Utilization of GOOSE in MV Substation

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Abstract— **Ethernet based communication standard IEC 61850 gaining its acceptance in various industrial and utility substations in the power transmission, sub transmission & distribution application. IEC 61850 based systems provides many advantages over existing legacy protocol used in MV (Medium Voltage) substation automation. IEC 61850 is a very large standard with many functions & services within it. One of the unique functionality supported by IEC 61850 is peer-to-peer communication commonly known as GOOSE (Generic Object Oriented Substation Event). GOOSE Messages offer advantages over conventional hard wiring in protection and control schemes like reduced copper inter panel wirings, faster transfer of signal, supervised signal transfer, flexibility and expandability. In this paper application of GOOSE in MV substation is discussed with the advantages of GOOSE over conventional protection and control scheme. Last section of the paper discuss about concerns and resolutions for GOOSE application in MV Substation.**

Index Terms— **MV Substation, IEC 61850, GOOSE, Hard Wiring**

I. Introduction

The IEC 61850 has proven its advantage for Electric Substation Automation in power transmission and sub transmission applications. However, MV substation automation still using other open protocol likes MODBUS, IEC 60870-5-103 etc. Latest Microprocessor based relays are no longer merely protection relay but have evolved to perform many other functions like integrated protection functions, comprehensive measurements, time stamped events, self diagnosis, disturbance records, circuit breaker control and circuit breaker monitoring functionality which facilitate effective power system operation. Now, it should not be wrong to mention these microprocessor based relays as Intelligent Electronic Devices (IEDs). The amount of information generated in substation automation systems has grown exponentially since the introduction of IEDs in power industry. Until recent years substation automation was realized with proprietary protocols or open protocols with certain limitations in communication of IEDs to SCADA (Supervisory Control and Data Acquisition). This led to communication related problems in the substation automation systems with the IEDs from different vendors. The IEC 61850 standard was introduced in order to harmonize substation communication and gain interoperability.

The IEC 61850 standard has been designed with in consultation of manufacturers and users to create uniform, future proof basis for the protection, communication and control of electric substation. IEC 61850 is an international standard for electrical substation automation which defines communication networks, engineering, full application coverage etc.

MV substation is having large numbers of IEDs with huge data for integration with SCADA system. This calls for the suitable protocol which can utilize all the functionality of IEDs and SCADA system. IEC 61850 supports peer-to-peer communication between IEDs in substation automation. GOOSE communication is now changing the tool for protection engineer from hardwired protection schemes to fast, supervised virtual wiring based protection and control schemes. MV substation is having different protection and control schemes which require lots of inter panel signals transfer. Until recent years the only option for this kind of protection and control scheme was hard copper wiring between the switchgears panels. GOOSE message has offer the option for the virtual wiring with many advantages over conventional practices. Faster Communication, supervised signals transfer, flexibility and expandability are the greatest advantages this technology has to offer.

II. Historical Background for MV Substation Automation

Electromechanical and Static Relays has successfully served MV Substation over the past years. Advent of microprocessor technology has introduced communication capability to protection devices. Various communication protocols are used for the MV Substation Automation. Open protocols like MODBUS, IEC 60870-5-103 and proprietary protocols like SPA, PROFIBUS, COURIER has served MV substation automation. All these protocols has some or the other limitations to utilize full potential of IEDs. These limitations like speed of communication, circuit breaker control support, time synchronization support, relay parameterization support, interoperability, multi master capability and level of standardization. Answer to these entire open questions is IEC 61850 which also has support for high speed horizontal communication to replace hard wiring for protection scheme with virtual wiring. The interfacing of control devices has traditionally been hard wired. Outputs from relay became the inputs to another device. Until IEC 61850 standard this was the only way of communication between two relays or IEDs in MV Substation. Let's take an example of one MV substation inter panel hard wiring for peer-to-peer communication. If we assume, one MV Switchboard having two incomer, one bus coupler, ten motor feeders, ten transformer feeders and two capacitor feeders amount of inter panel signals will be in the range of hundreds to implement various protection and control schemes like auto change over, reverse blocking, circuit breaker failure protection, motor under voltage trip trough bus PT etc. More the hard wiring is more

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the cost over entire life cycle of installation. Fig 1 shows the conventional way of hard wiring in MV Substation.

