Design Of Interlock High Voltage Bay Transformer 150/20 kV System Simulator

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Abstract. Simulator is a tool or means that is needed in learning to replace the role of a real system or equipment. The simulator providing a solution for repetitive operation of equipment. This is not possible on the actual equipment such as in a high voltage transformer of electrical distribution system. The purpose of this study was to design a simulator of a 150/20 kV transformer bay interlock system using a PLC as a control device and computer monitor as a display (human machine interface). In this simulator there are 15 states to describe the interlock system between the circuit breaker and the disconnecting switch both on the 150 kV side and on the 20 kV side. Interlock system design using state diagram method. PLC Ladder diagrams are written with CX-programmer software and HMI programming using CX-Supervisor software. The validity test of the simulator is done by using event validity techniques. The design results show that the overall interlock system runs as a whole with the percentage of validity is 100 percent or with a validity index 1, so it can be concluded that the simulator of the 150/20 kV transformer bay interlock system can be used as a learning tool to replace the real system.

Keywords : High Voltage Transformer, Simulator, PLC, CX Programmer, CX Supervisor.

1. Introduction

The role of substations is very important in the distribution of electricity from the power plant to the load center. The substation serves to increase the voltage through the step up power transformer between the generator and the transmission. While between the transmission line and the load contained in the distribution system, the voltage is lowered through a step down power transformer. The transformer and all its supporting components including the main part, auxiliary equipment, and protective equipment become important components in the substation to remain in a state ready to operate to serve load due to failure of the transformer will result in not channeling electrical energy to the load.(2)

The development of automation at the substation has been carried out by PLN in the context of monitoring and controlling the equipment to facilitate the operation and maintenance of all equipment contained in the substation. The automation system at the substation is equipped with IED BCU (bay control unit), IED Protection, server, gateway, and HMI. The automation system consists of 2 levels, namely Bay level and station level, where the bay level includes primary equipment while the station level includes secondary equipment.(11)

The development of the simulator becomes an inseparable part in order to provide information about the working principle of an equipment in an electric power system such as the power plant, transmission
and distribution systems. The simulator is able to provide a concrete understanding of a system that is not possible on real equipment because it will interfere with the system. The use of software such as Labview, SCADA Architecture, Simatic WINCC and hardware such as PLC (Programmable Logic Controller) is a solution to develop simulators that are able to describe the working principle of an equipment individually or a system as a whole. Based on this study the “Design Of Interlock High Voltage Bay Transformer 150/20 kV System Simulator” was carried out. (3)(6)(8)(11)(12).

2. Research Methods

2.1. Bay Transformer Simulator

The transformer bay simulator is a device that resembles a transformer bay, but it works slower than it really is. Bay transformer is a distribution of electricity in substations that are devoted to the transformer. In the transformer bay simulator there are several parts of the circuit:

Control Circuit
The control circuit in this simulator consists of input and output. The input consists of push buttons and output for auxiliary relays that will be used to disconnect the power and status circuits. All input and output equipment are connected to the CP1E-NA20DRA PLC and are processed as interlocks. In addition to the push button, the HMI that was designed with CX-supervisor software is used as a controller.

Metering circuit
Metering circuit is a circuit that serves to monitor electrical parameters in the transformer. In this simulator which is monitored namely the voltage on the primary and secondary side of the power transformer. The monitored voltage will be input to the analog input on the PLC, and displayed on the PC / Laptop.

Power Circuit
This power circuit functions as a breaker and connecting 3 phase power circuit. This power circuit uses auxiliary relays as breakers and connectors controlled by PLC. This auxiliary relay is likened to high voltage equipment in transformer bays such as disconnecting switches or DS, Circuit Breakers HV or 150kV, Circuit Breakers LV or 20kV and earthing switches or ES.

2.2. Block Diagram

Figure 1. shows a block diagram of a transformer bay interlock system. The block diagram shows the relationship between a single line 150 kV / 20 kV transformer bay diagram with a PLC and a PC.
The hardware used consists of a PLC, circuit breaker, disconnecting switch, transformer and voltmeter. PLC becomes the main component to control the entire system contained in the simulator. In the simulator, there are lights on the disconnecting switch and circuit breaker as feedback. The lights are red and green; the red lights indicate that the equipment is in a closed condition, while the green light indicates the equipment is in an open condition.

