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# Modelling and application of phasor measurement units for fault location

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*Wide area monitoring and control using Phasor Measurement Units (PMU's) will continue to remain as one of the integral components of large power systems for different important applications in power systems which includes dynamic state estimation, power oscillation monitoring, Transient Stability Assessment etc. A wide area measuring system is composed of a PMU with High Speed Communication Channels and Phasor data concentrators. This paper explores the modeling and application of a typical phasor measurement unit to monitor voltage and current swings for different types faults and disturbances in the standard four generator two area power system.*

***Keywords:*** *Phasors, phasor measurement unit, wide measurement and control, dynamic analysis.*

## 1.0 INTRODUCTION

Phasors are basic tools for AC circuit analysis usually, introduced as a means of representing steady state sinusoidal wave forms of fundamental power frequency. Even when a power system is not quite often in a steady state, phasors are often useful in describing the behavior of the power system. For example, when the power system is undergoing electromechanical oscillations during power swings, the wave forms of voltages and currents are not in steady state and neither is the frequency of the power system at its nominal value. Under these operating conditions, as the variations of the voltages and currents are relatively slow; phasors may still be used to describe the performance of the network, the variations being treated as a series of steady state conditions. [1, 3]. Ref. [5] presents a fault locating scheme for different types of faults in a power network.

This objective of this paper is to present the mathematical modelling of phasor measuring units for monitoring the voltage and current oscillations, in the standard two area power system [2]. Different types of critical faults are simulated in the two area power system and the power swings between the two areas in the tie lines are observed. The time domain simulation results help to classify the different types of critical faults in the system. This paper is organized as follows. Section 2 presents the basic phasor measurement process and modeling of PMU; Section 3 presents the modelling of the two area system with PMU Section 4 presents the simulation results. Section 5 presents the conclusion and future scope.

## 2.0 PHASOR MEASUREMENT UNIT ARCHITECTURE AND MODELLING

Consider the steady-state wave form of a nominal power frequency signal as shown in Figure 1.

If we start our observation of this wave form at the instant t = 0, the steady-state waveform may be represented by a complex number with a magnitude equal to the Root Mean Square(RMS)

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value of the signal and with a phase angle equal to the angle $\phi$. In a digital measuring system, samples of the wave form for one (nominal) period are collected, starting at t= 0, and then the fundamental frequency component of the Discrete Fourier Transform (DFT') is calculated according to the relation:

$$X = \frac{\sqrt{2}}{N}\sum_{k=1}^{N} X_k e^{\frac{-j2k\pi}{N}} \quad ....(1)$$

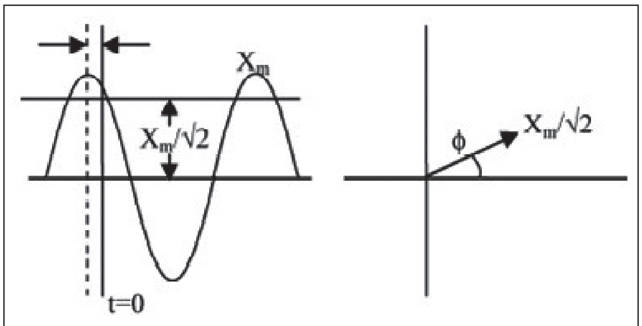


FIG. 1 PHASOR REPRESENTATION OF A SINUSOIDAL WAVEFORM

Where N is the total number of samples in one period, X is the phasor, and $X_k$ is the wave form samples. This definition of the phasor has the merit that it uses a number of samples (N) of the wave form, and is the correct representation of the fundamental frequency component, when other transient components are present. [4]

Figure 2 illustrates the two basic PMU architectures [9]. The basic block diagrams for the two schemes are similar and can be divided into:

- Sampling and filtering;
- Frequency and Phasor (Discrete Fourier Transform DFT) estimators.
- The main difference between the architectures is in the way the signal is sampled:
- A uniform (fixed) sampling rate;
- A non-uniform (variable) sampling rate.

The first architecture using uniform sampling simplifies the data acquisition process and the signal-processing analysis. Most of PMU algorithm development activities are based on exploring and improving uniform sampling methodologies [4]. As a result, this paper will focus on the uniform sampling rate approach.

