

20<sup>th</sup> July, 2012

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

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

Please find enclosed my third quarterly E. S. Cornwall Scholarship report outlining my period of employment from the 10<sup>th</sup> of April 2012 to the 30<sup>th</sup> of June 2012.

During my final quarter with ABB, I have been working in the test field, undertaking the system integration, system testing and ABB internal Factory Acceptance Testing (FAT) for the Millmerran and Bulli Creek 330kV iPASS substations. I have also had the opportunity to visit ABB's IEC 61850 System Verification Centre (SVC) and attend a technical presentation on the SVC.

It should be noted that due to the confidential nature of the work I have undertaken I am not able to include any technical information relating to ABB specific tools and processes.

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 10<sup>th</sup> of October, 2011 to the 10<sup>th</sup> of April, 2013. My first nine month placement is with ABB Switzerland in Baden, where I am working as part of the Substation Automation System (SAS) Engineering and Test Team. I have spent my final quarter with ABB working in the test field, where I have undertaken the system integration and testing of two of Powerlink's iPASS IEC 61850 secondary system upgrade projects – Millmerran and Bulli Creek. This experience has provided valuable insight into the configuration of IEC 61850 devices and networks and also into the testing methods and tools utilised by ABB. Due to the practical, hands-on nature of this work and also the trouble shooting that was undertaken, I feel that this work has greatly improved my overall technical understanding of IEC 61850 substation automation systems. In addition to this work, I have also had the opportunity to visit ABB's IEC 61850 System Verification Centre (SVC) and attend a technical presentation on the SVC.

This report is the third of six reports and outlines the work that I have undertaken from the 10<sup>th</sup> of April, 2012 to the 30<sup>th</sup> of June, 2012.

## **2 IEC 61850 Substation Automation System Testing**

### **2.1 Impact of IEC 61850 on Testing**

The application of the IEC 61850 standard for testing provides a number of benefits and advantages over conventional electrical interfaces, but at the same time it introduces several new issues and challenges. The most obvious change is the different way of wiring to obtain the signals. In a traditional system, the data exchange between devices used separate, hard wired connections between binary inputs and outputs (I/Os) for each signal. This approach is both costly and limiting (in terms of the number of I/Os available) and requires a large number of copper wires to be laid. Each of these wire connections must then be checked, creating a testing nightmare and any required change in configuration could potentially be very difficult and time consuming to implement.

IEC 61850 replaces these wire connections with an Ethernet network. The communication between the bay level devices is handled by the GOOSE mechanism and communication between the bay and station level devices for SCADA purposes is handled by MMS and the IEC 61850 protocol stack. This technology has the potential to eliminate thousands of copper wires in a substation, significantly reducing costs and simplifying installation and testing. The number of I/Os available is no longer limited to the number of available terminals and a change to the system configuration can be carried out through the engineering process simply by reconfiguring devices. However, before this technology can be adopted, new test equipment and software must be developed to allow the test engineer to 'connect' to these GOOSE messages and to monitor all data on the network (GOOSE, MMS, SV etc.). Due to the complex nature of the IEC 61850 standard, it cannot be applied without significant software support.

Similarly to how bay and station level status information is transformed into data on the station bus, IEC 61850 also specifies how instantaneous voltage and current values from the primary plant can be transformed into data called Sampled Values and sent over an Ethernet network. A device called a merging unit MU collects the signals from the sensors on the primary plant and merges the digitised values into a data stream that is published over the substation network. Therefore, in order to test substation devices, new test equipment that is able to simulate a merging unit by publishing Sample Values over a network needed to be developed.

Another important impact of IEC 61850 is that signals can no longer be physically isolated for testing purposes. This is of particular importance when testing system components in an energised substation. The IEC 61850 standard includes several features to address this issue. Some of these features will be discussed briefly in section 2.3.

