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IMPROVING THE PERFORMANCE OF INTELLIGENT SMART GRID MONITORING USING PHASOR MEASURMENT UNIT SCHEME

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Abstract

This work presents improving the performance of intelligent smart grid monitoring using Phasor Measurement Unit (PMU) scheme. This was achieved studying the load flow of the grid using Newton Raphson algorithm and then develop a PMU system for real time data collection and then transmit to the control center via software defined radio. The system was implemented using Simulink and tested. The result showed that the PMU sampling time is 10ms and then the transmitting time is 12ms. The system was integrated at the grid and used to monitor New haven, Ugwuaji and Onitsha Busses. The result showed that the PMU was able to monitor the Busses in real time.

Keywords: Smart Grid, Automatic Metering, Real Time, Phasor Measurement Unit, Remote Telemetry Unit

1. INTRODUCTION

Electrical grid is an interconnected network for delivering electricity from supplier to consumers. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distant sources to demand centers, and distribution lines that connect individual customers. It is an indisputable reality that electric power is one of the major and most important technologies that led to the rapid industrialization and globalization in the twentieth century (Gujar et al., 2013). However, today's electrical grid suffers from a number of problems such as ageing materials, poor maintenance, over load, faults, and losses among other problems.

Recently, economics, technology and environmental incentives are changing the face of electricity generation and transmission. Centralized generating facilities are giving ways to smaller, more distributed generation partially due to the loss of traditional economies of scale. Intelligent systems driven by microprocessors and computers need to be employed for online monitoring and control of modern large-scale power systems, in generation, transmission and distribution to overcome the complexities and drawbacks of the conventional instrumentation schemes. These intelligent systems form the basis of the smart grid.

A Smart Grid (SG) is an electricity network that can intelligently integrate the actions of all users connected to its generators, consumers and those that do both in order to efficiently deliver sustainable, economic and secure electricity supplies (Bin et al., 2016). This SG enables real-time communication between the various substations so distribution centers and consumers can tailor their energy consumption based on individual preferences, like price and/or environmental concerns. This creates new opportunities and markets by means of its ability to capitalize on plug-and-play innovation wherever and whenever appropriate (Gujar et al., 2013).

One important aspect of this SG is the need for real time supervisory data acquisition and control. This employed communication and control system technologies to collect phasor data and then convey to the monitoring unit for data analysis and better decision makings. However the effectiveness of the conventional state of the art data collection system which makes use of Remote Telemetry Unit (RTU) suffers issues of latency as the time taken to collect data, process and then convey to the control center suffers delay time lag and hence affects the reliability of the data analysis. This presents the need for a real time data collection and smart grid solution. Many solutions have been proposed in (Yoshio et al., 2017; Yun et al., 2017; Bin et al., 2016; Rory et al., 2015; Lars, 2015; Rochelle et al., 2016) among others have provided solution towards this real time smart grid performance, however despite their success, there is need for real time monitoring solution to be localized in the Nigerian grid.

To achieve this, the paper proposed the use of Phasor Measurement Unit (PMU) and automatic meter reading scheme (Waheed et al., 2013). This PMU are systems which can collect data in real time and synchronize with the grid for better monitoring performance. This when incorporated with the Nigerian grid will help improve management performance and decision makings like fault localization among others.

2. Empirical study

This research performance load flow study of the Nigerian National Grid using load flow analysis based on Newton Raphson Algorithm in (Ikule et al., 2019; Abdulkarem et al., 2014; Afolabi et al., 2015) to study data collected from the Transmission Company of Nigeria (TCN) of the 30Bus 330KV transmission network. From the study, three buses were identified and used for the system integration which are the Uwguaji, New Haven and Onitsha Busses respectively. The modeling of an equivalent bus system is presented in the figure 1;

