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Measurement of Sequence Voltages by Phasor Measurement Unit for WAMs

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***Abstract*- With increasing growth of power system both in terms of geographical as well as technological advancements, there arises a need for different tools to address disturbances in the power system network. The competence of system operators in taking real time decisions depends on their situational awareness derived from the data available with them in real time. Extended technological advancements in information communication technology have promoted the advent of phasor measurement units(PMU). Phasor Measurement Units have the potential to provide voltage and current phasors at the PMU location, which helps in understanding state and health of power system. This paper reviews various standards of PMU and a simple MATLAB modeling of PMU for a two bus system.**

***Keywords* – Phasor, Phasor Measurement Unit (PMU), MATLAB modelling; two bus system, Wide area measurement (WAM).**

I. INTRODUCTION

Phasor Measurement Unit(PMU), is described as a device which can measure phasors. PMU can also measure frequency, rate of change of frequency, power, circuit breaker status etc. In power system, phasors are used for analyzing phasors for attaining system stability. Mathematically an ac signal is given by

$x(t) = X_m \cos(wt + \emptyset)$................................. (1)

X_m - peak amplitude of the sinusoidal

$\emptyset$ - phase angle in radians

The phasor equivalent is given by

$X = (Xm/\sqrt{2})e^{j\emptyset}$ .... (2)

When these phasors are synchronized to a time reference, these phasors are called synchrophasors. This absolute time reference is a timing signal synchronised to Universal time coordinate such as GPS. And these synchrophasors are measured by PMUs, which are valuable aid to monitoring, protection and control functions of power system network. The PMU data also provide estimates of frequency, rate of change of frequency, real power flow, etc.

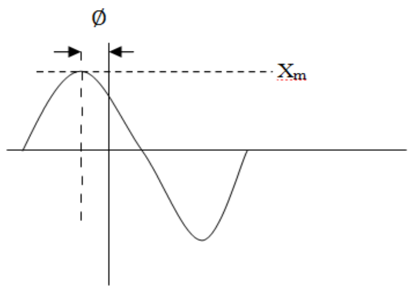

Fig- 1. Synchrophasor Interpretation

There are several methods used for estimating phasor from a sampled signal, but the most preferred method is Discrete Fourier Transform, as given below

$X = \frac{2}{N}\sum_{k=0}^{N-1} x_k\, e^{-j2\pi k/N}$ .... (3)

The PMU plays a crucial role in wide area measurement system(WAMS). The system state at a specific location is monitored by PMU at a rate of multiple samples per second. After time stamped through a common time reference, this data is fed to the Phasor Data Collector(PDC) through wideband communication medium. The PDC aligns the data and gives it to the Historian. The Historian archives the data for retrieval and post-dispatch analysis of the power grid.

II. PHASOR MEASUREMENT UNIT - STANDARDS

"IEEE Standard for synchrophasor for Power System-1344-1995", was the first IEEE standard for Synchrophasors, given in the year 1995.It mentions about UTC time co-ordination, waveform sampling requirements, accuracy etc. The next standard C37.118, completed in the year 2005, mentioned about Total vector error for measuring accuracy, where the estimated phasor was vectorially compared with the theoretical phasor for the same instant of time.

A. C37.118-2005 Synchrophasor Standard

This standard provides communication formats for real time data transmission. This standard defines PMU - a device capable of making, communicating and storing the synchronised phasor measurements. It specifies communication from PMU to PDC, a device used to archive and provide data for various analyses. The accuracy of measurement is given by vectorial difference of the measured and the theoretical value of the phasor at a given time instant, ‘i’. This is referred as total vector error (TVE).

$$TVE = \frac{|X_{measured} - X_{theoretical}|}{|X_{theoretical}|} * 100 \ldots\ldots (4)$$

