International Journal of Engineering Research (ISSN : 2319-6890)
Volume No. 2, Issue No. 4, pp : 269-273 01 Aug. 2013

Synchro-Phasors in Power System

V.Vanitha, R.Badrinath
Department of Electrical and Electronics Engineering,
Amrita Vishwa Vidyapeetham, Coimbatore, India
v_vanitha@cb.amrita.edu

Abstract

The Phasor Measurement Unit (PMU) is considered to be one of the most important measuring devices in the future of power system. The difference comes from its unique ability to provide synchronized phasor measurements of voltages and currents from widely dispersed locations in an electric power grid called synchrophasor technology .In SCADA system, the measured quantities remain constant during the data gathering process. Hence the dynamic characteristics of the power system cannot be estimated. Synchrophasor technology is used to overcome this drawback. The Global Positioning Satellite(GPS) is used for synchronisation between the PMUs at different places, which receive the signal from GPS simultaneously and start measuring voltage and current. Magnitude of voltage and current along with their angles are calculated from the coefficients of Fourier Transform. The objective of this paper is to implement the synchrophasor technology using PIC18F4550 by using Fourier Transform to measure the magnitude and phase angle of any quantity such as voltage or current or both and storing in database. Apart from this, the technology is implemented for different applications and results are verified.

Keywords: Phasor Measurement Unit, Synchrophasor, Fourier Transform, Zigbee

I Introduction

As the electric power grid continues to expand and as transmission lines are pushed to their operating limits, the dynamic operation of the power system is becoming a big concern. Traditional SCADA systems obtain data from meters, transducers and similar devices. This process guarantees that all the measured data were taken within a time window that is typically few seconds. When the system is in steady state, the measured quantities remain constant during the data-gathering process. But dynamic characteristic of the power system cannot be estimated accurately. Synchrophasors are time-synchronized phasor measurements, in which satellite synchronized clocks allow time-stamped measurements that enable data to be aligned on reference time base. In 1988, the Synchrophasor industry was first started by ArunPhadke. He was a pioneer in this effort at Virginia Tech where some of the first prototype phase angle measuring units that were synchronized to an internal time clock were built. The installation of Global Positioning Satellites (GPS) clock allowed the measurement of phase angles to be synchronized to a very accurate time clock. This allows for more adaptive and flexible protective relay schemes and special protection schemes that would lead a transmission grid to operate both reliably and economically as compared to traditional system.

II Basic Theory of Synchrophasors

Synchrophasors provide an accurate and complete view of a power system. New synchrophasor system for wide-area monitoring and control will aid the evolution of the existing grid into a smarter transmission grid. An internal high accuracy clock which is synchronized to Coordinated Universal Time (UTC) via a GPS provides the time tag or absolute time reference. The voltage waveform can be defined as a phasor with a phase angle and magnitude. The phase angle is measured by comparing the peak of the sinusoidal wave form to the time tag.

By installing PMUs at different places of the substations in a power system, the amount of real and reactive power flowing between the substations can immediately be determined. Knowing about the steady state real and reactive power flows along with voltage and phase angle can substantially assist "state estimation" programs ,which is the basis for all advanced power flow and contingency analysis programs in Energy Management System(EMS) centers[1]. By knowing the rate of change of angle and magnitude of the voltage, it can be determined whether the power system is nearing instability or not.

III working principle of synchrophasor

In a power system, whenever the measurement has to be started, GPS signal is sent to all the PMUs. PMU is a device (mostly microprocessor based) which reports the magnitude and phase angle of an analog and /or derived phasor with respect to the global time reference, as per the synchrophasor standards [2].These PMUs receive the signal at the same time without any time delay. After receiving this signal from GPS, the PMUs start to measure the voltage and current and calculates the phasor angle with the help of Fourier transform.

