Paper accepted for presentation at 2009 IEEE Bucharest Power Tech Conference, June 28th - July 2nd, Bucharest, Romania

Reducing Conventional Copper Signaling in High Voltage Substations with IEC 61850 Process Bus System

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***Abstract*-- This paper describes a practical IEC 61850 process bus architecture suitable for high voltage substations. The presented system eliminates the need for thousands of copper wires in a substation and replaces them with a few fiber optics cables, and can save utilities spending related to current installation and maintenance costs while at the same time increasing worker safety and power system reliability. The paper contains application example as well as description of experience from the real installation of the process bus system at 345kV substation.**

***Index Terms*— High voltage substations, Power system protection, Instrument transformers, Signal sampling, Time synchronization, Fiber optic cables, Communication protocols, Standardization**

I. INTRODUCTION

The IEC 61850-9-2 standard [1] focuses on transparency and standardization of data communications. Implementation issues such as suitable architectures, reliability, time synchronization, data sharing, maintainability, testability, and scalability remain outside the scope of the standard.

Robust and practical process bus architecture is a missing element on the road to implementing the next generation of Protection and Control (P&C) systems. In this paper, the architecture refers to the definition and structure of the process interface points, partitioning and allocation of functions to the devices, the underlying structure of time synchronization, settings and firmware management, failure-tolerant communication framework, required data throughputs and latency considerations, data traffic patterns, and other related aspects.

Careful analysis of the rules and symmetries occurring in topologies of high voltage substations allow for identification of process bus data traffic patterns, origins, destinations, and throughput required to accomplish a simple, robust, scalable and flexible IEC 61850 process bus architecture. The primary equipment itself drives a logical and natural architecture for a communication-based protection and control scheme.

This paper presents a practical process bus architecture conforming to IEC 61850-9-2 that fits the task of protection and control of substations by drawing from the universal topology rules of substations.

II. TECHNICAL ATTRIBUTES OF AN EFFICIENT PROCESS BUS ARCHITECTURE

Successful technical solutions are those that are simple and that address well-defined real problems. Therefore, development of a process bus protection and control system should be approached from the utility enterprise perspective that recognizes and addresses present needs of today's utilities – cost reduction and speed of deployment remaining at the same time reliable and secure. The proposed process bus system originates from the following enterprise objectives:

- Achieving cost savings
- Reducing project duration and outage windows
- Shifting cost from labour to pre-fabricated material
- Targeting copper wiring as main area for cost optimization
- Limiting skill set requirements
- Supporting optimum work execution
- Improving system performance and safety
- Using open standard communications

With cost, labour and time requirements predominantly associated with copper wiring, the next generation P&C system should replace copper wiring by placing electronic modules throughout the switchyard and using fiber communications for bi-directional exchange of data. On the surface this is yet another remote I/O strategy, known for decades in the factory automation field. When applied to protection and control, however, the remote I/O approach faces a level of difficulty far beyond what has been worked out and proven in the realm of factory floor automation.

A. Comprehensible and complete architecture

Each component of the system, including field (merging) units, Intelligent Electronic Devices (IEDs), communication infrastructure, signal datasets at protocol level, time synchronization method, etc. should be designed after a complete architecture is created demonstrating the ultimate shape of the system. The architecture needs to be simple and intuitive for all affected disciplines in the user's organization. It needs to follow today's proven protection fundamentals and

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978-1-4244-2235-7/09/$25.00

be fit for purpose – addressing the right problem with the right solution. The primary goal is to deliver switchyard data to the P&C devices and to send commands from the IEDs to the switchyard devices. Not all the process data is needed by all IEDs. The limited data requirements of each IED are clearly and unambiguously dictated by the virtually fixed power primary equipment arrangement. The process bus network need not be designed to accommodate arbitrary or evolving IED data requirements.

B. Reliability

When increasing the number of electronic devices and connections in a system, the system's reliability decreases with the increasing device count. This can be easily demonstrated by using typical Mean Time To Failure (MTTF) data and running calculations on hypothetical process bus architectures [2,3]. Each additional element in the system will increase the failure frequency. In a properly designed architecture compensating measures, which often increase system complexity and cost, should not be required to make up for artificially reduced reliability.

C. Minimal co-dependencies

According to today's power system protection rules a single zone of protection can be engineered and deployed with minimal interactions with respect to other secondary systems. This separation has proved an indispensable foundation of practical protection engineering, and needs to be retained in the next generation solutions. Without proper consideration, a firmware upgrade for a single digital component of the system may result in unexpected system behaviour and ultimately may trigger a firmware upgrade to adjacent devices. Such domino effects created by co-dependencies are undesirable, may introduce latent failure modes and ultimately would become obstacles in acceptance of the system.

