9th November, 2012

Mr Simon Bartlett
Chairperson
E. S. Cornwall Scholarship Advisory Committee
PO Box 1193
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Dear Simon

Fourth Quarterly Report - E. S. Cornwall Memorial Scholarship – Sarah Hiley

Please find enclosed my fourth quarterly E. S. Cornwall Scholarship report outlining my period of employment from the 23rd of July 2012 to the 23rd of October 2012.

This quarter I commenced work as a protection and control engineer with Iberdrola Engineering and Construction (IEC) in Glasgow. During my time with IEC, I will be working as part of a small team to develop a new substation automation standard for ScottishPower based on IEC 61850. This standardisation work will be carried out in conjunction with an IEC 61850 pilot project. Over the past few months, I have scoped the protection and control requirements for the pilot project and undertaken the high level design, required by ScottishPower, as part of the initial design phase. In addition to this, I have been involved in evaluating the various bay level devices available on the market and assessing their level of compliance with Iberdrola's IEC 61850 requirements as well as the specific requirements of the pilot project. I have also had the opportunity, this quarter, to attend the biennial CIGRE session in Paris and visit the University of Strathclyde.

It should be noted that due to confidentiality, I am not able to include specific information relating to customer projects.

I welcome the committee's feedback on this report and my goals for the next quarter.

Yours faithfully,

Sarah Hiley

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1 Introduction

My program of work under the E. S. Cornwall Memorial Scholarship is aimed at gaining international experience in substation automation systems using the IEC 61850 standard. More specifically, the program focuses on gaining technical experience with the design, integration and testing of such systems whilst working for an international manufacturer and power engineering services company. The program will also provide exposure to the challenges and issues that face organisations when adopting a new technology.

My tenure of the E. S. Cornwall Memorial Scholarship is from the 10th of October, 2011 to the 10th of April, 2013. My first nine month placement was with ABB Switzerland in Baden, where I worked as part of the Substation Automation System (SAS) Engineering and Test Team. This quarter I have commenced my second nine month placement in Scotland with Iberdrola Engineering and Construction (IEC), a subsidiary of the Iberdrola Group, where I am working as a protection and control engineer.

Iberdrola is a private Spanish multinational electric company that is striving to develop the areas of grid projects and clean technologies, especially wind power, all over the world. Iberdrola's structure includes four lines of business: Regulated Business (including Transmission and Distribution businesses), Liberalised Business, Renewables Business and Other Businesses (including IEC). Iberdrola has undergone significant growth in the past decade due to international expansion and now has a presence in forty countries across five continents, with its main activities currently being conducted in Spain, the USA, UK, Brazil and Mexico. In 2007, Iberdrola finalised a friendly takeover of ScottishPower, the transmission owner of the south of Scotland and also a provider of electricity and gas to other areas throughout the UK. I am currently working in IEC's Glasgow office, providing engineering services to Iberdrola's ScottishPower Energy Networks business.

Iberdrola have been very progressive in implementing the IEC 61850 standard. Iberdrola successfully installed their first IEC 61850 system in the Spanish distribution network in 2004. Since this time, Iberdrola have implemented a large number of multivendor IEC 61850 systems and have developed a comprehensive IEC 61850 substation automation system (SAS) specification for the Spanish distribution network. Iberdrola is now striving to develop IEC 61850 SAS standards for its other network businesses around the world, including ScottishPower Energy Networks. During my time with IEC, I will be primarily involved with this development work and the adaptation of the Spanish IEC 61850 standard to the ScottishPower networks. The standardisation work will be done in conjunction with the execution of an IEC 61850 pilot project.

This report is the fourth of six reports and outlines the work that I have undertaken from the 23rd of July, 2012 to the 23rd of October, 2012. As this is my first report for my current placement I have also included some background information on IEC and their philosophies toward IEC 61850 implementation.

