TESTING AUTOMATION AND CONTROL

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Abstract

During the commissioning of Substation Automation Systems (SAS) with Protection, Automation and Control (PAC) traditionally the focus of testing is on testing the protection system and its settings. Protection testing uses established methods, such as parameter testing per IED or new approaches like system-based testing. Standardization and proper testing tools increased the efficiency and reliability of protection testing dramatically. When looking at the time spent during commissioning, testing the automation and communication system nowadays consumes even more time than testing the protection. Automation systems became increasingly complex and the efforts for testing communication and proper operation of all signals transmitted to Supervisory Control and Data Acquisition (SCADA) systems grew dramatically. This paper describes a new approach to be used in all phases of the lifecycle of SAS. By utilizing the capabilities of the IEC 61850 engineering process and the data available in Substation Configuration Description (SCD) files it is possible to introduce new and more efficient methods for Factory Acceptance Testing (FAT) and Site Acceptance Testing (SAT). The approach identifies potential signals to be tested in the SCD file. Communication links and the used IEC 61850 services are recognized, documented and can be used for generating test plans. These test templates can be created during the specification phase, adapted for FAT and subsequently reused during SAT. The paper starts by describing the different phases in the life cycle of modern substation automation systems and collects utilities' experiences in testing SCADA signaling. Requirements for test equipment will be identified. An example for technical realization will be described.

1 IEC 61850

IEC 61850 was published as international standard in the early 2000s already and is the established norm for substation automation projects (SAS). Edition 2 [1] and the upcoming soon variant 2.1 increases the acceptance worldwide.

2 About testing

Since protection is available there is a need for testing recognized[2]. Protection devices are tested regularly and demonstrate functionality as well as parameter set. There are no such traditions for SAS and SCADA. This paper shows why this topic becomes important now.

3 Definitions in the standard

3.1 Data model and mode test

According to IEC 61850-7-4 [4] every IED contains a data model with logical nodes (LN). The LNs are organized in logical devices (LD). The node contains information as startup of protection or the position of circuit breaker. Additionally, every LN contains an attribute Mode (Mod). There are 5 of them defined:

- on
- blocked
- test
- test/blocked
- off

Taking into account the setting of an entire LD there is a resulting Behavior (Beh). Annex A2 contains a table showing the complex dependencies. [5].

3.2 Simulation indication

With edition 2 for GOOSE and Sampled Values [3] a new information was introduced allowing to distinguish between real and simulated values. This “S-indication” (simulated) is valid for the entire physical device (LN LPHD, Physical Device), its functionality can be compared with conventional test switches.

3.3 Interlocking CILO

All classes of LNs starting with C indicate “control”. So “CILO” [4] indicates interlocking and releases a control device once the conditions are fulfilled. The is one instance of this LN per switched device. All relevant position indications must be subscribed. Realizing the interlocking is a „local issue “only[4].

3.4 Supervising with LGOS

IEC 61850 7-4 [4] defines the class LGOS as LN. The first letter (L) indicates the system character of the node. This node was introduced with edition 2 and allows supervision of GOOSE subscription.

4 Life cycle of SAS

The standard does not describe the testing of SAS but the lifecycle of a project (part 4, [6]). Commonly used terms as FAT - Factory Acceptance Testing und SAT -Site Acceptance Testing appear.

Considering the entire cycle (Fig. 1) we can describe the project- from specification till working with equipment.

Fig. 1 Life cycle of SAS

The project starts on a desk specifying and using this for tenders. Part 6 of IEC 61850 describes the engineering of the SAS. Additionally, the none-IEC-61850 parameters as protection settings must be defined with vendor specific tools. The phase is finalized with FAT and the commissioning follows. This ends with SAT. But even after SAT maintenance might follow and security updates become more and more important.

5 Testing the SAS

5.1 Interlockings

Realizing interlockings in IEC 61850 was one of the first applications of IEC 61850 GOOSE [7]. The multicast mechanism makes it easy to transmit position indications of for instance disconnectors to other feeder’s bay controllers or centralized interlocking IEDs. Different approaches realizing interlockings have been discussed between utilities. There are advantages and disadvantages for the centralized as well as for the decentralized approach [7].

