disconnected itself from the network on 19 May 2021. After the initial investigation on the cause of the trip event, it was found the device tripped due to the Built In Test (BIT) functionality incorrectly interpreting that there had been a power electronics failure within phase 3 of the unit. The reason for the BIT failure and trip was that the BIT protection function was triggered incorrectly when there was insufficient phase current magnitude to the specified requirement. The current was in the range of 25A when it is required to be in the range of 40A as per the design. This failure was attributed to noise in the transducer measurement system under field trial conditions. This also explains why this condition was not observed in the factory testing prior to the installation at the UoW site.
To resolve this issue the software was modified to raise the phase current threshold at which the BIT function is triggered to above 40A to avoid the impact of noise on the triggering logic. After a period of software implementation and verification by the manufacturer, the software was successfully uploaded to the device and the EDGE-FCLi was reconnected to the grid on 19 July 2021.

BIT Trip 2

The EDGE-FCLi was successfully reconnected following the software modification implemented to resolve BIT Trip 1. However, the device only continued to operate until a further trip event occurred on 28 July 2021. After an initial investigation it was again observed that the device tripped due to a failure of the BIT protection function. The EDGE-FCLi control system logs various parameters in its internal memory and these log files were issued to the manufacturer to undergo a more detailed investigation into the cause of the error. While this investigation was ongoing the EDGE-FCLi was left disconnected from the 11kV network, and the site was restored to its normal configuration.
The manufacturer carried out an analysis of the detailed log files and reported that in the lead up to the error and discovered that the EDGE-FCLi successfully passed several BIT initiations; however, the timing duration of a BIT triggered on phase 2 of the device was much smaller than the nominal duration programmed into the software. This then caused the second trip as described above. Subsequently, the manufacturer has carried out extensive testing and simulations in their laboratory to try and replicate the fault. However, none of the investigations have yielded any root cause. The last step was to send the Micro Controller Unit (MCU) printed circuit board in the EDGE-FCLi back to the GridON factory for detailed inspection. Following receipt of the unit in Israel, GridON carried out an extensive inspection of the printed circuit board and found two metal filings lodged on the MCU electronics were the source of the BIT fault. The first filing was found to have no impact on the control system operation. However, the second filing broached two signal pins on the printed circuit board and analysis showed that this caused a resistive coupling between the two pins, spuriously triggering the BIT function and causing the issue at the site.
This is a highly unusual and unlikely event to occur to a piece of operational hardware and it is not known conclusively where the metal debris originally came from. It is probable, however, that the debris was generated from the drilling of the gland plate at the bottom of the LV cubicle to allow the multicore and LV cables to be terminated into the device. The MCU electronics have now been retrofitted with a plastic cover to avoid further debris interacting with the electronics. In future it may be advisable to drill the cable gland plates away from the LV cubicle to reduce the likelihood of stray metal debris finding its way on the sensitive electronics.

Telecontrol

An important aspect of the learning from the trial is related to the telecontrol configuration used on the EDGE-FCLi. The control engineers responsible for operating the device remotely have communicated feedback to the project team on improvements that could be made to this interface.
The control engineers' main concern was that the "IDLE" and "RECOVERY" mode labelling on the control screens was significantly different to traditional network equipment, which could cause some misunderstanding when trying to operate the device remotely. After a period of review, the "IDLE" and "RECOVERY" commands could realistically map to new labels "OFF" and "ON" respectively on the control screens. This is a much simpler description of the operational modes from a control perspective and aligns with the existing terminology for network equipment.
The learning point for future reference would be to engage with the control engineers in the detailed design phase of the project that deals with formalising the operational regime of the device that is being connected. In that way, there is greater visibility of the

telecontrol aspects earlier in the project delivery and reducing the likelihood of changes to the telecontrol configuration after device energisation.

