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Wide Area Protection Technique for Power Transmission Grids Using Phasor Measurement Unit

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Abstract—*Calamitous loss in power system occurs due to mal-operation of traditional backup protection system which is main cause of many cascaded trips in power system. Some defensive system is necessary to trip such failures in the power system. The basic objective of protection is to isolate only the components that affected due to fault while keeping remaining system stable. The latest power grids are complex, so needs to be monitored, control and protected through wide area measurement system (WAMS). Actual power system parameters measurements and calculations can be done with the help of synchronized Phasor Measurement Unit (PMU). The objective is to increase the overall efficiency and reliability of power system for all power stages via significant dependence on WAMS as distributed intelligence agents. The present methods that are been used for protection are not accurate as PMU because PMU uses Global Positioning System (GPS) for time synchronized data. This paper is based on novel wide area backup protection system using PMU as an alternate to the conventional distributed backup protection in substation. The proposed system has the capability of utilizing the designed PMU to analyze the power system in real-time.*

Index Terms: *Global Positioning System (GPS), Phasor Measurement Unit (PMU), Time Synchronization, Wide Area Measurement System (WAMS).*

1. INTRODUCTION

Electric utility have to face increasingly complex issues in a continuously evolving power system sector. The increment of the load leads the power system to become bigger and more complex. There are two issues reflected: 1) power grids are connected to operate closer to their maximum capacity and 2) there is an increased need for accurate and better monitoring of the system. From last few decades the risk of major outages in power system has increased because of low security margin and lack of modernization in transmission. To deal with new technologies like smart grids has introduced new standard for protection, control and monitoring system to increase the safety of power grids, reduce the unwanted blackouts, fast response to the drastic changes in the electrical system, provide reliability to electric power, detection of fault and system recovery as early as possible. But sometimes very minor disturbances can be raise by the chain of events leading to system wide effects. So here, wide area protection, control and monitoring system is essential for energy management system.

Wide Area Monitoring System (WAMS) is the new concept in power system that has the capability of real time monitoring. The definition of WAMS is described in the [1]. The features of WAMS are real time monitoring, utilize the communication system and synchronized central control. As we know that, power system is the complex system, various faults occur on the transmission line due which the system collapses [2]. When simple fault occur on the system it is considered as initial stage of the fault.

Many different techniques are introduced in the power system for the protection of the transmission line. One of the most widely used techniques in the power system is distance protection. In distance protection, the distance relay is used and it works on standalone decision and each relay operates independently according to different zone of protection. The distance relay operates when fault occurs between the relay location and selected reach point, while remains stable for the faults outside this zone [3].

Third zone of distance protection mal-operates in situations like load encroachment, power swing and voltage instability may lead to wide area blackouts [4]. Largest blackout in history occurred in July 2012 in India with two separate events on 30th and 31st. About 620 million people were affected due to this blackout. The blackout affected 22 states of India. Investigation shows that four factors were responsible for this blackout:

i. Inter-connected power transmission corridors get weak due to multiple existing outages.
ii. High loading on 400 kV Binna-Gwalior-Agra link.
iii. Inadequate response by State Load Dispatch Centers (SLDCs) to the instruction of Regional Load Dispatch Center's (RLDCs) to reduce overdraw by the Northern Region utilities and under draw/excess generation by the Western Region utilities.
iv. Loss of 400 kV Binna-Gwalior link due to mal-operation of its protection system.

In consideration of global security of power system, the action algorithm of conventional backup protection cannot be considered as best choices because of the operation of the individual relays are hardly coordinated each other. For system wide disturbances, wide area measurement will result very reliable and efficient. This type of application requires accurate phasor and frequency information from multiple synchronized devices. Wide Area Protection Control And Monitoring (WAPCAM) is a concept that involves the use of system wide information and communication of selected local information to a remote location to counteract the propagation of large disturbances. Recently, PMU plays vital role in wide area measurement and it gives very accurate and time synchronized data. On common time reference, it provides time synchronized data of voltage, current and frequency. The time synchronization is provided by global positioning system (GPS).

2. WIDE AREA SYNCHROPHASOR SYSTEM

A synchrophasor system consists of Phasor Measurement Unit (PMU), Phasor Data Concentrator (PDC), GPS satellite system, super PDC as shown in fig.2. The PMU collects the real-time data from the various remote areas and send it to local data concentrator called Phasor Data Concentrator via communication system. This system works as the backup protection system for WAPS and can be used in place of the conventional backup protection technique in power system. The relay works on shared and collected data through communication network. This proposed technique fulfills the high degree of reliability and stability as it works on shared decision against the standalone decision.