Realizing these approaches, the topic testing became important. Working groups with utilities in Germany have been discussing testing approaches and sequences [8] and brought the topic into the international standardization. Fig. 3 shows the components involved.

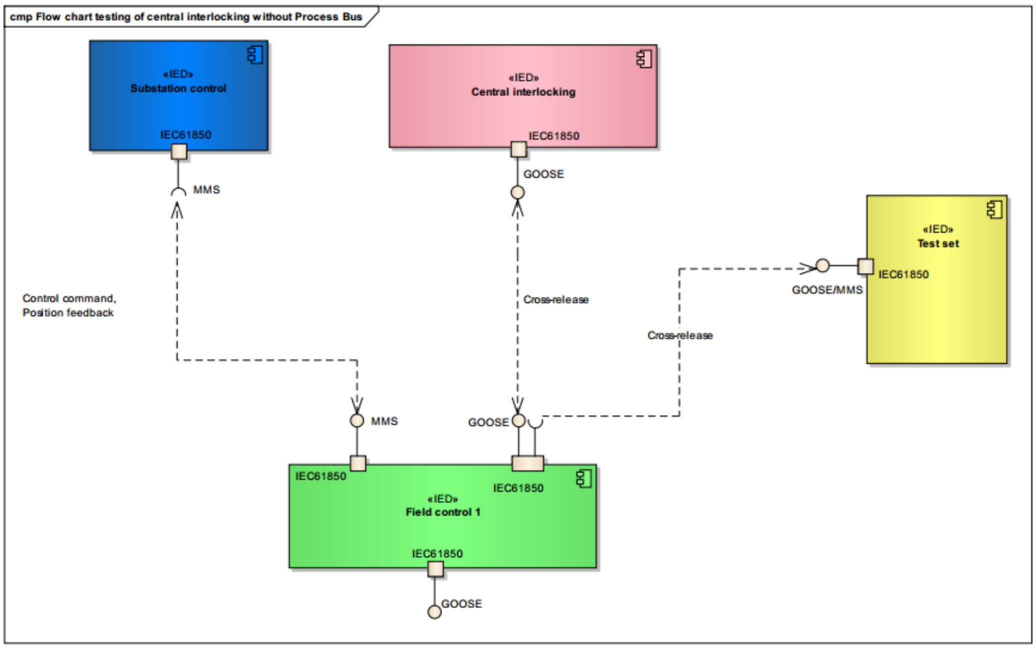

Fig. 2 Interlockings [8]

The testing scenario could be realized as in Fig. 3:

