STATE ESTIMATION ALONG WLS-PHASOR MEASUREMENTS IN POWER SYSTEM

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

POWER SYSTEM

SUBMITTED BY

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I, ANKIT KUMAR DHAIKAR, Roll No. 2K19/PSY/02 student of M.Tech. (Power System), hereby declare that the project Dissertation titled "**STATE ESTIMATION ALONG WLS-PHASOR MEASUREMENTS IN POWER SYSTEM**" which is submitted by me to the Department of Electrical Engineering Department, Delhi Technological University, Delhi in partial fulfillment ofthe requirement for the award of the degree of Master of Technology, is original and notcopied from any source without proper citation. This work has not previously formed thebasis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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DECLARATION

I hereby certify that the work which is presented in the Major Project-II project entitled STATE ESTIMATION ALONG WLS-PHASOR MEASUREMENTS IN POWER SYSTEM in fulfillment of the requirement for the award of the degree of Master of Technology in Power System. Delhi Technological University, Delhi is an authentic record of my own, carried out during a period from 2019 to 2021, under the supervision of S T Nagarajan.

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I hereby certify that the major project titled “**STATE ESTIMATION ALONG WLS-PHASOR MEASUREMENTS IN POWER SYSTEM**” which is submitted by ANKIT KUMAR DHAIKAR, Roll No-2K19/PSY/02 ELECTRICAL ENGINEERING DEPARTMENT, Delhi Technological University, Delhi, in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or fullfor any Degree to this University or elsewhere.

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ABSTRACT

Large Power System State Estimation, being a process to estimate voltage angle as well as the magnitude state for every bus of system of the power that is based on measurements which have been carried at only buses. The devices for the measurement of the earlier days, have only been able to give quantity measured magnitude. Nevertheless, a measurement device with the efficiency known as the Phasor-Measurement-Unit (PMU) which is helpful for the measurement of the phasor of voltage (both magnitude a well as the angle) of a bus at which it's placed as well as the phasors of current of directly connected lines are being used. Since PMUs are very costly, one cannot use PMU measurements only to estimate the state of a power system. Hence, phasor measurements are used as an additional measurement with traditional measurements to estimate the state of a power system.

In this project report, use of PMU measurements to estimate the state of a power system has been explained and a MATLAB program has been coded as well as a simulation has been carried out on IEEE-14 bus and IEEE-30 bus systems for verification of the method. The method uses, a distinct estimator model of the linear state to use the estimate for the state from the WLS, as well as the current measurements and the PMU voltage through the post-processing. First the model estimates the state in polar coordinates using WLS state estimation method from conventional measurements. Then this state, with PMU measurements, both expressed in rectangular coordinates, is used to estimate the final state of the system.

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LIST OF ABBREVIATIONS

PMU	Phasor Measurement Unit
WAMS	Wide Area Measurement Unit
WAMACS	Wide Area Monitoring And Control System
SCADA	Supervisory Control and Data Acquisition
PDC	Phasor Data Concentrator
GPS	Global Positioning System
UTC	Coordinated Universal Time
ROCOF	Rate Of Change Of Frequency
EMS	Energy Management System
SCDR	Symmetrical Component Distance Relay
RTU	Remote Terminal Unit
IEEE	Institute of Electrical and Electronics Engineering
URTDSM	Unified Real Time Dynamic State Measurement
PGCIL	Power Grid Corporation of India
CT	Current Transformer
PT	Potential Transformer
PLL	Phase Locked Loop
DFT	Discrete Fourier Transform
GPA	Grid Protection Alliance
PWS	Power World Simulator
PWDS	Power World Dynamic Studio
WSCC	Western System Coordinating Council
EHV	Extra High Voltage

LIST OF SYMBOLS

T_m Mechanical torque applied by the prime mover – retarding torque due tomechanical losses, N-m

T_e Electrical torque applied for the electrical power output + electrical losses, N-

mP_m Mechanical power supplied by the prime mover –mechanical losses, Watts

P_e Electrical power output supplied by the generators + electrical losses,

Wattsθ_m Rotor angle position w.r.t stationary axis, rad

✿$_m$ Rotor angle position w.r.t synchronously rotating reference axis,

radω_m Angular velocity of rotor, rad/sec

ω_{sm} Synchronous angular velocity of rotor,

rad/secP Number of poles in synchronous generator

M Moment of Inertia

D Damping factor of generator

V_t Generator terminal voltage magnitude measured by

PMUI_a Generator current magnitude measured by PMU

Φ Phase angle of the generator current w.r.t its terminal voltage measured by PMU

E_i Emf magnitude behind transient reactance

I_{bus} Current injected in the bus

V_{bus} Voltage of the bus with respect to ground

Y_{bus} Bus admittance matrix

W Standard Wiener Process

G Equivalent conductance

Σ Variance of load variation

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Increment in the usage of electricity causes highly extensive as well as interrelated big electric power system, which mainly consist of wide generating system, large and extensive transmission network requires high level of power system security assurance. With large and complex power system it is difficult to detect any faults or unwanted activities which sometimes may cause serious system failure. The main objective of our power system is to supply reliable and continuous power to all the consumers without any interruption. To achieve this objective there is a requirement of advanced and intelligent power system which depends on the real time information.

The system for the estimation of the power state is known to be a technique for the approximation of the magnitude of voltage and the angles for every bus in system of power at a certain time. To achieve this, the precise phasor measurements which are synchronized of every bus-voltage of system is used.

In recent years the selection of PMUs has made it conceivable to approve the expected network model and the estimations of system parameters. There are various methods to estimate the values of system parameters based on PMU measurements. One of the PMU based methodology is to build up a dynamic equivalent model of the dynamical system [15]-[18].

Though, these measurements are probable of having errors in the measurement or the failures of telemetry as well as Phasor Measurement Units (PMUs) are very expensive. Thus, a typical procedure for the approximation of the state to use a set of superfluous measurements for the filtration of the errors as well as for finding an optimal estimate. The measurements have power that is conventional as well as the measurements of voltage. Also, the others like the magnitude of the current or the voltage phasor measurements that are synchronized. The bus-voltage-phasors in the steady state is included in the definition of the state of system, (voltage angle as well magnitude).

The core of an online-security-analysis is the estimator of the state. As, it functions as a filter for the raw measurements of the system as well as provides the dependable system of the current states for applications such as the load-flow, contingency-analysis etc. The voltage, current, injections of the power as well as the measurements of the flow of power are included in the raw measurements.

The positions of the switch as well as the circuit breaker in substations have been processed using topology-processor, for the generating of a bus/branch-model for the system of power as shown in the Fig 1**.** The estimators of the state use diverse techniques for the estimation of state of every bus in system of power, for instance, most frequently used in WLS method.

1.2 SYNCHRONIZED PHASOR MEASUREMENT UNITS (PMUS)

PMU uses the GPS signals for synchronizing the measurements of the positive sequence in the phasors of the voltage at the network buses as well as the current phasors of the positive sequence in line that has been linked to the buses. Correctness of the synchronization has been considered better than fraction of a second, as well as group of measurements giving a snapshot of the real-time of power system state.

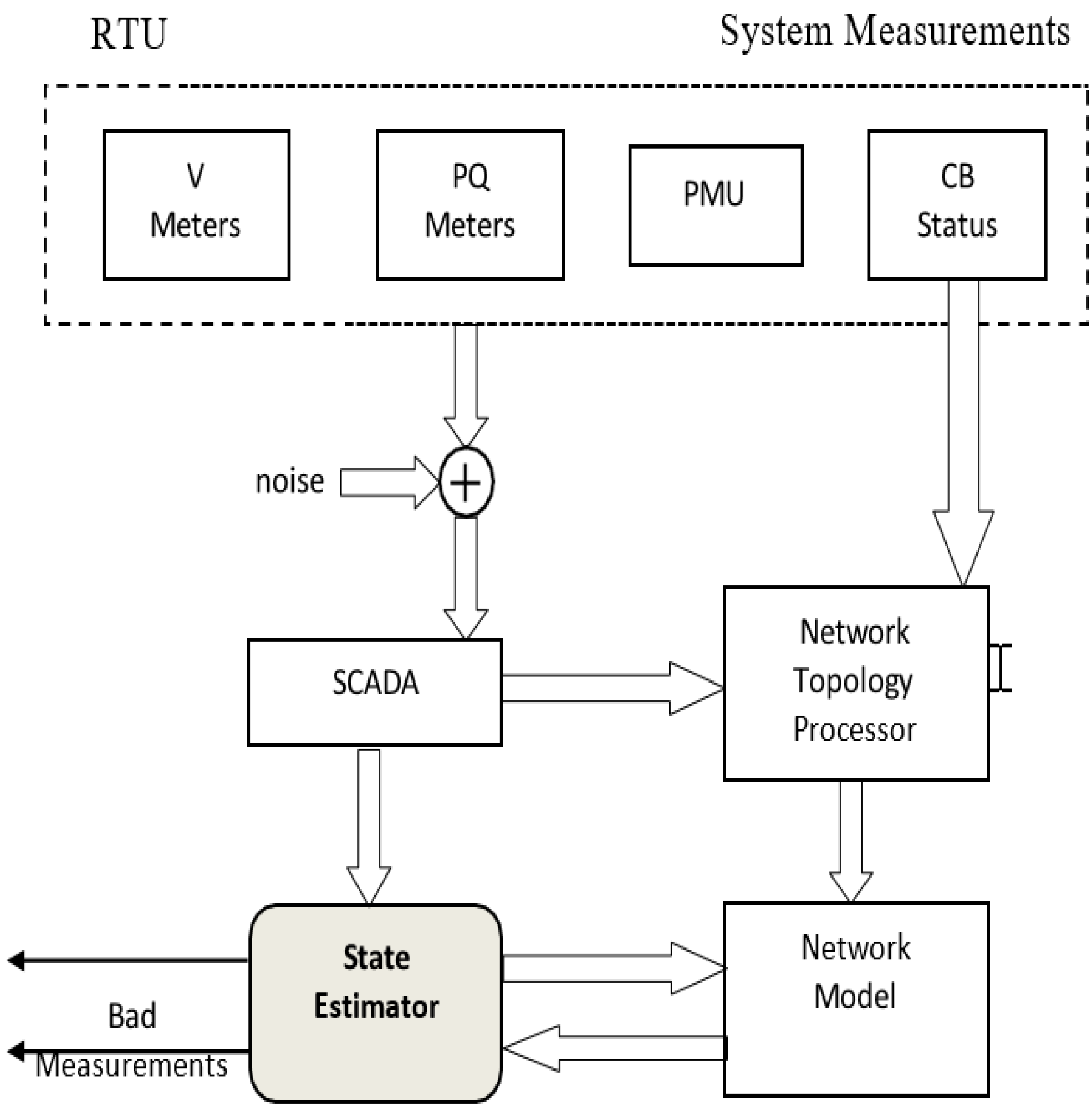

Fig. 1.1 State Estimation Block diagram

As, the voltages having sequence that is positive at every network bus contains power system of state-vector, it become very easy that the state approximation issue could be resolved with the use of the phasor-measurements widely.

With the help of these measurements, one is led to process for the measurement of the state system. Moderately, the approximating it with the use of the measurements having functions of the state which are nonlinear. But PMU are quite expensive and have been taken in use as extra measurements with the old-style measurements. The Fig 1.2 presents the working block diagram of typical PMU.