In addition to defining services and communication protocols, IEC 61850 also specifies a vendor independent configuration concept that utilises machine readable configuration information in a standardised format (Substation Configuration Language SCL). This approach not only simplifies engineering and test setup but also facilitates the availability of system wide configuration data that has the potential to greatly aid testing. Prior to IEC 61850, this data was usually out of the testing scope as access could only be obtained through many different, vendor specific methods. Now, with IEC 61850, a tester is able to look up the status of data for any device in the system by using a common tool. This has the potential to significantly extend the testing scope.

For these reasons, it was evident that a new suit of test equipment and software would need to be developed to efficiently manage and support the implementation of IEC 61850 systems and to incorporate all of the possibilities offered by the standard.

## 2.2 ABB's IEC 61850 Software Testing and Commissioning Tools

In the early stages of IEC 61850 development, ABB identified the need to redesign their existing engineering and testing tool environment in order to cope with the additional demands and challenges brought about by the standard. Although IEC 61850 is built on existing technologies such as Ethernet, MMS and TCP/IP, which already had well-established software tools, these tools were designed to focus on specialised tasks (e.g. communication analysis) and did not cover any substation automation application aspects and thus, were not able to meet the demands of IEC 61850. ABB's approach was to take these existing tools and identify the functional gaps in them. This information was then used to develop ABB's Integrated Testing Toolbox (ITT), a comprehensive suite of software testing tools for IEC 61850 substation automation systems. ITT was designed to hide the complexity of the components of IEC 61850 and instead focus on displaying application relevant data only. The main features of these diagnostic tools include:

- Use of the Substation Configuration Description SCD file for configuration
- Establishing connections to IEDs using configured data sets and control blocks
- Monitoring the health of the running system
- Checking data consistencies and configuration revisions against the SCD file
- Analysing and verifying running applications
- Decoding Ethernet traffic to the substation automation domain language based on the SCD file
- Showing addressing of logged data
- Device simulation
- Easy to interpret displays of IEC 61850 data for troubleshooting and diagnostics

## 2.3 IEC 61850 Testing Features

IEC 61850-10 is the part of the standard that specifies techniques for conformance testing. This includes outlining the various methods that can be used to correctly test for conformance and also the measurement techniques that must be applied when declaring performance parameters. This part of the standard aims to enhance the ability of the system integrator to successfully integrate and operate IEDs in accordance with IEC 61850.

In addition to specifying conformance testing guidelines, the standard also provides a number of features to support the testing of IEC 61850 devices in an energised substation. Some examples of these features include:

**Test Mode** – this feature allows all actions and reactions of the communication subscribers in a network to be clearly assigned to either 'normal mode' or 'test mode'. If a device is set to test mode each message to an external device (for both reporting and GOOSE messages) will have their test flag set to true so that all affected clients and GOOSE subscribers will know to ignore this information or handle it separately. A command coming from an external source is handled in the same way. That is, an IED in test mode must ignore any command that does not have its test flag set to true. Also, if the device mode is set to 'test blocked', the command will be processed and all reactions will be produced but no wired output to the process will be activated. This mode is particularly useful while performing tests with a device connected to the primary plant.

**Message Simulation** – message simulation enables IEDs to subscribe to GOOSE messages or sampled value (SV) messages from simulation or test equipment. Each GOOSE and SV message has a flag that indicates whether the message is original or produced by simulation and each IED has a data object that defines whether the IED shall receive the original or simulated message.

**Mirroring of Control Information** – this feature makes it possible to test and measure the performance of a control operation whilst a device is connected to the system. This is done by applying the control command to a controllable data object that essentially 'mirrors' the real data object executing the control function.

These three features can be combined to isolate and test a device in an operational system. For example, to test the performance of the main 1 protection (in a system with both IEC 61850 station and process bus), the protection IED is set to receive simulated messages, the logical device for the protection function is set to 'test' and the logical node representing the interface to the circuit breaker (XCBR) is set to 'test blocked'. A test device then simulates the appropriate sample value data with simulation flag set to 'true'. The protection IED receives this data and will initiate a trip. The XCBR will receive and process the trip but no output will be generated. The output can be verified by checking the data attribute that mirrors this control function.

