Study of PMU Technology for Power System Observability and Power System State Estimation

Pragati Jain, Rashmi Raghav

Assistant professor, Assistant professor
Department of Electrical and Electronics Engineering,
Dr. Akhilesh Das Gupta Institute Of Technology and Mangaemnet , New Delhi, India

Abstract : Indian Grid is expanding exponentially with increased number of interconnections between Regions, leading to complexities this is the reason of necessitating dynamic monitoring of parameters. The Synchronized Grid requires moving from element oriented to Wide Area Measuring Systems. Phasor Measurement Units (PMUs) provide time synchronized phasor measurements in a power system. Synchronicity in PMU measurements is achieved by time stamping of voltage and current waveforms using a common synchronizing signal available from the global positioning system (GPS). Phasor Measurement Unit (PMU) placement at all substations allows direct measurement of the state of the network. However, PMU placement on each bus of a system is difficult to achieve either due to cost factor or due to non-existence of communication facilities in some substations, and hence there is need to optimize the placement of PMUs. There are many methods to this problem. It is possible to get multiple solutions for the same system using the same method for optimal placement. The difference lies in the percentage of sub-stations covered under double or more observability with the same number of PMUs. This paper gives a Modified Graph Theoretical Approach for optimal PMU placement problem for IEEE 14 bus system

***IndexTerms* – Phasor Measurement unit, State Estimation, Power System Observability**

I. INTRODUCTION

With the increase of Power System complexity, collection of proper data has become significant for ensuring good performance of various controls. The peak demand is expected to increase more than 190 GW by 2019 which requires installed capacity of about 300 GW. Free flow of power across regional boundaries resulted in stabilization of the system frequency but caused large variations in bus voltages and line loadings. The conventional Supervisory Control and Data Acquisition/Energy Management System (SCADA/EMS) with only regional visibility was suddenly found to be inadequate to meet the requirements of system operation as a part of a large interconnection.[1],[2],[3] It is well known that the existing SCADA Systems does not have phase angle as an analog measurement. State estimator uses the SCADA inputs (analog and digital measurements) to estimate the system state viz. node voltage and angle. State estimator (SE) results are used for monitoring the angular separation between buses in the power system. However SE has its limitations. [4],[5],[6]It runs periodically as well on change of circuit breaker status and any monitoring based on SE output is very lethargic.[7]Furthermore the SE consequences are often imprecise and unpredictable in a rapidly growing power system due to limited network observability and dire statistics. Under these state of affairs power system image with the help of “Phase angle measurement” is the need of at the moment. The Wide Area Measurement System (WAMS) are the tools which provide real time phase angle measurement which is utilized for better image & help to increase the situational understanding of Power System Operators. The WAMS technology is the main building block for Smart Grid performance in Transmission Systems. The components of WAMS are Phasor Measurement Units (PMUs), Phasor Data Concentrators (PDCs), Visualization Aids, Application and Analysis modules, data achieving and storage etc. Analytical Software such as Linear State Estimator / Monitor, and Model Validation utilize PMU data for better grid management and planning.

In Power system a PMU cannot be placed on each bus as it has ability to measure data of neighboring buses to which it is connected, to measure state estimation and for power system observability there are many solutions, Graph Theoretical Approach (GTA) technique discussed in this paper.

II. STATE ESTIMATION

State Estimation is performed by processing a set of measurement field data which consists of real and reactive bus injections, real and reactive line flows and bus voltage measurements. Secure operation of power systems requires close monitoring of the system operating conditions. This is traditionally accomplished by the state estimator which resides in the control centre computer and has access to the measurements received from numerous substations in the monitored system. By collecting analog measurements and the status data of the circuit breakers from remotely monitored and controlled substations and feeding them as input into state estimation function, which can provide an estimate for all metered and un-metered electrical quantities and network parameters of the power system, detect and filter out gross errors in the measurement set and detect the topological errors in the network configuration.

