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IMPROVING THE REAL-TIME FAULT MONITORING IN 330KV POWER TRANSMISSION NETWORK USING WIDE AREA MONITORING TECHNIQUE

[1]Mbeke Peter C., [2]Ilo Fredrick U.

[1,2] Department of Electrical and Electronic Engineering; Faculty of Engineering; Enugu State University of Science and Technology, Enugu State, Nigeria.

Corresponding Author Email: [1]peterchuks83@gmail.com

ABSTRACT

This paper presents improving the real-time fault monitoring in 330KV power transmission network using wide area monitoring technique. The aim is to develop a real time fault monitoring system that will facilitate power system protection. This was achieved using Phasor Measurement Unit (PMU) and a strategic deployment model. The new monitoring system was implemented on a 32Bus, 330kv, transmission network using Simulink platform. The result when tested under fault condition showed that the new system was able to monitor all the bus with fault and notify for correction measured, reported in the recommendation.

Keywords: Power Transmission; Supervisory Data Acquisition and Control; Remote Telemetry Unit; Phase Measurement Unit; Wide Area Monitoring

1 INTRODUCTION

Power system is made of generation, transmission and distribution system. The generation part is the section where the necessary raw resources such as coal, hydro, wind, etc are converted into electricity and then transmit to the national grid (Daniel et al., 2019). The transmission network is coordinated by the Transmission Company of Nigeria (TCN) and is responsible to load shedding the generated power to the various Distribution Companies (Discos). This transmission network architecture has over 20,000KM of transmission lines with an average of 7.4% losses on daily basis according to the National Electricity Regulation Commission (Jumare et al., 2020).

According to Oludele et al., (2016) Supervisory Data Acquisition and Control (SCADA) is a section of the TCN which is responsible for the monitoring and data collection of the grid-behaviour. The SCADA is made up of data sampling section, communication section and then monitoring section (Hentea, 2008). The data sampling section is made up of Remote Telemetry Unit (RTU) which is responsible for phasor data collection from the grid. The communication section is made up of software defined radio which was used for transmission of data sampled to the monitoring centre (Zhou et al., 2016). The monitoring section is responsible for the supervision and collection of the data transmitted for interpretation by the engineer (Bowen et al., 2005).

The major problem with SCADA system was reliability of the data collection as it lacks integrity due to delay time resulting from the data sampling system (Hahn and Goundarasu, 2011). The RTU popularly used today for the modelling of SCADA lacks real time data sampling capacity and also poor data synchronized time (Choi et al., 2009). This was a major challenge as the total time taken to sample data and deliver to the control centre results to delay and impact on the integrity of data collection and hence analysis and decision making at the control centre (Alade, 2013).

To address this problem many researchers, like (Waheed et al., 2013; Sven et al., 2016; Rene et al., 2017) proposed the application of PMU. PMU has the capacity to sample data in real time and transmit to the grid. PMU was applied to many powers system wide area measurement systems, but solutions have not been obtained for the Nigerian national grid.

This paper therefore used wide area-based measurement system using PMU which collect real time data of the Nigerian 36-bus transmission network; this when achieved will ensure quality and good data analysis which will impact greatly on the optimization and proper management of the national grid.

2. LITERATURE REVIEW

SCADA is a system of different hardware and software elements that come together to enable a plant or facility operator to supervise and control processes. Figure 1 presented a simple SCADA setup;

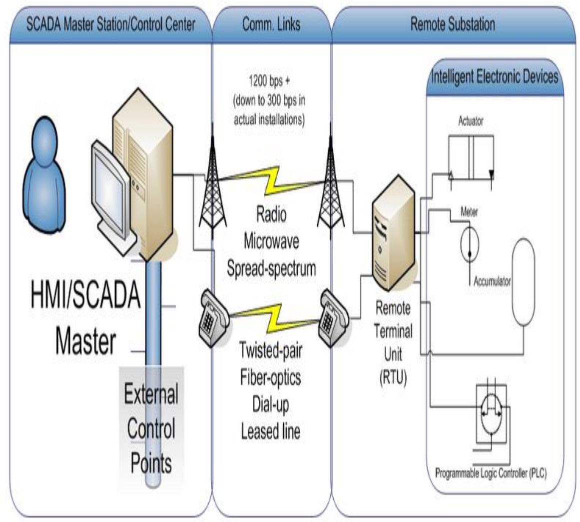

Figure 1: SCADA Setup (Danielle, 2020)