### **3 Work Experience**

Throughout the past few months I have completed the system level configuration, testing and ABB internal FAT for the Millmerran substation and I have also undertaken the system level configuration and partial system testing for the Bulli Creek substation. (Testing for Bulli Creek was still ongoing when I left ABB in June and the internal ABB FAT had not yet been undertaken.)

I found this hands-on experience to be invaluable. From a system level point of view, I have learnt how to configure and test the various IEC 61850 network components such as computers, switches and timeservers and I have also gained a much deeper understanding of ABB's MicroSCADA application. In addition to this, I have been working alongside the bay level engineers, which has allowed me to gain a better insight into the protection and control devices and the IEC 61850 communications across the station and process buses. I will provide a high level overview of this experience in the following sections.

#### **3.1 Simulation Testing using ABB's IEC 61850 System Simulation and Testing Tool**

A useful advantage of the IEC 61850 standard is that it facilitates data consistency checks in the design phase and also testing of the MicroSCADA application against the overall IEC 61850 Substation Configuration Description (SCD) file using a software simulation tool. This means that the majority of errors and inconsistencies can be detected and rectified prior to commencing factory testing.

Whilst the Millmerran and Bulli Creek systems were being manufactured, I was able to test the MicroSCADA application for each substation by simulating the bay level devices using the SCD file and ABB's System Simulation and Testing Tool. This work involved setting up the IEC 61850 OPC server, Data Access client and MicroSCADA application on one computer (as discussed in my first report) and then connecting a second computer to the network to simulate the devices. The devices can be simulated by simply importing the SCD file into ABB's simulation tool and setting the appropriate IP addressing. This then allowed me to directly apply changes to the IEC 61850 data in the simulated devices and check that this was correctly displayed on the MicroSCADA. This proved to be very advantageous as it allowed me to verify the substation SCD file, verify the mapping between the IEC 61850 database and the MicroSCADA and check that all required signals were correctly implemented. This saved a substantial amount of time during factory testing where time is most critical.

### 3.2 System Configuration for Millmerran and Bulli Creek

I was responsible for the setup and configuration of the IEC 61850-8-1 station bus network for both the Millmerran and Bulli Creek substations. This includes connecting and configuring the following station level devices:

- Station computer
- Ruggedcom RSG2100 Managed Ethernet Switches
- Meinberg NTP Servers (GPS X and GPS Y)
- Perle TCP / RS232 Converters (required to allow the Merging Unit parameters to be viewed and changed from the station computer)
- SNMP1000 supervision card (used to monitor the station computer's power supplies and temperature. This card is inserted into one PCI slot of the MicroSCADA server however there is no communication with the motherboard. The slot is only used to charge the battery of the card. MicroSCADA communicates with this card using SNMP over TCP/IP-Ethernet. The Ethernet port of the SNMP1000 card was externally connected to an Ethernet port on the server main board. Refer to Figure 1 below.)

An overview of the Millmerran system is shown in Figure 1. The devices that I was responsible for configuring are highlighted in yellow. The general configuration procedure for these devices was described in my second quarterly report, in relation to the work that I undertook for the Middle Eastern projects, and therefore will not be repeated here. The following paragraphs give a high level explanation of the systems being implemented for Millmerran and Bulli Creek.

