The Azerbaijani experiences in Digital Substation deployment. How Process Bus and IEC 61850 addresses Utility requirements

Saeid Shoarinejad *,   Jorge Seco, Jorge Cardenas [†]

* *Araz Energy, Azerbaijan,* [†] *GE Digital Energy, Spain*
Jorge.cardenas@ge.com

Keywords: Digital Substation, IEC 61850, Process Bus, Protection Relay, Substation Automation System (SAS); IED (Intelligent Electronic Device).

Abstract

This paper shows the experience of Araz Energy using a Process Bus Solution in four 110 KV (as retrofitted projects) Substations in Azerbaijan. Araz Energy proposal to BEG (Baku Electric Grid that is locally called "Baki Elektrik Shabakasi/ BES") was based on the Hard Fiber Process Bus system made by General Electric-Multilin (as part of General Electric Digital Energy). The use of the Process Bus System is key as it brings all the benefits of a Digital Substation and regular SAS (some vendors call it "DCS" for Substation Automation) and implies changes in the way a traditional substation is being designed, built, serviced and maintained. The experience described in this paper is based on the feedback gained and lessons learned from all perspectives in practice from four different substations where the same concept was applied. Since then the use of Digital Substations has become a landmark in the way Substations should be designed, operated & maintained..

1 Introduction

Process Bus Standard, as described in IEC61850-9-2, helps reducing dramatically costs and engineering efforts during installation and maintenance, resulting in less costs and enhanced security. Process Bus eliminates the need for thousands of different copper cables for controls & analog signals and substitutes them with fewer fiber optic ones (Plug & Play) . Figure 1 shows this concept. Digitization of primary equipment can be achieved with the use of a Process Interface Unit (PIU), installed close to the primary equipment in the substation switchyard. This PIU converts the analog signals of the primary equipment into digital signals. No need to duplicate signals or use interposing transformers.

2 Digital Substation

In order to get all the benefits that a full digital substation brings, special attention must be paid to Substation Design, because this decision affects all aspects of the project. The most evident sections are Substation layout, number of P&C panels, size of control room, the number of copper cables, the type of the required equipment and related sections' change. It will also change the way project engineering is done from the Protection & Control and generally SAS aspects. Engineering procedures, interconnection drawings, panels' shop drawings (such as wiring connections, terminal list, cable schedule, etc.), configurations, maintenance, control room design and size, cables' routes, trays and canals are also done in a different way. This fact is probably the most important driver for utilities to change their minds and designs (especially inside cities where land is so expensive) concerning building Substations in a classical/ conventional way. A radical change in staff philosophy (such as their knowledge in working with computers, software, etc.) is required in order to embrace this new way of conceiving Substations.

Process Bus architecture used for Dagliq substation is depicted in Figure 2 PIU/Bricks deployed together with hardware and software interfaces are shown on the drawing.

3 Opportunity Description

In 2008 BEG / BES opened the project to retrofit DAGLIQ substation (except power transformers). DAGLIQ is a distribution substation with different voltage levels (110/35/10 KV) consisting of two incomer lines at 110kV, two 40MVA power transformers, and 53 medium voltage feeders (35 & 10kV). The local power company, BEG, wanted to retrofit the substation due to its age. The first approach to this job was to substitute old equipment with new one, following the same classical approach. This meant changing the old P&C equipment with new digital relays, updating old schemes and following the same principles originally used.

Retrofitting of this substation was framed in the efforts of the power company in updating their facilities and thus reduce CAIDI & SAIDI rates. In addition, there was an interest in finding a solution to the growing need to find new ways to act more quickly and effectively in the event of occurrence of any electrical failure, increase the safety of its personnel, drastically reduce time and the costs of construction, operation and have a solution that would allow the easy expansion of the facilities. Solution to be adopted should address the current and future challenges of the utility, being the most important ones:
•Cost of installation & maintenance
•Time required to complete the job
•Number of utility staff required to be involved in the project
•Future proof design
•Easy to be upgraded / interoperability
•Level of autonomy to make simple changes

