International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Issue: 11 | Nov 2023 www.irjet.net p-ISSN: 2395-0072

DETECTION OF UNSYMMETRICAL FAULTS IN TRANSMISSION LINES USING PHASOR MEASUREMENT UNITS

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Abstract - *This paper introduces an innovative hybrid approach for identifying unsymmetrical faults in transmission lines within an Interconnected Network. The method leverages data collected by Phasor Measurement Units (PMUs), specifically focusing on Positive Sequence voltage and current measurements. Validation of the proposed fault detection technique is conducted using simulations on the IEEE 9 Bus System within the MATLAB/SIMULINK environment. The findings include illustrative results showcasing the effectiveness of the hybrid technique across different types of unsymmetrical faults.*

Key Words: **Phasor measurement Units (PMUs), Positive Sequence Voltage Measurement (PSVM), Positive Sequence Current Measurement (PSCM), UNSYMMETRICAL FAULTS**

1.INTRODUCTION

As the intricate network of power generation, transmission, and consumption evolves rapidly, it becomes essential to employ sophisticated sensor technology for ongoing monitoring. The occurrence of faults in transmission lines disrupts the normal functioning of the power system. Swift and precise fault diagnosis, encompassing detection, classification, and localization, plays a pivotal role in restoring the operational integrity of the power system.

The exploration of existing literature highlights two overarching categories of protection schemes for transmission lines:
1) methods incorporating Phasor Measurement Units (PMUs) and
2) methods that do not rely on PMUs.

The preference leans towards PMU-based techniques due to their associated advantages. The fundamental principle of these protection schemes involves comparing positive sequence voltage and current magnitudes at each bus, particularly during fault conditions within a system protection center.

This comparison aids in identifying the nearest bus to the fault. In contrast to conventional methods, which lack the precision of PMUs, the latter leverage GPS systems for time-synchronized data, enhancing their accuracy and reliability.

1.1 Phasor Measurement Unit

Phasor Measurement Units (PMUs) are specialized devices designed to gauge the frequency, magnitude, and phase angle of voltage and current in relation to a time reference. Serving as dedicated instruments, PMUs can be integrated into protective relays and other devices.

Introduced at Virginia Tech in 1992, PMUs play a pivotal role in power system monitoring and control. Diverging from conventional measuring instruments, PMUs capture analog waveforms and deliver digitized output, incorporating a GPS reference source for precision up to 1 microsecond. The high-precision synchrophasor data, encompassing both magnitudes and phase angles, is then transmitted to remote servers and local substations. This not only significantly enhances visibility but also accelerates accurate fault diagnosis. The advent of this technology promises an era marked by heightened monitoring, protection, and control of power systems.

1.2 Fundamental of PMUs

PMU technology delivers real-time phasor information, encompassing both magnitude and phase angle. The key advantage lies in referencing the phase angle to a global time standard, enabling the capture of a comprehensive snapshot of the power system across a wide area. Effectively harnessing this technology proves invaluable in averting blackouts and gaining insights into the real-time behavior of the power system.

As technology advances, microprocessor-based instruments like Protection Relays and Disturbance Fault Recorders (DFRs) incorporate the PMU module, seamlessly integrating it with existing functionalities as an extended feature. The recent surge in notable blackouts across global power systems has spurred widespread deployment of PMUs. Positive sequence measurements offer the most direct insight into the state of the power system at any given moment.

Consider a pure sinusoidal quantity given by

$$x(t) = X_m \cos(\omega t + \phi) \tag{1}$$

ω being the frequency of the signal in radians per second, and φ being the phase angle in radians. X_m is the peak amplitude of the signal. The root mean square (RMS) value of the input signal is $(X_m / \sqrt{2})$. Recall that RMS quantities are particularly useful in calculating active and reactive power in an AC circuit.
Equation (1) can also be written as

$$x(t) = \mathrm{Re}\{X_m e^{j(\omega t+\phi)}\} = \mathrm{Re}[\{e^{j(\omega t)}\}X_m e^{j\phi}]$$

It is customary to suppress the term $e^{j(\omega t)}$ in the expression above, with the understanding that the frequency is ω. The sinusoid of Eq. (1) is represented by a complex number X known as its phasor representation:

$$x(t) \leftrightarrow X = (X_m / \sqrt{2})e^{j\phi} = (X_m / \sqrt{2})[\cos\phi + j\sin\phi] \quad (2)$$

A sinusoid and its phasor representation are illustrated in Figure 1.

