

Power System Monitoring and Fault Identification using Modified PMU

**Dr. Ravi Ponnala¹, Dr. Muktevi Chakravarthy², Ch. Leelakrishna³, Dr. P. Vijay Babu⁴,
Dr. Dusarlapudi Kalyan⁵**

¹Vasavi College of Engineering, Hyderabad, India

²Dept. of EEE, Vasavi College of Engineering, Hyderabad, India

³Dept. of EEE, G. Narayanamma Institute of Technology and Science, Hyderabad, India

⁴Dept. of EEE, Chaitanya Bharathi Institute of Technology, Hyderabad, India.

⁵Dept. of EEE, Koneru Lakshmaiah Education Foundation, Guntur, India

Correspondence: ravi.ponnala@staff.vce.ac.in

Article History:

Received: 12-01-2025

Revised: 15-02-2025

Accepted: 01-03-2025

ABSTRACT:

The world's modernization resulted to a sharp rise in the demand for power. Decentralized power generation and the inclusion of renewable energy sources are making power system operation more complex. As a result, power system monitoring and measurement also became more complicated. One of the main disadvantages of power system monitoring is the slower rate of the measurement and monitoring data obtained from the current power system monitoring techniques, such as Supervisory Control and Data Acquisition (SCADA), and Energy Management Systems (EMS). As they only provide a limited amount of information on the parameters of the power system. Therefore, it is necessary to improve the current power system monitoring techniques for gathering data from the power system. Here the Phasor Measurement Units (PMUs) play an important role in modern power system monitoring because they provide high-precision real-time measurements of electrical parameters/characteristics. However, conventional PMUs frequently struggle with dynamic state tracking and effective data handling during post-fault investigation. This paper introduces the Modified PMU (MPMU) framework, which improves the monitoring of power system in dynamic state, by introducing the conditional based data storage system, the enhanced data is compressed, to enable efficient post fault analysis. Simulation results show that the suggested approach improves power system situational awareness while minimizing data processing latency.

Keywords: *PMU, Data Storage, Fault Identification, Power System Monitoring, Time Stamping.*

1. INTRODUCTION

Modern power grids' increasing complexity and real-time operational requirements necessitate the use of more sophisticated monitoring systems to ensure system stability and problem management. Phasor Measurement Units (PMUs) have developed as an important technology for real-time monitoring due to their capacity to deliver synchronized phasor measurements. However, classic PMUs struggle under dynamic state situations, where quick changes in system parameters can result in erroneous state estimation, large storage, excessive data buildup and difficult post fault analysis,

because of large amount of data storage, identifying fault condition is difficult. This study proposes a Modified PMU (MPMU) that addresses these constraints by:

- Improved Dynamic State Tracking: Adaptive signal processing approaches improve accuracy under transient circumstances.
- Optimize post-fault analysis by using data compression and intelligent storage technologies.

The suggested MPMU design ensures that power system operators obtain dependable and real-time data, enabling quicker fault detection and more effective grid control strategies.

The power grid is directly impacted by the sharp rise in electricity consumption brought on by modernization. The electricity system network became difficult to manage as a result of poor design and unplanned expansion to satisfy demand. Inaccurate measurements, slower reporting rates (one every 4-6 seconds) [1], and the lack of a common reference time at the measurement stations for precise phase comparison between the various stations are some of the drawbacks of the current SCADA and EMS technology [2], which is used for power system measurements and monitoring. The SCADA and EMS systems' limitations will be solved by the cutting-edge technology phasor measurements with time stamp [3]. In order to detect voltage magnitude, phase angle, frequency, and frequency change at quicker rates with a common reference time, IED is utilized. Everywhere in the world, a GPS signal can be used to acquire a common reference time. Faster data collection is necessary for the power system's dynamic monitoring[4]. The IEEE C37.118.1 standard states that at least 10 samples per second are needed for dynamic power system monitoring. However, a larger storage system is needed because of the increased data available. The data is saved under disruption conditions rather than in its whole. Only the live signal phsor values are displayed on the screen in the remaining conditions. Total data is recorded when a system fault occurs and is useful for post-disturbance investigation. Calculating the voltage and current phase angle and magnitude is crucial for dynamic power system monitoring. System failure results from variations in the voltage and frequency's impact on the load. The strain on the electrical grid is represented by the shift in the voltage angle. The pace at which the phase angle changes can be used to identify disturbances on the grid. The phase angle difference between the voltage and current phases can be used to calculate the real and reactive power flow in the line [5]. There are numerous phasor measurement techniques available for traditional phasor estimation of voltage and current. These include the following: Newton's approach [6], Wavelet Transform [7], State Estimation [8], Shifting Window Average method [9], Discrete Fourier Transform (DFT) method [10], and Kalman Filter [11]. When the sampling theorem is satisfied, DFT and shifting window average approaches are the most accurate for measuring phasors in a steady state.

