Quality Assurance requirements and experiences for GOOSE/SV configuration

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1 Abstract

It is said that the correct way to describe IEC 61850 is that it “is no mere protocol, but rather an engineering process to configure IEDs to communicate”. The Standard defines three engineering tools and six System Configuration Language (SCL) file types used in the off-line engineering process in IEC 61850-6. From the practical point of view whilst humans can “read” SCL files, it is impossible to gain a complete understanding of how the system works and which signals are being created and used by the various IEDs. This is due to the complexity of the syntax of the language and significant size of these files with hundreds of thousands lines. Meanwhile, SCL files describe communications between IEDs and understanding them is important at different lifecycle stages of the electric power facility.

Several IED Configuration and System Configuration Tools provide a kind of visualisation for SCL files either in tabular, or in primitive graphical form without some level of detail. These formats may be suitable for creating configurations, but it Is not easy to identify errors in the project. Errors need to be identified at the initial “desktop” engineering configuration, at FAT/SAT/Commissioning phases (missing/wrong virtual connections), to those which can lead to performance degradation of protection and control schemes.

The key objective of IEC 61850-6 SCL files is to configure IEDs to communicate in multi vendor projects. Vendor-specific are obviously needed as the IED Configurator Tool defined in IEC 61850 6, but many do not behave well for multi-vendor projects. Moreover in most cases those tools are mainly designed managing the ICD and CID files, which generally makes them hard-to-use for visualisation, analysis and validation purposes of the complete multi-vendor SCD. In any case, quality assurance principles would suggest that

we should not be using the same tool as we used to create the configurations as the tool for validating the configurations in case the tool itself is creating and hiding the errors.

GOOSE and Sampled Value configuration is usually prescribed or “explained” by the ubiquitous Excel Publisher/Subscriber matrix, often generated by humans. As an engineering process this offers very little scope for visualising and validating precisely how the communications are configured in the SCL files leaving the discovery of problems to the FAT/SAT/Commissioning phases requiring appropriate specialist tools. As a result, it is often a “trial and error” process when loading the SCL files to the individual IEDs. This is in direct contrast/conflict to the well-used approval processes for all the drawings and configuration files in wire-based schemes prior to loading in the IEDs.

2 Use of SCL for system design

It is known that the IEC 61850 standard unlike many other communication standards defines the System Configuration Language (SCL) that can be used to describe IED configurations and communication systems according to IEC 61850-5 and IEC 61850-7-x. It allows the formal description of the relations between the utility automation system and the process (substation, switch yard) [1].

2.1 SCL usage

There are two main purposes SCL is used for in nowadays projects:

1. Description of IED datamodel and capabilities,
2. Description of IED communication configurations.

There are also three more points for SCL that are not widely used so far in projects but are worth mentioning as further applications:

1. Description of the process (i.e. substation, or switchyard with its primary equipment) and functions mapping,
2. Description of protection settings (that in fact is a part of the IED datamodel description, but being optional, is not widely used to date),
3. Description of programmable logic, which was not defined by [1], but was later described by a technical report.

Mentioned usages of SCL as can be seen from above actually cover all use-cases for IED configurations. I.e. SCL file in a meantime can be used of the only configuration file for the IED, which might be very convenient from the point of view of maintainability and usability.

2.1.1 Human-readable SCL

The SCL is based on Extensible Markup Language (XML). The XML itself is a markup language that can be used for description of almost any kind of structured information. It defines a set of rules for encoding text-based documents in a format that is machine-readable specifically to eliminate human interpretation when passing information from one tool to the next. XML as text also remains human readable to some extent when needing to inspect certain sections of files.

IEC 61850-6 SCL is a subset of “all-purpose” XML which restricts it to a set of certain structures and syntax suited to all aspects of power utility automation systems both within the substation and throughout the grid for protection, SCADA, control, condition monitoring and metering. This so-called “restriction” is provided by SCL Schema defined by [1], providing certain rules for the structure of SCL documents.