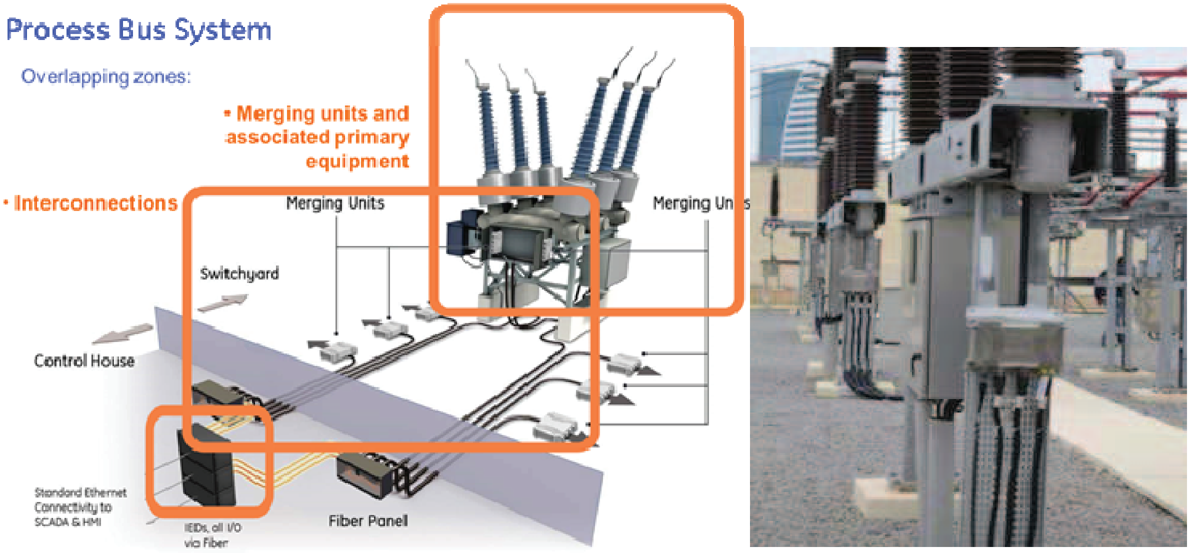

Figure 1

•Safety of the maintenance crew / time required to perform routine tests
•Remote controlling by SCADA centre through gateway (Protocols IEC 101, 104 where fiber optic cable or OPGW were/are available instead of adding RTU, marshalling rack, etc.)
•Saving control room building size and the related costs for new substations
•Considerable saving with deleting BCR (Bay Control Room) inside switchyard in substations with regular SAS
•Minimizing power downtime during Process Bus equipment and system installation for existing/under operation substations that is very critical point for the regions with high density loads and/or important consumers/facilities
•Overall saving in time.

The proposed solution was the substation completely digital using all the potential of the IEC 61850 Standard advantages. Initially, electric company was reluctant to this solution due to the absence of monitoring and automation in substations and lack of technical skills in IEC 61850. Finally, due to the quantifiable benefits that the full digital substation proposal brought, made the utility order a pilot project to Araz Energy to build a proof of concept substation. Target was to evaluate from first hand all the advantages that the new design should carry. Araz Energy proposal was backed with its extensive experience building substations and the technical support from GE Digital Energy.

4 Transmission and Distribution SE in Azerbaijan

Majority of Transmission & distribution substations in Azerbaijan are of old technology. Most of them have more than 40 years old and are based on the electromechanical technology. Since the first installation, some of them have been upgraded using a variety of different technologies and manufacturers. The result of all this is an old installed base combined with newer protection relays from different manufacturers and technologies. Engineering, Operation & Maintenance staff still follows the same old approach to run the installations; however, the staffs' mentality has considerably changed after operation of those substations.

5 Proposal & Challenges

Solution proposed was, as mentioned before, a full Digital Substation. The use of Process Bus was key in achieving many of the proposed targets as it enabled huge savings. As the utility had no real experience in using IEC 61850, Araz Energy leaded this project as Engineering, Procurement and Construction company (EPC), being. BEG took the responsibility of building P&C panels, cabling and installation manpower.

Dagliq Substation's voltage level is 110/35/10kV. A number of 8 hard fiber PIUs/Bricks were used to protect the HV section of the Substation. Hard fiber PIUs were connected to the line, CTs, PTs and power transformer protection relays, using fiber optics, avoiding most of the traditional field wiring. Fiber optic cables were in turn connected to patch panel installed inside the control panels located in the Control building and routed to the corresponding protection relays. Substation Single Line Diagram is depicted in Figure 2.