Supervisory control is a general term for a high-level of overall control of many individual controllers or multiple control loops (Oludele et al., 2016). It gives the operations supervisor an overview of the plant process and permits integration of operation between low-level controllers (Hentea, 2008). Data acquisition is the process of sampling signals by measuring a physical property of the real world in the form of signals and converting it from analogue waveform into digital numeric values so that it can be processed by computing machines (Danielle, 2020).

2.1 Key features of SCADA

Computers process the data and let personnel in charge to oversee and direct the status of the power system using the acquired data(FORTINET Incorporated, 2010). Personnel in charge were often operators and engineers who monitor the information remotely or locally. Now, the master station is tasked to supervise most of the system (Danielle, 2020);

2.2 SCADA for power transmission system

Transmission line corresponding circuit model parameters are often in error as compared to values measured by the SCADA system (Choi et al., 2009). Without a SCADA system, these errors cause the economic dispatch to be erroneous, and hence, lead to increased costs or incorrect billing. These errors could also affect state estimator analysis, contingency analysis, short circuit analysis, distance relaying, machine stability calculations, and transmission planning in case of expansion(Alade, 2013). Therefore, SCADA integration into the transmission system is significantly considered (Danielle, 2020);

Some main functions of SCADA in electric transmission system are as follows:

- Re-routing services for station maintenance
- Service restoration
- Protective relay interface/interaction
- Voltage regulation management
- Load tap changer control
- Transformer management
- Real-time modelling
- Automatic circuit isolation control and interactive switch control display
- Interface real-time single-line displays
- On-line operation and maintenance logs
- Automatic system diagnostics by using system-defined controller alarms (alarm management)

2.3 Wide Area Measurements system

Wide area measurement is a process of monitoring multiple and long distance connected transmission systems using a remote monitoring and measuring device like the PMU or the RTU (Chaudhuri et al., 2010). In a wide area measurements system (WAMS), the Phasor Measurement Unit (PMU) is considered to be one of the most important measuring devices that can provide synchronized phasor measurements of voltages and currents from different locations in an electric power system (Eissa et al., 2010).

These PMUs should be associated with a reliable high-speed communication system for transferring all measurements and indicators to a central position, e.g., a control centre, for evaluation and decision (Corsi, 2010). From this central position, action orders are then sent to different parts of the power system. Such- WAMS with digital processing and communications, making data flow and information management central, may be implemented in the smart grid (Eissa et al., 2010).

2.3.1 Importance of WAM in Power System

- ❖ Power system monitoring
- ❖ Load flow analysis
- ❖ Fault detection
- ❖ Improve the reliability of power system via transient stability analysis
- ❖ Margin and sensitivity of power system

3 METHOD

The method used in this study is the development of WAM for the 32bus, 330KV transmission network. The study utilized PMU and then developed a strategic placement model, which was employed as a means to reduce the number of PMU required for the supervision.

3.1 Modeling of the Wide Area Measurement System

Wide Area Measurement (WAM) is the process of monitoring and synchronized data collection from the interconnected 330KV grid network. WAM is made up of phasor measurement unit, phasor data concentrator. The PMU are the multi sensors positioned strategically at the busses for data collection while the phasor data concentrator synchronized the data collected from the PMU and then transmit via a software defined radio to the SCADA monitoring unit.

