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Basics

Approach to optimized Process Bus architectures

...careful design promises benefi ts for the future

The process bus according to IEC 61850 may replace a lot of conventional wires; connections with high importance, long tradition and special requirements. Is there an optimal solution?

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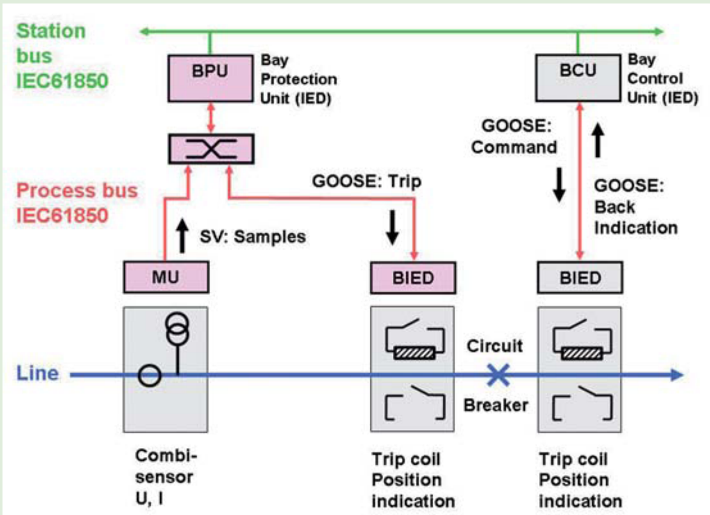

Figure 1 – Basic process bus architectures for protection and control (MU: Merging Unit, BIED: Breaker IED)

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The fast acceptance of the standard IEC 61850 [1] of the IEC TC57 resulted in a swift adaptation of existing IEDs or development of new ones by the suppliers. Owing to the strong demand of customers all over the world, hundreds of IEC 61850 based substation automation systems are already in operation today. In these systems, the communication between the station computer(s) with HMI and/or the NCC gateway(s) takes place according to the standardized data model and the services implemented on the basis of Ethernet. The standard also defines the communication of Sampled Values (SV) [2] for current and voltage as needed e. g. between non-conventional instrument transformers (NCIT) and IEDs for protection and other functions. This alone is often referred to as process bus, although from the user's point of view also trips, commands and position indications have to be exchanged between the switchgear and the bay level IEDs via this bus. To facilitate the interoperability of samples and overcome the sample synchronization issue, a recommendation regarding sampling rates and sample data-object combinations in the message has been issued by the UCA International Users Group [3]. The few process bus applications existing up to now all have some prototype character since the missing test procedures for the reliable dynamic behavior of the sampled values have still to be defined by the IEC TC38 and will supplement the coding rules of IEC 61850. Especially the step-response and the frequency-response curve are to be defined to ensure the required interoperability. Nevertheless, optimized communication architectures can and shall be discussed now in order to be prepared in time for all future application cases.

Instrument Transformers and Merging Unit

NCITs have been successfully field-tested for more than a decade, but were so far missing acceptance since they provided sensor-specific signals instead of the standardized 1/5 A and 110/220 V for current and voltage, respectively. IEC 61850 is already providing the common denominator for all NCITs. It should be noted that NCITs may either be physically separate or combined for current and voltage. They may be applied in a single or redundant configuration. Today, we see an increasing requirement for the process bus on the market, not only for non-conventional instrument transformers (NCIT), but also for conventional ones (CIT). Arguments for the conversion of the signals also from CITs are e. g. the replacement of parallel copper cabling by fiber-optical serial links resulting in simpler cabling and avoiding the highly-priced copper as well as the provision of clear galvanic decoupling of bay level IEDs from the primary process. The conversion of the proprietary signals of the NCITs, the A/D (Analog/Digital) conversion of the CIT's signals and the creation of messages with merged samples is done by the so-called merging unit (MU). It is not defined, whether the MU shall have point-to-point type connections to any IED or broadcast the stream of samples over a LAN, wherefore this is a matter of system implementation. If switches are needed, they may be discrete or embedded ones. This difference influences the system availability, but not the performance.

Basics of Process Bus Architectures

The services on the process bus are dominated by the SV (Sampled Value) service for current and voltage, and by the GOOSE service for trips, position information of switchgear as well as commands. These two publisher-subscriber services have been introduced for time-critical communication and support applications like protection and control. For commands, alternatively the client-server control service may be applied if the appropriate infrastructure is available. The basic data flow chains for the IEDs and the related serial links are shown in Figure 1. The switch may be replaced by two ports in the bay protection IED (bay protection unit, BPU). Especially for galvanic decoupling and zero interference, the serial links are all optical fibers.