The way PIUs and relays are connected is very straightforward and allows the use of the same signal to four different protection relays. Synchronization of samples is always ensured because of the four independent Digital cores that the PIU has. This feature allows a considerable saving in hardware as one PIU can share samples between four different IEDs. Sampling is independent for each core and it is managed by every protection relay. This system avoids the need for using network merging unit and solves the main technical issue of sample synchronization w/o need of an external synchronization device. All connections to the PIUs, between PIU & the patch panel and between relays & the patch panel(s) are “Plug & Play”, i.e. the related cables and connectors to PIUs, the patch panels and relays are all prepared in the factory and not in the site with no way to connect to a wrong female terminals on the PIUs, the patch panels and relays, that makes huge saving in time and skilled labours during installation and commissioning.

The scope of this project included also a complete SAS for this Substation. Araz Energy designed a complete Automation System maximizing IEC 61850 benefits. All four substations with Process Bus have gateway, GE UPS for redundant servers, monitors and printers, LVDC/LVAC panels, 120 VDC batteries and redundant chargers; and the last three of them have 68” DLP as monitor for the single line diagram of the substation, real time values, breakers’ status (provided by GE Power software package for Substation Automation) and so on.

5.1 Proposed Solution advantages

The implementation of a full Digital Substation faced some challenges but also brought many benefits to both the EPC and the utility.

Most of the challenges faced during this first Pilot project were related to the use of new tools and a new engineering concept, different from the conventional approaches for regular SAS that we had several experiences in that since 2000. New skills were required, primarily by the protection engineers, as the development of a new concept of standard substation needed to be built. As an example, the old interconnection schemes were substituted by using digital signals that the different protection relays can interchange between them. This is being achieved by GOOSE messages that IEC 61850 enables. Change from “hardware” to “software” world required engineers to be trained in the new software tools and its capabilities. The use of digital tools to substitute hardware brings many benefits in terms of flexibility, material cost saving and much less man-hours during substation construction than conventional and regular SAS. These benefits are also present during the operation of the substation, as reliability of new systems has been enhanced. The use of digital signals brings also benefits in safety as there is less need for operators to work with live parts (in reality, substations with regular and Process Bus SAS package could be simply unmanned). Also there is a huge improvement in reliability and time required for maintenance and PM as the SAS checks continuously “System Health” and stores periodically measures, events, profiles, etc. Digital relays allow a better analysis of faults with retrieving the stored Oscillographies, Sequence of Events and sending faults’ details to the remote operator & maintenance experts in their headquarter with hugely saving in maintenance & restoring costs and the experts’ time (as all utilities have shortages in such experts worldwide) in analysing the faults, symptoms & remedies, finding reliable ways to fix the faults/problems and quickly restore the substation & grid with no need to physically go to the substations Outage time is therefore reduced with saving considerable money for utilities.

The use of Process Bus technology resulted in saving time (big time) especially for retrofitting the existing substations, because less time and resources were required:
•Installations were made easier as there was no need to change existing trenches outside and channels and inside the control room
•Less P&C panels were needed
•Big reduction in testing and commissioning the whole installation

For the first installation, it was required to add a conventional mimic diagram on the P&C panels as well, because this was a new concept for them and wanted to be sure that they would be able to operate the installation in a traditional. Manual operation of switchgears was also possible. This fact increased the number of cables (conventional) and extra panel space (resulting in additional costs). The advantages found with this new technology, reduced costs and saving time in this project, convinced BEG to use the same technology in the new substations that were to be built for one of the most important events celebrated in Azerbaijan with international relevance, the Eurovision Song contest hosted in Baku during May 2012.

This first substation was not only used as a proof of concept, it, also, was the base for the standard substations to be built in the next future in the area.

The new Digital Substation and the use of Process Bus simplify and enables to make standard designs that can be easily replicated in different substations thanks to its flexibility. This fact reverts in additional cost reductions in the construction of new installations, easier and shorter maintenance and higher security to utility crew.

The scope of this project included also a complete SAS for this Substation. Araz Energy designed a complete Automation System maximizing IEC 61850 benefits. All four substations with Process Bus have gateway, GE UPS for redundant servers, monitors and printers, LVDC/LVAC panels, 120 VDC batteries and redundant chargers; and the last three of them have 68” DLP as monitor for the single line diagram of the substation, real time values, breakers’ status (provided by GE Power software package for Substation Automation) and so on. A comparison between the traditional and the Process Bus solution is summarized in Table 1:

