

Control System Design of the Cubicle 20 KV at Primary Electricity Distribution Substation

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Abstract: In the electrical field, effective and dependable management and distribution of electrical power are crucial for maintaining a continuous electricity supply to consumers. With technological progress, Supervisory Control and Data Acquisition (SCADA) systems have emerged as an efficient method for real-time supervision and regulation of electrical distribution substation activities. In practical terms, cubicles are employed to oversee the electrical distribution network. A cubicle is a medium-voltage panel that serves the purpose of managing, gauging, and safeguarding the electrical distribution network. Integrating cubicles with the SCADA system is necessary to achieve real-time oversight and control of electrical substation activities. Developing a SCADA system necessitates simulation to offer an understanding of how the SCADA system can be merged and operated in an authentic environment at the distribution substation. The design process of a SCADA simulation for a 20 kV cubicle panel at a primary electrical distribution substation is the focus of this study. A dummy is utilized to represent the Circuit Breaker (CB) in the cubicle, serving the function of disconnecting and controlling the electrical network. Measurement of voltage, current, power, and network frequency is carried out using a power meter. The dummy is linked to a Remote Terminal Unit (RTU) as the controller, which in turn connects to the Master Terminal Unit (MTU) via a telecommunications network. At the MTU, a Human Machine Interface (HMI) is incorporated to control and monitor the status of the dummy. The monitoring and control system simulated SCADA has the capability to oversee and manage five simulated components and show measurements for power meter parameters such as voltage, current, power, and frequency.

Keywords—dummy; cubicle; SCADA; HMI, RTU, MTU

1. INTRODUCTION

In the electricity industry, efficient and reliable management and distribution of electrical power is a key factor to ensure the continuity of electricity supply to consumers. These substations play a vital role in transmitting electricity from the transmission network to the distribution network, which ultimately reaches the consumers.

With technological advancements, the Supervisory Control and Data Acquisition (SCADA) system has become an effective solution for monitoring and controlling the operations of electricity distribution substations in real-time. SCADA allows for remote monitoring and control of electrical equipment, which not only enhances operational efficiency but also minimizes the risk of disruptions and equipment damage [1]. The SCADA system is widely used in industries for supervisory control and data acquisition in industrial processes [2]. Currently, SCADA systems operate in many private companies and government agencies, yet vulnerabilities and threats to these systems are rapidly increasing [3]. Despite these challenges, SCADA systems have been successfully used in industrial automation, reducing maintenance costs and increasing productivity [4].

The 20 kV cubicle system in primary electricity distribution substations is one crucial component requiring precise monitoring and control [5]. This system functions as a breaker and connector of electrical flow, as well as protecting the network from disturbances. Therefore, the

implementation of SCADA on the 20 kV cubicle panel is highly crucial [6].

This paper focuses on designing a SCADA system simulation for controlling the 20 kV cubicle panel. With this simulation, it is expected to provide a clear overview of how the SCADA system can be integrated and operated in a real environment at the distribution substation. Additionally, this simulation aims to identify potential challenges and solutions that might be encountered during actual implementation.

2. METHODS

2.1 System Requirements Analysis for SCADA

The design of this SCADA system aims to monitor and control the condition of the cubicle panels. The status of these cubicle panels is sent to the Master Terminal Unit (MTU) [7]. In this case study, there will be one incoming cubicle panel and four outgoing cubicle panels that will be monitored and controlled. Dummies are used as representations of the cubicles. There is also a power meter installed on the system network. The status of the cubicle panels and the readings from the power meter will be sent to the MTU.

For this paper, several software applications are used to map the communication network of the SCADA system and to design the Human Machine Interface (HMI) for the system:

A. NovaTech Configuration Director (NCD), used to create communication pathways from the cubicle panels and power meter to the Remote Terminal Unit (RTU).

B. Survalent ADMS Manager, used to manage the database server of the SCADA system.

C. Survalent SCADA Explorer, used to create the communication network mapping.

D. Survalent SCADA Status Point Viewer, used to view binary readings.

E. Survalent SCADA Analog Point Viewer, used to view analog measurement results.

F. Survalent SmartVU, used to design the Human Machine Interface (HMI) of the SCADA system.

2.2 Assembly and Installation of Component

In creating dummies as representation cubicle panels, dummies are created to represent cubicle panels. Each dummy consists of 4 relays, 4 sockets, 8 terminal blocks, and 1 steel section. The relays used are OMRON relays, type LY2N DC24; the sockets used are OMRON sockets, type PTFZ-08-E; and the terminal blocks used are screw-clamp terminal blocks from ENTRELEC. Additionally, there is a local/remote switch used to control the dummy, allowing it to be operated either remotely or locally. The components of the dummy are shown in Fig. 1.

In the dummy, 2 relays are used to indicate the open/close status and control, while the other 2 relays are used to manage the local/remote status. The dummy also includes 8 terminal blocks: 2 terminal blocks are used as voltage sources, 2 terminal blocks are used for open/close control, 2 terminal blocks are used for open/close status, and the remaining 2 terminal blocks are used for local/remote status.

In design the wiring diagram, a wiring diagram is designed to illustrate the cable connections of each component in the dummy. The purpose of designing the dummy wiring diagram is to ensure that the dummy functions correctly, providing information on the open/close and local/remote status, as well as controlling the open/close function of the dummy itself. The wiring is also configured so that when the local/remote switch indicates the local status, the dummy cannot be controlled remotely and can only be controlled remotely when the local/remote switch indicates the remote status. Additionally, the wiring diagram is created to show the connection between the dummy, Hardware I/O, and the power supply.

The dummy wiring diagram is shown in Fig. 2. Relay 1 and Relay 2 are used to indicate and control the open/close status. Since Relay 1 is normally open, the initial condition indicates an open status. When Relay 1's contact is activated or when a close control is applied, Relay 1 is activated, changing the status to closed. When Relay 2's contact is activated or when an open control is applied, Relay 2, which is normally closed, opens, cutting off power to Relay 1 and reverting the status to open. Additionally, Relays 3 and 4 are used to manage the local/remote status. If the local/remote

switch indicates the local condition, Relay 3's contact is activated, closing Relay 3 and indicating the local status. Conversely, if the local/remote switch indicates the remote condition, Relay 4's contact is activated, closing Relay 4 and indicating the remote status.