3.2 The Phasor Measurement Unit Model

The PMU was modeled using components such as micro processor, filter, phase locked oscillator, analogue to digital converter, satellite and modem. The block diagram of the PMU is presented in figure 2;

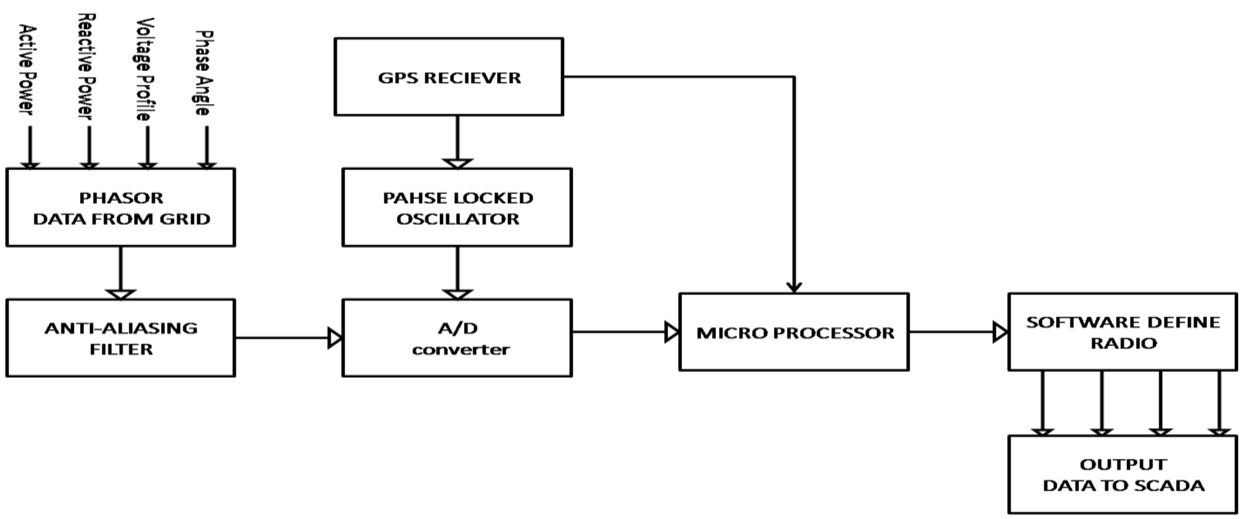

Figure 2: Modeling Block Diagram of PMU

From the figure 2, the load flow data of the transmission network was concentrated at the anti aliasing filter (made up of digital decimation filters) which removed any under sampled frequency from the data input and then sends to the analogue to digital converter which converts the time synchronized signal input with the GPS time signal from phase locked oscillator to digital signal and feed forward to the micro processor for transmission to the monitoring centre via the software defined radio.

3.3 Formulation of the PMU Solution for strategic placement

The objective functions of the PMU deployment problem to help minimize the high cost of PMU installation. The objective function is formulated as equation 1.

$$F = \min \sum_{i=1}^{N} P_i x_i \quad (1)$$

Where F is the objective function, x_i presents the binary decision variable related with the bus i; P_i presents the cost of the PMU at bus i.

$$x_i = \begin{cases} 1 & if\ PMU\ is\ at\ the\ bus \\ 0 & is\ PMU\ is\ not\ at\ the\ bus \end{cases} \quad (2)$$

This objective function was subjected to observability constraint for each i-bus associated with PMU to ensure that each of the bus is readable as shown in equation 3.

$$F_i = \sum_{i=1}^{N} a_{ij} x_i \geq Y \quad (3)$$

Where F_i is the observability constraint of each bus associated with the rule of equation 4;

$$F_i = \begin{cases} \neq 0 & if\ PMU\ is\ observable \\ = 0 & is\ PMU\ is\ not\ observable \end{cases} \quad (4)$$

Y is the vector size of all the PMU at the bus, a_{ij} is the binary connectivity matrix of the power system network whose elements are;

$$a_{ij} = \begin{cases} 1 & if\ i = j\ bus \\ 1 & if\ j\ and\ i\ bus\ are\ inter\ connected \\ 0 & if\ i\ and\ j\ bus\ are\ not\ connected \end{cases} \quad (5)$$

Having formulated the observability function for the relationship between the PMU and bus within the power system network, the System Observability (So) redundancy index was used to study the overall coverage the optimal placement of the PMU in the power system network as shown in the equation 6.

$$S_O = \sum_{i=1}^{N} a_{ij} x_i\ PMU \quad (6)$$

Where N is the sum of all the bus, a_{ij} is the binary observability; $x_i\ PMU$ is the optimal location and number of PMU observable by the N bus. The flow chart of the optimal placement model was presented in figure 3;