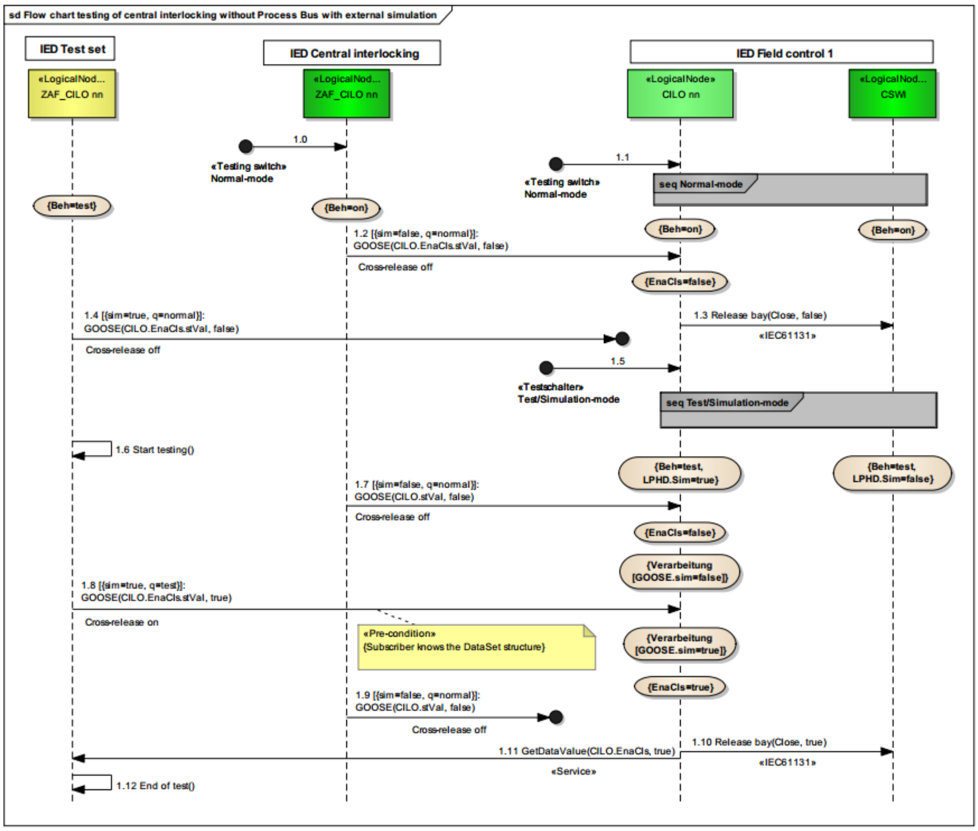

Fig. 3 Testing of interlockings [8]

5.2 One out of n

Another typical example is the one-out-of-n check. This avoids commands in case of other commands running. Fig. 4 shows an example for Select-before-operate (SBO) commands.

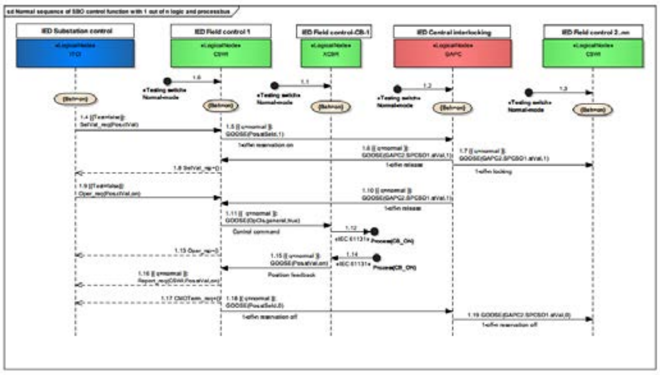

Fig. 4 SBO with 1-out-of-n check [8]

6 Testing approach

The method proposed should now be extended. Simulation of IEDs stays important during design, FAT, SAT and commissioning. An automated test set is proposed. This test extends the test from single IED testing and simulation to test the entire Substation Automation System (SAS). The need for simulation is there in all phases of project. Nevertheless, it is decreasing and different kinds of testing apply (Fig. 1).

7 The testing solution

7.1 Overview

The proposed testing solution shall consist of software and hardware (Fig. 5). To use a dedicated hardware and not just develop a PC application was chosen because of the following reasons:

- Guarantee cyber security and safe connection to substation network
- Real time capabilities to calculate Sampled Values and GOOSE
- Make it possible to deliver multi-IP simulation
- Connection to several networks
- Update possibility for security patches
- Licensing.

Fig. 5 Test setup

The software offers a toolbox for the different tasks.

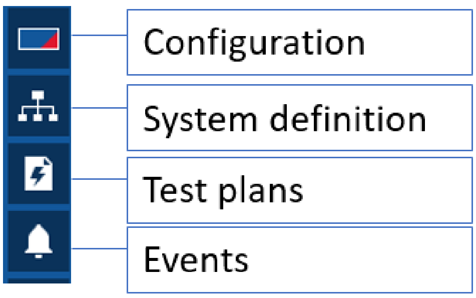

Fig. 6 Tools

7.2 System under test

As mentioned the entire system is under test now (Fig. 7).