The wiring diagram of the dummy to the Hardware I/O is shown in Fig. 3. As illustrated in the diagram, the dummy has 8 terminal blocks: 2 of these are connected to the power supply, 4 are connected to the input section of the Hardware I/O, where they indicate status, and the remaining 2 terminal blocks are connected to the output section of the Hardware I/O, which are used for control purposes.

The wiring diagram for the dummy is designed so that when the switch is in the local position, the output pins for open/close control are not powered, preventing remote open/close control. Conversely, when the switch is in the remote position, the output pins for open/close control are powered, allowing for remote control of open/close functions. Therefore, the wiring diagram for the open/close control output is designed to be powered from the remote status, ensuring that open/close control can only be performed when the status indicates a remote condition.

In this stage, the dummy, local/remote switch, Hardware I/O, and RTU are installed on the simulation rack. The simulation rack contains 5 pairs of dummies and local/remote switches that will be connected to the Hardware I/O. Each dummy has 4 pins connected to the input section of the Hardware I/O, specifically for open status, close status, remote status, and local status. Additionally, each dummy has 2 pins connected to the output section of the Hardware I/O for open and close control.

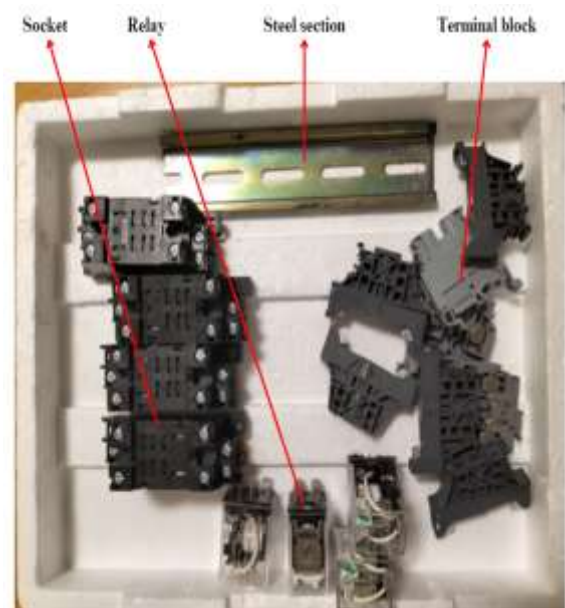


Fig. 1. Components of the Dummy

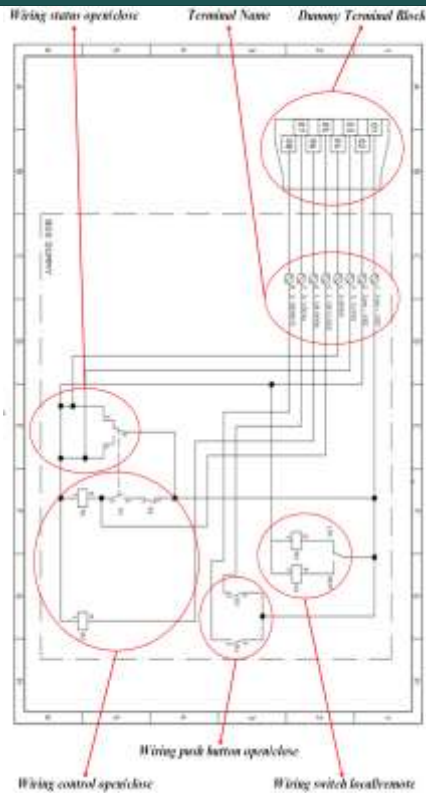


Fig. 2. Dummy wiring diagram

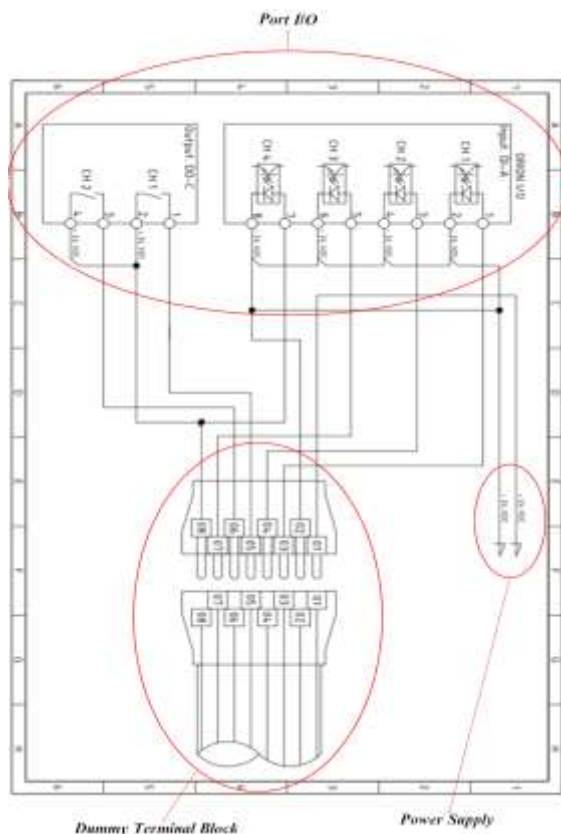


Fig. 3. Wiring diagram of dummy to Hardware-I/O

The installation of the dummy and local/remote switch on the Hardware I/O is performed as shown in Fig. 3. For the first dummy, the 4 input pins are connected to Card A at positions 1 to 8, where even-numbered positions are used to connect the Hardware I/O to the negative source, so the inputs are connected to positions 1, 3, 5, and 7 in the order of open status, close status, remote status, and local status. Additionally, the 2 output pins are connected to Card C at positions 1 to 4, where even-numbered positions are used to connect the Hardware I/O to the positive source, so the outputs are connected to positions 1 and 3 for open and close control, respectively.

For the second dummy, the 4 input pins are connected to Card A at positions 9 to 16, and the 2 output pins are connected to Card C at positions 5 to 8. For the third dummy, the 4 input pins are connected to Card A at positions 17 to 24, and the 2 output pins are connected to Card C at positions 9 to 12. For the fourth dummy, the 4 input pins are connected to Card B at positions 17 to 24, and the 2 output pins are connected to Card C at positions 13 to 16. For the fifth dummy, the 4 input pins are connected to Card B at positions 25 to 32, and the 2 output pins are connected to Card C at positions 17 to 20. The pin connections for dummies two through five are arranged similarly to the first dummy. The installation of dummy pins and local/remote switches to the Hardware I/O is illustrated in Fig. 4.