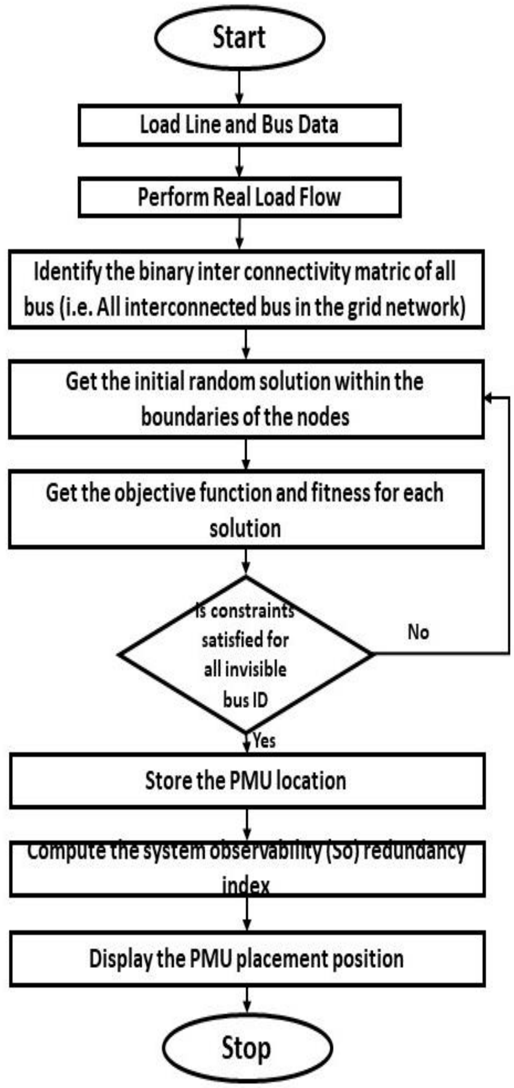

Figure 3: PMU Placement Flowchart

The flowchart showed the workflow of the optimal PMU placement model developed for the PMU deployment on the power system network for data collection. The model first established as objective function of the problem with equation 3 and then created a rule-based connectivity matrix of the power system network with equation 5 to identify the busses observable by the PMU and hence identifies the constraints and used system observability redundancy index model in equation 6 to display new location for PMU deployment.

3.4 Model of WAM System with strategic PMU deployment

The system was developed by integrating the PMU on the power system in place of the traditional RTU. The PMU was placed at the bus on the power system network using the strategic placement model which revealed that actual point for the PMU installation for bus observability, while minimizing cost of PMU. The single line model of the WAM at the 32 Bus, 330KV transmission network strategic placement is presented in figure 4;

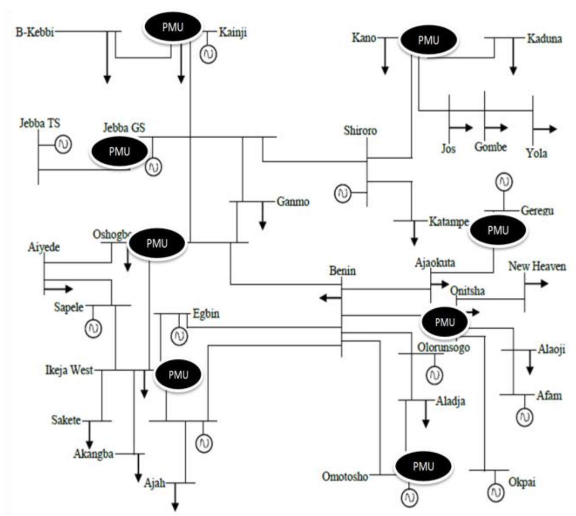

Figure 4: PMU placement or WAM

The figure 4 showed how the strategic placement model was utilized to reveal the observability point or PMU placement, so as to monitor the bus.

4. SYSTEM IMPLEMENTATION

The system was implemented using Simulink platform to put into reality the models of the PMU, and power system network developed. The transfer function model of the PMU developed using the model of the PMU developed earlier and presented in the figure 5, while the PMU system was presented in the figure 6.