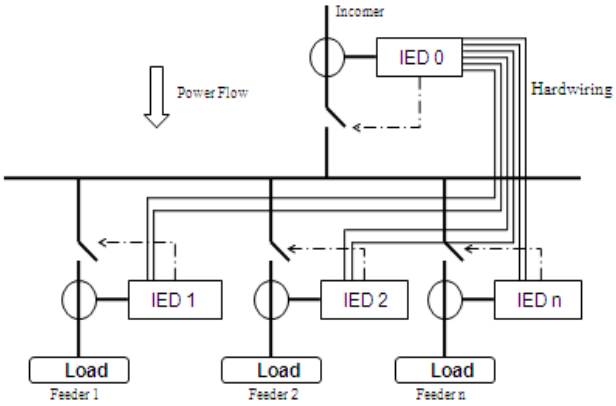

Fig 1 Conventional Hard Wiring in MV Substation

Now, we can imagine the quantum of inter panel wiring needed for MV Substation to implement various protection and control schemes. IEC61850 based substation automation and GOOSE message can replace all these hard wiring to virtual wiring between IEDs.

III. IEC 61850 AND GOOSE

High speed communications infrastructure in MV Substation has been needed for number of years. Modern IEDs offers many functionality for power system operation which should be integrated successfully to utilize full potential of IEDs. In this section, I briefly introduce the IEC 61850 standard, its main features and its benefits. In second part of this section details of peer-to-peer GOOSE communications and benefits are discussed.

A. IEC 61850

IEC 61850 is a standard for the design of electrical substation automation. IEC 61850 is a part of the International Electrotechnical Commission's (IEC) Technical Committee 57 (TC57) reference architecture for electric power systems [1]. IEC 61850 works on high speed switched Ethernet technology to meet high speed communication requirements in electric substation. IEC 61850 is not a former link serial protocol recast onto TCP/IP-Ethernet. IEC 61850 was designed from the ground up to operate over modern networking technologies and delivers an unprecedented amount of functionality that is simply not available from legacy communication protocols. These unique characteristics of IEC 61850 have a direct and positive impact on the cost to design, build, installation, commission and operate the power systems. A brief comparison between various protocols used in MV substation automation depicted in table no. 1 to appreciate advantages of the IEC 61850 protocol over legacy protocol used till date in MV substation [6]. Seeing the comparison table, we can say that the IEC 61850 is unique and most suitable protocol for electrical MV substation automation which can utilize full potential of modern IEDs and advantages of Ethernet technologies.

Table I
Comparison between Legacy Protocol and IEC 61850 for MV Substation automation

Functionality	**MODBUS** (Standard)	**IEC 60870 - 5 - 103** (Standard)	**Profibus**	**IEC 61850**
Speed of Communication	9.6 kBPS, 19.2 kBPS maximum	9.6 kBPS, 19.2 kBPS maximum	9.6 kBPS to 12 MBPS	100 MBPS
Circuit Breaker Control	×	×	×	√
Disturbance Record Uploading	×	×	×	√
Remote Relay Parameterization	×	×	×	√
Time Synchronization Accuracy	×	± 1 msec	×	± 1 msec
Peer-to-Peer Communication	×	×	×	√
Interoperability	×	×	×	√
Multi Master Capability	Master Slave	Master Slave	Master Slave	Master Master
Level of Standardization	De Facto	Most implementations using proprietary extensions	De Facto	Full application coverage defined in standard, including engineering

× - Not Supported, √ - Supported.

