# Tutorial on Networking for Digital Substations

Richard Hunt, Marcelo Zapella, Carlos Pimentel, Gustavo Silvano – GE Grid Solutions

## Introduction

A digital substation is one where all analog interfaces, such as current and voltage measurement, equipment status and alarms, and equipment control points are converted to digitized data directly at their source. This digital data, published using techniques described in the IEC 61850 standard, is then shared with other devices in the substation, and potentially beyond the substation as well. This allows substation control systems to be built faster and more efficiently, while using less materials and to unlock the value of data in the to operate the substation and its equipment better.

A digital substation therefore requires all devices in the substation to communicate with each other over Ethernet networks. These Ethernet networks must be designed to manage the various types of traffic and messages that IEC 61850 requires for sharing data between devices. This requires protection and control and substation automation engineers to have some understanding of Ethernet networks. The design and management of large and complex networks that move large amounts of traffic is a specialized field of knowledge, which may be intimidating to power system engineers.

However, it is not necessary for power system engineers to fully understand the complexity of Ethernet networks, but to simply understand enough to design and maintain networks that support the needs of a typical substation. This is actually very straightforward, as the traffic on the network in the substation does not change over time, because it is based on the substation physical design, operating requirements, and equipment, which only changes rarely, as part of capital projects. This means for any specific substation, the communications network can be designed once, and the design and configuration never need to change.

In summary, the knowledge to support networking in terms of power systems, is simpler than expected. The next sections will introduce the main points on digital substation networking and present a tutorial to the engineering team on how dealing with network definitions, configurations and validation, including a real case experience of Factory Acceptance Tests (FAT) for a digital substation project.

## From Analog To Digital

In conventional substations, the task of connecting protection and control equipment to signal sources requires proper engineering. Many variables are taken into account for choosing the wire infrastructure, e.g. current, signal attenuation, signal delay. When moving to a digital substation solution, wire infrastructure is replaced by network infrastructure, where data is transmitted from signal sources to protection and control equipment through the Ethernet standard. Obviously, the complexity of such solution is greater because all data traffics through the same physical network, there are several protocols involved and many more variables must be considered. This means that even more care must be taken when engineering the network in digital substations.

The first thing to consider is bandwidth. Just like wire gauge is chosen based on current, link speed must be appropriate to the amount of data being transmitted. In large networks, which is usually the case for digital substations, there is a huge amount of data traffic but not all of it is required to reach every device. As most part of IEC 61850 data uses multicast destination addresses, packets are forwarded everywhere in the network, forcing every link to be dimensioned to support the total network throughput. That can be avoided using traffic segregation, allowing each device to receive only the required data. The most commonly used solutions are virtual LANs (VLANs) and multicast address filtering. VLANs are great for allowing only specific data streams to traffic through a link, blocking everything else. Multicast address filtering, in the other hand, is best suited for blocking specific data streams to be forwarded to a link, whereas everything else flows normally.

Another aspect to be considered is latency. The same way long cables will introduce signal delay, long network paths and congestions add to the time data takes to go from one point to another, usually referred to as latency. This is especially important in IEC 61850 networks, where protection and control equipment must respond as soon as possible to events in the electric system. The best way to minimize latency is to ensure sender and receiver are as close as possible, i.e. reduce the number of hops between the devices, ideally being connected to the same switch. This will not only help data reach its destination faster, but also potentially reduce throughput in the so-called trunk links (connections between switches).

Prioritization is also a way of reducing latency as well as improving data delivery probability. When packets are prioritized, queueing is less likely to happen, thus ensuring that they are transmitted as fast as possible. In congestion situations when the throughput reaches the link bandwidth and packets need to be dropped, priority ensures that important data does not get lost. This can be easily done using Quality of Service (QoS) by choosing the appropriate priority level for each data stream so that the most important ones are preferable.

Moving from wire to network infrastructure raises reliability questions. In the analog world, the biggest threats against data integrity are wire damage and electromagnetic interference. In the digital world however, there are a lot more concerns, e.g. equipment failure, congestion, transmission errors. Redundancy protocols were created to address this problem. RSTP (Rapid Spanning Tree protocol), PRP (Parallel Redundancy Protocol) and HSR (High-availability Seamless Redundancy) are the most commonly used and depending on the network architecture, one, two or all of them can be used simultaneously.

**Performance Requirements For IEC 61850 Networks**

General information reporting and control commands have been digitized for decades with the advent of modern SCADA systems. A fully digital substation means taking the next step, which is digitizing the interfaces between primary equipment and protective relays and bay control devices. This interface across the switchyard is generically known as “process bus”. Process bus is the best way to look at and learn networking requirements in a substation, as process bus is the most demanding application in the digital substation.

Process bus requires 3 different types of messages across the Ethernet network.

**GOOSE messaging**. A GOOSE message contains a dataset of information. Individual dataset items may be used for indicating equipment status and alarms, and they may be used for control indications such as breaker trip and close flags. GOOSE messages will be published any time a dataset item changes state. GOOSE is the primary messaging between circuit breakers and protective relays and bay control units.

**Sampled Values (SV) messaging**. Sampled values are instantaneous samples of currents and voltages from instrument transformers, published by merging units (MUs) to the process bus network. Protective relays and bay control units subscribe to this data.

**Precision Time Protocol (PTP) messaging**. PTP is the other name for IEEE 1588 time synchronization through the network. PTP uses message exchanges between master and slave clocks to accurately measure and compensate for path delays between the clocks.