2. PHASOR MEASUREMENT WITH RECURSIVE DISCRETE FOURIER TRANSFORM

A phasor is a vector quantity that is used to describe the magnitude and phase angle of a signal. Figure 1 illustrates the fundamental phasor representation of a sinusoidal signal. The basic phasor is measured in relation to a local reference signal, while the synchrophasor is measured in relation to a common reference signal, such as Coordinated Universal Time (UTC) or the Global Positioning System (GPS) [12]. The phase angle between the global reference time (at $t=0$) and the sinusoidal

signal's peak point is determined as phasor and GPS time stamped is called in synchronized phasor measurements.

A sine wave is typically depicted as

$$x(t) = X_m \sin(\omega t + \phi) \quad (1)$$

the phasor representation of (1) is given by

$$X = \frac{X_m}{\sqrt{2}} e^{j\phi} = \frac{X_m}{\sqrt{2}} (\cos\phi + j\sin\phi) \quad (2)$$

where X_m : the maximum value of the signal

ϕ : initial phase angle of the signal.

Figure 1 shows the, sampled signal of sinusoidal waveform. By using this sampled data phasor value of a signal is calculated by using Recursive Discrete Fourier Transform (RDFT) technique. Each calculated phasor value is stamped with GPS time; it is called synchronized phasor measurements. These synchronized phasor measurements are provides the information about the signal's frequency, phase angle, magnitude, COF and ROCOF. The GPS or UTC is taken as a reference to calculate the phase of the signal [13].

The idea of synchronized measurements is phasor measurements with exact time tags; the idea of a measurement that provides direct information about the phase and goes beyond the straightforward notion of the root mean square[14].

Two performance classifications are introduced by IEEE C37.118.1 [15]: P-class, specifically designed for protective applications that need quick responses, M-class, which calls for greater precision in measuring applications.

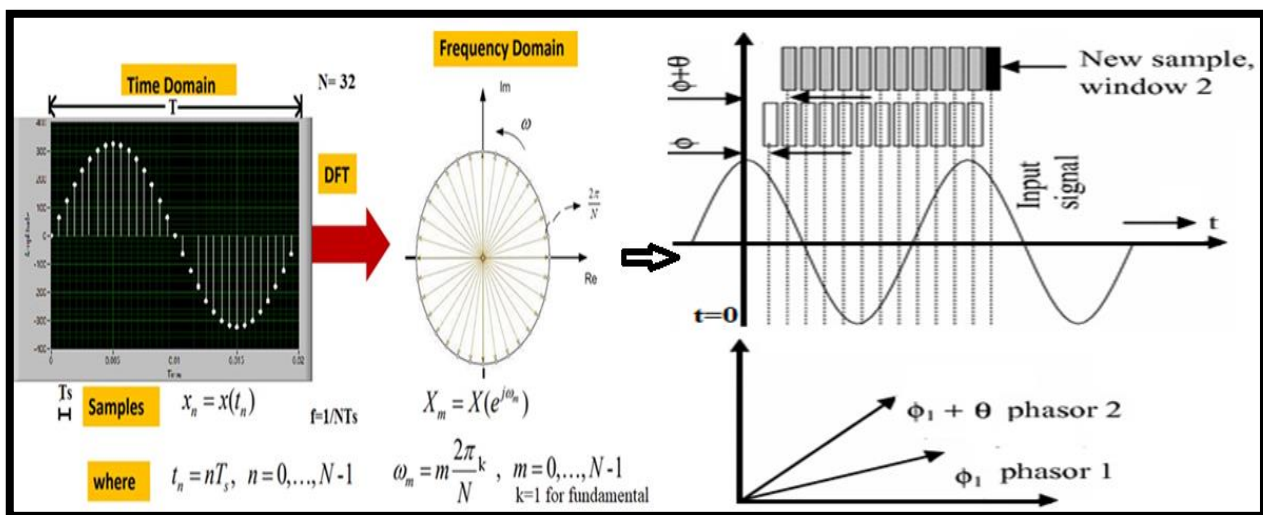


Figure 1 Basic phasor representation of a sinusoidal signal and phasor calculation with recursive DFT