The uniform sampling phasor measurement process is divided in to three main parts: phasor estimation using recursive or non-recursive) discrete Fourier Transform (DFT), frequency estimation, and post-processing (using calibration factors and filtering), as shown in Figure 3. Under off-nominal frequency operation, the post-processing layer is necessary to correct the effects caused by leakage phenomenon. Leakage phenomenon results from the truncation of sampled data outside the data window. Consequently, the estimated phasor is attenuated by two complex gains, $P_n$ and $Q_n$. From Equation (2), the effects of the complex gain Pn (shown in Figure 3) can be readily computed from the sampling window size (N), the frequency deviation ($\Delta\omega$) and the sampling period ($\Delta t$) [4].The magnitude of Pn is an attenuation factor, and the phase angle of Pn is a constant offset in the measured phase angles. As the window size (N) and sampling period ($\Delta t$) are fixed, Pn can be readily estimated for a frequency range and stored in a table (Block 1 in Figure 3). Inreal-time, frequency deviation estimation is necessary to compute the correct Pn value.

The complex gains introduce a magnitude and phase angle variation at frequency $2\omega 0 + \Delta\omega = 2\omega 0$ (approximately) in the estimated single-phase phasor.

$$P_n = \left\{ \frac{\sin \frac{N(\omega - \omega_0)\Delta t}{2}}{N \sin \frac{(\omega - \omega_0)\Delta t}{2}} \right\} e^{j(N\text{-}1)\frac{(\omega\text{-}\omega_0)\Delta t}{2}} \quad ....(2)$$

$$Q_n = \left\{ \frac{\sin \frac{N(\omega + \omega_0)\Delta t}{2}}{N \sin \frac{(\omega + \omega_0)\Delta t}{2}} \right\} e^{-j(N\text{-}1)\frac{(\omega+\omega_0)\Delta t}{2}} \quad ....(3)$$

