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Engineering Guidelines for IEC 61850 Based Digital SAS

Working Group B5.12

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1. SCOPE

The scope and aim of the SCB5.12 is to establish some general guidelines and engineering rules in order to harmonise the solutions according to user needs and expectations and vendor capabilities.

The work included the following steps:

1. Define the engineering requirements focusing in the “final user” (utilities)
2. Try to define the general requirements that the “final user” (utilities) would have for the engineering tools.
3. Identify which features correspond to these requirements or are available within IEC 61850.
4. Determine where there are gaps and how they can be filled.
5. Highlight possible work items for subsequent WGs.

The deliverable is this technical brochure providing engineering guidelines for IEC 61850 based substation automation systems.

2. ANALYSIS OF ACTUAL ENGINEERING

2.1.1. Introduction

The engineering process creates the conditions for adapting a Substation Automation System (SAS) to a specific substation and to the operating philosophy of the user.

Currently, there are different technologies used in electricity utilities. Technology changes to the Substation Automation System have a strong effect on the engineering process. Classification of SAS according to fundamental technology using either conventional technology i.e. electromechanical relays, electronic protection relays, RTUs for SCADA system or using distributed systems with the application of numerical technology. With time, distributed systems have had significant development and the communication standards from the station computer to control centres and to bay units and relay protection units have changed.

Figure 1 shows some of the different IEC communication protocols used in the Substation Automation System today in electricity utilities for distributed systems.

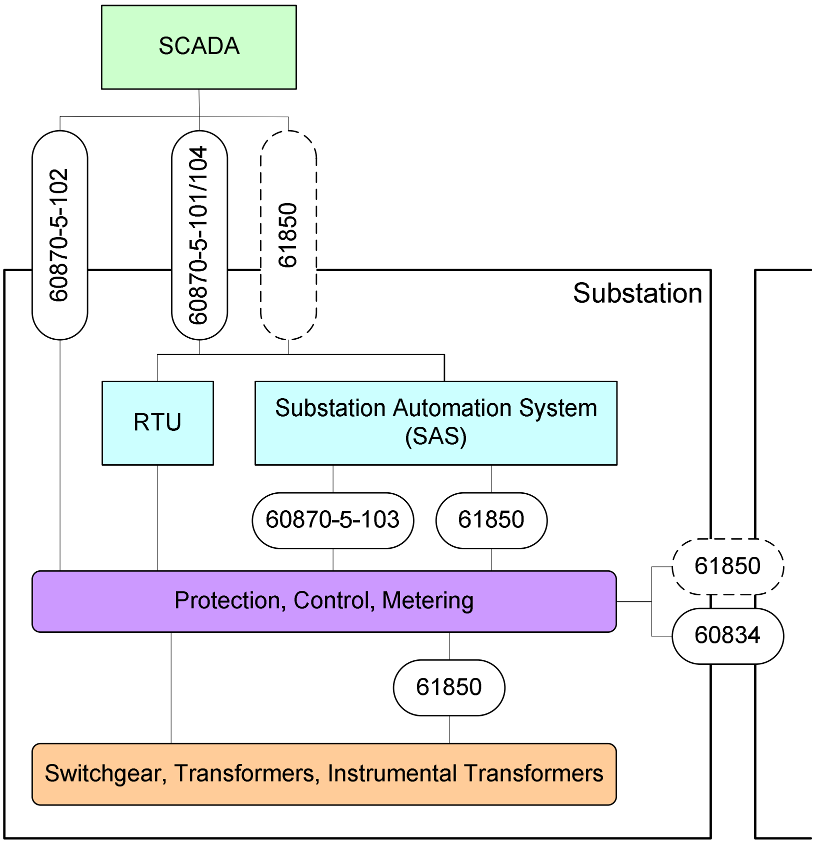

Figure 1. IEC Communication protocols in the SAS for distributed systems

This clause illustrates how the engineering process is influenced not only by technology but also by the organizational structures, procurement strategies and O&M strategies of the actors involved in the complete process.

2.1.2. Types of projects

SAS projects are generally of the following three types:

1. 'Green Field' construction. This is a new substation where the majority of construction and testing work may take place without impacting upon the availability of the primary system.
2. 'Brown Field' extension. This involves adding new circuits or equipment to an existing substation. Care is required during these works in order to avoid affecting adjacent circuits that must remain in service. Careful interfacing with station level functions is also required.
3. 'Brown Field' refurbishment. These projects are generally carried out on site. As with 2, above, great care must be taken to avoid unplanned outages and to ensure seamless integration with other functions within the substation.

The workflows in the engineering process differ according to the particular application. The following applications are defined:

Erecting a new substation

- Without template
- Using templates
- Based on an existing substation (delta engineering)

Modifications in an existing substation

- Reduction / expansion by one bay
- Changing the information scope in one IED (e.g. by modifying one function)
- Replacing an IED with a device from a different manufacturer without change to the functionality
- Replacing an IED due to a change in functional requirements
- Parameter changes
- Firmware exchange (functional modification)
- Firmware exchange (modifications in the area of communication) [5]

2.1.3. Actors in the engineering process

Different actors are involved during the engineering process. They are: manufacturer, suppliers (vendor), users (customer) and service providers, as depicted in Table 1.

Actors	Description
Manufacturer, suppliers (vendor)	The producer of IEDs, system equipment and / or supporting tools, e.g.: • Protection relay • Teleprotection • Controller • Network components • Communication equipments • Operator stations • Gateways • Data acquisition devices • Transformer controller • Interface equipment • Cubicles, boxes, cable ladders, etc. • Main clock system • Cables • Tools

Actors	Description
Users, customer	The user of installed systems, e.g.: • Owners, asset management • Plant operators • Network control centers • Substation services
Service providers	An organization that provides a specific service or services, e.g.: • Planning offices • Consultant • Assembly companies • System integrators • Services • Maintenance

Table 1. Actors involved in the engineering process

2.1.4. Actor roles in the engineering process

The actors involved in the engineering process can have different roles as described in [5]. Several steps of planning activities precede a substation automation project. The additional roles associated with planning steps are network planner, system planner, and substation planner. The actors in the engineering process can take different roles. The possible roles and the associated tasks are described in Table 2.

Role	Task	Result
System planner	Develops system plans	Overview diagram (Single-Line-Diagram).
Substation planner	Translates the network and system plans into a substation solution with components.	Overview diagram (Single-Line-Diagram). Block diagram.
System / plant engineer for secondary equipment	Translate utility guidelines into a specific substation / project planning.	Director Plan for Automation. Basic design criteria for the SAS. Requirement specifications for substation equipment. Communication infrastructure Planning.
Project / design engineer for secondary equipment	Translate system requirement specifications into a solution comprising the definition of the	Target specification for the equipment for a specific substation. Final System configuration

Role	Task	Result
	necessary hardware and software. Configuration of the SAS: i.e. the definition of the IEDs and their interfaces with one another and to the environment.	diagram. Block diagrams of protection and control. Communication infrastructure design
System integrator	Responsible for system integration including the engineering, delivery and mounting of all IEDs, factory and site acceptance tests and test operations. From the IEC 61850 point of view this is a crucial actor as long as the aim of the standard is to mix IEDs from different manufacturers	Released system ready for operation.
Device (IED) parameter setting engineer	Parameterizes the individual IEDs and integrates the functions in the individual IEDs.	Devices containing the parameters for the target system.
Construction engineer	Translates the specification into cabinets and wires.	Cabinets or components ready for assembly.
System verification engineer	Checks the correct behavior of the IEDs and of the overall SAS under various application conditions. Verifies each data and control point and the correct functionality within the SAS and between the SAS and its operating environment on the whole installed system using the final parameter set.	Tested system ready for release. Test report.
Device tester	Verifies the correct behavior of the IEDs and/or individual components of the SAS under environmental test conditions that correspond with the technical data. Releases the IEDs and system components.	Released IEDs and system components. Test report.

Role	Task	Result
Assembly, installation technician	Assembles the SAS consisting of multiple, interoperable IEDs from one, or more, manufacturers (installation and wiring).	System ready for commissioning.
Commissioning engineer	Stablish communications between the IEDs and places the entire SAS into operation, including the communication network.	System ready for system use (including SAT). Test report.

Table 2. Roles, tasks and results in the engineering process

2.1.5. Engineering steps

2.1.6. Overview

Different utilities have different mechanisms and priorities for the specification and delivery of substation automation projects. The following sections aim to outline the stages of development of the project's engineering in a general way, whilst acknowledging the variations caused by the many influences acting upon utilities in a global environment.

The customer's choice of procurement strategy affects the engineering process, the roles taken by the different actors and especially the content of the requirements specification. Two main alternative procurement strategies can be identified:

1. The first strategy focuses on flexibility as the method to reduce the total cost of ownership. The customer then, only specifies functional requirements and leaves to the supplier the task of putting together the optimal solution.

2. The other main strategy focuses on standardization to reach the same goal.

Because the flexibility strategy puts more responsibility for the design on the supplier, the customer only has to specify the basic requirements. In order to reach a higher degree of technical standardization, as in the standardization strategy, the customer should take more responsability in the design process than in the flexibility strategy. Thus, the requirements have to be more extensive and detailed. This puts higher requirements on technical knowledge, tools and documentation with a larger customer organisation compared to the other alternative.

The engineering process for IEC 61850 is part of the complete life cycle of substation automation systems. The output from the last phase will be used for maintenance and continued verification during the operation of the substation. The documentation (SCL- files and other documentation) may then be used as input to a new engineering project for refurbishment, extension, etc.

The choice of procurement strategy does not necessarily affect the choice of maintenance strategy but it is common that utilities that opt for the flexibility strategy also outsource maintenance. Thus, the organisation is streamlined with focus on asset management, not operation and maintenance.

2.1.7. Specification

The SAS specification generally takes the form of single line diagrams and block diagrams depicting the protection, control, monitoring, automation and visualisation functionality and the position and type of associated plant, switchgear and instrument transformers. These may be supplemented by text descriptions of the requirements, including site-specific details and non-standard functionality that needs to be highlighted.

Also, the SAS specification includes the basic requirements and preferred topology for the communication LAN. References to international, national and company specific standards and specification will also be included. The specification is normally functional in nature and only rarely will this comprise a parts list or bill of quantities.

Specifications for "Green Field" sites will require less detail than for "Brown Field" and will rely more heavily on standard schemes or designs.

The IED selection process varies between utilities. Some companies, with a philosophy of technical standardization, specify devices directly. Others leave the selection to the supplier, providing that they are selected from an approved list of devices for a particular function. The approval process may be conducted by the company, on a joint basis between many utilities and/or by third party certification or self-certification by the IED manufacturer.

The following elements may be part of the specification on a basic level:

- The single line diagram of the substation
- The single line diagram of the a.c. and d.c. auxiliary services
- Naming of devices – designation of HV equipment
- Signal lists and data flow requirements
    - Information for local registration and storage
    - Grouping of signals and alarms
    - Information to dispatch centres
    - Information for communication between IEDs (including communication services to be used)
    - Operational information, such as switching equipment status, analogue values (U, I, etc.), power transformer status (LTC tap, fan and pumps operation, winding and oil, temperatures etc.)
    - Information for maintenance support
    - Information for statistics and planning
    - Information for fault analysis

- The specification of functionalities to be performed (including performance figures and availability requirements (or failure scenarios) if applicable) and their allocation to the single line diagram
- Local HMI requirements (how to handle operations and from where)
- The interfaces both to the switchgear (process interface) and to the network control centre (protocol)
- Redundancy and topology requirements (on communication structure based on functional redundancy or minimum number of independent physical devices)
- Interface with existing systems
- The geographical layout (extension, buildings, cable channels, etc.)
- The environmental conditions, power supply
- Security requirements for the digital systems
- Required automation and monitoring schemes
- Hardware
- requirements
- Electromagnetic compatibility
- Test requirements and tools
- Documentation requirements
- Training for operation, engineering and maintenance

The following elements may be part of the specification on an extended level:

- All requirements according to the basic level of details on functional requirements
- Detailed single line diagram / function block diagram
- Substation address structure
  - Address catalogue
- Details on functionalities to be performed
  - e.g. interlocking, synchrocheck, automatic voltage control, automatic change-over of standby transformer, transfer of the protection actuation from the normal circuit breaker to the bus tie breaker, during normal breaker maintenance

    - Virtual control and selector switches, e.g. selection of single or three pole reclosing, LOCAL/ REMOTE bay control, bay in NORMAL/ IN MAINTENANCE condition

- Signal catalogue as a standardised description of quantity and quality of the required process information

- Templates for:

    - standard setting and parameterization list

    - Standard test check list

2.1.8. Design Process

The design process may begin with the submission of a Functional Design Specification or Design Intent Document which provides a commentary on the scope of the project and the sequence in which the work will be executed, highlighting any dependencies or major unresolved design issues.