D. Scalability

A successful system needs to be scalable. It is expected that initially deployed system continue its expansion one zone at a time as required. An expansion or modification should not raise any network congestion concerns, or other problems. The system must be both feasible and economically attractive in both retrofit and green-field installations.

E. Testability and maintainability

The system needs to be provisioned to facilitate testing and maintenance. Testing is defined here as verification and re-verification of a complete protection and control system after it has been deployed – initial commissioning, repair, periodically or after a major work such as protection system expansion, firmware upgrade or component replacement. Maintainability is defined as the existence of simple, safe and trusted means of performing firmware and setting changes and replacing faulty elements of the system.

F. Cyber security

The system needs to be secure from the cyber security point of view. The high data rates of the process bus traffic and the requirement of very high availability of this data create challenges for known cyber security solutions such as intrusion detection or encryption. Cyber security issues, if left unattended, may either slow down adoption of the solution by creating the need to augment it later for compliance, and/or may create extra cost and effort for the user when deploying and running the system. The optimum solution is to develop an architecture, which by its nature eliminates cyber security threats.

III. OBSERVATIONS ON SUBSTATION TOPOLOGIES

Power substations are structured following strict rules. The primary structure of any substation is divided into zones of protection. In order to minimize the size of an outage upon a protection trip, these zones typically span a single network element. Any protection zone is bounded by Current Transformers (CTs) that allow location of a fault, and Circuit Breakers (CBs) that allow isolation of the fault. These measuring and isolation boundaries are close to each other for better selectivity, and overlap in a certain way (the measuring zone is generally slightly larger than the isolating zone).

Traditionally, a single multi-function relay is used to provide protection for any given zone. Such a device needs access to all CTs surrounding the zone for a given principle of protection, and needs to control all CBs around such zone. Any given relay therefore, has well-defined data origins – there is no need to make all possible signals available to all possible relays. By the same logic, any given relay has well-defined signal destinations. These destinations (CBs) are generally coincident with the origins (CTs) as the measuring and isolation boundaries of protection zones are physically close to each other.

From the perspective of a relay there is a need for a bi-directional data exchange with points that bound its zone of protection. This creates a consistent one-to-many data traffic pattern. With the exception of a bus relay that may have a considerable number of CT/CB points surrounding its zone, all other known types of protection require access to just few points – typically all local three-phase conductors to the protected network element (CT/CB combination), and voltage from within the zone as needed.

Zones of protection are normally engineered to overlap in order to eliminate blind spots. Ideally this overlap should occur at the breakers, or at least within close proximity of the breakers. Engineering a precise fault measurement scheme without a corresponding means for fault isolation does not make economic sense (with a few exceptions such as transformer leads), therefore the situation depicted in Fig. 1 is typical. In this arrangement zone 1 protection measures CT-1 (among others) and trips the breaker, while zone 2 protection measures CT-2 and trips the same breaker. Breaker Failure (BF) protection may be integrated with either or both of the protection relays, or implemented as a stand-alone device. In any case, the BF device will measure the same currents as the two protection zones.

A field (merging) unit is defined as a device interfacing with both CTs and the CB at the intersection of the two zones of protection in Fig. 1. From that point of view such a unit needs to communicate with only 2 or 3 relays: the zone 1 and 2 relays, and potentially a stand-alone BF relay. This creates a universal one-to-many pattern for the bi-directional data traffic between the merging unit and its relays.

Detailed analysis of typical substation arrangements proves that the ability to feed four relays from a single merging unit covers all typical applications. For the few exceptions where more relays need to be fed from the same point, a second merging unit can be added and wired to the same signals.

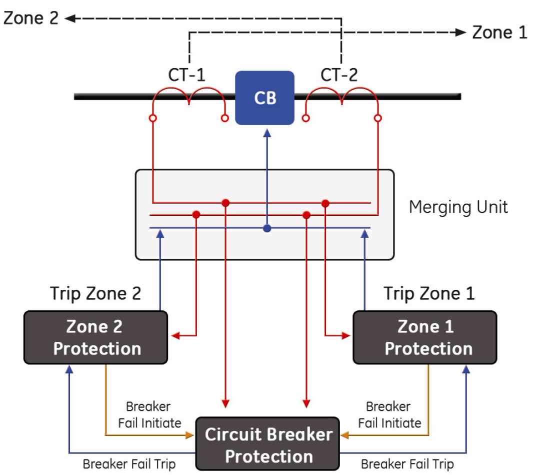


Fig. 1. One-to-many data traffic patterns.

Zones of protection span and overlap breakers and network elements throughout the entire substation. This means that if a single merging unit is used for a given point of interest in the switchyard, the following domino effect takes place: IED-1 may need data from merging unit MU-1; MU-1 may feed IED-2; which in turn will connect to MU-2 to perform its function; etc. This means that the one-to-many data patterns of IEDs intersect with the one-to-many data patterns of merging units, seemingly putting all IEDs and merging units in the same communication network, and leading to a LAN spanning the entire substation. This would introduce maintenance and reliability problems, but can be avoided by observing that only four logical connections from a merging unit are required, which can easily be provided on a dedicated point-to-point basis.