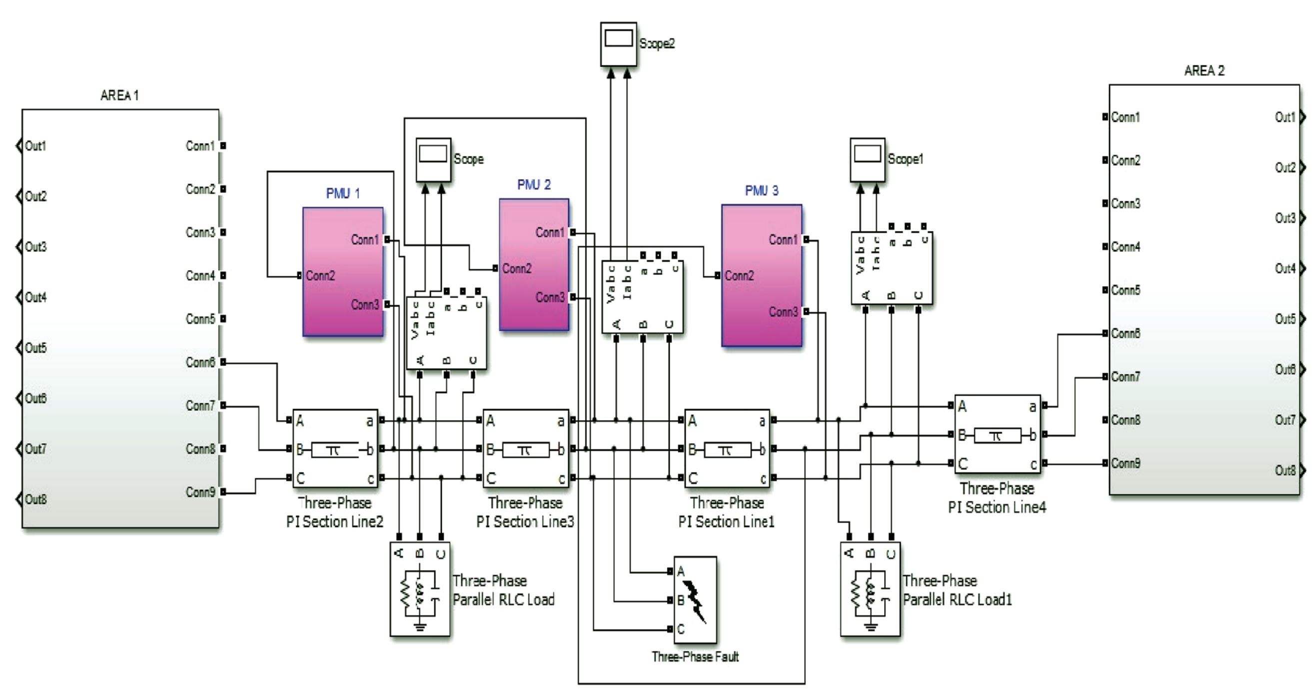


FIG. 5 MATLAB/SIMULINK BASED TWO AREA SYSTEM WITH PMU

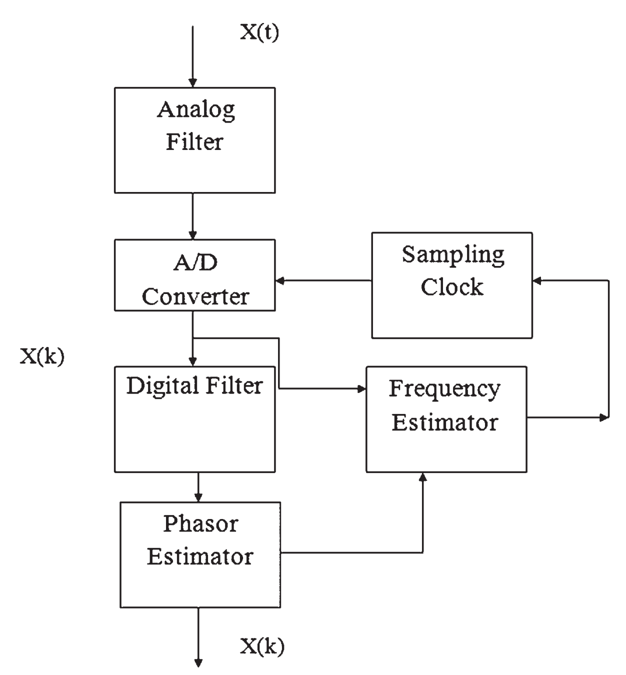


FIG. 2 PHASOR ESTIMATION UNIFORM SAMPLING

## 3.0 NUMERICAL EXAMPLES AND RESULTS

The PMU's are installed at different locations (Figure 4) on the two area 4 machine power system. PMU 1 is located at area 1(bus 6), PMU 2 is located at area 2 (bus10), PMU 3 is located in the tie line at bus 8. Figure 5 shows the simulink implementation of the two area power system with PMU models connected at appropriate locations.