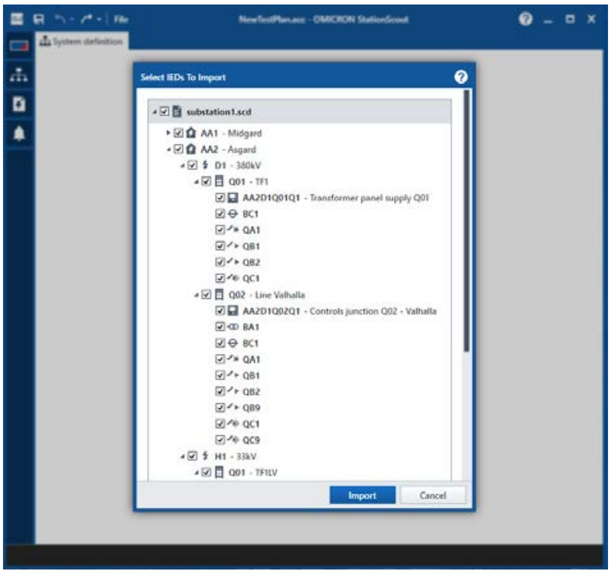

Fig. 7 System under test

7.3 ZeroLine

The entire system will be visualized (Fig. 8). All information available in SCD file will be used. This covers also the information in substation section (voltage level, bay….). The standard defines possibilities to model the elements of single line diagram. The norm under development currently, IEC 61850-6-2 [9] will extend this. Current SCD files do not contain this information. So, it is the proposal to work with "ZeroLine" to visualize the assets (Fig. 8). ZeroLine means grouping by voltage level, arranging the bays and corresponding assets.

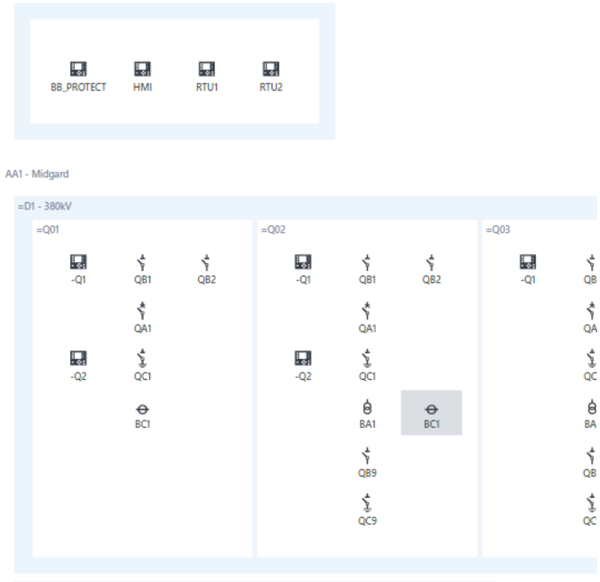

Fig. 8 ZeroLine

The navigation in huge SAS can be done as in map systems. (Fig. 9).

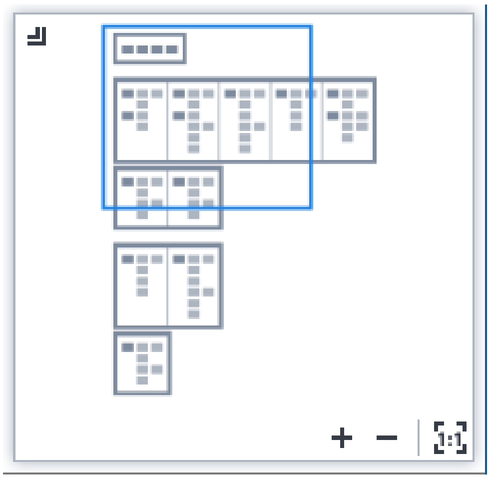

Fig. 9 Navigation

Clicking “Go-live” visualizes the existing status.

7.4 Tracing the signals

The functionality of the SAS transfers the message from its source to all receivers. If there is an error in this communication, the commissioning engineers needs to follow the signal on its way through the SAS. Finding such signal errors in the case of copper wiring was very time consuming, with IEC 61850 this becomes almost impossible to be done manually. The testing solution described here allows to view how signals propagate through the SAS, see Fig. 10. The architecture used allows to follow signals communicated as GOOSE as well as Reports. This makes trouble shooting communication problems quite easy.

