Testing of Switchgear Operation in an IEC 61850 based SAS using a Real-Time Simulator

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ABSTRACT

IEC 61850 has become the preferred standard for substation automation for many utilities around the world. However, its provisions to automate control systems in a substation remain a lesser-discussed topic of the IEC 61850 standard series. Testing and validation of control systems in an electrical substation such as high voltage switchgear controls can be a challenging task due to the unavailability of an accurate replica test system. However, such control systems can be conveniently tested in a virtual environment by modelling them inside a real-time simulator. This paper presents the use of a simulation model developed with standard IEC 61850 logical node classes for representation, testing and validation of switchgear and their associated controls in a digital substation automation system.

Keywords – IEC 61850, Substation Automation System, Switchgear, Intelligent Electronic Devices, Logical Nodes, Interlocks, Real-Time Simulator, MMS protocol, Control model

1. INTRODUCTION

Conventionally, protection devices and control/monitoring devices are installed and operated as separate systems in an electrical substation. The IEC 61850 series has standardized means to automate both protection and control functionalities in a substation automation system (SAS). Implementing protection schemes using IEC 61850 has been a well-researched area, while testing control systems in SASs is given less attention. A conventional local control system in a substation uses copper wires to control switchgear and make electrical interlocks. Procedure of testing such a control system is straightforward, nonetheless performing it can be a challenging task and, typically unfeasible to be carried out in a laboratory.

High voltage switchgear in an electrical substation operates in response to either a trip or a switch (open and close) command. In general, only intelligent electronic devices (IEDs) dedicated for power system protection can trip circuit breakers. Tripping of a circuit breaker is intended as a countermeasure to a severe system disturbance such as a fault in order to preserve the healthy operation of the power system as well as to protect equipment. Trip commands are, therefore, directly communicated to circuit breakers and carried out with the minimum possible delay. On the other hand, a circuit breaker can be switched as a control or an operational measure at the discretion of an operator. This can be done either locally (at the process level) with manual control or by a command from bay, station or remote level [1]. To grant accessibility to operators at different locations and to avoid conflicts between them, a concept called control authority is used, which designates an operator’s right to switch a specific circuit breaker. A prescribed set of control parameters determines where the control authority resides at a given point of time [1]. Moreover, proper operation of switchgear in a substation depends on other functions such as switch controlling, interlocking and synchronization as well. For example, a circuit breaker may be associated with interlocks at component, substation, and system levels and these interlocks must not be violated at all-times. Traditionally, all information exchange for switchgear operations in a substation are managed via hardwired copper connections existing between respective entities [2].

Modern real-time power system simulators are capable of simulating entire substations and perform closed-loop testing with multiple external IEDs using IEC 61850 communication protocols such as generic object oriented system events (GOOSE) [3], sampled values (SV) [4] and Manufacturing Message Specification (MMS) [3]. Real-time simulators, thus, provide means to conveniently test advanced IEC 61850 systems [5], [6]. These tests often require circuit breakers and circuit switches in the substation to be modelled inside the simulation case and have them interfaced with protection and control functions of external IEDs. Hence, representing switchgear and their associated controls in the simulation using standard data models is a key feature that an IEC 61850 test tool should possess.

The objective of this paper is to introduce real-time simulation for testing and studying of switchgear operations, controls and electrical interlocks available in IEC 61850 based SASs. A simulation model is developed to represent switchgear using IEC 61850 logical node classes XCBR, XSWI, CSWI and CILO [7]. A typical substation is simulated with switchgear controls and various operation scenarios are tested using a remote MMS client. The MMS client can represent several control originators to emulate different control levels present in a SAS. The substation is modelled in the simulation in such a way that various types of interlocks can be taken into consideration in testing. In addition, the real-time simulator has the capability to automate a number of switchgear operations through its scripting feature [7], which is used to automate test plans.

The remainder of this paper is organized as follows. In Section 2, switchgear controls models, control parameters and control authorities defined in IEC 61850 are briefly described. Implementation details of the simulation model for switchgear are discussed in Section 3. The arrangement of the test setup and details of a typical substation used as an example are provided in Section 4. Section 5 is devoted to results and discussion; it describes functional testing, switchgear control system testing and advantages of the proposed approach. Section 6 follows with the conclusion, where the key contributions of the paper are highlighted.

2. SWITCHGEAR REPRESENTATION AND CONTROLS IN IEC 61850

IEC 61850-7-4 has defined logical node classes for representing switchgear such as circuit breakers (XCBR) and circuit switches (XSWI) as well as for switch controllers (CSWI) and interlocking function (CILO) [8]. A brief description of each logical node (LN) class is given in Table I.

