Journal of NAMP 68, 1 (2024) 1-6

The Nigerian Association of Mathematical Physics

Journal homepage: https://nampjournals.org.ng

Development of Substation Automation System for the Nigerian Electricity Supply Industry: A Case Study.

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ARTICLE INFO

Article history:
Received xxxxx
Revised xxxxx
Accepted xxxxx
Available online xxxxx

Keywords:
Injection Substation, Substation Automation, Field level devices, Simulation Software.

ABSTRACT

Current Injection substations in Nigeria are manually operated to clear faults and anomalies. This process takes time and delays the restoration of service to customers. The current need of the industry therefore, is to device a way of using communication and control system in such a way that can allow real time action to take place. The aim of this article is to design a substation automation system (SAS) for the Nigerian Electricity Supply Industry (NESI) using the Oluku 15MVA, 33/11kV Injection substation as a case study.
The substation was evaluated to determine the state of the components/field level devices used and their suitability for automation deployment. Wiring diagrams/PLC interface for installed equipment at Oluku injection substation was developed, this was followed by the development of Substation Automation Communication System using SIEMENS SIMATIC STEP 7 PLC Automation and Simulation Software.
The designed SAS is scalable and could be adapted for any substation configuration. This innovative SAS is the first of such system to be developed in Nigeria.

1. Introduction

Over the years preceding the privatization of the power sector in Nigeria, it became increasingly apparent that the sector is grappling with huge challenges in the entire value chain. These challenges include infrastructural, operational, systematic, monitoring and control issues, particularly as it affects injection substations in Nigeria. Current Injection substations in Nigeria are manually operated to clear faults and anomalies. This process takes time and delays the restoration of service to customers with its attendant cost implication to both the utility companies and electricity consumers.

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https://doi.org/10.60787/10.60787/jnamp.v68no1.411

The current need of the industry therefore, is to design substation automation systems in such a way that can allow real time communication and control action to take place in the station even from remote locations. This will save time, guarantees continuity of service, and improved revenue to all participants in the electricity supply chain.

Substations form a very important node in the transmission and distribution of electrical power system. The main function of substation is to receive energy transmitted at high voltage from the generating station to a value appropriate for local distribution and provide facilities for switching [1],[2]. Substation automation is the act of automatically controlling the substation through instrumentation and control devices. Substation automation can also be defined as the process of using data from Intelligent Electronic Devices (IEDs), control and automation capabilities within the substation, and control commands from remote users using supervisory control and data acquisition (SCADA) to control power-system (switchyard) devices [3],[4]. The most important functions of substation automation system are control, monitoring, alarming, measurement, setting and monitoring of protective relays, control and monitoring of the auxiliary power system, and voltage regulation [5]. The success of any Substation Automation System (SAS) depends upon successful interoperability of all intelligent devices connected to the substation communication network [6]; thus, in line with the standards defined by the IEC 61850 as shown in Figure 1, substation automation systems architecture can be classified into three levels namely, station level, bay level and process level.

In station level, a PC based Human Machine Interface (HMI) enables control via installed software package(s) which contains an extensive range of SCADA functions. The station level contains alarm list or event list related to the entire substation, and it is a gateway for communication with remote control centers. The bay level comprises of circuit breaker and associated isolators, earth switches and voltage and current transformers. At this level, the intelligent electronic devices (IEDs) provide functions such as control (command outputs), monitoring (status indications, measured values) and protection. The IEDs are directly connected to the switchgear. While the process level consists of all the switchyard devices which are hardwired using copper cables and are connected to the bay level IEDs that are used for control and protection by means of fiber optic cables [7],[8],[9]. This substation automation architecture enables the system to carry out its three main functions which are data acquisition, supervision and control.

