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A Novel Wide Area Protection Classification Technique for Interconnected Power Grids Based on MATLAB Simulation

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1. Introduction

More recent technological advancements in microprocessor relays, combined with GPS receivers for synchronization and accurate time stamping, is providing users advanced relay systems with synchronized measurements, called synchrophasor measurements (IEEE Power System Relaying Committee, 2002; Phadke, 2002; Marek, 2002). Synchrophasor measurements together with advancements in digital communications, provides users with the power system state at a rate of twenty times per second. Synchrophasor measurements from different network locations when combined and processed in a central computer system will provide users with the absolute phase angle difference between distant network buses with an accuracy of tenths of an electrical degree. These types of central computer systems, equipped with wide-area protection and control algorithms, will be able to better address future system out-of-step conditions and other system problems because they will have a better knowledge of what happens throughout the power system. In addition, knowledge of online generation and load demand provided from synchrophasor measurement systems will aid in balancing better the generation and load during islanding, as well as minimizing load and generation shedding in order to preserve stability during major system disturbances. Time synchronized phasor measurements provide a dynamic view of a power system, combining these measurements in a central protection system (CPS); this capability is used to set up a wide area control, protection and optimization platform by means of new communication systems and (GPS), integrated application design is shown in Figure 1. Figure 1 shows an integrated application design based on phasor measuring units. When the system operates in extreme conditions, load shedding, generation shedding, or system islanding must occur to prevent total system collapse (Thorp et al., 1988; Centen et al., 1993; Guzman et al., 2002; Guzman et al., 2002). Typical causes of system collapse are voltage instability or transient angle instability. These instabilities can occur independently or jointly. In most cases, system wide-area disruptions begin as a voltage stability problem. Because of a failure to take proper actions for the system to recover, this voltage stability problem evolves into an angle stability problem. New monitoring, protection, and communications technologies allow us to implement economical local- and wide-area protection systems that minimize risk of wide-area system disruptions or total system collapse.

A real-time monitoring system collects "real-time information" of the transmission system that consists of measurements of selected system elements that are collected by SCADA and/or Intelligent Electronic Devices (IEDs) at various time intervals. These measurements are taken at generators, substations, and at selected other points on the system, and could be used, stored in local computer databases, or sent by telecommunication lines to remote computer databases. A real-time monitoring system should provide operators with real-time information about the transmission system's "functional status," (i.e., real-time information about the operational status of the transmission system and its components). This information includes direct measurements such as switching status of the transmission line (i.e., in service/out of service), amount of sag on the line, power flow in the line, and interconnection frequency. Other information is calculated from measurements such as whether equipment is being overloaded (Gjerde el at., 2001; Larsson et al., 2002; Zima et al., 2003; Rehtanz et al., 2002).

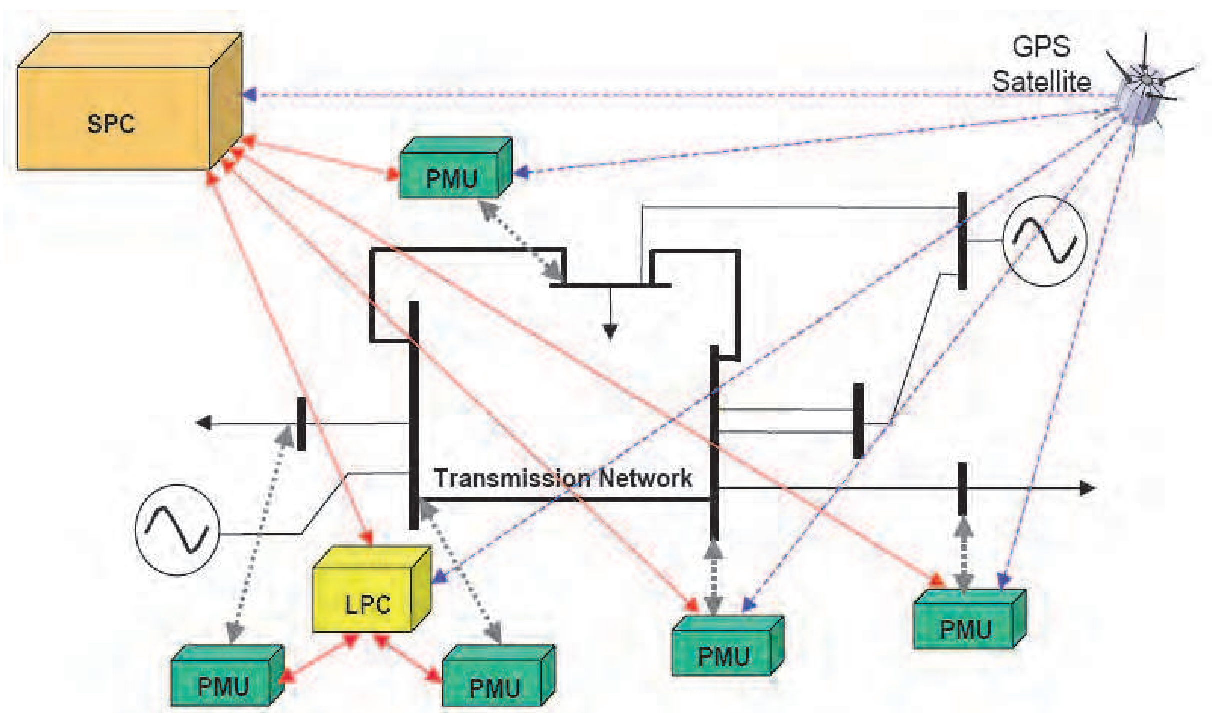

Fig. 1. An integrated application design based on Phasor measuring units.

Fault detection and classification are very challenging task for a transmission line with interconnected system. Different attempts have been made for fault classification using wavelet transform, the Kalman filtering approach, and neural network (Rehtanz, 2001; Zhang et al., 2004; Lin et al., 2004; Yu, 2003).
The electricity supply industries need tools for dealing with system-wide disturbances that often cause widespread catastrophic blackouts in power system networks. When a major disturbance occurs, protection and control measures overtake a greatest role to prevent further degradation of the system, restore the system back to a normal state, and minimize the impact of the disturbance. Continuous technological development in Information and Communication Technology (ICT), novel sensors and measurement principles in general have promoted the utilization of Phasor Measurement Unit (PMU), which is a technological enabler of Wide-Area Measurement Systems (WAMS) in power system protection and

control for better management of the system security through advanced control and protection strategies.

The electricity supply industries need tools for dealing with system wide disturbances that often cause cascading outages and widespread blackouts in power system networks. When a major disturbance occurs, protection and control measures overtake the greatest role to prevent further degradation of the system, restore the system to a normal state, and minimize the impact of the disturbance. Electrical measurements of the system, which may include synchronized phasors, are supplied to one or more wind farm controllers, which in turn perform a control function improving the damping of electromechanical oscillations or voltage performance in the utility system. The benefits are improved damping to electromechanical oscillations and better voltage profile and ultimately more efficient utilization of assets, reducing the necessity for installing new assets. Wide-area protection is becoming an important issue and a challenging problem in the power industry (Wang et el., 2005).

This study proposes a novel technique based on wide-area measurements for a power system. The study is very vital and needed in the current state regarding the electrical utility and the society as well to face future expansion of the electrical grid and to cover the demand of the increasing growth and solving the problem of peak period. The study is very beneficial also from the stability and security of the grid viewpoint in case of interconnection with other countries.

This study presents a new approach for fault detection and classification for interconnected system using the time synchronized phasor measurements. The scheme is depending on comparing positive sequence voltage magnitudes for specified areas and positive sequence current phase difference angles for each interconnected line between two areas on the network. The chapter will cover all fault events for fault classification. The Matlab/simulink program is extensively used to implement the idea. It uses to simulate the power system, phase measurement unit function, synchronization process, fault detection and classification.

2. Conventional protection schemes and a wide-area backup protection system

According to recent studies, 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 are unwanted trips and have been shown to propagate major disturbances. A CIGRE study found that 27% of bulk power system disturbances resulted from false trips of the protection system. The major reason of these conventional solutions lies in that local protection devices are not considering a system view and are therefore not able to take optimized and coordinated actions. 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. The recent complexity and enlargement of power systems makes it difficult to coordinate operation times and reaches among relays especially. In the existed relay protection system, mal operations of backup protection contribute a lot to system security and stability; furthermore, they are main reasons to system cascade tripping. To solve this problem, one proposal is to add an intelligent analyzing and controlling function in key process of protection functionality. 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 centers toward central or national control centers. 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 (Yan et al., 2008; Xiaoyang et al., 2008; Yangguang et al., 2010; Hui, et al., 2009).
Modem 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 with fault classification is reported in this chapter. This system is capable of acting as the substitution of conventional distributed backup protections in substation. The architecture and algorithm of the system are also introduced. 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-fiber networks (Zhiyuan et al., 2009; 2009).
The proposed system comprises a master system and several local units. The system is arranged as three layers. The bottom layer consists of PMUs with additional protection functionality. The next layer consists of several Local Backup Protection Centers (LBPCs), each of which interfaces directly with a number of PMUs. The top layer, System Backup Protection Center (SBPC), acts as the coordinator for the LBPCs. Connected together via fiber-optic communication links, these devices can process intelligent algorithms based on data collected locally. The structure can be seen as Figure 2 (Seong et al., 2008).
Local part of the proposed wide-area backup system comprises PMUs and LBPC, which are both installed in the station. PMUs are made up of DSP (Digital Signal Processor) and GPS (Global Positioning System). The DSP measures instantaneous voltages and currents of protected power system in real-time, and calculates the state variables, which provide vital information for backup protection system. Then, power system variable data is transferred to LBPC, LBPC samples digital inputs, and pre-processes the analog and digital signals, and then deliver pre processed results to SBPC via fiber-optic communications between the substation and SBPC. SBPC will be installed at Regional Control Center, and integrates various well-developed functions, such as data acquisition via communication, system monitoring, fault location, security analyzing, making tripping strategy and descending strategy to LBPCs, also, SBPC can do post-event playback and post-event data analyses. These functions employ PMUs to fulfil real-time demand (Testa et al., 2004).
LBPCs perform the correlative operations on the spot when receiving the strategy from SBPC, then fault will be isolated rationally. While it is not possible to prevent all contingencies that may lead to power system collapse, a wide area backup protection system that provides a reliable security isolated scheme and optimized coordinated actions is able to mitigate or prevent large area disturbances.