In existing Supervisory Control and Data Acquisition (SCADA) / Energy Management System (EMS) system the field data is obtained from Remote Terminal Units (RTUs). The status of power system is telemeter to the control centre through the RTU. In large complex power system, the data is transmitted to the nearest control centre and then goes up in hierarchy to the main control centre Internal Control Centre Protocol (ICCP). Therefore the data updation time at the

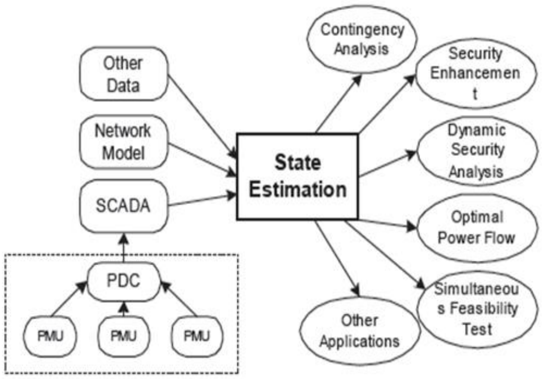

Figure 1:State Estimation role in Power System

main control centre is having a latency of few seconds ranging from 10 to 30 seconds. Based on this updation, the state of the power system is estimated using state estimator every few minutes or as and when required. But this estimation has its own limitations as data from different locations has time skew as the data is not time synchronized. Some of the data is reported directly by RTU and some is updated through ICCP. Even the data coming from different RTU/ICCP reaches in different scan group and through different channels of communication (microwave, PLCC, Fibre optic). Thus at times the estimation application result does not converge due to time skew in measured values or wrong parameter or telemetry failure and in some cases estimated results are not very accurate.

III. WIDE AREA MEASUREMENT SYSTEM (WAMS)

Advances in computing and communication technologies have led to sophisticated monitoring and control systems with capabilities far superior. In Power System WAMS is an example of such technologies. WAMS (Wide Area Measurement Systems) using Phasor measurement units (PMUs) are an advanced measurement system that provides synchronized measurements at a very fast rate[8] . Using WAMS technology it is proposed to implement nationwide Unified Real Time Dynamic Monitoring (URTDM) project which would provide planners and operators and other stake holders the tools to handle the upcoming challenges of power sector. This new technology will supplement the existing SCADA/EMS tools in Grid Management.

Since the start of the deregulation, power system operators are confronted with the need to monitor and coordinate power transactions taking place over large distances in remote parts of the grid. Each operating centre may have its own state estimator which processes the measurements given by its local substations. A system-wide area monitoring solution is needed when the power transactions are involved in several control areas. A central state estimator will collect wide area measurements and will solve very large scale state estimation problem. However, solving the large scale state estimation is not easy. Other than the problem of huge size of the interconnected system, each independent system operators may be reluctant to modify their existing system method in order to meet the new specifications imposed by the central state estimator for the large area solution. Then, a hierarchical multi-area state estimation is a solution for the individual system operators to keep their existing method and a central coordinator to determine the state of the overall system[9].

Synchro-phasor measurements provide intra second visibility to power system dynamics and enable faster control actions. Phasor Measurement Units (PMUs) sample power system voltages and current precisely and rapidly up to 12 to 16 samples per cycle. Further, the phasors computed are time synchronized enabling power system state determination and analysis of dynamic phenomenon using the information[10]. The wide area visibility based on remote measurements, and two way communications makes this technology suitable for adaptive relaying, adaptive islanding etc. Since the implementation of this new technology is cost intensive, it is required to optimize on the number of PMUs while at the same time ensuring the observability of the power system

IV. PMU – PHASOR MEASUREMENT UNITS

Till recent time, available measurement sets did not contain phase angle measurements due to the technical difficulties associated with the synchronization of measurements at remote locations. Global positioning satellite (GPS) technology alleviated these difficulties and lead to the development of phasor measurement units (PMU). Synchronized Phase Measurement Unit (PMU) is a monitoring device, which was first introduced in mid-1980s. Phasor measurement units (PMU) are devices, which use synchronization signals from the global positioning system (GPS) satellites and provide the phasors of voltage and currents measured at a given substation. As the PMUs become more and more affordable, their utilization will increase not only for substation applications but also at the control centres for the EMS applications. One of the applications, which will be significantly affected by the introduction of PMUs, is the state estimator.[11]

Synchronized phasor measurement techniques based on a time signal of the GPS (Global Positioning System) are introduced in the field of power systems. In order to obtain simultaneous measurements of different buses it is necessary to synchronize sampling clocks at different locations. A PMU which can increase the confidence in the state estimation result is practically introduced via the use of synchronized measurements[12]. Wide-area information from properly distributed PMUs enables the effective assessment of the dynamic performance of the power system and multi-area state estimation with independently operating system areas. Synchronized phasor measurement units are indispensable to get a second level state estimation. PMUs can measure voltage and currents as phasors. The error is small compared with the conventional measurements such as power injection and power flow measurements. Until very recently, the measurements used by the multi-area state estimators typically included only synchronized voltage phasors from the PMUs[13],[14].

