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Meeting requirements in an IEC 61850 station bus SAS

by

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SUMMARY

Due to the communication based approach of an IEC 61850 Substation Automation System (SAS), the local area network (LAN) plays a vital role for a successful implementation, as it is the media for interfacing between different IEDs of the SAS. Therefore, the LAN must not only fulfil all the communication requirements between all IEDs, but also has to cope with the general SAS requirements such as redundancy, system-independent (duplicity) architectures, fault-tolerance, recovery time, maintenance and so on, giving an homogeneous solution for both telecontrol and protection & control functions inside a SAS.

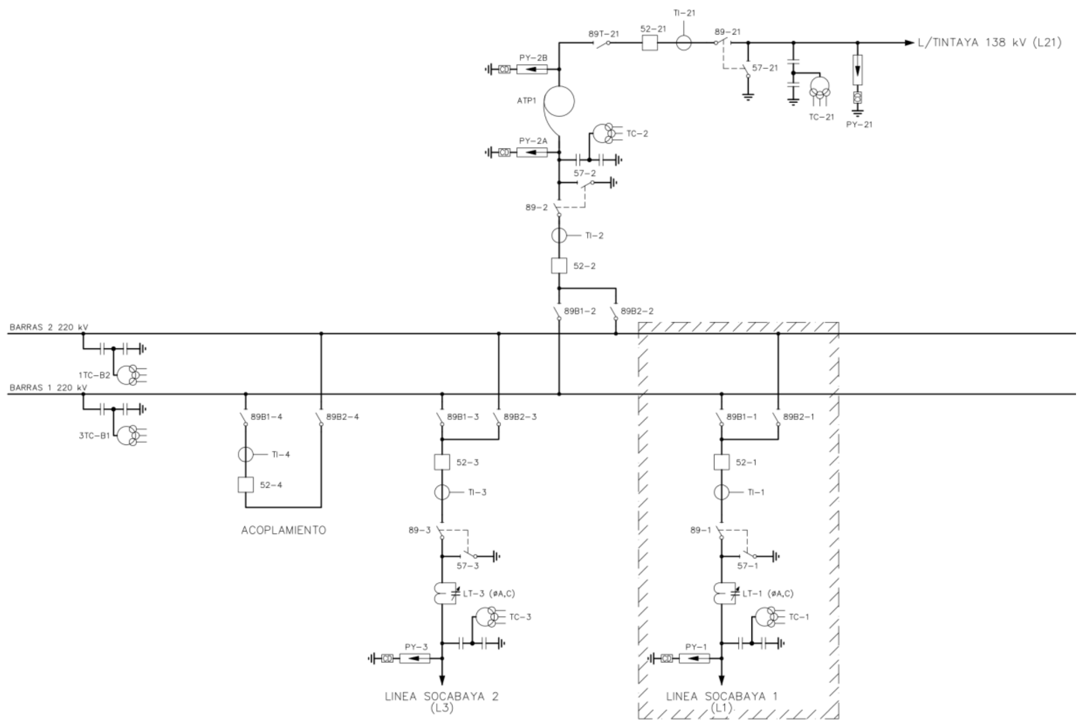
This paper describes the local area network architecture defined for the Tintaya Nueva 220 kV substation in Peru, where an IEC 61850 station bus was implemented and commissioned in 2014. In the first section of the paper, the general SAS requirements and constraints that affect the local area network are defined. In the second section, several possible LAN architectures are described and evaluated. In the third section, the selected local area network is explained in detail. The last section is about lessons learned for the future.

KEYWORDS

IEC 61850, switch, network, redundancy, fault tolerance, protection system, virtual LAN, IED, SAS, PRP, Goose, MMS, client, server

1. CONTEXT

Tintaya Nueva 220 kV substation is located in Tintaya, Perú, at 4.500 msl. It is a double busbar substation layout and a coupling bay. At the moment of project, there were two feeder bays to Socabaya, one transformer 220/138 kV bay at HV, one coupling bay and one feeder bay at the LV side of the transformer.



Communication between this new substation and the existing Tintaya 138 kV substation was done using two mono mode fibre cables of 24 optic fibres each.

All electronic devices and cabinets were located in the same building, except the field cabinets used for interfacing with primary elements at hardwired process level.

The substation automation system was composed of the protection system and related telecommunication equipments, the substation control system and the IP Ethernet-based management network.

The Tintaya Nueva substation control system was connected to the REDESUR control centre in Socabaya, Arequipa, and then connected to COES under ICCP protocol.

2. REQUIREMENTS

Following IEC 61850 philosophy, there are two subsystems in the Substation Automation System Protection & Control subsystem and remote control (often known as telecontrol) subsystem that need to interface between them. Communications between the involved IEDs using IEC 61850 communication protocols is done using an Ethernet-based network. Therefore, one of the key points of an IEC 61850 SAS is to find a network architecture that fulfils all the requirements of the different subsystems. That is, one network architecture will service for both Protection & Control and telecontrol subsystems.