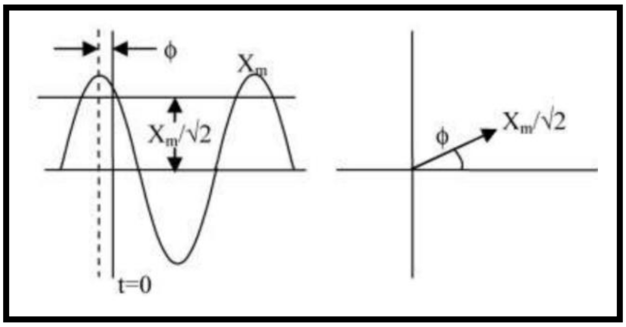

Fig - 1 : Phasor representation of a sinusoidal signal
(a) Sinusoidal signal. (b) Phasor representation.

2. FAULT DETECTION ALGORITHM

We present a innovative hybrid technique designed for the detection of symmetrical faults in transmission lines within an interconnected network, leveraging measurements obtained from Phasor Measurement Units (PMUs). Our fault detection method centers on Positive Sequence voltage and current measurements derived from PMUs.

The proposed algorithm adopts two distinct approaches. In the first approach, we scrutinize the values of Positive Sequence Voltage Magnitudes (PSVMs). Any alteration in the magnitude prompts a sequence check. If a sequence change is identified, the area experiencing this change is flagged as the faulty area. In the absence of a sequence change, the minimum value of PSVM helps pinpoint the bus or area closest to the fault.

If the first approach proves unsuccessful in identifying the faulty area, the second approach comes into play. This second strategy is initiated when the initial approach fails to detect minimum PSVMs. In this scenario, we focus on observing the magnitudes of Positive Sequence Current Measurements (PSCMs). A change in the sequence of PSCMs signifies the faulty area, while the absence of such a change designates the maximum value of PSCM as indicative of the bus or area nearest to the fault.

2.1 Simulation of Network Arrangement

The initial step in the fault detection process for transmission lines involves gathering system measurements. Represented as a discrete phase sequence analyzer block, the Phasor Measurement Unit (PMU) transforms 3-phase signals (V_{abc} or I_{abc}) into positive, negative, and zero sequence component magnitudes and angles. Each phase signal (V_a, V_b, and V_c) undergoes conversion into real and imaginary components through the application of Discrete Fourier Transform (DFT).

In this research endeavor, the measurement of positive sequence components (voltage or current) is executed using a sequence analyzer within MATLAB/Simulink. The Simulink model is configured without applying filters or conducting analog-to-digital conversion. Solely relying on the sequence analyzer block, the model processes analog signals to compute the necessary sequence values (PSVM, PSVAM, PSCM, and PSCAM). The simulation models are crafted using MATLAB/Simulink with SimPower Systems, specifically tailored for simulating various short circuit faults. Emphasizing simplicity, the models are designed with a minimal number of blocks, utilizing default settings whenever feasible.

2.2 Simulink Model

The simulation models are developed using MATLAB/SIMULINK with SimPower Systems. It is then used to simulate various short circuit faults. With a focus on simplicity, these models are intentionally developed with a minimal number of blocks, leveraging default settings whenever feasible. Figure 2 illustrates the Simulink model depicting the advanced Phasor Measurement Unit (PMU).