Once agreement between customer and supplier has been reached on the content of these documents, a Work statement document is issued. The supplier will then start the creation of electrical scheme designs and equipment accommodation arrangement drawings. Associated with this is the creation of device specific configuration, including those of the substation central units. These will be verified by the customer and should create an agreement to proceed with construction, including system configuration and assembly.

The following elements may be part of the design documentation:

- Simplified single line diagrams

- Short circuit study

- Detailed single line diagrams

- Electrical drawings of all the electromechanical equipment

- Schematic drawings, that include at least the following:

    - Single line diagrams

    - Panels front drawings

    - Wiring between all equipment, including terminals

    - Interlocking and other logics

    - Equipment list

    - Apparatus schematics (auxiliary relays, switches, etc)

- IED Listing model numbers, versions, etc

- Cabinet drawings (usually done by the cabinet manufacturer):

    - Interconnection drawings
    - Equipment position drawing
    - List of Materials
    - Cabinet drawings

- Interconnection drawings (for each wire in each cable, i.e. the terminals that are connected at both ends).
- Address scheme
- Network interconnection diagrams and communication network layout
- Cable list (used for cable laying, sometimes includes cable reel cutting instructions)
- Engineering of the Programmed Control, includes at least the following:
    - Signal list for every bay
    - Telecontrol list
    - Logics
    - Configuration files
    - HMI pictures presentations, including screen shots
- Protection Settings calculation
- Parameter lists, showing adjustable parameters
- FAT procedures and test cases
- SAT procedures and test cases

For substation automation systems based on communication buses the following additional elements may be included:

- Diagrams that show all the devices (for protection & control), clients, the data acquisition network, time synchronization and remote access network. Such diagrams show how the devices are connected to the acquisition network and if they have redundancy; how the device clocks are time synchronized (NTP, IRIG-B or other sources); and how the devices allows remote access.. Network parameters such as IP and MAC address for each device and the LAN Switch port number used by each device are usually represented in the diagrams. This diagram also shows the connection to stand alone oscillography when used.

2.1.9. System configuration and assembly

According to the documentation developed in the previous steps, the cabinets are manufactured, and the different IEDs are programmed.

As a result, the following documents would be produced:

- Cabinets internal wiring schematics
- Cabinets list of materials
- Cabinet assembly drawings
- IEDs configuration files
- HMI configuration files

2.1.10. Testing (Factory)

Prior to the factory acceptance test it is usual to request the manufacturer to provide type test certificates to ensure that the devices fulfil the project requirements. Sometimes these certificates must be provided with the offer. These certificates must, more often than not, be obtained in a third-party test laboratory.

There are several types of certificates:

- Hardware type test: With this test the hardware or the hardware/software combination is verified. This category includes for example:
    - Mechanical stress
    - Insulation tests
    - EMC tests
    - Temperature and Humidity Tests, etc.
- Functional conformance type test: With this test a specific function within a device is verified. Examples:
    - A protection function (Differential protection, distance protection, etc.)
    - A communication function (IEC 61850 conformance tests).

2.1.11. Factory acceptance test

The manufacturing phase of the SAS shall be concluded with the factory acceptance test (FAT) to demonstrate that the system is compliant with the project requirements.

The first step is to test as much of the system in the factory as is practicable. This will exclude connections to primary system components and telecommunications systems which will be simulated.

A satisfactory conclusion to the factory test will permit the site installation to proceed. Thereafter, significant effort is required to test all unproven functions and connections and to perform end-to-end and overall system tests. Both the supplier and the customer are normally involved in the review of the FAT results.

In some cases the customer’s requirement specifications for the project already define the test specification for the factory acceptance test. This is typically the case when the customer specifies the technical design of the substation. In other cases, typically when the customer only specifies requirements on a functional level, the supplier shall submit a test specification for the FAT and commissioning of the station automation system for the customer's approval. Prior to the FAT, for the individual bay level IED’s, applicable type test certificates shall be available.

The objective is to only deliver a system to site after it has been thoroughly tested and its specified performance has been verified.

The limitations of the FAT test are such that not all site conditions can be simulated in a test lab or sometimes not all the system devices are available.

In this case, the FAT shall be limited to sub-system tests and the complete SAS test shall be performed on site. It is recommended that for the FAT at least one device of each type should be available.

2.1.12. Installation and Commissioning

The next step is the assembly of the system in the on-site installation of the SAS with multiple devices, from the same or different vendor. This includes the installation of the devices in their cabinets, the installation of the Ethernet LAN (Local Area Network) and the wiring with the process level (circuit breakers, isolators, earthing switches, tap changers, etc.).

At this point the SAS is ready for the site acceptance tests and commissioning.

2.1.13. Site acceptance test

The commissioning at site requires detailed tests to verify the installation and to perform the entire system test that was not possible to check in the FAT.

Like in the FAT the responsibility of developing test specifications depends on the roles of the customer and the supplier. In the SAT case also, the customer may provide the specifications of the tests or the supplier should submit a test specification for SAT and commissioning of the station automation system for the customer's approval.

The SAT shall be done after installation of panels, power and control wiring and connections, to perform operational tests on all switchboards, to verify proper operation of switchboards/panels and correctness of all equipment in each and every requirement.

These tests include, for example, the point-to-point test of all the digital signals, measurements and commands, the link with the remote SCADA system which could not be tested in FAT, the visual inspection of all the installation, the performance of operation, sequence of events, interlocking schemes, etc.

As in the Factory Acceptance Tests happens, normally both the supplier and the customer are involved in the review of the results.

2.1.14. Documentation and Training

It is usual that, preceding site acceptance testing, the contractor or system manufacturer provides training for the customer operation and maintenance personnel.

In addition to the documentation developed during the design phase, the following elements should be part of the final documentation:

- FAT and SAT test reports
- Operation and Maintenance manuals
- As-built documentation

A uniform documentation of the hardware and the software is requested. The user side is in a transition phase from signal-oriented presentation towards object-oriented presentation. Support for the translation of data is then required.

A reduction of the expenditure is seen from user view in the realization of the following requirements:

- The system integrator can secure a common documentation of the overall system.
- Connection of the hardware documentation to the parameter documentation.
- The documentation can be easily integrated in the utility documentation system.

Documentation of the SAS will be used in all phases of the substations lifecycle, not only during maintenance but also in future projects.

2.1.15. Use of templates for standardized design

Standardisation of protection scheme designs and IED configurations are an effective means of reducing design and verification effort during the delivery of a SAS project. The limitation of this approach is that primary system configurations and environmental conditions are rarely standard, requiring bespoke site-specific modifications to be applied to the standard templates. The standard designs will also have a finite lifespan due to technology evolution and product obsolescence.

Templates are predefined sets of data models, e.g. for complete stations, bays or functions. Design templates play an important role for procurement projects with focus on standardisation. Some of the process steps described in chapter 5.5 can then be omitted, or input for the individual process steps is already available and does not have to be worked out anymore.

2.1.16. Tools

Software tools for the entire substation specification, engineering and maintenance depend on the device technology and their interrelation in the substation. Application of numeric technology carries along the use of software tools for parameter setting and testing of devices and their connection with the Substation Unit and Control Centre. There are also tools that allow experts (such as relay protection engineers and the engineers for maintenance of bay control units) to have remote access to data at the substation.

The engineering software tools can be divided according to the type of device subject to parameter setting. For instance, there are:

- Station Unit
- Bay control unit
- Protection Relay unit.

Beside the split up with respect to the devices, the software tools can be divided according to the life cycle phase in the substation:

- System Specification Tool
- System Configuration Tool
- IED Configuration Tool
- Wiring design tools (for example electrical designer)
- Simulation tools
- Computer aided protection engineering tools
- Tools for device testing
- Diagnostic tools
- Documentation tools
- Maintenance tools

Some tools span over several of the engineering phases, such as the tools for creation of common data.

Different tools and information formats may be used during different phases of the lifecycle. The transition between these phases will be easier if there is a transparent and common engineering process. Furthermore a well-defined common specification syntax and format facilitates the exchange of information in the engineering process, during a specific project or to re-use specifications from earlier projects. These formats might be based on XML-files.

A common requirement on software and documentation tools is that they support version handling. There is a need to keep track of the versions of the configuration files throughout the entire project.

2.1.17. Impact of training requirements on SAS engineering

In most cases SAS requires training programs in order to allow operators to use the station controller computer, get logs from IEDs or gateways and to perform maintenance procedures. If the network and the protocols used in the SAS are open, then it is recommended to include them in education programs.

2.1.18. Impact of maintenance requirements on SAS engineering

The choices made during the engineering process of the SAS have an immediate impact on the maintenance of the system. It is therefore necessary to take maintenance constraints into account in the engineering process.

2.1.19. General

Maintenance in substation automation systems involves ensuring, via repair, inspection or testing, that all the equipments and functions under service are operating according to requirements.

Different maintenance optimization strategies and methods may be employed (e.g. RCM II) through a complete management system that ensures quality.

2.1.20. RCM introduction [1]

RCM is the abbreviation for Reliability Centered Maintenance, and is a method used to determine what should be done to ensure that physical assets continue to perform the desired functions in current operation. Basically it works as illustrated in Figure 2.

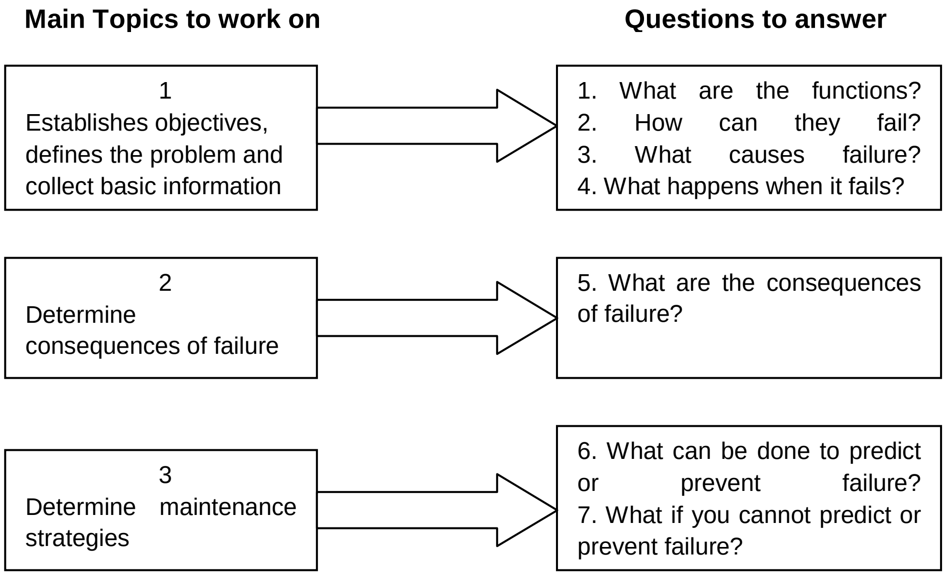

Figure 2. Main Topics and answers of RCM

For the first block there is a need to make a **classification** and grouping of the SAS and to know the limits for those systems that are targeted for maintenance.

It is necessary to identify the **limit of work** with the maintenance of the SAS, because personnel need to know all about the equipments within this limit (how it works, manuals, history of failure, etc).

As a third step the **operational context** is defined.

With these three steps described (Classification – Limits – Operational Context), it is possible to establish the following:

- Functions of the protection, control and automation system
- Functional failures
- Failure modes

All the failure modes and their consequences then have to be addressed. The priority of the problems will probably be the same as if the corresponding maintenance had not been undertaken. The RCM method provides a tool to determine the periodicity of the maintenance intervention, through their own equation.

Due to the diversification of the tasks to perform, a grouping of tasks by schedule is required, trying to cover as many of them in the same period if they do not alter too much the cost-benefit equation, obtained from the RCM analysis.

From this moment, the documents describing the duties and record keeping of the maintenance tasks that will be made in the SAS are prepared. The documents include for example:

- Rules of procedure to implement a full maintenance

- Rules of procedure to implement a reduced maintenance
- Check-lists for the operators [2].
- Maintenance log

2.1.21. Maintenance management [3]

For the design of management the following must be defined:

- Management strategies
- Structure management system
- Maintenance strategies
- Operational structure to carry out such management

Maintenance strategies depend on the type of SAS and obviously the criticality of the same but management statistics must be taken into account in all cases.

