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MONITORING AND DETECTION OF FAULT USING PHASOR MEASUREMENT UNITS

C.Anil Kumar[1], **K.Lakshmi**[2]
PG Scholar, K.S.Rangasamy College of Technology, Tiruchengode, Tamilnadu, India. [1]
Associate Professor, K.S.Rangasamy College of Technology, Tiruchengode, Tamilnadu, India. [2]

ABSTRACT: This paper presents the fault detection and classification in power system using Phasor Measurement Units (PMU). PMU detects the fault in less than seconds and it also gives a time synchronized values of current and voltage in digital form and it is given to local Phasor Data Concentrator (PDC). When major disturbance like blackouts occur, the protection and control actions has to be initiated against the power system degradation, which in turn restore the system to a normal state and minimize the impact of the disturbance. Wide Area Measurement System (WAMS) is emerging nowadays for monitoring and control the power system operations. The system frequency is measured by frequency-tracking method which depends on synchronized phasor measuring technology with high speed communication system and time transfer Global Positioning System (GPS). The proposed method has been validated in IEEE-9 bus system using Matlab Simulink model.

Keywords: Phasor Measurement Units, Time Synchronization, Overloading, Digital protection.

I. INTRODUCTION

The distance relays which are widely applied in the protection today and involve the determination of impedance achieve operating times of the order of a period of the power system frequency [1]. A distance relay is designed to only operate for faults occurring between the relay location and the selected reach point, and remains stable for all faults outside this region or zone. The resistance of the fault arc takes the fault impedance outside the relay's tripping characteristic and, hence, it does not detect this condition. Alternatively, it is only picked up either by zone 2 or zone 3 in which case tripping will be unacceptably delayed [6]. The distance relays are based on standalone decision, while each relay operates independently according to three different zone of operation [2]. The mal-operation or fail-to trip of protection is determined as one of the origins to raise and propagate major power system disturbances. A vast majority of relay mal-operations is unwanted trips and have been shown to propagate major disturbances. Backup protections in fault clearance system have the task to operate only when the primary protection fails to operate or when the primary protection is temporarily out of service [3]-[5]. The recent complexity and enlargement of power systems makes it difficult to coordinate operation times and reaches among relays.

In the areas of power system automation and substation automation, there are two different trends: centralization and decentralization. More and more dynamic functions are moving from local and regional control centres toward central or national control centres [7]. At the same time we also observe more “intelligence” and “decision power” moving closer towards the actual power system substations. Greater functional integration is being enclosed in substation hardware. In view of global security of power systems, the action algorithms of conventional backup protections possibly are not best choices because the operations of individual relays are hardly coordinated each other. Therefore, the principle of the protection design needs innovation to overcome the above problem. Modern protection devices have sufficient computing and communications capabilities to allow the implementation of many novel sophisticated protection principles.

Therefore, a novel wide-area backup protection system is reported in this paper. This system is capable of acting as the substitution of conventional distributed backup protections substation [8]. To ensure the fast responsibility of such a system to the emergent events, the communication requirements are discussed as well. Conclusively, the proposed system is designed by two ways. First, in substation, concentrate some conventional backup protection functions to an intelligent processing system; second, concentrate the coordinated and optimized processing and controlling arithmetic of all backup protection in a region into a regional processing unit. The communication of data among them is carried via optic-fibre networks. The relay decision is based on collected and shared data through communication network [9]. The suggested technique satisfies high degree of reliability and stability while it is based on shared decision rather than stand alone decision [10]. The suggested technique can see all the power system area and can deal with the transmission lines as unit protection. The primary purpose of these systems is to improve disturbance monitoring and system event analysis. These measurements have been sited to monitor large generating sites, major transmission paths, and significant control points. Synchronized phasor measurements provide all significant state measurements including voltage magnitude, voltage phase angle, and frequency.

In this paper, the fault detection and classification is discussed. Phasor and synchrophasor basics are covered in Section II. The nature of Wide Area Monitoring and control is reviewed in Section III. Section IV considers a possible approach towards the fault identification and classification. Section V summarizes the key points presented in this paper.