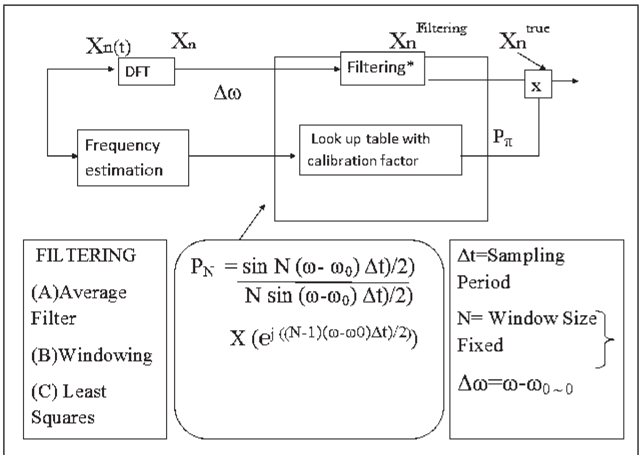


FIG. 3 PHASOR PROCESSING ALGORITHM FOR UNIFORM SAMPLING

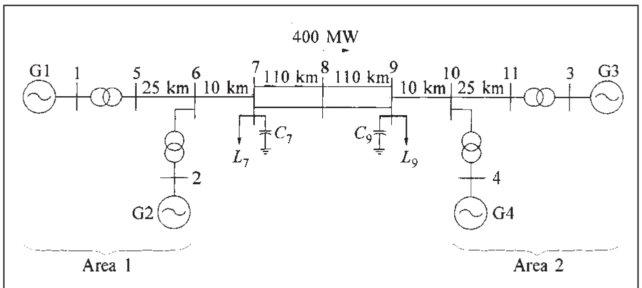


FIG. 4 TWO AREA 4 MACHINE POWER SYSTEM

### A. Single line to ground fault

A single phase fault is applied at bus 8 of the power system for duration of 0.1 seconds. PMU-2 being nearest to the affected bus measured the abnormal deviations in voltage and current phasors of all the three phases. Figure 6 shows the phase-A voltage phase angles measured by the three PMU's. at different locations.

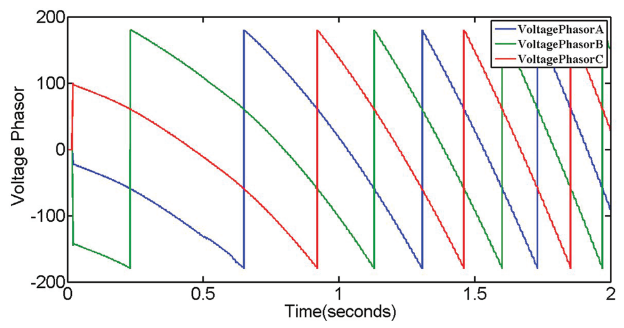


FIG. 6 VOLTAGE PHASOR MEASURED BY PMU1 NEAR AREA 1

Figure 7 shows the voltage phase angles measured by the PMU 2 at the tie line bus 8. Figure 8 presents the voltage phase angles measured by PMU 2 in area 2 at bus Comparing the phase angles of voltage it could be concluded that the fault is located closer to PMU 2 in the tie line bus.

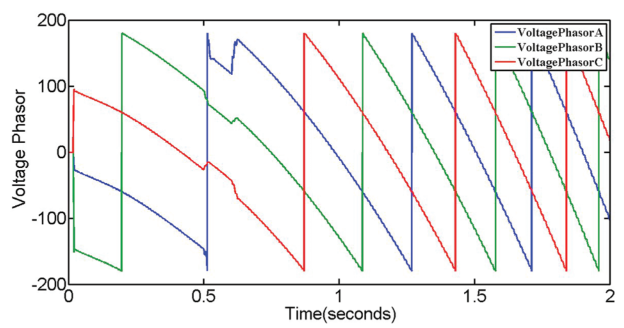


FIG. 7 VOLTAGE PHASOR MEASURED BY PMU2 AT TIE LINE BUS 8

### B. Double Line to Ground Fault

A double line fault is applied at bus 8 of the power system for duration of 0.1 seconds. PMU2 being nearest to the affected bus measures the abnormal deviations in voltage and current phasors of the three phases. Comparing the results of PMU 1, 2 and 3 as given by Figures 10, 11 and 12 respectively it is clear that the fault has taken place closer to bus 8. These time domain results reveal that a double line to ground fault is applied in the network. Figure 13 presents the tie line currents after the fault at bus 8. From the results it is clear that the current magnitudes shoot up in the two phases subjected to fault.

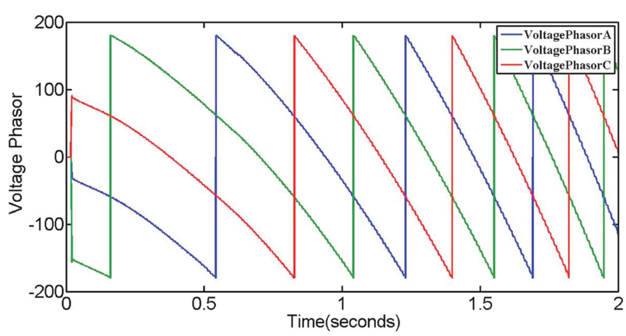


FIG. 8 VOLTAGE PHASOR MEASURED BY PMU3 NEAR AREA 2

Figure 9 presents the variations in tie line current flow recorded by PMU 2.

