Intelligent Control Systems for Futuristic Smart Grid Initiatives in Electric Utilities

Hossein Zeynal
KDU University College,
School of Engineering,
Damansara Jaya, 47400 Petaling Jaya,
Malaysia
h.zeynal@kdu.edu.my

Mostafa Eidiani
Mashhad Branch, Islamic Azad University,
Electrical Engineering Department,
Mashhad, Iran
eidiani@mshdiau.ac.ir

Dariush Yazdanpanah
Khorasan Regional Electric Company,
Mashhad, Iran
dariush_yaz@Yahoo.com

Abstract - **Substation Automation Systems (SAS) provide reliable bedrock for future smart grid development in electric utilities. Implementation of high quality SAS system enables one to experience less outage rate using the state-of-the-art computerized functions of monitoring, control, and protection. As a result, it can immensely reinforce the reliability index of smart grid systems. However, the inextricable interdependency of cyber and power components in an automated substation creates more vulnerable operation process. In this sense, unlike the power component outage in a substation, a failure of the cyber components in an Ethernet fashion can interrupt the operation as well. Therefore the proper selection of SAS package that offers more reliable performance may hedge massive mal-operation in the system. Since the introduction of multi-vendor SAS based IEC-61850 protocol, the interoperability of various SAS components with variety of manufacturer's brands is now possible. This paper surveys the most efficient and used SAS package and the configuration in a HV substation which leads to high reliable performance. Findings can pave the future smart grid development in an effective manner.**

Keywords - ***Intelligent Control Systems, Futuristic Smart Grid Initiatives, Electric Utilities***

I. INTRODUCTION

Since Siemens introduced the first digital/numerical and decentralized concept for Substation Automation Systems 20 years ago [1], [2], some major achievements and trends have happened [3]. The first Substation Automation Systems (SAS) typically had master-slave architecture in a star topology and used vendor-specific proprietary protocols within the Substation and to a Network Control Centre (NCC)/SCADA System [4].

Due to the non-interoperability of communication &data modeling, substation integration was very complex and risky. Therefore the user was often bound to one vendor [2], [5]. The usage of protocol converters was quite often essential. Needless to say, in those days the interoperability of engineering data was not even a topic of discussion [6].

The master-slave architecture itself created some additional system immanent limitations [5]:

• Station-wide automation functionality is located in the master
• Master represents a bottleneck
• Communication between master & slave is in polling mode only, i.e. not event driven
• No direct communication between two slaves Hardware, Communication equipment and the Human Machine Interface (HMI) were often from one vendor and thus development was constrained [7]. This led to limitations in functionality, performance and participation in new developments.

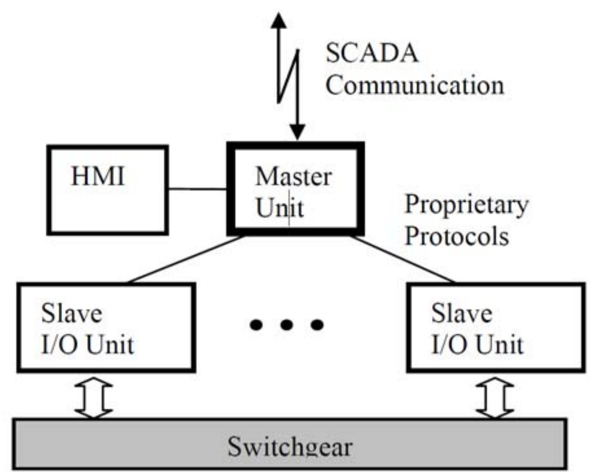

Figure 1. Initial architecture of a substation automation system

The configuration of a SAS was done offline using a PC/Workstation and then either programmed onto EPROMS or later directly loaded onto the master or I/0 units. These first substation automation solutions focused on getting operational data, e.g. voltage, current and the status of switching devices to a NCC. Displaying these data provided a snapshot of the current functional and operational status of the system, thus helping to easily run the substation, but they didn't offer a complete overview of the system [2].

In short, the first important milestone towards substation automation had been achieved. The use of microprocessor-based decentralized systems did, however, leave lots of room for improvement [6]. The rapid dissemination of IT and communication in today's world and the users' demand for a secure and sound investment have driven substation automation towards more standardization, interoperability, reliability and superior performance.