These maintenance statistics will be made by:

- The monitoring of work orders
- Mapping the news
- The analysis of faults in the power system (monitoring the performance of the SAS)

It is essential to have an adequate organizational structure to carry out the maintenance management, and for this subject the following must be taken into account:

- Human resources
- Economical resources
- Appropriate test equipment
- Staff training

We can summarize the process of SAS Maintenance Management by the schedule as in Figure 3.

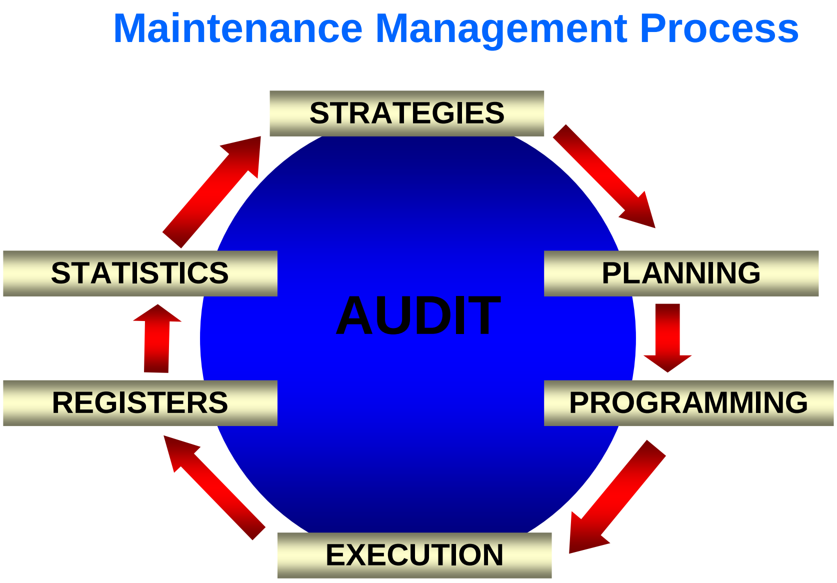

Figure 3. Maintenance Management Process

2.1.22. Impact of spare parts requirements on SAS engineering

Although the spare parts of traditional substation automation systems vary with the utility's requirements, the following is usually included :

I. The major dedicated and replaceable modules provided by vendors such as CPU modules of IED device, power modules and operation panel modules etc.

II. The commonly used, easily damaged universal equipments and universal devices are required by some utilities such as switch, computer's hard disk, network connector, network connection line, line and cable terminals, and line distribution frame in the panel etc.

Because there is a great variety of IED devices provided by different vendors in the traditional substation, and the different types of devices provided by the same vendors also have different modules (especially in the number and category of line terminals). In most cases, it is impossible to keep the spare parts for all modules and only the commonly used spare parts for all the different type modules can be stored for different vendors, for example, the power modules.

One way to analyze the need for spare parts is to determine the impact of a failure in every part, then analyze the time to get a new part from the manufacturer and finally the probability of failure. With that information it is possible to know what spare parts are needed and how many of each item is needed.

Some other considerations can be taken in account:

- The cost of storing spare parts.
- Reduce the possibility to get deprecated parts or IEDs.
- Time and special skills required to replace original parts.

In some cases, if SAS uses communication standards (protocols, transmission media – like Ethernet -, and others) and standard data model and services, replacing one device by other can be done by one from different vendor, reducing required spare parts; but this must consider if the SAS can continue to work without one of its element, performance and security risk reduction is allowed, e. g. for protection schemes, if redundancy exists and the feeder can be protected by a backup protection (may be a main 2 with the same main 1 protection functions) while the failed device is replaced by a new one.

3. REQUIREMENT FOR THE IEC 61850 SAS ENGINEERING PROCESS

3.1.1. Overview

The IEC 61850 series of standards describes a complete solution for substation automation that covers all phases of the engineering process and the commissioning and test phase. But it can also support the early project planning phase and the maintenance phase.

The following sub-clause describes the different steps in a general IEC 61850 project and engineering process and especially what is the typical input and output of the steps. The exact process may differ for a given use case as described in Clause 2.1.2. Thus, it has to be adjusted to each project. Furthermore, the exact content of the different input and output depends on the chosen procurement strategy. This especially affects the process steps where documentation is exchanged between roles supported by two (or three) different actors.

Document [5] describes the engineering processes for three of the main cases listed in 2.1.2:

1. Engineering process for a new substation (without the use of a design template)

2. Engineering process for a new substation (by use of a design template)

3. Engineering process for modifications in an existing substation

Design templates as in case 2 are typically used when the procurement strategy has a focus on standardization, but are not specified by the customer when the supplier is given flexibility to design the solution.

IEC 61850 prescribes the use of certain types of data files related to the engineering process. These are briefly introduced in the following sub-clauses.

The project phase descriptions are based on document [5].

The engineering work is often done in parallel, where different actors work on different parts of the delivery. This way of working has to be supported. 61850 Edition 2 includes extensions to address this need.

3.1.2. Specification

3.1.3. Specification - substation

The very first step in the IEC 61850 engineering process is to document the necessary requirements on the substation automation system. This step includes three phases; primary planning, secondary planning, and preparation of the system specification. The first two phases are independent of IEC 61850. They must be finalized at an early time in the project.

The preparation of the SSD (System Specification Description) file is an important part of the IEC 61850 engineering process and it is normally based on the text and diagrams of conventional specification. This work has typically been done by the supplier. The recommendation is that the SSD file is made by the system engineer for secondary equipment and used during the procurement phase. A complete SSD file is a prerequisite for a standardized design.

Process-Step	Input	Output	Responsible
Primary Planning	- Demand from the network planning	- Single-Line-Diagram	Substation planner
Develop planning of secondary equipment	- Single-line diagram - Function requirements - Technical system guidelines - System management concepts	Requirement specification with the following contents: - Function chart of the secondary system - Quantified project specifications (Information model - Process data – connection of network control center) - Function charts (logical diagrams - interlocking, switching authority, protection functions) - Plain text requirements (using IEC 61850 - object types/services for standardized design, combination devices, availability)	System engineer for secondary equipment
Creation of the SSD file	- Requirement specification	- .ssd-file	System engineer for secondary equipment

Table 3. Process steps in specification – substation

3.1.4. Engineering

The following picture has been taken from [5] and is a good summary of the engineering process for a new substation

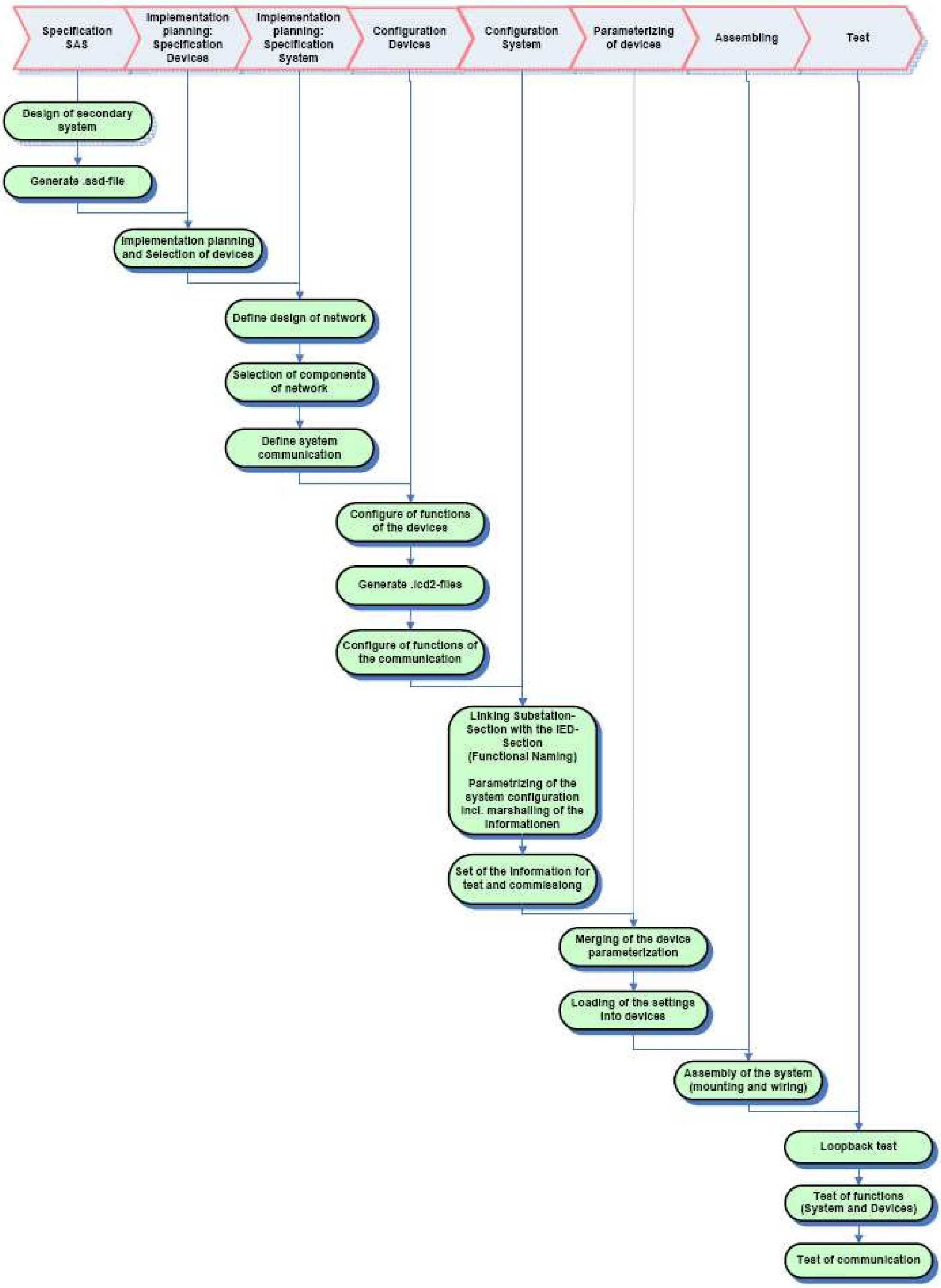

Figure 4. Engineering process for a new Substation

NOTE: The upload of the configuration and parametization to the IED would be done after assembling and before testing.

3.1.5. Engineering – Design - System specification

With a customer whose strategy is to be flexible about the design, the design of the substation automation system is done by the design engineer for secondary equipment (the supplier or the service provider). Project engineers for secondary equipment of the customers are then merely interested in the output, in the form of design documents showing the communication network design, network components (vendor and type), communication parameters, and selection of communication services.

Customers who standardise the design need to provide their own detailed specifications when selecting the network components. In this case, the use of templates is highly recommended [5]. The table below shows the process steps and the relevant input and output.

Process-Step	Input	Output	Role
Determination of the communication network design	- Function chart of the secondary system (selections, number of units) - Selected devices (manufacturer and product) - Plain text requirements	- Communication Network design - Target specification	Project engineer for secondary equipment
Selecting the communication network components	- Network design - Function chart of the secondary system - Requirements in written form (Use of IEC 61850 - Object types-Services if given by the customer, combination-device-solution, availability) - Proof of compatibility of the network components	- Selected communication network components (manufacturer and product)	Project engineer for secondary equipment
Determining the system communication	Requirement specification - Function chart of the secondary system - Quantified project specifications (information model - process data –connection of network control center) - Function charts (logical diagrams – interlocking, switching authority, protection functions) - Verbal requirements (using IEC 61850 - object types/services if given by the customer, combination devices, availability)	- System parameters (communication settings) - Selection of communication services (specifications for reporting and GOOSE) - Template in case of standardized systems	Project engineer for secondary equipment

Table 4. Process steps in engineering – system specification

3.1.6. Specification and selection of equipment

The necessary input to specification of the equipment is generated during the previous substation specification phase. The selection of equipment depends on the output from the secondary planning. Once the selection has been made, the next step is to collect the IED capability description (ICD) file, which the vendors must supply with every IED.

3.1.7. Specification of the communication network

According to CIGRE-119-2008 [6] the use of the communication network can be classified as:

- Data acquisition only network
- Interlocking and data acquisition

- Trip, interlocking and data acquisition

The total transmission time from one node in the network to another must be considered in all cases. In the study on transmission times all expected traffic on the network and any delay due to a failure of one node must be considered.

Reliability calculations are typically not done in substation automation projects if the same network structure has already been used in previous projects. But there might be better solutions for the same cost or less expensive solutions with the same reliability.

