Installation of PMU on 330KV Buses to Displace SCADA System as a Permanent Solution to Power Grid Failure in Nigeria

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Received: 27-03-24
Accepted: 11-07-24
Published:26-08-24

Abstract

Nigeria is facing formidable challenges from an ever-increasing power demand and an ever-more complicated electricity grid, which makes modern monitoring and control systems essential. The installation of Phasor Measurement Units (PMUs) on 330kV buses is examined in this research as a potential strategic replacement for the current Supervisory Control and Data Acquisition (SCADA) systems. The goal is to improve the power grid's real-time monitoring and control capabilities while providing a long-lasting and reliable remedy to lessen the recurring problem of power grid breakdowns, with its supervisory control and data gathering capabilities, traditional SCADA systems have been essential to the administration of the power grid. But as the complexity of the power grid rises, its shortcomings in terms of speed, accuracy, and real-time data synchronization become more noticeable. Because PMUs can monitor voltage and current phasors accurately and quickly, they provide a more sophisticated and dependable option, this study explores the technical aspects of PMU integration on 330kV busses and emphasizes the real-time synchronized data collecting capabilities of these devices. In the case of grid disruptions, the deployment of PMUs enables better situational awareness, quicker fault detection, and more effective decision-making. The research also looks at the feasibility and long-term advantages of using PMUs instead of conventional SCADA systems, highlighting the possibility of improved grid dependability and decreased downtime, Given the distinct obstacles that Nigeria's power industry faces, such as frequent disruptions and outages, this study promotes the proactive deployment of PMUs as an ongoing fix for power grid failures. The results are intended to forward the conversation on updating power grid infrastructure and promoting a more adaptable and robust electrical grid for the long-term, sustainable growth of Nigeria's energy sector. PMU research aids in the creation of procedures and standards that guarantee the compatibility of gadgets made by various manufacturers. Global power networks depend on the extensive deployment and efficient use of PMUs, which requires this standardization. In conclusion, research on PMUs has made substantial advances in our knowledge of power system dynamics, stability, and control. It has made it easier to develop techniques and technology that support the safe and dependable operation of contemporary electricity networks.

Keywords: Phasor Measurement Unit; Supervisory Control and Data Acquisition; Breakdown; 330kv-grid; Reliable

1.0 Introduction

The electrical grid is the system tying together the distribution, transmission, and generation facilities or power grid. It delivers electrical power from generators from the electricity plants to the transmission system, the distribution system, and finally to the residences, businesses, and offices of consumers where the electricity runs their appliances and machinery. The integration of electrical grid components with information infrastructure is commonly referred to as a "smart grid," and it has several advantages for both power producers and users. The electrical energy design is a man-made network that is incredibly large and complicated, the operation, control, and monitoring of such networks now face additional difficulties due to the rising demand for electricity and the restructuring of power systems. To keep things stable and the network's integrity there is consideration to the deployment of a Supervisory Control and Data Acquisition device. Typically, SCADA systems do not support synchronous data sets. Additionally, such systems have low sampling rates. Consequently, the information provided by the SCADA network shows the semi-stable condition of the system, and the command base workers lack the necessary knowledge of the dynamism of the system characteristics (Chen et al., n.d.). The SCADA system's drawbacks have led to the development of the wide-area measurement system (WAMS), which enables accurate data assessment(Patrick et al., 2013). The fundamental constituent of a WAMS is the Phasor Measurement Unit. The preceding drawbacks could be overcome by measuring the voltage and current angles, as well as by boosting the sampling rate and simultaneous measurement capacity(Mousavi-seyedi et al., 2014). The electricity utility's main goal is to protect the system from severe breakdowns and outages and to repeatedly and uninterruptedly transmit electricity. The power of supply identification is accomplished by the use of power network analysis. The complexity of the enormous organization causes fluctuations, defects, power outages, and erratic conduct in the electricity source, so it's crucial to spot the problem early on before it gets worse and negatively impacts how the framework and components function(Hojabri et al., 2019). State Estimation (SE) performs an essential role in evaluating the electricity network's existing fitness by eliminating errors and inconsistencies with the help of surveillance instruments such as SCADA and PMUs; SCADA The framework is crucial to the electrical system since it is dependable and easy to use, even if novel obstacles are present. To estimate the present state of the electrical system's performance, proactive oversight is needed in the distribution and transmission grid using system analysis tools, using contemporary tools, low sample rates, sluggish error detection, and a lack of time synchronization signals were discovered as problems with the SCADA system performance(Darmis & Korres, 2023). The SCADA applications in industry, a network sends and receives information or data from any events of supervising, billing, evaluating, doing monitoring of operational components, such as electrical devices, sensor devices, and communication. In the energy scheme by using SCADA, the whole electrical plant can be controlled remotely over long-distance communication links. SCADA can also be used for remote transitioning, and telemetering of grid networks, it is also used for message resolution with a web control Centre (NCC) with other stations also with the producing stations (Apagu, n.d.). The development of these devices in WAMS results from the PMUs being capable of tracking the electrical system instantaneously, but electricity framework observability can't be achieved solely through the deployment of PMUs; instead, the infrastructure for communication (IC), is a crucial part of the WAMS, which must be efficiently developed and put into operation to collect data from PMUs and deliver it to command center.

1.1 Background of the Study

The PMU, which delivers information including voltages and phase angle evaluations, is the system's brain, to determine the ideal number of PMUs to install in the system for power system analysis and system economic advantages, status estimate using synchro-phasor technology is provided as a further goal(Penshanwar et al., 2016). The development of such devices in a WAMS is facilitated by the use of PMUs for online power system monitoring, but to achieve full observability, it is also necessary to examine the issue of observability in the communication system(Bashian et al., 2019). In modern transmission systems, two primary measurement systems are deployed: SCADA and WAMS. The numerous benefits of supplementing traditional Synchro-phasor readings via WAMS are frequently utilized in SCADA and SE algorithms. A vital component of Energy Management Systems (EMS), SE offers electricity system managers an in-depth knowledge of the current operating conditions of the electricity system and helps them sustain the electrical grid's resilience and reliability(Zolin et al., 2021). The SCADA framework is supposed to deliver voltage magnitudes of busbars, active electricity via subsidiaries, and reactive electricity over subsidiaries, where a subsidiary signifies both a wire for transmission and a power transformer. This must be noted that steps-down transformers and the downstream electrical network they are connected to may be characterized as a load, and vice versa for the step-up transformers, which connect a generator to a load(Dobakhshari et al., 2020). PMU is an advanced version of SCADA; it's utilized to harmonize time for determining both voltage and current. Its primary placement was to ensure full power system observability. The PMU has the advantage of being able to estimate both the voltage and current emanating from linked buses, noting their magnitudes and inclinations. It also plays a significant role in the WAMS and has the enhanced feature of monitoring, they were applied in numerous nations, and methods for phasor measurement, installation costs for PMUs, synchronization, PMU and WAMS application, model validation, and parameter identification were employed(Gopalakrishnan, 2023).