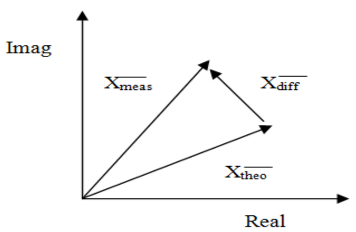

Fig- 2. Total Vector Error

TVE combines three sources of error: magnitude, phase angle and Synchronisation error. As per the standard real time communication of messages by PMU should support five types of frames: Data frames (binary format), Configuration frame-1, configuration frame-2, Header frame (ASCII text), Command frame (binary format). Also the message includes a unique ID identifying the message source or destination for the commands. Data frames may be either 16-bit integer or 32-bit floating point numbers. Along with synchrophasor measurements, analog values such as power flows and digital data such as circuit breaker status may be enclosed in the data frame. The configuration of a PMU is described by Configuration frame and Header frame, which are transmitted at starting of system. Out of the two configuration PMUs, one explains the PMU capabilities and the other defines the capabilities configured at a specified time. Header frames are disorganized text proposed for human understandable information. Command frame is initiated by the host to begin or end the transmission. The C37.118 protocol can be used with different communication mediums that include serial ports, wired Ethernet and fiber optic cable.

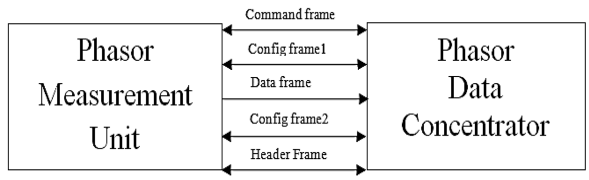

Fig- 3. PMU Data

B. Limitations of C37.118

Under dynamic conditions, Phasor measurement was not addressed in this standard. Also frequency measurements and communication compatibility with various communication protocols were not included, which led to revision of the standard. Since there is a significant impact of Measurement characteristics, two performance classes were defined. P class signifies quicker response but a precise operating range and reduced out of band filtering. M class provides absolute measurements with enhanced filtering. The frequency requirements included measurement of frequency and rate of change of frequency.

$$F_{error} = |f_{theoretical} - f_{measured}| \quad Hz$$

$$= |\Delta f_{theoretical} - \Delta f_{measured}| \quad Hz\ldots\ldots (5)$$

$$RF_{error} = \left| \left(\frac{df}{dt}\right)_{theoretical} - \frac{df}{dt}_{measured} \right| Hz/s\ldots (6)$$

Two new standards were developed for the purpose of development of Synchrophasor technology, i.e., C37.118.1 and C37.118.2 were the two new standards. C37.118.1 included all the synchrophasor measurement requirements and C37.118.2 was the standard regarding synchrophasor data transfer.

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III. APPLICATIONS OF PMU

Numerous amount of data can be obtained from PMU. These applications can be categorized into real time and offline applications. The real time applications include situational awareness through monitoring of magnitude, angle of three voltage/current phasors. It is also possible to visualize the sequence components of voltage/current phasor, frequency, rate of change of frequency, angular separation between pair of nodes. The offline applications include:

Forensic analysis of grid events	Identification of - Grid Incidents inter/other region - Fault type, i.e, LLLG, LLG, LG, LLL, LL - Fault nature (Short circuited or highly resistive) - Time of fault and sequence of events - Fault clearance time and probable location of fault - Possible protection operation/misoperation - Voltage recovery post fault clearance
Post-dispatch analysis of grid operation	Validation of - Steady state network model - Transfer capability declaration - Simulated short circuit current - Substation disturbance record - Substation event log Computation of - System inertia constant using df/dt - Frequency response characteristics
Detection of power system oscillations	Detection of - Time, duration, amplitude, frequency of oscillations - Type of oscillations, i.e, inter-area or local - Nature of oscillations (damped or undamped) Coherent group of generators

IV. SKETCH OF PMU TECHNOLOGY

The instantaneous values of voltage and currents are converted to a measurable range (typically in the range of ±10V) with the use of instrument transducers.

Fig.4. Working of PMU

These values are fed to the ADC. The low pass filter acts as anti-aliasing filter to remove high frequency noise. The digital signal processor calculates the phasor as well as the magnitude of voltage and current with the use of DFT algorithm. The GPS receiver receives 1pulse per second clock signal from GPS satellite in order to synchronize with the universal time co-ordinate, so as to realize synchronized measurements at multiple locations across the power system. Then the synchronized data are transmitted to the phasor data concentrators through the communication interface (for example serial communication).

