OPTIMIZATION OF

PHASOR MEASUREMENT UNIT

DISSERTATION

Submitted in partial fulfilment of the

Requirement for the award of

Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

By

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CANDIDATE'S DECLARATION

I Digvijay Singh student of MASTER OF TECHNOLOGY DEGREE (ELECTRICAL ENGINEERING) under school of Electronics and Electrical Engineering of LOVELY PROFESSIONAL UNIVERSITY, Punjab, hereby declare that all the information furnished in this dissertation report is an authentic record of my own work carried out under the supervision of Dr. Amit Kumar Singh, Assistant Professor, School of Electronics and Electrical Engineering. The matter presented in this dissertation has not been submitted to Lovely Professional University or to any other university or institute for award of any degree.

Signature of the Student

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Date:

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Signature of Supervisor

The M.tech Viva-Voce Examination of (Dissertation-II) has been held on ______________ and found satisfactory/Not satisfactory.

Signature of the Internal Examiner   Signature of the External Examiner

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I wish to express my sincere and heart full thanks to my guide "Dr. Amit Kumar Singh" Assistant professor, who guides me to take up this thesis in sync with global trends in scientific approach. I would also extend my gratitude to my family who always encourage me in this thesis work.

And I would like to thanks all the staff member of department of Electronics and Electrical Engineering who have been very co-operative with us.

Digvijay Singh

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CERTIFICATE

This is to certify that Digvijay Singh bearing registration number 11502763 has completed objective formulation of Thesis title “OPTIMIZATION OF PHASOR MEASUREMENT UNIT” under my guidance and supervision to the best of my knowledge, the present work is the result his original investigation and study. No part of thesis has ever been submitted for any other degree at any university.

The Thesis is fit for submission and the partial fulfilment of the conditions for the award of MASTER OF TECHNOLOGY (ELECTRICAL ENGINEERING).

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DECLARATION

I, Digvijay Singh student of MASTER OF TECHNOLOGY (ELECTRICAL ENGINEERING) in POWER SYSTEM under department of ELECTRICAL ENGINEERING of LOVELY PROFESSIONAL UNIVERSITY, Punjab hereby declare that all the information of this dissertation II report based on my own intensive knowledge and research. The matter present in this seminar has not been submitted to Lovely Professional University or to any other university.

This dissertation II does, to the best of my knowledge, contain part of my work which has been submitted to the award of my degree either of this university.

Date: Digvijay Singh

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ABSTRACT

The current scenario of power demand of the world is increasing at a very fast rate due to modernization and the industrialization. And there are some problems with the approval of new transmission lines. In order to meet the demand of world we are using the power transmission lines to the limit of stability limits. So with the loss of sudden generation or transmission line stability may get disturbed there may be collapse in line voltages, may be frequency changes and may current get suddenly high due to short circuit.

In order to meet the demand of load or continuous flow of power from source end to load end our system need to be stable at all the time. Main issue arises when there is fault accurse in the transmission line or distribution line or to the generation side then our system should remain stable.

For above reason we need to stable the system at all the time for that we need to continually monitor the system at all the times for that in these days we are using Phasor Measurement Units. Phasor measurement unit system provide us the magnitude and phasor both of line current and line voltage unlike SCADA (supervisory control and data acquisition). With the help of phasor measurement unit we can continuously monitor our power system and can see where fault accurse and according to that we can generate the control signal or control action can be taken. Hence the power system stability can be enhanced.

But these Phasor Measurement Units are not cheaper there are costlier so we cannot use them everywhere. The disposal investment of PMU device with the single price of $40,000 USD. So we do the optimization of the Phasor Measurement Unit. Which decreases the number of PMU used in system for monitoring and hence controlling cost will be less.

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LIST OF ABBREVIATIONS

DSDR	Digital system disturbance recorders
WAM	Wide area monitoring
FACTS	Flexible ac transmission system
WLS	Weighted least squares
SCDR	Symmetrical Component Distance Relay
SCDFT	Symmetrical Component Discrete Fourier Transform
UTC	coordinated universal time
ADC	Analog to Digital Convertor
DFT	Discrete Fourier transform
TSP	Traveling salesman problem
DFS	Depth First Algorithm
MST	Minimum Spanning Tree Method
GA	Genetic Algorithm
PSO	Particle Swarm improvement
SA	Simulated annealing
ASA	Ant Colony System
DE	Differential evolution
SCADA	Supervisory Control And Data Acquisition
RTU	Remote Terminal Unit
PLC	Programmable Logic Controllers
HMI	Human Machine Interface
PMU	Phasor Measurement Unit

RMS	Root Mean Square
GPS	Global Positioning Satellite
PDC	Phasor data concentrator
RTDMS	Real time dynamic monitoring system
SIPS	System Integrity Protection Schemes
VSLI	Voltage Stability Load Index
ESN	Echo State Network
NRLDC	Northern Regional Load Dispatch Centre

CHAPTER-I

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 Background

As we know electric power system is network of electrical devices, transmission and distribution and also component of electric system for use of good quality of power at the load end. Electric power system is network of electrical component that supply a region, homes and industries with power. Power system is a grid Electricity is associated with the presence of flow of electric charge. Electric power is product of two different quantities that is electric current and electric voltage. These both quantities varies with time and also kept at constant values in DC. Because most of our daily appliances use A.C. and some other like computer and digital equipment use D.C. power. A.C. power is a practical choice because it is easy to transform and generate. But D.C. remains practical choice for DC systems and it is more economical for transmit over high voltage. Electricity can be generated in different ways in different power plant like, solar energy system, hydroelectric energy plant, thermal power generation plant, wind power system, nuclear energy power plant etc.

In hydro power plant we use water for the production of electricity by making dams. In this kinetic energy is used to convert to electric energy.

In solar power plant we use solar energy to produce electric energy. In solar power generation we use solar cell to convert solar energy into electric energy. Solar cells are act as transducers. Which convert one form of energy into other. Solar cell produces DC output voltage at the end.

In wind power plants we convert wind energy into electric energy. For that we use wind turbines and then mechanical power generators for production of electricity. But there are some limitations with it that they are used at places where high speed of wind is present.

Thermal power plants are used to convert coal energy in electric energy. In this we burn the coal and generate steam from that and then that steam is used to rotate the turbine and that energy is converted into electric energy.

In nuclear power plant is we convert nuclear energy into electric energy. In these plants we generate heat to produce steam and then that steam is used to rotate the turbine system and then mechanical energy of turbine is converted into electric energy using generator.

In today’s world most of the countries in the world have been effected by number of power failure, blackouts and faults. These are caused by lack of investment in protection equipment and controlling system infrastructure, improper maintenance and continuously increase in demand of electric power that overset the power transmission and distribution system limits. And due to these companies who invest in power system are suffering from losses of billions of dollars. To achieve batter reliability and for continuous operation of power system new technologies are used to prevent the blackouts. Today we are implementing state of then art technologies, to get the good controllability and high reliability we do the state estimation from measurements obtain from PMUs. It is used to get the high controllability, high reliability and for real time monitoring of power system and to satisfy the consumers also by providing good quality of power. [1]

Network of electric system are very complex and are used to send or supply power to load end from generating stations. Electrical power system is the most complex system which continuously suffers from various disturbances or faults (switching or lightening etc.) all the time. Hence they are affecting system frequency, voltages of lines or power flow. Since power systems are dynamic in nature hence there is need of control system to so that system should remain in stable conditions during or after faults so that our power supply should be continue to the costumer or to the load end. One major difficulty in power system is that amount of active power consumed in addition to loss should always equal to active power product. If more and more power produce than demand then there is increase in voltage and frequency and also if there is less generation then there is decrease in voltage and frequency. And even small amount of deviation from frequency may become cause of damage to synchronous machines and loss of synchronization and other appliances. So we have to making sure that frequency is constant is work of transmission system operator.

Therefore there is need of live monitoring of these systems so that we can get the continuous status of system at all the times so that effect of problems and faults can be minimize and our system should remain in stable condition

Likewise as power system demand increases so power system network grow and become more and more complex as load increases our system become more and more stressed. So continuous monitoring as well as controlling of electric system is required.

1.2 PMU History

The origin of concept of Phasor Measurement Unit was from a particular relay i.e. symmetrical component distance relay (SCDR). This relay is used in dynamic relay technology. Calculation of voltage phase angle was first computed in 1983 by Dr. Phadke and Dr. Thorpe on theoretical basis. But PMUs comes in usage first time in field in the early 1990's. At that time there applications were very limited. They (PMUs) were used as a digital system disturbance recorders (DSDRs) only. [Modelling of PMU] at that point of time, PMUs usage for protection and control were any theoretical but not practical. But practically PMUs were continued to be used only DSRs. They came into practical use after the blackouts in 1996 and 2003. After that PMUs technology were highly encouraged for research for the use in protection and control system.

In 1965 after the blackout in north east of America starts the large amount of research in the field of real time data on the state of power system was started. The first paper to determine the importance of positive sequence phasor measurement was published in year 1983[36 full text thesis]. At the same time all around the global positioning satellite system was beginning to develop or become the part of it.

Moving on from Symmetrical Components Distance Relay (SCDR), Virginia tech were the first to develop the first prototype synchronised phasor measurement unit (PMU). In 1988 few Devices were installed in a few substations along the east cost of America, after it collaborate with Macrodyne in 1991 to produce the first commercial manufacture of PMUs. [2].

1.3 PMU In India

We can measure instantaneous voltage and current at any specific node in power transmission and distribution system can be measured with the help of PMU device. As there is increase in demand of power leads to use the power network at their critical limits. So there is need of continuously monitoring of power system. Which led to increase the use and development of PMUs.

In India first PMU was setup in Northern region in 2010, this project consist of PMUIs along with GPS installed at selected 9 sub substation in the grid. And the phasor data concentrator and other associated devices are placed at Northern Regional load dispatch centre (NRLDC) located at New Delhi.

Total of ….. PMUs are installed till 2016.

1.4 Objective

The objective of this thesis consist of:-

1) Optimization of PMU to decrease the total number of PMUs using MATLAB
2) By decreasing the total number of PMUs reduce the total controlling cost.
3) Use global search algorithm technique for optimization.

1.5 Thesis Organization

This thesis consist of total six chapters that can be briefly outline as given below:-

Chapter 1 this chapter contains the introductory part carried out in this thesis. Background and history, objective and thesis outline in this chapter is given in detailed.

Chapter 2 present the literature survey that is done for this thesis.

Chapter 3 covers the introductory part of controlling techniques and introduction to PMUs technology. Synchrophasor technology in accordance with IEEE C37.118 Standard, phasor estimation technique like zero crossing, non-recursive and recursive has been also discussed in this chapter. Applications of PMUs, challenges in PMUs, limitations in PMUs are also discussed in this chapter.

Chapter 4 contains the optimization general idea about the optimization and some techniques are also discussed in this chapter like genetic algorithm, global search algorithm.

Chapter 5 contains the research mythology which I have used in this thesis i.e. combination of global search algorithm and binary search algorithm.

Chapter 6 presents the result and some discussion about the results and compare them with other few techniques.

Chapter 7 contains some concluding remarks of this thesis work. Also future scope of work are been suggested for further work.

CHAPTER 2

Literature Survey

CHAPTER 2

LITERATURE SURVEY

In today's world it is essential to have a reliable power system because present economy is becoming fully dependent on electric power supplies. PMU with synchronized measurement is used to measure or determine the condition continuously in real time in wide area monitoring (WAM) technology. Electrical system continuously monitoring, analysis, or protection and control is done through PMUs measurements. Real time voltage and current at any specific branch or node in power transmission or distribution system network can be determine using a PMUs. Global positioning satellite are used for time sampling of measurement signals in PMUs.

In 2009, PMUs applications were discussed with the need of Synchrophasor technology in both online and offline time and also the development in recovery by US department of energy in act 'Smart Grid Program'. In offline mode of PMU perform the applications like Data visualization, and model validation also event analysis. [3]

S.K. Soonee et. Al. (2008)

Mr. S.K. Soonee he is member of Indian power Grid Corporation limited he has explain in his paper about the need of Phasor angle measurement for checking the status of wide area of grid and also the requirement of synchrophasor technology in Indian electric power system network. They explained in detail that the static stress across the grid and instability if grid is dependent on the phasor angle difference among different nodes. Phasor angle at any point can be measured with respect to the predetermine threshold limits. [4].

Bindeshwer Singh (2011).

Mr. Bindeshwar singh describe a brief points on applications of Phaser Measurement Unit in power network. The auther present the ststus of development of applications of PMU and review the applications of PMU and survey the applications which are integrated with FACTS controlers in power system control, protection as well as monitoring.[5].

Phadke. (1983)

In 1983 phadke Introduce the conception of phase estimation and describe the DFT calculation result for experiment performed in AEP power system simulation laboratory on theoretical basis. The author also describe the concept of PMU was originated from SCDR as a part of dynamic relay technology. [6].

D. Dotta

In this paper author shows PMU in Simulation in MATLAB software. The purpose of author is that to find the behaviour of PMU and to find the key factors that affect the performance of PMU under off nominal frequency operation. This is done for the academic and professional purpose and find how PMU work. The functioning of the simulator was evaluated with the help of simulated and real data from 2.88 kHz measurements. And finally the output obtain from the simulation result are compared with outputs of real PMUs. [7].

D.G. Hart (2001)

Author gives the introductory architecture of PMU, and define how the PMUs work in the real time with GPS and connected to other GPS with modems. PMU is broadly originated of three basic unit –

(1) Data Transmission Unit,
(2) Clock Synchronization Unit, and
(3) Measurement Unit.

The Clock Synchronization Unit contains of GPS receivers and phase-locked oscillators, which deliver the sampling clock to the Measurement Unit. The Measurement Unit can be farther divided into three basic constituent - Analog-to-Digital, Anti-aliasing filters, Phasor measurement Unit/ Processor. An anti-aliasing filter is used before signal sampling to fulfil the sampling theorem and to limit the bandwidth of a signal. An ADC (Analog to Digital converter) is then used to change over a physical quantity like voltage to a digital number/quantity that describe the amplitude. The Data Transmission Unit receives the measured data from the Measurement Unit and transmits it to some suitable communication protocol such as modem. [8].

Researchers and scientists utilize software which suits their work. For proper working in the areas of signal analysis and simulation of dynamic systems LabVIEW and MATLAB tools are mostly used. In 2012 a comparability was done based on practical performed with four comparisons i.e figuring with matrices, FFT calculation, Bode plot, and DC motor simulation [9].

MATLAB is more efficient tool for evaluating equations.

Phadke A. G (2006)

The author provide the history of PMU that they were commercially develop early in 1990's, iys applications were small in range it is used to work as only digital system disturbance recorders(DSDRs). At that point of time they were only used as DSDRs because at that stage PMUs usage for protection and control was only theoretically not practical. [10]

F.J. Marin, , G. Joya, F. G. Lagos and F. Sandoval (june 2003)

In this paper author presents the solution of optimal location of phasor measurement unit using genetic algorithm. By this method we determine the least number of PMUs that need to be install and there geographic distribution so that complete system should be observable. The GA encoding is based upon the binary genes. And one gene for each line used to indicate its corresponding phasor current measurement.[11]

MAO Anjia YU jiaxi GUO Zhizhong (2005)

This paper represents the use of PMUS with the SCADA. Although PMU is very good in measurement but there are same problems with PMUs are

1) Communication problems
2) Storage problems
3) Management problems
4) Error problems

And we can reduce these problems using PMUs with the SCADA[12]

Bei Gou (August 2008)

This paper presents the PMU placement based upon integer linear programming formulation. Accuracy an redundancy and robustness are increased with integration process of PMUs measurements in this paper author consider bout the situation with and without zero injection effect of busses measurements, and shows that the problem of finding the optimal location of PMUs can be removed of solved with the help of integer linear programming. [13]

S. S. Geramian, H. A. Abyane, K. Mazlumi (2008)

This paper present method to find particular locations for PMUs and with the help of this we can find the fault location of all the transmission and distribution network lines. Because the PMU installation cost is high so it is important to find the proper placement of PMUs such that fault location monitoring is achieve with min number of PMUs. The method is known as "one bus spaced placement strategy,". In this method accuracy of method is not dependent from fault type and its resistance. With the help of PMU based algorithms offer the calculation of fault place using synchronized voltage and current phasors. In this paper optimization is solved by genetic algorithm (GA). By using Genetic Algorithm different optimal PMU placement is achieved.

The above described method has been introduce in two methods

1st step is optimally find the least number of PMUs among all the network busses and

2nd step is find the fault location with the help of measurements obtain from the PMUs that are installed. This described optimization scheme advantages,

1st this method is economical and

2nd this method can also be applied on interconnected networks.[14]

S. Azizi1, A. Salehi Dobakhshari, S. A. Nezam Sarmadi, A. M. Ranjbar and G. B. Gharehpetian (2014)

This paper represents the novel number line programming for the improvement of Phasor measuring Unit to boost the network observability. The circuit rulers and therefore the observability operate is get from the Boolean algebra. which operate is employed to search out the optimum location of PMUs. The unified improvement model grant for considering the network growth situations and additionally confirm importance of important buses throughout the installation procedure in order that these buses is also put in with PMUs at primary stages. once the put in PMUs covers a series of management and protection applications besides the watching one, the described objective operate are often modified supported the conditions, though the remainder of multi-stage placement model remains the because it is as before. additionally to hide the network growth situation, the describe model is in a position of taking the importance of the observability of important buses at completely different stages under consideration, that may be a benefit on the far side the power of existing ways. What is more, because of absolutely exploiting the potential of the configuration, the obtained solutions square measure optimum. [15]

N.M. Manosakis, G.N. Korres and P.S. Georgilakis.(September 2011)

In this paper proposed literature review on different techniques for optimal placement of PMU has been discus and solution methodology. To solve optimal PMU placement problem we use different techniques i.e. mathematical programming, heuristic, meta-heuristic optimization techniques. [16]

M. R. Jegarluei, Ahmad Salehi Dobakhshari, Ali Mohammad Ranjbar and A. Tayebi(2014)

In this paper, the problem of optimization of phasor measurement units (PMUs) in a transmission and distribution system is considered so that fault on any line and anywhere can be find and also can be diagnosis. For this reason different PMU placement algorithm are used to find the fault location and it is done on the basis of impedance change in the network, achieving the total potential of the circuit laws throughout the system. Then associate another rule is then accustomed calculate the voltage and current wave forms within the line for locating the fault locations. This paper describe a fault-location rule for transmission networks victimization PMUs has been with success developed. The delineate rule first offers the minimum variety of PMUs for each pre and post fault observability. Not solely will the PMUs find the line during this methodology, however additionally the line is distinguished from suspected transmission lines. A companion rule has been accustomed input the voltage and current measurements by PMU send output the desired voltage and injected current of the line terminals. And it can be observed that with help of above algorithms the fault location on other non PMUs line can be determine easily. [17]

Zakir H. Rather, Z. Chen, and P. Lund (2016)

In this paper a pragmatic approach is used which is economically-effective improvement of PMUs placement while taking in mind the realistic constraints. The described approach it licates the PMUs in a stage-wise order. The detailed given method also describe the integration of wind energy system with grid and monitoring the wind generation syatem dynamics. The given approach is generally on practical basis for the placement of multistage PMUs with realistic conditions in mind. This method also have high future scope in research and also for robust software tool developer for PMUs placement. [18]

W. Li, X. Mou, and Zhimin Li (June 2012)

This paper describe the procedure to decrees the number of PMUs and determine their location for voltage stability through online. Since the cost of PMUs is high so optimal placement of PMUs is important such that we can monitor the real time system without effecting the system accuracy. In this paper method used to find the factors which are effecting the voltage stability of system is analytical index. This method is an effective to determine the optimal location of PMUs for voltage stability consideration and also for real time monitoring. the result getting from this method shows us that the voltage stability is function of only few busses parameter which verify the effect of PMUs placement index meyhod. [19]

Hany A. Abdelsalam, Reham H. Salem, A. Y. Abdelaziz, and Reham A. Osama. (2014).

