30th June, 2013

Mr Simon Bartlett
Chairperson
E. S. Cornwall Scholarship Advisory Committee
PO Box 1193
Virginia QLD 4014

Dear Simon

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

Please find enclosed my final quarterly E. S. Cornwall Scholarship report outlining my period of employment from the 24th of January 2013 to the 24th of May 2013.

During my final quarter with Iberdrola Engineering and Construction (IEC), I continued to work on the substation automation system (SAS) design for Scottish Power's first two IEC 61850 implementation projects: the Windyhill 132kV Switchgear Replacement project and the Chapelcross 132kV Switchgear Replacement project.

After completing my placement with IEC in May, I was able to take advantage of the travel opportunities facilitated by the scholarship and spend six weeks travelling overland from Europe to Vietnam before returning to Australia. During this time, I was fortunate to be able to arrange a meeting with a senior power automation engineer at the China Electric Power Research Institute (CEPRI) in Beijing, to discuss the IEC 61850 developments currently taking place in China.

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 the experience that I have gained throughout my scholarship tenure.

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 was from the 10th of October, 2011 to the 10th of April, 2013. My final placement with IEC in Glasgow extended slightly beyond my scholarship tenure and therefore this report will cover the work that I undertook through to the 24th of May, 2013.

In my final quarter with IEC I have continued to work on the substation automation design for Scottish Power's first two IEC 61850 implementation projects: the Windyhill 132kV Switchgear Replacement project and the Chapelcross 132kV Switchgear Replacement project. This work has involved a wide range of different tasks which included writing technical specifications, participating in design workshops, tender evaluation, producing technical drawings and gaining familiarity with the various design configuration tools used by Iberdrola.

In addition to my work with IEC, I have also had the opportunity to meet with a senior power automation engineer at the China Electric Power Research Institute (CEPRI) in Beijing, to discuss the IEC 61850 developments currently taking place in China.

This report is the last of six reports and outlines the work that I have undertaken from the 24th of January 2013 to the 24th of May 2013.

2 Work Experience

The key deliverables that I have carried out in my final quarter with IEC include:

- Finalising the Windyhill Design Intent Document (described in my previous report) and submitting it to Scottish Power for review.
- Participating in a workshop between IEC and key engineering and operations personnel from Scottish Power to work through and evaluate the technical solution proposed in the Design Intent Document.
- Updating the Windyhill Design Intent Document to incorporate Scottish Power's comments
- Evaluating the tenders received from a number of external design houses for the Windyhill protection and control works.
- Developing the Windyhill design documents and drawings that were required to be submitted to the external design house in order for them to produce the circuitry drawings and panel general arrangements. These drawings included general wiring schematics for each IED model and an SAS network overview diagram.
- Drafting the 110V DC Supply System Technical Specification for Windyhill including battery sizing calculations.
- Drafting a tender specification document outlining the scope and requirements for the protection and control works associated with Scottish Power's second IEC 61850 project – the Chapelcross 132kV Switchgear Replacement project.
- Gaining familiarity with a number of IED configuration tools including Iberdrola's iSAS@Works tool and Alstom's Micom S1 Agile.

These tasks will be discussed in more detail in the following sections.

2.1 Windyhill 132kV Switchgear Replacement Project

As discussed in my previous report, my work last quarter focussed on drafting a Design Intent Document detailing the proposed substation automation system design solution for the Windyhill 132kV Switchgear Replacement project, Scottish Power's first IEC 61850 implementation. Early this quarter, this document was submitted to Scottish Power for review. This was followed by a workshop, facilitated by IEC, with key engineering and operations personnel from Scottish Power to work through and assess the proposed solution. Throughout this process a number of issues were raised and modifications were made, resulting in the development of an SAS solution for Windyhill that satisfied the requirements of all stakeholders. An overview of the final solution is given in Section 2.1.1.

Following this review process, I updated the Design Intent Document to incorporate Scottish Power's comments and then developed the set of design drawings that were required to be submitted to the external design house to facilitate the production of circuitry drawings and panel general arrangements. These drawings included general wiring schematics for each IED model and an SAS network overview diagram.

In parallel with this work, I also evaluated the tenders received from a number of external design houses and made a recommendation for tender award based on this evaluation process. Once the tender was awarded, I attended a kick off meeting with the successful contractor to discuss the scope of works and the proposed SAS solution.

