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Research Article

Modified PMU for Power System Monitoring in Dynamic State and Effective Data Handling

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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. Phasor measurements using Intelligent Electronic Devices (IEDs) provide faster data gathering from the power system and more information about the parameters of the power system. In order to determine the phasor values of voltage, current, remaining power system operational parameters frequency, Change of Frequency (COF) and Rate of Change of Frequency (ROCOF), this IED gathers the voltage and current signal data from the power system more quickly and sends it to a software program. By using this software program, very quickly phsors, power system operational parameters are calculated.The calculated phasors gave the live representation of the power system feasible by appending a time tag to each phasor value. This is a crucial requirement for power system monitoring across a large area, leads to massive storage system of phasors and power system paprameters. To store only required and effective data and to avoid routine data storage, new storage method is proposed. This paper presents a phasor calculation technique, synchronized phasor measurements, effective data storage, and identifying of faults in the dynamic state.

Keywords: Phasormeasurements, Nonrecursive DFT, Frequency, Change ofFrequency, Time Stamping.

INTRODUCTION

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.

PHASOR MEASUREMENTS

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

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

where X_m: the maximum value of the signal

Ø: initial phase angle of the signal.

Consider the two bus system, bus 1 and bus 2 with voltages of V1 and V_2 respectively, as shown in figure 1. Comparing the two bus voltages with a common reference signal (UTC or GPS), bus 1 with voltage V_1 has a phase angle $\delta_1$and bus 2 with voltage V_2 has a phase angle δ_2.

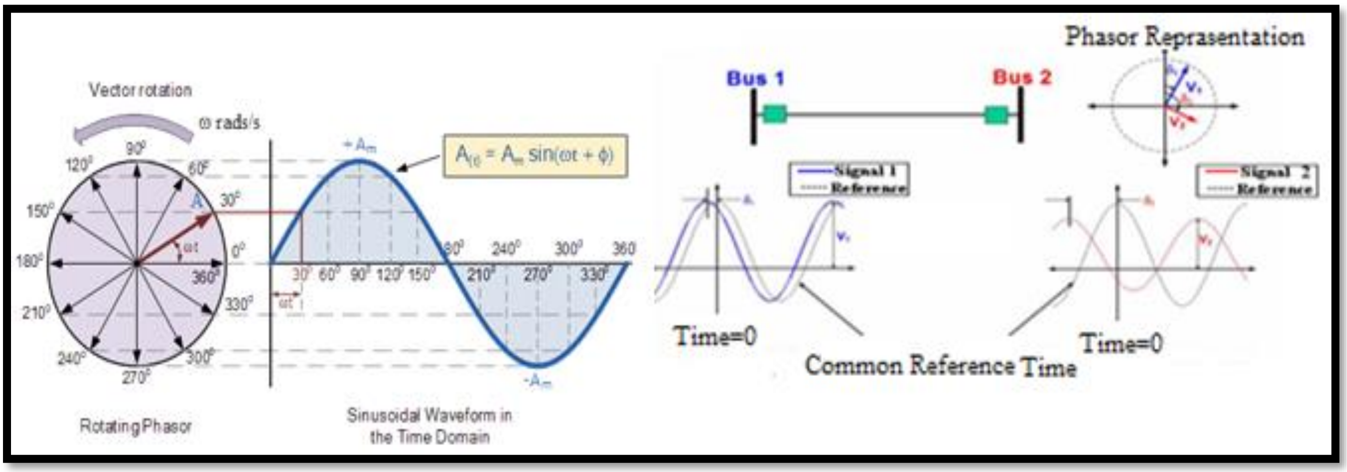

Figure 1 Basic phasor representation of a sinusoidal signal and phasor representation with a common reference time

Comparing the signals acquired at different measurement stations for power system monitoring is a huge benefit because the signals are measured with respect to a common reference time. Phasor Measurement Units (PMUs) are commercially available for phasor measurement purposes.

PHASOR MEASUREMENT WITH DISCRETE FOURIER TRANSFORM

One tool for synchronized phasor measurements is the Phasor Measurement Unit (PMU). It will measure a 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.

The data acquisition system, which is made up of an Analog to Digital Converter (ADC) and a signal conditioning unit is presented in [16]. 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. 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 18 samples per cycle and 900 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 non-recursive DFT. Figure 2 illustrates the non-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 (Φ + θ), where θ is the angle between the samples [19].