Consider further a Breaker Failure application. With reference to Fig. 1, when initiated from zone 1, the BF function should use CT-1 or CT-2 for the measurement, and upon breaker failure, it should issue a trip to all breakers surrounding zone 2, initiating their BF functions at the same time. Symmetrically, when initiated from zone 2, the BF function trips and initiates BF for all breakers of zone 1. This is a universal rule that holds true for all standard substation topologies.

Note that from this perspective, a merging unit that monitors CT-1 and CT-2 while controlling the breaker in between, is a suitable data exchange point (a "mailbox") for all involved IEDs. In order to function and issue a zone 1 trip, IED-1 needs to communicate with this merging unit, so it can also send a Breaker Fail Initiate (BFI) signal to the merging unit. In order to measure breaker current / position to perform its BF function, BF IED needs to communicate with the said merging unit, thus it can also receive a BFI from this merging unit. By the same logic, the BF IED can send the BF trip command to the said merging unit. This signal can be then forwarded by the merging unit to IED-2 and there executed as a trip and BFI for all breakers of zone 2.

The above observation shows how one could take advantage of the constraints imposed by switchyard topology to avoid challenges associated with passing BFI signals over station bus (isolation, testing, determinism) by building a fit for purpose architecture.

IV. PROPOSED ARCHITECTURE FOR A DISTRIBUTED IEC 61850 P&C SYSTEM

The proposed system includes merging units mounted at the primary apparatus, protection relays, pre-terminated outdoor cables, and fiber cross connect panels for making the physicals interconnections between merging units and relays.

To achieve the complete process bus solution the merging units shall be designed to interface with all signals typically used for substation automation and protection as close to their respective origins as practical, including AC currents and voltages from instrument transformers, breaker status and alarms, breaker control, disconnect switch status and control, temperature and pressure readings, etc.

The merging units designed for this purpose have been called Bricks to emphasize their ruggedness and their functions as building blocks of the process bus system. The Bricks are designed for harsh environments including temperature extremes, shock and vibration, electromagnetic compatibility, sun load effect, pressure washing and exposure to salt and other harsh chemicals. This enables the possibility of mounting them outdoor in direct proximity to switchyard equipment.

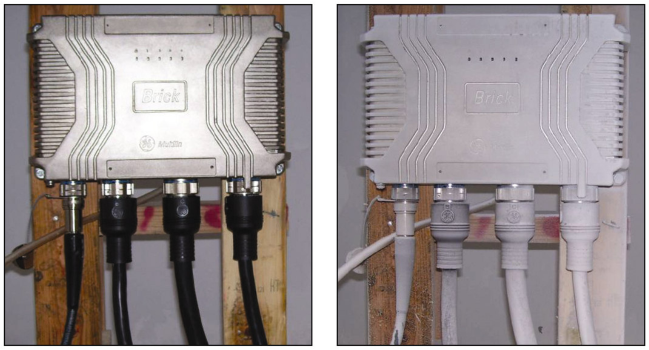


Fig. 2. "Brick" – ruggedized outdoor merging unit tested for dust: pre-dust inspection (left) and post-dust inspection (right)

Bricks collect CT/VT analogue signals as well as status signals from circuit breakers, disconnectors, earthing switches and transducers like pressure or temperature sensors, etc. The merging units apart from collecting from primary apparatus all status analogue and binary signals, transforming it to digital format and sending to protection and control devices also receive command signals through fiber optic communication link from the IEDs and perform the switching operations link opening or closing circuit breakers or disconnectors.

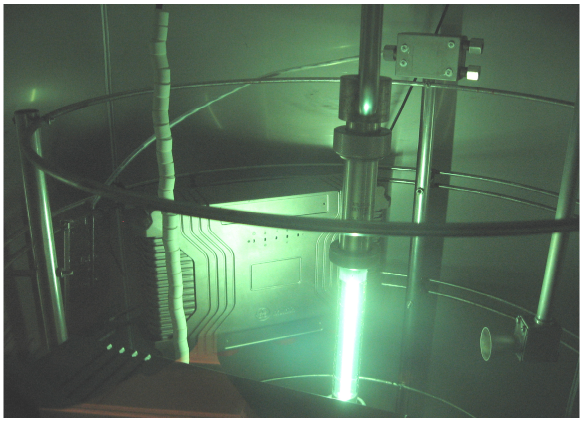


Fig. 3. Merging Unit under solar loading tests at the solar laboratory

The communication architecture depicted on Fig 4. is based on point-to-point topology. There are dedicated communication fiber optic links between each merging unit and protection and control IEDs. In order to achieve desired functionality each merging unit and each IED can support multiple point-to-point links. In the particular implementation of this architecture realized as commercially available system called HardFiber each merging unit supports four independent communication channels and each IED supports a maximum of eight communication channels.