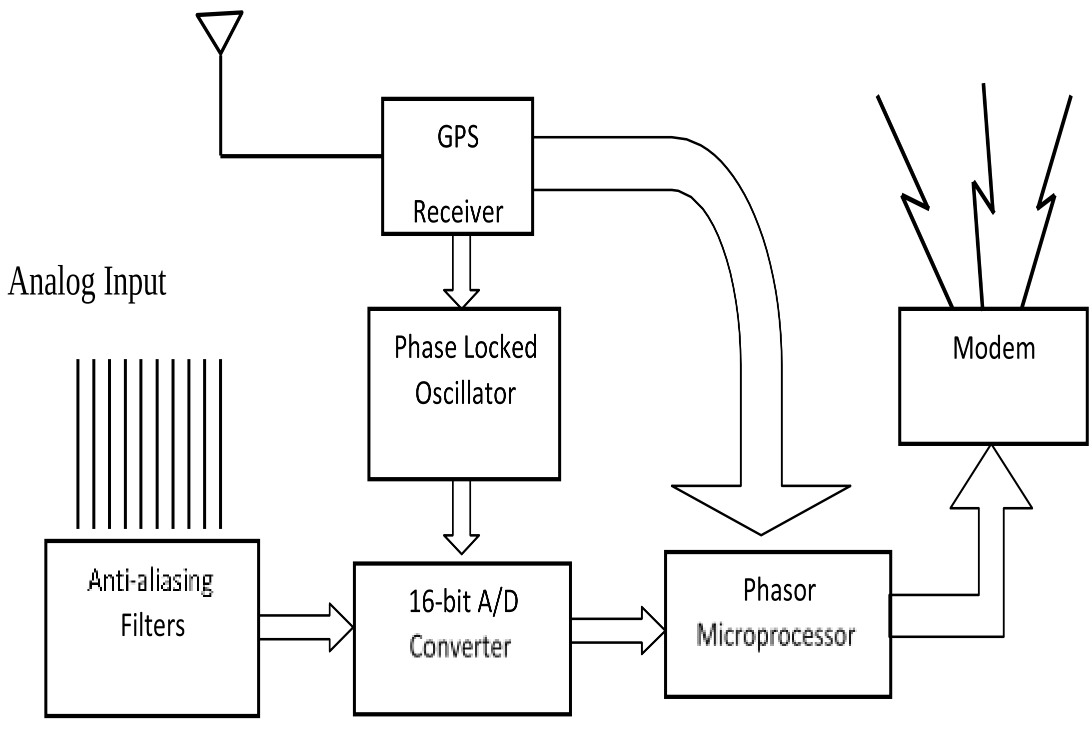

Fig.1.2 Functional block diagram of a typical PMU.

1.3 HISTORICAL OVERVIEW

The beginning of the advanced EMS system dependent on state estimators have been started with the consequence of the 1965 electric failure (blackout) of the North-Eastern power grid in North America. At Virginia Tech, the development of Phasor Measurement Unit (PMU) device was supported by different financing organizations throughout the years. The early development funding was funded by US Department of Energy, US Electric Power Research Institute and the US National Science Foundation [40].

The significant steps in the development of Phasor Measurement Units are as followings below:

1) Development of Symmetrical Component Distance Relay (SCDR)
2) Synchronization of sampling clocks (GPS)
3) Invention of the prototype PMU
4) Commercial PMU development
5) Installation in power system
6) Applications Research

The Symmetrical Component Distance Relay (SCDR) was developed in the early1970s. At that time, the available microcomputers were not furnished according to a distance relay algorithm necessities, which utilized symmetrical components of voltages and currents to obtain a single equation to solve 6 fault equations using symmetrical components of a three phase transmission lines [41]. GPS satellites were being deployed in mid 1980s in numerous quantities, and it was obvious that using as inputs for the sampling clocks in the digital relays measurement system GPS time flags, developed an extremely amazing estimation device, which would have the option to give image of the condition of the power system at any instant of time [42].

The synchronized PMUs with GPS were first introduced in 1988 by Dr. Arun G. Phadke and Dr. James S.Thorp at the Power System Research Laboratory of Virginia Tech. This advanced measuring device provides measurements of phasors with absolute real time reference synchronised with Global Positioning System (GPS). The initial PMU prototypes were built at Virginia Tech and the first PMU model 1690 was assembled in 1992 by Macrodyne (New York Independent System operator).

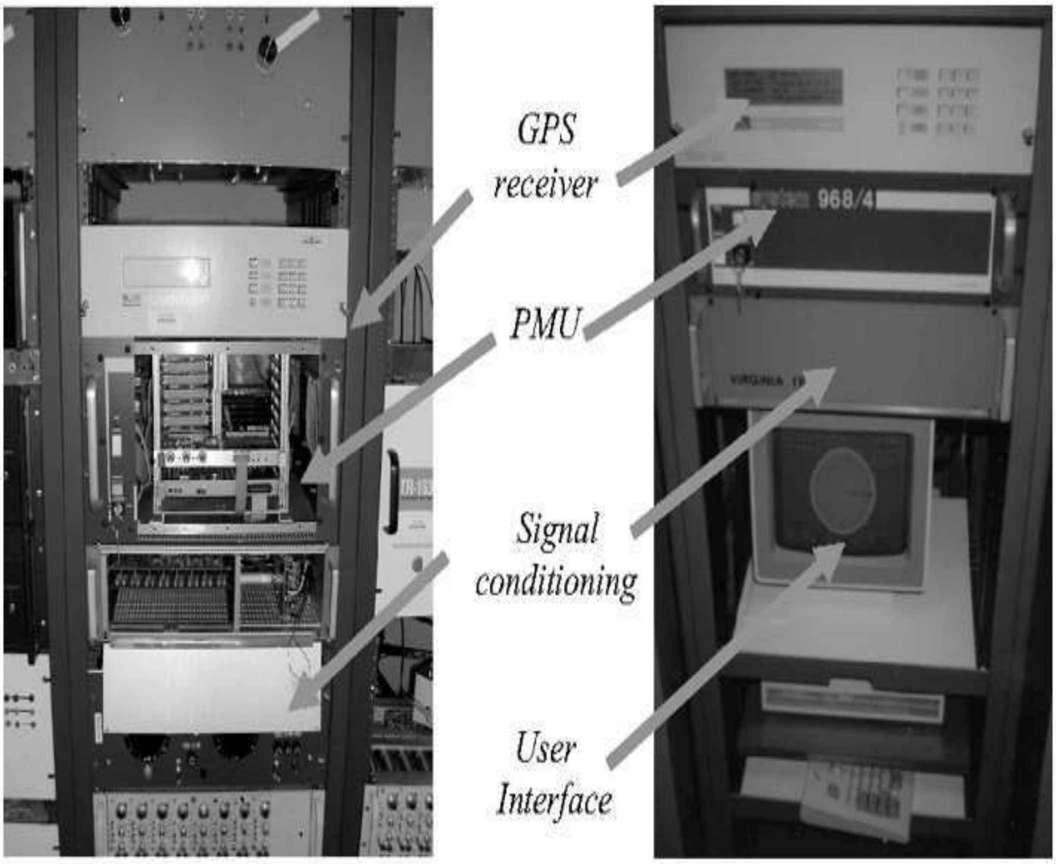

Fig.1.3. First PMUs developed at Virginia Tech [41]

Initially GPS receivers were very costly as they required to keep time detailed clocks made of internal crystal precisely till the following GPS satellite came into use. Therefore, limited number of satellites were deployed.

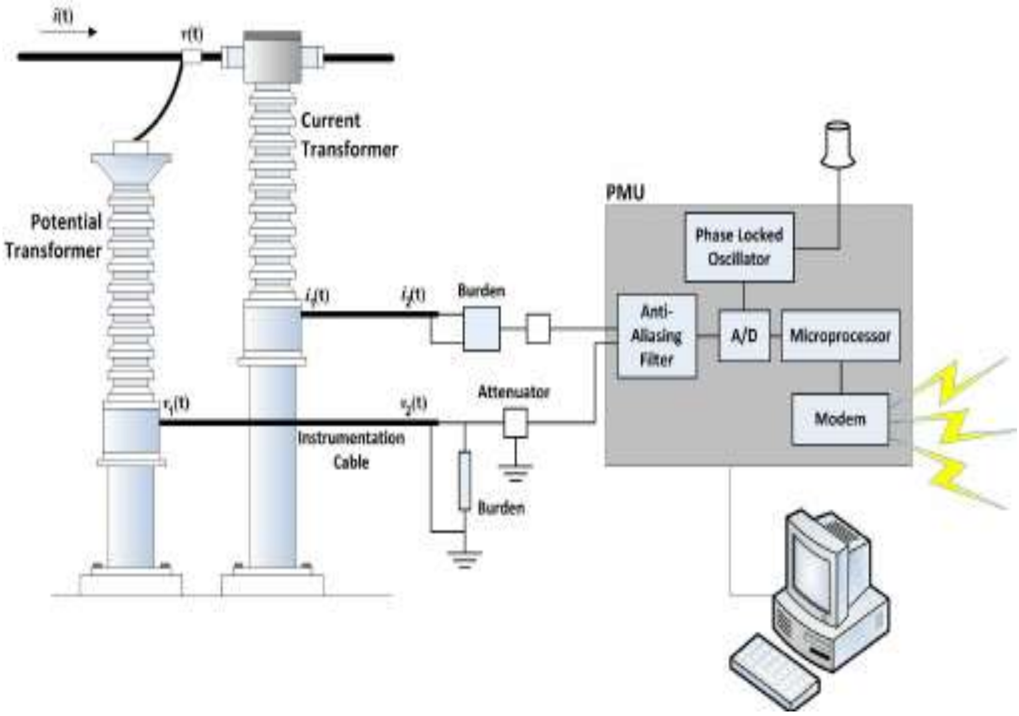

Fig.1.4 Installation of PMU In power system

Today, the complete chip set of GPS receiver could be easily obtained in less amount as compared to early cost.

1.4 Phasor Measurement Unit (PMU)

What is Phasor?

The Phasor is a fundamental electrical quantity which consist of magnitude and phase angle of electrical quantity with respect to reference quantity. The performance of the network is described using Phasors.

A pure sinusoid quantity is given as,

$$x(t) = X_m \cos(\omega t + \theta) \tag{1.1}$$

and its phasor representation is given as,

$$X = (X_m/\sqrt{2}\,)e_{j}\phi \qquad (1.2)$$

Where,

Xm is the magnitude of the sinusoidal waveform,

ω = 2πf, f is the frequency,

ϕ is the angular starting point for the waveform.

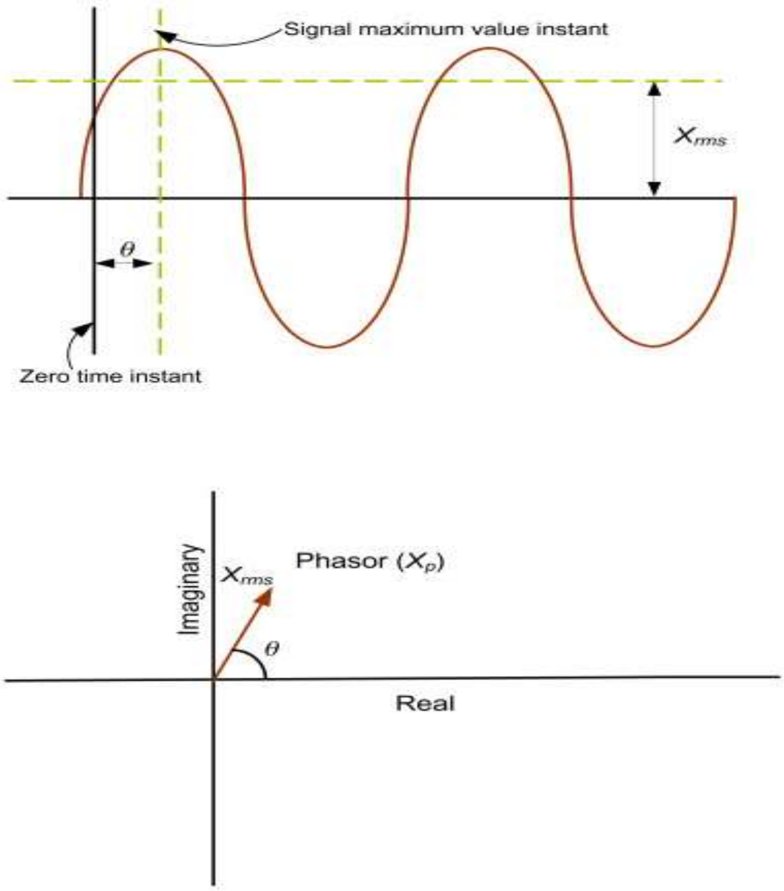

Fig 1.5. A sinusoid and its representation as a phasor

In the Fig. 1.5, the peak of the sinusoidal waveform is defined as the magnitude of the signal and the phase angle is defined as the sinusoidal distance peak of signal and the time reference (t = 0) distance difference.

Practically, the obtained signals are not pure sinusoid they consist of number of different frequencies which makes the signal corrupted. Therefore, the PMUs are synchronized with highly accurate GPS timeclock which provides the standard phase to all the PMU's installed in substations.