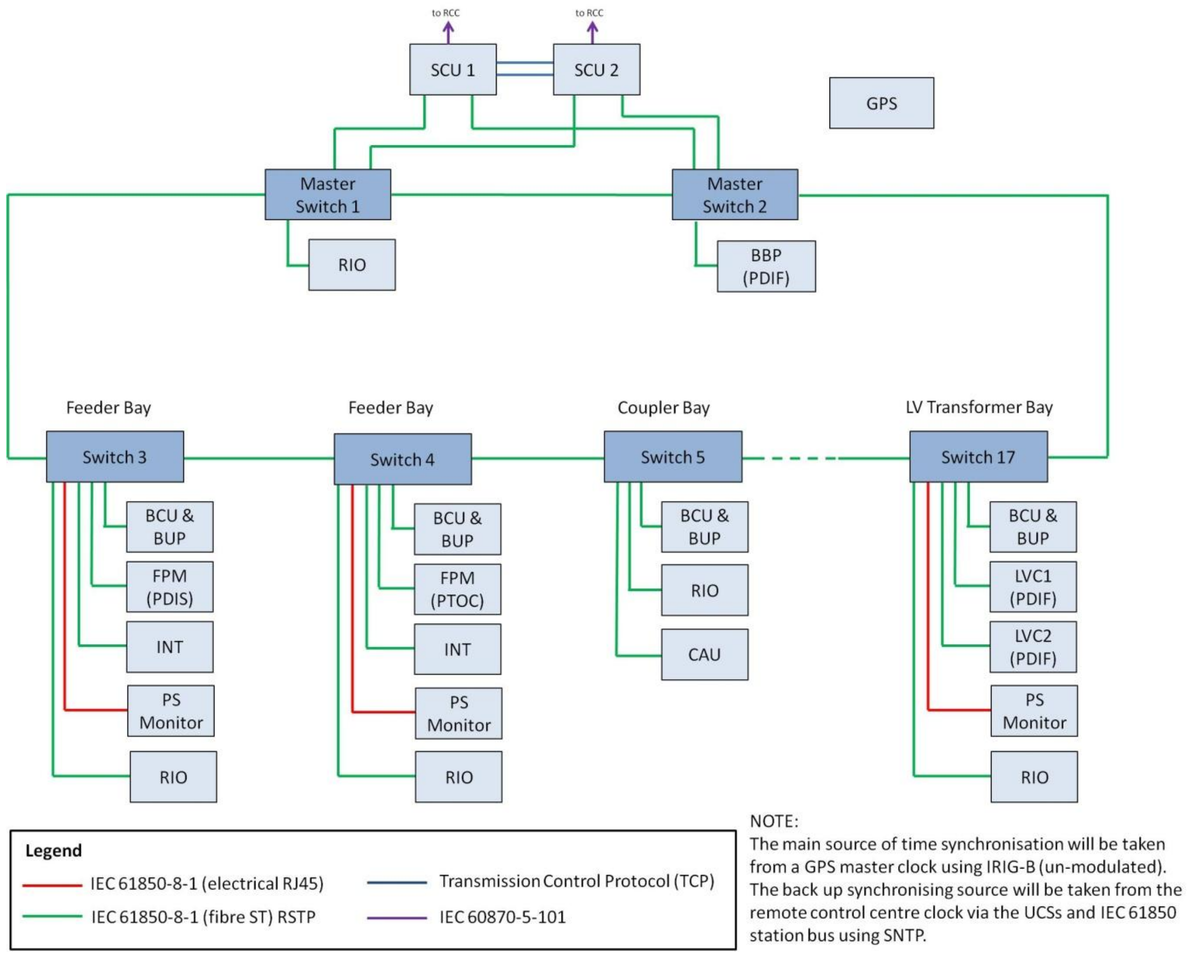
The next crucial step to be taken for the Windyhill project was to build a test facility and develop device configuration files to allow the proposed solution to be evaluated. In my final weeks with IEC I was required to finalise all IED model codes and prepare a schedule of the equipment to be ordered for the test system.

In order to develop device configuration files, I spent time familiarising myself with a number a configuration tools including Micom S1 Agile and Iberdrola's iSAS@Works. iSAS@Works will be discussed further in Section 2.1.2.

As this is my final report, I have included in the following sections a technical overview of the proposed Windyhill 132kV IEC 61850 substation automation system.

2.1.1 Windyhill System Overview

The following figure is a simplified overview of the Windyhill IEC 61850 substation automation system (SAS) showing each type of typical bay. The full system will have seventeen station switches, one per bay plus two station master switches. (An overview of the GIS switchboard arrangement was provided in my previous report.) The following sections will give a detailed explanation of the Windyhill SAS including process, bay and station levels.