II. PHASOR MEASUREMENT UNITS

Synchronised Phasor Measurement Units (PMUs) were first introduced in early 1980s, and since then have become a mature technology with many applications which are currently under development around the world. The occurrence of major blackouts in many major power systems around the world has given a new impetus for large-scale implementation of Wide-Area Measurement Systems (WAMS) using PMUs and Phasor Data Concentrators (PDCs) in a hierarchical structure [11]. Data provided by the PMUs are very accurate and enable system analysts to determine the exact sequence of events which have led to the blackouts, and help analyze the sequence of events which helps pinpoint the exact causes and malfunctions that may have contributed to the catastrophic failure of the power system. As experience with WAMS is gained, it is natural that other uses of phasor measurements will be found. In particular, significant literature already exists which deals with application of phasor measurements to system monitoring, protection, and control.

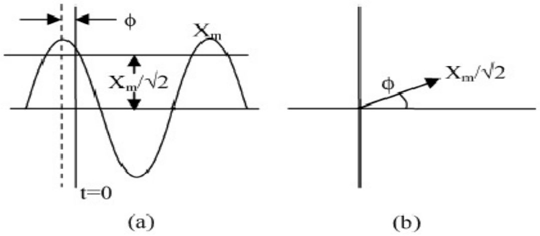

Fig. 1. Phasor representation of a sinusoidal signal. (a) Sinusoidal signal. (b) Phasor representation.

A pure sinusoidal waveform can be represented by a unique complex number known as a phasor. Consider a sinusoidal signal

$$x(t)=X_m\cos(\omega t+\phi). \qquad (1)$$

The phasor representation of this sinusoid is given by

$$X \equiv \frac{X_m}{\sqrt{2}}\varepsilon^{j\phi} = \frac{X_m}{\sqrt{2}}(\cos\phi + j\sin\phi). \qquad (2)$$

Note that the signal frequency ω is not explicitly stated in the phasor representation. The magnitude of the phasor is the rms value of the sinusoid $X_m/\sqrt{2}$, and its phase angle is ϕ, the phase angle of the signal in (1). The sinusoidal signal and its phasor representation given by (1) and (2) are illustrated in Fig. 1

Note that positive phase angles are measured in a counter clockwise direction from the real axis. Since the frequency of the sinusoid is implicit in the phasor definition, it is clear that all phasors which are included in a single phasor diagram must have the same frequency. Phasor representation of the sinusoid implies that the signal remains stationary at all times, leading to a constant phasor representation. These concepts must be modified when practical phasor measurements are to be carried out when the input signals are not constant and their frequency may be a variable. Although a constant phasor implies a stationary sinusoidal waveform, in practice it is necessary to deal with phasor measurements which consider the input signal over a finite data window. In many PMUs the data window in use is one period of the fundamental frequency of the input signal. If the power system frequency is not equal to its nominal value (it seldom is), the PMU uses a frequency-tracking step and thus estimates the period of the fundamental frequency component before the phasor is estimated. It is clear that the input signal may have harmonic or non harmonic components. The task of the PMU is to separate the fundamental frequency component and find its phasor representation. 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. 2.

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.

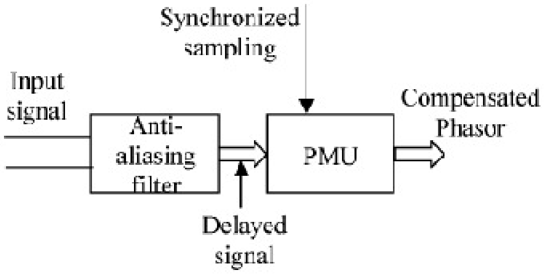

Fig. 2. Time Delay signal.

It should also be noted that the normal output of the PMU is the positive sequence voltage and current phasors. In many instances the PMUs are also able to provide phasors for individual phase voltages and currents.

III. WIDE AREA MONITORING AND CONTROL

PMUs create a picture showing the stability status of the nodes in the monitored area. PMUs take this picture at the same reference time. Using real-time information from PMUs and automated controls to predict, identify, and respond to system problems; a smart grid can automatically avoid or diminish power outages, power quality problems and supply disruptions.

Normal control measures are linked with permanent control activities, that can be either discrete, e.g., tap- changer and shunt devices, or continuous, such as frequency control. Normal control is defensive, *i.e.*, measures are taken to adjust the power system operational conditions to the present and near future probable situation. Normal control is usually repeated, e.g., tap-changer, reactive shunt devices, frequency control and AGC. The difference between normal and emergency control is the penalty for the power system if the control achievement is not performed. If a normal, protective, control deed is not performed, there is an increased risk for the failure of power system stability that stability will be lost if a severe disturbance occurs. If an emergency, corrective, control action is not performed, the system will go unsound. The response requirement (time and reliability) are normally higher for emergency control measures then for normal control actions. Emergency control functions are almost always habitual, while normal control measures can be either automatic or manual, e.g., in combination with alarms. The actions taken in the power system are however fairly similar for both normal control and emergency control.