	Traditional Hard-Wired Copper Solution	Presented Process Bus Solution
Materials	• Multiple small, individual materials are procured and installed as customized individual components of the system • Material quantity and type requirements vary from zone to zone and apparatus to apparatus due to variability in wiring	• Materials become finite set of standard components, with a small number of each type • Materials common across all zones and stations • Vast majority of physical system can be assembled in a controlled environment • Higher initial material cost for initial zone installed, with material costs greatly reduced for adjacent zones • Control buildings greatly reduced in size due to elimination of most bulky copper cables, terminal racks and AC and DC FT type test switches on relay panels.
Engineering	• Variability in engineering design largely in physical copper connections • Different applications require specialised designs to cater for different apparatus, different topologies • Design changes require significant manual labour to implement changes in the details of the copper connectivity	• Physical interfaces between merging unit and IED standardised • Only minor physical variability in mapping origins and destination of signals and information • Majority of variability transferred into software configuration • Firmware, settings and other engineering tools as simple as today
Drafting Labour	• Significant manual labour is required to document individual copper connections throughout the system • Modification or addition to the connectivity requires manual revisions to a potentially large number of drawings • Manual drafting is error prone and requires extensive, labour-intensive crosschecking and errors are often missed.	• Only documentation required for copper connections is in primary apparatus which can be standardised to equipment type and specified as deliverable as part of purchase of apparatus • Documentation of connectivity vastly reduced and simplified to single point-to-point fiber connections that can be summarized in tabular form • Facilitates automatically generated system and connection documentation
Construction	• Time-consuming manual labour has to be done in-situ where labour rates are generally higher and productivity generally lower, and is susceptible to errors • Some improvement can be realized with the concept of pre-constructed, pre-tested control buildings but the variability with the termination of field cables persists	• Construction effort vastly reduced for copper connections – virtually eliminated where merging units are installed by apparatus manufacturer • Chance for errors vastly reduced through standard physical connectivity • Faster installation of pre-constructed control buildings through simplified interface point to switchyard
Commissioning	• Integrity of each copper signal path via copper cabling needs to be verified between switchyard and IED • Errors in the physical wiring, regardless of the source, require troubleshooting and rework	• Continuous monitoring of architecture reduces protection misoperations from incorrect isolation or restoration following protection testing [5] • Construction errors limited to provisioning of communication between origin and destination of information • No high energy signals (AC or DC) present in the control building for greater personnel safety when working on protection and control systems
Ongoing Maintenance	• Maintenance activities currently risk-based or calendar-based, except in the event of spontaneous failure or misoperation • Routine testing requires isolation of high-energy signals from primary apparatus • Isolation and restoration of individual test/isolation points across multiple panels error-prone and risk misoperation of protection	• Continuous self-monitoring of all hardware and redundant measurements allows maintenance to be condition-based (event-driven, e.g. run-to-fail) • Continuous monitoring of architecture reduces protection misoperations from incorrect isolation or restoration following protection testing [5] • No high energy signals (AC or DC) present in the control building for greater personnel safety when working on protection and control systems
Switchyard Modifications	• Changes to the switchyard normally require significant addition or modification to existing control cables and wiring • Time needed to make these changes and the associated costs are directly related to the number and variability in copper connections • Reduced outage impact and complexity through reduced number of copper connections to be cut over.	• Multiple cores in a merging unit allow for additional zones to make use of unused capacity within the merging unit • Each zone can be conveniently engineered, installed and commissioned individually without impacting adjacent zones until final testing is to be performed
Project Management	• Amount of manual labour results in long project pipelines for design, construction and commissioning • Many hand-offs between stages in project result in many potential bottlenecks	• Procurement, engineering, construction more standardized with fewer handoffs and increased productivity • Up front decisions for material planning simplified, detailed design work can be done without complete physical details of installation
Operations	• Periodic testing of protection and automation systems required • Troubleshooting and replacement of failed components result in long Mean Time To Repair and potentially extend outage duration	• Redundancy and self-monitoring reduces or eliminates the need for periodic testing • Connectorized cabling, no internal settings on merging units facilitate fast replacement without requiring long outages to re-commission protection and control systems

