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Power System Reliability Enhancement Using Phasor Measurement Unit Technology (PMU)

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Abstract

The phasor measurement units (PMU) are considered to be the most important devices in the future of the power systems. PMU's were first developed in 1980's and from that time a lot of advancement has taken place. PMU provides high speed synchronized sensor data which is used for steady state and dynamic state estimation of power system, voltage stability enhancement of power system, adaptive relay protection scheme, optimal flow control, etc. PMU now covers more than 5% of the total nodes in U.S.A and the advancement is being carried out to install more units. Due to its high cost and limited resources its use is selective. When the demand on the power system increases then the contingency impacts on the grids also increases so there is a need for power system operation and control. In the previous times the research has focused mainly on network topology with the goal of designing such configuration which can provide complete observability with minimum number of PMU's. Recently we have introduced a new approach which makes use of stochastic models of the signals and measurements to achieve the complete observability, controllability and uncertainties in the power system states. Here we have a present a new approach to design the optimal placement of PMU in the system to enhance the reliability and voltage stability of the system. And I hope that this approach will provide a tool for the engineers to have a alternative in the form of PMU. And also a project is going on in India to integrate all the five national grids, and this can only be achieved with the help of PMU technology.

1. INTRODUCTION

Synchronized phasor measurement deals with the electrical waves on a grid to measure the condition of the system. A phasor is a complex quantity that has magnitude and phase angle of the sine waves found in the electricity. The measurements of phase that occurs at same phases are called Synchrophasor and PMU are the devices that allow their measurement. We use a number of devices like CT', PT's, circuit breakers, relays, ammeters, voltmeters, watt meters, fuses, isolators, etc. for measurement purposes and PMU will help in deciding to install these devices at proper locations. When the demand on power system increases then the contingency impacts on the grids also increases so there is a need of power system operation and control. This technology thus helps in handling the problem of voltage stability for online application in the power systems. This new approach requires very fast control and online implementation to rectify voltage collapse in the system in the quicker possible time. With the time the engineers have found that the quick monitoring and control is possible only with the help of PMU. The PMU devices permits the real time measurements which helps to overcome the disadvantages of the presently used devices to detect the slow and fast dynamics in the system. This report thus focuses on the approach to handle the problem of voltage instability in the system. The proposed method works in the field of real time stability monitoring and control. And this real time measurement is possible with the PMU technology. In 1981 the government of India had decided to work on the plan of national grid to achieve optimal transfer of power from surplus to deficit regions, maximum utilization of electrical resources for the diverse regions to ensure quality power transfer flow. The power grid corporation of India (PGCIL) is now working on the proposed plan of establishing a national grid to enhance the quality of power transfer between different regions. The national grid will help in exploiting the country's unevenly distributed resources in planned manner to full fill the required demand of electricity. The smart grids have their influence on generation, transmission and distribution. However the transmission system in smart grids is only possible with help of PMU's, assisting technology, wide area communication and computing. It will help in removing the threat of black outs in India. The power system used today are capable of taking actions in milliseconds to multi minutes time frames, but the PMU based system make decisions and take actions in 1oo millisecond time frame.

1.1 Use of Phasor Measurement Unit (PMU) for Large Scale Power System State Estimation:-

A phasor is a complex quantity that has magnitude and phase angle of the sine waves found in the electricity. The measurements of phase that occurs at same phases are called Synchrophasor and PMU are the devices that allow their measurement. We use a number of devices like CT', PT's, circuit breakers, relays, ammeters, voltmeters, wattmeters, fuses, isolators, etc. for measurement purposes and PMU will help in deciding to install these devices at proper locations:-

- Accurate and comprehensive planning.
- Better congestion tracking,
- Visualization and advanced warning systems.

1.2 Voltage Stability Enhancement Using Phasor Measurement Unit (PMU) Technology:-

The stability and security of power systems are of utmost importance to planning and of operation engineers. As the demand on grid resources increases, and the contingency impacts on the interconnected power grids became more threatening or severe, real-time determination of power system operation and control is needed. The proposed method builds on recent advanced in the area of real time voltage stability monitoring and control. It is based on the use of real-time measurements via Phasor Measurement Unit (PMU) technology. The design strategy will allow the real-time computation and controls, such as adjustments of voltage regulators or controllable series/shunt compensators, to arrest voltage instability at its onset. Disturbances, such as sudden loss of generation or lines, or more slowly changing loads, affects the system operating points and frequency. The ability to rapidly monitor and adjust to system changes for restoring an equilibrium point in generation to load balance is a goal of voltage stability assessment and control.