In this paper the optimization problem of Phasor Measurement Unit with considering the re configuration of distribution system. Ant colony optimization (ACO) method is used to determine the minimum loss problem. And for the optimal placement of PMU Greedy algorithm is used. For this greedy algorithm we have rules based upon which this method make decision. In this algorithm we give set of elements to the greedy algorithm which chose the next chromosome based upon priority till end results is meeting.[20]

K. Joseph. Makasa, , and Ganesh K. Venayagamoorthy, (2011)

This method present in this paper is different and new for state estimation to determine the voltage stability load index (VSLI) in network of power system with the help of measurements of optimally allocated phasor measurement units. With the help of neural network which is also known as Echo State Network (ESN) we determine the Voltage Stability load index. For VSLI for a given system we do not need any voltage phasor information at any bus. Since no-load voltage is dependent on system operating point and power system operating point is changing because dynamic in nature hence it might be difficult to get no load voltage phasor at each bus. This estimation is carried out by echo state network PMUs are placed only at pre-determined location and it is make sure that complete power system is completely observable for voltage stability monitoring.

The advantage of using neural network in power system is that first it is trained then it is use to obtain the output. This method of predicting outputs is less time consuming then other methods able of estimating the right outputs. such as power flow computation that involve solution of nonlinear equations iteratively. Input for this method is voltage magnitude and voltage phasors at each bus and the result shows high accuracy in VSLI estimation under disturbed and normal conditions. [21]

Milos Cvetkovic and Marija Ilic,(march 2011)

This paper presents the transient stability of electric power system with phasor measurement unit and flexible ac transmission system (FACTS). When we combine both the technologies they result a very powerful determination of measurements near real time and and controlling ability and also decreasing the effect of very fast disturbance. In this paper we propose very fast switching devices and accurate pmu measurements. In this paper we see how we can improve the control on FACTS devices and how we can make them more efficient.

We know we can use thyristor controlled switched capacitor as FACTS controller because its simple design and it has strong influence on power flow. Flow of power is controlled over the switching angel of thyristor. If energy flow is control properly then the large disturbance can be stabilized. The main step in controlling of power system network is to come up with that FACTS model which can fast determine the dynamic behaviour of the network. but simply enough to use to design to control only FACTS model is not enough also we have to modelled the transmission network as well. In this paper change in energy in the network is modelled control can be implemented. This paper control law consist of two parts;

1st is the rate of accumulated energy in the network and angular frequency of generators and 2nd is output of the system.

Both are communicated to TCSC in order of proper control. Energy base control has approvable performance. Problems in this system are choice of best way to the controller and choice of FACTS controller.[22]

Mehran Rashidi Ebrahim Farjah (2015)

In this paper author use the Lyapunov exponent method to find the optimal location of PMUs to get the real time monitoring of network and also for fully controlling of network and to improve the system stability. In this method we maximize the measurement dreduntancy index for those busses which are critical without any increase in number of PMUs for whole system observable. The robustness of given method is verified with respect to the change in operating point. We see that by this method the transient stability is improved with the real time monitoring of these busses. [23]

Farrokh Aminifar, Mahmud Fotuhi-Firuzabad, Mohammad Shahidehpour, and

Sharma, G, (2014),

the paper discuss the analysis of one MW PV solar plant designed on MATLAB. The key points of paper are designing of solar plant, estimating the power production depending on these estimation cost optimization of a plant is discussed. [24]

Bialasiewicz, T, (2008)

the PV array can operate in stand-alone or are connected to a grid. The current controlling is mainly used in applications related to a photovoltaic inverter. The main challenges offered by PV generation are efficiency and power quality. The maximum power point is a set of algorithms used to track maximum efficiency. The main goal of the paper is to reduce voltages of current ripple. [25]

Ton, D, (2008),

in this paper the SEGIS is projecting to develop the advanced form of energy repository systems and components that will boost the overall working of PV based applications systems. [26]

Bialasiewicz, T, (2008),

the paper focus on the modelling and operation a standalone PV power system in RPM-SIM. The inverter used for PV operation is operating in slave mode and also in master modes. It is noted that when the inverter is operated in the master mode for standalone applications then the setup give enhanced controlling of frequency and voltage of power system.

The study also discusses the cost effective operation and utilizations of renewable energy systems. The process is carried out with different values of temperature, varying insolation, irregular irradiance, dynamic wind speeds and uncertain load profile. The result discusses power quality of the system. [27]

Ram, S, et al (2009),

this article presents a new development of fuzzy logic power system operated by wet UPFCs oscillations in fact based on a comprehensive system for the delivery of multi - machine containing the generator,3 Transformers, 9 buses, recorded 4 and 2 UPFCs.

Fluctuations in energy systems should be taken seriously into account from the time an error occurs in any part of the system, otherwise, it could lead to instability mode disconnected from the power system. This paper presents this hybrid combination of UPFC Fuzzy - control strategy POD wet electro - mechanical oscillations. Strengthening part of the normal controller regulates the coordination of fuzzy controller. [28]

Vergara, S, (2011),

this work present the comparison of two types of solar energy sources: Photovoltaic (PV) plant and Concentrating Solar Power (CSP) plant. The key objective of work is to compare the economic aspect of both plants for generation of 40Mw plant .the paper discuss initial investment, maintenance, and production. [29]

Xue, Y, et al (2011),

the paper presents the inspection of the passive and transient behaviour at the common coupling point for a PV system connected to the grid. Specifically, the study is done to understand the effects of system specifications such as solar irradiance, change in loading condition and temperature on the voltage stability. The brunt of small interruption in system specifications to the transient feedback is analysed. [30]

Gouda, K, P, et al (2012),

This paper model and design and computer -aided electromagnetic switch direct current power system (PSCAD / EMTDC) in the unified power flow controller (UPFC) is simulated. UPFC series converter line, real flow / UPFC reactive power and voltage deviation UPFC bus converter / DC link shunt capacitor voltage control and reactive power.

UPFC through the DC link capacitor series converter requires real power converter is equipped with a ramp. UPFC bus voltage lines to control the flow of reactive power leads to excessive voltage excursion. [31]

Austria, R, et al (2012),

This paper analysis of harmonics issue that is limiting solar PV power generation in 12.47 KV distribution network, major capacitor are located at the substation. Inverter depended PV units introduce the harmonic current which excites resonant frequencies developed by the capacitor.

To increase the injection of PV power various measures like the repurposing of capacitor and installation of filters are taken. The paper also points out that PV penetration is also significantly influenced by tolerable limit endorsed by the utility. [32]

Manohar, K, et al (2012),

the paper presents a dynamic model of solar PV system connected to utility grid designed in MATLAB. The model has D & Q axis coordinates which are rotating in phase with grid voltages and reflecting systems characteristic precisely .the system comprises of a PV solar array, a controlling mechanism, distributed structure and a load.

The control mechanism offers two ways to control, firstly at common coupling point current is regulated which in turn regulates dc link voltage by achieving power factor control, while second is to attain closed-loop controlling by voltage control mechanism of PV output voltage, this offers smooth tracking of MPP.

Perturb and observe is used for MPP tracking. For fault analysis, LLLG is introduced the proposed system is simulated with and without fault during simulation of both the cases various power quality event are observed. [33]

Raut, B, et al (2013),

the paper talks about variable nature of solar PV generation which doesn't allow solar PV system to supply constant power. So in order to supply constant power to customer solar plant are synchronized with the grid, but again variable nature of solar PV generation can affect the grid parameter and Detroit power profile in a grid.so analyse this a 1kwp solar PV system is designed and connected to a grid . It is observed that on using Perturb and Observe the power output in enhanced by 23% than the system having no MPPT. The power electronic setup of converter and inverter introduce harmonics in the system which is dependent on solar irradiance.

It is observed that voltage THD is less responsive to a fluctuation of solar irradiance as compared to current THD which is highly receptive to change of solar irradiance. [34]

Belfiore, F, (2013),

The maintenance and operation of large-scale photovoltaic plants requires a management system that has to integrate and also has to be implemented throughout the entire life cycle. The problem related to the connection to the grid can often be critical, both in aspects convenience and continuity of the energy delivery. Breakage caused by either major interruptions downstream in the utility area or faults on the transmission line to the interconnection switchyard or should be identified and communicated quickly. [35]

Dris, M, et al (2013),

The work views the theoretical study of various MPPT topologies like Perturb & Observe, Fractional open circuit voltage,, and Incremental conductance, using real-time irradiance data for different weather conditions. It is observed that for a cloudy situation the incremental conductance offers higher efficiency. For low cost system Perturb and Observation technique is preferred as it requires only one sensor compared to IC using four sensors for same task. Using real-time irradiance data for different weather conditions. It is observed that for a cloudy situation the incremental conductance offers higher efficiency. With maximum power point tracking we can improve the efficiency and hence output of the system is increased is shown using Simulink model. For low cost system Perturb and Observation technique is preferred as it requires only one sensor compared to IC using four sensors for same task. Using real-time irradiance data for different weather conditions. [36].

Hussain, I, (2014),

the paper accord the grid synchronization of double stage solar PV system employed 2-level eighteen pulses double bridge voltage source converter with controlling based on PLL. Incremental Conductance serves the purpose for tracking maximum power point. Each VSC is connected to phase shift transformer to mitigate harmonics between various converter modules. The robust integration of PV solar system grid, the controller responses are enhanced and faster than earlier. The study has been carried out under various varying conditions. [37]

Zakir H. Rather, Zhe Chen, Paul Thøgersen, and Per Lund (2016)

A realistic approach for stage-wise PMU placement that considers real world constraints is proposed. The proposed pragmatic approach for multistage PMU placement is based mainly on practical realistic considerations instead of purely theoretical approach. Unlike previously reported methods, the proposed approach considers large scale wind integration in the system, coordination with other project activities such as transmission expansion planning, scheduled maintenance, and priority buses. The proposed approach is demonstrated on the Western Danish power system. Effective phasor measurement unit (PMU) placement is a key to the implementation of efficient and economically feasible wide area measurement systems in modern power systems. This paper proposes a pragmatic approach for cost-effective stage-wise deployment of PMUs while considering realistic constraints. Inspired from a real world experience, the proposed approach optimally allocates PMU placement in a stage-wise manner. The proposed approach also considers large-scale wind integration for effective grid state monitoring of wind generation dynamics. [38].

V. Krishna

Mr. V. Krishna told that the basic of a Synchronized Phasor Measurement Unit (PMU) is based on a Digital Signal Processor. The algorithm discribe for the implanting of proposed system is Recursive Discrete Fourier Transform (DFT) algorithm. The simulation for the discribed algorithm in LabVIEW software is discribed in this paper and the outcomes are obtained after simulation. [39]

Kang H. (2009)

In this paper Author describe the new tool to simulate PMU measurements. The tool is able to give you the ability to test and study operations offline before they are installed. With the help of the simulation application allow testing of Ethernet to assess traffic load and propagation delay of PMU data. The tool is able to give you the ability to test and study operations offline before they are installed. With the help of the simulation application allow testing of Ethernet to assess traffic load and propagation delay of PMU data. [40].

Mark Adamiak

Author examines different errors like sensor errors, off-nominal frequency components, timing errors and system harmonics with the issues of implementing measurements. Simulations of the various systems transient are signals and their output i.e. their phase responses has been delivered. [41].

AG. Phadke

Author describe the nearly accurate method for transmitting the phasor measurements to different far locations using various methods of synchronizing signals in the paper. The detail describes the condition of utilizing time synchronized sampling. [42].

Milos Sedlacek

Author explains in the paper the ground idea for determining the phasor with the help of zero crossing in the paper. It has been described that in zero crossing that we can compute phase of a signal only if a reference signal is provided.

Sourav Mondal. Proakis.

Author explained the simulation of both recursive and Non-recursive DFT phasor estimation algorithm using LabVIEW and using the test signal author compares the result between both DFTs. And explained the digital signal processing, algorithm and its principles and application in detail. Discrete Fourier Transform (DFT) also explained how signal from one domain to second domain can be converted for easy analysis and less calculations.

De La Ree (2010)

In 2010 international manufacturers proffer commercial PMUs which put together the existing industry standard for Synchrophasor. Synchronized phasor measurements had become a mature technology. With the event of major blackouts in power systems acrossPmus are installed based upon the value of data provided by PMUs on power transmission network of major power systems become an important activity. Author provides a brief discription to the PMU and WAMS technology and discusses the uses of these measurements for improved protection, monitoring, and control of power networks. [43]

CHAPTER 3

Controlling Techniques

CHAPTER 3

CONTROLLING TECHNIQUES

This chapter presents the PMU and its basic operation. SCADA, Synchrophasor technology in accordance with IEEE C37.118 Standard, its applications and basic components of PMUs and their detail also phasor estimation techniques like zero crossing, recursive and non-recursive DFT and Sliding DFT also challenges in PMUs and limitations of PMUs has been explained in the chapter.

3.1 Power System In Practice

A) Residential power system: - residential power system always take power supply from low power distribution power line. Because these operate on the rage between 110 volt to 260 volts depending upon national standards. Home appliances are protected with fuses. There we have earthing wires that protect from current shock. We also use voltage stabilizers at the load side that is just before the load so that load should be protected from the sudden change in power supply. Which protect our load from fault.

B) Commercial power system:- commercial power system are shopping systems large buildings loads bigger than residential loads are consider as the commercial loads. We have to place special requirements for protection from lightening, emergency power. Smoke control etc.

3.2 Controlling Techniques

3.2.1) Supervisory Control And Data Acquisition (SCADA)

Supervisory control and data acquisition is a control system architecture that uses computers, networks, data communications and graphic user interphase. For high level supervisory of power system. It also use other devices for measuring and controlling like programmable logic controller(PLC) and PID controller to interphase to the process plant. SCADA concept is like a remote access to a verity of a local control modules. The main attributes of SCADA is ability to perform supervisor operation over the wide area.

It can be seen from the diagram that we have different levels in the SCADA system.

Level zero we have sensors such flow, temperature, flow, pressure sensors, and final control element like valves etc.

Level one contain industrial input and output module and electronic processers.

Level two contain the supervisory computer for supervision which collect all the information from processer nodes on system and provide the operator control.

Level three contain the production control which is not directly control the process it control the process with output of product requires that is production targets.

Level four is the production scheduling levels.

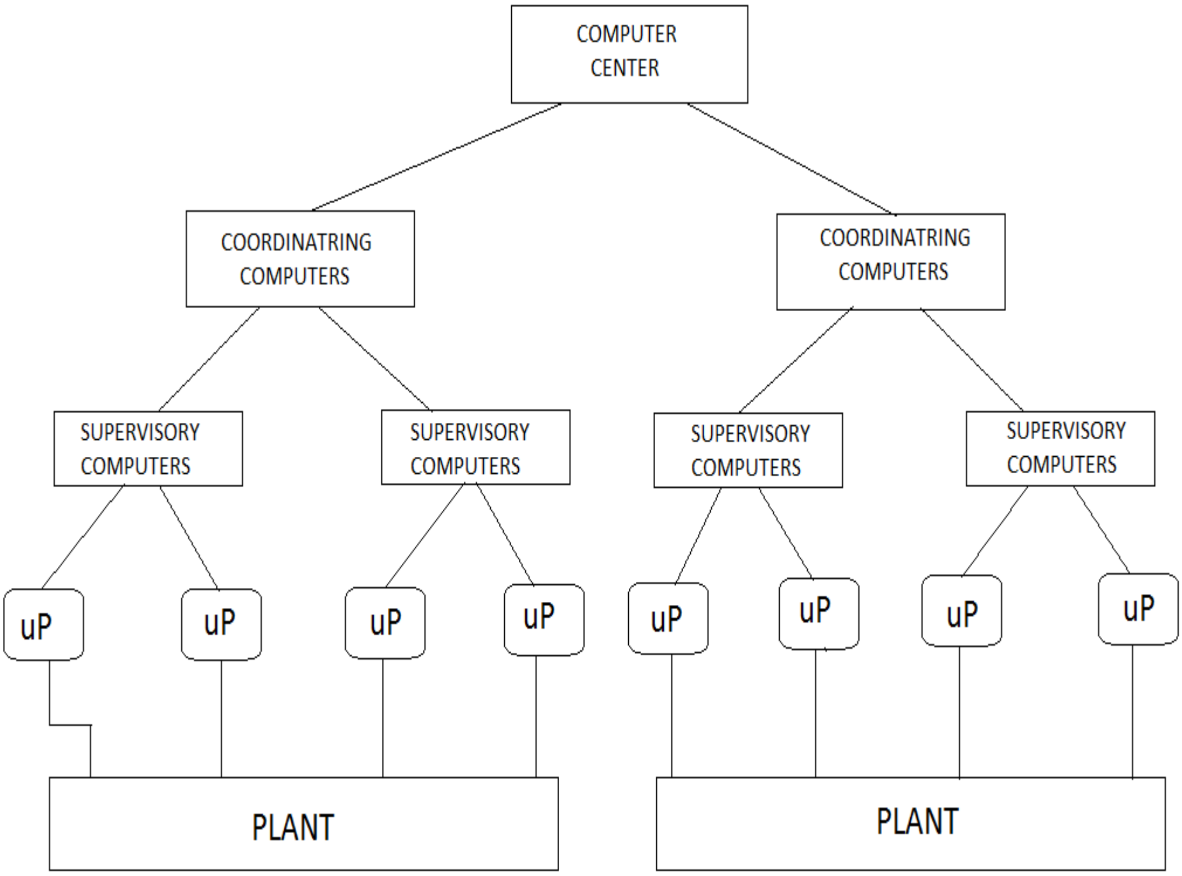


Fig 3.1 SCADA System

3.2.2 SCADA System Component

a. Supervisory computers
b. Remote terminal units
c. Programmable logic control
d. Communication infrastructure
e. Human machine interface

A) Supervisory Computers:- these are the core of SCADA system. It gathers data from the processer and sends back the commands to the devices connected in fields. It refers to the computer and software programming and communication with field connected controllers. It includes the HMI is the part of the computer in large scale system the master station may contain several Human Machine Interface (HMI). Supervisory computers provide the continuous control and monitoring in the event of several malfunctioning and breakdowns. These are the main station of the controller where all real time monitoring is done and with respect to that control signal is generated and that control signal is goes back to the small controlling units like embedded system that operate the end devices to control the output. The program saved in these computers are main part of the controlling system.

B) Remote Terminal Unit (RTU):- Remote Terminal Unit is also known as the RTU they are connected to sensors and actuators in the process. RTU are intelligent input and output system and they have embedded control capabilities. They are the small controlling unit. They control the small process or small units. They receive and signal to the main control centre. They are like panels near the process we can control that process from these units.

C) Programmable Logic Controllers (PLC):- Programmable Logic Controllers also known as PLC they are connected to the sensors and actuators. Programmable logic controller (PLC) is a multiinput and multoutput device which controls operation of the process. PLC is more complex than the embedded control capabilities than RTUs. PLC contain the memory in it a small memory to store the program. Program used in the PLC is made in ladder logic programming. PLCs are more often used in place of RTUs as field devices because they are more economical and configurable. Also they are easy to learn for the new person to the programming. But it is difficult to learn the embedded one in small time. And PLC handles more input and output devices at one time. It controls the process using relays. And we can reprogram the same PLC for any numbers of time and we can reuse it again and again but in embedded system to reprogram we have to use the new processer for new program. So PLC are more used than embedded system.

PLC Block Diagram.

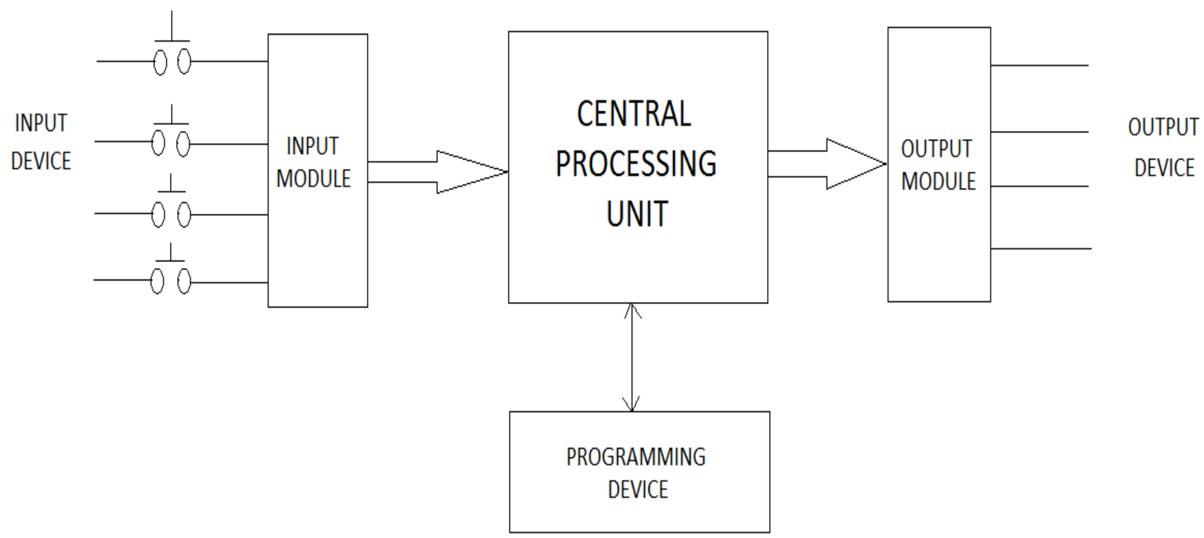


Fig 3.2 PLC

D) Communication Infrastructure:- They connect the RTU and PLCs with supervisory computers. And use the industrial standards or manufacture protocols. Both RTU and PLCs are real time control of the process. They use the last command from the supervisory control of the communication. Of the communication of the system fails between RTU or PLC to control system then there will be no effects on the control process the process will be continue without the monitoring. But if there is loss of communication then we cannot change the process by sending the signal to RTUs. So these communication networks are very important to monitor the process as well as to control the process.