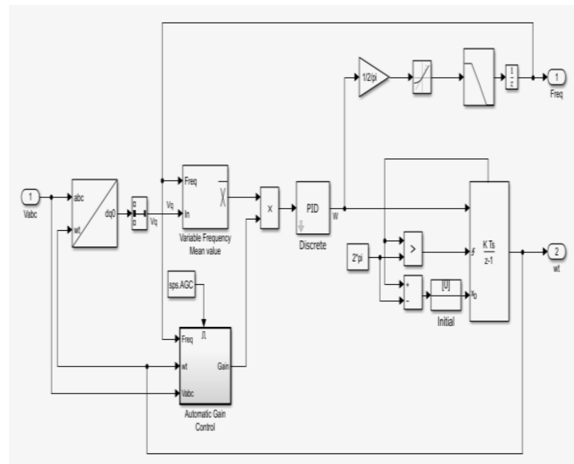

Figure 5: Transfer function model of the PMU

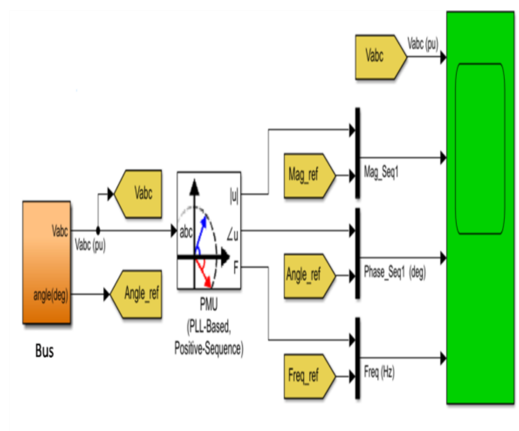

Figure 6: Simulink model of PMU

The figure5 and 6 respectively presented the implemented model of the PMU, the former showed the mathematical presentation of the model in time domain, while the later showed the Simulink model of the PMU. The Simulink model of the grid integrated with PMU was presented in figure 7.