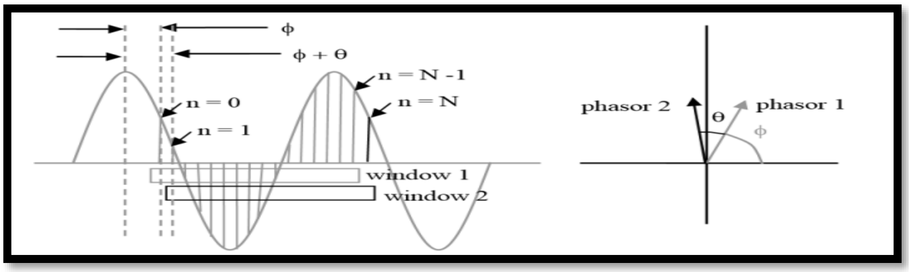

Figure 2 DFT based phasor calculation

Consider a discrete signal with sampling rate of Nf_0 is

$$x(t) = X_m \cos(\omega t + \emptyset) \quad (3)$$

N samples of the sinusoid x_n :{ n=0, 1... N-1} are obtained from

$$X_n = X_m \cos(n\theta + \emptyset) \quad (4)$$

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

the fourier series for the signal is given by

$$X_k = \frac{\sqrt{2}}{N}\sum_{n=0}^{N-1} x_n \left[\cos(kn\theta) - j\sin(kn\theta)\right] \quad (5)$$

$$X_{kc} = \frac{\sqrt{2}}{N}\sum_{n=0}^{N-1} x_n \cos(kn\theta) \quad (6)$$

$$X_{ks} = \frac{\sqrt{2}}{N}\sum_{n=0}^{N-1} x_n \sin(kn\theta) \quad (7)$$

K_{th} frequency component sin and cosin terms are represented with equation (6) and (7)

Window last sample is (N-1) the value is

$$X^{N-1} = \frac{\sqrt{2}}{N}\sum_{n=0}^{N-1} x_n \left[\cos(n\theta) - j\sin(n\theta)\right] = \frac{\sqrt{2}}{N}\sum_{n=0}^{N-1} x_n e^{-jn\theta} \quad (8)$$

$$X^{N} = \frac{\sqrt{2}}{N}\sum_{n=0}^{N-1} x_{n+1} \left[\cos(n\theta) - j\sin(n\theta)\right] = \frac{\sqrt{2}}{N}\sum_{n=0}^{N-1} x_{n+1} e^{-jn\theta} \quad (9)$$

LABVIEW BASED PHASOR IMPLEMETATION

A DFT technique is used to measure phasor values of the voltage and current signals[20]; different approaches are there to calculate the phasor values. By using Non-Recursive DFT based approach is used here due to it's more accuracy [21] . Figure 3 shows the voltage and current signals with non-linear load. The values shown in the same figure table are instant values of the signal, phasor values and its frequency with Global Positioning System (GPS) time stamping. With the GPS time stamp the measurements are are time synchronized. Which are useful to calculate the power flow in the system and dynamic state monitoring.

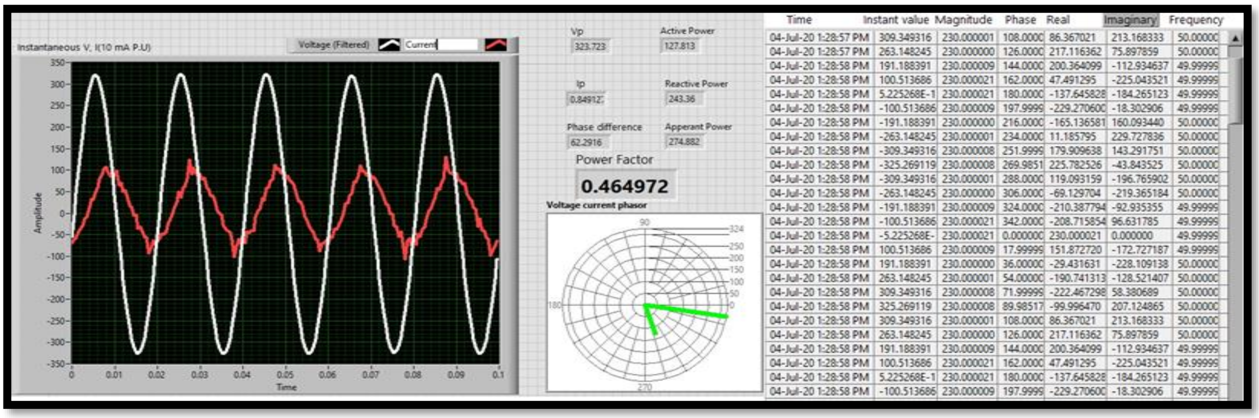

Figure 3 Voltage and current signals, phasor and power system parameters

Figure 3 shows thephasor measurement of voltage and current signal and values and phase angle values also accurately measured according to the signal values. Due to the sampling rate of 20, the phase angle between the two successive phasor values is 18 degree. Here polar plot is used to track the real-time image of the voltage signal phasor, the calculated phasor magnitude value is very accurate upto 4 decimal points.

IMPLEMENTATION OF PROTECTION CIRCUIT AND EFFECTIVE DATA STORAGE

LabVIEW based phasor calculation, less data storage and protection circuit is shown in Figure 4.The signal acqization and processing is presented in [22]. A trip signal is generated if the voltage magnitude +/- 5% change of rated value, or the frequency +/- 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 20kΩ 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 dta new method is adapoted, 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 nerly 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.

