International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 6, June - 2013

Synchrophasor Measurement Technology in Electrical Power system

Rohini Pradip Haridas
Department of Electrical Engineering, Amravati University, Maharashtra, India

Abstract

The electrical power system has been increasing in complexity at a rapid rate in last few decades For decades, traditional SCADA measurement has been providing power system information to system operators. These measurements are typically taken once every 4 to 10 seconds offering a steady state view of the power system behavior. However, for monitoring and control of such large grid only steady state information is not being sufficient. Synchronized measurement technology (Wide area measurement) is considered to be one of the most important technologies in the future of power systems due to its unique ability to sample analog voltage and current waveform data in synchronism with a GPS-clock and compute the corresponding frequency component from widely dispersed locations. This paper describes about the details of the synchrophasor measurement technology.

1. Introduction

Synchronized phasor measurement units (PMUs) were first introduced in early 1980s. Synchronized phasor measurements are becoming an important element of wide area measurement systems used in advanced power system monitoring, protection, and control applications. Phasor measurement units (PMUs) are power system devices that provide synchronized measurements of real-time phasors of voltages and currents. Synchronization is achieved by same-time sampling of voltage and current waveforms using timing signals from the Gobal Positioning System. The advantage of referring phase angle to a global reference time is helpful in capturing the wide area snap shot of the power system.

The occurrence of of major blackouts has given new impetus for large scale implementation of of wide area measurement systems using PMUs and PDCs. Data provided by PMUs are very accurate and enable the system analyst to determine the exact sequence of events which have led to blackouts. It also help to analyze the sequence of events which helps pinpoint the exact causes and malfunctions that may have contributed to the failure of power system.

A number of PMUs are already installed in several utilities around the world for various applications such as post-mortem analysis, adaptive protection, system protection schemes, and state estimation. Effective utilization of this technology is very useful in mitigating blackouts and learning the real time behavior of the power system.

2. Synchrophasor Measurement

A. Phasor Definition

A pure sinusoidal waveform can be represented by a unique complex number known as a phasor. Consider a sinusoidal signal

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

Where,

X_m is the peak value of the signal

w is the frequency of the signal in radians per second

ϕ is the phase angle in radians

The phasor representation of this sinusoidal is given by

$$X(t) = \frac{X_m}{\sqrt{2}} e^{j\phi} = \frac{X_m}{\sqrt{2}} (\cos\phi + j\sin\phi) \qquad (2)$$

Where,

$\frac{X_m}{\sqrt{2}}$ is the magnitude of the phasor i.e. the R.M.S value of sinusoid

ϕ is its phase angle

The sinusoidal signal and its phasor representation given by equations (1) and (2) are illustrated in figure 1

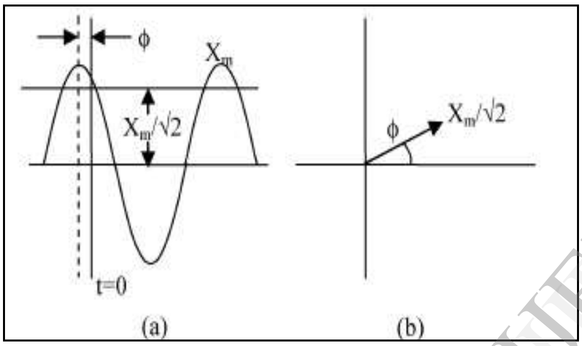

Fig1 Phasor representation of a sinusoidal signal. (a) Sinusoidal signal. (b) Phasor representation.

B. *Synchrophasor Definition*

Phasor measurements that occur at the same time are called “synchrophasor”. It is the term used to describe a phasor which has been estimated at a instant known as the time tag of the synchrophasor. In order to obtain simultaneous measurement of phasor across wide area of the power system, it is necessary to synchronize these time tags, so that all phasor measurement belonging to the same time tag is truly simultaneous.

Now consider a sinusoidal signal

$$v(t) = X_m \cos(2\pi ft + \phi)$$

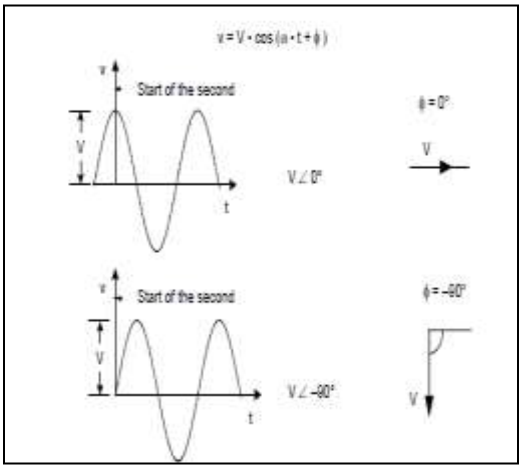

Fig 2 The convention for synchrophasor representation [23]

The time reference can be given by highly accurate clock with co-ordinated universal time (UTC). The phase is calculated by the phase shift between the peak of sinusoidal and the angle at reporting time. This angle is to be zero when maximum of v(t) occurs. In the second diagram of figure 2 positive zero synchronization with the second pulse, the phase angle is -90 degrees.With the universal precise time reference, power system phase angle can be accurately measured throughout a power system. The advent of GPS technology has made this economically and practically feasible. Thus, synchronized process provides a common reference for phasor calculation at all different location.