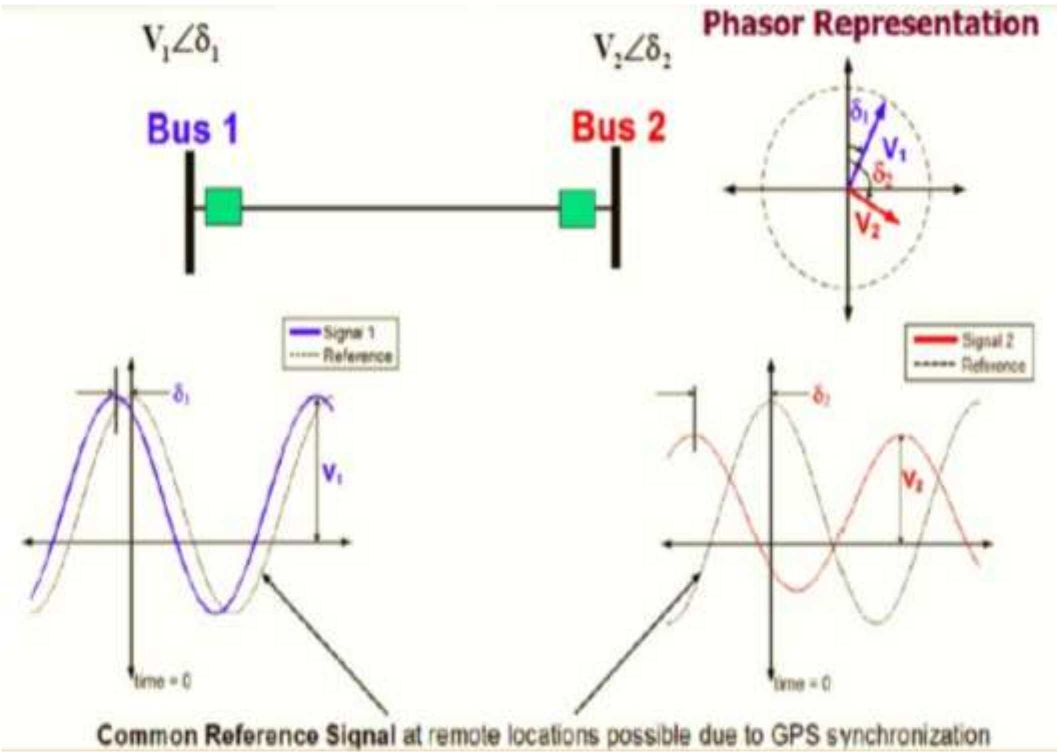

Fig.1.6 Data received by PMU

1.5 FLAWS IN CURRENTLY DEVELOPED PMUS

The available commercial PMUs in the market are very expensive and having guarded copyright limitations. The PMU schematics are not easily available due to company policies. The algorithms are secured by PMU copyright laws which includes the actual information of how exactly PMU works, how the measuring device can measure the phasors of voltage and current, what methodology applies to it and what algorithm it follows. Hence, these commercial PMUs are not allowed to use for educational and research purposes.

An open hardware platform is required to meet the desire requirements of the client. In the past, the development of low-cost PMU hardware platform might be very costly but presently, the availability of advanced, high performance and low-cost micro-controller platforms gives many opportunities to developed the desired open PMU hardware platform. For research or educational purposes, an open-source PMU has been manufactured that is very cost effective.

An open-source PMU has been developed using LabVIEW platform. The Open-Source PMU follows the IEEE (Institute of Electrical and Electronics Engineers) standards. In KTH Royal Institute of Technology, the Norwegian transmission system operator (Statnett SF) works with smarts lab and developed a software which provides toolkit for synchro-phasor applications.

1.6 STATE ESTIMATION USING PHASOR MEASUREMENTS.

Though, a measurement system of the state vector that is based on the phasor is a dependable method for the old-style-state-estimators, it has been known in many such cases, one cannot give the PMU-measurements in enough quantity for the accomplishment of the goal. It is found that the phasor measurements add to another measurements in enough quantity, correctness of the state-estimate has been enhanced. So, the diverse techniques have been adopted for the inclusion of phasor-measurements in the set of the old-style-measurement. A straightforward approach is to append the phasor measurements of the voltages as well as currents as the extra measurements to the old-style measurement set. The state-estimator as the outcome has been nonlinear as well as needs prominent changes in the original EMS-software. Another approach is leaving the software for the old-style-stat-estimation in its place but by the incorporation of phasor-measurements as well as the outcomes of old-style-state-estimator in the linear estimator which is being post-processed.

In this work, we study a different methodology to calculate the state Jacobian matrix as well as the state matrix of dynamic system 'A' without knowing the values of system parameters of the implicit model of the system which are important to estimate the matrix by utilizing algebraic properties withdraw through the real- time series of Phasor Measurement Unit estimations of phasors of voltages and current.

In this work, we assumed that all the generator buses have available PMUs, by Utilizing the measurements extracted from these PMUs figured rotor angles as well as rotor speeds [10]-[15] and the designed dynamic system are energized by stochastic load discrepancies [15] [16]-[18]. This method uses the Lyapunov equation [19].

[20] to linearize the system equations and then Covariance matrices is calculated but they depend on system parameter like Emf of the generating unit therefore sample covariance matrix is estimated using the real time data of rotor angle and rotor speed. By using Covariance matrix of PMU based measurements, the dynamic state Jacobian matrix is computed assuming that generator moment of inertia is known. This technique is not completely based on measurement as we have to accept the data of generator moment of inertia M which is generally known at the same time, above all, we need not require any data of the system

model like system parameters and network topology. To estimate the entire dynamic system state matrix A requires the information of generator damping coefficients D.

If in any case, the damping D of generator is not known or unsure, then this proposed method also build up a method for calculation of damping parameter (D), but this requires information of the system model like variances of load variations and electromotive force of generator (emf), while all this information is not essential for calculation of the Jacobian matrix.

The guesstimate of dynamic state Jacobian matrix using the anticipated method which is based on PMU capacities have various applications. This matrix can be utilized for the purpose of model validation. By making comparison between the calculated dynamic state Jacobian matrix using assumed system model and the estimated dynamic state Jacobian matrix utilizing the PMU based proposed method, any undetected changes in the system model can be distinguished. Also, the approach of calculating damping D of generator using proposed method can be utilized to approve the assumed the Damping D values of the assumed system model connected generators. There are some different applications investigated by researchers in [21]-[23].

In this work, utilizing the estimated dynamic state system matrix the critical eigenvalues are evaluated that are the right most points of the eigenvalue plots which provides the good information of the proximity of instability of the designed system [24]. The estimated right as well the left eigenvectors of the perilous eigenvalues may additionally be assessed to anticipate the retort of the system as well as accordingly designed the emergency control actions [22] [25]. Fig.1.1 shows the complete architecture of the thesis work.

1.7 WLS State Estimation

Increasing demand of electricity causes increase in size of power grid. The wide generating system, large and extensive transmission network requires high level of power system security assurance. With large and complex power system it is difficult to detect any faults or unwanted activities which sometimes may cause serious system failure. The main objective of our power system is to supply reliable and continuous power to all the consumers without any interruption. To achieve this objective there is a requirement of advanced and intelligent power system which depends on the real time information.

Traditionally, the measuring units installed at substations provides both analog and digital information which includes information of power flow, frequency and circuit breaker status and then send to load center using control and analyzing units such as Supervisory Control And Data Acquisition System (SCADA) or Energy Management System (EMS). The limitation of EMS and SCADA is the estimation of phase angle difference between two substations is done using the available data and many times also calculated offline which leads to inaccuracies. The deployment of Wide Area Measurement System (WAMS) advanced technologies gives opportunity to avoid these problems [1].

The Phasor measurement units (PMUs) measures both magnitude and phase angle of the current and voltage, this information is analysed for keeping an eye on the conditions of power network. In transmission lines the flow of active power is directly proportionate to difference of sine angle at the two terminals of the line between voltages. Hence, angle difference information of voltage between two terminals is very important factor to monitor and control purposes in power system [4].

The expanding development of distributed energy resources in the power system requires highly intelligent systems for accurately monitoring and control of power flow purposed. Before, these resources power is flowing uni-directional manner from generating station to consumers, but now by using renewable sources which can install anywhere easily such as solar PV, customers can generate their own power. This causes change into distribution, the system now becomes bidirectional i.e, generated power can flow in both directions. With this change in the power system, transmission and distribution systems need to be continuously monitored by utilizing advanced technologies, for example, – PMUs and μPMUs.

Initially, the operating company generates the electrical power and feed it to power grid, from where it is transferred to consumers simply i.e, there is only one side power source. Presently, Consumers are generating their won power using solar PV panels, wind turbines etc., and to earn money they sell the power to the electric grid or feeding electric power to the grid back. Due to this procedure, voltage and current must be estimated and managed so as to guarantee the quality and standard of the power feeding to grid by customers through meters, for example, phase synchronicity, frequency and voltage.

Various techniques are suggested for the integration of the phasor measurements to classical WLS algorithm. Most of the working state estimators in the contemporary control centers have been bought as a feature for large software package that belongs to EMS role for controlling the center computer. This has been considered improbable that the state estimation software can accommodate the phasor V as well as I measurements in the input set lest they have been transformed in the corresponding P as well as Q measurements. One of best and efficient methods has been extra phasor measurements via a step that is being post processed.

Synchro phasor technology and the PMU device is introduced in the structure of modern electric power system, due to which the system major achievement of power networks like dependability, steadiness and regulatability has arrived at greater improved levels. The accompanying sections have, different applications andfundamental advantages of enforcing in power systems the PMUs shall be spoken to.

1.8 WIDE AREA MONITORING SYSTEM (WAMS)

WAMS is an advanced idea to retaining Active steadiness of the transmission system, primarily created on Phasor Measurement Unit. Presently, numerous nations are anticipatory enforcing their power grid with WAMS.

In contrast to past observing system, WAMS is built dependent on time-synchronized estimation, novel processing innovation, and correspondence innovation to accomplish the synchronization of information procurement and actual footage from device and system in appropriated areas.

The continuous actual information being conveyed to the central station of control wherein system administrator shall have the option to quantify and examine the information anytime and at power system network's every point.

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The continuous actual information shall be conveyed to the central control station wherein system administrator shall have the option to quantify and examine the information anytime and at power system network's every point.

The advantages of Phasor Measurement Unit (PMU) over Supervisory Control and Data Acquisition System (SCADA) is shown in Table 1.1 as followings,

Table 1.1. Comparison between PMU and SCADA

SCADA	**PMU**
Analog Measurement	Digital Measurement
2 to 4 samples per cycle (resolution) is possible in SCADA SYSTEM	Up to 60 samples per cycle (resolution) is possible in PMU
Phase angles cannot be measured (No common reference. Magnitudes provide "half" the information)	Phase angles can be measured (GPS UTC common time/phase reference) (Better Monitoring of States)
Local Monitoring	Wide Area Monitoring
Steady State (Observability)	Dynamic (Observability)

Fig.1.8 Station Phasor Measurement Unit

Wide area monitoring system has extra practical benefits over orthodox structures and can slowly substitute the conventional supervisory control and data acquisition (SCADA) system for steady-state observations. Additionally, wide area monitoring system can examine the oscillation present in the network, display and could analyse the static stability of the network, carry out the timestamp for fault localization and stumble on the voltage instability of the network. To this point it is considered to be the most advanced approach to stumble on and keep away from extensive blackout. The PMUs are installed optimally in the power system, the controllers can apprehend abnormal events inside the electricity network via the computing in the network control center.

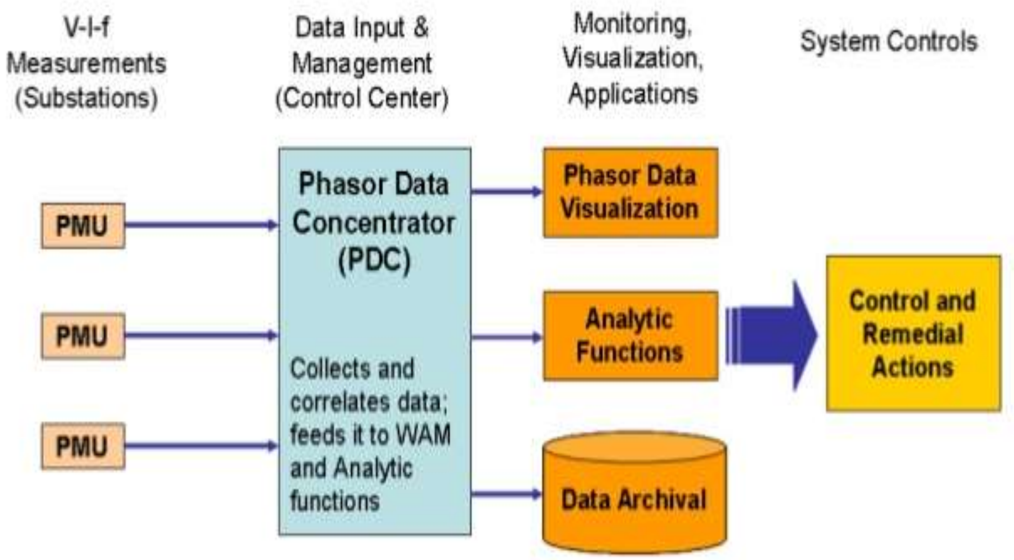


Fig.1.9 Wide Area Measurement System with installed PMU

1.9 THESIS ORGANIZATION

The outlines of this thesis are as follows:

Chapter1: The basic introduction of Study of proposed method based on PMU measurements for estimation of Dynamic state Jacobian Matrix and Dynamic system state matrix.