3.1.7.1. Data Acquisition

Using the network does not require complicated design other than to assure data is sent between IEDs and Host IEDs. The redundancy concept for data acquisition in most cases applies only to transmission substations.

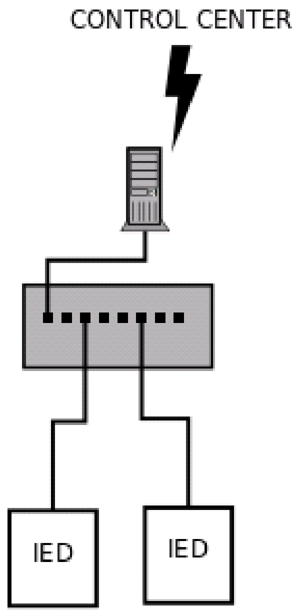

Figure 5. Simple network design suitable for data acquisition

3.1.7.2. Interlocking and Data Acquisition

Substation busbar arrangements require bay to bay interlocking. In order to make the switchgear operation safe, if the required signals are interchanged by hard wired then the network design could be as simple as that pointed out for Figure 5.

However, if communications are employed instead of hardwiring, the network design is more complicated, as it must assure safe operation even in the case of one element failure.

This includes a failure on the LAN switch(es) used to transmit the required GOOSE messages or on the IED that is publishing the information used by other subscribers to perform interlocking.

Utilities have different interlocking logic for each busbar arrangement and the actions to be taken in case one element fails must be specified. Maybe adding redundancy to the network and establishing a safe operation state in case a server IED fails (maybe remembering the last state before messages drops and/or a predefined state if the message is absent).

Interlocking does not require short times to perform the operation, and then the network design just requires standard transmission times.

3.1.7.3. Trip, Interlocking and Data acquisition

What is stated for Interlocking and Data Acquisition applies also to a scenario with trips, but with additional special attention on transmission times and redundancy.

If the SAS uses GOOSE messages for tripping of circuit breakers, maybe using a kind of I/O module located close to the switchgear, the network must consider the following:

- Total traffic on the network, MMS interchanges GOOSE messages and other communication, such as time synchronization.
- GOOSE message prioritization
- Confine GOOSE messages to the substation LAN by using VLANs and configuring broadcast filters at the LAN switches.

The total time for tripping must be as short as possible. As long as the processing of the input and output signals takes some milliseconds, it is commonly accepted that the transmission time should not be more than 0,5 ms.

If a utility uses a kind of redundancy to trip circuit breakers, like two trip coils, it is a good idea to have network redundancy or, at least, have a hard wired path to the trip coils. Redundancy can add delays on total transmission time, depending on the network architecture. This time must be considered by the utility in the protection coordination and the electric network stability studies.

Using tree architectures can avoid time delays due to a network’s node fault, but it is difficult to achieve redundancy. Rings can in some architectures help to have a simple but efficient redundancy but lots of nodes will add time delays in the event of node failure.

Nevertheless, the internal switch latency time for modern switches with 100 Mbps ports is in the order of 5 µs. This means that, in a LAN with 20 or 30 nodes, the total time added is about 100 µs or 150 µs, which is normally acceptable.

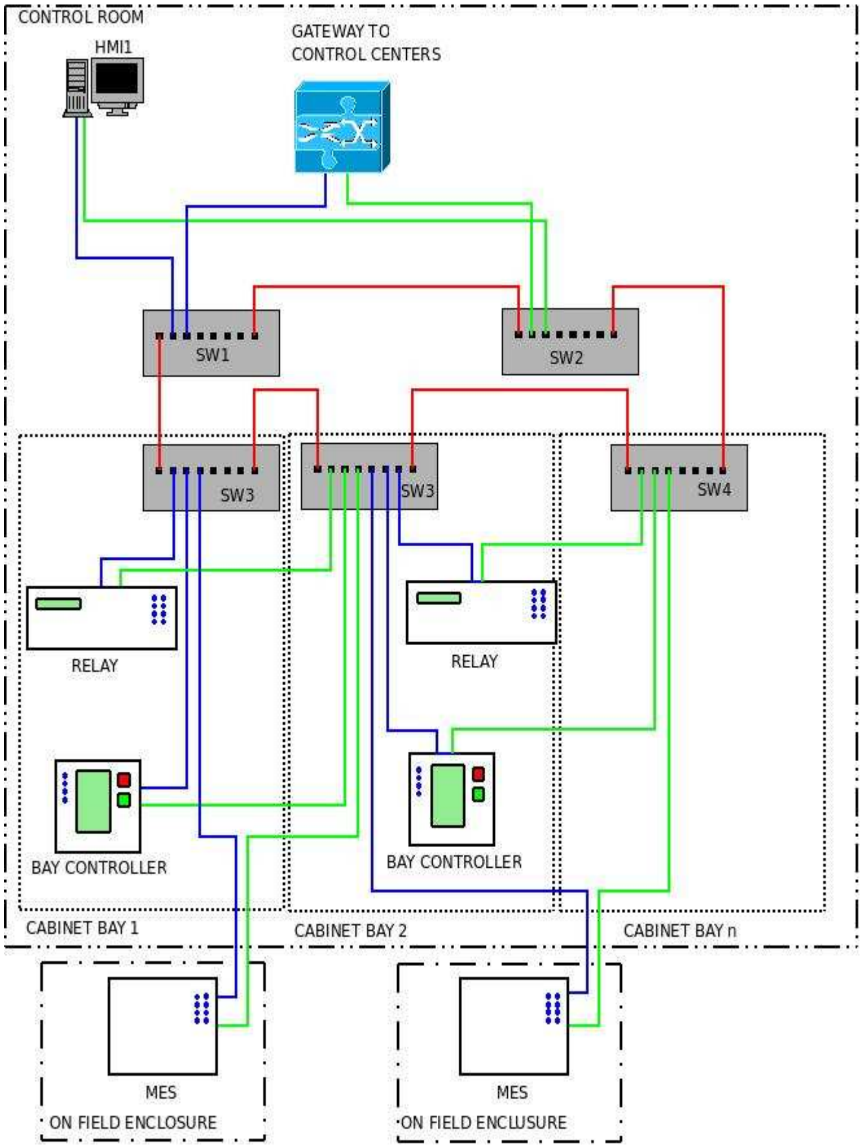

Figure 6. Example on simple network design for data acquisition, interlocking and tripping with IEC 61850 Edition 1 IEDs

IEC 61850 standard Ed.1 does not cover communications network redundancy.

Edition 2 is expected to fill this gap. The working group that is specifying this issue (IEC 61850-90-4) is in progress at the moment this report has been written, but it is expected that the recommendations about communication network redundancy will be based in [10].

Some objectives of the redundancy solutions should be independent from application, not to need dual IP addresses or dual MAC addresses and no lost of packets in case of single failure to guarantee GOOSE message delivery.

These are some examples of networks proposed by the 62439 standard:

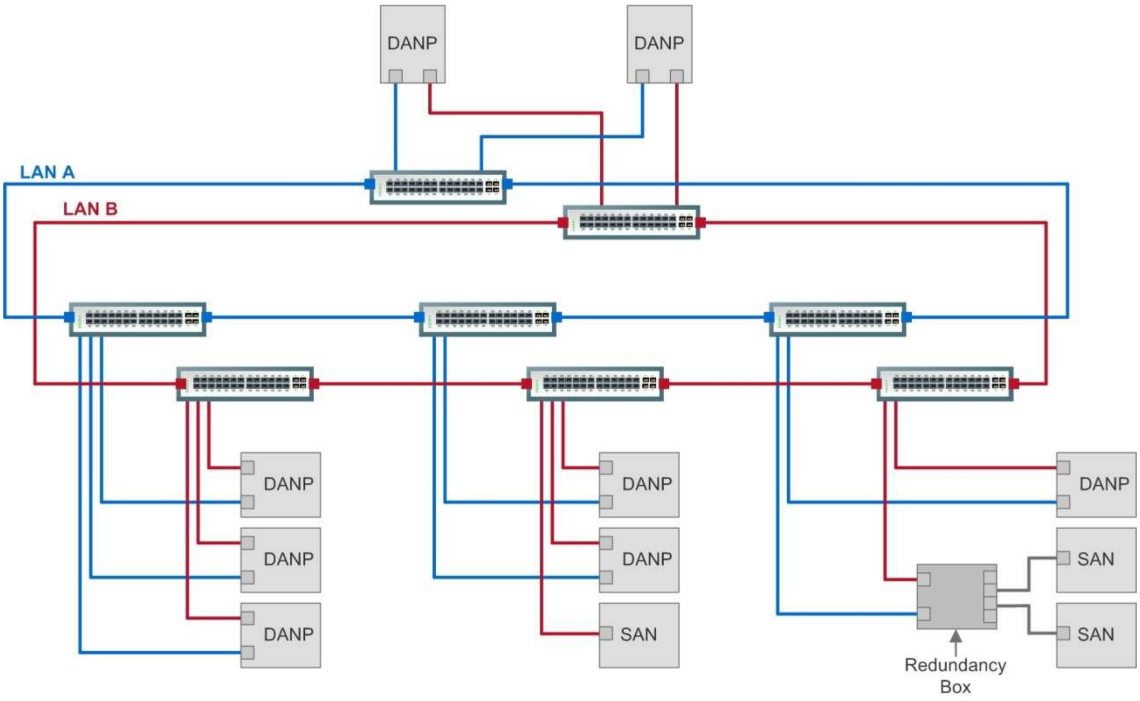

Figure 7. Redundant network based on PRP (Parallel Redundancy Protocol). DANP: Doubly attached node implementing PRP

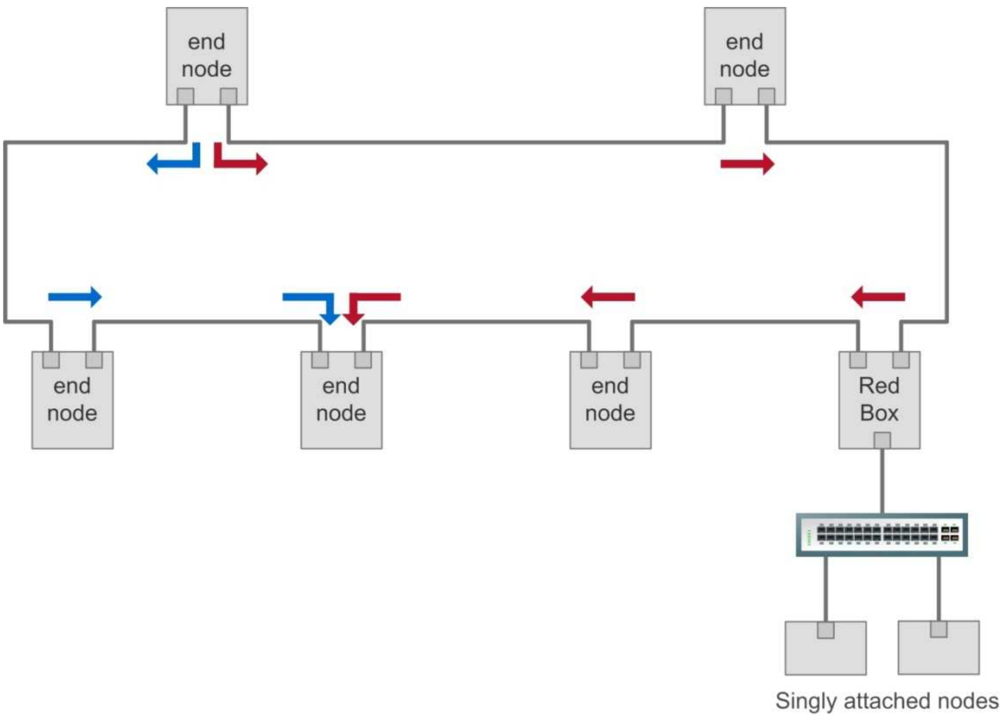

Figure 8. Redundant network based on HSR (High Availability Seamless Ring)

3.1.8. Engineering - System and equipment configuration, parameterization, data input

The configuration of equipment is typically something that is done by the supplier. The customer is then only interested in the output in the form of function-oriented device parameterization and the documentation/circuit diagram. The configuration of the communication will generate communication-oriented device parameterization.

The system configuration is a key step in the IEC 61850 engineering process. This is fully done by the system integrators. The system integrator imports the system specification description file and the IED capability description files for the different IEDs and generates a substation configuration description (SCD) file.

The next step is the parameterization of the IEDs themselves. The engineer responsible for parameterizing the device uses the substation configuration description file together with parameters related to the requested functionality and communication interface to set the parameters of each IED.

