ISSN: 0974-5823 Vol. 6 No. 3 December, 2021

International Journal of Mechanical Engineering

Phasor Measurement Unit to Control Multi- Area Frequency in Remote Location Using Global Positioning System

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Abstract-: Phasor Measurement Unit (PMU) is a basic building block of wide area measurement system. Information of frequency, phase angle and magnitude are evaluated using PMU in real time. Power system control and analysis of stability is very important tool for securing the operation of power system. The complex power system is needed effective control and monitoring of power system using wide area measurement system (WAMS). The synchronized real time operations of wide area power system are controlled by wide area measurement system through a communication network for reliable operation. In this paper, proportional integral differential (PID) controller is proposed to controls the frequency of two generators, far from each other and synchronizes it with a single reference remote location by global positioning system (GPS). In this scheme, the measurement of frequency of both generators taken at the respective ends with the help of PMU.

Keywords: GPS, PMU, Real time, WAMC, Synchrophasors, wide-area.

1. Introduction

The demand of electricity is growing but the strength of transmission line is not growing in same speed, resulting they are approaching towards its limit [1]. Thus avoid this, efficiency as well as reliability has to be increased [2]. Wide Area-measurement System (WAMS) is way to check this issue in collaboration with Phasor Measurement Unit (PMU). PMU has application in both transmission and distribution network [3][6].

An AC signal has both magnitude and phase which is represented by phasor [9]. In synchrophasors all the system are synchronized globally with a common clock [10].In the working of synchrophasors any waveform is compared with its cosine; which will work on the synchronized global time as shown in fig 1.

There is a regularity guideline of IEEE for synchrophasors named C37.118, which guide for lag of time, data, accuracy & reporting rate. Data volume is reduced through phasor measurement unit which will decrease the data rate & storage of communication system.

Total vector error (TVE) shows the accuracy of PMU. Through TVE magnitude, phase and timing error is measured, IEEE limits its value to 1% on PMU. For 1% TVE, Table 1 shows the values.

For controlling and optimization, synchrophasor devices are widely used. Advancement in microprocessors is also phasing out electromechanical relays [7-8].

In the next section, the mathematical model of PMU is described. In section 3, proposed Wide area measurement system is explained. Section 4 contains various results and discussions for different load and no load conditions. In section 5, the work is concluded.

2. Mathematical Model of Phasor Measurement Unit

PMU measurements are global time synched with great accuracy on source, so transmission rate will not affect the system. PMU values show the current state of flow of power in the system at a defined instant. By channel's interference different signals have different propagation delay but the indexing of time will give a clear picture of overall power system at any instant. For synchronization GPS can be used as an efficient tool.

Assuming a sinusoidal quantity

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

ω - frequency of the signal in radians per second,

$\emptyset$ - phase angle in radians.

X_m- peak amplitude of the signal.

The root mean square (RMS) value of the input signal is $(X_m/\sqrt{2})$.

Equation (1) can also be written as

$$x(t) = \mathrm{Re}\{X_m e^{j(\omega t+\phi)}\} = \mathrm{Re}[\{e^{j\omega t}\}X_m e^{j\phi}] \quad (2)$$

It is customary to suppress the term $e^{j(\omega t)}$ in the expression above, with the understanding that the frequency is ω. The sinusoid of Eq. (1) is represented by a complex number X known as its phasor representation:

$$x(t) \leftrightarrow X = \left(X_m/\sqrt{2}\right)e^{j\phi} = \left(X_m/\sqrt{2}\right)[\cos\phi + j\sin\phi] \quad (3)$$

A sinusoid and its phasor representation are illustrated in Figure 2.

