An IEC 61850 Process Bus Solution

Process Bus

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As part of a series of turnkey projects undertaken in 1999, Powerlink introduced an integrated substation design known as Intelligent Plug and Switch System - iPASS - an outdoor hybrid switchgear solution with intelligence built into the primary switchgear. This article will examine an IEC 61850 based SAS solution that is being considered as a favored upgrade option for Powerlink’s iPASS secondary system replacement project.

The Queensland – New South Wales Interconnector (QNI) included the establishment of four substations constructed as part of a series of turnkey projects commencing in 1999. Under these projects an integrated substation design known as Intelligent Plug and Switch System – iPASS was introduced to Powerlink’s Transmission Network. These substations are now the backbone for an essential system interconnection, and the ongoing reliability and supportability of the substation design is imperative. Subsequent to the QNI project, the use of the iPASS technology was extended to two more substations within Powerlink’s Transmission Network. Powerlink is now planning the replacement of all iPASS secondary systems including the electronics mounted on the primary equipment prior to 2013.

The iPASS system is an outdoor hybrid switchgear solution with intelligence built into the primary switchgear. There are different electronic modules used for the control and supervision of the switchgear (Circuit Breakers and Disconnector / Earthing switches) and the acquisition of the current / voltage samples (for control and protection functions) are derived from the Non-conventional Instrument Transformers (NCIT). The electronic modules are an integral part of the Substation Automation System (SAS) that interface with the bay-level equipment using a proprietary fibre optic process bus.
In 2004 the UCA Users Group released an Implementation Guideline for a digital interface standard using IEC 61850-9-2 process bus for the transmission of current/voltage samples. This is also referred to as IEC 61850-9-2LE (Light Edition). There have been several pilot projects implemented worldwide that support the new interface convention. However, there are only limited automation devices available on the market which provide IEC 61850-9-2LE interface connectivity. Since the release of the Implementation Guideline, companies have implemented the new interface standard in Merging Unit devices (MU) and bay-level devices of their current protection and SAS platforms.

This article focuses on the application of Sampled Value (SV) process bus according to IEC 61850-9-2LE using current MU technology for the transmission and distribution of SV data streams to control and protection applications. It looks at different secondary system architectures and MU configuration options and analyzes the protection system reliability aspects in order to successfully deploy new technology in Powerlink’s future iPASS secondary system replacement projects.

### Merging Unit Concept

IEC 61850-9-2LE was developed using the concept of a MU. According to the Implementation Guideline the Logical Device MU contains the Logical Nodes TVTR (voltage transformer) and TCTR (current transformer). The main function of the MU is to combine the current and voltage inputs from a three phase system including the zero sequence components and to transmit the measured values as a SV data stream to all IEDs (Intelligent Electronic Devices) subscribing to that data. The IED performing the MU function may contain several logical MU devices.

IEC 61850-9-2LE defined two distinct sampling rates for the SV-based process bus:
- 80 samples per nominal system frequency cycle
- 256 samples per nominal system frequency cycle

In the 50 Hz power system this translates to 4,000 Hz and 12,800 Hz. 80 samples per cycle is sufficient to satisfy most of the common protection functions, whereas 256 samples per cycle is used for high-speed functions such as power quality monitoring. Separate SV streams must be synchronized to a common time base when being used for the same function. SV applications typically require an accuracy of <1µs which is accomplished by using a precise one pulse per second (1PPS) timing signal.

The NCIT solution for iPASS can be best described by referring to Figure 1. The electronic current and voltage sensor, also called CP (combination of CT and PT) is a single-phase unit, designed for use in Gas-Insulated Switchgear (GIS) products. The CP is based on a modular design and has two fully redundant measuring systems.

The primary converter contains two Rogowski coils for current measurement and gas capacitors for voltage measurement. The transducers are built into the GIS enclosure. A redundant set of Secondary Converters (CPSC) is sampling the currents and voltages measured by the transducers and then sending the sampled values to the MU. The CPSC has two fibre optic data outputs PPL1 and PPL2. Both outputs can be used for protection applications, or alternatively, one output can be used for revenue metering. The point-to-point data link between CPSC and MU is a proprietary solution, implemented as a serial data link with a fixed time delay.