The specific requirements for the Protection & Control subsystem are, among others, the following:

- Two protection systems, primary or A and secondary or B, with no common points of failure for the main protection functions
- N-1 fault tolerance for the whole Protection & Control subsystem for the main protection functions
- Related protection functions (50S/62 – RBRF, 79 – RREC, disturbance recorder) accessible from both protection systems

The specific requirements for the telecontrol subsystem are, among others, the following:

- N-1 fault tolerance at station level for supply source, IEDs and communication paths to the bay level
- Redundant power supply for all IEDs
- N-1 fault tolerance at bay level for supply source and communication paths to the station level

At the moment of the design/engineering phase of the project, there were some restrictions in the IEDs implementation which are important to remark as they have implications about the chosen network architecture:

- The protection IEDs should be well known models in the company
- The protection IEDs did not support PRP at procurement stage
- PRP Redundancy Boxes did not exist at procurement stage

As a summary, the goal was "*designing the network architecture to fulfil with the requirements of both Protection & Control and Telecontrol subsystems of the SAS*".

3. ARCHITECTURES

3.1 PROTECTION AND CONTROL SUBSYSTEM ARCHITECTURE

The protection subsystem is compound by several IEDs depending on the type of the associated bay as is shown in the following table:

Number of Bays	Bay Type / IED	Primary Prot.	Secondary Prot.	3rd Winding Prot.	Circuit Breaker Prot.	Disturbance Recorder
1..n	Line	X	X		X	X
1..n	Transformer HV	X	X	X	X	X
1..n	Transformer LV				X	X
1	Coupling Bay				X	
1 (*)	Busbar	X	X			

(*) Busbar protection IEDs allocated at station level.

As it was stated in section 2, two protection systems, primary or A and secondary or B, with no common points of failure for the main protection functions are deployed:

- Primary and Circuit Breaker Protections are assigned to Primary or A protection system.
- Secondary and 3rd Winding Protections as well as Disturbance Recorder are assigned to Secondary or B protection system.

- In terms of data interchanges, it is possible to classify the protection functions deployed by the above IEDs attending to their communication needs:
    - No communication needs
    - Communication needs inside a Protection System (A or B)
    - Communication needs between Protection System A and B
    - Communication needs between a Protection System (A or B) and busbars system protection (A or B)
    - Communication needs between a Protection System (A or B) of a bay and Protection System (A or B) of another bay

None of the above IEDs implements PRP and no other interoperable redundancy protocols are used.

Data interchanges are implemented by two means:

- GOOSE messages: used in data interchange between protection IEDs and also for commands from the BCU to protection IEDs
- MMS connection: used for reporting function information from protection IEDs (servers) to the BCU (client)

3.2 TELECONTROL SUBSYSTEM ARCHITECTURE

The telecontrol subsystem is compound by the IEDs indicated below:

- An Analog/Digital (A/D) Converter per bay for operation measures (active power, reactive power, voltage, current)
- A Bay Control Unit (BCU) per bay
- A redundant Substation Control Unit (SCU) at station level.

The A/D Converter sends information to the BCU through an MMS communication.

The BCU communicates with all the IEDs associated to its bay by mean of a client/server connection (MMS) playing the role of the client in all cases. Each BCU communicates also with the SCU by mean of a client/server connection (MMS) playing the server role.

Furthermore, the BCU has to established certain commands to primary and circuit breaker protection IEDs using GOOSE messages.

The SCU is compound by two identical IEDs working in a host-standby redundant scheme. These IEDs are responsible of collecting all the information sent by the different BCUs by mean of client/server connections (MMS). This information is grouped and sent to the Control Centre using 60870-5-101 protocol. Additionally, this connection is used to deliver the commands from the Control Centre to the correct BCU which in last step, will send the command hardwired to the switchyard or through GOOSE messages to protection IEDs.

