2013 Smart Grid Conference (SGC)
December 17-18, 2013, Tehran, Iran

Real Time Substation Distributed Control System Simulator Development Based on IEC 61850 Standard for a Sample Substation (Case Study: Sheikh Bahayi Substation 400/230/63KV)

Dr. Mohsen Montazeri, Amir Alavi, Hosein Rahmat jou, Jalaleddin Mehr Ardestani, Hamed Jadali pour
Faculty of Electrical and Computer Engineering
Shahid Beheshti University, Shahid Abbaspour College of Technology
Iran Islamic Republic of, Tehran

***Abstract*— In this paper a real time simulator of distributed control system (DCS) is developed according to IEC 61860 standard. IEC 61850 is the most important standard used in Smart Grid. In the first part, different parts of the control system is modeled and simulated according to IEC 61850 standard. For the modeling and simulation of communication network protocols which are based on the mentioned standard (GOOSE and INDUSTRIAL ETHERNET), OMNeT++ simulation platform is applied. HMI pages of the simulator which are completely in line with the main control system, has been developed using .NET framework. The developed simulator may be used in evaluating IEC 61860 standard and in educating operators of high voltage substations. Additionally primary equipment such as transformers, breakers, disconnectors and the secondary equipment such as distance relays and differential relays has been also modeled and simulated in MATLAB/Simulink.**

Keywords: real time simulator, high voltage substation, DCS, IEC 61850, OMNeT++

I. INTRODUCTION

According to IEC 61850, SAS of high voltage substation is divided into two levels named station and bay levels and in each level there are related equipment.[1] The basis for the mentioned automation system is designed based on the intelligent electronic devices (IEDs) according to IEC 61850 and is used for monitoring, controlling and protecting bays at its lowest automation level.[2] The operator at the station level uses the HMI to control and monitor the equipment of high voltage substation[3].

In the present paper we would suggest a method used in developing a real time simulator of substation distributed control system. The developed simulator consists of three parts: graphical user interface, simulated model of substation automation system with the use of OMNeT++ platform according to IEC 61850 standard, primary and secondary equipment models in the MATLAB/Simulink software. All these simulations communicate with each other in a real-time manner using inter process communication techniques.

This paper is organized as following: section II presents the general structure of the simulator. Next section describes overall concepts of modeling and simulation of primary and secondary equipment. Then in section IV the mentioned standard is introduced and in the V section the method of modeling of substation automation system is explained. In section VI the development of HMI pages is explained and finally the results from this simulation are analyzed in last section.

II. DISTRIBUTED CONTROL SYSTEM OF SUBSTATION REAL TIME SIMULATOR STRUCTURE

Structure of developed simulator is illustrated in Fig. 1.

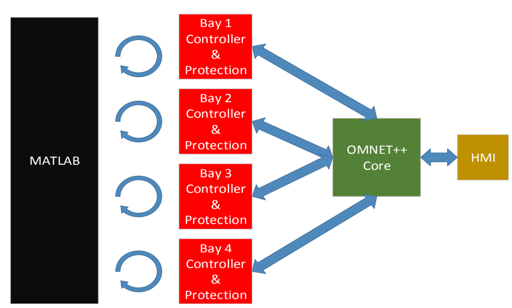

Figure 1: Structure of developed simulator according to IEC 61850 standard

At the lowest level, MATLAB/Simulink software is used as the dynamic simulator for primary equipment. In order to make the development of simulator easier, protection algorithms are also modeled in this software. To make the developed model more similar to the physical system, a case study was considered on the sheikh bahayi substation. Fig. 2 shows the single line diagram (SLD) of sheikh bahayi substation.

