

# Design and Modeling of Substation Time Critical Information Dissemination Model using Publisher-subscriber Communication Service Mapping

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## Abstract

**Objectives:** For the efficient and reliable operation, substation IEDs status must be monitored consistently and event information must be disseminated timely between substation levels. **Methods/Statistical Analysis:** Traditional power grid substations are facing infrastructural, operational, automation, systematic, monitoring and control issues. The smart grid concept and advancement in instrumentation and automation has open up the potential of substation automation system through which substation automation, intelligence and control is achieved, but devices interfacing, interoperability, time critical information exchange, substation devices status monitoring and data dissemination type issues are still in research phase. **Findings:** In this research work, substation bay level IEDs time critical data information dissemination model is designed by IEC 61850 standard using publisher subscriber communication. Based on IEC 61850 substation devices data object and interfacing models, a novel substation communication service mapping is proposed for the time critical data information dissemination. The proposed communication service mapping is based on abstract service communication interface technique by which an object oriented data and object models and communication service is directly mapped at Ethernet data link layer. **Application/Improvements:** To disseminate the data message using the proposed communication service an IEEE 802 based Ethernet frame structure is designed and configured using abstract syntax notation one technique.

**Keywords:** Data Dissemination, IEC 61850, IEEE Ethernet Frame, Publisher-Subscriber Communication, Substation

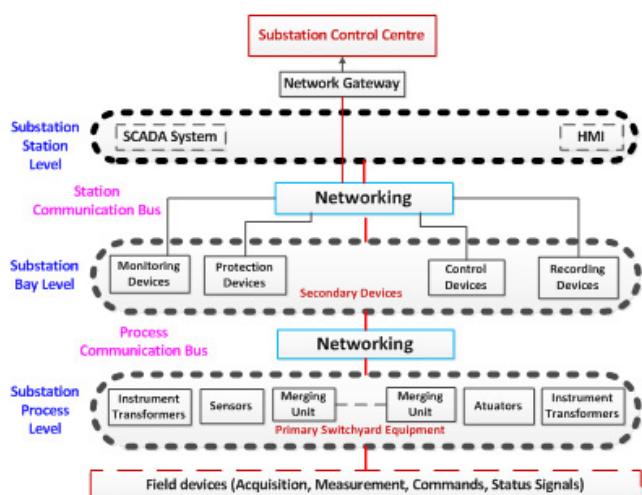
## 1. Introduction

The conventional dumb electric grid has a multi-level hierarchical network which corresponds to multi-state architecture built-on to transfer the generated electrical energy by centrally located power production units which are facing many operational challenges. These challenges include infrastructural, operational, systematic, monitoring and control issues. For the reliable and efficient substation functionality three core elements, i.e., (i) data acquisition and measurement, (ii) data information dissemination and exchange, (iii) devices status monitoring and control are the fundamental parameters<sup>1</sup>. With the

introduction of instrumentation and automation and especially the smart grid, it becomes possible to transform from dumb electric substation to smart substation by means of substation automation system (SAS) concept to transport and distribute electricity automatically and efficiently. Figure 1 illustrates the traditional SAS architecture, where the switchyard and outdoor field data can be acquired through sensors, actuators, merging units, instrument transformers. SAS can automate the substation monitoring, data logging, protection, and control functions by using IEDs and SCADA system but substation devices interfacing, data information dissemination issues are still in research phase<sup>2</sup>. The SAS architecture

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and network is categorized into process, bay and station layers<sup>3</sup>. Substation process level defines the switchgear devices and component like sensors, actuators, merging units (MUs), etc. Process bus is the fundamental network communication across process level equipment and substation bay level IEDs. The Sampled Measured Values (SMV) including voltage and current values are acquired through bay level devices and are then converted into digital form through MU as an input to the IEDs. The station bus connects the bay level IEDs or SCADA system together to achieve the control of the system. The MU is an interface used to convert the analog field data into digital form and acquired SMV from process equipment to bay level equipment through process bus<sup>4</sup>. The rest of paper proceeds as follows: Section 1 discusses the basics of substation automation system, IEC 61850 substation communication and networking and service mapping is discussed in Section 2. In Section 3, the time critical substation event information and data event message dissemination process is proposed, the IEEE 802 Ethernet frame configuration is designed for substation data dissemination in Section 4. The work is concluded in Section 5.



