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IMPROVING THE PROTECTION OF 330KV TRANSMISSION LINE USING PHASOR MEASUREMENT UNIT (PMU) BASED RELAY

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ABSTRACT

This paper improves the protection of 330kV transmission line using a Phasor Measurement Unit (PMU) based relay. This aim is to ensure that accurate line protection is provided on the TCN Alaoji-Onitsha 330kV Transmission Line and by extension the entire grid if PMUs are recommended and deployed on the interconnected lines which will enhance the present use of Supervisory Control and Data Acquisition (SCADA) for System Grid Operations Management. In this study, the 330kV Transmission 31-Bus Bars and Lines with their respective parameters were characterized. To achieve this, the TCN Onitsha-Alaoji 330kV Transmission line was simulated with and without the deployment of Phasor Measurement Units. This was implemented using Power System Analysis Toolbox (PSAT) MATLAB toolbox blocks for electric power system analysis and simulation. The simulated result was presented, discussed, and compared. Results of simulations showed that the PMU-based protection scheme improved the protection of the Nigeria 330kV transmission line (Onitsha-Alaoji Line) by 34% relative to the conventional protection scheme.

Keywords: PMU, SCADA, PSAT, TCN, Transmission line, Alaoji-Onitsha, Protection

1 INTRODUCTION

Today's Nigerian unbundled electricity industry, with its complex and weak wattage grid system, comes with its challenges of transmission grid protection and control. The standard power transmission network protection scheme is characterized by imprecision and poor sensitivity in fault detection. In this case, the protective relay sometimes trips the breaker when there's no fault and sometimes fails to trip when the network is under a fault situation. This, on one hand, cause an unnecessary interruption within the network and on the opposite hand allows fault current to meet up with the ability components. This causes damage to power components and may cause severe physical injury or maybe death to network operator's workers. Sustained faults within the network cause system instability, frequent outages, and cascaded blackouts. Electricity consumers and power operators pay heavy prices for outages caused by ineffective protection systems on our transmission networks. to boost the performance of the ability transmission network, there's a desire for a more accurate and efficient technique in real-time to capture grid dynamics, for system disturbance and post-mortem analysis which enables prompt protection and control, hence the location of phasor measurement unit (PMU based relay(s) at the target bus or buses to reinforce the relay's and promptly take charge actions. A phasor estimation unit may be a gadget that's utilized in assessing the greatness and also the staging point of a phasor amount (for example voltage, or current) in an electric power system with the help of a unified system of synchronization. Time synchronization is sometimes provided by GPS and allows synchronized real-time measurements of multiple remote points on the grid (Bertsch et al., 2013). PMU can record the samples from a waveform in a tremendous fast succession and reproduce the phasor quantity-that is that the magnitude and angle measurements. This emergent measurement is termed synchro-phasor. The time synchronization afforded with PMU is kind of essential because it enables the grid's supply to accurately match the facility demand. A standard source of an influence outage is frequency imbalance which is caused by a mismatch between the ability supply and therefore the power demand. Zima et al (2016) PMUs also can be wont to measure the frequency within the installation. Normal business PMU can report estimations with extremely high worldly goals within the request for 30-60 estimations each second. This aid designs in investigating dynamic occasions within the lattice which is absurd with customary SCADA estimations that produces estimation every 2 or 4 seconds. This development has allowed engineers to hold out a more accurate evaluation of dynamic occurrences within the facility network. Before the emergence of this technology, it remained very difficult to hold out analysis of those dynamic events because the traditional SCADA system may be a sufficient interruption of 1 to 4 seconds between measurements. Hence it was impossible to stay a real-time track of the network, as a result of the sophistication of PMU and its accuracy in real-time measurements, it's considered to be the backbone of the longer-term power grid.

A PMU can either be a frenzied device, or its functions will be incorporated into a protective relay or another device The PMU is used to be used wide-area measurement to gather phasor parameters from substations and transmit them to the center. The information collected is synchronized with the world positioning satellite system in a very UT1 coordinate and transmitted to the center through the phasor data concentrator. Therefore, this paper will employ a PMU-based relay to observe the Nigerian 330kV grind system for real-time and accurate fault detection and prompt control action.