2 Background

2.1 Iberdrola Engineering and Construction (IEC)

Iberdrola Engineering and Construction (IEC) is a leading energy engineering company that develops projects in more than thirty countries, in the areas of transmission and distribution, generation, renewable energy and nuclear energy. Its strategic areas are the United States, the United Kingdom, Latin America, the Middle East, Russia and the countries of Eastern Europe.

In Scotland, IEC and ScottishPower Energy Networks signed a Master Agreement whereby IEC will perform engineering and construction management services for ScottishPower transmission infrastructure projects. The portfolio for this agreement includes new projects as well as upgrade and expansion projects. IEC UK is currently working on 150 substation and transmission line projects.

In Spain, IEC has had significant experience with implementing IEC 61850 projects and developing Iberdrola's IEC 61850 Spanish Specification documents. IEC have also been very active in the *"E3 – Spanish Electricity Companies for Studies on IEC 61850"* working group since its inception in 2008. This working group has carried out extensive IEC 61850 development work which forms the basis of Iberdrola's Spanish specification. The E3 group will be discussed further in the following section.

2.2 E3 Working Group

The E3 working group was formed by representatives and specialists from Spanish manufacturers, utilities and integrators who recognised the need for companies to come together to share experiences with IEC 61850 in order to develop a set of unified criteria for the minimum requirements that IEC 61850 devices must meet in order to be installed in their substations. This is the result of the common standpoint reached by all participants after the experience gained from several pilot projects.

The main objectives of the working group are as follows:

- Share information among companies and walk together through IEC 61850
- Generate a minimum common specification of an IEC 61850 substation automation system (SAS) that should be valid for the companies in the group
- Lead the technological gap between now-available IEC 61850 systems and the desired final picture
- Improve efficiency and optimise IEC 61850 deployment
- Drive the manufacturer's developments to align with user requirements

The E3 group's early experiences with IEC 61850 implementation, demonstrated a need for the development of further specifications in order to enhance interoperability and to ensure that the user can gain the maximum benefit from the standard. In order for utilities to realise the full potential of IEC 61850, additional requirements need to be defined and then, most importantly, these requirements must be met by manufacturers.

In order to achieve this, the E3 group has published a comprehensive specification that outlines the minimum requirements for substation protection and control equipment used in IEC 61850 systems. The companies in the E3 group have agreed to demand, from their suppliers, compliance with all of

the requirements included in this document. As this document forms the basis of Iberdrola's IEC 61850 SAS specification, I will include a brief overview and summary of the key requirements. For further information, the full E3 specification document can be downloaded from the following link:

https://sites.google.com/site/e3groupiec61850/documents-2

The document firstly presents three case studies that represent the typical substation topologies present in Spain and defines all of the corresponding operational prerequisites for the SAS. It then defines the minimum requirements that the SAS should comply with regarding: LAN network topologies, IED configuration capabilities and processes, communication services, synchronization, security and process bus. Finally, methods for system deployment for a number of different scenarios are discussed. The document also includes a number of detailed technical Annexes that describe how to use/extend IEC 61850 to implement various functions such as HMI and graphical screen modelling, logic implementation and GOOSE and SV subscription.

One of the main aims of the specification is to ensure a high level of interoperability. The engineering of the first IEC 61850 substations in Spain demonstrated that although interoperability between IEDs from different manufactures was possible, extra work was necessary to achieve a higher degree of it. For this reason, the E3 group has specified rules to ensure coherent data modelling and communication services and also the minimum IED capacities in terms of data sets, control blocks, GOOSE messages etc.

The other key focus of the E3 group is to set out extra requirements to allow utilities to reap the full benefits of IEC 61850. The central idea being that an IED must be able to be completely configured from one, single CID file and the need for proprietary configuration tools (e.g. for modelling of PLC logic equations and modelling of graphical displays etc.) must be eliminated. Standard CID file loading, validation and activation procedures are also defined. These requirements bring significant cost benefits to utilities and simplify the engineering phase. For example, Iberdrola has already developed their own system configuration tool that is capable of completely configuring all of the 3rd party IEDs used in their standard IEC 61850 systems, including full configuration of the HMI i.e. single line diagrams, event/alarm lists etc.