All three of these message types are multicast messages. This means the messages are published to the network, and any device connected to the network can subscribe to this data. GOOSE messages, SV messages, and PTP messages will therefore be everywhere on the network. With a large number of devices publishing data, it is necessary to understand how this impacts network bandwidth to prevent overloading of the network, and switch ports.

***Messaging Bandwidth***

GOOSE transmits a heartbeat message cyclically to prove the publishing device is still alive, typically once per second. GOOSE is intended to transmit spontaneous messages on the state change of any dataset item in the GOOSE message. To overcome possible frame loss, a GOOSE message retransmits some number of times up until the heartbeat message interval, One GOOSE application in an IED generates about 1 kbit/s of data in steady-state and about 1 Mbit/s during spontaneous messages.

The PTP message bandwidth depends on the network topology, considering the number of IEDs, the Ethernet Switch type (if it supports PTP or not) and PTP mode: peer-to-peer (P2P) or end-to-end (E2E). PTP as defined for power system applications (in C37.238 or 9-3) publishes once per second and has a bandwidth comparable to steady state GOOSE messages.

While GOOSE and PTP have similar requirements on the process bus network, SV traffic is even more demanding, but it is easily predictable. An SV frame as specified in IEC 61850-9-2LE represents 1 sample in an acquisition system with a sampling rate of 80 samples per cycle. This frame has an approximate size of 140 bytes, consuming a bandwidth of approximately 5 Mbit/s (50 Hz system) or 6 Mbit/s (60 Hz system) per stream. For measurement, the sampling rate is 256 samples per cycle, with 8 samples sent in a single frame at a lower rate, resulting in a bandwidth of up to 10Mbit/s for systems at 50 Hz and 12 Mbit/s for 60 Hz.

So as the number of devices on the network increases, messaging traffic consumes more bandwidth, which can decrease network performance. The goal must be to maintain overall substation performance, especially for protective relaying.

***Messaging Latency***

The IEC 61850-90-4 Technical Report [1] focuses on the engineering of a local network used to meet the IEC61850 requirements for substation automation. It describes the aspects related to protection, such as tripping over the network (GOOSE), the multicast data transfer from merging units with large volumes of Sampled Values and high precision clock synchronization. Among other matters, the technical report outlines different approaches to network topology and redundancy, which will be covered in a later section.

Referring to messaging performance, the technical report shows the expected IEC 61850 traffic and maximum delay of high priority messages, as in Table 1 below:

**Table 1: IEC 61850 Message Performance Requirements**

| *Message* | *Max. Delay (ms)* | *Bandwidth* | *Application* |
|---|---|---|---|
| GOOSE (Trip) | 3 | Low | Protection |
| GOOSE (other) | 10 to 100 | Low | Protection |
| Sampled Val. | 4 | High | Process Bus |
| PTP | - | Low | General Phasors, SVs |
| MMS (low speed) | < 100 | Low | Control |
| MMS (med speed) | < 500 | Low | Control |

Note there is not a maximum delay specified for PTP. The PTP network directly calculates and compensates for the delay over each possible path, so by definition the protocol itself defines the fastest path between the devices.

**Tutorial for Network Definitions**

In the substation environment, the network infrastructure must operate without the presence of operators and in some cases does not have connection to the Internet for remote management. In other words, the network infrastructure must be reliable and single failure proof, the architectures must consider redundant paths in case of link failures and the switches operating parameters must be configured to ensure the flow of information even in situations of network stress. Furthermore, whenever an unexpected situation occurs, the network infrastructure must be capable of warning/alarming the substation supervisory for attention/assistance.

Based on the application requirements, the substation infrastructure and technology definitions initiate by choosing the primary instrumentation, followed by protection & control devices and its functionalities, their location on buildings and the data communications protocols (SV, GOOSE, PTP, SNMP, etc.). The network infrastructure definition is the next step, starting by selecting the networking equipment, deciding the interconnection between devices and the network topology including redundancy. The last steps would be network configuration, validation from the architectures and redesign if necessary. To illustrate this macro workflow, Figure 1 presents the engineering steps to define the network architecture from a substation.