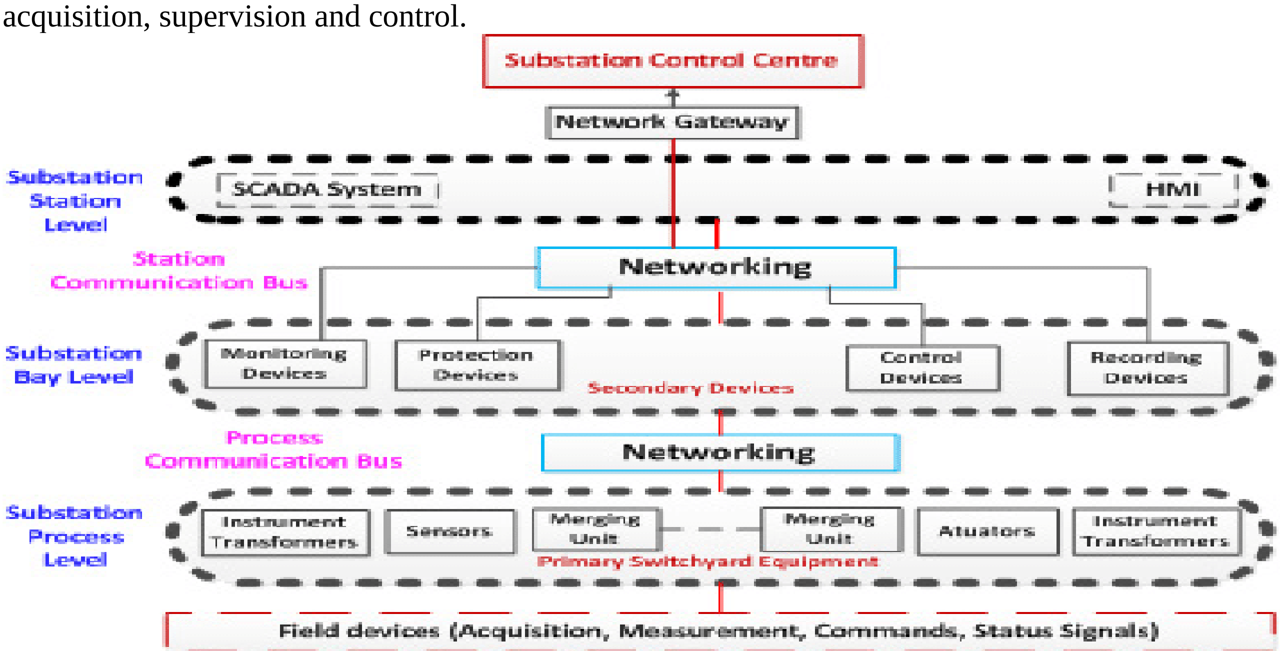

Figure 1: Substation Architecture [3]

The SAS architecture presented in Figure 1 was adopted for the design of a substation automation system for the Oluku 15MVA, 33/11kV injection substation.

Thus, this ground-breaking research is timely and imperative if Nigeria must enjoy the benefits of an enhanced fully automated power system and break free from the burden of foreign automation companies by developing its first Substation Automation Systems locally.

2.0 Methodology

The methodology that was used is as presented in this section.

2.1 Description of the Case Study

Oluku NIPP 15MVA, 33/11kV Injection substation is located along the Benin-Lagos express road, in Oluku community just before the Benin by-pass, Edo state, Nigeria. The substation is fed by Ihobvor 33kV feeder which radiates from the Ihovbor 132/33kV transmission station. It was not proposed to have SCADA or SAS. It is a Type A-A4 substation. A Type A-A4 injection substation has one line circuit and one transformer circuit at the switchyard. A circuit consists of 2No. isolators, 1No. set of current transformers and 1No. circuit breaker. Altogether, a Type A-A4 injection substation has 4No. isolators, 1 set of voltage transformer, 2 sets of current transformers, 2No. circuit breakers and 1No. injection transformer.

2.2 Design of Substation Automation System for Oluku Injection Substation

The substation was evaluated to determine the state of the components/field level devices used and their suitability for automation deployment. Wiring diagrams/PLC interface for installed equipment at Oluku injection substation was developed, this was followed by the development of Substation Automation Communication System using SIEMENS SIMATIC STEP 7 PLC Automation and Simulation Software.

The entire system was designed, simulated and visualized on Siemens TIA platform. Program instructions were written in Ladder Logic to execute the daily protection, control, metering and recording (bearing in mind relevant standards and thresholds prescribed by the NERC code) tasks hitherto carried out by a DSO. The program instructions were compiled, debugged successfully and simulated using Siemens PLCSIM. An HMI with several screens was designed for the visualization and parameterization of the control processes within the automation system. The system was accessed from a remote location with a mobile device or remote computer through transmission control protocol/internet protocol (TCP/IP) and control instructions were successfully sent and received. A data logger was built for automatic logging of common substation events.