Chapter 2: This section gives the brief description/reviews of the quality work done by different researchers in the history of PMU's and other related topics.

Chapter 3: The development of laboratory setup of PMU architecture on MATLAB platform is explained. PMU connection tester and power world simulation has been done in this chapter.

Chapter 4: In this chapter, the results and plots are obtained using proposed method and system-based method, using that errors are estimated and plot is shown. The simulation results of bus system of IEEE-14 as well as IEEE-30 Bus system have been shown in this chapter.

Chapter 5: This chapter includes the conclusion and the future work on this work

CHAPTER 2

LITERATURE REVIEW

The PSEE issue has been idea of a lot of works since late-sixties. Prof Schweppe who is a leading researcher in Power Systems Engineering Group at MIT, gave the first proposal for the growth of the idea for the state-estimation for the power-systems-monitoring. Since then, idea has been addressed for attention of a lot of researchers from the universities, research-centers as well as the industries.

- In 2006, J. S. Thorp, Ming Zhou, A. G. Phadke and Virgilio A. Centeno, *[*2] revised the method for integrating phasor measurements with the traditional state-estimation-system. A direct application for the theory of state estimation by attaching the measurements for the phasor of the currents as well as the voltages as additional measurements to the old-style measurements that is taken in usage in most of the EMS state-estimators have been given review of. The state estimator as the outcome is again nonlinear as well as needs prominent changes in the existing EMS software. They have given another approach, leaving the old-style-state-estimation software in the place, as well as deliberates an alternative technique for the incorporation of phasor- measurements as well as the outcomes of the old-style-state-estimator in the linear estimator which is being post-processed. They gave the conclusion that, second method needs few computation techniques as well as it provides results which are more precise and aren't requiring any changes in the EMS software.

- A. G. Phadke, Ming Zhou J. S. Thorp and Virgilio A. Centeno, and "*An*

Alternative for Including Phasor Measurements in State Estimators," IEEE Trans. Power Syst., vol. 21, no. 4, pp. 1930–1937, Nov. 2006. The growing utilization of the phasor measurement units which are synchronized in real-time. It is important to take the applications of the measurements in brief into consideration. A natural application of the measurements is in area of the state estimation. Direct application of state-estimation-theory indulgences measurements for phasor of the currents as well as the voltages as the extra measurements to be attached to the old-style measurements are currently being used during the EMS state-estimators. State estimator in the outcome needs important changes into the original EMS software as well as, it is nonlinear again. This report suggests an tactic, that leaves the old-style software for the state estimation, as well as it deliberates a novel technique for the incorporation of measurements of phasor as well as the outcome of the old-style state estimator in a linear estimator that is being post-processed. This report represents the fundamental theory as well as verifies the simulations of two substitute strategies. It is being shown that, novel method gives the same outcome as of the state estimator that is nonlinear as well as it doesn't needs much changes in existing EMS software.

- Gómez Expósito, Antonio presented "Power system state estimation: implementation as well as the theory" in New York. In this paper they have explained the strategies that are used in the state estimation of the electric power systems, this text gives a broad overview of the power system operation as well as checks on role of the state estimators in the general management of energy. It utilizes plenty of instances, tables, models as well as the guidelines for the examination of new facets of the state estimation, testing the observability of the network as well as the techniques for assuring the computational efficiency. It contains a lot of tutorials that help in the analyzation of the issues, posed by inclusive current measurements in its existing state estimators as well as it illustrates the practical solutions for these tasks. Two expert researchers gave the report in the field that Power System State Estimation, precise detailed topics which weren't ever covered in so much of depth by anyone, inclusion of the novel robust state estimation techniques, approximation of the parameters as well as the topology errors, as well as uses the ampere measurements for the state estimation. It even gives introduction to several methods as well as computational problems which are involved in implementation and the formulation of the WLS approach, it shows statistical tests for detecting and identifying the bad data in the system measurements. It also reveals the substitute topological as well as the numerical formulations of network observability issue.

- R.F. Nuqui, A.G. Phadke presented "Hybrid Linear State Estimation Utilizing Synchronized Phasor Measurements." in Power Tech, 2007 IEEE Lausanne. We give a model that helps to enhance the SE of the power system that has phasor measurements that are synchronized on the basis of two-pass approach. Firstly, the pass contains execution of the old-style state estimation issue with no phasor-measurements. State vector solution has been attached using the second pass with the vector of the phasor measurements as well as helps to solve linear state estimation issue of the rectangular variables. This model has been considered non-invasive as phasor measurements haven't taken in integration with old-style state estimation inputs of the real/reactive power as well as the magnitudes of the voltage. Outcomes of test reflect how effective the technique was, that was proposed, of the phasor integration in enhancing the state estimator solution quality.

- Fang Chen, Zhiyuan Pan,Li Han and Xueshan Han“*State Estimation Model and Algorithm Including PMU*”, Restructuring as well as Power Technologies, Electric Utility Deregulation along with the Third International Conference, April 2008, pp - 1097 – 1102. Because of wide application of PMU in the power system, the old-style power system state estimation undergoes a vital change. In the following report, old-style state estimator is expected as functioning typically when the PMU data is not present. Further, with the installation of the PMU in the power system, the report helps in exploring the considerable role of the PMU in the power system state estimation. Firstly, deliberates variance in between the PMU measurement as well as the SCADA measurement that helps to explain the impact of PMU on the old-style power system state estimation. Further, assuming correct value to be obtained from the PMU, it excerpts simplicity of old-style power system state estimation with the SCADA data only, as well as suggests the condensed power system state estimation model, like the old-style ones. It reflects subsequent modifications to handle the bad data recognition, issues of observability as well as accuracy in the estimation, and solution algorithm of the power system state estimation online. It presents the PMU data gives direct measurement of the state that helps in simplification of the old-style state estimator as well as it doesn’t any kind of modification in the existing state estimator. The outcome of the simulation for IEEE 13 bus system validates the rationality of report.

- Yunzhi Cheng, Bei Gou and Xiao Hu “A Novel State Estimation With The Use of Synchronized Phasor Measurements”, in the ISCAS 2008. IEEE International Symposium on 18-21 May 2008, pp. 2817 – 2820. WLS state estimator which is formulated with the use of the conventional measurements and is non-linear in the power industry is most commonly used such as, line flow as well as the injection measurements. WLS state estimation has a concern for the computational burden while the integration of the PMU measurements. The state estimator that is distributed are capable of solving this issue of integration, has been suggested for this purpose. Though, inconsistency in between the integrated state estimator as well as the distributed state estimator exists. The report suggests an idea for the formulation of the state estimation in novel method that is capable for the formulating it together with the old-style measurements and the PMU measurements effortlessly as well as resourcefully. The suggested estimator has been checked on the IEEE 118-bus system as well as the ERCOT 5514- bus system.

- Zivanovic, R and Cairns, C, "*Implementation of PMU technology in state estimation: an overview*." IEEE AFRICON 4th, Vol. 2, Sept. 1996, pp - 1006 – 1011 presented diverse alternatives for implementing the PMU method in power system static state estimation. Several alternatives in using the PMU measurements in power system state estimation have been shown as well as checked. In this simulation study that is performed on the IEEE 14-bus test system, it has been found that the PMU measurements help in increasing the confidence in the outcome of the state estimation. The report also examines the probability to use a novel linear state estimation algorithm that is parallel with the current nonlinear estimator. It has been shown that the linear estimator has firm merits. This issue having varying angle references of estimator as well as the angle measurements has been examined as well as all of the probable solutions have been presented.

- Roy Moxley PE, Chuck Petras PE, Chris Anderson, and Ken Fodero II, "*Display and Analysis of Transcontinental Syncrhophasors*", Schweitzer Engineering Laboratories, Technical Papers, 2004. The report briefs about the the implementing methods for project that is designed for the accomplishment of four key goals: 1. To send synchro phasor data transversely in a wide-area network (WAN). 2. Aligning as well as correlating data from various sites. 3. Displaying as well as updating data in the real time for showing the relationships among the sites. 4. Taking a record of data along with using some of the example data which we provide with some observations about making the tool useful. Some issues that were encountered as well as overcame from, had varying communications latencies from loss of communications, differing locations, data-buffer overflow, extreme network traffic as well as the graphic display for more than one user.

CHAPTER 3

MODELLING OF WLS STATE ESTIMATION USING PHASOR MEASUREMENTS

In the technique phasor measurements have been added into state estimation via a step that is being post processed. Following technique has two processes. First procedure attains state vector in the polar co-ordinates from the predictable measurements with the use of the WLS state estimation algorithm. Secondly, state vector from the WLS state estimation, that was the first process, along with the vector for measurements from the phasor have been presented in rectangular coordinates for the formation of a novel measurement set as well as for the formation of a linear state approximation process in which the iterative techniques aren't needed.

3.1 WLS STATE ESTIMATION MODELLING

Suppose that set of measurements 1z that consists of a non-synchronized data of the active as well as the reactive power flowing into the network elements, voltage magnitudes at buses as well as the bus injections. It has been supposed that a poor data has eradicated from the measurement set with use of casual techniques. Measurements with nonlinear role of state vector *x* that is a set of the voltages of the positive sequence at all of network buses.

$$z_1 = h_1(x) + e_1 \tag{3.1}$$

In which the h_1 has been the nonlinear role of state vector x that has been presented in the polar coordinates as well as the e_1 in error of the measurement vector that has a covariance matrix R_1.

The Jacobian matrix, H_1 given by

$$H_1(x) = \frac{\partial h_1(x)}{\partial x} \tag{3.2}$$

The Gain matrix, $G_1(x^k)$ given by

$$G_1(x^k) = \left[{H_1}^T(x_k){R_1}^{-1}H_1(x_k)\right]^{-1} \tag{3.3}$$

The error covariance matrix of approximation x is given by

$$Con([x]) = [{H_1}^T {R_1}^{-1} H_1] \tag{3.4}$$

And the state vector is obtained from,

$$[x^{k+1}] = [x^k] + [G_1(x^k)]^{-1}\, G_1(x^k)\left[{H_1}^T {R_1}^{-1}\right][z_1 - h_1(x^k)] \tag{1.5}$$

This is a reiterative technique as well as the reiterations that continues till one of the two conditions has been satisfied. First condition will be the extreme number of the permissible reiterations has been surpassed. On the other hand, second condition is that the modification in the state variables has fallen in an tolerable range.

$$max|\triangle\, x^k| \leq \mathcal{E}$$

The state vector obtained from equation 3.5 is in the polar co-ordinates which is to be transformed into the co-ordinates that are rectangular using a rotation matrix given by,

$$K = \begin{bmatrix} \cos\delta_1 & 0 & 0 & -|E_1|\sin\delta_1 & 0 & 0 \\ 0 & \cos\delta_2 & 0 & 0 & -|E_2|\sin\delta_2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ \sin\delta_1 & 0 & 0 & |E_1|\sin\delta_1 & 0 & 0 \\ 0 & \sin\delta_2 & 0 & 0 & |E_2|\cos\delta_2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{3.6}$$

Where, $|E_1|, |E_2| \dots . |E_n|$ are magnitudes and $|\delta_1|, |\delta_2|, \dots . . |\delta_n|$ are respective angles.