Two distinctly different types of MU devices were considered for use with the CP: the MUP (Merging Unit used for Protection) and the MUM (Merging Unit used for revenue Metering). This article considers only the application of the MUP, as Powerlink only uses the CP for Protection. The MUP shown in Figure 2 contains four Logical Devices type MU and features:

- Three sets of optical inputs, each allowing for connection of a three-phase current/voltage measuring system (CP1, CP2 & CP3). Each CP is internally connected to a Logical Device MU.
- IEC 61850-9-2LE defined two distinct sampling rates for the SV-based process bus
- 80 samples per nominal system frequency cycle
- 256 samples per nominal system frequency cycle
A critical issue defining the network topology is whether the station-level network would be used for high-speed protection trips between IEDs.

A fourth Logical Device MU that can be used for current summation in a one and a half breaker scheme, the summated inputs are configurable from any two of the three optical inputs.

One optical 1PPS input that can be replicated to five optical 1PPS outputs if configured to act as time master. The MUP can be configured as time master or time slave.

Five switched optical IEC 61850-9-2LE Ethernet ports for the transmission of SV data streams, allowing the connection

The MU of up to 5 IEDs performs the synchronizing of the current/voltage samples received from the different SC units which are all free running. The port mapping of the built-in Ethernet switch is configurable, allowing the user to direct the SV data streams produced by the internal MU Logical Devices to the individual IEDs connected to Ethernet ports.

Additionally, the MUP port-mapping feature allows the user to receive a SV data stream from another MU device on one of the Ethernet ports and to direct the data to any of the IEDs connected to the remaining MUP Ethernet ports. This functionality overcomes limitations associated with an IED with only one physical Ethernet port for SV process bus where it requires SV data streams from two different physical MU devices.

Substation Automation System Considerations

When designing an IEC 61850 SAS, one of the biggest challenges is the network architecture. In order to define the architecture, the basic requirements need to be identified and agreed upon, and some of the major considerations are:

- Avoiding “common mode” failure
- Ensuring access for maintenance in an orderly manner (i.e. safe and secure isolation and access)
- Meeting the relevant rules (e.g. NER)

The issues relating to which physical network topology to select also depend on some of the logical architecture (i.e. where the various functions reside, and how they communicate with each other). IEC 61850 defines a set of communication services to be used between process and bay-level functions and between bay and station-level functions. The standard does not preclude a single network for all functions on all levels. In fact, the standard does not actually make any recommendation or reference for or against any specific architecture. However, due to “isolation and access” issues (for maintenance etc.), it can actually be beneficial to have distinctly separate networks: the process-level network also referred to as Process Bus and a station-level network or Station Bus. The decision to use fully separated Process Bus or to merge Process Bus along with the main substation LAN can be affected by the actual application requirements and any limitations dictated by the products (i.e. number of available Ethernet ports). In current installations, a ring topology appears to be the most common for the station-level network. It has to be noted that with only a few process-level network trials implemented world-wide, the suppliers are still formulating their own views.

One of the most critical issues when defining the network topology is whether the station-level network would be used for high-speed protection trips between IEDs (i.e. whether trip signals would traverse the network, or be directly connected via copper or fiber). If GOOSE (Generic Object Oriented Substation Event) messaging is used for inter-bay inter-locking and inter-tripping, then a higher level of redundancy is required. GOOSE messaging is not yet commonly used for protection functions. In the few cases where GOOSE messaging has been used for protection functions, it was implemented in a mixture of single and double networks to satisfy redundancy requirements.

Time distribution network reliability is critical for the SV-based process bus operation. Without synchronized time sampling, it is impossible to combine SV streams generated by multiple physical devices (NCITs and MUs). Unsynchronized SV outputs cannot be used for differential protection, synchrophasor measurement, or digital fault recording.

Pascal Schaub
was born in Zurich, Switzerland. He received the BS diploma in computer science from the Technical University in Brugg-Windisch in 1995. In 1996 he joined ABB where he worked in different positions in the area of substation automation design and products with a leading role in the research and development of control and protection systems, non-conventional instrument transformers and field bus technology. Currently he is working with Powerlink Queensland as a Principal Consultant for Digital Technology Infrastructure in Brisbane, Australia. Pascal is responsible for the research and evaluation of new technologies and standards used in power utility automation, and to have a leading role in the implementation of new digital technologies within the organization.
The application of SV according to IEC 61850-9-2LE leaves us with a total of two mission critical networks:
- Process Bus Ethernet based LAN
- 1PPS Time Synchronization Network

Should GOOSE messaging be used for high-speed protection trips between IEDs, the station-level network has to be added to this list.