If the source frequency is constant, the phase angle from the measurement will be constant all the time. However, in the real time, the system frequency will not be constant; it is different from its nominal value so the phase will vary at different times. The IEEE standard assumes the waveform in the steady-state with rated frequency.

3. Basic Concept of Measurement

In a wide area measurements system, the phasor measurement unit (PMU) is a device that can provide synchronized phasor measurements of voltages and currents from widely dispersed locations in electric power network.

In many PMUs the data window in use is one period of the fundamental frequency of the Input signal. In real time, the power system frequency is not equal to its nominal value. If the power system frequency is at off nominal value, the PMU uses a frequency-tracking step and thus estimates the period of the fundamental frequency component before the phasor is estimated. Again the input signal may contain the harmonics. Thus the task of the PMU is to separate the fundamental frequency component and find its phasor representation. The most common method for estimating the phasor is to sample the analog waveform and apply DFT.

The main elements of Phasor Measurement Unit (PMU) is as shown in figure 3

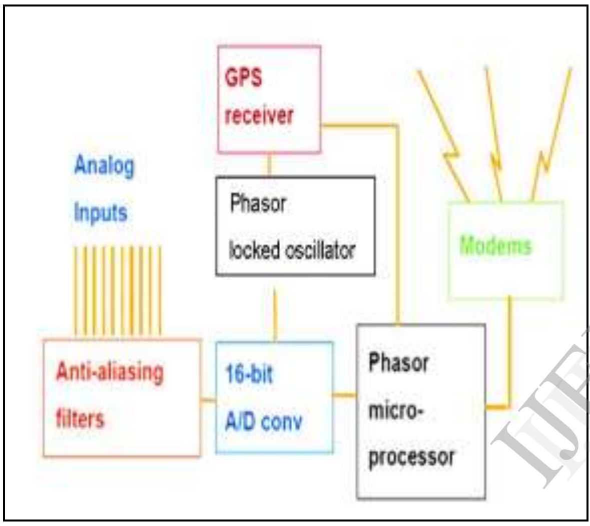

Fig 3 Block diagram of Phasor Measurement Unit [25]

The analog inputs are the voltages and currents obtained from the secondary winding of the three phase voltage and current transformers. These analog inputs go into an antialising filter. Antialising filter are analog devices which limit the bandwidth to satisfy the Nyquist criterion. Thus they are used to filter out the input frequencies that are higher than the Nyquist rate."As in many relay designs one may use a high sampling rate (called oversampling) with corresponding high cut-off frequency of the analog anti-aliasing filters. This step is then followed by a digital 'decimation filter' which converts the sampled data to a lower sampling rate, thus providing a 'digital anti-aliasing filter' concatenated with the analog anti-aliasing filters [25]". The analog AC waveforms are digitized by an analog to digital convertor for each phase. A phase lock oscillator along with Global Positioning System reference source provides the needed high speed synchronized sampling with 1 microsecond accuracy. The phasor microprocessor calculates the phasor using digital signal processing technique and uploads to phasor data concentrator.

The key features of the phasor Measurement Unit (PMU)

Synchronicity: PMU device must be precisely synchronized with the clock signal as a sampling basis. The synchronization error of the sampling pulse is less than 1us.

Speed: PMU measuring device must have high-speed internal data bus and external communication interfaces to meet a large number of real-time data measurement, storage, and send outs.

Precision: PMU measuring device must have a high enough accuracy. The signal phase shift in PMU device measuring points must be compensated.

Large capacity: PMU measuring device must have enough storage capacity to ensure long-term recording and saving of temporary data.

4. Synchrophasor Standards

A. Standard IEEE 1344

The concept of synchronized phasor with the power system was introduces in the 1980s and the first synchrophasor standard, IEEE 1344[23] was introduced in 1995. It was created to introduce synchrophasors to the power industry and set basic concepts for the measurement and methods for data handling. It introduced a Phasor measurement unit (PMU) which is a device and estimates synchrophasor equivalent quantities for an AC input. It also introduced synchronized measurement using precise timing sources, formalized an extension for IRIG-B which has been adopted by industry.