978-1-4799-3040-1/13/$31.00 ©2013 IEEE

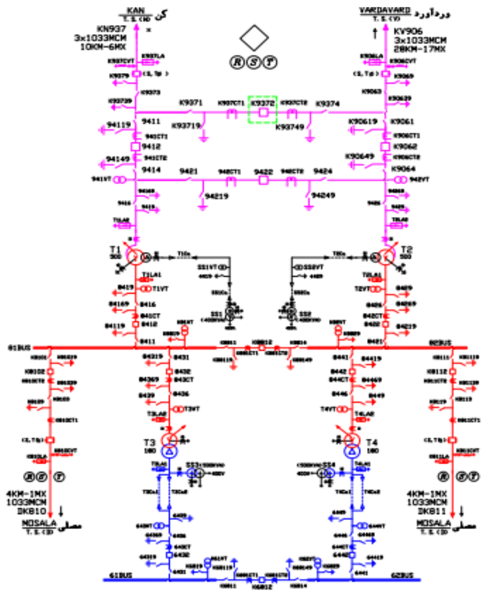

Figure 2 : Single line diagram of sheikh bahayi substation

At a higher level, simulation of communication system of the substation automation system lies, which is done using OMNeT++ simulator. In this part the communication network of substation is simulated according to the IEC 61850 standard. Finally at the highest layer, HMI which is developed based on the .NET technology, connects to devices based on IEC 61850 client/server protocol suit.

III. Modeling and Simulation of Primary and Secondary Equipment

High voltage substations including different electrical equipment which the most important ones include, power transformers, lines in input and output of substation, cables, current and voltage transformers ,breakers, disconnectors and line trap are modeled.

Characterization and modeling the equipment for all frequency is not possible nor needed. Therefore, specific description is used for power system components in the study frequency range that include some of the details.

Additionally different protection relays have been modeled like differential protection relay and distance protection relay. The outputs of simulation are evaluated and are very close to behavior of power system and real protection devices used in substation that can be used in a real-time simulator for any purpose.

IV. Introduction of IEC 61850 Standard , Modeling and Simulation of the Substation Automation System on it's Basis

Modeling based on the IEC 61850 is divided into two parts. In the first part, information modeling of equipment and in general the substation automation system information model which is discussed in this section. The second part is modeling and simulating of the substation communication system which is discussed in the next section. [4]

IEC 61850 standard provides a collection of models including standard object models, communication models, services and conformance testing to be used in substation automation system. In this standard each function is divided into some subfunctions which are done by IEDs. Each IED is able to do one or more subfunctions. IED is equivalent to physical device (PD) and each PD is divided into some logical device (LD). Each LD is further divided into some logical node (LN) which is the smallest part of a function capable of transferring data. IEC 61850 standardizes this LNs.[5] Nowadays this standard is widely used worldwide for it provides many privileges some of which are mentioned below:

1) Specifying the open protocols to be used in the protocol suit suggested by IEC 61850.

2) The opportunity to use different control and protection equipment made by different vendors such as ABB and SIEMENS.

3) Lower installation and maintenance costs due to using highly configurable devices in different situation.

4) Easy development of high voltage substation and the opportunity of using the legacy devices that do not support IEC 61850.[6]

Protocols used in the last version of IEC 61850 standard is illustrated in Fig. 3.

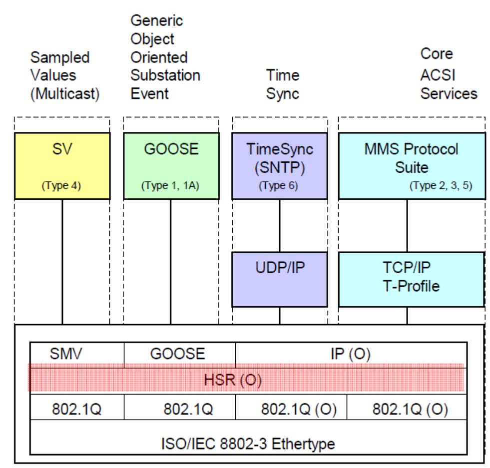

Figure 3 : Communication protocols in IEC 61850

As the dynamic process simulation of the primary equipment in the developed simulator, has been simulated using MATLAB software and a distinct computer has been used for simulation, we did not simulate Sample Value (SV) and Simple Network Time Protocol (SNTP) protocols. Generic Object Oriented Substation Event (GOOSE) and Manufacturing Message Specification (MMS) constitute the largest part of the traffic in communication network of substation automation. GOOSE protocol has been used to send real time data between different IEDs. These data include protection command (trip messages, etc.) and different status change events. MMS protocol connects automation devices in a client/server manner and based on the TCP/IP protocol. HMI receives the data and sends operator commands based on this protocol. In this developed simulator HMI uses the mentioned protocol in order to communicate with devices and to read and write values.[7]