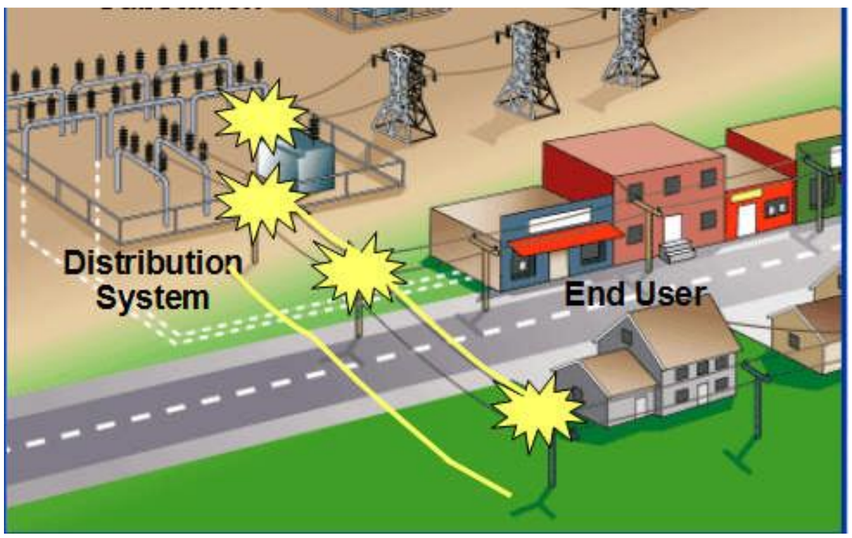

Fig. 1: Power Grid Topology

1.2 Statement of the Problem

This study looks into the possibility of replacing SCADA systems with Phasor Measurement Units (PMUs) installed on 330kV buses in order to answer the urgent need for a more sophisticated and long-lasting solution to power grid failures in Nigeria

The complex dynamics of the contemporary electricity grid are difficult to monitor and regulate with the accuracy and speed that the SCADA system now in place is unable to provide. Due to the deficiencies in the current system, there have been extended outages, ineffective problem finding, and poor decision-making during grid disruptions

The goal of this study is to determine whether replacing SCADA systems on 330kV buses with PMUs is a practical and long-term way to address power grid issues. By doing this, it hopes to provide insightful information for creating a power grid infrastructure that is resilient and adaptable to Nigeria's unique demands and challenges

1.3 Research Questions

i. What are the critical nodes and transmission corridors in the 330kV Nigerian grid network that require prioritized placement of Phasor Measurement Units (PMUs) for enhanced monitoring and control?

ii. How does the optimal placement of PMUs contribute to improving voltage stability and power flow control within the 330kV grid network, and what are the specific technical challenges associated with these improvements?

iii. What communication infrastructure is required for real-time data exchange between PMUs and the central monitoring and control systems in the 330kV grid, and how can it be optimized for seamless integration?

iv. What are the interoperability challenges between PMUs and existing Supervisory Control and Data Acquisition (SCADA) systems in the 330kV grid, and how can seamless data integration be achieved to enhance overall grid monitoring and control capabilities?

v. How can a comprehensive framework for the optimal placement of PMUs be developed, considering the unique characteristics of the 330kV Nigerian grid network, and what practical recommendations can be proposed for grid operators and policymakers?

1.4 Aim

Installation of PMU on 330kv Buses to displace SCADA System as a permanent solution to Power Grid failure In Nigeria

1.5 Research Objectives

i. To expedite data integration and enhance overall grid monitoring and control capabilities, look into PMU interoperability with current 330kV Supervisory Control and Data Acquisition (SCADA) systems.

ii. To evaluate the performance of PMU placement under different scenarios of power system such as normal, faulty and disturbance conditions

iii. To enhance the effectiveness of the monitoring system, determine the best places to put PMUs geographically within the 330kV grid, considering variables including transmission line lengths, nodal features, and regional load patterns

Designing of 330kV Nigerian grid network, to create a thorough framework for PMU placement that offers useful advice to grid operators and policymakers on how to improve the high-voltage transmission system's dependability and efficiency My literature search strategy is summarized in the flow chart below Searches were focused on Engineering journals such as IEEE, Science Direct, Springer Open, and Energies. These are tier-one journals for engineering research. I relied mainly on journals having to bear in mind the key criteria of currency, relevance, authority, accuracy, and purpose.