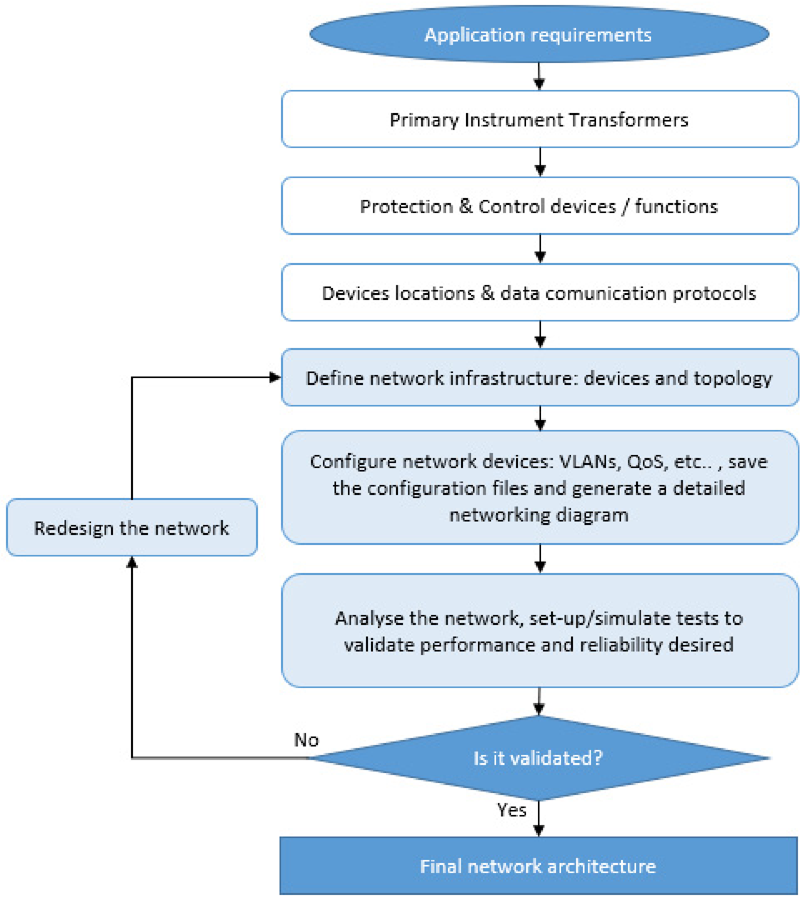


**Figure 1 – Engineering steps for network communication definitions**

***Network equipment selection***

Although networking equipment may have a wide list of functionalities and characteristics, to fulfill the performance requirements from a 61850 network the following main points must be observed when selecting a networking equipment:

- Industry hardened design, ready to operate in harsh environment (same as relays) and preferable with redundant power supply and dry-contact relay alarm;
- Number and type of Ethernet ports, depending on interconnection required between devices;
- Ports speed and switching capacity. As previously showed IEC 61850-9-2LE sampled values usually consumes a bandwidth of 5 Mbit/s (50 Hz system) or 6 Mbit/s (60 Hz system) per stream, but it may reach up to 12 Mbit/s for measurement applications. Thus, consider trunk links (connection among switches) and a few edge links (for relays, DFRs) may transmit multiple SV stream;
- Layer 2 functionalities, such as MAC filtering and VLANs for traffic segregation;
- Switching latency and Quality of Service to ensure fast and uninterrupted data switching;
- Transparent clock operation with hardware-based time stamping, when using IEEE 1588v2 time synchronization;
- Support to desired redundancy protocols, such as RSTP, PRP and HSR.

Besides the above listed points there are many others, such as Cybersecurity features to avoid malicious attacks, SNMP for management/monitoring, IGMP for PMU applications and Layer 3 functionalities in case of large substations with multiple areas, to mention a few, but the paper's focus is on the main network concepts.

***Network topology definition***

A good practice while defining the network architecture is to ensure sender and receiver are as close as possible, as this is the best way to minimize packets latency and data bandwidth in trunk links. High throughput in trunk links can also contribute to lower latency, as data from several ports is merged into a single one and queueing may be necessary, especially when devices are synchronized, and data is sent simultaneously. Figure 2 illustrates the difference between having several streams traverse a trunk link and connecting publisher/subscriber in the same switch in a way that data does not need to be forwarded to the trunk link.

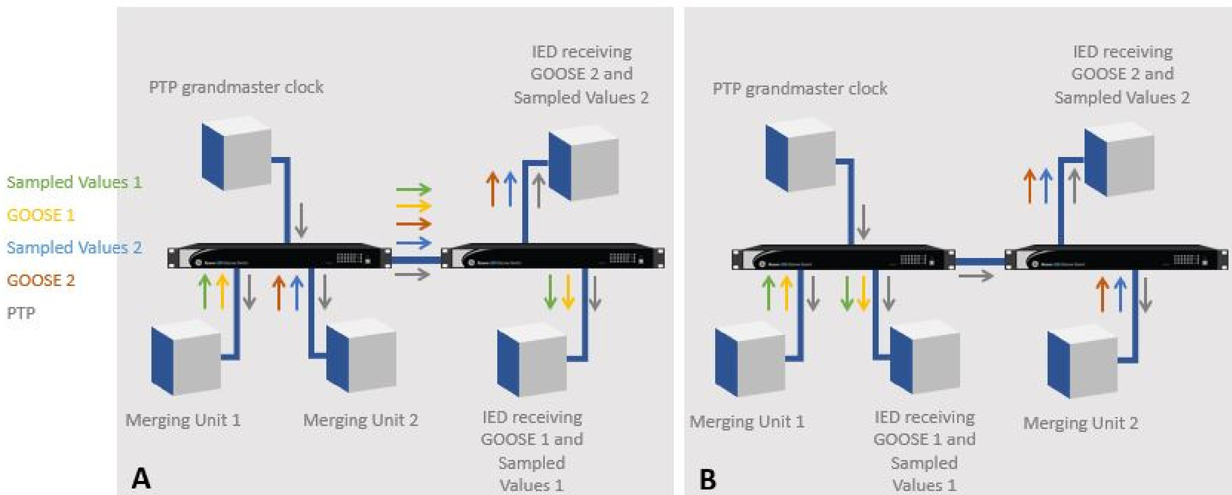


**Figure 2 – Good practice on IEDs connections to avoid several streams in trunk links**

In addition, redundancy is a usual requirement for network topologies to avoid any single point of failure, so it is recommended to start the network design by considering full redundancy, as it may be removed later from the parts that are do not needed. The reverse approach would require further efforts, which may even lead to a complete network reengineering. Numerous protocols provide partial or full network redundancy on the MAC layer, the most common and recommended by IEC 61850 are the RSTP, PRP and HSR; the concepts are described in IEC 62439-1.

