Considering the Process Bus

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1 Abstract

There has been a lot of discussion about process bus of late as you would expect as the industry starts to move from trials to full deployment in expanding their IEC 61850 solutions.

However some engineers and managers are talking about their implementation program for IEC 61850, they are very quick to add "*but not process bus*". This can be easily misconstrued that process bus is a bad idea or just a silly thing to do and is confusing those less aware of the detail behind the technology. This risk is that this may lead many organisations to just discard the significant benefits of process bus and limit their IEC 61850 implementation to the station bus applications in control room for the relays and SCADA system, or worse still consider that the whole IEC 61850 technology base is immature or in some way flawed.

This paper seeks to step back a little and consider the imperatives to using process bus in the right context, based on sound engineering principles and analysis.

2 Defining the Process Bus

Most sketches of Ethernet topology in a substation generally indicates the process bus as that part of the Ethernet network that carries signals in the substation yard as shown in Figure 1.

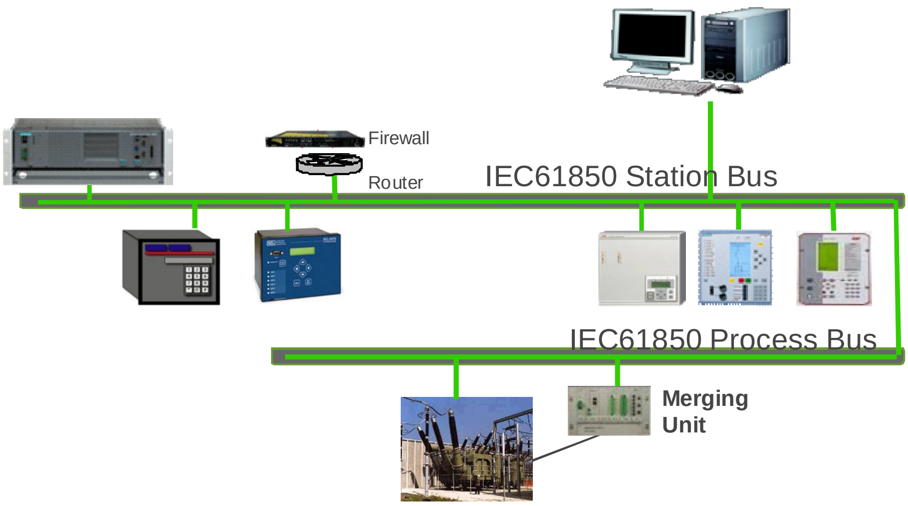


Figure 1 Typical representation of SAS Station and Process Bus

There are a number of elements that contribute to equipment and signals outside the control rooms which include:

- Trip/close commands
- Sampled values (SV) (instantaneous digital values representing the primary analogue value)
- Non conventional instrument transformers (NCIT – optical CT/VT, Rogowski coil)
- Status information (open/closed, on/off)
- Condition monitoring information (such as transformer gas monitoring & temperature
- Control signals such as for voltage regulation or fan controls
- VOIP Telephone in the yard

- Video surveillance of plant and for security
- Maintenance, test, & operating staff connecting a laptop in the yard

Some of these signals could be considered as ‘station bus’ related, or perhaps not even in the realm of IEC 61850 at all, and hence “of course” will be included in what is operating over the fibre running in the yard. This highlights the problem of context and confusion in the statement “*We are not using process bus*”. This list at least indicates there are several reasons why the Ethernet LAN will extend out into the yard even now as shown in Figure 2 which shows part of Substation Automation System LAN architecture with the control room at the top and the yard below. Here a dual ring serves the X protection system (red) and Y protection system (blue) located in various cubicles and a number of network switches for LAN connectivity. For emphasis the bay on the right shows the Y system simplistically in single line format using conventional equipment and wiring and shows a CT circuit, CB trip close coils, CB open/closed status and some condition monitoring equipment. It can be taken that the LAN based system will incorporate at least the same functionality along with other LAN enabled functions.