In addition to the main specification, a supplementary questionnaire document has also been published by the E3 group (also available for download from the above website). This document provides an excellent means of assessing the current and future capabilities of manufacturers in terms of their ability to meet the E3 group requirements.

By coming together in the E3 group, the major Spanish utilities have been successful in driving a number of manufacturers (mostly based in Spain) to meet these requirements.

All organisations worldwide who share a common view are welcome to join the E3 working group.

3 Work Experience

For the duration of my nine month placement with IEC, I will be primarily working on ScottishPower's first IEC 61850 implementation project. This pilot project will be done in conjunction with the development work for ScottishPower's new standard for IEC 61850 substation automation systems. This standard will be based on Iberdrola's Spanish SAS specification and the requirements outlined by the E3 group. (Iberdrola's IEC 61850 SAS standard is known as 'iSAS' and will be referred to as this from here on.)

The work that I have undertaken to date includes:

- Reviewing ScottishPower's protection and control standards to understand existing practises and the operational requirements of the system
- Reviewing the E3 group specification document and the IEC 61850 specification work already done by IEC
- Scoping the protection and control requirements for the proposed ScottishPower IEC 61850 pilot project and documenting these requirements as part of the System Construction Authorisation report
- Developing the Main Connections and Protection diagram for the pilot project
- Determining which protection and control functions will be implemented in each device and how this would be modelled using IEC 61850 i.e. determining which logical nodes and data exchange services will be required
- Assessing the IEDs currently on the market to determine their level of compatibility with both iSAS and ScottishPower requirements
- Assisting in the development work for Iberdrola's global iSAS specification

I have found this work to be very interesting and challenging and it has provided a great deal of insight into Iberdrola's IEC 61850 experience and current philosophies. It has been very beneficial to be undertaking bay level engineering, as this provides a different perspective to my previous role as a station level engineer with ABB. From this new perspective, I am continually gaining more knowledge and understanding of the IEC 61850 standard and system implementation. It has also been interesting to learn about the current practises in the UK and to see first-hand how a company is handling such a significant technological shift. The following sections will discuss this experience in more detail.

3.1 iSAS Development

Iberdrola is currently developing a high level, global iSAS specification, which is being adapted from Iberdrola's Spanish specification and the E3 requirements, to suit the needs of all of Iberdrola's utilities throughout the world. The standard outlines general and functional system requirements (e.g. SAS architecture, time synchronisation, security etc.), the engineering and configuration process, requirements for the station and bay level IEDs and standard testing procedures. The IEC 61850 design standards being developed by Iberdrola's utilities in the USA, UK, Brazil and Spain, must meet the requirements outlined in this document. So far, I have assisted in drafting a section describing a number of additional functions including GOOSE and SV subscription modelling, HMI and graphical screen modelling, logic modelling and the modelling of physical inputs and outputs.

The majority of the work that I have undertaken this quarter, however, has been related specifically to ScottishPower's iSAS development. This work is being done in conjunction with the design for a pilot project, which will be discussed further in the following section.

Prior to my commencement with IEC, high level scoping of device requirements in terms of IEC 61850 had been undertaken and liaisons with various manufacturers of protection devices to discuss the iSAS requirements had commenced. Each of these manufacturers was asked to complete the E3 compliance questionnaire (discussed above) which gave a clear indication of the manufacturer's current level of compliance, as well as their willingness to develop their IEDs to better meet the iSAS requirements in the future. A comprehensive specification (directly adapted from the Spanish specification) for the substation control unit had also been prepared prior to my start with IEC and discussions with manufacturers in regards to this was underway.