The data acquisition system, it is made up of an Analog to Digital Converter (ADC) and a signal conditioning unit. The received signal is attenuated and filtered out in the signal conditioning unit in accordance with the analog to digital converter's specifications. The converted digital signal is run

through a phasor estimator, which provides the signal's phase angle and magnitude. The calculated values are time synchronized using a time synchronization receiver and a local clock, which functions as a GPS or UTC signal [16]. This is accomplished by employing a GPS Disciplined Oscillator (GPSDO) to transform the 1 pps GPS signal to 3600 PPS. One crucial factor in the entire PMU measurement process is the incoming signal's sampling [17]. In this work 32 samples per cycle and 1800 is the sampling frequency. However, PMUs are quite expensive commercially. Phasors can be computed using IED and LabVIEW's Non-Recursive Discrete Fourier Transform (DFT) approach in place of commercial PMUs [18].

One of the methods for phasor measurements is the Recursive DFT. Figure 1 illustrates the Recursive windowing technique. The phasor 1 is calculated using window 1, while the phasor 2 is calculated using window 2. When it comes to reference time, the first sample in window 1 lags by an angle Φ , but the first sample in window 2 ($n = 1$) lags by an angle $(\Phi + \theta)$, where θ is the angle between the samples [19].

Consider a signal from equation (1) in discrete mode, with “N” samples for the sinusoid $x_n : \{ n=0, 1... N-1 \}$ are obtained as

$$X_n = X_m \cos(n\theta + \phi) \quad (3)$$

where $\theta = \frac{2\pi}{N}$,

the fourier series for the signal is given by

Recursive DFT technique is best suitable for the phasor estimation with less complexity in the windowing technique. In this DFT technique the phasor is estimated by using the DFT formula at N^{th} sample, as given below:

$$X^N = \frac{\sqrt{2}}{N} \sum_{n=0}^{N-1} X_n e^{-jn\Phi} \quad (4)$$

For this N^{th} sample phasor calculation the n values are 0 to N-1

And at $(N+1)^{\text{th}}$ sample phasor is calculated as

$$X^{N+1} = \frac{\sqrt{2}}{N} \sum_{n=1}^N X_{n+1} e^{-jn\Phi} \quad (5)$$

For this $(N+1)^{\text{th}}$ sample phasor calculation the ‘n’ values are 1 to N. $(N+1)^{\text{th}}$ sample phasor is calculated only X_{n+1} sample value is added to the at N^{th} sample phasor value and 1st sample value is removed from the N^{th} sample phasor value

3. LabVIEW BASED DYNAMIC STATE MONITORING

A RDFT technique is used to measure phasor values of the voltage and current signals [20]; different approaches are there to calculate the phasor values. Recursive DFT based approach is used here due to it's more accuracy [21] and less time for computation. Figure 2 shows the current signal and

reference signal with controllable load. The values shown in the same figure table are instant values of the signal, phasor magnitude and phase angle with GPS time stamping and %Total Vector Error (%TVE). With the GPS time stamp the measurements are time synchronized. Which are useful to calculate the power flow in the system and dynamic state monitoring.