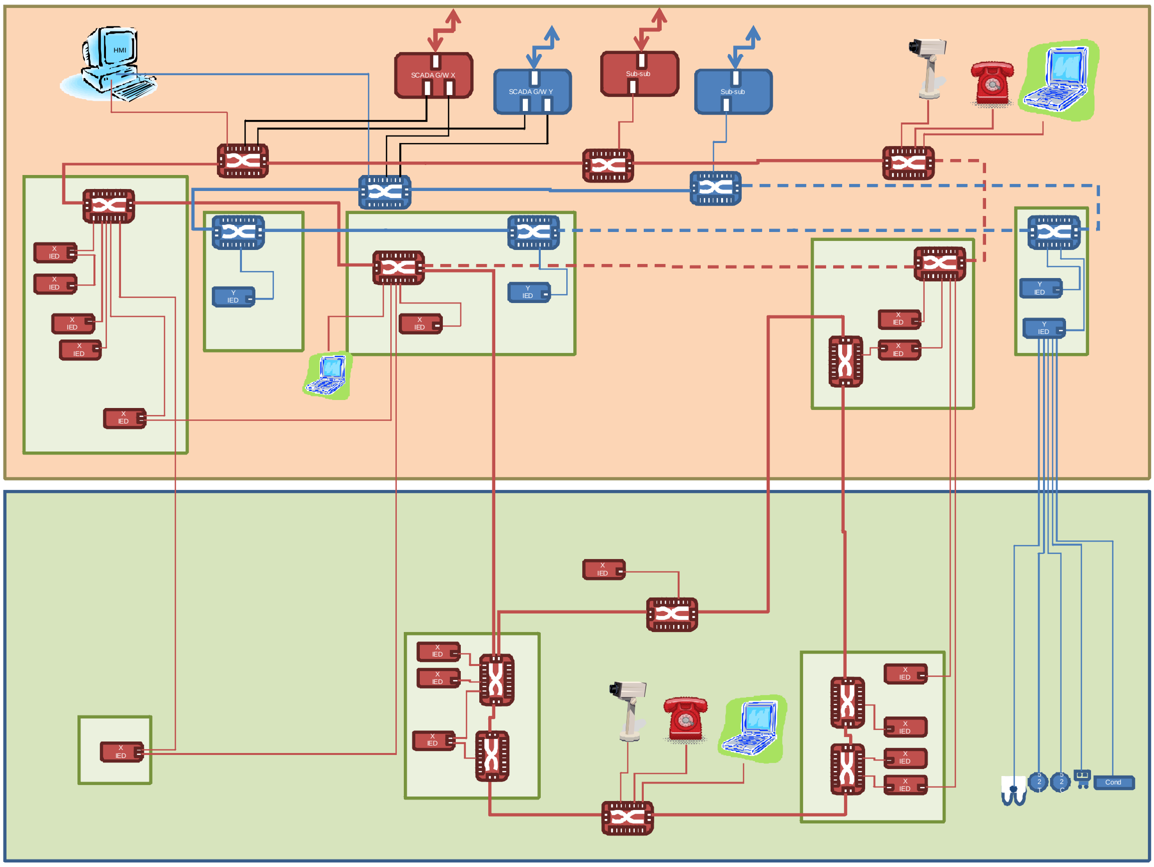
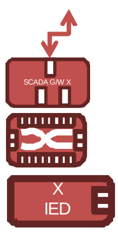


Figure 2 Total SAS LAN - Control Room above, Yard below



Gateway to SCADA System Control Centre or other substation

Network Switch with multiple ports

IED for protection, condition monitoring, MU etc with one or more ports

Consider the cost of a typical X and Y protection panel – adding the cost of a couple of distance relays on the panel, the cost of the panel itself, it is not uncommon to end up with only about 25-30% of the installed cost of the panel. If a typical panel is between say $100,000 to $120,000, the difference between this and the direct cost of the devices to do the job required (two distance functions) and the cost of a suitable enclosure is cost directly and indirectly related to wires! Wires are expensive. If this thought is extended to the entire substation, there is a strong driver that the engineering community should be seeking to bring the full benefits of process and station bus to the substation.

Introducing IEC 61850 has an immediate effect on the difficulty of producing hundreds of drawings all cross referenced with wire numbers and terminations – this work load effectively disappears. As the design progresses to construction, installation and commissioning, the maintenance of these drawings also disappears.