In early days we were using SCADA and other controlling techniques for continuously monitoring of system and control actions were generated according to that fault. But there are some demerits of SCADA like it monitor the system status once in 4-6 seconds. So there may be chances of generating wrong controlling action due to this much large interval because our power system are dynamics and may change in no time. So with the years of research engineers has found that these online monitoring and controlling can be done by synchrophasor technology in this we use phasor measurement unit (PMU) measurement. These measurements also helps to overcome the problems like track the fault location with available monitoring devices.

Other problem with SCADA is in SCADA we can monitor or take measurement of only magnitude of a particular quantity in SCADA we do not take the phasor quantity or angel of current or voltages of the line. And also the time of monitoring of the SCADA is very small that is the time between two readings is very large approximately 4-6 seconds and this time gap is very large monitoring this may couse to the generation of wrong controlling signal and only with magnitude we cannot control or understand the system and faults or disturbances properly. Because if we have a more information like magnitude as well as angels of quantities we can control the system more efficiently.

3.3 Synchrophasor technology

3.3.1 History of Synchrophasor

In 1965 in north east of America blackout was happen. AN understanding of the machine challenge is Couse of development of Symmetrical part Distance Relay (SCDR). This used an advance relaying algorithmic program that was supported measure of zero sequence, positive sequence and negative sequence voltages and currents at the conductor. The most advantage of this algorithmic program was that it needs process of just one equation to find the all doable fault. Which what light-emitting diode to development of algorithmic program for hard the algorithmic program for hard symmetrical part of voltages and currents, which was Symmetrical part separate Fourier remodel (SCDFT). This helps in identifying the positive sequence component of the measurement to be of great significance.

The positive sequenced phasor can be calculated using three individual voltage phasor through the principle of symmetrical component

$$X_1 = \frac{1}{3}(X_a + aX_b + a^2X_c)$$

Where Xa, X_b and X_c are the three voltage phasor and a is their anguler sapration

Where a= 120^0

The first paper which describe the importance of positive sequence phasor measurement was published in 1983[44]. At the same time global Positioning Satellite system was developing and they become the best part of time synchronising measurement from remote terminal locations inside the power system. Now in present time system is capable of achieving synchronisation accuracies of greater than 1 μs, equivalent to 0.018^0 on a 50 Hz system.

3.3.2 Representation in Phasor

A phasor shows a time independent and analytical condition of sinusoidal wave. This Synchrophasor is used to represent the AC system analysis. Below equation is representation of a sinusoidal signal.

$$x\ (t) = X_m\ \cos(\omega t + \varphi\ )$$

This above equation can be represented in phasor form as: -

$$X = \frac{X_m}{\sqrt{2}} e^{j\varphi} = \frac{X_m}{\sqrt{2}} (\cos\varphi + j\sin\varphi) = X_r + jX_i$$

Where root mean square value is represent by $Xm/\sqrt{2}$ of given signal

And phasor angle is represent by φ.

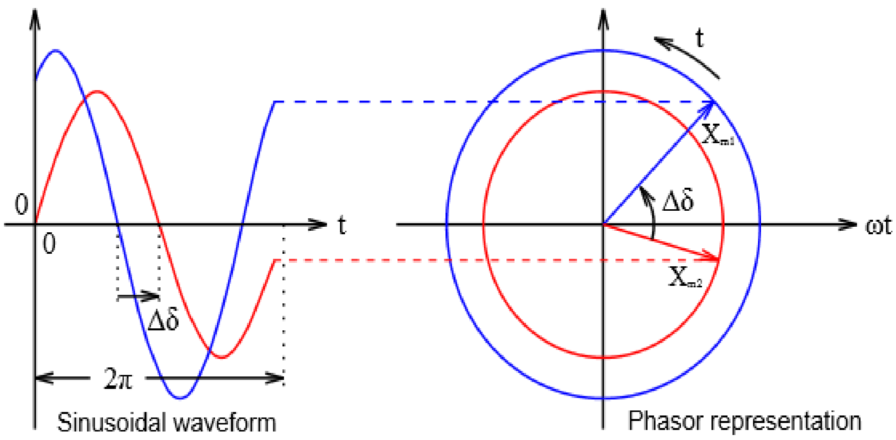


Fig. 3.3 Phasor representation of sinusoidal signal [60]

The above diagram represent the phasor representation of signal one is standers sin signal and with the time shifted signal. Both sin signal are of 2π period, but one is time advance of period $\Delta\delta$ i.e. the phasor difference between both the signal is $\Delta\delta$.

For absolute time reference Synchrophasor use coordinated universal time (UTC). If we use UTC as our one time reference then globally measurement no matter of locations of sampling can be compared directly. [45, 46].

The X is the Synchrophasor representation of the signal x(t) in Equation.

In second Equation where φ is the instantaneous phase angle relative to a cosine function at the nominal system frequency synchronized to UTC. Number of pulses generally one per second signal (PPS) generated by some very precise clocks is used as the reference for the sampling of waveform.

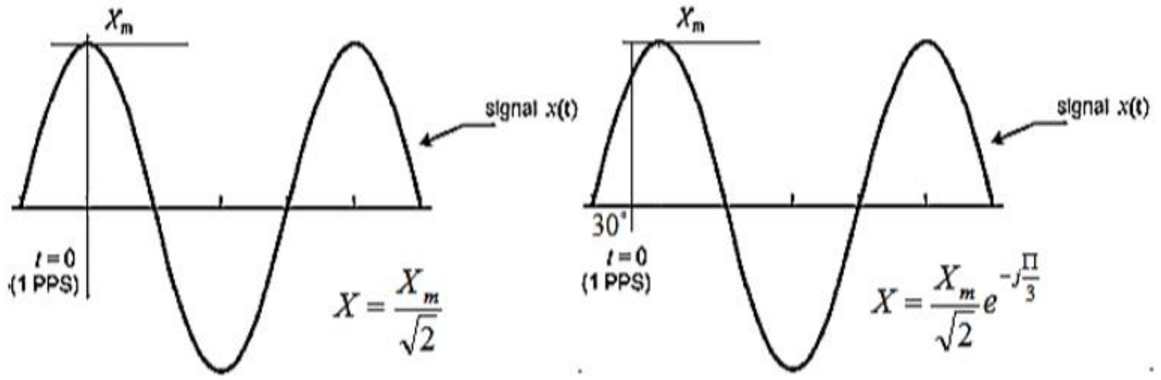


Fig. 3.4 Synchrophasor representation [61]

In above figure we can see the how PPS signal is used as reference signal to measure phasor illustrates how PPS signal is used as a reference to measure phasor. There is phase difference is zero if he PPS signal coincides with the peak of the measured waveform as shown in first case of the figure, and can be represent is equation as:

$$X = X_m/\sqrt{2}$$

For the second case, where the phase difference between the reference peak and the measured signal peak is 60 degrees, the phasor representation is given by:

$$X = \frac{X_m}{\sqrt{2}} e^{-j\frac{\pi}{3}}$$

A practical power system really operate on its fundamental frequency or nominal frequency.

If frequency $f \neq f0$ and $f < 2f0$,

Where f0 is the fundamental frequency of a sinusoidal wave,

The observed phasor will have a constant magnitude. But phase angle change at the rate of $2\pi (f - f0)\ T0$, where $T0 = 1/f0$ and, as shown in figure. [45, 46].

There is phase difference is zero if he PPS signal coincides with the peak of the measured waveform as shown in first case of the figure. Number of pulses generally one per second signal (PPS) generated by some very precise clocks is used as the reference for the sampling of waveform.

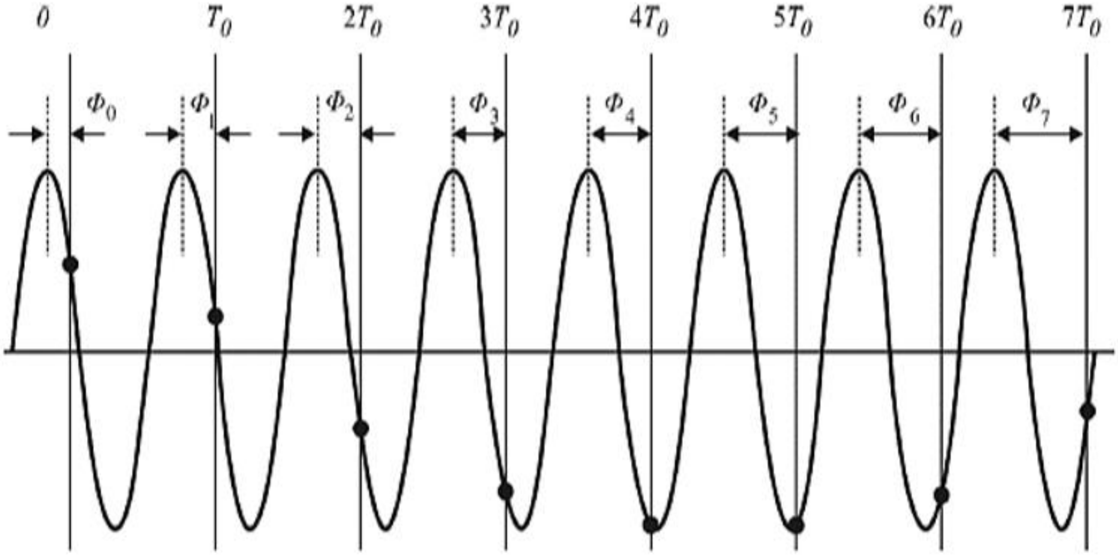


Fig. 3.5 A sinusoid signal showing uniform increase in phase angle[61]

In phasor system some things we have to keep in mind that positive phase angel are measured in counter clockwise or anticlockwise direction from the real axis. And if we include number of phasors in one diagram then they all should be of same frequency. When we represent the phasor signal it actually represent the signal in stationary form. If phasor is constant at all the time this means signal is constant at all the time.

Since this signal is advance therefore in phasor the angel is represented in anticlockwise if the signal is delayed by some angel then in phasors the angel is taken in clockwise direction. And for magnitude in phasors we always consider the root mean square value.

Today the rapidly evolving scenario of distribution grid where the increasing the presence of distribution generators asked for increasing measurement accuracy faster reporting rate and higher communication capabilities.

Above signal represent the phasor of sinusoidal signal which is advance by angel $\Delta\delta$. That is a cosine wave which has maximum peak at –ve value of fie value. And in phasor representation it is representing by the phasor deviated by an angel fie from the real axis. Since this signal is advance therefore in phasor the angel is represented in anticlockwise if the signal is delayed by some angel then in phasors the angel is taken in clockwise direction. And for magnitude in phasors we always consider the root mean square value.

3.4 Phasor Measurement Unit (PMU)

Today in world many countries are affected by many power failures, Because of factors like lack of investment in power system infrastructure, increase in demand of electricity and inadequate asset of maintenance. These things overstress the power transmission and distribution system. Hence companies who invested in power system are suffering from loss of billions of dollar, and it is inconvenience customers as well as for companies. In order to decrease these blackouts the network is required to obtain batter controllability and high reliability and also the stability of power system. And there are many devices that are able to measure and control the power system but now in these days Phasor Measurement Unit(PMU) is most popular because of its different features. The PMU which is used to measure real time data of power system. In real time data we take voltage and current wave forms which include the magnitude as well as phasor of the signal and this data is synchronised with the GPS clock signal. These PMUs are integrated with GPS receiver. And there is one base station which receives continuously synchronous data if there is phase difference between difference PMUs is detected. Phase Measurement Unit called the Synchrophasors are precise grid measurement of electrical signal to determine the situation or condition of the electrical distribution system. PMU measurement generally takes 30 measurements in one second to a common time reference.

Chaeles steinmez was first to introduce the concept of using phasor to describe the AC waveforms in 1893. In 1988 virginia technical researchers Dr. Padke and Dr. Throp develop the first Phasor Measurement unit. In PMU time stamped phase value is simply called as the Synchrophasor. Earlier Synchrophasor capability into protective relay products, thereby making PMU much more affordable. Now these Synchrophasor are available widely from protective relays and meters. There are much more applications that can leverage these data to improve the condition of our power system. Today we use Synchrophasor in many diverse applications for example wide area control, situational awareness, event analysis and stability assessment. It all depends upon us how we process the data once we get it. Weather we use it for controller to make informed decisions, or to island the system. Manage generation or shed load. It needs the mechanism to process it in flexible and easy to understandable manner.

We can use this Phasor Measurement Unit for disturbance recording in power system in wide area monitoring system. Disturbance recording is defined as the change in phasor or RMS value of signal over a long period of time. Disturbance recording is done for future use that hoe power system work in different conditions and power system faults, such as an out-of-step condition, as opposed to power equipment faults, such as a short circuit. The time interval for these "long term" events can range from 1 second (in the case of a fault and high-speed reclose) to many minutes (in the case of system oscillations). The fast sample rates (30 to 60 phasors per second) of today's synchrophasor-based disturbance recording devices can be used to analyse both power system faults and the more traditional power equipment faults. The term Dynamic Swing Recorder (DSR) is also often used to describe a device that captures disturbance data over a long period of time.

Triggers are necessary to initiate recording for the typical DSRs. These typical DSRs have a discrete record length. For continuous recording, triggers provide markers into the key pieces of data during an event. The ability to "share" triggers between multiple sites is also necessary in order to capture a wide-area view of an event. There are different type of triggers available in DSRs, as follows:

1) Magnitude triggers, on voltage, current, frequency, real power, reactive power and apparent impedance

2) Rate-of-change triggers, on voltage, current, frequency, real power, reactive power and apparent impedance
3) Harmonic content triggers, on a specific harmonic frequency, or on total harmonic distortion
4) Delta frequency triggers.
5) Contact triggers, such as breaker operation or communications channel operations
6) Symmetrical components trigger. Frequency rate-of-change and voltage rate-of-change triggers are the most commonly applied triggers.

Previous papers explained that real power rate-of-change triggers also have the sensitivity and selectivity to trigger recording for power system faults, without triggering recording for power equipment faults.

The minimum sampling rate required by NERC is 6Hz. However, a higher sampling rate, such as 30Hz or 60Hz, provides a more accurate picture of the measured electrical quantities during a power system event, providing frequency responses up to 15 and 30Hz respectively. The term Dynamic Swing Recorder is a generic term to describe any device capable of capturing RMS or phasor values of electrical quantities. While typically a DSR is simply a function available in a digital fault recorder, other devices may have the capability to capture this type of data. One such device is the Phasor Measurement Unit (PMU), a device that measures synchrophasors, a highly accurate time-synchronized phasor measurement. The typical PMU is designed to communicate these synchrophasors to system operators for real-time control of the power system. However, some PMUs have the ability to trigger on system anomalies, and record synchrophasor data, to meet the requirements of disturbance recording.

Phasor Measurement Unit is measuring the phase angel to global reference which helps in capturing the wide area snapshot of power system. If we use it effectively then we can prevent our system from blackout and for learning real time behaviour of power system.

Phasor measurement unit (PMU) is a device used to measure the supply waves in lines using a common time source for synchronization. Time synchronize allow to synchronize multiple remote measurement points. PMU is a standalone device that measure 50/60 Hz ac current and voltage and provide frequency and phasor measurement. PMU calculate system frequency, line voltage and/or current phasor at high sampling rate along with GPS time stamp. Phasor measurement unit using synchronization signal from the GPS satellite system have developed into a mature tool.

When a phasor is time stamped with the GPS system then it is called the synchrophasor. This synchronization allows the measurement in different in location to be synchronized and time aligned. Basically GPS is used to provide the common time to all the measurement taken at a time for synchronization. For this each system is to be connecting with minimum four GPS satellites at each time there are total of 32 satellites all around the earth which cover the total 5 continents of earth all the time. The need of connect with four satellites is the send four signal to one GPS receiver one send the latitude second send the longitude and third send the altitude of a location and fourth signal is used to remove the time error.

PMU is use in power system for different purpose and different applications like Protection, real time monitoring, State estimation, and Fault location of transmission line. PMU gives both online (real time). And offline (not real time) applications.

Online applications are such as wide area monitoring and visualization, oscillating detection, frequency stability monitoring, state estimation and current stability monitoring.

In offline applications PMU does the post event analysis, Data visualization, and Model validation. In post event analysis reconstruction of sequence of events after a disturbance has accrued are done. It helps the team of engineers to study the various data and to understand the behaviour of the system during fault and also record data for future usage throughout the grid to understand and reconstruct the timeline easily and time saving.

Other main characteristic of PMU is high accuracy and reporting rates as well as digital communication interface for measurement transmission. Due to wide area of possible applications many PMUs have been installed. Today the rapidly evolving scenario of distribution grid where the increasing the presence of distribution generators asked for increasing measurement accuracy faster reporting rate and higher communication capabilities. PMUs can also be integrated with supervisory control and data acquisition but SCADA operate at lower frequency rates.

Phasor technology provide the high resolution time synchronized data for wide area monitoring i.e. for real time or online monitoring of number of system or stability monitoring

We have different communication method for PMUs like communication into of out of substation include internet connection via fibre or via cable. It may be the serial connection via dial-up technology like on telephone or on radio link. Synchrophasor data can be send by using either internet of by the serial connections. If an internet connection is used then the user can use any of the protocol from User Data Protocol or Transmission control Protocol.

3.4.1 Basic Structure Of PMU

PMU is a device which measure the real time voltage and current and voltage phasor of a network and state estimate the measurements to get all the required variables for controlling and monitoring purpose and frequency of a given node. Due to wide area of possible applications many PMUs have been installed. Today the rapidly evolving scenario of distribution grid where the increasing the presence of distribution generators asked for increasing measurement accuracy faster reporting rate and higher communication capabilities. PMU measure both the magnitude and the phasor of the waveform and give output which is used to find the unknown components used for controlling and monitoring purpose.