3.3 IEC 61850 INTERCHANGES

The following tables summarize the data interchanges between IED´s

	GOOSE Subscriber							
GOOSE Publisher	PP	PS	PI	OSC	PDB	MC	BCU	SCU
PP		x	x	x	x			
PS	x		x	x	x			
PI				x	x			
OSC								
PDB	x	x	x	x				
MC								
BCU		x	x					
SCU								

	MMS Client							
MMS Server	PP	PS	PI	OSC	PDB	MC	BCU	SCU
PP							x	
PS							x	
PI							x	
OSC							x	
PDB								
MC							x	
BCU								x
SCU							x	

Interchanges data between Line Bay IEDs

	GOOSE Subscriber					
GOOSE Publisher	PI	OSC	PDB	MC	BCU	SCU
PI		x	x			
OSC						
PDB	x	x				
MC						
BCU	x					
SCU						

	MMS Client					
MMS Server	PI	OSC	PDB	MC	BCU	SCU
PI					x	
OSC					x	
PDB					x	
MC					x	
BCU						x
SCU					x	

Interchanges data between Coupling Bay IEDs

		GOOSE Subscriber												
		HV-BAY								LV-BAY				SCU
GOOSE Publisher		PP	PS	PI	PT	OSC	PDB	MC	BCU	PI	OSC	MC	BCU	
HV-BAY	PP		x	x	x	x	x			x	x			
	PS	x		x	x	x	x			x	x			
	PI					x	x							
	PT	x	x	x		x				x	x			
	OSC													
	PDB	x	x	x		x								
	MC													
	BCU			x										
LV-BAY	PI										x			
	OSC													
	MC													
	BCU									x				
SCU														

		MMS Client												
		HV-BAY								LV-BAY				SCU
MMS Server		PP	PS	PI	PT	OSC	PDB	MC	BCU	PI	OSC	MC	BCU	
HV-BAY	PP								x					
	PS								x					
	PI								x					
	PT								x					
	OSC													
	PDB													
	MC								x					
	BCU													x
LV-BAY	PI												x	
	OSC													
	MC												x	
	BCU													x
SCU									x				x	

Interchanges data between IEDs considering two bays: High Voltage and Low Voltage Transformer Bays

(PP – Primary Protection; PS – Secondary Protection; PI – Circuit Breaker Protection; BCU – Bay Control Unit; PT – Tertiary Transformer Protection; OSC – Disturbance Recorder; MC – Operation measurands; PDB – Differential Busbar protection)

3.4 NETWORK ARCHITECTURE

The fundamental design criteria for this network are as follows:

- High reliability and high availability:
  - A single failure of network elements, either a switch or a link, shall not affect the operation of the system.
  - A single failure of network elements shall not affect the main protection functions of a protection system
- The time transfer of critical information like GOOSE message must be low, easily predictable and deterministic as far as possible.
- The network architecture must be highly maintainable.

Rugged switches that compliant the EMI immunity requirements of the IEC 61850-3 were selected in order to archive high reliability.

High availability is achieved by means of a redundant network design. The LAN design includes two switches per each bay and two switches at station level. With this approach, a good option is to build two independents Ethernet LANs (LAN-A and LAN-B), interconnected if necessary.

Several network topologies, which satisfied the network design criteria, were studied in order to find the most suitable one. These topologies were: double ring and double star.

In all the studied solutions, an identical topology is proposed for LAN-A and LAN-B to facilitate maintenance.

Double Ring with connection at bay level

In a ring, each switch is only connected to two neighbour switches, forming a physical loop, as shown in figure1.

The protection system A of each bay is connected to switch A whereas that protection system B is connected to switch B in order to prevent a single point of failure.

The control & proteccion IEDs connected to station level (SCU, PPB, etc..) and mULC at bay level are devices with a double access interface using PRP (DANP, Double Access Node using PRP), connected both LANs.

Without compromising the N-1 requirement, data interchanges between Protection system A (PP) and Protection system B (PS) must be possible. For this propose, a direct link between each switch A and each switch B is enabled. However, PRP traffic must be forbidden in these links as PRP is a protocol designed to operate over two non-interconnected LANs.