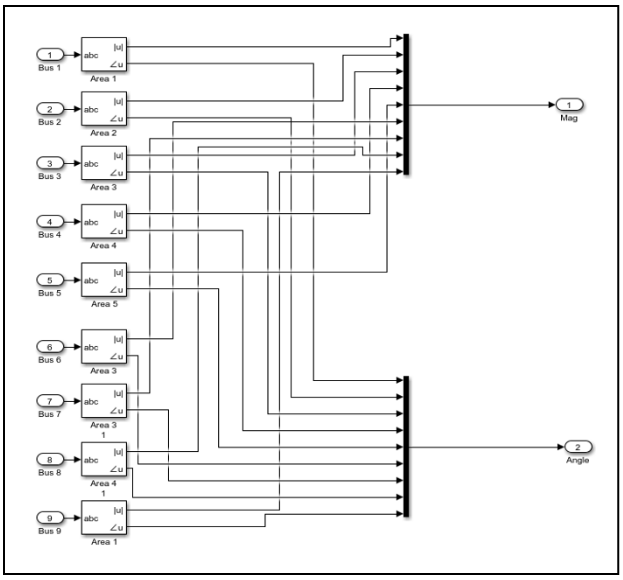

Fig – 2 : New PMU design for all Buses

3. Results

In the Matlab/Simulink environment, all faults are introduced within the time window of 0.2 to 0.4 seconds, and the simulation is conducted for a total duration of 0.5 seconds.

Figures 3-11 illustrate that during the specified time frame, the Positive Sequence Voltage Magnitude (PSVM) value near Area 9 undergoes a change or drops to its minimum, signaling its close proximity to the fault location. In such cases, the first condition for fault detection is satisfied, obviating the need to examine the second condition. Similar observations and results can be extrapolated for faults occurring between other buses. It's important to note that fault detection using PSVM may encounter limitations, particularly when the fault occurs at the midpoint of the transmission line.

Diverse faults are simulated between Bus 6 and Bus 9. In certain scenarios, the PSVM magnitude remains constant before and during the fault. This uniformity makes it challenging to discern, using PSVM alone, which transmission line (Area 6 or Area 9) is affected, as no voltage variation occurs during the fault. Consequently, fault detection through PSVM proves unfeasible, and in such instances, the first condition fails. In these cases, the second condition is invoked, utilizing Positive Sequence Current Magnitude (PSCM), which reveals that Area 1 is closest to the fault, evident from its maximum value.

