The Journal of CPRI,
Vol. 10, No. 1, March 2014 pp. 51-56

Wide Area Monitoring, Protection and Control: Requirements and Applications in Power System Protection

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Due to the large scale network complexities, system wide disturbances in power systems are a challenging issue for the power industry. When a major power system disturbance occurs, protection and control actions are required to stop the degradation of the system and restore to a normal state thereby minimizing the impact of the disturbance. Improvements in planning and operation of the grid could be achieved by Wide Area Monitoring, Protection and Control (WAMPAC) Applications. The purpose of wide area monitoring system is to monitor, assess, enable and automatically take necessary action to mitigate the harmful effects due to disturbances or faults in the system. This paper discusses in details WAMPAC. The present work also gives an overview of the Phasor Measurement technology and it benefits, requirements and applications for WAMPAC strategies.

Keywords: *Out-of-step protection, Phasor measurement unit, Power swing detection, WAMPAC, Wide area protection.*

1.0 INTRODUCTION

In the late 1980s synchronized phasor measurement techniques had been used for power system monitoring applications and the first phasor measurement unit (PMU) product appeared on the market in early 1990s. PMUs, the devices used to measure synchronized phasors, are placed on some selected locations to measure time stamped voltage and currents of a power system. The intermittent exposure of the power system to serious disturbances lead to power supply interruptions and in a traditional protective relaying strategy, decisions are made based on local measurements only. Wide area protection strategy offer better immunity to the disturbances and improves the power transfer limit and economics of operation by better detection and control methods. In order to preserve the system integrity, except those disconnected by isolation of the faulted elements, the system should be intact with a sufficiently safe power angle.

2.0 CONCEPT OF SYNCHRONIZED PHASOR MEASUREMENT

A phasor is a vector consisting of magnitude and angle that corresponds to a sinusoidal waveform at a given frequency as shown in Figure 1.

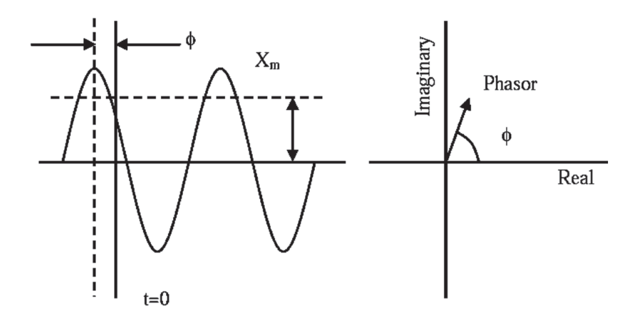

FIG. 1 A SINUSOID AND ITS REPRESENTATION AS A PHASOR

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A synchrophasor is defined in IEEE C37.118 as "a phasor calculated from data samples using a standard time signal as the reference for the measurement" [1].The phase angle of the phasor is arbitrary as it depends upon the choice of the axis and the length of the phasor is equal to the rms value of the sinusoid.

Measuring devices are placed at different locations in a power grid to capture voltage and current waveforms, from which phasor can be calculated. Thus, synchrophasors measured across an interconnected power grid will have a common time reference and can be compared directly [2]. The working of PMU is shown in Figure 2.

