Improvement in Wide Area Interconnected Network System Using Synchronized Phasor Measurement Unit

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Abstract-*This paper proposes a new adaptive phasor measurement unit (PMU) based protection scheme for wide area interconnected transmission lines network. This method uses positive sequence voltage and current phasors at both ends of a transmission line to determine the faulted area on the transmission line. The DFT (discrete Fourier transform) is used to compute the phasors of voltages and currents. High accuracy in fault location is achieved by using PMUs placement over a wide area measurement transmission system. This scheme gives the overall snapshot of the system by time synchronizing the data from all remote stations by using communication channel. The conventional system is not able to satisfy the time-synchronized requirement of power system. Phasor Measurement Unit (PMU) is enabler of time-synchronized measurement, it communicate the synchronized local information to remote station. This paper features simulation of interconnected network system for 220 KV line using MATLAB Simulink.*

Keywords: Digital protection, Global positioning system(GPS), Phasor Measurement unit (PMU), synchrophasor, time synchronization, Wide Area Measurement System (WAMS).

1. Introduction

Nowadays, complex interconnected systems exist due to modern power system involved in the process of continuous development. Wide area interconnection leads to major blackouts those results in serious effects on the system. The risk of major outages for power grid has increased from last few decades because of low security margin and lack of enhancement in transmission. Regarding to this, 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 [1].

A huge number of publications are there for protection of transmission lines. But on the other side, there are few published on applications of wide area transmission lines protection. The technique suggested in the paper for wide area protection is using PMU. This new technology i.e. Phasor Measurement Unit (PMU) provides both magnitude and phase angle phasor information in real time [4]. Effective utilization of this new technology is very much helpful to mitigate blackouts and to learn the real time behavior of the power system. As the power system bus voltage angle is closely linked with the behavior of the network, its measurement in real time is very much powerful tool for operating a network. This paper introduces protection scheme depending on comparing the positive sequence voltage magnitude for specified area and positive sequence current phase difference angle for each interconnected line between two areas on the network. The

objective of this paper is to present a new wide area measurement technology which will be helpful for monitoring, control as well as protection of power system from sudden large power system disturbance. Also mitigate the chances of blackouts and gives continuous reliable quality supply using fast GPS technology.

PMU devices are now installed everywhere in the world to get GPS time synchronized information. With the advancement in technology, the microprocessor based instrumentation such as protection Relays and Disturbance Fault Recorders (DFRs) incorporate the PMU module along with other existing functionalities as an extended feature. Some important applications of PMU are as follows:

- Power system automation in smart grids
- To prevent total system blackout
- Load management and control techniques
- Increase in the reliability of power system
- Wide Area measurement, protection and control, in whole area of regional transmission networks, and local distribution grids.

2. Synchrophaser

A. Classical Definition of PMU

A phasor equivalent of an AC signal $X(t) = Xm \cos(\omega t + \phi)$ is represented as the complex quantity are as follows:

$$X = \frac{Xm}{\sqrt{2}} e^{j\Phi} = \frac{Xm}{\sqrt{2}} (\cos\Phi + j\sin\Phi) \quad (1)$$

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

Where Xr and Xi are real and imaginary rectangular components of the complex number phasor value. The magnitude of the phasor is the rms value of sinusoid$(Xm/\sqrt{2})$ and its phase angle is **Φ**, the phase angle of the signal in (1). This is illustrated in fig.1.
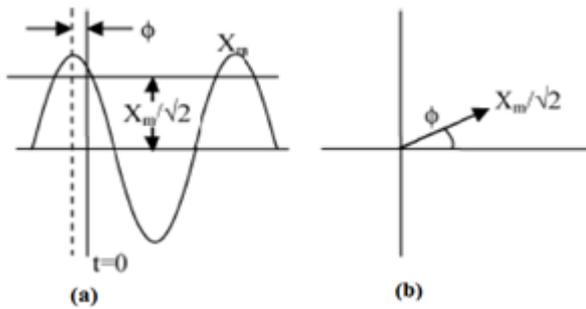
Figure 1: Phasor representation of sinusoidal signal(a) sinusoidal waveform (b) Phasor reprentation

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 phasor 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. This will be discussed in the next section.