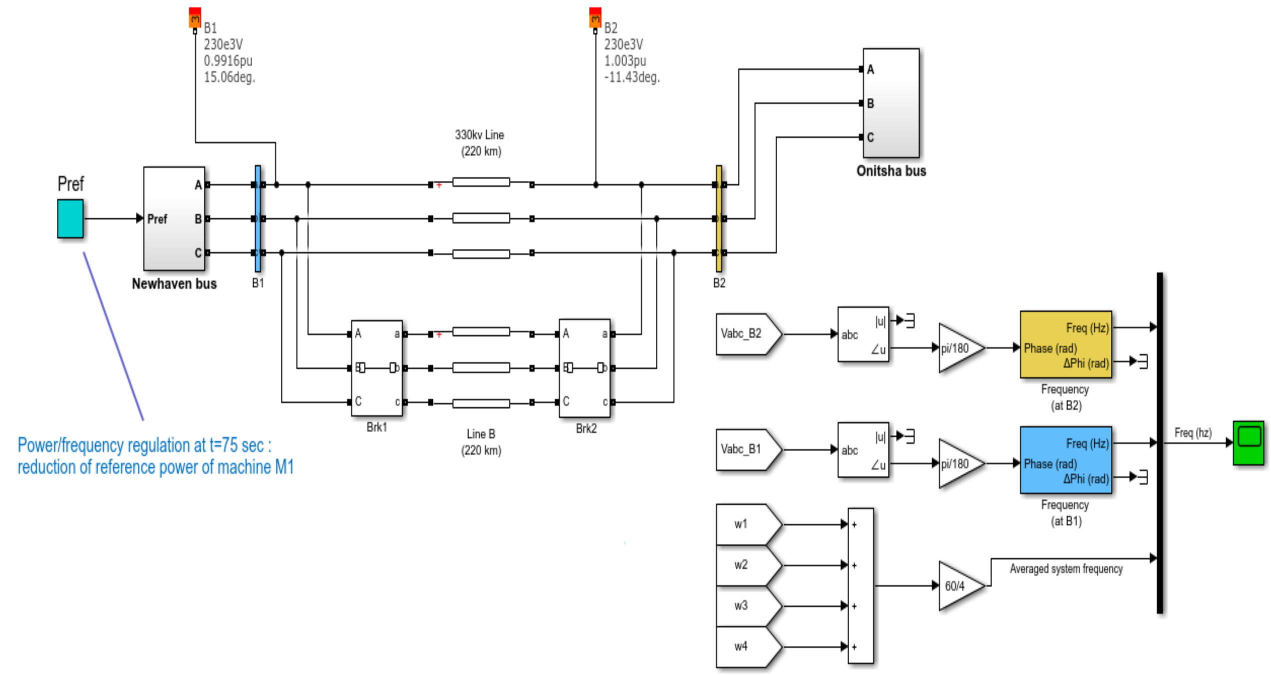

Figure 7: Simulink Model of the WAM with PUM

The figure 7 presented the Simulink model of the power system network with the WAM. The model showed how the PMU was deployed to the 330KV bus of Onitsha and Newheaven or real time monitoring. The breakers mounted were used as a protection device so that when fault is detected by the WAM, the relay in the breaker can pick up the current or voltage and trip the breaker for the power system protection. From the Simulink model it was also observed that only one PMU was utilized for the monitoring of fault in the two bus. This was because the strategic placement model developed was able to read and identify that one PMU is sufficient for the monitoring of bus.

5. RESULTS AND DISCUSSION

5.1 Results for the Simulation of SCADA with PMU

Having identified poor state of design components like the RTU as a major constraint to the integrity of the SCADA, the study modeled PMU and used to improve the TCN SCADA and simulated the output as shown in figure 8;