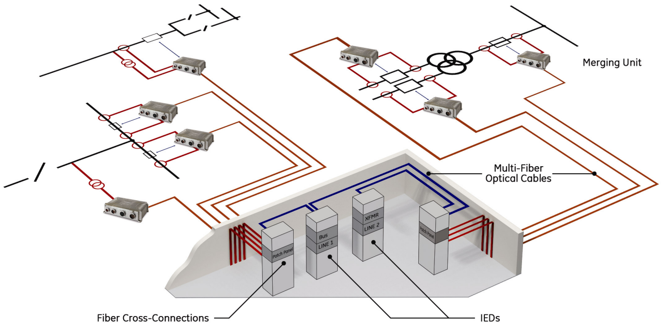


Fig. 4. Fit-For-Purpose Process Bus Architecture for Protection and Control

Having four independent communication ports at the merging unit means that here are four logical merging unit within on physical device. In fact in the presented system the merging unit contains four independent digital cores each composed of a microcontroller with individual bi-directional (bi-di) fiber links providing dedicated point-to-point communications with a single relay. Due to this design the devices highly increases its reliability as there are four independent CPUs running independent instances of firmware code serving communication point-to-point data streams instead of having one central processing unit running the same piece of firmware/software to handle multiple communication channels. Apart from the four digital cores for communications there is also one shared common input/output microcontroller within the merging unit, implementing a fail-safe design strategy that ensures total isolation and independence of the digital cores.

Each Protection and Control IED receives the signals to perform its function over a secure and dedicated network consisting of direct hard-fibered links to each of the associated IEC 61850 merging units. Due to the completely deterministic data traffic on these dedicated links, a simple and robust method is used for synchronization whereby each relay controls the sample timing of the connected merging unit cores over the link without relying on an external clock for process bus data synchronization.

The data communication from the merging units to the P&C IEDs is realized through IEC 61850-9-2 Sampled Values using as physical media pre-terminated fiber cable connected to a cross-connect patch panel that directs the appropriate signals to each relay. The communication carrying control commands from the relays to the merging units is realized via the same pre-terminated cable using IEC 61850-8-1 GOOSE messages.

Enhanced security and availability of protection is optionally supported via duplicated merging units. No protection or control algorithms are implemented within the merging units; instead their sole function is to be a high-speed robust IEC 61850 interface to the switchyard.

All cables are connectorized and pre-terminated for ease of deployment and replacement, using standard military/avionic grade components. The outdoor fiber cables contain a pair of DC supply wires to provide control power to the merging units including the internal wetting voltage for field contact sensing (e.g. auxiliary switches, gas alarms, etc.) within the switchgear associated with each merging unit, independent from the control power in the field.

Cross-connect panels are used to land and organize the outdoor cables, and to distribute and individually fuse the DC power to the merging units. Standard patch cords are used to accomplish “hard-fibering”, making all the necessary IEC 61850 connections between the relays and the merging units as dictated by the station configuration on a one-to-one basis, without the use of switched network communications.

V. APPLICATION EXAMPLE

In reference [2] a benchmark substation topology has been proposed for the purpose of illustrating applications for process bus architectures.

This station is a 10-breaker, arbitrary combination of a ring bus and breaker-and-a-half arrangements with two transformer banks that will be used to illustrate the proposed solution. Only one system is shown (main 1 or main 2), the merging units are deployed non-redundantly, and auto-reclose control is integrated within the line relays. Breaker Failure protection may be done in a number of ways in this architecture, and is not addressed in this example for simplicity.

Fig. 5 presents the station topology, more details on IEDs list and all their associations can be found in [2].

Note that the count of IEDs is identical to a traditional solution. The second transformer bank is protected via bushing CTs, and two extra relays are used to provide differential protection for the HV and LV leads. Alternatively a single two-zone differential relay can be used to protect the HV and LV leads, reducing the number of IEDs to 10.

The IEDs do not carry the overhead of physical I/O. Instead the I/O interface is provided via a total of 16 merging units, marked B1 through B16. These units make available a total of 128 single-phase AC inputs. Almost 80% of them are utilized in this benchmark case. A total of more than 250 digital inputs are available on the 16 merging units allowing to interface breaker and disconnect positions and alarms. On average each merging unit feeds 2.625 IEDs. Two 16-position patch panels are required, 16 outdoor fiber cables, 14 indoor fiber cables, and 42 patch cords are needed to cross-connect IEDs and merging units.