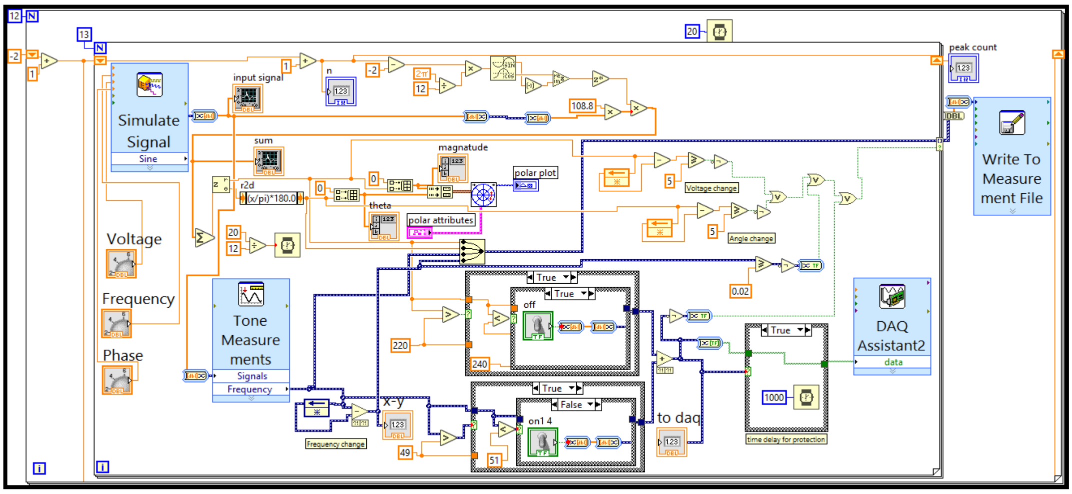

Figure 4 Protection circuit implementation against variation of voltages and frequency with less data storage.

Figure 5 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.

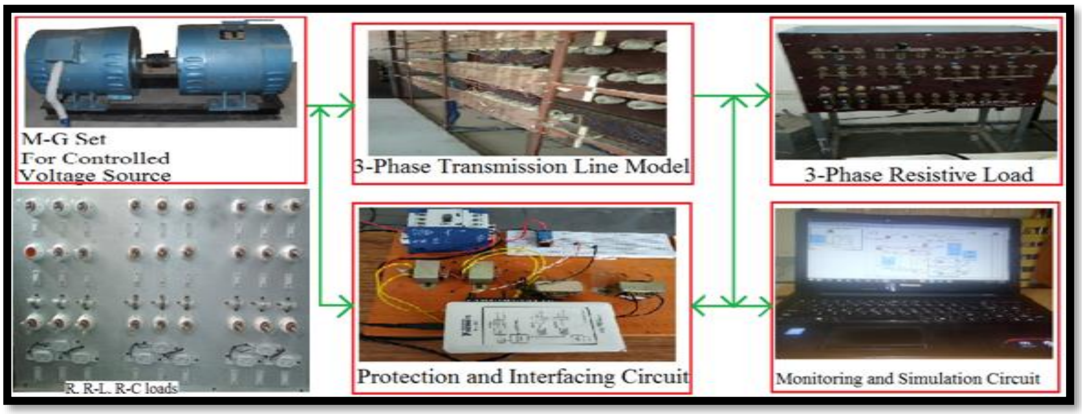

Figure 5 Hardware model of the work for creating different test conditions.

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 voltage and frequency

Time(GPS)	**Inst. value**	**Mag.**	**Phase In deg**	**Frequency**	**COE**	**RO COF**	**%TVE**	**Trip signal**
21-01-2025 11:17:04.552	0	229.97	0	49.99	-	-	0.1	-
21-01-2025 11:17:04.563	100.48	229.97	17.99	49.99	0	0	0.1	-
21-01-2025 11:17:04.573	191.43	229.95	35.98	49.98	0.01	1	0.3	-
21-01-2025 11:17:04.583	262.98	229.95	53.97	49.98	0	0	0.2	-

21-01-2025 11:17:04.593	309.69	229.95	71.94	49.98	0	0	0.3	-
21-01-2025 11:17:04.603	325.01	229.97	89.96	49.99	-0.01	-1	0.5	-
21-01-2025 11:17:04.613	309.49	230	107.99	50.00	-0.01	-1	0.5	-
21-01-2025 11:17:04.623	262.93	230	126.99	50.00	0	0	0.3	-
21-01-2025 11:17:04.633	191.03	230	143.97	50.00	0	0	0.4	-
21-01-2025 11:17:04.643	100.43	229.97	161.98	49.99	0.01	1	0.5	-
21-01-2025 11:17:04.653	0	229.95	179.99	49.97	0	0	0.6	-
21-01-2025 11:17:04.663	-100.03	229.92	197.95	49.95	0.02	2	1	✓

CONCLUSION

In this papera DFT based phasor mesument technique is used to calculatephasor values of the voltage 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 the voltage signal, it shows the power system in real time, voltage magnitude and phase angles in the single screen. In power system monitoring, the recorded voltage magnitude and instantaneous phase angles are related to a common reference time, which is very advantageous. For every 20 milliseconds, the phase angles and voltage magnitude are time stamped and stored in the file in normal operating coditions. 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 deviationin 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.

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