Table I: IEC 61850 logical node classes for switchgear and their associated control functions [1]

Logical Node Class (IEC 61850-7-4)	**Description**
XCBR	Circuit Breakers - Switches with short circuit breaking capability
XSWI	Circuit Switches - Switches without short circuit breaking capability
CSWI	Switch Controller - Control all switching conditions above process level
CILO	Interlocking Function - Enable a switching operation if interlocking conditions are fulfilled

Fig. 1 illustrates an example of information flow between the LNs associated with switchgear operations in a typical SAS [9]. The XCBR LN instance (representing a circuit breaker) resides in the process level (equipment level) and CSWI and CILO LN instances (representing, respectively the switch controller and the interlocking functions of that beaker) are in bay level. The XCBR LN instance can be assessed and controlled through the CSWI by a remote client. In this case, a remote MMS client at station level is shown controlling with the process level circuit breaker via the switch controller at bay level. Here, it is assumed that the IED carrying the switch controller has MMS server functionality. By their very nature, the LN instances XCBR, CSWI and CILO are interconnected with each other. The switch controller takes control inputs to determine the standing of control authority for that particular switch. Furthermore, the CILO LN instance typically takes external inputs to determine the status of the interlock. Also, note that the XCBR exchanges information such as trip signals and circuit breaker statuses with bay level protection IEDs independently from switch controlling function.

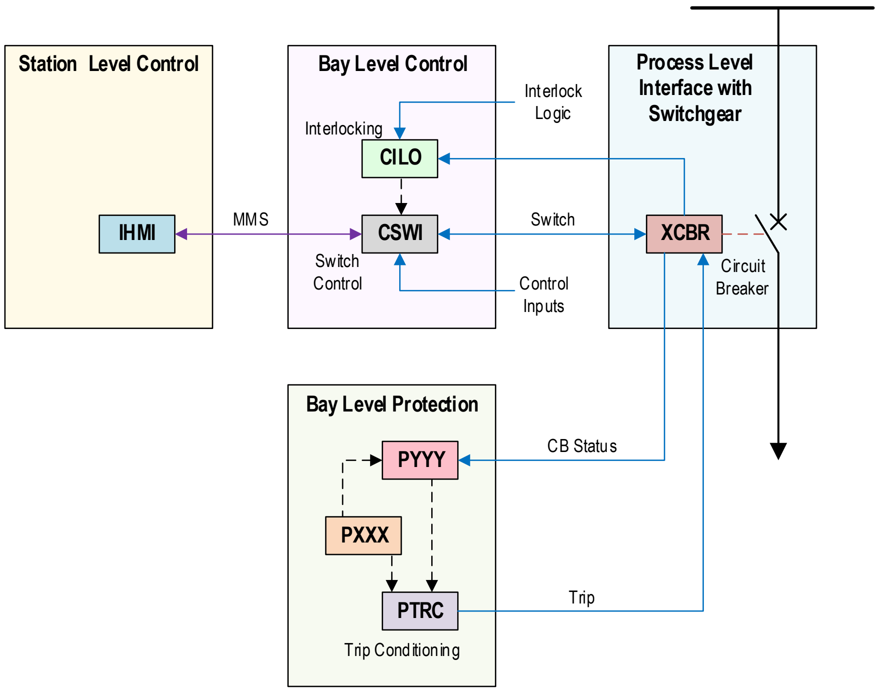


Fig. 1 Information flow between logical nodes associated with switchgear operations in a SAS

2.1. Control Models in IEC 61850

In order to facilitate control functionalities IEC 61850 has introduced a concept called the control model, which provides a predefined way for a client to change the state of internal and external processes of a controllable entity. As per IEC 61850-7-2, an external client is capable of changing the state of data object instances of controllable common data classes (CDC) with the “ctlModel” data attribute not set to “status-only” [10].

As different applications require different control behaviours, the standard defines four control model types as;

- Direct control with normal security
- Select Before Operate (SBO) control with normal security
- Direct control with enhanced security
- SBO control with enhanced security

“Direct” control models allow a client to operate the control object from a single command. This does not prevent multiple clients from trying to perform conflicting control actions. “Select before operate” models, on the other hand, require a client to “select or reserve” the control object prior to operation. Then, it is the only one allowed to perform control actions on the object for a period of time. “Enhanced security” provides an additional supervision of the status value by the control object at the end of the command sequence (the “*CommandTermination*” message). “Normal security” provides no such additional supervision.

Operating a control object (for example a switch controller) in a data model can only be performed by a command from an operator (an entity referred to as the originator in the standard) that holds the control authority for that object. Originator category (or orCat) indicates type/location of the operator that has sent the request to control the object. The originator categories defined in the standard are shown in Table II. For the purpose of switchgear controls, this work focuses on three originator categories only, which are bay-control, station-control and remote-control.

Table II: Originator Categories (orCat) defined in IEC 61850-7-3 [8]

Originator Category (orCat)	**Description**
not-supported	Value shall not be used
bay-control	Control operation issued from an operator using a client located at bay level
station-control	Control operation issued from an operator using a client located at station level
remote-control	Control operation from a remote operator outside the substation
automatic-bay	Control operation issued from an automatic function at bay level
automatic-station	Control operation issued from an automatic function at station level
automatic-remote	Control operation issued from an automatic function outside of the substation
maintenance	Control operation issued from a maintenance/service tool
process	Status change occurred without control action

2.2. Switchgear Control Parameters and Control Authority

An originator's right to possess the control authority for a particular switch depends on a prescribed set of control parameters as defined in Annex B of IEC 61850-7-4 [1] and are shown in Table III.