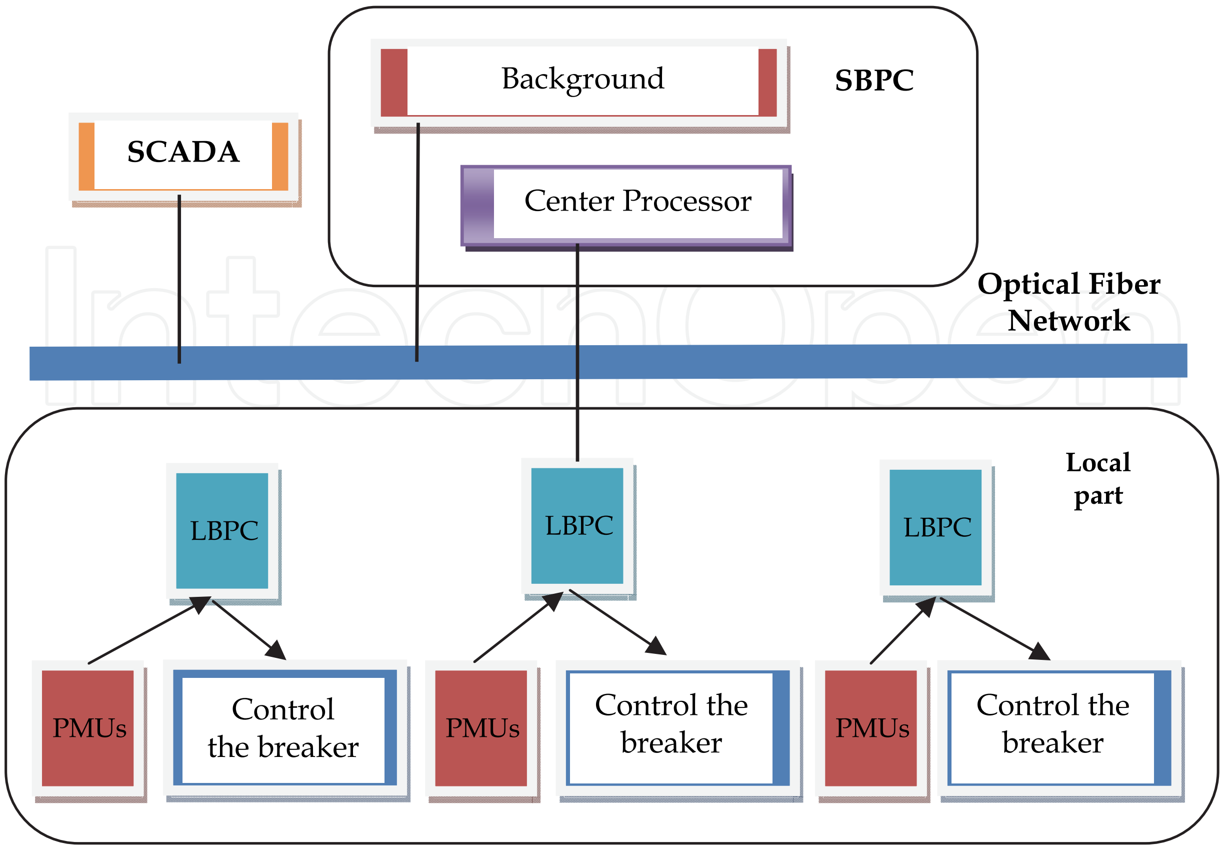

Fig. 2. General configuration of wide-area backup protection system General configuration of wide-area backup protection system.

3. Technology issues in wide area protection

3.1 Monitoring and protection for wide area disturbances

The disturbance in the power system usually develops gradually; however some phenomena, such as transient instability, can develop in a fraction of second. Regardless of the phenomena and available measures, any protection/control procedure during an emergency should consist of the following elements:

Identification and prediction - A fast identification of the specific phenomena, from the power system parameters and from the predisposing factors, is required to start the procedure to return the power system to a healthy state. An emergency may be identified from the primary consequences which are either directly or not-directly observable from local measurements (Begovic et al., 2004). Further, secondary consequences need to be predicted to avoid adverse impact of protection/control measures.

Classification - Disturbance classification is based on the constraints that are violated, severity and combination of violations, time scale of the phenomena, and utility control policy. Classification should include identification of the place of a disturbance (eg. the procedure may be different if a disturbance is caused by an internal or an external event).

Decisions and actions - The choice of the measures is strongly related to the level of priority during emergency. These levels are:

- stop the degradation of the system,
- return the system to a secure state, and
- Consider the economical and social impacts.

Coordination - Different measures may be used to solve different problems. An uncoordinated action may not be economical or secure (e.g. trip of the plant on under-frequency protection before operation of the last step of the system under-frequency control). An intelligent coordination of the protection and control actions is a major challenge and a major requirement for any successful emergency procedure (Terzija et al., 2010).

Corrections - After control measures have been applied, the system can be in an improved but unsatisfactory state. This is acceptable, since it may be advantageous to implement initial measures to stop further degradation of the system and then to continue with more optimal actions when time allows. For example, initial load can be shed merely to stop rapid frequency decline; and additional load, required to return frequency to normal, can be calculated more accurately (Terzija et al., 2011).

Time scale - For any of the previous elements, available time is a vital factor in selecting appropriate actions. A trade-off between optimal methods and time is very often required. The decision time includes selection of the remedial measure and implementation of remedial measure.

3.2 Inputs to control and protection systems (Moxley et al., 2007; Phadke et al., 2009; Jetti et al., 2006)

The state of the power system is represented by several network parameters. Thresholds, trends, patterns, and sudden changes of these parameters provide key information to detect an emergency. Some of the key system parameters which constitute the possible inputs to improved protection and control systems are:

Active power flows in the network - If the limits on active power are violated, the system is in a viability crisis. For the overloaded transformer, a loss-of-life occurs. Thus guidance for loading is established to assure a long life. The limit for the transmission line loading is set by transient and steady-state stability conditions (usually long lines), voltage collapse conditions (usually medium lines), and thermal conditions (usually short lines).

Voltage magnitude and reactive power flows - The voltages in the power system as well as sudden voltage changes need to be contained within a small range. The voltage and reactive power and their rate-of-change can provide valuable information on voltage instability.

Angles between buses - Stability limits for every line will be satisfied, if the difference in angles across the line does not exceed a certain limit. Detection of the out-of-step condition can prevent instability, and, consequently, cascading.

Impedance - Unstable swing, stable swing, and fault condition may be detected and distinguished by observing behavior of the impedance loci at the local bus. A typical out-of-step blocking or tripping scheme is accomplished by "blinders" or circles in R-X diagram and timers.

Resistance and rate-of-change of resistance - These parameters may be used to speed-up the out-of-step detection.

Frequency - Frequency deviation from the nominal value is a result of power imbalance. In modern interconnected systems, frequency deviation usually occurs in the islanded area (a definite indicator of "in extremis" crisis).

Rate of change of frequency - Unlike frequency, rate of change of frequency is an instantaneous indicator of power deficiency in the islanded area. The oscillatory nature of the rate of change of frequency needs to be considered in utilizing this feature.

Spinning reserve - The spinning reserve quantity, distribution, and the speed of its' dynamical response are factors that influence the effectiveness of the spinning reserve during an emergency. The speed of the dynamic response for the hydro units the first few seconds after a demand is made is relatively slow compared to thermal units. Consequently, the spinning reserve needs to be distributed throughout the system on both hydro and thermal units. The spinning reserve needs to be considered in load shedding schemes to optimize shed load.
Load - Load is a non-linear function of voltage and frequency. These changes in load impact power system imbalance and frequency behavior. Further, load changes with the season and the time of the day. In addition, underfrequency load shedding programs specify percent of the total load that should be shed at each step. As load changes, actual load for shedding does not correspond to planned load.
Relays and breaker status - Operation of the protective relays (desired or undesired) and network configuration have an essential impact to disturbance propagation. If undesired operation may be avoided by detecting hidden failures or by adapting relay settings to prevailing system conditions, unwanted transition of the system to a less desirable emergency state may be prevented. Further, equipment unavailability because of maintenance and testing needs to be recognized and considered.
Modeling of the power network is required to simulate disturbances and to choose features that will be extracted. The disturbance in the power network usually develops gradually; however some phenomena, such as a rise of transient instability, can develop in a fraction of second. Selection of appropriate power network analysis tools is important (load flow, transient stability, mid and long term dynamic models, EMTP, etc.).

3.3 Performance requirements for wide area measuring system sensors

It is very important to understand the functionality, limitations, and various relevant performance requirements of wide area measuring systems (WAMS). This information is helpful in:

- Understanding the application benefits and limitations of WAMS for protection and emergency control of power systems.
- Detailed specification of WAMS.

Following is a sample list of parameters that are important in the application and use of WAMS. For certain applications of WAMS, some parameters will be more or less important than for other applications of WAMS. Similarly, some parameters may have stricter specifications for some applications than for other applications. The following types of applications could be considered as general broad categories (Yi et al., 2006):

- System operation (Real time applications, for system protection, or for manual or automatic control)
- System maintenance (applications such as disturbance analysis)
- System planning (applications such as model validation)

4. Wide Area Protection (WAP)- A strategy to counteract large area disturbances (Wenxin et al., 2006; Xiupeng et al., 2007; Zhang et al., 2010; Moraes et al., 2008)

In view of the increasing probability for outages due to the system overloads, which are caused by the ever-increasing demand for electric power, utilities are examining what

modern information technology can contribute to improve this situation. Our proposal to review the present protection strategy to counteract large area disturbances addresses the potentials that are derived from the advances in system operational, protection and control techniques. It will be explained how the application of numerical technology can avoid catastrophic disturbances to occur or at least to keep the impact of single fault within certain limits.
In contrast to the requirements for protection relays designed to protect individual plant objects, system protection schemes intended to prevent voltage or frequency instabilities have to cope with the loss of generation on a large scale and/or loss of one or more transmission lines. Information technology offers digital applications, in terms of numerical adaptive protection relays, integrated disturbance recorders and fast broadband communication much greater functionality and overall efficiencies than conventional analogue techniques.