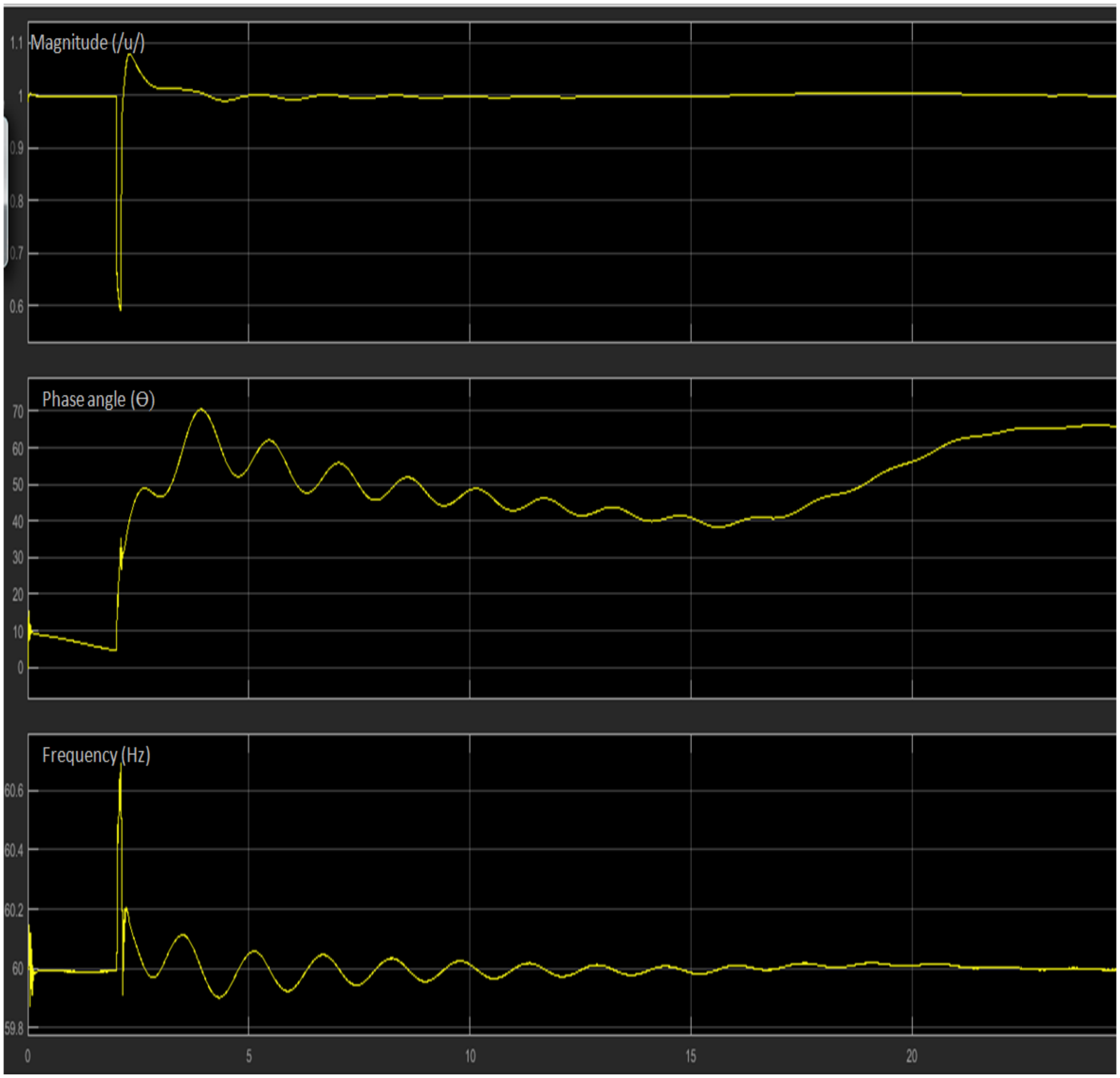

Figure 8: Simulation result of the SCADA with PMU on the 330KV network

The figure 8 presented the SCADA monitoring performance of the 330KV transmission lines, considering the key load flow parameters such as frequency, phase angle, voltage profile and time. The result showed that the PMU was able to read the flow of power along the transmission network and report back to the control centre SCADA.

5.2 Result of system integration of the WAM

This section presented the performance of the model used to strategically install the PMU on the 32Bus, 330KV transmission network. This was achieved via the observation of the bus and formulation of the power system network matrix considering rule based such as those with

PMU, those observable with PMU and those not observable with PMU of which the data was used to perform fitness and identify the location for PMU installation as shown in figure 9;