Some utilities decide to configure and parameterize the IEDs by themselves in order to guarantee an optimal maintenance (independent of the supplier) of the systems. Therefore it is important to get “easy to use” tools, allowing to easily implement the configuration required for the system..

While utilities use functional names to identify substation components and functions the manufacturers typically use product names to identify IEDs and associated logical devices. To get an intuitive structure and naming in a vendor-independent environment the tools should support the use of functional names. The actual IED names used in the SCL files may be either functional names or product names. In the latter cases there is a need to specify the translation between the two reference systems.

3.1.9. Assembly

The goal of factory assembly is to assemble and build the system according to the specification, which is formally described in the results of the engineering process. The starting conditions and input for the Factory assembly are [4]:

- The SCL configuration files, as for example ‘substation configuration description’, *.scd describing the complete substation configuration with single line diagram, communication network, IED configurations, binding information (e.g. trip matrix) or ‘configured IED description file’, *.cid for each IED describing all configuration parameters relevant for that IED.

- IEDs that comply to:

    - Communication according to the *.cid file, which means conformant with the applicable MICS (Model Implementation Conformance Statement), PICS (Protocol Implementation Conformance Statement) and PIXIT (Protocol Implementation Extra Information for Testing). This should be tested in the conformance tests.

    - Performance and additional requirements for testing according to PIXIT

3.1.10. Installation and commissioning tests (FAT / SAT)

The installation and commissioning tests are made to verify that the system delivered meets the specified requirements. In case specific requirements have been put on the implementation of IEC 61850, then this is the time to verify those requirements, as well as make sure the system can handle unexpected stimuli (negative testing).

This part of the process shall be documented in the Inspection and Test Plans (ITPs).

The process includes three steps as described in the table below:

Process-Step	**Input**	**Output**	**Role**
Signal test	- Wiring manual/circuit diagrams - Quantified project specifications (information model - process data –connection of network control center) - .scd file	- Test protocol signal test	System tester
Function test (system and devices)	- Function charts (logical diagrams – interlocking, switching authority, protection functions) - requirements (using IEC 61850 - object types/services, combination-devices, availability)	- Test protocol Function test	System tester, Device tester
Communication test (availability and performance)	- Network design - requirements (using IEC 61850 - object types/services, combination-devices, availability) - .scd-file	- Test protocol of communication test	System tester

Table 5. Process steps in installation and commissioning

In the case of IEC 61850 systems, some tools for network analysis can be very helpful in the commissioning. For example “network sniffers” can help on GOOSE analysis, (published and status changes) and MMS for Reports, request and responses. In order to get advantage of its filter features, the System’s documentation, as described on Clause 3.1.11, must include enough information to find the required frame for GOOSE messages or TCP/MMS requests/responses.

3.1.11. Documentation

General requirements on documentation are presented in Chapter 2.1.14.

3.1.11.1. IEC 61850 specific documentation requirements

For IEC 61850 the following information is added:

- Table with GOOSE messages published and subscribed for each device. Maybe using a database (exportable to spreadsheets like Excel) could be useful. This information (including receivers) may be included in the signal list (station level). The table must have at least: GoID, Publisher, Description, Multicast MAC Address, GoCB, DataSet and VLAN. GoID could include an integer consecutive number, in order to get unique ID for the GOOSE in the system. DataSet could referencing the table of datasets. This information is already included in the SCD and this table could be an output of the engineering tool.

- Table with Reports published by each device. Maybe using a database (exportable to spreadsheets like Excel) could be useful. The table must have at least: ReportID, DataSet, IED, Description and Report Configuration (buffered or unbuffered, and others). ReportID could include an integer consecutive number, in order to get unique ID for the Report in the system. DataSet could reference the table of datasets. This information is already included in the SCD and this table could be an output of the engineering tool.

- Table with the DataSet used by GOOSE and Report. Maybe using a database (exportable to spreadsheets like Excel) could be useful. The table must have at least: DataSetID, DataSet's name, data objects content and the GOOSE's or Report's ID. DataSetID could include an integer consecutive number, in order to get unique ID for the Report in the system. Content, must describe for each data object: the Logical Device, Logical Node and attribute; data type could be useful. This information is already included in the SCD and this table could be an output of the engineering tool.

- Include in the logic diagrams the use and function of GOOSE messages and Sampled Values.

- All the SCL files.

3.1.12. Support for different reference systems

IEC 61850 makes a recommendation to use IEC 61346-1 and –2 as basis for the reference and naming system for the substations. Although these standards are becoming more widespread and release under the new name IEC 81346 this is not the only reference system. The software tools should support both standard and customer specific reference systems, such as RDS-PP (Reference Designation System for Power Plants), IEC 61346/81346, customer-specific, etc.

A other point to take care to, is in the gateway the conversion of the IEC 61850 telegrams into IEC 60870-5-101 / -104-telegrams. The mapping of the IEC 61850 quality attributes to the IEC 101 / 104 quality flags should be done according to the IEC 61850-80-1 recommendation.

3.1.13. Global requirements for tools

The requirements for next generation tools should focus on:

1. System-orientation: Current generation tools and systems are constrained by a device and technology-dependent orientation. As SAS shift to distributed autonomous solutions integrated system design, testing and management becomes a sine qua non requirement. Moreover, to enable significant productivity gains the engineer must be able to concentrate on the automation solution rather than on the details of the adopted implementation technology.

2. Model-orientation: Object and model-oriented approaches, together with standard application and industry solutions, introduce significant simplification when compared to current signal and document approaches.

3. Broad scope: Broad tool support for the many technical aspects (functions, communications, security, etc.) but also targeted at the different engineering roles and processes (architect, integrator, tester, etc.) during the entire SAS life-cycle (specification, design and configuration, commissioning, operation and maintenance, etc.) is envisioned.

4. Openness: Tools, like systems, are expected to exhibit a high degree of diversity (multi-vendor, multi-technology or multi-generation) and therefore tool openness and interoperability will be fundamental. International standards and frameworks such as IEC 61850, IEC 61131-3 or others should be promoted and considered tool cornerstones.

5. Productivity Enabler: Tools have a significant potential for automating routine operations thus freeing the user to concentrate on higher value-added activities. This can be achieved in many ways by promoting reuse of definitions, performing automatic checks, limiting redundancy of input or enhancing visualization and analysis capabilities, among others.

6. Integration. Integrated user interface environments including unified access to common features such as copy-paste, wizards, templating or others characterizes all modern tools in any mature engineering domain. Integration means however not only common user interface but also semantic cross-function integration. An analysis tool for system testing, as a small example, should present information according to the object/function model and description of the SAS to be easily used by an automation engineer. The realization of this vision is however constrained by issues like industry practice, complexity, cost-effectiveness, availability of technology, maturity and application of standards. It is a step by step process that will take time.

For more information about this issue, [7] is a very good approach.

3.1.14. Tools identified by the standard

Some software tools for the engineering process when using IEC 61850 Standard are the System Specification Tool and the IED Configuration and System Configuration Tools. The engineering is shown in Figure 9 and the parameter files such as SSD-File, ICD-File, SCD-File and CID-File are exchanged among the software tools.

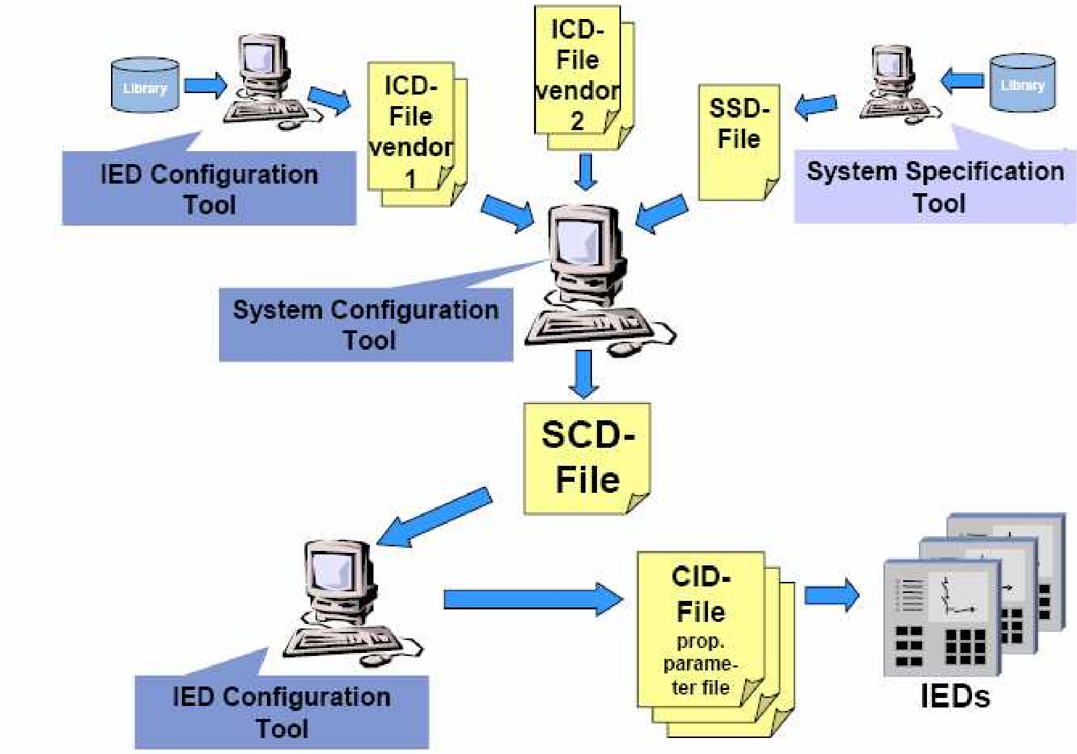

Figure 9. Engineering – IEC 61850

3.1.14.1. System Specification Tool

Depending on whether the flexibility strategy or the standardization strategy has been adopted this tool would be used by the utility itself or by the system integrator, in which case this tool could be integrated into the system configuration tool.

This tool will be employed by customers/integrators to develop the SSD-file for the required system specification. It must allow defining:

- Single line diagram (SLD) of a substation with all power equipment and protection, and controlled function of the substation automation system
- Logical scheme of substation automation system with basic functions and their allocation to bays and devices of the switchyard, number and description of levels (process level: sensors, actuators; bay level: protection, control; station level: station host, station HMI, NCC Gateway)
- Text blocks and diagrams which describe interconnection of the functions between power equipment and bay within the switchyard
- Well known process information data for local system and control centre (signals lists, measurements, grouping signals, alarms)
- Telecommunication capabilities for communication to the Control Centre, communication between relay protection in another substation and other needed communication.

- Redundancy requirements for the local communication system, as well as for the protection and control functions.
- Data naming convention.
- The result is the generation of the system specification (.ssd-file).

There are several system specification tools available, such as Helinks and SCT.

3.1.14.2. System Configuration Tool

The requirements for the system configuration tool depend on the strategy of the utilities. Certain utilities want to keep the know-how in order to be able to modify or to adapt the system after the delivery. For this reason the engineering of the system is done by the utility's engineers. To facilitate the task of the engineering's crew a "user's friendly" and "easy to use" system configuration tool should be available.

Based on this premises this tool would include the documentation tasks and some of the maintenance tasks.