And the converted state vector becomes,

$$\begin{bmatrix} V_R \\ V_I \end{bmatrix}_{SE} = [K][x] \quad (3.7)$$

Let a group of the voltage having positive sequence as well as the current phasors be, z_2 . Error measurement covariance matrix of phasor measurements has been supposed of being, R_2. Both measurement phasors as well as the error covariance matrix are in polar coordinates, and hence, they must be transformed to rectangular coordinates.

$$\begin{bmatrix} \begin{bmatrix} V_R \\ V_I \end{bmatrix}_{PM} \\ \begin{bmatrix} I_R \\ I_I \end{bmatrix}_{PM} \end{bmatrix} = [K] \begin{bmatrix} \triangle V_{polar} \\ \triangle I_{polar} \end{bmatrix} \quad (3.8)$$

$$R_2' = K . R_2 . K^T \quad (3.9)$$

The novel measurement set M is consists of the following:

1. The direct state output from WLS, (Equation 3.7)
2. PMU voltage measurements; (Equation 3.8)
3. PMU current measurements. (Equation 3.8)

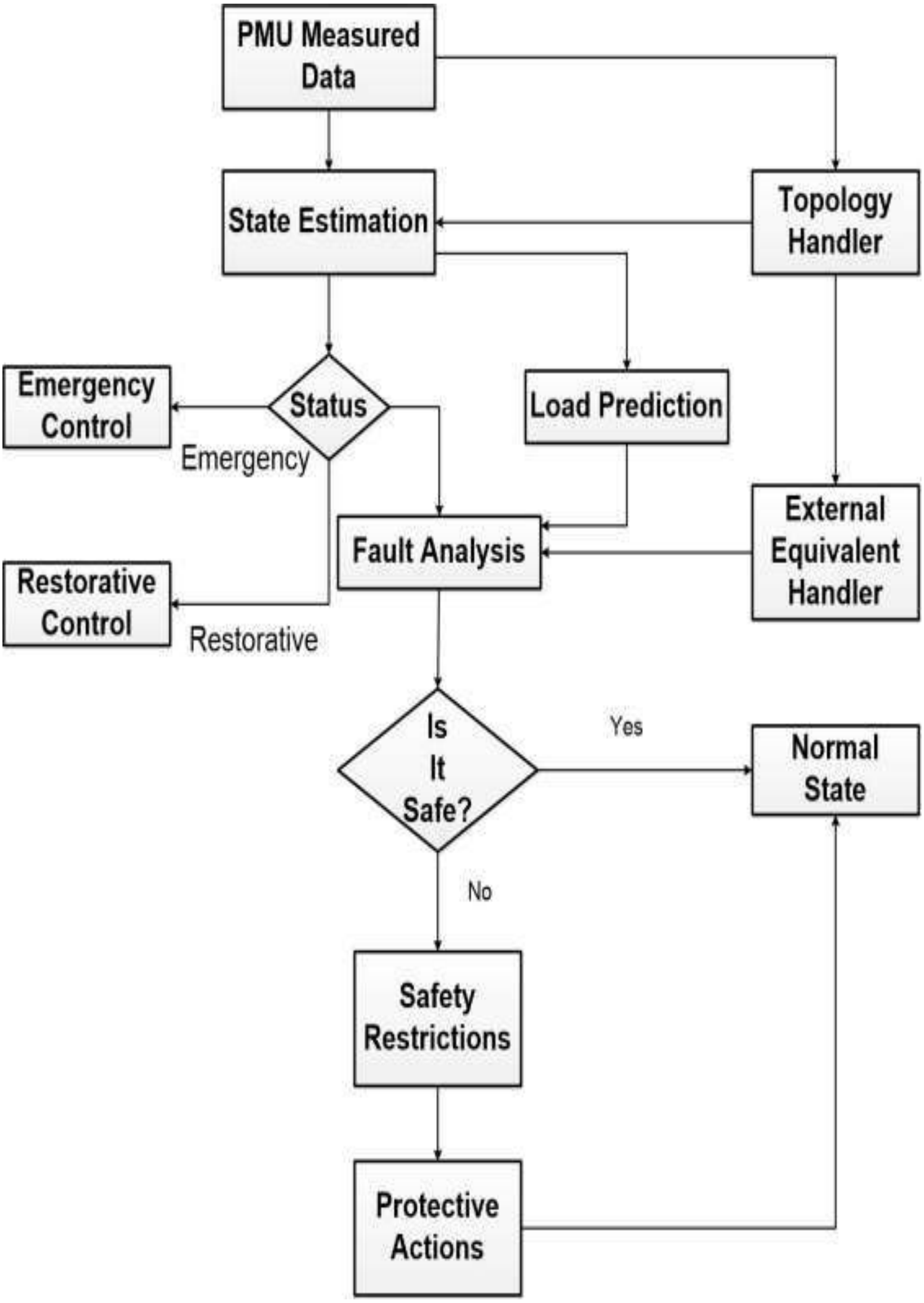


Fig.3.1 Flow chart of State Estimation based on PMUs

The new measurement model can be written as:

$$M = \begin{bmatrix} \begin{bmatrix} V_R \\ V_I \end{bmatrix}_{SE} \\ \begin{bmatrix} V_R \\ V_I \end{bmatrix}_{PM} \\ \begin{bmatrix} I_R \\ I_I \end{bmatrix}_{PM} \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \\ H_{31} & H_{32} \\ H_{41} & H_{42} \\ H_{51} & H_{52} \\ H_{61} & H_{62} \end{bmatrix} \begin{bmatrix} V_R \\ V_I \end{bmatrix} + \begin{bmatrix} e_{VR}^{SE} \\ e_{VI}^{SE} \\ e_{VR}^{PM} \\ e_{VI}^{PM} \\ e_{IR}^{PM} \\ e_{II}^{PM} \end{bmatrix} \tag{3.10}$$

Equation 9 can be written as:

$$[M] = [H'].[V] + [e]$$

in which subscript of the R and I reflect real as well as the hypothetical features of current measurements as well as voltages. Also, SE and PM show that the approximated value of the old-style state estimator as well as the phasor measurements.

State estimation could be resolved with no reiteration directly with the use of the following Weighted least square solution of the Equation (3.10) as presented:

$$V = [G']^{-1}.[H'][R']^{-1}.M \tag{3.11}$$

Where $[G']$ is the new gain matrix given by,

$$[G'] = [H']^T[R']^{-1}[H']$$

$[R']$ is the new covariance matrix.

3.2 ELEMENTS OF NEW JACOBIAN MATRIX $[\boldsymbol{H'}]$

These sub matrices of coefficient matrix that follow from structure of measurement model:

$$H_{11} = I \qquad H_{12} = 0$$

$$H_{21} = 0 \qquad H_{11} = I$$

in which, I is an $N \times N$ Identity matrix and 0 is the $N \times N$ Null matrix as well as that N is number of the buses in system.

H_{31} is a $P \times N$ matrix, P denotes quantity of the PMUs. Every row i resembles the PMU i as well as it is having all zeros except one at jth column equivalent with the V_{Ri}^{pmu} index in state vector.

$$H_{31i} = [0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 1 \quad 0 \quad 0]$$

$$H_{32} = 0_{(P\times N)}$$

$$H_{41} = 0_{(P\times N)}$$

H_{31} is a $P \times N$ matrix, P denotes quantity of the PMUs. Every row, i resembles the PMU i as well as it is having all zeros but except one at jth column equivalent to V_{Ri}^{pmu} index in state vector.

$$H_{42i} = [0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 1 \quad 0 \quad 0]$$

Now, we will grow the components of the H' equivalent to PMU current measurements. It is shown that π -model of the communication division in the

Fig 3.2. The current I_{pq} has been presented:

$$I_{pq} = V_p Y_{po} + \left(V_p - V_q\right) Y_{pq}$$

Transforming everything in the rectangular element yields:

$$\begin{bmatrix} I_{pq\,R} \\ I_{pq\,I} \end{bmatrix} = \begin{bmatrix} \left(G + G_{po}\right) & -\left(B + B_{po}\right) & -G & B \\ \left(B + B_{po}\right) & \left(G + G_{po}\right) & -B & -G \end{bmatrix} \begin{bmatrix} V_{pR} \\ V_{pI} \\ V_{qR} \\ V_{qI} \end{bmatrix}$$

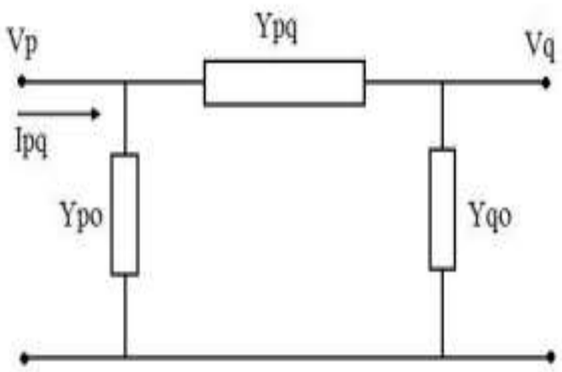


Fig 3.2. π Model of Transition Branch

Therefore, H_{51} is an $L \times N$ matrix in which L denotes number of the PMU current measurements whose components would be of pure conductance while the H_{52} is an $L \times N$ matrix having pure components.

In contrast, H_{61} has been an $L \times N$ matrix that has pure susceptance components as well as ones having $L \times N$ matrix H_{62} would be of pure conductance.

3.2.1 COVARIANCE MATRIX ' R

The variations in the meter measurements have been given in the terms of variations or the typical deviations on angle as well as the magnitude. This model needs covariance matrix components that are equivalent to the phasor in the elements in the rectangular shape.
So, following changes are important:

$$\sigma^2_{|V_R|} \approx \sigma^2_{|V|}.cos^2\delta + \sigma^2_{|\delta|}.|V|^2 sin^2\delta$$

$$\sigma^2_{|V_I|} \approx \sigma^2_{|V|}.sin^2\delta + \sigma^2_{|\delta|}.|V|^2 cos^2\delta$$

$$\sigma^2_{|I_R|} \approx \sigma^2_{|I|}.cos^2\phi + \sigma^2_{|\phi|}.|V|^2 sin^2\phi$$

$$\sigma^2_{|I_I|} \approx \sigma^2_{|I|}.sin^2\phi + \sigma^2_{|\phi|}.|V|^2 cos^2\phi$$

In which, δ and ϕ are phasor angle having compound as well as currents. $\sigma_{|V|}$ and $\sigma_{|\delta|}$ from typical state estimator could be assessed from the gain matrix directly to meeting opinion, i.e., R_1' can be obtained from the Equation (3.12) as given below:

$$[R_1{}'] = [K'][H_1^T R_1^{-1} H_1].[K']^T \quad (3.12)$$

where,

$$K' = \begin{bmatrix} \cos\delta_1 & 0 & 0 & -|V_1|\sin\delta_1 & 0 & 0 \\ 0 & \cos\delta_2 & 0 & 0 & -|V_2|\sin\delta_2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ \sin\delta_1 & 0 & 0 & |V_1|\sin\delta_1 & 0 & 0 \\ 0 & \sin\delta_2 & 0 & 0 & |V_2|\cos\delta_2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Thus, the new covariance matrix R' could be derived as:

$$R' = \begin{bmatrix} R'_1 & 0 \\ 0 & R'_2 \end{bmatrix} \tag{3.13}$$

where R'_2 is obtained from the Equation 8.

CHAPTER 4

SIMULATION RESULTS

A simulation has been carried out based on the above state estimation algorithm on IEEE-14 and IEEE-30 bus systems. It is expected to be the solution of the load flow based on the generation of the measurements with the proper measurement-errors and the load flow of the base case taken to be the initial point.

Measurements for old-style-state-estimation containing the active as well as the flow of the reactive power, active as well as the injections of the reactive power, along with the magnitudes of the voltage. The measurements of the Phasor are voltages as well as the currents phasors. Measurements have been spread uniformly across system.

The solution of the load flow has been expected for giving original value of the state-vector and any random number generating system for the addition of the errors to quantities that are measured with the proper typical-deviations have been used. Every PMU is expected to check the bus-voltage as well as the line-currents in all of the lines originating on the bus.

Phasor-angles have been adjusted to conform with the convention that angle of the swing bus is 0°.

4.1 Data for IEEE-14 and IEEE-30 bus system

The input data that is used in the simulation is given in the table 1.2 and 1.3 for the IEEE-14 and IEEE-30 bus system respectively.