The IEC 61850 consists of ten parts under the general title *Communication networks and systems in substations.* The main objective of IEC 61850 standard is to provide a set of standard model structures for data and rules defining how to exchange these data [1]. IEDs from different manufactures that comply with these model definitions can then understand, communicate and interact with each other. For the configuration of IEC 61850 based system, the standard specifies a Substation Configuration Language (SCL) that is based on Extensible Markup Language (XML). The various SCL based configuration files include: a. System Specification Description (SSD) file that outlines substation automation project, b. IED capability description (ICD) file which describes available services from IEDs and functions (LNs), c. Substation Configuration Description (SCD) file that describe relationship among the IEDs in the substation automation project and their information exchange structures, d. Configured IED description (CID) file that is the final file to download into an IED to enable its configured functions.

The main benefits of IEC 61850 based Substation automation are as follows:

- Standardized device object models provide a higher level of interoperability between different manufacturers.
- SCL files are used for the configuration of the system and SCL can also be used to precisely define user requirement for substation and devices.
- IEC 61850 supports GOOSE and GSSE (Generic Substation Status Events) for exchange of data and status between IEDs over the station LAN without having to wire separate link for each IED. This

feature reduce wiring cost by utilizing substation LAN bandwidth for these information exchanges and construction cost by reducing the need for trenching, ducts, conduit etc.

- Easy expansion to accommodate future system growth.

B. *GOOSE Message*

IEC 61850 is having powerful feature for peer-to-peer communication that is GOOSE & GSSE messages. The difference between GOOSE & GSSE is GOOSE message may include many data type like analog, binary and integer value while GSSE message is limited to support only fixed structure of binary event status data. Both GOOSE & GSSE Message are multicast service which allows simultaneous message delivery to multiple IEDs in MV Substation automation [8].

To handle the large data in MV Substation automation, IEC 61850 standard has defined different message types based on how fast the messages are required to be transmitted among network IEDs. Table 2 lists the message types

Table II
IEC 61850 Message Types and Performances [1] [8]

Type	Name	Performance Class	Example	Requirements (Transmission Time)
1A	Fast Message Trip	P1	Trips	10 ms
		P2/P3		3 ms
1B	Fast Message Others	P1	Commands Simple Message	100 ms
		P2/P3		20 ms
2	Medium Speed Messages		Measurands	100 ms
3	Low Speed Messages		Parameters	500 ms
4	Raw Data Messages	P1	Output data from transducers and instrument transformers	10 ms
		P2/P3		3 ms
5	File Transfer Functions		Large Files	≥1000 ms
6	Time Synchronization		Time Synchronization	(Accuracy)

GOOSE messages are Type 1 or 1A fast messages used for various scheme in substation automation. GOOSE messages are generally binary value data intended for protection and control scheme. GOOSE messages are mapped directly to Ethernet Technology TCP/IP to optimize its decoding and overall transfer time. Each GOOSE message is having name of data set to include in the message and a given parameter max time to wait between message publications. The data set is nothing but collection of binary or analog data elements to be sent in each message. Once started, GOOSE messages are continuously broadcast at a specific time interval to ensure reception of the data as specified in IEC 61850-8-1. The frequency of broadcast slows with each time interval until a maximum time period is reached in order to better manage network bandwidth. GOOSE message will continue to be broadcast at the maximum wait time period until a value in the message's data set changes. The message retransmission scheme is necessary to perform transmission from one to many IEDs and to allow the subscriber IEDs to know that the communications channel is healthy.

Ethernet traffic may slow down GOOSE message; however using managed Ethernet switch GOOSE message prioritization and segregation can be done in Ethernet network via IEEE 802.1p and IEEE 802.1q respectively[8]. Also, it is worth to mention that GOOSE messages are sent at level 2 of the ISO/OSI TCP/IP stack [7]. As a result, GOOSE message cannot be transmitted through routers and firewalls. Hence, outsiders will have a difficulty to access or sending any threats to substation automation LAN. So, GOOSE and Ethernet LAN is secured for electric substation automation.