PMU consists of three basic units can be given as:-

i. Synchronization Unit with clock
ii. Measurement Unit which measure voltage and current waveforms
iii. Data Transmission Unit to transmit data

3.4.2 Structure of PMU

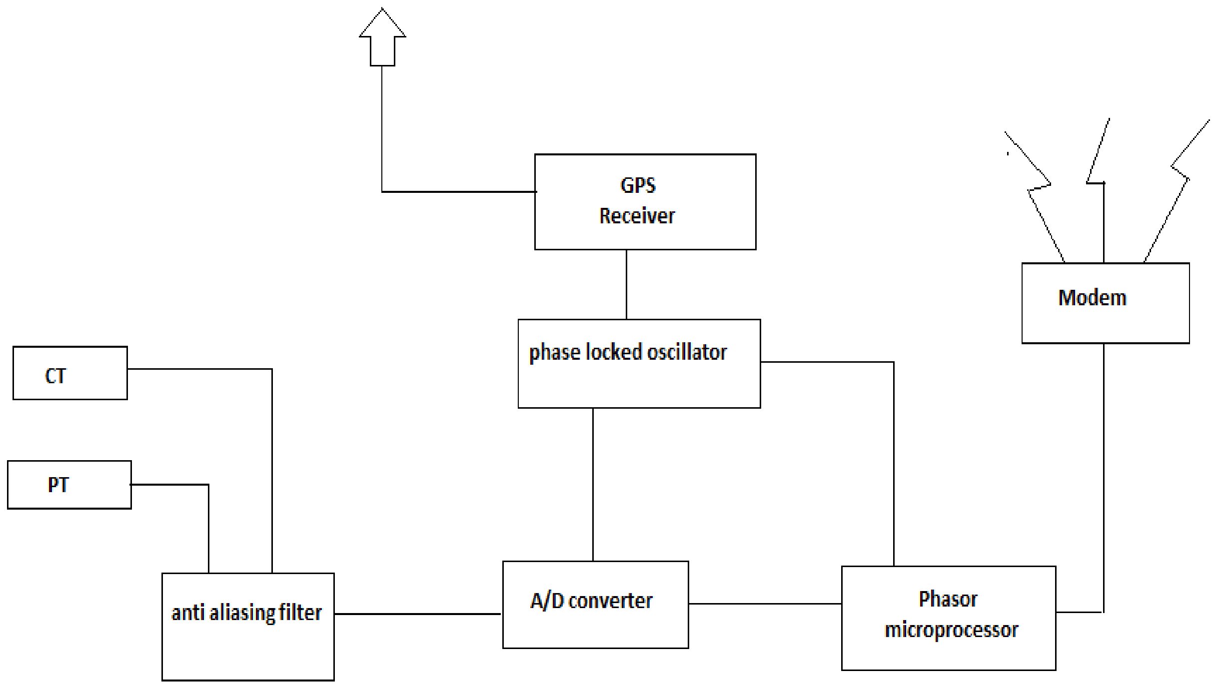


Fig 3.6 Structure of PMU

The Clock Synchronization Unit consist of GPS receivers and phase-locked oscillators, which deliver the sampling signal to measurement unit. The GPS receiver receives the one pulse per second which is generated by an accurate clock and GPS receiver detect this one PPS. Which provide the sampling clock to the Measurement Unit. These both provide high range of accuracy and high-speed synchronized sampling with 1 microsecond accuracy. Actually PLL is an electronic circuit having a variable frequency oscillator and a phase detector. Oscillator generate the periodic signal. The phase detector compares the phase of standard signal with the phase of measurement signal there is change in system if there is phase difference is present and no action is taken till there phases are matched with each other.

3.4.3 PMU Model Diagram

We can do the modelling of PMU in Simulink toolbox in MATLAB. Actually PLL is electronic circuit having a variable frequency oscillator and a phase detector. Oscillator generate the periodic signal. The phase detector compares the phase of standard signal with the phase of measurement signal there is change in system. Which is used for numerical computing allows plotting of functions and data, and interfacing with programs using languages including C, C++.

The main parts of PMU model are described below: -

1) Analog filter for filtering the input signal.
2) ADC for sampling.
3) Measurement Unit for state estimation.

3.4.4 PMU Model Diagram:-

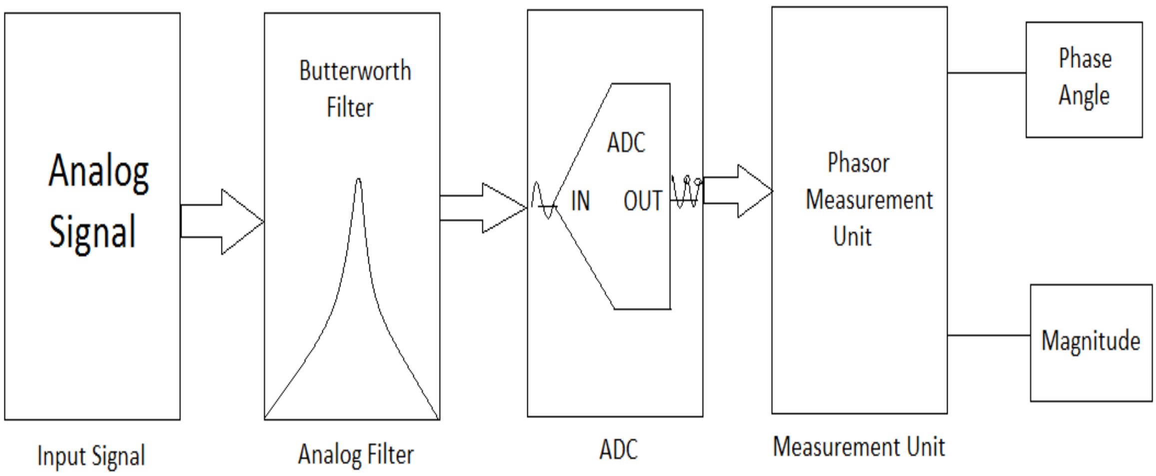


Fig. 3.7 PMU Model

3.5 Description Of Components Of Phasor Measurement Unit

CT and PT are current transformer and potential transformers they are used to measure current and voltage value respectively. They are placed in fields and they are used to measure current and voltage values from the fields. These values are given to the anti-aliasing filters.

According to nyquest sampling theorem the sampling rate should be twice the maximum frequency present in the frequency of interest for that we use anti-aliasing filters. Anti-aliasing filters are filters used select the particular bandwidth of the signal to completely satisfy the sampling theorem over the particular band. Anti-aliasing filters are low pass filters.

Analog to digital converter is used to convert the analog signal to the digital signal basically in A/D converter we use to do sampling of the signal getting from current transformer and potential transformer. And sampling is done according to the nyquest criteria i.e. sampling theorem.

Since PMUs are time stamped devices with GPS signal hence the all contain GPS receivers and GPS receiver receive signal from GPS satellite. There are total of 32 satellites and each GPS receiver is connected with four satellites each time as earth rotates about its axis then first GPS satellite is disconnected from the GPS receiver and the fifth GPS satellite is get connected at the same time. Total of 32 satellites are covering the total of five continents of earth. Each PMU is connected with four GPS satellites at one time and continually they time synchronized the all PMUs connected in wide areas.

Phase lock oscillators are offered to cover the frequency up to range110GHz utilizing high performance FET (field effect transistor) oscillators. They are used to produce desire frequency and output power. Phase locked oscillators are working with internal or external reference signal. And phase noise depends upon the quality of reference signal. They have qualities like they have low phase noise and high output power.

Phasor microprocessor is used to further signal filtering and getting the desired output from the given signal. In phasor microprocessor generally Fourier transform of the signals are done i.e. discrete Fourier transform. After Fourier transform we get the desired information from the signal and that information is send to the PDC through the modems we can also send them with wires but as PMUs are placed at different places hence they are sending signal through wireless transmission.

Modem is used to wireless transmission of the signals taken from the measurements of current transformer and potential transformer. After signal processing with signals from each block of PMU important information Is send to the PDCs through wireless. As discus earlier we can also use the lane system to send the signals but these PMUs are not located nearby they are located very far from each other and also our control unit is also at the main station so we use the wireless transmission. And then these signals are send to control centre through a communication channel from PDCs.

3.5.1 Analog Filter

Analog filter is used to filter out the noises in the input signal to avoid any aliasing errors. The IEEE C37.118 standard makes it compulsory to use this filter which band limits the input signals. Because the measured signal is send to the controlling unit which is far away then there my addition of disturbance due to internal system or there may be noises present due to external system so the are designed to band pass filter with centre frequency f0 = 50HZ and bandwidth Δf = 10 Hz. The filter response should be flat therefor the Butterworth band-pass filter is used as analog filter due to its maximally flat response in pass-band. The Butterworth filter of 2nd order is chosen to obtain better results.

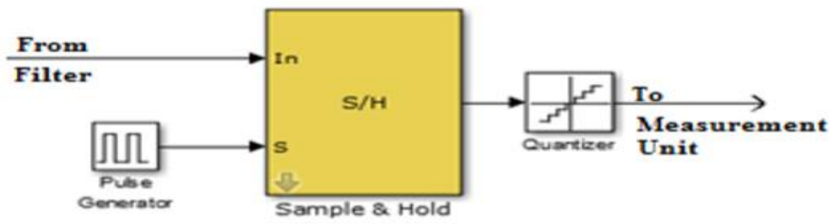
3.5.2 Analog to Digital Convertor

In the present work ADC consist of different parts as given below

1) Pulse generator,
2) Quantizer and
3) And the sampling and holding circuit

Sampling and holding circuit gives the equivalent result of an Analog to Digital Converters (ADC). Sample and hold circuit used to converts the input signal into digital signal. In PMU GPS receiver is used for time stamping. In the work pulse generator has been used. Pulse generator generates 6400 pulses for sampling rate of 128 samples/cycle in 1 second and 1000 pulses for sampling rate of 20 samples/cycle as input signal has been sampled in accordance with output of the pulse generator. PMUs are not located nearby they are located very far from each other and also our control unit is also at the main station so we use the wireless transmission. To round off the error quantizer is used and discretize the input at the interval of 0.5. Sampling in ADC is done for different sampling rates i.e. for 20 samples/cycle and 128 samples/cycle. Because the measured signal is send to the controlling unit which is far away then there my addition of disturbance due to internal system or there may be noises present due to external system so the are designed to band pass filter with centre frequency f0 = 50HZ.

A) Diagram Of Analog To Digital Converter



3.8 Analog to Digital Convertor [61]

3.5.3 Measurement Unit

Measurement unit it is used to measure Phase angle and Magnitude of the voltage signal. For this we use different phasor estimation techniques such as zero crossing, DFT (Recursive and Non-recursive) and sliding DFT are used to measure Phase and Magnitude of the current signal as well as voltage signal. And in this we use different techniques are used to improve accuracy, and reliability. To increase efficiency of power system PMU data must be correct and precise for batter controlling and monitoring.

3.6 Wide Area Measurement

PMU installation is a part of the wide area monitoring network contains the PMUs throughout the grid at selected locations in order to cover the entire grid. The analog inputs to device are the input voltage and current obtain from the CT and PT located in substations.

3.6.1 Architecture Of Wide Area Network

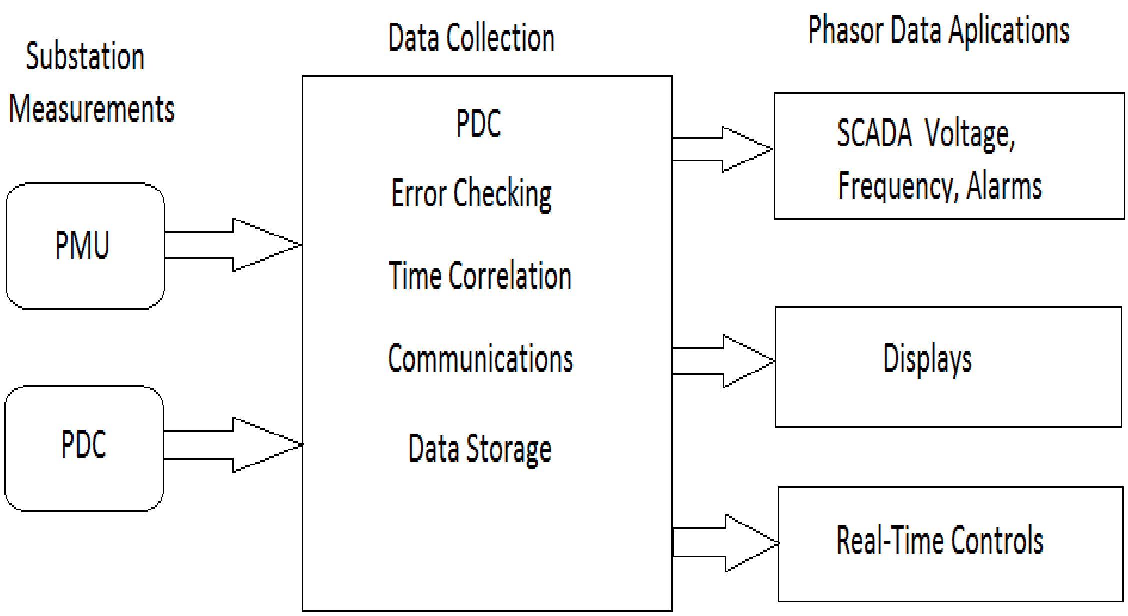


Figure 3.9 Wide Area Network

PMUs are located at the substations and they will provide the time stamped positive sequence of voltage and current of all monitoring busses. These measurements go in small measurement data storage device which is accessible to the remote locations for diagnostic purpose. The device next to hierarchy are commonly known as phasor data concentrators. PDC has a typical function like they gather data from several PMUs and reject the bad data. Than alien the data in time stamped and make a record.

3.7 PMU Utilization In Power System

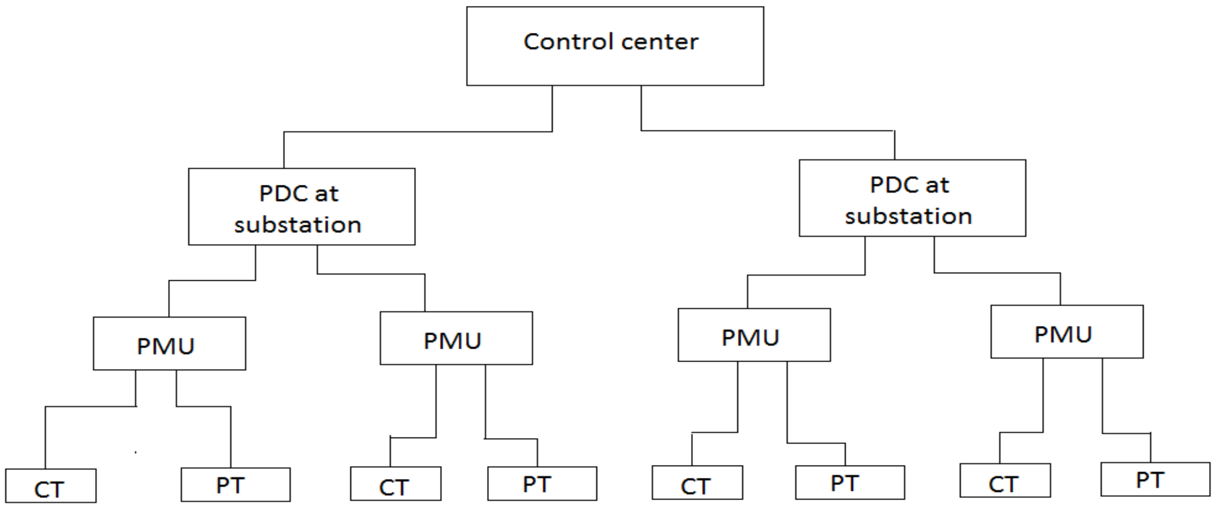


Fig 3.10 PMUs utility in power system

3.8 Phasor Data Concentrator (PDC)

Phasor data concentrator receives the time synchronized phasor data from multiple phasor measurement units to produce real time, time aligned output data stream. One Phasor data concentrator can exchange the phasor data with other Phasor data concentrator at other location through the use multiple PDCs multiple layer of concentration can be implemented within an individual synchrophasor data system. A Phasor data concentrator is design to process streaming time series data with real time.

PMUs are located at the substations and they will provide the time stamped positive sequence of voltage and current of all monitoring busses. These measurements go in small measurement data storage device which is accessible to the remote locations for diagnostic purpose. The device next to hierarchy are commonly known as phasor data concentrators. PDC has a typical function like they gather data from several PMUs and reject the bad data. Than alien the data in time stamped and make a record.

3.9 Real Time Dynamic Monitoring System (RTDMS):-

Real time dynamic monitoring system (RTDMS) is a synchrophasor software application for providing real time wide area situations of operation. Also provide the reliability coordinates and it has capability of monitoring and analyze the dynamics of power system.

RTDMS provide critical information like:-

1) Phasor angel difference
2) Oscillation and damping or can say small signal stability
3) Frequency instability
4) Generation and load imbalance
5) Power angel sensitivity
6) Power voltage stability

3.10 Phasor State Estimation Techniques

Phasor are primarily used for ac circuit analysis that is introduced as a mean of illustration of steady state curving signal of power frequency. Activity these voltage phasor in real time permits operators to ascertain and reply to approaching grid stability issues. Phasor are untypically helpful in describing the behaviour of the facility system although the facility system isn't in steady state. As an example, throughout power swings once the facility system is undergoing mechanical device oscillations, the voltages and currents signal area unit neither in steady state neither is the frequency of the facility system at its face value. underneath these reasonably conditions the variations within the voltages and currents area unit comparatively slow, phasor is also accustomed describe the performance of the network and also the variations being treat as a sequence of steady state conditions.

There are different type of methods that are used for state estimation as listed below [5].

i. Zero Crossing
ii. DFT
iii. Sliding DFT
iv. Least Error Squares
v. Kalman Filters
vi. Demodulation
vii. Phasor measurement angle changing

But we don’t use all of them because they all are not accurate and not easy to use. Out of above given techniques Zero crossing, DFT and Sliding DFT phasor estimation techniques have been used generally.

3.10.1 Zero Crossing

Zero crossing is one of the technique used for state estimation. This technique is uses with phase difference estimation algorithm. In zero crossing algorithm we detect the zero level crossing in measured signal and standard signal for phase difference estimation. In this algorithm pre-conditioning of signal is required in practice. So that it can be prevent additive zero crossings caused by additive noise and signal harmonic components before detection of crossings of zero level. In this method different signals are multiplied with reference sinusoidal signal but the condition is that the frequency of all the signals must be same or with in allowable limits. This technique find the mean value or we can say the DC component of the signal because the mean value is sine of the phase difference of the standard signal and measured signal. The real part or the phasor vector of measured signal is given by phase shift. Then we Multiply this signal by sine reference signal i.e. reference signal shifted by 90° in reference to the first one and finding the mean value by low-pass filter give the imaginary part of the phasor xn of measured signal.

Phase difference of measured signal with the reference signal can be found by using function.

$$tan{-}1(\text{Im } xn/\text{Re } xn).$$

In next step we repeat the same process with the next signal and find the phase difference between standerd signal and second signal. Phase difference of their fundamental harmonic components in case of sinusoidal signals can be distorted by higher harmonic components. The phase difference to be obtain in both the signal is given by the equation.

$$\varphi = \varphi 2 - \varphi 1$$

Above method is one of the best method to measure the phase angle between two busses and find the status of the system. Phase difference was then computed in a straightforward fashion by sending the measured delays to a central point or central control unit. [47].

3.10.2 DFT

DFT is discrete Fourier transform technique this technique is widely used in phasor estimation. In discrete Fourier transform we can use two algorithms to find out the phase i.e. recursive algorithm or non-recursive algorithm. The algorithm that does not take into account data from previous window and calculate phasor estimate fresh is called non-recursive algorithm [48].

Consider a sinusoidal input signal with frequency ω.

$$\text{X(t)}=\sqrt{2}X\sin(\omega t + \varphi)$$

Assuming that x(t) is sampled N times per cycle of the 50 Hz signal to produce the sample set $\{xn\}$ can be given by equation.

$$x_n = \sqrt{2}\sin(\frac{2\pi n}{N} + \varphi)$$

The Discrete Fourier Transform of $\{xn\}$ consist of fundamental frequency component which is given by equation below.

$$X^n = \frac{\sqrt{2}}{N}\sum_{n=0}^{N-1} x_n \cos(2\pi n/N) + j\frac{\sqrt{2}}{N}\sum_{n=0}^{N-1} x_n \sin(2\pi n/N)$$

In recursive algorithm we take the data from previous window in reordered form. And the fundamental frequency component is given by equation.

$$X^{n+1} = X^n + \sqrt{2}/N(x_{N+n} - x_n)e^{-jn\theta}$$

In DFT (Discrete Fourier Transform) we transform the input signal from time domain to frequency domain. The frequency domain contains exactly the same information as the time domain, just in a different form. Because in frequency domain calculations become easy and also the calculations decreases. If we know one domain then other can be calculated.

In frequency domain X(k) consists of two parts i.e. real Re X(k) and imaginary Im X(k) with which magnitude and Phase of the signal at each point.

3.10.3 Sliding DFT

Sliding DFT is advancement of DFT. This processes have one more advantage that it requires fewer computations than the DFT for real time spectral analysis. The sliding DFT (SDFT) algorithm performs an N-point DFT on time samples within a sliding-window. The time window is then advanced one sample and a new N-point DFT is calculated. Then spectral components of a shifted time sequence are the original (upshifted) spectral components multiplied by $ej2\ \pi k/N$ where k is the DFT bin of interest then the SDFT can be calculated with the help of equation below.

$$S_k(n) = S_K(n-1)e^{\frac{j2\pi k}{N}} - x(n-N) + x(n)$$

Where spectral component is represent by (n).

Comparison of computations in different techniques is given bellow:-

For the N-point output

1) For the sliding DFT the computations done is N
2) For DFT it is (N^2)
3) And for FFT (N $\log(N)^2$) [49].