Table III: Control parameters governing the control authority for switch operation

Control Parameter	**Description**
XCBR/XSWI.Loc	Represents the status of an actual switch at the process and allows taking over the manual control authority
LLNO.MltLev	Enables for more than one originator to hold control authority at the same time
CSWI.Loc	Represents the control behaviour of the logical node (bay level)
CSWI.LocSta	Represents the switching authority at station level

Note that the four parameters above are defined for each controllable circuit switch. Combination of values of those control parameters determine where the control authority resides for that particular circuit switch. The relationship between control parameters and control authority is illustrated in Table IV as per Annex B of IEC 61850-7-4 [1].

Table IV: Relationship between control parameters and Control authority as per Annex B of IEC 61850-7-4

Control Parameters				Control Authority at each Level				
Switch	Bay Control			Manual Control	Originator Category (OrCat)			
XCBR.Loc XSWI.Loc	LLNO.MltLev	CSWI.Loc	CSWI.LocSta	Process	Bay	Station	Remote	
True	False	Not Applicable	Not Applicable	Always Allowed	Not Allowed	Not Allowed	Not Allowed	
False	False	True	Not Applicable	Always Allowed	Always Allowed	Not Allowed	Not Allowed	
False	False	False	True	Always Allowed	Not Allowed	Always Allowed	Not Allowed	
False	False	False	False	Always Allowed	Not Allowed	Not Allowed	Always Allowed	
True	True	Not Applicable	Not Applicable	Always Allowed	Not Allowed	Not Allowed	Not Allowed	
False	True	True	Not Applicable	Always Allowed	Always Allowed	Not Allowed	Not Allowed	
False	True	False	True	Always Allowed	Always Allowed	Always Allowed	Not Allowed	
False	True	False	False	Always Allowed	Always Allowed	Always Allowed	Always Allowed	

3. DEVELOPMENT OF THE SIMULATION MODEL

This section presents the development of a simulation model for IEC 61850 representation of switchgear in a real-time power system simulator. This implementation is based on an entity called a switch object, which is a combination of three LN instances, one each from XCBR (or XSWI), CSWI and CILO. Information flow between these LN instances are internal to the model. A switch object takes the control parameters described in Section 2.2 and an interlock logic as inputs. A particular switch object can be mapped to a desired circuit switch in the simulation for control operations. A remote client can access the switch object for control purposes using the MMS protocol. Binding of external trip signals (published as GOOSE messages) to the corresponding circuit breaker is achieved using a generic input (GGIO LN instance), and done independently from the switch object. Fig. 2 depicts the Information flow between logical nodes associated with switchgear operations in the simulation model.

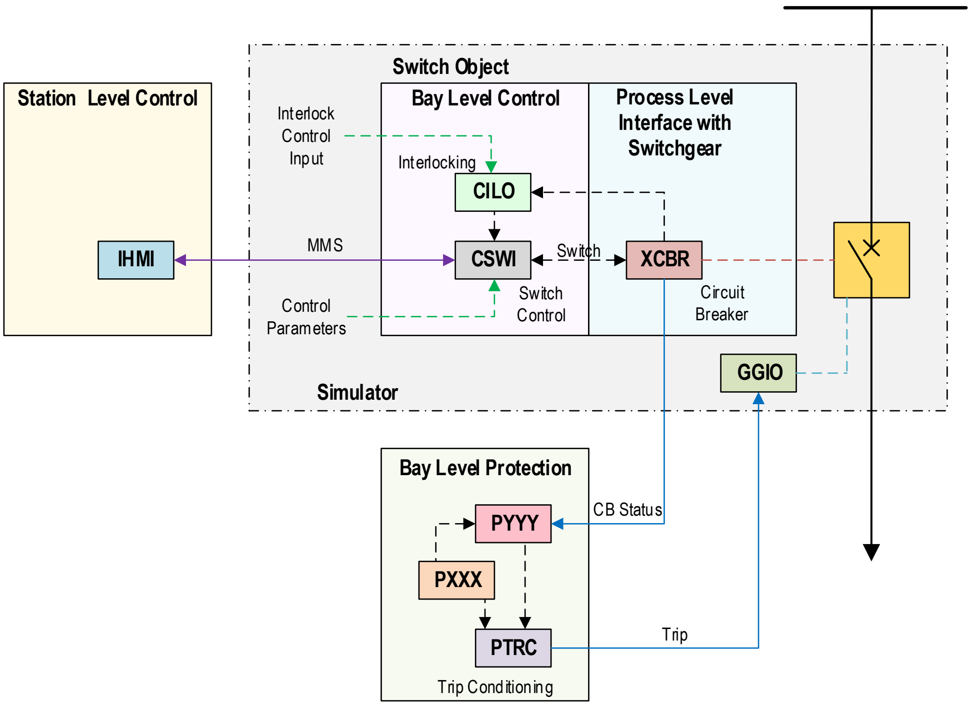
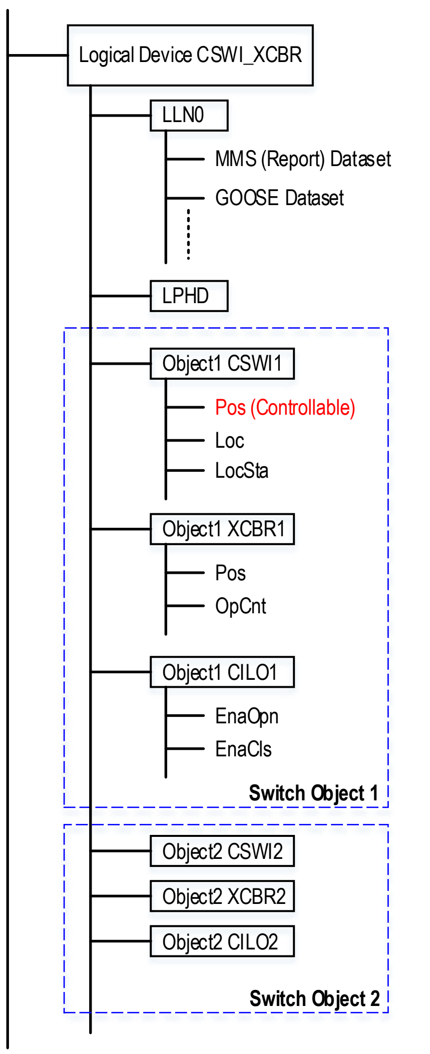