Since then, many vendors emerged when introducing better technology to deal with automation process in the substations [8]. Although IEC 61850 paved the road of interoperability between various SAS vendors but most of

978-1-4799-3251-1/13 $31.00 © 2013 IEEE
DOI 10.1109/AIMS.2013.65

utility have a solid tendency to procure the SAS package from a certain manufacturer, albeit it is not general [9].

Among the renowned SAS vendors are ABB, Siemens, General Electric (GE), Alstom, SEL, Toshiba, and Schneider Electric. These are, however, the most used brand in utilities which are offering a constant support, competitive price, IEC61850-compliance, high reliability.

This paper is organized as follows; at section 2 the description on 3-layer automation process in substation is given. In addition, the layer on which computerized network is cast is also explained here. Then in section 3 the discussion on the SAS products offered by each dominant vendor is addressed. At the end, the conclusion is drawn in section 4.

II. SUBSTATION AUTOMATION SYSTEM

Substation automation systems were designed to increase efficiency of the control and communication schemes installed in electric substations. In this sense, SAS is purposely planned to cast a local computerized network at a substation to enhance the response time for any unpredictable event as fast as possible. The main substation automation (SA) function consists of several sub-functions which are appropriately interfaced [9].

There are basically two types of equipment in a substation: (i) primary equipment and (ii) secondary equipment. Primary equipment include transformer, switchgear etc. Secondary equipment includes protection, control and communication equipment. Further, secondary equipment are categorized into three levels in IEC-61850 standards. There are station level, bay level, and process level equipment. A typical diagram indicating the above three levels of equipment is shown in Fig. 2.

Human Machine Interface (HMI) and Communication Unit (ComU) reside in the station level. HMI is the interface to the operator at the substation. Here, an operator can control and monitor the substation locally in the substation. 'ComU' is the interface between substation and Master Control Center (MCC). These devices are connected to bay level devices via station bus. The substation control system will communicate with protective devices and bay processing unit through station bus. The station bus is specified in the IEC-61850-8-1 part of the standard.

A conceptual substation automation system based on the IEC 61850 standard is evolved and depicted in Fig. 3. In this conceptual scheme the station level equipment consists of station computer with a database, the operator's workplace, interfaces for remote communication etc. Bay level equipment consists of control, protection and monitoring units per bay.

Process level equipment consists of typically remote Inputs/Outputs, intelligent sensors and actuators as shown in Fig. 3.

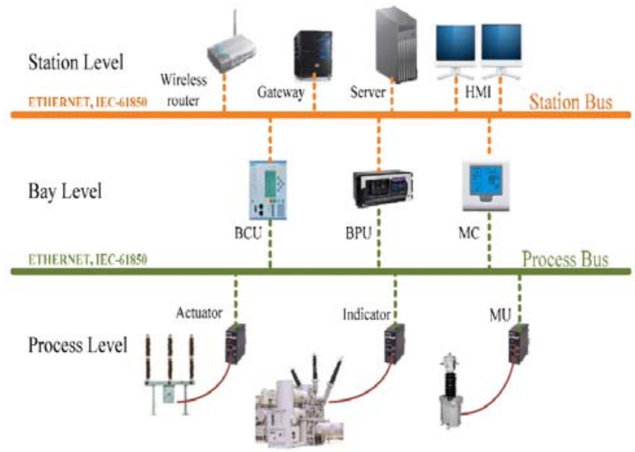

Figure 2. Substation automation layout

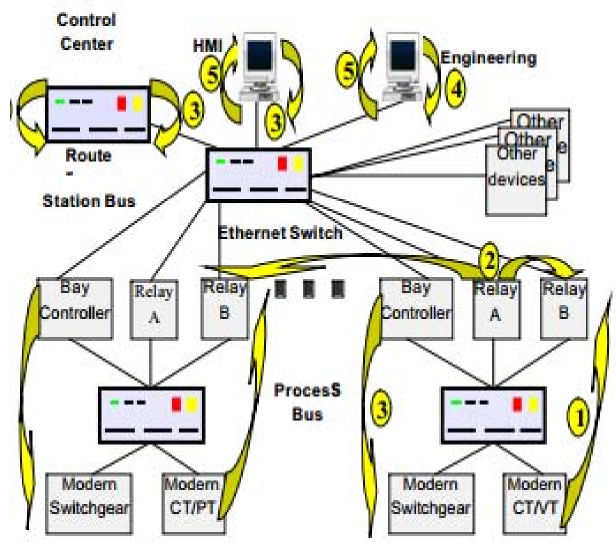

Figure 3. Conceptual substation automation topology

The station level equipment communicates with bay level equipment through station bus. Further, bay level equipment communicates with process level equipment through process bus as depicted in Fig. 3.