B. Phasor measurement concept

PMU is a device that is used to collect and provide instantaneous phasor from desire places of applications, attached with an instantaneous time and date of measuring called time stamped data. Estimated phasor are called as synchrophasors. The phasor that is estimated from samples using a standard time as the reference for a measurement, and has common phase relationship as remote sites.

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, 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. Very fast recursive discrete Fourier transform (DFT) calculations are normally used in phasor estimation calculations. In the suggested technique, a positive sequence voltage and phase angle of the positive sequence current is used. Since sampled data are used to represent the input signal, it is essential that antialiasing filters be applied to the signal before data samples are taken. The antialiasing filters are analog devices which limit the bandwidth of the pass band to less than half the data sampling frequency (NY Quist criterion). If Xk{k=1, 2, 3,........., N-1} are the N samples of the input signal taken over one period, then the phasor representation of an input signal is given by,

$$X = \frac{\sqrt{2}}{N} \sum_{K=0}^{N-1} xk\, e^{-jK\frac{2\pi}{N}} \qquad (3)$$

The peak value of the fundamental frequency thus obtained is then converted to rms value by dividing by $\sqrt{2}$. The DFT calculation eliminates the harmonics of the input signal. However, the non-harmonic signals and any other random noise present in the input signal leads to an error in estimation of the phasor. The error estimation due to these effects has been discussed in the open literatures.
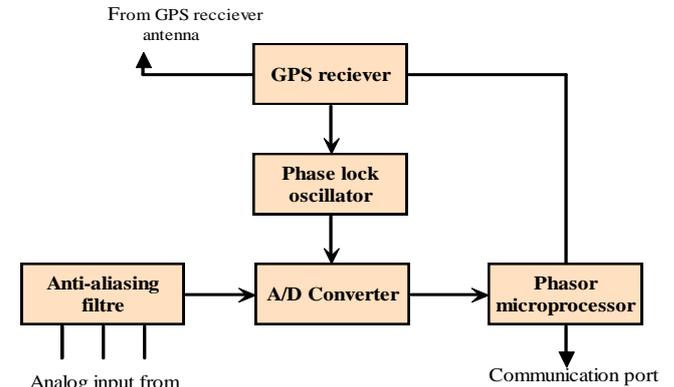

Figure 2: Block diagram of PMU

Fig.2 shows the analog power signal from current transformer and voltage transformer are converted into digital signal by analog to digital converter (A/D) passed through low pass filter. The GPS signal receiver consists of an antenna and receiver circuits, which detect the 1PPS (pulse per second) synchronizing signal from the GPS satellites A GPS receiver signal provides a precise timing pulse, which then correlates with sampled voltage and current inputs typically the three phase voltages of a substation and the currents in line, transformers and loads terminating at the substation. From these data samples, positive sequence voltage and current are calculated and time stamped so that the exact microsecond when the phasor measurement is taken is permanently attached to it. The data taken can then be transmitted to a remote site over any available communication link. Positive sequence phasor data from all substations equipped with such devices are collected at an appropriate central site using data concentrators or exchanged between local units for protection or control applications. Collecting these measurement data and collating it provides a basic for new, very powerful technique for monitoring, protecting and controlling.

3. Proposed Technique

The condition of the fault occur on transmission line is mainly detected by two components. First is reduction in voltage of the transmission line because of the fault occurrence. The other component is the direction of the power flow after occurrence of the fault. Fault current direction is determined with the help of phase angle with respect to reference quantity. Direction of fault will be known by comparing the phase angle of the transmission line voltage and current. Mostly the voltage is used as 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 condition [10, 11]. Power flow in a given direction will result in a phase angle between voltage and current varying around its power factor angle$\pm\Phi$. When the direction of power is opposite this angle becomes$(180 \pm \phi)$ and when the fault goes in reverse direction, the phase angle of the current with respect to voltage will be$(180 - \phi)$ [11].