Fig. 2 Information flow between logical nodes associated with switchgear operations in the simulation model, the switch object and its internal connections

The network interface card (NIC) of the simulator is interfacing all communication with external IEDs to the simulation. Together with certain other components in the simulation, it is mimicking an IEC 61850 compliant IED. Switch objects can be created as a part of configuring the data model of this “virtual IED”, using its IED configurator tool. Control model type is chosen when the switch objects are first created. All four standard types of control models are supported with an additional and non-controllable “status-only” option. Type of the switch (XCBR or XSWI) is also selected at this point. All three LN instances (XCBR/XSWI, CSWI, CILO) of the switch object are created simultaneously in the data model and remain locally interlinked. Switch objects with all of their related LN instances exist in a dedicated Logical Device (LD) in the data model. Furthermore, the LD carrying the switch objects has a dataset each for MMS (reports) and GOOSE communication. There, the information given in Table V are available for each switch object created in the data model.

Notice that a switch object in the simulation exists independently from the circuit switch, control parameters and interlock inputs it is linked to, regardless of them originating from inside the simulation or elsewhere. This enables, for example, a switch object to be connected to an external circuit breaker and to other external inputs, if the user so wishes.

Table V: Available information in the MMS and GOOSE datasets for a single switch object

Data Attribute	Description	Data Model
MMS Dataset		
CSWI.Pos.StVal	Status value of the switch (controller), this should reflect the status of the linked circuit switch	
CSWI.Loc.StVal	Local (Bay level) control behavior	
CSWI.LocSta.StVal	Control authority at station level	
CILO.EnaOpn.StVal	Interlock signal for enabling the switch open operation	
CILO.EnaCls.StVal	Interlock signal for enabling the switch close operation	
XCBR/XSWI.Pos.StVal	Status value of the switch position	
XCBR/XSWI.OpCnt.StVal	Operation counter of the switch	
GOOSE Dataset		
XCBR/XSWI.Pos.StVal	Status value of the switch position	
XCBR/XSWI.Pos.q	Quality of the switch position	

IEC 61850 data model of the LD carrying the switch objects is depicted in the third column of Table V. Here, the hierarchy of the data model is shown from logical device level to data object level only. Two switch objects with corresponding logical nodes are also highlighted. Note that the data object "CSWI.Pos" (representing the controller switch) is an instance of a controllable common data class (controllable double point - DPC). The control model (cltModel) chosen at the instantiation of the switch object is in fact that of the CSWI.Pos data object. Remote MMS clients are accessing and controlling this data object within the capabilities of its control model, when performing control operations on the corresponding switch.

As far as switchgear representation is considered, the IED in the simulator acts as a MMS server as well as a GOOSE publisher. Its MMS server capabilities enable remote clients to access, monitor and control switch objects. On the other hand, publication of switch positions (XCBR.Pos.StVal) as GOOSE messages supports protection schemes such as auto-recloser and breaker failure as well as enables status monitoring in external IEDs. The developed model is tested and validated by using it in detailed simulation cases with both MMS and GOOSE communication interfaces. The next section demonstrates the use of the developed switchgear model in testing and validation of controls systems in a substation.

4. TEST SETUP AND EXAMPLE CASE

All IEC 61850 communication interfacing to the simulation requires a NIC to be connected to the real-time simulator and have it configured. Schematic of a typical setup showing connections between devices is presented in Fig. 3. Here, the main processors of the simulator run the modelled electrical substation, including its circuit switches. The NIC, together with the GSE component, facilitates a communication interface between the main simulation and external IEDs.

Ethernet local area network (LAN) ports of the NIC physically connect the simulator to external IEDs through the communication network. Notice that both GOOSE (Ethernet) and MMS (TCP/IP) traffic use the same physical communication link of the NIC, despite Fig. 3 depicting the two separately for clarity. A remote MMS client connects with the MMS server running on the NIC to access and control switch objects, and thereby to operate circuit switches in the simulated electrical system. GOOSE communication between the simulator and external IEDs occurs according to the well-known GOOSE publisher-subscriber mechanism. In contrast, the MMS protocol has a TCP/IP based client-server architecture.