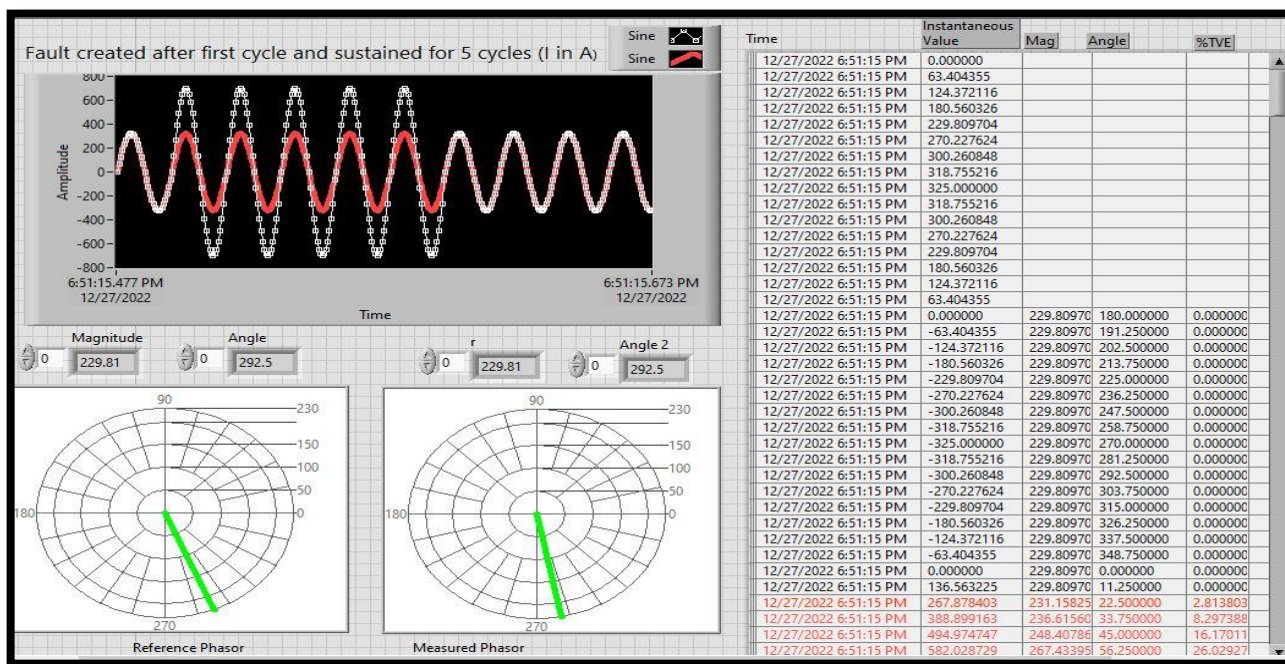


Figure 2 %TVE based fault monitoring system

Figure 2 shows the phasor measurement of current signal and reference phasor waveform, when the %TVE is greater than the 1% then it is identified as fault condition.

The proposed MPMU framework makes significant changes to both the hardware and software components of standard PMUs, Improved Dynamic State Estimation:

The MPMU includes an Adaptive Phasor Tracking Algorithm (APTA), which dynamically adjusts sampling rates based on system conditions. This methodology employs Wavelet Transforms to detect transient events, adjusts phasor estimation methods based on signal frequency fluctuations, and minimizes mistakes in voltage and current phasor computations during dynamic events. Optimized Data Handling Mechanism to handle data overload, the MPMU uses a two-stage data processing technique.

1. Real-time data compression uses Singular Value Decomposition (SVD) to remove unnecessary information. Saves only critical event data for post-fault investigation
2. Intelligent Data Storage: - Used a hybrid storage system with conditional based storage. It reduces the routine data storage. Accelerates the retrieval of fault-relevant information, these improvements ensure that only valuable data is saved and evaluated, lowering computational costs while retaining excellent accuracy.

4. IMPLEMENTATION OF PROTECTION CIRCUIT AND EFFECTIVE DATA STORAGE

LabVIEW based phasor calculation, less data storage and protection circuit is shown in Figure 3. The signal acquisition and processing is presented in [22]. A trip signal is generated if the voltage magnitude $\pm 5\%$ change of rated value, or the frequency $\pm 1\%$ change, or COE exceeds 0.01 Hz or ROCOF more than 1 or % Total Vector Error (TVE) more than 1%. Calculation of %TVE presented in [18]. The myDAQ D0 port is used to apply trip signal to the relay contact. To limit the current, this digital output is applied to the relay via a $20\text{k}\Omega$ resistor [23]. The contactor is attached to this relay coil. The contactor is open and that fault system will be separated from the healthy system if the phasor value or magnitude variations exceed the permitted range. Here total data is stored in the file is taken 1.98GB data per day. With massive storage system requires large memory, and post fault analysis is difficult due to more routine data.

To avoid routine data storage and to store only effective data new method is adopted, i.e every instant data is visualized on the screen, but data is stored only during disturbance/ fault condition or once in every 20msec. Due to this total data stored in the file is reduced the required memory is nearly 99MB per day. For any post disturbance analysis, this data is enough and easily analyzed to know the type of disturbance/ fault in the power system also for future reference. During the voltage phasor's magnitude changes, such as during a transient period or a fault state, the data is stored in the file completely. Since the voltage is constant under typical working conditions, data is not stored in the file during this time, which lowers the need for data storage. By eliminating the conditionally based loop indexing, whole data can also be stored under critical conditions.