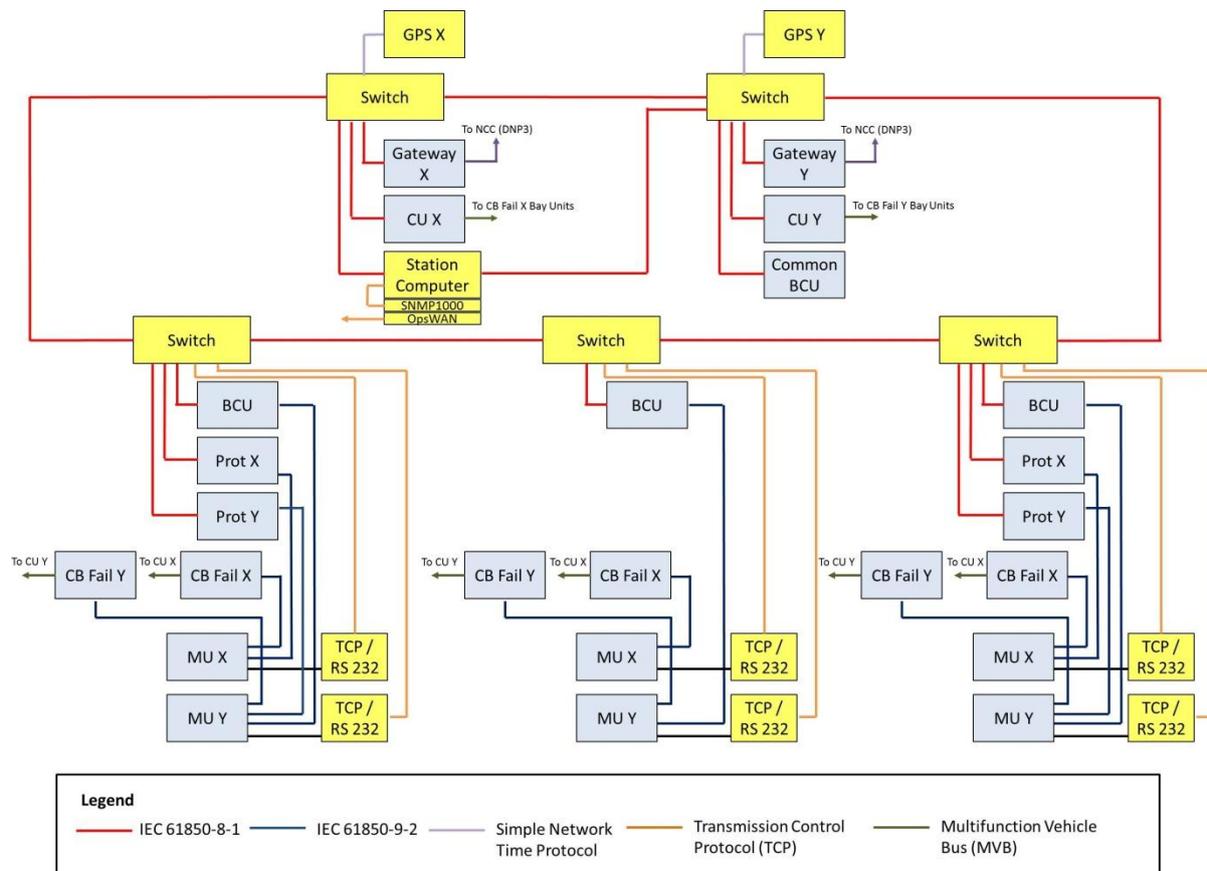


Figure 1: Millmerran System Overview

Millmerran 330kV substation is a breaker and a half configuration, consisting of three diameters (each with two line bays) and one spare bay. Only one of these diameters requires a secondary system upgrade and therefore the system overview figure above is for one diameter only. Bulli Creek 330kV substation is also a breaker and a half configuration and consists of three diameters (each with two line bays), one transformer bay and four line reactor bays. The secondary systems for all of the bays at Bulli Creek require upgrading and are within the scope of work. The secondary system for Bulli Creek is very similar in principle to the Millmerran system shown in Figure 1 but with an additional 11 bays.

The Substation Automation System (SAS) being implemented in these projects is based on ABB's SAS600 series, including MicroSCADA Pro Control System SYS 600. The SAS600 series is based on IEC 61850 and is fully compliant. The bay level comprises Relion 670 series protection and control IEDs as well as REB500 Busbar protection system, with IEC 61850 for station and process bus.

