GPS Based Phasor Technology in Electrical Power System

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***Abstract*—The electrical power system has been increasing in complexity at rapid rate in last few decades. Traditional SCADA systems are based on steady state power flow analysis and therefore cannot observe the dynamic characteristic of the system. 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 Global 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 [1]. The GPS based phasor measurement technology provides the dynamic view of power system. This paper gives the introduction to GPS based phasor measurement techniques in power system.**

***Index Terms*—GPS, synchrophasor, PMU, SCADA**

I. Introduction

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.

GPS based 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 Global 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 major blackouts has given new impetus for large scale implementation 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 [2].

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.

A. Phasor Basics

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

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

where,

X_m is the peak value of the signal

ω is the frequency of the signal in radians per second

θ is the phase angle in radians

The phasor representation of this sinusoidal is given by where,

$$X = X_r + jX_i = (X_m/\sqrt{2})e^{j\theta}$$
$$= x_m/\sqrt{2}(\cos\theta + j\sin\theta) \quad (2)$$

where,

$x_m/\sqrt{2}$ is the magnitude of the phasor i.e. the r.m.s. value of sinusoid.

θ is its phase angle.

The sinusoidal signal and its phasor representation given by 1 and 2 are illustrated in Fig. 1.

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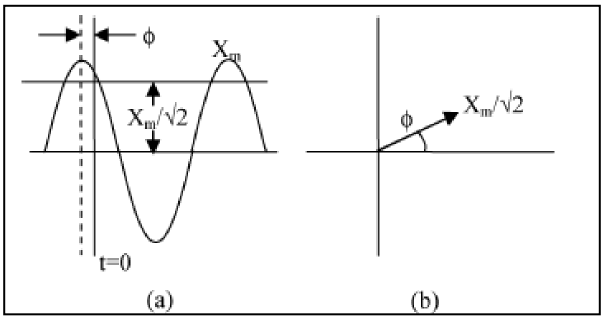

Figure 1. Sinusoidal signal and its phasor representation

The phase angle is the distance between the signal's sinusoidal peak and specified reference and is measured using an angular measure. Here the reference is fixed point in time t=0. The positive phase angles are measured in counterclockwise direction from real axis. The phasor magnitude is related to the amplitude of the sinusoidal signal.

As the frequency of the sinusoidal is implicit in the phasor definition, it is clear that all phasors which are included in a single phasor diagram must have the same frequency. Phasor representation of the sinusoidal implies that the signal remains stationary at all times, leading to a constant phasor representation. These concepts must be modified when practical phasor measurements are to be carried out when the input signals are not constant, and their frequency may be a variable.

B. Synchrophasor

Phasor measurements that occur at the same time are called "synchrophasor" [2]. It is the term used to describe a phasor which has been estimated at an 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.

II. Structure of Phasor Measurement Unit

The main elements of Phasor Measurement Unit (PMU) are as shown in Fig. 2.

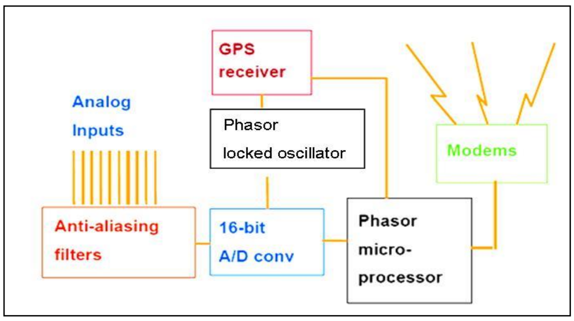

Figure 2. Basic block diagram of PMU

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 anti aliasing filter. Anti aliasing 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 [3]". 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.

A. Global Positioning System

The synchronized time is given by GPS uses the high accuracy clock from satellite technology. The first GPS system was developed by United States, Department of Defense. Without GPS providing the synchronized time, it is hard to monitor whole grid at the same time.

The GPS system consists of 24 satellites in six orbits at an approximate altitude of 10,000 miles above the surface of the earth. They are thus approximately at one half the altitudes corresponding to a geosynchronous orbit. The positioning of satellite in orbits and the positioning of orbital plane is such that at any given instant at least six satellites visible at most location on earth. Often as many as 10 satellites may be available for viewing. The civilian-use channel of the GPS transmits positional co-ordinates of the satellite from which the location of a receiver station on the earth could be determined. In addition, the satellites transmit a one pulse per second signal. This pulse as received by any receiver on earth is coincident with all other received pulses within 1 microsecond and often in practice is found to be much more accurate.