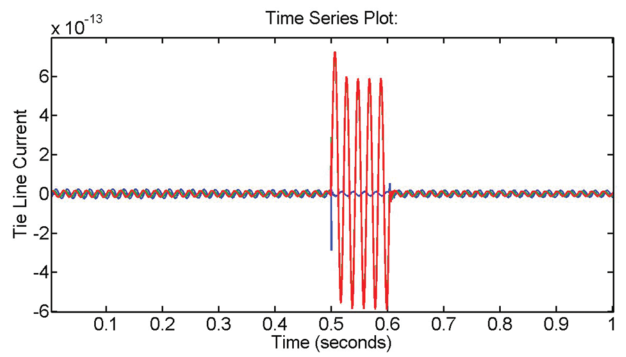


FIG. 9 TIE LINE CURRENT DURING FAULT

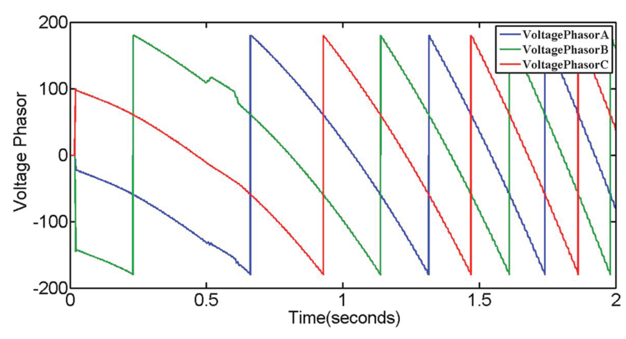


FIG. 10 VOLTAGE PHASOR MEASURED BY PMU 1 NEAR AREA 1

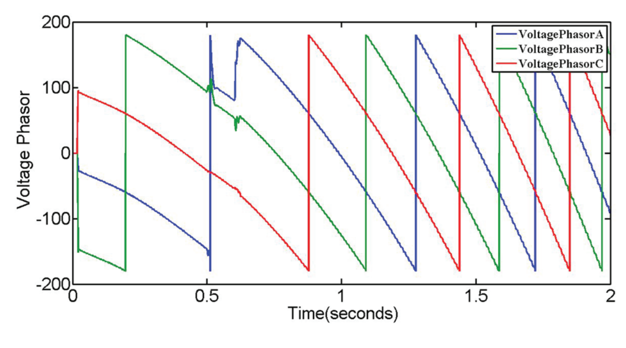


FIG. 11 VOLTAGE PHASOR MEASURED BY PMU 2 AT TIE LINE BUS 8

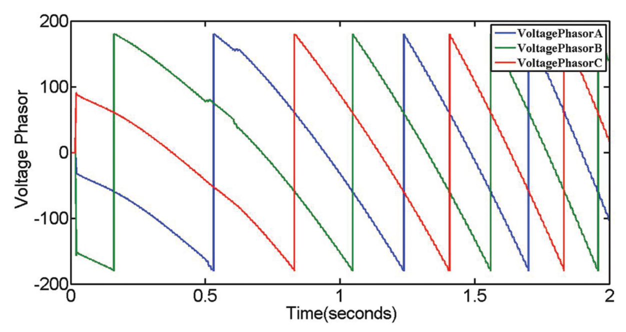


FIG 12. VOLTAGE PHASOR MEASURED BY PMU3 NEAR AREA 2.

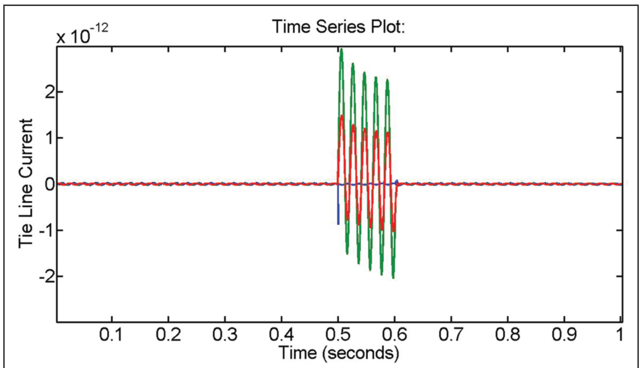


FIG. 13 TIE LINE CURRENT DURING FAULT

## C. Three Phase Fault

A three phase fault is applied to bus 8 of the power system. PMU-2 being nearest to the affected bus measures the abnormal deviations in voltage phase angles and current phasors of the three phases. Comparing the results of PMU1, 2 and 3 as given by Figures 14, 15 and 16 respectively it is clear that the fault has taken place closer to bus 8. From the results it is clear that the current magnitudes shoot up in the three phases subjected to fault. (Figure 15). Figure 17 shows the variations in tie line current after the fault closer to bus 8.

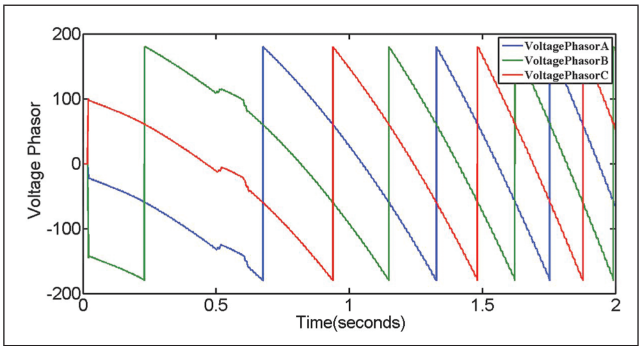


FIG. 14 VOLTAGE PHASOR MEASURED BY PMU 1 NEAR AREA 1

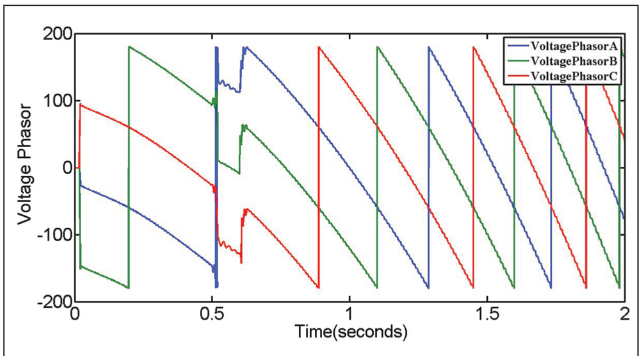


FIG. 15 VOLTAGE PHASOR MEASURED BY PMU 2 AT TIE LINE BUS 8

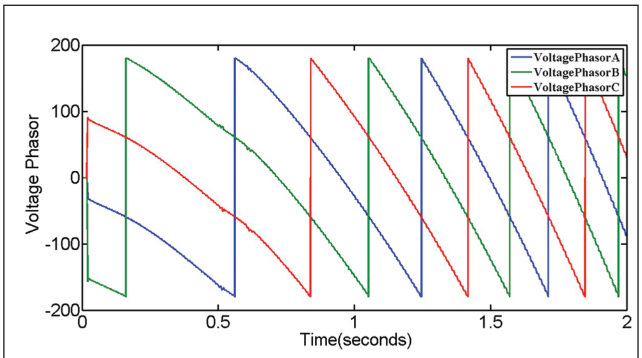


FIG. 16 VOLTAGE PHASOR MEASURED BY PMU 3 NEAR AREA 2

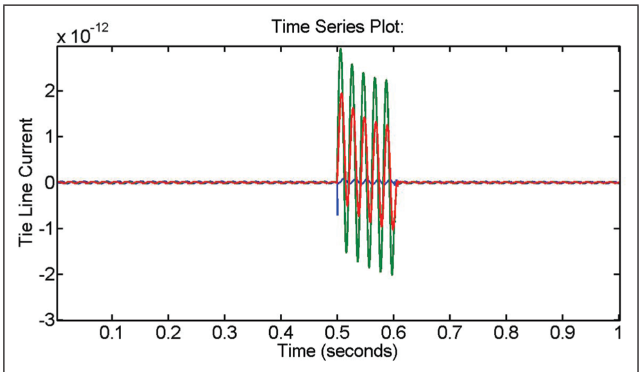


FIG. 17 TIE LINE CURRENT DURING FAULT

## 4.0 CONCLUSION AND FUTURE SCOPE

This paper presented a fault location scheme using phasor measurement units for a two area power system. The results obtained from the PMU could be further taken up for post processing and design of an effective protection system.

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