First Digital Substation in TransGrid – Australia: A journey, Business case, Lessons

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Abstract

IEC61850 has now been accepted 'almost unequivocally' as preferred standard for substation communications. Utilities and industries across the world are at various stages of adoption of this standard. The extent of utilization of this standard in majority of installations around world is at 'station bus' level with IEC61850-8-1 reporting and GOOSE. Moving further along the digitization chain, it is foreseen that numerous benefits can be availed if process values (e.g. currents/voltages/switchgear status) are digitized as close to the source as possible (i.e. in the switchyard) and utilized in a comprehensive automation system.

TransGrid carried out an extensive assessment of substation secondary system design based on implementation of IEC61850 at station and process bus level which brought out the business case for full digitization. The first substation to realize this technology is the Avon 330 kV switching station, which is due for commissioning in late 2017. In this Digital Substation merging units are installed in outdoor cubicles placed close to the high voltage equipment; digitized currents/voltages/analogues/alarms/statuses/tripping signals are then transferred to the Protection, Control, Metering and Condition Monitoring system via fibre optic cables over an Ethernet network utilizing IEC61850-9-2LE and IEC61850-8-1 standards. Completely independent Systems A and B from different manufacturers are used with architecture based on IEC62439-3 PRP at station and process bus level, to meet redundancy and reliability requirements. Time synchronization is based on IEEE1588 standard. There has been special focus on standardization and re-usable engineering- these are some of the crucial factors to achieve cost reduction.

The paper describes some of the design principles, architecture adopted and its benefits, estimated cost savings, challenges faced and lessons learnt. We envisage that the Digital Substation technology implemented can bring about substantial cost reduction in green-field as well as brown field builds and paves the way for efficient integration of asset monitoring systems.

1 Introduction

Protection and control systems have evolved from discrete boxes per function and hardwired interconnection to highly integrated numerical devices. This helped reducing the number of boxes, connections and eventually led to compact panels. This technological evolution curtailed capital costs for the materials for green field as well as Protection and Control expansion/replacement projects. With maturity in design, benefits along this axis seem to have plateaued. The quest now is how to achieve further cost reduction. IEC61850 standard offers numerous benefits along the life cycle of automation systems – right from design and engineering to deployment and operation. As opposed to being just a communication protocol, IEC61850 addresses whole gamut of processes such as engineering, tools, validation and so on. Utilities and industries world-wide have adopted IEC61850 quite well. However, the implementation is predominantly focused on 'Bay level' and 'Station level'. Figure 1 depicts conceptual segregation of substation automation systems on three levels – 'Process', 'Bay' and 'Station'.

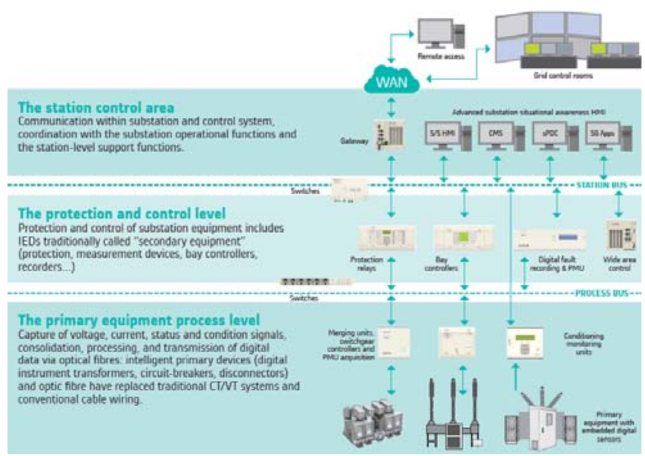

Figure 1: Digital Substation Architecture

Digital substation, in which primary process data (currents, volts, status etc.) are digitized close to the source, has enormous potential to drive down CAPEX as well as OPEX.

The example presented in this paper, Digital Substation – Avon, is a culmination of TransGrid's efforts to find out a solution that can deliver low cost refurbishment projects for the secondary systems assets with 20 years life and also deliver cost effective connections for renewable connection projects. Ever increasing penetration of renewable/low inertia generation sources present different challenges for protection system and Digital Substation technology helps to prepare for such energy transition.

2 TransGrid's journey to Digital Substation

TransGrid followed quite a rigorous process to choose the technology that could deliver business objectives. Projects such as transition to Digital Substation involve not only technological change but has an impact on culture and operational practices as well and therefore it was very important to ensure management buy-in and clear identification of benefits roadmap. The journey began with the market search. From the beginning no technology was excluded nor was any preconceived ideas held to ensure the most appropriate solution could be obtained. The research investigated fourteen secondary systems manufacturers, of which only four could offer a Digital Substation solution with products that were either already on the market or were in the prototype stage.