After all five dummies have been installed and connected to the Hardware I/O, the next step is to install the local/remote switch and RTU on the simulation rack. To connect the local/remote switch and relays for local/remote control, specifically relays 3 and 4, two additional terminal blocks are added to the dummy. The RTU is only connected to the power supply, as it will be linked to the Hardware I/O and the master via Ethernet cables.

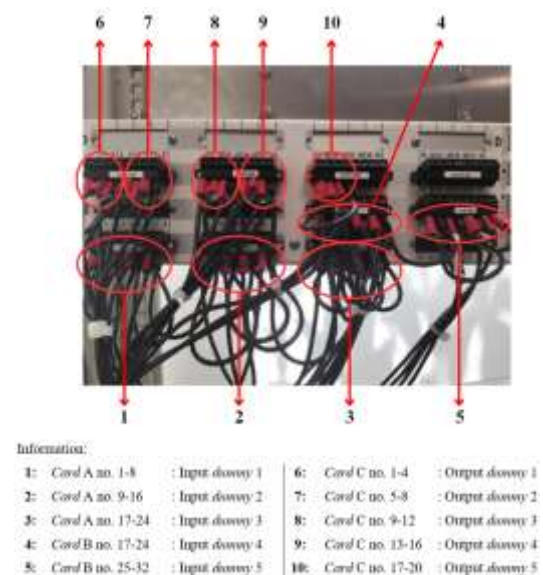


Fig. 4. Installation pin from dummy to Hardware I/O

2.3 Communication Network Mapping

In communication network mapping, the mapping of input and output positions on the Hardware I/O is carried out to connect the dummy devices with the SCADA system network. This process involves assigning point names to each channel number on the Hardware I/O device. The mapping of points and channel numbers is based on the wiring diagram that has been set up from the dummy to the Hardware I/O.

In the wiring diagram, it is evident that the input positions on the dummy are not all on the same card. Therefore, in this mapping, the placement of points and channel numbers must also be distributed across different cards. In this prototype, Card A and Card B are used as inputs from the dummy, resulting in the input mapping as shown in Table 1.

In the wiring diagram, it is observed that all output positions are located on Card C. Therefore, the point names and channel numbers can all be mapped to Card C, resulting in the output mapping as shown in Table 2.

The DBI point is obtained by combining two input points into a single input point. This approach aims to reduce the number of input points sent to the server, making it more efficient, and simplifies the design of the HMI. In this prototype, the open-close and remote-local statuses of each dummy, previously mapped, will be combined into a single point, resulting in the mapping shown in Table 3.

Table 1: Input point mapping results on hardware I/O

Point Name	Card	Channel	Type
INCOMING_STATUS_OPEN	Card A	0	Binary
INCOMING_STATUS_CLOSE	Card A	1	Binary
INCOMING_STATUS_REMOTE	Card A	2	Binary
INCOMING_STATUS_LOCAL	Card A	3	Binary
FEEDER_1_STATUS_OPEN	Card A	4	Binary
FEEDER_1_STATUS_CLOSE	Card A	5	Binary
FEEDER_1_STATUS_REMOTE	Card A	6	Binary
FEEDER_1_STATUS_LOCAL	Card A	7	Binary
FEEDER_2_STATUS_OPEN	Card A	8	Binary
FEEDER_2_STATUS_CLOSE	Card A	9	Binary
FEEDER_2_STATUS_REMOTE	Card A	10	Binary
FEEDER_2_STATUS_LOCAL	Card A	11	Binary
FEEDER_3_STATUS_OPEN	Card B	8	Binary
FEEDER_3_STATUS_CLOSE	Card B	9	Binary
FEEDER_3_STATUS_REMOTE	Card B	10	Binary
FEEDER_3_STATUS_LOCAL	Card B	11	Binary
FEEDER_4_STATUS_OPEN	Card B	12	Binary
FEEDER_4_STATUS_CLOSE	Card B	13	Binary
FEEDER_4_STATUS_REMOTE	Card B	14	Binary
FEEDER_4_STATUS_LOCAL	Card B	15	Binary

Table 2: Output point mapping results on hardware I/O

Point Name	Card	Channel	Mode
INCOMING_CONTROL_OPEN	Card C	0	Pulse
INCOMING_CONTROL_CLOSE	Card C	1	Pulse
FEEDER_1_CONTROL_OPEN	Card C	2	Pulse
FEEDER_1_CONTROL_CLOSE	Card C	3	Pulse
FEEDER_2_CONTROL_OPEN	Card C	4	Pulse
FEEDER_2_CONTROL_CLOSE	Card C	5	Pulse
FEEDER_3_CONTROL_OPEN	Card C	6	Pulse
FEEDER_3_CONTROL_CLOSE	Card C	7	Pulse
FEEDER_4_CONTROL_OPEN	Card C	8	Pulse
FEEDER_4_CONTROL_CLOSE	Card C	9	Pulse

Table 3: Double bit binary input point mapping results on hardware I/O

Binary Input Point Name	Status	DBI Point Name
INCOMING_STATUS_CLOSE	Status A	INCOMING_STATUS_CO
INCOMING_STATUS_OPEN	Status B	
INCOMING_STATUS_LOCAL	Status A	INCOMING_STATUS_LR
INCOMING_STATUS_REMOTE	Status B	
FEEDER_1_STATUS_CLOSE	Status A	FEEDER_1_STATUS_CO
FEEDER_1_STATUS_OPEN	Status B	
FEEDER_1_STATUS_LOCAL	Status A	FEEDER_1_STATUS_LR
FEEDER_1_STATUS_REMOTE	Status B	
FEEDER_2_STATUS_CLOSE	Status A	FEEDER_2_STATUS_CO
FEEDER_2_STATUS_OPEN	Status B	
FEEDER_2_STATUS_LOCAL	Status A	FEEDER_2_STATUS_LR
FEEDER_2_STATUS_REMOTE	Status B	
FEEDER_3_STATUS_CLOSE	Status A	FEEDER_3_STATUS_CO
FEEDER_3_STATUS_OPEN	Status B	
FEEDER_3_STATUS_LOCAL	Status A	FEEDER_3_STATUS_LR
FEEDER_3_STATUS_REMOTE	Status B	
FEEDER_4_STATUS_CLOSE	Status A	FEEDER_4_STATUS_CO
FEEDER_4_STATUS_OPEN	Status B	
FEEDER_4_STATUS_LOCAL	Status A	FEEDER_4_STATUS_LR
FEEDER_4_STATUS_REMOTE	Status B	

In creating the communication pathway between hardware I/O and RTU, the communication pathway between the Hardware I/O and the RTU is established. The points created on the Hardware I/O in the previous stage can be connected to the RTU using the DNP3 protocol [8]. In this setup, the Hardware I/O will act as a slave, sending information and receiving commands from the RTU, which serves as the master. Therefore, a DNP3 Server port is configured on the Hardware I/O, while a DNP3 Client port is set up on the RTU.

