Review of digital substation equipment and technical specification in Indonesia

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Abstract. Digital substation concept improves substations in advance by enhancing the equipment at station level, bay level, and process level. This enhancement of substation requires changes of equipment at those levels. The design needs to meet each equipment’s compatibility with the others. However, some manufacturers of the digital substation in Indonesia provide different specifications for the equipment at the same level. This condition causes challenges of implementation design of the digital substation in existing substations. To enhance existing substations including conventional substation and modern substation, the digital substation specification and equipment are reviewed. The reviews are based on digital substation standards including communication protocol, network redundancy, and time synchronization. After the specification study, the provided equipment in Indonesia are compared based on their technical specification. The technical specifications are compared at station level, bay level and process level based on provided equipment in Indonesia. The compatibility study is analyzed by using provided equipment, following with the implementation study in Indonesia. This paper provides reviews of the technical specification gap of existing substations compared to the digital substation. Finally, the consideration of choosing technical specifications also provided when implementing the digital substation in Indonesia.

1. Introduction

Currently the utility as the owner of the substation is a good challenge at the time of construction, repairs without maintenance of the substation. These challenges are environmental problems, operational, capital expenditure, security issues, need for assistance with renewal/repair of substations, requests for workmanship projects with lower costs and faster time, increased demand for substation assets, and the development of information technology in various sectors including electricity [1]. One of the challenges of its development is digital substation because of these challenges. The substation is called a digital substation compiling all data in the substation to be questioned through an Ethernet network so that in this substation there are no more cables/cabling for input-output signals, measurements, and clocks. Moreover the wiring in digital substations is usually only for power supply [2,3].

The implementation design of the digital substation in Indonesia meet challenges to optimize existing equipment in the design. This paper provides analysis of implementation design of the digital substation in the existing substation including conventional and modern substation. First, the equipment and
technical specification are explained. Following with brief explanation of conventional, modern and digital substation. Finally, the implementation design is analyzed following with conclusions.

2. Equipment and technical specifications of digital substation

Some new technologies that support the emergence of the digital substation are Intelligent Electronic Devices (IED) that support process buses, which consist of merging units and Switchgear Control Units (SCU), networking and time synchronization, and Non-Conventional Instrument Transformers (NCIT).

Local Human Machine Interface (HMI) provides monitoring and control facilities for substation equipment to the operator. Gateway is an interface between substation and control center needed for monitoring, remote control, and data acquisition. IED is an electronic device in the form of a processor that can receive or transmit data/control from or to another device or system [4].

IEDs on digital substation must support data communication on the IEC 61850-8-1 (Generic Object Oriented Substation Events (GOOSE)) process bus and IEC 61850-9-2 (sampled value (SV)). Merging unit functions to convert analog quantities from NCIT/Conventional Instrument Transformer (CIT) voltages and currents to digital IEC 61850-9-2 (SV). SCU functioned to digitize the status of the switchyard equipment and send it using the IEC 61850-8-1 (GOOSE) communication protocol. Ethernet switch functioned to connect between equipment (server, workstation, IED Bay Control Unit (BCU), IED Protection, other IED, merging unit, SCU, etc.) in a LAN. For digital substation, GPS is needed to synchronize the time of all equipment used by digital substation, so that all equipment gets an accurate and synchronous time. GPS on digital substation must support the time synchronization recommended in IEC 61850 [5]. NCIT is functioned to measure the voltage current and send it in digital form. NCIT consists of two types, electronics and optical. Configurator and testing tool used to perform configuration and testing on digital substation equipment and systems. For the configurator used, it depends on the brand and type of equipment, because each manufacturer has its own configurator.

2.1. Communication protocol at digital substation

IEC 61850 communication services on digital substation include client-server is a point-to-point communication used for monitoring and control purposes. The communication uses Manufacturing Message Specification (MMS). Client-server is used for command, reporting, log, file transfer. The standard used is IEC 61850 part 7 and 8. GOOSE is a real-time multicast data, which can be used in many ways for example for interlocking. GOOSE includes binary data, indication, and command. The standard used is IEC 61850 part 8-1. (SV). Sampled value is also a real-time multicast data, which contains measurement data from the process level. The standard used is IEC 61850 part 9-2, IEC 61850 part 9-2 LE (light edition).