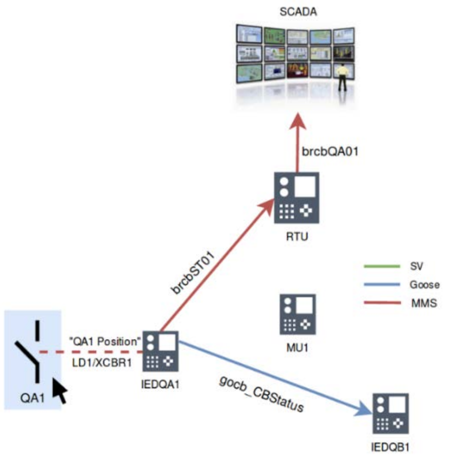

Fig. 10 Transmitting the position indication

The software makes it possible visualizing the links. The by controller communicates with SCADA (Fig. 11).

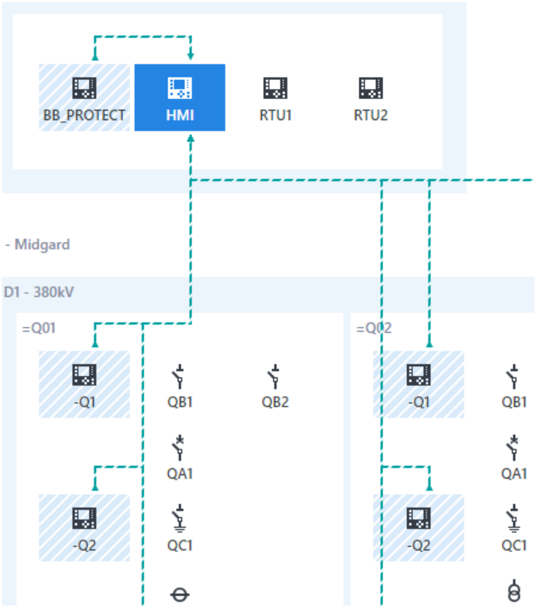

Fig. 11 Tracing the signal

The huge amount of information might confuse- filters can help (Fig. 12).

Fig. 12 Filter

Doing so filters for instance to GOOSE and Reports (Fig. 13).

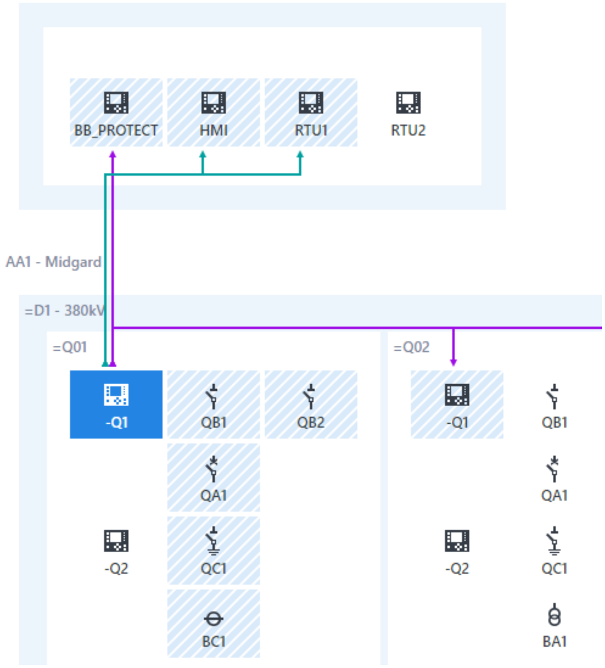

Fig. 13 Filtered information

7.5 Names

The names in the data model. None IEC 61850 experts and users might expect more information. The software recognizes the names, detects the purpose and visualizes accordingly. Names could be adapted (Fig. 14)- for instance in own language.

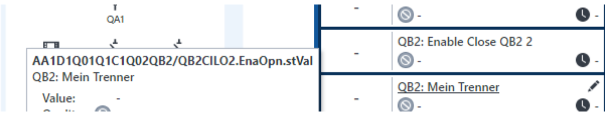

Fig. 14 Signal names

7.6 IEC 61850 in the background

IEC 61850 can be visualized as well- in the example as DataSet (Fig. 15) and GOOSE Control Blocks (Fig. 16).

