Experiences in organisational development and specifying IEC 61850 systems

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1 Abstract

The first six years of the existence of IEC 61850 has seen some 4000 implementations worldwide giving us great confidence in the technology delivering on its promises. The more recent substations have well demonstrated protection and automation functionality and a greater understanding of how to specify and choose devices for multi-vendor interoperability.

At the heart of the substation automation system (SAS) is the fundamental issue that it is a fully integrated SYSTEM involving not just protection IEDs, but also condition monitoring devices (sensors and processing units), primary plant, HMI, gateways, telecommunication systems. If the system is to perform as a system the requirements must be well defined at the outset so that the procurement and implementation are consistent to those objectives.

The system must be specified and designed to achieve the operational requirements in a holistic sense, not just as a collection of individual elements that happen to come together as pieces of a puzzle. Furthermore, the specification must consider the extent of the immediate implementation and plan for the ultimate and continued expansion of the system and functionality throughout the substation.

In many cases the issues are not just the interaction between the Logical Nodes, but more fundamentally the organisation's structural requirements associated with different groups and the physical facilities each are more comfortable to use, albeit a philosophy and paradigm shift to some degree is inevitable. The organisational understanding and commitment ("buy-in") must be integrated into the concept development as well as the specification processes which itself is a significant process.

This paper presents the experiences in specifying IEC 61850 systems from the end user perspective, independent of specific vendor choices. It explores the issues associated with defining the operation of the SAS, the individual functions, the interfaces between elements and the implementation requirements in the SAS model.

2 Elements of the SAS

The SAS comprises various IEDs generally previously referred to as the secondary system of the substation such as:

- Protection relays
- Controllers
- Meters
- Network Switches
- Time synchronization source
- SCADA gateway/RTU
- Station computers
- Station Human Machine Interfaces (HMI)
- Information servers
- etc

The SAS also comprises various sensors and condition monitoring equipment IEDs as part of the primary equipment which are also included in the SAS such as:

- Switchgear
- Power transformers
- Instrument transformers
- Capacitor banks & reactors
- Static VAR compensators
- Flexible AC Transmission

The above equipment are connected via the IEC 61850 Station and Process Bus as shown in Figure 1. These two Bus may be physically independent or operate over the same LAN.

In principle the Process Bus relates to signals emanating from, or being sent to, the primary plant and their intelligent [communication based] interfaces whilst the Station Bus relates to signals between other IEDs and control systems in the substation.