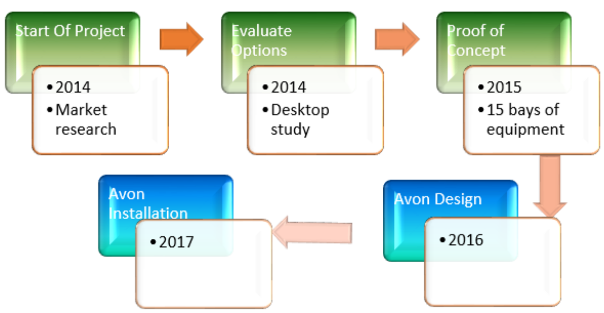

Figure 2: Project Journey

Samples of the new equipment and prototypes were obtained from the manufacturers and bench testing was completed to test functionality and learn more about the technology. From this early testing, there were issues with the IEC 61850 standards either being ahead of the available equipment or being well behind the available equipment. An example of the standard being ahead was the release of IEC 61850 Edition 2 which contained enhanced simulation and testing that was not yet available in the IEDs. An example of the standard being behind was the IEC 61850-9-2LE (Implementation Guideline) which only dictated one pulse per second fibre optic connection but the merging units were available with IEEE 1588 Precision Time Protocol (PTP) which was not in the standard.

Based on early testing, three options were investigated for implementation.

1. Station bus implementation
2. Station bus + Process bus implementation
3. Station bus + Process bus + LPIT (low power instrument transformers)

Following Figure 3 summarizes detailed desktop comparison of three options.

Reduction	Station	Process	Process with LPITs
Cost	2%	11%	9%
Cable trench	40%	93%	93%
Cabinets	7%	47%	30%

Figure 3: Desktop comparison results.

Based on the desktop comparison of the options, a station bus + process bus solution without LPIT was chosen for implementation. This option allowed the greatest cost reduction for the mix of expected projects and enabled the implementation of LPITs in the near future.

From the four manufacturers with Digital Substation technology, three were chosen to do a proof of concept. TransGrid procured five bays of merging units from each manufacturer with associated IEDs, switches and PTP clocks. These three systems were tested for functionality and performance. All of these three systems' five bays were implemented onto the one network to simulate a more typically sized transmission substation with fifteen bays. Proof of Concept stage gave valuable insights on what optimizations can be achieved, what were limitations with specific equipment/technology and this laid basis for the future design and optimizations. It also provided feedback to manufacturers on strengths/improvement areas and helped the product evolution

At completion of testing in 2015, the three systems were compared on functionality, performance and price. From this comparison two systems were selected for implementation in the first substation – Avon. The two systems were from GE and NR.

3 Project description

Avon 330 kV switching station is located 100 km south of Sydney and brings together three 330 kV transmission lines.

The Avon Substation secondary systems project involves replacing all the cabling and secondary equipment including protection, control, metering and condition monitoring systems. The project does not involve the replacement of batteries, chargers, AC/DC distribution system and backup generator. As the substation was built with direct buried cables without conduits, there is no existing cabling infrastructure. New cabling infrastructure is required to be added to the site during construction phase.

The substation joins three 330 kV feeders to a common busbar as shown in Figure 4