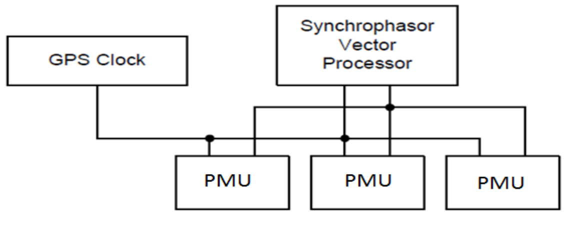


Figure 1 General block diagram of Real Time Synchrophasor Technology

International Journal of Engineering Research (ISSN : 2319-6890)
Volume No. 2, Issue No. 4, pp : 269-273 01 Aug. 2013

Figure 1 shows the general block diagram of Real Time synchrophasor technology. The PMUs are placed at different locations in the transmission line. A reference signal is generated at all PMU. The characteristic of the reference waveform is identical at all PMUs at any instant of time. Whenever GPS signal is received the phasor measurement of local waveform is calculated with reference to the reference waveform.

The purpose of the Synchrophasor Vector Processor (SVP) is to collect synchronous phasor measurements (SPMs), collect logical inputs, perform vector and scalar calculations, make decisions, produce outputs and report data[3].

The requirement of communication channels depends on the application that it has been used. These ranges from one message per minute to one per cycle. For some applications, serial communications at 9600 bps will work. For high-speed applications where large amount of synchrophasor data's are transmitted, an Ethernet or similar communication channel may be required.

IV Fourier Transform

Fourier series was developed by Baron Fourier. It took Fourier another twenty years to develop the Fourier transform which made the theory applicable to a variety of disciplines. Fourier analysis is now also used in thermal analysis, image processing, quantum mechanics and physics. In this paper, Fourier Transform has been used to determine the magnitude of voltage and current and along with their phase angles. Fourier analysis is a linear algorithm that can take a time domain signal into the frequency domain and back[4]. In complex representation, the Fourier equation is written as

$$f(t) = a_0 + \sum_{n=1}^{\infty} (a_n \sin \omega_n t + b_n \cos \omega_n t)$$

Where

$$a_n = \frac{2}{T} \int_0^T f(t) \sin(n \omega t)\, dt$$

$$b_n = \frac{2}{T} \int_0^T f(t) \cos(n \omega t)\, dt$$

T is the time cycle, ω is the frequency and n is the harmonic order. Once the Fourier coefficients of the signal are known, which frequencies are present in the signal and in what quantities can easily be estimated. This is very similar to doing chemical analysis on a compound, figuring out what elements are there and what relative quantity. The process of finding the coefficients is multiplying the signal with successively larger frequencies of a fundamental wave and integrating the results. This is easy to do in software. The results obtained successively are the coefficient for each frequency of the harmonic wave.

After determining the Fourier coefficients the magnitude and angle of the signal can be found by

Magnitude $= \sqrt{a_n^2 + b_n^2}$

Angle $= \tan^{-1} \frac{b_n}{a_n}$

V Simulation of Fourier Transform in MATLAB

In order to implement Fourier Transform in simulation , MATLAB C code has been used. In MATLAB C code , fundamental component has been generated along with third, fifth and seventh harmonics. The main objective of the simulation is to determine the magnitude and phase angle of the fundamental component. Flow chart for the Fourier Transform is shown in Figure 2.In this simulation, 620 samples are taken within 20ms and Fourier transform is implemented. From this algorithm, the Fourier coefficients are determined, from which the magnitude and angle of the fundamental component are found out. Figure 3 shows the simulation results.