Table 1. is a condition that becomes the reference for disconnecting switch and circuit breaker operation. The conditions in table 1 are used to design ladder diagrams in the CX programmer software.

Table 1. 150/20 kV transformer high voltage bay interlock system

| Tested equipment | Operation          | CB HV | DS BUS 1 | DS BUS 2 | CB LV | Earthing Switch | Target      | Result       |
|------------------|--------------------|-------|----------|----------|-------|-----------------|-------------|--------------|
| DS Bus 1         | Closing/Opening    | Open  | -        | Open     | -     | -               | Close/Ok   | Close/Ok     |
| DS Bus 1         | Closing/Opening    | Open  | -        | Close    | -     | -               | Close/Ok   | Close/Ok blok|
| DS Bus 1         | Opening            | Close | -        | Open     | -     | -               | Close blok | Close blok   |
| DS Bus 2         | Closing/Opening    | Open  | Open     | -        | -     | -               | Close/Ok   | Close/Ok     |
| DS Bus 2         | Closing/Opening    | Open  | Close    | -        | -     | -               | Close/Ok   | Close/Ok blok|
| DS Bus 2         | Opening            | Close | Open     | -        | -     | -               | Close/Ok   | Close/Ok blok|
| CB HV            | Closing            | -     | Open     | Open     | Open  | -               | Close blok | Close blok   |
| CB HV            | Closing            | -     | Close    | Open     | Open  | -               | Close Ok   | Close Ok     |
Table 2. shows the condition of the disconnecting switch and the circuit breaker on the transformer bay interlock system during load transfer from bus 1 to bus 2.

Table 2. Interlock system on the load transfer condition

| Tested equipment | Operation      | Interlock    | CB HV | DS REL 1 | DS REL 2 | CB Bus Kopel | Target    | Result       |
|------------------|----------------|--------------|-------|---------|---------|--------------|-----------|-------------|
| DS Bus 1         | Closing/Opening| Close        | -     | -       | Close   | Close        | Close/Ok  | Close/Ok    |
| DS Bus 1         | Closing/Opening| Close        | -     | -       | Close   | Close        | Close/Ok  | Close/Ok    |
| DS Bus 1         | Closing/Opening| Open         | -     | -       | Close   | Close        | Close/Block| Close/Block |
| DS Bus 2         | Closing/Opening| Close        | -     | Close   | -       | Close        | Close/Ok  | Close/Ok    |
| DS Bus 2         | Closing/Opening| Close        | -     | Close   | -       | Open         | Close/Block| Close/Block |
| DS Bus 2         | Closing/Opening| Open         | -     | Close   | -       | Close        | Close/Block| Close/Block |

2.3. Hardware Design
Figure 2. shows the design of the CP1E-NA20DR-A omron PLC wiring. In Figure 2, it appears that there are 8 digital inputs and 2 analog inputs used for addressing disconnecting switches, circuit breakers, earth switches, and voltages on the primary and secondary sides of the transformer. Kontak output PLC digunakan sebagai indikator disconnecting switch, circuit breaker, dan earth switch.
2.4. Software Design
The design of the control system on the PLC uses ladder diagrams. Ladder diagram design using CX-Programmer V9.4. and designing visual displays on the HMI to display test and simulation results using the CX-Supervisor. After completing the ladder diagram, the next step is to create a visual display design with the CX-Supervisor software. The advantages of CX-Supervisor with other scada software namely CX-Supervisor already supports with Omron PLC brands. The design of the HMI aims to make it easier for users to observe the performance of the control system. Through this visual display, the PLC work process can be monitored in realtime and facilitates trouble shooting when a system error occurs.