2 POWER GRID PROTECTIONS

The invention of the primary electromechanical over-current relay at the start of the last century heralded the emergence of grid protection. Within the primary three decades of the last century, there was an enormous development in facility protection technology. Most of the protection principles currently employed in grid protection such as; overcurrent, directional, distance, and differential protection were developed within that era (Awais et al., 2016). The overwhelming growth in science and technology especially electronics and technology greatly improved the workability of relays; hence facility protection. There has been an amazing improvement in the materials, components, and hardware structure of relay protection devices. Against this backdrop, colossal progress had been witnessed within the relay protection software, algorithms, architecture, etc. it's pertinent to say that since the evolution of grid protection technology from the last century to the 1990s, relay protection schemes had evolved through a series of developmental stages. Bilik et al (2015) assert that the scheme began with a conventional mechanical device, and later advanced to semiconductor, and interested in stylish integrated circuits and microprocessor technologies.

Consistent with Schdev (1979), microprocessor-driven digital and numerical relays are fast replacing the normal relays in facility protection infrastructures. Nevertheless, the key relaying principles are still dominant so far. For instance, the employment of a centralized substation protection system enthusiastic about a centralized automatic data processing system conceived within the late 1960s has remained potent to present-day grid protection. This development was an evolution within the annals of the history of power systems' protection. This is often because it had been the primary breakthrough in integrating power systems' protection. The ability system protection devices were able to observe not only the individual units of the plant but also a piece of the whole network. Although the initiative wasn't widely accepted then thanks to limitations imposed by lack of sophistication in technology (Abdelkader et al., 2017).

The introduction of microprocessors into the protection system within the 1980s also aligned with the normal technique in this it adopted a decentralized processing approach that focused on the protection of individual units of the system. However, there was little centralized protection which functions as backup protection and hence functioned as secondary protection. Notably, the introduction of “adaptive protection” and “artificial intelligence” (AI) based protection within the 1980s and 1990s repositioned grid protection.

The adaptive protection made use of Inverse Definite Minimum Time Over current (IDMT) protection. The idea was a brand-new style of relay protection that may change the performance, characteristics, set value consistent with the operation mode, and fault condition of the ability system. The foremost idea behind the innovation was to enhance the performance of the protection by improving the response of the system, increasing reliability, and increasing the economic benefits (Abdelkad, et al,2017). By 1990, there was an incredible expansion in the development of computer and electronic technology. It had been within this era that 3artificial intelligence technology like artificial neural networks (ANN), genetic algorithms, evolutionary algorithms, and mathematical logic which has found wide applications in power grid protection was developed. Ever since then, AI technology is employed to spot fault types, measure fault distance, achieve direction protection, etc. This has led to a rise in speed and accuracy of fault detection and analysis which is paramount to the long-run development of an intelligent grid protection technology. These developments little doubt have improved the general performance of relay protection. However, it's worrisome that these developments have focused only on enhancing the standard relaying techniques. Much progress has not been recorded in devising new relaying techniques from both Adaptive and computing techniques. With the continual expansion of the ability network witnessed within the 1990s and therefore the ever-increasing demand for a quick fault clearance to reinforce system stability; researchers delved into non-power system frequency fault detection to extend the speed of response of relay. This gave birth to what's now referred to as “transient protection relays”. This system makes use of fault-generated transient for gear mechanism protection. It’s pretty remarkable because it opened ways for the event of recent relaying techniques. Studies have shown that the fault-generated high-frequency transient may be detected and quantified. Currently, many researchers have geared efforts toward the detection of high-frequency transient (Aldelkader et al., 2017). Within the same vein, the inculcation of novel communication systems like global positioning systems (GPS) in power systems is another milestone that can't be neglected. This method ushered in prospects for a replacement relay principle that will protect large area power network. This becomes even more attractive and feasible due to the breakthrough recorded within the area of data technology. The arrival of cloud computing and large data techniques have largely improved the performance of power grid protection especially wide-area and integrated protection (Vignesh et al., 2015). Recently there is a surge in the development of communication infrastructures and this has allowed for the transmission of information over a wide area.