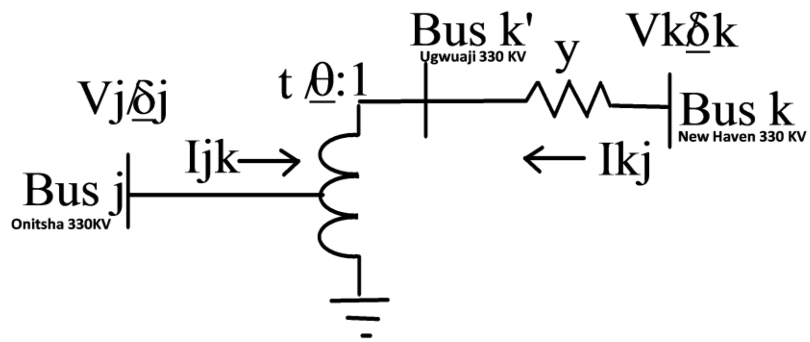

Figure 1: Equivalent Bus diagram of the network

The figure 1 presented the equivalent model of the three selected bus network showing the load flow from the sending end (Ijk) to the receiving end (Ikj). The bus Ugwuaji is presented as (k'), bus New haven (k), and bus Onitsha (j); y is the bus resistance, V is the voltage profile for bus k, k' and j. the continuous load flow formulation is presented in the next section.

2.1 Power flow formulation

To develop the model for the power flow in the busses, it is key to relate the bus current and voltage injected complex current at bus-k which is denoted by I_k may be expressed in term of complex bus voltage E_k and E_m as follow (Aribi et al., 2015).;

$$I_k = y_{k0}E_k + y_{km}(E_k - E_m) = (y_{k0} + y_{km})E_k - y_{km}E_m = Y_{kk}E_k + Y_{km}E_m \quad (1)$$

Where $Y_{kk} = y_{ko} + y_{km}$ and $Y_{km} = -y_{km}$

Similarly for bus m,

$$I_m = y_{mo}E_m + y_{mk}(E_m - E_k) = (y_{m0} + y_{mk})E_m - y_{mk}E_k = Y_{mm}E_m + Y_{mk}E_k \quad (2)$$

Where $Y_{mm} = y_{mo} + y_{mk}$ and $Y_{mk} = -y_{km}$

The above equation can be written in matrix form as:

$$\begin{bmatrix} I_k \\ I_m \end{bmatrix} = \begin{bmatrix} Y_{kk} & Y_{km} \\ Y_{mk} & Y_{mm} \end{bmatrix} \begin{bmatrix} E_k \\ E_m \end{bmatrix} \quad (3)$$

Where the bus admittances and voltage can be expressed in more explicit form (Akintunde et al., 2014):

$$Y_{ij} = G_{ij} + jB_{ij} \quad (4)$$

$$E_i = V_i e^{j\theta_i} = V_i(\cos\theta_i + j\sin\theta_i) \quad (5)$$

Where i = k,m and j = k,m

The Complex power injected at bus k is given by ;

$$S_k = P_k + jQ_k = E_k I_k = E_k \, (Y_{kk} E_k + Y_{km} E_m) \quad (6)$$

Where I_k^* is the complex conjugate of the current injected at bus k

Applying the value of Y_{ij} and E_i in S_k we get,

$$S_k = V_k(\cos\theta_k + j\sin\theta_k)[(G_{kk} + jB_{kk})V_k(\cos\theta_k + j\sin\theta_k) + (G_{km} + jB_{km})V_m(\cos\theta_m + j\sin\theta_m)]^*$$

The expression for real and reactive power injected at k-th bus can be determined by taking real and imaginary parts of the above expression of S_k.