3. RESULT AND DISCUSSION

3.1. System Validation and Design Result
System validation is by testing each part to ensure that each part is functioning properly in accordance with its objectives, then testing the system as a whole. Several things will be tested and validated, including:
1. Validation between the primary voltage and the voltage input at the analog input on the PLC.
2. Testing whether the hardware parts (PLC, Step down transformers, auxiliary relays) work according to the control system made or not.
3. Testing the visual appearance on a PC / Laptop.
3.2. Functional Analysis
The testing of PLC digital I/O component functions aims to ensure that PLC digital input and output components can work using a control system through hardware or software (CX-Supervisor). Table 3 shows the results of testing the function of PLC digital input and output components.

| Component Name | Type | Address | Function OK | Function Not OK | Simulation Type |
|----------------|------|---------|-------------|----------------|-----------------|
| DS 1 Open      | Input| I: 0.00 | 100%        | 0%             | Hardware        |
|                |      | W0.0    | 100%        | 0%             | Software        |
Figure 5 a and b shows one of the Interlock testing disconnecting switch 2 for open operation on ladder diagram and HMI, if disconnecting switch 2 wants to be opened, the CB HV must be open. Then if the operation of disconnecting switch 2 is for on load transfer, the requirements that must be met are, disconnecting switch 1 close > CB bay coupler close > CB HV close.
Overall testing results are shown in Table 4 and 5.

### Table 4. Testing of 150 kV/20 kV bay transformer interlock

| Tested equipment | Operation          | CB HV | DS BUS 1 | DS BUS 2 | CB LV | Earthing Switch | Target   | Result          | %  |
|------------------|--------------------|-------|----------|----------|-------|-----------------|----------|-----------------|----|
| DS Bus 1         | Closing/Opening    | Open  | Open     | -        | -     |                 | Close/Ok | Close/Ok        | 100%|
| DS Bus 1         | Closing/Opening    | Open  | -        | Close    | -     |                 | Close/Ok | Close/Ok        | 100%|
| DS Bus 1         | Opening            | Close | -        | Open     | -     |                 | Close    | Close           | 100%|
| DS Bus 2         | Closing/Opening    | Open  | Close    | -        | -     |                 | Close/Ok | Close/Ok        | 100%|
| DS Bus 2         | Closing/Opening    | Open  | Close    | -        | -     |                 | Close/Ok | Close/Ok        | 100%|
| CB HV            | Closing            | -     | Open     | Open     | Open  |                 | Close    | Close           | 100%|
| CB HV            | Closing            | -     | Close    | Open     | Open  |                 | Close    | Close           | 100%|
| CB HV            | Closing            | -     | Open     | Close    | Open  |                 | Close    | Close           | 100%|
| CB HV            | Closing            | -     | Open     | Close    | Open  | Close           | Close    | Close           | 100%|
| CB HV            | Closing            | -     | Open     | Close    | Open  | Close           | Close    | Close           | 100%|
| CB HV            | Closing            | -     | Open     | Close    | Open  | Close           | Close    | Close           | 100%|
| CB HV            | Closing            | -     | Open     | Close    | Open  | Close           | Close    | Close           | 100%|
| CB LV            | Closing/Opening    | Close | -        | -        | -     | Open            | Close/Ok | Close/Ok        | 100%|
| CB LV            | Closing/Opening    | Open  | -        | -        | -     | Open            | Close/Ok | Close/Ok        | 100%|
| CB LV            | Closing/Opening    | Open  | -        | -        | -     | Close           | Close/Ok | Close/Ok        | 100%|
| Intertrip        | Open CB HV         | Opening | CB HV | -        | -     | -               | CB HV,CV | CB HV,LV        | 100%|

### Table 5. Testing of 150 kV/20 kV bay transformer load transfer interlock

| Tested equipment | Operation          | CB HV | DS BUS 1 | DS BUS 2 | CB Bus Kopel | Target | Result | %  |
|------------------|--------------------|-------|----------|----------|--------------|--------|--------|----|
| DS Bus 1         | Closing/Opening    | Close | -        | Close    | Close        | Close/Ok | Close/Ok | 100%|
| DS Bus 1         | Closing/Opening    | Close | -        | Close    | Open         | Close/Block | Close/Block | 100%|

8
4. Conclusion
From the research conducted by the author, it can be concluded that:

1. Building a 150 / 20kV high voltage bay transformer system interlock simulator design, where the close status uses red lights and the equipment open status uses green lights.
2. PLC wiring and ladder diagram control have been designed with CX-Programmer V9.4 Software where wiring consists of control wiring, monitoring wiring and power wiring.
3. HMI has been designed using CX-Supervisor, where HMI can monitor equipment status, control equipment and monitor power transformer voltages.

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