Furthermore, testing is a laborious process. Factory Acceptance Testing (FAT), Site Acceptance Testing (SAT) and detailed commissioning often repeats the same tests; and the same tests are carried out repeatedly bay by bay on systems using the same circuit design. All this is designed to prove the scheme functions as it required to; and, that the physical construction of the design has been faithfully completed, all in the full context of the primary and secondary systems. An IEC 61850 substation automation system however offers the possibility to automate the specification of the test program but more importantly eliminates differences in physical construction and hence eliminating the need for repetitive testing.

Our fundamental imperative in engineering must be to deliver efficient cost effective designs to the organisation and hence issues of network architecture, capacity, redundancy as well as performance and location of LAN switches in the yard cannot be avoided for long.

Over the last few years of deployment of IEC 61850, even the early adopters who suffered the teething problems of vendors and their own understanding of the principles behind IEC 61850, are now resolute in their choice of IEC 61850 as their engineering process.

Certainly there are some fundamentals of interoperability that must be given their proper consideration such as the compatibility of the PICS[a] between devices and not just relying on a Conformance Certificate as evidence of “plug and play” compatibility. The simple analogy is that telling you I have a drivers licence does not in itself prove I can successfully drive any vehicle from a motor cycle to a car, a truck, a bus or a formula one racing car; nor in any circumstance in off road conditions, a suburban street or race tracks; or perhaps in a different country with different road rules and perhaps even driving on the other side of the road. Neither is a Conformance Certificate sufficient on its own for knowing a particular device is suitable for your needs unless the full context of the test that the certificate represents is known.

So if delivering vast cost savings and efficiency is such a prime motivator what is behind so many stating “*but not process bus*”. It would seem reasonable to assume that the concerns are focused on the first three items (trip/close, SV and NCIT), and possibly the fourth (open/closed indications) so these aspects deserve some focus in this discussion in terms of the engineering behind them.

Knowing the context of what you require is the first essential step and then informed selection must closely follow.

3 Circuit Breaker Status and Commands

Process bus brings with it a fundamental change in the way signals are sent to and from the circuit breaker including breaker status and the close and trip commands, all now relying on a communication network. Hence it is quite right that we take a cautious look at this for reliability, after all we have been conditioned by the spasmodic behaviours of office LAN systems when gigabyte print spooling delays our latest dissemination of email jokes!

[a] PICS: Protocol Implementation Conformance Statement – detailed information on what communication processes have been implemented in the device

Of course a good question is "why bother?" It can be easily dismissed as a trivial objective to replace "a couple of wires for trip and close and CB open/close status". The reality is, as shown in Figure 3, that there is quite a large number of wires involved in even a single circuit breaker system compounded by marshalling kiosks yet further increasing the number of wires and terminations.

A single circuit breaker can easily have several connections for multiple trip and close coils and a dozen or more contacts for circuit breaker status indication from the auxiliary palette switches. The benefits of an IEC 61850 solution for CB interfaces starts with simplifying wiring. The subtlety of this is that not only are wires eliminated but the consequences of wires are also reduced in respect of drawings and test programs.