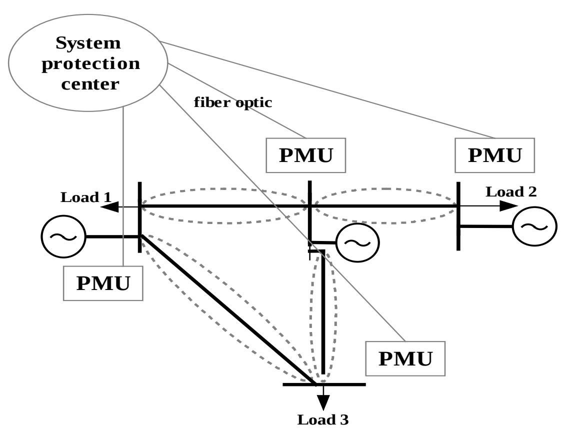

Fig. 1: Wide area backup protection system

PMUs measure the bus voltage(s) and line currents. The measured values are sent to a Phasor Data Concentrator (PDC) at the control center. The PDC correlates the data by time tag to generate system-wide measurement. The PDC exports these measurements as a data stream as soon as they received and correlated. System Protection Center (SPC) receive data stream and takes decision for wide area protection. This protection scheme is designed to detect abnormal system conditions and take necessary actions before the fault intended to minimize the risk of wide area disruptions and isolate the faulted segment from overall power system. WAPS depend on wide area measurements to take according actions depending on wide area monitor of the overall network.

Wide area backup protection system

PMU measures positive sequence voltage magnitude and current phase angle of a power system in real-time with synchronized time stamped data. The synchronization is achieved by same-time sampling of voltage and current waveforms using timing signals from different common time reference frame, such as the Global Positioning System (GPS) Satellite or any other reference timing signal generator. A phasor is pure sinusoidal wave and its phasor representation is given below:

$$X = \frac{Xm}{\sqrt{2}}(Xr + jXi) \quad (1)$$

$$X = \frac{Xm}{\sqrt{2}}(cos\Phi + jsin\Phi)$$

Where Xm is the amplitude of the filtered synchronized vector and θ is the phase angle relative to a cosine function at nominal frequency. As per IEEE C37.118, it specifies that the angle θ is 0 degrees when the maximum of the signal to be measured coincides with the GPS pulse and -90 degrees if the positive zero crossing coincides with the GPS pulse [5].

For phasor estimation many methods are available at present condition like Kalman filtering, zero-crossing detection, least square, filter-based methods, methods based on wavelet transform, but most commonly used method is Discreet Fourier Transform (DFT). The DFT is very fast recursive calculation of phasors. The sampling clocks are usually kept at constant frequency even though the input signal frequency may vary by a small amount around its nominal frequency [6].

3. PROPOSED TECHNIQUE

The transmission line fault occurrence is detected by two components. First in reduction of transmission line because of the fault and second component is direction of power flow after the fault. Fault current direction is determined by considering the phase angle with respect to reference quantity. Fault direction can be detected on comparing the phase angle of the transmission line voltage and current. The voltage is used as reference polarizing quantity. The Phasor of fault current lies within forward and backward areas with respect to reference Phasor, according to the fault condition [7, 8]. Flow of power in a given direction will result in a phase angle between voltage and current changing around its power factor angle $\pm\phi$. When the direction of power is opposite, this angle becomes $(180 \pm \phi)$ and when the fault travels in opposite direction, this phase angle of the current with respect to voltage will be $(180 - \phi)$ [8].

The main theme of this technique is only to detect the faulted area. Positive sequence voltage magnitude at main bus for each area is compared to decide the faulted area. After that, positive sequence current angles absolute differences are calculated for interconnected line with this faulted area. After comparing these angles with each other, the maximum value of absolute angle difference is considered as faulted line. This operation can be mathematically shown as follows:

$$\text{Min}\ \{|V1|, |V2| \ldots |Vm|, \ldots..|Vn|\} \tag{3}$$

Where, PMU measures the positive sequence voltage magnitude of area "1", "2", "3", "m", to "n". When the fault occurs on the grid output of the (4) shows the minimum positive sequence voltage magnitude. From this calculation the nearest area to the fault can be determined. In this case this area is shown by "m".

After that there is need of comparing the absolute differences of positive sequence current angles of interconnected lines connected to this faulted area "m" with the interconnected nearby area and then selecting the maximum one. This can be shown as:

$$\text{Max}\ \{|\phi m1|, |\phi m2|, |\phi m3|, \ldots \ldots .|\phi mn|\} \tag{4}$$

Where, m and n are the interconnected area which shows the absolute difference of the positive sequence current angle of the transmission line. This can be shown as:

$$|\Delta\phi mn| = |\phi mn - \phi nm| \tag{5}$$

4. SIMULATION AND RESULTS

The five bus network as shown in fig. 2 is taken for the case study. MATLAB/Simulink is used to simulate -the network and the proposed algorithm is implemented and investigated. The PMU placement is also done as shown in fig. 2.