IEC 61850-9-2 (SV) is unidirectional communication from the merging unit to the bay level (IED). Data transmission at sampled value through the physical layer in the form of optical fiber and data link layer in the form of Ethernet with the ability of 100Mbit/s. The IEC 61850-9-2 (SV) standard is very broad, so the interpretation is still very wide. This causes difficulties in interoperability between manufacturers [6]. To facilitate implementation and enable interoperability, Utility Communication Architecture (UCA) international users group created a guide that defines the application profile for IEC 61850-9-2, commonly referred to as IEC 61850-9-2 light edition (IEC 61850-9-2 LE). The existence of IEC 61850-9-2 LE as a guide in the implementation and interoperability of IEC 61850-9-2. The difference between IEC 61850-9-2 and IEC 61850-9-2 LE can be seen in Table 1.

| Specification                  | IEC 6180-9-2 | IEC 6180-9-2 LE |
|-------------------------------|--------------|-----------------|
| Arranged by                   | IEC          | UCA International Users Group |
| Sampling rate from analog value | free parameter | 80 samples per cycle for protection and metering, 256 samples per cycle for power quality |
| Datasheet content             | configurable | 4 voltages and 4 currents including voltages : 3 phase + neutral with quality currents : 3 phase + neutral with quality |

Table 1. Difference between IEC 6180-9-2 and IEC 6180-9-2 LE.
IEC 61850-9-2 LE has a sampling rate 80 or 256 samples per cycle. 80 for protection and metering, or 256 for power quality. Neutral current and/or voltage can be measured or reduced. Sampled value is sent using multicast on a LAN network. It also established logical devices "merging unit" and synchronize sampling. Each SV message carries 4 voltages and 4 currents (i.e. voltages: 3 phase and 1 neutral with their quality, current: 3 phase and 1 neutral with their quality). The value sent is the primary value along with the quality information of that value. The operation range of current is 1mA to 2.14mA and the voltage is 10mV to 21.4mV.

2.2. Network redundancy of digital substation
Redundancy allows for alternative routes from source to destination. There are two types of redundancy, namely active redundancy (both active links at the same time) and passive redundancy (one active link, the other in standby mode). Redundancy protocols that are often used are Rapid Spanning Three Protocols (RSTP), High Seamless Redundancy (HSR), and Parallel Redundancy Protocol (PRP). RSTP is not recommended for the process bus because recovery having frame loss [7]. PRP is recommended when the amount of IED is large and easy to be simulated. PRP more expensive than HSR because requires an Ethernet switch and more fiber optic. Ethernet switch in PRP for process bus require large bandwidth. HSR is recommended for ring configuration with a small amount of IED. HSR is cheaper than PRP. HSR can be used in the process bus to reduce costs. Require large bandwidth to avoid data congestion especially for Sampled Value. The comparison among the network redundancy protocols is summarized in Table 2.

Table 2. Comparison of network redundancy in the digital substation.

| Parameter                      | RSTP                  | PRP                   | HSR                   |
|--------------------------------|-----------------------|-----------------------|-----------------------|
| Recovery time                  | Depend on IED         | 0 second              | 0 second              |
| Frame loss                     | Yes                   | No                    | No                    |
| Redundancy                     | Yes/no                | Yes                   | Yes                   |
| End Node Attachment            | Single                | Double                | Double                |
| Network Topology               | Single meshed, pseudo | Double star           | Redundant ring        |
|                                | ring                  |                       |                       |
| Addition of new equipment      | Require to reconfigure| Easier, without fault | Easier, possible to fault |
|                                | RSTP, possible to fault|                      |                       |
| Amount of IED                  | No limit, consider    | No limit, consider the | Limited by manufacturer |
|                                | network bandwidth     | network bandwidth     |                       |
| Interoperability               | Yes                   | Yes                   | Yes                   |
| Cost                           | Require Ethernet switch| Require Ethernet switch | Integrated in IED without |
|                                | supported to RSTP     | more fiber optic, expensive| external switch, no fiber optic |
|                                |                       | twice of HSR          | added                 |
| Bandwidth                      | Full                  | Full                  | Half                  |

2.3. Time synchronization for digital substation
Time synchronization needs to be done for all equipment on the digital substation, especially for equipment whose work is very dependent on time accuracy such as: merging unit, Differential Protection, Fault Recorder, PMU and others. Time synchronization on digital substation is very important, for example SV frames from various merging unit may have unequal delay and IED protection will not work properly unless the SV frame is synchronized. Time synchronization reference on digital substation is generally based on satellite time. The reason to use satellite as a time reference is that it does not require money, is everywhere, and is reliable.