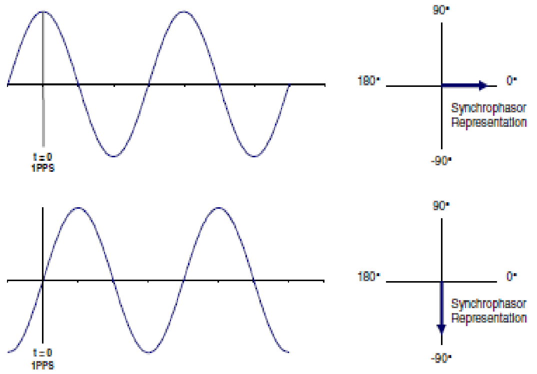

Fig. 1. Synchrophasor representation

DFT and Phasor representation

A sinusoidal $x(t)$ with frequency kf_o with a fourier series

$$x(t) = a_k \cos(2\pi k f_o t) + b_k \sin(2\pi k f_o t)$$

$$= \{\sqrt{(a_k^2 + b_k^2}\} \cos(2\pi k f_o t + \phi)$$

where $$\phi = \arctan\left(\frac{-b_k}{a_k}\right) \qquad (4)$$

has a phasor representation

$$X_k = \frac{1}{\sqrt{2}} \{\sqrt{(a_k^2 + b_k^2)}\} e^{j\phi} \qquad (5)$$

where the square-root of 2 in the denominator is to obtain the rms value of the sinusoid. The phasor in complex form becomes

$$X_k = \frac{1}{\sqrt{2}} (a_k - jb_k) \qquad (6)$$

Using the relationship of the Fourier series coefficients with the DFT, the phasor representation of the *k*th harmonic component is given by

$$X_k = \frac{1}{\sqrt{2}} \frac{2}{N} \sum_{n=0}^{N-1} x(n\Delta T) e^{-\frac{j2\pi kn}{N}} \qquad (7)$$

$$= \frac{\sqrt{2}}{N} \sum_{n=0}^{N-1} x(n\Delta T) \{\cos(\frac{2\pi kn}{N}) - j\sin(\frac{2\pi kn}{N})\}$$

(8)

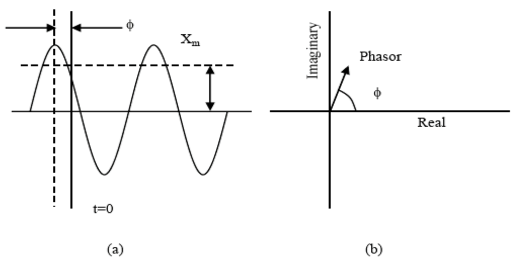

Fig. 2**:** *A sinusoid (a) representation as a phasor (b). The phase angle of the phasor is arbitrary, as it depends upon the choice of the axis t = 0. Note that the length of the phasor is equal to the RMS value of the sinusoid.*

Using the notation $x(n\Delta T) = x_n$ and $2\pi / N = \theta$ (θ is the sampling angle measured in terms of the period of the fundamental frequency component)

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

(9)

$$X_{kc} = \frac{\sqrt{2}}{N} \sum_{n=0}^{N-1} x_n \cos(kn\theta) \qquad (10)$$

$$X_{kc} = \frac{\sqrt{2}}{N} \sum_{n=0}^{N-1} x_n \sin(kn\theta) \qquad (11)$$

then the phasor X_k is given by

$$X_k = X_{kc} - jX_{ks} \qquad (12)$$

Fig. 3 shows the basic configuration which is also an introduction of PMU. PMU is a advancement of symmetrical component of distance relay. Transformer's secondary winding is used to extract the current & voltage of line. Positive sequence and measured through all the three phases of voltage and current.

For analog to digital converters, all the signals are converted into the voltage levels with the help of transformers or shunts. Anti-aligation filter will decide the sampling rate so that no overlapping of signals occur. Generally analog filters are preferred for this purpose which will have the cutoff frequency equivalent to half of nyquist frequency. If signals are over-sampled then decimation filter are employed for conversion of sampling rate. GPS receiver is used for the time synchronization of the system. The GPS will provide the clock which will be locked by phase locked loop.

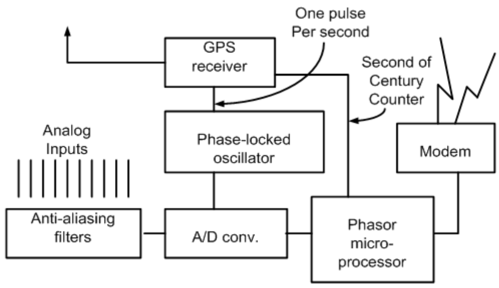

Fig. 3: Basic elements of the PMU

3. Block diagram of Wide- Area Measurement System

In power system PMU acts as a transducer which calculate the parameters that has to be controlled for wide area, it can be frequency stabilization, voltage and current control or according to the requirement of the system for distributed generation. In this proposed work the frequency of two generators apart from each other is synchronized to a reference location.