Generator circuit breaker tripping

If the EDGE-FCLi detects a network fault, experiences a device malfunction, or loses its auxiliary LV supply, the unit disconnects itself from the network by tripping its feeding circuit breakers (CB22, CB24) and CB26 that supplies the CHP generators at UoW.
When the project team was carrying out the remedial works to prepare the device for reconnection following BIT Trip 2, it was observed that the automatic tripping of CB26 was an unnecessary action, especially when cycling the LV auxiliary supply to the EDGEFCLi during testing and commissioning activities. There is a risk that the CHP generators can be accidentally disconnected unnecessarily leading to a customer outage. After a review of the protection scheme, the tripping of CB26 does not serve any identifiable technical purpose and therefore the decision was made to remove the associated trip links from the circuit breaker trip circuit.
Note: The following sections are only required for those projects which have been completed since 1st April 2013, or since the previous Project Progress information was reported.

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The Outcomes of the Project

The main outcomes of the project are:

- The successful design, development, and testing of an EDGE-FCLi, a novel prototype solid-state fault current limiter. The device has been developed from TRL4 “Bench Scale Research” to TRL6 “Large Scale Deployment to a commercial scale device” as per the original aims of the project.
- The selection of the University of Warwick 33/11kV primary substation as an optimal location for the installation of the EDGE-FCLi. The EDGE-FCLi was connected in series with the university’s three existing 1.4MW CHP generators fed directly onto the 11kV primary busbar.
- The successful installation, commissioning, energisation, and trial of the EDGE-FCLi on the 11kV network at the trial site.
- The production of policy documentation that capture how to operate, control, inspect and maintain the EDGE-FCLi:
o STANDARD TECHNIQUE: OC1Z Operation and Control of GridON 11kV Embedded Distributed Generation Electronic Fault Current Limiting Interrupter (EDGE-FCLi)
o STANDARD TECHNIQUE: SP2CAE Inspection and Maintenance of GridON 11kV Embedded Distributed Generation Electronic Fault Current Limiting Interrupter (EDGE-FCLi)
- The dissemination of learning from the project Through regular six-monthly reports and several presentations to the electricity distribution industry. Refer to the closedown report for a full summary list of all six-monthly reports and industry presentations given forthe EDGE-FCLi.
- The production of an EDGE-FCLi Performance report that summarises the performance of the EDGE-FCLi through the testing and trial phases of the project.
The production of the closedown report to summarise and capture the learning items generated throughout the project along with all associated closedown activities.

Data Access

The salient performance data from the short circuit testing was presented in the last annual report. The full short circuit test report can be requested by third parties.
No additional data has been gathered during this project. Reference is made to our Energy Data Hub, which is our central data store for easy access to all of the existing data that WPD currently share with the industry, regulator and customers.

Detailed network plans are also available via our Data Portal.

Foreground IPR

No foreground IPR has been generated.

Planned Implementation

The project has demonstrated the successful design, development, and trial of the EDGE-FCLi, a novel prototype solid-state fault current limiter. The device has been developed from TRL4 “Bench Scale Research” to TRL6 “Large Scale Deployment to a commercial scale device” as per the original aims of the project. Nevertheless, there are design and operational learning points that

should be addressed before a wider deployment of the technology. For further detail refer to the project closedown report.

The EDGE-FCLi is now a device that can be used as an alternative method for DNOs to connect generation at fault level constrained sites without having to use expensive traditional reinforcement. The deployment of the EDGE-FCLi at new locations on the 11kV network, however, should be carefully analysed with reference to the learning points captured in this document and the main project closedown report; the specific customer and site requirements that will differ from the trial site in this project; and any future learning or data generated by the ongoing monitoring of the EDGE-FCLi installed at the UoW trial site.

Whilst the EDGE-FCLi has shown good technical performance in the testing phases, there were instances where it had to be disconnected from the UoW 11kV network for significant periods of time due to technical difficulties with elements of the EDGE-FCLi control system. These issues have now been resolved; however, they have led to a lack of uninterrupted operation and the device has yet to experience a real-world network fault. It would be prudent to monitor the device at UoW for a further nominal time period (e.g., 12 months) before beginning to consider the EDGE-FCLi as an BaU alternative. This monitoring period will allow additional data to be gathered on the reliability and availability of the unit in the field, and the validity of inspection and maintenance intervals. Furthermore, it will give suitable additional time to witness the device operating for a real-world network fault. A further appraisal of the EDGE-FCLi can then be made after the monitoring period has concluded.

Other Comments

Not Applicable

Standards Documents

Not Applicable