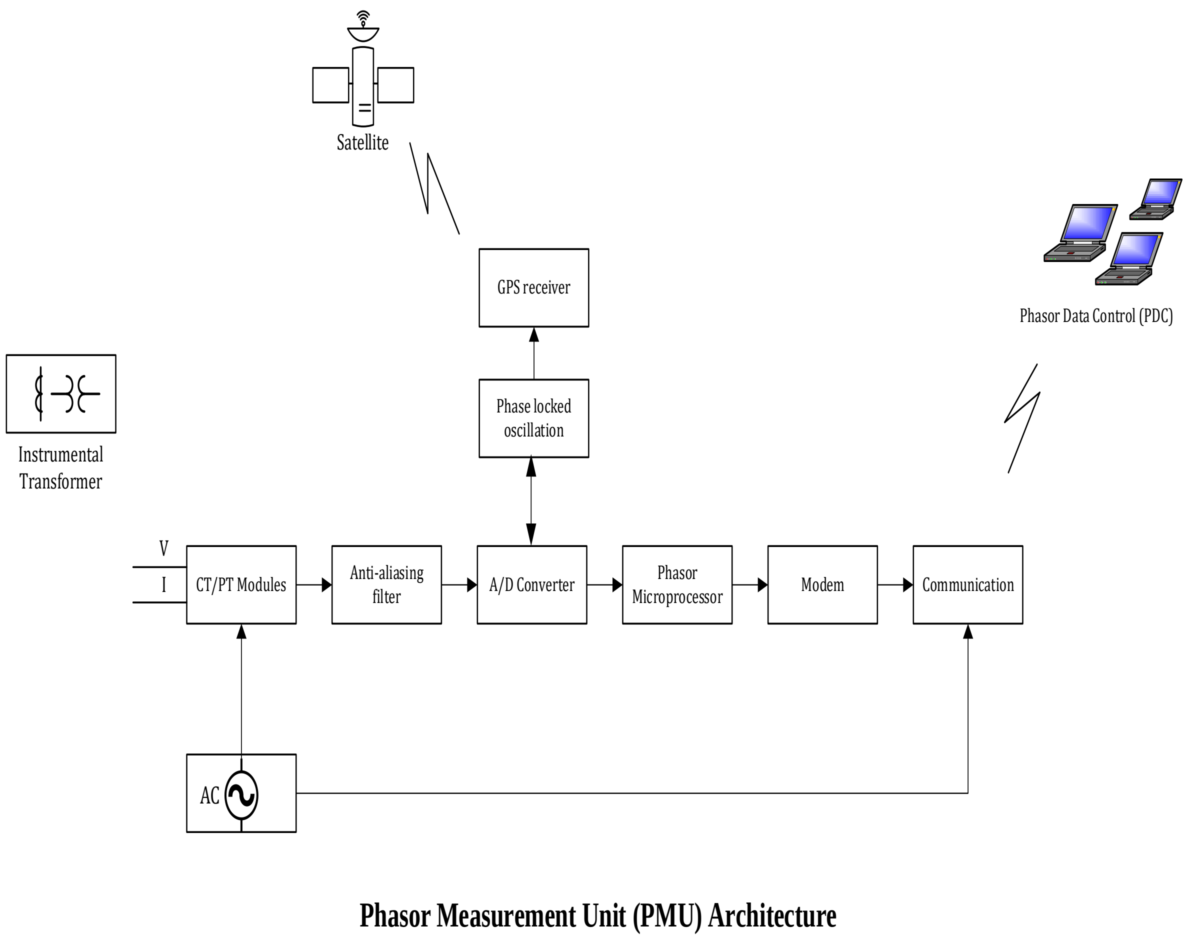

Fig 2: Phasor Measurement Unit (PMU) Architecture

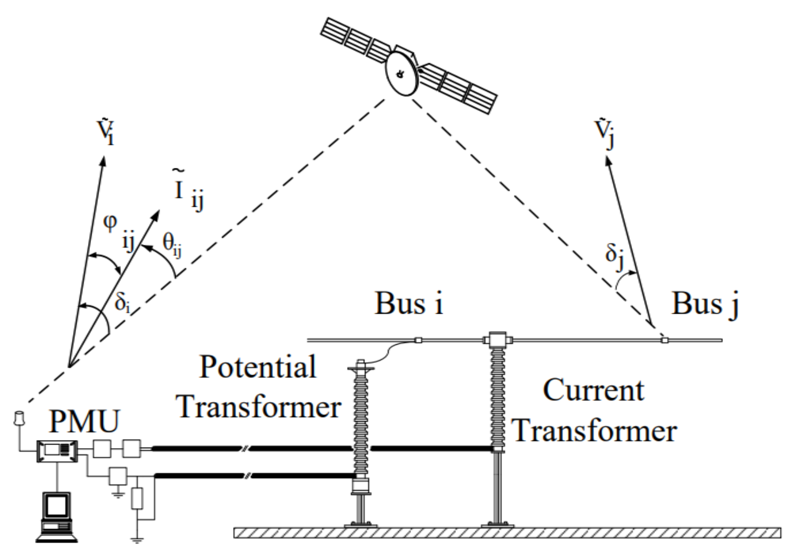

Fig. 3: Instrumental Transformer Link to Bus Bar

2.0 PMU Evolution In Some Selected Countries Worldwide

A. India

The Indian electrical grid was expanding more quickly, and as a result was divided into five parts: the Eastern, Southern, Northeastern, Western, and Northern. Those areas were currently fully harmonized, except the Southern region, which is linked by an end-to-end high voltage direct current system. A combination system made up of 6000 Mega Watt HVDC, 765-kilo volt alternating current, and 6800-kilo volt has progressed technically in recent years and has been used to install several larger power plants with capacities of about 400 MW. By 2027. The highest supply is anticipated to increase to 500 gigawatts, and the entire installed capacity should be around 700 gigawatts. Given the significance of realizing the constant change situation of the network in the context of increasing electricity framework, the creation of intellectual grid adaptive islanding with a WAMS and self-healing features is essential. To accomplish this, the principal transmission utility of The Power Grid began constructing the Remedial Action Scheme (RAS), WAMS, and other elements of the conceptual electrical network.

B. Mexico

Monitoring a low-frequency harmonic in the use of compromised networking and their protection mechanisms has advanced from PMU information in the years throughout power system perturbation because Mexico has been using PMU since the 1990s. On March 10, 2005, two of Mexico's four electric networks the National and Northwest Grid began running side by side. We were able to replicate the variations that occurred during the synchronous operations by using the WAMS after the system ultimately parted Once the connecting lines were coupled, the entire region experienced noticeable inter-area fluctuations, During the years to come, real-time non-online PMU investigation was utilized to analyze unstable hazards, involving restricting fluctuations with alerts and computing reactive power voltage and active power frequency curvatures of generators at dissimilar phases of load generation and system configurations. Other power systems data, such as frequency, phase angle, voltage, real power, and reactive power, are estimated in the PMUs directly. Future three-dimensional studies of the dynamic behavior of remote relays and transmission line vibrations are possible.

C. North America

The first PMU technology model was developed at Virginia Tech in the early 1980s. Due to catastrophic blackouts that occurred in Canada and the Northeast of the United States in 2003, synchronized measurement played a significant role in enhancing the reliability of the North American grid(Dagle, 2010). The U.S. Department of Energy (DOE) used data that was collected from PMU during the blackout in its research. Data transmission from the Eastern Interconnection Phase Project (EIPP) to the Tennessee Valley Authority (TVA) has begun, Various PMU systems, which are essential to the Phasor Data Concentrator, as well as businesses like Ameren, American Transmission Company, and American Electric Power, etc. California ISO started working on research and prototype testing in the western part of the United States in 2002. The implementation of real-time PMU data analysis, data visualization applications, and dynamic stability evaluation were all enhanced by using the newest technology(Science, 2012). Several additional companies are today up and running in Alberta. The union of the Western and Eastern North American initiatives resulted in the formation of the NASPI, which now includes Canada and Mexico.

D. Brazil

Since the end of the year 2000, currently, the Brazilian Independent System Operator has been engaged in two WAMS-related programs that point to the implementation of a significant internet and physical scale mode. This scheme is progressing well besides takes already accomplishing many objectives, including tools for system description and design, as well as for confirming experimental application installations. Each substation has a PMU, a State Power Dispatching Center (SPDC), and a primary phasor data concentrator that was completely a part of the arrangement design. To ensure the precise and dependable operation of every PMU, the installations were made to re-harmonization of islands, closed-loop systems in their particular Brazilian National Power System Connectivity (SIN) parts, fluctuations of the watching network with inadequate damping devices, monitoring of the concerns of the electricity grid, and fluctuations of the monitored network.

E. China

In 1995, PMU was initially incorporated into the Chinese electrical grid network. Between 1995 and 2002, the Sichuan electrical power grid network centers built the central station of the data concentrator of the WAMS, and about 30 to 40 PMUs were deployed. The PMUs installed in the Chinese electricity network successfully captured the low-frequency oscillations' dynamic processes. PMUs were still being sold commercially by Chinese manufacturers by the end of 2002. To introduce the PMU that has been installed in the power grid of Chinese power plants with an output of at least 100 MW, several key 220 kV substations, and all substations with an output of 500 kV or above. The installed PMU count on the actual system is over 3000.

F. Russia

The fourteen National power systems, which participated in coordinating from Tajikistan to the Kola Peninsula besides from the western border of Ukraine to Lake Baikal, constitute the synchronized coupling of Central Asia, Siberia, and Eastern Europe. The Russian WAMS energy grid comprises three control structures and spans the largest geographic area in the world with its eight time zones. The first one consists of transducers mounted at substations and multipurpose computing communication servers. The second level is made up of control centers connected to dispatch centers and dispatch offices that are assigned to UPS of Russia. PMU and uninterrupted power supply are today primarily employed for low-frequency fluctuation surveillance, network representation evaluation, and observation, real-time power system control, and system manager's ability to create new schemes and processes for power system alternative control. PMUs are a helpful tool for analyzing the synchronous interconnection's dynamic behavior.

G. Europe

WAMS and PMU have expanded dramatically in recent years, with practically every country in Europe now having one. 30 PMUs would be outfitted in Italy, according to the plans. Three universities in Sweden have created an experimental system with three PMUs. In Denmark, there are two PMUs established for research. The Swiss furthermore used WAMS(Johnson & Moger, 2021). These devices (GPS or DCF77) all have high current and high voltage precision (class 0.2), as well as perfect coordination of the times, the application of coordinated phasors as a component of its self-protective approach to take command, the center continuously monitors variations in phase angle among an area and the rest of the country. Once the angle separation exceeds the limits, the province's connection lines will separate from the rest of the country.

H. North African

Four regions make up the monitoring of the North African power system: Libya, Tunisia, Algeria, and Morocco. Algeria (Chefia) and Tunisia (Jendouba), Algeria (HassiAmeur) and Morocco (Bourdim), Morocco (Melloussa), and Spain (Puerto of the Cruz) are all connected by the 400 kV network. Monitoring of the power system interconnection must take into account the active power, reactive power, node voltage, frequency, and phase angle. Using PMU technology in this regard yields accurate measurement results. The WAMS was created to increase grid reliability and stability through vibration identification, early warning of power system disruptions, and data processing techniques. The technique was employed in numerous interconnecting electrical systems, including the North African interconnection power system where PMUs were used. The decentralized control architecture has been presented for each area. We integrated numerous PMUs into our technology, and each PMU communicates with a local PDC in this area and a large PDC, with all data being transferred to the monitoring system (Tsebia & Bentarzi, 2018).