Protection, system protection, an emergency control contain remedial measures, *i.e.*, actions are really needed to save the component or the system. Protection could very well be regarded as binary (on/off) emergency control, but by custom, protection is quite precise. Angle control is more exact if based on PMUs. Without PMUs power flow is an indirect method of measuring and controlling the angle. The measures are similar as for power flow control. PMU is a device for synchronized measurement of ac voltages and currents, with a common time (angle) reference. The most common time reference is the GPS signal, which has a precision better than 1 microsecond. In this way, the ac quantities can be calculated converted to Phasor (complex numbers by their magnitude and phase angle), and time imprinted. The primary purpose of these systems is to improve disturbance monitoring and system event analysis. These measurements have been sited to monitor large generating sites, major transmission paths, and significant control points. Synchronized phasor measurements provide all significant state measurements including voltage magnitude, voltage phase angle, and frequency.

Most of these phasor measurement systems have been implemented as real-time systems. With these systems, Phasor Measurement Units (PMUs) installed at substations send data in real time over dedicated communications channels to a data concentrator at a utility control centre. This approach allows the data to be used in System Protection Canter (SPC) as well as being recorded for system analysis and monitored via SCADA system. PMUs measure the bus voltage(s) and all the significant line currents. These measurements are sent to a Phasor Data Concentrator (PDC) at the control centres. The PDC correlates the data by time tag to create a system-wide measurement. The PDC exports these measurements as a data stream as soon as they have been received and correlated. System Protection Centre (SPC) receive Data stream and make a wide area protection depending on wide area view. This principal of operation is used in this paper. WAPS schemes are designed to detect abnormal system conditions, take pre-planned corrective actions intended to minimize the risk of wide-area disruptions and isolate the faulted segment from the overall power system . WAPS depend on WAMs to take hieratical action depending on wide area monitor of the overall network.

IV THE SOLUTION METHODOLOGY

The proposed technique is based mainly on two components to identify the faults on the transmission lines. The first component is the voltage reduction due to fault occurrence. The second component is the power flow direction after fault occurrence. The phase angle is used to determine the direction of fault current with respect to a reference quantity. The ability to differentiate between a fault in one direction or another is obtained by comparing the phase angle of the operating voltage and current. The voltage is usually used as the reference polarizing quantity. The fault current phasor lies within two distinct forward and backward regions with respect to the reference phasor, depending on the power system and fault conditions. The normal power flow in a given direction will result in the phase angle between the voltage and the current varying around its power factor angle ±ϕ. When power flows in the opposite direction, this angle will become (180±ϕ). For a fault in the reverse direction, the phase angle of the current with respect to the voltage will be (180-ϕ).

The main idea of the proposed technique is to identify the faulted area. This can be achieved by comparing the measured values of the positive sequence voltage magnitudes at the main bus for each area. This can result in the minimum voltage value that indicates the nearest area to the fault. In addition to that, the absolute differences of the positive sequence current angles are calculated for all lines connected with the faulted area. These absolute angles are compared to each other. The maximum absolute angle difference value is selected to identify the faulted line. The above two keys of operation can be mathematically described as follows:

$$\text{Min}\ \{\ |V_1, V_2|, \dots\ |V_m|, \dots\ |V_n|\} \quad (3)$$

Where $|V_n|$ is the positive sequence voltage magnitude measured by PMU and located at area “1”, “2”, “3”,..., “m”, to “n”.

For a fault occurred on the grid, the output from (3) is the minimum positive sequence voltage magnitude which indicates the nearest area to the fault. Suppose that the nearest area to the fault is indicated by number “m”. The next step is to compare the absolute differences of positive sequence current angles for all lines connecting area “m” with all other neighbouring areas and then selecting the max one.

