Role of Synchronised Phasor Measurement Units in Power System

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Abstract— In the present era, with the expansion of power system the complexity and challenges in terms of grid stability, security and safety is increased. So more accurate, reliable monitoring and control systems are required. SCADA system is capable only to provide steady state view of the power system with high data latency. Synchronised phasor measurement unit is one of the important equipment in this regard. This paper presents a review of phasor measurement units in power system and smart grids. PMUs have great potential in the power system monitoring, control and protection. The historical development, principle working, applications and other related aspects are discussed in this paper.

Keywords— PMU-Phasor measurement unit, PDC-Phase data concentrator, SCADA-supervisory control and data acquisition system, GPS-global positioning system, WAMS-Wide area measurement system, RTDS- Real time digital simulator, GSM-Global system for mobile.

INTRODUCTION

In mid 1980s PMUs were developed. Phasor measurement unit (PMU) is a device or a function in a multifunction device that produces synchronized phasor, frequency, and rate of change of frequency (ROCOF) estimates from voltage and/or current signals and a time synchronizing signal [7].

The Bonneville Power Administration (BPA) is the first utility to implement comprehensive adoption of synchrophasors in its wide-area monitoring system. WAMS is one or more networks of measuring devices that may include phasor measurement unit (PMUs), local recorders, legacy equipment, or advanced technologies that are GPS-synchronized over a geographically diverse area [7].

PMU technology provides phasor information (both magnitude and phase angle) in real time [4].It is possible to obtain synchronized phasor measurements using PMU. The advantage of referring phase angle to a global reference time is helpful in capturing the wide area snap shot of the power system. Whenever any disturbance or fault occur the protection or control system has to be initiated for power system degradation, minimize the impact of disturbance, isolates the unhealthy part and restores the power system to normal healthy state.

1. *Phasor Basics*

A pure sinusoidal waveform can be represented by a unique complex number known as a phasor. Consider a sinusoidal signal[8]

$$\boldsymbol{x(t) = X_m cos(\omega t + \theta)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\boldsymbol{(1)}$$

where,

X_m is the peak value of the signal

$\boldsymbol{\omega}$ 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,

$$X = X_r + jX_t = (X_m/\sqrt{2})\, e^{j\theta}$$

$$= x_m/\sqrt{2}(cos\Theta + jsin\Theta) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where

$x_m / \sqrt{2}$ is the magnitude of the phasor i.e. the r.m.s. value of sinusoid
The sinusoidal signal and its phasor representation given by (a) and (b) are illustrated in Fig. 1.

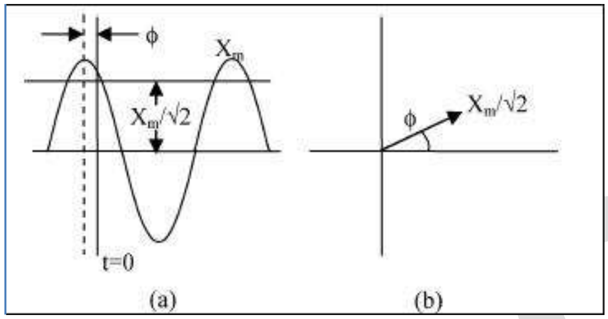

Fig 1. (a)Sinusoidal signal and (b) its phasor representation

2.Block diagram of PMU

The main elements of Phasor Measurement Unit (PMU) are as shown in Fig. 2.[8]