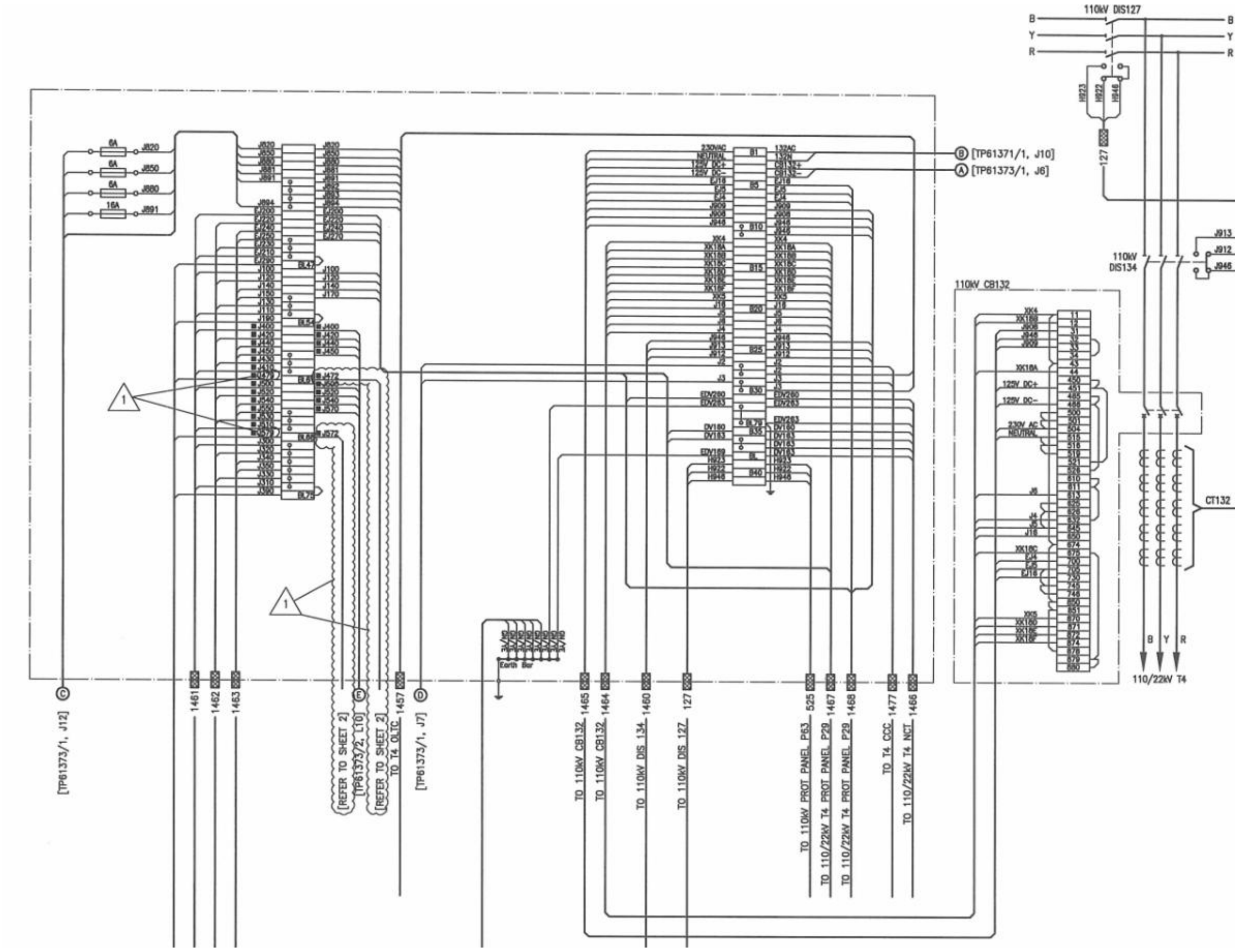


Figure 3 Complexity of CB wiring

We are already seeing the industry starting to use trip commands and these projects are already showing that IEC 61850 GOOSE tripping is faster than hard wiring. However undoubtedly this has not been achieved by allowing an inexperienced engineer or IT specialist to connect it up and cross their fingers.

As an example, in order to guarantee the three millisecond response time application to application (not just between device terminals) this requires appropriate engineering considering the latency of the network due to the number of switches amidst the highest network loading. It also requires the right choices of priority tagging and VLAN policies as well as LAN redundancy and segregation arrangements.

Of course the reliability of a communication network and its components must also be engineered in for failure modes including hardware MTBF, operation in the substation with interference and high temperatures, denial of service, data storms and of prime concern cyber and access security. The results of these first projects using GOOSE tripping will be closely watched and analysed but will no doubt gain increasing acceptance.

4 Current and Voltage Measurements

The next aspect of Process Bus is to consider the benefits of eliminating extensive CT and VT wiring. A typical conventional CT circuit is shown in Figure 4 with hundreds of wires and terminations per bay.