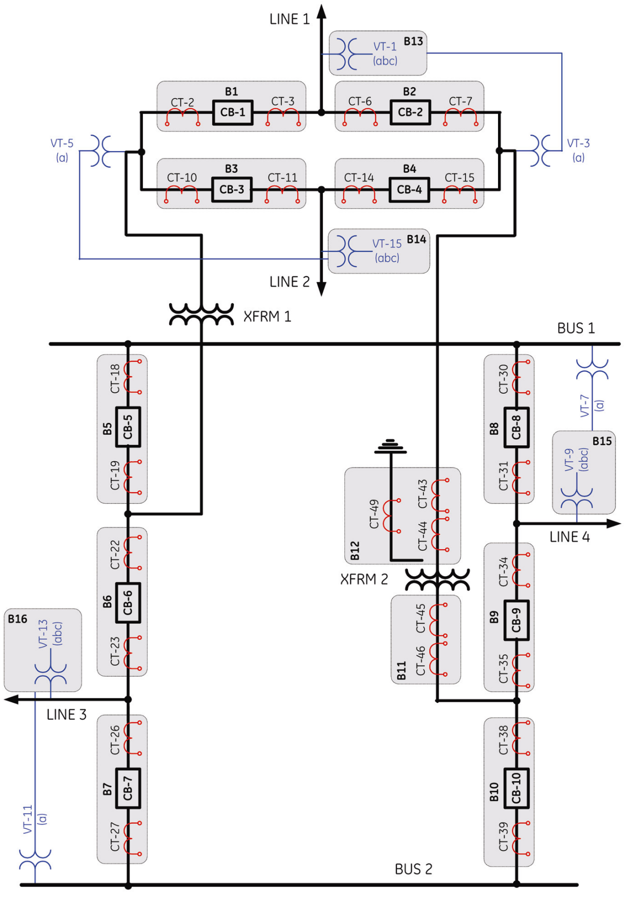


Fig. 5. Practical application example for Process Bus

VI. KEY TECHNICAL CHALLENGES

The two top technical challenges for the next generation P&C architecture are data sharing and sampling synchronization for AC inputs. A number of other technical issues such as firmware management simplify themselves once these two fundamental problems are solved. Note that neither of the two challenges is encountered in today's hard-wired protection applications: analogue signals are delivered via wires to each individual relay.

The proposed approach each merging unit contains a common I/O structure and four digital cores. The I/O structure is controlled independently of the relays and digital cores by low-level hardware. The concept of a common I/O structure allows for a single compact field device and its associated wiring. That I/O structure is isolated from the digital cores using appropriately deployed hardware buffering. In this way it is impossible under reasonable failure conditions for the digital cores to interfere with the common I/O hardware or one another.

The cores are totally isolated on the hardware level and are comprised of independent microcontrollers running independent firmware instances, and communicating with IEDs via independent fiber transceivers. The interface to the common I/O structure and the power supply circuitry is engineered to ensure total independence of the digital cores. Each digital core is associated with a specific IED, and each core runs as if it were the only core in the merging unit.

The independent cores combined with the concept of point-to-point connectivity allow solving the two key technical challenges.

Each relay operates in its own "time zone", developing its own explicit sample and hold signal (S&H) internally to match the needs of its specific application algorithms. This S&H signal is sent using IEC 61850 GOOSE messages to all merging units connected to the relay (up to 8 in the proposed architecture). Owing to the point-to-point connectivity, any foreign data traffic is prevented, and the GOOSE messages are delivered to the merging units in a short and very consistent time. In this implementation the S&H jitter is kept below 1 microsecond, with no need to run phase locked loops to average out random jitter. The payload of the GOOSE messages is a dataset controlling the local sampling and the outputs of the merging units (trip, close, interlock).

The common I/O structure of the merging unit collects AC samples based on its own free-running S&H clock at a relatively high rate. Individual copies of such physical samples are presented via independent digital links inside the merging units to each of the four digital cores. These cores, upon receiving their virtual S&H signals in the form of GOOSE messages, re-sample their own stream of physical samples to obtain and return virtual samples in precise synch with the requesting IEDs. In this way each merging unit supports 5 time references: one local and one for each of the 4 relays, all running asynchronous to each other.

Each relay receives its samples synchronized with its own S&H clock. The high physical sampling rate allows high accuracy of re-sampling required for metering and sensitive protection functions.

In this IEC 61850 architecture each relay can sample following its own frequency tracking scheme and different relays can apply different sampling rates. None of the sampling or protection functions are dependant on a central clock or on a large number of complicated distributed phase lock loops either within an open standard or proprietary that need to synchronize before the system can start producing and consuming data.

The concept of independent digital cores in the merging units facilitates not only independent timing zones, but also independent "firmware zones". Upon start up each relay checks the firmware revision on all connected merging unit cores. If the revision does not match the firmware on the relay, the relay automatically loads the appropriate firmware to the connected core, while the other cores continue normal operations unaffected and unaware of the changes occurring in their neighbour. This operation lasts only milliseconds and is entirely transparent to both the user and the system.