5. Phasor measurement technology

The technology of synchronized phasor measurements is well established. It provides an ideal measurement system with which to monitor and control a power system, in particular during conditions of stress. A number of publications are available on the subject. The essential feature of the technique is that it measures positive sequence (and negative and zero sequence quantities, if needed) voltages and currents of a power system in real time with precise time synchronization. Fig. 3 shows the connections of PMU in the bay level.

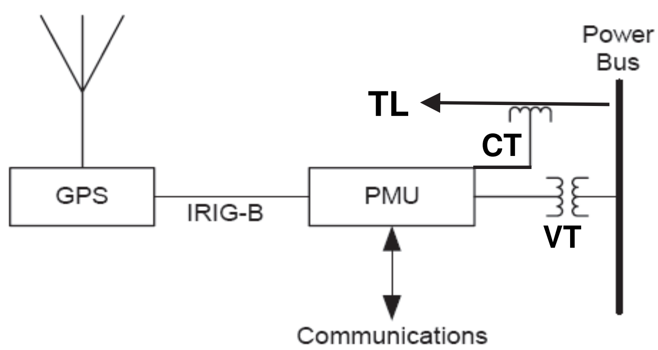

Fig. 3. Phasor measuring unit connections.

Precise time synchronization allows accurate comparison of measurements over widely separated locations as well as potential real-time measurement based control actions. Very fast recursive Discrete Fourier Transform (DFT) calculations are normally used in phasor calculations. The synchronization is achieved through a Global Positioning Satellite (GPS) system.

5.1 Discrete fourier transform technique

The Discrete Fourier Transform (DFT) technique is a short-time variation of the Fourier analysis. Like the Fourier analysis, the DFT assumes that a signal is made up of a fundamental frequency and harmonics of that frequency. While the Fourier transform is applied to signals in the continuous time domain, the DFT is applied to time-domain signals represented by sequences of numbers. Another major difference is that in the Fourier transform, the signal is assumed to exist from time - to + but in the DFT, the signal exists for a small duration of time (called window). The components of different frequencies determined by the DFT analysis can be combined to recreate the original waveform.

6. Phasor measurement unit simulation (Sybille et al., 2000)

Figure 4 shows a typical synchronized phasor measurement system configuration. The GPS transmission is received by the receiver section, which delivers a phase-locked sampling clock pulse to the Analog-to-Digital converter system. The sampled data are converted to a complex number which represents the phasor of the sampled waveform. Phasors of the three phases are combined to produce the positive sequence measurement. Figure 4 shows the Matlab\Simulink simulation of the PMU.

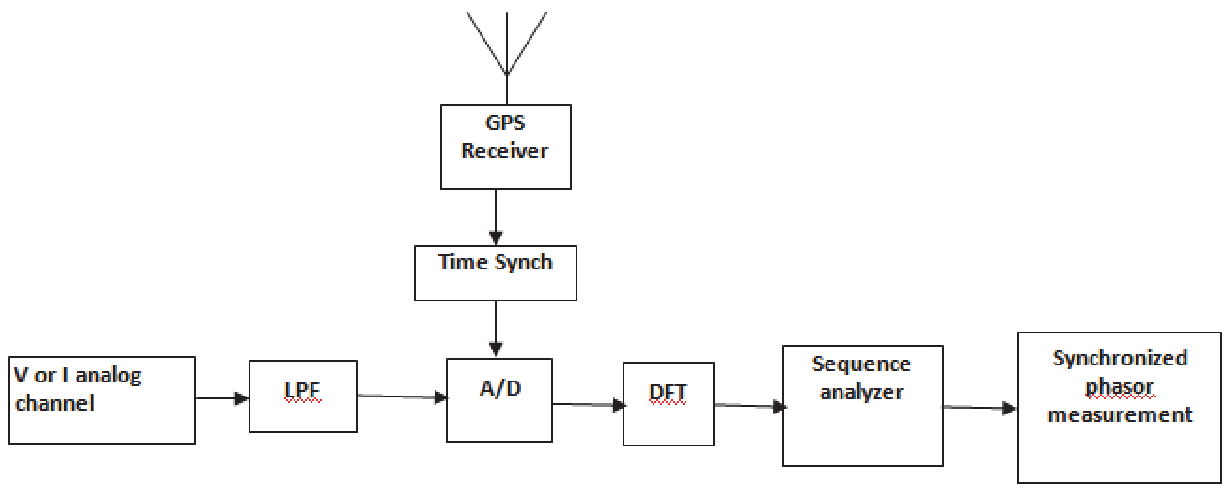

Fig. 4. Block diagram of the Synchronized Phasor Measurement System (PMU).

The basic Phasor measurement process is that of estimating a positive-sequence (also negative and zero are available), fundamental frequency phasor representation from voltage or current waveforms. As indicated by Fig. 3, the analog power signal is converted into digital data by the analog to digital converter. For example, if the voltage is needed to be measured, the samples are taken for each cycle of the waveform and then the fundamental frequency component is calculated using (DFT). The positive sequence phasor can be calculated as follows;

$$V = 1/3\ (Va + \alpha .\ Vb + \alpha 2.\ Vc) \quad (1)$$

Where $\alpha = j \angle 120°$ and Va, Vb, and Vc are the DFT phasor coefficients of each of the three phases.

Figure 5 shows a simple block diagram explaining the procedure of measured voltage or current analog signal. The external time source is an absolute time reference from a global positioning system (GPS) receiver, which delivers a phase-locked sampling clock pulse to the Analog-to-Digital converter system. The sampled data are converted to a complex number which represents the phasor of the sampled waveform. Phasors of the three phases are combined to produce the positive sequence measurement. A time stamp is generated to associate with the comtrade report via communication port to phasor data concentrator. The figure includes a hardware low-pass filter (Hardware LPF) for anti-aliasing and an analog-to-digital (A/D) converter for analog-to-digital conversion. The system of supervision permits capturing records of the same event at different points in the power system with a unique time reference, the phasor measurement units at present are located strategically, with the purpose of capturing information on the impact of contingencies at the local or system level.

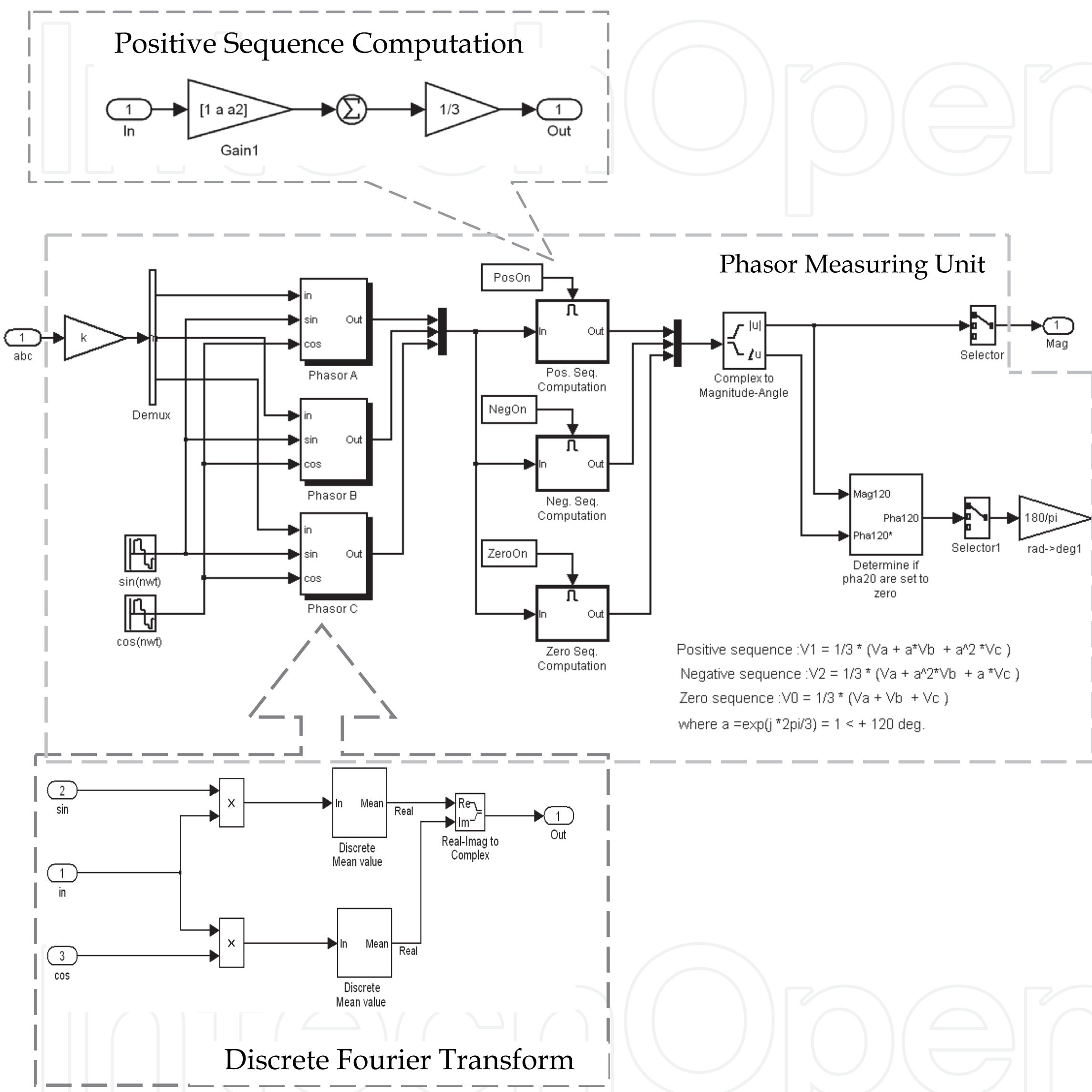

Fig. 5. PMU block diagram using Matlab/Simulink.