1.3 Methodology Of PMU:-

The whole system consists of two modules, the sensor module and the PMU module. Sensor module constitutes the PTs (Potential Transformer) and CTs (Current Transformer). The three phase instantaneous values of voltage and current are inputted to the A/D converter though the PT (Potential Transformer) and CT (Current Transformer). There the analog LPF is used as anti-aliasing filter the second module is the PMU module which uses the Digital signal processor for the calculation of phasor as well as the magnitude of voltage and current and GPS Receiver. The processor and all other electronic circuitry come under the PMU module. The recursive DFT algorithm is used for reduction of computing time. The phasor calculation is done only by executing the MAD (Multiply and Add) operations, and the DSP is good for such calculation. Since the DSP is the high-speed signal processor, if necessary, other state variables can be computed in the each phasor every sampling intervals. The measurements and calculations are done for a single phase system. The GPS receiver receives lpps (Pulse Per Second) clock signal synchronizing to the UTC with high accuracy from the GPS satellites. In such a way the synchronized measurement at multi-points in the power system can be realized. Next is the communication part which uses Serial communication to transmit data to the utility computer. All the modules mentioned above are shown in Fig.1. The separate sections are described briefly below.

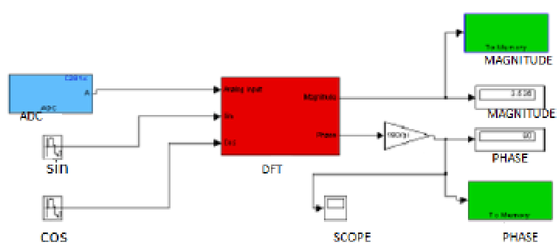

Fig.1 phasor measurement for single phase analog input

1.3.1 GPS Receiver:-

The GPS system has 24 active satellites. The satellites describe orbits that let any point in the Earth to have line sight 24 hours a day with different satellites. The GPS system proportionate services as the position in geographical coordinates, the altitude above the sea, velocity and direction of a moving object, the magnetic derive in degrees, the time by the UTC (Universal Coordinated Time), the signal 1pps and others[8].

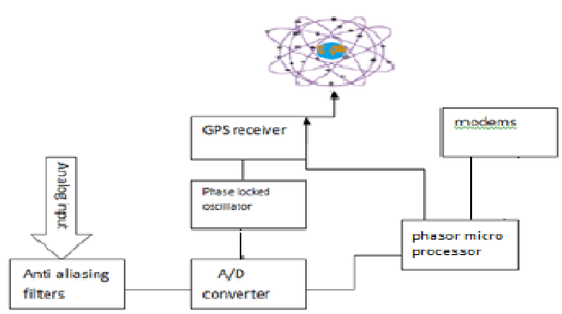

Fig.2 General Block Diagram of PMU

These are arranged in six orbital planes displaced from each other by 60° and having an inclination of about 55° with respect to the equatorial plane. The satellites have an orbital radius of 16,500 miles, and go around the earth twice during one day. They are so arranged that at least six satellites are visible at most locations on earth, and often as many as 10 satellites may be available for viewing. The most common use of the GPS system is in determining the coordinates of the receiver, although for the PMUs the signal which is most important is the one pulse per second. This pulse as received by any receiver on earth is coincident with all other received pulses to within 1 microsecond. There are four satellites in each of the six orbits, which orbit around the earth with a period of half a day. The GPS satellites keep accurate clocks which provide the one pulse per second signal. The time they keep is known as the GPS time which does not take into account the earth's rotation. Corrections to the GPS time are made in the GPS receivers to account for this difference so that the receivers provide UTC clock time. A terrestrial GPS receives the signal from one or more satellites (for example, to calculate the geographical coordinates it is required the reception of the signal from three satellites). Once the receptor detects the signal with good strength from at least one satellite, it decodes the UTC and transmits it in synchronization with the 1pps signal from each one of the instruments that measure the phasor [8].