The Station Level comprises the Station Computer/HMI, X and Y Central Units for Bus Bar and Circuit Breaker Fail protection, Bay Control Units (BCU), two redundant dedicated GPS master clocks that provide the synchronisation of the entire system, OpsWAN connection and two RTU gateways that enable redundant communications to the Network Control Centre (NCC). The Bay Level comprises the protection and control IEDs. The data exchange among the bay level IEDs and between bay level and station level IEDs takes place via the fibre-optic station bus according to the IEC 61850-8-1 standard. The station bus has been implemented in a single ring topology using IEC 61850-3 compliant Ethernet switches. Dual connections between the station computer and the station level Ethernet switches have been implemented for increased availability.

The process bus facilitates communication between the process level devices (eg the iPASS units) and the bay level devices. Physically, an optical fibre links the CT/VT sensors installed on the primary Switchgear to the Merging Units (MUs) installed in each bay panel. The station and process level networks are two physically separate LANs. The process bus between the Secondary Converter (SC) and the MU is based on ABB's Multifunction Vehicle Bus (MVB). The process bus between the MU and protection/control IEDs is based on the IEC 61850-9-2 LE (Lite Edition). In these projects, the process bus is being used for Sample Value (SV) data. Each bay has its own separate LAN.

To achieve full redundancy, two independent systems, X and Y, have been implemented, requiring duplication of secondary converters, merging units and protection units. The GPS clock and Time Synchronisation network are also duplicated as time synchronisation is critical to the protection system.

### **3.3 Test Setup and Equipment**

For Millmerran, the entire system (as shown in Figure 1) was set up in ABB's test field and every device was tested. As Bulli Creek is a much larger system, only typical bays (i.e. one feeder bay, one coupler bay, one transformer bay and one reactor bay) were setup and tested. It has been agreed that the full system testing and customer FAT will be carried out in Australia, in conjunction with Powerlink, at a later stage. Testing of the RTU devices and communication to the Network Control Centre (NCC) was not in the scope of work for ABB Switzerland.

The following diagram shows the test setup and equipment used to generate the merging unit inputs. An Omicron PC controlled CMC256-6 test set was used to generate the measurement signals required for testing i.e. the measured currents and voltages in the primary plant. An Omicron CMLIB-A transducer was then used to convert the low level signal outputs of the CMC into signals with 0-2V amplitude. The test adapters then convert these analogue signals into Multifunction Vehicle Bus (MVB) signals, ready to be input into the Merging Units (MUs). The splitters simply split each input signal into three output signals (3x3Ph) which are then connected directly to the associated MUs. The Merging Units themselves merge three measurement signals from the splitter outputs (i.e. CT/VT sensors) and convert them into IEC 61850-9-2 protocol. Five IEDs can be connected to each MU.