3.0 Literature Review

To ensure network observability, it is necessary to discover the weak buses and identify the strategic locations for PMUs because PMUs are favored for installation at vulnerable buses in electrical energy grids. To resolve where to install the most PMUs at the vulnerable buses in the electrical network, the voltage failure nearness needle, cable resilience directory, quick voltage resilience index, and a reinvigorated voltage equilibrium indicator leveraging load flow compliance are all utilized. The developed method's efficacy is examined and verified using an analysis technique, which dependent on the binary buses-to-buses connectivity matrix, provides the quantity of PMU locations necessary for making the electricity grid visible(Babu et al., 2020). Modern dispatching heavily uses digital microprocessor technology, for the global development of power systems is the introduction of WAMS. WAMS among the greatest priorities uses a well-researched technique for quantifying angular data in numerous remotely located components of the electrical system, with the right by eliminating or minimizing constraints on the flow of electricity ability, information gathered or obtained from PMUs can be used to increase the efficiency of sustaining the electrical network in an operational state and to save money(Chakrabarti et al., 2009). PMU is a sophisticated metering equipment that accurately measures the both circuits' electrical current and voltage harmonics in the grid station to which it is directly attached. This measurement is done in real-time and synchronization. The tool is connected to the busbars of the electricity network in electricity distribution as well as transmission processes to offer time-synchronized evaluation using the GPS; nevertheless, the installation and upkeep expenses associated with the equipment are unobtainable for the electrical utilities; As a result, numerous techniques for optimization are being established recently in efforts to address the best placement of PMU difficulties to diminish the global price by providing full electrical coverage(Angioni et al., 2017). PMUs are an intentional choice because of their unique capacity to give precise bus voltage as well as current phasor measurements. However, it is customary to deploy just a few PMUs in a system due to their expensive price and need for communication facilities. Contemporary electrical systems are designed to accommodate the installation of highly accurate PMUs as well as conventional meters, which will improve network security, surveillance, and control; The genetic algorithm (GA), one of the well-known intelligent optimization methods, is utilized to look for the ideal collection of PMUs (Shahriar et al., 2018) SE is a crucial component of energy management systems (EMS), giving power system operators a comprehensive understanding relating to the current working conditions of the energy system that will assist them in maintaining the grid's reliability and security. Both primary measuring frameworks, the SCADA and WAMS, are used in contemporary electrical fields are deployed. Numerous benefits of supplementing traditional SCADA and SE processes with synchro-phasor evaluation from the grid(Ghasemkhani et al., 2015). This study presents a data-driven technique to improve situational awareness in power distribution systems. It analyzes the kinds of frequent events recorded in distribution feeders and uses data from PMUs to categorize them. The classification of periodic incidents within the distribution networks as coming from the network's transmission side, happening inside the feeder network, or process-induced is proposed as a three-stage method. PMU data from Riverside Public Utility (RPU) and Lawrence Berkeley National Laboratory (LBNL) are used to test the suggested technique(Duan et al., 2020). To make smart distribution networks fully observable while taking into account the network's asymmetrical structure, a Binary Integer Linear Programming (BILP) model is developed. To lower the expenses compared to the balanced scenario with the full extent of the zero injecting qualities, three test networks the IEEE 13-buses topology, 37-buses topology, and 123-buses test feeders are evaluated as unequal, the model that is currently being presented also addresses the single PMU outage contingency, which by its very nature upsurges the numeral of PMUs, in this study, however, this addition is constrained so that end buses aside from those that are critical can be seen from at least one way rather than from two paths(Moradi-sepahvand et al., 2019). In this context, the paper outlines the different analyses founded on PMU for full observability and monitoring of integrated electrical energy network systems, the study reveals majority of the contemporary study is concentrating on ideal PMU placement (OPP) sooner than the invention and modeling of PMU. The PMU is the core of the smart grid strategy as it delivers details such as voltage and phase angle measures of all buses of the system and thereby sustains the plan observability (Zolin et al., 2021). The introduction of PMUs with an elevated replenishing rate is appropriate for the allocation group and will deliver real-time synchro-phasor data such as voltage phasors, current phasors, frequency, and rate of evolution of. The classical PMUs employed in transmission electrical grids are inappropriate for radial allocation webs due to their high price and communication restrictions. The monetary anxiety is relieved by the most suitable possible placement of PMUs on the buses of smart RDN. The optimal PMU placement (OPP) crisis is determined by bringing into account two techniques: the first is to maximize redundancy while compromising the cost criteria, and the second is to minimize overall deployment costs while maintaining full system observability (Kotha et al., 2022). The state estimation and the synchro-phasor measurements. To assess and compare the effectiveness of the suggested algorithms, simulations are run on a variety of test systems of varying sizes(Jovicic et al., 2021). In this work, a PMU placement scheme is proposed to lessen the power system's vulnerability to cyberattacks. A much-stage PMU placement method was conceived to lessen the electrical energy system's susceptibility over probable erroneous data injection invasions using onward active programming to circulate the asset's cost of PMUs over a period horizon. An index is also proposed to measure the susceptibility of grid nodes to inaccurate data injection. The suggested method will likewise guarantee the integral observability of the grid in its foremost stage and advance observability levels in succeeding stages. Simulation results are provided for IEEE 14-buses topology, IEEE 39-buses topology, and IEEE 118-buses trial systems, taking the impact of zero injection buses (ZIB) into consideration(Khajeh et al., 2015). The installation of PMUs in electrical energy grids is primarily focused on the electrical transmission network, and experimenters are constantly expanding PMUs for their facility in the electrical transmission cable. However, due to improvements in allocation networks, precisely for smart allocation networks, an instrument called a PMU that develops real-time synchro-phasor information from the client voltage level is going to be established and could present a unique understanding into contemporary electrical energy systems as likened to present commercial PMUs, these units can be produced at a cost that is a mandate of extent more downward. This allows for the deployment of many more PMUs, which would give the distribution grid a considerably greater resolution(Jain & Bhullar, 2018). Due to the rapid development and increasing importance of PMUs for use in future distribution networks, it is unrealistic and unaffordable to equip every bus with PMUs due to their high cost, necessitating the determination of the distribution system's optimal placement with the fewest possible PMUs. This is done by using a greedy algorithm to determine the optimal PMU a combination of a node choice technique and data entropy evaluation for the best position (OPP) (Wu, 2018). To create and put into operation a live fault identification testing simulation using genuine computer parts, this article performed an investigation. The system of monitoring and the fault location problem are some of the most important concerns in the operation of electricity systems and supervision. The impedance-based problem location method is integrated into the system to estimate the distance to the fault in the transmission line(Khoa & Tung, n.d.). The goal of the proposed method was to improve contextual comprehension in the distributed network by keeping an eye on how different network components, such as loads and distributed energy resources (DERs), are working or not. The suggested technique creates an analogous circuit that symbolizes the event utilizing voltages following the substitution hypothesis in circuit theory, when smart meter measurements are available, the suggested technique for monitoring and estimating conditions in networks of distribution is to modernize the system states behind an occasion, such as a hasty load transition, that occurs in between 5 to 15-minute intermissions. Allocation system SE is often not real-time because of the numerous nodes and the limited number of measurement sources; instead, it is frequently performed once every 5 to 15 minutes, Applications requiring real-time monitoring and control are quite interested in this technique. This technique was created to update the SE outcomes, an alternative circuit is created according to the adjustment principle in the concept of circuits using the before-the-event and post-event input information. At the substation and the ending of the preceding input or laterals, PMUs are installed(Liu et al., 2020). PMU use has become crucial in the immediate monitoring, shielding, and even management of unique and complicated allocation systems because synchro-phasor technology spreads a new window for electrical power technique observability. PMUs can deliver harmonized objective information such as frequency, voltage and current phasors, oscillation, and temperature for electrical energy systems (Hojabri et al., 2019). A measurement tool known as a PMU, or distribution-level PMU (D-PMU), estimates the harmonized electrical voltage and electrical current worth of electrical energy power allocation networks. The synchronized data obtained by PMUs can be used for monitoring, diagnostic, and management applications on distribution networks, allowing operators to see the dynamic states of the distribution network in real-time. In this paper, we discuss the most recent work on PMUs, including applications for PMUs, monitoring and diagnostic capabilities, control applications, and the best locations for PMUs(Cui & Weng, 2019). It is necessary to find the best locations to install PMUs in the network for an observable system, with the least amount of investment. This optimal placement of PMUs (OPP) is a binary optimization problem of a combinatorial nature. PMUs are used for wide-area monitoring of power system states. PMUs measure synchronously real-time voltages at various buses and current phasors that are flowing toward these buses(Nasrun et al., 2019). In this paper, it is suggested to employ a PMU-based technique for calculating fundamental phasors, and periodic contribution is then estimated using the sine harmonic phasor produced by the PMU. The preciseness of the harmonic phasor estimated by PMU and the traditional swift Fourier modification are compared in the case of the frequency of the signal departing from rated; ultimately, a PMU-based harmonic phasor calculation(Dusabimana & Yoon, 2020). In this research, a dynamic variable-weight state estimate of the distribution network has been accomplished using measurement data from the -PMU in conjunction with SCADA(Wang, 2017). Rapid improvements in measurement and computing technologies are bringing about a fundamental change in the way that electricity networks operate across the globe. Developing electricity networks' self-healing functionality necessitates the immediate detection and localization of transmission line defects throughout the whole electricity grid. A unique help vector machine-based defect localization process is suggested in this report to specifically recognize and localize all fault kinds in power grids(Ravi et al., 2022). PMU positioning in electrical systems usually happens beneath the assumption that all of the system's buses will have simple bus agreements. This does not guarantee the visibility of sophisticated buses under operational conditions in which lines located at complicated buses aren't linked to one another at a single busbar. It is an innovative approach for PMU positioning that considers (Gopakumar et al., 2015). High-speed and coherent real-time information on the electrical network that is not achievable in conventional SCADA systems could be provided with this cutting-edge technology, The investigation focuses on the analysis of the traditional SCADA system, which focuses on RTUs, and makes suggestions for how to incorporate this innovation, PMU, into SCADA networks to improve security first, followed by monitoring and controlling system in advanced electrical systems(Bentarzi et al., 2018).