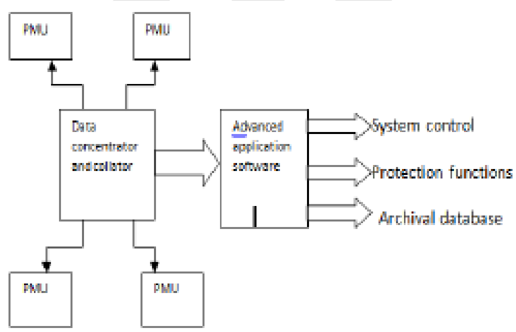

Fig.3 PMU utilization in a power system

Each PMU uses the 1pps signal to synchronize its own measurement system. The 1pps signal has a TTL level and is generated in the GPS receiver system. Once the receiver detects a satellite, the receiver synchronizes the rise time of the 1pps with the reception of the UTC. The 1pps signal has a pulse width of 10 microseconds; the rise time takes usually less than 20 nanoseconds and a period of exactly one second ±100 nanoseconds. In the other hand, UTC is synchronized with a reference from a Cesium atomic clock of high stability that is contained in each satellite. The clock of each satellite is synchronized with a master clock, so each satellite sends the UTC signal at the same time. For any application where a GPS is required for synchronization, the rise time of the 1pps signal has to be used because this is synchronized at each repetition of the UTC [8].

1.3.2 Processor:-

In this project, DSP processor is used to calculate the phasor. The important factors leads to the selection of DSP instead of standard PIC Controller is the DSP's multiply accumulate feature (MAC) that PIC Microcontroller does not have. This valuable if you want to perform true digital signal processing math such as FFT (one example). Doing an FFT computation in a standard microcontroller will take a long time compared to performing it on a MAC of the DSP. Also DSP provides diagnostic monitoring with FFT of spectrum analysis effectively and enables enhanced real time algorithms. Since recursive computation is easy and non-recursive algorithm requires costly high end processors, DSP processor is selected for the calculation of phasor.

1.3.3 Current And Voltage Transformer:-

In substations the PMU is place at the output side of the measurement transformer where the voltage is 110V ac. The supply voltage of ADC used in TMS320F2812 trainer is 3.3V. So the 110V ac supply has to be stepped down to the voltage required for the kit. For this purpose a 6-0-6V step down transformer is used which is followed by an opamp circuit which again step down the voltage to get the desired voltage for the ADC. The ADC module has 16 channels, configurable as two independent 8-channel modules to service event managers A and B.

1.3.4 ADC Module:-

The ADC module in the F2812 has been enhanced to provide flexible interface to event managers A and B. The ADC interface is built around a fast, 12-bit ADC module with a fast conversion rate of 80 ns at 25-MHz ADC clock. The ADC module has 16 channels, configurable as two independent 8-channel modules to service event managers A and B. The two independent 8-channel modules can be cascaded to form a 16- channel module. Although there are multiple input channels and two sequencers, there is only one converter in the ADC module [9].

1.3.5. Real-Time JTAG and Analysis:-

The F2812 implement the standard IEEE 1149.1 JTAG interface. The user can also single step through non-time critical code while enabling time-critical interrupts to be serviced without interference. The F2812 implement the real time mode in hardware within the CPU. Additionally, special analysis hardware is provided which allows the user to set hardware breakpoint or data/address watch-points and generate various user selectable break events when a match occurs [9].

1.4 Synchrophasor Definition And Measurements:-

Synchrophasor is a term used to describe a phasor which has been estimated at an instant known as the time tag of the synchrophasor. In order to obtain simultaneous measurement of phasors across a wide area of the power system, it is necessary to synchronize these time tags, so that all phasor measurements belonging to the same time tag are truly simultaneous. Consider the marker $t = 0$ in Fig. 1 is the time tag of the measurement. The PMU must then provide the phasor given by (2) using the sampled data of the input signal. Note that there are anti aliasing filters present in the input to the PMU, which produce a phase delay depending upon the filter characteristic. Furthermore, this delay will be a function of the signal frequency. The task of the PMU is to compensate for this delay because the sampled data are taken after the anti aliasing delay is introduced by the filter. This is illustrated in Fig. 3. The synchronization is achieved by using a sampling clock which is phase-locked to the one-pulse-per-second signal provided by a GPS receiver. The receiver may be built in the PMU, or may be installed in the substation and the synchronizing pulse distributed to the PMU and to any other device which requires it. The time tags are at intervals that are multiples of a period of the nominal power system frequency. It should also be noted that the normal output of the PMU is the positive sequence voltage and

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current phasors. In many instances the PMUs are also able to provide phasors for individual phase voltages and currents.

