Date of Submission

August 2017

Network Innovation Allowance Closedown Report

Notes on Completion: Please refer to the appropriate NIA Governance Document to assist in the completion of this form.

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.

Project Closedown

Project Title	Project Reference
Enhanced Real-Time Cable Temperature Monitoring	NIA_SPEN0003

Project Licensee(s)	Project Start Date	Project Duration
Scottish Power Energy Networks	Apr 2015	2 Years 1 Months

Nominated Project Contact(s)

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Scope

The scope of this project will include:

1. Enhancing the cable temperature monitoring system developed in previous SPEN's Tier 1 LCNF project by conducting additional diagnostic tests and validations.
2. Carrying out data analysis of historical cable temperature data for at least 12 month period to Identify temperature hotspots and causes of temperature bottlenecks.
3. Design the architecture of an ANM system informed by real-time cable temperatures.
4. Updating the relevant policy documents and provide recommendation for full business adoption of the DTS system.
5. Dissemination of the outcomes and learning points through workshops with other UK DNOs and conferences as appropriate.

Objective(s)

The objectives of this project are:

1. Use 12 month period cable temperatures of wind farm circuits to demonstrate the additional network capacity and boost the confidence in deploying cable temperature monitoring systems.
2. Design the ANM system informed by real-time cable temperatures.
3. Provide recommendations for full business adoption of DTS system.
4. Disseminate the key lesson learnt within SPEN and to other UK DNOs.

Success Criteria

1. Production of the data analysis report on at least a 12-month period which includes identifying the thermal pinch points and their causes and recommendations for elevation of thermal constraints.
2. Designing an ANM system informed by real-time cable temperatures.
3. Providing recommendations for developing and updating relevant policy documents for adopting DTS in full business as usual.
4. Receiving feedback from other UK DNOs on dissemination of findings and lessons learnt.

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

The project has largely met its original aims and objectives. A summary of project performance is given in the following

"Use 12 month period cable temperatures of windfarm circuits to demonstrate the additional network capacity and boost the confidence in deploying cable temperature monitoring systems"

• The second section of Dungavel circuit was energised in September 2015. From that date on, Dungavel circuit was loaded with the respective windfarm and therefore we have been able to observe the thermal behaviour of the four cable circuits under in different loading conditions.

• In order to boost the confidence in DCR system, data flow within the Dynamic Cable Rating (DCR) system architecture has been checked and it was confirmed that the data flow was healthy. Measured and calculated data have been recorded in SPEN's data historian (PI) for every 30 minutes intervals and for each cable circuit. We have developed a data analysis tool which helps us to generate various reports on loadings of the cable circuits and corresponding cable temperature variations.

• A 12 month period of DCR data and the overall system performance were analysed. Headroom for additional generation was identified by:

- Comparing historic windfarm outputs against calculated DCR Short Term Permissible Loadings (STPL) at the same time. STPL is one of the calculated parameters by DCR system and represents the maximum allowable loading of the circuit for the next 24 hours. This is an indicative parameter that shows the available capacity headroom on a real-time basis ; and
- Simulating the thermal behaviour of the circuits for a hypothetical increase in windfarm outputs to calculate the maximum permissible circuit loading if the conductor temperature should remain with the 78C. For this simulation, we used an actual windfarm generation profile but allowed the increase in maximum generation.

The results showed that 20% additional capacity can be unlocked in the exiting circuits. This is recommended to be utilised by using a closed-loop control ANM system, which controls the output of the generators based on real-time cable temperature measurements.

"Design the ANM system informed by real-time cable temperatures"

- We organised several meetings with ANM suppliers to discuss the communication between our DCR system and their ANM solutions. The existing DCR system architecture includes communications through SPEN's secured corporate network. The real-time loading of the circuits and also the DCR output parameters are also available on SPEN's Real Time System (RTS). This architecture requires any ANM scheme to communicate with DCR through SPEN's RTS. We have confirmed with one of the ANM suppliers that the communications between DCR and their ANM systems can be established based on the existing RTU arrangements in the East Kilbride South substation.
- DCR system reports the real-time (every 30 minutes) maximum temperature and STPL of the cable circuits. After discussions with manufacturers and our internal operation engineers, we have concluded that the primary parameter to consider to inform the controlling algorithm for adjusting the windfarm output would be the STPL. STPL would provide adequate and understandable information for windfarm operator and SPEN control engineers. The real-time cable temperature and fibre temperature was recommended as the secondary and tertiary as checking parameters to ensure the primary controlling algorithm would function as expected. The checking parameters may trigger alarm notification and immediate curtailment of the windfarm output if temperature passes the alarm level. A high level functional specification for the control algorithm has been also developed.
- Health check on the monitored data is essential to ensure incorrect data are filtered out. If monitored data are not available or identified as incorrect the necessary process for curtailing the wind farm output back to a conservative output level should be in place.