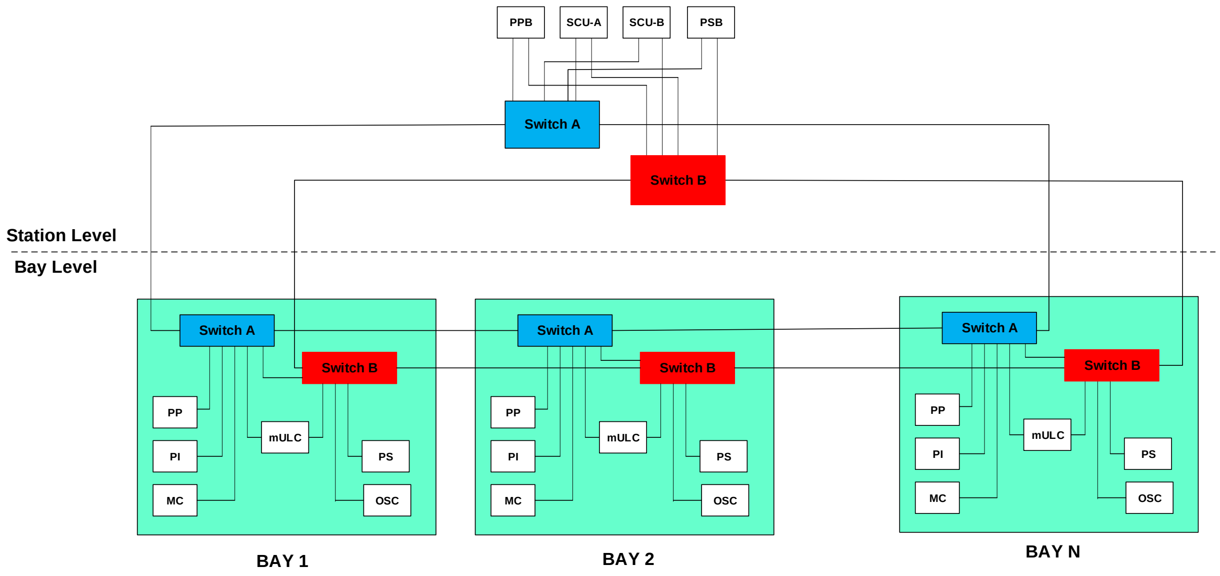


Fig.1 Double ring with connection at bay level

These connections complicate the design of the network. Due to this, the final topology is not exactly two independent rings but a collection of multiple rings, as show in figure 2.

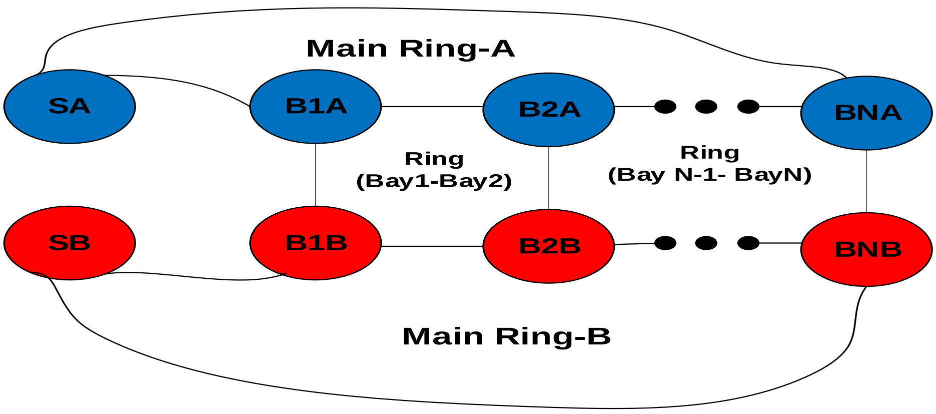


Fig.2 Detail of double ring with connection at bay level.

In this topology, a protocol against loops is necessary to ensure that frames do not circulate indefinitely. A possible solution is to use MSTP (Multiple Spanning Tree Protocol) which allows multiple instances of Spanning Tree Protocol per Virtual LAN.

The main drawbacks of this topology are:

- Non deterministic time transfer through the Ring. The time transfer will increase with number of switches that frame across and the routes depend on the convergence of the prevent loop protocol (MSTP in our case). With every change in the network, MSTP will update the routes and, therefore, the transfer time will vary.
- The network engineering is very complex and the maintenance is difficult.

Double Star with core switches connected

In a star topology, there is a core switch with links to the rest of the switches. This basic star topology is adopted for each LAN, as show in figure 3.