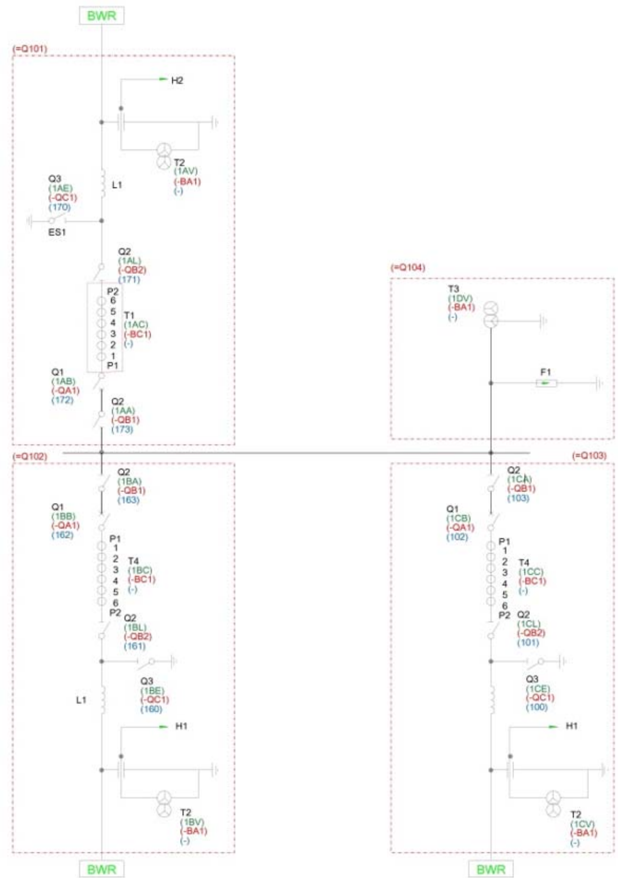

Figure 4: Avon Substation Single Line Diagram

Avon Substation was chosen as the first site to implement the Digital Substation technology due to;

1. Its small size.
2. Minimal variety in design standards requiring implementation.
3. Its close proximity to Sydney and maintenance depots.
4. Its scope of replacement included cables and all secondary systems.

4 Technology installed, Design principles

The implemented design was based on following guiding principles;

1. Change all data to IEC61850: Although Ethernet networks support all protocols the core of the system would use all services under IEC61850. All non-IEC61850 interface points would require conversion from their native protocols. This simplified the system interfaces as well as the protocols used at the station level.

2. Digitise everything as close to the source as possible: Digitisation close to the source allows each piece of data to be digitised once and used multiple times. It also minimises the number of connections, and reduces cable sizes and lengths.

3. Use the Power of the Ethernet: Ethernet technology offer robust and reliable communication infrastructure. Ethernet switches can be used in multiple topologies to achieve desired level of redundancy and reliability. Due to flexibility of Ethernet topology, it can be selected independent of associated system as you can nearly always meet your requirements.

4. Different manufacturers – less interoperability issues: Two redundant secondary systems are provided at Avon, each from different manufacturer. This was implemented to limit interoperability as earlier testing had revealed interoperability issues. If a fully interoperable system was to be implemented then not only would the lowest common functionality be implemented but it would take a long time to test and require us to implement logic to make the devices behave in the same manner.

5. Blank slate approach: While the core protection philosophy that has been followed in TransGrid's existing design is preserved, much of the communication network and signal flows have been designed with 'blank slate' approach. Trying to replicate the existing design in entirety using digital substation technology would severely undermine its benefits. Implementation of modern design would apparently require staff and contractor's retraining.

Implementation details:

1. Network technology:

   The network design was critical to the success of the project as lot of new technology was leveraged to implement the Digital Substation.

   To increase reliability of the overall system Parallel Redundancy Protocol (PRP) was implemented on both No. 1 and No. 2 systems. PRP was common functionality on most merging units and IEDs. One option that was investigated had both No.1 and No.2 systems on the same single PRP network. When you compare one or two networks, having duplicated networks did not increase the overall port count as the IED and merging unit connections were still the same. The cost of Ethernet switches is highly dependent on number of ports. Hence having completely segregated networks had similar port counts to that of a single network and therefore had minimal cost impact but delivered greater segregation and redundancy.

To minimise connections to the yard and allow compensated time correction to end devices PTP was implemented over the same Ethernet connection.

To handle the large volume of sampled values, VLANs were assigned to each IEC61850-9-2LE stream. This created a virtual point to point connection for instrument transformer sampled values. This ensured that each IED received on its Ethernet port only the data it required and no additional information.

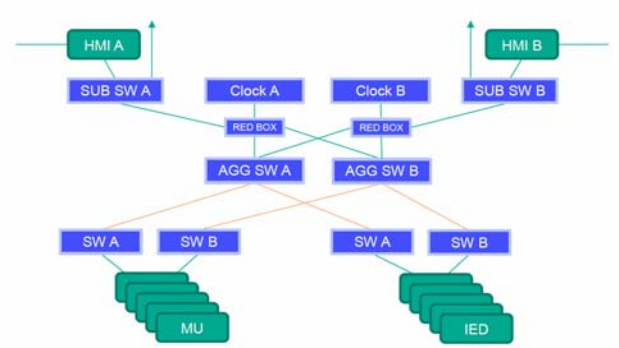

Figure 5: Network topology for One System

2. Sampled Values:

   In 2014, the products on the market implemented IEC61850-9-2LE. Throughout the investigation and proof of concept stages of the project many merging units were tested with many IED's and without exception they were all interoperable under the standard. Hence IEC61850-9-2LE was adopted for the final implementation with the only exception of the use of PTP for time synchronization, instead of 1 PPS.