The main theme of this technique is only to detect the faulted area. Comparison of the measured values of the positive sequence voltage magnitude at main bus for each area is used to achieve this. The result of this, the minimum voltage value which shows the nearest area to the fault. Additionally, the absolute differences of the positive sequence current angles are calculated for all lines interconnected with this faulted area. On comparing these angles with each other, the maximum absolute angle difference value is selected to identify the faulted line. This operation can be mathematically shown as follows:

$$\text{Min } \{|V1|, \lfloor V2 \rfloor \ldots |Vm|, \ldots \ldots |Vn|\} \tag{4}$$

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 to compare the absolute differences of positive sequence current angles for all lines connected to this faulted "m" with the interconnected nearby area and then selecting the maximum one. This can be shown as:

$$Max \{|\phi m1|, |\phi m2|, |\phi m3|, \ldots \ldots |\phi mn|\} \tag{5}$$

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 show as:

$$|\Delta\phi mn| = |\phi mn - \phi nm| \tag{6}$$
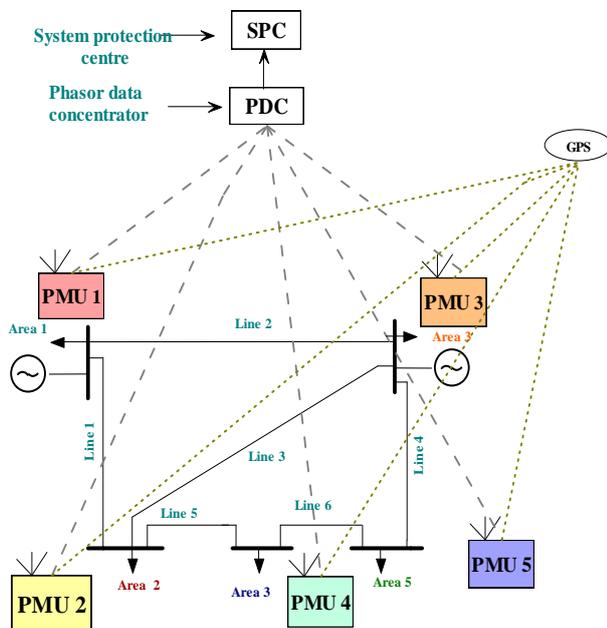
4. Transmission Line Model

Figure 3: Matlab Simulink block diagram

As shown in fig.3 above, 220KV 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 that line using MATLAB software. The values shown are in per unit on 100 MVA (base) in table no. I.

Table 1: Transmission line parameter R

1	Generator	100 MVA, 220 KV, 50Hz, Synchronous machine pu model
2	Transformer	220kv/13.8 kv, 50 HZ, 100 MVA
3.	Load 1	220kv, 50MW, 24Mvar, RL load
4.	Load 2	50MW, 220kv, 100MW, 48Mvar, RL load
5.	Load 3	50MW, 220kv, 800MW, 38Mvar, RL load
6.	Load 4	220kv, 120MW, 58Mvar, RL load
7.	Load 5	220kv, 150MW, R load
8.	Synchronous machine	13.8 KV, 100 MVA

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/km,C0= 7.85*10−9f/km.The distributed parameter model of transmission line is considered for analysis. A sampling frequency of 20 KHz for a system operating at a frequency of 50 Hz is used in this study. To demonstrate the potential of the approach only few cases of fault occurrence are demonstrated here.