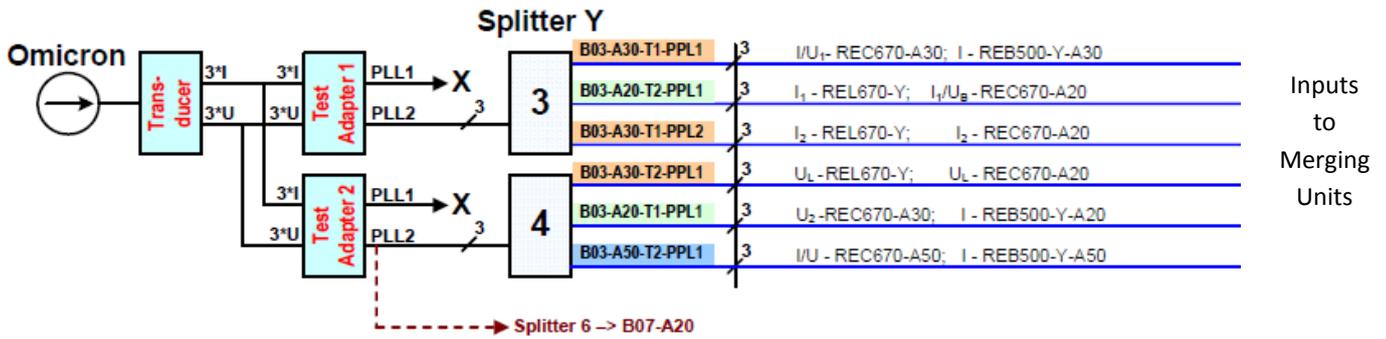


Figure 2 – Test setup used to generate Merging Unit Inputs

### 3.4 Scope of Testing

This section gives an overview of the testing work that I have undertaken. I was responsible for the system level testing only and therefore this section does not include the bay level testing that was also undertaken. I was, however, present during a significant amount of the bay level testing so I was able to gain some insight into this as well. In addition to testing the system I was also responsible for preparing and finalising all system level test documentation. The tests undertaken for the system level fall under four main categories as follows:

#### MicroSCADA Application Testing

Firstly, the MicroSCADA application itself was checked. This means checking that all links, process pictures, trend displays, menu functions and all basic monitoring such as event, alarm and blocking lists are correct and as per the specification. These checks were repeated for all MicroSCADA user logins as different users have different menus as well as different control and access rights.

Once these preliminary checks were complete, point-to-point tests were carried out in conjunction with the bay level engineer. Point-to-point refers to generating a signal in the protection or control device and checking that it is correctly displayed on the MicroSCADA in the appropriate process pictures and alarm/event lists. Every required signal, for each device in the test system, was checked in this way. Point-to-point tests confirm that the IEC 61850 OPC server and DA client are correctly configured and that all IEC 61850 data mapping is correct in the MicroSCADA. Likewise, point-to-point tests were also carried out for all SNMP signals, verifying the SNMP OPC server, DA client and MicroSCADA configuration.

Finally all MicroSCADA control functionality such as operating primary plant, selecting circuit breaker close modes, enabling and disabling functionality such as Auto reclose (AR) and Emergency Voltage Regulation (EVR) etc. was checked in conjunction with the bay level engineer.

#### System Redundancy Tests

A number of redundancy tests were carried out for the IEC 61850 ring configuration, GPS devices and for the station computer power supplies and hard disks. To test the IEC 61850 ring redundancy, a number of events were continuously generated at the bay level, while each ring segment was sequentially disconnected for thirty seconds and then restored for thirty seconds. During this time, the MicroSCADA was continuously monitored to ensure that all process states and measurement values remained valid at all times and that none of the generated events were lost in the MicroSCADA. When disconnecting the ring segments on either side of the station computer the teaming of the network cards is also tested and confirmed. To test the redundancy of the power

supplies, hard disks and GPS devices each item was switched off individually and the system was monitored for a period of time to ensure that the redundant device took over the complete operation with no interruptions to the system and also that the failures were correctly indicated on the MicroSCADA. The device was then restored and the system monitored accordingly.

### **Time Synchronisation**

Once the GPS receiver is synchronised to the correct time, the synchronisation of all system level devices was verified. To test the synchronisation of the station computer, the computer time setting was modified and then monitored until the GPS set the computer back to the correct time. This procedure was repeated with only the X system GPS in service and again with only the Y system GPS in service. The same procedure was also applied to both RTU gateways.

### **Remote Desktop and Advanced Monitoring Features**

For Millmerran and Bulli Creek, one port on the MicroSCADA server was configured to allow remote access via Powerlink's OpsWAN. To test this facility, a number of external computers were connected to the network to ensure that all computers can open a Remote Desktop connection to the server and are also able to open a MicroSCADA screen.

A number of advanced monitoring programs have been installed on the server, in addition to the MicroSCADA application, to allow the configurations of all devices in the system to be viewed and modified. The functionality of these programs and also the accessibility of all the devices were checked from the server and also from a Remote Desktop connection. Checking the availability of the MUs also verifies that the TCP / RS232 converters are functioning correctly.

## **3.5 Challenges & Outcomes**

Some minor issues were encountered during testing which provided a number of good learning opportunities for me. Through rectifying these problems I learnt a number of useful troubleshooting techniques as well as gaining a better understanding of computers and networks. I have also developed a good working knowledge of ABB's IEC 61850 analysis and testing tools, as I have had to use these tools to identify and rectify problems. A number of issues were also encountered within the MicroSCADA application. This also proved to be a very valuable learning experience as I was able to gain more in-depth knowledge of ABB's MicroSCADA application. All in all, I have found this practical experience to be extremely beneficial and it has greatly improved my overall understanding of IEC 61850 substation automation systems.

