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Synchronised PMU based Cascading Failure Protection Strategy for 220 KV Interconnected Transmission Network

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Abstract:
Cascaded events can be attributed to improper operations of third zone of distance protective relays.This paper proposes a novel time-synchronized wide area backup protection system using PMU as an alternate to the conventional system in substation. 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.PMU is a key element and it communicate the synchronized local information to remote station through communication channel. The main purpose of this proposed technique is to improve disturbance monitoring and system event analysis. This idea is implemented and obtained from 220KV interconnected power system network using the MATLAB/ Simulink package.

Keywords:
Smart grids,Disturbance Fault Recorder (DFR), Global positioning system(GPS), Phasor Measurement unit (PMU), synchrophasor, grids, time synchronization, Wide Area Measurement System (WAMS), DFT(Discrete Fourier Transform).

1. INTRODUCTION:

Power grids are among the most important critical infrastructure in a modern society. The effects of a major blackout have become more serious as a result of the wide area interconnections. 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. Effective utilization of this new technology is very much helpful to mitigate blackouts and to learn the real time behaviour of the power system. As the power system bus voltage angle is closely linked with the behaviour 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. Theobjective of this paper is to 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:

a) Power system automation in smart grids
b) To prevent total system blackout
c) Load management and control techniques
d) Increase in the reliability of power system
e) Wide Area measurement, protection and control, in whole area of regional transmissionnetworks, and local distribution grids.

2. Synchronised Phasor Measurement

A. Synchrophasor

Consider the steady-state wave form of a nominal power frequency signal as shown inFig. 1. If we start our observation of this waveform at the instant t = 0, the steady-state waveform may be represented by a complex number with a magnitude equal to the rms value of the signal and with a phase angle equal to the angle Φ. In a digital measuring system, samples of the waveform for one (nominal) period are collected, starting at t = 0, and then the fundamental frequency component of the Discrete Fourier Transform (DFT) is calculated according to the relation

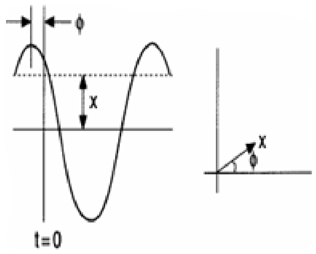

Fig.1. Phasor representation of a sinusoidal wave form

$$X = \frac{\sqrt{2}}{N}\sum_{K=1}^{N} X_K e^{\frac{-j2K\pi}{N}} \qquad (1)$$

Where: **N** is the total number of samples in oneperiod, X is the phasor, and X_K is the wave Form samples**.** This definition of the phasor has the meritthat it uses a number of samples (N) of thewave form, and is the correct representation of the fundamental frequency component, when other transient components are present. When the input signal frequency is different from the nominal frequency, an error is introduced in the magnitude and the phase angle of the phasor. A synchrophasor system composed of PMU, phasor data concentrator (PDC), GPS satellite system as shown in figure 5 below. The microprocessor determines thepositive sequence phasors according to therecursive algorithm and the timing message from the GPS, along with the sample number at the beginning of awindow, is assigned to the phasor as itsidentifying tag. The computed string of phasors, one for each of the positive sequence measurements, is assembled in a messagestream to be communicated to a remote site.

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 synchrophasor. 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. Fig.2. shows a functional block diagram of a typical PMU. The GPS receiver provides the 1 pulse-per-second (pps) signal, and a time tag, which consists of the year, day, hour, minute, and second. The time could be the local time, or the UTC (Universal Time Coordinated).The l-pps signal is usually divided by aphase-locked oscillator into the required number of pulses per second for sampling of the analog signals. In most systems being usedat present, this is 12 times per cycle of the fundamental frequency. The analog signals arederived from the voltage and current transformer secondaries.