The field units (merging units) do not have inherent firmware or settings, all signal mapping and configuration is controlled from each connected IED. In this way the user is not exposed to the problem of permutations of firmware and settings among the relays and merging units (the domino effect). No dedicated software tools are required to deal with the merging units. A traditional relay setup program is sufficient to setup the system. All the IEC 61850 terminology has been hidden to the user.

VII. REAL INSTALLATION OF THE PROCESS BUS SYSTEM

The first pilot installation of P&C system based on the IEC 61850 process bus architecture presented in this paper is at an American Electric Power (AEP) 345kV substation in Columbus, Ohio. Two distance relays and one breaker failure relay are used to protect two 345kV transmission lines in a breaker-and-a-half arrangement as shown in Fig. 6. This is a retrofit installation and the process bus P&C system is deployed in parallel with an existing conventional P&C system.

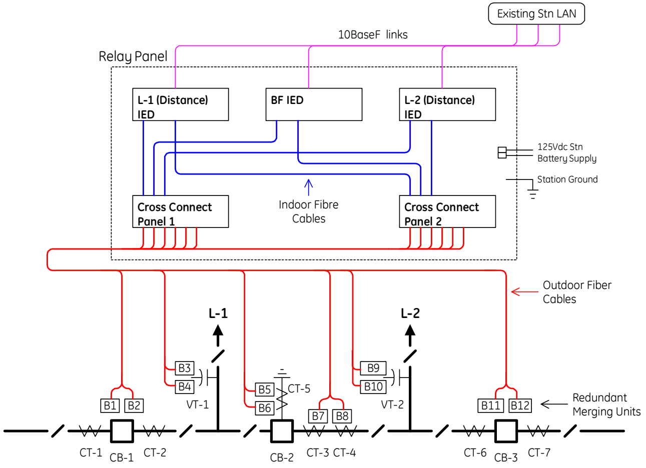


Fig. 6. Actual Installation of Process Bus System at AEP

In this installation, duplicate Bricks (merging units) are employed on each circuit breaker and on each bank of voltage transformers. Each circuit breaker Brick (numbers 1, 2, 5, 6, 9 and 10 in the Fig. 6.) acquires the three-phase bushing CTs on each side of the breaker or the freestanding CTs, breaker position and any alarm contacts, as well as outputs to trip and close the breaker. The Voltage Transformer Bricks (numbers 3, 4, 7 and 8 in the Fig. 6.) inputs the three phase VT signals and line disconnect position, as well and outputs to open and close the line disconnect.

A. *Project Execution*

Standardized components had been used during the project, copper terminations that end at merging units installed at primary apparatus in the switchyard, and purpose-driven, point-to-point architecture that simplify procurement, engineering, drafting, construction, commissioning, maintenance, and operations. The project was executed in few simple steps listed below.

1) *Site survey*

A site survey was performed to determine the physical locations of the merging units and to measure the physical lengths for the pre-fabricated and pre-connected fiber and copper cables. Merging units and relays were selected according to application needs and cables were ordered as per the site survey results.

2) *Configuring the System*

The configuration of the presented process bus based system was no different than the current practices of setting the relays except the additional step of mapping the I/O to their respective merging units. Each merging unit is mapped using its serial number, digital core number and order code. This process is very intuitive and straightforward and there is no need for specific knowledge of IEC61850 terminology to do this. Setting the rest of the functions of different relays remains exactly same as it is done using conventional way. More importantly there is no need for any special software tools to configure this process bus system; the existing IED software tool itself is used.

3) *Factory Acceptance Testing (FAT)*

The P&C system presented here promotes the shift from Site Acceptance Testing (SAT) to Factory Acceptance Testing (FAT). The process bus system consisting of connectorized cables, merging units and pre-configured relay panels, is shipped as a completely tested entity. This transfers the maximum amount of design and construction to a controlled environment rather than on-site. Whole of the process bus system was assembled at factory in the way it would be installed at site and tested thoroughly.

4) *Installation and Commissioning*

The installation and commissioning phase of the pilot project involved the following tasks

a) Mounting the merging units out in the switchyard in pre-determined locations (Fig. 7).
b) Making and verifying the copper interfaces to the primary apparatus using the pre-connected cables

c) Routing and connecting the outdoor fiber cables between the merging units and control house
d) Powering up the whole system and verifying that the relays and the merging units do not report any errors.
e) Placing the whole system in service and verifying that the measurements reported by the process bus system are consistent with the conventional system.

It is worth noting that mounting of merging units and making the copper interfaces have to be done for this pilot installation, as it is a retrofit. However, for Greenfield or fresh installations the merging unit can be made part of the primary apparatus. This means the merging units will come mounted and pre-wired in the primary apparatus, significantly reducing site work.