**Figure 1.** Standard substation automation system architecture and network.

## 2. IEC61850 - Substation Communication Networking and Service Mapping

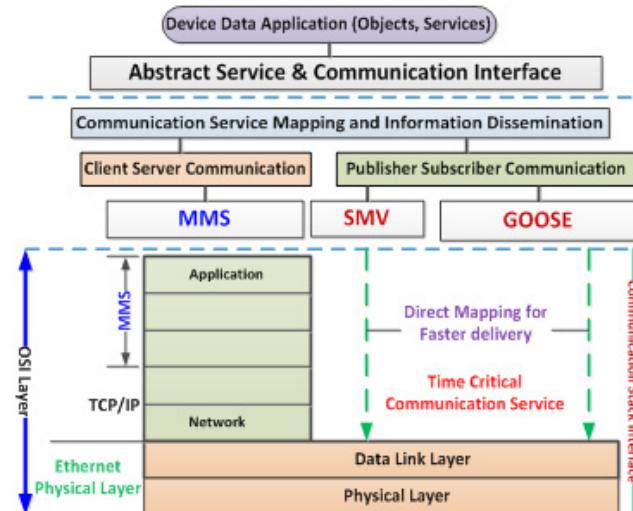
Interfacing and interoperability between various devices or IEDs manufactured by different vendors is a major challenge in SAS. IEC 61850 is a protocol especially

designed to solve the substation devices interfacing and interoperability issues so that different vendors designed and manufactured devices to operate synchronically and perform efficiently<sup>5</sup>. After solving the substation devices interfacing and interoperability issues, the faster communication and networking across the substation IEDs must be established to enhance the substation operation and data information dissemination process. At the bay level, different IEDs are responsible monitor, protect, control and record the substation functions and tasks<sup>6</sup>. Using IEC 61850, substation information can be transferred into digital form through MU and communication networking solution can ease the substation status information dissemination for monitoring, Protection and Control (P&C) and Circuit Breaker (CB) functions and applications. IEC 61850 is a substation communication protocol particularly designed to develop the interoperability across the substation nodes and IEDs by means of Abstract Service and Communication Interface (ASCI) models. An abstract interface model exclusively describes what types of services are required instead of how these services are being offered. Object oriented models characterize the information dissemination between the substation nodes by representing data according to the device's data interface and object models. To cover all the substation functions and aspects, data object models and communication service are mapped and interfaced with data abstract and data interface models. To illustrate the overall substation working functionalities, monitoring, protection, control of substation data, communication and information dissemination between the IEDs or devices nodes at physical process level, the substation data object model are represented by substation configuration language (SCL) by using standard extensible mark-up language<sup>7</sup>. At substation physical level, the data abstract models are layered into logical devices are the set of logical nodes defined by data objects characterized by a number of data attributes. The logical devices are typified by the switchyard equipment to specify the MU, P&C and CB nodes for monitoring, protection and control applications of substation. Logical nodes classify the operational state of logical device like CB operational state. The data object describes the operational properties and logical nodes status. The data attributes of substation object model characterize the basic operational state values and control values of substation data objects. The communication mapping between substation layers is defined by 7-layer Open System Interconnection (OSI)

communication service classified as client-server and publisher-subscriber communication service. Client-server communication service is a connection-oriented communication that make use of the all the 7- OSI layers model for data information dissemination and exchange. With this service, whatever the node elements or devices which are available on the communication network will gets the information being exchanged or communicated using TCP/IP or UDP/IP. With client-server communication service by using all seven layers' data delivery is confirmed but it can be slow, which this service only suitable for those applications where data information delivery is not that critical. Client server communication is typically suited for measurement values, metering information exchange, event recording, fault recording, event reporting and logging, and more importantly Manufacturing Message Specification (MMS).

Publisher-subscriber communication is a dedicated application oriented communication service, where only specified node elements or IEDs will receive the data information who has declared the interest to receive the substation information. With publisher subscriber communication service direct mapping at data and physical layer of OSI model is possible, so faster delivery of data information can be potentially achieved but data information exchange and delivery is not guaranteed, so it is best suited for time critical information applications<sup>8</sup>. SMV and Generic Object Oriented Substation Event (GOOSE) are the application examples of publisher subscriber communication service which specified for time critical information exchange and messaging services<sup>9</sup>. Based on IEC61850 substation devices data object and data interface models, a novel substation communication service mapping is proposed for the time critical status monitoring and information dissemination as shown in Figure 2. The application domain of the substation specifies the devices data functional services or applications to communicate with substation's different layers. To develop interoperability between substation devices, ASCI technique is used in a way that substation device is modeled and mapped at Specific Communication Service Mapping (SCSM) to synchronize the substation events and functions. By SCMS technique, the substation time critical SMV and GOOSE data messages are specifically mapped at Ethernet layer for faster data information delivery between different substation nodes. For the efficient and reliable operation, substation bay level IEDs status must be monitored consistently and event information must