The DNP3 Server port is used for communication with the RTU as a slave. This port must be configured so that the protocol functions correctly. The default port value for DNP3 is 20000. The address of the Hardware I/O and RTU are connected by entering the Hardware I/O address in the Address field and the RTU address in the Destination Address field, with the hardware I/O address set to 1 and the RTU address set to 2.

Other parameters can be adjusted as needed. For instance, the Hardware I/O is configured to synchronize its system time with the server time every 10 minutes. This precaution helps mitigate issues if the device becomes inactive or disrupts its system time, ensuring that the system time is periodically synchronized with the server time.

The point mappings from the previous Input and Output stages are forwarded to the RTU through the DNP3 Server port. Points placed on this port will have new addresses different from those on the Hardware I/O Card. Additionally, the DBI point mappings will also be placed on this port with different types and point addresses. Thus, the DNP3 Server port mapping for Hardware I/O is as shown in Table 4 for outputs and Table 5 for inputs.

The DNP3 client port on hardware I/O is used for communication with Hardware I/O as a master. Similar to the configuration of the DNP3 Server port on Hardware I/O, the DNP3 Client port must be set up properly to ensure the protocol operates correctly. The DNP3 Server port on Hardware I/O has a default port value of 20000. The Client Address is the address assigned to the RTU, which was previously set in the Destination Address field on the DNP3 Server port of Hardware I/O, so it should match, which is 2. The Host/Server IP Address should be set to the IP Address of the Hardware I/O, which is configured to 10.0.1.50 in this prototype.

In the RTU settings, the Device Address is set to the Address value that was configured on the DNP3 Server port of Hardware I/O, so it should match, which is 1. Other parameters can be adjusted as needed. For instance, in this prototype, Hardware I/O is configured to synchronize its system time with the server time. Therefore, the Send Time Sync parameter must be checked to ensure time synchronization with the server operates correctly.

Table 4: Output port mapping results of the DNP3 server on hardware I/O

Point Name	Type	Address
INCOMING_CONTROL_OPEN @Card C	Binary	0
INCOMING_CONTROL_CLOSE @Card C	Binary	1
FEEDER_1_CONTROL_OPEN @Card C	Binary	2
FEEDER_1_CONTROL_CLOSE @Card C	Binary	3
FEEDER_2_CONTROL_OPEN @Card C	Binary	4
FEEDER_2_CONTROL_CLOSE @Card C	Binary	5
FEEDER_3_CONTROL_OPEN @Card C	Binary	6
FEEDER_3_CONTROL_CLOSE @Card C	Binary	7
FEEDER_4_CONTROL_OPEN @Card C	Binary	8
FEEDER_4_CONTROL_CLOSE @Card C	Binary	9

Table 5: Input Port Mapping Results of the DNP3 Server on Hardware I/O

Point Name	Type	Address
INCOMING_STATUS_OPEN @Card A	Binary	0
INCOMING_STATUS_CLOSE @Card A	Binary	1
INCOMING_STATUS_REMOTE @Card A	Binary	2
INCOMING_STATUS_LOCAL @Card A	Binary	3
FEEDER_1_STATUS_OPEN @Card A	Binary	4
FEEDER_1_STATUS_CLOSE @Card A	Binary	5
FEEDER_1_STATUS_REMOTE @Card A	Binary	6
FEEDER_1_STATUS_LOCAL @Card A	Binary	7
FEEDER_2_STATUS_OPEN @Card A	Binary	8
FEEDER_2_STATUS_CLOSE @Card A	Binary	9
FEEDER_2_STATUS_REMOTE @Card A	Binary	10
FEEDER_2_STATUS_LOCAL @Card A	Binary	11
FEEDER_3_STATUS_OPEN @Card B	Binary	8
FEEDER_3_STATUS_CLOSE @Card B	Binary	9
FEEDER_3_STATUS_REMOTE @Card B	Binary	10
FEEDER_3_STATUS_LOCAL @Card B	Binary	11
FEEDER_4_STATUS_OPEN @Card B	Binary	12
FEEDER_4_STATUS_CLOSE @Card B	Binary	13
FEEDER_4_STATUS_REMOTE @Card B	Binary	14
FEEDER_4_STATUS_LOCAL @Card B	Binary	15
INCOMING_STATUS_CO @LogicPak	Double-bit Binary	0
INCOMING_STATUS_LR @LogicPak	Double-bit Binary	1
FEEDER_1_STATUS_CO @LogicPak	Double-bit Binary	2
FEEDER_1_STATUS_LR @LogicPak	Double-bit Binary	3
FEEDER_2_STATUS_CO @LogicPak	Double-bit Binary	4
FEEDER_2_STATUS_LR @LogicPak	Double-bit Binary	5
FEEDER_3_STATUS_CO @LogicPak	Double-bit Binary	6
FEEDER_3_STATUS_LR @LogicPak	Double-bit Binary	7
FEEDER_4_STATUS_CO @LogicPak	Double-bit Binary	8
FEEDER_4_STATUS_LR @LogicPak	Double-bit Binary	9

The point mappings for Input and Output sent from Hardware I/O through the DNP3 Server port are mapped again on the DNP3 Client port of the RTU to be received. This mapping is done by rewriting the point name, type, and address according to the mappings on the DNP3 Server port of Hardware I/O, as shown in Table 4 and Table 5.

In creating the communication pathway between the power meter and RTU, the communication pathway between the Power Meter and the RTU is established. The Power Meter is used for various electrical measurements such as voltage, current, power, and others. In this prototype, a PowerLogic ION6200 power meter by Schneider Electric is used, which communicates with the RTU via the Modbus protocol. In this setup, the RTU acts as the master, requesting information from the power meter, which serves as the slave [9]. Therefore, a Modbus Client port is configured on the RTU.