When double line to ground fault occurs on the transmission line, the faulted signals of three phase voltage signals and three phase current signals are shown below in fig. 5. The fault is located on line 3 connecting area "2" and area "3" as shown in fig 3. When fault occur the line connected between areas"2" and area"3" are affected. The double line to ground faults voltages are shown in fig.4. Three phase current of the lines related to faulted area in fig. 5. Similarly, different fault conditions are simulated on the system using the proposed technique algorithm.
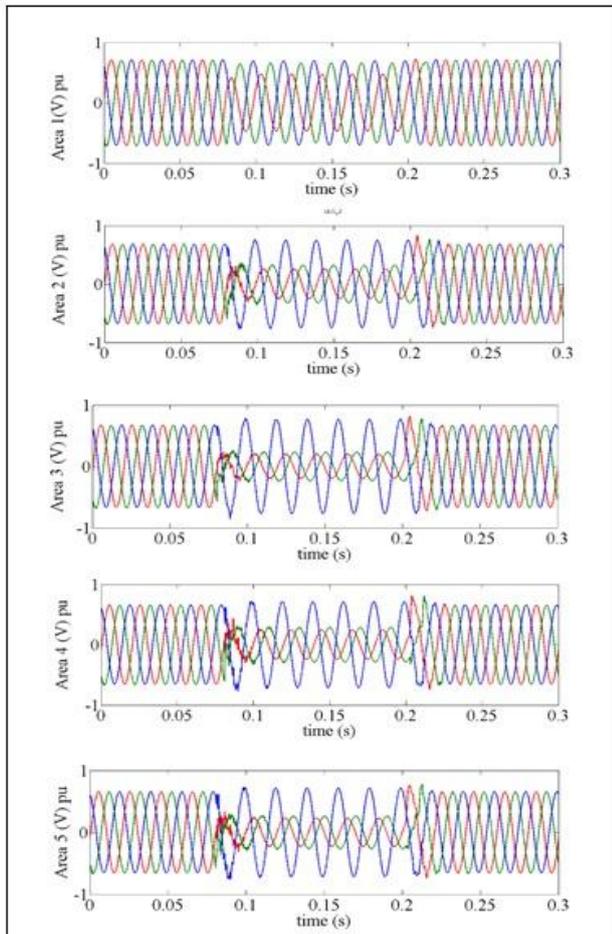
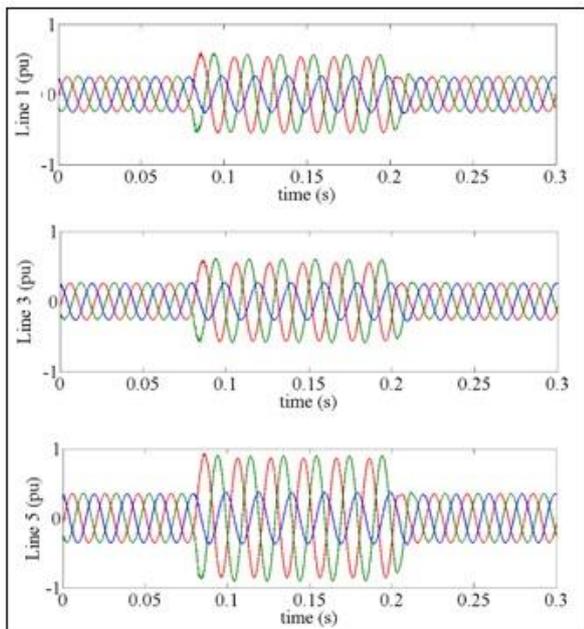**Figure 4:** Three phase voltage signals at each bus.

Figure 5: Three phase current signals for all lines connected to the faulted area

5. Conclusion

The paper addresses the main reason for the execution of WAPCAM system. PMU is used as the main protection for wide area. Proposed technique is very much helpful than the existing techniques which reduces the chances of blackouts. The survey of simulation results for various fault conditions. The proposed algorithm structure is suitable and effective for different network conditions as a backup protection (third zone) and also identified the faulted line all over the interconnect system. Unlike the present techniques, it provides reliable protection to the power system so that it can be applied to any practical power system. Test results from MATLAB simulation seems to be satisfactory. It is very much helpful to overcome the problem of Blackouts.

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