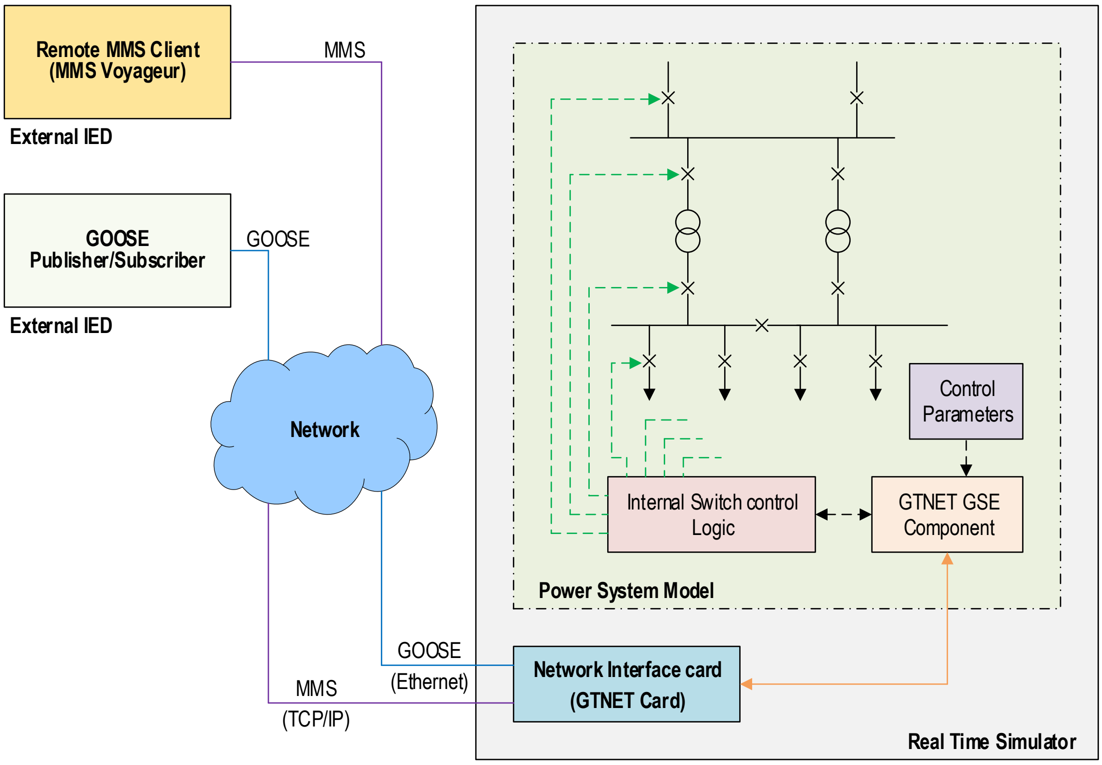


Fig. 3 Schematic of connection setup between devices

The next section demonstrates the use of the developed switchgear model in testing and validation of control systems in a substation. A typical substation arrangement is used in the example case to demonstrate switchgear controls under various operational scenarios. Substation topology used in the example case is shown in Fig. 4. It comprises of two 230 kV incoming feeders, two 31.5 MVA, 230/33 kV, Y-Δ transformers, and four 33 kV distribution feeders. This substation has 29 circuit switches in total as shown in Fig. 4, including 11 circuit breakers (XCBR), 16 isolators (XSWI) and 2 earth switches (XSWI). All circuit switches in the simulated substation are represented in the data model (of the IED in the simulator) using switch objects. This requires 29 switch objects in the data model. Appendix A provides the switchgear interlocks of the substation used in the example case. Control parameters described in Section 2.2 are dynamically set in the simulation using internal signals and fed into the switch objects as inputs.