In this closed loop system, steady state error is minimized with the help feedback sensors. Major issues in this, is to control reference signal. In fig. 4, two small generators are synchronized to a global reference signal.

synchrophasors generated by PMU delivers a reference signal via PID controllers. Reference signal & signal at generators are compared for controlled. In present work, control loop uses the information of phase & frequency, which are coupled. But in large system other factors like loading and power factor etc. affect these parameters. Coupled frequency as well as phase angle data in reported by PMU.

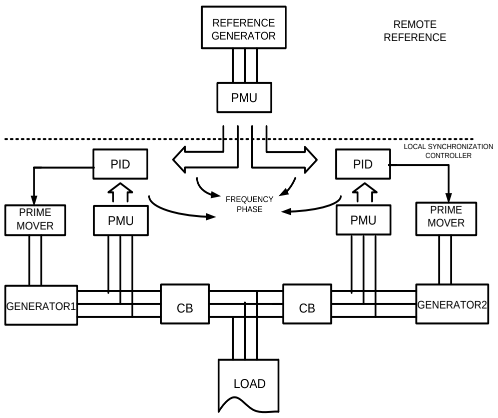

Fig. 4: Controlling scheme layout

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In figure 5, the block diagram to control the speed is shown. As already discussed the frequency is the angular velocity, RPM of prime mover. In this case Hydroelectric turbine and governor are considered, here the frequency is controlled by the RPM of Turbine. The speed of turbine is governed by the opening and closing of gate which is controlled by servomotor.

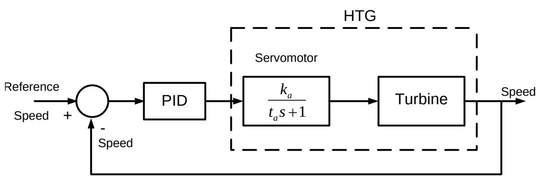

Fig. 5: Block Diagram representation of control of speed of Turbine

4. Results and Discussions

The simulation is done using MATLAB\Simulink. The results are shown for different load disturbances and no load disturbance.

4.1. No Load Disturbance

This is the first case when load is constant the output is given below:

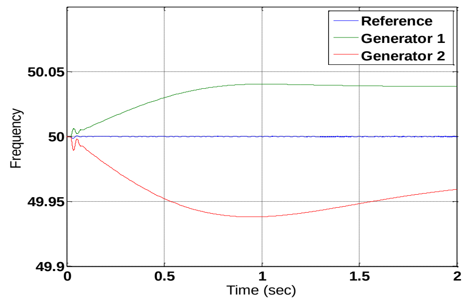

Fig. 6: When no load change occurs

Figure 6 shows the output frequencies of generator 1, generator 2 and reference frequency. These are the results when PID controller is used. Its shows that in 1 sec frequency stabilizes at 50.04 Hz for generator 1 and 49.96 Hz for generator 2. It shows 0.02 % error from the reference frequency.

4.2. 2% Load Disturbance

In this case 2% load change occurs at different times. Load change occurs at 0.1, 0.2, 0.4 and 1 secs

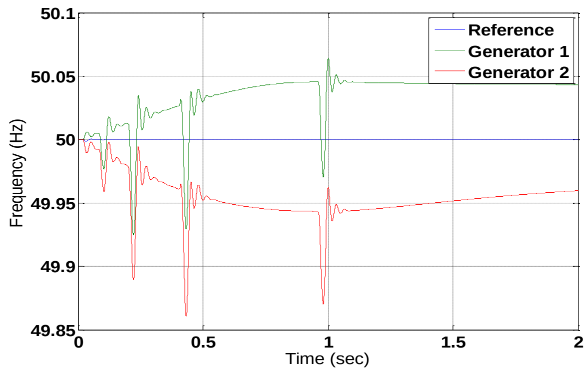

Fig. 7: output for 2% load disturbance applied at different instants of time

Figure 7, shows the output frequencies of generator 1, generator 2 and reference frequency. In this case the load at 0.1, 0.2, 0.4 and 1 secs the increase in load is applied. As the load is increased the speed of generator reduces and hence the frequency is decreased, as it can be seen in figure 6.

4.3. 5% Load Disturbance

In this case 5% load change occurs at 0.2 to 0.4 sec.