The main benefits for GOOSE in substation automation are as follows:

- Fast signals transfer between substation IEDs
- Reduced copper wiring for protection and control schemes.
- GOOSE messages are supervised signals transfer which ensures high system availability.
- Flexibility and expandability for protection and control schemes

IV. APPLICATION OF GOOSE MESSAGE IN MV SUBSTATION

MV Substation automation requires integration of large quantum of data. As discussed in previous sections, legacy protocol cannot utilize full potential of modern days IEDs. The IEC 61850 is the better choice for the MV Substation automation. The IEC 61850 supports high speed GOOSE messages for horizontal communication between substation IEDs. In this section, utilization of GOOSE messages in MV Substation application discussed.

A. *Utilization of GOOSE in MV SUBSTATION*

In conventional MV Substation, if a protection signal or interlocking signal from one device to other device to be connected until GOOSE only way was hard wiring between the devices. For example, if a signal was needed on multiple devices, either the sending device would need a contact per the receiving device or the contact itself would need to be multiplied or cascaded in order to be connected to all receiving devices. This makes inter panel wiring a massive job and high cost for installation and life cycle management for MV Substation. IEC 61850 based substation automation provides unique tool to overcome this complexity of MV substation i.e. GOOSE message.

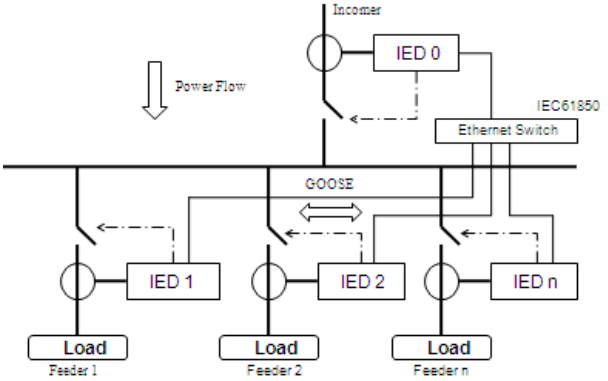

Fig 2 IEC61850 Based MV Substation

As shown in Fig 2 almost all the copper hardwiring between inter panel is replaced by virtual wiring inside MV Substation. There are certain protections and control schemes in MV substation which requires hard wiring between inter panel like Bay Interlocking, Inter-Bay Interlocking, Reverse Blocking, Breaker Failure Protection, Arc Fault Protection, Triggering of Disturbance Recording and many more. To understand the benefits of GOOSE in MV Substation next subsection will discuss Breaker Failure Protection using GOOSE message in MV Substation.

B. Breaker Failure Protection using GOOSE message in MV Substation

Breaker Failure protection also known as 50BF as per ANSI protection code is essential in MV Substation. The purpose of 50BF is to minimize the damage to power systems and other equipment during a fault condition in which a circuit breaker fails to open after receiving a protection trip from IED or electromechanical relays. To simplify, when there is a fault seen by feeder IED, IED sends trip command to the respective circuit breaker. If the circuit breaker fails to operate in specific amount of time, IED sends a trip command to upstream breaker to clear the fault. Here, fault clearance time is the essence of the protection scheme. Until GOOSE hardwiring was the only choice for the signal transfer from one IED to other IED. In hardwired system, the signal must go through an output contact on the sending IED then again on an input contact on the receiving IED. The IEC 61850 is the fastest substation automation communication standard currently available in the marketplace. Using GOOSE message it's possible to reduce the fault clearance time in circuit breaker failure scheme and overall relay co-ordination time in large MV Network. Fig 3 shows the set up for circuit breaker failure protection scheme using GOOSE communication. Here, we have used ABB's native IEC 61850 IED type REF615 for Feeder Protection.