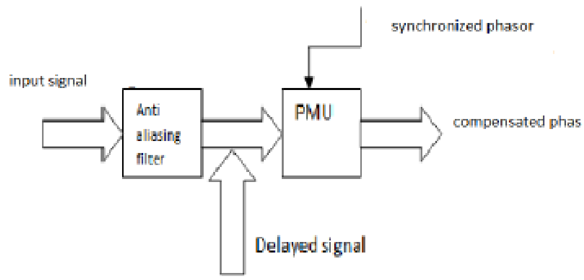

Fig.4 Compensating for signal delay introduced by the anti aliasing filter.

2. APPLICATIONS OF PMU

The synchronized phasor measurement technology is relatively new, and consequently several research groups around the world are actively developing applications of this technology. It seems clear that many of these applications can be conveniently grouped as follows:-

- Power System Real Time Monitoring
- Advanced network protection
- Advanced control schemes

3. OUTLOOK OF PMU

PMUs facilitate innovative solutions to traditional utility problems and offer power system engineers a whole range of potential benefits, including:-

- Precise estimates of the power system state can be obtained at frequent intervals, enabling dynamic phenomena to be observed from a central location, appropriate control actions taken.
- To ensure acceptable quality of the power supplied to the consumers
- Post-disturbance analyses are much improved because precise snapshots of the system states are obtained through GPS synchronization.
- To analyze the vulnerability of the system against any contingency. This is known as security assessment of the power system networks.
- Advanced protection based upon synchronized phasor measurements could be implemented, with options for improving overall system response to catastrophic events.
- Advanced control using remote feedback becomes possible, thereby improving controller performance.

4. THE COMPARISONS BETWEEN SCADA SYSTEM AND PMU SYSTEM

The following comparisons between SCADA and PMU systems are given in below in Table 1.

ATTRIBUTE	*SCADA*	*PMUs*
Measurement	Analogue	Digital
Resolution	2-4 samples per cycle	Upto 60 samples per cycle
Observability	Steady State	Dynamic/Transient
Monitoring	Local	Wide-area
Phase Angle Measurement	No	Yes

Fig. Table 1

5. PMU PLACEMENT RULES

The following PMU placement rules were proposed in [3]:

- Rule 1: Assign one voltage measurement to a bus where a PMU has been placed, including one current measurement to each branch connected to the bus itself (Fig. 1).
- Rule 2: Assign one voltage pseudo-measurement to each node reached by another equipped with a PMU.
- Rule 3: Assign one current pseudo-measurement to each branch connecting two buses where voltages are known (Fig.1.b). This allows interconnecting observed zones.
- Rule 4: Assign one current pseudo-measurement to each branch where current can be calculated by the Kirchhoff current law. This rule applies when the current balance at one node is known, i.e. if the node has no power injections (if N-1 currents incident to the node are known, the last current can be computed by difference).

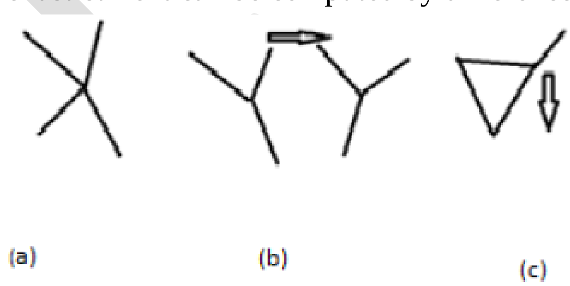

Fig.5 PMU placement rules

6. ALGORITHM

A. Depth First:-

This method uses only Rules from 1 to 3 (it does not consider pure transit nodes). The first PMU is placed at the bus with the largest number of connected branches if there is more than one bus with this characteristic, one is randomly chosen. Following PMUs are placed with the same criterion, until the complete network visibility is obtained, as depicted in (Fig.6)

B. Graph Theoretic Procedure:-

This method was originally proposed in 1993 and is similar to the Depth first. Algorithm, except for taking into account pure transit nodes (Rule 4).