So the real power injected at k-th bus is (Aribi et al., 2015);

$$P_k^{cal} = V_k^2 G_{kk} + V_k V_m [G_{km} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_k - \theta_m)] \quad (7)$$

Similarly the reactive power injected at k-th bus is

$$Q_k^{cal} = -V_k^2 B_{kk} + V_k V_m [G_{km} \sin(\theta_k - \theta_m) - B_{km} \cos(\theta_k - \theta_m)] \quad (8)$$

From the model designed in equation 7 and 8 it is obvious that at bus K, the power injected flows through the ith elements of the line network. Howevr in a practical field or real life station, the many busses will be employed for the transmisison network. Hence the model in eaution 7 and 8 are the combination of the power flow in each of the transmission element at each bus. The generic net active power and reactive power injected at bus k are:

$$P_k^{cal} = \sum_{i=1}^{n} P_k^{ical} \quad and \quad Q_k^{cal} = \sum_{i=1}^{n} Q_k^{ical} \quad (9)$$

Where P_k^{cal} and Q_k^{cal} are active and reactive power flows contributed by the mutual admittance elements i.e from k-bus to m-bus.

2.2 Software Defined Radio (SDR)

Software Defined Radio (SDR) is a communication device which has a transmitter to convey data collected from the bus to the control center. The SDR was developed using the International Electrical Electronic Engineering (IEEE) C37.118Format and the Transmission Control Protocol (TCP)/Internet Protocol (IP) 10/100/1000/Base Tx, Frequency 45-55Hz. This SDR provided modulation control, waveform requirements and evolving standards over broad frequency range.

2.3 Development of the PMU

The PMU is a data collection device which unlike the Remote telemetry Unit (RTU) has the ability to collect phasor parameters in global positioning satellite time (GPS). This PMU has the filter which collects the input signal. The GPS receiver synchronized the data collected at Universal Time Coordinate (UTC) using a phase locked oscillator (Zhou et al., 2016; Waheed et al., 2013) . The Analogue to digital converter (ADC) was used to convert the phasor parameters collected into digital signal for the micro-controller system to process and then transmit to the control center using the software defined radio. The block models of the PMU are presented in the figure 2;

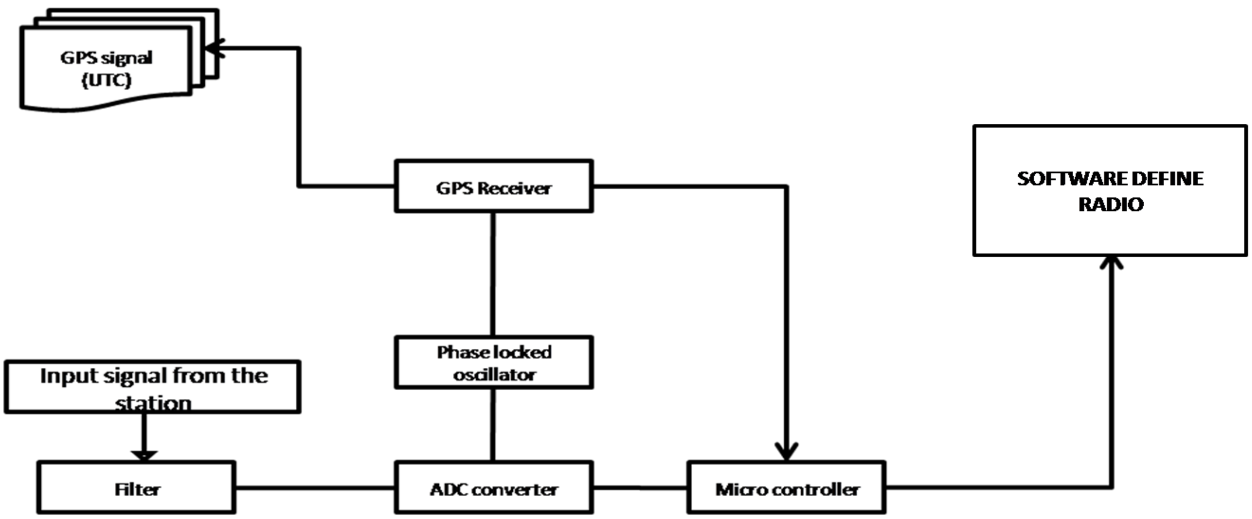

Figure 2: Block diagram of PMU

The PMU used the relationship between the sampling time, positive sequence components of the n number of phase input frequency, reporting time and sampling to synchronize the time of data collection as in the equation 10;