3.0 Results and Discussion

Figures 2 and 3 present snapshots of the various interface developed for the station under review. These includes snapshot of the network program instruction for network 15 and 17, snapshot of the developed HMI interface for the transformer auxiliary protection. The developed complete wiring diagram of Oluku substation automation system is presented in Figure 4.

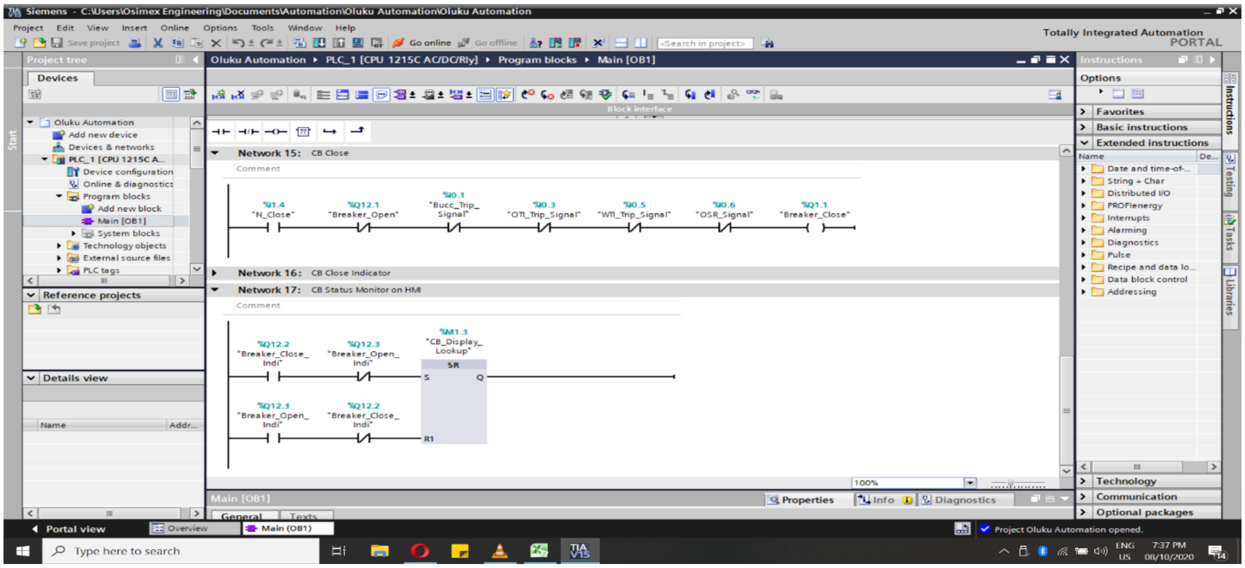

Figure 2: Snapshots of Network 15 and 17 program instructions – CB Close Instruction and CB Status Monitor on HMI