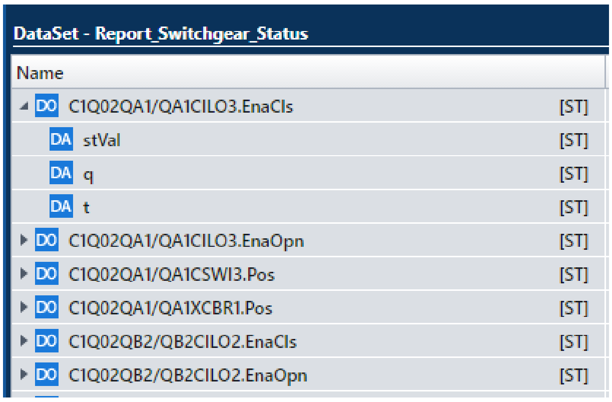

Fig. 15 IEC 61850 DataSet

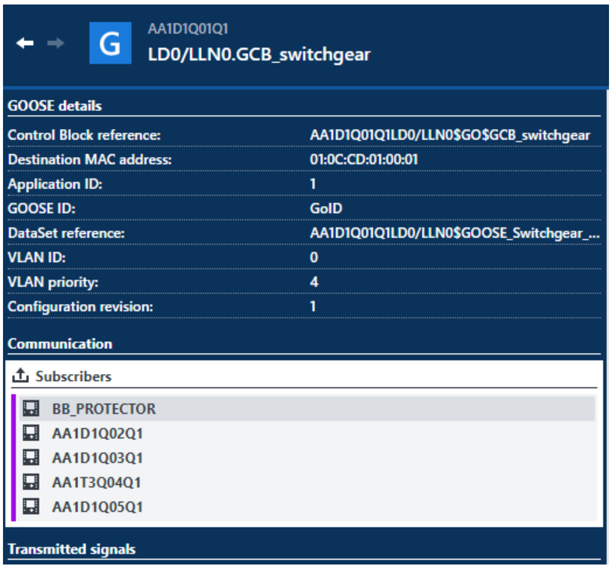

Fig. 16 IEC 61850 GOOSE

7.7 Analysis and trouble shooting

Data models of modern IEDs can be huge. Grouping and sorting the information automatically will help. The most important status information become visible. The software analyses the values and shows them (Fig. 17).