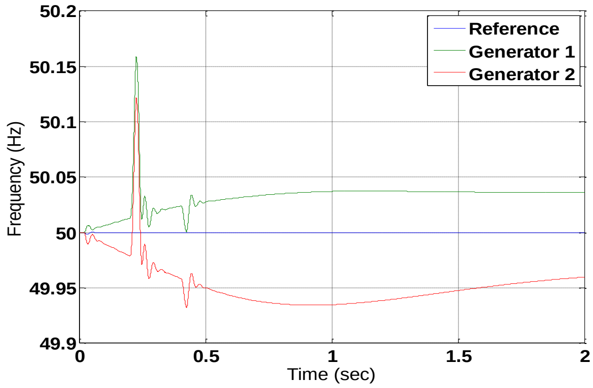

Fig. 8: output for 5% load disturbance from 0.2 to 0.4 sec

Figure 8 shows the output frequencies of generator 1, generator 2 and reference frequency. In this case, load is decreased from 0.2 to 0.4 secs. As the load is decreased the speed of generator increases and hence the frequency is increased, as it can be seen in figure 7.

4.4. 10% Load Disturbance

Figure 9, shows the output frequencies of generator 1, generator 2 and reference frequency. In this case, at 0.1 and 0.4 sec the load is decreases, and at 0.2 and 1 sec load is

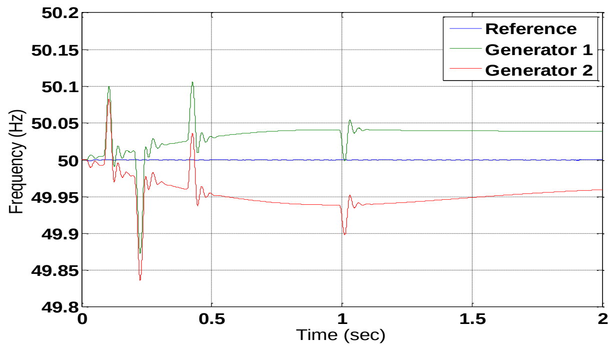

Fig. 9: output for 10% load disturbance applied at different instants of time

increased. As the load is increased the speed of generator reduces and hence the frequency is decreased (at 0.2 and 1 sec), as the load is decreased the speed of generator increases and hence the frequency is increased (at 0.1 and 0.4 sec), it can be seen in figure 8.

4.5. 20% Load Disturbance

Figure 10, shows the output frequencies of generator 1, generator 2 and reference frequency. In this case, 20% load change applied at 0.2 sec, load is increased. As the load is increased the speed of generator reduces and hence the frequency is decreased, as it can be seen in figure 9.

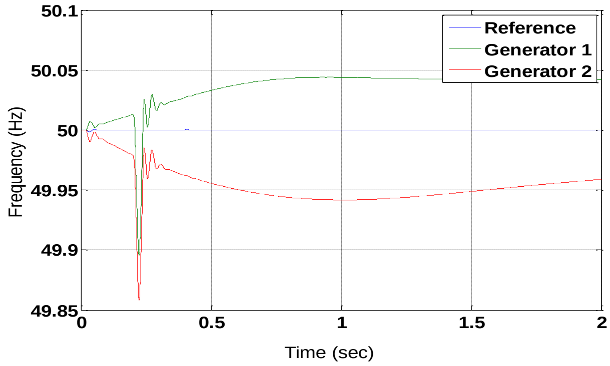

Fig. 10: output for 20% load disturbance is applied

5. Conclusion

Phasor Measurement Units are an excellent asset to the power system protection and control toolset and are set to continue to revolutionize the way the power system is operated. IEEE C37.118 should be regarded as the first step towards a unifying standard to allow complete cross compatibility between all Phasor Measurement Units. PMU is considered as the most promising measurement technology for monitoring the power systems. In this paper PMU technology in Wide-Area monitoring and Control System is used. Measurements from PMU contain the information about phasor and frequency, measurement taken from two PMU's from two different generators has been sent to controller and synchronized to a reference location. Also it compares the results for different load disturbances and stabilizing the frequency with in 0.1 second.

Table 1

1% TVE

Phase	0.573^0
Synch of time (50 Hz)	31.8 µs
Synch of time (60 Hz)	26.5µs

IEEE standards don't include frequency on its changing rate. PMU works as frequency transducer [5].

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