Table 1

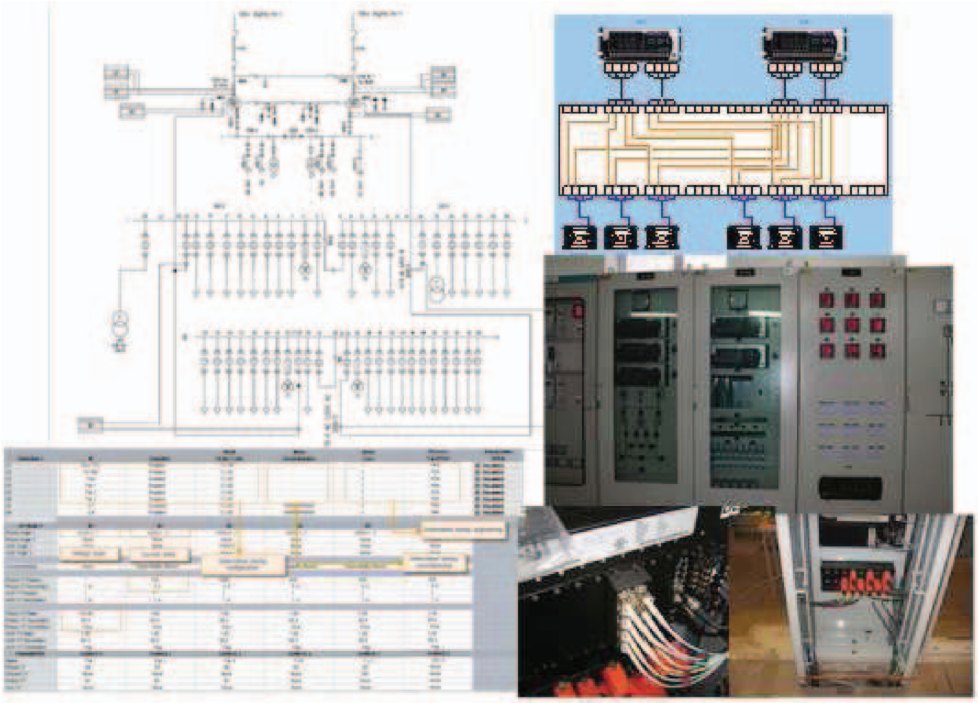

Figure 2

After the construction of this pilot substation three more Transmission & Distribution substations were built using the same technology to leverage all the advantages described earlier and take the full advantage of the new possibilities that Digital Substations bring.

Araz Energy signed EPC contract for all three substations at the end of July 2011, and commissioned them in the following dates: Bayil in Oct. 2011, 227 on December 2011 and DARNAGHOL on January 2012

Reduction in time achieved in the execution of the main tasks is resumed in table 2 and Figure 3 (*):

Task	Process Bus	Regular SAS way	Difference (in days)
Engineering (Detailed & complete Design)	50 days	90 days	40
Panels' production & wiring	30 days	90 days	60
Installation and cabling	30 days	60 days	30
Test and commissioning	30 days	90 days	60
Relay configuration	45 days	30 days	-15
Total	185	360	175

Table 2

(*) Note: Above-mentioned specific statistic data (tables and figures) is based on following parameters in Azerbaijan that would be different in other countries (based on local requirements, regulations, specifications and layouts, manpower's' rate of performances & skills, etc. :

1. Manpower (culture, efficiency, expertise, etc.)
2. When the customer asks for Process Bus system plus conventional mimic for manual controlling as well; otherwise, installation and cabling will decrease from 30 days to 15 days, test & commissioning from 30 days to 15 days and relay configuration from 45 days to 30 days
3. Coordination with the other disciplines (switchyard equipment, canals for cables, constructions of structures, control room, etc.) in the country
4. This table is for the substations under retrofit and renovation, so it would be different for a new substation (much less time is required)
5. Configuration time decreases over more practices to much less than required times for regular SAS substations because of modularity and typicality of the Process Bus System. So the showed numbers are average, and we do believe it would be 20 to 25 days for our future project (depends on the size substations, number of relays, number of bays, etc.).
6.All mentioned percentages on the tables 2 and 3 and graphs of 4 & 5 will definitely vary with voltage level, number of bays, incoming and outgoing feeders, switchgear configurations, and so on.

Overall savings with using this new Digital Substation Process Bus design: 49% (as per above-mentioned notes and facts).