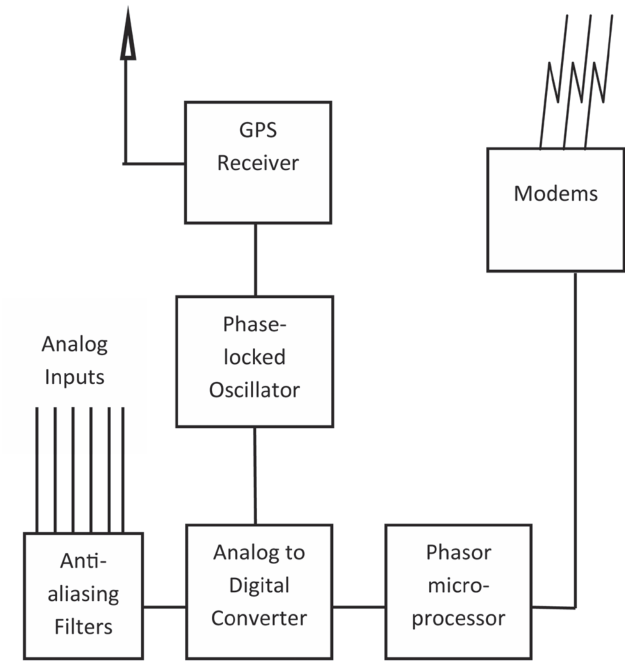

FIG 2 BLOCK DIAGRAM OF PHASOR MEASUREMENT UNIT

Time stamped synchronized measurements represents actual system conditions at any given time and can be utilized in protective relaying. Phasor data from different buses where PMUs are provided are collected at a central site using a phasor data concentrator (PDC) or the data can be exchanged between local PMUs for protection and control purposes as shown in Figure 3.

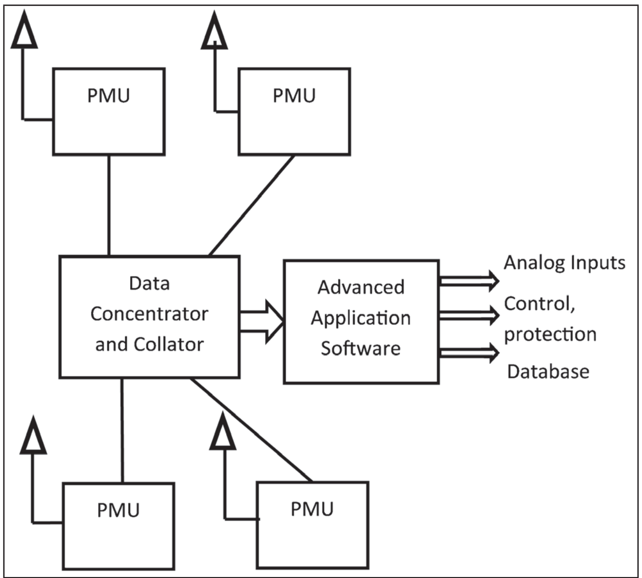

FIG. 3 PMU UTILIZATION IN A POWER SYSTEM

3.0 REQUIREMENTS

To implement the phasor measurement technique in a consistent and economical way, the following basic requirements has to be satisfied in order that the different desired applications can utilize the installed PMUs, thereby reducing the difficulties in integrating applications.

3.1 Consistent performance of all measuring units

A wide area protection system based on phasor measurement technology will have different types of products from different manufacturers. The system needs a consistent performance from all installed PMUs to meet its application requirements[3]. This implies the need for a standard. Industry requirements are outlined in IEEE C37.90 and other requirements in IEEE C37.118.2-2011.

3.2 Future-proof system design

The power system network topology is changing or getting added up day by day and the implemented wide area protection system should not be just for the existing system but also for many future applications[3].

3.3 Observability

The whole Wide-Area Measurement System (WAMS) that is implemented must provide the complete numerical as well as topological observability of the system.

3.4 Adaptive relaying

Wide area protection schemes should be able to sync-in with local protective devices to aid in adaptive relaying and to handle catastrophic events or outages.

4.0 OPTIMAL LOCATION OF PHASOR MEASUREMENT UNITS

The Problem here is to decide upon the minimum number of PMUs and where it should be placed so that the complete system is observable. This can be solved either by conventional optimization techniques such as Linear Programming (LP) or by Non-Linear Programming (NLP) and Dynamic Programming or by advanced heuristic or modern meta-heuristic optimization techniques. If we want to avoid problems such as trapping at local optima or difficulties in handling constraints, advanced heuristic and modern meta-heuristic optimization techniques are preferred[4].

Research activities done on the optimal placement problem shows that the observability of the whole system can be achieved by placing n/5 to n/4 number of PMUs, where 'n' is the number of buses in the system/network [5]. A good PMU placement algorithm should be able to handle conditions such as loss of a unit, a communication channel, phasing of PMU etc. Also, if a minimum number of PMUs are used, so that the system is just observable, loss of a communication channel itself may lead to unobservable spots in the grid[4].