be disseminated timely between different substation levels of the as per IEC 61850 recommendations, by which substation event information messages are classified into seven types according to messages dissemination time considering two distinct feature requirements; whether it is a time critical or non-time critical event information message. The non-time critical event information data messages are disseminated by means of client-server communication, whereas time critical event information messages are disseminated using publisher-subscriber communication. In this research work, specifically time critical data messages are being considered and classified as type 1 and type 4 data messages. The GOOSE message being the Type 1 data message is further classified into type 1(a) and type 1(b) messages, characterized for tripping of substation and event status changing updates information messages which must be transmitted within 1-3 and 1-10ms respectively as per IEC 61850 recommendations with highest priority level of 7. The type 4 message is another high speed raw data message responsible to acquire the raw information from primary switchyard equipment in form of SMV of current and voltage with priority level of 6.

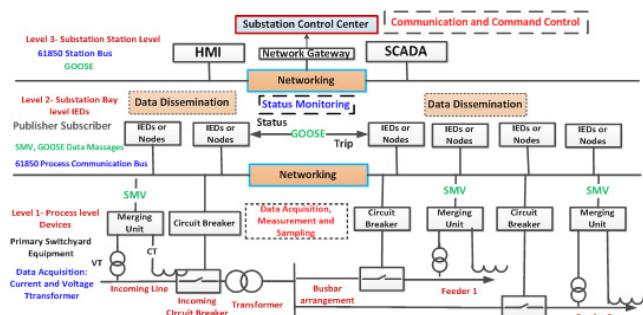


**Figure 2.** Proposed substation communication service mapping using IEC 61850.

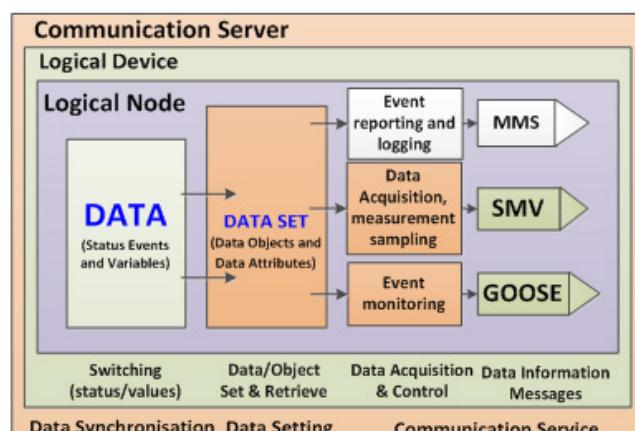
### 3. Proposed Publisher-subscriber Communication Service mapping for Status Dissemination

Based on substation message classifications and dissemination requirements, publisher-subscriber

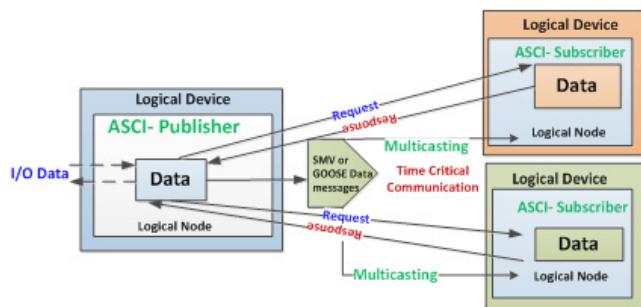
communication service, high speed time critical event information GOOSE and SMV messages, a novel integrated IEC 61850 based communication mapping and status dissemination model is proposed as shown in Figure 3. The publisher-subscriber based substation status dissemination is an event specified application which relies on substation status variables and status events entities, representing some physical quantities like current and voltage or any device node state like circuit breaker position whether open or closed respectively. The acquired measured value from MU or SMV is a status data variable regarded as status event placed into an event information messages and disseminated through publisher to subscriber communication service mapping. The proposed substation status dissemination data object model is given away in Figure 4, where the data object model is presented at logic node acquiring the substation status variables and event data further being classified into data attributes and variables sub-categorized into (i) SMV messages to characterize the data measurement and sampling values and (ii) GOOSE messages to visualize