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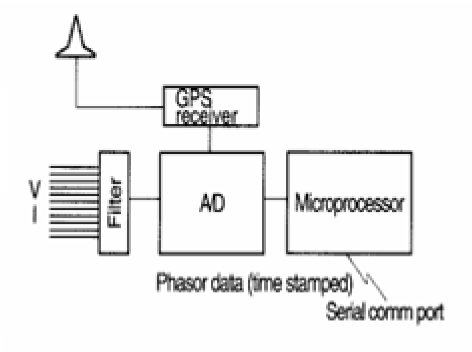

Fig. 2. Phasor measurement unit block diagram

Consider the problem of measuring thepositive sequence voltages at two substationsseparated by many miles. If the data samplesused at the two stations were synchronizedprecisely, and the absolute time of thesampling process recorded, then one couldsend the measurement to a remote locationwith the accompanying time stamp, and byaligning the time stamp of the measurementsobtained from different stations one wouldobtain simultaneous positive sequencemeasurements very few cycles as shown inFig. 3.

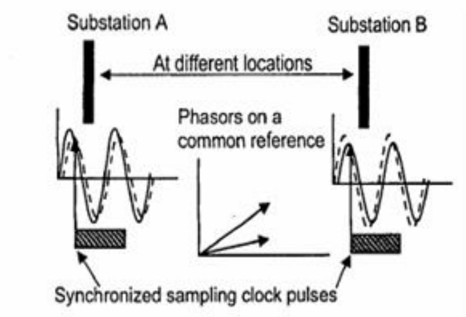

Fig.3. Synchronized samples for measuring phasors with a common axis

Precise synchronization of sampling clocks became possible with the advent of GPS satellite system. At present it is possible to achieve synchronization accuracies of 1 µs or better which corresponds to 0.021o for a 60 Hz signal and 0.081o for a 50 Hz signal, such accuracies are perfect for measuring frequency voltages and currents.

C. Conventional Problems:

Distance relays have been successfully used for many yearsas the most common type of protection of transmission lines. The first zone of distance relays is used to provide primaryhigh speed protection and it covers about 80 to 85 per cent ofthe line without any time delay. The resulting 15% safetymargin ensures that there is no risk of the Zone 1 protectionover-reaching the protected line due to errors in the current andvoltage transformers, inaccuracies in line impedance dataprovided for setting purposes and errors of relay setting andmeasurement of the distance protection must cover theremaining 15% of the line. The second zone covers theremaining portion of the line plus 25 per cent of the next lineand operation time is set to about 0.25 to 0.5 seconds. Thirdzone covers the entire area protected by the first and secondzones plus 25 per cent of the next long line (third line) anddelay time is set between 0.6 to 1.5 seconds. This zone is usedfor backup protection.Distance relays are designed to measures the impedancebetween the relay location and the fault. If the resistance of thefault is low, the impedance is proportional to the distance fromthe relay to the fault. A distance relay is designed to onlyoperate for faults occurring between the relay location and theselected reach point and remains stable (or inoperative) for allfaults outside this region or zone. It is based on standalonedecision, while each relay operates independently according tothree different zone of protection as shown in Fig.4.

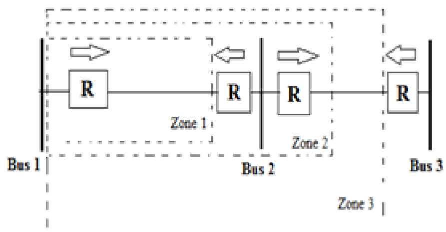

Fig.4. Distance Protection Relay: zone 1, zone 2 & zone 3

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 arehardly coordinated each other. Therefore, the principle of the protection design needsinnovation to overcome the above problem.

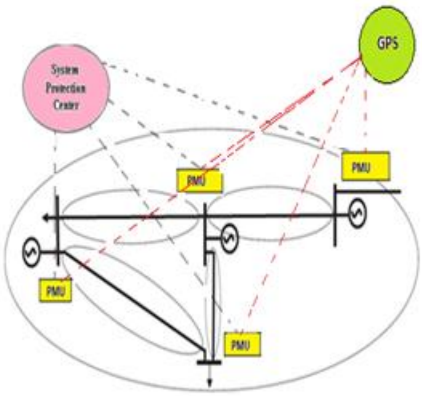

Fig.5. The new protected zones of the proposed relay.

The communication of data among them is carried via optic-fiber networks as shown in fig 5.The relaydecision is based on collected and shared data through communication network. The primary purpose of these systems is to improve disturbance monitoring and system event analysis.