$$T_s = \frac{1}{f_n * N_{sr}} \quad (10)$$

Where: Ts is the sampling time, Fn presents the positive sequence components of the phasor signals (frequency), N_{sr} is the sampling rate. From the model of equation 8, the reporting rate which determines the interval over the length at which each even occurs is reported at a k factor related as;

$$Rt = k * T_s \quad (11)$$

Where: Rt is the reporting rate, and Ts is the sampling time.

2.4 Automatic metering Technology

This is work employs an automatic metering technology (Rochelle et al., 2016) that autonomously collects wide area measured data from the phasor state estimate using the receiver controller and deliver the data wirelessly to the control center the software defined radio transmitter properties which includes the data rates, frequency multiplexing technique, on or off signal code, transmission frequency within range (125KHz to 135KHz). The data transmitted are in the form of standard consumption message signal and interval data message using the hopping pattern and coupled to the transmitter.

2.5 System Block Diagram

The system block diagram in figure 3 presented the bus network integrated with the phasor measurement unit developed as shown for real time smart grid wide area measurement and monitoring. The PMU was installed at the three selected buses for phasor parameter data collection, the AMR was used to convert the data from phasor format to packet data for modulation by the SDR via the transmitter to the control center. At the headquarters (TCN) the SDR used its receiver to receive the data and then the AMR re-convert to readable format for analysis.