**Figure 3.** Proposed publisher subscriber communication service mapping.



**Figure 4.** Proposed substation status dissemination data object model.



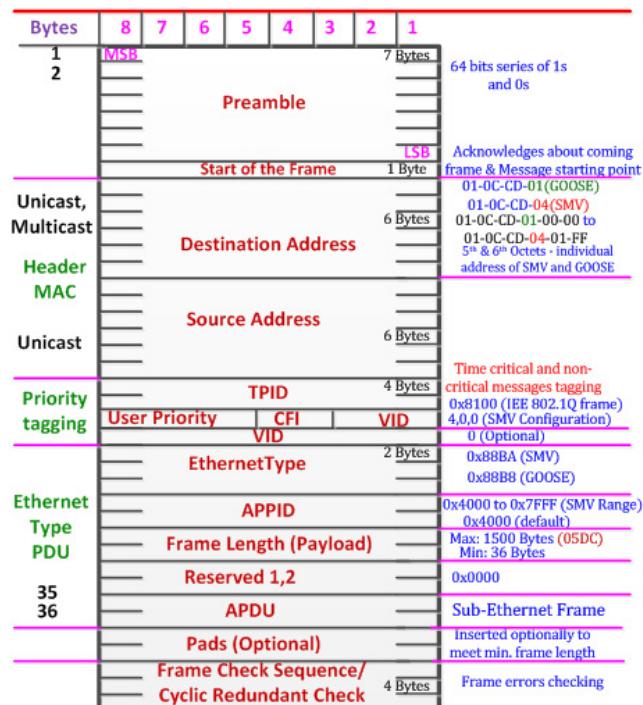
**Figure 5.** Design of application device model using publisher-subscriber communication.

the status monitoring and control elements of substation. SMV messages are the time critical time triggered event data messages, which acquire the voltage and current values from instrument transformers and directly maps these messages on Ethernet data link layer for faster delivery using Application Protocol Data Unit (APDU). SMV data information messages are transmitted at specified sampling frequency rate, so due to heavy traffic SMV messages are not repeated, which reduces data messages dissemination reliability. For this reason, SMV message are disseminated with pre-defined priority tagging, so that potential delay or even data message lost can be estimated easily. GOOSE messages are also time critical but event triggered data messages, effectively disseminating the messages like trip, status information, status change, start, stop and etc., mapped directly using APDU so data message dissemination is not guaranteed exclusively. To make sure of the data message dissemination delivery, GOOSE messages are multicasted over and over again as given away in Figure 5. In publisher-subscriber service is a node based request response data service, here specifically interested IEDs will receive the network data information.

#### 4. IEEE 802 Ethernet Frame Design and Data Messages Configuration

The substation event data messages (SMV/GOOSE) are encapsulated into a merging unit which digitizes the data and arranges them into the data frames and organized from the unprocessed data packets for data traffic generation. The SMV/GOOSE data messages are recognized using IEEE 802 Ethernet frame and transmitted by means of Ethernet frames using encoding & decoding techniques. The source IEDs encodes the raw type data

information using ASN.1 based basic encoding rules, while at the destination side message is decoded and these data values are defined. IEEE 802 Ethernet frame is alienated into three layers as shown in Figure 6. 1<sup>st</sup> layer is Ethernet frame structure for SMV/GOOSE data messages, 2<sup>nd</sup> layer is APDU, which contains ASDU as a sub layer. 3<sup>rd</sup> layer is phase measurement of primary switch yard values. Preamble is a 64-bit series of 1s and 0s string variables which informs the substation about upcoming data frame(s), its position and point of starting of the frame.



**Figure 6.** IEEE 802 ethernet frame design structure for SMV/GOOSE data messages.

**Header MAC:** The frame destination address holds the physical MAC address in hex-decimal form with six octets range. For SMV and GOOSE frame 01-0C-CD-01-00-00 to 01-0C-CD-04-01-FF is default address. The initial three octets (01-0C-CD) indicate destination position while fourth octet is 01 and 04 for GOOSE and SMV respectively defining the type of data message. The individual addresses of SMV and GOOSE message is represented by 5<sup>th</sup> and 6<sup>th</sup> octets respectively.