Figure 1. View of part of SCL file

In practical applications SCL files, describing the configuration of real-world substation could exceed millions lines of code. Although being human-readable, the sheer size and coding makes them extremely hard for humans to be interpret, understand and analyze what the system is intended to do, i.e. it is very difficult to trace a signal sent from one IED to another as is possible by “line chasing” on wire-based system drawings.

2.1.2 Human-written Excel Matrices for GOOSE-communications

One of the most impressive features of IEC 61850 is undoubtedly GOOSE message protocol defined in IEC 61850-8-1 enabling protection and automations systems with real-time communication capabilities. GOOSE protocol, being Layer-2 multicast protocol as defined by [2] and [3] uses “Publisher-Subscriber” association model, where one message published on the network can be subscribed by any number of IEDs without nominating them in the publishing IED configuration.

IEC 61850 defines somewhat strict rules for description of GOOSE publishing. SCL file describes dataset published with the GOOSE-message as well as GOOSE Control Block configuration and GOOSE Communication Parameters. However GOOSE-subscription cannot be seen from SCL-file in a glance — in a standard way GOOSE-subscriptions are defined in “Inputs” sections of Logical Nodes (or in certain cas ing and GOOSE-subscriptions.

In order to overcome mentioned issue many engineers ended up with creation of Excel matrices for GOOSE publishing and subscriptions. In rare cases such kind of matrices were created automatically based on SCL-file, where in most cases — manually.

The Excel table for GOOSE (or SV) publishing and subscription still have major drawbacks:

- If created manually this table might contain errors;
- Not flexible enough to give a fast overview of GOOSE(SV)-message and it’s contents;
- Might be hard-to-maintain and analyse in case of many IEDs in the project;
- Have no capability for further automation of analysis.

With potentially hundreds of IEDs on each axis it is not all that easy to verify the configuration. In any case, it is wise to use a different visualisation tool of the configuration than the tool used to create the configuration as the same tool may inherently hide the errors – if they were able to be created by using the spreadsheet, they may also be missed when looking at the spreadsheet.

2.2 SCL Tools Overview

IEC 61850 standard describes the engineering process for an automation systems with the use of set of tools [4]:

– **system specification tool (SST)**: allows specifying the system and device requirements regarding the needed system functional and process capabilities;
– **system configuration (system design) tool (SCT)**: allows selection of needed IEDs based on a system (requirements) specification, and defines the communication connections between the IEDs of the system and the logical relations between IED functionality and the primary equipment. Often the system configuration tool includes a system specification tool;
– **IED configuration (parameterization) tool (ICT)**: allows making the detailed parameterization of an IED based on a system design and requirement specification beforehand and a system description delivered by the system configuration tool after the system configuration process.

In order to enable interoperable exchange of engineering data between IED parameterization tools of different manufacturers and the system configuration tool, as well as between different system configuration tools handling different system parts as separate projects, [4] defines the use of SCL syntax for configuration files transferred between the mentioned tools. This continues through all activities of the lifecycle of the system as discussed in [5] and [6].

System Specification tool as defined by the standard is referred to when specification of system functionality and process capabilities is required and usually never goes deeper into communication dataflow and protocol configurations. Whereas System Configuration as well as IED configuration tools are both used for system (or IED) configuration and export of final configuration including GOOSE- and SV-communications configuration.

In most cases, however, the intended purpose of those tools is configuration, but not visualizations and configuration analysis. So in case of use of different tools the user could either suffer from lack of tool interoperability (especially in multivendor-projects) or application-specific analysis. There are many horror stories of vendor-specific ICT, even SCT, not accepting/understanding the SCL files produced by a different vendor's tool, in some cases even rejecting the changes made by the previous tool and reverting the contents to what the second tool "thinks" the content should be according to its own capabilities!