Nearly all the LNs needed for modeling the devices and information in a high voltage substation have been mentioned in the 7-4 part of the standard under the title of: Basic communication structure for substation and feeder equipment – Compatible logical node classes and data classes. Designation of these LNs to LDs and IEDs are determined by the requirements of the automation system, available devices at the market, the designer's attitudes and other factors. For example standard has determined XCBR logical node for modeling of circuit breaker. XCBR may be considered along with other LNs in one IED as a Bay Controller Unit (BCU) or individually and as a single IED. First state without process bus and second state with process bus.[8]

XCBR logical node and any node in general are divided into subparts called Data. These data are shown for XCBR logical node in Fig. 4. As shown in this figure and in M/O section some data are mandatory (M) and some are optional (O). Each data consists of several date attributes. These data attributes are determined through attribute types which are shown in front of each data in the figure. It should be noted that different data can have similar data attributes. For instance in XCBR logical node, "blkopn" and "blkcls" data are SPC. Attribute types are mentioned in 7-3 section of the standard.[4]

XCBR class				
Attribute Name	Attr. Type	Explanation	T	M/O
LNName		Shall be inherited from Logical-Node Class (see IEC 61850-7-2)		
Data				
Common Logical Node Information				
		LN shall inherit all Mandatory Data from Common Logical Node Class		M
Loc	SPS	Local operation (local means without substation automation communication, hardwired direct control)		M
EEHealth	INS	External equipment health		O
EEName	DPL	External equipment name plate		O
OpCnt	INS	Operation counter		M
Controls				
Pos	DPC	Switch position		M
BlkOpn	SPC	Block opening		M
BlkCls	SPC	Block closing		M
ChaMotEna	SPC	Charger motor enabled		O
Metered Values				
SumSwARs	BCR	Sum of Switched Amperes, resetable		O
Status Information				

Figure 4 : XCBR Class

In this project in order to model equipment and information, Visual SCL software is used. In this software we can easily picture equipment and information models graphically. To do this, sample substation is divided into 11 bays and for each bay two IEDs are noted; BCU (for controlling) and BPU[1] (for protecting). Also an IED performs busbar differential protection function on the 400KV bus separately. Thus 23 IEDs are used totally. In this design, 244 LNs are used which come from 14 logical node types.

Related LNs are designated for protecting and controlling tasks to these IEDs. For instance typical BCU consists of XCBR, XSWI, CSWI and CILO logical nodes. Then this software transforms this model into XML[2] code. Substation Configuration description Language (SCL) is stated in 6th part of the standard. Equipment and information model of the sheikh bahayi substation are shown as Visual SCL software below.

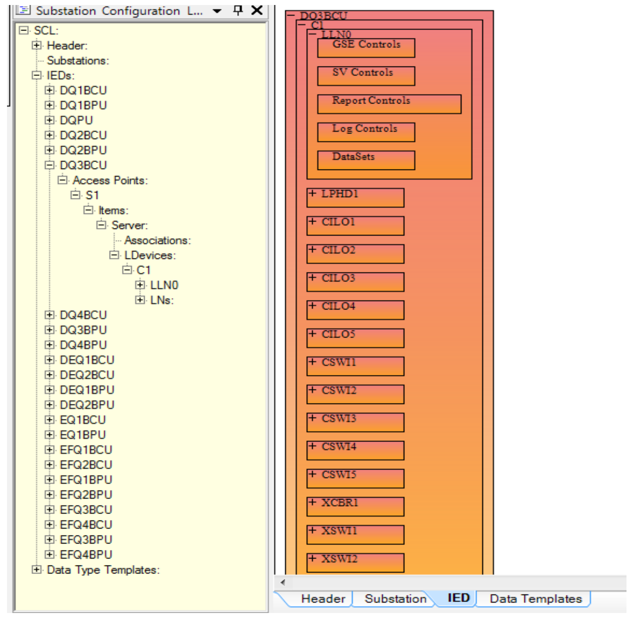

Figure 5 : Equipments and information model of sample substation in Visual SCL software.