The IEDs Powerlink is planning to use support IEC 61850-9-2LE on one physical Ethernet port, leaving a second Ethernet port for the station-level communication according to IEC 61850-8-1. The IEDs also feature one 1PPS input for Time Synchronization of SV data streams.

The physical capability of the IEDs reduce the number of network topologies possible for the iPASS upgrade solution. The resulting network architecture will therefore need to be based on having separate physical networks for Process Bus and Station Bus applications.

**Comparison of Merging Unit Layouts**

To determine an appropriate architecture for the Process Bus it is important to understand and consider the functional limitations of the equipment as well as any other overriding requirements. Currently the Australian National Electricity Rules (NER – Section 5.1.9) require that Protection Systems must have sufficient redundancy to clear short circuit faults with any one single Protection element out of service. At this time, to comply with the rules as they are written would require the CPSC, MU and Protection IED to be duplicated.

A majority of Powerlink’s iPASS installations are 1½ Circuit Breaker (CB) layouts and it is this arrangement that will be the basis of the discussion and analysis. The primary plant layout and configuration of the switchgear (including the number of NCITs – six per Diameter) is predetermined as the iPASS equipment is installed and operating with the original Protection and Control System. Therefore the original design philosophy for fully overlapping protection zones utilizing all NCITs in each Diameter shall continue in the new system.

With the number and location of NCITs already determined, the issue to be addressed is the number of MUs per Diameter and their connection to both the NCITs and Protection and Control IEDs. To address the NER requirements, the Protection system shall require duplication. The analysis considers only one of the duplicated systems as the outcome would be the same for both.

The two configurations were considered - two MUs per Diameter or three MUs per Diameter. CB Fail protection can be performed as a sub function of the Feeder Protections, which would require an additional Protection IED for the Center CB, possibly included into the Bay Controller IED as a sub function, or implemented in a separate system. Utilizing such a system would also enable Bus Zone Protection to be performed. Irrespective of the solution used for CB Fail or Bus Zone, a single measuring point per CB (9-2LE connection including Time Synchronization) is required. While this needs to be considered and included in the overall design, for clarity, this has been omitted from the following discussion and analysis for MU layouts.

Figure 3 shows a typical layout of a single Diameter using only two MUs. Only the PPL1 signals from each CPSC are used for the input into the MU. The first MU is synchronized from a GPS or can operate off its own...
internal clock. The Time Synchronization of the second MU is required to be derived from the first MU. The Protection IED for Feeder 1 requires the summation of two separate NCITs to determine the total current flowing. Both NCITs used for this measurement are connected to the same MU. A similar situation exists for the Protection IED for Feeder 2. The Bay Control Functions for the Q10 and Q20 Bay Control IEDs are each derived from a single MU. The Bay Control Functions for the Q30 Bay Control IED requires the combination of both MUs. This results in a critical dependency on the Time Synchronization between the two MUs to enable the Q30 Bay Control IED to perform the synchro-check function (RSYN).

Figure 4 shows a layout of a single Diameter using three MUs. Only the PPL1 signals from each CPSC are used for the input into the MU. The first MU is synchronized from a GPS or can operate off its own internal clock. The Time Synchronization of the second and third MUs are required to be derived from the first MU. The Protection IED for Feeder 1 requires the summation of two separate NCITs to determine the total current flowing. With the connections shown in Figure 4, the currents are derived from two separate MUs resulting in a critical dependency on the Time Synchronization of these two MUs. A similar situation exists for the Protection IED for Feeder 2. The Bay Control Functions for the Q10, Q20 and Q30 Bay Control IEDs are each derived from a single MU and therefore are independent of the Time Synchronization system of the MUs.

Figure 5 shows an alternate layout of a single Diameter using three MUs. All three MUs are synchronized individually to GPS Clock or can operate individually off their own internal clock. There is no constraint or dependence between the MU clocks. The MU connections for this layout utilize the second output signal (PPL2) from both CPSCs on the Q30 Centre CB.

The Protection IED for Feeder 1 still requires the summation of two separate NCITs to determine the total current flowing. However, with the connections shown in Figure 5, the currents are derived from the same MU. There is no critical dependency on the Time Synchronization with any of the other MUs. The same is also true for the Protection IED for Feeder 2. The Bay Control Functions for the Q10, Q20 and Q30 Bay Control IEDs are each derived from a single MU and therefore are independent of the Time Synchronization system of the other MUs. If we consider the previous three layouts and their MU connections with respect to equipment failure, access for maintenance or repair, then Table 1 would summarize the impacts for each layout for the worst case.