Table 1 summarizes capabilities of SCT and ICT in different areas based on the practical experience and overview of the authors with modern tools, where "-" means the capability is unavailable, "+" the capability is available, "+/-" means that the capability could either be available or unavailable dependent on the tool, or could be poorly implemented by the tool user or overviewed.

Table 1. Summary of SCT and ICT tool capabilities

	System Configuration Tool	IED Configuration Tool
Visualization of communications	+	-
Multi-vendor	+/-	-
Analyze project	+/-	-
Vendor-specific analysis	-	+
Application-specific analysis	-	+/-
Trace changes in the project	-	-

2.3 SCL Challenges

Provided the aforesaid authors see that being unable to properly analyze SCL-file on the early design stage, commissioning and maintenance personnel shall face much worse problems at FAT, SAT or commissioning, potentially leading to the breakdown of project deadlines or errors in configuration and further performance of the system.

3 Required Quality Assurance on different stages

In order to eliminate misconfigurations and optimize configuration special quality assurance measures shall be taken into account on different stages of the project.

3.1 Overview

Figure 2 shows different kinds IEC 61850 system manipulations, including SCL-file analysis as well as real-world signal tracing and analysis, providing maximum quality assurance on different stages of the project.

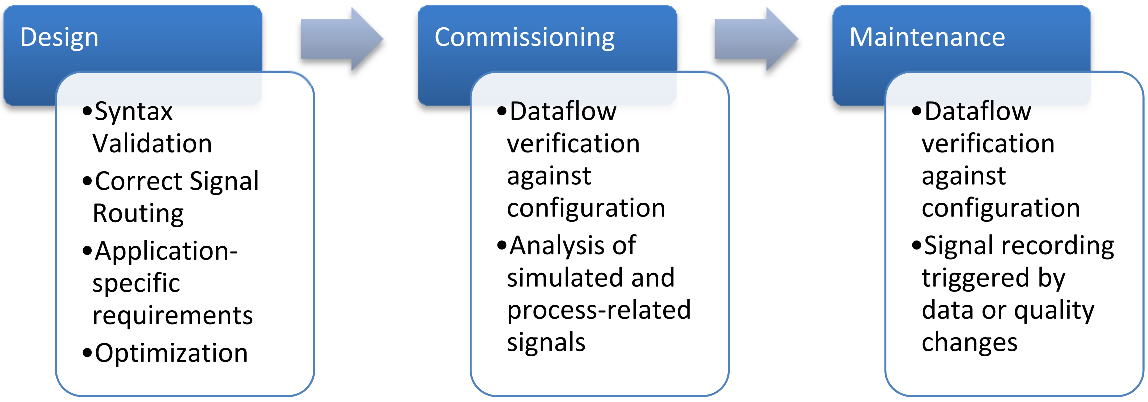

Figure 2. Quality Assurance Measures for different project stages.

At the Design Stage personnel would usually work with SCL-file only (i.e. without real IEDs to configure) so the main aim here is to provide valid SCL-file for further stages with correct signal routings and optimized configuration, taking application-specific requirements into account.

At Commissioning stage the engineer is required to make sure that the configuration loaded to IEDs actually matches the original configuration, which could be achieved by real data-flow verification against SCL configuration. Also simulated and process-related signals shall be analysed in order to ensure proper performance of the system both in normal and test conditions. Part of this stage includes validating that the IED communication configuration is in fact correct according to the System Integrator's "as built" SCL files, and in reverse that the "as built" SCL files accurately represent the "as operating" configurations [7].

Finally at Maintenance stage (i.e. system normal operation) it is required to confirm that actual system dataflow matches the designed configuration and any kind of data or quality change, including loss-of-connection, shall trigger the event recorder. This stage also includes verifying that there are no changes since the system was last validated by comparing the sniff of the network traffic "today" with the previous sniff at commissioning or in the last annual maintenance [7].