3. The Proposed Solution:

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 isused to determine the direction of fault current with respect to a reference quantity. Theability to differentiate between a fault in one direction or another is obtained by comparingthe phase angle of the operating voltage and current. The voltage is usually used as thereference polarizing quantity. The fault current Phasor lies within two distinct forward andbackward regions with respect to the reference Phasor, depending on the power system andfault conditions. The normal power flow in a given direction willresult in the phase angle between the voltage and the current varying around its powerfactor 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 thevoltage will be (180°-Φ).The main idea of the proposed technique is to identify the faulted area. This can be achievedby 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 nearestarea to the fault. In addition to that, the absolute differences of the positive sequence currentangles are calculated for all lines connected with the faulted area. These absolute angles arecompared to each other. The maximum absolute angle difference value is selected toidentify the faulted line. The above two keys of operation can be mathematically describedas follows:

$$\text{Min}\ \{|V1|, |V2|,..\ |Vm|, \ldots|Vn|\} \quad (2)$$

Where: |Vn| 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 (2) is the minimum positive sequencevoltage magnitude which indicates the nearest area to the fault. Suppose that the nearestarea to the fault is indicated by number "m". The next step is to compare the absolutedifferences of positive sequence current angles for all lines connecting area "m" with all other neighboring areas and then selecting the max one. This can be explained as:

$$\text{Max}\ \{|\Delta\phi m1|, |\ \Delta\phi m2|\ldots,|\ \Delta\phi mn|\} \quad (3)$$

Where: |Δϕmn| is the absolute difference of positive sequence current angle for a
transmission line connecting area "m" with area "n".
This can be described by (4).

$$|\Delta\phi mn| = |\phi mn - \phi nm| \quad (4)$$

4. The 220 KV interconnected power system network model, Results & Discussion

The given network is used to simulate in MATLAB Simulink and the proposed solution is implemented with PMU placement in each bus as shown in figure below:

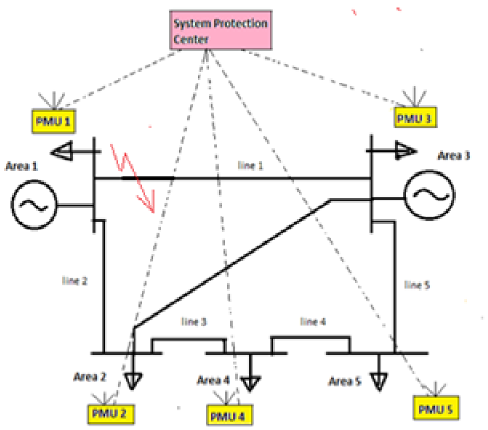

Fig.6.Test model for 220 KV interconnected transmission line network

The above model consisting generating station and load interconnected with 100 km. Transmission lines are simulated with MATLAB/ Simulink package with symmetrical and unsymmetrical fault conditions between "area 1" & "area 3". The transmission line positive and zero sequence parameters are given as follows:

R_1 = 0.10809 Ω/km.
R_0 = 0.2188 Ω/km.
L_1 = 0.00092 H/km.
L_0 = 0.0032 H/km.
$C_1 = 1.25x10^{-8}$ F/km. & $C_0 = 7.85x10^{-9}$ F/km.

For analysis, considered as a distributed parameter model and sampling frequency of 20 KHz for a system operating at a frequency of 50 Hz is used.

The ratings of machines and loads are taking at 100 MVA base valueas shown in Table 1:

1.	Generator	100 MVA, 220 KV, Synchronous Machine PU model
2.	Transformer	220 KV/13.8 KV, 100 MVA
3.	Load -1	220 KV,50 MW, 24 Mvar, RL
4.	Load-2	220 KV, 100 MW,24 Mvar, RL
5.	Load-3	220 KV,80 MW, 34 Mvar, RL
6.	Load-4	220 KV,120 MW,58 Mvar, RL
7.	Load-5	220 , 150 MW, R

A. Discrete Fourier Block Set:

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. However, most commonly used method is DFT. The DFT is very fast recursive calculation of phasors.Discrete Fourier transform block computes the fundamental value of the input phase current signal over a running window(it is the number of samples required to compute the phasors using DFT) of one cycle of the specified fundamental frequency as shown in Figure 7. First outputs return respectively the magnitude and phase degrees of the fundamental. The magnitude is taken as a percentage from its steady state value. The rate of change of this percentage is compared with a threshold value. For the first cycle of simulation, the outputs are held constant to the value specified by the parameter "Initial input".