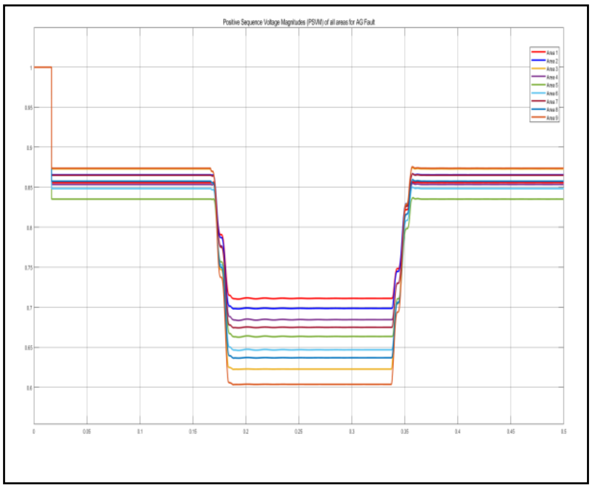

Fig - 3 : PSVM for AG Fault b/w Area 6 and 9

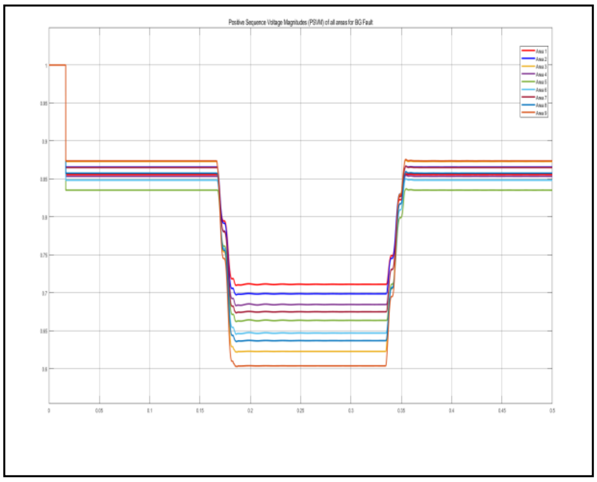

Fig - 4 : PSVM for BG Fault b/w Area 6 and 9

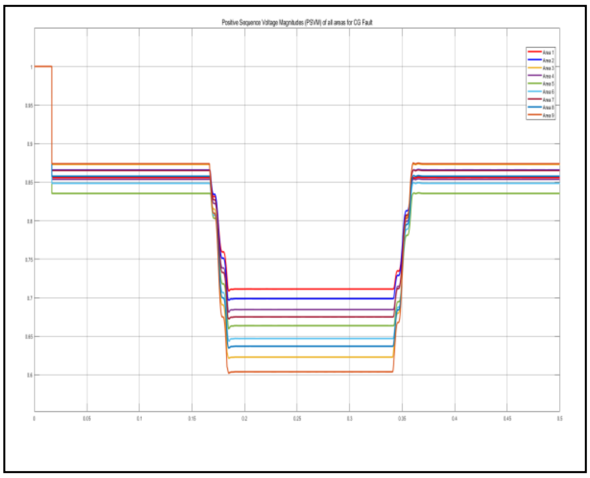

Fig - 5 : PSVM for CG Fault b/w Area 6 and 9

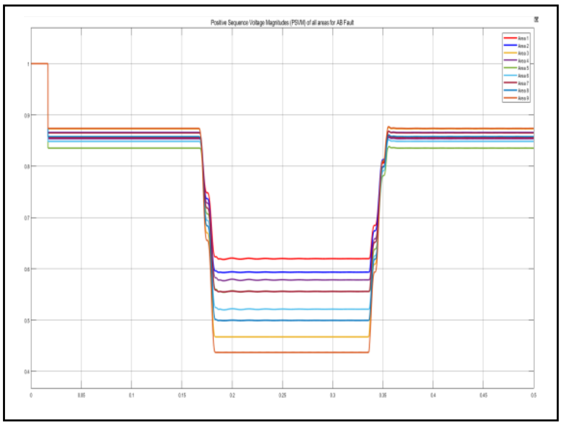

Fig - 6 : PSVM for ABG Fault b/w Area 6 and 9

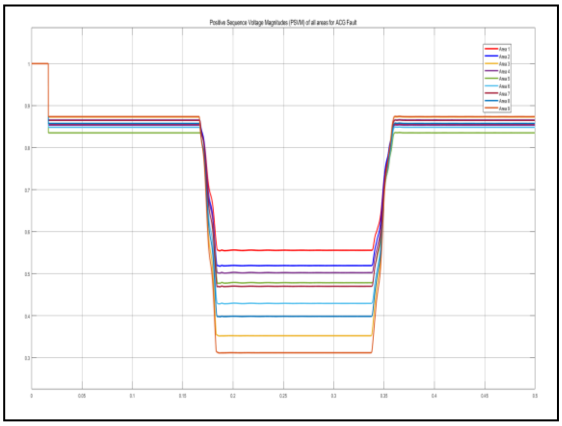

Fig - 7 : PSVM for ACG Fault b/w Area 6 and 9

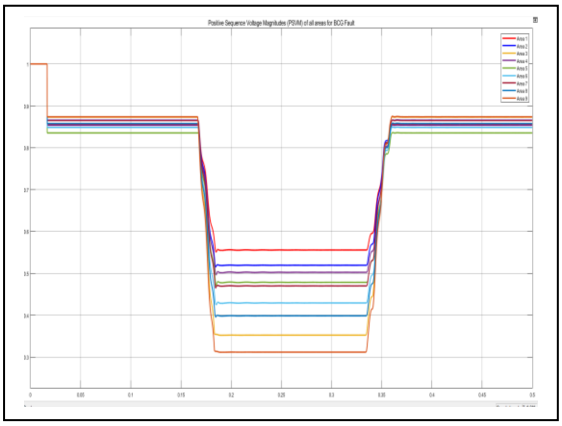

Fig - 8 : PSVM for BCG Fault b/w Area 6 and 9

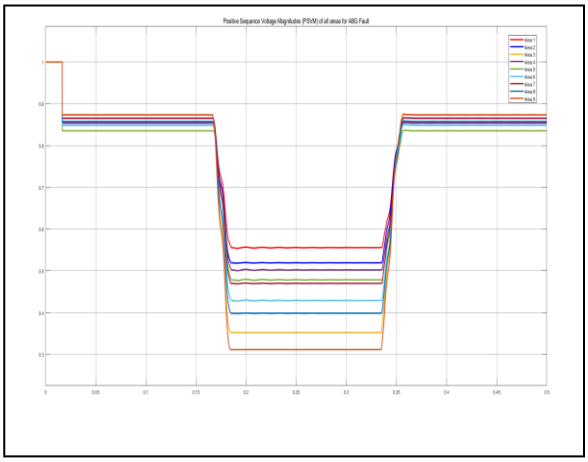

Fig - 9 : PSVM for AB Fault b/w Area 6 and 9

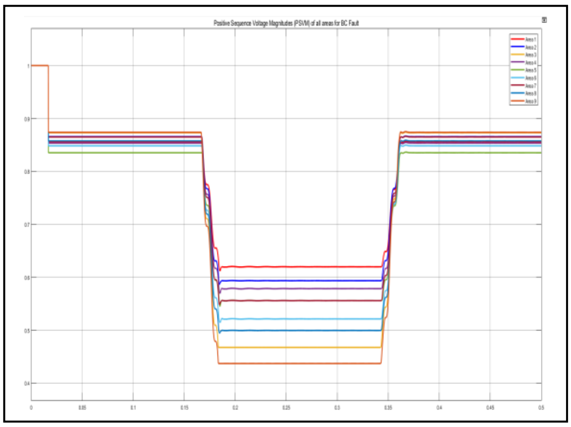

Fig - 10 : PSVM for AC Fault b/w Area 6 and 9

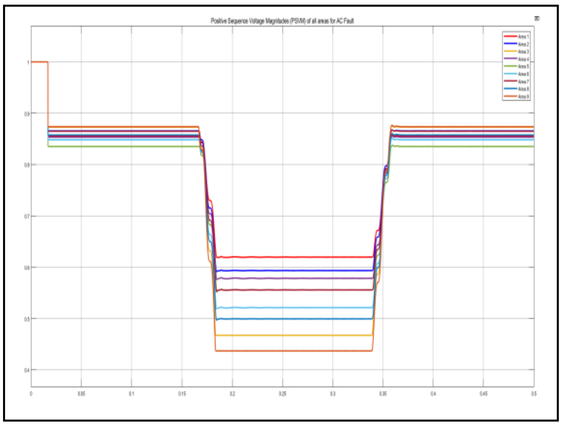

Fig - 11 : PSVM for BC Fault b/w Area 6 and 9

4. CONCLUSION

This paper introduces an innovative sequence-based technique for the detection of faults in transmission lines. Leveraging the Positive Sequence-based approach, the proposed framework utilizes data obtained from Phasor Measurement Units (PMUs), capturing both voltage and current information. Through simulations, the effectiveness of the framework is demonstrated, successfully detecting various fault types across the network's faulty lines. Notably, the framework proves capable of identifying short circuit faults in both balanced and unbalanced systems.

As the implementation of smart grid technologies gains momentum, the role of PMUs becomes crucial in the context of Wide Area Monitoring Systems (WAMS). The WAMS offers key advantages, including dynamic wide area measurements characterized by faster rates and enhanced accuracy. However, achieving observability for an entire power system with the minimum number of PMUs remains an ongoing challenge.

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BIOGRAPHIES

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