The Modbus Client port on the RTU is used for communication with the power meter as the master [10]. In this configuration, the baud rate and device address must match the settings on the power meter to enable communication between the two devices. The ION6200 power meter operates at a baud rate of 9600 bps and has a device address of 2.

Measurement values from the power meter can be received by the RTU by creating point addresses with corresponding Modbus registers [11]. Each measurement aspect has different Modbus registers and types. In this prototype, the RTU will retrieve data including voltage,

current, power, power factor, and frequency. The resulting power meter ION6200 measurement mapping is shown in Table 6.

In creating the communication pathway between RTU and MTU, the communication pathway between the RTU and the MTU is established. Points created on the RTU in the previous stage can be connected to the MTU using the DNP3 protocol. In this setup, the RTU acts as a slave, sending information and receiving commands from the MTU, which serves as the master. Therefore, a DNP3 Server port is configured on the RTU.

The DNP3 Server port on the RTU is used for communication with the Master Terminal Unit as a slave. The port is set to the default value of 20000, consistent with the previously configured ports. The destination address can use the default address of the SCADA server, which is 1024. Other parameters should be aligned with the configuration of the DNP3 Server port on the Hardware I/O. In the event with time settings, unlike the Hardware I/O, which only checks class 1 indicating binary input/output, the RTU must check class 2 due to the presence of analog input types that need to be sent to the Master Terminal Unit.

The point addresses from the DNP3 Client and Modbus Client ports are forwarded to the Master Terminal Unit through the DNP3 Server port on the RTU [12]. The mapping of the DNP3 Server port on the RTU is shown in Table 7 and Table 8.

Table 6: Power logic ION6200 power meter mapping results

Point Name	Type	Modbus Register
VLN_R	Integer	40100
VLN_S	Integer	40101
VLN_T	Integer	40102
VLN_AVG	Integer	40103
VLL_RS	Integer	40104
VLL_ST	Integer	40105
VLL_TR	Integer	40106
VLL_AVG	Integer	40107
I_R	Integer	40108
I_S	Integer	40109
I_T	Integer	40110
I_AVG	Integer	40111
FREQUENCY	Integer	40115
POWER_FACTOR	Integer	40116
POWER_P	Integer	40120
POWER_Q	Integer	40121
POWER_S	Integer	40122

Table 7: Input Port Mapping Results of the DNP3 Server on RTU

Point Name	Type	Address
VLN_R @ION6200	Analog	0
VLN_S @ION6200	Analog	1
VLN_T @ION6200	Analog	2
VLN_AVG @ION6200	Analog	3
VLL_RS @ION6200	Analog	4
VLL_ST @ION6200	Analog	5
VLL_TR @ION6200	Analog	6
VLL_AVG @ION6200	Analog	7
I_R @ION6200	Analog	8
I_S @ION6200	Analog	9
I_T @ION6200	Analog	10
I_AVG @ION6200	Analog	11
POWER_P @ION6200	Analog	12
POWER_Q @ION6200	Analog	13
POWER_S @ION6200	Analog	14
POWER_FACTOR @ION6200	Analog	15
FREQUENCY @ION6200	Analog	16
INCOMING_STATUS_CO @Orion I/O	Double-bit Binary	0
INCOMING_STATUS_LR @Orion I/O	Double-bit Binary	1
FEEDER_1_STATUS_CO @Orion I/O	Double-bit Binary	2
FEEDER_1_STATUS_LR @Orion I/O	Double-bit Binary	3
FEEDER_2_STATUS_CO @Orion I/O	Double-bit Binary	4
FEEDER_2_STATUS_LR @Orion I/O	Double-bit Binary	5
FEEDER_3_STATUS_CO @Orion I/O	Double-bit Binary	6
FEEDER_3_STATUS_LR @Orion I/O	Double-bit Binary	7
FEEDER_4_STATUS_CO @Orion I/O	Double-bit Binary	8
FEEDER_4_STATUS_LR @Orion I/O	Double-bit Binary	9

Table 8: Output port mapping results of the DNP3 server on RTU

Point Name	Type	Address
INCOMING_CONTROL_OPEN @Orion I/O	Binary	0
INCOMING_CONTROL_CLOSE @Orion I/O	Binary	1
FEEDER_1_CONTROL_OPEN @Orion I/O	Binary	2
FEEDER_1_CONTROL_CLOSE @Orion I/O	Binary	3
FEEDER_2_CONTROL_OPEN @Orion I/O	Binary	4
FEEDER_2_CONTROL_CLOSE @Orion I/O	Binary	5
FEEDER_3_CONTROL_OPEN @Orion I/O	Binary	6
FEEDER_3_CONTROL_CLOSE @Orion I/O	Binary	7
FEEDER_4_CONTROL_OPEN @Orion I/O	Binary	8
FEEDER_4_CONTROL_CLOSE @Orion I/O	Binary	9

In design the SCADA server on MTU, the creation of a station, communication line, and RTU in the SCADA server database is carried out. A station can be considered the central hub for all activities taking place on the SCADA server. Therefore, the initial step in designing the SCADA server is to create the station first. A station must have at least one communication line and one RTU, so status points for both must be created within the station.

The next step is to create the communication line in the SCADA server database. The status points of the communication line created in the previous station are linked to the link status in the communication line. The protocol used should match the one used by the RTU to communicate with

the master, which is DNP 3.0 with TCP/IP connection type [13]. Other parameters can follow default settings. In the connection section, the IP address and port used by the RTU are specified.

Following this, the RTU is created in the SCADA server database. The status points of the RTU created in the previous station are linked to the link status in the RTU. The RTU device is connected to the Master Terminal Unit by selecting the communication line that has been created and using the ComLine setting in the connection parameters. The address parameter is filled with the RTU address that was determined earlier, which is 2. In the DNP section, ensure that the master number is set to the default value, which is 1024, as this is the destination address configured in the RTU's DNP3 Server port.

On the RTU, the status points for the open-close and local-remote conditions of the panel cubicle are mapped. In the telemetry section, input parameters are matched by selecting the configured RTU and the point number according to the DNP3 Server port mapping results of the RTU. Similarly, the output parameters are matched. However, unlike the status points for the open-close conditions, the control parameter is not checked, as there is no remote control system for this status.