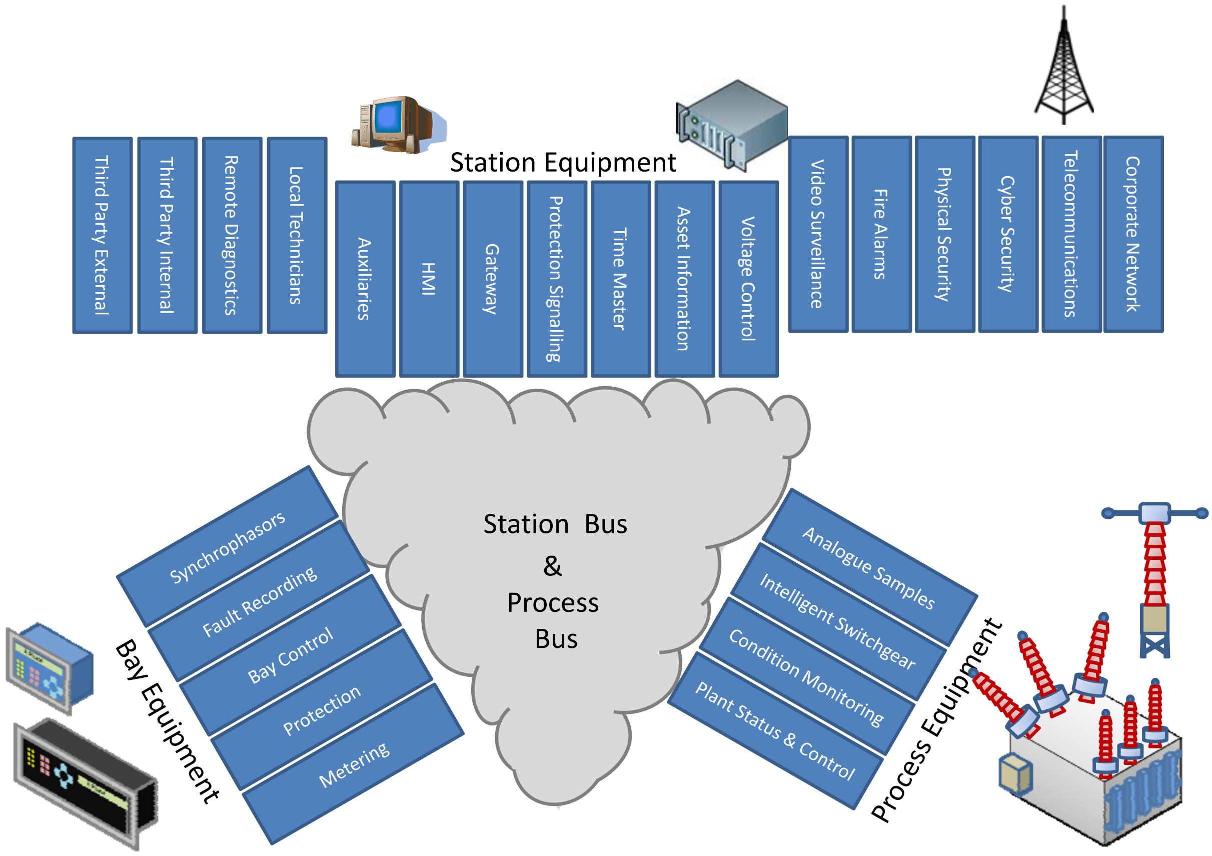

Figure 1 Elements of a Complete SAS

The IEDs collectively provide the required functionality of the SAS using combinations of wire based and LAN connections as shown in concept in Figure 2.

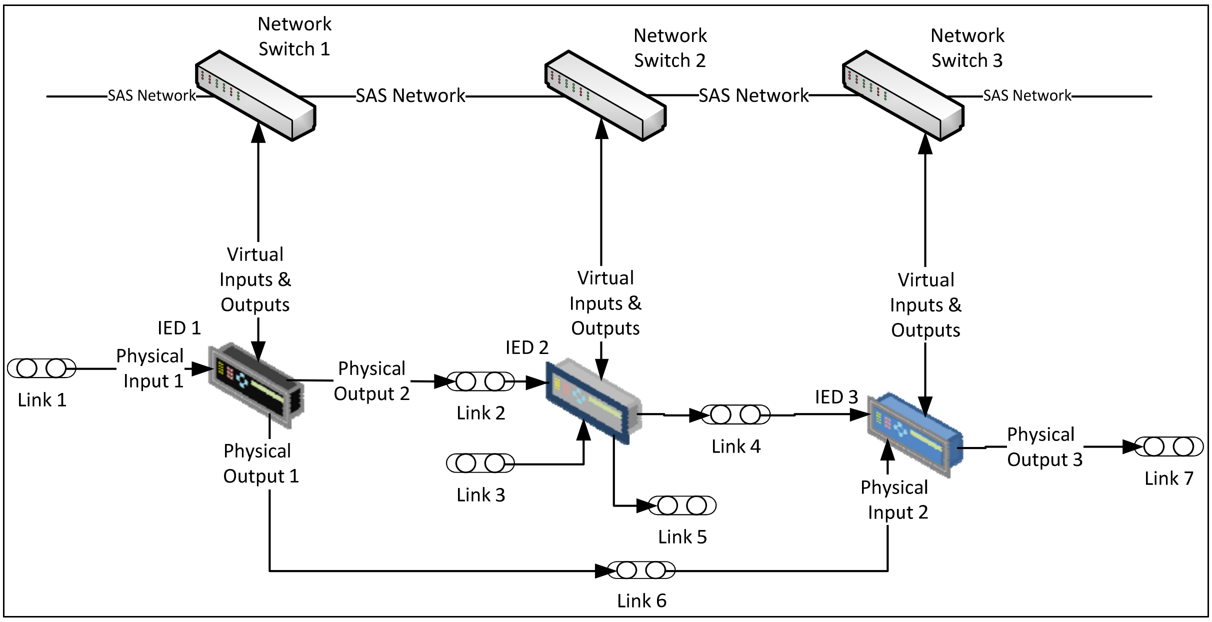

Figure 2 Generic SAS Concept

The IEDs have various input signals which may either be physical inputs as hard wired connections, or "virtual" inputs as messages being received from other IEDs via the SAS Local Area Network (LAN). These inputs represent information about the substation plant and equipment, the position of operator control switches or information from other IEDs.