5.0 APPLICATIONS

Conventional protection strategies isolate the faulted portion of the system quickly thereby ensuring the safety of humans and power equipments / components. But whenever very quick deterioration of the system takes place, blackout may happen before any action could be taken by the local protective element because decisions are based on local measurements only. It is very clear that it is quite difficult to maintain the stability of the whole system if only local measurements are used for protection[6]. Synchrophasor system can be used for real-time wide area protection and control applications such as

- Power swing detection and out-of-step relaying
- Load shedding
- Power system analysis
- Synchrophasor assisted black start
- Distributed generation anti-islanding and automatic generator shedding
- Fault location and line reclosing utilizing synchrophasors
- Verifying voltage and current phasing
- Voltage instability prediction
- Loss of field protection
- Bus differential and line differential protection
- Negative and zero sequence line differential protection
- Alarms for encroachment of relay trip characteristics
- Controlled islanding
- Detection of power system inter area oscillations
- Synchrophasor based line backup protection [7], [8].

6.0 NEW TRENDS IN ADAPTIVE OUT-OF-STEP PROTECTION

Out-of-step, pole slip and just loss of synchronism are equivalent designations for the condition where the impedance locus travels through the generator. When the impedance goes through the transmission line the phenomenon is also known as power swing. However, all of them refer to the same event, loss of synchronism[9].

Figure 4 shows a simple transmission system consisting of a multi-circuit line over which a power of $P_{initial}$ is being transferred. If one of the lines lost due to a fault, the power input of the generator remains the same, considering no action by the governor, the system settles to a new rotor angle δ_2, (if a double circuit line is considered and the total power can be transferred with a single circuit) in the case of a stable power swing.

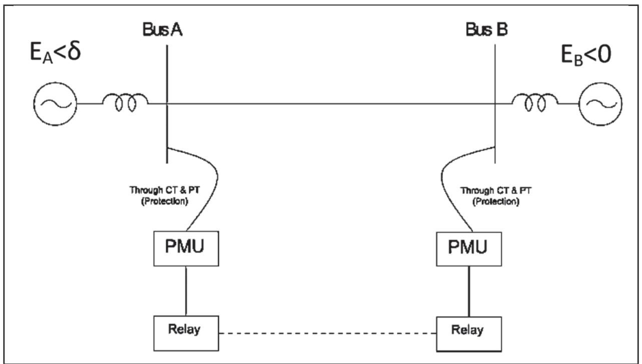

FIG. 4 A SIMPLE TRANSMISSION SYSTEM WITH PMUS INSTALLED

If a single circuit is not able to transmit the initial power $P_{initial}$, the rotor angle δ increases drastically with respect to time, and is an indication that the generators are getting out-of-step and is referred to as unstable power swing. Traditionally, the discrimination between faulted condition and a stability oscillation is achieved by the analysis of speed of movement of trajectory in the R-X plane as shown in Figure 5. Upon detecting an out-of-step condition, the protection system has to permit a selective tripping, so that the whole system is separated into islands where load generation balance is achieved to a maximum extent [10]. At present the locations where out-of-step tripping is permitted are decided by planning studies. A real time simulation is a much better option to decide upon that a swing is from which portion and whether it will recover. Phasor measurement units are installed at the selected buses and the phasor data from the PMU is fed into the relay and the relay computes the rotor angle between the two buses or equivalent systems and uses this angle difference together with the breaker status to determine the stability of the swing and further remedial action[11].

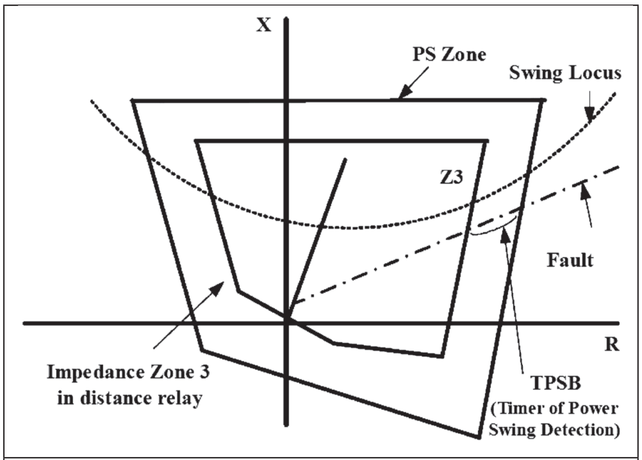

FIG. 5 GENERAL POWER SWING CONDITION

Figure 6 shows typical out-of-step characteristics of mho type and blinder type relays. The inner blinder and zone are utilized to detect a power swing and the outer one is to start a timer.