V. 2BUS SYSTEM TEST MODEL & RESULTS

To analyze the performance of a PMU, a simulink model of a PMU has to be built. The output of the P.T is passed through a low pass filter to filter out high frequency noise, which is then sampled to obtain discrete data. Discrete Fourier transform is performed on this discrete data to extract the phasor estimates of the voltage.

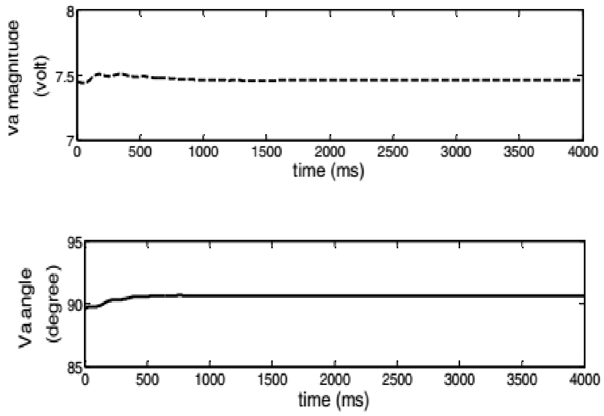
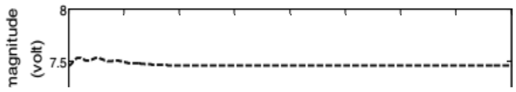


Fig.5. Voltage magnitude and phase angle of Phase 'a'



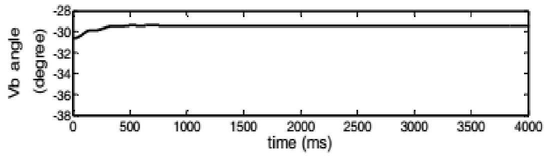


Fig.6. Voltage magnitude and phase angle of Phase 'b'

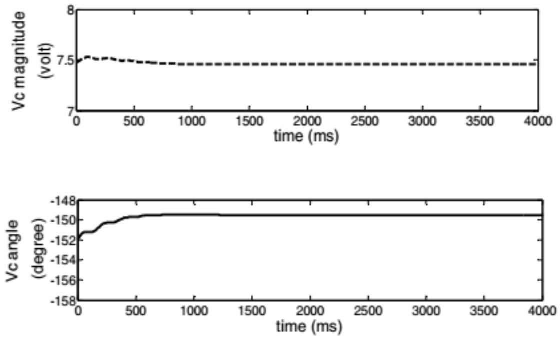


Fig-7. Voltage magnitude and phase angle of Phase 'c'