Based on this analysis, ScottishPower is assessing a number of bay level IEDs that could be used to meet the requirements of the IEC 61850 pilot project. This includes IEDs for bay control, feeder protection, busbar protection, transformer connections protection, backup overcurrent protection and fault recording. I was required to review the requirements and assess the IEDs that are currently on the market to determine their current level of compatibility with both iSAS and ScottishPower requirements. This involved reviewing manuals and IEC 61850 conformance statements and configuration files to better understand the functionality of each device, the configuration process and the IEC 61850 capabilities and performance. I have also attended meetings with both ScottishPower and a number of manufacturers to discuss these requirements in more detail.

I was also required to prepare a spread sheet detailing how the protection and control functions would be allocated to each of the IEDs. I was then required to analyse how each of these functions could be modelled using IEC 61850. Based on this analysis, I determined which logical nodes would need to be implemented in each device and the number of logical node instances required. I also analysed the signalling requirements between the bay level IEDs and the bay and station level IEDs and, for each device, listed the GOOSE and MMS signals that would need to be published or subscribed to. This analysis will be used in the next level of discussions with manufacturers to assess which specific requirements each IED currently meets and which areas will need further development.

In addition to finalising the bay level requirements, the next step now is to determine the optimum system architecture taking into account the topologies recommended in the E3 group specification as well as ScottishPower's current operational requirements in terms of security, reliability and operability. Once the desired topology is finalised, I will be working to develop specifications for the remaining station level devices, namely for the switches and GPS time servers.

3.2 IEC 61850 Pilot Project

ScottishPower's IEC 61850 pilot project is currently in the initial design phase. When I started with IEC in July, the Project Information Pack (a document containing the high level project scope and requirements) had already been issued by ScottishPower to IEC and IEC was beginning to draft the System Construction Authorisation (SCA). The SCA is a comprehensive document that details the requirements for all civil, switchgear and secondary system works for a specific project. This includes the high level design with the initial set of drawings, the delivery strategy, commissioning staging, risk assessment and the project program.

My initial task was to familiarise myself with ScottishPower's current protection and control philosophies and the high level requirements of the pilot project. I was then required to scope the protection and control aspects of the project and input this information into the SCA. This involved determining:

- the most suitable protection schemes for each item of plant
- the control functionality required for each item of plant e.g. auto reclose, synchronising, tap changer control etc.
- feeder remote end works
- the communications requirements for each feeder
- temporary protection scheme requirements in order to facilitate staged commissioning
- AC and DC supply requirements

As part of the SCA, I was required to develop the Main Connections and Protection Diagram. This drawing shows a single line representation of the substation, detailing the current and voltage transformer specifications and connections to the various protection and control functions.

The draft SCA has now been finalised and has been submitted to ScottishPower for review.

(I hope to provide specific details about this pilot project in a later report, following official approvals.)

4 Additional Opportunities

4.1 Paris CIGRE Session

This quarter, I was very fortunate to have the opportunity to attend the biennial CIGRE session in Paris. CIGRE, the Council on Large Electric Systems, is an international association that aims to bring together experts from around the world to share best practises and work together for the betterment of the power industry. The 2012 CIGRE session provided a unique opportunity to listen to contributions from international senior executives, experts and specialists through official presentations, panel discussions, technical meetings and poster sessions. A technical exhibition was also held in conjunction with the session, which gave all delegates the opportunity to discover the latest technological developments in power systems engineering including new services, tools, equipment and materials. The session and technical exhibition brought together around 6000 senior executives, engineers and experts from the worldwide power industry.

CIGRE is made up of sixteen study committees, each focussing on a specific technical domain within the field of power systems. The B5 Protection and Automation study committee is closely related to my scholarship topic and therefore, I made it a priority to attend the sessions presented by this group. I also attended the sessions for the B3 Substations study committee and was fortunate to have the opportunity to be an observer during a technical meeting.