2.1 Phasor Measurement Unit (PMU)

Synchronized phasor measurement unit was devised within the 1980s, and has since then evolved into an essential technology with various applications that are currently being developed everywhere the planet (Bertsch et al, 2013).) The occurrence of major blackouts in many power systems across the globe has given a brand new impetus for large-scale implementation of wide-area measurement systems (WAMS) using PMUs and phasor data concentrators (PDCs) in data structure (Martinez et al., 2015). The PMU provides accurate and detailed data that allow the system analysts to research the 000 and true sequence of activities that led to the outage and also helps to point to the precise causes and malfunctions that occasioned the catastrophic failure of the facility systems. As researchers still explore WAMS, it's obvious that other uses of PMUs will certainly be found. Notably, there are already works of literature that house applications of PMUs to system monitoring, system protection, system control (Bertsch et al, 2013).

2.2 Phasor Measurement Unit Application to Grid Protection

A phasor measurement unit (PMU) is a device which estimates the magnitude and phase of an electrical phasor quantity (such as voltage or current) during a power systems network employing a quadruple time source for synchronization. The GPS provides time synchronization and makes it possible to possess synchronized real-time measurements of the many remote points on the network. PMUs are capable of recording samples from a waveform in quick intervals and constructing again the phasor quantities which are composed of angle measurement and magnitude measurement. The measurements so obtained are cited as synchro-phasor. Synchronizing the time is paramount because an imbalance within the supply and demand introduces frequency imbalance which may be a potential source of blackout (Zima, et al., 2016). The frequency during a power network is measured accurately using PMUs. Commercially available PMUs can provide measurements with very high temporal resolution within the order of 30-60 measurements per second. This is often a good feat for the system engineer who can now analyse dynamic events within the network which don't seem to be possible at first with the standard SCADA which only generates measurements between every 2 or 4 seconds. This accuracy and precision of the PMU have equipped utilities with improved control and monitoring potentials and such has been ranked collectively of the foremost significant measuring systems within the next generation of the ability system. It’s warrant note that PMU may be a technology and not hardware and must be placed in an exceedingly particular place. Hence, there are dedicated PMUs likewise as those incorporated into other devices.

3 METHOD USED.

The method adopted in this project was designed to sequentially deliver the four objectives of this study. The case study protection scheme for the Alaoji-Onitsha bus is first modelled in Simulink/Matlab. The proposed scheme for the enhancement of the protection system (PMU based transmission line protection scheme) was also modelled in Simulink/MATLAB. Faults were then introduced in the modelled existing and proposed protection scheme to see how they responded to the faults in terms of accuracy of fault detection. After simulation, results obtained from the existing protection system are then compared with the result obtained from the proposed protection system to determine the performance of the proposed PMU based scheme.

3.1 Development of the Existing Test Network Protection Scheme

The developed Simulink model of the case study transmission line is presented in figure 3.1. To obtain the performance of the existing protection scheme, the model of figure 3.1 was simulated.