Note that redundancy is meant to increase substation operation reliability, but it does not ensure high availability by itself. Device characteristics play a major role to ensure availability, by having a high MTBF (Mean Time Between Failure) and low MTTR (Mean Time To Repair). RSTP is the most widely used loop breaking protocol a mechanism created to solve the problems that arise when a loop is inserted into a LAN, as it converts a meshed network to a logical tree, by blocking ports that would introduce loops and leaving only one path available between devices as shown in Figure 3. Although RSTP is widely used for loop breaking, it provides redundancy by recalculating a new path in the network if a trunk link failure occurs. In case of failure in the edge link or in the Ethernet switch itself, the RSTP will also calculate a new path but the attached devices will be isolated from the network. As RSTP is performed by Ethernet switches and takes in the order of milli-seconds to recover from a fault, it is not well suited for the process bus, but may be used for control and management on the station bus level.

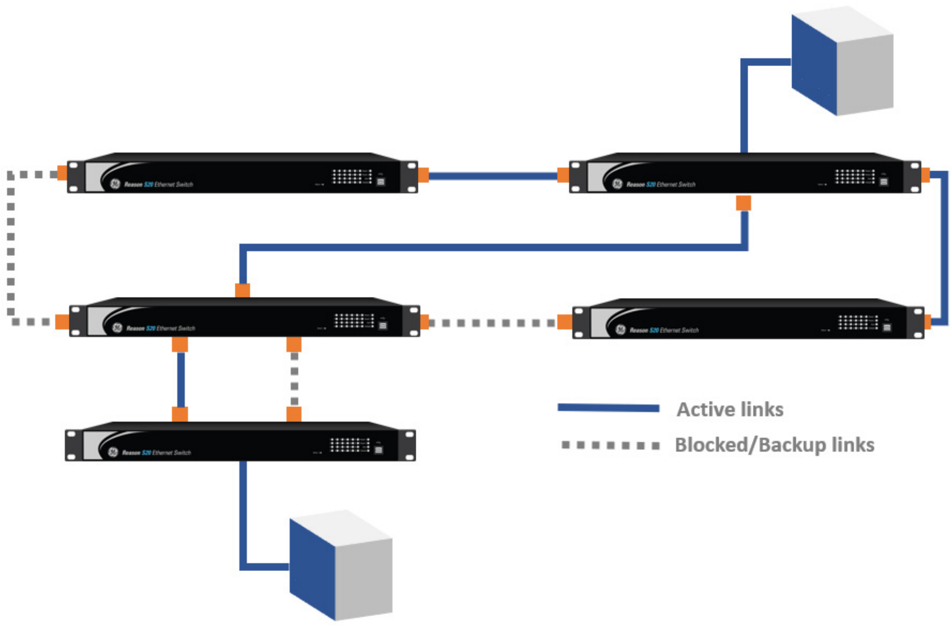


**Figure 3 – Example of RSTP network topology.**

Different from RSTP, the redundancy protocols PRP and HSR are implemented on the end-devices, provide seamless failover operation, and protecting the system against link (trunk or edge) or even network device failures. The PRP topology is equivalent to having two process bus networks where both operate in parallel, and in case of any failure in one, the other is used as backup. End-devices are connected to both networks, sending and receiving packets to/from both. In summary, PRP redundancy relies on a complete duplication of network devices, meaning it is the most effective redundant protocol but also the most expensive. An effective way of using PRP on substation networks is by combining the process bus and the station bus on the same physical network and segregating the buses by using virtual LANs.

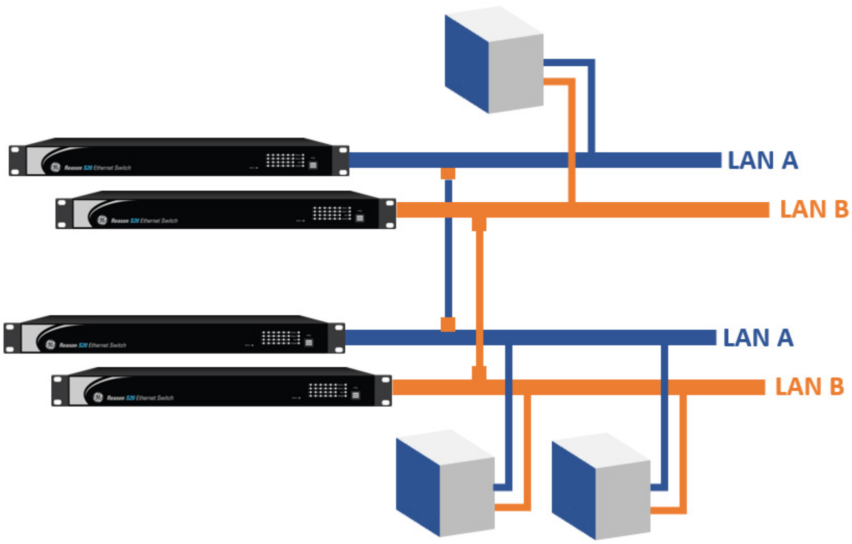

**Figure 4 – Example of PRP network topology.**

HSR operates in a ring topology, and as the protocol is supported by the devices, HSR can operate without dedicated Ethernet switches. On a HSR network, each device sends the same frame on both directions sail safeguarding the system against a single point of failure in the ring. Although HSR provides seamless redundancy and is cheaper than PRP, there are two main concerns when using a large ring in a process bus. The first is related to reliability, as once the ring is composed by many devices, the possibility of two failures increase, to which the network is not prepared for. The second is related to bandwidth, as all devices on the ring must support all the data flow in the network. To avoid that, HSR networks are usually composed by multiple rings with a small number of devices each, and redundancy switches (Redbox) interconnecting them all. The interconnection may rely on other topologies, such as HSR, by creating a ring of rings (not recommended due to bandwidth limitations), or PRP (most commonly used).