It is also very important that there is only one System Configuration Description (SCD) file for the entire project, and all changes to the system configuration are contained in that SCD at all stages of the project and lifecycle of the system. This ensures the SCD-file to be the necessary and "single source of truth" of configurations of all IEDs in the project at any point of time.

3.2 SCL Syntax Validation

SCL Syntax Validation is the basic and mandatory step of IEC 61850 project analysis and quality assurance. SCL syntax as already mentioned is defined by SCL Schema, described by [1]. The IEC 61850 standard as distributed by International Electrotechnical Commission includes SCL Schema as the set of XML (*.xsd) files used for SCL-file syntax validation. There are several important notes to be made:

1. To the date there are two versions of SCL Schema, that are valid for SCL-file validations (Ed.1 and Ed. 2) and more to come (Ed.2.1, etc.).
2. There are two Ed.2 schemas (rev. A and rev. B) with only one valid (rev. B), however certain tools that were not updated on-time might use obsolete version of SCL-schema.
3. In certain cases vendors might slightly modify XSD-files in their IED Configuration Tools in order to overcome certain issues with their internal configuration files. Which might lead to interoperability issues.

Based on the aforementioned statements we conclude that the best possible option especially in multi-vendor project is to use the third-party validation tools in order to have an arbitrator in case of interoperability issues with SCL configurations.

3.3 Visual Analysis

As mentioned previously, SCL files in most cases contain information, required to show end-to-end GOOSE- and SV-communications between IEDs and down to Data Attribute signal mapping. This makes it possible to visualize all communications between IEDs in the form of “data cables” as shown in Figure 1.

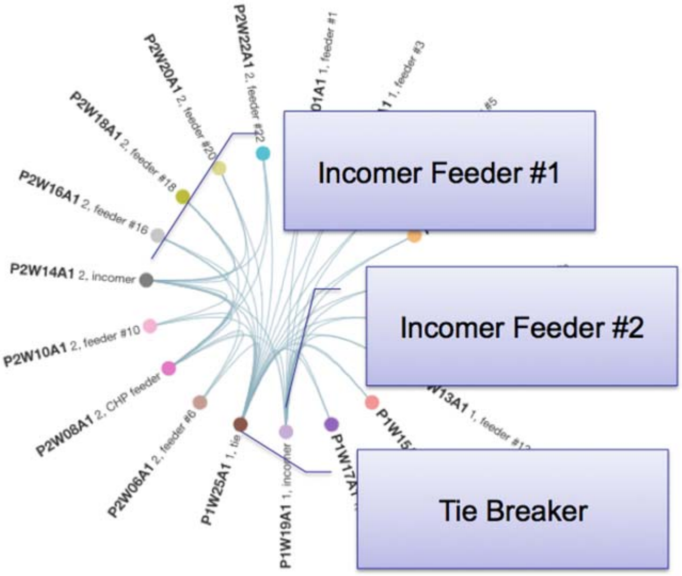

Figure 3. Result of visualization of GOOSE communications.

Visualization of GOOSE communications as “cables” makes application-specific dataflow absolutely obvious and traceable, where in case of any misconfiguration a designer shall see it in a glance.

Deeper visualization for Data-Attribute inputs mapping allows pattern tracing for multiple-times subscribed data. Which gives the user additional means to get rid of erroneous mappings, as, for example, shown in Figure 4.

Figure 4. Identification of wrong mapping for Data Attribute subscription.

3.4 Automated Configuration Analysis

Although visualization itself gives an excellent means of configuration analysis and error identification, it still relies on human mindfulness and expertise, which might not be a case in certain conditions, especially for big projects. That is why it is very important to have automated configuration analysis with application-specific implementation in mind, in order to get maximum quality and performance of the system.

The list of top checks that were automatically performed for studied substation configuration files is provided below:

- GOOSE is not subscribed by any IED
- Dataset contains attributes not subscribed by any IED
- Quality flag is not transmitted or not subscribed by any IED
- Duplicate GOOSE/SV destination MAC-address

The below paragraphs describe each check, its performance and the result achieved in case of real project analysis and optimization with the use of Tekvel Park service performing this kind of tests.