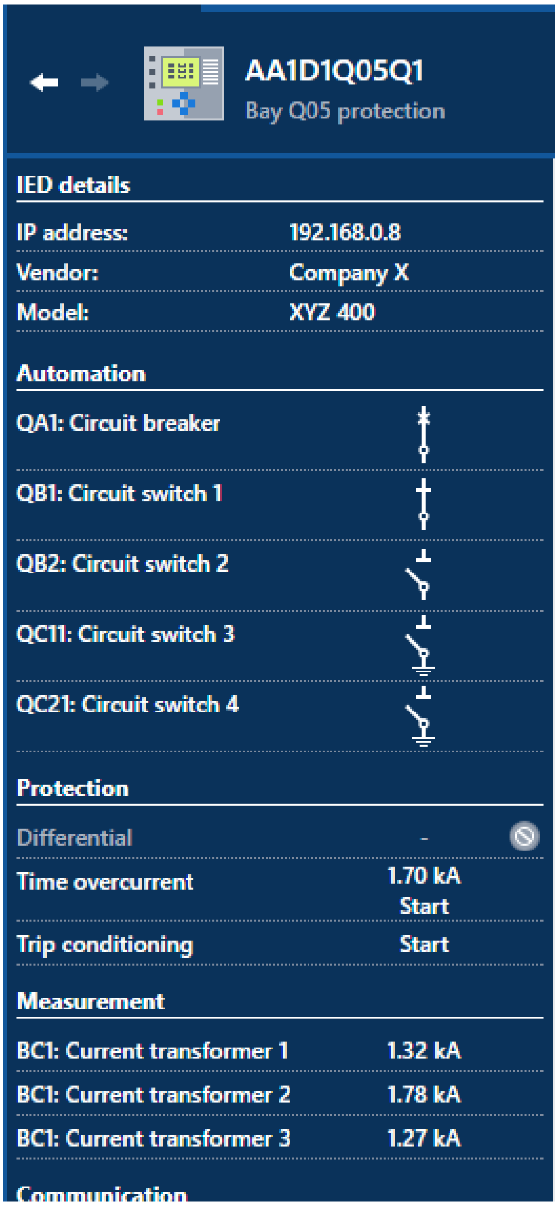

Fig. 17 Grouping

7.8 Test Plans

If tests are documented and recorded they can be used in different phases. Fig. 18 shows a test plan ready for re-usage at another phase of SAS project. Sequences can be performed and assessed automatically

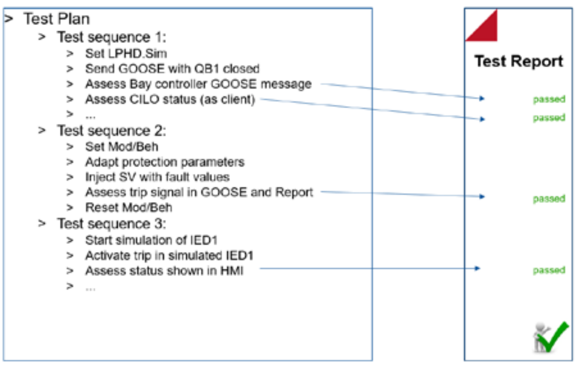

Fig. 18 Test plan and test report

7.9 Logic testing

Logic is used in interlockings, as described already, as well as in any other substation automation function. Test logic conditions are implemented in control devices. Testing such logic functions is an essential part of FAT as well as SAT. In case of interlocking simulated or real switchgear status is considered and evaluated. To represent the result of interlocking logic conditions, IEC 61850 represents the status of the release in the logical node CILO. As depicted in Fig. 19, the proposed solution reads the value out from the data model and assesses the interlocking behavior by reading the CILO values automatically. It is essential to understand that the behavior of the logic shall be tested in any stage of the lifecycle of an SAS. So even after IED-change or firmware upgrade the entire test once performed can be repeated. Issues occurred can be solved, afterwards the test can be repeated ("test-fix-repeat").

Note: Not-existing assets will be simulated, so this approach allows testing at any stage.

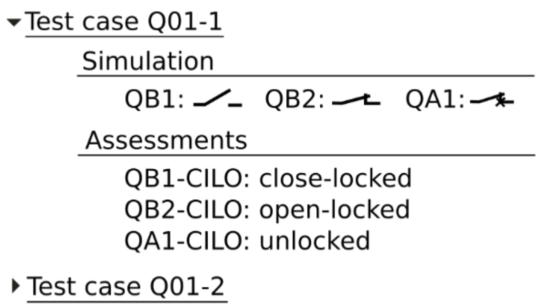

Fig. 19 Testing the interlocking

7.10 Test after firmware upgrade

Putting a SAS in operation meant in the past extensive testing during FAT and SAT but neither routine testing nor updates of firmware (frozen) for the next 10 up to 20 years. This is not valid anymore.

Protection relays in substations also must be patched with security updates. The problem is that afterwards everything from that relay needs to be re-tested, also all communication. Until now there was no proper way to re-test the communication. Everything had to be done by hand.

The solution proposed offers automatic testing and assessment. The whole communication of the device can be easily re-tested after the firmware update by executing the test plan already prepared for that device (Fig. 20).