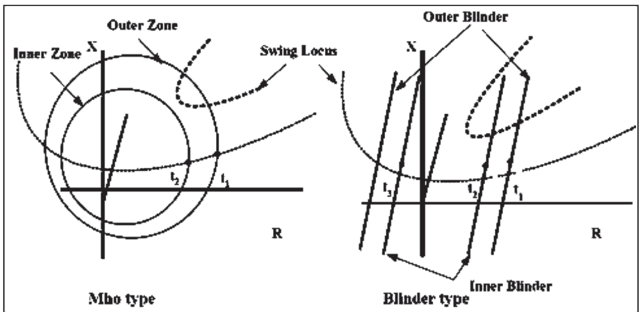

FIG. 6 TYPICAL OUT-OF-STEP CHARACTERISTICS

If the locus of impedance crosses the inner zone before the timer runs out, a fault is declared, else it concludes as a power swing. Also if the locus remains within the inner zone longer than a certain amount of time or crosses the opposite blinder it concludes as an unstable swing, else as a stable swing. The tripping or blocking functions are initiated for an unstable power swing only. A group of generators going out-of-step with the rest of the power system is often a precursor to a complete system collapse. Whether a transient will lead to stable or unstable condition has to be determined quickly and reliably before appropriate control action is taken. Regardless of a stable or unstable power swing, an unanticipated operation of distance relay occurs more often and in order to secure a fine operation of the relay during the swings, Power Swing Blocking (PSB) function and Out-of-Step Tripping (OST) functions are integrated with the distance relays. Although phasor measurement units have been used for out-of-step detection, improvements can be made in out-of-step protection schemes by making the relay adaptive to the changing system conditions.

A systematic procedure is to be identified and followed to set the optimal location for the adaptive protection scheme and has to be confirmed based on other methodologies or practical experience. Even though the power swing protection philosophy is simple, it needs a lot of studies to implement it due to the system complexity and changing topology at different operating conditions. The various studies needed are:

- Transient stability studies have to be done to check whether the system is operating within the constraints for all possible system operating conditions.
- Location of the power swing loci during various disturbances in the system.
- Identify the optimal point of system separation when out-of-step protection operates (based on load-generation balance and impedance between islands)

7.0 MAIN CHALLENGES FACED IN IMPLEMENTING PHASOR MEASUREMENT TECHNIQUE

Some of the key issues and challenges faced in the implementation of Wide area monitoring in power system protection are as follows [12], [13-18]:

- Optimal placement problem (OPP) of PMUs have to be tackled so that the numerical as well as the topological observability of the system is not compromised.
- Implementation of WAMS based adaptive relaying schemes for distance relaying may be a challenging task during stressed conditions in the system due to overreaching of distance relays.
- Testing and validation of PMUs.
- Inadequate / improper communication frame work.
- Customization of intelligent alarms and displays (real time as well as off-line) for alerting the operator.
- Tools to tag disturbances and power system events to synchrophasor data and integration of synchrophasor data in SCADA / EMS displays.
- Data retention/storage, retrieval and tools for post-dispatch analysis.
- Special care has to be taken for implementing wide area distance relaying strategies for compensated transmission lines containing series FACTS devices because the zones of protection depends on the control parameters of the FACTS devices[12].

8.0 CONCLUSION

Synchrophasor technology provides the time coherency required for wide area monitoring, protection and control. Phasor measurement units provide innovative solutions for power utility problems and also facilitate a precise post-disturbance analysis since the power system states are time stamped. Even though, the expenditure to install a large number of PMUs limits a quick changeover from present RTU based SCADA systems to synchrophasor technology, still it provides time synchronized measurements across the grid and new monitoring, protection and control schemes in hybrid mode are being implemented today. With the advancement of phasor measurement technology and increasing number of PMUs planned for installation, power utilities, manufacturers and research institutions are looking for the optimal solution for the PMU placement problem and also for its applications in protection and control. For this, a strong interaction is required among utilities, academia, research institutions, manufacturers, and application developers. With advancement in technology, wide area monitoring system based protection and control should be part of new strategies being developed for power swing detection and out-of-step protection schemes and also for dealing the communication delays.

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