B.Standard IEEE C37.118-2005

This standard defines synchronized phasor measurements used in power system applications. It provides a method to qualify the measurement, tests to be sure the measurement conforms to the definition, and error limits for the test. It also defines a data communication protocol, including messages formats for communicating this data in a real time system.Explnation, examples, and supporting information are also provided.

In the first major improvement, C37.118 [24] added a method for evaluating a PMU measurement and requirements for steady-state measurement. Total vector error or TVE compares both magnitude and phase of the PMU phasor estimate with the theoretical phasor equivalent signal for the same instant of time. TVE provides an accurate method of evaluating the Pmu measurement

Second C37.118 expanded the communication method to include higher order collection and improved identifications. The basic status was improved to include indications of data quality.PMU identification was added to all messages. The concept of phasor data concentrator (PDC) which included data from several PMUs introduced. Data type and classes were indentified. The underlying data communication protocol was left to users, and several industry based standard methods have been developed that support C37.118.The standard C37.118-2005 has been very successful.

Dynamic measurements were not addressed in C37.118-2005 due to time and test experience constraints In addition, frequency measurements have always been a part of the data reporting, but the standard has no requirements for them. These issues and the growing need to address the communication compatibility with standard IEC61850.

5. Comparison Between SCADA and PMU

Table 1. Comparison between SCADA and PMU

Factors	**SCADA**	**PMU**
Measurement	Analog	Digital
Resolution	2-4 samples per	Up to 60 samples per cycle
Phasor Angle Measurement	No	Yes
Monitoring	Local	Wide-area
Observability	Steady state	Dynamic/Transient state
Time Synchronization	No	Yes

6. Phasor Estimation Techniques

Frequency and phasors are the most important quantities in power system as they reflect the power system situation. The contamination of signal has caused the frequency measurement errors and therefore it is important to investigate the new approaches for phasor and frequency measurements.The possible digital algorithms of PMU measurements are assumed to be;

- Modified Zero Crossing Techniques[9]
- Prony Analysis [10]
- Newton Method [11]
- Phasor Angle Analysis Newton Method[12]
- Least Error Square Error Techniques[14]-[15]
- Kalman Filter Techniques[16]
- Smart Discrete Fourier Transform[13]-[17]
- Wavelet approach, and [18]

- Adaptive Neural Network Approach[19]-[21]

For real time use most of the aforementioned method has tradeoff between accuracy and speed.

7. Phasor Technology-World wide research, developments and applications

A) North America

The first digital PMU version was developed at Virginia Tech. later Macrodyne designed and built commercial unit. Currently there are more than 40 North American utilities that have PMU installed for analysis of power system problems.

B) France

The development of a coordinated scheme was carried out based on centralized comparison of the voltage angles of the system obtained from PMUs.

C) Scandinavia

There is a great potential for PMU applications in Scandinavia. Smart control based on Phasor measurement can be used as an alternative to adding new transmission lines by increasing power transmission capacity.

D) China

The China State Grid will have about more than 250 PMUs installed. Researchers in China are putting more emphasis in improving systems security and reliability using PMU.

E) India

The PMU pilot project in Northern Region, India consists of PMUs along with GPS installed at Selected 4 substations of the NR Grid. The system provides phase angle difference, along with phase voltage magnitudes, power flow, frequency and rate of change of frequency

F) Other Countries

It has been reported that have installed and integrated PMU for research to develop working prototypes for wide area monitoring and control: Japan, Switzerland, 4 units; Cortia, 2 units; Greece, 2 units; Mexico, more than 4 units and South Africa, 2 units.

8. Conclusion

Synchronized phasor measurements are becoming an important element of wide area measurement systems used in advanced power system monitoring, protection, and control applications. Phasor measurement units (PMUs) are power system devices that provide synchronized measurements of real-time phasors of voltages and currents. Synchophasors provide high speed (sub second) coherent data that are not available with traditional SCADA measurements in order to monitor power system dynamics.Data provided by PMUs are very accurate and enable the system analyst to determine the exact sequence of events which have led to blackouts. It also help to analyze the sequence of events which helps pinpoint the exact causes and malfunctions that may have contributed to the failure of power system.

A number of PMUs are already installed in several utilities around the world for various applications such as post-mortem analysis, adaptive protection, system protection schemes, and state estimation. Effective utilization of this technology is very useful in mitigating blackouts and learning the real time behavior of the power system.

