EH2741 Communication and control in Electric power system
Project 2 Communication & Control Systems

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1 Question 1

In this section we will specify the functions of the solution from the control room to process level using SGAM functional layer. Figure 1 is shown below which indicate all the functions that we will use for substation automation and communication between SCADA system and substation.

Figure 1: SGAM Model Functional Layer

a. Audit:
   - Usage: Audit the SCADA system and the control functions.
   - Links: Linked with SCADA, Volt/VAR control and frequency control.

b. SCADA:
   - Usage: Including sub functions supervisory control, data acquisition and archiving. Monitoring the transmission substation, sending fault
clear command and communicating with HMI for presenting the status of the substation.

- **Links:** Linked with HMI, audit, all the data acquisition functions, the data engineering functions and other SCADA systems. The SCADA function sends information to HMI, which visualize the status of the system and receives command from HMI and sends it to the corresponding control functions and IEDs. SCADA also sends required information to Audit. SCADA receives data from RTUs, PDCs and front end, and then send them to data engineering function. Different SCADA systems may also have communication between each other.

c. Volt/VAR control

- **Usage:** Using the voltage measurements to monitor and keep the voltage levels at the substation within the required range.
- **Links:** Linked with Audit and SCADA. The control function get measurement data from SCADA and compare it with the set values. If the protection function is activated, the control function would send a control command to SCADA and SCADA will send it to corresponding IEDs. The control function also sends operation records to Audit.

d. Frequency control

- **Usage:** Using the measurements to monitor and keep the active power balance between supply and load in the system.
- **Links:** Linked with Audit and SCADA. The control function get measurement data from SCADA and compare it with the set values. If the protection function is activated, the control function would send a control command to SCADA and SCADA will send it to corresponding IEDs. The control function also sends operation records to Audit.

e. Data Engineering (data engineering server)

- **Usage:** Receiving data from SCADA systems (measurements, status, commands and operation records etc.), processing them, saving them and archiving them.
- **Links:** Linked with SCADA systems.

f. Local data acquisition

- **Usage:** Getting measurements and other data from data connector, monitoring the field digital and analog parameters and transmits data to the SCADA. It contains setup software to connect data input streams to data output streams, defines communication protocols, and troubleshoots installation problems.
• Links: Linked with data acquisition, SCADA and corresponding functions of IEDs for bus bar, transformers and circuit breakers.

g. Data acquisition
• Usage: Collecting measurements data from functions like MMXU, aggregating the data and sending the data to RTUs.
• Links: Linked with measurement functions like MMXU and Local data acquisition (RTU).

h. TVTR
• Usage: Function for voltage transformers to measure voltage of the place where the VT is installed.

i. TCTR
• Usage: Function for current transformers to measure voltage of the place where the CT is installed.

j. GGIO
• Usage: The general input and output function of the IED to take in data and output data.

k. MMXU (CT/VT)
• Usage: The measurement function for CT/VT to store the measurements data.

l. CILO
• Usage: Interlocking function at station or bay level. Receiving control and setting from RTU and sending acknowledge to RTU in case of changing setting.

m. XSWI
• Usage: Function of all kinds of switching devices not able to switch short circuits: load breakers, disconnectors, earthing switches, high-speed earthing switches. Also gives status and operation acknowledge to RTUs.

n. XCBR
• Usage: Function of circuit breakers. Also gives status and operation acknowledge to RTUs. Receiving control commands and settings from RTU.

o. PTOC
• Usage: Function of over current protection. Receiving control signals and settings from RTU and sending acknowledge to RTU in case of changing setting.

p. PTOV

• Usage: Function of over voltage protection. Receiving control signals and settings from RTU and sending acknowledge to RTU in case of changing setting.

q. PDIF (bus bar)

• Usage: Function of differential protection of bus bar. Receiving control signals and settings from RTU and sending acknowledge to RTU in case of changing setting.

r. ATCC

• Usage: Function of automatic tap changer change of transformers. Also sends status and operation acknowledge to RTUs.

s. PDIF (transformer)

• Usage: Function of differential protection of transformers. Receiving control signals and settings from RTU and sending status and operation acknowledge to RTUs.

t. MMXU (PMU)

• Usage: The measurement function for PMU to store the measurements data (phasor parameters). Sending the data to data engineering function of PDCs.

u. Data engineering (PDCs)

• Usage: Receiving phasor parameter measurement and status data from PMUs, processing them, saving them, archiving them and sending them to SCADA system.

2 Question 2

Voltage, current and phasor parameters of bus bar, transformer condition and also circuit breakers condition are measured for the purpose of SCADA. The information exchange between the involved functions and components using SGAM information layer are shown below in Figure 2. Figure 2 shows the information layer of the SGAM of the system. As we can see from the figure, the left most IED takes in measurements of voltage, current from voltage transformer and current transformer through functions like TCTR, TVTR and MMXU. The IED processes the measurements then sends the measurements by function GGIO to the data collector. The data collector (data acquisition) collects
measurements from a group of IEDs and sends the aggregated data to the corresponding RTU. The RTU (local data acquisition) gets data from data collector and sends it to SCADA server (SCADA function). For PMUs (MMXU), the measurements are collected and sent to PDCs, confirmed by an acknowledgement from PDC. The PDCs then will process the data from different PMUs and send measurements data to SCADA server, confirmed by an acknowledgement from SCADA server. The SCADA server will send the relevant data to HMI to present the status of the system and to CRM for auditing.