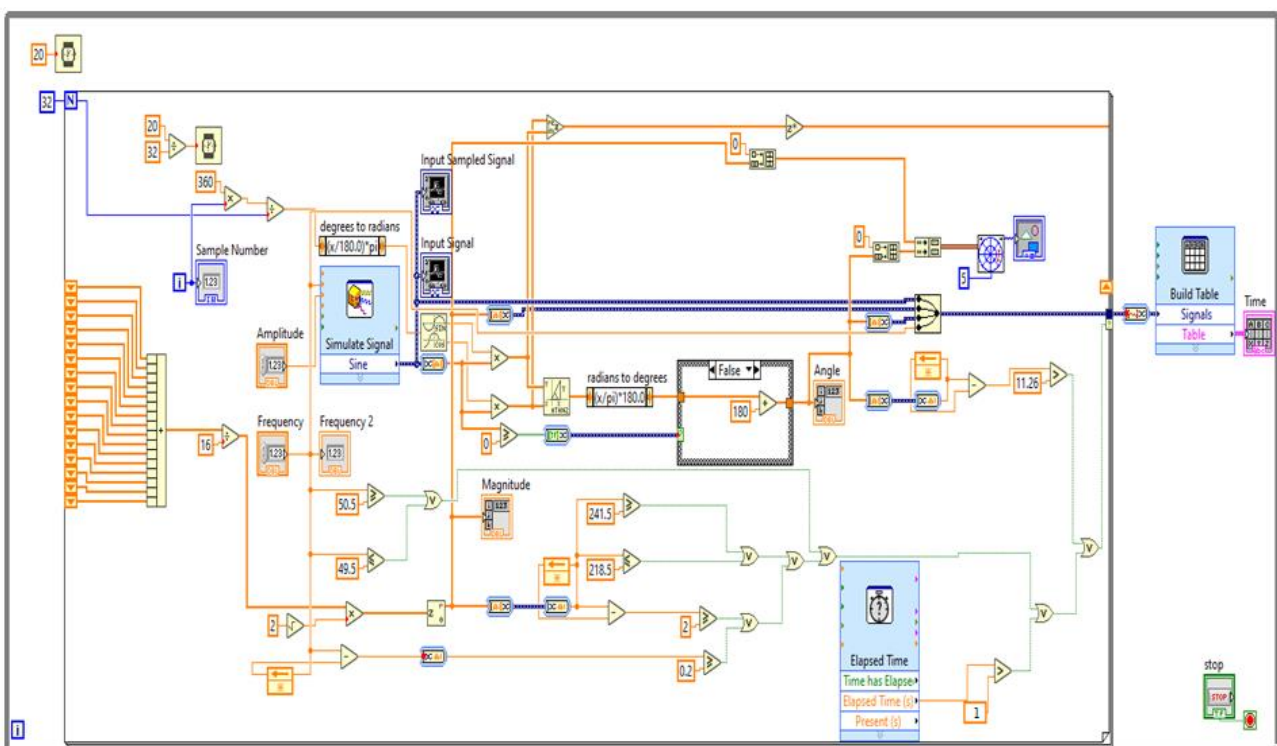


Figure 3 Protection circuit implementation against variation of voltages and frequency with less data storage.

Figure 4 depicts the laboratory-based experimental setup. Six amps of load current are used in a single phase system to produce experimental findings. Using LabVIEW software, the voltage magnitudes at both ends are compared using voltmeter readings and the sending and receiving end voltages as well as the instantaneous voltage phase angles.