Process Level

After considering the current level of commercial maturity of process bus products, it was not considered feasible to implement an IEC 61850-9-2 process bus at Windyhill. Therefore, a conventional solution will be used, where current and voltage signals will be hard wired to the protection and control IEDs.

Due to the large number of DC signals to and from the GIS and the limited input/output (I/O) capability of the bay control unit, it was decided to implement a mixture of conventional wiring and GOOSE messaging over fibre optics for the DC process signals. Conventional hardwiring is used for the more critical signals such as circuit breaker and isolator controls. Remote input/output devices (RIOs), connected via fibre to the IEC 61850 station bus, will be used for the less critical signals such as general GIS indications and earth switch controls. Depending on the type of bay, two to four remote input/output (RIO) devices will be installed per bay, within the GIS local control cubicles (LCCs). RIO devices will also be used for the substation common alarms. The RIO devices will communicate with the Bay Control Units (BCUs) and Common Alarm Unit (CAU) using IEC 61850 GOOSE messaging. This solution reduces cabling and provides the opportunity to become familiar with RIO devices as a first step toward process bus implementation.

Bay Level

The Windyhill SAS is a multivendor solution with the protection and control IEDs coming from five different manufacturers. Bay control at Windyhill will be accomplished using a single Bay Control Unit (BCU) per Circuit Breaker (CB). Each BCU will be responsible for monitoring and controlling the plant within its respective bay. In addition to the BCUs, another device will be used as a Common Alarm Unit (CAU) to collect signals that cannot be assigned to a specific bay. Backup Protection (BUP) will be integrated within each BCU. Depending on the particular feeder, the Feeder Protection Main (FPM) will consist of either high set over current (PTOC), current differential (PDIF) or distance (PDIS) protection. The transformer low voltage (LV) bays will have duplicate low impedance differential Low Voltage Connections (LVC) protection. Busbar Protection (BBP) will consist of a single, centralised, low impedance bus zone scheme with an overall busbar check zone for security. A separate IED is required for remote end intertripping (INT) to meet Scottish Power's reliability requirements.

IEC 61850 MMS services will be used for all indications and alarms. MMS services will also be used to facilitate protection switching. It is proposed to use GOOSE communications for Delayed Automatic Reclose (DAR), intertrip send, process level alarms/indications, earth switch control and the coordination of the high break contacts used in the circuit breaker trip circuitry.

Station Level

The station bus architecture is based on the Iberdrola Global iSAS Standard's recommendation for medium criticality substations. The topology consists of a single, optical ring of managed switches with redundant master switches. The Windyhill system will consist of seventeen switches in total (one per bay plus two master switches); therefore a single ring is recommended for this application. (The E3 group document recommends the use of multiple rings when more than twenty switches are required in order to avoid latency.)

The network ring configuration and the master switch redundancy guarantees that if one of the LAN switches becomes inactive, the devices attached to the other switches still have at least one physical path to each other. The protocol used to handle this redundancy is Rapid Spanning Tree Protocol (RSTP). As Scottish Power does not require duplicate protection systems at 132kV, implementation of a redundant station bus architecture using Parallel Redundancy Protocol (PRP) was not considered necessary.

Redundant substation control units (SCUs) operating in hot-standby mode will be implemented. Each SCU will have redundant connections to the station bus so that failure of a master switch will not result in loss of communications to one of the SCUs. The redundant SCU system will be seen as a single device (with a single IP address) by the devices connected to the station bus.

Redundant gateway functionality is included within the SCU devices and each SCU will have redundant, serial connections to each remote control centre (RCC). As we will work with a redundant SCU and redundant physical paths to each RCC, in order to avoid any conflict, sniffer devices will be required to make the double redundant link (two different physical paths and two different physical SCUs) be seen as one by the RCC. IEC 60870-5-101 protocol will be used for the communications to the RCC. Similar to the station bus, the redundant SCU system will be seen as a single device by the RCC.

Two time synchronisation sources will be provided at Windyhill for time stamping. A GPS based master clock will be used as the main source and will be required to synchronise all IEDs using IRIG-B. The second synchronisation source will be taken from the RCC master clock via the SCU and IEC 61850 station bus using Simple Network Time Protocol (SNTP).