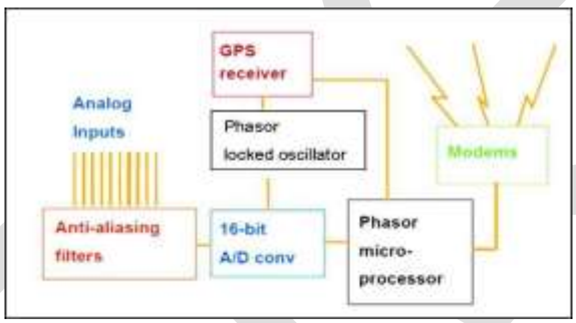

Fig 2. Basic block diagram of PMU

Analog inputs- Current and voltage transformers are employed at substation for measurement of voltage and current. The analog inputs are the voltages and currents obtained from the secondary winding of the three phase voltage and current transformers.
Anti-aliasing filters- The analog inputs go into an anti-aliasing filter. It limit the bandwidth to satisfy the Nyquist criterion. As per Nyquist theorem, to reconstruct signal after sampling, without introducing error, sampling frequency must be greater than twice the maximum frequency of the signal to be sampled. Thus they are used to filter out the input frequencies that are higher than the Nyquist rate [8].
A/D converter-It converts the analog signal to the digital one.
Phase lock oscillator and GPS reference source -Phase lock oscillator along with Global Positioning System reference source provides the needed high speed synchronized sampling, Global Positioning System (GPS) is a satellite-based system for providing position and time. The accuracy of GPS-based clocks can be better than 1 μs [7] . It consists of 24 satellites orbiting in 6 geo-synchronous orbits such that at any given instant 4 satellites are visible from any point on the earth surface.
Phasor microprocessor -The phasor microprocessor calculates the phasor using digital signal processing technique and uploads to phasor data concentrator.
Phasor data concentrator (PDC) -The electrical parameters measured by a number of PMUs are to be collected by some device either locally or remotely, this function is performed by Phasor Data Concentrator (PDC). A PDC forms a node in a system where phasor data from a number of PMUs is collected, correlated and fed as a single stream to other applications. Phasor Data Concentrator (PDC) is a function that collects phasor data and discrete event data from PMUs and possibly from other PDCs, and transmits data to other applications. PDCs may buffer data for a short time period but do not store the data[7].
In a hierarchal set up the PDCs can also be used to collect the data from number of down stream PDCs.[13]
PDC is differentiated into:-

- Nodal PDC(NPDC)
- Master PDC (MPDC)
- Super PDC (SPDC)

3.Synchrophasor standards

1. 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 [8]. It was created to introduce synchrophasors to the power industry and set basic concepts for the measurement and methods for data handling.

2. 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. The concept of (PDC) which included data from several PMUs introduced [8]. In India this standard is mainly used [13].

APPLICATIONS OF PMU

The various applications of PMU are as follows [13]:-

1. Real time monitoring and Control
2. State estimation[1]
3. Real Time Congestion Management
4. Post-Disturbance analysis
5. Power System Restoration
6. Automated control

The measurement obtained through PMUs installed in the grid helps to calculate the complete view of current state of the power system. State estimation measurements run at fixed interval of time gives a snapshot of the system at that time [10].

If we are able to predict dynamic changes of the power system one step ahead it will be very beneficial for security analysis and allows more time for the grid operator to take quick, timely control decisions in case of an emergency. Most reports on blackouts show that majority of the blackouts were preventable and PMU helps to achieve this objective. The accuracy of state estimation is largely dependent on the accuracy of measuring devices. PMUs are much more accurate than SCADA.

PMU can measure both voltage and current phasors at the installed bus. The measurement of voltage angle along with voltage magnitude was not possible with SCADA but PMU can directly measure it.

Detection of imbalance in three phase system

PMU can also be used for the detection of imbalance in three phase power system[6]. Frequency deviation s& imbalances causes serious contingencies leading to blackout. Ill effects of voltage imbalances are :-

1. Increase in losses
2. Overheating of machinery
3. Insulation degradation
4. Reduced life of motors and transformers

A generalized likelihood ratio test (GLRT) is developed and shown to be a function of the negative-sequence phasor estimator and the acceptable level of imbalances for nominal system operations [6]. In [6] a statistical model that captures characteristics of imbalance from PMU output is developed. For a perfectly balanced power system the PMU output is a single complex sinusoid, whereas under imbalance the symmetrical components at PMU output have two related frequencies. Detection of imbalance is done using negative sequence in addition to positive sequence component. Under perfectly balanced conditions only positive sequence component is present while negative & zero components are absent.

For Industrial applications

The industrial area is also prone to disturbances and contingencies. The potential of PMU can also be used in industrial areas for fault localisation. It is very important to develop methods to locate faults quickly and to take appropriate protective measures to reduce the impact of fault. In[2] a fault localisation method is proposed based on the online monitoring of the duration of signal which is needed to get from one point to other, where length of cable is known to us. As PMU measurements are time synchronised, they should observe differences in time of occurrence of significant disturbances in the grid & localise the disturbance source.

Identification of faults

Whenever any fault occurs in the power system for monitoring and detection of the faults basically there are two components [14]:-

1. The first component tis the voltage reduction due to the occurrence of the fault or contingency.
2. The second component is that the power flow direction reverses due to fault occurrence.