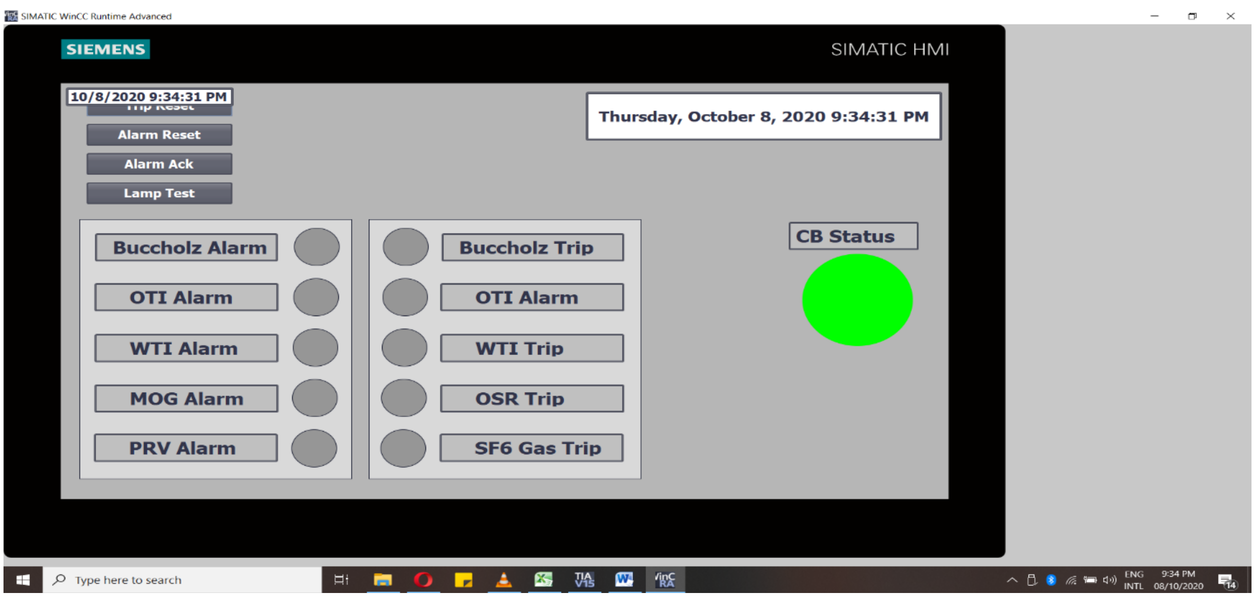

Figure 3: Snapshot of the Developed HMI Interface for the Transformer Auxiliary protection.

The program interface shown in Figure 3 is the circuit breaker close command and the Circuit Breaker (CB) status feedback to the substation. Network 15 program line shows that for a close command to be applied to the breaker from the HMI screen or from the automation panel, the circuit breaker must previously be in an open position. Also, there must be no active trip signal coming from the Buccholz trip circuit, the Winding Temperature Indicator (WTI) trip circuit, the Oil Temperature Indicator (OTI) trip circuit and the Oil Surge Relay (OSR) trip circuit.

Network 17 shows the program line for monitoring the CB status. This section of the control program ensures that the status of the CB is indicated on the HMI screen and on the SAS panel at all times regardless of where the breaker open or close command was initiated. This is vital for operator and service personnel safety to prevent accidents or electrocution, resulting from false indication of the breaker position before maintenance works at the switchyard or feeder lines are done. There are 218 networks for the control program of this substation

Figure 3 shows one of the developed HMI screens for the local and remote control of the substation and is used to monitor the transformer auxiliary protection. When any of the indicated fault occurs in the transformer, the GREY indicator by the side of the particular fault lights up in RED. If it a fault that results in the trippage of the CB, the CB status indicator will change. Green indicates CB OPEN position while RED indicates CB CLOSE position. The push buttons at the top left-hand corner of the HMI screen can be activated by a single click on the HMI screen locally or a command sent remotely via SMS or over the internet. Lamp Test button is used to test if all the indicator lamps are still functional on the SAS panel. Alarm Ack button is used to acknowledge and stop the alarm bell after a fault is observed. Alarm Reset button is used to reset the alarm signal which will normally persist even after the alarm acknowledgement. It can only be reset after the fault leading to the alarm is cleared. Similarly, Trip Reset button is used to reset the trip signal after the fault that resulted in the trip had been cleared. There are 45 HMI screens for the control of the Oluku injection substation.

This prototype SAS was designed for Oluku 1x15MVA 33/11kV injection substation which was not originally designed and constructed with automation in mind. This made it impossible to automated certain control functions of the substation without carrying out a measure of retrofitting. Unlike most existing SAS, this system has an extended remote control capabilities executable via GSM network as well as over the internet. The only weakness of this redundant control measure is possibility of hacking. Substation security which is not part of the scope of this work, can be used to enhance this weakness in future works.

4.0 Conclusion and Recommendation

The design and simulation of Nigeria’s first substation automation system was successfully carried out in this work and tested using Oluku 1x15MVA 33/11kV injection substation parameters as a case study. Hence from this study, automation has become an essential part in designing a Substation. Automation removes human errors, automates the system efficiently through the use of intelligent electronic devices. It should be noted that the winding temperature indicator (WTI) and oil temperature indicator (OTI) mounted on the injection transformer in Oluku substation are only capable of sending signals to the control room at two set points: alarm at 75^oC and trip at 95^oC. This is because the trigger for the alarm and trip signals is an analogue pointer in the device.