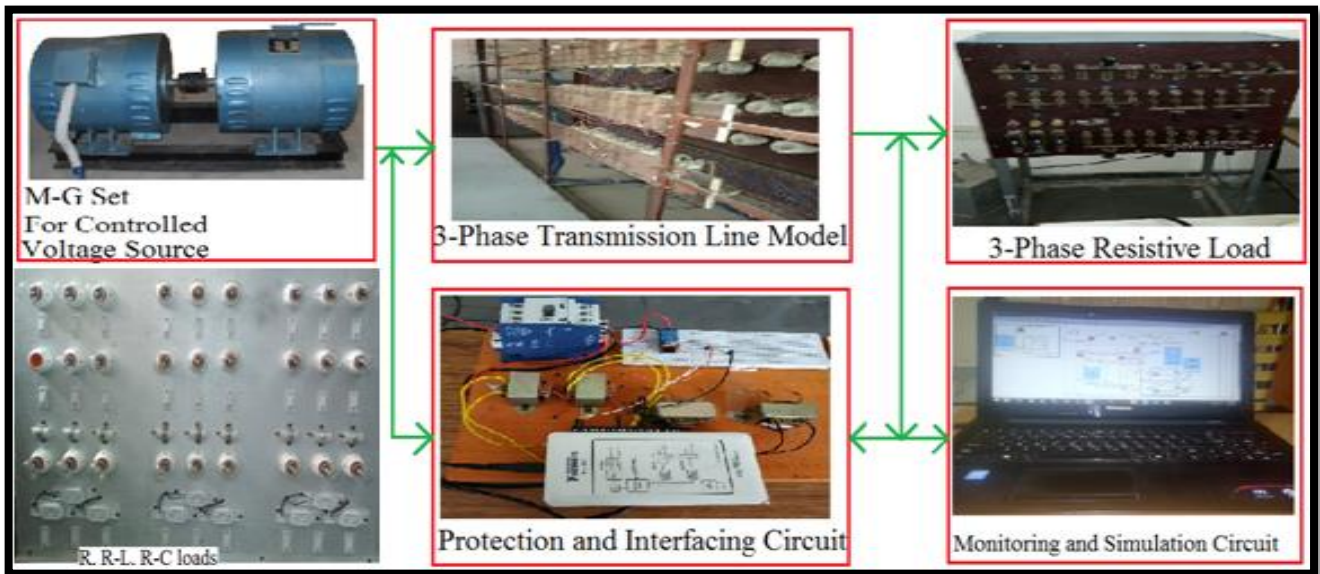


Figure 4 Hardware model of the work for creating different test conditions.

Any amendments to the system parameters in terms of its measurement rates, accuracy can be implemented by changing the software program without requiring a change in hardware. Only necessary data will be stored in the write to measurement file thanks to the conditional-based storage mechanism. 90% of the time, the power system runs normally, thus there's no need to save any data during this time. Only data is saved in the file whenever there is a change in the voltage phasor's magnitude because of a fault, load change, or dynamic state. If total data must be stored using the software program, all that needs to be done is enable the index in the for loop (LabVIEW) and remove the condition. The total data will then be stored in the file. The data in the table 1 is enough for monitoring and protection and better than [24] of in dynamic state according to std. IEEE C37.118.

Table:1 Laboratory based experimental values with variation in current and frequency

Date Time(GPS)	Inst. value	Mag.	Phase In deg	Frequen cy	COF	RO COF	%TVE	Trip signal
13-02-2025 11:17:04.552	3.34	7.665	0	49.99	-	-	0.1	-
13-02-2025 11:17:04.563	6.38	7.665	11.25	49.99	0	0	0.1	-
13-02-2025	8.76	7.665	22.5	49.98	0.01	1	0.3	-

11:17:04.573	10.32	7.665	33.75	49.98	0	0	0.2	-
13-02-2025	10.83	7.665	45	49.98	0	0	0.3	-
11:17:04.583	10.31	7.665	56.25	49.99	-0.01	-1	0.5	-
13-02-2025	8.76	7.666	67.5	50.00	-0.01	-1	0.5	-
11:17:04.593	6.36	7.666	78.75	50.00	0	0	0.3	-
13-02-2025	3.34	7.666	90	50.00	0	0	0.4	-
11:17:04.603	0	7.665	101.2	49.99	0.01	1	0.5	-
13-02-2025	-3.33	7.665	5	49.97	0	0	0.6	-
11:17:04.613	-13.34	7.664	112.5	49.95	0.02	2	1	✓
13-02-2025	6.38	7.665	123.7	49.99	-	-	0.1	-
11:17:04.623	8.76	7.665	5	49.98	0.01	1	0.3	-
13-02-2025	10.32	7.665	11.25	49.98	0	0	0.2	-
11:17:04.633	10.83	7.665	22.5	49.98	0	0	0.3	-
13-02-2025	10.31	7.665	33.75	49.99	-0.01	-1	0.5	-
11:17:04.643	8.76	7.666	45	50.00	-0.01	-1	0.5	-
13-02-2025			56.25					
11:17:04.653			67.5					
13-02-2025								
11:21:04.216								
13-02-2025								
11:21:04.226								
13-02-2025								
11:21:04.236								
13-02-2025								
11:21:04.246								
13-02-2025								
11:21:04.256								
13-02-2025								
11:21:04.266								

The MPMU reduced phasor estimation errors by 35% compared to traditional PMUs.