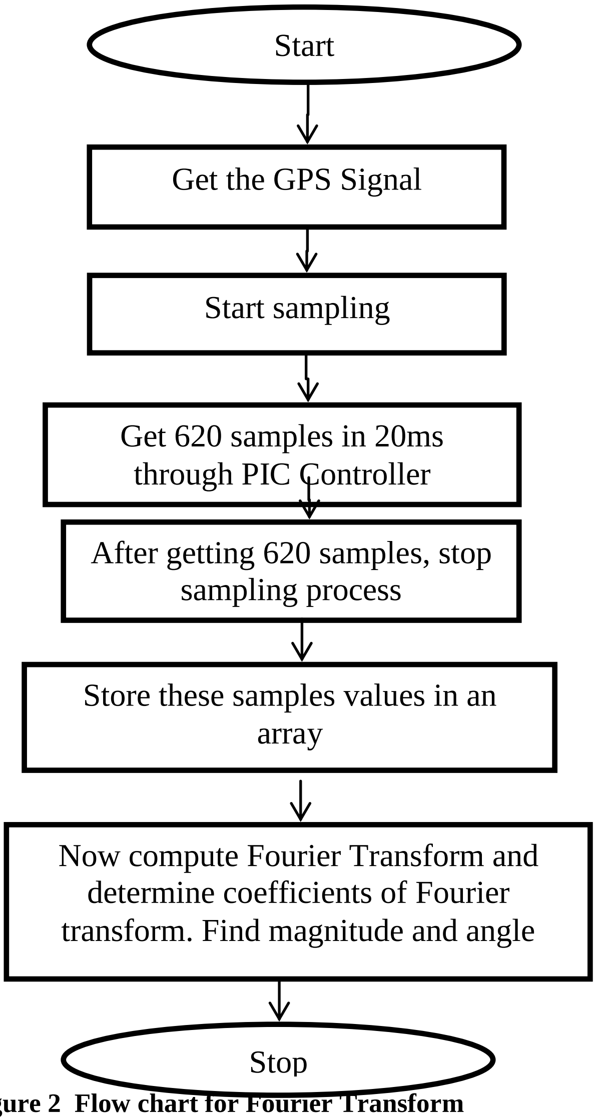
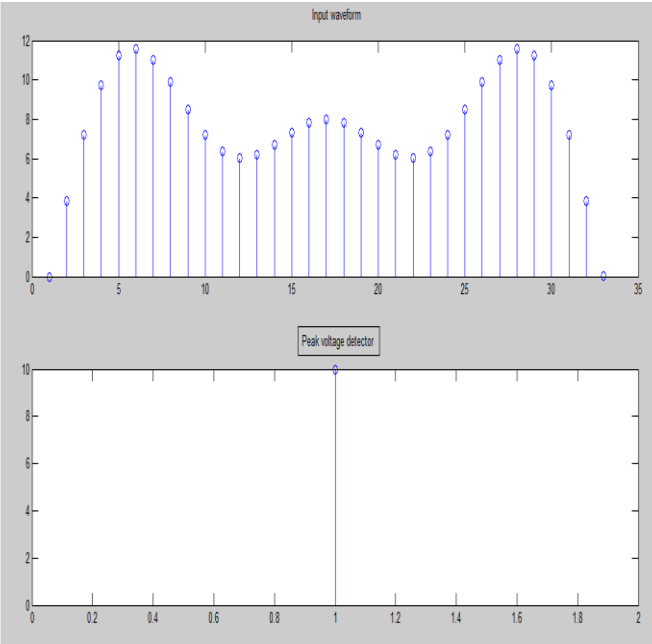


Figure 2 Flow chart for Fourier Transform



Voltage=10V , Angle =25 degrees

Figure 3 Simulation result of Fourier Trasform

VI Hardware Setup of PMU

The sensors used for the voltage and current sensing in PMU are LEM manufactured. The sensors are LA 25-P for current sensing and LV20-P for voltage sensing. The MPLAB PICkit 3 is used, which allows debugging and programming of PIC and dsPIC Flash microcontrollers at a most affordable price point using the powerful graphical user interface of the MPLAB Integrated Development Environment (IDE). In order to burn the program into the PIC18F4550, LabProg+ and PIC Kit 3 programmer is used.

A LCD of 2x16 ASCII-text is installed on a dotted PCB board, with 4 data pins and 3 command pins as input/output. A 5V DC supply is given to the LCD. A 10 k pot is used to adjust the contrast of the display. In this application LCD is used to display the Coefficients of Fourier transform, Magnitude of Voltage and Current along with the angles.