3.11 Applications Of Phasor Measurement Unit To Power System

1) It check real time operation of grid and support the operation providing information of number of areas.
2) PMUs data is used for planning purpose.
3) For the control applications.
4) Large Motors
5) SIPS
6) Capacitor Bank Performance
7) For Disturbance Recording
8) Analysis of Load Shedding Schemes
9) Post disturbance analysis
10) Power system restoration
11) State estimation
12) Real time control
13) Adaptive protection

In the industrial atmosphere, there are many processes in which we start and stop number of times depend upon requirement and sometime problems may accrue for example either abort a start-up or undesired shut-down.

Capacitor Banks are used to help to maintain the flat voltage profile on the transmission and distribution system. They are installed on top of the tower or in the control unit side they are large in size and also they are heavy in nature. Capacitor banks are installed with some type of automatic control switches so that they can be switched in during faulty conditions and switch off during the normal conditions or we can say after fault clearance. And system frequency capacitor banks can also take these measurements as their reference for switch on and off. Analyses of Load Shedding Schemes Under frequency and under voltage to protect from system collapse we use load shielding scheme.

In PMU we have to do state estimation for eliminating the errors and estimate the state of the system as in real as possible because in PMU we have different transducers that have a particular error limits those error leads to wrong estimate the system stage and this may cause to wrong generation of control signal and may by wrong tripping of system. So to stop these problems or controlling and monitoring the system more efficiently we need to remove these errors and find real state of the system.

For this we use different state estimation techniques and the techniques are listed below all are not very accurate we use generally 2 or 3 techniques.

1) The maximum likelihood criterion
2) The weighted least squares criterion
3) The minimum variance criterion.

3.12 Challenges In Phasor Measurement Unit

1. Selecting suitable location for PMU
2. Low frequency oscillation monitoring
3. Communication delays
4. Integration of this technology with SCADA
5. Difficult to predict the distorted power system waveforms
6. Large computational requirements
7. Development of tools for depth analysis of system
8. High investment

There are number of challenges in Phaser Measurement Unit installation. As listed above PMUs are costly hence we need to install them at particular location only through optimization for that we have different optimization techniques. The main problem with PMUs is Cost problem which leads to the selection of location of installation of PMU. Because to install one PMU require more money and to reduce that money we try to minimize the number of PMUs in the system. After installation it is difficult to predict that the measured wave is original or distorted. And after that large computation is required.

3.13 Limitations Of PMU

1. Out of band frequency difficult to realize in testing
2. Not focused on communication issues

3.14 Calibration Of PMU

1. We need the calibration of PMU to remove errors in station sensors
2. For time synchronization accuracy
3. For removal of inherent error in the PMU devices over time

For above reasons we have to do the calibration for the PMUs. And it is done with the help of device called as standard test set. This test signal is capable to produce the GPS based synchronized signal.

Before installation of PMUs in the field we need to test the PMUs for their proper working. If there are errors in any PMU set. Then we remove it by calibration. Now but during testing of Phasor Measurement Units we face some difficulties like

Harmonic distortion according to the standard testing of any device over frequency then we have to check for the harmonies situation in the system for up to the 50^{th} harmonic but in real it is difficult to produce the 50^{th} harmonic for testing signal. And we also get difficulty during the testing of out of band difficulties. And for communication also we get some difficulties for testing of communication in control network we need more data to check the reliability of the communication of the network.

CHAPTER 4

Optimization

CHAPTER 4

OPTIMIZATION

4.1 Optimization

Optimization saturates what we do and drives almost every aspect of engineering.

-Dennis Bernstein

As indicated by above quote it can be said that optimization is a part of almost everything that we do. For example personal schedule need to be optimized, teaching style need to be optimized, economic style need to be optimized biology system need to be optimized, optimization is a fascinating area of study because not only of its algorithms but also its universal applicability.

4.2 Unconstrained Optimization

Optimization is applicable to all areas of life. Optimization algorithm can be applied to any thing. The possible applications of optimization is limited only by imagination. This is the reason why optimization become the widely researched area in past few decades.

Let's take an engineering example optimization is used to find the best robot path for a particular task. Suppose in your manufacturing plant you have a robot, and you want to do a particular task in such a way that it takes minimum time and with least power consumption. For that there are so many possible ways in which that task can be done but which is optimized one means which is best path so that minimum time and minimum power consumption is done by the robot this task is done easily quickly with the help of optimization. Optimization can find you the good solution (if not exactly the best).

Optimization algorithms are also used to train the neural network and fuzzy logic system. Because in neural network we have to figure out the network architecture and neural weights in order to get the best possible performance.

An optimization problem is problem of either minimizing a function of to maximize the function. Because in optimization some time we try to minimize a function or some time we need to maximize the function. These two problems can be easily converted to other forms as shown.

$$\begin{aligned} \min_x f(x) \quad &\Longleftrightarrow \quad \max_x[-f(x)] \\ \max_x f(x) \quad &\Longleftrightarrow \quad \min_x[-f(x)]. \end{aligned}$$

The objective function is F(x).

Independent variable is x.

The term independent variable or specific element refers to x or some time some specific element in x depending upon the context.

When we try to minimize the function then we call the function as cost function.

And when we try to maximize the function then the function is called as the fitness function.

$$\min_x f(x) \quad \Rightarrow \quad f(x) \text{ is called "cost" or "objective"}$$
$$\max_x f(x) \quad \Rightarrow \quad f(x) \text{ is called "fitness" or "objective."}$$

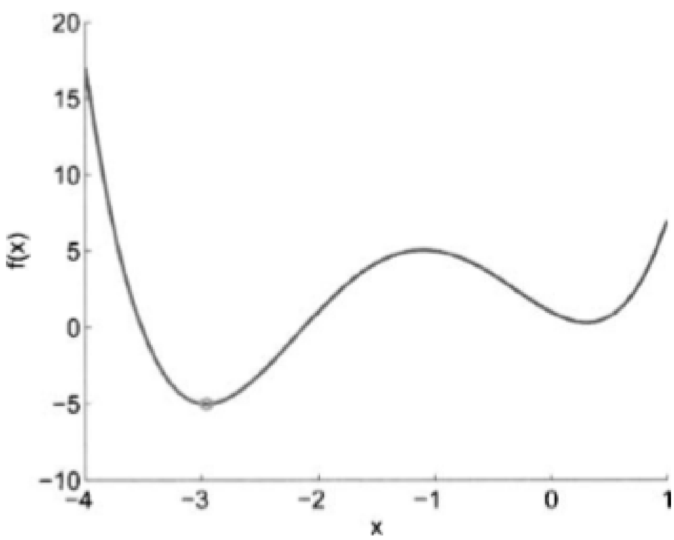
Consider a problem

$$\min_x f(x), \text{ where } f(x) = x^4 + 5x^3 + 4x^2 - 4x + 1.$$

Since f(x) is a quartic polynomial (also called fourth order or fourth degree), we know that it has at most three stationary points, that is, three values of x at which its derivative f'(x) = 0. These points are seen from Figure to occur at x = -2.96, x=1.10, and x = 0.31. We can confirm that f'(x), which is equal to 4x3 + 15x2 + 8x- 4, is zero at these three values of x. We can further find that the second derivative of f(x) at these three points is

$$f''(x) = 12x^2 + 30x + 8 = \begin{cases} 24.33, & x = -2.96 \\ -10.48, & x = -1.10 \\ 18.45, & x = 0.31 \end{cases}$$

We know from mathematics that the second derivative or a function at a local minimum is positive and second derivative of a function at a local minimum is negative.



4.1 Plot of example minimization problem [62]

A simple minimization problem. f(x) has two local minima and one global minimum, which occurs at x = -2.96.

The function of Example has two local minima and one global minimum. It can be noted that the global minimum is also a local minimum. For some functions minx f(x) occurs at more than one value of x if that occurs then f(x) has multiple global minima.

4.3 Constrained Optimization

Many times an optimization problem is constrained. That is, we are presented with the problem of minimizing some function f(x) with restrictions on the allowable values of x,

Consider the problem 2

$$\min_x f(x) \quad \text{where} \quad f(x) = x^4 + 5x^3 + 4x^2 - 4x + 1$$
$$\text{and} \quad x \geq -1.5.$$

This is the same problem as that in Example except that x is constrained. A plot of f(x) and the allowable values of x are shown in Figure, and an examination of the plot reveals the constrained minimum. To solve this problem analytically, we find the three stationary points of /(x) as in Example while ignoring the constraint. We find that the two local minima occur at x = -2.96 and x = 0.31, as in Example. We see that only one of these values, x = 0.31, satisfies the constraint. Next we must evaluate f(x) on the constraint boundary to see if it is smaller than at the local minimum x = 0.31. We find that

$$f(x) = \begin{cases} 4.19 & \text{for } x = -1.50 \\ 0.30 & \text{for } x = 0.31 \end{cases}$$

If the constraint boundary were farther to the left, then the minimizing value of x would occur at the constraint boundary rather than at the local minimum x = 0.31. If the constraint boundary were left of x = -2.96, then the minimizing value of x for the constrained minimization problem would be the same as that for the unconstrained minimization problem.

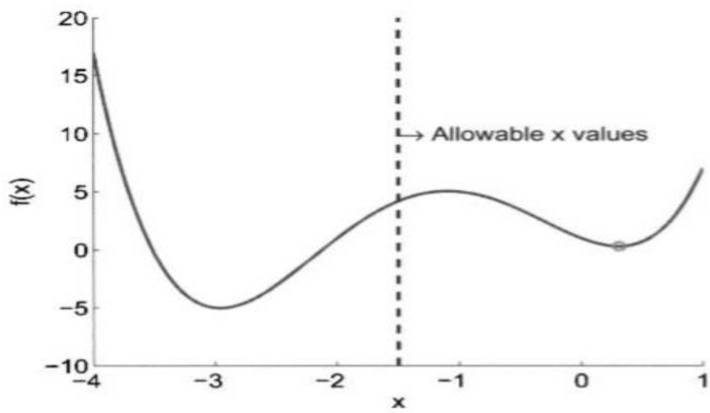


Fig. 4.2 Plot of example Constrained Optimization [62]

Real-world optimization problems almost always have constraints. Also, the optimizing value of the independent variable almost always occurs on the constraint boundary in real-world optimization problems. We all want to obtain the best result for the function.

4.4 Multi-Objective Optimization

Not only are real-world optimization problems constrained, but they are also multi objective. This means that we are interested in minimizing more than one measure simultaneously. For example, in a motor control problem we might be interested in minimizing tracking error while also minimizing power consumption. We could get a very small tracking error at the expense of high power consumption, or we could allow a large tracking error while using very little power. In the extreme case, we could turn off the motor to achieve zero power consumption, but then our tracking error would not be very good.

Consider the Example

Minimize the both function [f(x) and g(x)]

Where f(x) = $x^2 + 5x^3 + 4x^2 - 4x + 1$

And g(x) = $2(x + 1)^2$

The first minimization objective, is the same as that in Example 2. But now we also want to minimize g(x). A plot of f(x), g(x), and their minima, are shown in Figure 2.3. An examination of the plot reveals that x = -2.96 minimizes, while x =-1 minimizes g(x). It is not clear what the most preferable value of x would be for this problem because we have two conflicting objectives. However, it should be obvious from Figure 2.3 that we would never want x < -2.96 or x> 0.31. x decreases from -2.96, or increases from 0.31, objectives f(x) and g(x) both increase, which is clearly undesirable.

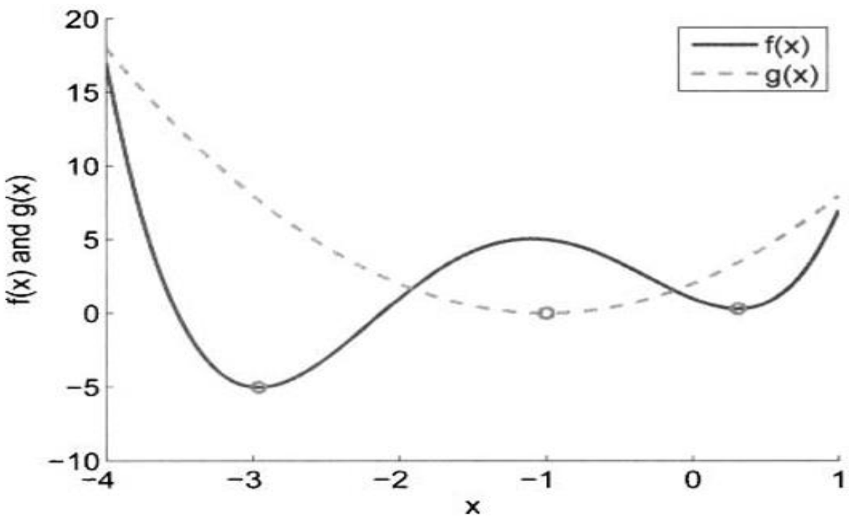


Fig. 4.3 Plot of example Multi-Objective Optimization [62]

4.5 Multimodal Optimization

A multimodal optimization problem is a problem that has more than one local minimum. We saw an example of a multimodal problem in Figure 2.1, but there were only two local minimum in that problem so it was fairly easy to handle. Some problems, however, have many local minima and it can be challenging to discover which minimum is the global minimum.

4.6 Combinatorial Optimization

Up until now we have considered continuous optimization problems; that is, the independent variables have been allowed to vary continuously. However, there are many optimization problems. These types of problems are called combinatorial optimization problems.

The traveling salesman problem (TSP).We can easily enumerate all of the possible solutions for a four-city TSP. Searching through all possible solutions of a combinatorial problem is called a bruteforce search, or exhaustive search. If you have time to do that, then it is often the best way to solve a combinatorial problem because it guarantees a solution. But how many possible solutions exist for a general n city TSP? A little thought shows that there are (n-1)! Possible solutions. This number grows very rapidly, and for modest values of n it is not possible to calculate all possible solutions. Suppose the business person needs to visit one city in each of the 50 states in the USA. The number of possible solutions is 49! = 6.1 x 1062. Could modern computers calculate this number of possible solutions? The universe is about 15 billion years old, which is 4.7 x 1017 seconds. Suppose a trillion computers were running since the beginning of the universe, and suppose each of those trillion computers could calculate the distance for a trillion possible solutions every second. Then we would have calculated the distance for a total of 4.7 x 1041 possible solutions. We would not even have scratched the surface of solving the 50-city TSP. Here is another way of looking at the complexity of the TSP. There are somewhere between 1020 and 1024 grains of sand on earth. If each grain of sand on earth were an earth-like planet with the same amount of sand that earth has, then the number of possible 50-city TSP routes would still be much greater than the total number of mini-grains of sand. Obviously it is impossible to do a brute force search for the solution of such a large problem.

We see that some problems are so large that a brute-force approach is simply not feasible. Also, combinatorial problems like the TSP don't have continuous independent variables and so they cannot be solved with derivatives. Although we can never be sure that we have the best solution to a combinatorial problem unless we try every possible solution, optimization provide a powerful way to find good solutions. Optimization are not magic, but they can help find at least a good solution (if not the best solution) to these types of large, multidimensional problems.

In general, the Optimization algorithms can be classified into three categories as given bellow: [50].

1. Deterministic Method
2. Heuristic Method
3. Meta Heuristic Method

Different type of techniques which comes under different type of groups are listed as.

4.7 Heuristic Method

In Heuristic Method we do the approximation so it is Approximation type of Algorithm, it is a one class of mathematical algorithm that do the optimization or to determine the location of PMUs so that complete system is observable with in the computational time and the system memory. Heuristic Methods used to find the good solution when an exhaustive search is impractical. But there is one problem with heuristic method that the final output obtain from Heuristic Method cannot be guaranteed to be exact solution.

The Algorithms which comes under **Heuristic Method** are

i. Depth First Algorithm (DFS)
ii. Domination Set (DS)
iii. Greedy Algorithm (GA)

4.8 Meta-Heuristic Method

Meta Heuristic Method, these are advance or improved version of the Heuristic Method, Meta Heuristic Method is some kind of intelligence search method and it covers with discrete variables also with discrete cost function [51]. What we do in Meta Heuristic Method is combining different algorithms to find out the optimized solution for the location of PMUs.

The Algorithms which comes under **Meta-Heuristic Method** are listed below:-

i. Genetic Algorithms (GA)
ii. Particle Swarm Optimization (PSO)

4.9 Deterministic Methods

Deterministic method is method which can predict behaviour based upon previous measurements. These algorithms are first trained with the theoretical inputs. In other words, we give particular inputs to generate the output. And this algorithms is most familiar and mostly used.

The Algorithms comes under **Deterministic Methods** are

i. Integer Programming
ii. Binary Search Method

Now some of above algorithms are explained below

4.10 Depth-First Algorithm (DFS)

Depth-First Algorithm is a type of Heuristic Method. To find the optimal location of PMUs in IEEE standard 57-Bus system and in 14- Bus system Depth-First Algorithm is used. We all know that there are lot of similarity in our power networks, therefor different type of several graph theories have been used to solve the optimization problem. Farsadi has done his work on Depth First Algorithm to determine the optimal location of PMU in IEEE standerd 57 Bus system and 14 Bus system. In this algorithms we first find the bus which is connected with highest number of buses connected and locate the PMUs to those buses. If there was more than one bus with same number of connections then in this condition one randomly bus is chosen and PMU is placed there and with same method PMUs are place until all network observability is obtained.

If we compare this algorithm with other algorithm with other optimization algorithms with PSAT software then the Detpth First Algorithm don't give you the best solution for the given system.

This approach is described in Fig. below.

4.10.1 Depth-First Algorithm Flow Chart

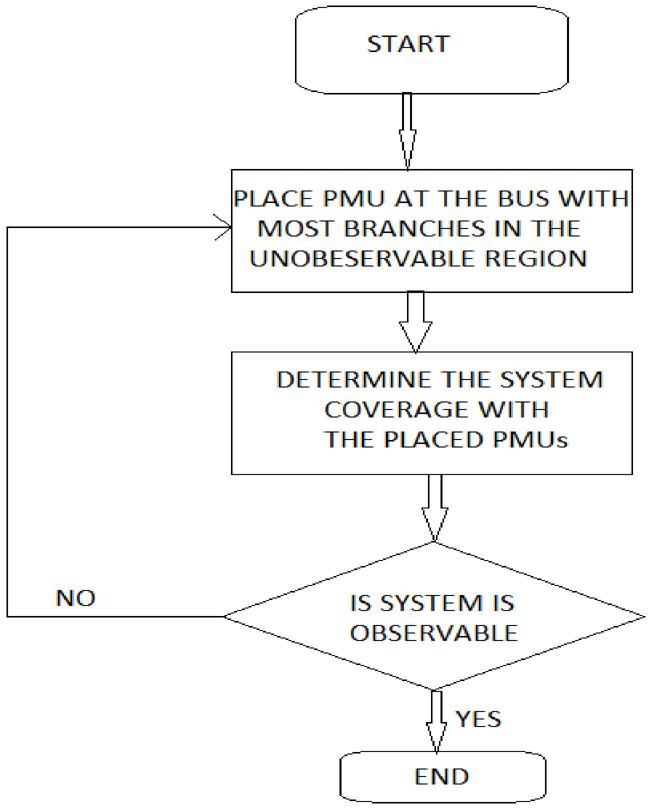


Fig. 4.4 Depth-First Algorithm Flow Chart

Advantage of Depth-First Algorithm DFS are

1) DFS is high efficient computationally.
2) DFS has high convergent speed as compare to other algorithms such as Simulated Annealing Method (SA)
3) And DFS use Minimum Spanning Tree Method (MST).

But there is one problem that this algorithm is failed in considering network, so it is not sure the result will be best optimal result.

4.11 Domination Set

Domination set theory is mostly used in different graph Theories, with the help of Domination Set we find the minimum number of points where we locate our device which cover the whole network for observing the whole graph. Author Haynes [52] use the domination set for complex power network. From the measurement of PMUs of voltage and phase angle, the author mathematically gives rules for optimization and investigated the theoretical properties of $\gamma p(T)$ in trees T with restrictions. Consider a network shown in figure 4.5 the network is 6- bus system. And domination set theory is applied to this network. In figure we can see that the nodes with red colours are location given by domination set theory to make the network observable.