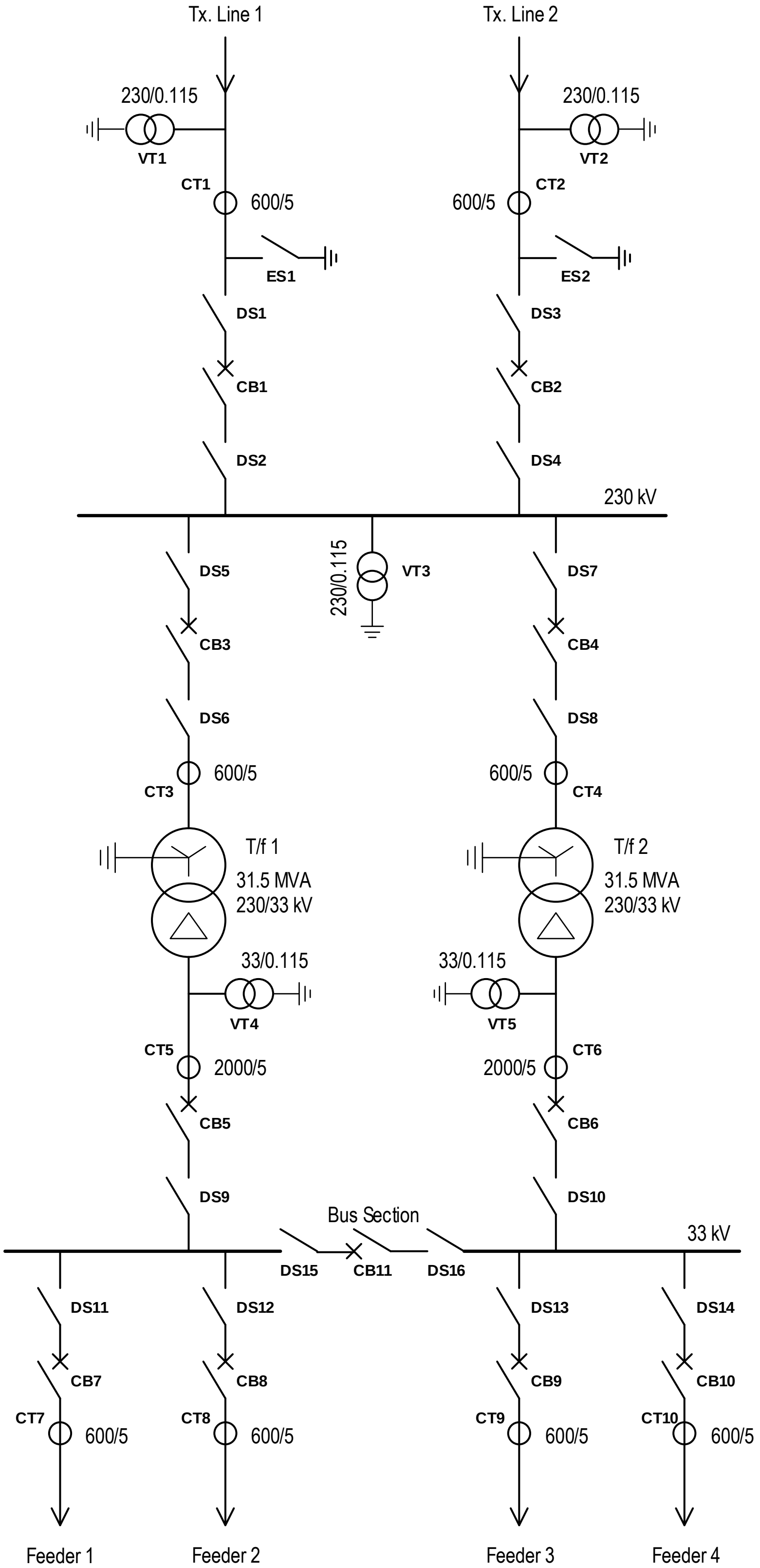


Fig. 4 Single line diagram of the substation used in the example case

5. RESULTS AND DISCUSSION

Testing carried out in this work was two-fold. In the first phase, functional aspects of the developed simulation model were extensively tested to confirm its correct operation and performance. The next phase was intended to test it in an application environment, where switch objects were incorporated into a simulation case to evaluate their performance under realistic scenarios.

The data models of simulated switch objects were accessed, monitored and controlled by a MMS client. A MMS client program available in the interface software of the real-time simulator was used as the MMS client for testing in this work [11]. However, any correctly configured MMS client can connect to the MMS server of the simulation model. This MMS client program can test the connection setup with the server device, browse the data model of the server device, read and write server data and perform control operations. In this paper, the focus is only on performing control operations on the server device. In addition, it has a capability to emulate different originator categories and command service types. As discussed before, only three originator categories that are commonly seen in a substation environment were tested in this research.

5.1. Functional Testing of the Developed Model

Annex B of IEC 61850-7-4 [1] provides eight different scenarios, where the combination of control parameter values determine the obtainability of control authority for each level. A switch can receive control commands from either bay, station or remote level controls (process level control is omitted as it bypasses the bay level switch controller, i.e. CSWI). Therefore, a switch object needs to be tested from all three levels for a single set of control parameters. This requires 24 switch operations (48 if both open and close operations are considered) to be performed. In addition, there are three possibilities for the interlock check; interlock check bypassed, interlocks checked but violated and interlocks checked and satisfied. Each of these requires a dedicated round of testing (48 operations each), which produces a total of 144 test switching operations per switch object.

Notice that a particular switch object has a chosen control model; hence, the abovementioned test procedure must be applied to confirm the correct functionality of all four control models. A comprehensive testing of the simulation model as explained above was carried out covering all aspects of its functionality. This required 576 (144x4) operations in total. In addition, a separate set of tests were carried out to verify the intended operation of each control model according to their state machines as defined in IEC 61850-7-2 [10]. These included numerous tests such as checks for timeouts, sequence of operation, appropriate *AddCause* etc.

Since a large number of cases were required to be tested, scripting feature of the real-time simulator was used to automate the testing of the simulation model [7]. This facilitated convenient and effective testing with minimal interaction. The simulated switchgear model performed as intended in each switch operation. Therefore, functional testing ensured that of the developed simulation model for switchgear operated in correct order under all possible control conditions.

5.2. Testing of Switchgear Control System

The example substation described in Section 4 was simulated in the real-time simulator with switch objects instantiated for each circuit switch. The control model for switch objects selected was “SBO with enhanced security”. Operation of each switch object was tested according to a test plan developed by the authors considering practical consideration in a SAS. A sample test plan for CB1 is provided in Appendix B and similar a test plan was used to test other switch objects.

All switching operations of the example substation exhibited expected performances. Appendix B also shows test results for switching operations of CB1. Similar performances were observed for other switch objects. This guaranteed that the switchgear controls of the example substation were operating as expected under selected scenarios.