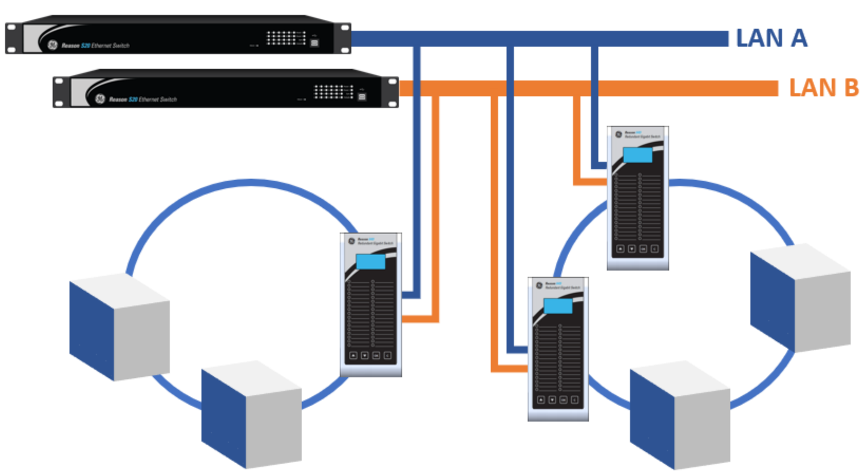

**Figure 5 – Example of HSR network rings interconnected through a PRP network.**

***Network configuration***

In a 61850 network, special functions may be required to ensure the switches will perform appropriate treatment of substation automation traffic across the network. Defined in IEEE 802.1Q [2], functions as VLANs and Quality of Service (QoS) are designed to implement flow control, traffic shaping, or queuing differential services in the network. Class of Service (CoS) is used in support of QoS, and it assigns priority values to data messages in order to discipline the network traffic. The basic challenge is that GOOSE, Sampled Values and Precision Time Protocol messages are multicast, operating at the basic data link layer (Layer 2) of a network switch. They will pass through the entire network on a first-in, first-out basis in switch buffers unless properly managed.

Virtual LAN technology allows separation of traffic through logical networks. In power system communication, where IEC-61850 messages are expected with different priority and usage, there will be only one physical path for each IED and the packets must be separated logically.
When using VLAN traffic segregation, multicast messages are forwarded only onto the VLAN that the multicast message belongs to. Thus, GOOSE, Sampled Values and PTP traffic will flow separately from each other. Finally, as the traffic is separated, IED equipment that expects to receive only GOOSE messages will not have its network interface interrupted by Sampled Values data, for example.

An example of expected VLAN traffic segregation is shown in Figure 6. In this example, there are 3 VLAN configured, one for PTP traffic, one for Sampled Values traffic and another one for GOOSE traffic. The Merging Unit is the publisher of GOOSE and Sampled Values messages, and it is the only slave clock of PTP synchronization. Note that a ring physical topology is used for example purposes, as it is a common physical network topology in power system communication.

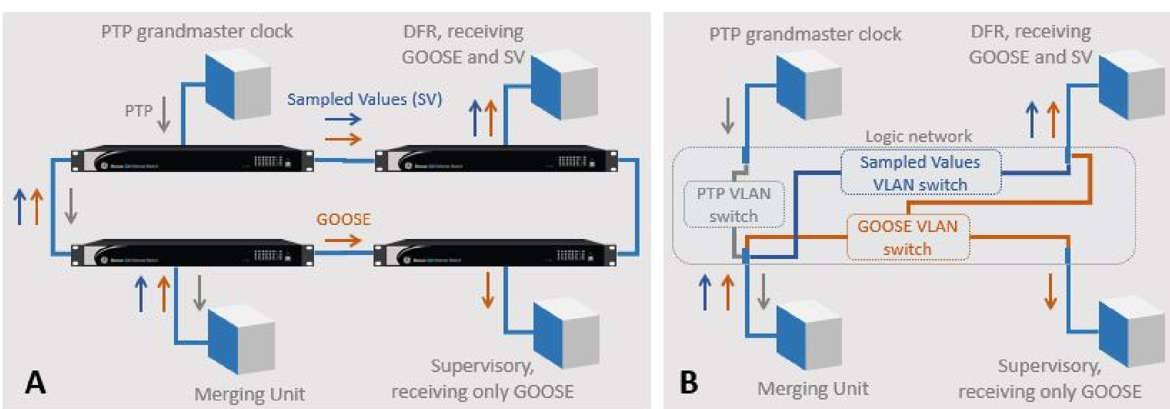


**Figure 6 –Power system communication, (a) Physical network (b) logical network using VLAN.**

Lastly, to make sure high priority packets will not be dropped in the case of high traffic flow, Quality-of-Service (QoS) mechanisms must be used to ensure critical data will not be lost. The QoS spares part of Ethernet port bandwidth to be used only by these messages. When using QoS, if low priority data reaches its bandwidth (which is the Ethernet port bandwidth minus the spared bandwidth to high priority messages), there will be low priority data loss. High priority data will not be affected, as it has guarantee of bandwidth. Such situation is shown in Figure 7.