7. Communication issues (De La Ree et al., 2010; Hall et al., 2003; Naduvathuparambil et al., 2002; Klump et al., 2005)

Standard communication systems are adequate for most phasor data transmission. The issue for data communications includes speed, latency and reliability. Communication speed (data rate) depends on the amount of Phasor data being sent. Communication links used by WAPS include both wired (telephone lines, fiber-optics, power lines) and wireless (satellites) options. Delays associated with the link act as a crucial indicator to the amount of time-lag that takes place before action is initiated. The delays are an important aspect and should be incorporated into any power system design or analysis, as excess delays could ruin any control procedures adopted to stabilize the power grid.

Although more and more control systems are being implemented in a distributed fashion with networked communication, the unavoidable time delays in such systems impact the achievable performance. Delays due to the use of PMUs and the communication link involved are due primarily to the following reasons:

Transducer delays: Voltage transducers (VT) and current transducers (CT) are used to measure the RMS voltages and currents respectively, at the instant of sampling.

Window size of the DFT: Window size of the DFT is the number of samples required to compute the phasors using DFT.

Processing time: The processing time is the time required in converting the transducer data into phasor information with the help of DFT.

Data size of the PMU output: Data size of the PMU message is the size of the information bits contained in the data frame, header frame and the configuration frame.

Multiplexing and transitions: Transitions between the communication link and the data processing equipment leads to delays that are caused at the instances when data is retrieved or emitted by the communication link.

Communication link involved: The type of communication link and the physical distance involved in transmitting the PMU output to the central processing unit can add to the delay.

Data concentrators: Data concentrators are primarily data collecting centers located at the central processing unit and are responsible for collecting all the PMU data that is transmitted over the communication link.

8. Phasor data concentrators PDC

A Phasor Data Concentrator is a logical unit that collects phasor data, and discrete event data from PMU's and other PDC's, and transmits data to other applications. PDC's should have storage capability to buffer data for a reasonable time to allow data alignment and other vital tasks. Thus, a PDC is capable of receiving, aligning, storing and transmitting GPS-synchronized data.

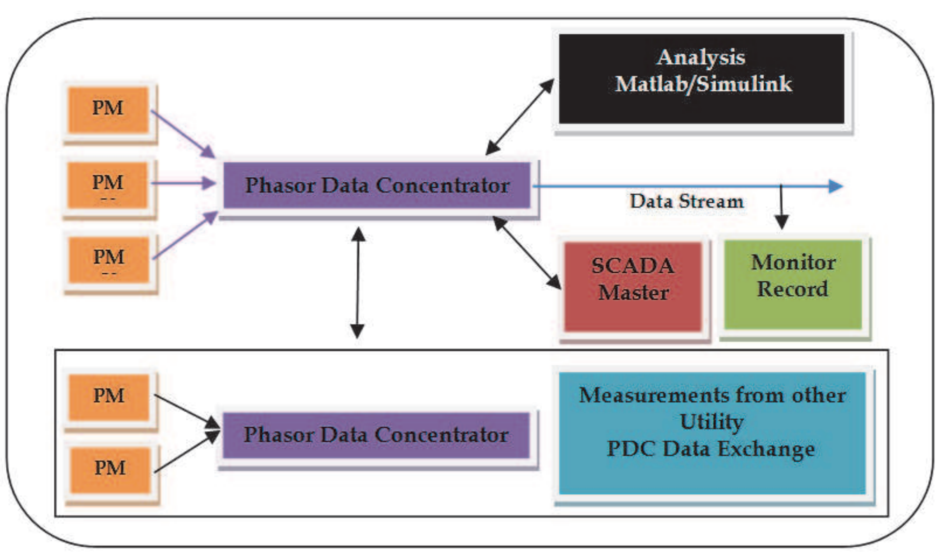

Fig. 6. Phasor data concentrator.

Specification	Suggested Minimum Requirement
Input Data Format	IEEE1344, upgrade to PC37.118 in 2005 if available Optional: COMTRADE, OPC
Output Data Format	COMTRADE. IEEE 1344. Upgrade to PC37.118 in 2005 if available. (Optional: PDC Stream, PDCxchng)
Data Alignment	Adopt BPA standard*
Output Data Rate	It should support IEEE1344 and PC37.118 (future). Default value: 30 samples per second
Streaming Channels	User Defined Configuration
Continuous Data Retention	32 Days

Table 1. Phasor data concentrator suggested minimum requirements.

Table 1 summarizes the minimum requirements for a phasor data concentrator. The minimum requirements enable applications of streaming phasor data and event capturing. Figure 6 shows the PDC (Bhargava et al., 2008).
It is important to note that it is possible that a PDC may receive data from PMUs from different manufacturers. Aligning data from different manufacturer PMUs may be a complex task that requires knowledge of the characteristics of each unit. For application level one, the alignment of data is done on the basis of the time tag that each PMU data has. This may result in misalignments of several microseconds. For streaming data applications and event capturing applications, this misalignment is not critical. For other applications it may be critical.

9. Conventional problems

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. 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 (Horowitz et al., 2009).

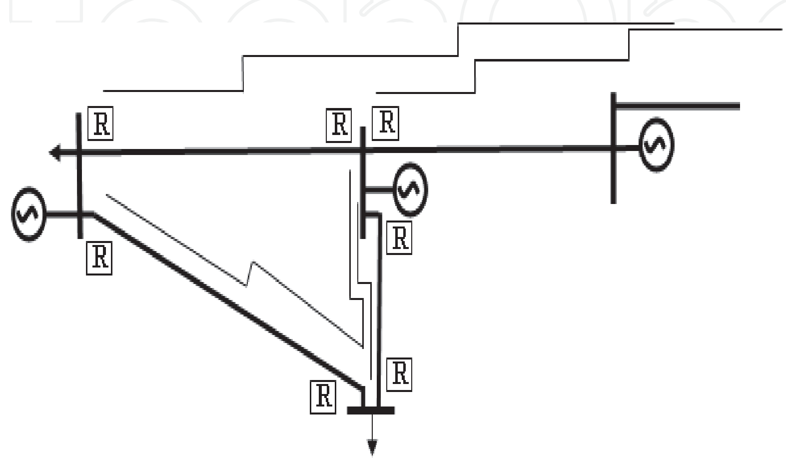

Fig. 7. Three zones of operation for each stand alone relay.

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 (Eissa, 2009). The distance relays are based on standalone decision, while each relay operates independently according to three different zone of operation, see Figure 7.

The mal-operation or fail-to trip of protection is determined as one of the origins to raise and propagate major power system disturbances (Tang, et al., 2006). 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. 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 centers toward central or national control centers. 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.

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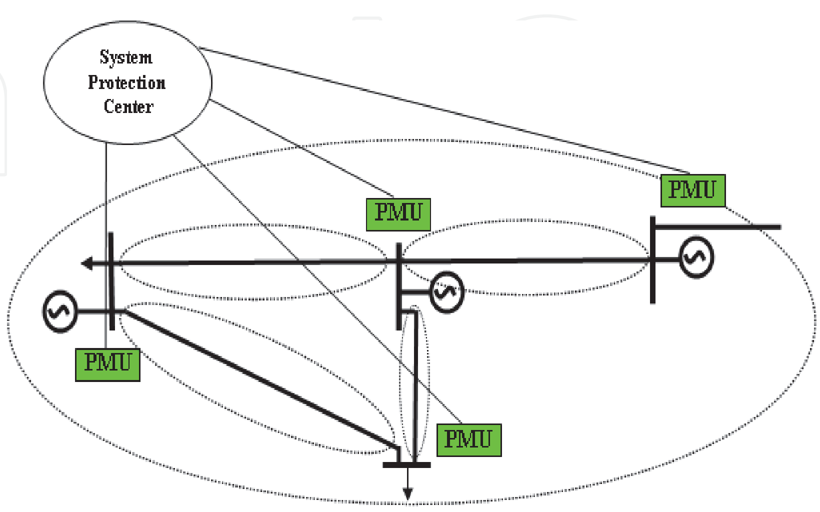


Fig. 8. The new protected zones of the proposed relay.

The communication of data among them is carried via optic-fiber networks. The relay decision is based on collected and shared data through communication network. The suggested technique satisfies high degree of reliability and stability while it is based on shared decision rather than stand alone decision. The suggested technique can see all the power system area and can deal with the transmission lines as unit protection, see Figure 8. 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.

10. 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 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 (Eissa 2008, 2009, 2005). 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) (Dissertation, 2008).