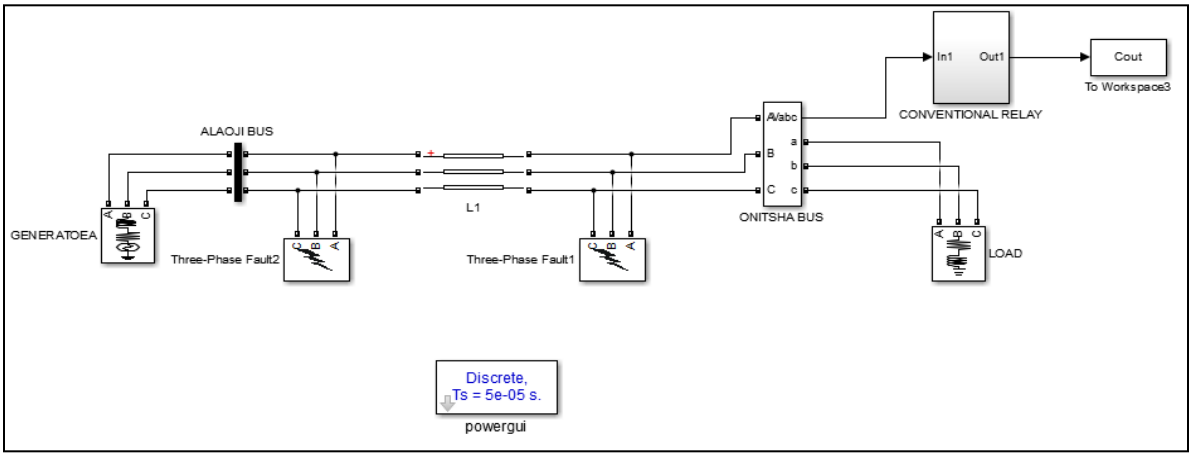

Figure 3.1: Simulink model of the Alaoji-Onitsha 330kV Transmission Line with the conventional protection scheme implemented

3.2 Model of a PMU-Based Protection Scheme of the Test Network.

PMU is reckoned as one of the most important measuring devices in power systems. This is owing to its ability to effectively measure the synchronized voltage and current phasor in power systems. The recent upsurge in the deployment of PMU in major power systems networks was made possible by the advances made in GPS technology. The GPS can accurately time pulses in the order of 1 microsecond and has become readily available in recent times. The availability of GPS has in a great measure influenced the commercialization of PMU. The future of power systems is much dependent on PMU. This is as a result of its distinct ability to accurately provide synchronized phasor measurement of voltages and currents from an infinite bus bar. Field experience and simulations are in tandem with the idea that PMU can holistically transform how power systems are monitored and controlled.

3.3 PMU Mathematical Model

By providing synchronised phasor measurements in a protection scheme, the

PMU facilitates the accurate and timely detection of frequency and phase angle related faults in power networks at a very high sensitivity.

The mathematical expressions of synchronised phasor measured signal (Synchro0phasor) as presented by Onisokonikumen (2015) is presented thus:

For evaluation of the phasor of nominal frequency signals let us take a constant frequency signal as with the nominal frequency of the power system *f*.

$$x(t) = X_m \cos(2\pi f t + \emptyset) \qquad (3.1)$$

Where

$$X = X_r + X_i = \left(X_m/\sqrt{2}\right)e^{j\emptyset} = X_m/\sqrt{2}(cos\emptyset + jsin\emptyset) \qquad (3.2)$$

Where $\frac{X_m}{\sqrt{2}}$ is the rms value of the signal (t) and $\emptyset$ is the instantaneous phase angle relative to a cosine function at nominal system frequency synchronized to UTC. This angle is 0°when the maximum of (t) occurs at the Coordinated Universal Time (UTC) second rollover one pulse per second (1PPS time signal), and 90°when the positive zero crossing occurs at the UTC second rollover. The additional clarification for the synchro-phasor definition is shown in equation 3.3

$$x(t) = X_m cos(\omega_0 t + \emptyset)$$
$$= X_m \cos(2\pi f_0 t + \emptyset) \qquad (3.3)$$

Where f_0 represents the nominal angular system frequency (50 Hz or 60 Hz). This definition also specified that in general cases where the amplitude is a function of time $X_m(t)$ and the sinusoidal frequency is also a function of time (t), a function $g = f - f_0$ is defined. In this function, f_0 is the nominal frequency and g represents the difference between the actual and nominal frequencies. The equation 3.3 can be rewritten as:

$$x(t) = X_m(t)\cos(2\pi \int f dt + \emptyset)$$
$$= X_m(t)\cos(2\pi \int (f_0 + g)dt + \emptyset)$$
$$= X_m(t)\cos(2\pi f_0 t + (2\pi \int g dt + \emptyset)) \qquad (3.4)$$

$$X(t) = \left(X_m(t)/\sqrt{2}\right)e^{j(2\pi \int g dt + \emptyset)} \qquad (3.5)$$