The scope of the B5 Protection and Automation study committee includes:

- Improved concepts of Substation Automation Systems
- Technical recommendations for IEC 61850
- Application of numerical protections and substation automation systems
- Methods to improve the performance of protection systems
- Protection implications of new generation technologies

More specifically, the discussions that took place at the 2012 CIGRE session were in relation to the following two preferential subjects:

PS1 – Impact of future network components on protection and automation systems

PS2 – Utilisation and application of remote access for protection and automation systems

Some of the key experiences discussed related to:

- **Wide Area Monitoring, Protection and Control (WAMP&C) systems** designed to increase system stability and prevent large contingencies such as cascading outages and power system blackouts. For example, one of the presentations outlined the country wide WAMS project currently being implemented in Brazil. The system uses synchrophasor measurements taken from thirty phasor measurement units (PMUs) to identify system oscillations in real time and enable corrective measures to be taken to damp these oscillations.
- **Adaptive protection and control schemes** – for example, Siemens presented an adaptive line differential scheme where the value of the restraint current is adjusted in response to online calculated errors and an example from the UK for a wide area protection scheme was presented where the frequency tolerance is relaxed when a wide area disturbance is detected in order to prevent cascaded tripping of distributed generation. Also, Japan presented an

innovative integrated stability control system that maintains angle and voltage stability using online adaptive controls.

- **Substation Automatic Restoration Systems (SARS)** – Japan presented the SARS currently in use and how they have made a major contribution to improving the reliability of the power system.
- **IEC 61850 substation automation system implementation** including experiences with NCITs and process bus installations from a number of manufacturers and utilities. For example, Iberdrola presented promising results from a process bus pilot project at the Benavente substation in Spain and French utility RTE presented two pilot projects (each employing different types of NCITs and metering) – one at a 400kV AIS substation and one at a 225kV GIS substation. Powerlink's Loganlea iPASS substation refurbishment project was also presented by ABB.
- **Schemes to accommodate distributed generation in the grid**. For example, a concern for network operators is being able to reliably detect the islanding of distributed generation. Alstom Grid UK presented a protection relay that incorporates a novel islanding detection method that is based on an accumulated phase angle drift measurement. The method has been tested extensively in real time simulations and shows very good levels of both sensitivity and stability.
- **Remote access to substations** – a large number of the presentations given related to developments and requirements for substation remote access including the increasing need for cyber security. The potential benefits of using the IEC 61850 standard for the communications between the substations and remote control centre was also highlighted.

One of the main concepts that I took away from this session was that with the rapidly increasing complexity of power systems, more and more focus needs to be given to the response of the protection system to dynamic network phenomena such as dynamic loading, voltage stability and transient stability. Experiences have shown that major disturbances and blackouts are often caused by protection operations and therefore, it is important to consider protection devices when studying system stability. The analysis of these problems can also help to derive new, innovative and adaptive protection schemes that can improve system stability and performance and prevent unnecessary power supply interruptions. The other dominant theme throughout the session was the key role that the IEC 61850 standard will play in enhancing these special protection schemes and the next generation of smart substations.

I am extremely grateful to have had the opportunity to attend this conference. I found it to be a very valuable experience and I look forward to further involvement with CIGRE throughout my career.

4.2 University of Strathclyde Visit

The University of Strathclyde, located in Glasgow, is one of the leading technical universities in Scotland, with approximately 16 000 undergraduate students and 10 000 post graduate students. The university has a very strong industry focus and strives to translate world-leading research into industrial developments through effective knowledge exchange. In particular, the Institute for Energy and Environment, within the Electronic and Electrical Engineering Department, has established itself as one of the leading centres for research and teaching internationally. The Institute is one of the largest electrical power engineering and energy technology university research groups in Europe, with a £35 million portfolio of activities. It provides an extensive range of services to industry and the public sector, including research collaboration, knowledge exchange, continual professional development and consultancy services.