Analog points from the power meter readings are also mapped on the RTU. In the telemetry section, input parameters are configured by selecting the configured RTU and the point number according to the DNP3 Server port mapping results of the RTU.

2.4 Integration of Analog and Status Points with HMI

In creating HMI design graphics, the design of the HMI graphics for the SCADA system is created based on the existing electrical distribution system. This involves drawing a schematic of the electrical distribution network that will be controlled. The HMI design is crafted to allow the operator to clearly visualize the real-time status of the system [14].

Using the **add line** feature in the Survalent SmartVU editor toolbar, the HMI for the electrical distribution network is illustrated with lines connecting cubicles to one another, as shown in Fig. 5.

The **Pmacro** menu in the Survalent SmartVU application will be used to display Circuit Breaker (CB) Open/Close status, Local/Remote Switch status, and readings from the power meter. Pmacro is useful for providing information to the operator regarding the status of the CB (whether it is open or closed), the status of the switch (whether it is local or remote), and the readings from the power meter. This information is presented as different graphics for each status, making it easy for the operator to understand.

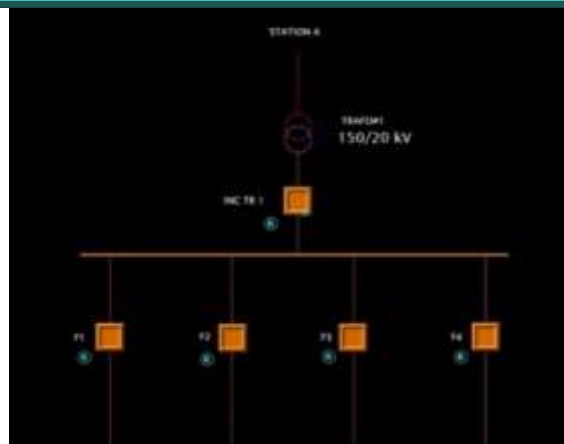


Fig. 5. Design the HMI Layout for the System

In connecting HMI design with database server, the connection between the SCADA server and the HMI design created is established. This can be done by selecting the **Pmacro Resource** menu in the Survalent SmartVU editor toolbars. This menu will only appear when the Pmacro symbol is clicked.

The Pmacro CB for INC TR 1 is connected to the point **INCOMING_STATUS_CO**. This is done by clicking on **Pmacro CB INC TR 1** and then **Browse**. Afterward, select **INCOMING_STATUS_CO** to map the Pmacro. The Pmacro CB allows the operator to view the status and control the CB from the HMI screen. The same process is followed for Pmacro CBs for Feeder1, Feeder2, Feeder3, and Feeder4 with the point names as listed in Table 9.

Pmacro Local/Remote Switch for INC TR 1 is connected to the **INCOMING_STATUS_LR** point. This is done by pressing Pmacro Switch Local/Remote INC TR 1 and Browse. Then choose **INCOMING_STATUS_LR** to map Pmacro. Pmacro Switch Local/Remote allows operators to know whether the switch status is local or remote from the HMI screen. The similar way is also done for the Pmacro Switch Local/Remote for Feeder1, Feeder2, Feeder3, and Feeder4 with point names according to Table 10.

The Pmacro analog value for line-neutral voltage is connected to the analog point **VLN_AVG**. This allows the operator to view the measurement data from the power meter on the HMI. The connection process involves linking the analog point with the Pmacro analog value. Similarly, the Pmacro analog value is used to display frequency, line-line voltage, current, active power (P), reactive power (Q), and apparent power (S), as detailed in Table 11.

At line section mapping, line section mapping is performed on the HMI diagram that has been created using the line section menu on the Survalent SmartVU editor toolbars. Line section mapping allows the operator to see information about whether the power lines are connected to the voltage source. All component names, equipment types, and line section connections are listed in Table 12.

Table 9: Result of connecting Pmacro CB with status points

Pmacro	Point Name	Type
CB INC TR 1	INCOMING_STATUS_CO	Status
CB F1	FEEDER_1_STATUS_CO	Status
CB F2	FEEDER_2_STATUS_CO	Status
CB F3	FEEDER_3_STATUS_CO	Status
CB F4	FEEDER_4_STATUS_CO	Status

Table 10: Results of connecting Local/Remote switch Pmacro with status points

Pmacro	Point Name	Type
Switch L/R INC TR 1	INCOMING_STATUS_LR	Status
Switch L/R F1	FEEDER_1_STATUS_LR	Status
Switch L/R F2	FEEDER_2_STATUS_LR	Status
Switch L/R F3	FEEDER_3_STATUS_LR	Status
Switch L/R F4	FEEDER_4_STATUS_LR	Status

Table 11: Results of connecting Pmacro analog with analog points

Analog Value	Point Name	Type
Average Line - Neutral Voltage	VLN_AVG	Analog
Average Line - Line Voltage	VLL_AVG	Analog
Average Current	I_AVG	Analog
P Power	POWER_P	Analog
Q Power	POWER_Q	Analog
R Power	POWER_R	Analog
Frequency	FREQUENCY	Analog

Table 12: Line section mapping on HMI

Name	Equipment Type	Connection
ST_1	Station Transformer	-
SST_1	Substation Transformer	ST_1
CON_SST_1	Conductor	SST_1
CB_INC	Breaker	CON_SST_1
BUS_1	Bus	CB_INC
CB_F1	Breaker	BUS_1
CB_F2	Breaker	BUS_1
CB_F3	Breaker	BUS_1
CB_F4	Breaker	BUS_1
FM_FEED_1	Feeder Main	CB_F1
FM_FEED_2	Feeder Main	CB_F2
FM_FEED_3	Feeder Main	CB_F3
FM_FEED_4	Feeder Main	CB_F4
CON_FEED_1	Conductor	FM_FEED_1
CON_FEED_2	Conductor	FM_FEED_2
CON_FEED_3	Conductor	FM_FEED_3
CON_FEED_4	Conductor	FM_FEED_4

3. RESULT AND ANALYSIS

3.1 INITIAL HMI DISPLAY TESTING

In the design of the SCADA server database, the point addresses used to create status points and analog points are those sent through the RTU's DNP3 Server port. This ensures that the data sent and received by the SCADA MTU server is accurate and reflects field conditions. This is evident from the

initial HMI display, which shows that the status points and analog points are correctly received by the SCADA MTU server. The initial display indicates that all Circuit Breakers (CBs) are in the open state and that remote control is functioning as expected, as shown in Fig. 6. Additionally, measurement data such as the average line-to-neutral voltage, average line-to-line voltage, average current, active power (P), reactive power (Q), apparent power (R), and frequency from the power meter readings are also displayed correctly, as shown in Fig. 6.