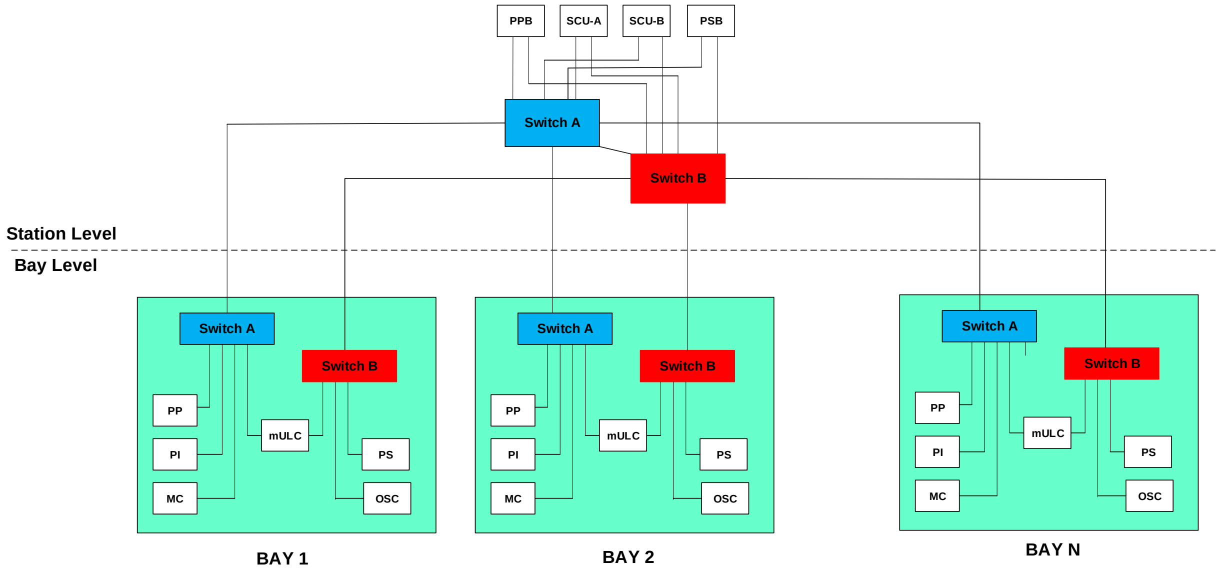


Fig.3 Double ring central switches connected.

The core switches are interconnected to allow the data interchanges between protection system A and protection system B.

This topology is not complex, it has not physical loops and the maximum number of hops is four so the latency is more deterministic and predictable than the ring topologies.

The main drawback of this topology is the failure of any of the core switches or of the link between both. Any these failures would lead to a connectivity loss between protection system A and protection system B. This connectivity loss would affect to all the bays at the same time. To improve this limitation, a double star with connection at bay level is proposed.

Double Star with connection at bay level

This topology is formed by a double star. The interconnection between protection system A and protection system B is not done at the core switches. Instead, this interconnection is done between the switches at each bay.

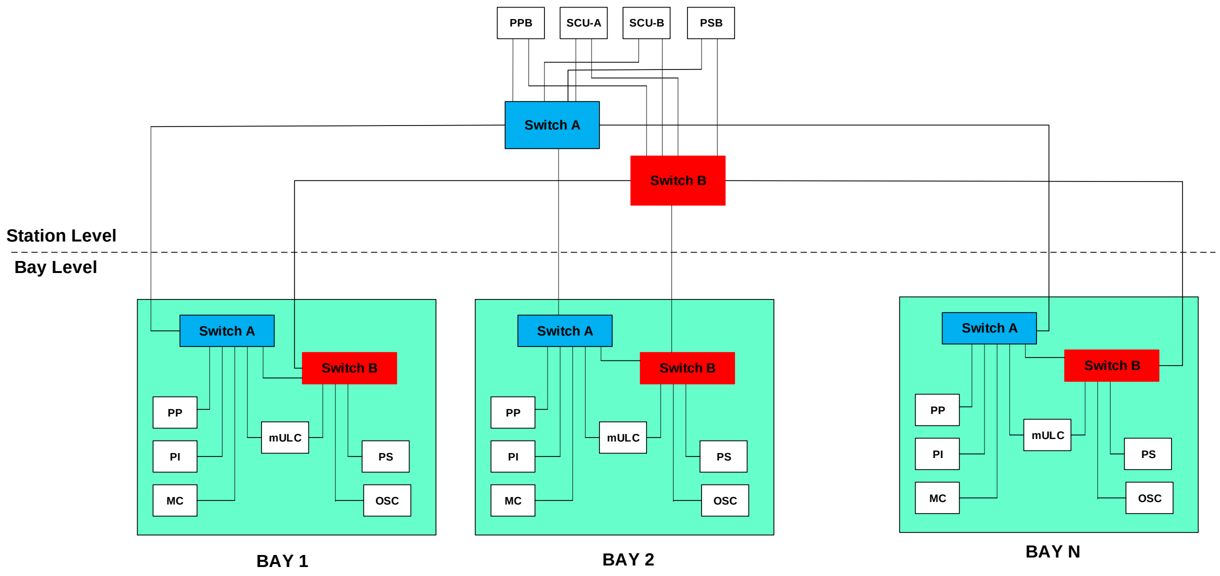


Fig.4 Double start with connection at bay level

These links at bay level convert the double star in multiple rings as show in figure 5.

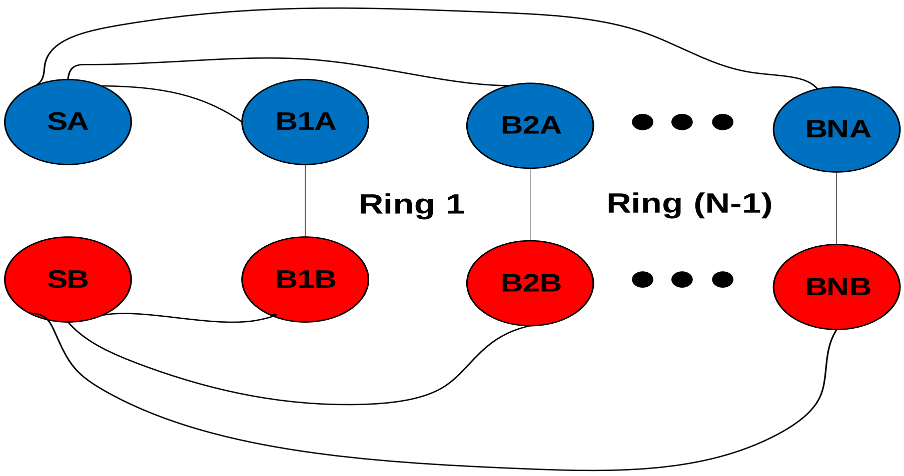


Fig.5 Fig.2 Detail of double start with connection at bay level.