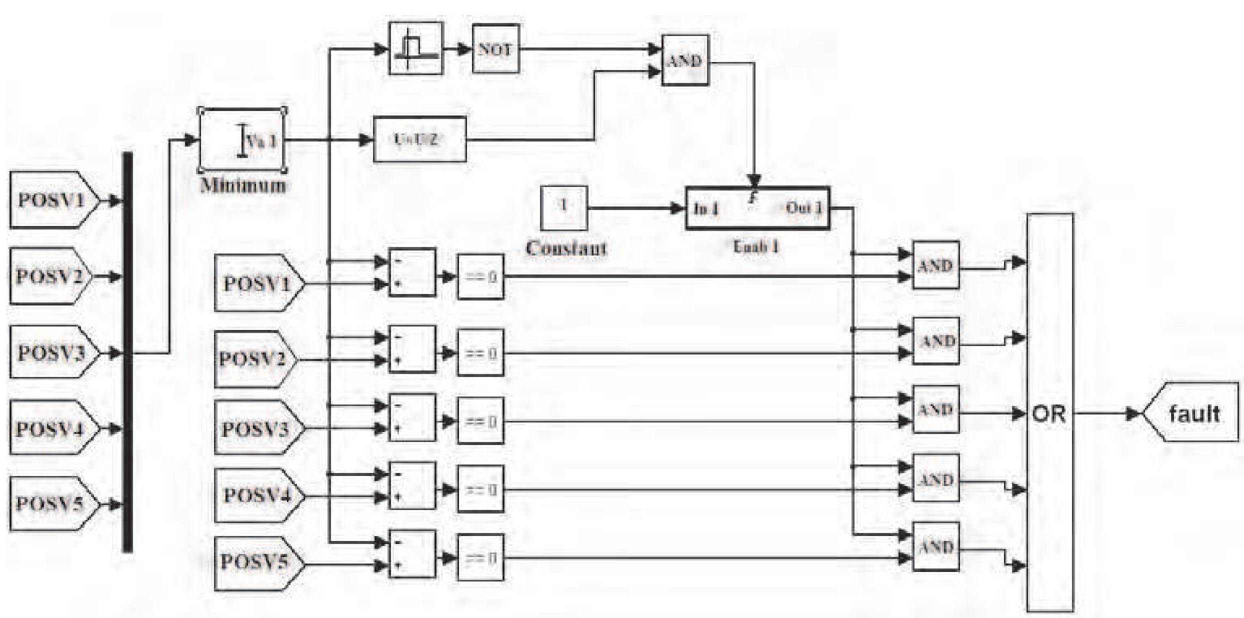


Fig. 9. Matlab/Simulink block diagram shows selecting the minimum value.

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:

$$\text{Min}\{|V1|, |V2|,.. |Vm|, \ldots |Vn|\} \tag{2}$$

where |Vn| is the positive sequence voltage magnitude measured by PMU and located at area "1", "2", "3",…,"m" , to "n". Figure 9 shows the Matlab simulink block diagram responsible of the selection of the nearest area to the fault based on comparing positive sequence voltage magnitudes. POSV1, POSV2... POSV5 are the input signals of positive sequence voltage magnitudes collected from 5 areas on the network. The minimum voltage magnitude is indicated by the Minimum block which identifies the value and/or position of the smallest element in each column of the input, or tracks the minimum values in a sequence of inputs over a period of time.
The Minimum block output is shown in Figure 10. The graph shows the o/p from the Matlab/Simulink simulation, which is the minimum positive sequence voltage magnitude during fault. Any decrease in the signal magnitude is indicated by the Detect Decrease block which determines if the input signal is strictly less than its previous value or not, the status can be recognize as:

- The output is "1", when the input signal is less than its previous value.
- The output is "0", when the input signal is greater than or equal to its previous value.

The threshold value of the input signal is detected by the Interval Test block which outputs "1" if the input is between the values specified by the Lower limit and Upper limit parameters. The block outputs "0" if the input is outside those values.

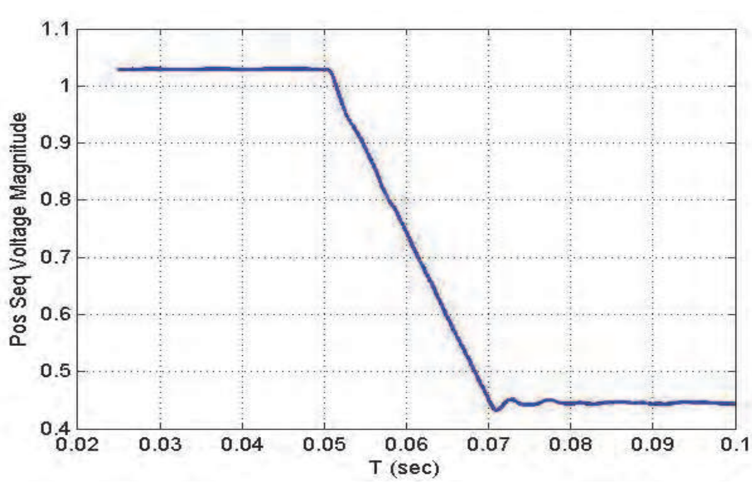


Fig. 10. The Minimum block output from the Matlab/Simulink.

For a fault occurred on the grid, the output from (2) 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 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 $|\Delta\phi mn|$ 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).

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

Figure 11 shows the Matlab/Simulink block diagram responsible of the selection of the faulted line from all lines connecting to the faulted areas; the absolute difference between positive sequence current angles at line terminals for each line is given. The maximum current angle difference is indicated by the Maximum block which identifies the value and/or position of the largest element in each column of the input, or tracks the maximum values in a sequence of inputs over a period of time.

Figure 12 shows the output from the Maximum block shown in Figure 11. The graph shows the maximum absolute difference of positive sequence current angle during internal fault. The threshold value of the input signals is detected by the Interval Test block. Figure 13 shows the maximum absolute difference of positive sequence current angle during external fault. Discrete on/off delay timer block given in Figure 11 is used to ignore big changes in angle difference which associated with change in current direction in any line due to external faults.

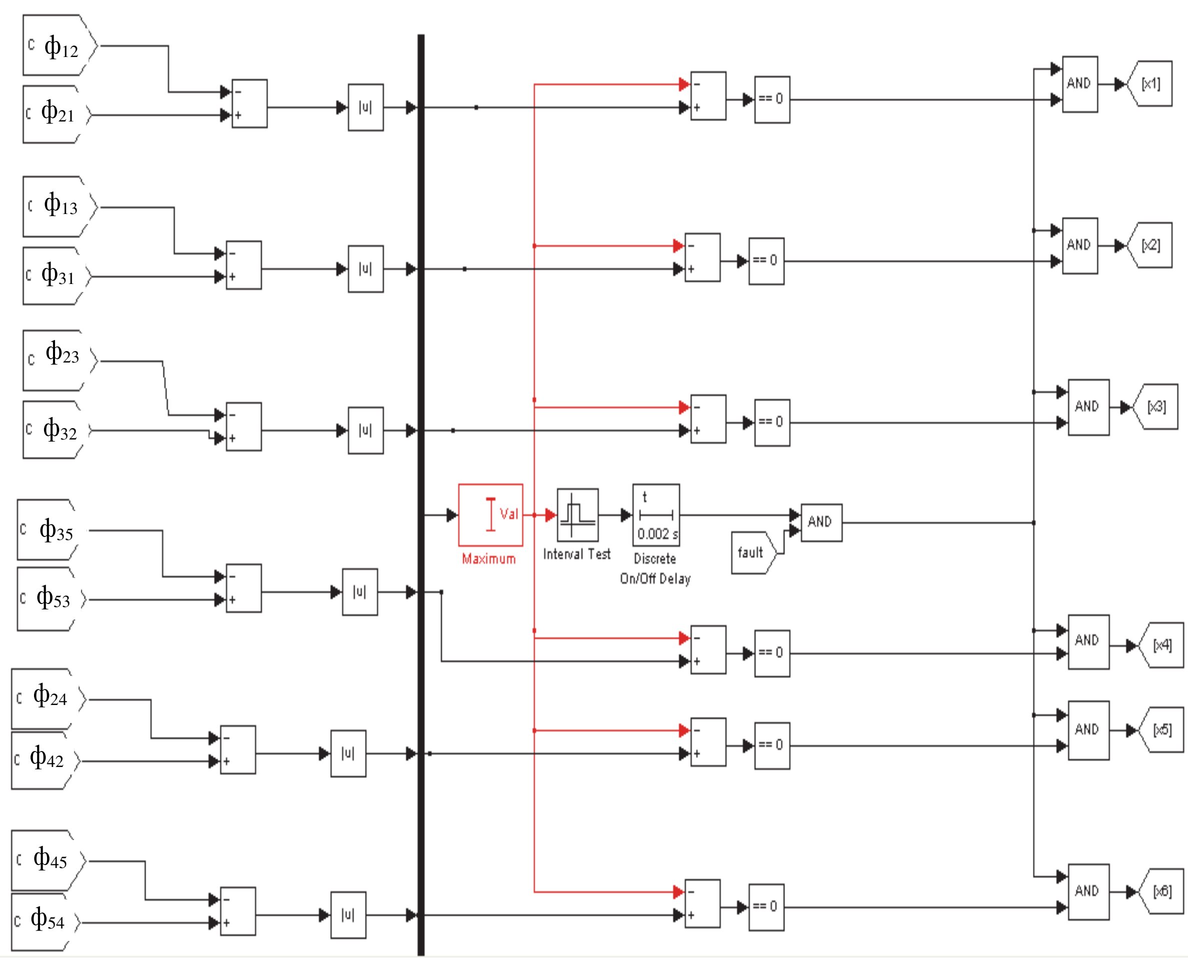


Fig. 11. The Matlab/Simulink block diagram responsible of the selection of the faulted line.

Part of the 500/220 kV Egyptian interconnected electrical network is used for the study; five main buses that represent five different areas with 500 kV are selected to verify the suggested technique. Figure 14 shows the selected five areas from the overall network. In the single line diagram, each bus represents the selected area in the simulation that can connect the 500 kV network with 220 kV network through three single phase 500/220 kV power transformers. The system is simulated using the Matlab/Simulink with a sampling frequency of 20 kHz for a system operating at a frequency of 50 Hz. By means of measuring positive sequence magnitude of three phase to ground voltage and positive sequence current angle difference between sending and receiving ends, we make a new criteria to deal with faults (single, double and three phase to ground faults). This new criteria will detect faults and select the nearest area to the fault. Also, the new criteria will distinguish between internal and external faults in the interconnected lines.