The IEDs also have various output signals which may also either be physical outputs as hard wired connections, or virtual outputs as messages being sent to other IEDs via the SAS LAN.

The physical interconnection of the LAN Switches (ring/star, redundant LANs, cross connection etc.) is determined in consideration of several factors for reliability, accessibility, maintainability, performance and cost.

3 Elements for Operation of the SAS

Depending on the LAN configuration and IED capabilities certain steps must be taken when physically disconnecting a device from the LAN or disconnecting connections between the LAN Switches.

Operating the SAS requires personnel on site to,

- monitor,
- control (switch on/off),
- modify,
- configure,
- test,
- block,
- enable/disable,
- substitute,
- isolate, or
- replace

various individual or collective functions or IEDs of the SAS. Some of these activities may also be carried out by personnel remote from the substation.

The SAS has changed from being based almost entirely based on individual wire connections between devices to incorporating communication between devices using IEC 61850. This enables real time operating functions and schemes to be created which operate via the SAS LAN. This requires staff to be able to undertake the tasks described above in consideration of both the hard wired connections and virtual connections via the SAS LAN.

The IEC 61850 Standard itself has defined various commands, modes, information and messages as capabilities specifically for the purpose of controlling the SAS for various purposes including personnel based activities. It is not the intent of the Standard to define why, where, how or to what extent, if at all, these capabilities are implemented in any particular SAS.

Operation and testing of IEC 61850 based systems must provide for both the wire based inputs and outputs of the SAS and its individual IEDs, but also sending and receiving of the IEC 61850 messages via the LAN.

A patented Operator and Test Interface (OTI) provides two vital components for physical access to the automation system:

- Operator physical safety
- Avoiding LAN disruption

The OTI eliminates the need to access the rear of the panels where all the electrical and LAN connections are made.

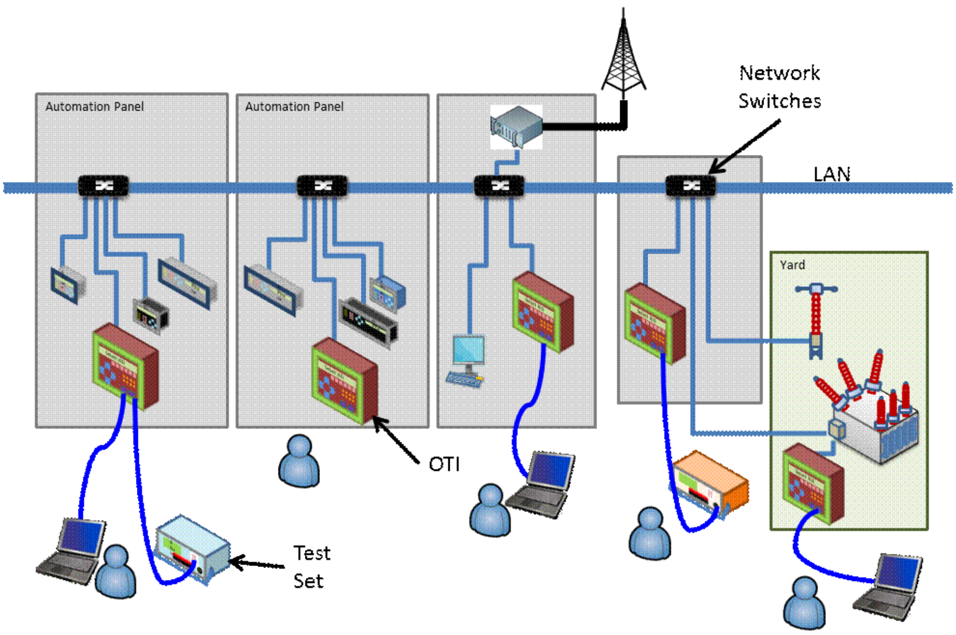

Figure 3 Operator & Test Interface - Human Interoperability

The rear panel has a variety of terminals and live wires in a confined space which should only be accessed when absolutely necessary for physical modifications to the system. Connections for testing of the system should be done via the OTI front panel to minimize operator difficulty and electrical hazard.