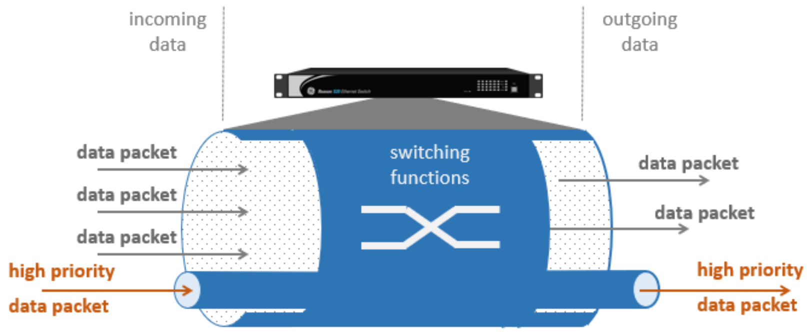


**Figure 7 – Packet prioritization in a high traffic flow condition.**

Overall, it is recommended to separate each Sampled Values stream, each GOOSE stream and PTP with a unique VLAN. That is the best way to ensure complete management of IEC 61850 traffic, and avoid unnecessary load where data is not required. The priorities defined for each message type in IEC 61850-90-4 should be followed when configuring QoS, which is usually done by setting appropriate PCP values in the VLAN tags.

**Table 37 – IEC 61850-5 interface traffic**

| Function Type/Message | | Interface (Table 1) | Protocol | Max. delay ms | Bandwidth | Priority | Application |
|---|---|---|---|---|---|---|---|
| 1A. Trip | GOOSE | 3,8 | L2 Multicast | 3 | Low | High | Protection |
| 1B. Other | GOOSE | 3,8 | L2 Multicast | 10 to100 | Low | Medium High | Protection |
| 2. Medium Speed | MMS | 6 | IP/TCP | <100 | Low | Medium Low | Control |
| 3. Low Speed | MMS | 6 | IP/TCP | <500 | Low | Medium Low | Control |
| 4. Raw Data | SV | 4 | L2 Multicast | 4 | High | High | process bus |
| 5. File Transfer | MMS | 6,7 | IP/TCP/FTP | >1 000 | Medium | Low | Management |
| 6. Time Sync | Time Sync | | IP (SNTP) L2 (PTP) | | Low | Medium High | General Phasors, SVs |
| 7. Command | MMS | 6 | IP | | Low | Medium Low | Control |

**Figure 8 – Table 37 from IEC61850-90-4 showing the priority for each message type.**

**FAT for Digital Substations**

A substation protection and control (PAC) system conceived using IEC 61850 provides benefits related to ease of equipment installation, configuration, and project execution, as most of the interconnection between equipment is made logically through a switched network. In this scenario, most of the tests related to performance, interlocking operational diagrams and protection functions can be simulated in a software-based simulator. Also, these functions can be (and should be) tested before equipment goes to the field.

Thus, in a digital substation project, factory acceptance tests (FAT) should be considered as a crucial part of commissioning. A complete system FAT can be performed, where messages and field actuations can be simulated through software. Utilities can do performance tests in their system before equipment is even delivered to the field. Also, as equipment interconnection is mainly performed through logical configuration, any logical issue, protection maloperation or operational error can be fixed during FAT, before equipment leaves the factory, in a controlled scenario.

Performing the real tests during FAT, commissioning test time drastically decreases. Using analog interfaces, all interconnection between equipment is made through hardwired cables between panels, and signals are brought from the yard through copper cables. Most of commissioning time is spent checking the actual interconnection of the copper cables. In a switched network environment, where a shared network is used for all station and process bus messages, these interconnections are “virtualized” through VLANs, Multicast Filtering and QoS queues at the switches. If the network is tested in the FAT, field tests are basically checking the signals that go to the merging units in the yard are properly processed. So, checking analog signals, all protection actuation and interlocking logic controls does not need to be re-done in the field, as it was previously performed. This means that field testing time spent decreases from months to days or weeks, depending on the size of the substation.

***Main requirements***

To guarantee time savings in field services in a digital commissioning project, there are some points that utilities, end users and manufacturers should pay attention to: project drawings, FAT requirements, and scenario simulation.

The beginning of a well-executed project of a digital substation is not so different from a project for a conventional one. However, as most signals in a digital substation are available to IEDs through a switched network, the network project should be much more detailed than it is generally done today. Three-line diagrams and terminal block interconnections are replaced by switch ports configuration, VLAN, multicast MAC destination, QoS class definitions, and so on. Thus, a more detailed architecture should be represented for proper network configuration. Figure 9 is a good example of how a network should be represented in a project for proper IED configuration.