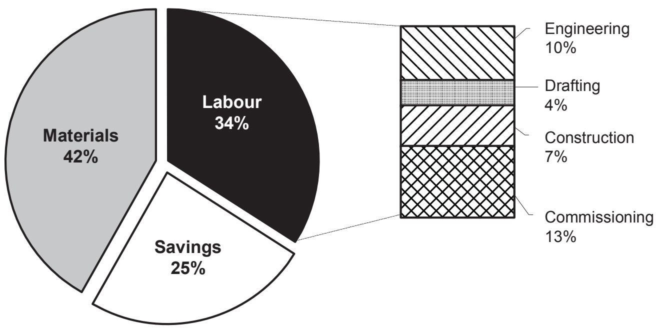

Figure 3

6 Conclusions

The use of IEC 61850 Standard in substations means bringing clear advantages compared to the traditional way of designing, operating and maintaining Electric Substations. Although Process Bus reinforces the advantages found with IEC 61850, but its adoption by utilities has been slow. Electric utilities used to argue that the technology was not mature enough, even though GE has a technically working solution since 2008 with tenths of installations working worldwide. The main reason behind this slow adoption is that this new concept requires a disruptive change in utility mind-set. A considerable effort is required to understand, train and implement changes to adopt the old hardware-minded structures and start thinking in the advantages that this new technology brings to all the stakeholders. A special effort must be done in continuous training in order to keep updated and get the maximum benefit from the new technologies. Full benefits of the new technologies are only gained if utility engineering, operation and maintenance crew are trained on a regular basis and time by time.

Summary of the benefits perceived and measured from this project by the utility:

•Time reduction:

•Standardization 44% time reduction in Substation Detailed Design and shop drawings

•Wiring : 67% less time needed for wiring works

•Cable trays and canals/trenches: 70% less cost and time needed for cable trays' installations and making canals/trenches for the cables

•Installation: 50% less man-hours during installation works (this will decrease a lot over time after more practices)

•Start-up: 67% less time needed for commissioning and testing (this will decrease a lot over time after more practices)

•Configuration : 50% more time needed for IED set ups (this will decrease a lot over time after more practices)

•Documentation (e.g. "As Built Drawings"): 65% less time needed for documentations because of the system's modularity and typicality

•Number of cores of CT and their burdens would be decreased including its costs

•Less P&C panels (much lower costs for making and wiring panels in Process Bus System versus conventional and regular SAS)

•Less civil/ construction costs of control room versus conventional and regular SAS substations

The overall time reduction is close to 50%. The only aspect where more effort was required was during configuration stage; however, the configuration time gets less and less after more practices because of modularity and typicality. We have to note that this time can also be drastically reduced if substation configuration is standardized.

Difference in material cost is very similar if we compare the regular SAS versus the Digitized Substation (with Process Bus). Switchgear Costs are lower in the conventional substation, while the Digital Substation with Process Bus uses less copper and less hardware (less IEDs, no DI, no DO, no AI and no AO on the relay and their related wirings in the control panels, less cores in CTs, no BCR, etc.).

Taking into account the different aspects involved in the lifecycle costs, advantages exceeds dramatically disadvantages in all aspects, being economics and implementation time, only 2 of them. Some of the Advantages found are listed below:

•Flexible. Changes and upgrades are easily made through software

•Enables standardization. Same configuration can be used in similar installations

•Open. IEC 61850 makes it possible to use equipment from different vendors

•Scalable. Process Bus and the concept of IEC 61850 make it easy to make a design based on building blocks, easily expandable

•Safer. Digital systems avoid the use of live wires and enhance crew safety

•Future proof. IEC 61850 has been designed to accept older and nowadays' versions of primary equipment of substations to maximize backwards compatibility

•Easier maintenance & applying full PM. Digital systems check continuously the status of the connections and the health of the different IEDs. It is, also, possible to keep historic records of the installations and to save pre-fault status to make a root cause analysis. Also, the system is easily maintainable (just replacing PIU with a new one during less than 30 minutes, changing power supply and CCU cards inside the relays during 15 minutes, and so on)

•Leaving existing cables of conventional substations on the trenches/ canals as are to save more costs concerning under retrofit/renovate substations when the case is urgent.

References

[1] Rich Hunt, John Coursey, Stephen Hirsch, Jorge Cardenas "Simplifying protection system design for distribution substations".

[2] Jorge Cardenas, Iñaki Ojanguren, Ignacio Garces. "CIRED 2011IEC 61850-9-2 Process Bus: operation experience in a real environment".

[3] Richards, S., Pavaiya, N., Boucherit, M., Ferret, P., Vandeleene. "Cigré 2014 Feedback on On-Service Deployment of the Fully Digital Substation".

[4] M. Adamiak , B. Kasztenny ,J. Mazereeuw, D. McGinn, S.Hodder "Considerations for IEC 61850 Process Bus deployment in real-world protection and control systems: a business analysis".