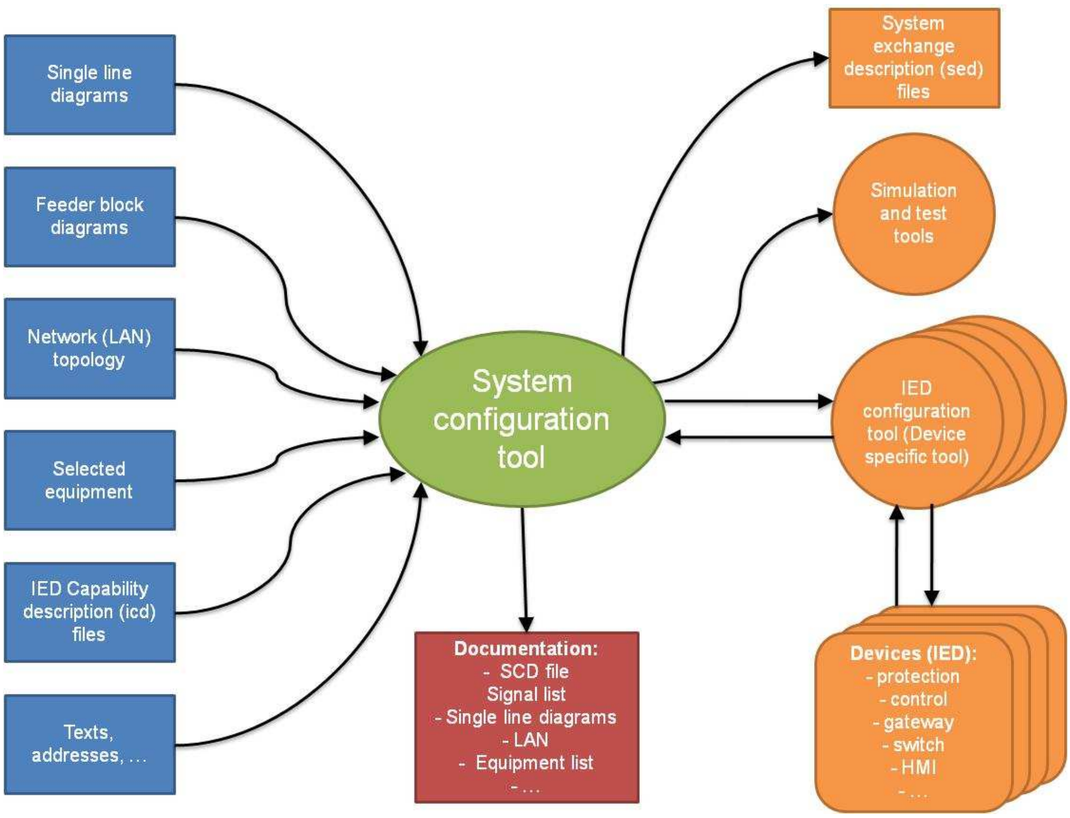

Figure 10. input and output to independent system configuration tool

Some utilities have developed the idea to have **one** supplier independent tool, which is able to handle all the information (refer to Figure 10). Inputs to the tool are shown to the left and output to the right.

The capabilities of this system configuration tool should be:

- Handle the (IEC 61850) information of the whole SAS

- Import of SSD files (or develop them depending on the utility strategy)
- Import of the device models (ICD files)
- Handle additional information (i.e. texts, addresses for the remote SCADA system, authorities, …) needed by the gateway, the HMI and other IEC 61850 clients
- Assures and checks the system consistency
- Maintenance of different versions of databases, exported files
- Configuration of communication settings
- Configuration of communication functions (reporting, GOOSE-request-communication, Sampled Values)
- Generates SCL files for the different IED configuration tools
- Generates files for the simulation and test tools
- Generates the documentation (diagrams, lists, …)
- Compares versions
- Import SCL files modified by the IED configuration tools

Such a tool will drastically simplify the engineering and maintenance process as well as assure a consistent system. This has been highlighted by some utilities that due to the lack of this tool are developing their own one.

On the other hand, there are several technical difficulties that should be solved in order to develop this tool:

- A function coming from different suppliers should have identical parameter settings. This could be solved using “plug-ins” or “extensions” to the tool specially designed by every IED manufacturer.
- As long as different vendors could develop this tool, every such tool would have different interfaces, and in the end every utility would select the one which best fits to their needs. This could be solved using some kind of “graphical interface” that could be personalized for every utility keeping the rest of the tool unchanged.
- How to test that this tool covers all existing and future IEDs. Again a possibility could be to use the manufacturer depending “plug-ins”.

At this moment we consider that this tool requires a very high degree of collaboration from different manufacturers, and probably some kind of standardization should be done from an international institution.

3.1.14.2.1. Requirements on documentation

The SCL files constitute the key documentation of the SAS. However, the XML files in SCL are not very reader friendly. Thus there is a need for tools that can transform the SCL files into a more understandable form that is closer to the traditional way of documenting the substation automation system.

For documentation purposes, some popular text editors and spreadsheets could be used.

Tasks for these tools are a collection of:

- Signal lists
  - Data table with the GOOSE’s, MAC and ID designation
  - Reports in each device with its client and data about its type
  - Datasets associated to GOOSE and reports.
- Logic diagrams for each bay IED to know when and how a communicated signal is used.
- Circuit Breakers Switching schemas
- Function plans
- Test protocols.

The use of **visual languages** [7] should be boosted. In the same way as wiring, cabinet or other CAD diagrams, visual languages can be adopted for representing distributed systems according to IEC 61850 (please note that the SCL is meant for machine parsing and generation and not an end-user language).

Herein we present a set of sketches as proposals for diagrams that can serve as a visual notation for SCL models, a useful aid for many purposes such as design, testing, diagnoses, etc.:

1. *Communication Network Diagram:* Diagrams present the network architecture of a system including device nodes (switches, routers, servers, IEDs, etc.) and network links together with other information such as network addressing. Such diagrams are common today in any computer network domain to convey the physical network structure.

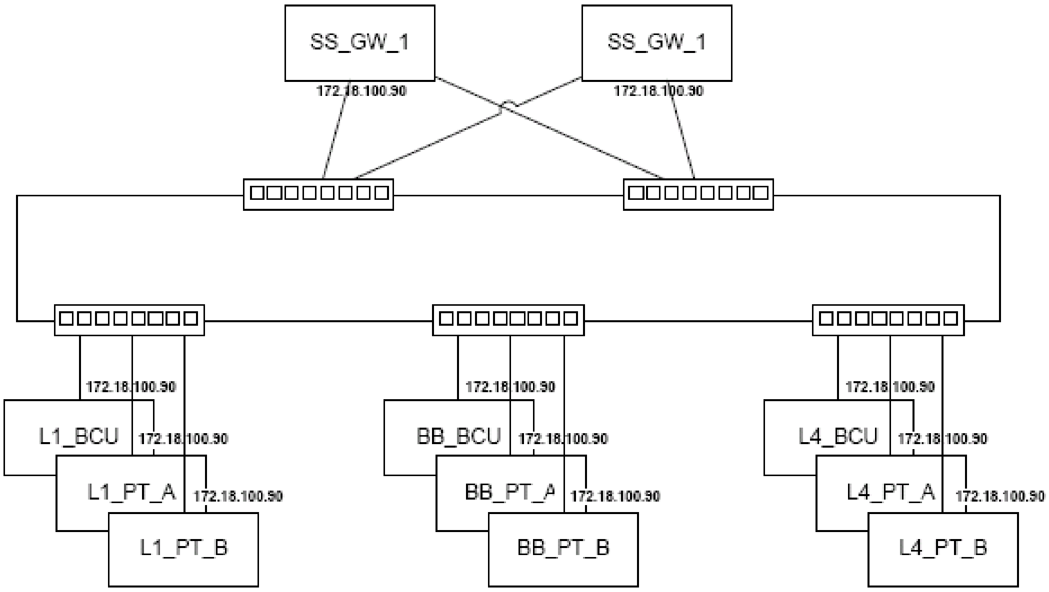

Figure 11. Example of communication network diagram presentation for a simple ring configuration

Note:

SS_GW: Substation Gateway

L1_BCU: Line 1 - Bay Control Unit

L1_PT_A: Line 1 – Protection A

L4_PT_B: Line 4 – Protection B

BB_BCU: Bus Bar Bay Control Unit

2. *Data Flow Diagrams:* In a distributed SAS the physical architecture of the system is not sufficient to describe the global interactions between IEDs for an automation engineer. The relevant data flows (client/server, GOOSE, SMV or other) comprehend an independent logical structure that must be clearly understood for many engineering purposes and can be represented by another diagram type.

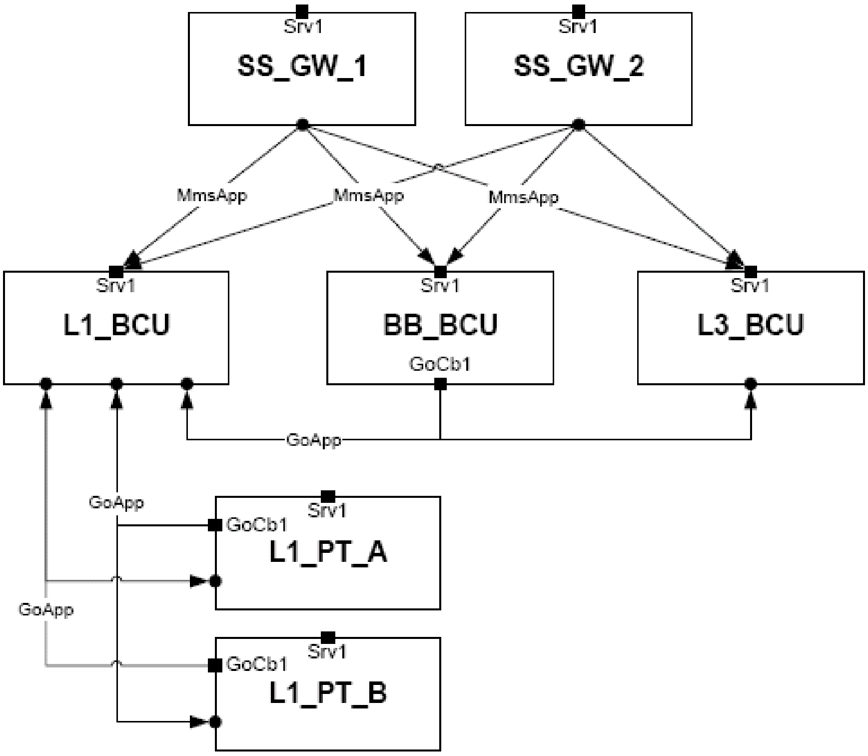

Figure 12. Example of Data Flow Diagram

3. *Functional Diagrams:* Data flow diagrams are critical to understand communication interactions between IEDs but not to understand detailed functional relationships. The input/output associations between logical nodes of one or more devices can be represented by a function-block-like diagram type. This diagram considers logical nodes as entities which encapsulate behavior like IEC 61499 function blocks.

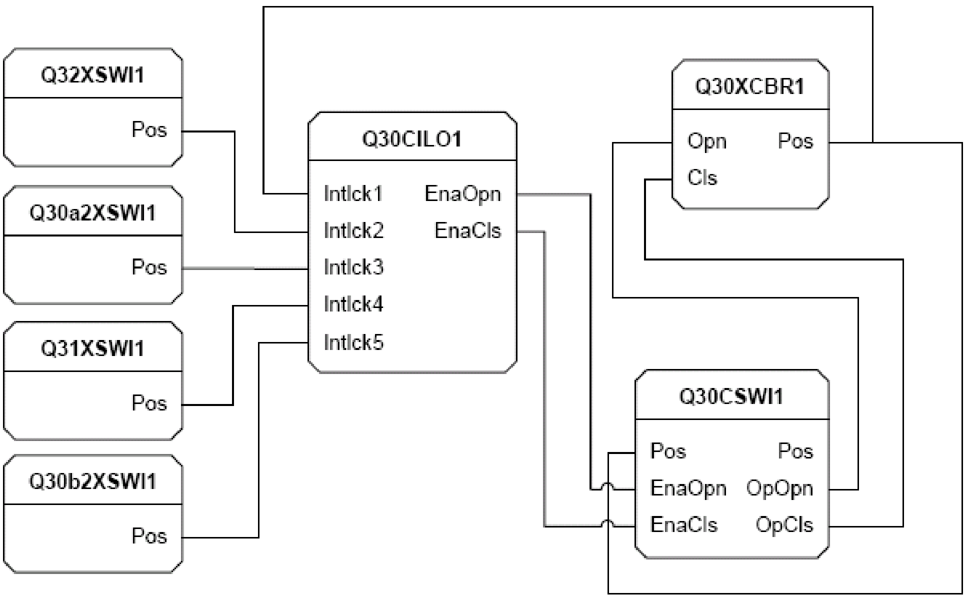

Figure 13. Example of functional diagram

4. *System Diagrams:* Visualizing a specific distributed or local function is the main goal of functional diagrams. To represent the overall functionality of a system (or sub-system) functional diagrams would be cluttered and of limited value. System diagrams include the single line diagram of the substation together with the associations to logical nodes that virtualize, monitor, control or protect a given equipment or system component. Allocation of logical nodes to devices is also represented in such diagrams. Several variants of this diagram type have been used in papers to illustrate case studies or examples and have already been made available in some engineering tools.