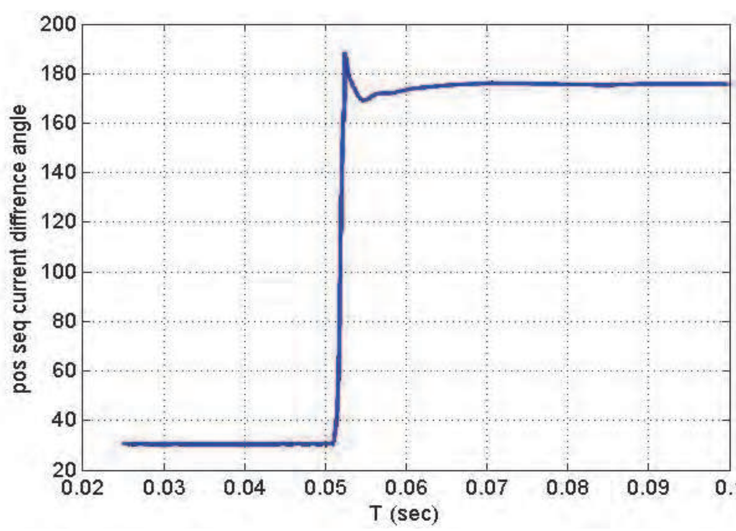


Fig. 12. Maximum absolute difference of positive sequence current angle due to internal fault.

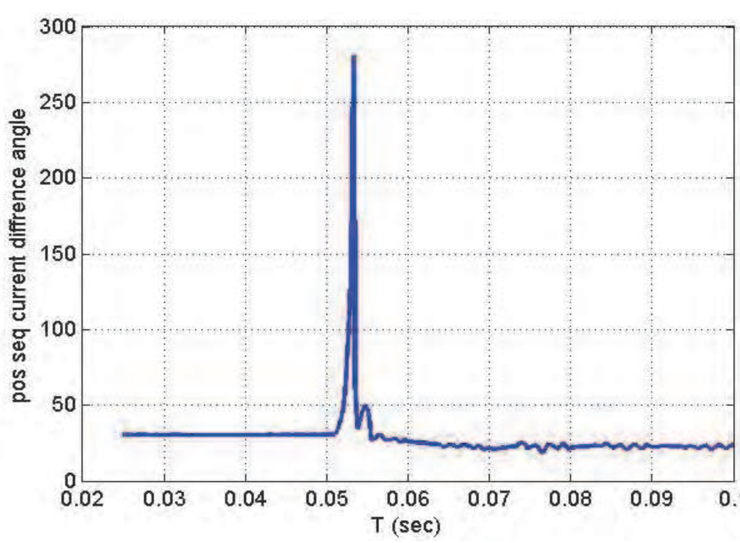


Fig. 13. Maximum absolute difference of positive sequance current angle due to external fault.

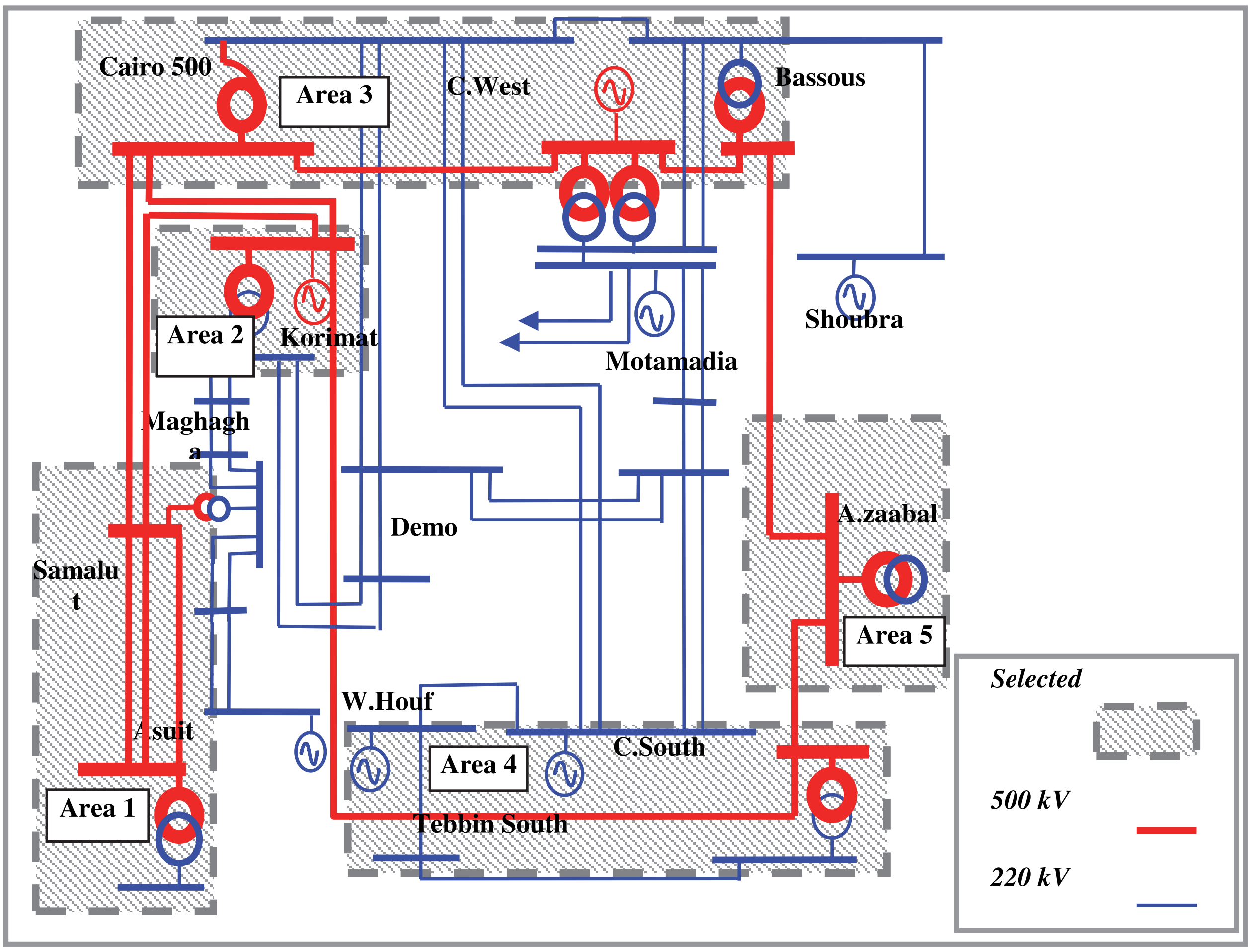


Fig. 14. The selected five areas from the overall network.

11. Case study

An extensive series of study is examined on the power system given in Figure 15. All fault events are studied and a sample of the results is given here. As mentioned above, the studied network is classified into 5 neighboring areas. The 5 areas are connected with each others by six lines. Three phases to ground fault are located on line 1 which connecting area "1" with area "2", see Figure 15. Fault location is placed away from area "1" and area "2" by 100 and 45 km respectively.

11.1 Short circuit on transmission line 1(Samalot-Kurimat)

The suggested technique is used to be verified under different fault conditions, the fault data is generated from power system configuration simulated using the Matlab/Simulink. A short circuit is located on transmission line (TL1) as shown in Figure 15.The total length of the faulted transmission line is 145 Km. Each fault type (three phase, double phase and single phase to ground fault) is tested. Different locations of fault along the transmission line are tested to affirm the criteria as being effective and operate successfully.

11.2 Three phase to ground fault

A three-phase to ground fault is located on transmission line (TL1) .The distance between fault location on the transmission line and the nearest bus (Kurimat) is 45 Km. The 3-phase voltage signals measured from Kurimat bus bar is recorded and displayed in Figure 16. The 3-phase current signals for all transmission lines away from Kurimat are recorded and displayed in Figure 17.

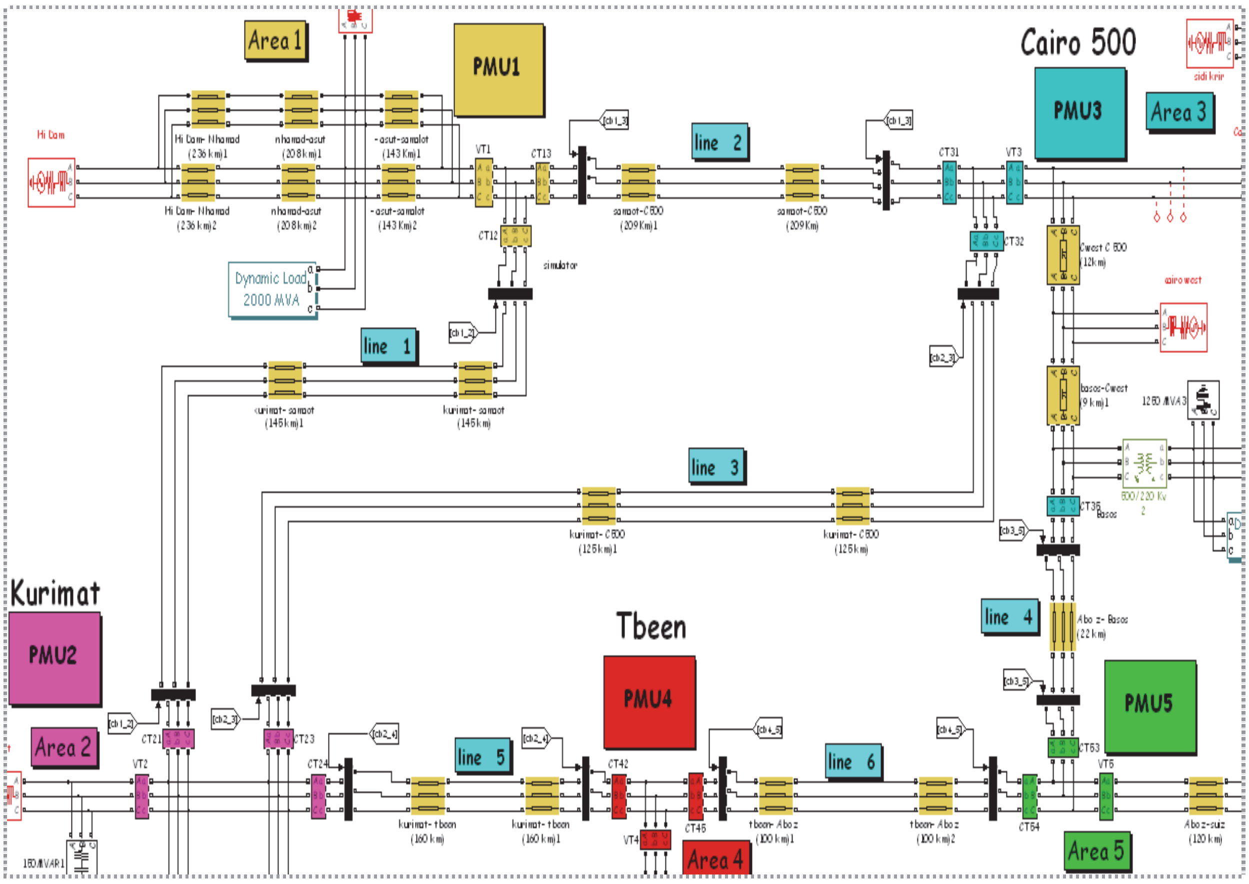


Fig. 15. Matlab/Simulink Block diagram of the interconnected network.