## **4 ABB's IEC 61850 System Verification Centre (SVC)**

I have recently had the opportunity to visit ABB's IEC 61850 System Verification Centre (SVC) and to also attend a technical presentation that outlined the various functions of the SVC and the work currently being undertaken. Through these activities I have gained a much greater appreciation and understanding of this important facility. In this section I will give some background into the SVC and describe its main functions and the system setup.

When the IEC 61850 standard was first introduced, ABB established a system verification and validation centre to ensure correct system implementation with IEC 61850. The SVC was setup to perform two types of testing: Verification and Validation. The aim of verification testing is to ensure that a product meets all of the defined substation automation and IEC 61850 requirements. Conformance testing is a critical part of IEC 61850 implementation. Part 10 of the standard specifies how to test for conformance, as well as the specific measurement techniques that must be applied when declaring performance parameters. ABB's SVC has been officially qualified by the UCA (Utility Communications Architecture) International Users Group to test and certify a products conformance to the IEC 61850 standard and confer the user's group label to them. Validation testing is more high level than verification testing and focusses on the behaviour of the product in a specified environment and whether the product is meeting the operational needs of the environment.

Every single product, system component, application and tool must be tested in the SVC, in a real life system environment, to prove its functionality before it can be released for use in customer projects. The centre not only tests individual devices but also tests their integration into larger systems. It should be noted that even though two devices are proven to be conformant to the IEC 61850 standard, this does not guarantee that the two devices will be interoperable. Therefore, in addition to conformance testing, the SVC also carries out interoperability tests that look at the dynamic interaction between IEDs in a substation automation system. This type of test setup also permits the verification of the performance of services provided by the communication equipment such as switches. Performing these types of tests in the SVC, as a kind of type test, significantly reduces the risks for customer projects.

Another important role of the SVC is to provide support and understanding of the standard and to build expertise in testing methods and third party device integration. It also ensures a common understanding of the IEC 61850 engineering process and provides the means to exchange experience between the IEC 61850 experts within ABB.

Figure 3 shows a high level representation of the SVC system setup. The installation represents all areas of ABB's automation activities for low voltage distribution applications through to high voltage transmission applications. As depicted in the figure, this includes systems at four different voltage levels – 245kV, 132kV, 33kV and 11kV.