In the conceptual scheme, these two stations and process buses are realized through the standard Local Area Network (LAN). Station bus is created by installing a multi-port Ethernet switch. Switch is a device in the computer network that filters and forwards data packets between LAN segments. Generally Router, Human Machine Interface (HMI) and Engineering console are connected with Ethernet switch at station level. Router facilitates data communication between substation and Master Control Centre (MCC). HMI enables the operator to monitor and operate the switching elements in the substation through Graphical User Interface (GUI) at substation level. The engineering console, as depicted in Fig 3, provides computer aided control decision, which can be implemented at primary equipment level through local HMI. If station level node has to communicate with process level node, it will send the message to bay level node through Ethernet switch. Ethernet switch will send the message to the appropriate node at bay level. This bay level node executes its function and forwards the message to process level node through Merging Unit. Merging Unit acts like a switch and provides the appropriate path to messages. Eventually, the function will be performed by the process level devices.

The main focus of IEC-61850 standard is to support the substation functions through the communication of (numbers in brackets refer to those in Fig. 3):

- Sampled values for CTs and PTs (1),
- I/O data for protection and control (2),
- Control and Trip signals (3),
- Engineering and configuration data (4),
- Monitoring and supervision signals(5),
- Data to Control-center (6),
- Time-synchronization signals, etc.

Other functions such as metering, condition monitoring and asset management are also supported in IEC-61850. Many functions are implemented in IEDs as shown in Fig. 5. Several functions may be implemented in a single IED or one function may be hosted by multiple IEDs. IEDs communicate among each other by information exchange mechanisms of the standard. Therefore, functions distributed over more than one IEDs may also be implemented in the conceptual scheme.

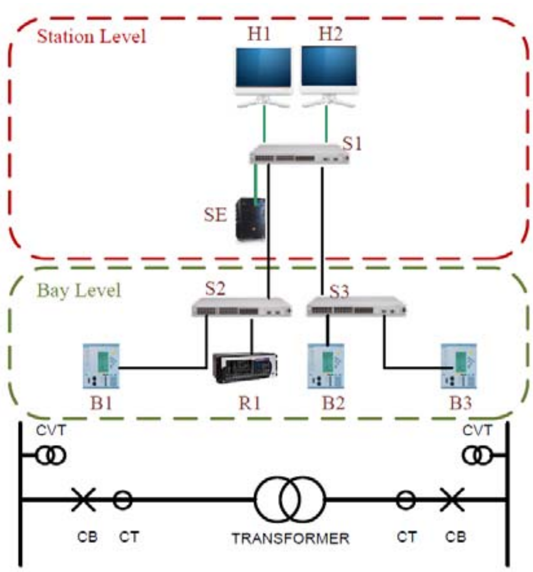

Figure 4. Three levels of an SAS

As shown in Fig. 4, the SAS devices are arranged in accordance with the power section. On the bay level, B1 and B3 are considered for use as equipment on the HV and LV sides, respectively, of the transformer, and another BCU (B2) and one protection unit (R1) are dedicated to the transformer. Moreover, on the station level, redundant HMIs and servers are shown. The process level and the process bus are not included in this application because the connections between power equipment and bay-level devices are hard-wired and not aggregated with the SAS. Switches S1and S2 and the connection between them are for the station bus. For the control task, the load point is the BCU. Because the server manages commands, if no connection exists between the BCU and the server, the load will not receive the data.

III. SAS PACKAGES IN THE MARKET

If one planned to shop for distribution automation gear then it is expected to see a lot of suits. This is, however. Challenging which involved with equipment that runs into tens of thousands of dollars a unit. And it is dominated by some of the biggest players in energy infrastructure manufacturing.

Take ABB, for example. The Swedish-Swiss engineering giant's SAS 600 Series of substation automation products provides remote control and monitoring functions for distribution-level to extra-high-voltage substations, working alongside a range of intelligent electronic devices (IEDs).