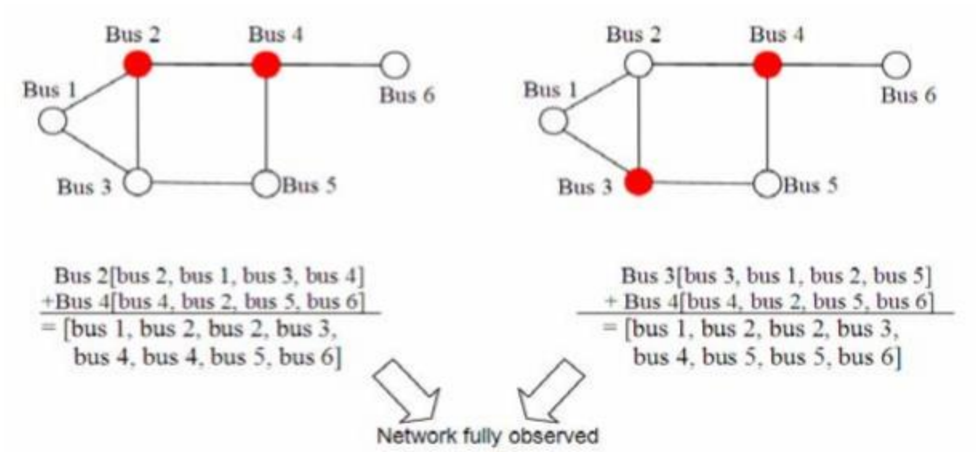


Fig. 4.5 6-bus system with Domination Set[63]

In this paper the author describe the rules for domination set theory and the procedure for the domination set theory is clearly describe during the procedure and with flow diagram. Paper present the solution for the IEEE standard 14- bus system and for 39 bus system New England however the precise location of PMUs are not describe in this paper.

4.12 Greedy Algorithm

Greedy algorithmic rules are used to find out the smallest number of PMUs required to get the fully observable network.

Basically, Greedy algorithmic rule give choices in step with one rule and that is at every stage, opt for and place the PMU to the bus which covers the highest variety of uncovered buses,

$$X=S\_i1, S\_i2\ldots S\_ik.$$

Whereas X wasn't empty.

4.13 Genetic Algorithm

4.13.1 History Of Genetic Algorithm

Charles returned home to England in 1836 at the age of 27. Almost immediately after his return to England, he began working on his book Origin of Species [Darwin, 1859], which would end up being a decades-long project. He also was active in writing journal papers and speaking at conferences. He continued studying and learning as he began putting together a coherent theory of natural selection. Natural selection says that the most fit individuals survive and pass on their characteristics to their offspring. This is how adaptation takes place - through the "survival of the fittest." As Charles continued working on his book, he was hesitant to publicize his theory of evolution. Having studied the ministry for three years, he knew that his theory could generate a storm of controversy because of its possible contradiction with the Bible. He wanted to build an air-tight case and a true magnum opus before publishing his results.

Genetic algorithms (GAs) are the earliest, most well-known, and most widelyused EAs. GAs are simulations of natural selection that can solve optimization problems. In spite of the above quote by Kenneth De Jong, GAs often serve as effective optimization tools. De Jong's quote emphasizes the point that GAs were originally developed to study adaptive systems rather than to optimize functions. GAs comprise a much more broad class of systems than function optimizers. We can use GAs to study the dynamics of adaptive systems, to provide advice to fashion designers [Kim and Cho, 2000], to provide design tradeoffs to bridge designers [Furuta, 1995], and for many other non-optimization applications. Sometimes the dividing line between an optimization algorithm and a non-optimization algorithm is fuzzy because all algorithms attempt to function as well as possible. In any case, our main interest in GAs in this book is their specific application as optimization algorithms. To begin our study of GAs, we observe some basic features of natural selection.

1) A biological system includes a population of individuals, many of which have the ability to reproduce
2) The individuals have a finite life span.
3) There is variation in the population.
4) The ability to survive is positively correlated with the ability to reproduce.

Genetic algorithms simulate each of these features of natural selection. Given an optimization problem, we create a population of candidate solutions, which we call individuals. Some solutions are good, and some are not so good. The good individuals have a relatively high chance of reproducing, while the poor individuals have a relatively low chance of reproducing. Parents beget children, and then the parents drop out of the population to make way for their offspring. As generations come and go, the population becomes more fit. Sometimes one or more "supermen" evolve to become highly fit individuals that can provide near-optimal solutions to our engineering problem

Crossover is first genetic operator it take 2 people represent as a folk and these folks produce one or two new people and the new one referred as offspring.

The author Marin [31] utilized Genetic algorithmic program to work out the optimum variety of phasor mensuration units in an exceedingly facility network.

From the equation represent below the best results are obtained with

a=1, b=2 and c=1.

$$f = aN_{PMU} + bN_H + cN_{PMU}N_H$$

In above equation a, b and c are constants.

The below steps are used in genetic algorithm.

1st step: in first step observe the network, to produce the chromosome corresponding to the network.

2nd step: in second step produce initial population according to the network.

3rd step: For every chromosome, calculate their fitness function.

4th step: after that selection operator is applied.

5th step: crossover operator is applied in this step.

6th step: use mutation operator.

7th step: then use elitist strategy.

8th step: after that go back to step number three and repeat until they complete gene generations.

Power system	λ	∂ [%]	b	ph	$R=ph/b$
IEEE 14-bus	3	21.4	6	4	0.66
IEEE 30-bus	7	23.3	8	3	0.38
IEEE 57-bus	12	21.1	7	3	0.43
IEEE 118-bus	29	24.6	10	5	0.50

Table 4.1 list for number of PMUs required using GA [11]

Consider three individuals: Chris has two brown-eye genes, Kim has two green-eye genes, and Terry has a brown-eye gene and a green-eye gene. Since Chris has two brown-eye genes, Chris has brown eyes. Since Kim has two green-eye genes, Kim has green eyes. Since Terry has one brown-eye gene and one green-eye gene, and the brown-eye gene is dominant, Terry has brown eyes.

Chris: brown/brown - brown eyes

Kim: green/green - green eyes

Terry: brown/green - brown eyes

If Chris and Terry mate, they will each contribute one eye-colour gene to their offspring. Their offspring could therefore have either two brown-eye genes, or else one brown-eye gene and one green-eye gene. All of their offspring will have brown eyes since brown is dominant. If Chris and Kim mate, their offspring will all have one brown-eye gene from Chris and one green-eye gene from Kim. All of their offspring will have brown eyes since brown is dominant. If Terry and Kim mate, their offspring will have either one brown-eye gene and one green-eye gene, or two green-eye genes. Their offspring could either have brown eyes or green eyes.

4.14 Particle Swarm improvement (PSO)

Particle Swarm improvement (PSO) methodology was given by Eberhart and Kennedy in 1995 [53] for researching social behaviour, particularly for simulating the movement of organisms during a bird flock. it's a population-based search rule that exploits a population of people to probe promising regions of the search house. The population here referred to assist named is termed a swarm and also the people area unit called particles.

As mentioned by Sadu, Kumar and Kavasseri [54], PSO is the best method to find the location of PMUs to make complete network observable. Particle Swarm improvement provide high performance by giving less number of iteration and hence less time consuming method as compare to other original algorithms. Like Original organism rule (CLONALG) [35] and adaptive organism rule (CLONALG) [55].

Author Ahmadi [56] describe the binary particle swarm improvement (BPSO) method for the best placement of phasor measuring units. The author gives the success outputs for the PMUs at précised locations.

4.15 Deterministic ways

In computing, a settled rule are often outlined as a rule that's ready to determine the behaviour of the system. In alternative system give specific parameter to the input of the system and from that the expected outcomes are generated. Settled rules area unit out and away the foremost studied and acquainted reasonably algorithm.

4.16 Integer Programming

Aminifar [57] developed a method for Phasor Measurement Unit of contingency forced placement in the network either they are complex or simple networks. By the use of applied mathematics and with simulation model the line outage and the fault location in transmission and distribution network is obtain with the help of measurements obtain from the PMUs. And the final results, the desired range of PMUs in every state of affairs are compared.

By the use of applied mathematics and with simulation model the line outage and the fault location in transmission and distribution network is obtain with the help of measurements obtain from the PMUs

4.17 Binary Search

This BS algorithm rule that are planned, by Chakrabarti and Kyriakides [58] are not to verify the minimum number of PMUs required. A thoroughgoing BS algorithm was used to calculate the smallest range of PMUs required to create system absolutely noticeable. Generally we can say complete range of network is measured as.

$$N_{solution} = \frac{P!}{N_{PMU}!(P - N_{PMU})!}$$

Where total number of busses are represented by parameter P and

Number of PMUs required are represented by the parameter N_{PMU}.

It can be seen that whole buses within the power network can have an effect on the whole machine time in an exceedingly random relation. For the aim to reduce the execution time amount is introduce the theoretical edge to reduce the number of PMUs required to observe the network completely. This is derived from equation. [57].

$$N_{PMU}^{ub} = [(N + s/2)/3]$$

Where number of busses in power system in network is represent by parameter N

And unknown power injection number is S.

According to author [58], if the given system is not observable with the any combination of PMUs got from the algorithm then the number of PMUs are increased by one for example NPMU= (NPMU+1). And if given system is observable then the number of PMUs are decrees by one value for example NPMU= (NPMU-1). This search is continuously going on till the minimum number is obtain with which our network is completely observable. An exhaustive set of combinations of size (NPMU-1) was examined for observability before concluding that NPMU is the minimum number of PMUs.

Through the above described procedure ensure the complete observability of the network underneath traditional operational conditions moreover as underneath the outage of one cable or one PMU.

It can be seen that whole buses within the power network can have an effect on the whole machine time in an exceedingly random relation. For the aim to reduce the execution time amount is introduce the theoretical edge to reduce the number of PMUs required to observe the network completely. As indicated by above quote it can be said that optimization is a part of almost everything that we do. For example personal schedule need to be optimized, teaching style need to be optimized, economic style need to be optimized biology system need to be optimized, optimization is a fascinating area of study because not only of its algorithms but also its universal applicability

4.17.A Flow Diagram for Binary Search Algorithm:-

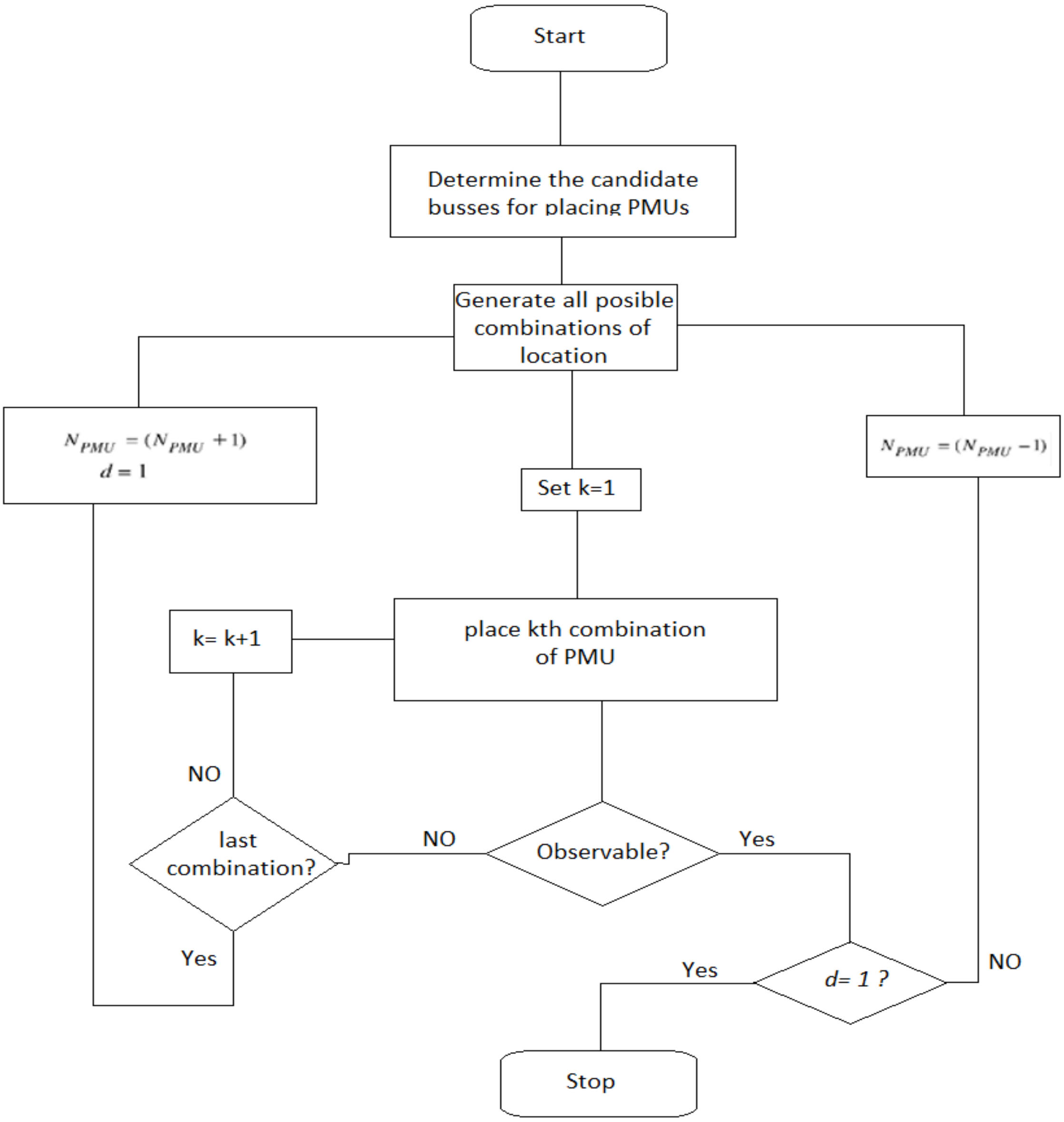


Fig. 4.6 Binary search algorithm [42]

4.18 The Rules of Network Observability

Rules for network observability are based on nodal voltage and the branch current. Different rules have been used to observe the network to make sure that the given network is observable absolutely evident.

Rule 1: PMUs are put in that buses from where we can find the voltage phasor and current phasor of all its incident branches area unit known. These area unit referred to as 'direct measurements'. in keeping with the operate of the phasor measuring unit, a PMU situated at Bus D, shows that we can find the voltage is a directly measured.

In Rule 1, the known parameters measured by PMU are VD, IAD, IBD and ICD. And PMU measure the branch currents and the characteristic of transmission line are

$$R_{AD} + \mathrm{j}X_{AD},$$

$$R_{BD} + \mathrm{j}X_{BD},$$

$$R_{CD} + \mathrm{j}X_{CD}.$$

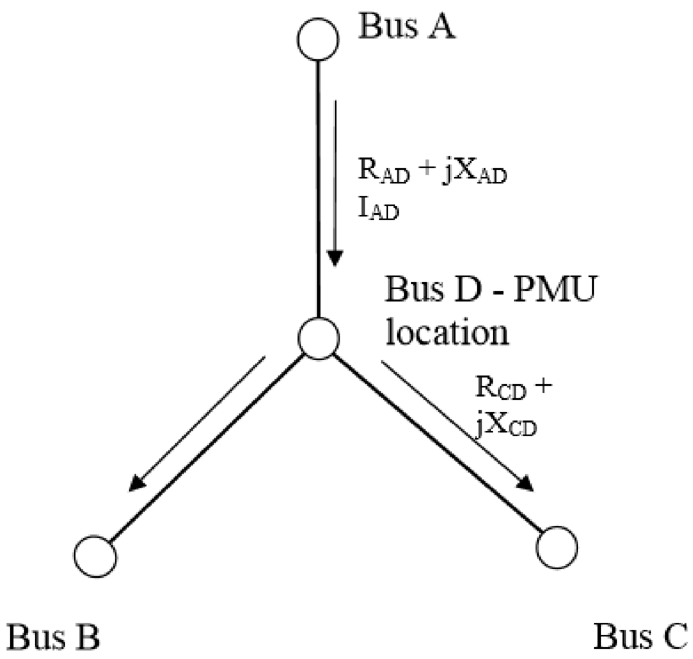


Fig. 4.7 1st rule of observability [63]

Rule 2: In rule 2 if the voltage and current phasor of one bus are known the the voltage phasor at the opposite finish of the branch are often obtained exploitation equation. These area unit referred to as 'pseudo measurements'.

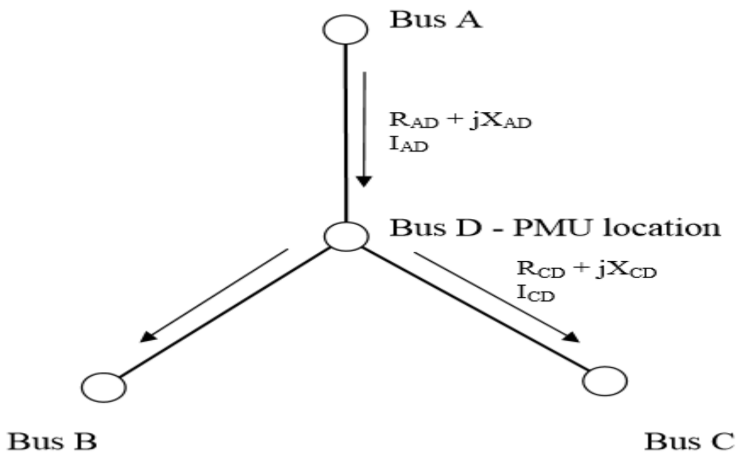


Fig. 4.8 2nd rule of observability [63]

After getting the known parameter from measurement like line resistance and voltage magnitude and the currents of branch are resolved exploitation the subsequent formulas:

$$V_A = V_D + I_{AD} (R_{AD} + jX_{AD})$$

$$V_B = V_D - I_{BD} (R_{BD} + jX_{BD})$$

$$V_C = V_D - I_{CD} (R_{CD} + jX_{CD})$$

Rule 3:

If we know the voltage phasors at the branch end, then this measurement is known as 'pseudo measurements'. And the branch phasor is obtain directly.

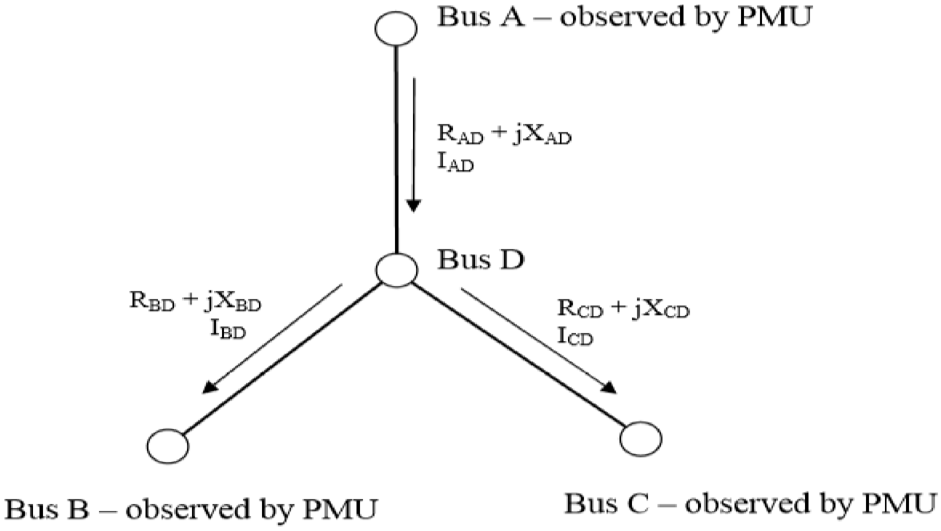


Fig. 4.9 3rd rule of observability [63]

Under this condition, assumptive the voltage magnitude if bus A, B, and C are unit ascertained and obtain from the measurements of PMUs. The equation for unknown variables are given bellow.

$$V_D = V_A - I_{AD} (R_{AD} + jX_{AD})$$

$$V_D = V_B + I_{BD} (R_{BD} + jX_{BD})$$

$$V_D = V_C + I_{CD} (R_{CD} + jX_{CD})$$

$$I_{AD} = I_{BD} + I_{CD}$$

4.19 System Observability Redundancy Index (SORI) Method

For best PMU placement, SORI is a crucial issue for showing the steadiness of the ability network. Because of a different variety of optimum solutions being out there when we use the optimisation formula, Bus Observability Index (BOI) [59] are enforced to point the performance on quality of optimisation. To find the one best solution for the optimization we use the System Observability Redundancy Index. Which use the following formula to get the best result. The best combination is considered with high value of SORI. Consequently, most| of the bus index is restricted to highest property (ηi) of a bus.

$$\beta_i \leqslant \eta_i + 1$$

In order to pick the foremost favourable outcomes among variety of best solutions obtained exploitation completely different optimisation ways. Therefore, the simplest optimisation technique are elite supported the SORI. The SORI are often calculated exploitation Equation, wherever γ represents System Observability Redundancy Index.

$$\gamma = \sum_{i=1}^{n} \beta_i$$

4.20 Hill Climbing

Actually, hill climbing is a family of algorithms with many variations. If you want to get to the highest point in a landscape, one reasonable strategy. This process is continued until there are no directions which lead you higher, at which point you have reached the top of a hill. This is a local search strategy, and is called hill climbing. A better strategy would be to look around, estimate where the highest point is, and then estimate the best way to get there. This would eliminate the problem of zigzagging your way to the top, or getting stuck at the top of a small hill that is lower than the globally highest point. But if visibility is low, a local search strategy may be your best course of action.