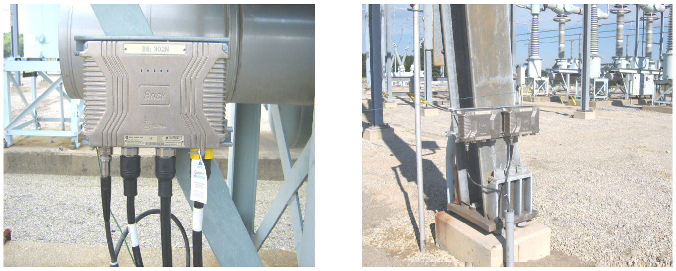


Fig. 7. Merging units and outdoor fiber cables being installed in the switchyard

B. *Operational Experience*

This pilot installation consisting of 12 merging units, 3 relays, 2.72 km length of outdoor fiber cable and 24 point to point fiber connections is in service for more than six months since August 2008.

The process bus system has been operating without any anomalies and has remained operationally consistent with the conventional system. There have been many external fault conditions and the process bus system has captured the fault conditions very close to the way the conventional system has done. One of the lines picking up load upon commissioning is illustrated in Fig. 9.

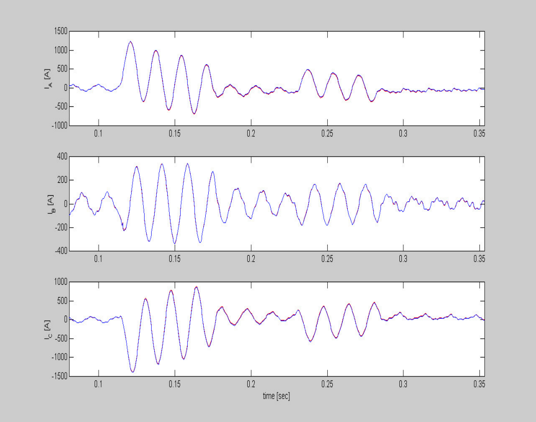


Fig. 8. Comparing current signals between process bus (Blue) and conventional (Red) systems for an external fault

It can be clearly seen that the performance of the process bus system in terms of acquiring the power system inputs, is almost the same as that of the conventional system.

The rugged merging units mounted outdoors on the switchyard structures have performed well serving under varying environmental and electromagnetic field conditions. Fig. 10 presents the internal temperatures recorded by various merging units. The diagnostics logs in the merging unit also record the receive and transmit optical signal levels along with various diagnostic conditions such as DC power loss, processor reboot, ADC circuitry problems, output driving circuits problems, contact input wetting supply problems and various communication failures.

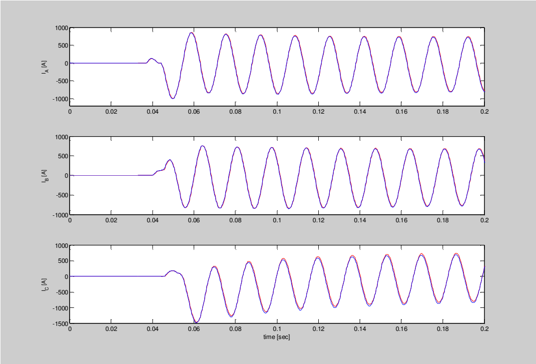


Fig. 9. Comparing current signals between process bus (Blue) and conventional (Red) systems during the load pickup on one of the 345kV lines

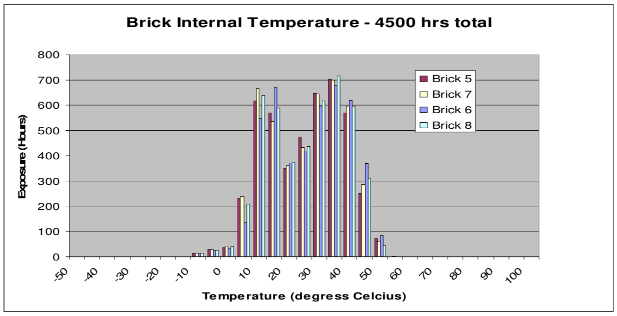


Fig. 10. Merging units internal temperature histogram

VIII. CONCLUSIONS

The paper describes a novel approach for implementation of IEC 61850-9-2 process bus, which permits deployment of this technology without being forced to modify the design of primary equipment and reports on a pilot installation for a 345kV transmission line application.

Introducing a point-to-point communication architecture for process bus helps to achieve a robust protection and control application on dedicated fiber optic links where the Ethernet traffic is fully deterministic. Therefore no complex configuration for Ethernet switches is needed (e.g. priority tagging, network restoration protocols, etc.) as there are no issues with congestion, collisions or delays on communication links. Also no advanced central clocks are necessary at process bus segment of communication network as each IED can be a time synchronization or data synchronization master for all merging units it is connected to.