LAN access security is maintained with connections only via the OTI front ports. These ports themselves can be subject to Role Based Access Permissions within the device and/or authorization from the User Access Permissions Server and/or from the System Control Centre Operators according to the company's security implementation. The Control Centre Operators can validate the connection in accordance with the Work Procedures lodged for the site work and knowledge of who is in the substation. Once access is granted, the equipment can communicate with the LAN as if directly connected. Security can be further maintained with time-out or log-off systems associated with staff leaving the premises.

It is inappropriate and indeed a risk to the operation of the entire SAS, and potentially the power system at large, for personnel to undertake their activities mentioned above by simply physically disconnecting the IEDs from the SAS LAN as each connection has many signals being exchanged with the IED for the correct functioning and performance of the SAS as a whole.

Temporary connections to the LAN can be made through the OTI front plate eliminating the risk of inadvertent LAN disruption. The LAN itself is formed by numerous connections between the LAN switches and the IEDs as well as from one switch to another. Unlike screw terminals which are well identified and require tools to disconnect and make connections, LAN connections appear similar (as shown below), can be readily removed by hand and are easily confused. The OTI front ports avoid the possibility of disconnecting the wrong cables in the rear of the cubicles.

It remains necessary to be able to monitor, control, block or substitute functions and associated messages whilst the SAS is operating in whole or in part with the electrical facility in service or undergoing commissioning or test.

For each task to configure the system for test, or reinstate it to normal operation, the OTI will send the sequence of commands and verify the response of each IED. Standardized sequences reduce the risk of critical steps being missed which would otherwise lead to inadvertent power system outage. This has the added advantage of increasing operator confidence with complex integrated systems.

Every IED on the network at some time will need testing, maintenance, upgrade and/or replacement for one reason or another. The OTI provides the mechanism for operators to place the automation function IEDs into the correct configuration to enable those tasks to be carried out safely and reliably. As an IED itself, the OTI unit also may need to be maintained and hence has to be able to be removed from service without affecting the SAS operation.

However any activity involving isolation or testing of a function(s), device(s) or system must incorporate procedures for both hardwired signals as well as LAN based signals in order to undertake the activity in safety and without compromising the SAS operation.

4 Elements of the Implementation Process

The approach to implementing IEC 61850 encompasses a number of elements generally referenced directly or by implication in CIGRE Technical Brochure 326.

In more detail the implementation process will vary in degree of need depending on the extent to which the asset owner has already investigated and developed solutions and the overall project delivery approach with in-house and outsourced activities.

- Business Case Development
- Implementation Strategy
- SAS Architecture and Function Allocations
- Equipment Procurement Requirements
- Engineering Tool Procurement

- Engineering procedure development
- Project delivery methodology
- Scheme development
- Commissioning and operation processes
- Migration path planning and project management
- Asset management information system interface
- Staff development programs
- Technical Steering Committee and Mentor roles to support the asset Owner, Operator and Maintainer

The following elements form the overall approach to implementation of IEC 61850 in a general sense. They are provided here as an outline of the activities that need to be undertaken by asset owners to varying degrees depending on their business model and internal/external resourcing strategies.

4.1 Business Case and Implementation Strategies

An important step for the introduction of IEC 61850 as the core of the Substation Automation System is the identification of the business drivers and hence the definition of the business case. This will drive the implementation strategy as well as the implementation as such.