Hill climbing may or may not work well, depending on the shape of the hill, the number of local maxima, and your initial position. Hill climbing can be used by itself as an optimization algorithm. It can also be combined with an EA, which would combine the global search ability of an EA with the local search ability of hill climbing. The results of a hill climbing algorithm can strongly depend on the initial conditions. It therefore makes sense to try hill climbing with several different randomly generated initial conditions. This approach of putting a hill climbing algorithm inside an initial condition loop is called random restart hill climbing. The vast majority of the computational effort of a heuristic algorithm is typically consumed by fitness function evaluations.

4.21 More Recent Evolutionary Algorithms

4.21.1 Simulated Annealing

In Simulated annealing (SA) optimization we use the crystallizing reengage and cooling of chemicals. Crystalline lattices are fascinating examples of the optimization ability of nature. A crystalline lattice is an arrangement of atoms or molecules in a liquid or solid. Some familiar examples that are common to most people’s everyday experiences are the crystalline structures of quartz, ice, and salt. At high temperatures, crystalline materials don’t exhibit much structure;

high temperatures give the materials a lot of energy, which contributes to a lot of vibration and disorder. However, as the temperature decreases, the crystalline materials settle into a more ordered state. The particular state into which they settle is not always the same. A material that is heated and then cooled multiple times will settle into a different equilibrium state every time, but every equilibrium state tends to have low energy.

4.21.2 Ant Colony Optimization

Ants are simple creatures but they can accomplish a lot by working together. The quote at the beginning of this chapter presents ants as a paradigm of hard work, but they can also be portrayed as the epitome of selfless cooperation. A single ant does not have much to offer. A solitary ant might wander aimlessly in circles until it dies of exhaustion [Delsuc, 2003]. The average ant has only 10,000 neurons in its brain, which doesn't seem like enough to accomplish much. But ants join together in colonies that can number in the millions. A one-million member ant colony has a collective neuron count of 10 billion, which begins to rival the neuron count of an average human. Ants seem to operate as a single entity and are therefore sometimes referred to as a super organism.

Ants communicate mainly by using pheromones, which are chemical substances that they excrete. When ants travel along a path to a food source and bring food back to their colony, they leave a trail of pheromone. Other ants smell the pheromone with their antennas, follow the path, and bring more food back to the colony. In the process, ants continue to lay down pheromone, which other ants continue to smell, and the path to the food source is reinforced. The shortest path to the food thus becomes more attractive over time as it is strengthened by positive feedback. Sometimes the food source is depleted or an obstacle prevents travel to the food source. When ants travel along a path and do not find food, they wander until they do find food. If they do not return to their colony using the original path, they do not deposit any additional pheromone on that path. As time passes, the pheromone on the original path evaporates, fewer ants take the original path, more ants take the new path to the new food source, and a new optimal path is discovered by the ants.

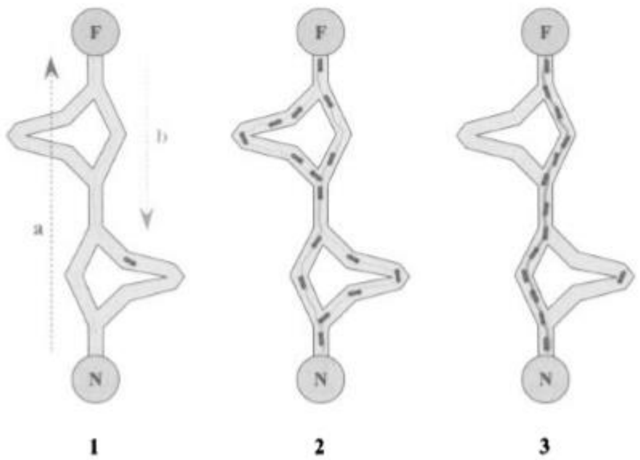


Fig. 4.10 Ant Colony Optimization scheme [62]

Ants depositing and following pheromone. (1) The first ant travels in the direction indicated by a, finds a food source F, and returns to the nest N in the direction indicated by 6, laying a pheromone trail as it travels. (2) The ants follow one of four possible paths from N to F, but pheromone reinforcement makes the shortest path more appealing. (3) The ants tend to follow the path with the most pheromone, continuing to reinforce its desirability, while the pheromone on the longer paths evaporates.

4.21.3 Ant colony system

The extension of Ant System (AS) is ACS. In spite of their common roots, AS and ACS are quite different in their behaviour and performance. ACS is characterized by two main extensions to AS. First, a local pheromone update is implemented by each ant as it constructs its solution. As soon as an ant travels from city i to city j. The second extension that ACS makes to AS is the use of a pseudo-random proportional rule for candidate solution construction.

4.22 Particle Swarm Optimization

Suppose that we have a minimization problem that is defined over a continuous domain of d dimensions. We also have solution for N candidate population denoted as, i 6 [1, iV]. Furthermore, suppose that each individual xi is moving with some velocity Vi through the search space. This movement through search space is the essence of PSO, and it is the fundamental difference between PSO and other EAs. Most other EAs are more static than PSO because they model candidate solutions and their evolution from one generation to the next, but they do not model the dynamics of the movement of the candidate solutions through the search space. As a PSO individual moves through the search space, it has some inertia and so it tends to maintain its velocity. However, its velocity can change due to a couple of different factors.

First, it remembers its best position in the past, and it would like to change its velocity to return to that position. This is similar to the human tendency to remember the good old days, and to try to recapture the experiences of the past. In PSO, an individual travels through the search space, and its position in the search space changes from one generation to the next. However, the individual remembers its performance from past generations, and it remembers the search space location at which it obtained its best performance in the past.

Second, an individual knows the best position of its neighbours at the current generation. This requires the definition of a neighbourhood size, and it requires that all of the neighbours communicate with each other about their performance on the optimization problem.

4.23 Differential Evolution

Rainer Storn, Kenneth V. P. develop the Differential Evolution (DE) around 1995. Like many new optimization algorithms, DE was motivated by real world problems: for example Chebyshev polynomial coefficients solution, and digital filter coefficients optimization. DE made a quick and impressive entrance into the world of optimization.

4.24 A Basic Differential Evolution Algorithm

DE is a population-based algorithm that is designed to optimize functions in an n-dimensional continuous domain. Each individual in the population is an dimensional vector that represents a candidate solution. DE is basically the idea of taking the difference vector between two individuals, and adding a scaled version of the difference vector to a third individual to create a new candidate solution.

CHAPTER 5

Research Approach

CHAPTER 5

RESEARCH APPROACH

5.1 Hybrid Approach Global Search Algorithm And Binary Search Algorithm

Global Search algorithm is a branch of science, math and numerical analysis which deals with the improvement of group of function based upon some criteria. Typically a group of rules are used to improve the results. This method is good for finding the location for PMUs in best way. Although this method is approximation method but with hybrid approach this method become good and there is improve in chance in giving best results for optimization. In relevance the best PMU placement, variety of authors have confirmed that the tokenism PMU location may be known by the methodology employed in international Search improvement.

Generally the Global Search algorithmic rule see the situation of the tokenise variety of PMUs when looking all the doable combos. Within the looking method, an oversized variety of combo's square measure generated, that results in the consumption of in depth procedure time and memory area within the user's pc, particularly in an exceedingly complicated power network. As an answer, in chapter 5 we will see the bunch of innovative steps square measure introduced to find the tokenise variety of PMUs required, including: the reduction of single association bus and double association of bus with high number of connections. And after that calculating the lower bound and upper bound, after that domination set theory is applied to find the minimum number of PMUs required with the help of binary search algorithm. This method can avoid the gratuitous combos generated by the world Search algorithmic rule. What is more, within the thought of a traditional rules with help of zero-injection impact we see the number of PMUs required to complete observable of the network in addition to that we will see that what is effect of zero injection on the optimization, for that we will first find the zero injection busses and eliminate the PMU placement on those busses. The overall size of the facility network can scale down by eliminating the quantity of zero-injection buses, which boosts the partitioning speed.

The following formula shows the overall variety of combos in kth, wherever

N represents the network dimensions and

k represents the number of PMU required.

$$\sum_{k=1} C_k^N = \frac{N!}{k!(N-k)!}$$

Exhaustive Search is used to employ the complete vary of prospects from k=1 to k=N,untill network is totally noticeable. In this approach a pc will pay a bigger role with high RAM because it can process easily the combination produced in the system. And the number of PMUs required can be determine with the lower and upper bounds.

5.2 Calculation Of Lower And Upper Bounds Using Domination Set

Domination set is used in graph theory and is used to determine the locations by which whole network can be covered and may be a decision making downside in procedure complexness theory that is classical, non-deterministic, polynomial (NP) and that is complete in nature. This idea is used to determine the number of PMUs that is required for a network for network to be completely observable. The lower and upper bounds are determine mathematically by formulas and the upper bound is one third of the total nodes in the network. According to the theory network can be completely observable if it one third of total are covered.

Lower bound: $\frac{k+2}{3}$ Upper bound: $\frac{n}{3}$

It is noted that the results of such bounds are going to be associate degree number. per the higher and lower bounds, the quantity of PMUs required are going to be restricted in an exceedingly set of bounds. This is often associate degree economical thanks to downsize the overall variety of prospects, that results in a discount within the entire execution time likewise as within the use of storage device area.

5.3 Binary Search Algorithm Application

While computing, with Binary Search algorithm we determines the number of zeros and number of ones in an array. [30]. In the program search module for finding the number of ones starts to determine the single connection busses and also to determine the busses which are connected to the high number of busses.

1) Step 1st it tells the shortest sequence and compare the value in array at position n/2 with key k.
2) Step 2nd If A[n/2] > k, it compare key k with the midpoint of the first half of the sequence.
3) Step 3rd If A[n/2] < k, it compare key k with the midpoint of the second half of the sequence.
4) And If A[n/2] = k, then it return n/2.

In the projected methodology, we find the number of PMUs required in the network to make the whole network observable and with the help of lower bound and upper bound using these above rules we determine the minimum number of PMUs required to completely cover the PMUs. Binary search algorithm we find the number of PMUs required. Binary search algorithm has rules which simplifies to find the best verity of PMUs required to render the network totally noticeable. Binary search algorithm starts with the lower bound. Meantime, international Search algorithmic rule generates all the doable combos during this worth. The best result is considered if the any combination from all is capable for making the complete network observable. Else, Binary Search algorithmic rule are going to be applied to search out key k.

Secondly after that binary search algorithm starts to find out the system Observability with N number of PMUs where N is number of PMUs determine with the help of lower and upper bounds. And check if the system is observable with these number of PMUs if the given network is observable then the total number of PMUs are decrees by one then again check the observability of the network weather the given network is observable or not if the given network is observable then the number of PMUs again decrees by one and again check the observability and if the given network is not observable then the total of N number of PMUs are used to determine the system real time data.

As incontestable on top of, the best resolution is merely performed within the hand-picked digit, which can ignore the generation of gratuitous combos, and cause an extra reduction of the overall execution time.

System Observability Redundancy Index will be applied within the implementation of this hybrid algorithmic rule. It’s a major methodology for choosing the foremost economical resolution.

5.4 Global Search Algorithm Application

This algorithm is understood as a ‘brute-force attack’ and can be defined as the branch of above algorithm which make the double combinations except the single connection busses. By checking any single combination, the best placement method is going to be determined if the mixture is ready to watch either the system is ready for complete observable of the network. And the method determine the smallest amount of PMUs by which the complete network is observable.. The ultimate resolution is certain to reach a smallest number of PMUs within the placement method. Associate degree example are going to be given to explain the procedure of complete Search.

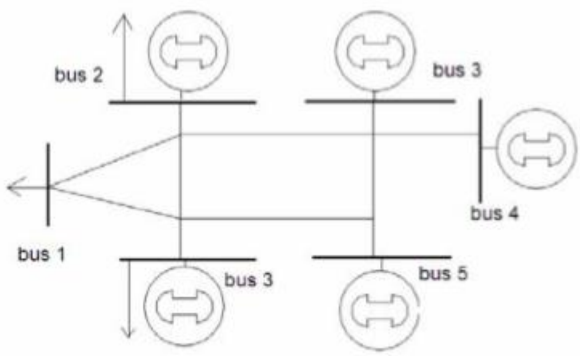


Fig. 5.1 6-bus system [63]

Consider the above example 6-bus system only 2 PMUs are required to make the complete system observable. And will combinations and it starts from [1 2] as associate degree initial worth, then the count goes up to total number of busses. As a trigger, the previous digit is ready to hold by one. Above method is repeated till the first digit is smaller than second digit by one.

For example combinations formed in 6-bus system are given bellow.

1 2

1 3

1 4

1 5

1 6

2 3

2 4

2 5

2 6

………

………

5 6

After that based upon property of every bus, any combination are going to be hand-picked and see that the system is completely observable. The total number of combinations are determine by the following formula.

$$\sum_{k=1} C_k^N = \frac{N!}{k!(N-k)!}$$

Number of bus system is denoted by parameter N and

Number of PMUs required is denoted by parameter k.

5.5 PMU Placement for covering single connection buses in network

To begin with, after making the combinations we start to decrees the combination because to decrees the computation time of optimization we need to reduce the total number of combinations as much as possible hence for that first we calculate the connectivity matrix connectivity matrix is binary matrix of n*n order. Where n is number of bus system. And the bus connected to particular bus id take as 1 and if it is not connected then taken as 0, now to decrees the combination we use one method that is do nit place the PMU on single connection bus but connect the bus very next to which it is connected so that our single connection bus is observable and also the us to which it is connected. By this method we fix the one bus in combinations on which it is sure that PMU is connected. The bus very next to which it is connected so that our single connection bus is observable and also the us to which it is connected.

5.6 GSA Implementing on IEEE 14-bus system

First we use the Global search algorithm on small bus system but we can also use it on any number of busses. To the matter of best PMU placement are going to combine different rules they are GSA, rules of lower and upper bound and Binary Search algorithmic rule. The IEEE commonplace 14-bus system, is shown in fig 5.2 can 1st be thought of and studied beneath traditional operation with and while not zero-injection impact.

5.7 IEEE Standard 14-Bus System Diagram

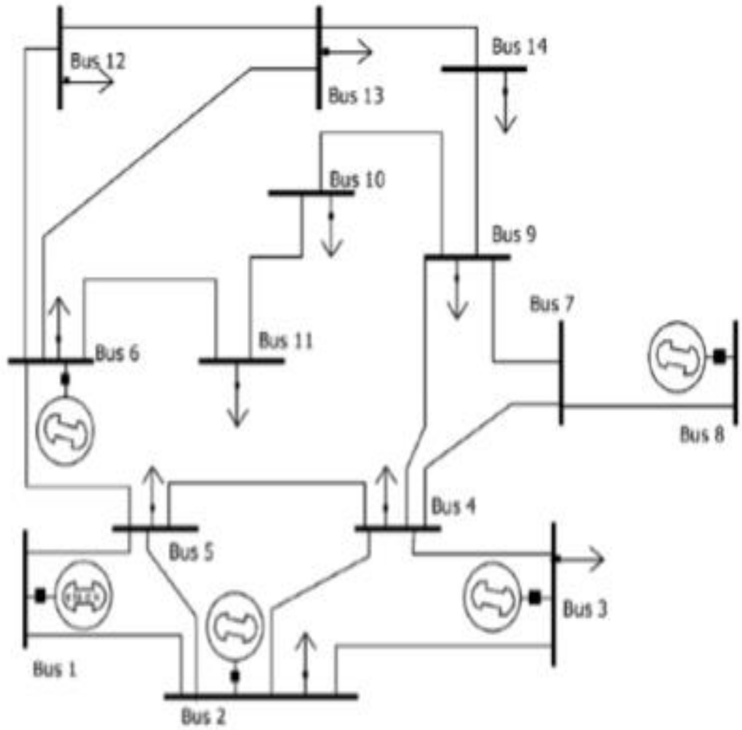


Fig. 5.2 IEEE 14-bus system [64]

5.8 Procedure Without Zero Injection Effect

Equation which shows the connectivity matrix or binary matrix is shown below. And denoted by matrix A.

$$A_{k,m} = \begin{cases} 1 & if\ k\ and\ m\ are\ connected\ with\ each\ other \\ 0 & if\ \ otherwise \end{cases}$$

Meanwhile, in the programing y-Bus is converted into binary matrix or to connectivity matrix. Matrix A presents the binary matrix of the IEEE customary 14-bus system. The IEEE commonplace 14-bus system, is shown in fig 5.2. and the binary matrix for 14 bus system is shown bellow.

$$A = \begin{bmatrix} 1 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 \end{bmatrix}$$

Above matrix is obtain through MATLAB programing for that we required the 14-Bus system data then write the program for Y-Bus system. From that after forming the Y-Bus matrix make all the non-zero elements 1 and other all zero elements remains zero.

Secondly, find the single connection bus with the help of binary search algorithm. And find the adjutant bus to that single connection bus to which it is connected. In 14-Bs system bus number 8 is single connection bus and it is connected to bus number 7 only hence bus number 7 is fixed in the combinations. Or we can say that one PMU is fixed to bus number 7. And bus 8 is eliminated from the combinations.

5.9 Flow Diagram without zero injection effect

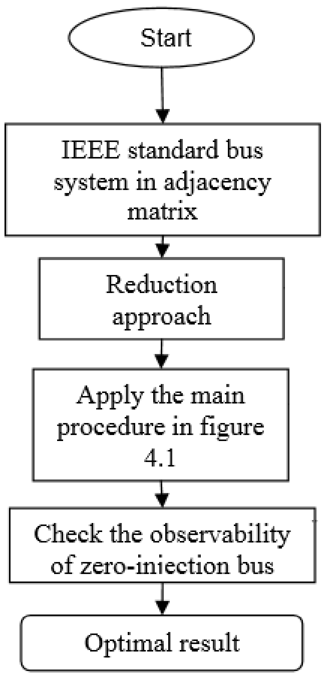


Fig. 5.3 Flow Diagram without zero injection effect

With the help of equation shown below for lower bound and upper bound we can calculate the worth of PMUs required.

Lower bound: $\frac{k+2}{3}$ Upper bound: $\frac{n}{3}$

We can calculate the lower and upper bound from the above equations where k is the number of busses with high degree. For example in this program we consider the bus as high degree which is connected to more than 4 busses including itself.

Lower bound: $\frac{7+2}{3}=3$ Upper bound: $\frac{14}{3}=4$

As a result of above equations the set bound are 3 and 4 and they are integer.

By above method in this system will check that weather our whole network is hide or not is yes then our system is observable with 3 PMUs but in 14-Bus system with 3 PMUs we cannot make our system observable with this.

The combinations formed in this process which system will check are

1	2	7
1	3	7
1	4	7
1	5	7
1	6	7
1	9	7
1	10	7
1	11	7
1	12	7
1	13	7
1	14	7
..	….	..
...	….	..

After checking the network observability, it is find that 3 PMUs cannot make our system observable. None of the combos is competent to look at the whole system. Now the second bound is 4. After that our system make the combination of 4 and check the observability for the system. In addition, Binary Search rule is applied to work variety four because the best variety of PMUs required. Now with 4 sets of PMUs the combinations are given as.

1	2	3	7
1	2	4	7
1	2	5	7
1	2	6	7
1	2	8	7
1	2	9	7
1	2	10	7
1	2	11	7
1	2	12	7
1	2	13	7
1	2	14	7
..	..	….	..
..	..	….	..

There square measure 3 doable solutions that offer the entire variety of PMUs as four. These combos can have PMUs placed at bus a pair of,

2, 6, 7 and 9,

2, 7, 10 and 13

2, 7, 11, and 13,

Above method gives us the best three solutions for optimal location of PMUs and to pick the best one out of three we use the SORI as explained in previous chapter and that will give us the best result for optimization.