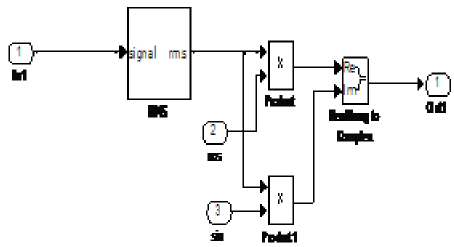

Fig.7. DFT Simulink Block

A. The output voltage and current waveform related to faulted area

The single phase to ground fault are located on interconnected transmission line between area "1" and area "3". The transition of fault occurring time is 0.08 seconds and fault clearing time 0.2 seconds. The output single phase to ground faults voltage waveforms are shown in fig. 8.

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Three phase current of the lines related to faulted area in fig. 9. Similarly, different fault conditions are simulated on the system using the proposed algorithm. During a single-phase-to-ground fault, consider fault resistance (R_0) = 30 Ω and ground resistance (R_g) = 10 Ω.

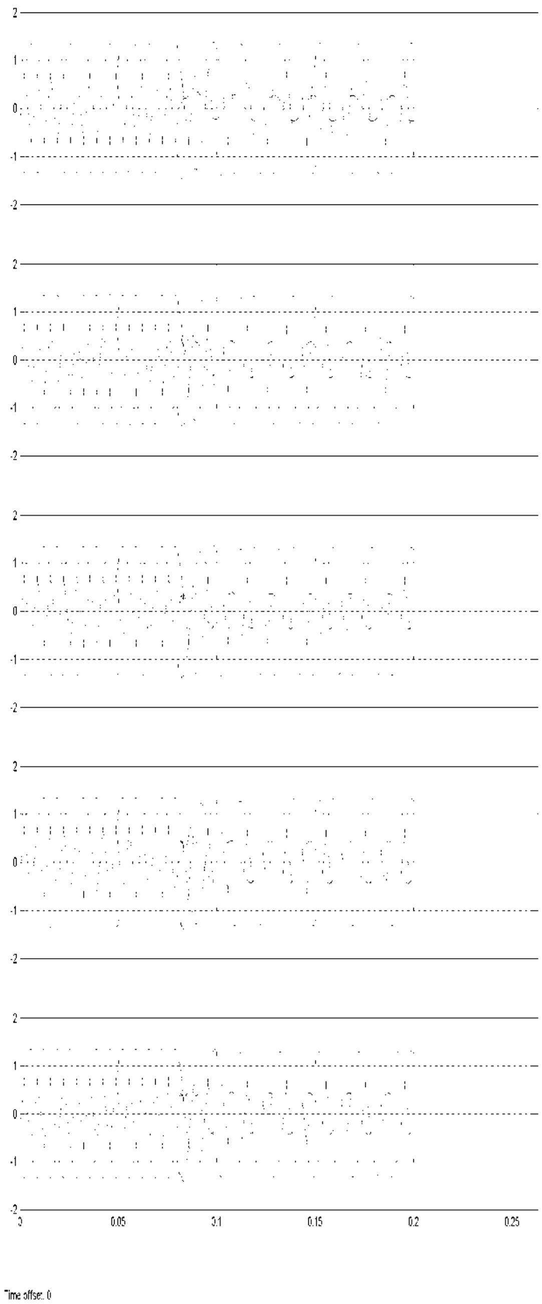

Fig.8. Three phase voltage signals at each area

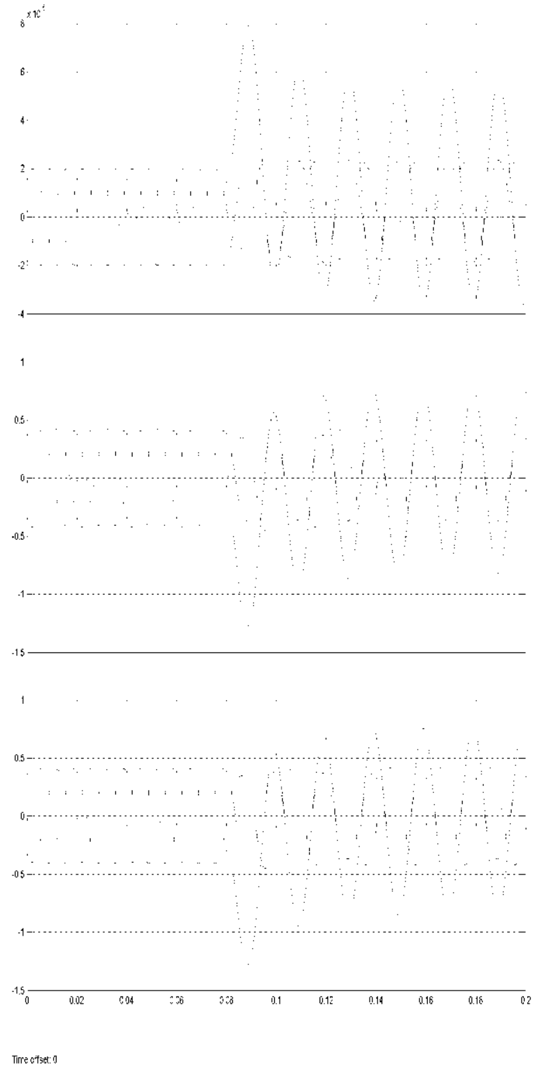

Fig.9. Three phase current signals for all lines connected to the faulted area ("area1")