The selection of the MU connections can have a major impact on the availability and operation of the system. A system designed with three MUs per diameter using both PPL outputs from the CPSC, has less operational impact following a failure. Taking this into account the preferred solution would use both PPL outputs and three MUs per Diameter. This solution is also readily acceptable to any of the CB Fail and Bus Zone Protection implementations.

### Proposed Architecture

The proposed network topology for Powerlink’s iPASS upgrade solution is shown in Figure 6. The station-level network is implemented in a single-ring LAN (Local Area Network) topology. It is proposed that GOOSE would not be used for inter-tripping between protection IEDs over the station bus as there is still no universal method/tool available that would allow Powerlink to perform a safe and secure isolation of the “virtual” trip signals for maintenance and commissioning. The two protection systems Main X and Main Y are physically and electrically separated in order to satisfy the NER requirements.

The GPS clock and Time Synchronization network providing the 1PPS signal to the MUs is to be duplicated as it is part of the protection system. The proposed layout of the MU shall be in accordance with option 3. (Table 1). The process and station-level networks are physically separate LANs in accordance with the applied philosophy and the limitation posed by the IED’s capabilities. The process-level network is only being used for the transmission and distribution of SV data and each bay has its own process bus LAN. GPS clocks, Communication Gateways and HMI have a dual attachment to the two station Ethernet switches for improved availability.

### Future Considerations

The following issues also have to be considered when implementing an IEC61850 Process Bus Solution in the future: Many utilities would want to use NCITs in conjunction with conventional CTs and VTs in their SAS.

### Table 1. Impact for a single failure on the protection and control system

<table>
<thead>
<tr>
<th>Failure Type</th>
<th>Impact of Failure</th>
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<tbody>
<tr>
<td>Failure of an single CPSC</td>
<td>Option 1: 2 MU per diameter</td>
</tr>
<tr>
<td></td>
<td>1 x Fdr Prot</td>
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<tr>
<td></td>
<td>1 x Bay Ctrl</td>
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<tr>
<td>Failure of single MU</td>
<td>1 x Fdr Prot</td>
</tr>
<tr>
<td></td>
<td>2 x Bay Ctrl</td>
</tr>
<tr>
<td>Loss of Time Synchronization to or between MU</td>
<td>1 x Bay Ctrl</td>
</tr>
</tbody>
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The selection of the MU connections can have a major impact on the availability and operation of the system.
Using inputs from NCITs and conventional instrument transformers within the same function (i.e. current differential protection) is referred to as “Mixed Mode” application. The input signals have to be timely correlated as the signals might have been sampled with different time sources and at different sampling rates. ABB has implemented Mixed Mode within the protection and control IEDs. Other suppliers are performing this function within their MU device. Mixing the two concepts in a single SAS is possible, but poses some interoperability challenges.

Being left with two mission critical networks for the transmission of SV is not ideal. The international standard IEEE 1588 “Precision Time Synchronization Protocol” would allow integrating the communication function and the time distribution on one physical network. This standard uses bidirectional communications combined with hardware level time stamping to provide precise clock synchronization. It is also capable of compensating for transmission medium delays and offers additional services for automatic election of the best master clock device. Because hardware assisted functionality is required for sub microsecond accuracy, IEEE 1588 hardware has to be supported in both Ethernet switches and the end device. IEEE 1588 is expected to be included in future editions or amendments of the IEC 61850 standard and to be implemented in the future generations of IEDs.

For critical applications, it is likely that dual networks will be a common architecture, and some utilities may even request dual attachment of an IED, which would require the support of a redundancy protocol in the IED. The first edition of the IEC 61850 standard did not specify in detail the underlying hardware of the networks, believing that solutions for industrial Ethernet would find the way into substation automation. The absence of a commonly accepted redundancy solution is now threatening the whole interoperability concept, since suppliers have started to release product supporting proprietary redundancy solutions, effectively preventing their ability to build a multi-vendor system when the interfaces do not fit.

The IEC committee SC65, WG15 “Highly Available Automation Networks” has recently published the IEC standard 62439 which specifies several redundancy methods, one of them applicable to substations. Hopefully we will soon see products that support the new standard.