"Provide recommendation for full business adoption"

- We organised various internal stakeholder meetings to identify requirements for full business adoption of the DCR system. It included discussions about the internal policy document, the technical specification of DCR system for future implementation, Ownership of the system, operation and maintenance (O&M) requirements etc.
- We have developed the first generic specification for a complete DCR system using DTS technology. This document has been reviewed and approved internally and it is now a live document within SPEN. This will inform the future replication of the DCR/DTS solution.
- We have developed a draft of a policy document which provides a clear instruction that where and when a DCR system should be deployed for future cable installations at different voltage levels. This project is now under final stage of review by relevant experts within SPEN.

- We have provided a recommendation on changing the exiting asset rating policy to consider cyclic rating approach for sizing the windfarm cable circuits. This includes using conservative cyclic rating (which are higher than continuous cable rating) for future/exiting wind farm connections.

"Disseminate the key lesson learnt within SPEN and to other UK DNOs"

- Details of the project have been disseminated in Low Carbon Network Innovation (LCNI) conference in 2015 and 2016.
- A short video overviewing the project has been prepared and was shown at the LCNI conference in 2016.
- Technical papers have been presented in international conferences as follows:
  - "Windfarm Cable Temperature Monitoring: Implementation and Learning", 15th Wind Integration Workshop, 2016.
  - "Cyclic Rating of Windfarm Cable Connections", CIRED 24th International Conference on Electricity Distribution, 2017.
- As part of raising awareness within the SPEN business about the DCR and DTS technologies and their merit, various internal stakeholders, such as planning engineers, operation engineers, policy holders and real-time system management teams, were identified and invited to various internal dissemination sessions. During these sessions, the stakeholders were briefed on the purpose and the progress of the project, while also identifying effective processes for bringing the DCR system to BaU.
- DCR historic data were shared with the University of Manchester to provide academics with field data for further research to be carried out. Subsequently, two MSc dissertations were produced, namely the "Modelling and Control of Battery Energy Storage Systems and Cable Temperature for Windfarms Application" and the "Optimization of Energy Storage Systems for Windfarms under Cable Temperature Monitoring".

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

None

Lessons Learnt for Future Projects

The following lessons learnt may be considered for replication the DCR project or for other innovation projects:

• As the windfarm outputs vary with time It would be more appropriate to consider a cyclic load profile for sizing of the cable circuits rather than conventional industry approach which considers a continuous load profile. It was demonstrated that the using a conservative cyclic ratings for windfarm cable circuit can potentially offer in average 10% greater carrying capacity than the conventional continuous ratings.

• The thermal pinch points are usually located around certain areas, for example around deep burial installations, close proximity with other cable circuits or heat sources etc. for future cable circuits installations, if these locations can be identified in the design stage, they could be avoided, thus avoiding potential thermal bottlenecks that could limit the thermal rating of the cable circuits.

• The data analysis on DCR data and desktop studies on thermal behaviour of the four 33kV windfarm cable circuits suggested that a 20% additional wind power can be exported using the existing circuits if wind farms consider participation in an ANM scheme informed by a DCR system.

• For a successful integration of a new solution into business as usual, it is important to:

- have an early engagement with relevant parts of business and people who will ultimately deploy the solution. The ownership within business and roles and responsibilities should be developed, clarified and agreed in the course of projects rather than at the end of projects to inform a quick handover.
- The essential documentations including technical specifications informing project replications and policy documents informing when and where the solution should be deployed need to be developed and approved in the course of project.
- The operation and maintenance procedure and requirements should be developed and essential trainings should be provided before complementation of the project.