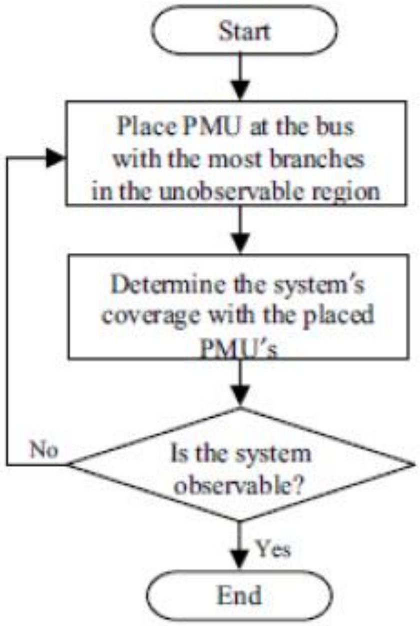

Fig. 6. Flowchart of the Graph Theoretic Procedure

C. Bisecting Search Method:-

Fig.5 and 6 depicts the Pseudo-code of the simulated annealing procedure and the flowchart of the bisecting search method. Refer to fig.7 for the description of this method.

D. Recursive Security N Algorithm:-

This method is a modified depth first approach. The procedure can be subdivided into three main steps: 1) Generation of N minimum spanning trees: Fig.7 depicts the flowchart of the minimum spanning tree generation algorithm. The algorithm is performed N times (N being the number of buses), using as starting bus each bus of the network.

- Rule 1: a PMU is placed at the node;
- Rule 2: the node is connected at least to two nodes equipped with a PMU.

Rule 2 is ignored if the bus is connected to single-end line.

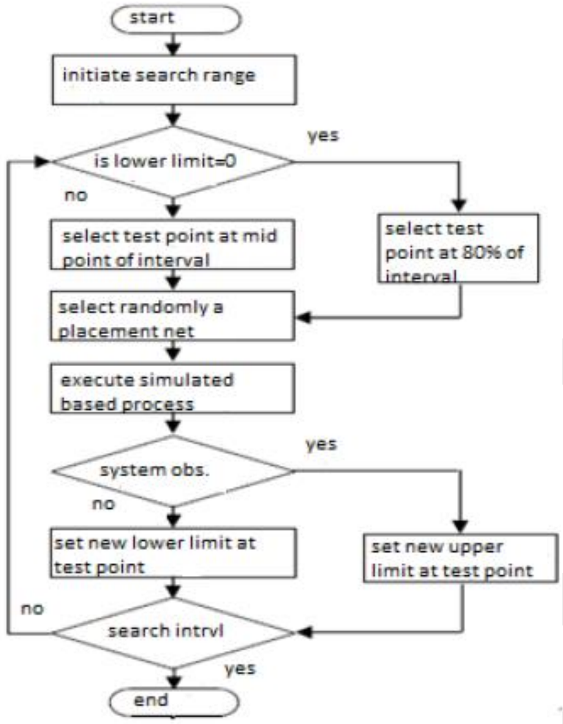

Fig.7. Bisecting search method

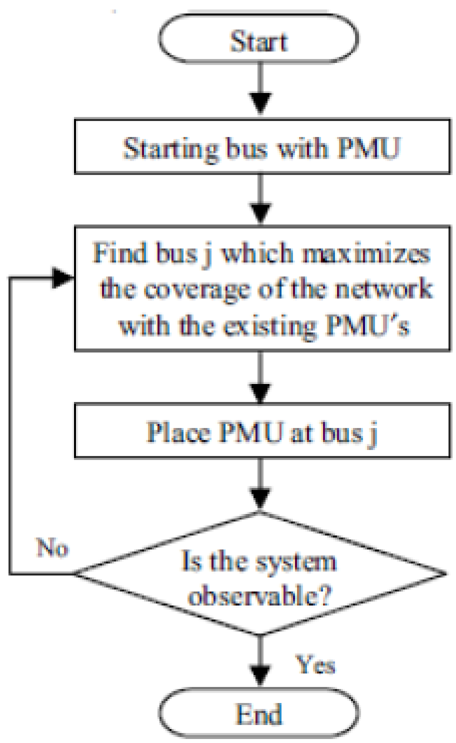

Fig.8 Recursive N Security Method

CONCLUSION

Application of PMU technology is power system is shown in this paper. In the previous times the research has focused mainly on network topology with the goal of designing such configuration which can provide complete observability with minimum number of PMU's. Recently we have introduced a new approach which makes use of stochastic models of the signals and measurements to achieve the complete observability, controllability and uncertainties in the power system states. Here we have a present a new approach to design the optimal placement of PMU in the system to enhance the reliability and voltage stability of the system. And I hope that this approach will provide a tool for the engineers to have a alternative in the form of PMU. And also a project is going on in India to integrate all the five national grids, and this can only be achieved with the help of PMU technology.

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