- Reduced data storage requirements by 50% while maintaining essential event details.

- Reduced post-fault analysis execution time by 40%, resulting in better fault localization and recovery [25].

5. CONCLUSION

This paper describes an improved Modified PMU (MPMU) design that considerably enhances power system monitoring in dynamic conditions while also streamlining data handling for post-fault analysis. The combination of adaptive signal processing and optimal data storage leads to improved fault detection and shorter reaction times. The DFT based phasor measurement technique is used to calculate phasor values of the current signal, these values are time stamped with GPS time gave the live representation of the power system. The polar plot is used to represent the phasor values of the current signal, it shows the power system in real time, current magnitude and phase angles in the single screen. In power system monitoring, the recorded current magnitude and instantaneous phase angles are related to a common reference time, which is very advantageous. For every 20 milliseconds, the phase angles and current magnitude are time stamped and stored in the file in normal operating conditions. During disturbance conditions complete data is stored in the file. The defective system is automatically isolated from the remaining, healthy system within the designated safety time with deviation in the phasor, frequency, or COE or ROCOF or %TVE of permissible values. Knowing the precise state of the system at any given time allows the system operator to take the appropriate action in the event of abnormal situations, which is very beneficial. Because of its adaptability, this technology can be used with any kind of system by simply altering the software rather than the hardware. With this approach, the power system is monitoring in dynamic state, merely stores the necessary data and taking protection against faults in dynamic state according to IEEE std C37.118.

REFERENCES

- [1]. A. H. Mahjoub and N. H. Dandachi, "Power Systems Monitoring & Control Centers Sharing SCADA/EMS Information in the Age of Enterprise Mobility," 2007 Innovations in Information Technologies (IIT), Dubai, United Arab Emirates, 2007, pp. 312-31
- [2]. R Përvetica, N Përvetica, V Rexhepi, M Purellku, "An analysis of the failures in the power system using the SCDA/EMS database" - st International conference, CIGRE, 2019
- [3]. Joshi, P.M.; Verma, H. Synchrophasor measurement applications and optimal PMU placement: A review. *Electr. Power Syst. Res.* 2021, *199*, 107428.
- [4]. Biswal, Chinmayee, et al. "Real-time grid monitoring and protection: A comprehensive survey on the advantages of phasor measurement units." *Energies* 16.10 (2023): 4054.
- [5]. X. Jia *et al.*, "Analysis of Power Flow Characteristics of Power Grid Considering Temporal and Spatial Correlation of Meteorological Factors," 2021 *IEEE/IAS Industrial and Commercial Power System Asia (I&CPS Asia)*, Chengdu, China, 2021, pp. 758-764, doi: 10.1109/ICPSAsia52756.2021.9621712.
- [6]. Banerjee, P.; Srivastava, S. An Effective Dynamic Current Phasor Estimator for Synchrophasor Measurements. *IEEE Trans. Instrum. Meas.* 2015, *64*, 625–637.