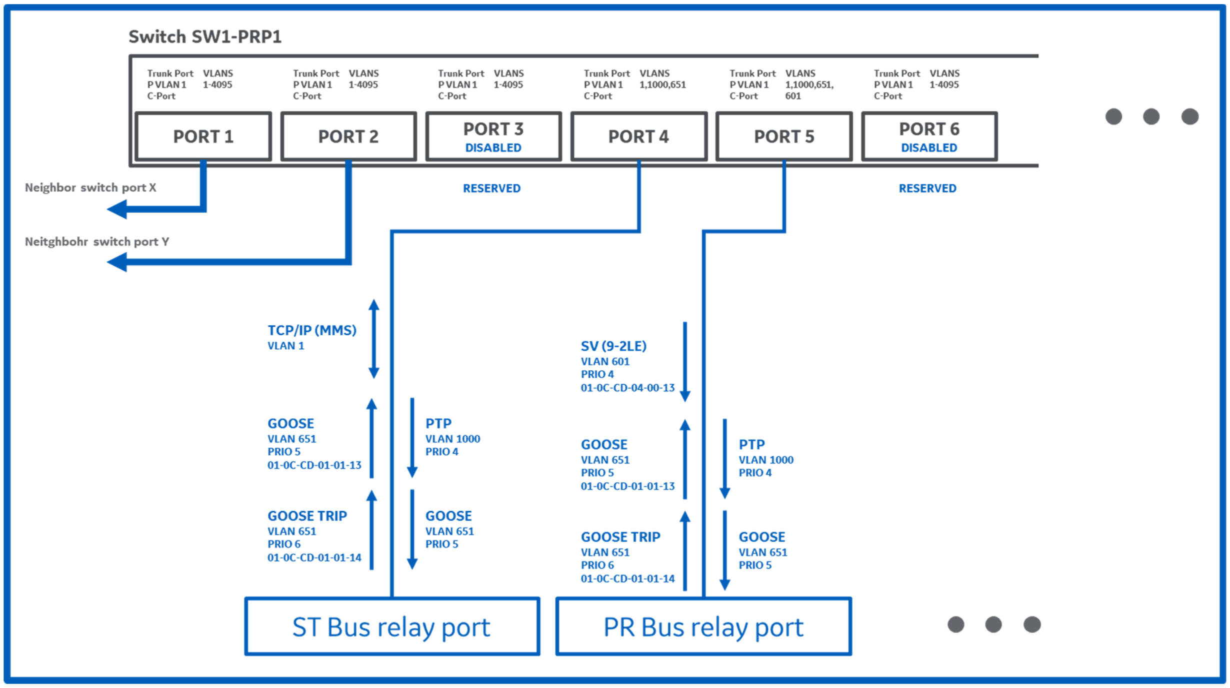


**Figure 9 - Example of network project containing IED configuration information.**

In addition, FAT requirements should guarantee that the system and its performance are tested in this controlled scenario. Therefore, all logic and protection functions should be tested in that phase of the project. FAT plans should consider system testing not only in normal operation but also in contingencies situations, such as overload on the network or failure in IED connections. For a completely new substation, it is required that all panels are mounted and interconnected as they will be in field, so that a real simulation of the system is performed. Proper time must be scheduled for users to run all the necessary tests with the actual system. For a system expansion, where FAT is performed only for a few bays, utilities can use software-based traffic simulators to test network performance, and real-time power system simulation or protection test-sets to ensure protection performance. In both situations, networking load, along with IED and switch behavior must be verified for worst case scenarios such as when there's a loop in the network or when a temporary overload occurs, like broadcast storms for example.

***Real case study***

The best way to understand FAT requirements is through an actual project. The project used in this example is composed of a main substation and three additional bays in two adjacent substations. The project has in total six 220 kV bays, six 60 kV bays, one 22.9 kV bay and one 10 kV bay. There is a full PRP network, where process and station bus share the same physical infrastructure with logical traffic segregation done using VLANs.

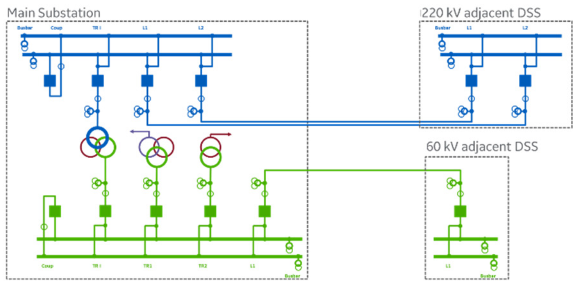


**Figure 10 - Single Line Diagram from example system.**

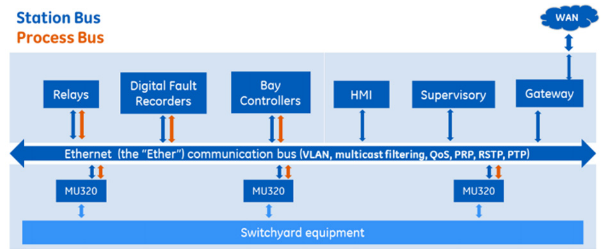


**Figure 11 - Process and Station Buses strategy: single shared switched network infrastructure**.

The first step, that is, network project detailing, was executed before the FAT, so all the network design details were already defined in the project. This means that the IEDs connected in each switch port, VLAN IDs for each stream, QoS queues, MAC destination addresses, GOOSE and SV IDs and APP IDs, were selected and described at the network project. With this information, all network configuration for each IED was done in advance by the field team.

With the detailed network design, network configuration and initial checks (equipment health and network status with all equipment connected), including GNSS clocks, Ethernet switches and all Merging Units were performed in two days of engineering work in factory during FAT.

In this FAT, protection and control equipment was not available while the network was configured and checked, so the step of having all equipment connected to check the behavior of the entire system in a real scenario was not performed. Even though the relays were validated separately using a dedicated process bus for FAT testing, this was a simulated check, not a complete system test, so the benefits of predicting system issues before commissioning were not enjoyed. However, the IED configuration for protection and automation functions was tested, so the main benefits of configuring and checking the IEDs before going to site could still be enjoyed. even though it could be improved, as logical interconnections for the interlocking diagrams and the protection functions itself were tested and validated.