In the initial HMI display test, the SCADA system is able to show the status of the electrical network and the results of simulated electrical measurements. This indicates that the SCADA system functions as a monitoring tool for the electrical network within a specific area. The use of the SCADA system enhances the efficiency of network monitoring by allowing operators to assess the state of the electrical network without needing to go on-site.

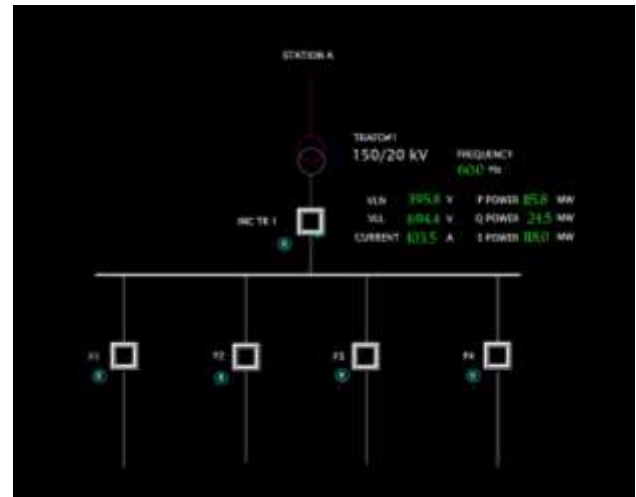


Fig. 6. Initial state of HMI

3.2 Testing Local or Remote Status

The local/remote switch is designed to be manually controlled only. The switch is placed on the local panel and serves as a safeguard during network maintenance. Field technicians can turn the switch to the local position during maintenance, thereby preventing network control through the HMI panel and allowing control only from the local panel.

The HMI display with the switch set to local for the incoming CB, outgoing feeder 1, feeder 2, feeder 3, and feeder 4 is shown in Fig. 7. The switch display changes from blue with an 'R' logo to red with an 'L' logo. This indicates that the CB cannot be controlled via the HMI but can only be controlled from the local panel.

The HMI display with the switch on the CB incoming, outgoing feeder 1, feeder 2, feeder 3, and feeder 4 set to remote is shown in Fig. 8. The switch in the remote condition is represented by a blue circle with an 'R' logo. This means

that the CB can only be controlled through the HMI panel and cannot be controlled locally.

The circuit breaker (CB) can only be controlled through SCADA when the status is set to remote. This is due to the wiring design, as shown in Fig. 2, where the control voltage source can only flow when the status is remote and will be cut off if the CB is in the local status.

As per its function, SCADA plays a crucial role in supervising the electrical network in a specific area and controlling the flow of electricity within that network. With SCADA, operators can monitor and control the electricity distribution from a central control room, thereby enhancing the efficiency of the electrical distribution system.

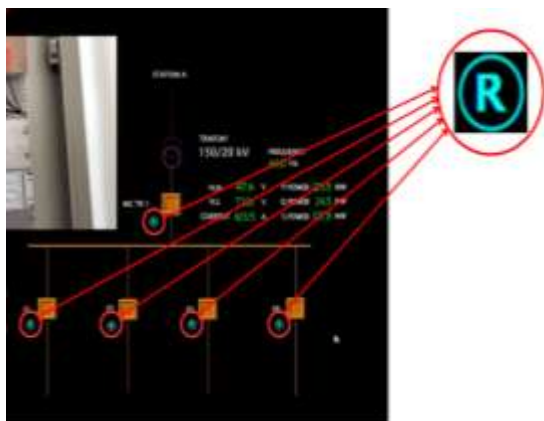


Fig. 7. Condition when all switches are in Local Position

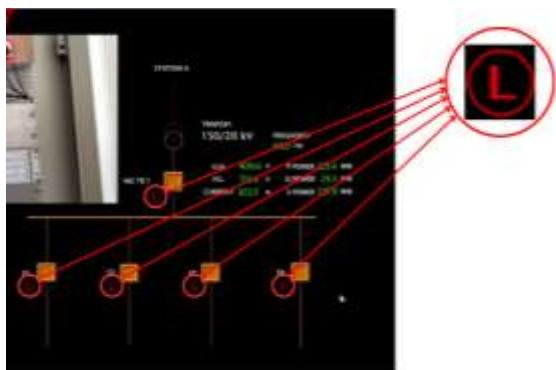


Fig. 8. Condition when all switches are in the local position

3.3 Testing Circuit Breaker (CB) Control

The state of the circuit breaker (CB) and electrical lines on the HMI display is indicated by different colors. A CB is considered open when its symbol is white and closed when its symbol is orange. A white color on the electrical line indicates that the line is not connected to the voltage source, while an orange color indicates that the line is connected to the voltage source. Different colors on the transformer signify different voltages: 150kV is shown in red, and 20kV is shown in orange.

When the CB INC is changed from an open to a closed state, the color of the CB INC symbol changes to orange. This causes the network after the CB INC to be connected to the voltage source, leading to a change in color of that network section to orange. However, since CB F1, CB F2, CB F3, and CB F4 are in an open state, the electrical lines after these CBs are not connected to the voltage source, resulting in those lines appearing white on the HMI. The HMI display when CB INC is closed and the other CBs are open is shown in Fig. 9.

When CB INC and CB F1 are closed, the colors of CB INC and CB F1 turn orange. This causes the network after these CBs to be connected to the voltage source, resulting in the network turning orange. However, since CB F2, CB F3, and CB F4 are open, the electrical lines after these CBs are not connected to the voltage source, causing these lines to appear white on the HMI. The HMI display when CB INC and CB F1 are closed can be seen in Fig. 10.

When CB INC, CB F1, CB F2, CB F3, and CB F4 are all in the closed condition, the color of these CBs turns orange. This causes the network beyond these CBs to be connected to the voltage source, resulting in the network color changing to orange. The HMI display when CB INC, CB F1, CB F2, CB F3, and CB F4 are all in the closed condition can be seen in Fig. 11.