VII Applications of synchrophasor in power system

In this paper, the synchrophasor technology is implemented for three applications:

(a)Measuring RMS voltage of three phase supply

(b) Wireless communication of PMU using Zigbee module

(c) Measurement of voltage and current in RL circuit

1.Measuring RMS voltage of three phase supply

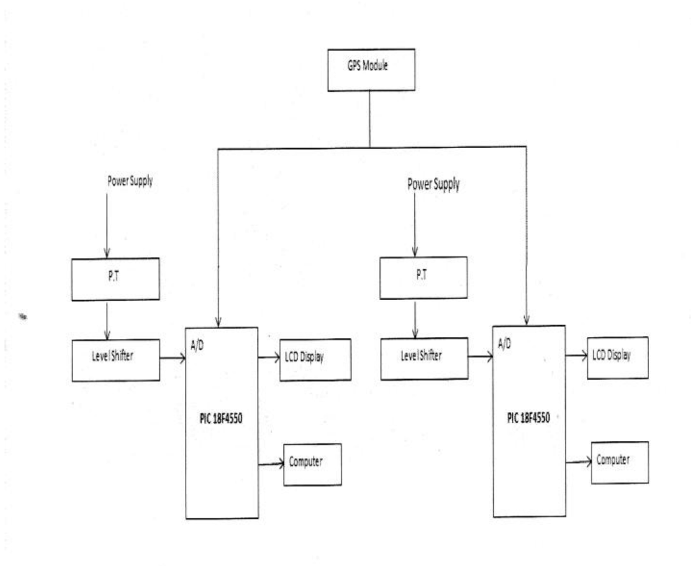


Figure 4 Block diagram of setup for measuring RMS values of three phase supply

Figure 4 shows the block diagram of experimental setup of PMUs in any two phases(RN and YN or YN and BN) of a three phase supply to determine the magnitude and phase angle of RMS voltages. GPS signal has been used to synchronize both PMUs. Power supply is given to PIC 18F4550 through level shifter.Potential transducer has been used as a sensor to sense the voltage. Figure 5 shows the experimental setup and Table 1 shows the results of measuring voltages in RN and YN of a three phase supply. Table 2 shows the results of measuring voltages in YN and BN of a three phase supply. Results confirm the phase displacement of 120 degrees between two phase voltages of the three phase supply.

Figure 5 Experimental setup for measuring RMS values of three phase supply

Table 1 Measurement of voltages in RN and YN of a three phase supply (PMU 1-RN phase,PMU 2-YN phase)

S.No	PMU 1		PMU 2		Phase difference between V1 and V2
	Voltage V1(V)	Phase Angle (Degree)	Voltage V2(V)	Phase Angle (Degree)	
1	74	48.81	73	170.11	121.3
2	73	246.36	73	366.64	120.28
3	74	179.65	74	298.35	118.7
4	72	114.71	72	234.13	119.42
5	74	92.89	73	210.75	117.11

Table 2 Measurement of voltages YN and BN in a three phase supply (PMU 1-YN phase,PMU 2-BN phase)

S.No	PMU 1		PMU 2		Phase difference between V1 and V2
	Voltage V1 (V)	Phase Angle (Degree)	Voltage V2(V)	Phase Angle (Degree)	
1	62	23.14	61	144.98	121.84
2	61	213.75	63	331.75	118
3	62	117.89	61	238.58	120.69
4	63	119.95	62	241.62	121.67
5	61	190.01	62	309..45	119.44

2. Wireless communication of PMUs using Zigbee module

Figure 6 shows the Zigbee module used for wireless communication between PMUs. This application is used in getting data of electrical quantities from two different substations which are quite apart from each other.Here PMUs communicate wirelessly using Zigbee module. Figure 7 shows the experimental setup of PMUs to measure the voltages at two different substations and send through wireless communication. Three Zigbees are used here.