V. Using OMNET ++ Simulation Platform For Modeling IEDs According To IEC 61850

OMNeT++ simulator is used to simulate computer networks in learning and analyzing network topology. This simulator does the simulation by processing discrete events via a predetermined processing algorithm. Regarding that IEC 61850 standard uses Ethernet in its protocol layers, and that the INET framework library did modeled Ethernet layers and TCP/IP in OMNeT++ platform, this simulator was chosen.

In Fig.6 a sample model of automation network for switchgear in OMNeT++ is shown.

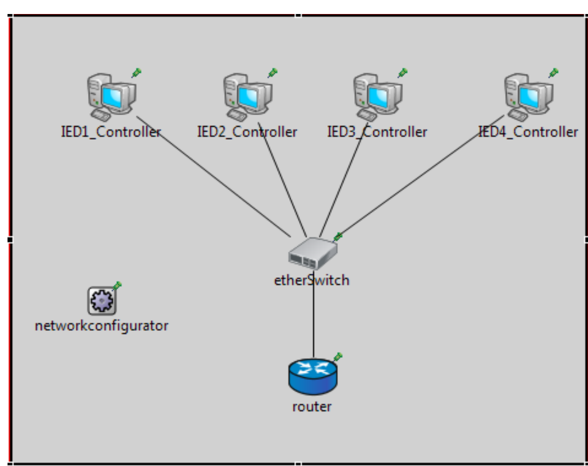

Figure 6 : A simple model of switchgear network according to IEC 61850 standard

[1] Bay Protection Unit
[2] eXtensible Markup Language

The core of OMNeT++ stimulator, there is not a determined structure to communicate with MATLAB/Simulink software in default. Since the point is real time simulation and that the primary and secondary equipment models are being simulated in MATLAB/Simulink software, we need module to be able to satisfy this need in OMNeT++.

To do so, by designing and adding software modules, we managed to offer these options. The module developed for this purpose is demonstrated in general in Fig. 7.

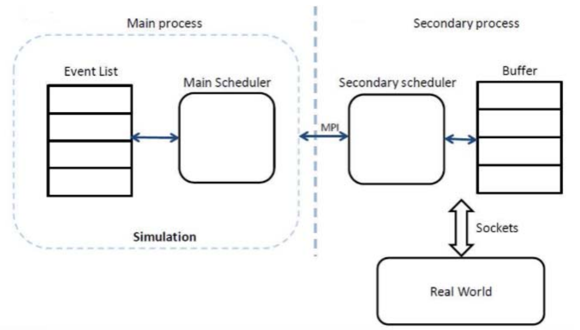

Figure 7 : Designated module in OMNeT++ simulator

In Fig. 8, the internal structure of a developed IED is shown according to IEC 61850 standard. The App component implements the application logic of IED. GooseController block is used for goose packet encapsulation and controlling. TCP block maintains the MMS communication according to its specification.

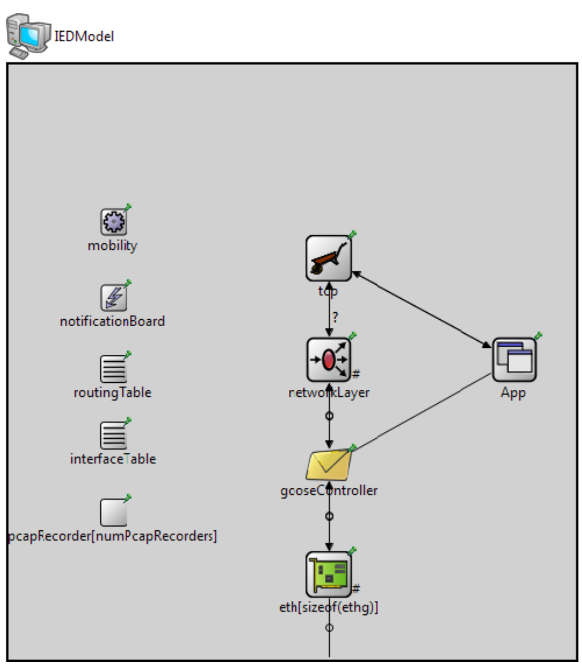

Figure 8 : Internal structure of a developed IED in general.