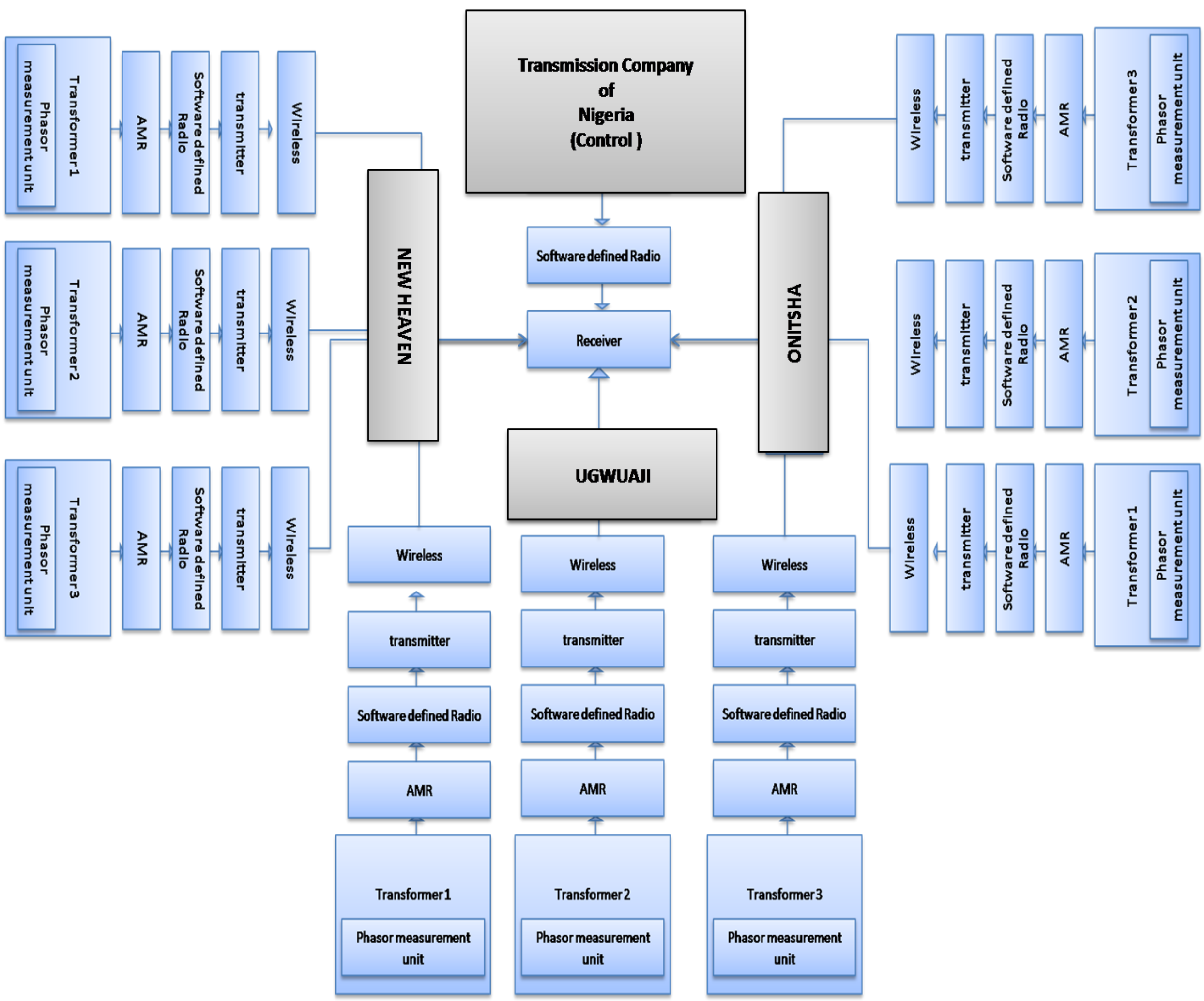

Figure 3: System block diagram

3. SYSTEM IMPLEMENTATION

This section presented the implementation of the new system using communication toolbox, power system toolbox, control system toolbox and Simulink environment. The PMU developed was deployed to monitor the bus models developed in figure 1 using the power flow formulation to monitor the bus behaviors and then collect the data with PMU for remote transmission with SDR to the control center. The simulink was presented in figure 4;