The output waveform from the five PMUs is shown in fig. 10, which distinctly shows the five positive sequence voltage magnitudes for different five areas during single phase to ground fault. The minimum voltage value which is indicates the nearest area to the fault (i.e. area 1).

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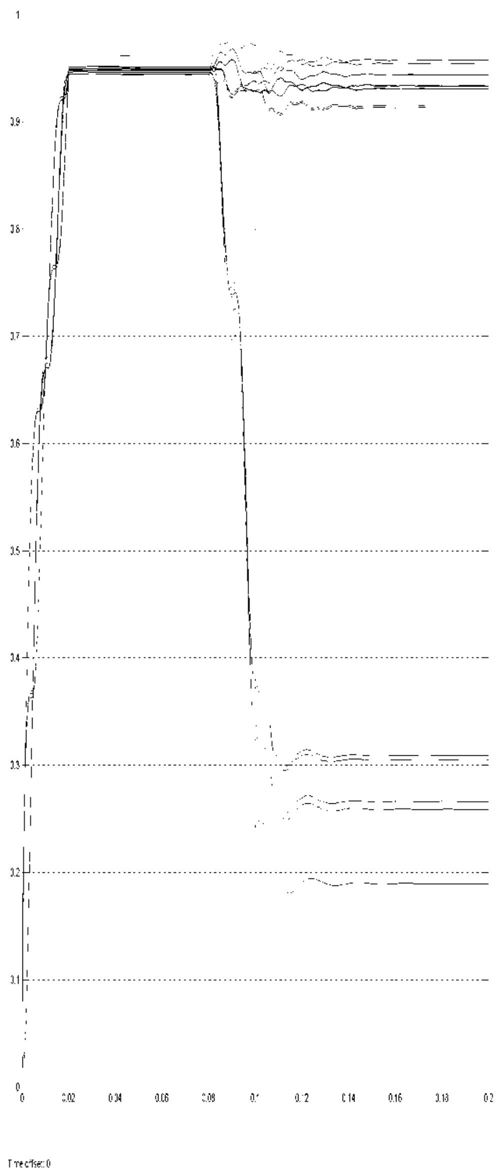

Fig. 10 PMUs output

5. Conclusion:

The simulation results for various fault conditions have been examined. The transition period of different faults are concluded at 0.08 second and clearing at 0.5 second. A proposed algorithm is used as an adaptive PMU based main protection scheme for wide area measurement system. PMU provides all significant state measurement including voltage magnitude, voltage phase angle, and frequency.

A sampling rate is calculated as $50x10^{-6}$ seconds. This proposed solution is to improve disturbance monitoring and system events analysis. It is rather helpful to overcome the problem of Blackouts Test results from MATLAB/Simulink seems to be satisfactory.

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