3. Merging Units:

   It was recognized that the failure rates of merging units installed in the yard would be higher due to greater temperature change. Devices were selected that had the highest chance of a longer life. However, failures are expected to occur and to minimise time to repair, plug connectors were used for the connections. This was to make replacement in the field significantly faster, particularly in adverse weather conditions. Configurations of the devices was also standardized to minimize testing effort once replaced.

4. Functions implemented:

   The system implemented all substation functions including Protection, Control, Metering and Condition Monitoring via the merging units. This required digitisation in the yard of binary signals, current transformers, voltage transformers and analogue sensors.

5. Physical infrastructure:

   Sealed outdoor boxes without heaters house the merging units. The outdoor boxes are double skin enclosures with a small footprint and a light colour to help dissipate the merging unit heat.

   From the outside boxes two multicore fibre optic cables run back to the centralised building. Only AC, DC auxiliary supplies and the fibre cables run from the yard to the control room.

5 The business case

The business case for Digital Substation for TransGrid rests on following drivers.

Reduction in copper cabling/trenching:

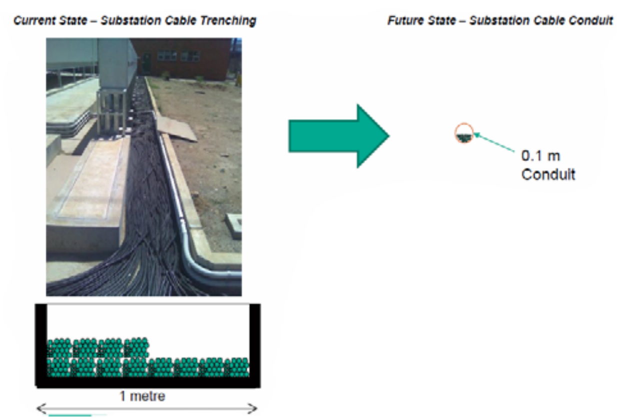

Figure 6: Cabling reduction

This is a major benefit for secondary systems for green field substations and also for refurbishments where secondary cabling needs to be altered due to aging or design changes. Figure-6 depicts scale of savings that can be expected when fibres are used instead of copper. Also, there are many related benefits such as

- Reduced cabling complexity
- Reduced requirement for trenching/civil costs- 95% volume reduction
- Reduced project commissioning time
- Reduced commissioning labour
- Reduced design drawings – 90% reduction
- Reduced terminations and associated verification costs

Reduction in building size:

Process bus IEDs are typically half the size compared to traditional IEDs. This allows more IEDs accommodated in a panel and therefore drastically reduced panel space required within a substation. Some of the substations under

TransGrid's simulation could achieve 80% reduction in panel space compared to traditional substation.

Faster commissioning of substations:

Due to smaller size of panels and limited cabling involved, almost entire secondary system for a substation can be built and thoroughly tested in a laboratory. Not only does this allow greater control over quality of testing but it can be done at a fraction of cost of testing done at remote sites. It is much easier to engage vendors or specialists to address specific issues when tests are done in a lab rather than a remote site.

Once the system leaves lab with thorough functional and interface checks done, the site work is reduced to perform minimum commissioning checks. This drastically reduces labour costs and time associated with commissioning – about 50% savings are expected. This is a significant advantage in countries where labour cost is very high.

Standardisation – Reduction in System drawings:

Standardisation was heavily used at the bay level to make merging unit configuration similar and to allow changes to the copper interface without changing the underlying digital messages. Hence the bay information is always the same even though the primary equipment may vary. In this way the interface between data digitisation and data usage is standardised. This also made significant reduction in the number of drawings – approx.. 90% - required to implement the design.

This approach opens up possibility of standard indoor and outdoor cubicles that can be ordered irrespective of the project, therefore making asset management efficient. Also, timeframes for projects can be significantly reduced allowing for improved completion period without paying high acceleration costs.

Simplified maintenance:

With better defined test and simulation modes in Ed2 of IEC61850, maintenance and commissioning tests can be done efficiently. Also, visualisation, test and diagnostic tools are evolving that can greatly help maintenance regime. Remote diagnostics is possible that can result in less visits to site.

The cumulative savings expected in this first Digital Substation project is expected around 30% - this has so far exceeded initial expectation and with more implementations and design maturity increased levels of savings are anticipated.

6 Lessons learnt

There were valuable lessons learnt during the entire exercise of market study, proof of concept tests and eventual implementation.

Business driven change:

From the outset TransGrid had embarked on this journey with clear business objectives in mind. Financial and technical benefits were rigorously analysed and internal stack holder engagement was in place throughout the process. Success of projects that demand departure from conventional practices depend largely on sound framework and strong management buy in.