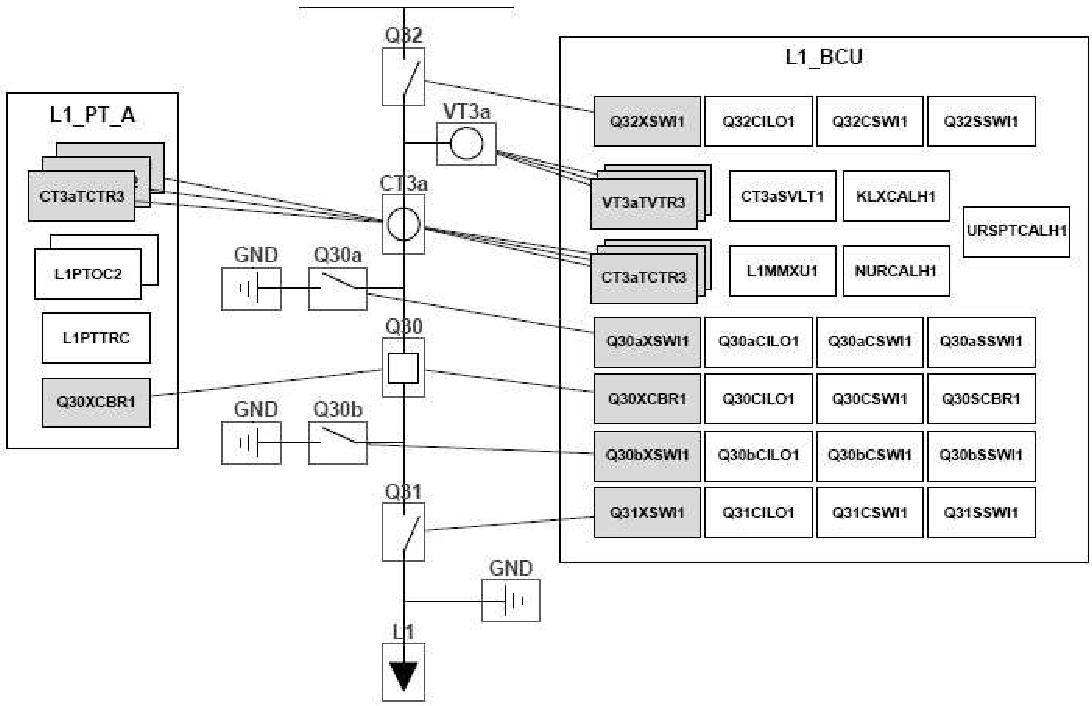

Figure 14. Example of System Diagram

3.1.14.2.2. Requirements on Maintenance

Maintenance tools are not developed yet, without practical tools useful for the utilities. Some requirements for them would be:

- Only one environment for all the IEDs, that allows the modification of settings and export/import them to simulation tools.
- Only one environment for all the IEDs that allow modifying the logics and export/import them to logics simulation tools.
- Suitable revision handling
- Only one configuration file for every IED

From the hardware point of view some requirements have been detected for maintenance purposes:

- Protection device test set with support of GOOSE generation and subscription.

- Mobile PCs with the required maintenance software tools installed. Defensive measures should be defined to avoid virus infection of the SAS from these maintenance PCs.

3.1.14.3. IED Configuration Tool

Configuration tools are the most developed tools of this group. Every manufacturer has his own tool. In some cases it is required to download the configuration into the IED.

This can be the most important impediment for multivendor substations as every IED requires a different IED configuration tool, with different revisions, etc. Which in practice makes it nearly impossible to perform maintenance in a multivendor substation in an efficient way.

Capabilities for these tools are:

- Configuration of the device functions (e.g. protection-, control-, automation functions)
- Generation of a file for device parameter setting
- Generation of the device model (.icd-file)
- Download of a device parameter setting file in the target system

3.1.14.4. Tools for Device Testing

Tasks for device testing tools are:

- Simulation / stimulation of process signals
- Simulation / stimulation of communication signals
- Testing of devices and system functions and verification of the expected behaviour.
- Monitoring signals changes on Reports, GOOSE publications and Sampled Values
- Integration with the system configuration tool

For example, these tools could be:

- Browsers (Client / Subscribers simulation), required to review the IED internal data structure and to detect if some changes have occurred in it.
- Simulators (Servers / Publishers simulation), required to simulate the behaviour of any IED to test the client communication capabilities.
    - Hardware
    - Software

- Time measurement, required to validate the response time from the IEDs and to compare with other architectures
- Network analysis, required to analyze the Ethernet packages exchanged in the network and to detect where the problem is (in the server, the client or in the network itself)
- FTP Clients, required to download/upload the configuration files into the IEDs
- SCL visualization and edition, to audit XML compliance with the standard

NOTE that IT security has to be considered, especially for browsers and ftp clients.

Device testing tools could support the use of predefined test procedures.

3.1.14.5. Diagnostic Tools

Tasks for the diagnostics tools are:

- Listen to and log the communication
- Retrieve and present of device models (according IEC 61850)

For example:

- RTDS (Real Time Digital Simulator) - To validate the behaviour of the merging units
- Primary Communicated Equipment Simulator - To substitute the injection equipment.

3.1.15. Tools for Creation of Common Data

According to CIGRE-119-2008 [6]; if replacement of one device from one vendor by another from different vendor is required, the data model must be the same in order to avoid system configuration changes. This is defined as interchangeability in IEC 61850-2 but it is not supported by the standard.

In order to achieve interchangeability from the data model's point of view, utilities can define the IED data model including: the Logical Devices (LD) and their names; the Logical Nodes (LN) which the LD must contain; the Data Objects (DO) in each LN; and the attributes the DO must have, mandatory for both IEC 61850 standard and by the utility.

Most IED vendors, establish a fixed part on the LD's and LN's name and a fixed number of LDs. These practices make interchangeability impossible and when the time comes to add new IEDs the System configurator must import the XML device description in order to acquire its capabilities. To prevent this, the LD's name must be modifiable by the user, therefore no fixed part must be allowed by the utility.

The current available equipment and IEC 61850 standard version 1.0, do not force vendors to provide sufficient flexibility for utilities in order to reach interchangeability. IEC

61850 version 2.0 and a new IED's platform will help, but it is up to the utilities to establish the required IED conformance tests.

3.1.15.1. Example on naming conventions

For IEC 61850 edition 2.0 Mexico has, as one example, created a document describing a Data Model to reach interchangeability. Some vendor's devices already comply with this document.

If a Logical Device defines the representation of a substation's function, the System will feature a LD for a distance protection (named PDIS) with multiple LNs related to this protection function; another for a circuit breaker (named XCBR), with LNs for its alarms, control and status information; and so on. In the end the System will possess sufficient LDs for each circuit breaker in the substation. In order to have unique names (as defined by IEC 61850), they will be conformed as defined in Table 6.

YYY	Three (3) Character for the Substation ID
#####	Five (5) Characters for the line's or circuit breaker's ID
ZZZ	Three (3) Characters for the Physical Device.
XXXX	Four (4) Characters for the function name

Table 6. Dissection of LD's name specified in Mexico

TEX93100PP1PDIS	This LD name refers to a distance protection function (PDIS), located in a Primary Protection 1 (PP1), associated to the line number 93100 in a substation Texcoco with the TEX identification.

Table 7. Example of LD's name for a distance protection

The System Vendor can select the required IEDs and how many LDs (functions) they feature. If an IED is used for protection, bay controller and measurement, it should have, at least, one LD for distance protection, one for each circuit breaker, one for each isolator and one for the measured values. If the system features IEDs near to the switchgear (MES), these could hold the LDs for circuit breakers and isolators.

When defining a Logical Device for each function, a list containing all Logical Nodes must be prepared. It is not required to list all Data Object (DO) and its Data Attributes (DA) for each LN, it suffices to establish that the LNs must include the above DO and DA, marked as mandatory in IEC 61850 standard. Just list the DO and DA, to be established as mandatory by utility.

3.1.16. Spare parts

Because the communication services replace the traditional hard-wired circuit in the IEC 61850 based substation, on one hand, the number of IEDs’ line terminals will decrease obviously and the hardware of different IED devices provided by the same vendors varies little (the software varies more), the overall number of IED devices and of their modules is nearly the same. Therefore, the number and category of IED devices for the spare parts will decrease obviously; usually belonging to category I specified in the table below. Of course, it is not feasible to standardize the modules of IED devices from different vendors. On the other hand, with communication devices and subordinate components used more widely, this category plays a more and more important role in the IEC 61850 based substation automation system. the number and category of spare parts for these devices must increase, usually belong to category II specified below.

Furthermore, besides the common tools required for installation and engineering in a traditional substation, the installation and engineering of optical communication systems requires some specialised tools, and even some special test tools. These are the mandatory tools in the installation and engineering of the IEC 61850 based substation and might be categorized in the section tools.

Table 8 lists the possible category I and II spare parts for IEC 61850 based substation.

Item	Part	Purpose	Note
Category I: for the IED (included MU)	CPU module	For IED	Special according to different vendors
	Power module		
	I/O Boards		
	Communication interface module		
	Operation panel		
Category II, for communication devices and subordinate component	The major communication switching parts	For Ethernet switch	Special according to different vendors
	Optical fiber attachment	maintenance	Commonly used
	Pluggable optical transceiver		
	RJ45 plug		
	Twisted pair cable		
	Ethernet protocol test equipment		
	Electro-Optical converter		
	Optical power meter		
	Pigtail		
	Fibre cable		
	Line distribution frame in panel		

Table 8. possible category I and II spare parts for IEC 61850 based substation

From the utility point of view a very common strategy is to change the whole IED when any failure has been detected and then send it to the supplier to fix it. In this case, parts included in category I could be exchanged for several spare IEDs depending on the time needed to get a new one from the supplier.

If a real interchangeability between IEDs from different vendors could be achieved, this would reduce dramatically the number of spare IEDs required for a large utility.

3.1.17. Education, instruction

The advent of the IEC 61850 standard made it possible the use of Ethernet based high speed and reliable local area networks (LAN), allowing sharing of information among several IEDs, as well as the distribution of such information to the different users. This standard also helps to solve the problem of expanding the digital systems, as it offers the guarantee of interoperability between IEDs from different manufacturers, substantially reducing the cost of the system expansion.

On the other hand, this new technological stage represented by the IEC 61850 standard still does not have the necessary proliferation among the protection and control engineers of most utilities. It is urgent to start a training program involving the technical staff, including people from the engineering, operation and maintenance departments.

The training program shall include basic and advanced information about the IEC 61850 standard application and on all the related subjects such as local área network communication, use of engineering tools and test procedures. The program shall also include on-the-job training performed on the manufacturer or integrator offices, during the SAS development, integration, as well as factory and site test activities.

In order to overcome the lack of experience of the technical staff of the utilities, the installation of a IEC 61850 Test Platform or a Test Lab is being proposed. This test Lab or Platform may consist of an assembly of protection and control IEDs, connected by a communication LAN and with the necessary test equipment. The main goal of this Test Lab is to allow the engineering and maintenance people to gain experience in dealing with this new technology.

The Test Lab shall also allow the performance of functional and interoperability tests. It shall be possible to verify whether the SAS, including the communication LAN and the IEDs, will adequately execute the protection and automation functions in use, maintaining the performance specified. The most critical point will be the operation of the distributed functions involving IEDs from different manufacturers and considering the most unfavorable scenario for data flow and other signals which may occur in the communication LAN.

4. ITEMS TO BE DEVELOPED IN FUTURE IEC 61850 EDITIONS

Based on the content of this report the following gaps in the IEC 61850 standard, products and tools can be identified:

- IEC 61850-4 has to identify that there are different 1) use cases and 2) procurement strategies used. This affects the relationships and roles between the actors (customer, supplier, system integrator) involved.
- There is a general need for harmonization between the different parts of IEC 61850 and thus the tools and solutions developed based on these individual parts. For example names used in the first version of part 6 do not match the names used in the part 7-x series of standards.
- Many customers typically do not want to specify logical nodes in the requirement specification but define the functions and logical devices and associate these with the physical devices of the single line diagram. There is a need for an intermediate step where only logical devices are listed by use of logical device types.
- Focus on the interaction between different phases and activities, not links between actors.
- Support for parallel engineering activities with compilation at the end.
- Country specific letters are not allowed in the IEC 61850 object references, but can in some tools still be used in the SCL. This could lead to conflicts when an SCL file from one system is imported to another.
- Develop methods for system tests (a system test includes activitities to verify the behaviour of the complete SAS)
- Add support for RCM in IEC 61850
- Development of maintenance tools as described in 3.1.14.2.2
- The SCL file describes the substation network structure. Can this be used as a model for reliability calculations?
- The IEC 61850 Edition 1 standard does not define the use of redundant communication ports. Therefore, any vendor which uses two ports simultaneously or applies any type of switching from one port to the other is using a proprietary solution and will not be interoperable with other vendors IEDs.
- A logical function could be implemented in redundant systems. i.e. LD/functional redundancy, where one system at the time is active. Other functions which use the logical function always want to get input from the active function and do not care about which. How to redirect service requests and use hardware independent names?