Bus	Type	Vsp	Theta	Pgi	Qgi	Pli	Qli	Qmin	Qmax
1	1	1.060	0	0	0	0	0	0	0
2	2	1.045	0	40	42.4	2 1.7	12.7	-40	0
3	2	1.0110	0	0	23.4	94.2	19.0	0	0
4	3	1.0	0	0	0	47.8	-3.9	0	0
5	3	1.0	0	0	0	7.6	1.6	0	0
6	2	1.070	0	0	12.2	11.2	7.5	-6	4
7	3	1.0	0	0	0	0.0	0.0	0	0
8	2	1.090	0	0	17.4	0.0	0.0	-6	4
9	3	1.0	0	0	0	29.5	16.6	0	0
10	3	1.0	0	0	0	9.0	5.8	0	0
11	3	1.0	0	0	0	3.5	1.8	0	0
12	3	1.0	0	0	0	6.101	1.6	0	0
13	3	1.0	0	0	0	13.5	5.8	0	0
14	3	1.0	0	0	0	14.9	5.0	0	0

Table 1.2 Input Bus data for IEEE-14 Bus System

Bus	Type	Vsp	Theta	Pgi	Qgi	Pli	Qli	Qmin	Qmax
1	1	1.06	0	0	0	0	0	0	0
2	2	1.043	0	40	50.0	2 1.7	12.7	-40	50
3	3	1.0	0	0	0	2.4	1.2	0	0
4	3	1.06	0	0	0	7.6	1.6	0	0
5	2	1.021	0	0	37.0	94.2	19.0	-40	40
6	3	1.0	0	0	0	0.0	0.0	0	0
7	3	1.0	0	0	0	22.8	10.9	0	0
8	2	1.01	0	0	37.3	30.0	30.0	-10	40
9	3	1.0	0	0	0	0.0	0.0	0	0
10	3	1.0	0	0	0	5.8	2.0	0	0
11	2	1.082	0	0	16.2	0.0	0.0	-6	24
12	3	1.0	0	0	0	10.2	7.5	0	0
13	2	1.0741	0	0	10.6	0.0	0.0	-6	24
14	3	1.0	0	0	0	6.2	1.6	0	0
15	3	1.0	0	0	0	8.2	2.5	0	0
16	3	1.0	0	0	0	3.5	1.8	0	0
17	3	1.0	0	0	0	9.0	5.8	0	0
18	3	1.0	0	0	0	3.2	0.9	0	0
19	3	1.0	0	0	0	9.5	3.4	0	0
20	3	1.0	0	0	0	2.2	0.7	0	0
21	3	1.0	0	0	0	17.5	10.2	0	0
22	3	1.0	0	0	0	0.0	0.0	0	0
23	3	1.0	0	0	0	3.2	1.6	0	0
24	3	1.0	0	0	0	8.7	6.7	0	0
25	3	1.0	0	0	0	0.0	0.0	0	0
26	3	1.0	0	0	0	3.5	2.3	0	0
27	3	1.0	0	0	0	0.0	0.0	0	0
28	3	1.0	0	0	0	0.0	0.0	0	0
29	3	1.0	0	0	0	2.4	0.9	0	0
30	3	1.0	0	0	0	10.6	1.9	0	0

Table 1.3 Input Bus data for IEEE-30 Bus System

4.2 Results of Bus System for IEEE 14

The results of the newton Raphson load flow analysis of the IEEE-14 and IEEE-30 bus system are presented in the table 1.4 and 1.5 respectively.

Bus No.	V (PU)	Angle (Degree)
1	1.0600	0.0000
2	1.0450	-.98911
3	1.0700	- 12.7492
4	1.032	- 10.2420
5	1.166	-8.7602
6	1.0700	- 14.4469
7	1.0457	- 13.2368
8	1.0800	- 13.2368
9	1.0305	- 14.8202
10	1.0299	- 15.0360
11	1.04671	- 14.85821
12	1.0533	- 15.2973
13	1.0466	- 15.33513
14	1.03193	- 16.07117

Table 1.4 Newton Raphson Load Flow Analysis for IEEE-14 Bus System

Bus No.	V (PU)	Angle (Degree)
1	0.9865	0.0000
2	0.9700	-6.2635
3	0.9474	-8.8420
4	0.9384	-10.903
5	0.9335	-16.493
6	0.9395	-12.997
7	0.9287	-15.0443
8	0.9449	-13.9608
9	0.9667	-16.483
10	0.9472	-18.3445
11	1.0093	-16.483
12	0.9746	-17.698

13	0.9954	-17.6908
14	0.9559	-18.737
15	0.9492	-18.7299
16	0.955	-18.2800
17	0.9442	-18.5724
18	0.9352	-19.495
19	0.9306	-19.6063
20	0.9339	-19.3582
21	0.9328	-18.982
22	0.9372	-18.723
23	0.93321	-18.9957
24	0.9232	-19.0788
25	0.9270	-18.7784
26	0.9070	-19.2593
27	0.9395	-18.2962
28	0.9398	-13.7920
29	0.9 177	-19.7604
30	0.905	-20.8272

Table 1.5 Newton Raphson Load Flow Analysis for IEEE-30 Bus System

The results of the simulation have been presented on the following tables and figures.

- Fig 4.1 and 4.2 shows voltage angle estimation errors and voltage magnitude estimation error with no use of the phasor measurements (PMU) on IEEE-14 bus system. The output data for the same is presented in table 1.6.

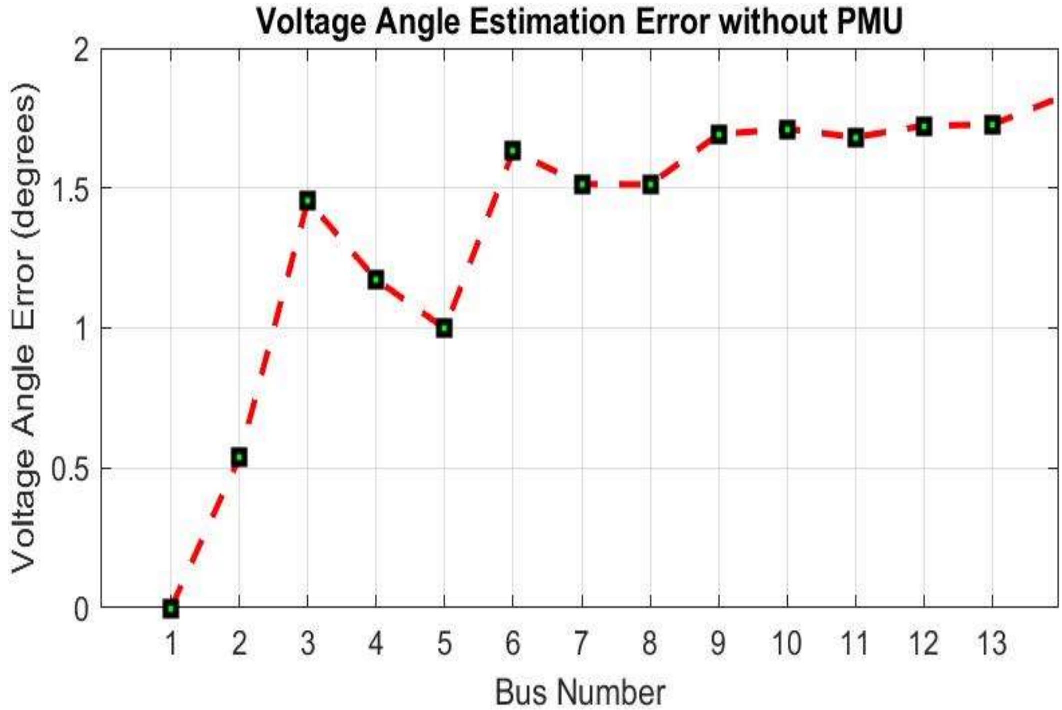


Fig 4.1. Voltage Angle Estimation Error without PMU for IEEE 14 Bus System

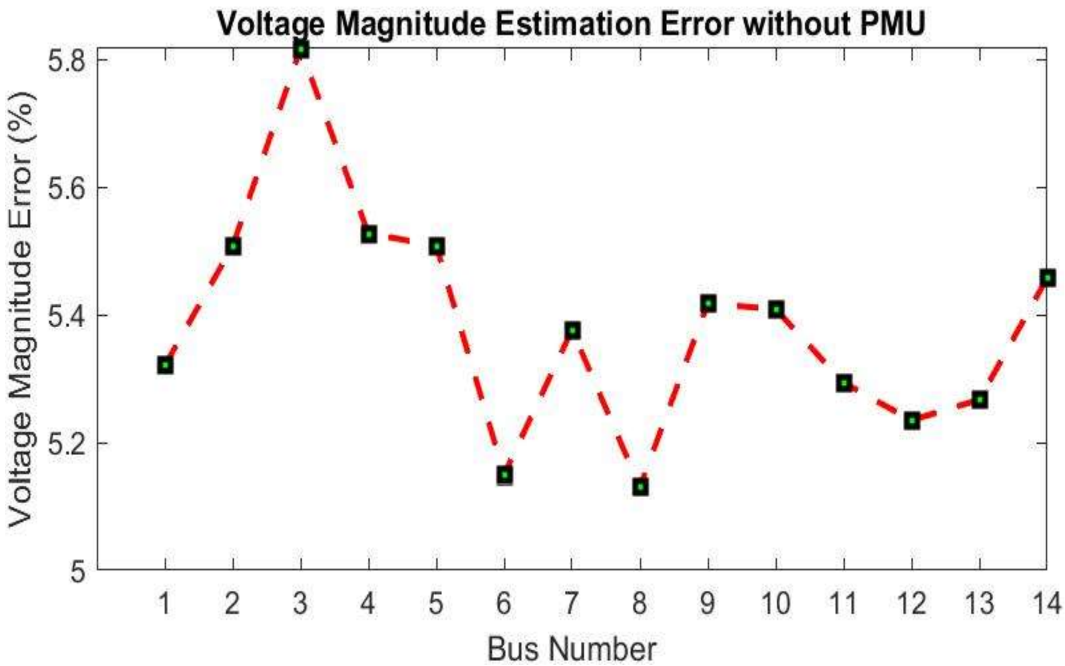


Fig 4.2. Voltage Magnitude Estimation Error (%) without PMU for IEEE 14 Bus System

Bus No.	V (PU)	Angle (Degree)
1	1.0068	0.0000
2	0.9899	-5.5265
3	0.95218	- 14.2039
4	0.9579	- 11.5
5	0.96215	-9.7583
6	1.085	- 16.0798
7	0.9929	- 14.75610
8	1.0287	- 14.7500
9	0.9763	- 16.5125
10	0.9758	- 16.7476
1 1	0.9932	- 16.5397
12	1.0009	- 17.0203
13	0.9940	- 17.0583
14	0.9647	- 17.8967

Table 1.6 State Estimation without PMUs for IEEE-14 Bus System

- Fig 4.3 and fig 4.4 shows voltage angle estimation errors and voltage magnitude estimation errors respectively using phasor measurements (PMU) on IEEE-14 bus system. The output data of which is shown in table 1.7.