Phase angle measured by PMU is used for the determination of fault current with respect to the reference quantity. The nominal power flow will result in phase angle between voltage & current around its power factor angle $\pm\phi$. [14]. When power flow direction reverses due to fault it becomes $(180\pm\phi)$.

It is concluded that minimum voltage value indicates the nearest area to the fault and maximum absolute angle difference is selected to identify the faulted line in the power system [14].

Comparison between SCADA and PMU [8]

TABLE1 Comparison between SCADA and PMU

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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
Analogy	X-Ray	MRI

It is concluded that PMUs are much more accurate than the SCADA system and helps in dynamic state monitoring. But in the present power system it cannot completely take place the SCADA system. But the combination of both technologies is used.

RELATED ASPECTS

Testing of PMU and PDC with RTDS

Real time digital simulator tests the performance requirements of PMU & PDC according to IEEE standards. In [5] the tests are created in RSCAD software of RTDS. It can also be used for testing of protection and control devices. It examine the PMU compliance with frequency range, signal magnitude range, phase angle range, harmonic distortion. Using the PMU-PDC platform with RTDS the steady state and dynamic state tests are developed and performed for the SEL-451 PMU. For both test categories the synchrophasor measurements captured by the PMU under test are evaluated over the Total Vector Error (TVE), Frequency Error (FE) and Rate of Change of Frequency Error (RFE). For the step change tests of dynamic state, the response time, delay time and maximum overshoot are also calculated. SEL-451 PMU conforms to the limits defined by the standards for both the steady and dynamic state tests. The tests are conducted at 50 Hz frequency and at 50 frames per second sampling rate for the PMU under test [5].

Failure of communication link

The goal of PMU installation is to do real time monitoring of the power system. Various PMUs in the power system send its data to PDC & further monitoring and control actions are taken. This network configuration is prone to failure in the event of damage to the dedicated communication path between PMUs and PDC. In [4] usage of GSM/GPRS (Global system for mobile) communication between PMUs to establish alternate pathways of communication to ensure smooth operation until the original communication path is established, is proposed. It allows use of dedicated monitoring of PMU using smart phone. Spider follows a variant of mesh topology to achieve this objective [4].

Optimal PMU placement

For complete observability optimal placement of PMU is mandatory. As PMUs are costly equipment so judicial use important. It decided contingency cases along with base operating conditions. Two methods are used for the determination of optimal placement are [11]:--

1. Numerical observability
2. Topological observability based methods
3. Numerical observability based approach utilizes the information matrix or the measurement jacobian reflecting theconfiguration of the system and measurement set[11]. It involves huge matrix manipulation and computationally expensive. Various techniques based on this concept are, simulated annealing [A. B. Antonio and R. A. TorreBo], Tabu search[H. Mori and Y. Sone], Genetic Algorithm[B. Milosevic and M. Begovic] based methods. These techniques require large convergence time. However topological based methods utilize the graphic theoretic concept e.g. Depth Search method[R. F. Nuqui and A. G. Phadke], Spanning tree method[T. A. Baldwin, L. Mili, M. B. Boisen, and R. Adapa], Integer linear programming methods[B. Xu and A. Abur].In [11] a voltage stability based contingency ranking has been carried out to screen flow critical contingencies. This has been tested on IEEE 14 bus system, New England 39 bus system and Northern Region Power grid-246 Indian bus system.

In [12] based on greedy heuristic & relaxation, a branch and bound algorithm to find the globally optimal location is proposed. The optimal location is obtained in at most 19 iterations.

If acknowledgement is there wishing thanks to the people who helped in work than it must come before the conclusion and must be same as other section like introduction and other sub section.

CONCLUSION

This paper presented a brief review on phasor measurement unit & its related aspects in the power system. PMU is a promising device for smart grids to provide protection, monitoring and control. Many utilities including India are employing power projects to install PMUs in their existing power systems. Due to its features it is clear that most transmission networks will be employing it in the future. It can be used for numerous applications as discussed above, like fault detection, imbalance detection, voltage sags and swells, in industrial enterprises. But optimal placement is mandatory to completely fulfil our objectives, only then we can completely visualise power system effectively. Overall the power system security, reliability increases manifolds with the introduction of PMUs.

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