This quarter, I was fortunate to be able to visit the university and meet with the head of the Department of Electronic and Electrical Engineering. I was then given a comprehensive tour of the Institute of Energy and Environment, where I visited a number of test laboratories and met with faculty members from each of the key power research groups including; Advanced Electrical Systems and Power Systems, Power Electronics Drives and Energy Conversion, Renewable Energy Technology and High Voltage Technology and Electrical Plant Diagnostics. This gave me a great deal of insight into the institute's current portfolio of activities and its relationships with industry partners. Its research capabilities cover a broad spectrum of areas and in particular, it is at the forefront of smart grid research, where it is delivering novel contributions in the technical, policy, economic and energy market areas.

The institute has developed strong relationships with a number of industry partners (including ScottishPower) and is currently involved in a diverse range of industry and government funded research programmes. Its research activities are concentrated within internationally recognised centres of excellence that are closely aligned to industry and government needs. For example, one such centre is the Scottish Power Advanced Research Centre (SPARC). This centre was established to undertake research specifically aligned with ScottishPower's business strategy, in the areas of asset technology, investment strategy and system development.

Some of the current projects/developments discussed during my visit included:

Northern Isles New Energy Solutions –this project aims to support Shetland Island's sustainable energy future by developing and managing the electricity distribution network more effectively to allow renewable energy to play a bigger part in meeting Shetland's energy needs. It is being developed by Scottish and Southern Energy (SSE) in conjunction with a range of local stakeholders.

Key aspects of the project include:

- Replacing old inefficient storage and water heaters in 1,000 homes with modern 'smart' storage heaters which help to balance the electricity network
- Adding a new electric boiler to the existing district heating system
- Deploying new technology on the network that will allow more small scale renewable generators to connect to the network
- Introducing new commercial arrangements to encourage businesses to change the times at which they use most energy
- Installing a 1MW battery at a local power station

This project will help with the planning and development of energy infrastructures in the Northern Isles.

Flexible Networks for a Low Carbon Future – the aim of this project is to trial a combination of smart network interventions and customer energy efficiency measures at three network locations to demonstrate how they can release capacity on the high voltage network. This will allow greater take up of low carbon technologies without the need for expensive network reinforcement. The technologies being trialled include solar PV, heat pumps and electric vehicle charging points. This project is being developed with ScottishPower.

Power Networks Demonstration Centre – Strathclyde University, in conjunction with leading energy companies including ScottishPower and SSE, is currently developing a world-class facility for researching and developing state of the art electrical transmission, distribution and generation innovation. The facility will provide a realistic and controllable test bed that will accelerate the development and demonstration of new technologies, from advanced power grids to electric cars and household appliances.

5 Planned Future Experience

Throughout my first quarter with IEC, I have scoped the protection and control requirements for the IEC 61850 pilot project and analysed a number of different bay level IEDs to assess how well they meet both project and iSAS requirements. Various meetings with manufacturers have taken place to discuss and negotiate the implementation of these requirements. Based on this work, ScottishPower will now choose the most appropriate devices for the IEC 61850 pilot project. Once the selection of bay level IEDs has been finalised, my next step will be to gain familiarity with Iberdrola's IEC 61850 IED configuration tool, as well as the required proprietary configuration tools in order to work toward developing configuration files for each IED to facilitate testing. I will also be working toward developing schematic diagrams for each device outlining input and output circuitry.

In terms of the station level, the next step is to determine the optimum system architecture taking into account the topologies recommended in the E3 group specification as well as ScottishPower's current operational requirements in terms of security, reliability and operability. Once the desired topology is finalised, I will be working to develop specifications for the remaining station level devices, namely for the switches and GPS time servers.

I will also be undertaking additional project tasks (not related to the iSAS development work), such as providing input into additional SCA documents and writing a specification outlining the communication services required for the pilot project. I am also planning to undertake a site visit as part of this work.