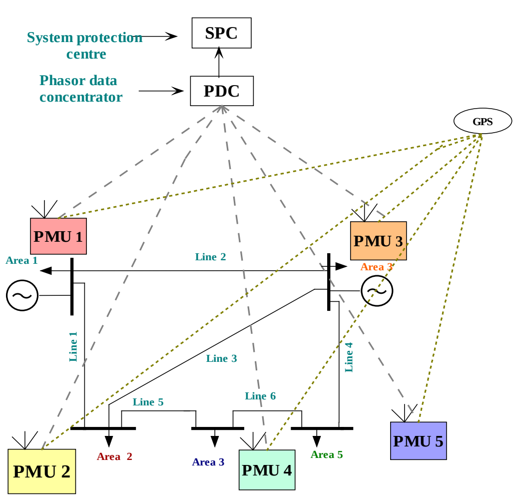

Fig. 2: The five bus system network taken under study

The system consists of 220 KV interconnected transmission line network, 100 km transmission line. Generating station on one side and on the other side is load both are connected through interconnected lines. Different fault conditions are simulated on line 1. The values shown are in per unit on 100 MVA (base) in table no. I.

Table 1: Transmission Line Parameters

1.	Generator	100 MVA, 220 kV, 50Hz, Synchronous Generator pu model
2.	Transformer	220 kV/13.8 kV , 100 MVA
3.	Synchronous machine	13.8 kV, 100 MVA
4.	LOAD 1	220 kV, 50MW, 24MVar, RL load
5.	LOAD 2	220 kV, 100MW, 48MVar, RL load
6.	LOAD 3	220 kV, 80MW, 34MVar, RL load
7.	LOAD 4	220 kV, 120MW, 58MVar, RL load
8.	LOAD 5	220 kV, 150MW, R load

The transmission line positive and zero sequence parameters are R1=0.10809Ω/km, R0=0.2188Ω/km, L1=0.00092H/km, L0=0.0032H/km, C1=1.25*10−8f/k , C0=7.85*10−9f/km. The distributed parameter model of transmission line is considered for analysis. To demonstrate the potential of the approach only few cases of fault occurrence are considered.

5. SIMULATION MODEL

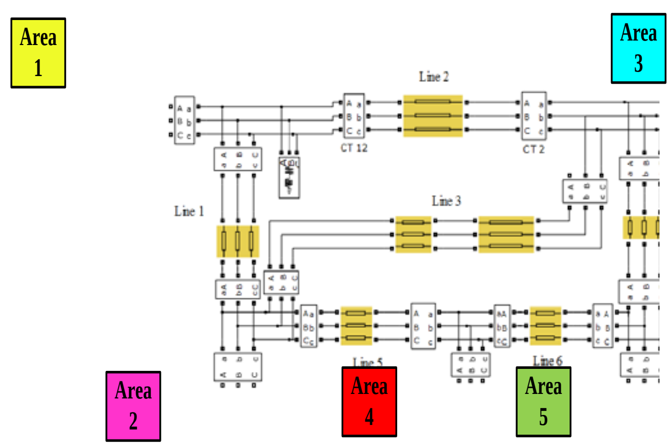

Fig. 3: Simulink model of five bus network system

Simulink model of five bus network system is shown in fig. 3. When three phase to ground fault occurs on the transmission line, the faulted signals of three phase voltage signals and three phase current signals are shown in fig. 4 & 5. The fault is located on line 1 connecting area "1" and area "2". When fault occurs, line connected between area "1" and area "2" is affected. Fig. 4 shows the output of three phase to ground voltage while fig. 5 shows output of three phase current of the lines connected to faulted area. Also, different fault conditions are simulated on the system using proposed technique.