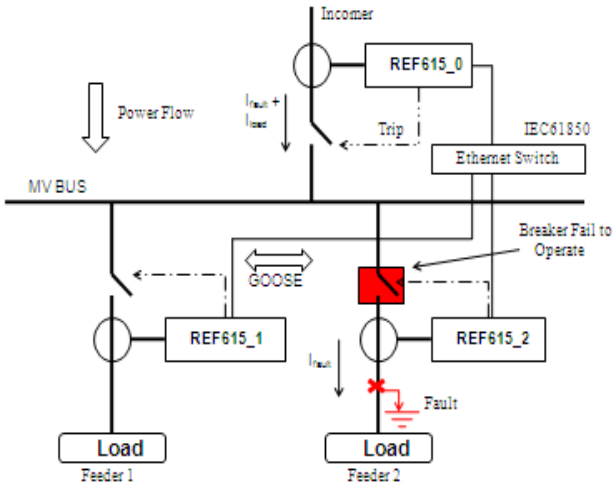

Fig 3 GOOSE Communication for Circuit Breaker Failure Protection Scheme

Circuit breaker failure protection is achieved by monitoring the time delay between the trip signal and actual opening of the circuit breaker. If the fault current has not been interrupted within a set time delay from the circuit breaker trip, the breaker failure protection is initiated. This is realized by sending a trip signal to adjacent circuit breakers in order to ensure that the fault is isolated. This trip signal can be sent via GOOSE Communication.

By using GOOSE Communication you can reduce the copper wiring for signal transfer between IEDs, secondly complete elimination of time delay introduced by output relay operation time in IED2 and input filtration time in IED1 which means faster clearance of fault compared to hardwired Digital Input and Digital Output in conventional protection scheme. In well designed Ethernet network GOOSE prorogation time delay can be minimized to meet performance class P1 or P2/P3 using priority tagging and VLAN. Studies shows that signal transfer time in copper inter panel wiring is in the range of 8 – 20 msec while GOOSE timing in native REF615 relay is conforming IEC 61850 Standard criteria Type 1A, Class P2/P3 messages and its around 3 to 4 msec [3][6]. Less is the fault clearance time less is the electrical stress to substation equipment means enhanced electric life of substation equipment. GOOSE message also helps in better relay coordination due to its faster operation. GOOSE messages are supervised in Ethernet network; any failure of communication link will be reported to substation operator to take necessary action. However, in conventional scheme, hardwired signals are never monitored for its healthiness. It means you won't be able to know the status of hardwiring till the failure of protection scheme and severe damage to substation equipment or during routine maintenance in substation might be at interval of 2 to 3 years based on maintenance practice adopted by protection engineer. Extensive hard wiring is not only costly in the initial installation, but because the whole switchgear is split into separate panels for transportation, inter-panel wires have to be reconnected and possibly retested at site which will increase erection and testing time and total project cost. Later in the switchgear life cycle any addition or modification in protection schemes calls for extra hardwiring in conventional substation which may increase engineering time or plant shutdown time while in GOOSE based system it is very easy to add or delete any virtual wires within minimal time. This makes the system easily expandable and flexible to accommodate any changes in protection schemes, as well as changes in substation configuration and network topologies.

Using GOOSE based communication system it is easy to implement so many other protection and control schemes to gain above advantages in MV Substation Automation.

V. SIMULATION AND TESTING OF VIRTUAL WIRES IN GOOSE BASED MV SUBSTATION

As discussed earlier conventional MV Substation might have bunches of copper inter panel wiring for protection and control schemes; testing of these schemes becomes the real challenge for the protection engineer. In conventional hard wired substation, testing of various schemes are performed using secondary or primary injection testing, continuity checks or loop checks etc. This makes the testing a time taking process in commissioning and maintenance of MV Substation.