Figure 18 shows the five positive phase sequence voltage magnitudes (PSVM), minimum value is selected which indicates the nearest area to the fault area (2). Figure 19 shows the absolute differences of positive phase sequence current angles (PSCA) for all lines connecting to the faulted area (2) with all neighboring areas (1, 3, and 4). The angles difference of line (1) terminals is the maximum (=180°), this means that the current is reversed from one terminal only, and then it is clear that the fault is internal on transmission line TL1.

12. Fault type classification technique

All faults are identified as a phase fault or a ground fault, one parameter, λzero, is derived for fault classification:

$$\lambda_{zero} = \frac{1}{3}\left|I_a + I_b + I_c\right| \tag{5}$$

The fault is classified as a ground fault if λ_{zero} is greater than threshold value. Once the fault has been classified, the specific fault type is determined by comparing all rate of change of phase currents with an predetermined disturbance detection pickup, The fault typing software module is employed when the measured parameter exceeds a prescribed threshold (e.g., when a measured correct exceeds an overcurrent pickup).

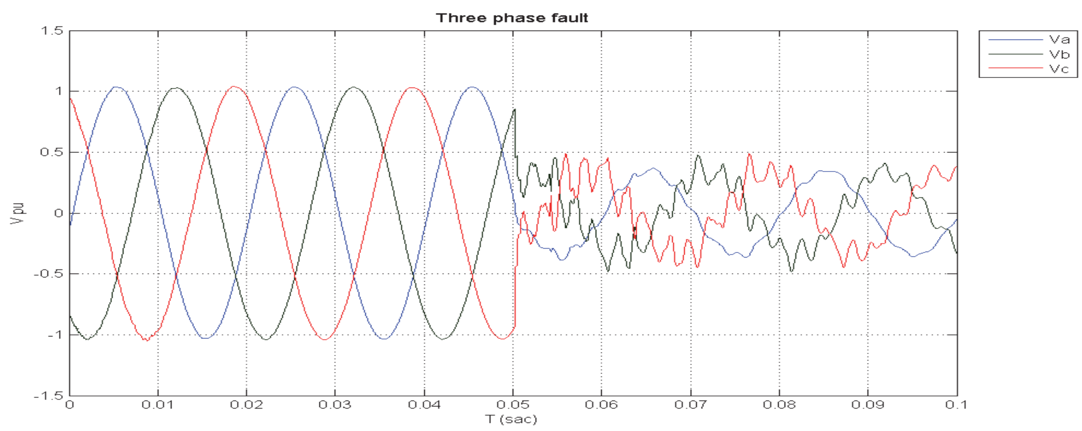


Fig. 16. Three phase voltage signals at Kurimat busbar.

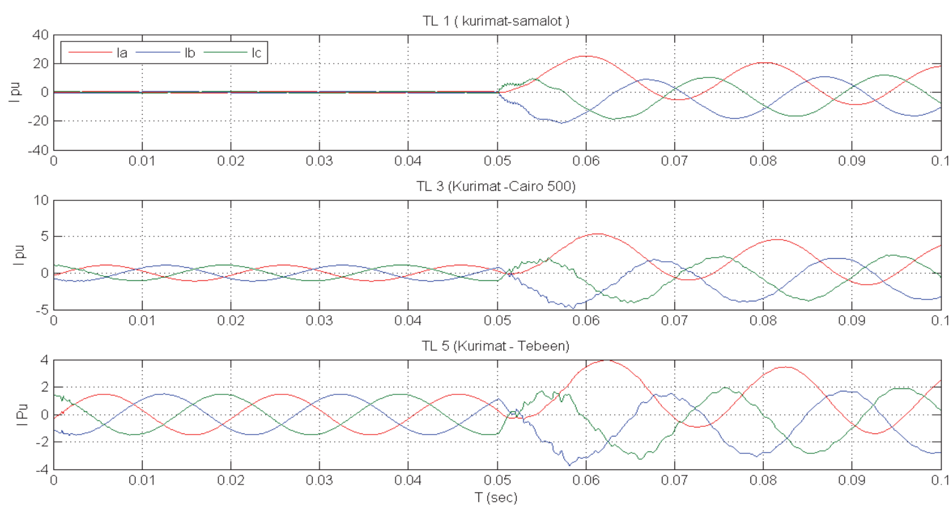


Fig. 17. Three phase current signals for all lines connected to Kurimat.

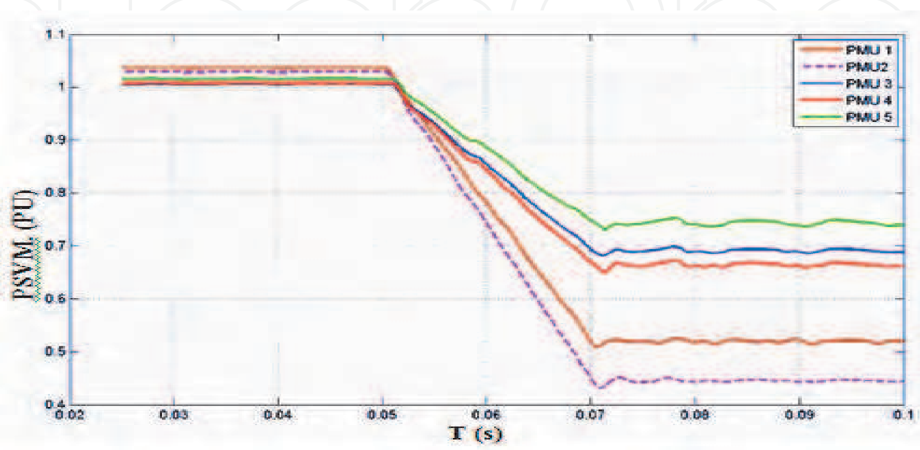


Fig. 18. Positive sequence voltage magnitudes.

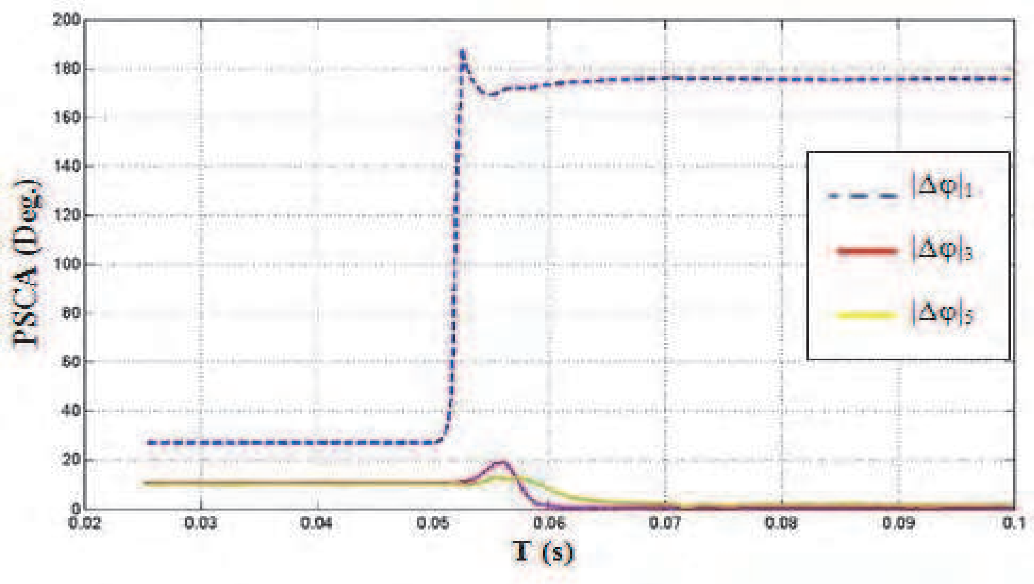


Fig. 19. Positive sequence current angle absolute differences for all lines connected to the faulted area.

Discrete Fourier transform block computes the fundamental value of the input phase current signal over a running window of one cycle of the specified fundamental frequency as shown in Figure 20. First and second 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".
As shown in Figure 21, the input three-phase current is used to calculate zero sequence components to classify the fault type. Then each phase current signal is taken as a percentage from its steady state value. Then the rate of change of the percentage of phase current magnitude is compared by a threshold value to identify the faulted phase.