Alstom similarly has a wide selection of substation automation control systems, including substation bay controllers, gateways and switches, and markets IEDs such as protection relays and measurement devices under the MiCOM product banner.

And General Electric (GE) last year unveiled an array of controllers as part of its distribution automation product offering.

ABB has been by far the most acquisitive company in distribution automation, but Alstom bought the smart grid software developer UISOL in 2010 and subsequently GE has picked up Lineage Power Holdings, FMC Tech and Opal Software.

Schneider Electric, meanwhile, has acquired the distribution management system maker Telvent and Areva's distribution grid business, among other smart grid-related deals, while Siemens has grabbed Site Controls, Energy4U and eMeter.

This consolidation looks set to continue in the short term as the major vendors capitalize on a growing demand for distribution automation; GTM Research forecasts the market for equipment could hit $3bn per year by 2015 in the US alone.

A. ABB 600 series [10]

Based on the vast experience in protection and substation automation (SA) as well as the expertise in IEC61850, ABB has fully implemented the new standard in its products, systems and tools. To verify the proper implementation of IEC61850 throughout its portfolio, ABB has established a System Verification Centre (SVC*). Each and every product, system component, application and tool is tested in a real-life system environment to prove its appropriate working and performance – functionally and interactively. Complete systems are verified to ensure they fully meet the requirements in terms of communication, integration, functionality and performance.

The benefit of advanced power system management requires the automation of local operations and the collection, evaluation and forwarding of data on the power system status and plant condition to higher-level systems. The Substation Automation Solutions provide the remote control and monitoring functions for all kind of substations starting from distribution level up to extra high voltage substations. The ABB Intelligent Electronic Devices (IEDs) for protection and control are an integral part of the SA system. The SAS and IED together lay the foundation for all the higher-level remote functions such as advanced power system management and the monitoring of the condition of the equipment while it is in service. Station level systems are easy to use and to adapt to customer specific requirements. Our scalable modular systems reflect the typical needs and availability aspects for the following range of applications:

•Transmission, sub-transmission and distribution substations
•Utilities and industries
•New installations and refurbishment of existing substations
•Gas and air isolated switchgear

B. Siemens Sicam Pas [11]

At Siemens Energy Automation Division, the innovation is built to benefit the customers. For that purpose, Power Automation contributes largely to establishing international standards and their timely implementation. A state-of-the-art system SICAM® PAS (Power Automation System) fully complies with IEC 61850. Networking and IT capabilities, interoperable system structure and integration into existing systems are characteristics of SICAM PAS that make it sound investment for the future. SICAM PAS makes configuration and commissioning easy, saves you time, and helps increase the efficiency of operations management.

A successful automation system is the foundation for a high level of functionality and flexibility. Naturally, that also includes comprehensive options for tele-control, communication and for connecting peripheral equipment. That's certainly the case, at least, with the innovative SICAM RTUs automation components.

SICAM PAS (Power Automation System) meets all the demands placed on a distributed substation control system - both now and in the future. Amongst many other standardized communication protocols, SICAM PAS particularly supports the IEC 61850 standard for communication between substations and IEDs.

C. Sel-Substation Automation [12]

Improve system reliability, manage assets, and monitor and control the power system more safely and economically with transmission and substation automation solutions.

D. GE GESA [13]

The GE Substation Automation system provides standard network interfaces, open-layered multi-protocol support, and centralized network management to efficiently communicate between generating plants, substations, and operation centers. Legacy protocol devices can be combined with MMS/UCA2 and DNP 3.0 compliant IEDs or a host of other protocols including open ModBus® /TCP and ModBus® RTU over a high speed fiber optic communication network to accommodate the optimum combination of devices. Comprised of communication equipment, protocols, gateways, HMIs,engineering tools, GE's multilingual UR (Universal Relay) family of IEDs and the D25 IED, the GE Substation Automation System directly interfaces with EMS and SCADA systems incorporating GUIs (Graphical User Interfaces) for local and remote control, application development, database management, and enterprise connectivity.

E. Alstom Ds Agile [14]

DS Agile is the latest in turnkey automation solutions for digital substations. It combines cutting-edge hardware, software, communications and highest technology engineering to IEC 61850 standards. DS Agile is a fully scalable solution, in terms of functionality, architecture and services that can be tailored either to single substations or to a harmonized system across multiple substations.