Apart from satellites, other options for time synchronization are Glonass, Baidou, Gallileo. There are several protocols used for time synchronization on digital substations, Network Time Protocol or Simple Network Time Protocol (NTP/SNTP), Inter-Range Instrumentation Group (IRIG-B), and Precision Time Protocol (PTP). IEC 61850 accepts IRIG-B, PPS and PTP for this time synchronization application on digital substation, but only PTP can work redundant and can be mapped in the Ethernet protocol and
like other IEC 61850 messages. The comparison of time synchronization methods that can be applied in digital substation is shown in Table 3.

| Parameter                  | IRIG-B               | NTP/SNTP            | PTP                  |
|----------------------------|----------------------|---------------------|----------------------|
| Accuracy                   | 1-10 micro second    | 50-100 millisecond  | 20-100 nanosecond    |
| Amount of equipment        | Limited              | Many, depend on Ethernet network | Many, depend on Ethernet network |
| Distance of Equipment      | Limited by voltage drop | depend on Ethernet network | depend on Ethernet network |
| Redundancy                 | hard                 | Yes                 | Yes                  |
| Media                      | copper wire, fiber optic | Ethernet            | Ethernet             |
| Supported network          | n/a                  | PRP, HSR, RSTP      | PRP, HSR, RSTP       |
| Wiring                     | Slower and require wires (copper/optic) to equipment | Fast, requires Ethernet network only | Fast, requires Ethernet network only |

3. Conventional, modern and digital substation

From time to time the substation experiences development [8]. The development of substations to date can be divided into three types. Conventional substations (wired substation) are substations that still use hardwired both in the switchyard and in the control/protection panel. Modern substation with station bus is a substation that has implemented the IEC 61850 communication protocol on the station bus only, while from switchyard to control/protection panel still uses hardwired [9]. Digital substation (substation with station bus and process bus) is a substation that has implemented the IEC 61850 communication protocol both in the station bus and in the process bus.

Digital substation architecture is generally divided into three levels. At station level, digital substation equipment includes the gateway, server, workstation and software (local HMI) and other equipment such as printers. Bay level of digital substation includes IED BCU (controller), IED Protection, and other IEDs such as IED AVR, IED kWh meter, etc. Finally, at process level includes merging unit, SCU, CIT, NCIT and other equipment in the switchyard. Whereas the buses on digital substation are divided into two. Station bus includes of an Ethernet network that connects existing equipment at the station level and at the bay level. This Ethernet network is built using an Ethernet switch. Status and measurement data contained in the IED (bay level) are sent to the server and gateway (station level) via Ethernet with the IEC 61850 protocol. While the control is sent from the server or gateway (station level) to the IED (bay level).

Process bus connects equipment at the bay level and at the process level. This Ethernet network is usually built using an Ethernet switch. The current and voltage magnitude of NCIT/CIT are converted to digital in the form of SV by merging unit, while the status of other switchyard equipment (such as CB - circuit breakers, DS - disconnecting switches, etc.) is digitized in GOOSE by SCU and the data is sent in process bus. IEDs that require the data will retrieve the data from the Ethernet network (process bus). Bandwidth requirements in the process bus are very high, for 1 SV (sampled value) requires 5 Mbps. For this reason, the backbone for the process bus must have a high bandwidth (1 Gbps).

Some differences in the equipment used by digital substation compared to modern substations are IED digital substation must support IEC 61850-9-2 (SV), in contrast to modern substations that support the IEC 61850 protocol but generally do not support IEC 61850-9-2 (SV). Merging unit in digital substation is new equipment, whose function is to digitize the analogue voltage current to a sampled value. Whereas in modern substations it still uses an analogue voltage current through hardwired. And then SCU function is the status of the switchyard equipment and sends it with the IEC 61850-8-1 (GOOSE) communication protocol, whereas modern substations still use hardwired. Ethernet switch functions to meet the needs of large bandwidth, especially in sending data sampled value (current and voltage), then the Ethernet switch bandwidth on the process bus is expected to use 1 Gbps, whereas the modern substations have not implemented the process bus, so it does not require Ethernet switch on the process bus, but only needs an Ethernet switch at the bus station. The GPS used on the process bus must
support the time synchronization recommended on IEC 61850, whereas modern substations have not implemented the process bus, so it does not require GPS on the process bus, but only need GPS at the bus station. NCIT in digital substation can be paired with merging unit or CIT paired with merging unit, whereas in modern substations only use CIT that is hardwired and connected to the IED.