- CIM vs IEC 61850 – how do they relate to each other and how can they be combined in tools?

- Documentation processes for IEC 61850 SAS. One of the great benefits of IEC 61850 is the self documentation aspects and the elimination of the need to produce thousands of connection wiring diagrams showing every wire between every device. With “one source of truth” induces being the SCD file the ability of monitoring any change in the devices with flags, extracting IID files even automatically. These features will mitigate documentation problems related to the configuration of the SAS. However there is one very important aspect of designing an SAS that has to be considered – the Design Approval process. The steps involved in this process are all paper based. In a virtual world individual signal flow documentation on a wire by wire basis does not exist e.g. GOOSE messages are defined with data sets which collate several signals e.g. CB open/closed status into one message.

- As documentation for a logical device there could be an overview logical diagram showing LDs and the relation between them in order to follow the functionality and the signals coming from input to output.

- It may be needed to reproduce an .scd-file in case the file has been lost. It should be possible to download the configuration from the IED to the System Configuration Tool in order to conform the .scd.

- Standardized download files and upload files to IEDs, meaning vendor-independent, is required. This may be managed if a part of the IED configuration tools should be integrated in the IED. The integrated tool should convert the standardized file to the IED specific file and make it possible to add vendor specific data .

- While utilities use functional names to identify substation components and functions the manufacturers typically use product names to identify IEDs and associated logical devices. To get an intuitive structure and naming in a vendor-independent environment the tools should support the use of functional names. The actual IED names used in the SCL files may be either functional names or product names. In the latter cases there is a need to specify the translation between the two reference systems.

- There is a need for tools that can transform the SCL files into a more understandable form that is closer to the traditional way of documenting the substation automation system.

- Every manufacturer has his own tool. This can be the most important hindrance for multivendor substations as every IED requires a different IED configuration tool, with different revisions, etc. which in practice makes nearly impossible to perform maintenance in a multivendor substation in an efficient way.

- Most IED vendors, establish a fixed part on the LD's/LN's name and a fixed number of LDs. These practices make interchangeability impossible and when the time comes to add new IEDs, the System configurator must import the XML device description in order to acquire its capabilities. To prevent this, the LD's name must be modifiable by the user, therefore no fixed part must be allowed by the utility.

- The current available equipment and IEC 61850 standard version 1.0, do not force vendors to provide sufficient flexibility for utilities in order to reach interchangeability. IEC 61850 version 2.0 and a new IED's platform will help, but it is up to the utilities to establish the required IED conformance tests.

- For IEC 61850 edition 2.0, Mexico has created a document describing a Data Model to reach interchangeability. Some vendor's devices already comply with this document.

- SNMP features are not modeled in IEC 61850 Edition 1.

- In order to achieve interchangeability from the data model's point of view, utilities can define the IED data model including: the Logical Devices (LD) and their names; the Logical Nodes (LN) which the LD must contain; the Data Objects (DO) in each LN; and the attributes the DO must have, mandatory for both IEC 61850 standard and by the utility.

5. PROPOSALS TO MITIGATE IDENTIFIED GAPS AND FUTURE WORK

There is a need to investigate what problems will be solved with the release of Edition 2 of IEC 61850 and what will require additional specifications.

Some gaps are not related to the standard itself but to the way processes, tools and equipment are implemented.

SCD file is a very important file for substation extension (brown field) and some tools to work with them should be developed.

Requirements that would facilitate the maintenance and would be highly appreciated are:

- A single interface to configure any IED
- One tool to update the SCD file
- Only one configuration file per IED to completely configure it (not only the communication issues but the control and protection issues)
- Possibility to download a configuration file directly to the IED without using the IED configuration tool.
- In order to fill the above mentioned gaps and to improve drastically the engineering process a powerful system configuration tool as described in chapter 3.1.14.2 is needed. This vendor independent tool will simplify and reduce the cost of the engineering and maintenance process.

6. SUMMARY

Two different engineering strategies for the utilities have been defined: flexibility and standardization (chapter 2.1.1). The first one leaves the responsibility for designing the optimal solution to the vendor (cost effective), while in the second one is the utility who designs the solution (more control).

In both strategies the different roles involved in the engineering have been detected (chapter 2.1.4), some of them will be done by the utility's personnel while others will rely on the vendors and the integrators. We have found that the main differences between IEC 61850 and other electronic SAS are related to communications, while the rest of the roles are nearly the same.

The main requirements for the engineering software tools have been defined. We consider that maintenance tools are the less developed ones. In order to have different suppliers and facilitate maintenance, one only tool for all the IEDs would be desirable.

We consider that IEC 61850 is one step ahead, but we consider that there are several issues that should be further developed in future editions and implementations of the standard (Chapter 4). Interchangeability and easy maintenance in multivendor SAS would be highly appreciated.

7. ANNEX

7.1.1. Abbreviations

CID Configured IED Description

HMI Human Machine Interface

ICD IED Capability Description

IED Intelligent Electronic Device

IID Instantiated IED Description

IP Internet Protocol

IT Information Technology

ITP Inspection and Test Plan

FAT Factory Acceptance Test

GOOSE Generic Oriented Substation Events

MAC Media Access Control

MICS Model Implementation Conformance Statement

MMS Manufacturing Message Specification (ISO 9506)

PICS Protocol Implementation Conformance Statement

PIXIT Protocol Implementation Extra Information for Testing

RCM Reliability Centered Maintenance

RTU Remote Terminal Unit

SAS Substation Automation System

SAT Site Acceptance Test

SCD Substation Configuration Description

SCL Substation Configuration Language

SCADA Supervisory Control and Data Acquisition

SNMP Simple Network Management Protocol

SSD System Specification Description

VLAN Virtual Local Area Network

7.1.2. References

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7.1.3. Questionnaire results

The responses received to the questionnaire has been very low, the consequence is that the results and statements cannot be considered completely representative.

7.1.4. INTRODUCTION

The questionnaire prepared by Cigré WG12 was sent to a large number of companies whose work is related to substations. The main objective of the questionnaire was to ask companies to analyze the influence of the IEC 61850 standard on their engineering process. Seven companies replied to the questionnaire.

The profile of the enterprises that responded to the questionnaire is quite diverse, albeit short in number and is summarised in the following table:

Name	**Country**	**Sector**
Svenska Kraftnät	Sweden	Distribution
Vattenfall Eldistribution AB	Sweden	Distribution
Beijing Sifang Automation CO.,LTD	China	Manufacturer-supplier
ABB AB (Substations)	Sweden	Substations eng.
NOK	Switzerland	GEN+trans
Comisión Federal de Electricidad (CFE)	México	GEN+TRANS+DIST
Luz y Fuerza del Centro	México	GEN+TRANS+DIST

The answers received are varied but a common trend is easily identified: all of the companies expect to obtain a number of benefits from the implementation of a substation system automation protocol, mainly, from a time reduction in the engineering cycle enabled by interoperation between IEDs and, a simplification in the interpretation of information. However, as their experience is still short, few of them have already stated benefits.

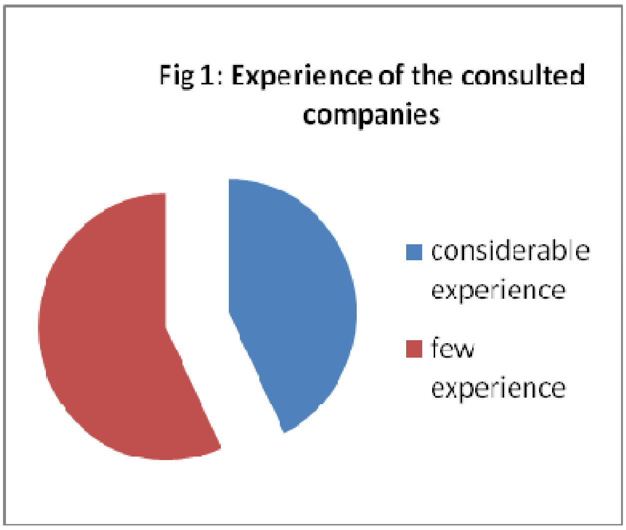
7.1.5. RESPONSE ANALYSIS

7.1.5.1. Standardization or customization

The IEC 61850 transmission protocol is a standard that permits simplification of data transmission and communication between different devices in a substation. The idea that standardization is the path of choice is clearly evident from the response to the survey. As a consequence of this policy, 50% of the distribution companies consulted, anticipate a reduction in substation costs, in part due to increased competition between suppliers, but more so as a consequence of the general standardization process expected to result in reductions in project execution time and easier data interpretation; although most of those polled predict that a reduction in the flexibility of the project is a price that they will have to pay. In fact, all of the engineering companies consulted, consider it impossible to execute a project without a certain level of customization to meet the special requirements of the respective job.

7.1.5.2. Benefits expected from IEC 61850

When asked to describe the benefits expected from IEC 61850 integration, the answers obtained from enterprises with limited experience in working with the standard are diversified.



As an example, a distribution venture with limited knowledge in the application of the standard expects that the standard will simplify their work and improve quality while simplifying wiring, while the other distribution company anticipates some simplification in their work as a benefit of one common protocol being used by all suppliers. Another view, from a Mexican distribution, transport and generation company, highlighted the benefit from being able to integrate information from substations IED's and send it to central control, in order to take ensure that the best decisions are taken when operating the power system.

On the other hand, the enterprises that are more familiar with the IEC 61850 standard go further. As an example, one of these companies, a European engineering venture, expect to reduce engineering times as a result of integration, standardization of documentation and improvements in the support of concurrent engineering, while a Mexican company whose work is related to generation, distribution and transport businesses, expect the standard to simplify specifications, communications and IED configurations and to realize a reduction in the use of diagrams and text descriptions. A Chinese manufacturer that responded to the poll, an IEC 61850 pioneer in China, remarked that besides interoperation, opportunities to simplify the engineering life cycle and save time were attributed to the SCL standard interface language.

7.1.5.3. Implementation results

7.1.5.3.1. Impact on the engineering life cycle

When discussing the future and impact on the engineering life cycle, the engineering companies that responded are the most convergent in their answers, as they all expect to improve and increase the use of Substation Configuration description Language, SCL, thus simplifying the process.

As for the distribution companies polled, both of whom were from northern Europe, one believes that the standard will influence them but does not state how, while the other one does not expect the standard to influence them too much until they become more familiar with it, but leave the door open to improve their engineering process when they familiarize themselves with the IEC 61850 standard.

Another aspect is seen by the GEN+DIST+TRANS firms who expect to raise their productivity and cut process times while increasing the reliability of the system thanks to a decrease in the number of problems encountered, but pointing out that the realization of any benefits will depend on the tools available.

7.1.5.3.2. Benefits seen from experience with the IEC 61850

Just two companies have the necessary experience with which to state benefits that can be attributed to the standard. On the one hand, a GEN+DIST+TRANS firm, noted the benefits during the FAT tests at an IEC 61850 substation, where the system reconfiguration was relatively easy without hardwire modifications. They were also able to change the protection functions from one device to another in order to improve performance in a very short time. On the other hand, an engineering company checked the interoperation between IEDs and noted the time reduction in the process for when the ICDs from the vendors are valid, and that is not always true, as they pointed out.

7.1.5.4. Additional work for suppliers

The question regarding whether or not IEC 61850 is seen as a way of transferring additional work to suppliers, was answered only by an engineering venture, who advised that this is only the case if something is abnormal, because they do not have the necessary tools or they are not sufficiently familiar with the standard. In their opinion, experience and the power of the tools are the most important contributors to improving how communication problems are solved and making ICD tests easier.

7.1.6. CONCLUSIONS

The answers show a general tendency towards the acceptance of IEC 61850 although the incorporation of some tools into design processes and the required engineering skills must be assumed in order to become familiar and adapted to the aforementioned standard.

However, some companies, generally, the distribution ones, only show a small interest in adapting to the standard and seem more passive in this process than the engineering ones; as one of them explains, their demands are the same independent of the solutions. It seems significant that a generation, distribution and transport venture has shown great interest in including the IEC 61850 standard in their engineering life cycle after noting some small profits gained in their first experience, looking for greater efficiency and productivity.

There is no longer any doubt in the existence of easily observable benefits in the implementation of the standard, likewise there is a cost in adaptation to absorb in order to optimize the change.

The other important conclusion to note from the response to the enquiry is the one given by the Chinese supplier; that says that even with some of the tools that have already been developed, the communication analysis process available to identify errors is still too complicated.