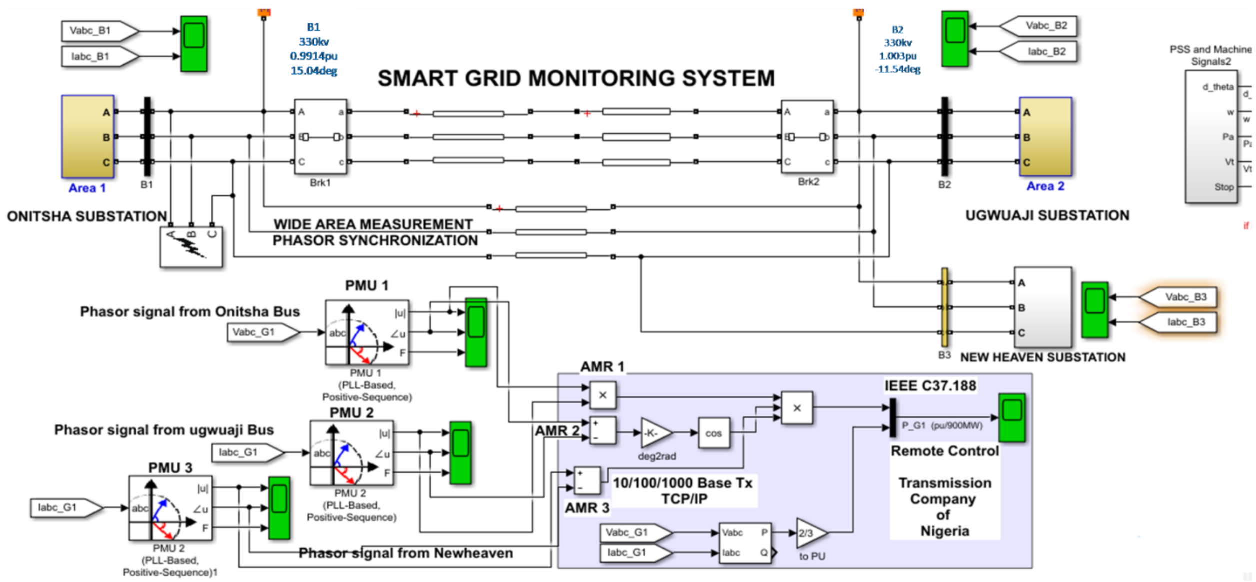

Figure 4: Simulink model of the new system

The simulink in the figure 4 presented the wide area application of the system developed for the monitoring of the grid. The performance of the simulink was measured using the simulation parameters in the table 1;

Table 1: Simulation parameters

Description	Value
Lines capacity	330kv
Nominal frequency	50Hz
Per C.T Ratio	1600:1= 1600A
Per V.T Ratio	3000V
Positive Sequence Impedance	Z.(p.u)= 0.0037+j0.0029Ω/km
Zero Sequence impedance	Zo (p.u)= 0.028+j0.0868Ω/km
Positive Sequence capacitance	8nf/km
Zero sequence capacitance	3.5nf/km
Surge impedance	300ŋ
Thermal rating	1360A
Conductor type/size	381.7mm^2 (single circuit)

4. RESULTS AND DISCUSSION

The result presented the performance of the simulation performance using the PMU on the grid. The result measured the time of synchronization of the PMU and also the phasor parameters collected from the monitoring process. The result of the PMU for data collection and synchronization was presented in the figure 5;

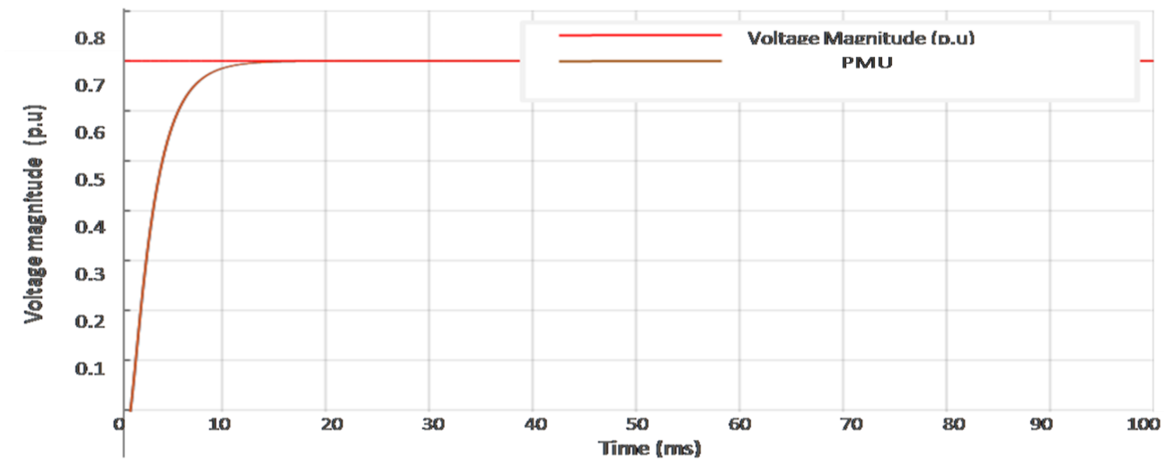

Figure 5: The response performance of the PMU

The figure 5 presented the step response performance of the PMU when used to monitor the bus performance of the grid. The result presented the step response of the PMU with the sampling time in equation 9 used to measure the time the phasor data were collected which was 12ms and then transmitted using the model in the equation 10 at 12ms. The response time of 12ms is classified as real time based on (Kopetz, 1997; Kuo and Lee, 2006) which presented time less then 20ms as software real time.