Finally, for cases where $X_m(t) = X_m$ is constant and g $= \Delta f$ is a constant offset from the nominal frequency, $\int g(t) = \int \Delta f dt = \Delta f t$so that the new synchrophasor representation becomes:

$$X(t) = \left(X_m/\sqrt{2}\right)e^{j(2\pi \Delta f t + \emptyset)} \qquad (3.6)$$

Further clarifications were introduced to frequency and Rate of Change of Frequency (ROCOF) estimation:

$$x(t) = X_m \cos[\Psi(t)] \qquad (3.7)$$

Frequency is now defined as shown in equation 3.8

$$f(t) = \frac{1}{2}\frac{d\Psi(t)}{dt} \qquad (3.8)$$

ROCOF(t) is also defined as shown in equation 3.9

$$ROCOF = \frac{df(t)}{dt} \qquad (3.9)$$

The computation of synchrophasor is performed in relation to the system nominal frequency f_0. Representing the cosine argument as$\Psi(t) = \omega_0 t + \varphi(t) = 2\pi[f_0 t + \varphi(t)/2\pi]$, introduces a new frequency formula as shown in equation 3.10

$$f(t) = f_0 + d[\varphi(t)/2\pi]/dt^2$$
$$= d(\Delta f(t))/dt \qquad (3.10)$$

Equation 3.3 shows that signal frequency is a key component of the synchro-phasor, hence the ability of the PMU to provide frequency measurements.

4. Implementation of Simulink Model of PMU Based Protection Scheme in MATLAB

The model of the proposed PMU-based protection scheme on the test network was developed in Simulink. In other to determine its percentage performance against the existing scheme. A model is required for the simulation and evaluation of the proposed PMU-based technique. The required Simulink blocks were imported into a new Simulink model space from the SIMSCAPE library. Blocks include a transmission line, a three-phase voltage supply, bus bars, RLC load, PMU, scopes, and ‘to workspace’, relay, etc. The imported blocks are then connected before configuring them to reflect the parameter obtained from characterization.

To obtain the performance of the proposed protection scheme (PMU-based relay), the model of figure 3.2 was simulated and compared with the result obtained with the existing scheme.

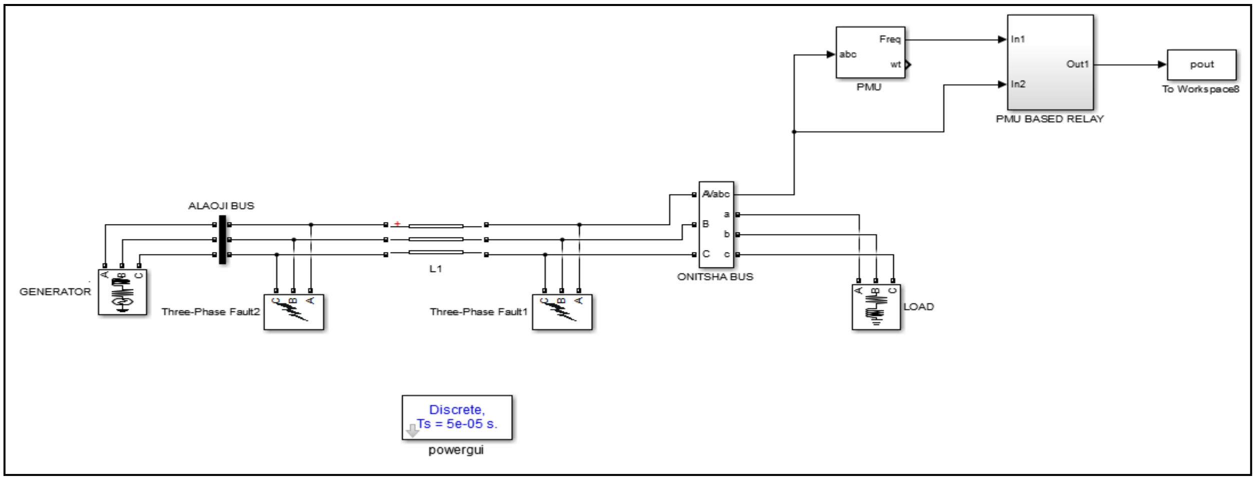

Figure 3.2: Simulink model of the Alaoji-Onitsha 330kV line with the proposed PMU-based protection scheme implemented.