2, 6, 7 and 9 offers a better SORI price.

5.10 Procedure With zero injection Busses

A zero-injection bus are those busses which are neither connected to load nor connected to the generating station. The zero injection busses can be divided as bellow. [57]:

1) The imperceptible bus also will be known as noticeable with the help of Kirchhoff's current law (KCL) to zero-injection bus.

2) The zero-injection bus also will be known as noticeable with the help of KCL at the zero-injection bus.

In this projected technique, bus number 7 is zero injection buss in 14-Bus system and bus connected to the bus number 7 are 8,9,4 and we need to see that these busses must be observable to make bus number 7 observable.

5.11 Main procedure

The final result for 14 bus system is 3 busses with zero injection effect and those are

2, 6, and 9

These busses gives you the best result for the optimization problem.

Also from above analysis we can see that with zero injection effect decrease the number of PMUs of the observability.

Now if we apply the same procedure for 57 bus system and repeat all the rules with 57-Bus data then we can get the PMUs location to make the 57-Bus observable.

5.12 IEEE 57-bus System

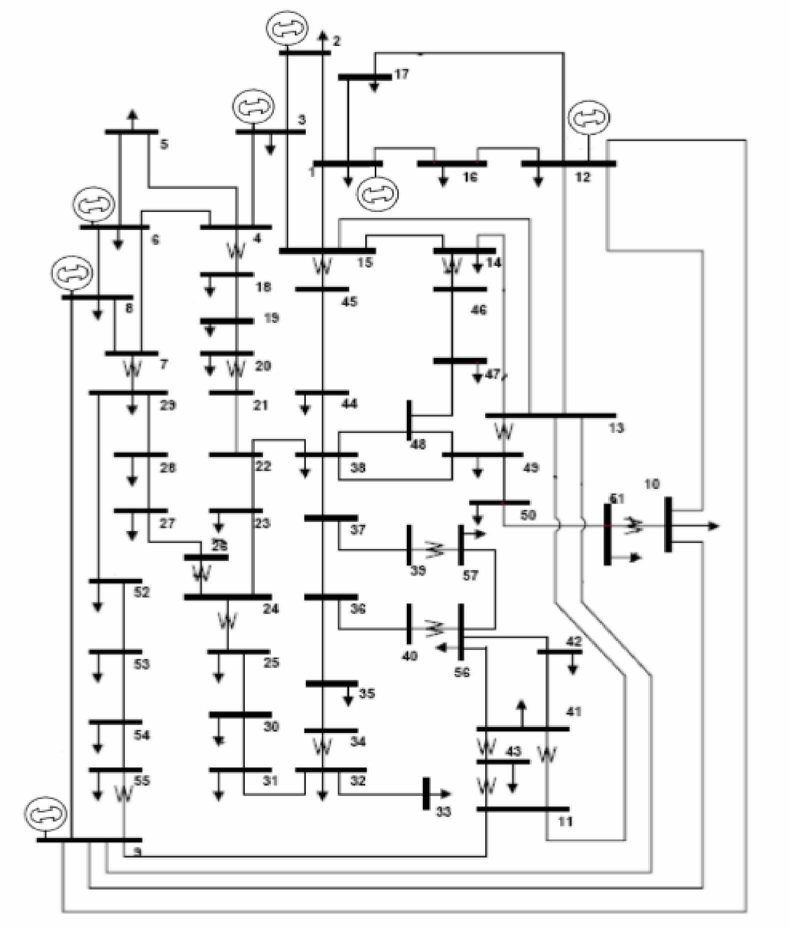


Fig. 5.4 IEEE 57-bus system [64]

Since the 57 bus system is larger than 14-Bus system so there will be more combinations.

Data for 57 bus system is given bellow.

Single connection bus is bus number 33

Bus connected to 33 bus system 32,

The results obtain from the optimization of 57 bus system are given bellow without using the zero injection method.

Sol =

1 3 9 10 12 16 18 19 20 28 31 32 38 42 49 53 56 57

Global search algorithm use total of busses to make the complete system observable.

First this method make the combinations of PMUs and make the system observable after that one PMU is decreased to check weather our system is observable or not but with 18 PMUs system become observable.

If we see the results with considering zero injection busses then the number of PMUs required are 11.

And the busses on which PMUs are installed are

Zsol=

1 3 13 15 25 26 32 38 42 52 56

As from results without zero injection total number of PMUs required are 18 to observe the complete 57 bus system network but if we use the zero injection method the quantity of PMUs decrease considerably and total number of PMUs required are 11 only.

5.13 Flow Diagram

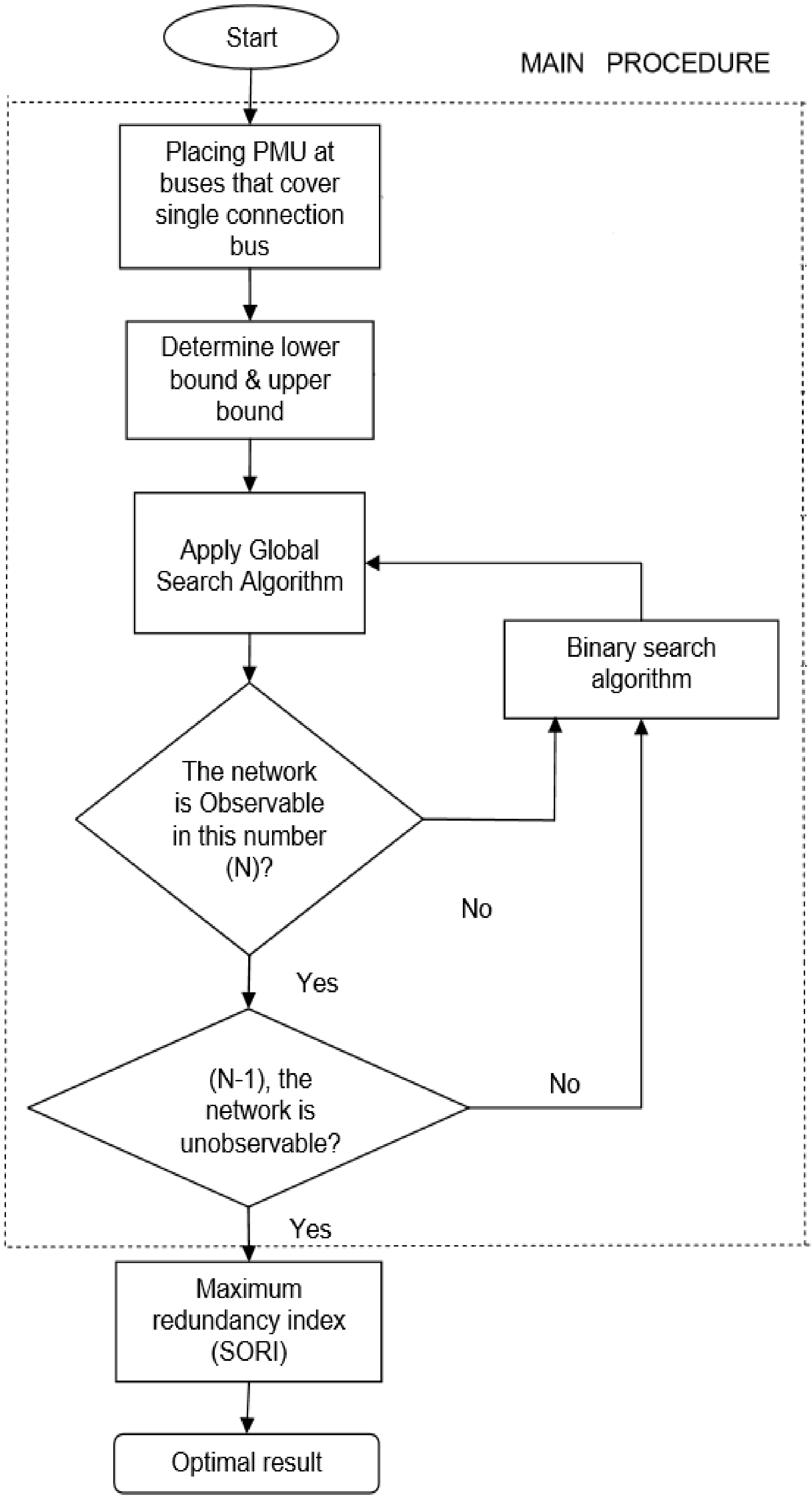


Fig. 5.5 flow diagram for global search algorithm

CHAPTER 6

Results And Conclusions

CHAPTER 6

RESULTS AND CONCLUSIONS

6.1 Results

The problem of optimal PMU placement in power network Observability was investigated. A new PMU placement optimization method was introduced base on breadth-first algorithm and greedy algorithm. By employing the MatLAB. Simulation results on IEEE standard 57-bus test systems were presented to demonstrate the effectiveness of hierarchical algorithm. Large-scale network will be implemented in the future work.

Result for Global search algorithms are shown below with and without zero injection busses

Without Zero Injection Busses

Total number of PMUs require are 18

And the busses at which PMU is placed

Sol =

1 3 9 10 12 16 18 19 20 28 31 32 38 42 49 53 56 57

With Zero Injection Buses

Total number of PMUs required are 11

And the busses which are installed with PMUs are given as

Zsol=

1 3 13 15 25 26 32 38 42 52 56

From the above results we can see that with zero injection we can find the results of PMUs optimization precise and network can be observed with less number of PMUs.

As from results without zero injection total number of PMUs required are 18 to observe the complete 57 bus system network but if we use the zero injection method the quantity of PMUs decrease considerably and total number of PMUs required are 11 only.

6.2 Future Scope

This method is good for the optimization and in this method we have lot more scopes to do the work. Due to the increasing development of power networks, their control systems and protection requirements are becoming complex. In recent years, the theory of synchronized phase angle measurement has verified that it brings a deep-seated advantage for the network real-time protection.

Furthermore, along with the device of Phasor Measurement unit, these applications will enhance, in reality, the power system monitoring, control and protection. In this thesis, the author has aimed to ensure that the number of PMUs required for supervising the power network is minimal. If the premise is network Observability, installation with less PMUs can be transferred in combinational optimization problems. But the time take for finding the optimal location of PMUs is more and so next can be the decrease in time of compilation of the program.

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Appendices

APPENDIX A

Program of Hybrid Approach based on Global Search Algorithm

➢ Standard IEEE 57 Bus System Line Data

```
% Line Data for Y-Bus Formation.

function linedata = linedata57r()            % Returns linedata.

%           |  From |  To    |    R       |    X      |    B/2 | Tap | Status|
%           |  Bus  | Bus    |            |           |        | Set |       |
linedata = [ 1        2        0.0083     0.0280     0.1290     1       1 ;
             1        15       0.0178     0.0910     0.0988     1       1 ;
             1        16       0.0454     0.2060     0.0546     1       1 ;
             1        17       0.0238     0.1080     0.0286     1       1 ;
             2        3        0.0298     0.0850     0.0818     1       1 ;
             3        4        0.0112     0.0366     0.0380     1       1 ;
             3        15       0.0162     0.0530     0.0544     1       1 ;
             4        5        0.0625     0.1320     0.0258     1       1 ;
             4        6        0.0430     0.1480     0.0348     1       1 ;
             4        18       0.0000     0.5550     0.0000     1       1 ;
             5        6        0.0302     0.0641     0.0124     1       1 ;
             6        7        0.0200     0.1020     0.0276     1       1 ;
             6        8        0.0339     0.1730     0.0470     1       1 ;
             7        8        0.0139     0.0712     0.0194     1       1 ;
             7        29       0.0000     0.0648     0.0000     1       1 ;
             8        9        0.0099     0.0505     0.0548     1       1 ;
             9        10       0.0369     0.1679     0.0440     1       1 ;
             9        11       0.0258     0.0848     0.0218     1       1 ;
             9        12       0.0648     0.2950     0.0772     1       1 ;
             9        13       0.0481     0.1580     0.0406     1       1 ;
             9        55       0.0000     0.1205     0.0000     1       1 ;
             10       12       0.0277     0.1262     0.0328     1       1 ;
             10       51       0.0000     0.0712     0.0000     1       1 ;
             11       13       0.0223     0.0732     0.0188     1       1 ;
             11       41       0.0000     0.7490     0.0000     1       1 ;
             11       43       0.0000     0.1530     0.0000     1       1 ;
             12       13       0.0178     0.0580     0.0604     1       1 ;
             12       16       0.0180     0.0813     0.0216     1       1 ;
             12       17       0.0397     0.1790     0.0476     1       1 ;
             13       14       0.0132     0.0434     0.0110     1       1 ;
             13       15       0.0269     0.0869     0.0230     1       1 ;
             13       49       0.0000     0.1910     0.0000     1       1 ;
             14       15       0.0171     0.0547     0.0148     1       1 ;
             14       46       0.0000     0.0735     0.0000     1       1 ;
             15       45       0.0000     0.1042     0.0000     1       1 ;
             18       19       0.4610     0.6850     0.0000     1       1 ;
             19       20       0.2830     0.4340     0.0000     1       1 ;
             20       21       0.0000     0.7767     0.0000     1       1 ;
             21       22       0.0736     0.1170     0.0000     1       1 ;
             22       23       0.0099     0.0152     0.0000     1       1 ;
             22       38       0.0192     0.0295     0.0000     1       1 ;
             23       24       0.1660     0.2560     0.0084     1       1 ;
             24       25       0.0000     1.1820     0.0000     1       1 ;
             24       26       0.0000     0.0473     0.0000     1       1 ;
```

```
25        30        0.1350    0.2020    0.0000    1       1 ;
26        27        0.1650    0.2540    0.0000    1       1 ;
27        28        0.0618    0.0954    0.0000    1       1 ;
28        29        0.0418    0.0587    0.0000    1       1 ;
29        52        0.1442    0.1870    0.0000    1       1 ;
30        31        0.3260    0.4970    0.0000    1       1 ;
31        32        0.5070    0.7550    0.0000    1       1 ;
32        33        0.0392    0.0360    0.0000    1       1 ;
32        34        0.0000    0.9530    0.0000    1       1 ;
34        35        0.0520    0.0780    0.0032    1       1 ;
35        36        0.0430    0.0537    0.0016    1       1 ;
36        37        0.0290    0.0366    0.0000    1       1 ;
36        40        0.0300    0.0466    0.0000    1       1 ;
37        38        0.0651    0.1009    0.0020    1       1 ;
37        39        0.0239    0.0379    0.0000    1       1 ;
38        44        0.0289    0.0585    0.0020    1       1 ;
38        48        0.0312    0.0482    0.0000    1       1 ;
38        49        0.1150    0.1770    0.0030    1       1 ;
39        57        0.0000    1.3550    0.0000    1       1 ;
40        56        0.0000    1.1950    0.0000    1       1 ;
41        42        0.2070    0.3520    0.0000    1       1 ;
41        43        0.0000    0.4120    0.0000    1       1 ;
41        56        0.5530    0.5490    0.0000    1       1 ;
42        56        0.2125    0.3540    0.0000    1       1 ;
44        45        0.0624    0.1242    0.0040    1       1 ;
46        47        0.0230    0.0680    0.0032    1       1 ;
47        48        0.0182    0.0233    0.0000    1       1 ;
48        49        0.0834    0.1290    0.0048    1       1 ;
49        50        0.0801    0.1280    0.0000    1       1 ;
50        51        0.1386    0.2200    0.0000    1       1 ;
52        53        0.0762    0.0984    0.0000    1       1 ;
53        54        0.1878    0.2320    0.0000    1       1 ;
54        55        0.1732    0.2265    0.0000    1       1 ;
56        57        0.1740    0.2600    0.0000    1       1 ; ];
```

Program for Formation Of Y-Bus Matrix:-

```
% Program to form Admittance And Impedance Bus Formation....
% with Transformer Tap setting..

function ybus = ybus57r()  % Returns ybus

linedata = linedata57r(); % Calling "linedata59.m" for Line Data...
fb = linedata(:,1);       % From bus number...
tb = linedata(:,2);       % To bus number...
r = linedata(:,3);        % Resistance, R...
x = linedata(:,4);        % Reactance, X...
b = linedata(:,5);        % Ground Admittance, B/2...
a = linedata(:,6);        % Tap setting value..
z = r + i*x;              % Z matrix...
y = 1./z;                 % To get inverse of each element...
```

```
b = i*b;                 % Make B imaginary...

nbus = max(max(fb),max(tb));     % no. of buses...
nbranch = length(fb);            % no. of branches...
ybus = zeros(nbus,nbus);         % Initialise YBus...

 % Formation of the Off Diagonal Elements...
 for k = 1:nbranch
     ybus(fb(k),tb(k)) = ybus(fb(k),tb(k))-y(k)/a(k);
     ybus(tb(k),fb(k)) = ybus(fb(k),tb(k));
 end

 % Formation of Diagonal Elements....
 for m = 1:nbus
     for n = 1:nbranch
         if fb(n) == m
             ybus(m,m) = ybus(m,m) + y(n)/(a(n)^2) + b(n);
         elseif tb(n) == m
             ybus(m,m) = ybus(m,m) + y(n) + b(n);
         end
     end
 end

 %ybus;
 %zbus = inv(ybus);
```

Formation Of Binary Matrix:-

```
% Formation of Binary matrtix or connectivity matrix;
% from ybus matrix;
% calling function ybus59r.m for admitance matrix;
function binarymatrix = binarymatrix57r()
binarymatrix = ybus57r;
 nonzero=find(binarymatrix);
 % find the nonzero elements in admitance matrix i.e. ybus matrix;
 % formation of binary matrix or connectivity matrix;
% binarymatrix(nonzero)=1; convert the all non zero elements to 1;
binarymatrix(nonzero)=1;
```

Main Program:-

```
function maxb1 =pmuplacement1()
% zi is zero injection busses in 57 bus system.%
```

```
zi = [ 4 7 11 13 15 21 22 24 26 34 36 37 39 40 45 46 48];
s = binarymatrix57r;
dbstop if error
zid=[];
%zid is the matrix which contain busses which are connected to zero
%injection busses%
 for i=1:length(zi);
      t=find(zid==zi(i));
      if isempty(t)==1;
          a=zi(i);    %find the ZI bus
          zib=find(s(a,:)~=0);    %find all the connections on the ZI bus
          for k=1:length(a);
              s(zib(k),:)=s(zib(k),:)+s(a,:); %reflash connection map
              zid=[zid,zib];
          end
      else
      end
 end
 zid
c=0;
len=length(s);
ib=[];
is=[];
obs=zeros(1,len); % obs used to find the number of 1 in array used to find
the connection of a bus%
k=0;
for i=1:len;
    findone=find(s(i,:));
    if length(findone)==2;
        % loop to determine the single connection bus%
        ib = [ib,findone];
        is = [is,i];
    end
    if length(findone)>=3
        k=k+1;
        % use to find the number of busses with higher number of
        % connections.%
    end
end
ib
is
```

```
LB=ceil((k+2)/3);    %lower bound %
UB=floor(len/3);     % upper bound%
maxb=1:len;
maxb=setdiff(maxb,is);
n=min(LB,UB);
%select minimun from lower bound and upper bound%
n
found=0;
flagif=0;
LB
UB
k
maxb
maxb1=setdiff(maxb,zi);
maxb1
ia=setdiff(ib,is);
ia
%observability loop %
while 1
    for t=1:1000    %random
                 tstart=tic;
        while 1          ind=randperm(length(maxb1));
            ind=ind(1:(n-length(ia)));
            if isempty(find(ind==33,1));
                break
            end
        end
        indx1=setdiff(maxb1,ind);
        indx2=setdiff(indx1,maxb1);

 indx=[maxb1(ind),ia];
 for ii=1:(n);
     obs=obs+s(indx(ii),:);
     obs(indx(ii))=1;
 end
 % loop for checking the observability with N-1 number of PMUs%
 if isempty(find(obs==0,1));
     found=1;
     obs=zeros(1,len);
     break
     elseif toc(tstart)>=5;
```

```
    telap=toc(tstart);
      break
 else
     found=0;
     obs=zeros(1,len);
 end
    end
    if found
        if flagif~=1
            n=n-1;
            flagif=1;
            sol=indx
        else             n=floor((n+LB)/2);
            sol=indx
        end
    else
        if flagif~=1
            n=ceil((UB+n)/2);
        else
            break
        end
    end
end
ind
indx
rsol=sort(indx);        %final result%
rsol
```