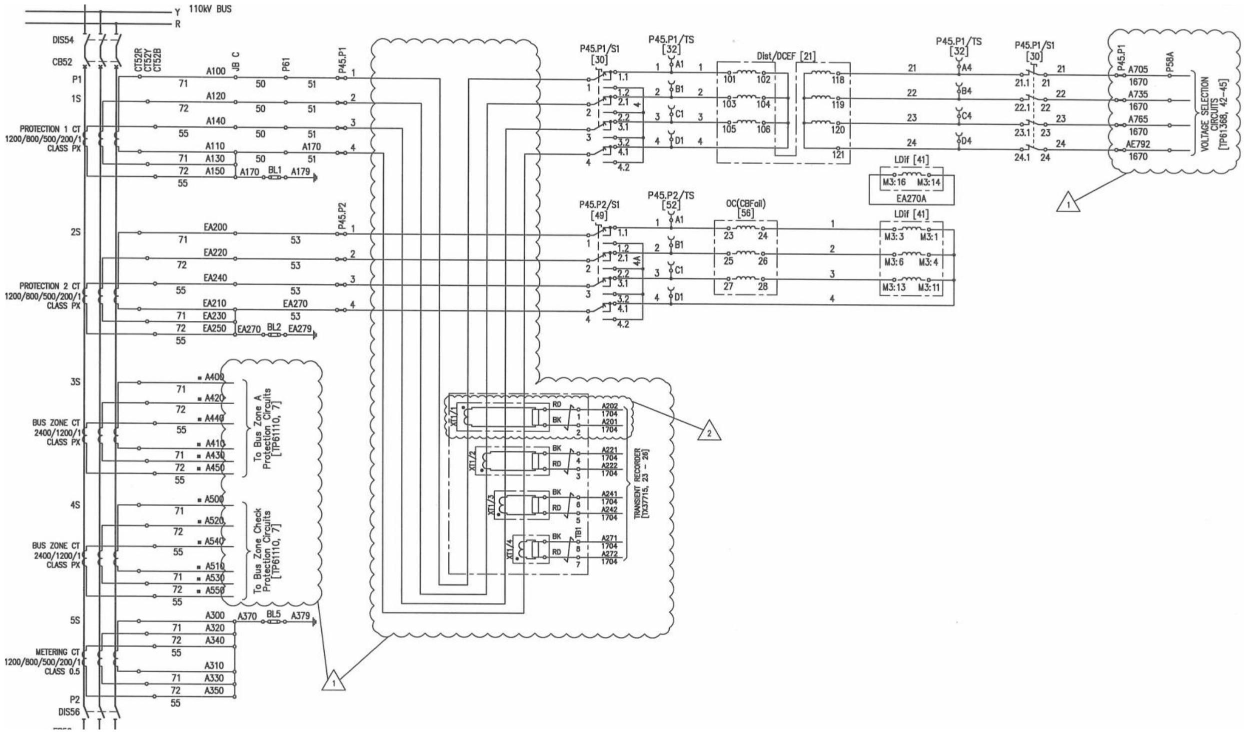


Figure 4 Extensive wire count of conventional CT circuits

One of the first observations of a bay of conventional CT circuits is that the same current is measured several times, in this case five, but possibly eight times allowing for two line protections, two bus protections, two independent CB fail protections and two metering cores. An IEC 61850 solution simplifies this by at least half in only requiring two protection cores and two metering cores due to different dynamic range performance. If the sensors can be replaced by Non Conventional Instrument Transformers with high accuracy over far wider ranges, then just a pair of X and Y cores will suffice. IEC 61850 Part 9 defines the process of instantaneous sampling of the current and voltage waveforms and distributing these Sample Values on the LAN to the protection devices.

Quite often the question of using process bus is confused between use of Sampled Values and the slightly different aspect of changing to Non Conventional Instrument Transformers so let us be perfectly clear:

- NCIT may or may not imply use of SV.
- SV may or may not imply use of NCIT.

This is because we have the following configurations for the so called Merging Units (MU) which are the source of the IEC 61850 Sampled Values

- NCIT input, IEC 61850 SV output
- Conventional sensor input, IEC 61850 SV output
- NCIT input, analogue output (1A/110V or low level 0-10V)
- Conventional sensor input, analogue output

The third and fourth solutions are arguably of limited interest except with relays that can only cope with conventional analogue inputs which is therefore not involved in the issue of deployment of the process bus. This leaves consideration of the first two solutions as the deployment of process bus involving IEC 61850 Sampled Values.