Requirements for Time-synchronization

All analog data used for calculation (impedance) or comparison (differential) by protection functions must be time-coherent. This generates a requirement to synchronize the different sources (IEDs) of related data to each other with an accuracy of up to ± 1 µs (accuracy class T5 in [4]) . The time-synchronization method used today between different IEDs is PPS (1 pulse per second). The future alternative will be IEEE 1588, an add-on standard to Ethernet.

Only data values with the above-mentioned relationship have to be highly synchronized. If all channels to be combined or compared in the application are collected by the same MU as is normally the case with the currents and voltages of all phases in one bay, then no external synchronization is needed, because the MU guarantees their synchronization. If the signals are coming from different MUs, then these have to be synchronized. This also raises the question as to how many MUs are needed for a certain function, but this is a matter of availability in case of losses, accepted or unwanted dependence, and of geographical distance.

Therefore, one principle to be followed when designing an optimized architecture is to minimize the number of MUs needing to be highly synchronized, i.e. to design so-called synchronization islands.

The combination of MUs and BIEDs (Breaker IED) into EMU (Extended MU) e. g. in one bay is possible, but may be limited by the switchyard topology (large distances at least in AIS substations), and by availability and independency requirements as mentioned above. In addition, the possible integration of BIEDs into the circuit breakers and isolators may be an alternative in future.

Figure 3 – NCIT (Rogowski coil for current, capacitive divider for voltage) of ABB for GIS with two independent sets of U-I sensors and sensor electronics

Redundancy and Independency Requirements

Single points of failure and redundancy:

If there is a single functional chain, e. g. from the MU via the protection IED to the Breaker IED, any failure in the chain will result in the loss of functionality. Regarding the process bus according to IEC 61850, we have to consider that for all protection-related chains there are instrument transformers at one end of the chain and the circuit breaker at the other. Also the power supply of the IED has to be taken into consideration. If such a dependence is not acceptable, redundancy for weak points or a complete redundancy has to be built up.

Communication Redundancy:

As shown in Figure 2, bay units for protection and control with two station bus ports may be connected to two separate communication systems. This achieves communication redundancy without touching the application. Communication redundancy is not yet standardized

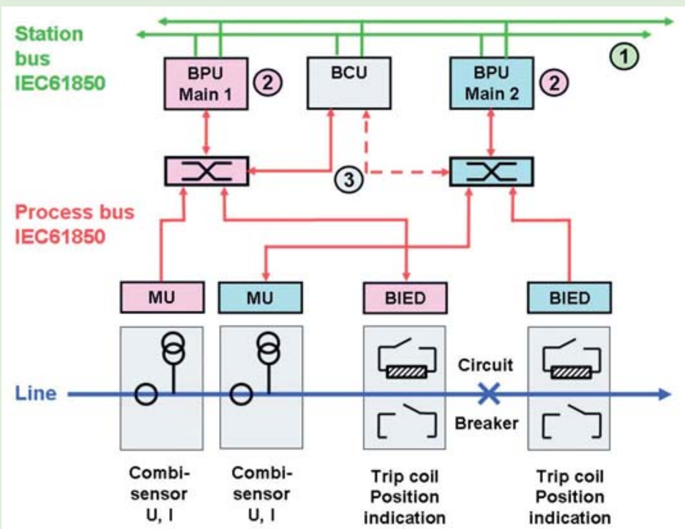

Figure 2 – Process bus architecture with control as well as Main 1 and Main 2 protection where (1) means communication redundancy, (2) application redundancy and (3) the potential source redundancy

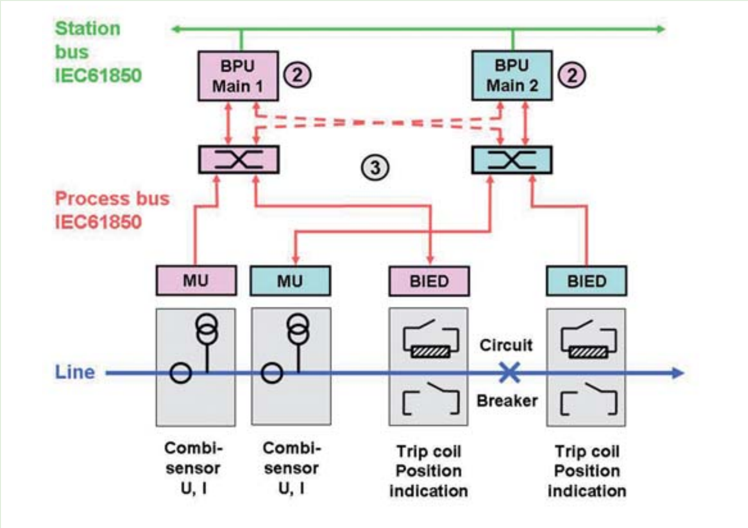

Figure 4 – Source redundancy regarding MU and BIED with application near switches (2) application redundancy (3) source redundancy