Over this physical topology, a double star logical topology using VLANs is implemented for PRP devices. In order to allow data interchanges between protection system A and protection system B, point to point logical links, using VLANs, are enabled in each bay.

This topology was the implemented one in Tintaya Nueva 220kV.

3.3 ENGINEERING ADOPTIONS

During the engineering process, the following adoptions were defined:

- Assign a different multicast address to every GOOSE message
- Assign a specific way of naming GOOSE messages
- Assign a different AppID to every GOOSE message
- Define different GOOSE messages in a publisher to different subscribers

4. ADOPTED ARCHITECTURE

The adopted network architecture was a mesh topology for GOOSE traffic, and a double independent star for TCP/IP traffic. Protection IEDs, as they did not have PRP implemented, were considered as SAN devices, while the BCU and SCS of the telecontrol subsystems were DAN devices.

The use of VLAN made this architecture possible; the link between switches at bay level was only visible for GOOSE messages, but not for TCP/IP traffic and thus, there were no loop in the network from the point of view of PRP protocol.

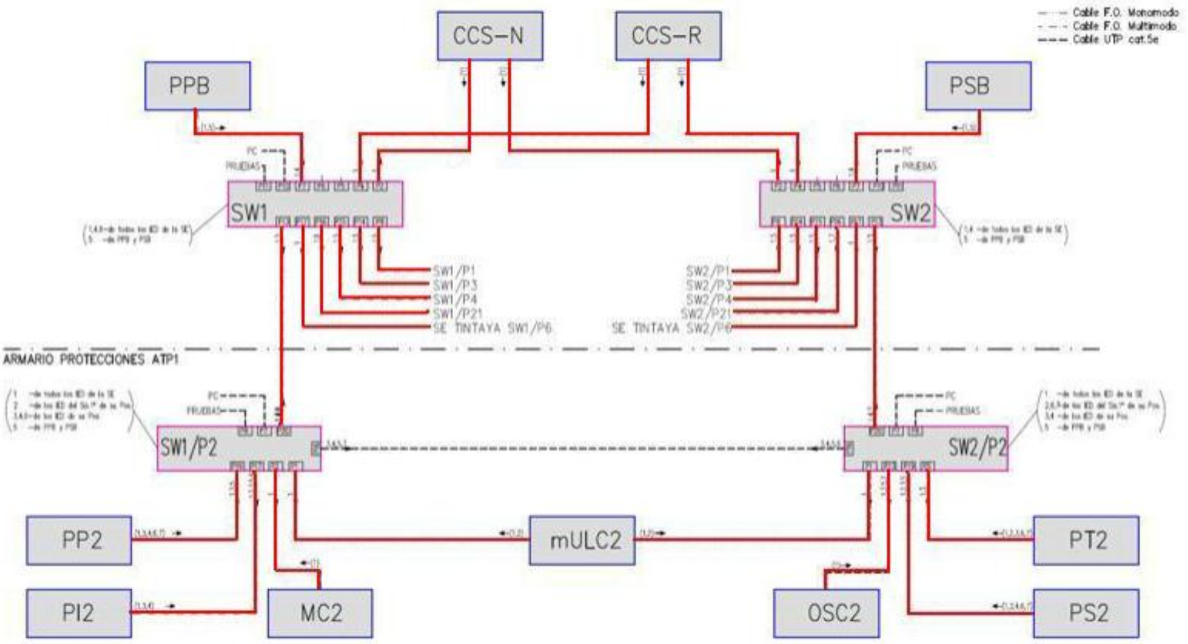
For protection and control subsystem, there is a GOOSE visibility between both protection systems using specific VLANs. The following table shows the VLANs defined in the project:

VLAN number	Description
1	TCP/IP traffic
2	GOOSE traffic inside a per-bay protection system
3	GOOSE traffic at bay-level between protection systems
4	GOOSE traffic sent to the differential busbar protection IEDs
5	GOOSE traffic sent from the differential busbar protection IEDs
6,7	GOOSE traffic between IEDs at both sides of a transformer bay
9	GOOSE traffic for synchronism information
10	GOOSE traffic for interchange of information with other companies

VLAN 1 to 5 will be studied in the following sections.