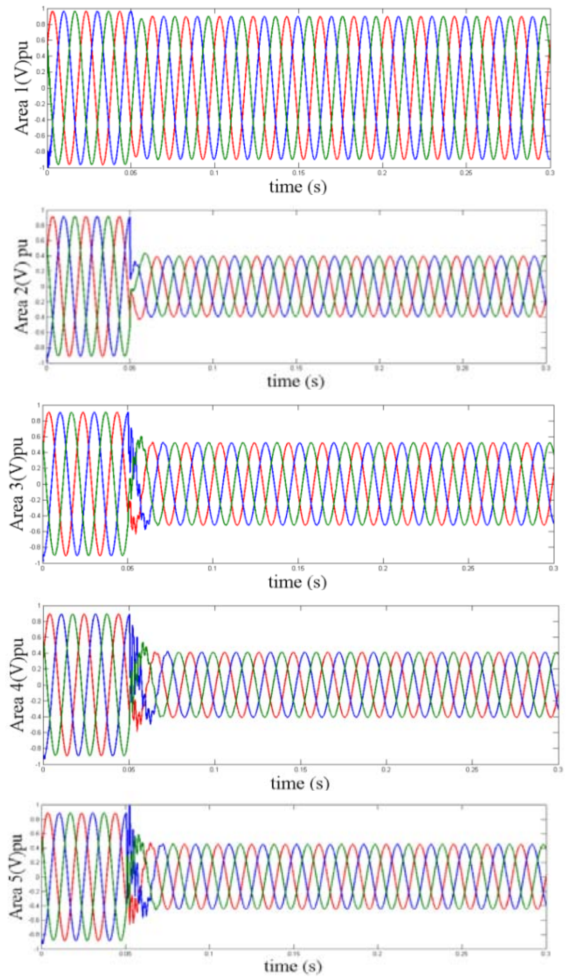

Fig. 4: Three phase voltage signals at each area.

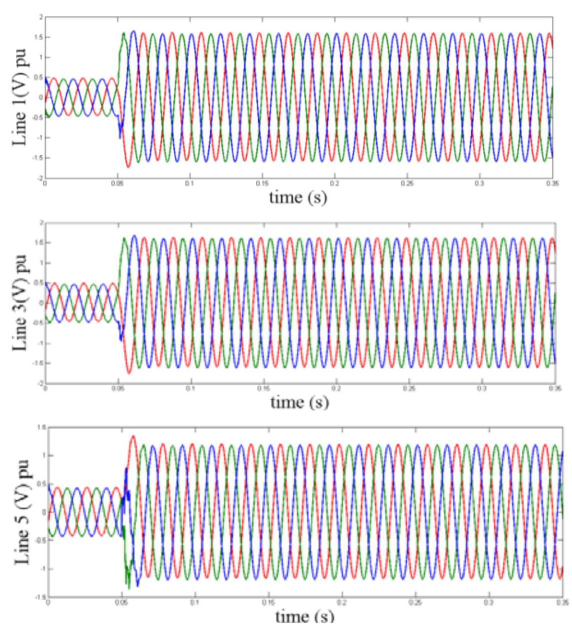

Fig. 5 : Three phase current signals for all interconnected lines to the faulted area (area "1")

Fig. 6 shows the output from the five PMUs, the graph shows the five positive sequence voltage magnitudes (PSVM) for five different areas during fault. The minimum value is selected which shows the nearest area to the fault (area "2"). After that faulted line needs to be identified.

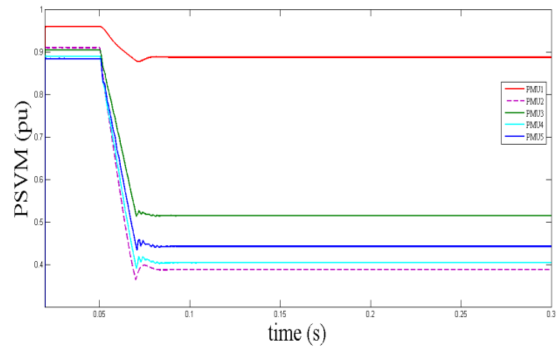

Fig. 6: positive sequence voltage magnitudes

Absolute difference of positive sequence current angles (PSCA) for all lines interconnected with the faulted area (area "2") with all other neighboring areas (areas "1", "3", "4") and the maximum absolute difference of positive sequence current angle with line 1 is shown in fig 6 & 7.

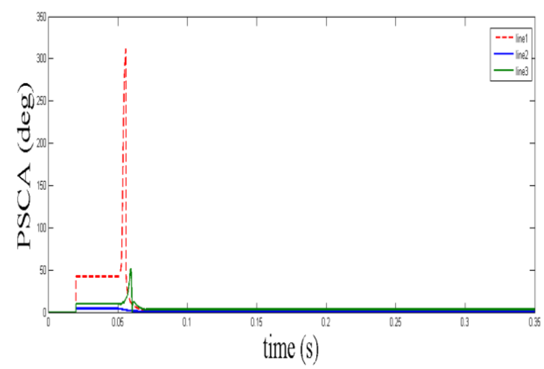

Fig. 7: Positive sequence current angle absolute differences for interconnected lines to the faulted area.

6. CONCLUSION

The paper presents a new protection technique for transmission grids using Phasor synchronized measuring technique in a wide area system. The protection scheme has successfully identified the faulted line all over the interconnected system. The algorithm uses the positive sequence voltage and current synchrophasor measured at each line end, and its main objective is to detect different fault locations. Unlike the present techniques, it provides reliable protection to the power system so that it can be applied to any practical power system.

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