**Priority tagging:** To disseminate the high priority time critical data messages, they are usually tagged as priority tagging messages. TAG Protocol Identifier (TPID) is a message identifier to identify whether message is

GOOSE or SMV data message. Typically, TPID is specified at 802.1Q encoded frames with 0x8100 as a default value. To alienate the GOOSE and SMV messages from the non-time critical traffic Virtual Identifier (VID) is used, which is an optional field.

**Ethernet-PDU:** To identify the SMV and GOOSE trip and GOOSE status data messages, a unique Ether-type values are defined through Ethernet Type field. The data packet frames and application associated with GOOSE and SMV data messages are identified by Application Identifier (APPID) field. Frame length field defines the Ether-type PDU header, total APDU length and number of octets it contains. Reserved fields are reserved for future applications and potential extension. Pad is a conditional field with minimum frame length data. Cyclic Redundant Check field is used for redundancy or error checking. Ethernet data frames sequence is verified through frame check sequence field.

## 5. Conclusion

Traditional power grid substations are facing infrastructural, operational, automation, systematic, monitoring and control issues. The smart grid concept and advancement in instrumentation and automation has open up the potential of substation automation system through which substation automation, intelligence and control is achieved, but devices interfacing, interoperability, time critical information exchange, substation devices status monitoring and data dissemination type issues are still in research phase. For the reliable and efficient substation functionality three core elements, i.e., (i) data acquisition and measurement, (ii) data information dissemination and exchange, (iii) devices status monitoring and control are the fundamental parameters. For the efficient and reliable operation, the substation bay level IEDs status must be monitored consistently and event information must be disseminated timely between different substation levels.

In this research work, substation bay level IEDs time critical data information dissemination model is designed by IEC 61850 standard using publisher subscriber communication, based on which the substation data interfacing and object models are designed to interpret the substation operational characteristics of IEDs. Using these data interfacing and data object models, a new communication mapping is proposed for the time critical data information dissemination. The proposed publisher subscriber service mapping is based on ASCI

technique by which an object oriented data and object models and communication service is mapped specifically at Ethernet layer. The SMV/GOOSE event messages are organized using IEEE 802 Ethernet frame and transmitted by means of Ethernet frames using encoding & decoding techniques. The source IEDs encodes the raw type data information using ASN.1 basic encoding rules, while at the destination side message is decoded and these data values are defined.

## 6. Acknowledgement

Authors acknowledge the support of Mehran University of Engineering and Technology Jamshoro for providing necessary laboratory resources to conduct this research work.

## 7. References

1. Sahito A.A, Halepoto IA, Uqaili MA, Memon ZA, Memon, Larik AS, Mahar MA. Analyzing the impacts of distributed generation integration on distribution network: A corridor towards smart grid implementation in Pakistan. *Wireless Personal Communications*. 2012; 85(2):545–63.
2. McDonald JD. Substation automation IED integration and availability of information. *IEEE Power and Energy Magazine*. 2013; 1(2):22–31.
3. Gungor VC, Lambert FC. A survey on communication networks for electric system automation. *Computer Networks*. 2006; 50(7):877–97.
4. Halepoto IA, Shaikh MZ, Chowdhry BS, Uqaili MA. Design and implementation of intelligent energy efficient conveyor system model based on variable speed drive control and physical modeling. *International Journal of Control and Automation*. 2016; 9(6):379–88.
5. Mackiewicz R. Overview of IEC 61850 and benefits. *Proceeding of IEEE Power Systems Conference and Exposition, (PSCE'06)*; 2006. p. 623–30.
6. Sidhu TS, Yin Y. Modelling and simulation for performance evaluation of IEC61850-based substation communication systems. *IEEE Transactions on Power Delivery*. 2007; 22(3):1482–9.
7. He W, Tang C, Zhang X, Zhu SN, Yuan H, Miao W. The design of data structure for IED based on IEC61850. *Proceeding of China International Conference on Electricity Distribution (CICED' 2006)*; 2006. p. 1–6.
8. Nguyen-Dinh N, Kim GS, Lee H. A study on GOOSE communication based on IEC 61850 using MMS ease lite. *Proceeding of International Conference on Control, Automation and Systems (ICCAS'07)*; 2007. p. 1873–7.
9. Hyctor L, Montez C, Stemmer M, Vasques F. Simulation models for IEC 61850 communication in electrical substations using GOOSE and SMV time-critical messages. *Proceeding of IEEE World Conference on Factory Communication Systems (WFCS)*; 2016. p. 1–8.