3.1 Phasors Measurement Unity (PMU)

A PMU is an electronic device used in the power system to measure and analyze electrical quantities such as voltage, current, frequency, and phase angle, among others. The IEEE defines a PMU " as a tool that generates coordinated phasors, frequency, and rate of change of frequency (ROCOF), and infers a time-matching signal from both voltage and current signals, The difficulties can be successfully overcome by using a newly designed PMU which can deliver up to 120 time-tagged observations per second, but those PMUs must have the required features connected to the distribution system's vulnerability factors. The PMU is capable of providing highly accurate and synchronized measurements of these quantities in real-time, which is essential for the efficient and reliable operation of the power system(Muhayimana & Toman, 2022). PMUs obtain and determine the analog signal spectrum as required by taking readings from instrument transformers (CTs and PTs) and sending them to neighboring PDCs via an aliasing mixer. To acquire the desired digital signal, data are then sent through an analog-to-digital converter in the central processing unit, where the signals' magnitude, as well as phase, are determined and data time is coordinated by a random sampling clock. following the GPS receiver signal(Biswal & Mathur, 2015).

Phasor and its visual interpretation:

3.2 Power System Observability

When calculating the bus voltage phasors at all of the system's buses using Kirchhoff's and Ohm's law's known or fictitious measurements, the power system is taken to be entirely observable. Topological and numerical observability are two different types of system observability. By measuring the Jacobian matrix's entire rank, the earlier one is ensured. The latter, though, explicit revelations are made. The system's overall observability in this study is calculated by accounting for topological observability.

A distribution network must be observable to function securely and effectively to boost the network's accuracy and dependability. All the bus voltages and line current phasors must be independently established to be considered completely observable. The installation bus's voltage phasors and the event's lines' current phasors are measured by the PMU. Lines variables and Ohm's law can be used to determine the voltage phasors of buses that are close to the current bus. All buses connected to the bus-installed -PMU are hence observable. For example, the installed bus's voltage phasors and the lines' 1-2, 2-3, and 2-4 current phasors are directly measured by a -PMU when it is installed at bus 2 in Figure 2. The voltage phasors of buses 1, 3, and 4 are then determined using these measurements.

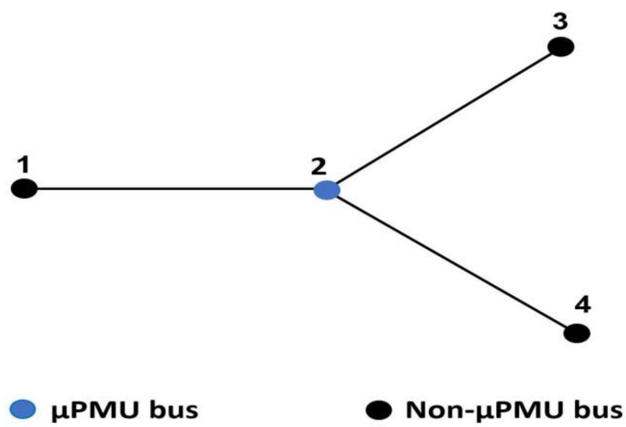

Fig. 4: µPMU and Non µPMU Buses

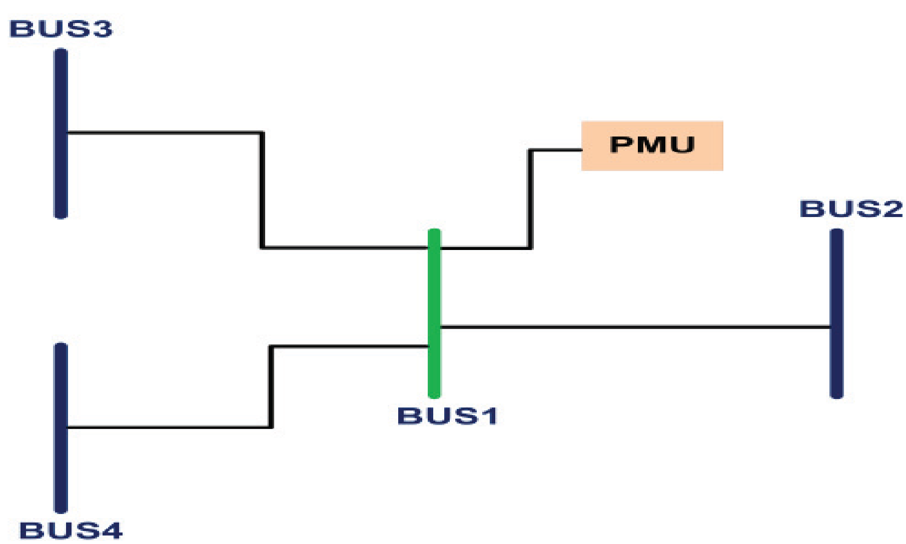

Fig. 5: **Graphical Representation of 4 Buses with PMU**

To demonstrate the PMU observes the bus voltage phasor at where it is situated as well as the current phasors across the branches linked to that bus, as illustrated in Fig. 5 That improves the system's overall observability. A PMU can immediately measure the voltage phasor of bus 1 as well as the current phasors of lines 1-2, 1-3, and 1-4 once it is connected to the bus. Bus 1 is said to be immediately observable because of this. The KVL and Ohms laws, along with known information, can be used to determine the voltage phasors of buses 2, 3, and 4. The result is, that these buses are indirectly observable, making the entire system visible(Kotha et al., 2022).