Using the technology advantage offered by IEC 61850 standard and GOOSE messages it is very much possible to test the various protection and control schemes from the

Substation HMI. GOOSE Tools give an engineer the ability to monitor or reproduce any GOOSE message. A laptop can be used to set up complicated automated testing by sending GOOSE message to the IEDs and monitoring the same. This helps protection engineer tremendously with testing and engineering time, because there are no temporary wired signals to be set up and any addition/deletion or rewiring can be setup to correct the scheme quickly. GOOSE tool makes testing very much easy and very fast compared to conventional method used in MV Substation.

VI. CONCERNS AND RESOLUTION FOR GOOSE IN MV SUBSTATION

Ethernet Technology based IEC 61850 and GOOSE messages offering tremendous advantages to make MV Substation Automation easier and reliable. There are certain concerns regarding application of GOOSE in MV Substation have been reported from the date of standard publication. These are as follows:

- *Expert Staff for Advance Technology:* As discussed earlier there are numerous advantages offered by IEC 61850 and GOOSE; however, operation and maintenance staff expertise are required to manage the MV Substation. This concern is an entrance barrier to IEC 61850 and GOOSE technologies. There is no doubt that different skill set is required to maintain and operate MV Substation with these new technology which may add complexity and introduce an additional training requirement for operation and maintenance personnel. This challenge is not new to energy industry. Energy industry has successfully accepted numerical relays or nowadays IEDs from the conventional electromechnical relays to get the benefit from microprocessor technology. We should not forget continuous professional development is the key success factor for any industry.
- *Signal transfer time in Hardwired scheme and GOOSE:* MV industry might have feelings that hardwire signals are faster than GOOSE. However, repetitive testing and study shows that GOOSE messages are faster or at least equivalent to hardwired signals. It is always recommended to use KEMA certified IEDs for MV automation solution to ensure interoperability and high speed GOOSE.
- *Network Traffic and GOOSE Speed:* In MV Substation number of IEDs for integration is more, hence, this is the valid concern when handling large MV Substation automation project. Correctly designed Ethernet network with utilization of various Ethernet tools like priority tagging and VLAN can surely eliminate this risk in MV Substation automation.
- *Failure of System with failure of Ethernet network:* Ethernet network is having nondeterministic nature; hence, redundant network design may address this concern correctly. With advent of latest IEDs, it is possible to build redundant network from IED level. Carefully network topology selection and network design may resolve this matter.
- *GOOSE Message and IED's CPU Loading:* Large MV Substation might have many GOOSE messages in their network and unnecessary processing of GOOSE message may load IED's CPU and IED's performance may decline. However, this concern is not valid as IEDs filters GOOSE message based on the destination multicast address. As discussed further filtering is possible by Ethernet switch using VLAN tags. Hence, careful network design is must in large network.
- *Loss or corruption of GOOSE Message in transit:* GOOSE messages are having special retransmission technique to ensure data availability to all the subscribers in the Ethernet network. GOOSE messages are constantly sent by transmitting IEDs and may contain the value of various signals as defined in the data set. Any signal change within the data set speeds up transmission repetition of the GOOSE messages so that the risk of reception failure or corruption is reduced. GOOSE messages are constantly monitored by associated IEDs and any failure in reception of GOOSE message can suitably alarmed by IED or Substation automation system to overcome above concern.
- *Testing of GOOSE based substation:* As discussed earlier GOOSE Tool may be used to test virtual wiring in the MV Substation. It is possible to reproduce or monitor the GOOSE message using GOOSE tool from Substation Automation HMI to test virtual wiring.

VII. CONCLUSION

Latest Ethernet technology based IEC 61850 and GOOSE has proved its worthiness for transmission and sub transmission projects. Compared to legacy protocol used in MV Substation automation IEC 61850 based substation automation is having numerous advantages as discussed in this paper.

Need for special skill sets for operation and maintenance personnel of MV substation is must for the effective and efficient operation and maintenance of IEC 61850 based automation system. Initially the use of GOOSE might be more expensive if the above costs are taken into account; however, in the long run the use of GOOSE is more cost effective and reliable solution due to its advantages and flexibility in MV Substation automation.

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