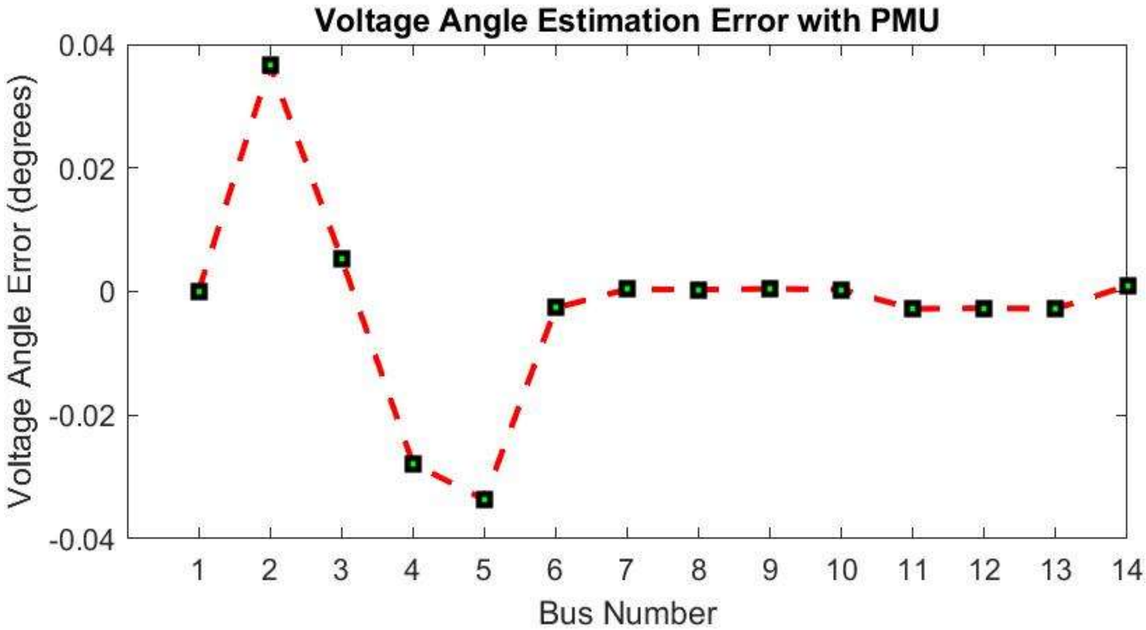


Fig 4.3. Voltage Angle Estimation Error with PMU for IEEE 14 Bus System

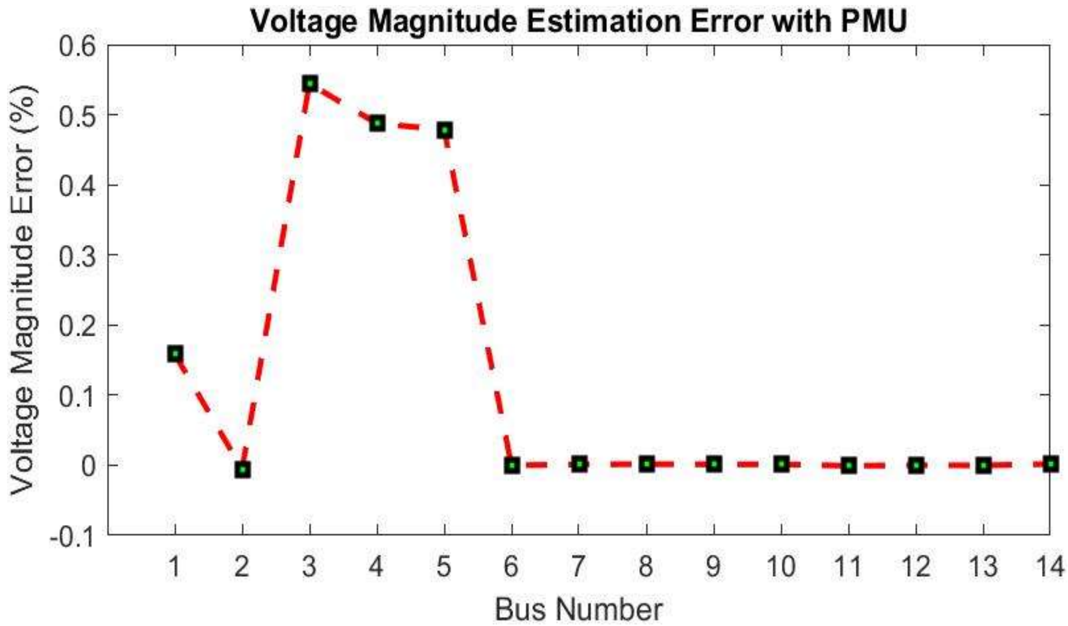


Fig 4.4. Voltage Magnitude Estimation Error with PMU for IEEE 14 Bus System

Bus No.	V (PU)	Angle (Degree)
1	1.0584	0.0000
2	1.0455	-5.0258
3	1.0046	-12.7546
4	1.0083	-10.242
5	1.02318	-8.7264
6	1.0700	-14.4443
7	1.0457	-13.2372
8	1.0800	-13.23761
9	1.0305	-14.8206
10	1.0299	-15.0364
1 1	1.04641	-14.8553
12	1.0533	-15.2946
13	1.0466	-15.3285
14	1.0 193	-16.0727

Table 1.7 State Estimation with PMUs for IEEE-14 Bus System

4.3 Results of Bus System for IEEE 30

- Fig 4.5 and fig. 4.6 shows voltage angle estimation errors and voltage magnitude estimation errors respectively, with no use of the phasor measurements (PMU) on IEEE-30 bus system. The output data for the same is presented in table 1.8.

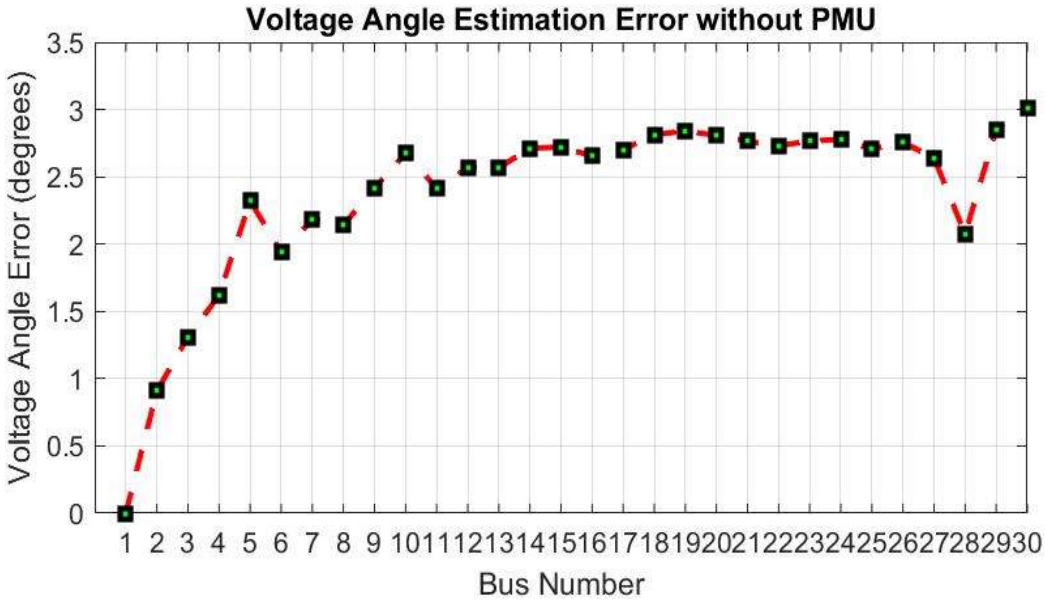


Fig 4.5. Voltage Angle Estimation Error without PMU for IEEE-30 Bus System

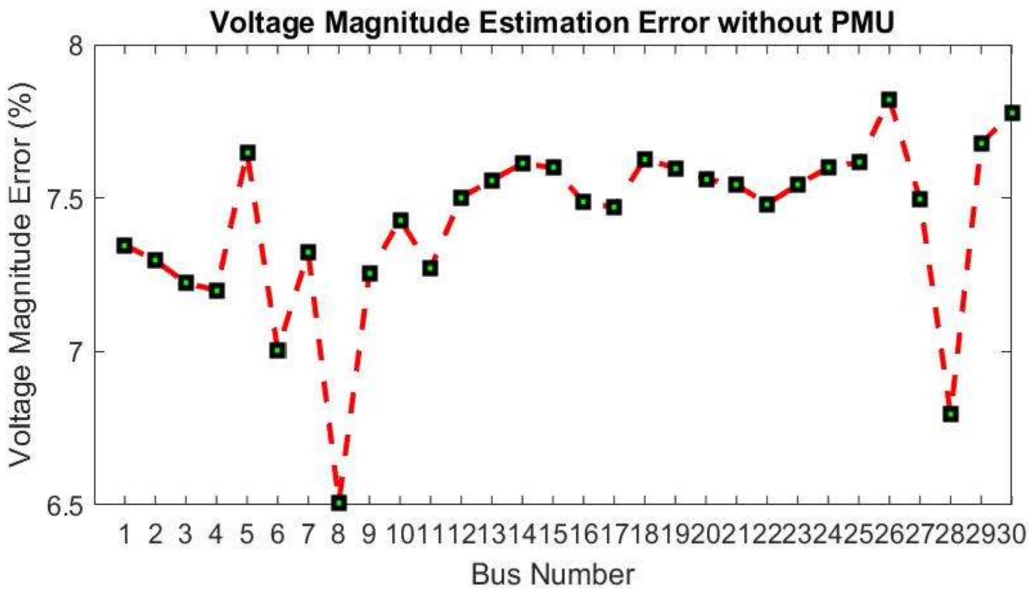


Fig 4.6 Voltage Magnitude Estimation Error (%) without PMU for IEEE-30 Bus System

Bus No.	V (PU)	Angle (Degree)
1	0.9865	0.0000
2	0.9700	-6.2635
3	0.9474	-8.8420
4	0.9384	- 10.903
5	0.9335	- 16.493
6	0.9395	- 12.997
7	0.9287	- 15.0443
8	0.9449	- 13.9608
9	0.9667	- 16.483
10	0.9472	- 18.3445
11	1.0093	- 16.483
12	0.9746	- 17.698
13	0.9954	- 17.6908
14	0.9559	- 18.737
15	0.9492	- 18.7299
16	0.955	- 18.2800
17	0.9442	- 18.5724
18	0.9352	- 19.495
19	0.9306	- 19.6063
20	0.9339	- 19.3582
21	0.9328	- 18.982
22	0.9372	- 18.723
23	0.93321	- 18.9957
24	0.9232	- 19.0788
25	0.9270	- 18.7784
26	0.9070	- 19.2593
27	0.9395	- 18.2962
28	0.9398	- 13.7920
29	0.9 177	- 19.7604
30	0.905	-20.8272

Table 1.8 State Estimation without PMUs for IEEE-30 Bus System

- Fig 4.7 and fig 4.8 shows voltage angle estimation errors and voltage magnitude estimation errors respectively, with no use of the phasor measurements (PMU) on IEEE-30 bus system. The output data of which is shown in table 1.9.

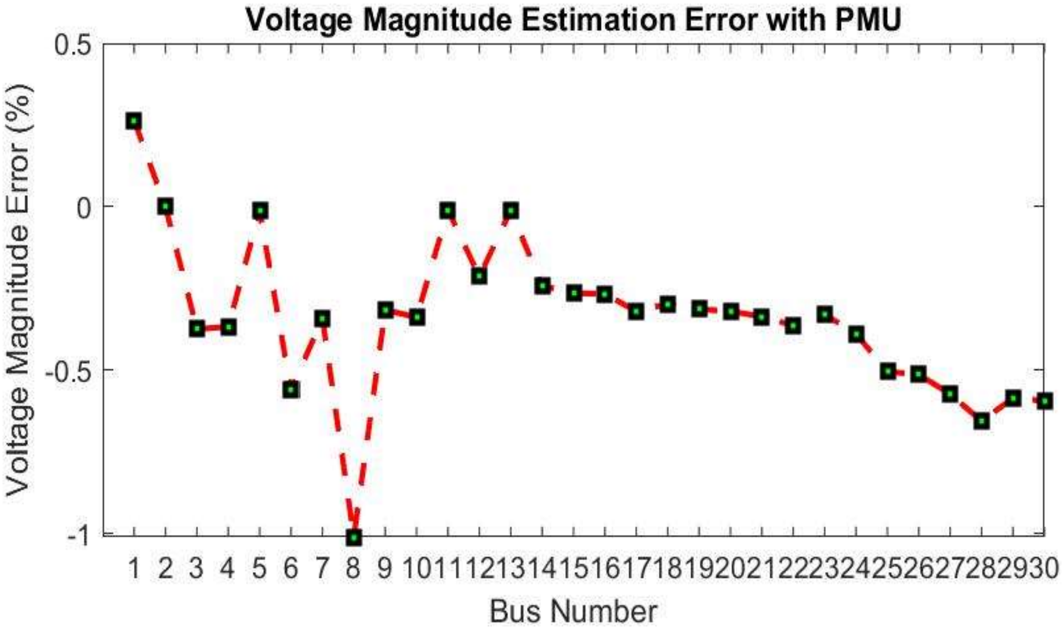


Fig 4.7. Voltage Angle Estimation Error with PMU for IEEE 30 Bus System

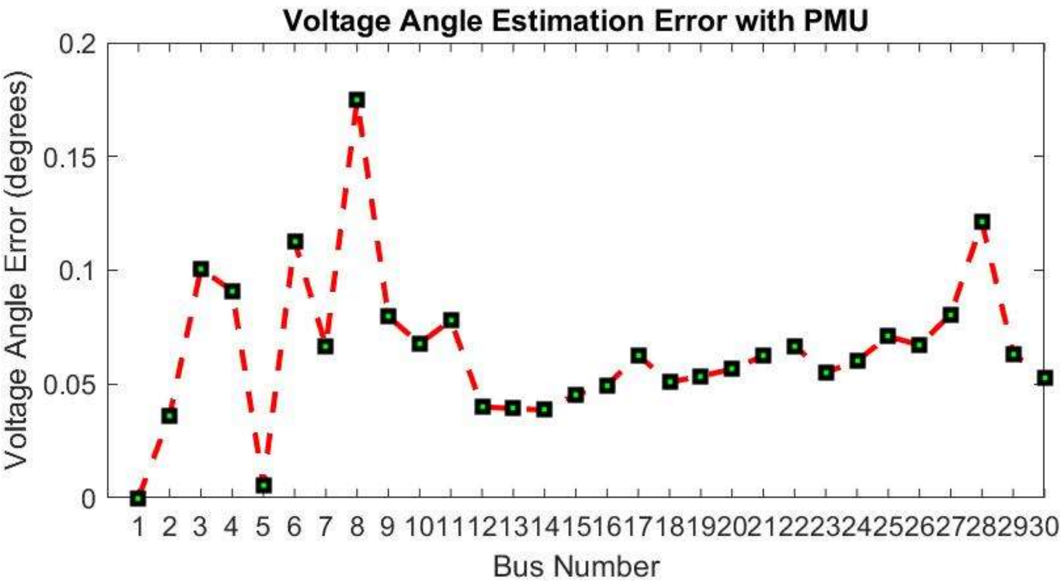


Fig 4.8. Voltage Magnitude Estimation Error (%) with PMU for IEEE 30 Bus System

Bus No.	V (PU)	Angle (Degree)
1	1.0574	0.0000
2	1.0430	- 5.3904
3	1.0234	- 7.633
4	1.0142	- 9.3750
5	1.022	- 14.2795
6	1.0352	- 11.2708
7	1.0054	- 12.9326
8	1.0021	- 12.9921
9	1.0424	- 14.2441
10	1.0248	- 15.7384
11	1.0823	- 14.3425
12	1.0527	- 15.245
13	1.0721	- 15.2638
14	1.0344	- 16.0404
15	1.0277	- 16.0537
16	1.03322	- 15.6746
17	1.02419	- 15.9323
18	1.01144	- 16.6575
19	1.0097	- 16.893
20	1.02127	- 16.6068
21	1.0215	- 16.280
22	1.0256	- 16.0477
23	1.0228	- 16.2845
24	1.0030	- 16.3609
25	1.0082	- 16.2429
26	0.9904	- 16.5709
27	1.0202	- 15.7365
28	1.0243	- 12.8374
29	1.0003	- 16.970
30	0.9888	- 17.8592

Table 1.9 State Estimation with PMUs for IEEE-30 Bus System

CHAPTER 5

CONCLUSION AND REFERENCE

5.1 CONCLUSION

In this project report an efficient method for power system state estimation with Weighted Least Square method using PMU measurements has been explained. The following conclusions have been established with supporting theory and simulations on IEEE-14 and IEEE-30 bus systems.