4. Implementation design of digital substation to existing substation

The implementation of digital substation in this research is grouped into new substation and existing substation. Upgrading conventional substations to digital substation is done by adding digital bay extension on conventional substations without changing the existing. In other words, is adding a new bay using digital substation technology, and without changing existing conventional substations. Modern substations have Substation Automation System (SAS) that only applies in bus stations. Upgrade modern substations can be done by add digital bay extension on modern substations without changing the existing [10].

In the implementation design of the new substation the time synchronization used with GPS in accordance with the protocol used (PTP, NTP, PRP, etc.). In the process level retrieval of analogue/measurement data (current, CT/PT voltage) by using NCIT along with merging unit that supports the protocol used (IEC 61850-9-2 LE: SV, PRP, HSR, PTP). It also can be done by using CIT along with merging unit that supports the protocol (IEC 61850-9-2 LE: SV, PRP, HSR, PTP). Binary data retrieval/indication (CB, DS status) can be designed by using SCU that supports the protocol used (IEC 61850-8-1: GOOSE, PRP, HSR, PTP). There are merging unit products where the SCU function is included in the merging unit, so this product can be used for retrieval of analogue and binary data.

The bay level designed by using IED protection, IED control (BCU) and other IEDs that support the protocol used (MMS, IEC 61850-8-1: Report, IEC 61850-8-1: GOOSE, IEC 61850-9-2 LE: SV, PRP, HSR, PTP, etc.). The number of Ethernet ports for each IED must be sufficient to connect to the process bus and station bus according to the architecture that will be used. In the station level designed using a server (with workstations and local HMI) that supports the protocol used (MMS, IEC 61850-8-1: Report, PRP, RSTP, PTP, NTP), and using a gateway that supports the protocol used (MMS, IEC 61850-8-1: Report, PRP, RSTP, PTP, NTP, IEC 60870-5-101, IEC 60870-5-104, DNP3). Following with establish communication from the gateway to the control center with the specified protocol (IEC 60870-5-101, IEC 60870-5-104 or DNP3). Finally, install other necessary peripherals such as a printer, etc.

The process bus is done by building a reliable Ethernet network for the process bus (PRP, HSR). For backbone process buses it is recommended to use 1 Gbps. Ethernet switches must support the protocol used (PTP). Using fiber-optic (outdoor) as a medium for data communication between devices or Ethernet switches. The station bus build by establish an Ethernet network for the bus station (PRP, RSTP, PTP, NTP). Ethernet switches must support the protocol used (RSTP, PTP, NTP). Using Fiber Optic as a data communication medium between IED and Ethernet switches. Whereas servers, workstations and peripherals such as printers can use UTP/STP cables. The implementation design to the existing substation, every application of digital technology must anticipate issues/problems that may arise. In the construction of digital substation, it must be ensured that all equipment can be integrated and function properly and have reliable performance.

When upgrading the modern substation, if existing SAS equipment (such as servers, workstations, local HMI, gateways, IEDs) is retained (not replaced), it must pay attention to compatibility and interoperability between existing equipment and new equipment. This issue has been mentioned in the previous chapter, namely the backward compatibility issue between IEC 61850 edition 1 and edition 2, because it is possible between existing equipment and new equipment, different editions. If it is not compatible, existing SAS equipment can be upgraded. For all equipment recommended using IEC 61850 with the same edition, all issue 1 or all issue 2. Digital bay extension on conventional substations is still unchanged, while the extension bay uses digital substation technology. Cases like this will likely cause problems because it integrates two different technologies. One problem that arises is the mixed-mode that has been explained in the previous sub-chapter on digital substation issues and issues. For its application, further study is needed.
5. Conclusion
Design of digital substation technology in process bus includes network redundancy is PRP/HSR, time synchronization is PTP, and data communication is SV, GOOSE. In station bus includes network redundancy is PRP/RSTP, time synchronization is PTP/NTP, and data communication is MMS, Report, GOOSE. Digital substation has many advantages including lower copper wire requirements, less transportation and space, shorter secondary equipment installation, cost savings (installation, operation and maintenance), shorter outages, increased security and asset utilization. While issues in digital substation include maturity, interoperability, reliability, time synchronization, network configuration and bandwidth management, mixed mode, backward compatibility, temperature and humidity. For the application of existing SAS in PLN in the framework of digital substation technology, there are still some problems that have not been handled properly such as interoperability and uniformity of the ICD/CID file format. The pilot project can be used to study digital substation technology before it is fully implemented. Before digital substation is applied, it must anticipate issues/problems that may arise.

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