When CB F1, CB F2, CB F3, and CB F4 are closed, their color turns orange. However, because CB INC is open, the power lines beyond CB INC are not connected to the voltage source, causing these lines to appear white on the HMI. Since CB F1, CB F2, CB F3, and CB F4 are located after CB INC, the power lines beyond these CBs also remain disconnected from the voltage source, even if these CBs are closed. The HMI display when CB F1, CB F2, CB F3, and CB F4 are closed can be seen in Fig. 12.

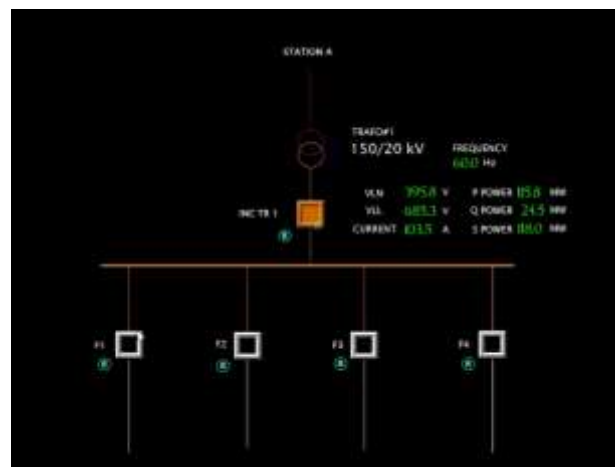


Fig. 9. HMI display when CB INC TR 1 (Incoming 1) is closed

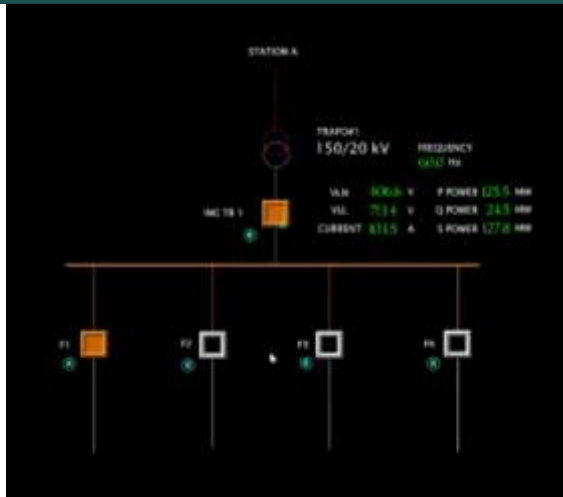


Fig. 10. HMI display when CB INC TR 1 and CB F1 are closed

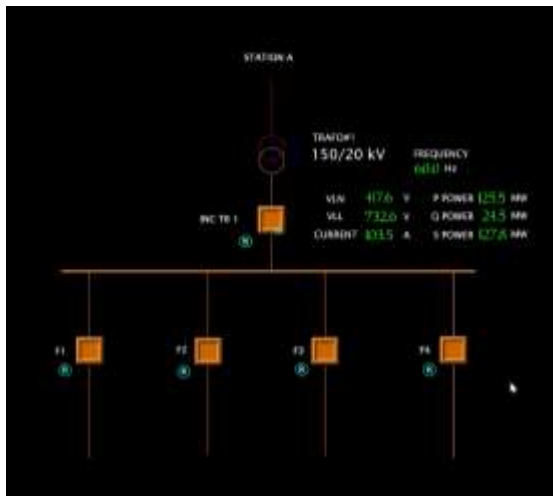


Fig. 11. HMI Display When CB INC TR 1, CB F1, CB F2, CB F3, and CB F4 are Closed

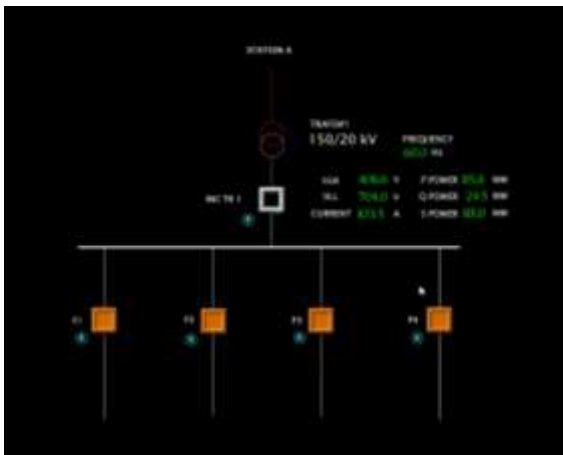


Fig. 12. HMI display when CB F1, CB F2, CB F3, and CB F4 are closed

This aligns with the HMI design, where the status points and analog points created on the SCADA server can be displayed using interactive PMacro symbols. This allows the status of circuit breakers (CB) to be clearly visualized using color differences. The line sections created on the SCADA HMI are used to display the status of a segment of the electrical network by providing a connection line from upstream to downstream with color visualizations. Thus, operators can easily understand and control the status of the electrical network through the interactive display on the HMI.

In the testing of CB control, the SCADA system can display the status of the electrical network and the results of simulated electrical measurements. This indicates that the SCADA system acts as a controller for the electrical flow within the network. The use of the SCADA system can enhance the efficiency of electrical network control by allowing operators to manage the network without having to go out into the field.

4. CONCLUSIONS

Status points and analog points are displayed on the HMI using PMacro, making them interactive. The status points shown on the HMI include the open/close status of the CB and the local/remote switch status. The open/close status of the CB can be controlled through the HMI by pressing the CB symbol. A CB is in the open status if the CB symbol is white, while it is in the close status if the symbol is orange. The local/remote switch status is indicated by different colors. A switch is in the local status if the symbol is red with an 'L' logo, and in the remote status if the symbol is blue with an 'R' logo. Dummy devices can only be controlled through SCADA when in the remote status because the voltage used for control is cut off when the dummy is in the local status. The HMI display shows analog points such as the average values of line-to-neutral voltage, line-to-line voltage, current, real power (P), reactive power (Q), apparent power (R), and frequency from the power meter readings. The HMI display shows the condition of the power line, indicating whether it is connected to the voltage source or not, through color differences. If the power line is white, it is not connected to the voltage source. Conversely, if the power line is orange, it is connected to the voltage source. The use of the SCADA system can enhance the efficiency of monitoring and controlling the electrical network because operators can know and control the electrical network without having to go on-site.

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