- It’s found that the error in estimation using PMUs is very less (more accurate) compared to estimation without PMUs.
- The results show that the angle measurements have effectively enhanced the performance of the state estimation algorithm.
- It has been found that, the using phasor measurements in a step that is being post-processed reduces computation time.
- It’s also found that as the size of power system increases, the accuracy of estimation decreases.

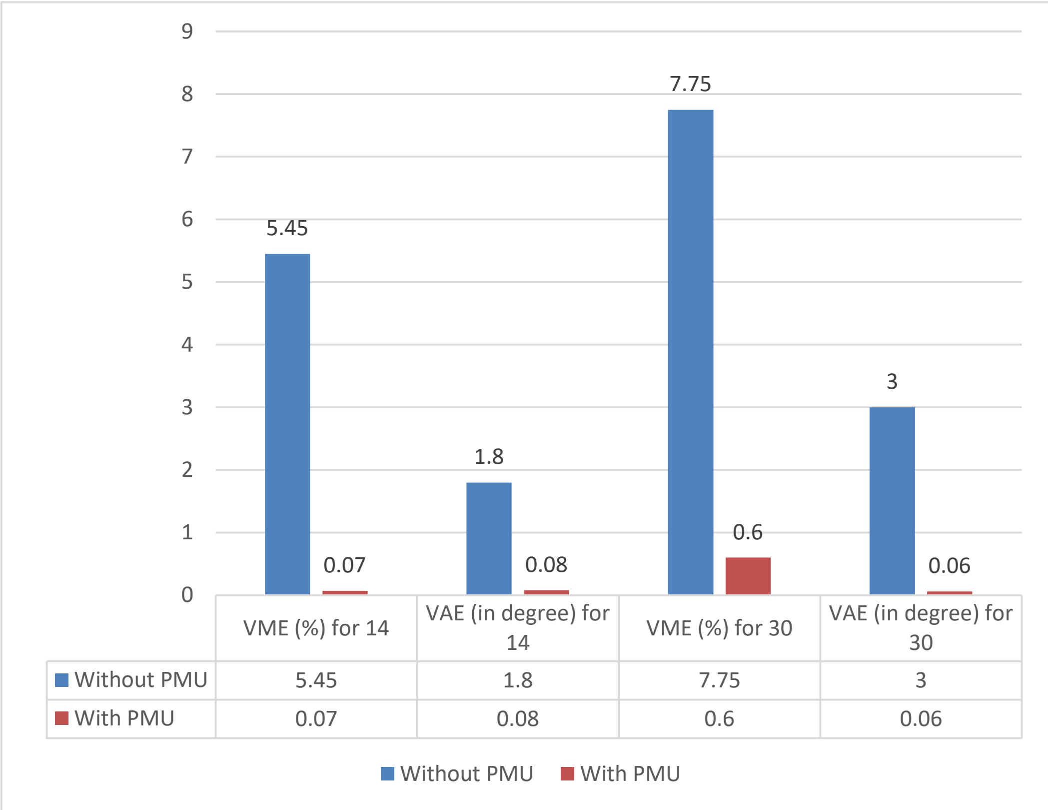


Fig 5.1. Graphical Representation of Errors Comparison Before and After Designing PMU.

5.2 FUTURE SCOPE OF WORK

- Using synchro phasor technology in wide area monitoring system (WAMS), the real-timemonitoring, control and protection can be achieved.

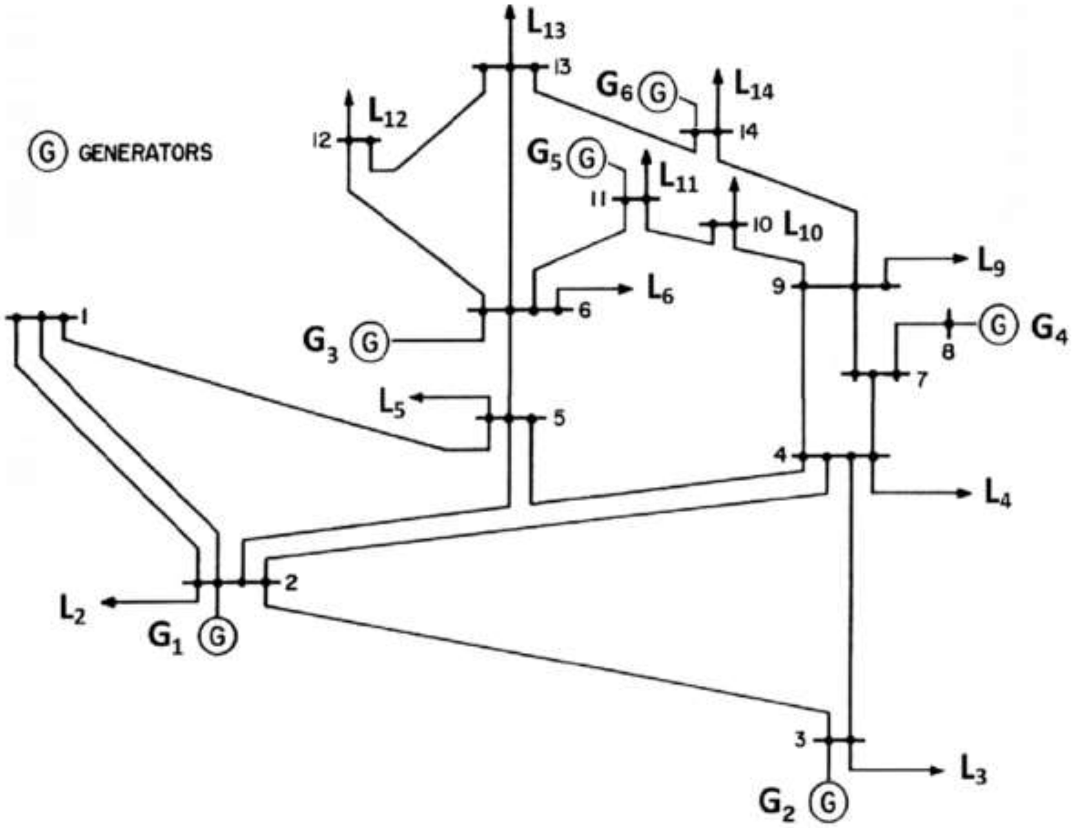
- In the future work, we plan to research this proposed technique for estimation of Dynamic state Jacobian matrix and dynamic system state matrix based on PMU measurements for higher order models, largesystem consisting of large number of buses, system consisting of renewable generators, high series resistance transmission lines, non-symmetric Y-bus cases, series/shunt compensation applications, and so on.

- The estimated dynamic state Jacobian matrix and dynamic system state matrix can also be utilized for future work in evaluation of online oscillations analysis, model validation and other electric power system control and protection operations such as economic dispatch, system security, state estimation,congestion relief and preventive control design.

INDEXING

1. Line Diagram of the IEEE 14-Bus System

Fig 6.1



All generator busses are assumed to have available PMU

2. Line Diagram of the IEEE 30-Bus System

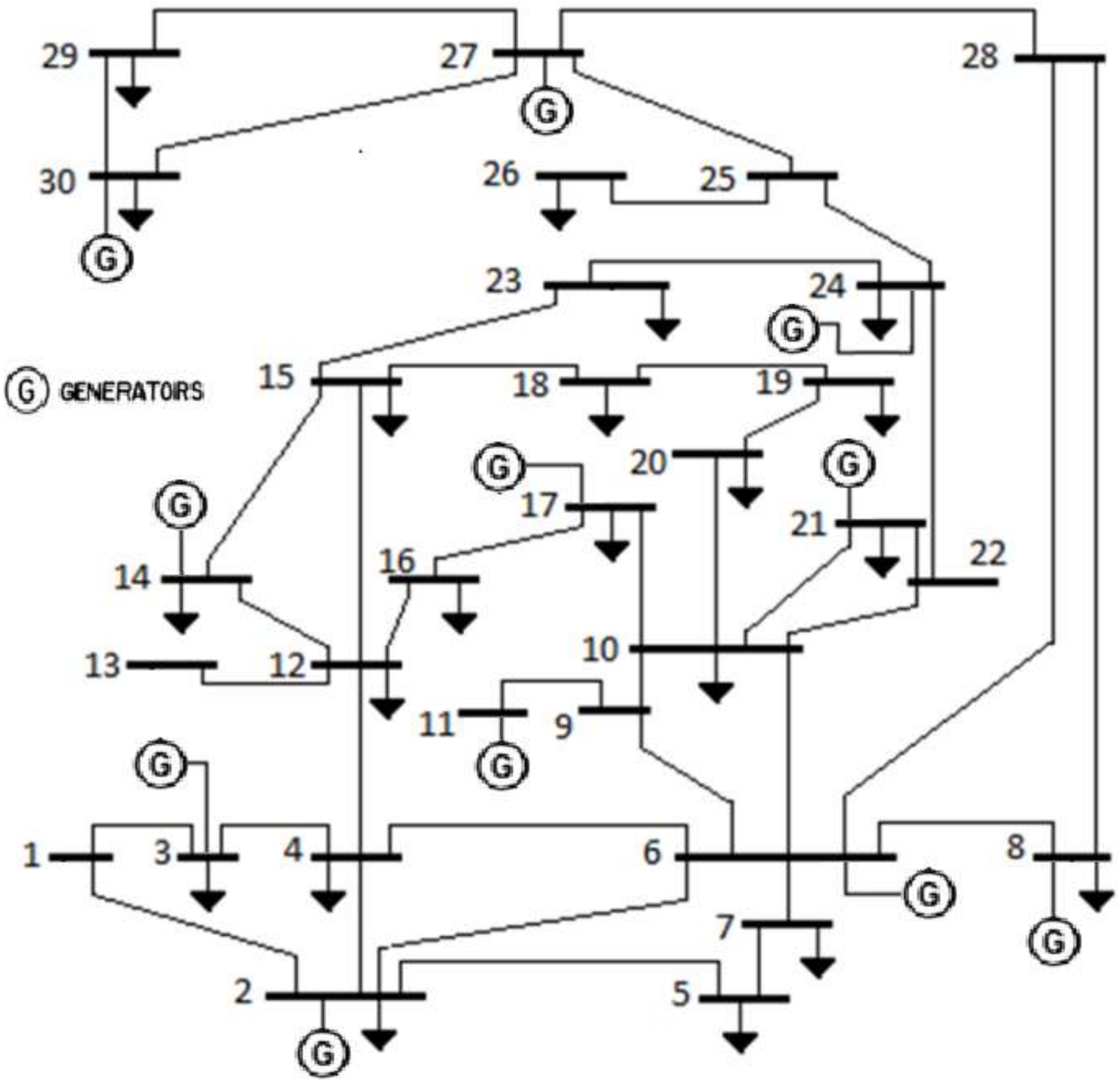


Fig 6.2

All generator busses are assumed to have available PMUs

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