4.1 Merging Unit Technology

It is well known that one of the main advantages of process bus is about eliminating thousands of wires in the yard, leading to savings in the weight of copper, extensive marshalling boxes, terminations, tagging, & testing. This benefit can be achieved without using NCIT at all and just using the tried and proven conventional (existing) CT and VT. This simply requires the use of Merging Units that take conventional CT 1A and VT 110V signals as inputs and provide IEC 61850 SV as the output (second configuration above). The engineering question is then should we have any concerns or hesitation in this?

As shown simplistically in Figure 5 conventional systems take the 1A and 110V from the instrument transformer all the way in (via huge numbers of wires and terminals) to the relay. The relay then has an analogue input module that does the analogue to digital (A/D) conversion and the internally sampled values are communicated over the internal mother board bus to the relay CPU. The relays we have used to date have done this conversion to a proprietary structure inside the relay but never the less it is creating sampled values used by the processor, with all the issues as time synchronization and signal processing.

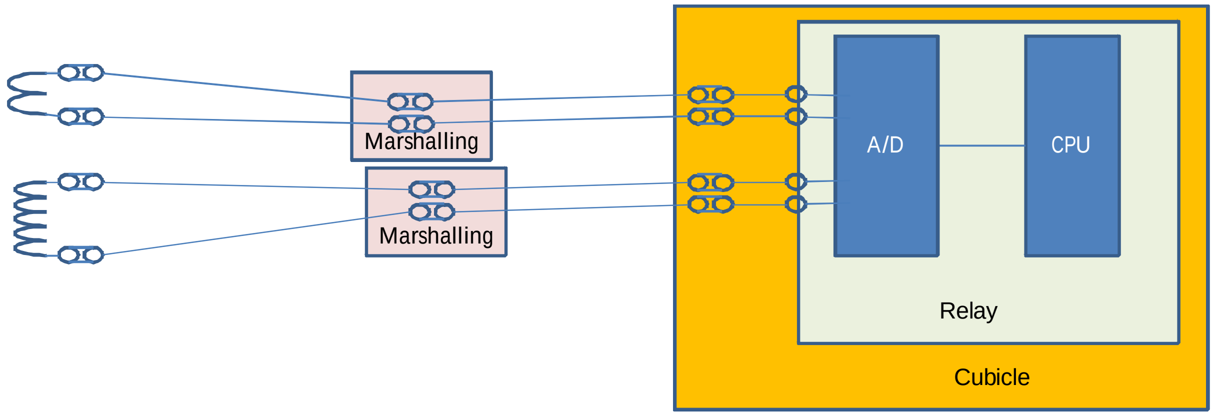


Figure 5 Traditional relay & sensor configuration

So if we consider a MU application in Figure 6, we have the same process of an A/D conversion in the MU and the relay is still directly using the SV but now with a defined LAN in between which can deliver the SV data stream to more than one device. This can eliminate multiple cores of CT as we are no longer constrained by the different analogue performance requirements on the CT for different applications such as circulating current differential schemes compared to line protection.

Figure 6 IEC 61850 Merging Unit based sensor and IED

The difference between Figure 5 and Figure 6 lies in that previously the failure of the A/D module affected only that device and the time synchronization problems and signal processing compensation were limited to a few inputs on that device.

On the other hand, an MU potentially influences much more than a single device and of course is reliant on a communication network. Hence aspects such as switches, propagation delays, redundancy, bandwidth and VLAN must be correctly engineered, which of course means we have to know what all these aspects are and their interrelated criteria. This is no different to specifying the CT knee point voltage, winding resistance and excitation current in consideration of the relay performance requirement is the context of system X/R transients, and the size of the relay and lead burdens.

Hence locating a Merging Unit out in the yard, whether with conventional CT/VT or NCIT, saves hundreds of wires per bay. Even if the Merging Unit is located just inside the control room, the saving in multiple CT / VT cores can still be achieved on the basis of sampling the waveform once and sharing the data stream to several devices.

4.2 NCIT technology

The first configuration is arguably the basis of the pure digital substation in the ideal world, and equally arguable is that it is not that far away from full commercial availability as NCIT technology becomes commercially available in the very near future, perhaps even later this year. There are already many systems that have been in service as long ago as 1984 using Merging Units and non conventional instrument transformers so the NCIT technology itself is well proven and has effectively only been awaiting a suitable interface platform such as IEC 61850 to be integrated with the protection functions. We can also take confidence in the extensive use of NCIT in metering applications fro independent power producers connecting to the grid – when the IPP is generating onto the grid, the current can be 10 or more times that when idling and consuming power from the grid, a similar dynamic range performance we demand for protection operation but with even higher linearity and accuracy. Recognizing that whilst we don't use equipment which puts power system security at risk, neither do we use technology that puts the utility revenue stream at risk.