The performance of the PMU when deployed at the TCN for the monitoring of the three selected buses modeled in the equation 1 and 2 respectively. The buses were measured using the continuous power flow formulation in the equation 5 for bus voltage profile, active power in equation 7 and reactive power in equation 8 as presented in the table 2-5.

Table 2: PMU Based Grid Monitoring for Ugwuaji Bus

Report (UTC)	V[p.u.]	P Flow	Q Flow
Feb. 29 2022 11:35:00	0.943033	0.021565	0.241136
Feb. 29 2022 11:35:00	1.000311	0.000614	0.018424
Feb. 29 2022 11:35:00	0.991724	2.324954	18.54851
Feb. 29 2022 10:35:00	0.997643	2.241081	19.11358
Feb. 29 2022 09:35:00	0.946013	0.736981	6.30645
Feb. 29 2022 07:35:00	0.986123	0.007259	0.06163
Feb. 29 2022 06:35:00	0.933222	0.636623	4.430379
Feb. 29 2022 05:35:00	1.004011	0.006172	0.052461
Feb. 29 2022 04:35:00	1.044211	0.131603	1.126146

Feb. 29 2022 03:35:00	0.943033	0.031638	0.271237
Feb. 29 2022 02:35:00	1.004223	0.323727	2.252874

Table 3: PMU Based Grid Monitoring for New Haven Bus

Report (UTC)	V[p.u.]	P Flow	Q Flow
Feb. 29 2022 11:35:00	1.000302	0.018853	0.154181
Feb. 29 2022 11:35:00	1.000344	0.009071	0.088289
Feb. 29 2022 11:35:00	1.000311	0.088555	0.068876
Feb. 29 2022 10:35:00	0.981268	0.017853	0.159181
Feb. 29 2022 09:35:00	0.988903	0.123436	1.047949
Feb. 29 2022 07:35:00	0.960772	0.574485	6.423791
Feb. 29 2022 06:35:00	0.931060	0.017853	0.154181
Feb. 29 2022 05:35:00	1.000322	0.04753	-4.49868
Feb. 29 2022 04:35:00	0.999970	0.529768	5.156408
Feb. 29 2022 03:35:00	0.988903	0.125687	1.223355
Feb. 29 2022 02:35:00	0.993249	0.071948	0.610319

Table 4: PMU Based Grid Monitoring for Onitsha Bus

Report (UTC)	V[p.u.]	P Flow	Q Flow
Feb. 29 2022 11:35:00	0.981032	0.017853	0.154181
Feb. 29 2022 11:35:00	1.000021	0.123436	1.047949
Feb. 29 2022 11:35:00	0.958026	0.574485	6.423791
Feb. 29 2022 10:35:00	0.998455	0.048096	0.37141
Feb. 29 2022 09:35:00	1.000400	0.002907	0.023255
Feb. 29 2022 07:35:00	0.947704	0.007692	0.067116
Feb. 29 2022 06:35:00	0.945670	0.010792	0.075107
Feb. 29 2022 05:35:00	1.000323	0.073173	6.980696
Feb. 29 2022 04:35:00	0.903033	0.017853	0.154181
Feb. 29 2022 03:35:00	1.008000	0.123436	1.047949
Feb. 29 2022 02:35:00	0.991724	0.574485	6.423791

5. CONCLUSION

The need for smart grid monitoring has been a positive move toward the remote control, protection, analysis, monitoring of power system equipments. However the complex nature of these power systems makes the monitoring and control challenging, especially when the SCADA network is not designed properly. This problem was formulated in this study using empirical studies based on load flow analysis and then developed a PMU system which used synchophasor and phased looped oscillator to synchronize the data collection in real time and ensure optimal monitoring of the Nigerian 330KV grid.

6. CONTRIBUTION TO KNOWLEDGE

i. Real time monitoring system was developed for the Nigerian 30Bus 330KV grid network.

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