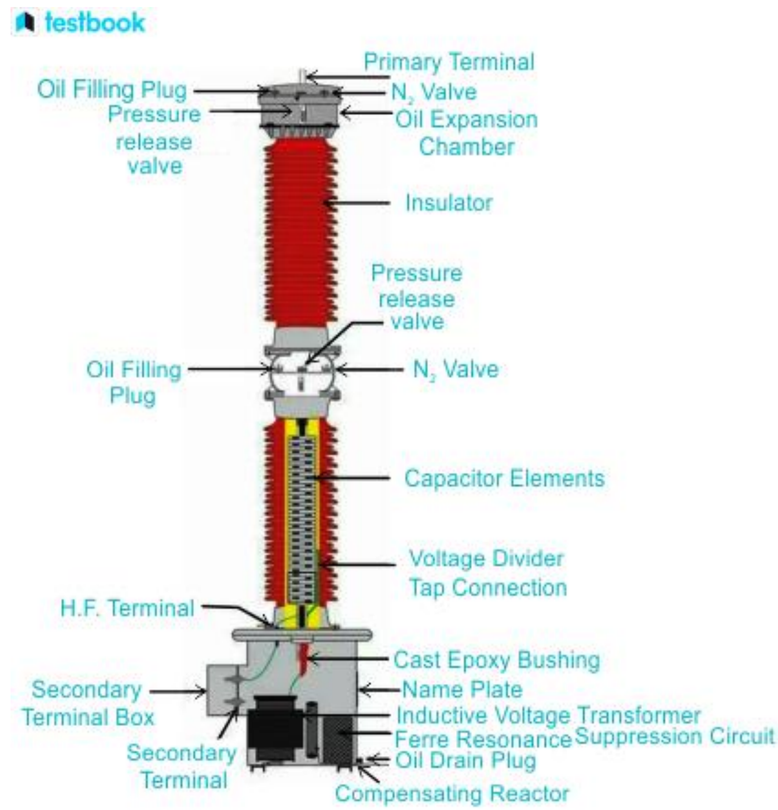

Fig. 6: Potential Transformer

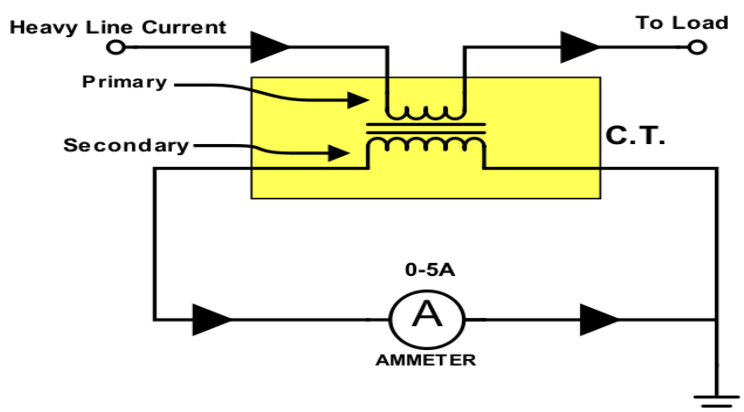

Fig. 7: Current Transformer

Suppose considering a pure sinusoidal quantity that is

$$x(t) = \sqrt{2} \times \sin(\omega t + \varphi) \quad (1)$$

ω being the angular frequency of the signal in radians per second, and φ being the phase angle in radians.

Equation (1) can also be written as

$$x(t) = Re\{Xe^{j(\omega t+\varphi)}\} \quad (2)$$

The sinusoid of Eq. (1) is represented by a complex number $X*$ known as its phasor representation

$$xt) = \left(\frac{X}{\sqrt{2}}\right)e^{j\emptyset} = \frac{X}{\sqrt{2}}(\cos\emptyset + \sin\emptyset) \quad (3)$$

The choice of the axis at t = 0 determines the phasor's phase angle, which is arbitrary. The sinusoid's root mean square value is the same as the length of the phasor. It is claimed that only a pure sinusoid can have a phasor representation. In reality, many signals with different frequencies might distort a waveform, making it necessary to isolate the signal's single-frequency component. Then, using a Fourier transform is possible to extract the wavelength component that a phasor represents.

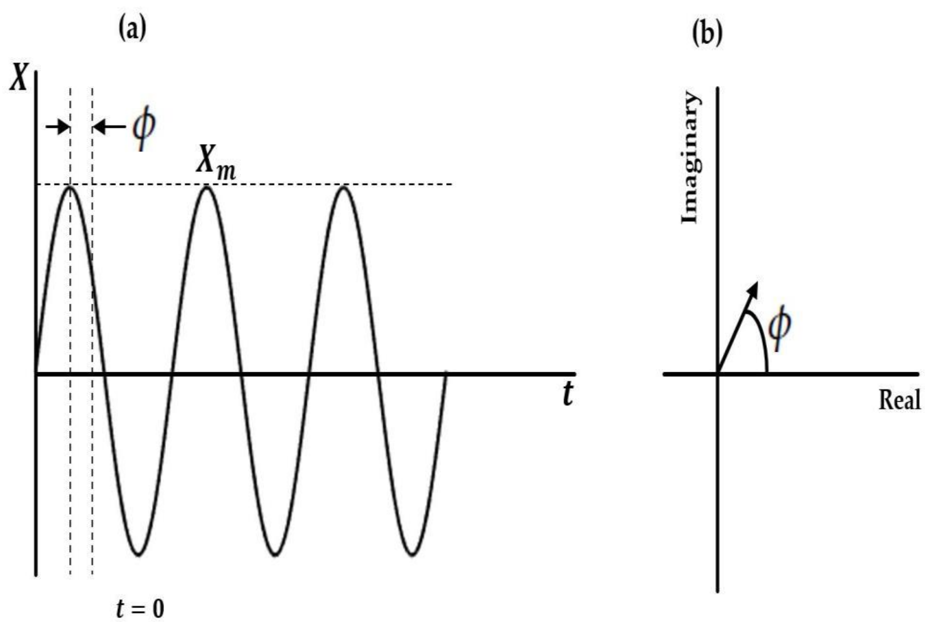

Fig. 8: (a) Sinusoidal Waveform; (b) Phasor Representation

3.3 Synthesis of the Ideal -PMU Placement Problem

The primary goal of the OPP problem is to achieve complete system observability, ensure that every minimum of one PMU monitors each bus in the network as a whole, and reduce the total cost of installing PMUs to the lowest level practical. For the N-bus distribution system, the restriction value for the OPP problem is defined as:

$$Min \sum_{i=1}^{N} Ci \times Oi$$

Ci Oi illustrates each bus's visibility and is defined as follows: reflects the total capital cost of the PMU placed at bus-i

$$0 = \begin{cases} = 1 & bus\ i\ is\ observable \\ = 0 & bus\ i\ is\ unobsevable \end{cases}$$

The number of branches connected at the bus in a radial distribution system determines the price for each PMU based on the total number of channels, the above-constrained optimization function is used to deploy PMUs as little as possible. The cost of every -PMU is assumed to be the same for maximum system redundancy, which changes the objective function to reliability and resiliency benefits. Distribution networks' dependability and resiliency can be improved by cutting down on both the length of outages and the number of customers who are affected by them, additionally contributes to a shorter turnaround time for service restoration by facilitating quicker line reclosing, forensic investigation, black-start, island resynchronization, and generation synchronization, as well as quicker fault location and location identification. By detecting oscillations and taking steps to restore network stability, one can lessen interruptions. One can also limit the number of outages by spotting probable equipment failures and fixing them before they occur (Eto et al., 2014). The accuracy and speed of line reclosing and generator synchronization can be monitored and enhanced using phase angle. PMU data can be used to evaluate the events that take place when interruptions in the distribution network happen so that the operator can identify the causes. Distribution networks experience a variety of events, however, the traditional models used to monitor distribution networks are unable to accurately forecast the network behavior under various network disturbance situations.