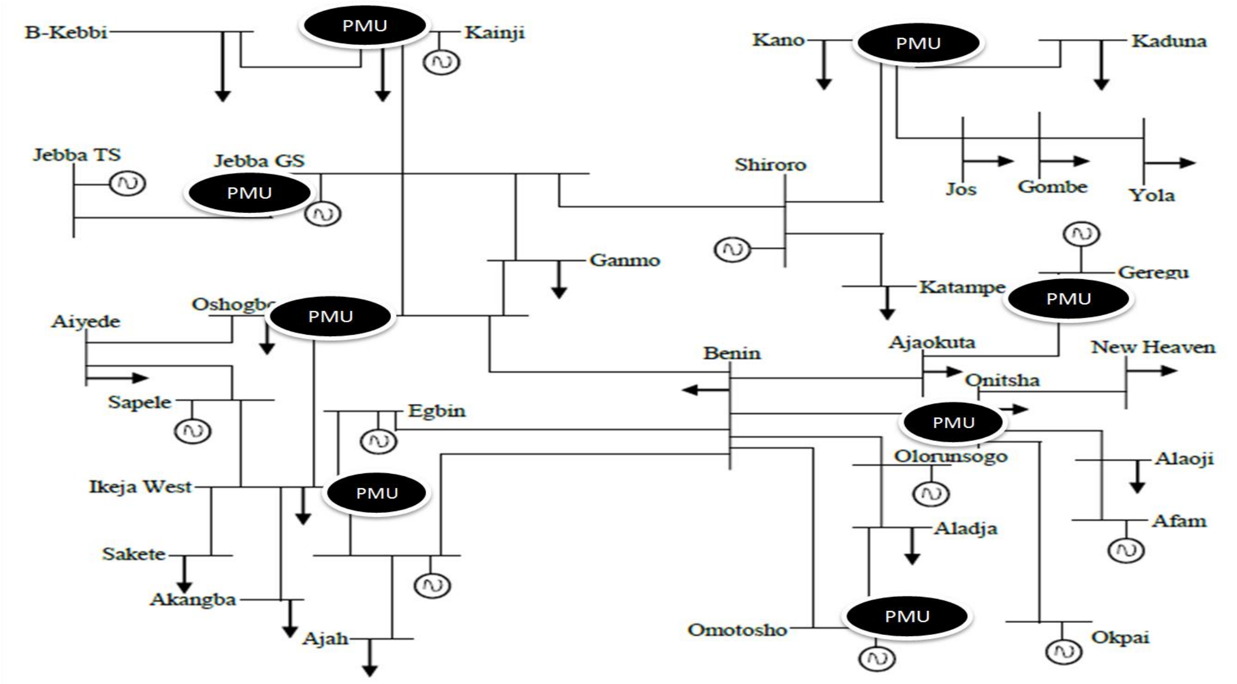

Figure 9: Result of the PMU deployment and system integration

The figure 9 showed how the bus was observed by the rule-based optimization model developed and then showed where the PMU are deployed. The result showed that with the model, only 8 PMU were need for the monitoring of the grid which is very good and economical. The result was analyzed with graph as in figure 10 and then presented as;

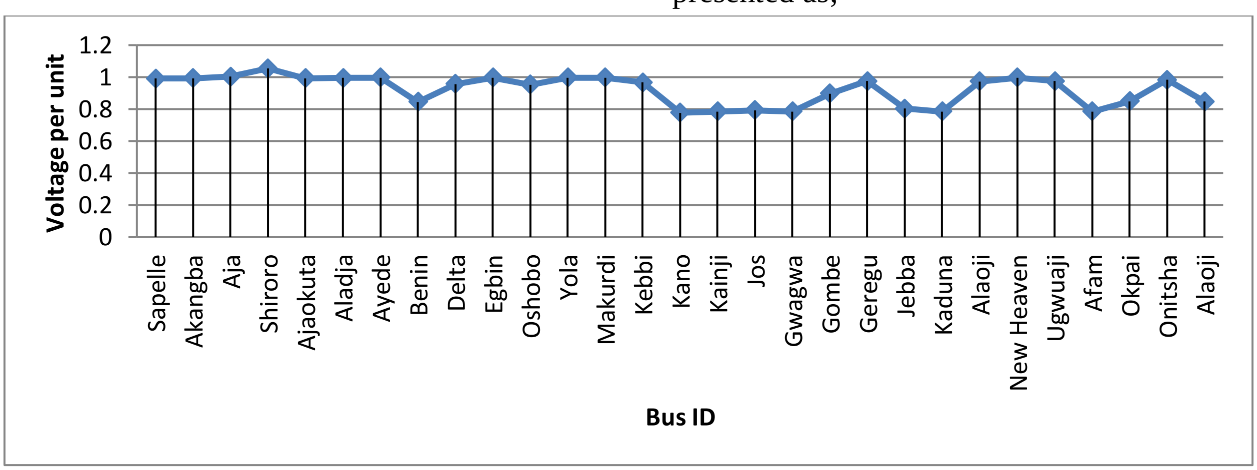

Figure 10: Graphical analysis of the SCADA data with PMU

Corresponding Author Tel: +234 803 082 6599

The figure 10 presents the result of the SCADA with PMU. The result showed that Benin, Kano, Kianji, Jos, Gwagwa, Jebba, Kaduna, Jebba and Afam, Alaoji and Okpai Bus are all faulty. The implication of this result is that more faulty bus was identified in the time of instability by the PMU. This is because the PMU has the ability for data collection and synchronization in real-time. This as a result, enables the system to identify all the unstable bus and report to the SCADA as shown and discussed above.

6. CONCLUSION

This research has successfully presented am improved system for real-time monitoring of multi area 330KV transmission network using strategic wide area monitoring system. The study developed a PMU system and used to replace the conventional RTU which suffers delay data sampling time which is not good to the integrity of data collection at the SCADA centre. The study developed a rule-based model which helps in the strategic deployment of the PMU to reduce cost and then implemented it on the grid using Simulink platform. The PMU was then deployed at the 32bus, 330KV transmission network and used for WAM.

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