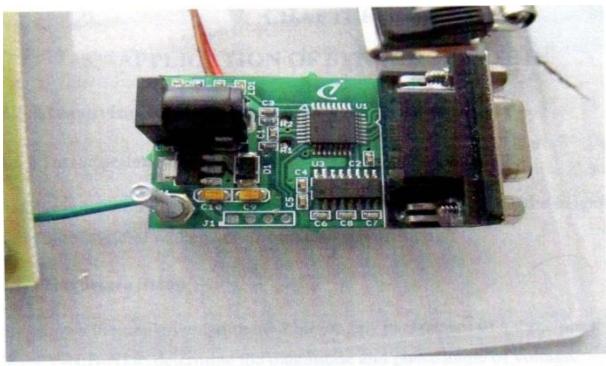


Figure 6 Zigbee module

First and second Zigbee module is connected to PMU 1 and PMU 2 respectively.Third Zigbee module is connected to computer.Third zigbee module acts like a Master and other two Zigbee modules work as slave.Whenever the user wants to measure the signal,the 'S' character is sent from master Zigbee module to slave Zigbee module, which in turn receives the character and starts computing.The controller starts sampling and computes the Fourier coefficients, Then the magnitude and phase angle of voltage are computed and sent to the computer through master Zigbee. The computer receives the data and stores in the database. Database is created using MATLAB.In MATLAB database, the data are received and stored along with the time and date they have received the data.The values that are received through Zigbee module can be seen through Hyper terminal as shown in Figure 8 or by Extra Putty as shown in Figure 9.

Figure 7 Experimental setup of PMUs at different locations

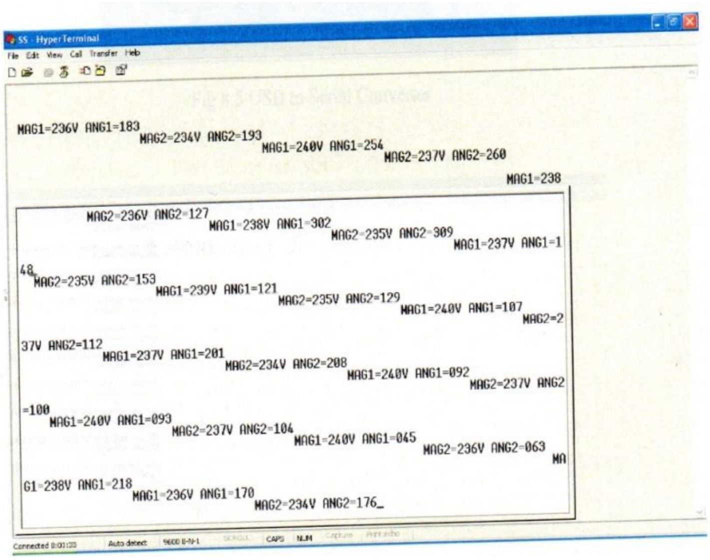


Figure 8 PMU readings using hyper terminal

(ISSN : 2319-6890)
01 Aug. 2013

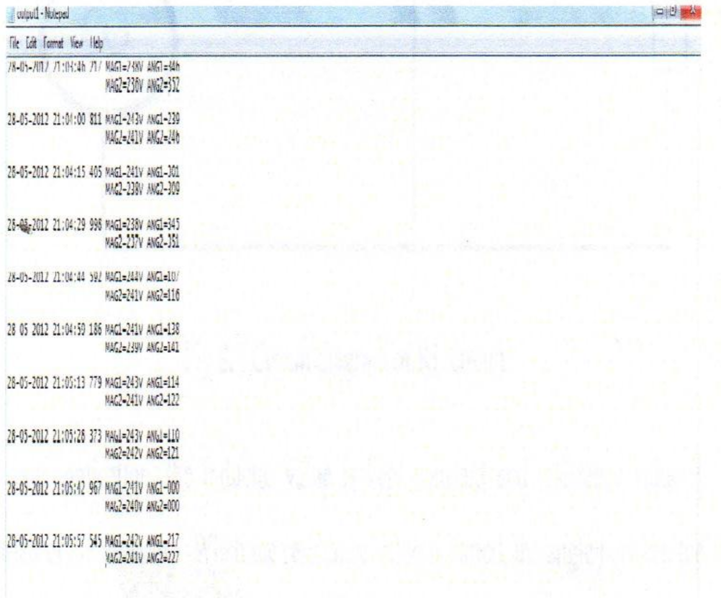


Figure 9 PMU database

3. Measurement of voltage and current in RL circuit

In this application, a known value of inductance and a variable resistance are connected to a single phase supply as shown in Figure 10.