3.4 Techniques for Measuring Phasors

The phasor prediction model's goal is to obtain the phasor representation. Usually, the basic frequency of the electrical system's configuration frame is one period, Sample waveform data are assembled transversely. Commercial PMUs now sample at rates that are noticeably higher than the initial standard of 12 cycles per second. The phase angle, or angle across the value of the moment and the highest point of the input signal, is determined using the root mean square (RMS) values of the input signal. The input signal was anticipated to have been filtered using the Nyquist criterion for the chosen sample rate, and the angular If the input signal's frequency deviates from the actual frequency, corrective and amplification should be applied to compensate for it. The fractional process frame is not necessary for phasor estimating in the multiple-cycle window when the estimator of the data window needs to be moved from one period to another PMU (Gopalakrishnan, 2023). Additionally, synchronization signals can be transmitted via terrestrial fiber-optic networks. PMUs, which employ the precision time protocol to synchronize clocks over computer networks with precision down to the sub-microsecond range, may also be synced. The IEEE Standard 1588 - 2019 quantifies Precision Time Protocol version 2, and the IEEE Standard C37.238 - 2011 specifies its outline for use in power systems. A grandmaster clock located at the top of each system synchronizes the various clocks to establish a universal time(Alghamd & Schukat, 2020).

4.0 Methodology

4.1 Materials

MatLab Simulink toolbox 2022b, Power Syste m Software Engineering PSSE, power system analysis toolbox (PSAT), E-Tap, Core i5 PC with 16GB RAM and dedicated SSD capacity of 512GB.

The step-by-step procedure for actualizing the aim and objectives of this research work are itemized below:

Step 1: Review of Related work: Conduct a thorough review of existing literature related to PMU placement in power systems, to identify the latest advancements, methodologies, and challenges in PMU placement

Step 2: Collection of Data and Analysis of Major Grid collapses in Nigeria and the causes for the past 30years

Step 3: Collection of Data of the existing Nigerian 330kV Transmission network from National control center (NCC) Oshogbo through the System Operator unit of the Transmission Company of Nigeria (TCN).

Step 4: Model and perform Load flow analysis of Nigerian 330kV Ringed Transmission network, the Nigerian ten (10) regional 330kV ringed Transmission network to obtain dynamic state basic parameters of synchronous system bus voltages, phase angles, line current, real and reactive power flowing in each line respectively.

Step 5: Data Collection: Gathering of relevant data about 330kV Nigerian power system, including network topology, load profiles, generation patterns and historical system events, obtaining information on existence of PMU installations and their performance

4.1 Research Methodology

i. Review of Related Work:
Perform a comprehensive analysis of the body of research on PMU installation in power systems. Recognize the most recent developments, approaches, and difficulties in PMU placement. Recognize the various factors that go into the best possible placement of PMUs

ii. Data Collection
Collect essential information about the power system, such as load profiles, generation patterns, network structure, and past system events. Find out about the functionality of the PMU installations that are currently in place.

iii. Modeling and Simulation
Model the power system that is being studied by using power system simulation tools (e.g., MATLAB, PSSE, MATPOWER). Run several simulations to assess how the location of PMUs affects system performance and observability.

4. Optimization Algorithm
Use optimization methods to determine the best places to put PMUs, such as Smell Agent Optimization is an example of common optimization approaches. Consider limits includin g financial restrictions, communication infrastruct ure, and regional constraint.

5. Validation
Make sure the suggested PMU placement plan is supported by case studies or actual data. To confirm the efficacy of the suggested methodology, compare the simulation findings with the actual behavior of the system.

6.Cost Benefit Analysis
Assess the advantages and disadvantages of putting the suggested PMU location into practice. Consider elements like PMU costs, communication infrastructure, and possible increases in system reliability.

5.0 Result and Outcome

i. Optimal PMU Placement Strategy: In order to improve system monitoring capabilities and optimize grid observability, the research aims to determine the most advantageous places for PMU installation. Anticipation: The created algorithm will produce a set of recommendations for the best PMU placement, improving the resilience and reliability of the grid.

ii. Improved Grid Stability and Resilience: The purpose of the research is to improve the overall stability and resilience of the Nigerian 330kV AC grid by strategically placing PMUs. Anticipation: The application of the suggested PMU placement approach will result in increased grid stability, quicker fault identification, and better disturbance response

iii. Rules for Planners and Grid Operators: It is hoped that the outcomes of the study will offer insightful recommendations to policymakers and grid operators, assisting them in making defensible choices on the deployment of PMUs for improved grid monitoring and control

6.0 Discussion

i. **Improved Grid Reliability:** It is anticipated that the integration of PMUs will greatly increase Nigeria's electricity grid's dependability. PMUs give operators a more complete understanding of the dynamics of the grid by supplying precise and synchronized real-time data, which facilitates the early detection and resolution of possible problems.

ii. **Diminished Downtime:** PMUs enhanced situational awareness and quicker fault identification are expected to minimize downtime during power system outages. Timely fault isolation and identification can speed up restoration efforts and reduce the financial losses brought on by extended outages.

iii. **Enhanced Decision-Making:** During grid disruptions, PMUs' high-speed data collecting capabilities facilitate quicker and more informed decision-making. As a result, problems may be addressed more effectively and efficiently, lessening the effects of disruptions and guaranteeing the electricity system runs more smoothly.

iv. **Scientific Advancement:** The use of PMUs in power grid monitoring and control is an example of technical progress. This study has the potential to accelerate the adoption of cutting-edge technologies in Nigeria's electricity industry and establish the nation as a pioneer in the continent's contemporary grid infrastructure

7.0 Conclusion

PMUs are crucial tools for continuous monitoring, control, and surveillance of electrical networks, as this critical literature review research demonstrates. They provide synchronized measurements of phasors, which can be utilized for real-time monitoring and observation of the state of the electrical power grid network. They measure electrical power grid values such as voltage and current signals at every given place on the grid network. This paper's goals are to present an overview of electrical power grid systems, smart grid technologies, SCADA, PMUs, and the global development of PMUs, including their price, cost of installation, range of applications, power system reliability evaluation and oversight, fault identification and evaluation, reliability of electricity monitoring and control, security and management of power devices, and real-time monitoring and control of electrical power systems are all included. Additionally, numerous methods such as analog-to-digital converters, communication technologies, and global positioning systems for time synchronization are used to make PMUs operational.

Reference

Alghamd, W., & Schukat, M. (2020). A Detection Model Against Precision Time Protocol Attacks. IEEE, 1–3.

Angioni, A., Lipari, G., Pau, M., Ponci, F., & Monti, A. (2017). A Low Cost PMU to Monitor Distribution Grids. IEEE, 1–6.

Apagu, S. (n.d.). TRANSMISSION COMPANY OF NIGERIA.

Babu, R., Raj, S., & Bhattacharyya, B. (2020). Weak bus-constrained PMU placement for complete observability of a connected power network considering voltage stability indices. Protection and Control of Modern Power Systems, 8, 1–14.

Bashian, A., Assili, M., Anvari-Moghaddam, A., & Catalão, J. P. S. (2019). Optimal design of a wide area measurement system using hybrid wireless sensors and phasor measurement units. Electronics (Switzerland), 8(10), 1–1. https://doi.org/10.3390/electronics8101085

Bentarzi, H., Tsebia, M., & Abdelmoumene, A. (2018). PMU based SCADA enhancement in smart power grid. Proceedings - 2018 IEEE 12th International Conference on Compatibility, Power Electronics and Power Engineering, CPE-POWERENG 2018, 1–6. https://doi.org/10.1109/CPE.2018.8372580

Biswal, A., & Mathur, H. D. (2015). Optimized PMU Stationing for Wide Area Monitoring of Power Grid. Procedia Technology, 21, 2–7. https://doi.org/10.1016/j.protcy.2015.10.002

Chakrabarti, S., Kyriakides, E., Bi, T., Cai, D., & Terzija, V. (2009). Measurements Get Together. IEEE Power and Energy Magazine, 7(1), 41–49. https://doi.org/10.1109/MPE.2008.930657

Chen, T., Ren, H., Sun, Y., Kraft, M., & Amaratunga, G. A. J. (n.d.). Optimal Placement of Phasor Measurement Unit in Smart Grids Considering Multiple Constraints. XX(Xx), 1–11.