5. SIMULAITON AND RESULT

This chapter is devoted to simulation and analysis of results obtained for the overall evaluation of the performance of the technique. The model of the existing protection scheme and that of the proposed PMU-based scheme was simulated and the results obtained were used to evaluate the performance of the proposed scheme.

4.1 Result of the Characterization of the Existing Protection Scheme of the Test Network

Results of simulations of the conventional scheme carried out are presented in Table 4.1. The result of table 4.3 was obtained by simulating several occasions of three-phase fault on the test network with the existing protection system.

Table 4.1: Simulation results for existing Protection scheme

EVENT N0	CONVENTIONAL RELAY	ACTUAL
1	0	0
2	0	1
3	0	1
4	0	1
5	1	1
6	1	1
7	1	1
8	0	0
9	0	0
10	0	0
11	0	0
12	1	1
13	1	1
14	1	1
15	1	1
16	1	1
17	1	1
18	0	0
19	0	1
20	0	1
21	0	0

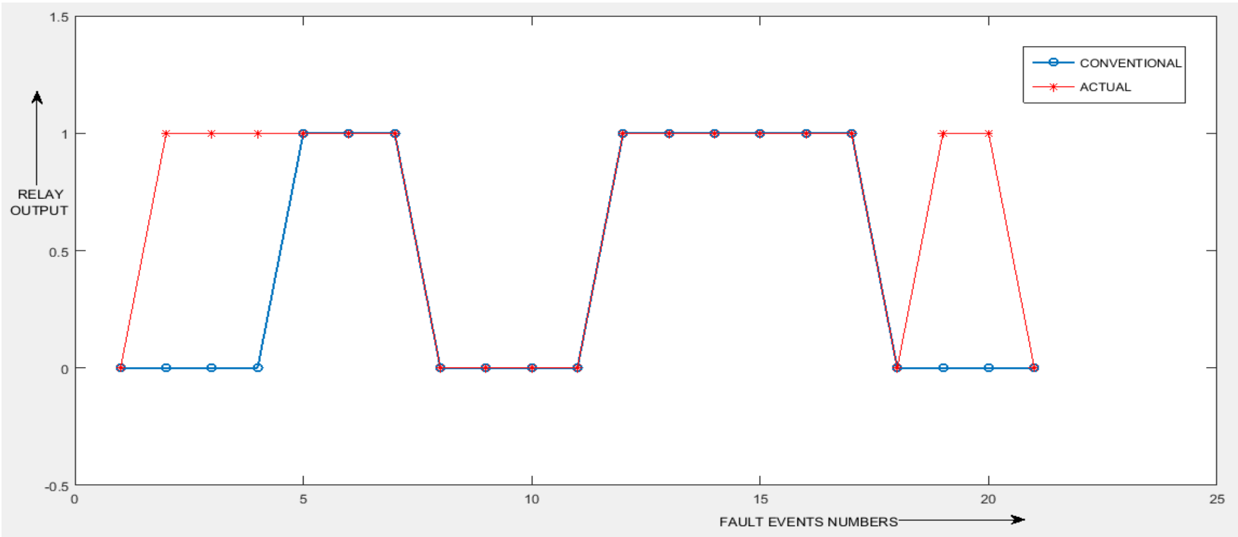

Figure 4.1: Plot of relay outputs against fault events for conventional relay and actual outputs

5.2 Discussions on Characterization Results

In table 4.1, output, '1' represents the presence of fault while output, '0' represents the absence of fault. From figures 4.1 and table 4.1, it can be seen that for a total of 9 times, the conventional/existing scheme detected the presence of fault correctly relative to 14 actual fault events. The above result shows that the conventional and or the existing schemes have 64% accuracy in fault detection. This percentage accuracy in fault detection for the system requires high availability and reliability.