Phasors are basic tools of AC Circuit Analysis, usually introduced as a means of representing steady state sinusoidal wave forms of fundamental power frequency. Even when a power system is not in a steady state, phasors are often useful in describing the behaviour of the power system. For example, when the power system is undergoing electromechanical oscillations during power swings, the wave forms of voltages and currents are not in steady state and neither is the frequency of the power system at its nominal value. Under these conditions, as the variations of the voltages and currents are relatively slow, phasors may still be used to describe the performance of the network, the variations being treated as a series of steady state conditions.

In Figure shown, the steady state waveform of nominal frequency signal is considered. Observation of the wave form is started at the instant t = 0, the steady-state wave form is represented by a complex number with a magnitude equal to the rms value of the signal and with a phase angle equal to the angle Φ. In a digital measuring system, samples of the wave form for one (nominal) period are collected, starting at t = 0, and then the fundamental frequency component of the Discrete Fourier Transform (DFT') is calculated using equation 3.1

Where N is the total number of samples in one period, X is the phasor, and Xk is the wave form samples. This definition of the phasor has the merit that it uses a number of samples (N) of the wave form, and is the correct representation of the fundamental frequency component, when other transient components are present.

$$X = \frac{\sqrt{2}}{N}\sum_{k=1}^{N} X_{k^2} - j2k\frac{\pi}{N} \quad (3.1)$$

When the input signal frequency is different from the nominal frequency, an error is introduced in the magnitude and the phase angle of the phasor. That error can be used to determine the frequency of the input signal.

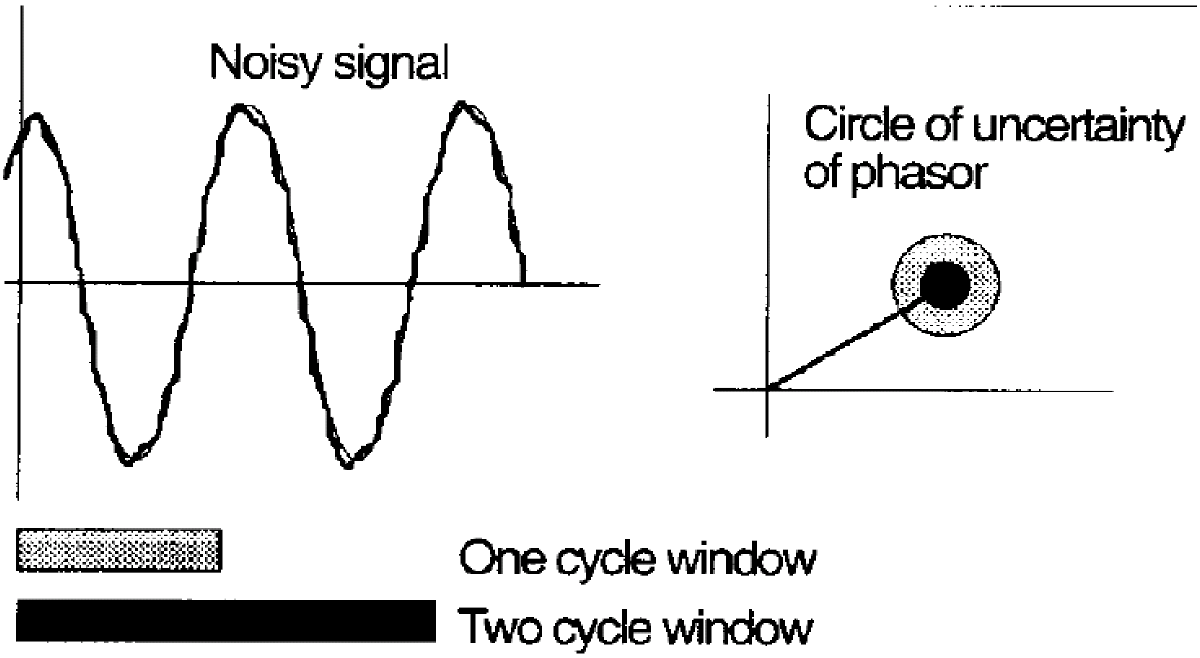

Figure 2: Data Window and Uncertainty in Phasor Measurement

Often the input signal contains frequencies that are not harmonics of the fundamental frequency. In such cases, the phasor calculation is once again in error. We could treat the extraneous non harmonic components (error) as a noise signal. Then the computed phasor which has an uncertainty associated with it can be represented as shown in Figure