• Most of suppliers may only be capable of providing stand-alone solutions which may not be necessarily appropriate for integration into a secure corporate network and communicating with Network Management System. This should be properly evaluated at an early stage before selecting the supplier by involving IT and Real Time System departments.

• Some of the suppliers may join a partnership to provide a solution, in this way different parts of a solution may be provided by different suppliers. In order to achieve a sustainable solution for the business, we should ensure that the business engagement between suppliers will not impose any risk to the quality, delivery time and budget of the project. Also, suppliers need to provide commitment to any O&M and future system developments, if required.

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.

The Outcomes of the Project

The following documents and tools were developed as part of Business as Usual integration:

- **Policy document** - A company policy for the application of a DCR system using DTS technology for real-time monitoring of underground cables has been drafted. This document is now under final review and it provides a guidelines where DCR system, DTS solution or as a minimum provision of micro-duct at time of installation should be considered.
- **Technical specification** - A technical specification document for DCR systems associated with underground power cables was prepared based on the findings of the project and with reference to the SPEN systems and internal procedures . The document specifies requirements for the supply, installation and integration of a DCR system that deploys DTS technology and associated software to determine the rating of a cable circuit and its conductor temperature.
- **Excel analysis tool** - An analysis tool was developed in Excel that utilises the programming language Visual Basic Application (VBA). This tool retrieves historic DCR data from SPEN's PI server and produces various statistics and graphs for a period requested by the user. The purpose of this tool is to allow SPEN engineers to have a quick and easy access to DCR data and corresponding cable circuits in a graphical and understandable fashion.
- **Cyclic Cable Rating tool**: A cyclic cable rating tool was developed by University of Southampton. The purpose of the tool is to convert historical loadings of a wind farm cable circuit or a windfarm outputs into representative cyclic load profile. This reprehensive load profile can be used together with BaU cable rating calculation tools, such as Cable Rater (CRATER) and CYMCAP, to determine the cyclic thermal rating of a cable circuit.

Planned Implementation

The following items are recommended to be considered for future implementations within SPEN:

• **Central DCR Calculation Engine** – It is recommended that SPEN develop a central DCR calculation engine linked to the Network Management System. A central calculation engine will have the following benefits:

- **A better value for money for customers**: For implementing future DCR systems, SPEN will only require to procure the DTS equipment without any need to include the DCR calculation engine in the tendering requirements. This will allow more suppliers to participate for a competitive tendering. The total DCR system cost is expected to reduce for future implementation.
- **Flexibility to amend, modify and upgrade:** The features of the DCR calculation engine can be customised to accommodate the specific SPEN requirements. That may include adding new circuits, amending cable models, communications with SACAD systems etc. The calculation algorithms will be open source if developed internally to SPEN, so it will provide better understanding and visibility, therefore it allows SPEN to move away from "black box" models which suppliers provide typically.
- **Avoiding interface with multiple DCR software:** The end users within SPEN do not need to operate different DCR applications. A standard central calculation engine will provide consistency with DCR implementation, and significantly reduces the time and effort for learning the new applications and troubleshooting required.
- **Alternative connection offers for windfarm cable circuits**: SPEN are considering to provide alternative windfarm connections offer, complementary to the conventional connection offers. This will include connections based on the cyclic rating and also connection offers which include implementation of an ANM scheme informed a DCR system.
- **Approval of the DCR application policy:** Approve of the developed DCR application policy is currently in process. This document is under final review and modifications.
- **Application of DCR together with an energy storage for windfarms:** It is recommended that further work considers the application of DCR systems and energy storage systems for maximising wind power outputs. DCR could be complemented by an energy storage system that would be controlled according to cable temperature. At times of high temperatures, thus high export, the system can store energy if the cable temperature may approach the permissible temperature. At times of low cable temperatures, the storage system can discharge and supplement the energy generated by the windfarm itself.
- **Application of retrofit solutions for temperature monitoring:** As demonstrated, the thermal pinch points are usually located around certain areas. Monitoring only specific parts of the circuit, such as the pinch points, can provide sufficient visibility of the thermal behaviour of the entire cable. At the moment, there is no commercially ready retrofit solution for temperature monitoring in the market. This can be an opportunity for carrying out an innovation project in order to develop a fit-for-purpose monitoring solution. These sensors could communicate their recordings back to a central calculation engine and inform any DCR calculations.

Other Comments

None