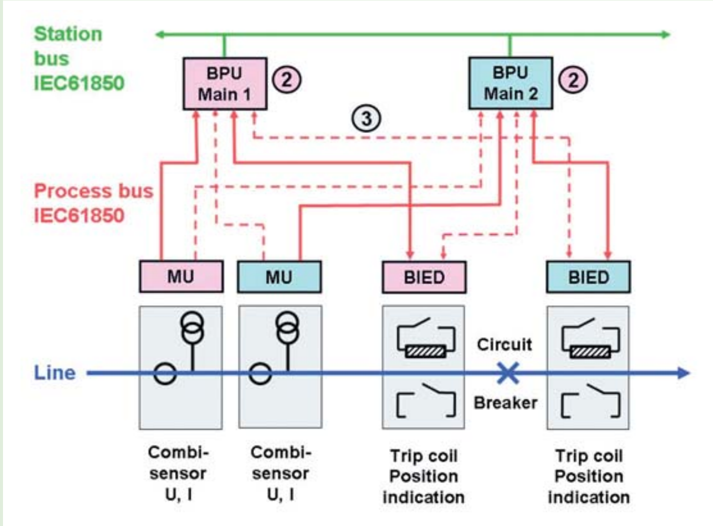

Figure 5 – Source redundancy regarding MU and BIED without switches (2) application redundancy (3) source redundancy

in IEC 61850 as needed for interoperability, but the related work is in progress in IEC TC57.

Application Redundancy:

Traditionally, the instrument transformers have more than one core to feed various functions in an optimized and independent way. With the very broadband and fast responding NCITs, the argument for optimized "cores" dedicated to different functions becomes obsolete, but not the one for independency. A special case is the pair of Main 1 and Main 2 protection units on transmission level. It implies not only hardware and functional redundancy, but also protection devices to come from different suppliers in order to avoid systematic errors and to increase the fault coverage of the protection system. An alternative is the use of two protection functions with different principles e. g. line differential and line distance protection. Traditionally, circuit breakers are not duplicated, but they have different "trip coils" for different protection and control functions.

To avoid any dependency, dedicated and completely indedendent chains for both Main 1 and Main 2 protections determine the process bus architecture (Figure 2). As mentioned above, this starts with the instrument transformer and in Figure 3, a fully redundant U-I sensor with independent power supply and communication links for each part is shown. Main 1 and Main 2 protections have to be provided by two separate IEDs. Furthermore, critical maintenance procedures or fire hazards may be in favor of two separate cubicles, i.e. one for each protection. In the same way as the redundant or dedicated instrument transformer cores are replaced by two independent sensor electronics and MUs, the two trip coils are substituted by two breaker IEDs (BIED). The redundancy introduced by Main 1 and Main 2 is an application redundancy that is also realized with redundant IEDs.

Source redundancy:

The bay control unit (BCU) is normally a single IED and has no application redundancy (Figure 2). This asymmetry between control (one BCU) and protection (two BPUs) may be resolved by either source redundancy (for position indications), with two communication ports in control devices (Figure 2) or by application redundancy i.e. having a backup control function integrated in each of the two protection devices. Source redundancy implies also the sink redundancy for commands to the BIEDs. It has been shown in [6] that the application redundancy for protection and control results in an optimized solution with the absolute minimum of two IEDs per bay in transmission substations, linked to redundant station bus architectures i.e. to two parallel station busses (communication redundancy).

To utilize the benefits of both sensor electronics and merging units, but also to overcome the loss of any of these sources, it was proposed to use source redundancy for protection as well. Simply interconnecting the two switches in Figure 2 is of no help. Apart from introducing an additional communication delay, this would also introduce a common error mode for both systems. Therefore, the BPUs need to have two inputs for the two redundant sources. This means that the switch related to Main 1 has additionally to be connected with Main 2 and vice versa (Figure 4). Note that with BPUs having two ports, the MU and BIED may be directly connected without the use of a switch. Having no EMUs means for the source redundancy without switches four process bus ports for each BPU (see Figure 5), but using EMUs only two are needed.

Source redundancy has to avoid common mode failures in the jointly used sources, i.e. in the MUs and BIEDs. In case CITs are used, one instrument transformer may feed two merging units. This shifts the potential risk or a common mode failure to the instrument transformer itself. When NCITs are employed, two separate sensor electronics each feeding one MU are feasible and in use, e. g. as visible in Figure 3.

The source redundancy does not necessitate any new definition in the standard since the incoming data and the used services are already available. Whether the application is able to handle this redundancy either in a hot-hot or a hot-standby mode is a local issue and, therefore, does not have to be standardized.