Cui, Q., & Weng, Y. (2019). Enhance High Impedance Fault Detection and Location Accuracy via -PMUs. 1, 1.

Dagle, J. (2010). The North American SynchroPhasor Initiative (NASPI). IEEE PES General Meeting, PES 2010, 1–3. https://doi.org/10.1109/PES.2010.5590048

Darmis, O., & Korres, G. (2023). A Survey on Hybrid SCADA / WAMS State Estimation Methodologies in Electric Power Transmission Systems.

Dobakhshari, A. S., Azizi, S., Abdolmaleki, M., & Terzija, V. (2020). Linear LAV-based state estimation integrating hybrid SCADA / PMU measurements. The Institution of Engineering and Technology, 14, 1583–1590. https://doi.org/10.1049/iet-gtd.2019.1850

Duan, N., Stewart, E. M., & Member, S. (2020). Frequency Event Categorization in Power Distribution Systems using Micro PMU Measurements. IEEE Transactions on Smart Grid, 1–11. https://doi.org/10.1109/TSG.2020.2967641

Dusabimana, E., & Yoon, S. G. (2020). A survey on the micro-phasor measurement unit in distribution networks. Electronics (Switzerland), 9(2), 1–16. https://doi.org/10.3390/electronics9020305

Eto, J., Yang, S., & Lesieutre, B. (2014). Improving Reliability Through Better Models. Ieee Power & Energy Magazine, 44–51.

Ghasemkhani, A., Monsef, H., Rahimi-Kian, A., & Anvari-Moghaddam, A. (2015). Optimal Design of a Wide Area Measurement System for Improvement of Power Network Monitoring Using a Dynamic Multiobjective Shortest Path Algorithm. IEEE Systems Journal, 11(4), 2303–2314. https://doi.org/10.1109/jsyst.2015.2469742

Gopakumar, P., Jaya, M., Reddy, B., & Mohanta, D. K. (2015). Transmission line fault detection and localisation methodology using PMU measurements. The Institution of Engineering and Technology, 9(11), 1033–1042. https://doi.org/10.1049/iet-gtd.2014.0788

Gopalakrishnan, R. (2023). Phasor Measurement Unit Across the World and Variables Influencing the Cost of Installing a Phasor Measurement Unit. International Conference on Sustainable Computing and Data Communication Systems (ICSCDS-2023), 994–999.

Hojabri, M., Dersch, U., Papaemmanouil, A., & Bosshart, P. (2019). A Comprehensive Survey on Phasor Measurement. Www.Mdpi.Com/Journal/Energies, 1–23.

Jain, A., & Bhullar, S. (2018). Micro-phasor Measurement Units (l PMUs) and Its Applications in Smart Distribution Systems (pp. 81–92). Springer Singapore. https://doi.org/10.1007/978-981-10-8249-8

Johnson, T., & Moger, T. (2021). A critical review of methods for optimal placement of phasor measurement units. International Transactions on Electrical Energy Systems, 31(3), 1–25. https://doi.org/10.1002/2050-7038.12698

Jovicic, A., Bilgic, B., & Hug, G. (2021). Linear State Estimation Considering Refresh Rates of RTU and PMU Measurements. IEEE Madrid Power Tech, 1–6.

Khajeh, K. G., Bashar, E., Rad, A. M., & Gharehpetian, G. B. (2015). Integrated Model Considering Effects of Zero Injection Buses and Conventional Measurements on Optimal PMU Placement. IEEE Transactions on Smart Grid, 1–8.

Khoa, N. M., & Tung, D. D. (n.d.). Design and Implementation of Real-time Fault Location Experimental System for Teaching and Training University Students.

Kotha, S. K., Rajpathak, B., Ramesh, B., & Khedkar, M. K. (2022). Optimal Placement Of Micro- PMUs for Real-time Monitoring of Inter-Connected Smart Distribution Networks. 2nd Asian Conference on Innovation in Technology (ASIANCON) Pune, India. Aug 26-28, 2022 2022, 1–5.

Liu, Y., Wu, L., & Li, J. (2020). D-PMU based applications for emerging active distribution systems : A review. Electric Power Systems Research, 179(February 2019), 106063. https://doi.org/10.1016/j.epsr.2019.106063

Moradi-sepahvand, M., Mashhour, E., & Mortazavi, S. S. (2019). Electrical Power and Energy Systems Optimal placement of a combination of single-phase and three-phase µ PMUs for observability of smart distribution networks with asymmetrical structure. Electrical Power and Energy Systems, 105(September 2018), 592–601. https://doi.org/10.1016/j.ijepes.2018.09.001

Mousavi-seyedi, S. S., Member, S., & Aminifar, F. (2014). Parameter Estimation of Multi-Terminal Transmission Lines Using Joint PMU and SCADA Data. IEEE Transactions on Power Delivery 1, 8977(c), 1–9. https://doi.org/10.1109/TPWRD.2014.2369500

Muhayimana, O., & Toman, P. (2022). A Review on Phasor Measurement Units and their Applications in Active Distribution Networks. IEEE PES/IAS PowerAfrica, 1–5.

Nasrun, M., Sabo, A., Izzri, N., & Wahab, A. (2019). A Review on Synchrophasor Technology for Power System Monitoring. 2019 IEEE Student Conference on Research and Development (SCOReD), 58–62.

Patrick, O., Tolulolope, O., & Sunny, O. (2013). Smart Grid Technology and Its Possible Applications to the Nigeria 330 kV Power System. Smart Grid and Renewable Energy, 04(05), 391–397. https://doi.org/10.4236/sgre.2013.45045

Penshanwar, M. K., Gavande, M., & Satarkar, M. F. A. R. (2016). Phasor Measurement unit technology and its applications-a review. International Conference on Energy Systems and Applications, ICESA 2015, Icesa, 318–323. https://doi.org/10.1109/ICESA.2015.7503363

Ravi, A., Saranathan, M., Hari, P., & Achuthan, K. (2022). A Comprehensive review on the current trends in Micro-Phasor Measurement Units A Comprehensive review on the current trends in Micro- Phasor Measurement Units. IOP Conf. Series: Materials Science and Engineering, 1–15. https://doi.org/10.1088/1757-899X/1258/1/012045

Science, C. (2012). REAL TIME VOLTAGE STABILITY MONITORING AND CONTROL. August.

Shahriar, M. S., Habiballah, I. O., & Hussein, H. (2018). Optimization of phasor measurement unit (PMU) placement in supervisory control and data acquisition (SCADA)-based power system for better state-estimation performance. Energies, 11(3), 1–15. https://doi.org/10.3390/en11030570

Tsebia, M., & Bentarzi, H. (2018). North Afican Power System Monitoring using PMU Technology. The 9th International Renewable Energy Congress (IREC 2018), March, 1–7. https://doi.org/10.1109/IREC.2018.8362565

Wang, S. (2017). Estimation of Distribution Network Based on Data. IEEE, 1–5.

Wu, Z. (2018). Optimal Micro-PMU Placement Using Mutual. Www.Mdpi.Com/Journal/Energies, 11(1917), 1–19. https://doi.org/10.3390/en11071917

Zolin, D. S., Ryzhkova, E. N., & Federation, R. (2021). Wide Area Monitoring System (WAMS) Application in Smart Grids. International Youth Conference on Radio Electronics, Electrical and Power Engineering, 1, 1–6.