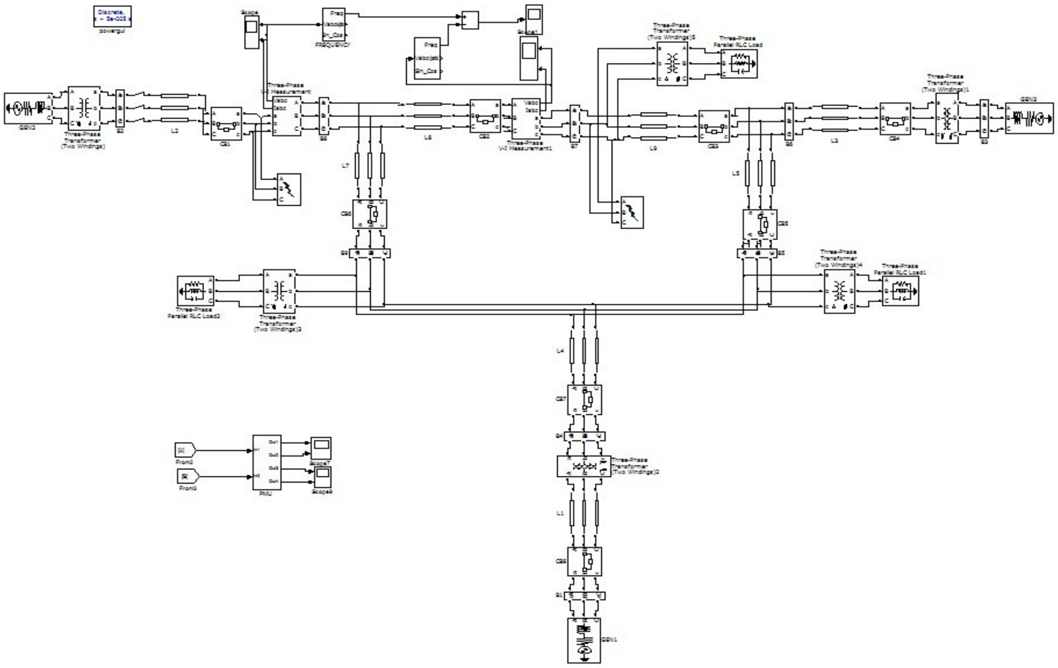

Fig. 3. IEEE-9 Bus System Using PMU

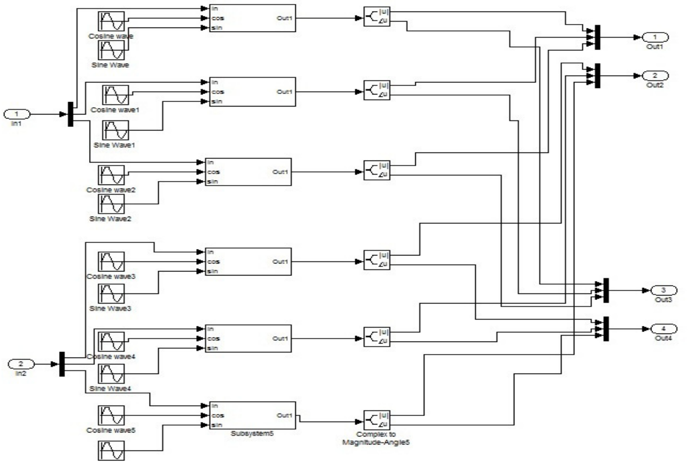

Fig. 4. Block Diagram of Phasor Measurement Unit

In the fig.3 the output signal from the PMU is the positive sequence voltage $|\mathrm{V_n}|$ and the positive sequence currents $|\mathrm{I_{12}}|$ & respectively. For the proposed technique, only positive sequence voltage magnitudes and positive sequence current angles are selected. The phase angle of corresponding voltages and current are calculated. The fig.4 describes the blocks of PMU and it gives the output voltage and current for the fault area.