The choice of NCIT over conventional sensors is about eliminating all the problems of copper wire based CT and VT. These include open circuit CT explosions, gassing, CT saturation, poor low end accuracy, saturation problems, the need for multiple cores (metering, line protection, bus protection, circuit breaker failure), CVT transient performance and frequency response which are all eliminated or at least reduced by NCIT. Moreover, the opportunity brought by NCIT for lighter and smaller body mass is to eliminate the need of a separate stanchion for the sensors which translates into the total land requirement savings for the substation – itself a substantial justification for consideration of NCIT.

Simply put, NCIT as the input to the MU is a valid and already well proven technology with benefits in many respects which could be deployed regardless of the IEC 61850 decision. However, given the use of an MU with IEC 61850 output, this does make the step to NCIT much easier simply because there is an interface requirement that may as well be an IEC 61850 output Merging Unit connected to an IEC 61850 relay.

4.3 Time Synchronisation

Network issues have been at the heart of the consideration of how to successfully deploy IEC 61850. This has led a number of important inclusions even in the Ethernet standard itself with priority tagging and VLAN enhancements in order to achieve practical deterministic network behaviour.

However if there is one thing that really sets process bus apart from station bus is the requirement to transmit Sampled Values. This is a constant data stream of the instantaneous values of the primary current and voltage waveform which is subsequently used by the relay algorithm. This certainly imposes a large network traffic and hence bandwidth requirement especially in large substations.

Key to the use of the sampled values is time synchronisation. As an example a distance algorithm will only work correctly if it is using the current and voltage measurement from the same instant in time – clearly using samples taken a several milliseconds apart is not going to give the right impedance or direction answer due to the apparent magnitude and phase angle difference.

Time synchronisation of the Sampled Values is certainly something that must be handled correctly amidst a complex and real time system. For example, a single relay may need to get the SVs from one MU supplying current from the feeder CTs and another MU supplying the voltage from the bus VTs. Another example of course is bus bar protection where the SVs must be synchronised across many MUs which may be quite far away from each other, and hence with a different number of intervening network switches to each MU introducing different delays as to when the samples at a particular instant actually arrive at the relay.

Hence the MUs must have a mechanism to uniformly time stamp each sample it provides. Given that these samples are taken at least 80 times per cycle, it is not absolutely necessary to sample the waveforms at precisely the same nanosecond. Signal processing techniques have been deployed since the late 1980's to time align samples taken slightly offset to each other provided that it can be established that they are a related pair of samples by the time stamp.

Whilst time synchronisation is a prerequisite, it is not a stumbling block to deployment of process bus even now. We can take considerable confidence from the fact that several vendors have low impedance bus bar protection schemes in service for more than 10 years using pre - IEC 61850 technology. These systems have reliably provided synchronisation to the distributed field/peripheral units and the central processing unit.

At present, time synchronisation is performed by a GPS system and IRIG-B signal distributed within the substation and is already common use even for protection purposes. The ideal solution is of course to use the LAN itself to distribute time synchronisation data. The solution is the new standard IEEE 1588 which will enable even higher levels of time accuracy in the network which will further enable the applications needing even faster sampling rates than protection such as power quality and synchro-phasor measurements.

However even in advance of IEEE 1588, the IEC 61850 9-2 LE specification was released to provide a means to deploy process bus in advance of IEEE 1588. The LE edition hence allows for the time synchronisation to be achieved using a 1 pulse per second (1pps) signal, with the only downside that it requires a separate connection to the MU. IEEE1588 would eliminate this separate time synchronising network as it uses the same LAN connection as the SVs. However, process bus solutions can already be deployed using 1pps.