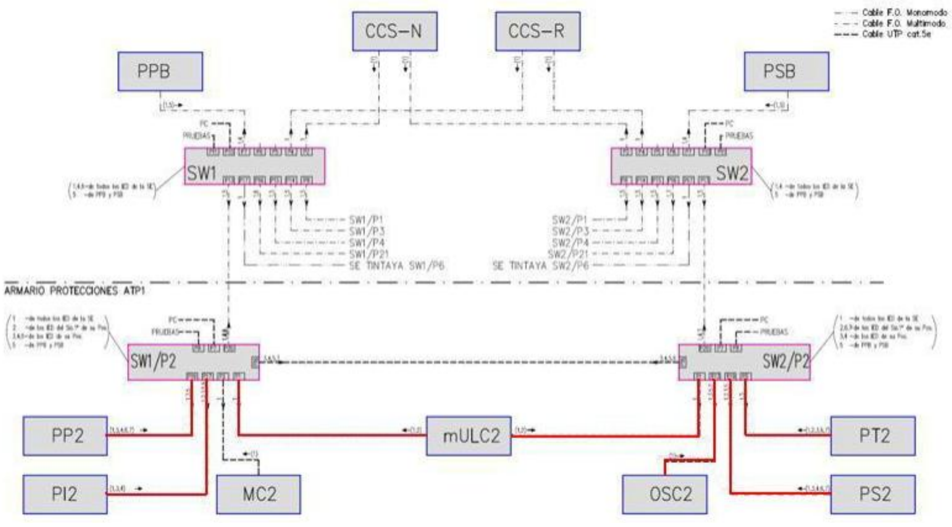
4.1 VLAN 1: TCP/IP traffic

This VLAN was assigned to convey all TCP/IP and other network protocols traffic. The VLAN is invisible for the trunk links connecting both protection systems at bay level. The following figure shows this VLAN visibility.



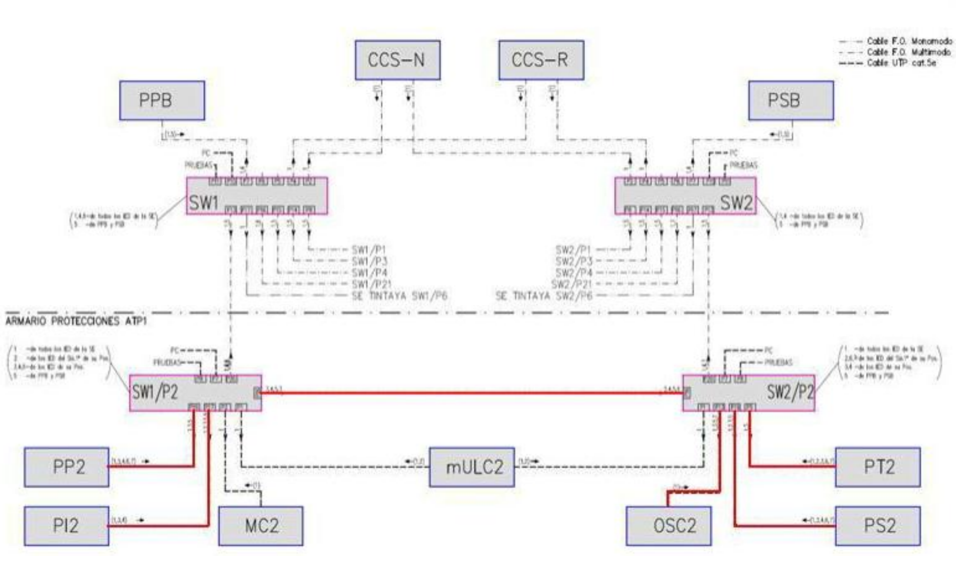
4.1 VLAN 2: Communication for the same protection system in a bay

This VLAN was assigned to all interchanges of GOOSE information between IEDs in the same protection system of the same bay. The traffic is isolated in a per-bay, per-protection system mechanism. The following figure shows this VLAN.