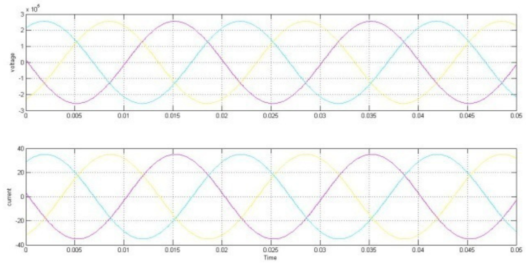

Fig. 5. System Bus Voltage and Current Before Fault

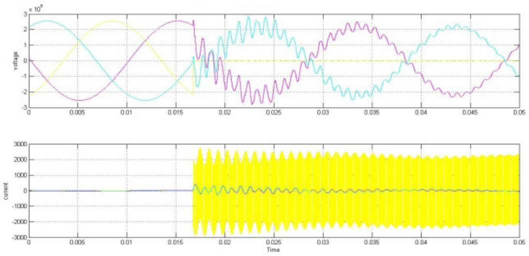

Fig. 6. System Bus Voltage And Current Under LG Fault

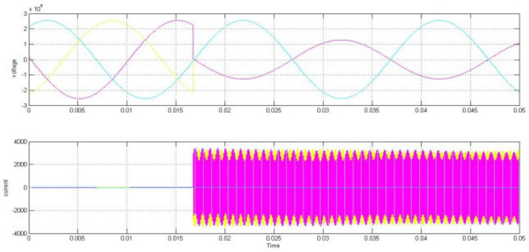

Fig. 7. System Bus Voltage And Current Under Line To Line Fault

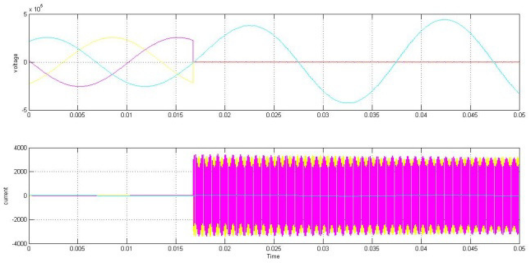

Fig. 8. System Bus Voltage And Current Under Double Line To Ground Fault

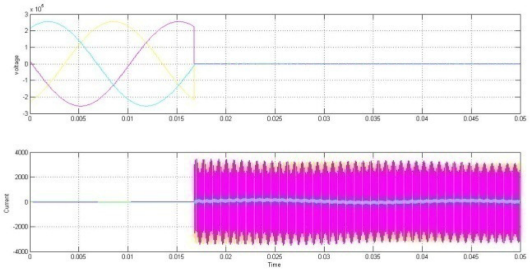

Fig. 9. System Bus Voltage And Current Under Symmetrical Fault

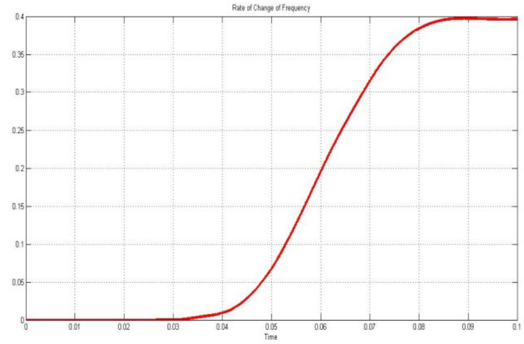

Fig. 10. Rate of Change of Frequency

Fig. 5. Shows the system voltage and current at the bus2 before fault. In Fig. 6. shows the system voltage and current under line to ground fault. In Fig. 7. shows the System bus Voltage and Current under Line To Line Fault. System Bus Voltage and Current under Double line to ground fault is shown in Fig. 8. In Fig. 9. System Bus Voltage and Current under Three Fault. Fig. 10. Shows the rate of change of frequency is reduced in during the fault period. The symmetrical fault current is greater than unsymmetrical fault current. The occurrence of unsymmetrical fault is more than the symmetrical fault but the symmetrical fault is very severe in nature. In this proposed methodology the PMU is installed in the IEEE-9 bus system and the fault analysis is carried out. The

various types of fault analysis are conceded and the waveform is obtained.

VI. CONCLUSION

This paper presents a new protection technique for transmission grids using phasor synchronized measuring technique in a wide area system. By using Wide Area Protection System the fault detection is very fast and it is reliable. The protection scheme has successfully identified the faulted line all over the interconnect system. The relay has a very fast detection time. The relay is based on sharing data from all areas.

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AUTHORS

C. Anil Kumar received his B.E. degree in Electrical and Electronics Engineering from Anna University, Chennai in 2009. Now he is currently pursuing his M.E.

degree in Power System Engineering from Anna University, Chennai. He is a member of ISTE.

K. Lakshmi received her B.E degree in Electrical and Electronics Engineering from Bharathiar University, Coimbatore and M.E degree in Power Systems from Annamalai University, Chidambaram. She is currently doing Ph.D in power system at Anna University, Chennai. She has published technical papers in International and National Journals and Conferences. Her research interests are power system optimization in Deregulated power markets, operational planning and control in restructured power system.