The solution for optimizing the process bus architecture in general for all substations depends on the dedicated single line diagrams used and the many individual placements of instrument transformers in substations worldwide. It also depends on whether single instrument transformers or combined current and voltage sensors are used. In the following, some application examples for non-conventional combined current and voltage instrument transformers i.e. sensors are given. The examples are all based on the base MU which provides the samples for current and voltage over the process bus as serial link according to IEC 61850-9-2 [2] respectively IEC 61850-9-2LE [3].

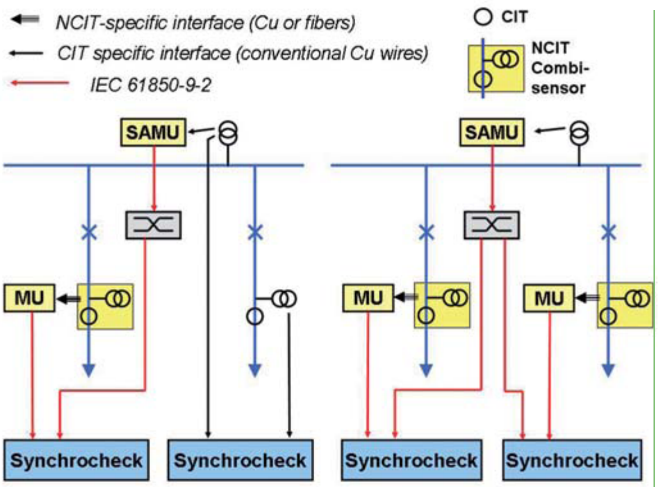

Figure 7 - Migration with the help of a SAMU

Synchronization and the Number of MUs

As mentioned above, the single line diagram, the architecture of the functions and the allocation of instrument transformers to the single line diagram have to be considered for the optimized process bus architecture. A common question is whether there is a busbar voltage transformer. This is studied for a 1½ breaker arrangement, where two lines are connected by a diameter with three breakers to a busbar on each of the diameter ends. It is possible to only use three combi-sensors, but with the use of six of these, no busbar voltages have to be collected via switches. As shown in [7], two synchronization islands are optimal, since they represent the minimum but fulfil all synchronization needs per line (Figure 6). The two islands are possibly implemented each with one IED, i.e. one per line. Here, no external synchronization is needed.

Retrofit and Migration

In industrialized countries, almost no new substations are being built, but there is a great need for retrofitting old ones. The retrofit usually has to be done whilst the substation is in service and interruptions of the power flow have to be kept to a minimum. Introducing the process bus always involves the replacement of the protection, which is done step-by-step in this case. According to the progress of the refurbishing work, new process-bus-based instrument transformers (for example NCIT both for current and voltage) will be used in parallel to existing conventional ones [8] . In this transition phase, problems have to be solved with functions needing currents or voltages both from refurbished and non-refurbished bays, i.e. partially provided as samples according to IEC 61850 over the process bus and partially as conventional hardwired ones. Examples for such functions are the compensation of parallel lines, the synchrocheck function and the transformer differential protection. Here, the architecture is reaching its final optimized state step-by-step by temporarily using a stand-alone merging unit (SAMU) to convert the signals from CITs to IEC 61850 SV messages (Figure 7).

Busbar voltage

The busbar voltage is an element to be considered when optimizing process bus architectures, since it is sometimes directly measured at the busbar, but often only substituted by the voltage of one of the connected bays according to the actual busbar image. With IEC 61850, this voltage may be distributed properly over the process bus as explained in [9] .

Conclusion

There is not just one optimal process bus architecture. The optimum design depends on a lot of external factors like geography, philosophy of instrument transformer distribution, retrofit versus new substation, and finally available interfaces at and redundancy strategies for the used IEDs. These factors also lead to different procedures for optimizing the process bus architecture. Therefore, only careful design of the architecture, considering also the different kinds of redundancy in the right way, will allow the user to exploit all the benefits of the process bus according to IEC 61850 in the future.

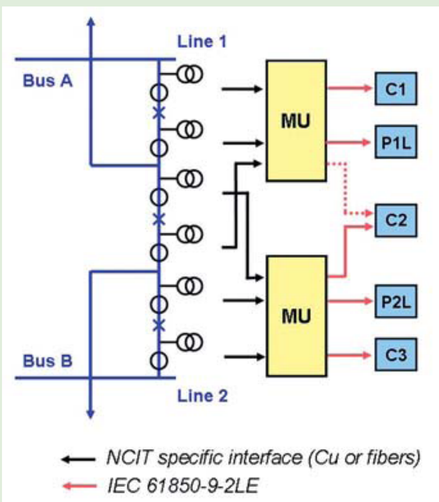

Figure 6 – Optimized process bus architecture for a 1 ½ breaker arrangement with combi-sensors i.e. all NCITs

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