Elements to be considered when preparing the business case include the following:

- Correlate benefits of IEC61850 based engineering solutions against the asset owner's key business drivers and Balanced Scorecard,
- Liaise with and survey/document the asset owner's operator's and maintainer's key internal stakeholders and their opinions for how IEC 61850 could be implemented,
- Indicative investment costs the asset owner could expect to outlay to investigate and implement the strategy under a capital project scenario excluding project capital costs

The business case will identify the aspects of IEC 61850 that are of key importance for the asset owner. While defining the implementation strategy and the elements of the implementation, it is important to keep the focus on the business drivers to ensure the success of the project.

As part of the implementation strategy, the following issues need to be considered in summary and non-exhaustively:

- Steps for the introduction of IEC 61850
- Identification of a pilot project
- Training program and facilities requirements
- Processes to engage and develop skills of service providers for design, construction, operation and maintenance
- General Migration plan

4.2 SAS Definition – Design Concept Specification

Vital to the deployment of a Substation Automation System is the definition of the functions and architecture of the complete system together with an overall view of the ultimate deployment evolution.

This report will fundamentally describe the nature of the asset owner's SAS environment and will provide a reference for how the SAS system is to be realised in any project in a physical sense as the agreed high level requirements.

Some of the essential issues in considering this architecture will involve total X and Y LAN segregation, cross connection points of the LAN to enable functions at the Bay Controller, Gateway and HMI levels, intertrip handling, condition monitoring access and operational constraints and telecommunication interfaces etc. The extent of these considerations apply to the entire SAS as shown in Figure 1.

IEC 61850 at its heart allows functions to be allocated anywhere within the SAS. However the asset owner will need to have a defined set of fundamental principles for the allocation of these functions such as SCADA and operator initiated Trip/Close, connections to primary plant, plant status inputs, Automatic Voltage Regulation, Auto Reclose, Interlocking, Disturbance Recorder capture etc. These principles then form the basis of detailed implementation designs and System Integration.

This step is required in order to identify the functions, and hence Logical Node requirements, as well as the signalling services that must be supported within the SAS and the individual devices– e.g. what functions reside in the Bay Controller vs. Relays vs. Gateway, both as entire functions and as needing exchange with other physical devices. This may also include explicit statements regarding what functions must not reside in certain devices. Stakeholder engagement in this step is essential to identify the Reliability (including cyber security), Accessibility (including isolation), Maintainability and Performance requirements of the SAS.

In essence, various functions will need to be evaluated into their component parts and allocated to individual components of the SAS in order that the required functionality can be specified in consideration of the current and future SAS operation. In the partial example of a hypothetical SAS shown below, the process bus interfaces at this stage are assumed to remain hard wired conventional equipment (red elements) but will ultimately be included in the SAS architecture. Similarly the 'P' functions will largely reside within the Protection IEDs. Allocation of these elements within the SAS directly affects the complexity of functions and capabilities of the IEDs, as well as the definition of the physical and communication interfaces to support the scheme operation as shown in Figure 4 (IEC 61850 Part 5 Fig 10).

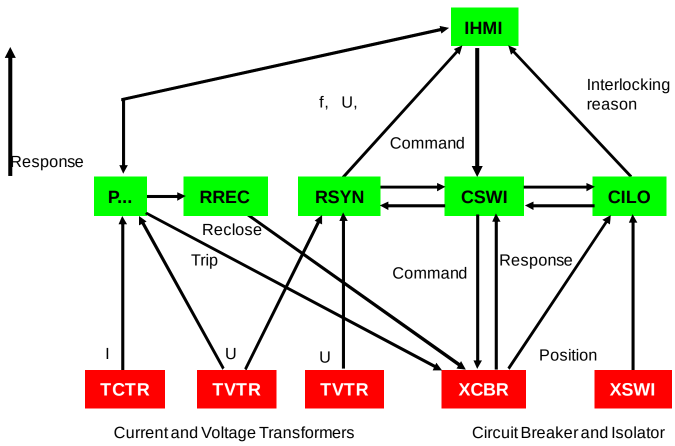

Figure 4 SAS Signal Flow Definition

4.3 IED & System Procurement (Relays, Controllers, Condition Monitoring, HMI, Network Switches)

This specification will be developed based on the results of the work in Element 1 and 2.