F. Schneider Electric [15]

Schneider Electric Substation Automation Solutions (SAS) provide easy migration from legacy protection and automation schemes to modern, forward-looking standards like IEC61850. The SAS provides a scalable solution that can deploy quickly and easily, additionally, it can be woven into existing systems or function as a stand -alone. Schneider Electric also offers the utility a way to minimize the cost of upgrades thru retrofit solutions, such RTU's, relays, and meters.

G. Toshiba Gsc1000 [16]

Toshiba's GSC1000 Substation Automation System, based on the IEC 61850 standard, now supports optional redundant configurations. The structure in each bay is now served using a two-port BCU and protection relays connected to alternate Ethernet Local Area Networks (LAN). The two ports for each device are configured in a Hot Standby arrangement, with the status of each being recognized not only by the station computer (SAS server) but also by the BCUs themselves. This configuration further enhances reliability and operational safety for the most demanding of system requirements.

IV. CONCLUSION

This paper presented the most used substation automation systems (SAS) brand in utilities. From the reference list of each manufacturer, it can be deduced that the ABB 600 series outruns all other contenders. It is due the quality of the service rendered, number of ABB branches spread all over the world which ease one to technically get helped. Siemens, since its first SAS package which is IEC 61850-compliant, SICAM offered many opportunity to the customer to benefit such a complete package. Siemens SICAM, however, grabbed major part of the substation automation projects around the world. ALSTOM DS Agile has recently come up with enhanced IEC 61850- complaint package that attracted many utilities in adopting their automation systems based on DS Agile. Nevertheless, GE, SEL, Toshiba have also largely taken parts in substation automation developments in many countries in Asia, Europe, Middle-east, America.

ACKNOWLEDGMENT

The authors acknowledge the financial support from Research Committee, KDU University College, Damansara Jaya, 47400 Petaling Jaya, Malaysia, as well as Khorasan Regional Electric Company (KREC), Mashhad, Iran.

REFERENCES

[1] Humphreys, S., Substation automation systems in review. Computer Applications in Power, IEEE Transaction on , 1998. 11(2): p. 24-30.
[2] Won-Seok, C., et al. The study of substation automation systems based on IEC 61850. in Electrical Machines and Systems (ICEMS), 2011 International Conference on. 2011, USA
[3] Kirkman, R. Development in Substation Automation Systems. in Intelligent Systems Applications to Power Systems, 2007. ISAP 2007. International Conference on. 2007, Italy.
[4] Carr, J., Considerations in the Adoption of a Full Scale Distribution Automation System. Power Apparatus and Systems, IEEE Transactions on, 1981. PAS-100(3): p. 1167-1172.
[5] De Dominicis, C.M., et al. Experimental evaluation of synchronization solutions for substation automation systems. in Instrumentation and Measurement Technology Conference (I2MTC), 2010 IEEE. 2010, Japan.
[6] Vadiati, M., et al. Future trends of substation automation system by applying IEC 61850. in Universities Power Engineering Conference, 2008. UPEC 2008. 43rd International. 2008, Canada.
[7] Trabulus, S. General configuration of automation system within a high voltage power substation. in Electrical and Computer Engineering, 2000 Canadian Conference on. 2000, Vankuor.
[8] Jian-Cheng, T., V. Green, and J. Ciufo. Testing IEC 61850 based multi-vendor substation automation systems for interoperability. in Power Systems Conference and Exposition, 2009. PSCE '09. IEEE/PES. 2009, China.
[9] Matsuda, S., et al. Issues overcome in the design and application of IEC 61850-compliant substation automation systems. in Advanced Power System Automation and Protection (APAP), 2011 International Conference on. 2011, UK.
[10] ABB Inc. [available] at: http://www.abb.com/industries/
[11] SIEMENS [available] at: http://www.energy.siemens.com/us/en/automation/power-transmission-distribution/substation-automation/
[12] SEL Automation [available] at: https://www.selinc.com/automationsystems/
[13] GE electric [available] at: http://www.gedigitalenergy.com/Automation.htm
[14] Alstom [available] at: http://www.alstom.com/grid/products-and-services/Substation-automation-system
[15] Schneider electric [available] at: http://www.schneider-electric.com.my/malaysia/en/products-services/
[16] Toshiba [available] at: