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Modelling of Phasor Measurement Unit and Phasor Data Realisation with 2 Bus System

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***Abstract*— This paper presents the modeling of Phasor Measurement Unit in MATLAB as well as Phasor data realization with 2 bus system. With the help of simulink model of 2 bus system comprising of PMU block in MATLAB, the real time data are obtained to understand the dynamic responses or changes, occurred in the system either in healthy condition or in faulty condition. With the help of data gathered in these situations it becomes easier to identify the unbalancing in established electrical power system & accordingly preventive action can be taken to isolate or handle the worst situation, if any within the prescribed time limit.**

Keywords*— *Phasor measurement unit, positive sequence, negative sequence, zero sequence, discrete fourier transform.

I. Introduction

Now-a-days, Phasor measurement unit becomes the integral part of any existing power system for the study & analysis purpose of their variable dynamic parameters. In any power system some parameters like voltage, current, phase angle, balance in active & reactive power continuously changes. Sometimes, slight changes in these parameters greatly affect the whole system, but remains undetected. However, post mortem analysis is used to analyze the data & its impact on the existing system but the faulty conditions remain undetected. So, it is a tedious work to detect the same. However, with the evolution of Phasor measurement unit this task becomes easy because it keeps all the data related with the variation in voltage, current and phase angle in the existing system where it is installed & implements it for analysis purpose wherever it is required. Hence, Phasor measurement unit is realized in MATLAB to study its nature & working capability.

II. Phasor Measurement Unit

Phasor Measurement Unit has been defined by IEEE as "a device that produces synchronized Phasor, frequency, and rate of change of frequency (ROCOF) estimates from voltage and/or current signals and a time synchronizing signal."[1]. Basically, the Phasor measurement unit (PMU) is a micro processor based device that uses the ability of digital signal processor in order to measure 50/60 Hz AC waveforms (voltages & currents) at a typical rate of 48 samples per cycle (2400/2880 samples per second) [2].

Figure 1 shows the function block diagram of a typical PMU. Analogue inputs are derived from the voltage and current transformer [3]. A PMU may collect data from different locations in the system simultaneously and normally requires data from all three phases to extract the positive-sequence component, which is normally of interest and contains information that can be used to assess the state of the power system.

The signals derived from the secondary winding of the voltage and current transformer are first converted (via A/D converters) to voltage signals with a typical range of ±10V [4]. The sampling rate must be at least twice of the cut-off frequency of the filter to satisfy the Nyquist criterion. Oversampling is used in many systems due to the better stability and accuracy that it offers [5]. The GPS (Global Positioning System) receiver normally generates a one pulse-per-second signal to the phase-locked oscillator to lock the phase of the sampling clock. Higher sampling rate is always looking forward so that the accuracy of the estimation can be improved [4]. The coordinates of GPS receivers of PMUs at measuring points all over the world is determined by the satellites through GPS system. The GPS receiver also creates time stamps for the output of the microprocessor. The error of synchronization with modern units is of the order of a few hundred nanoseconds [4]. The microprocessor uses the digital signal from the A/D converter to calculate the quantities required, including the magnitude and phase angle (calculated by the application of discrete Fourier Transform) of the voltage and current, the measured frequency and in some cases the rate of change of frequency. The quantities of different measuring point can be communicated and compared using the time stamps, regardless of any time delay associated with the communication system. Finally, the principal output of the PMU is the time-stamped measurement to be transferred over the communication links through suitable modems to a higher level in the measurement system hierarchy.

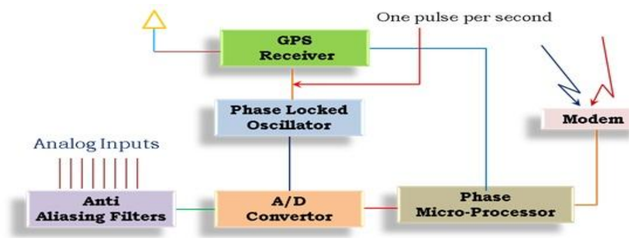

Fig. 1. Functional Block Diagram of a typical Phasor Measurement Unit

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III. Realization of Phasor Measurement Unit in MATLAB

The basic block diagram of phasor measurement unit is already discussed in previous section which becomes the basis of realization of phasor measurement unit in MATLAB. Hence, figure 2 shows the phasor measurement unit block implemented for MATLAB simulation. It is a subsystem consisting of three ports. Each port is connected with each phase in 3-φ system.

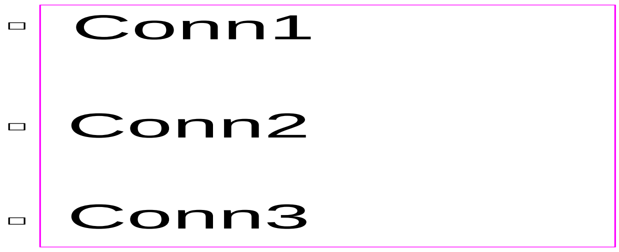

Fig. 2. PMU Block implemented for MATLAB Simulation

Figure 3 shows the main components of phasor measurement unit in MATLAB. It consists of potential transformer, low pass filter, analogue to digital converter with discrete Fourier transform & sequence analyzer. Figure 4 & Figure 5 shows the realization of potential transformer part as well as LPF part in MATLAB.

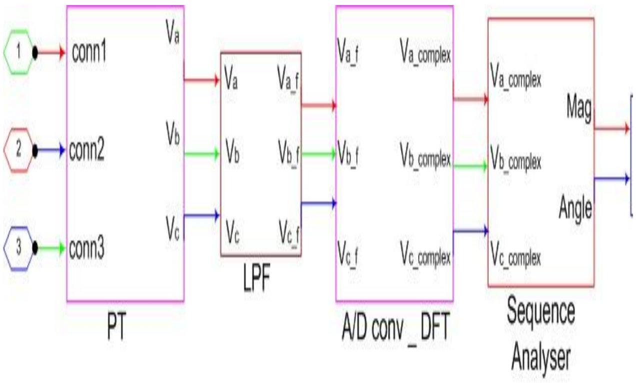

Fig. 3. PMU components in MATLAB

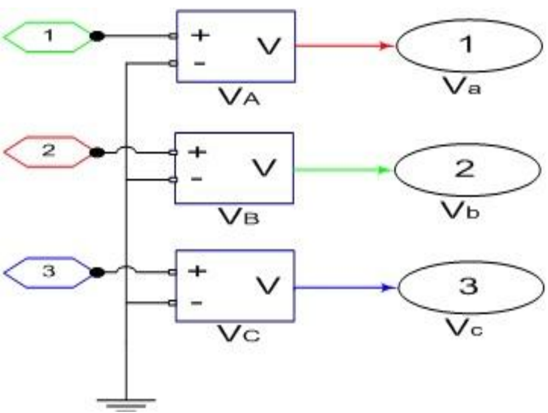

Fig. 4: Potential Transformer part in PMU in MATLAB

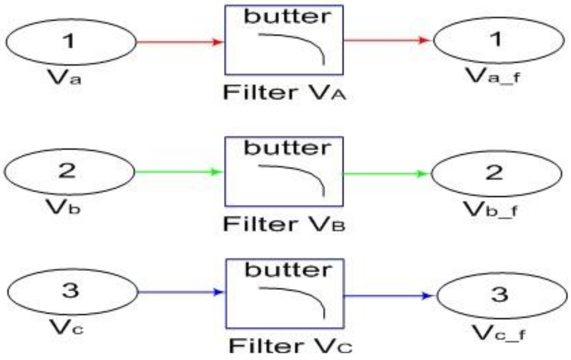

Fig. 5. Realization of Low Pass Filter in PMU

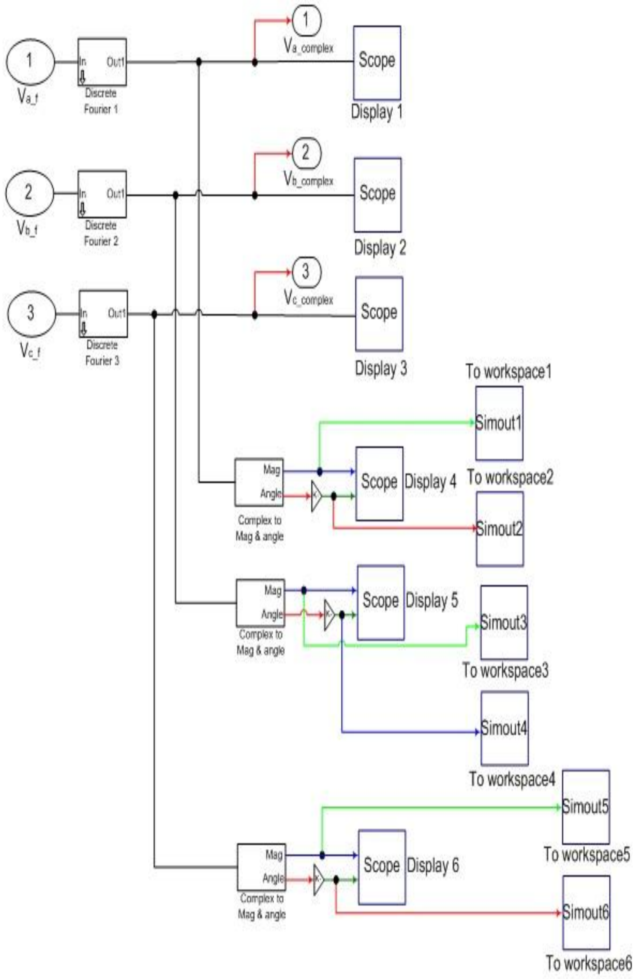

Fig.6. Analog to Digital Convertor with DFT part of PMU in MATLAB

Figure 6 shows the realization of analog to digital convertor with DFT in MATLAB. Hence, the outputs passes through the Low Pass Filter is used as an input for this part. Obtained complex values of each phase can be realized by putting a scope as shown in figure 6. Then, these complex values are converted into its magnitude & angle part for further processing and the obtained values are kept in corresponding simout / workspace parts.

Now, these complex values are used as the inputs for embedded MATLAB function which is actually a sequence analyzer part of phasor measurement unit. From this part, positive sequence voltage is obtained consisting of both magnitude & phase angle by using the equations as given below and it is also shown in figure 7, how positive sequence voltage can be obtained. The negative and zero sequence quantities are not taken into consideration.

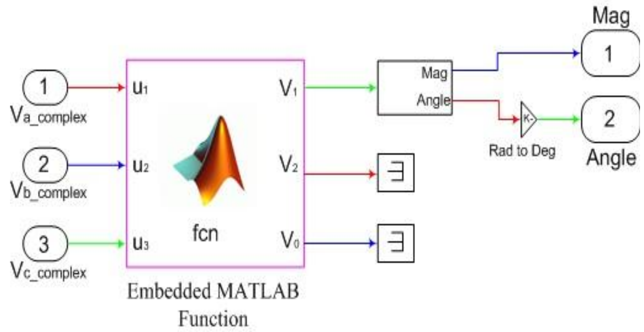

Fig. 7. Sequence Analyzer part of PMU in MATLAB

$$Function[V_1, V_2, V_3] = fcn(V_a, V_b, V_c)$$

$$V_1 = \frac{1}{3}\left(V_a + \alpha V_b + \alpha^2 V_c\right) \text{ ; Positive sequence voltage}$$

$$V_2 = \frac{1}{3}\left(V_a + \alpha^2 V_b + \alpha V_c\right) \text{ ; Negative sequence voltage}$$

$$V_1 = \frac{1}{3}\left(V_a + V_b + V_c\right) \qquad \text{ ; Zero sequence voltage}$$

Where α = -0.5+j0.866

Generally, positive sequence voltage is the value of voltage in normal condition. In case of any fault or unbalancing, these values will be changed. So, it becomes essential to take care of these values at each moment. In this context, phasor measurement unit does the same where it contains all the required data which changes continuously. Practically phasor measurement unit has a bulk data storage capacity & it checks and compares the changes in data obtained & accordingly makes the precise decision.

IV. Case Study with 2 Bus System

Hence, 2 bus systems are taken as a simulation model in MATLAB / SIMULINK for study & analysis purpose and realize the phasor measurement unit in the system. In this system there exists a generator with a load connecting with a distributed line. A phasor measurement unit is also connected with the line to keep the data, used in analysis. Hence, with the help of phasor measurement unit, it becomes easy to analyze the proposed system which in turn make easy to predict the possible variation / changes. The obtained results are discussed in next section.

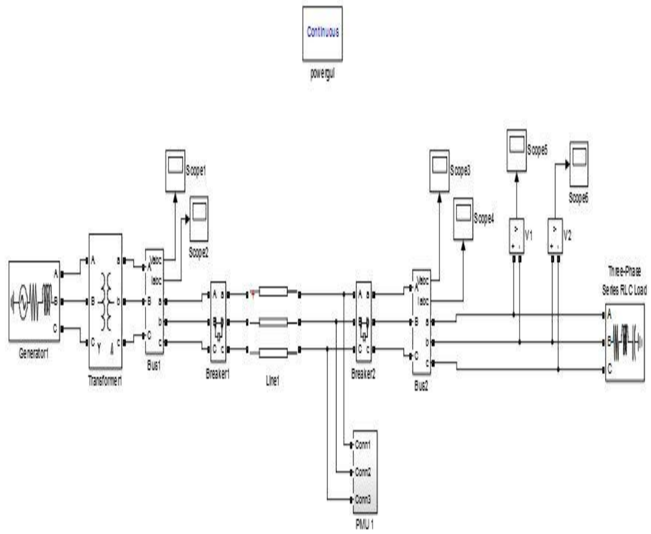

Fig. 8. Simulink Model of a 2 Bus system with PMU

This system consists of:

a.	Generator	- 01 no.
b.	3-φ transformer	- 01 no.
c.	3-φ series RLC Load	- 01 no.
d.	3-φ circuit breaker	- 02 no.
e.	Distributed Transmission Line	- 01 no.
f.	Phasor Measurement Unit	- 01 no.
g.	Scope (for measurement)	- 04 no.

In this system, only positive sequence voltage & its angle are taken into consideration for study & analysis purpose.

V. Data Used in Simulink Model

Data used in the Simulink model in MATLAB as shown in figure 8 are as below.

i. Three Phase Source i.e. Generator

Base Burden: 100 MVA, Base Voltage: 13.8kV, Phase Voltage (in RMS): 13.8kV, Nominal Frequency: 50Hz

ii. Three Phase Transformer

Two Winding, star delta (D11), Nominal Power: 60MVA, Nominal Frequency: 50Hz, Star Winding Parameters, Phase Voltage: 13.8kV, Resistance (in pu): 0.002, Inductance (in pu): 0.08, Delta (D11) Winding Parameters, Phase Voltage: 220kV, Resistance (in pu): 0.002, Inductance (in pu): 0.08, Magnetization Resistance (in pu): 500, Magnetization Inductance (in pu): 500.

iii. Bus 1 & Bus2

Phase Voltage (in RMS): 220kV

iv. Three Phase Series RLC Load

Phase Voltage (in RMS): 220kV, Nominal Frequency: 50Hz, Active Power: 1000W, Inductive Reactive Power: 100VAR, Capacitive Reactive Power: 100VAR.

v. Distributed Line Parameter

Nominal Frequency: 50Hz, R1 = 10.3864 (ohms/km), R0 = 0.01273 (ohms/km), L1 = 4.1264mH (H/km), L0 = 0.9337mH (H/km), C1 = 7.751 nF (F/km), C0 = 12.74 nF (F/km), Transmission Line Length: 100 km

vi. Circuit Breaker

Initial Status: closed, Breaker Resistance: 0.001 ohms, Snubber Resistance: 1e6 ohms, Snubber Capacitance: infinity (Farad).

Figure 9 shows the Simulink model of 2 bus system with intended 3- φ fault. In this system, with the help of 3- φ fault analyzer, the given system is studied and observed for all possible types of faults i.e. for LLLG fault, LLG fault, LG fault, LLL fault & for overloading conditions also. Hence, PMU also observes the system & keep the data of all variation / changes in the parameters, basically positive sequence voltage and current for all these possible fault conditions.

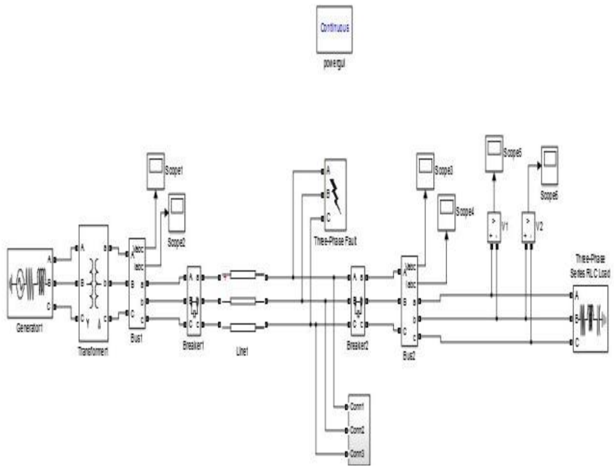

Fig. 9. Simulink Model of a 2 Bus system with PMU with intended 3-φ Fault

VI. RESULT

In normal condition i.e. in the system having no intended fault, the positive sequence voltage as observed by phasor measurement unit is 2.328e+05 V & -105.5° as shown in figure 10. Positive, Negative & Zero sequence voltage is also shown in figure 11, 12& 13 respectively to see the nature.

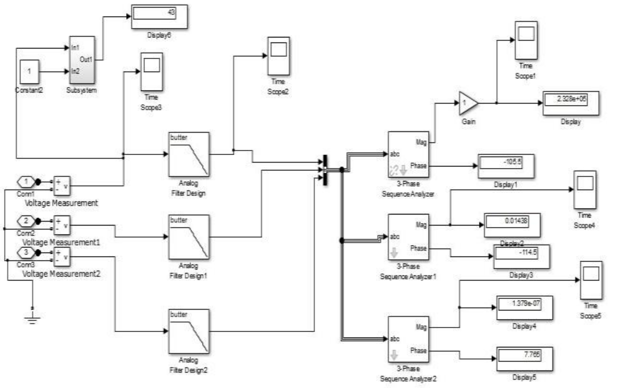

Fig. 10. Positive Sequence Voltage & Phasor Output in PMU

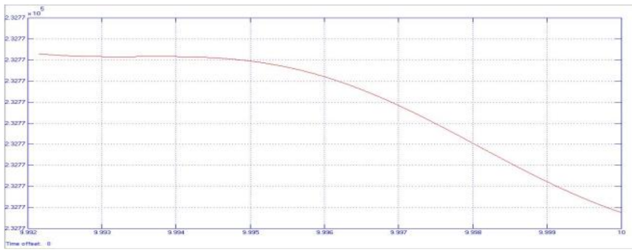

Fig.11. Positive Sequence Voltage of 2 Bus System observed by PMU Model

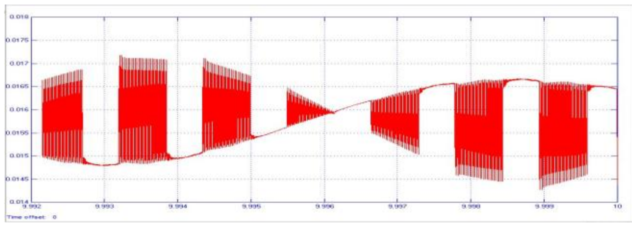

Fig. 12. Negative Sequence Voltage of 2 Bus System observed by PMU Model

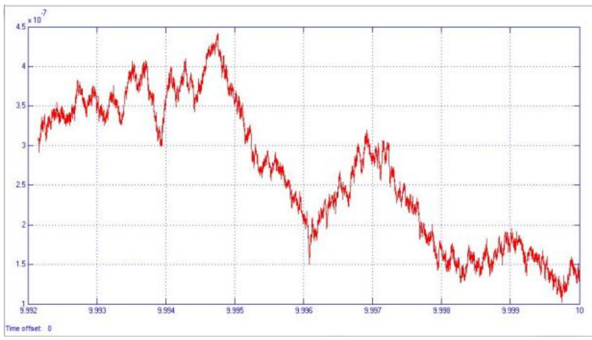

Fig. 13. Zero Sequence Voltage of 2 Bus System observed by PMU Model

In the same way, positive sequence voltage & phasor may also be obtained with different conditions i.e. for LLLG fault, LLG fault, LG fault & LLL fault, etc. For LLLG fault condition, the positive sequence voltage as observed by phasor measurement unit is 2.324e+05 V & -105.6° as shown in figure 14. Positive, Negative & Zero sequence voltage is also shown in figure 15, 16 & 17 respectively to see the nature in faulted condition.

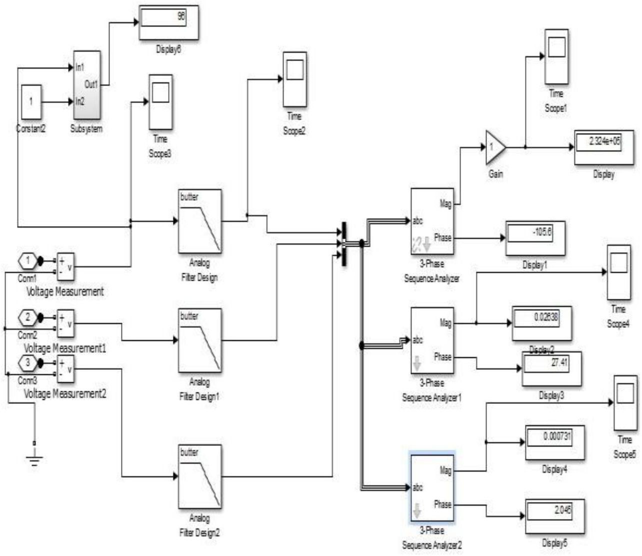

Fig. 14. Positive Sequence Voltage & Phasor Output in PMU Model for LLLG Fault

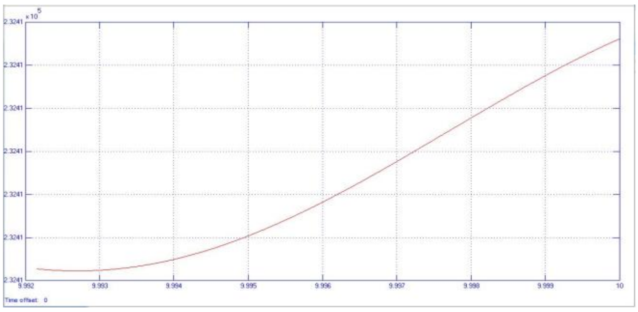

Fig. 15: Positive Sequence Voltage of 2 Bus System observed by PMU Model for LLLG Fault

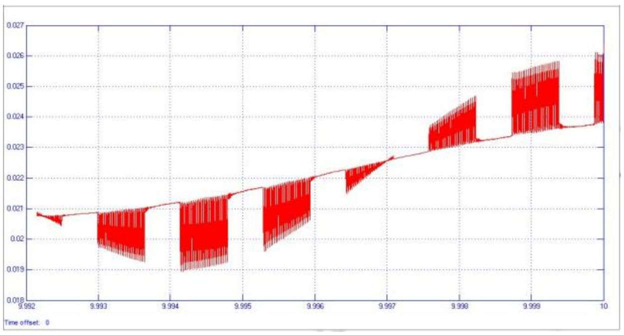

Fig. 16. Negative Sequence Voltage of 2 Bus System observed by PMU Model for LLLG Fault

Fig.17. Zero Sequence Voltage of 2 Bus System observed by PMU Model for LLLG Fault

Similarly, for LLG Fault, LG Fault, LLL Fault & overloading, positive, Negative & Zero sequence voltage and phasor may be obtained by PMU model.

VII. CONCLUSION

The traditional power system monitoring, protection and control measures are based on local measurements. However, it is quite difficult to maintain the stability and security of the system on the whole, if only local measurements are employed in the monitoring, protection and control schemes. One promising way is to provide a system wide protection and control, complementary to the conventional local protection strategy. The main disadvantage of the present conventional method of system monitoring is the inappropriate system dynamic view, or the uncoordinated local actions, like those in decentralized protection devices. Solution to the above can be achieved through dynamic measurement system using synchronized phasor measurement units. This paper enlightens the importance & application of phasor measurement unit in power system. For the study and analysis purpose, phasor measurement unit is realized in MATLAB & it is shown that how phasor measurement unit works to gather the phasor data i.e. voltage, current & phase angle, etc for both faulted condition or for healthy condition. PMU also reflects the status of system for positive, negative & zero sequence condition. Thus, PMU make the complete study & observation of the whole system for each condition at each moment.

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