5.3. Discussion

The previous phases of testing demonstrated the validation of switchgear associated control functions (above process level) in a SAS. Although the testing was performed using a PC based MMS client program, the testing procedure presented in this work can be applied to test a control system of a real SAS. The simulation model presented in this paper helps providing an appropriate testing environment for real switch controllers (operators) in a SAS to be tested, individually as well as a group. Real controllers can interface with switch objects in the simulation in a similar manner as explained above. Testing and verification of the electrical interlocks in the SAS is another advantage for the users.

This approach of testing can be taken into a more sophisticated level by interfacing switch objects simulated with actual circuit breakers via hardwired I/O connections of the simulator. This provides an IED functionality to conventional circuit breakers (for testing purposes), which a majority of them currently in the field do not have. Furthermore, if a user desires to have a circuit breaker under test integrated into the simulated circuit, a breaker model can be used as a replica to represent the real circuit breaker. Here, the breaker model in the simulation can be made to operate according to the status of the real circuit breaker by using proper I/O interfacing. This approach even allows taking signals external to the simulator as inputs into the switch object (such as interlock inputs) for a particular breaker.

Ultimately, switchgear controls are incorporated into the coordinated operation of the entire SAS, including both protection and control systems. Certain circumstances in a substation demand both protection and control operations, hence proper coordination among them is a necessity. In addition, both control and protection functions in a digital SAS may share the same communication network and often some engineering configurations (such as the SCD file) as well. Therefore, testing a digital SAS (with both protection and control systems in place) as an integrated system with the maximum interfacing of real IEDs is the best method available for verification of functionality, configurations and coordinated operation of IEDs.

6. CONCLUSION

This paper has presented the development of a simulation model to represent high voltage circuit switches in a SAS using IEC 61850 models. Basic concepts of the IEC 61850 standard series related to switchgear modelling are introduced in order to lay the groundwork for subsequent discussions on implementation of the simulation model. Then, a detailed description is provided on implementation of the simulation model and the comprehensive test setup developed for testing is also explained. The results section explains the procedures employed for testing and validation of the developed model as well as its application in a test setup for testing of switchgear controls with a summary of results.

The work presented in this paper highlights numerous benefits of using a simulation model for representing high voltage circuit switches for testing of switchgear controls in a SAS. Appendices A and B provide the existing electrical interlocks and the test plan used in testing switchgear controls of the simulated SAS.

7. APPENDIX A – INTERLOCKS

Interlocks of the substation used in the example case are provided in Table VI. Interlocks of symmetrical bays are not shown as they are identical.

Table VI: Interlocks of the substation used in the example case

Bay Type	Switchgear Object	Interlock	
		Open	Close
Tx. Line 1	CB1	--	DS1 DS2
	DS1	CB1	CB1 ES1
	DS2	CB1	CB1
	ES1	--	DS1 Remote CB
T/f 1 - HV	CB3	--	DS5 DS6 CB1 CB2 CB11
	DS5	CB3	CB3
	DS6	CB3	CB3
T/f 1 - LV	CB5	--	DS9
	DS9	CB5	CB5
Feeder 1	CB7	--	DS11
	DS11	CB7	CB7
Bus Section	CB11	CB3 CB4 CB5 CB6	DS15 DS16
	DS15	CB11	CB11
	DS16	CB11	CB11

8. APPENDIX B – SAMPLE TEST PLAN

A sample test plan prepared for the circuit breaker of an incoming feeder (Tx. Line 1) with test results are given below. The control model of the switch object selected is "SBO control with enhanced security"

Test Plan - Tx. Line 1 : CB1

A. Operation with Single Level Control Authority

A.1 Operate CB1 from Process Level Control

1. Operate CB1 from the process level control
   a. Set XCBR.Loc = True, LLN0.MltLev = False, CSWI.Loc = False and CSWI.LocSta = False
   b. Open/close CB1

Intended operation: *CB1 will operate*	[√] Satisfied [ ] Unsatisfied
Comments: *CB1 operates as it is always allowed to operate switches from the process level control.*	

A.2 Operate CB1 from Bay Level Control

2. Operate CB1 from the bay level control without control authority
   a. Set XCBR.Loc = True, LLN0.MltLev = False, CSWI.Loc = False and CSWI.LocSta = False
   b. Open DS1, DS2 and CB1and close ES1 (from process level)
   c. Set the originator category to "bay-control"
   d. Select the switch object with value "close"

Intended operation: *CB1 will NOT be selected (or operated); the response from the CB1 control model should indicate the "lack of access authority".*	[√] Satisfied [ ] Unsatisfied
Comments: *CB1 did not respond positively for the select command, as the switch is NOT allowed to be operated from the bay level control.*	

3. Operate CB1 from the bay level control with control authority; with interlocks unchecked
   a. Set XCBR.Loc = False, LLN0.MltLev = False, CSWI.Loc = True and CSWI.LocSta = False
   b. Open DS1, DS2, CB1 and ES1 (from process level)
   c. Set the originator category to "bay-control"
   d. Disable interlock check
   e. Operate the switch

Intended operation: *CB1 will NOT operate; the response from the CB1 control model should indicate the "Object not being selected".*	[√] Satisfied [ ] Unsatisfied

   f. Select the switch object with value "close"

Intended operation: *CB1 responds positively to the select command.*	[√] Satisfied [ ] Unsatisfied

   g. Wait until deselect timer expires and then operate

Intended operation: *CB1 will NOT operate; the response from the CB1 control model should indicate the "Expiration of the timer".*	[√] Satisfied [ ] Unsatisfied

   h. Select the switch object with value "close"
   i. Operate before the deselect timer timeout
   j. Check the command termination

Intended operation: *CB1 responds positively to both select command and operate command; CB1 completes the operation and sends a positive "commandTermination" to the client.*	[√] Satisfied [ ] Unsatisfied
Comments: *CB1 operates as the switch is allowed to be operated from the bay level control and the interlock condition are unchecked.*	

4. Repeat test 3 by setting XCBR.Loc = False, LLN0.MltLev = False, CSWI.Loc = True, CSWI.LocSta = False and the switch object value to "open"

   Note: - CB1 operated as intended. However, test results are not provided to limit the length of the paper.