The GPS satellites provide a very accurate time synchronization signal, available, via an antenna input, throughout the power system. This means that that voltage and current recordings from different substations can be directly displayed on the same time axis and in the same phasor diagram. Fig. 3 shows how GPS works to organize the synchronization time.

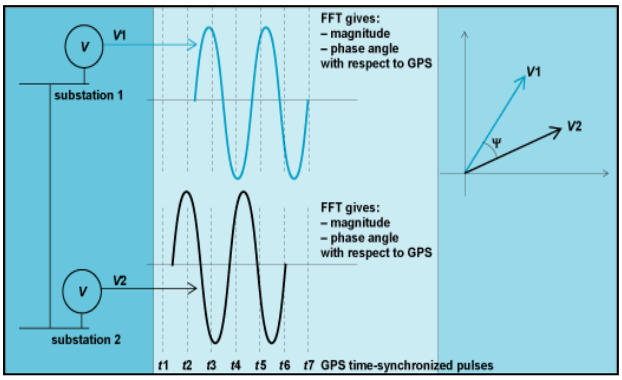

Figure 3. GPS time synchronization

B. Phasor Network

The simplest form of the phasor network consists of two nodes, one phasor measurement unit (PMU) at node 1 that communicates with one phasor data concentrator (PDC) at node 2.A typical phasor network is as shown in Fig. 4.

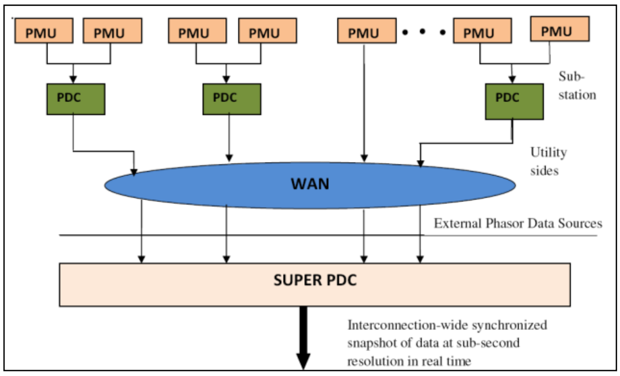

Figure 4. Phasor networks

The PMUs are installed in power system substations. The selection of stations where these installations take place depends upon the use to be made of the measurements they provide. The PMU provides the measurements of time-stamped positive sequence voltage and currents of all monitored buses and feeders along with the frequency and rate of change of frequency. The measurements are stored in local data storage which can be accessed from remote location for post –mortem analysis. There may be some local application task which requires PMU data; in that case it can be made available locally for such tasks.

The PMUs are connected to the PDC at utility centre where the data is aggregated .the main function of PDC is to gather data from several PMUs reject bad data and create coherent record data from a wider part of power system. A personal computer connected to the output of PDC provides the users with software such as RTDMS (real Time Dynamic Monitoring System) and displays locally measured frequencies, primary voltages, currents, MWs and MVARs for system operators. Additionally may PDCs belonging to different utilities can also be connected to common central PDC known as Super PDC. It aggregates the data across the utilities to provide an interconnection-wide snapshot.

C. Comparision between SCADA and GPS Based Phasor Technology (Table I)

TABLE I. COMPARISON BETWEEN SCADA AND GPS BASED PHASOR TECHNOLOGY

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

III. PHASOR ESTIMATION TECHNIQUES

Phasors are the most important quantities in power system operation. Phasor can constitute the state of the power system. It is therefore essentional to find the best algorithm for estimating the phasor and implements it. The possible digital algorithms of PMU measurements are assumed to be

- Modified level crossing techniques [3]
- Prony analysis [4]
- Newton method [5], [6]
- Least error square error techniques [7]
- Kalman filter techniques [8]
- Smart discrete fourier transform [9]-[14]
- Wavelet approach [15]
- Adaptive neural network approach [16]-[18]

IV. 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 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. Explanation, examples, and supporting information are also provided.

In the first major improvement, C37.118 [19], [20] 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.

V. 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 [21].

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. 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.

F. Existing Phasor Measurement Units in 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.

VI. Conclusion

GPS based phasor technology provides high speed (sub second) coherent data that are not available with traditional SCADA measurements in order to monitor power system dynamics. With the growing interest in phasor technology (PMUs) throughout the world, it is clear that these systems will be implemented in most major Electrical networks.

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