3.4.1 GOOSE is not subscribed by any IED

There are two most-possible cases for “free-floating” GOOSEs in the project:

1. The IED default configuration included pre-configured GOOSE control blocks that were not removed or re-configured.
2. Some subscriber IED was missing or subscription for an existing IED is missing.

The first case doesn’t directly influence performance of the system and possibly could lead to no negative results. However in the described case the substation network would be flooded with unused GOOSE-messages, that potentially could lead to increased delays under storm conditions as well as much harder traffic analysis using network sniffers.

In case of real substation, authors have implemented analysis for one substation, where 5 out of 6 GOOSE-messages actually published on the network were never subscribed by any IED. Elimination of those excessive GOOSE-messages have decreased GOOSE-message network load by six times.

The second case (where subscriber IED is missing or not configured) is an actual error of configuration, which can be fixed at an early stage.

3.4.2 Dataset contains attributes not subscribed by any IED

Cases of existence of not-subscribed dataset elements are nearly the same as for not-subscribed GOOSE-messages:

1. The Dataset was pre-configured by the vendor and left default during system configuration,
2. Intended subscription for the Dataset element is missing.

As well as previously described for GOOSE message, excessive attributes in the dataset would not influence the performance directly, but the larger GOOSE-frames could lead to longer transmission on processing times. During the studies of the real substation configuration, authors have found datasets with 90 data attributes inside, where only 3 were mapped to subscribers’ inputs (see Figure 5).

As for the second point, again, the non-existence of internal reference mapping might mean that the subscription has been lost (misconfigured), that calls for immediate configuration revision.

Statistics

SCL file has **1924** minor and **0** critical error(s). Check the table below for details

Detailed information

Element	Element Type	Warn level	Description
PI_PROT/PTRC8Trgeneral ST	FCDA	Minor	Dataset includes FCDAs not subscribed by any IEDs. May be there is a room for dataset optimization
PI_PROT/PTRC9Trgeneral ST	FCDA	Minor	Dataset includes FCDAs not subscribed by any IEDs. May be there is a room for dataset optimization
PI_PROT/PTRC10Trgeneral ST	FCDA	Minor	Dataset includes FCDAs not subscribed by any IEDs. May be there is a room for dataset optimization
PI_PROT/PTRC11Trgeneral ST	FCDA	Minor	Dataset includes FCDAs not subscribed by any IEDs. May be there is a room for dataset optimization
PI_PROT/PTRC12Trgeneral ST	FCDA	Minor	Dataset includes FCDAs not subscribed by any IEDs. May be there is a room for dataset optimization
PI_PROT/PTRC13Trgeneral ST	FCDA	Minor	Dataset includes FCDAs not subscribed by any IEDs. May be there is a room for dataset optimization
PI_PROT/PTRC14Trgeneral ST	FCDA	Minor	Dataset includes FCDAs not subscribed by any IEDs. May be there is a room for dataset optimization

Figure 5. Excessive dataset elements published in GOOSE-message.

3.4.3 Quality flag is not transmitted or not subscribed by any IEDs

Quality attributes are the important feature of IEC 61850-based systems. Validity flag of quality attributes might be used in algorithms for intelligent blocking of certain functions or functional blocks. Not using quality flags might lead to incorrect operation of the system in "bad-quality" conditions as well as in case of loss of communications. That is why quality flag transmission for each CDC as well as it's mapping to the input is very important and must be checked.