5. Operate CB1 from the bay level control with control authority; with interlocks checked and violated
   a. Set XCBR.Loc = False, LLN0.MltLev = False, CSWI.Loc = True and CSWI.LocSta = False
   b. Open DS1, DS2, CB1 and ES1 (from process level)
   c. Set the originator category to "bay-control"
   d. Enable interlock check
   e. Select the switch object with value "close"

Intended operation: *CB1 responds positively to the select command.*	☑ Satisfied ☐ Unsatisfied

   f. Operate within the allowed period of time

Intended operation: *CB1 must NOT operate. The response to the operate command from the CB1 control model should indicate the "violation of interlocking".*	☑ Satisfied ☐ Unsatisfied
Comments: *CB1 is selected but did not operate as the interlock conditions are VIOLATED.*	

6. Operate CB1 from the bay level control with control authority; with interlocks checked and satisfied
   a. Set XCBR.Loc = False, LLN0.MltLev = False, CSWI.Loc = True and CSWI.LocSta = False
   b. Close DS1 and DS2 and open CB1 and ES1 (from process level)
   c. Set the originator category to "bay-control"
   d. Enable interlock check
   e. Select the switch object with value "close"
   f. Operate within the allowed period of time
   g. Check the command termination

Intended operation: *CB1 responds positively to both select command and operate commands; CB1 completes the operation and sends a positive commandTermination to the client.*	☑ Satisfied ☐ Unsatisfied
Comments: *CB1 closes as the switch is allowed to be operated from the bay level control and the interlock condition are satisfied.*	

7. Repeat test 6 by setting XCBR.Loc = False, LLN0.MltLev = False, CSWI.Loc = True, CSWI.LocSta = False and the switch object value to "open"

   Note: - CB1 operated as intended. However, test results are not provided to limit the length of the paper.

A.3 *Operate CB1 from Station Level Control*

8. Station level operation
   a. Repeat test 2 by setting XCBR.Loc = True, LLN0.MltLev = False, CSWI.Loc = False and CSWI.LocSta = False and the originator category to "station-control"
   b. Repeat tests 3-7 by setting XCBR.Loc = False, LLN0.MltLev = False, CSWI.Loc = False and CSWI.LocSta = True and the originator category to "station-control"

   Note: - CB1 operated as intended. However, test results are not provided to limit the length of the paper.

A.4 *Operate CB1 from Remote Level Control*

9. Remote level operation
   c. Repeat test 2 by setting XCBR.Loc = True, LLN0.MltLev = False, CSWI.Loc = False and CSWI.LocSta = False and the originator category to "remote-control"
   d. Repeat tests 3-7 by setting XCBR.Loc = False, LLN0.MltLev = False, CSWI.Loc = False and CSWI.LocSta = False and the originator category to "remote-control"

   Note: - CB1 operated as indented. However, test results are not provided to limit the length of the paper.

B. Operation with Multiple Level Control Authority

B.1 Operate CB1 from Bay, Station and Remote Level Control

10. Operate CB1 from the bay, station and remote level control with control authority is ONLY granted to bay and station levels.
    a. Set XCBR.Loc = False, LLN0.MltLev = True, CSWI.Loc = False and CSWI.LocSta = True
    b. Close DS1 and DS2 and open CB1 and ES1 (from process level)
    c. Set the originator category to "bay-control"
    d. Select the switch object with value "close"
    e. Operate within the allowed period of time

Intended operation: *CB1 responds positively to both select command and operate commands; CB1 completes the operation and sends a positive commandTermination to the client.*	[√] Satisfied [ ] Unsatisfied

    f. Set the originator category to "station-control"
    g. Select the switch object with value "open"
    h. Operate within the allowed period of time

Intended operation: *CB1 responds positively to both select command and operate commands; CB1 completes the operation and sends a positive commandTermination to the client.*	[√] Satisfied [ ] Unsatisfied

    i. Set the originator category to "remote-control"
    j. Select the switch object with value "close"
    k. Operate within the allowed period of time

Intended operation: *CB1 will NOT be selected (or operated); the response from the CB1 control model should indicate the "lack of access authority".*	[√] Satisfied [ ] Unsatisfied
Comments: *Only bay and station levels have the control authority, hence allowed to operate.*	

11. Operate CB1 from the bay, station and remote level control with control authority is granted to all control levels.
    a. Repeat test 10 by setting XCBR.Loc = False, LLN0.MltLev = True, CSWI.Loc = False and CSWI.LocSta = False

    Note: - CB1 operated from all levels as intended. However, test results are not provided to limit the length of the paper.

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