5.3 Simulation Result of the Proposed PMU based Protection Scheme of the Test Network

Results of simulations of PMU based protection scheme carried out are presented in tables 4.4. By introducing the same fault occasions introduced during characterization into the PMU based protection scheme, the results obtained were used to compare and contrast with the characterization results for an effective evaluation of the new technique. Table 4.2 shows the obtained result.

Table 4.2: Simulation results for existing and proposed protection scheme

EVENT N0	PMU BASED RELAY	ACTUAL
1	0	0
2	1	1
	1	1

4	0	1
5	1	1
6	1	1
7	1	1
8	0	0
9	0	0
10	0	0
11	0	0
12	1	1
13	1	1
14	1	1
15	1	1
16	1	1
17	1	1
18	0	0
19	0	1
20	1	1
21	0	0

Table 4.3: Total relay trips on faults for conventional relay and PMU-based relay

RELAY TYPE	**TOTALTRIPS ON FAULTS**
CONVENTIONAL RELAY	9
PMU BASED RELAY	12
ACTUAL	14

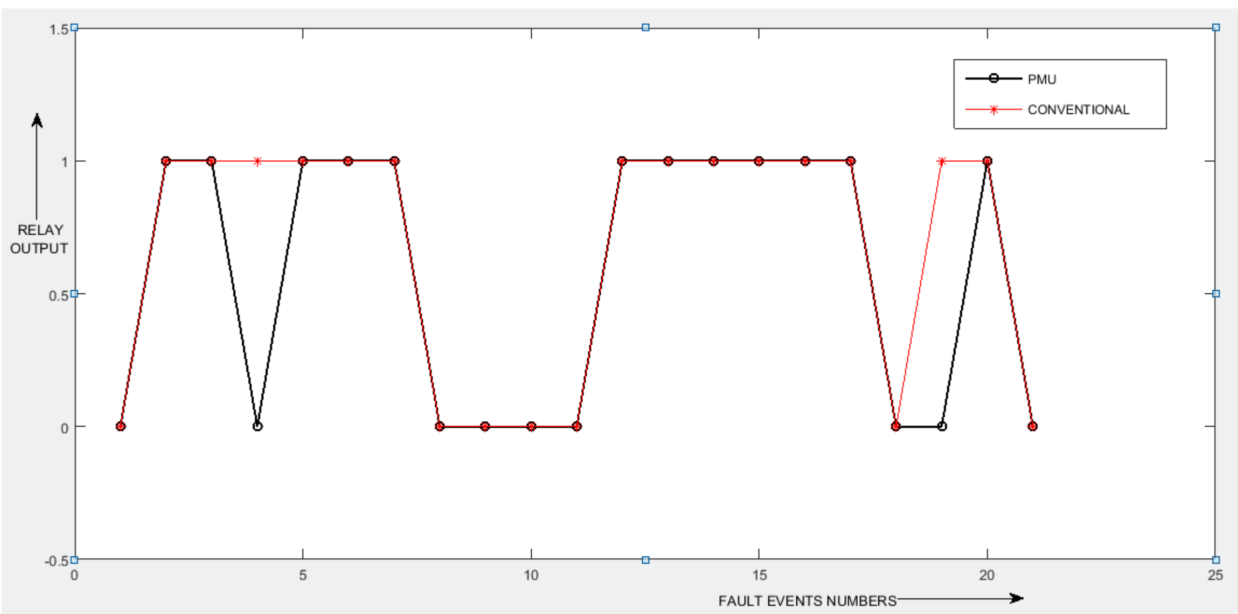

Figure 4.2: Plot of relay outputs against fault events for PMU-based relay and actual outputs