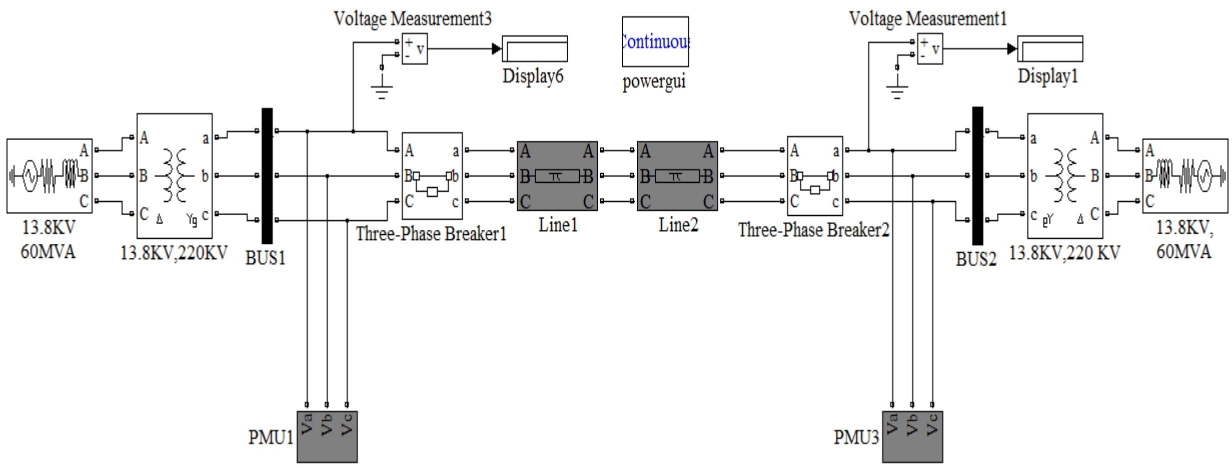


Fig- 8. Simulink model of a 2-bus test system

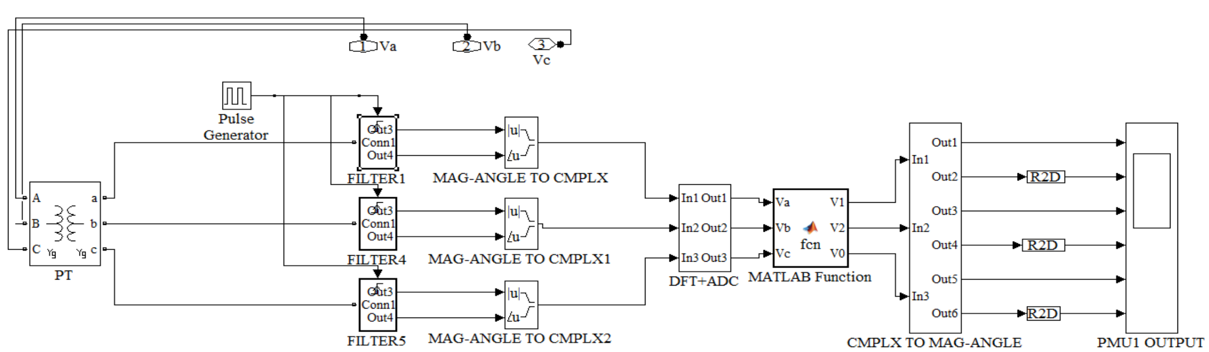


Fig- 9. Sub system Simulink model of the PMU

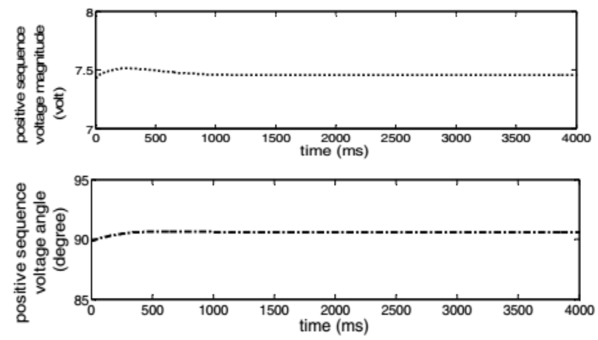


Fig.10. Positive sequence magnitude and angle for phase 'a' of PMU1

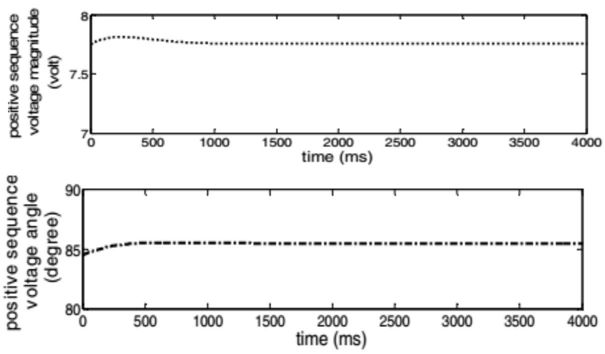


Fig.11. Positive sequence magnitude and angle for phase 'a' of PMU2

VI. CONCLUSION

It can be observed that under normal condition, Va, Vb and Vc magnitudes are equal, i.e. 10V and phasors are displaced 120° apart with Va at 90°, Vb at -30° and Vc at -150° as shown in fig. 5-7. When we pass these phasors through a sequence analyzer, we obtain the positive, negative and zero sequence output. Positive sequence output of both the PMUs is compared to verify the synchronized output as shown in fig.10 and fig.11. The positive sequence voltage magnitude and angle of PMU 1 is 7.5V,90° and that of PMU 2 is 7.6V,86° respectively.

Real-time testing and analysis of hardware of a PMU involves huge expenditure and time. For overcoming such restrictions, matlab Simulink based approach has been demonstrated in this paper. The PMUs are the building block for large power grids and their performance determines the performance of WAMS for monitoring and control of modern power grids.

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