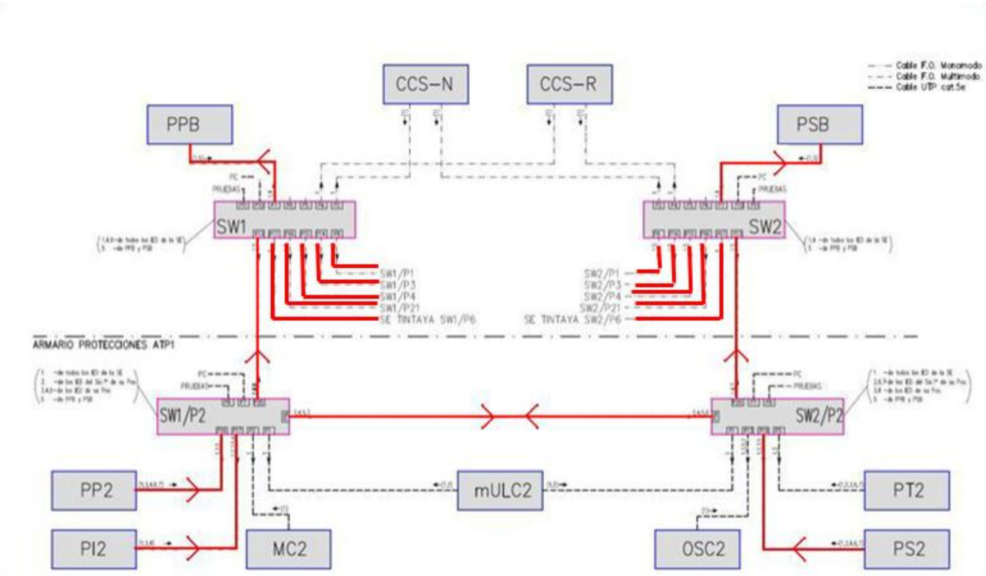
4.2 VLAN 3: Communication for related protection functions

This VLAN was assigned to all interchanges of GOOSE information between IEDs of the same bay but in different protection system. This VLAN conveyed GOOSE information for breaker failure function, auto-recloser and also for the stand-alone disturbance recorder. The following figure shows this VLAN. The traffic is isolated at bay level.



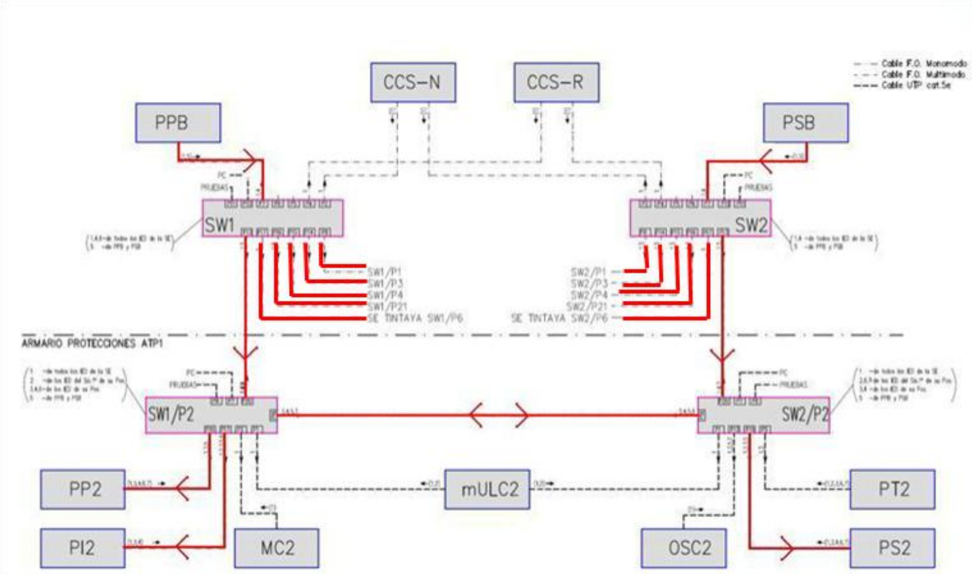
4.2 VLAN 4: GOOSE information to the differential bus bar protections

This VLAN was assigned to all interchanges of GOOSE information published by protection IEDs and subscribed by the differential busbar protection IEDs. It must be noted that VLAN 4 is forbidden to be forwarded from station level to bay level, otherwise a loop would be declared in the network architecture. The following figure shows this VLAN.



4.2 VLAN 5: GOOSE information from the differential bus bar protections to IEDs

This VLAN was assigned to all interchanges of GOOSE information published by the differential busbar protection IEDs and subscribed by bay level IEDs. The following figure shows this VLAN.



5. LESSONS LEARNED

Once this project has been commissioned, there are some lessons learned which the most relevant are the following:

- Using PRP for protection IEDs will increase dramatically the availability of the complete substation automation system
- Network switches configuration is key as any configuration error can cause a loop in the network and thus making the SAS unavailable
- Specific drawings were designed to document the network switches configuration
- Specific test protocols were defined to verify the network switches configuration
- Using PRP for all IEDs will reduce the number of VLANs used
- Defining different multicast address to every GOOSE message made possible test all the publish-subscription Goose interchanges between all IEDs using the multicast filtering capability of the network switches
- Making protection systems totally independent would reduce network requirements as the interconnection between the two LANs would not be necessary

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