A different solution is perfectly feasible where a 1-to-1 relationship is established between the relay and the MU as a proprietary match effectively as a physical separation of what used to be the analogue input module of the relay into a separate box. This eliminates the synchronisation issues of multiple MUs if each MU needs only supply SVs to one relay and hence is clearly a useful solution for such single device (non switched) network architectures. At worst, in fifteen or twenty years when the secondary system is up for its next refurbishment, this would mean a re-assessment of the choice of the same proprietary match. However, even though the MU needs replacing at the same time as the relay, this is likely to be the case with any MU electronics life expectancy, and technology options will no doubt be more common place.

4.4 Traditional Protection Engineering Principles

The issue of industry confidence in the process bus also requires application and challenging of our traditional protection engineering requirements and desire for proven performance.

For example, whilst we happily use a multi-core conventional CT from any vendor with any vendors relay, interoperability of a MU from vendor 'A' with a relay from vendor 'B' must be absolute in as much as we know what are the mutual requirements of a CT knee point voltage and the ability of the relay in regards to saturation and X/R ratios before we are happy to put the system into service. The process bus requires understanding the performance of the Ethernet switches in how data and time synchronisation is distributed. It simply boils down to making sure we have adequately specified and understood the correct performance requirements of each component.

At another dimension, the aspect at higher voltages of duplicate but different vendors devices to eliminate common mode failures between devices is topical, in some cases a requirement of the national rules. If extended to the MU, does this imply we need two different MU vendors as the MU is another box of electronics?

Another reliability related question is whether two different non conventional sensors (e.g. one optical and one Rogowski coil) are needed? This then also challenges the choice of physical mounting of the two different sensors from two different vendors, as distinct from a multi-core CT on one CT post.

Equally the physical installation of the MUs needs careful thought. Some vendors have MU boxes that can be bolted to the base of the CT post, whilst others have units that would need a suitable enclosure.

What is clear is that the industry needs to give vendors more direction about the physical nature of the MU and must come to an understanding in our specifications of how we prove performance and the factors that dictate our confidence in reliable operation of the protection scheme.

5 Conclusion

The benefits, and arguably the imperative for moving to adopt process bus in some form encompassing IEC 61850 based Merging Units are significant. So perhaps to those that so quickly say " *… but not process bus*", we must as a starting point ask for clarification of what they mean by "process bus" – is it the substation LAN in the yard in general or specifically CB trip/close, Sampled Values and NCIT?

Following that, the engineering discussion can be based on the degree of confidence (or risk mitigation) in the basis of the technology.

CB trip/close and status information requires careful network design for security and reliability of processing time but brings significant engineering and testing benefits.

Merging units providing Sampled Value outputs will lead to significant savings in substation design, construction, test, operation and maintenance.

NCIT is a a further benefit that can be brought to substation design, reducing the number of sensor cores, increasing accuracy and dynamic range at the same time as eliminating the problems and consequences of conventional CT/VT.

In all of this time synchronisation even today is not preventing successful scheme operation. Equivalent protection functions have been using time synchronisation techniques for well over 20 years. Certainly IEEE 1588 is the ideal solution, but current techniques are valid.

Finally, the consideration of "*process bus – to do or not to do?*" should not forget our tried and proven principles of protection engineering, although some of these may need new evaluation in light of new technology solutions.

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7 Biography

Rodney Hughes has more than twenty five years in the international power industry with a wide range of expertise in the strategic direction of substation, power system and telecommunication design. He graduated from Sydney University in 1980 and joined AREVA (then GEC) Protection & Control as a Protection Applications Engineer. In 1985 he was appointed as General Manager for the Protection & Control business in Australia through to 1998 during which time he was responsible for introducing several generations of AREVA's technology to the market changing from electromechanical to static to digital to numeric and communicating systems. Rod moved to France as AREVA's (then ALSTOM) HV Protection Product Director in charge of the R&D, marketing and production for distance and bus bar protection for the world market. In 2001 he moved back to Australia as the Protection & Telecommunications Manager for ElectraNet, the 275kV and 132kV transmission utility in South Australia and was subsequently appointed as the Plant Strategy & Technology Manager in 2003. He is now the Technical Director for Maunsell AECOM Power & Energy with responsibilities for developing IEC 61850 based expertise and applications. He has served on CIGRE Australia's Panel B5 since 1985 and was appointed as Convener in 2003. He has contributed as editor to the publication of Technical Brochure 326 on IEC 61850 implementation.

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