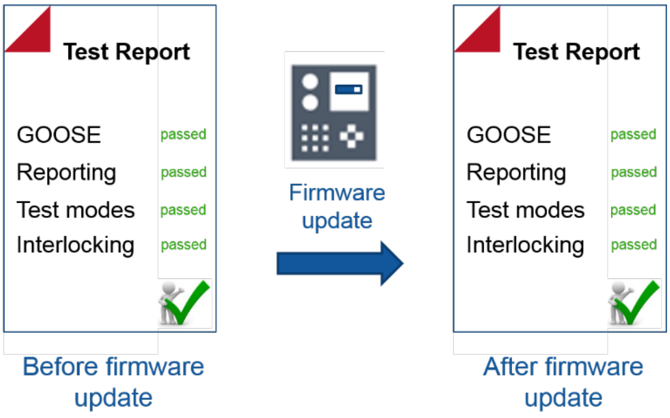

Fig. 20 Test after firmware update

7.11 GOOSE Supervision

As visualized in Fig. 13 the GOOSE is sent out as multicast – one to many. So every IED which is a member of this multicast will receive this information. Taking and using this information is called "subscription". But how do I learn that the function was subscribed successfully? Of course, testing the reaction of the system will show that this works. Nevertheless using this information just from IED's data model would be easier. IEC 61850 defines as discussed already the logical node LGOS. As a system node, the data attributes describe the status of

GOOSE subscription. More and more vendors are providing this information. Fig. 21 shows the information stored. If the subscription fails this can be indicated. (Fig. 22)

BB_PROTECTOR • Data Model • PROT • AA1D1Q02Q2LGOS1

LN AA1D1Q02Q2LGOS1 GOOSE subscription

Name	Description	Value
DO Beh	Behaviour	on
DO NamPlt	Name plate	
DO NdsCom	Subscription needs commissioning	false
DO St	Status of the subscription	true
DA stVal [ST]	Status value of the data	true
DA q [ST]	Quality of the attribute(s) representing the value of the data	good
DA t [ST]	Timestamp of the last change in one of the attribute(s) representing the value of the d...	2018-06-25 09:05:18.000
DA d [DC]	Textual description of the data	
DO SimSt	Status showing that really Sim messages are received and accepted	false
DO ConfRevNum	Expected configuration revision number of the GOOSE message	0
DO RxConfRevNum		0
DO LastStNum	Last state number of received GOOSE	0
DO GoCBRef	Reference to the subscribed GOOSE control block	AA1D1Q02Q2Control/LLN0GOQB9

Fig. 21 LGOS

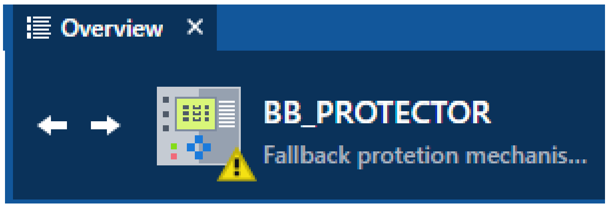

Fig. 22 Subscription failed

8 Simulations

As mentioned already simulation is important in any stage of SAS. As explained the amount of simulation might decrease but there is a need in any stage. Starting with specification and while engineering means no real equipment is available. The approach allows to simulate any missing equipment. For the first step this means everything. Simulating the IEDs involved in communication makes it possible to check communication links, DataSet engineering and data models. Very often the local HMI (client) is not available while setting up the IEDs. Simulating this SCADA system delivers confidence that the IEDs are configured properly.

In commissioning phase also IEDs might be not available and need to be simulated. Testing communication to higher level SCADA (control center, national control center) is an important step while putting into operation. Those “bit-tests” are very time consuming and require the attention of the colleague in the control center. Any problem occurring increases the probability that the test has to be stopped and repeated. So simulation of client is very helpful to avoid frustrations like this. On the other hand, once performed tests can be repeated easily and save time.

9 Outlook

There are several possibilities extending this approach. Since analog injection is required at least once during the testing this has to be possible. In modern digital substations the real time capable hardware has issue the signals as Sampled Values according to IEC 61850-9-2 and IEC 61869-9.

During the last decade protection, automation and control grow together, there is no clear border between the different tasks. Modern testing approaches must consider this. Also protection testing moves from single-device testing to system testing and solutions are available. Such approaches must be used together and will deliver holistic testing procedure.

10 Conclusions

Automation and control functions become more and more important because of their wide application in modern substation automation systems. Performing such tests automatically brings an enormous potential for cost saving and enhances the reliability of the grid. Testing solutions are available

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