VI. Developing Human Machine Interface of High Voltage Substation

As HMI is one of the most important parts of each simulator. .NET technology and C# language programming have been used to develop HMI pages. Among the properties of the HMI pages, single line diagram of substation, voltage , current and power values, frequency and status of switches, circuit breakers, tap changers and protection signals is shown. Transformer temperature is also modeled and is shown to the operator. The main goal was to develop HMI pages similar to proprietary software in market.

In addition, the operator is able to command switches, circuit breakers and tap changers. In Fig. 9. The view of substation's HMI that is developed using C#.NET is presented. Interlocking logic in the simulated substation automation system are also controlled by the related IEDs.

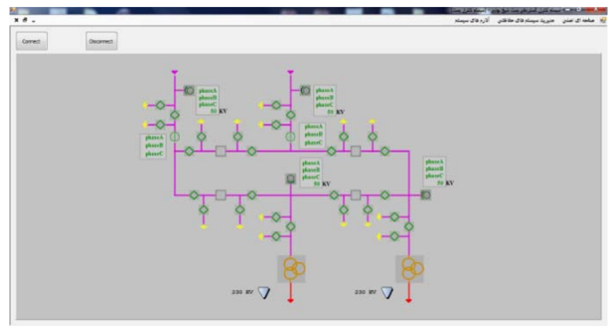

Figure 9 : HMI of high voltage substation.

VII. Conclusion

Regarding the developed industrialized simulator according to the latest standard and the real time structure of it, we can use this simulator for 2 purposes: 1) In designing and making substation automation systems for high voltage substations according to IEC 61850 standard using native technical knowledge and evaluating its performance with special attention to cyber security, reliability, safety, etc. 2) In teaching new operators of high voltage substation.

References

[1] J.L. Pinto de Sá, R.Cartaxo, "Implementing Substations Automatic Control Functions Designed With Petri Nets on IEC 61850". IEEE TRANSACTIONS ON POWER DELIVERY, Apr. 2011, Vol. 26, No. 2, pp. 1119-1127.

[2] Lin Zhu, Dongyuan Shi, Xianzhong Duan, "Standard Function Blocks for Flexible IED in IEC 61850-Based Substation Automation", IEEE TRANSACTIONS ON POWER DELIVERY, Apr. 2011, Vol. 26, No. 2, pp. 1101-1110.

[3] Il-Hyung Lim, Tarlochan S. Sidhu, "Design of a Backup IED for IEC 61850-Based Substation", IEEE TRANSACTIONS ON POWER DELIVERY, Oct. 2013, Vol. 28, No.4, pp. 2048-2055.

[4] Neil Higgins, Valeriy Vyatkin, Nirmal-Kumar C. Nair, Karlheinz Schwarz, "Distributed Power System

Automation With IEC 61850, IEC 61499, and Intelligence Control", IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNITICS-PATR C: APPLICATIONS AND REVIEWS, Jan. 2011. Vol. 41, No. 1, pp. 81-92.

[5] K. P. Brand, C. Brunner , W. Wimmer, "DESIGN OF IEC 61850 BASED SUBSTATION AUTOMATION SYSTEMS ACCORDING TO CUSTOMER REQUIREMENTS", in CIGRE Plenary Meeting, 2004, Paris, Session of SC B5, Paper B5-103.

[6] T. S. Sidhu, Y. Yin, "Modelling and Simulation for Performance Evaluation of IEC 61850 Based Substation Communicaton Systems", IEEE TRANSACTIONS ON POWER DELIVERY, Jul. 2007, Vol. 22, No. 1, pp. 1482-1489.

[7] T. S. Sidhu, P. K. Gangadharan, "Control and Automation of Power System substation using IEC61850 Communication", in Control Applications, Aug. 2005, Canada, pp. 1331-1336.

[8] T. S. Sidhu, M. G. Kanabar, P. P. Parikh, "Implementation Issues with IEC 61850 Based Substation Automation Systems", in Fifteenth National Power Systems Conference (NPSC), Dec. 2008, Bombay, pp. 473-478.