- [7]. J. Ren and M. Kezunovic, "Real-Time Power System Frequency and Phasors Estimation Using Recursive Wavelet Transform," in *IEEE Transactions on Power Delivery*, vol. 26, no. 3, pp. 1392-1402, July 2011.
- [8]. J. A. de la O Serna and J. Rodriguez-Maldonado, "Instantaneous oscillating phasor estimates with Taylor-Kalman filters," *IEEE Trans. Power Syst.*, vol. 26, no. 4, pp. 2336–2344, Nov. 2011.
- [9]. Zhang P, Xue H, Yang R, et al. Shifting window average method for phasor measurement at offnominal frequencies. *IEEE Trans Power Deliv* 2014; 29(3): 1063–1073.
- [10]. Saeed Afrandideh, Mohammad Reza Arabshahi, Seyed Mahdi Fazeli, "Two modified DFT-based algorithms for fundamental phasor estimation", *IET Generation, Transmission and distribution*, 01 June 2022, DOI : <https://doi.org/10.1049/gtd2.12516>
- [11]. Amirat, Y.; Oubrahim, Z.; Ahmed, H.; Benbouzid, M.; Wang, T. Phasor Estimation for Grid Power Monitoring: Least Square vs. Linear Kalman Filter. *Energies* 2020, 13, 2456.
- [12]. M. Meriem, B. Hamid and O. Abderrahmane, "An Investigation of Different PMU phasor estimation techniques Based on DFT Using MATLAB," *2020 International Conference on Electrical Engineering (ICEE)*, Istanbul, Turkey, 2020, pp. 1-6, doi: 10.1109/ICEE49691.2020.9249818.
- [13]. S. You *et al.*, "Calculate Center-of-Inertia Frequency and System RoCoF Using PMU Data," *2021 IEEE Power & Energy Society General Meeting (PESGM)*, Washington, DC, USA, 2021, pp. 1-5, doi: 10.1109/PESGM46819.2021.9638108.
- [14]. A.G. Phadke, Bogdan Kasztenny, "Synchronized Phasor and Frequency Measurement Under Transient Conditions", *IEEE Transactions on Power Delivery* 2009, 24(1):89 – 95.
- [15]. IEEE Standard for Synchrophasor Measurements for Power System IEEE Standard C37.118.1-2011, 2011.
- [16]. R. Ponnala, M. Chakravarthy, and S. V. N. L. Lalitha, "Dynamic state power system fault monitoring and protection with phasor measurements and fuzzy based expert system," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 1, pp. 103–110, Feb. 2022, doi: 10.11591/eei.v11i1.3585
- [17]. A. Jain, A. Bhardwaj, S. Kumar and S. Bhullar, "Implementation Techniques for Frequency Phasor Estimation in Phasor Measurement Units (PMUs)," *2018 3rd International Conference On Internet of Things: Smart Innovation and Usages (IoT-SIU)*, Bhimtal, India, 2018, pp. 1-6.
- [18]. R. Ponnala, M. Chakravarthy, and S. V. N. L. Lalitha, "Development of Laboratory Model PMU for the Phasor Calculation of Fundamental Component for the Power System Fault Identification Dynamic State and Effective Data System for the Post Disturbance Analysis" *International Journal of Electrical and Electronics Research*, vol 10, issue 4, pp.1306-1314, Dec-2022

- [19]. J. Song, A. Mingotti, J. Zhang, L. Peretto and H. Wen, "Fast Iterative-Interpolated DFT Phasor Estimator Considering Out-of-Band Interference," in *IEEE Transactions on Instrumentation and Measurement*, vol. 71, pp. 1-14, 2022
- [20]. R. Ponnala, M. Chakravarthy, and S. V. N. L. Lalitha, "Performance and comparison of different phasor calculation techniques for the power system monitoring," *Bulletin of Electrical Engineering and Informatics*, vol 11, no. 3, June 2022, pp. 1246-1253, doi: 10.11591/eei.v11i3.3833.
- [21]. M. Meriem, B. Hamid and O. Abderrahmane, "An Investigation of Different PMU phasor estimation techniques Based on DFT Using MATLAB," 2020 International Conference on Electrical Engineering (ICEE), Istanbul, Turkey, 2020, pp. 1-6
- [22]. R. Ponnala, M. Chakravarthy, and S. V. N. L. Lalitha, "Effective monitoring of power system with phasor measurement unit and effective data storage system" *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 5, pp. 2471–2478, Oct. 2022 10.11591/eei.v11i5.4085.
- [23]. Yi Liu, Ding Dang, and Seon-Keun Lee "Research on the Protection System for Smart Grid Based on Phasor Information at Circuit Breakers" , *Energies* 2024, 17(14), 3455.
- [24]. D. M. Laverty, R. J. Best, P. Brogan, I. Al-Khatib, L. Vanfretti, and D. J. Morrow, "The Open PMU platform for open-source phasor measurements," *IEEE Trans. Instrum. Meas.*, vol. 62, no. 4, pp. 701–709, Apr. 2013.
- [25]. Kunac, A.; Petrović, G.; Despalatović, M.; Jurčević, M. A Low-Cost Test Platform for Performance Analysis of Phasor Measurement Units. *Electronics* 2024, 13, 245. <https://doi.org/10.3390/electronics13020245>