3 Question 3

The communication solution that we choose for communication with the transmission substations is described in this section.
3.1 Physical media

The function of the physical layer is to transmit and receive of raw bit streams over a physical medium. Considering the safety, reliability and security of the whole communication system we choose to use the physical medium instead of wireless transmission. In this way we can reduce noise interference and risk of losing packets. For the substation level communication which means transfer information from CT/VT to merging units and then come to IED, we use power line carrier communication (PLCC). Since the PLC equipment is located within the substation, and thus the security is very high [1]. For the communication between IED and RTU, PMU and PDC, we use optical fiber as the transmission medium. The reason why we choose optical fiber is because it has low operating cost and high channel capacity, and there are no licensing requirements at the same time the cable is immune to electromagnetic interference and ground potential rise.

3.2 Data Link layer protocols

The function of the link layer protocols is to transmit data frames between adjacent nodes connected by physical layer. The date link layer has the capability of physical addressing, which means if the frames are to be sent to the different systems on a network, then a header is attached to the frames which define the sender and (or) receiver address. It also contain the function of error control, flow control and access control mechanisms. Here we use the Ethernet protocol as our data link protocol which is widely used in the substation LAN. At the same time in order to fulfill the requirement of the reliability and security we need to add a Media Access Control (Mac) layer. In our case Carrier sense multiple access with collision detection scheme is used to implement MAC sublayer. In this scheme, each node checks the channel (multiple access) whether it is free and cannot start the transmission until the channel is free (carrier sense).[1].

3.3 Network layer protocols

The network layer is responsible for moving network-layer packets known as datagrams from one host to another. Here we use Internet Protocol which defines the fields in the datagrams and how the end systems and routers act on these fields [2]. Normally the network layer will add a header to the packet data and route the data packets to the destination host.

3.4 Transport layer protocols

The transport layer is to transports application layer messages between application endpoint. There are two transport protocols within the Internet which are Transmission Control Protocol (TCP) and User Datagram Protocol (UDP). Since the TCP provides a connection-oriented service which includes guaranteed delivery and flow control. At the same time, a congestion-control mechanism
is also provided. On the other hand, UDP can not provide flow control nor congestion control [2]. Take into account the reliability and safety requirement of the substation design we choose TCP.

3.5 Application layer protocols

Application layer is the topmost layer, which provides the network access to the use. Also it can provide services like file access and transfer, mail services and directory services [1][3]. We use IEC-61850 as our application level protocols which can be mapped to manufacturing message specifications (MMSs), generic object-oriented substation events (GOOSEs), sampled measured values (SMVs). The main advantage is that IEC0-61850 can fully incorporate the IED interoperability when the IEDs are from different vendors [1]. On the other hand, since we installed the PMU (phasor measurement unit), we also need IEEE C37.118 Synchrophasor standard.

The protocol selection that use SGAM templates are shown below Figure 3 as well as the complete OSI layer descriptions of the communication links.

Figure 3: SGAM Model Communication Layer
4 Question 4

In this section we need to explain step-by-step the end-to-end flow of how a single measurement moves through the communication system from a CT/VT in a transmission system substation to the process all the way to the central system to be presented in the human-machine interface. We first take a look at the following diagram which shows the physical path that data takes from the sending through intervening link-layer switch and router to the receiving end system. As we mentioned above we will use IEC 61850 as our application layer protocol which include the MMS, GOOSE and SV. At the same time, we also use IEC 60870-5-104 for RTU to SCADA system and Inter-control center protocol (ICCP) for communication between the different SCADA systems.

![OSI Model](image)

Figure 4: OSI Model

4.1 End-to-end flow

a. The 3 phase current transformer or voltage transformer will measure the value and then send the data to the merging unit which will convert the
data from analogue to digit value and then send it to appropriate IED. For this communication process IEC 61850 Sample Value application protocol will be used. Since all the transmissions are within the LAN, only four layers are need which are application layer, transport layer, data link layer and physical layer.

b. Consider the communication between the RTU and the IED we need to implement the IEC 61850 MMS protocol. The communication process is typically shown in Figure 4. At the sending terminal, the application-layer message is passed to the transport layer, then the transport layer will take the message and appends additional information (here we use TCP as transport layer protocol so the header information include source/destination port, sequence number and so on) that will be used by the receiver-side transport layer. As we mentioned before TCP also can detect packet loss problem or packet not delivered, it can redeliver it. Then transport layer passes the segment to the network layer, which will add network-layer header (here we use IP as network layer protocol which will add IP address to the segment) in order to routing the packet across the network from source to destination. Media Access control will take the job to send the packet to the physical media. In our case Carrier sense multiple access with collision detection scheme is used to implement MAC sublayer. In this scheme, each node checks the channel (multiple access) whether it is free and cannot start the transmission until the channel is free (carrier sense). Above all is about how the encapsulation works, when the segments come to the receiving end a similar de-encapsulation process will take place to finish the communication[1].

c. After the IED receive the data from the merging unit and then it will send the processed data to the RTU. The communication between the RTU and the SCADA system will experience the similar process as we mentioned above the differences are the application layer protocol will be the IEC 60870-5-104 instead of the IEC 61850-8-1.

d. What we mentioned above is about the vertical communication, actually we also have the horizontal communication which happened between different IEDs and different SCADA systems.

References