**SVC System Configuration:**

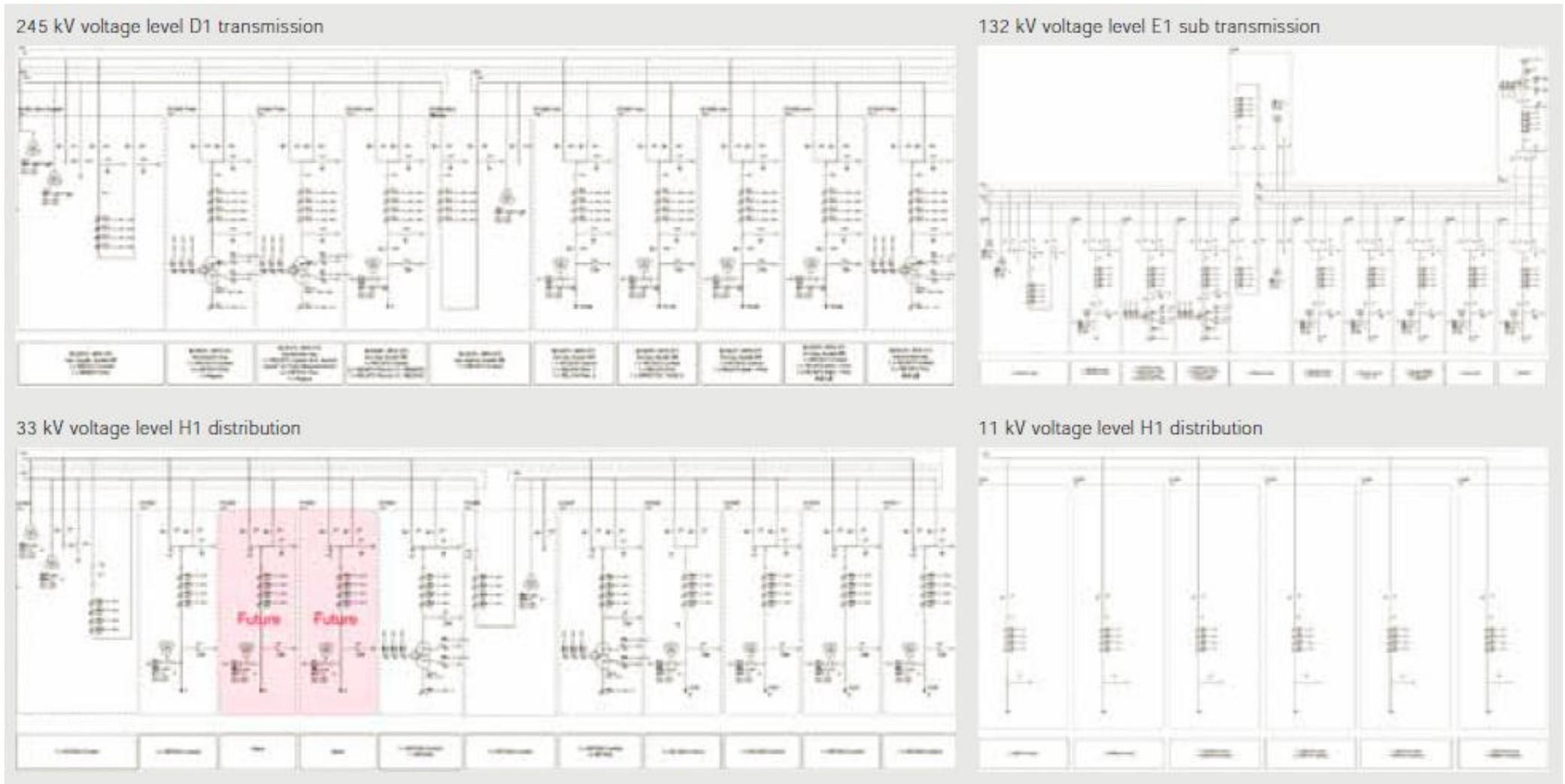


Figure 3: SVC System Configuration – Single Line Overview (Figure from ABB Review, 2010)

## **5 Planned Future Experience**

This quarter concludes my nine month term with ABB Switzerland. On the 23<sup>rd</sup> of July I plan to commence my next nine month placement in Scotland with Iberdrola Engineering and Construction (IEC), a subsidiary of the Iberdrola Group. Iberdrola is a private Spanish multinational electric utility that is striving to develop the areas of grid projects and clean technologies, especially wind power, all over the world. 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 will be working for Iberdrola's engineering and construction subsidiary, IEC, whose services include project management, engineering, supply, construction and commissioning, turnkey projects and operational support. I will be working in IEC's Glasgow office and will be providing engineering services to ScottishPower Energy Networks.

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 and since this time have implemented a large number of multivendor IEC 61850 systems and have also, in conjunction with the other main Spanish utilities, produced a comprehensive specification for substation protection and control equipment in accordance with the IEC 61850 standard.

Throughout my nine months with IEC I will be working as a protection and control engineer and initially, I will be assisting my colleagues in the adaptation of Iberdrola's IEC 61850 specification document to the ScottishPower networks. I believe that this work will afford excellent insight into IEC 61850 design and implementation, including the extensive IEC 61850 development work that has been carried out in Spain over the past few years. I will also gain knowledge of the protection and control philosophies currently employed in the United Kingdom and will be in a position to see the impacts that this new technology has on current practises.