4.3.1 Develop Equipment Specifications.

The asset owner's standard procurement specifications detail the protection and other IED application performance requirements (applications such as distance protection, current differential, autoreclose, disturbance recording etc.). In addition, the principle objective of this work will be to establish detailed requirements for the IEC 61850 specification elements of the equipment. This covers such aspects of Logical Nodes to be provided and allocated in specific devices, the supported ACSI, Communication interface capability parameters, fixed and virtual ICD definitions, tool requirements etc.

4.3.2 Tender Evaluation & Specific Vendor Discussions

Successful SAS implementations require validation of the suitability of the chosen devices for the scheme communication requirements as Conformance Certificates only relate to compliance to the Standard for the elements implemented. It is therefore necessary to closely review current and future services to be provided that will provide interoperability in the final deployment.

Additional to the function and communication implementation reviews, it is also necessary to validate, possibly requiring demonstration, that the vendors IED tools can import and export the Substation Configuration Language (SCL) files (SSD, SCD, ICD, CID, IID and SED) produced and used by the engineering test, commissioning and operational processes with full compatibility and interoperability.

4.4 Engineering and Operational Tools

There are a variety of tools that may be used within the scope of specification, design, commissioning and maintenance of an IEC 61850 based substation.

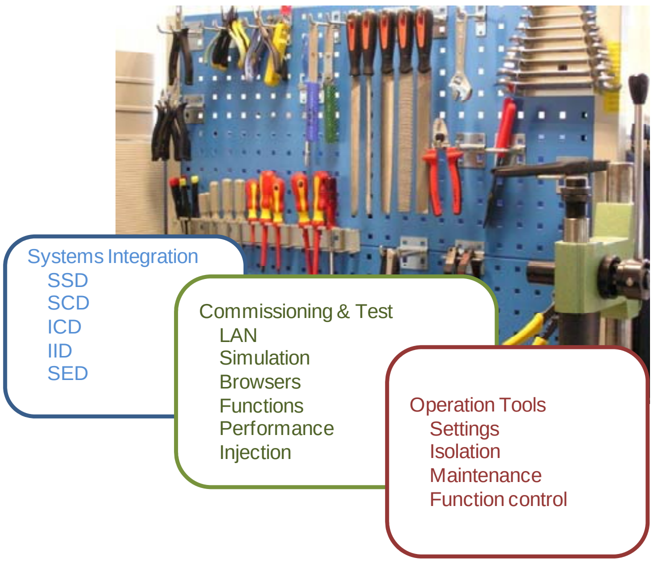

Figure 5 Suite of SAS Tools - IEC 61850 specific and non specific

In the broader view of an Asset Owner and the Engineering Process, it is vital to consider the requirements for information management and procedural interfaces throughout the engineering lifecycle

These processes include amongst many systems and individuals

- o Relay setting files and version issue and history management
- o I/O listings

- Master Station HMI configuration
- Local HMI configuration
- Alarm policy
- Wiring Schedules
- Test programs and result records
- Temporary settings
- Isolation procedures and facilities
- etc

These ‘utility proprietary’ systems must be maintained for the existing legacy solutions in as much as being adapted to or with the IEC 61850 engineering process.

4.5 SAS Introduction and Implementation Standardisation

The essential justification and benefit of IEC 61850 is in creating a range of Reusable Engineering Designs that form the standards and templates for each project to be delivered.

This involves establishing the communication system, the functional interactions, the message structures and controls for correct performance of the SAS.

An important step in the introduction of an IEC 61850 based SAS consists therefore, in the development of the relevant schemes and design templates.

The level of work offered for the introduction and the implementation of the standards depends on the approach chosen by the asset owner in the implementation strategy, use of internal/external engineering and the role of the system integrator and vendors.