HMI Configuration

For Windyhill, the HMI displays will be configured within the CID files of each bay level IED in the system. Each BCU will contain an IHMI logical node for the modelling of the graphical screens (including the single line diagram), visual indicators and interaction buttons for its respective bay.

The IEC 61850 standard defines the IHMI logical node but this has been extended by the E3 group (using the IEC 61850 extension rules) so that it can be used to fully model the complete HMI functionality required by Iberdrola. Refer to the E3 group specification Annex B for more details on HMI and graphical screen modelling (https://sites.google.com/site/e3groupiec61850/documents-2).

The mapping of signals to HMI displays will be done using the 'd' data attribute. For a device to be iSAS compliant, there must be a configurable 'd' data attribute (DA) within every data object of the device's data model. (i.e. The 'd' DAs are configured for each signal within the CID files of each device in the system.) The SCU is capable of analysing the information contained within the 'd' DA and updating its internal data base with this information.

Configuration Management

For iSAS compliant devices, configuration management is handled automatically by the Substation Control Units (SCUs). For a device to be iSAS compliant, it must be able to be fully configured by a single IEC 61850 CID file and it must have specific data attributes that identify the version of the configuration of the IED. In an iSAS system, the SCU creates and maintains the IEC 61850 Substation Configuration Description file (SCD file) by grouping all of the individual CID files of the devices connected to it. It then monitors the data attributes that identify the configuration version and updates its own database and the SCD file whenever a change is detected.

2.1.2 Iberdrola's iSAS@Works IEC 61850 System Configuration Tool

In order to achieve the most simple and effective engineering and configuration process possible, Iberdrola has identified that a single engineering and configuration tool for fully engineering and configuring all IEDs in an automation system is essential. It avoids the need to use one or several engineering and/or configuration tools per IED, saving money (some vendor specific software can be very expensive), time (no need to switch between different software programs) and human efforts (no need to learn how to use vendor specific software programs).

For these reasons, Iberdrola have developed their own configuration tool called iSAS@Works, which can be used to fully configure any iSAS compliant device, irrespective of the manufacturer. For the IEC 61850 systems implemented by Iberdrola in the Spanish distribution network, this is the only tool required to configure and test all protection and control devices within a substation including the Human Machine Interface (HMI). For Windyhill, it will be used to configure the substation control units (SCUs), Bay Control Units (BCUs), HMI and the high set overcurrent protection devices. Due to the tight timeframes associated with the Windyhill project and the lengthy timeframes associated with manufacturer's developments, it was not possible to implement a fully iSAS compliant solution and therefore some devices will still require vendor specific tools for their configuration.

2.2 Chapelcross 132kV Switchgear Replacement Project

In addition to Windyhill, I have also continued to work on Scottish Power's second IEC 61850 project: the Chapelcross 132kV Switchgear Replacement project. Chapelcross is located in the south of Scotland and consists of fourteen AIS bays in a double busbar configuration. Like Windyhill, the switchgear at this site has reached the end of its life and it is proposed to replace it with a new, GIS switchboard, installed in a new building, adjacent to the existing 132kV switchyard.

The SAS design solution for Chapelcross will be very similar to the Windyhill solution discussed in Section 2.1.1. This quarter I have drafted the technical specification for the protection and control works to be carried out by an external contractor. This involved detailing the protection, control and telecommunications requirements for Chapelcross and all remote ends to enable the contractor to produce the circuitry drawings, panel general arrangements and cable schedules in accordance with Scottish Power's policies.

3 <u>Additional Opportunities</u>

After completing my placement with IEC in May, I was able to take advantage of the travel opportunities facilitated by the scholarship and spend six weeks travelling overland from Europe to Vietnam before returning to Australia. During this time, I was fortunate to be able to arrange a meeting with a senior power automation engineer at the China Electric Power Research Institute (CEPRI) in Beijing, to discuss the IEC 61850 developments currently taking place in China. The following sections will give some background into CEPRI and the IEC 61850 experiences discussed.

3.1 China Electric Power Research Institute (CEPRI)

CEPRI is a comprehensive research institute and a subsidiary of the State Grid of China Corporation. CEPRI has been actively involved with IEC 61850 standard development and implementation for more than 10 years and have conducted in excess of ninety IEC 61850 model tests for a large number of Chinese and international manufacturers including ABB, GE, Siemens, Areva, NARI, Sifang and Dongfang Electronics. In addition to this, CEPRI have also undertaken substation automation system integration and testing for a large number of substations throughout China. In particular, two projects that were mentioned during my meeting were the Guilin 500kV substation in Guangxi province and Waichen 220kV substation in Zhejiang province.