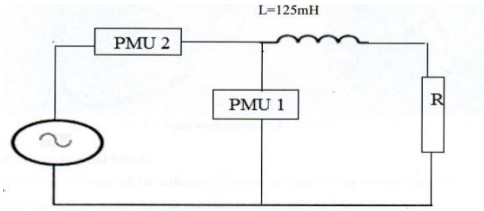


Figure 10 Circuit diagram of RL circuit

PMU 1 is connected to measure voltage, which is connected in parallel.PMU 2 is connected serially in order to measure current in RL circuit.In this application, the inductor value is kept constant and resistance value is varied in the rheostat.Whenever the resistance value is varied,the angle between the voltage and current changes.Experiment is conducted for different values of resistance. Figure 11 shows the hardware setup of RL circuit and Table 3 shows the results. Results show that the calculated values and experimental values are approximately same with an error of 5%

VIII Conclusion

A MATLAB Simulation for determining the magnitude and phase angle of voltage was done using Fourier Transform technique.A database was created using MATLAB. Hardware setup was made for PMU using PIC18F4550 and it was used for three different applications such as voltage measurement of three phase supply, wireless communication of PMU using zigbee and measurement of voltage and current in RL circuit and results were verified in all the cases.

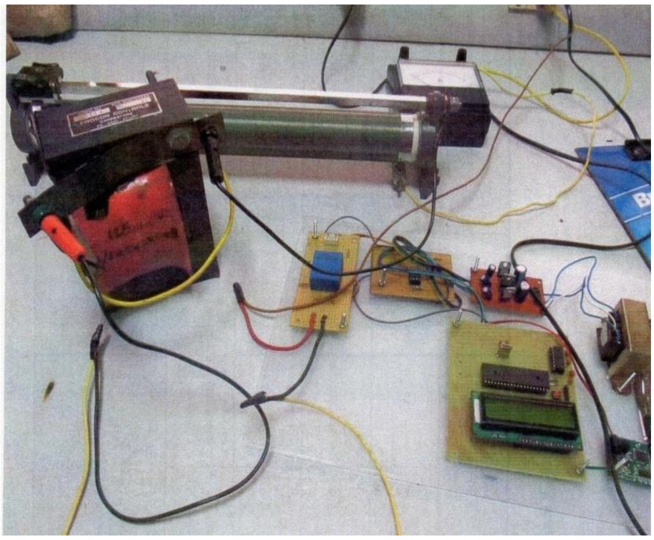


Figure 11 Hardware setup of RL circuit

Table 3 PMU readings in RL circuit

S.No	Resistance	Measured Value				Measured Value of Φ (Degree)	Calculated Value	
		PMU 1		PMU2				
		Voltage (V)	Angle (degree)	Current (A)	Angle (Degree)		Current (A)	Φ (degree)
1	225	232	162.83	1.1	173.16	10.33	1.01	9.88
2	175	231	256.68	1.3	269.92	13.24	1.28	12.72
3	150	232	16.26	1.5	32.74	16.48	1.47	14.66
4	135	229	217.6	1.7	235.5	17.9	1.62	16.46

References

i. *Ming Zhou, "Advanced system monitoring with phasor measurement", Ph.D, Virginia Polytechnic Institute and State university, 2008.*

ii. *C37.118-2005- IEEE standard for synchrophasors for power systems. Power System Relaying Society: IEEE Power Engineering, 2006.*

iii. *G.Benmouyal, E. O. Schweitzer, A. Guzmán, "Synchronized phasor measurement in protective relays for protection, control, and analysis of electric power systems" Proceedings of the 29th Annual Western Protective Relay Conference, Spokane, WA, October 2002.*

iv. *Marco Lixia.,"IEEE 1588 synchronization in distributed measurement ystems for electric power networks", Ph.D, University of Cagliari,2012*