There are already many installations worldwide and in Australia which have proved the performance of the IEC 61850 technology. However if the benefits of Reusable Engineering are to be obtained throughout the whole of asset life and from one project to another, we generally recommend following the following the four steps as the engineering process outlined in IEC 61850 Part 6 using the System Configuration Language files, in contrast to just using equipment vendor specific device level configuration tools:

1. the specification of the substation; i.e. the creation of the SSD file
2. the creation of the ICD files for the IEDs
3. the system engineering: i.e. the creation of the SCD file, comprising:
    a. instantiating the IEDs and allocation of the IEDs to the process
    b. design of the communication network
    c. design of the data flow for the information that needs to be transmitted to control centres and local HMIs (i.e. configuration of reporting)
    d. design of the data flow required to implement the protection and control schemes)i.e. configuration of GOOSE messages)
    e. SED files for integration in neighbouring substations
4. the loading of CID files to individual devices together with any proprietary configurations and extracting the complete IID file

We can provide assistance in each of these phases to develop specifications and implementations based on the SCL files and the definition of the SAS developed in Element 2 combined with the IED and Tool procurement in Elements 3 and 4.

4.6 Staff development

The final element is the provision of training throughout the asset owner's organisation and its service providers for specification, design, construction, commissioning, operation and maintenance covering

- general awareness at the managerial level of the standard and its business implications and requirements,
- detailed appreciation of the scope of IEC 61850 engineering at the technical and project management levels ,
- hands on expertise for the systems integrators, testing, commissioning and operating staff.

These levels of competency and the generic training programs must build on each other to aid in the change in understanding and skill sets from a wire based environment to a virtual system.

Figure 6 Competency Development Programs

5 Tool Requirements for the Substation Lifecycle

The focus of IEC 61850-6 is on the design, configuration and commissioning process of a substation. However, through the whole life cycle of a substation automation system, there are engineering, operation and maintenance activities which require a range of software tools. These tools create or rely on information in the IEC 61850 System Configuration Language (SCL) files.

An asset owner's ultimate objective is to obtain a complete suite of tools which can be used by all the parties throughout the life cycle of a substation. This is not limited to system specification, system configuration and IED configuration tools as described in IEC 61850-6.

This objective will require a range of tools to be integrated the desire for an integrated solution cannot be too highly emphasised.

The IEC 61850 tool suite will form part of the total substation engineering process. There are additional activities which in principle are not part of, but are related to, the IEC 61850 tool environment, e.g. physical wiring schematic drawings.

As an overall requirement, the tools must be usable in a multi-user multi-project collaborative engineering process involving the asset owner and various third parties using the asset owner's or their own individual computer environments directly or by remote access. As such it is preferred that the tools not be encumbered by limited licencing or hardware locks (dongles) to individual users or computers. However tools are required to incorporate relevant role based access and use permissions (view/edit) as well as single user edit control (check in/out) features to maintain integrity of the SAS design and operation.

The life cycle of a substation can be broadly categorized as the following general Tasks, each with a wide diversity of activities undertaken by various personnel according to the organisation policies, in/out sourcing models and responsibilities within the life cycle chain:

- Pre Design / Libraries
- Design, quality assurance, validation and approval
- Implementation (including construction, configuration, FAT, SAT and commissioning)
- Operation
- Maintenance (including monitoring and testing)

The different tool elements manipulate and use various pieces of information including but not limited to:

- Power system topology arrangement and operational parameters
- the run time information made available by the IED (the data model)
- the description of the data flow between IEDs
- communication parameters
- IED specific information related to the functionality (e.g. protection and control parameters, description of logics)
- I/O connectivity of the IED (hard-wired and communications based)
- Documentation of inputs and outputs in support of activities

Each Task is described below as indicative of the objective of the tool relevant to that Task.

5.1 Pre design / library Tasks

These tool elements are required to support the design and modification of libraries including the following tool elements:

- Specification of typical feeder / bays (single line diagram, data model, functional requirements)
- Specification of typical protection and control schemes
- Specification of testing requirements / testing scripts for the typical functions
- Specification and evaluation of IED capabilities in respect of the asset owner's requirements to be included in the library of accepted IEDs
- Specification of naming standards and restrictions

5.2 Design Tasks

These tool elements are required to support the different steps of the design of a substation including the following elements:

- Specification of the substation (Single line diagram, data mode, functional requirements)
- IED pre configuration
- IED instantiation
- Scheme development
- IED logic development (proprietary / IEC 61850)
- IED parameterisation for the specific application
- IED I/O assignment (hard-wiring
- Legacy IED interface design and configuration (physical digital/analog and virtual)
- Gateway configuration including the configuration of the communication part towards the Master station
- HMI configuration
- Import and conversion of legacy IED configuration
- SAS communication network and time synchronisation system
- Telecom infrastructure configuration
- Desktop testing of SAS configuration (operation simulation and verification without using the IEDs)
- SCL file conformance validation