In order to automate the system for hourly data logging of oil temperature and winding temperature (instead of only the instance logging of alarms and trips), it is recommended that a digital sensor or a more advanced analogue sensor be installed so that instantaneous voltage or current corresponding to the oil temperature and winding temperature can be read from the control room.

Injection substation automation will benefit the NESI in the following ways: The cost of deploying staff/maintenance personnel, fuelling, operational cost and hazard allowance will be reduced; it is safer, as it will help to reduce exposure to hazard; it will help to reduce hostilities to staff of distribution companies in some communities; it will help to checkmate anomalies and cut revenue leakages due to unscheduled outages, and there will be better utilization of personnel, as the DSO can be trained and assigned more responsibilities. It also makes fault detection and clearing faster through the use of distance relaying.

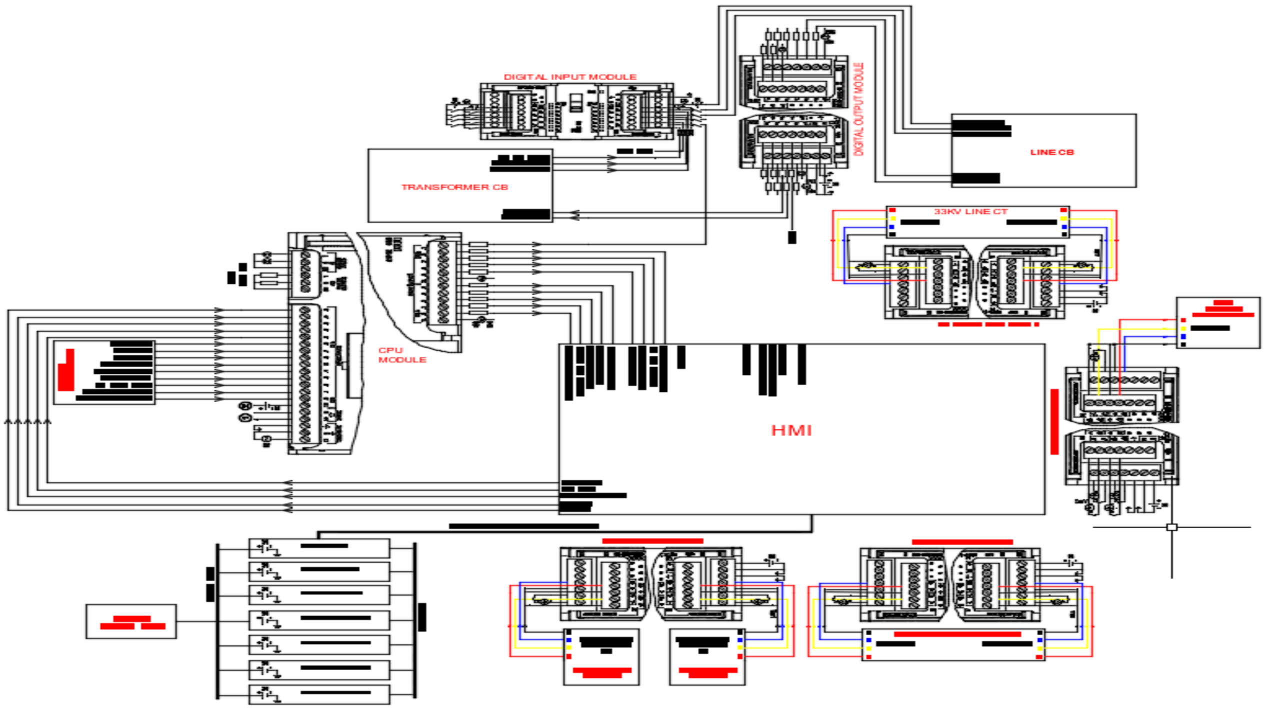

Figure 4: Complete connection diagram of the SAS for Oluku.

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Acknowledgements

This research was funded by the TETfund Institutional Based Research Fund (2023/2024). We also acknowledge Prof. James A. Momoh and Staff of the Tactical Unit (Chairman's Office), Nigeria Electricity Regulation Council (NERC) for their assistance.