The benefit from interfacing protection and control IEDs by fiber optic only is the elimination of conventional I/O boards from IEDs and huge reduction in copper wiring in relay cabinets. Instead of several I/O boards with dozens of copper connections the new generation of IEDs contain just one communication card with few fiber optic ports. Apart from cost reduction at design, manufacturing, installation and commissioning stage it also provides advantages for IEDs maintenance. With this concept the relay cabinets in control building would not need thousands of copper wires and thousands of connection terminals. These connections can be replaced by few fiber optic cables and by software configuration of digital signal mappings.

The paper presents a robust process bus architecture for distributed protection, metering and control that targets copper wiring as a major cost, labour and time factor, and replaces copper wiring for protection and control purposes in the switchyard and the control room with fiber-based communication. The described system introduces rugged merging units that solve practical problems such as outdoor fiber cabling and connectivity in harsh conditions, weatherproofing, commissioning, maintenance, and expandability. These merging units shall be designed to interface all process interface measuring and control points at a given switchyard location using a common device and working with a standard I/O structure: status inputs, binary output commands, transducers and sensors, and instrument transformers.

The work presented in this paper reflects the actual development of a complete system encompassing all major protection application types. The main goal at the design stage was developing a system that could provide a real benefit for the end user in terms of cost reduction, project duration decrease and simplification of the system architecture.

A future work on the presented system could include implementation of interface to the Non-Conventional Instrument Transformers (NCIT's) in the Bricks (Merging Units) once market acceptance grows for NCIT's and more new installations are delivered with this technology.

Such primary apparatus with pre-installed optical interface would pave the way to the concept of a fully digital plug-and-play substation.

IX. REFERENCES

Standards:

[1] IEC International Standard "Communication networks and systems in substations - Part 9-2: Specific Communication Service Mapping (SCSM) – Sampled values over ISO/IEC 8802-3", (IEC Reference number IEC/TR 61850-9-2:2004(E), IEC, Geneva, Switzerland).

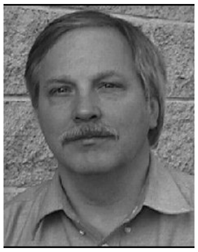
Papers from Conference Proceedings (Published):

[2] M.Adamiak, B.Kasztenny, J. Mazereeuw, D. McGinn, S. Hodder "Considerations for Process Bus deployment in real-world protection and control systems: a business analysis" presented at 42 CIGRE Session, Paris, August 24-29, 2008, paper B5-102.

[3] B.Kasztenny, D.Finney, M.Adamiak, E.Udren, J.Whatley, J.Burger, "Unanswered Questions about IEC 61850 - What needs to happen to realize the vision?" (Proceedings of the 31st Annual Western Protective Relay Conference, Spokane, WA, 2005).

X. BIOGRAPHIES

David McGinn holds a degree in Electrical Engineering from the University of Waterloo, is a registered professional engineer in the Province of Ontario, and is a member of the IEEE. David worked was a Senior Protection and Control Engineer with Hydro One, Ontario, Canada. During his 30 years at Hydro One, he had positions doing field commissioning and trouble-shooting of P&C equipment, head office support for field P&C personnel, design of the Integrated Protection And Control System product, and protection application engineering. He was also at times the Hydro One representative to the Northeast Power Coordinating Council's Task Force on System Protection and the Canadian representative to the North American Electric Reliability Council's Interconnection Dynamics Working Group. Currently David McGinn works in GE Digital Energy, Multilin, and holds the position of Application Engineer.



Mark Adamiak (M'76, SM'95, F'05) received his B.S. and M.E. degrees from Cornell University in Electrical Engineering and an MSEE degree from the Polytechnic Institute of New York. He started his career with American Electric Power (AEP) in the System Protection and Control section where his assignments included R&D in Digital Protection, relay and fault analysis, power line carrier, and fault recorders. In 1990, Mark joined General Electric where is activities have ranged from development, product planning, and system integration. In addition, he has been actively involved in developing the framework for next generation relay communications and was the Principal Investigator on the Integrated Energy and Communication System Architecture (IECSA) project. He is a Senior Member of IEEE, past Chairman of the IEEE Relay Communications Subcommittee, and a member of the US team on IEC TC57 - Working Group 10 on Substation Communications.

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Jorge Cardenas received his Engineering degree from the Universidad de Ingenieria (Peru) in 1977 and his MBA from the Universidad Politecnica de Madrid (Spain) in 1998. Jorge began his career with the Utility Electroperu (Peru) as a Protection & Control Engineer, and in 1987 he moved to ABB (Spain) as a HV equipment Sales Engineer, and than promoted to a Control Design Engineer. In 1989 he joined GE, where he has held several positions. Currently Jorge works as EMEA-Application Manager with GE Digital Energy, Multilin. He authored several papers presented on protective relay conferences around the world. He is a member of CIGRE organization.