3.4.4 Duplicate GOOSE/SV destination MAC-address

In accordance with [2], Annex B, in order to increase the overall performance of multicast message reception (e.g. GOOSE, GSSE, and sampled values), it is preferable to have the Media Access Control (MAC) hardware perform the filtering. The hash algorithms in the various integrated circuits do vary. It is recommended, as a system integrator, to evaluate the impact of these algorithms when assigning destination multicast addresses. This, in turn, would suggest that "good practice" is to use unique MAC-address to be used for different groups of message types, e.g. Sampled Values segregated from GOOSE from MMS, or messages from High Voltage side IEDs segregated from LV IEDs . So in order to gain optimal system performance, especially under heavy load (such as Sampled Values), it is recommended to analyze configuration against uniqueness of destination MAC-addresses.

Authors' practical experience shows that in one project analyzed, all the GOOSE messages in the HV substation in service had the Destination MAC address parameter duplicated for all of them making HASH filtering algorithms absolutely impossible.

4 Conclusion

1. The analysis of SCL-files of in-service substations with the help of special tools showed several systems working with major and minor configuration errors that happened due to the lack of proper analysis and supervision at design and commissioning stage:
   a. Incomer feeder has not been subscribed to the breaker failure signal from one of the outgoing feeders at MV substation, which could lead to the failure of breaker failure function.
   b. All GOOSE messages in HV substation have been published with the same destination MAC-address, making it impossible to apply HASH-filtering algorithms and efficient MAC Address filtering mechanisms in LAN switches, which in turn could lead to unwanted delays under storm conditions when IEDs are "flooded" with messages irrelevant to their operation.

   c. The third project of the HV substation analysed during the study showed that only 3 out of 90 elements in the dataset transmitted via GOOSE were subscribed by other IEDs in the project, that resulted in purposeless network load.
2. Application of visualisation and automated analysis to SCD file showed the following results:
   a. Visualization of GOOSE and SV communications based on SCD file provides means to discover and eliminate up to 70% of configuration errors at the design stage
   b. Automated system configuration analysis based on SCD file provides means to optimize communication flow up to 30%

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Biography: Rodney Hughes

Graduating from Sydney University in 1980, **Rod Hughes** has over 36 years' experience in the power industry across Australia and internationally specifically involved in protective relay, instrumentation and metering solutions. Rod's application experience is acknowledged world-wide and covers the earliest moves from electromechanical relays to electronic, microprocessor, communicating and numerical relays, and has been a champion of adoption of IEC 61850 in the region. He has served in senior management roles with a vendor (including living in France for three years), transmission utility and consulting firms. His own private consulting firm was established in 2009 focused on application of conventional and IEC 61850 systems and "technology change management" advisory services. Rod has provided many highly acclaimed protection application courses to hundreds of protection specialists across Australia and New Zealand. Over the last 8 years he has become one of the few industry recognised vendor-independent Australian trainers for IEC 61850. Keen to assist the industry at large, he is a prolific contributor to protection and IEC 61850 forums on LinkedIn. He is one of the longest serving members of the CIGRE Australia B5 Panel and was the previous Convener of the Australian Panel with two Merit Awards.

Biography: Alexey Anoshin

Alexey Anoshin received Master's degree at Moscow Power Engineering Institute in 2008. Earlier in 2005 started his professional career as Engineer in Switchgear Department at Tavrida Electric company. In 2010 became a Marketing manager at Profotech. Since 2012 co-founder and director of TEKVEL R&D Ltd. Alexey Anoshin is a member of IEC TC57 WG 10 and several working groups of CIGRE B5.

Biography: Aleksandr Golovin

Aleksandr Golovin has graduated with Master's degree at Moscow Power Engineering Institute in 2008 (Relay protection and automation department). Since that time he has been involved in development of products and solutions for digital substations. He has worked as a head of engineering department and then as chief technical officer at Profotech where he was responsible for fiber-optic current and electronic voltage sensors development. Since 2012 he is holding position of chief technical officer at TEKVEL Ltd. He has been involved in an implementation of a set of pilot projects, including those ones with IEC 61850-9-2LE process bus. Aleksandr is a member of the working group (WG) 10 of the IEC TC 57 and member of several WGs of CIGRE B5.