5.3 Implementation Tasks

These tool elements are required to support the different steps during implementation of the SAS, the FAT and final SAT including the following elements:

- Device level testing (IED parameters; IED logics; IED I/O wiring)
- Functional system level testing and debugging including function oriented communication analysis
- Performance testing including verification of communication network configuration and time synchronisation
- Gateway testing
- HMI and alarm testing
- SAT – verification of field wiring
- End-to-end testing of distributed schemes – inter-substation and intra-substation
- Failure mode performance verification
- Interoperability and Factory Acceptance Testing - configuration and testing

5.4 Operation Tasks

These tool elements are required to support the different activities during daily operation of the substation. In addition to support the configuration of information as designed, it is required to also support the history cycle (creation, approved, issued, applied, modified) of configuration changes and the “as operating” information.

This includes the following elements

- Condition monitoring of primary and secondary equipment (including communications equipment)
- Permanent / Temporary settings for power system topology operational changes
- Alternate settings
- Isolations
- Routine test of equipment and functions
- Primary equipment maintenance
- Power system events extraction, storage and analysis
- Primary equipment failures extraction, storage and analysis
- Secondary equipment failures extraction, storage and analysis
- Communication network equipment failures extraction, storage and analysis

Tool elements dealing with equipment failure are required to handle the mechanisms for graceful degradation of the system. The replacement / repair part is supported by tool elements of the maintenance group.

5.5 Maintenance Tasks

These tool elements are required to support the different activities during maintenance of the substation in case of equipment failures or retrofit / extensions of the substation. In addition to support the configuration of information as designed, it is required to also support the history cycle (creation, approved, issued, applied, modified) of configuration changes and the “as operating” information. Some of these activities imply use of the same or similar tools as used in Design and Implementation Tasks.

This includes the following elements:

- Topology changes in the substation primary arrangement
- Extensions of the substation
- Refurbishment of primary or secondary equipment
- Scheme enhancements in terms of performance or functionality
- Isolations
- Telecom network modifications and performance testing
- Repair / replacement of primary equipment
- Repair / replacement / upgrade of secondary equipment
- Setting / Configuration/ Logic changes of secondary equipment Repair / replacement / upgrade of communication network equipment
- Setting / Configuration changes of communication network equipment
- Managing IP and MAC address changes

6 Conclusion

There has been over 100 years of experience and technology applied to the engineering and physical implementation of wire based systems. These designs, processes, tools and skill sets are virtually second nature to engineering professionals deploying these conventional systems.

However the extent of change for an organisation should not be misunderstood. The design considerations have to be interpreted into new automation systems and new operational facilities. This flows into procurement and the entire engineering process.

Whilst this is a significant program of work, world experience is showing that this can be achieved within a reasonable time frame. It does however require identification of all the aspects and a program to deal with their individual requirements. With this done, an asset owner is set to reap the benefits of "Reusable Engineering" and "*More Projects in Faster time frames, with Less resources, Less money, Higher reliability and Lower operational cost*".

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Biography

Rod Hughes has over 30 years' experience in protection and automation systems. He has been the General Manager of one of the major relay vendors in Australia/New Zealand, Technical Director for development and marketing in Europe, Engineering Manager for a transmission utility in Australia and a State Manager and Technical Director in large multi-disciplined consultancies.

Rod is currently Convener of CIGRE Australia B5 Panel for Protection & Automation and Australian representative to the international Study Committee B5.

Rod has been a co-author of CIGRE Technical Brochure 326 "Implementation of IEC 61850" and has been involved in a number of other TBs as author or final editor.

Rod is convener of CIGRE Working Group B5.39 "Guidelines for documentation of digital substation automation systems".

Rod is now an independent consultant specialising in assisting organisations through the change management, business case, specification, implementation and training for IEC 61850 systems. Rod has presented many papers and provided various training courses from introduction to practitioner training in IEC 61850.

Christoph Brunner is (Less than 200 words per author)