Proactive vendor support and involvement:

This project commenced at a stage where some of the products were in development or market release stage. As the proof of concept tests progressed, it provided valuable feedback to manufacturers for their development roadmap. At the same time, TransGrid benefited by active involvement of manufacturers at the design stage.

Involvement of TransGrid in design:

The entire design and validation was conceptualized and driven by TransGrid engineers with manufacturer's help at relevant stages. This was beneficial as TransGrid's know how on their specific requirements and legacy systems translated to functional specifications and subsequent engineering design. This helps reducing gap between intended and eventual outcomes.

Product specific issues:

Compliance to IEC61850 standard in itself does not guarantee compliance to the functional specifications. We realised during implementation that some of the products and engineering tools needed work-arounds to fit to the intended design and engineering processes. Sometimes firmware changes were needed to overcome deficiencies.

Vendor specific tools/ top-down vs. bottom-up engineering:

IEC61850 standard advocates top-down engineering approach wherein the 'super' tool creates system wide file that generates files for individual IEDs. In our implementation, we found that the system engineering is neither at any extreme but a mix of top-down and bottom-up approaches. Using vendor specific tools did not prove a limitation especially since No.1 and No.2 systems are independent of each other.

Control functions in the switchyard:

Initial design at the stage of proof of concept was based on data collection in the switchyard through merging units and processing in the substation through protection and control IEDs. However, during implementation we realized that placing control functions close to the switchgear (i.e. Logical Nodes CSWI/CILO etc. in the merging unit) simplifies engineering and minimise message traffic between switchyard and substation building. It is important for merging unit to support such functionality.

Validation on realistic system rather than a single bay:

Some Utilities tend to do pilot trials on a single bay. We have realized that having a realistic system (with number of bays) in a lab and running tests uncover issues that are otherwise not detectable on single bay installation. The system on which proof of concept was done was very close to the real substation and this provided valuable inputs to engineering design.

7 What's next for Digital Substations?

The Digital Substation makes it possible to roll out advanced applications in the substation, contributing to a smarter power grid. Some examples are given below, but many other possibilities are on the horizon as the processing capability of the substation system and component IEDs grows in scale [3]

Situational awareness:

Situational awareness (SA) is a broad-based concept, with application domains as varied as healthcare and aircraft navigation. SA comes into focus in the SCADA control rooms, where operators need to continuously make sense of data to ensure system stability. In substations, SA includes monitoring and understanding the state and environment in real time, and the ability to precisely anticipate future problems in order to take proactive corrective action. Digital substations offer local and wide-area situational awareness, allowing dynamic management of power flows, and optimum condition-based management of substation assets. At the substation level, the digital substation can integrate, process and display – through clear and intuitive dashboards – a large array of monitored parameters.

Figure 7: Situational Awareness – HMI view

Wide Area Automation and Communication:

A wide area network interface can be integrated into the grid operator's wide area control systems and defence plans, which allows implementation of fast inter-substation control and protection schemes. The benefits of receiving and responding to the operational data from other substations within the network include a reduction in both the frequency and the reaction time to network events. Another application enabled by wide area automation is recording and collection by phasor measurement units (PMUs), which can also be concentrated and relayed to the control centre and analysed by online stability solution to track power system oscillations and anticipate contingencies. Digital substation sensors and control systems can be configured to work seamlessly with their software platforms for grid operator control rooms, allowing a real-time data exchange at both the substation operational and asset management levels.

8 Conclusion

TransGrid's first Digital Substation is due to be installed in 2017. TransGrid have followed a process that has delivered complete renewal to all secondary systems within a substation. Starting with research, then completing a proof of concept and finally implementing Avon Digital Substation.

Very important aspect of the entire process is that this was a business-driven innovation and it rested on a sound business case with short as well as long term financial benefits. There were valuable lessons learnt during the process that will guide future designs.

Avon Digital Substation is just the beginning of the journey; the present strategy for secondary systems puts TransGrid on a new path with Digital Substations. Future enhancements will add LPITs, have more integration with switchgear and could lead to full virtualization of the systems.

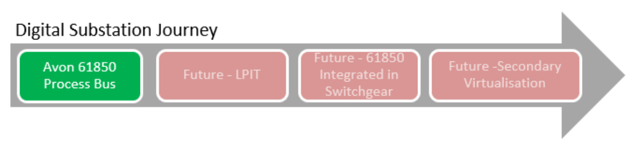

Figure 8: Digital Substation journey

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