I was able to discuss a wide range of technical aspects including the station and process bus architectures used at each voltage level, use of GOOSE messaging and time synchronisation as well as the challenges faced during the initial IEC 61850 installations. The main problems encountered were during the development of the IEDs. CEPRI had to work very closely with manufacturers to ensure a consistent approach when implementing the IEC 61850 data model (particularly in relation to the data attributes defined as optional in the standard) in order to minimise interoperability issues and to ensure that the required functionality could be met. It was also seen that many of the functions, especially protective functions, required by the power utilities in China were not defined according to the standard. The functions were realised using generic logical nodes or by adding extensions. It was interesting to see that the issues faced in China were very similar to what has been experienced by Iberdrola and the utilities within the E3 group in Spain.

It was also very interesting to hear how progressive China has been with IEC 61850-9-2 process bus developments. China is one of the first countries in the world to implement this technology and one of the few countries to implement multivendor solutions. Process bus systems have now been successfully installed in approximately thirty substations throughout China, however, the implementation of 9-2 has proven to be very challenging, particularly in terms of time synchronisation of the Merging Units, as only a small number of devices currently support IEC 61588.

Similarly to the E3 group in Spain, CEPRI have been heavily involved with local and international manufacturers and have been able to drive manufacturer's IEC 61850 developments to align with the requirements of the local utilities. CEPRI have also developed their own IEC 61850 configuration and testing tool that is capable of fully configuring and testing a range of devices from various manufacturers commonly used in China.

I found my visit to CEPRI to be very worthwhile and informative and would like to thank the scholarship committee and CEPRI for the opportunity.

4 Conclusion

As this is my final quarterly report, I would like to briefly summarise the experiences that I have gained throughout my scholarship tenure and how these have enabled me to meet my original objectives.

My program of work consisted of the following two placements:

- ABB Switzerland, Baden, Switzerland – October 2011 to June 2012 (9 months)
- Iberdrola Engineering and Construction (IEC), Glasgow, Scotland – July 2012 to May 2013 (10 months)

For my first placement with ABB, I was working as part of the Substation Automation System (SAS) Engineering and Test Team where I undertook the system level detailed design, system integration and testing for two of Powerlink's iPASS IEC 61850 secondary system upgrade projects – Millmerran and Bulli Creek. In addition to these two projects, I was also involved with setting up and configuring the system level devices for four new IEC 61850 substations being installed in the Middle East and was able to witness the on-site commissioning testing for an IEC 61850 retrofit project at a European substation. I also had the opportunity to visit ABB's IEC 61850 System Verification Centre (SVC) and the Laufenburg substation, which was the first high voltage substation in the world to be retrofitted with an IEC 61850 compliant system. This placement enabled me to gain broad experience with the design, configuration and testing of IEC 61850 substation automation systems and gave me exposure to various different systems being installed throughout the world. It also provided valuable insight into IEC 61850-9-2 process bus technology.

My second placement with IEC in Glasgow complemented my first placement by allowing me to experience the adoption of the IEC 61850 standard from the perspective of a transmission network service provider. During my time with IEC, I worked as a protection and control engineer and undertook the substation automation system design for Scottish Power's first two IEC 61850 implementation projects. A substantial part of this work involved adapting Iberdrola's Spanish IEC 61850 specification to meet the requirements of Scottish Power. This work afforded excellent insight into IEC 61850 design and implementation, including the limitations within the standard itself and the efforts required from utilities to ensure that the full benefits of the standard can be realised. I also gained exposure to the extensive IEC 61850 development work that has been carried out in Spain as well as an understanding of the protection and control philosophies currently employed in the United Kingdom. I was also in a position to see how the implementation of this new technology impacted on current standards and practises.

In addition to this work, I undertook a number of industry and site visits and attended the biennial CIGRE Session in Paris. These activities gave me some insight into the IEC 61850 developments taking place outside of Europe and gave me a better appreciation of the international power community.

As I conclude my final report, I would like to thank the Scholarship Committee, the University of Queensland and Powerlink for providing me with the opportunity to gain invaluable, international experience and broaden my professional career. I would also like to thank my colleagues at ABB in Baden and IEC in Glasgow for welcoming me into their teams and sharing a wealth of knowledge and experience. The scholarship has played a pivotal role in my development as a young engineer, both professionally and personally and I am very grateful to have had such an incredible opportunity.