PAC system installation at site took a few days, instead of weeks, which was clearly understood as a benefit of a digital substation when compared to conventional systems. Also, as protection and interlocking functions were tested in FAT, commissioning was basically checking if yard connections to merging units were correct. This was performed by checking the IEDs measurements, which took much less time to complete in comparison to the usual approach.

On the other hand, after connecting all IEDs to the network, some integration issues were identified, mainly related to time synchronization, configuration mismatch and bad network performance. These issues could have been predicted in FAT and would have minor impact on the project if early detected. However, as the equipment was already installed, the impact on the project was higher than planned, and the time on site for commissioning too.

Even though the system was not fully functional as expected, the issues found didn't prevent the system to start operating. As the main protection and automation functions were running, it was possible for the substation to be energized on time. Although FAT was not performed with a full system, it was enough to guarantee the safe operation of the main functions. The synchronization protocol was temporarily replaced, so time-dependent functions, such as differential protection, continued to operate while field engineers were investigating the issues. In addition, as the system design implements a full PRP network, field engineers were able to perform several diagnostics in one network, while the other one was running normally.

### *Final comments from real case FAT*

After the project was delivered and issues presented were diagnosed, it was observed that there are several advantages for project execution related to a full digital system using a shared infrastructure composed by switched network in a PRP architecture:

- Time spent for project execution (project, FAT and commissioning) is lower if compared to conventional systems;
- Time for commissioning decreases from months to days or weeks, depending on substation size;
- Diagnosis and fixing issues can be performed in a live system, with no need to shut down transmission lines and busbars;
- Protection and automation control services are now related to network diagnosis, which is safer and easier to be performed if compared to tradition substations;

In addition, there are some points that utilities and manufacturers should pay attention to avoid delays on the project and unwanted execution issues:

- Network project should be detailed enough so field engineers do not need to decide or load IED parameters in the field, as it is in general done nowadays;
- FAT tests should be planned to guarantee that the system will be simulated in a real situation, with all merging units, switches and IEDs in operation, so field issues can be detected and diagnosed before equipment ships to site;
- Network should be designed in a manner that a live system can be tested and diagnosed without compromising power system operation, or the operation of nearby bays, in case that a shutdown is mandatory.

## Conclusion

Fully digital substations are already a reality, with installed base growing more and more every year. One of the most challenging parts of moving to this kind of substation is the network engineering. Not because it is difficult to manage, but because it is a completely new field of knowledge to current power system engineers. Also, because it plays a fundamental role in this solution, as the network carries all the data needed for protection and control applications.

Real projects have shown us that neglecting its importance, and simply expecting a plug and play behavior from network devices, can lead to system failure, jeopardizing the entire substation. Even though some people might see it as a barrier against adopting full digital substations, learning a few new concepts doesn't overcome in anyway the benefits brought by such solution. The main concerns, and how to address them, have been presented in the few pages of this article. It is just a matter of getting familiar with the protocols and putting thoughtful consideration into this part of the project. Disruptive technology requires people to adapt. Only then can we unleash the full potential of digital substations.

**References**


[1] "Communication networks and systems for power utility automation part 90-4: Network engineering guidelines", IEC 61850-90-4 Technical Report, Edition 1.0, August 2013.
[2] "IEEE Standard for Local and metropolitan area networks, Virtual Bridged Local Area Networks", IEEE 802.1Q-2005, December 2005.
[3] C. A. Dutra, I. H. da Cruz, S. L. Zimath. "Característica do barramento de processo em uma rede de comunicação baseada em IEC 61850", XXII SNPTEE, October 2013.
[4] L. B. Oliveira, M. Zapella, A. Sarda, W. Zanatta. "Managed Ethernet Switches Performance over IEC 61850 Networks: Applications with High Traffic Flow", DPSP, March 2016.


**Authors**

**Rich Hunt**

**Rich** is a Senior Product Manager with GE Grid Solutions, focusing on digital substation solutions for protection and control systems. Rich has over 30 years' experience in the electric power industry with both utilities and solution providers, and has authored more than 35 technical papers presented at more than 90 conferences. Rich earned the BSEE and MSEE from Virginia Tech, is a Senior Member of IEEE, a member of the Main Committee of the IEEE Power System Relaying Committee, the U.S. representative to the CIGRE B5 Technical Committee, and is a registered Professional Engineer.

**Marcelo Zapella**

**Marcelo** is Product Manager at GE Grid Solutions, responsible for Reason Ethernet Switches and Time Synchronization product line. Holding a Bachelor's Degree in Electrical Engineering from UDESC in Brazil, Marcelo has earned experience in Electrical Power Systems in last years, by professionally acting at GE's position and academically coursing Master's classes.

**Carlos Pimentel**

**Carlos** has a Degree in Electrical Engineering from UTFPR in 2011. He has 5 years of experience in the electricity sector and currently holds the Application Engineer function in GE Grid Solutions - Reason Product Line, being part of the Global Applications and Support team.

**Gustavo Silvano**

**Gustavo** is an Automation and Control Engineer with 7 years of experience working on embedded software development for electric power system applications. At his current role in GE Grid Solutions as Emerging Technologies Engineer, he is helping the R&D team to stay on top of state-of-the-art technology.