References

[1] M. Donolo, “Advantages of synchrophasor measurements over SCADA measurements for the power system state Estimation,” SEL application Note (LAN 2006-10)
[2] M.V.Mynam, Aia Harikrishna, andVivek Singh,’’synchrophasors Redefining SCADA Systems,” Schweitzer Engineering Laboratories, Inc. 2011.
[3] M.Adamiak, B.Kasztenny, andW.Permerlani, “Synchranopasors: Defination, measurement, and application,’’ 59thAnnu. Georgia Tech Protective Relaying, Atlanta, GA, Apr.27-29, 2005.
[4] D.Ree, V. Centeno, J.S.Thorp, and A.G.Phadke, “Synchronized phasor measurement applications in Power Systems”,

IEEE Transactions Smart Grid, vol.1, no.1, pp. 20-27, June, 2010.

[5] A.G. Phadke, and BogdanKasztenny, “Synchronized phasor and frequency measurement under transient conditions,” IEEE transactions on power delivery, vol.24.no.1, pp89-95, Jan.2009.

[6] Sarmadi, S. Nourizadeh, S. Aziz, R. RahmatSamii, and A. M. Ranjbar, “A power system buildup restoration method based on wide area measurement systems,” European Transactions on Electrical Power, vol. 21, no. 1, pp. 712–720, 2011.

[7] A.G.Phadke ,J.S.Thorp and K.J. Karimi, "State Estimation with Phasor Measurements",IEEE Transaction on PWRS, Vol. 1, No. 1, pp 233-241, Feb. 1986.

[8] R. Burnet, A.G.Phadke, “Synchronized phasor measurement of a power system event”, IEEE Transactions on power systems, vol.9, No.3, pp1643-1650, 1994.

[9] M. S. Sachdev and M. M. Giray, "A digital frequency and rate of change of frequency relay," *Transactions of the Engineering And Operating Division, Canadian Electrical Association*, vol. 17 part 3, pp. 78-sp-145, 1978.

[10] J.F. Hauer, C.J. Demeure and L.L. Scharf, “Initial results in Prony analysis of power system response signals,” IEEE transactions on power systems, vol. 5, no. 1 pp 80-89 ,February 1990

[11] A. Girgis and F. M. Ham, "A new FFT-based digital frequency relay for load shedding," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-101, pp. 433-439, 1982.

[12] A. G. Phadke, J. S. Thorpe, and M. G. Adamiak, "A new measurement technique for tracking voltage phasors, local system frequency, and rate of change of frequency," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-102, pp. 1025-1038, 1983.

[13] F. P. Dawson and L. Klaffke, "Frequency adaptive digital filter for synchronization signal aquisition and synchronized event triggering," presented at PESC 98 Record. 29th Annual IEEE Power Electronics Specialists Conference, New York, NY, USA, 1998

[14] M. Wang and Y. Sun, "A practical, precise method for frequency tracking and phasor estimation," *IEEE Transactions on Power Delivery*, vol. 19, no.4, pp.1547-52, Oct. 2004.

[15] M. S. Sachdev and M. M. Giray, "A least error square technique for determining power system frequency," *IEEE Transaction on Power Apparatus and Systems*, vol. PAS-104, pp. 437-444, 1985.

[16] M. M. Giray and M. S. Sachdev, "Off-nominal frequency measurements in electric power systems," *IEEE Transactions on Power Delivery*, vol. 4, pp. 1573-1578, 1989.

[17] A. Girgis and T. L. Hwang, "Optimal estimation of voltage phasors and frequency deviation using linear and non-linear Kalman filtering: theory and limitations," *IEEE Transaction on Power Apparatus and Systems*, vol. PAS-103

[18] J.-Z. Yang and C.-W. Liu, "A New Family of Measurement Technique for Tracking Voltage Phasor, Local System Frequency, Harmonics and DC Offset," presented at Power Engineering Society Summer Meeting, 2000.

[19] T. Lin, M. Tsuji, and E. Yamada, "A wavelet approach to real time estimation of power system frequency," presented at SICE 2001, Tokyo, Japan, 2001.

[20] P. K. Dash, D. P. Swain, A. Routray, and A. C. Leiw, "An Adaptive Neural Network Approach for the Estimation of Power System Frequency," *Electrical Power Systems Research*, vol. 41, no 3, pp. 203-210, June 1997.

[21] I. Kamwa and R. Grondin, "Fast adaptive schemes for tracking voltage phasor and local frequency in power transmission and distribution systems," *IEEE Transactions on Power Delivery*, vol. 7, no.2, pp. 789-95, April 1992.

[22] Chakrabati, Saikat and Kyriakides, “Measurements get together,’’IEEE Power and Energy Magzine2009, 7(1).pp41-49.

[23] IEEE Standard 1344-1995 (R2001) “IEEE Standard for Synchrophasors for Power Systems”.

[24] IEEE Standard C37.118-2005 (Revision of IEEE Std 1344-1995) “IEEE Standard for synchrophasor for power systems’’.

[25] A.G.Phadke and J.S.Thorp,”Synchronized Phasor Measurements and Their Applications” IBSN 978-0-387-76535-8