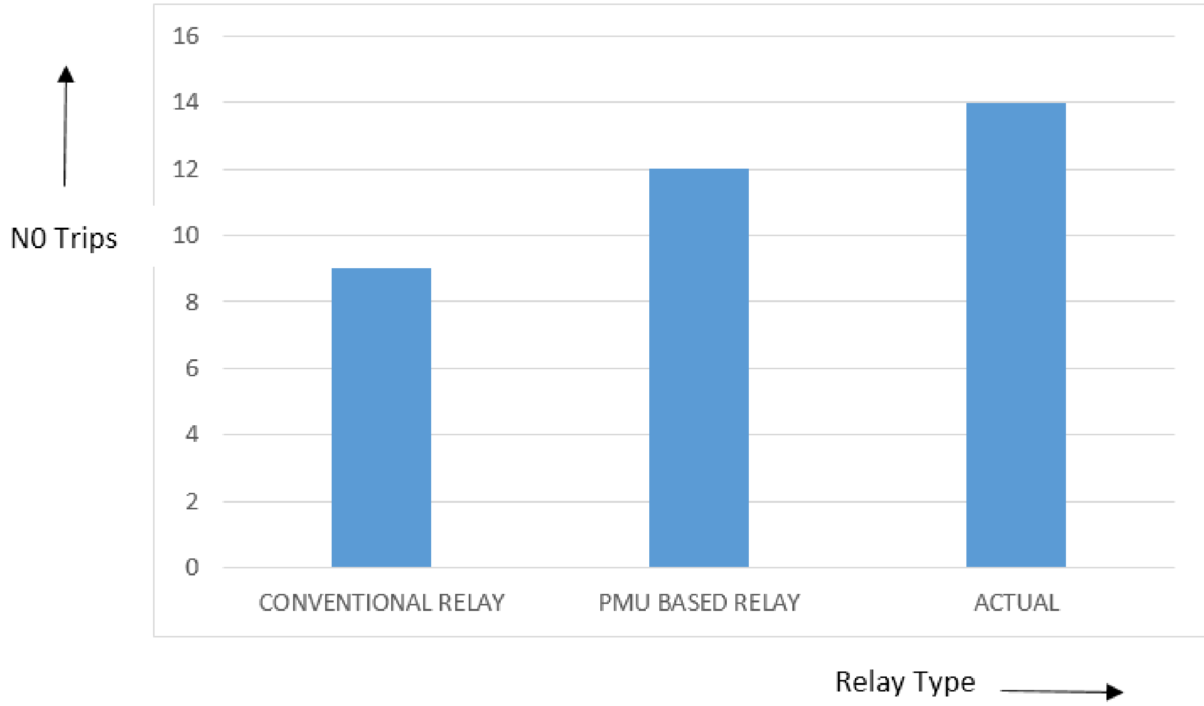

Figure 4.3: Bar Charts showing total fault events for conventional relay, PMU-based relay and actual fault events

5.4 Discussions on the Results of Simulation of the Proposed PMU based Protection Scheme.

In evaluating the performance of the proposed PMU-based protection scheme, the number of correct fault events obtained with the conventional/existing scheme is compared with the number of fault events obtained with the PMU-based scheme using the actual fault event as a reference point.

From figures 4.2 and 4.3, and tables 4.2 and 4.3, it can be seen that the PMU-based scheme detected the presence of fault correctly for a total of 12 times relative to 14 actual fault events. The above result shows that with PMU-based scheme has 86% accuracy in fault detection as against 64% obtained with the existing scheme. This shows that the PMU-based scheme improved fault detection in the test network by 34.3% regarding the existing/conventional relay. The PMU based relay achieved this due to its ability to accurately, detect faulty voltage values and faulty frequency readings.

As a result, the PMU-based scheme detects faults due to ineffective voltage and current reading and inefficient frequency reading. On the other hand, the conventional relay relies only on the defective voltage reading to detect ineffectively. It is, therefore, unable to detect faults due to undesirable frequency values. From the result, it can be concluded here that the PMU-protection scheme relay enhanced the protection of the Alaoji-Onitsha 330kV line by 34.3%.

6. CONCLUSION

In conclusion, the PMU can detect frequency-related faults, the use of PMU based relay protection scheme improved the protection of the Nigeria 330kV transmission line (Onitsha-Alaoji Line) by 34% relative to the conventional protection scheme. It is recommended that a PMU based protection scheme be installed and connected to multi-bus networks like the Nigeria transmission grid network for the enhancement of performance of the transmission grid network.

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