The circle of uncertainty is inversely proportional to the square root of the data window. More data used in computing the phasor is beneficial and the wave form is sampled by the measurement system continuously, and each time a new sample is achieved, a new phasor is obtained with a data window including the latest sample

1. NEED FOR SYNCHRONIZATION

When several voltages and currents in a power system are measured and converted to phasors, they are on a common reference if they are sampled at the same instant precisely. This is easy to achieve in a substation, where the common sampling clock pulses can be distributed to all the measuring systems. However,

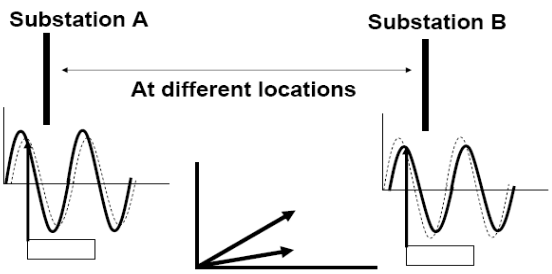

Figure 3: Phasor Measurement at different locations

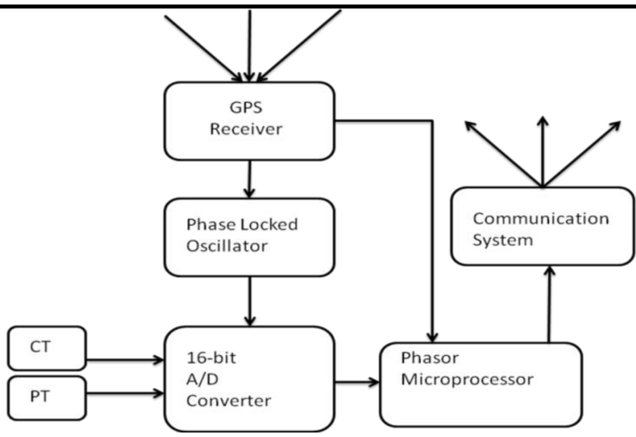

Figure 4: GPS connection with PMU

V. Solutions to compute State Estimation and Power System Observability with PMU

Optimal PMU Placement Solutions have been reported by many authors, such as Simulated Annealing (SA). The SA formulation was further extended to solve the pragmatic phased installation of PMUs. PMU Placement Method Based on optimal meter placement strategy for the PMU's was tested on many IEEE standard networks. In a phasor measurement placement method based on the topological observability theory using graph theorem analysis is proposed. A minimal number of buses with measurements is found through both a modified bisecting search and simulated annealing-based method. PMU Placement for Power System Observability using method proposed by Madtharad was used and also a placement-site reduction technique is introduced. Many authors has proposed Simulated annealing for solving the optimal PMU placement in the power system for state estimation. And few authors has proposed Phasor measurement in Dynamic State Estimation of Power System using Graph Theoretical Approach.

1. Graph Theoretical Approach

A simple and efficient technique was developed using the graph theoretical principles and the same has been applied for working out optimum number of PMUs for various Grid. It works on the basis of three cases:

- Measurement only by PMU - This case does not involve any assumptions and it does not try to take advantage of any pseudo measurement buses. Hence, this can be considered as the worst case scenario.
- Measurement by PMU and Pseudo measurement - This case we have taken advantage of pseudo measurement buses. Hence bus parameters are assumed through their initial parameters measured.
- Measurement by PMU, Pseudo measurement and some flow measurement - This case consider the situation where some conventional flow measurements may be present.

VI. CONCLUSION

Emerging technologies like Wide Area Measurement System (WAMS) using Phasor Measurement Unit (PMU) provide advanced measurement system that will utilize synchronized measurements from geographically distant locations and increases the situational awareness by monitoring a wide area of power system in real time. WAMS Technology in transmission system is one of the essential building blocks of Smart Grid implementation for transmission. The PMUs are installed at Substations for acquiring data and through wide band communication media; this data is transferred to Control Centre. At Control centre, suitable hardware & software is provided for analyzing PMU data and to provide useful inputs to operator. Technologies based upon WAMS facilitate real-time visualization of power systems, real-time congestion management, and design of an advanced warning system, validation and fine tuning of system model

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