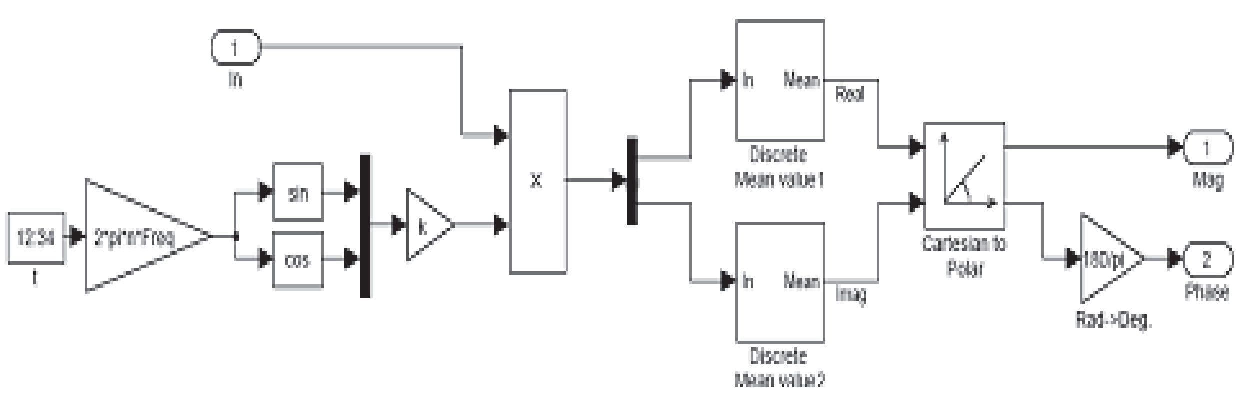


Fig. 20. Discrete Fourier block set.

Three phase fault is applied on TL1 Samalout–Kurimat. Fault resistance = 50 Ω. Fault Distance = 50 %, Figure 22 shows fault recorder display at each terminal of the faulted transmission line. The fault is recorded as symmetrical fault. As shown in Figure 23, zero sequence current magnitude is zero.

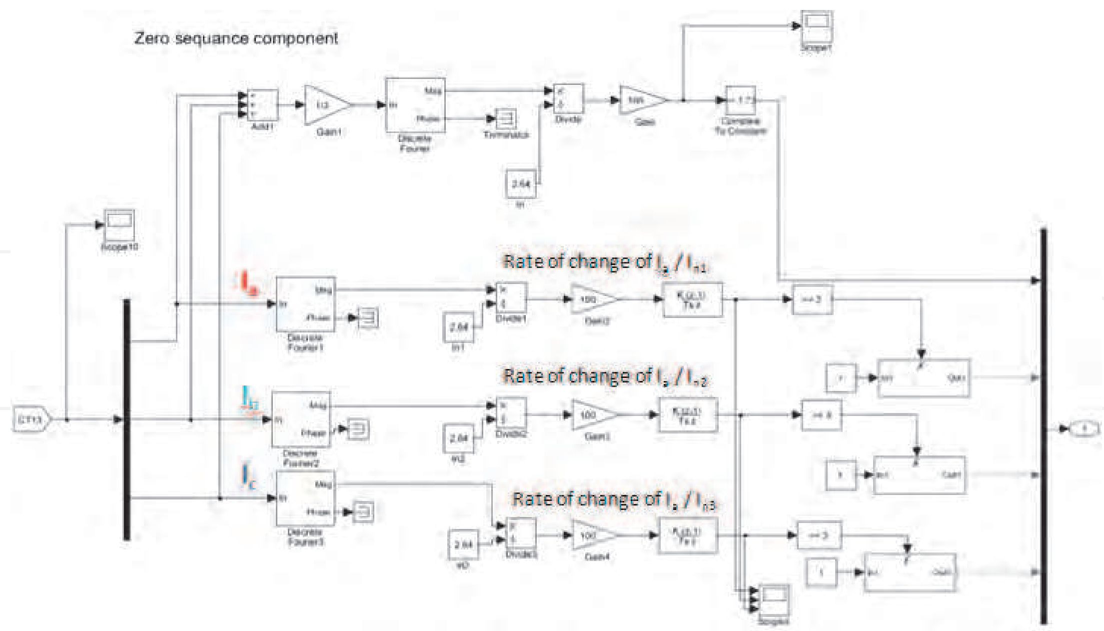


Fig. 21. Fault Classification Blockset.

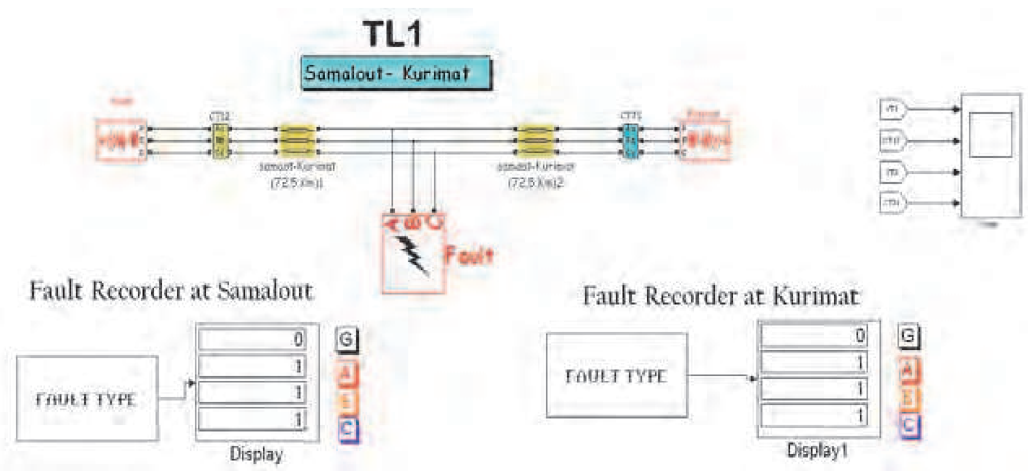


Fig. 22. Fault recorder at each terminal display that fault type is three phase fault.

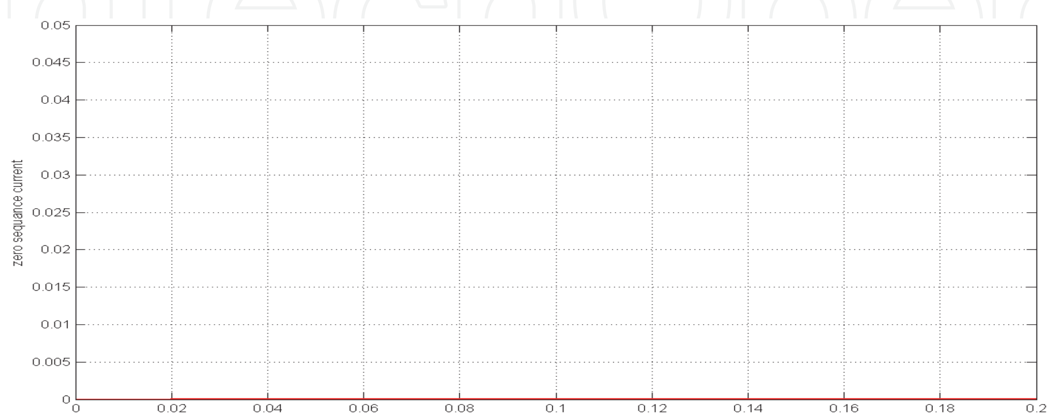


Fig. 23. Zero sequence component current magnitude during fault.

13. Conclusion

The chapter outlines a novel idea for fault detection and classification using Phasor measurement units in a wide area system. The idea has successfully identified the faulted line on a large power interconnected system. The idea descried in this paper represents a new state-of-art in the field of interconnected grid protection and classification. The idea is based on sharing data from many PMUs. The new idea also calssified the fault types for the interconnected system. The idea used a center protection unit for collecting the data and issued the tripping signal. The idea is implemented and investigated using the powerful Matlab/Simulink package. Power system configuration, fault detection, fault calculation, discrimination, and classification are achieved through the Matlab/Simulink program.

14. Acknowledgment

This chapter is written, revised and analyzed by the author. Some parts of the chapter are cited from MSc dissertation done in Helwan University-Faculty of Engineering-Cairo-Egypt by Eng. Mohamed Magdy. The MSc dissertation is supervised by Prof. Mohammed El Shahat Masoud and the author of the chapter.

15. References

Phadke, A. (2002). Synchronized Phasor Measurements a historical over view. *Virginia Polytechnic Institute and American Electric Power Bhargava*.0-7803-7525-4/02/IEEE

Marek Zima. (2002). Special Protection Schemes in Electric Power Systems. *Literature survey*, (June 2002).

Thorp, J. S; Phadke A. G; Horowitz, S. W. & Begovic, M. M. (1988). Some Applications of Phasor Measurements to Adaptive Protection. *IEEE Transactions on Power Systems,* Vol. 3, No. 2, (May 1988).

Centeno, V; De La Ree, J; Phadke, A. G.; Mitchell, G; Murphy, J; Burnett, R; (1993). Adaptive Out-of-Step Relaying Using Phasor Measurement Techniques. IEEE Computer Applications in Power, (October 1993).

Guzman, A & Tziouvaras, D (2002). Local and Wide-Area Network Protection Systems improve power system reliabili, *Schweitzer Engineering Laboratories, E. O. ty. Inc. Pullman, WA, USA, Ken E. Martin Bonneville Power Administration Vancouver*, WA, USA, Aviable from, www.naspi.org/resources/archive/prtt/waps_wprc04.pdf

Guzman, A; Mooney, J. B; Benmouyal, G; Fischer, N. (2002). Transmission Line Protection System for Increasing Power System Requirements. *55th Annual Conference for Protective Relay Engineers, College Station, Texas,* (April 2002).

Gjerde, P. O & Mangelrod, R. (2001). Optimisation of Protection Performance During System Disturbances. *CIGRE 2001 SC 34 Colloquium*, (Septemper 2001).

Larsson, M & Rehtanz, C. (2002). Predictive Frequency Stability Control Based on Wide-Area Phasor Measurements. *Proc. 2002 IEEE Power Engineering Society Summer Meeting, (2002).*

Zima, M; Korba, M & Andersson, G. (2003). Power Systems Voltage Emergency Control Approach Using Trajectory Sensitivities. *2003 IEEE Conference on Control Application, CCA, Istanbul*, (June 2003).

Rehtanz C & Westermann, D. (2002). Wide Area Measurement and Control System for Increasing Transmission Capacity in Deregulated Energy Markets. *Proc. 2002 Power Systems Computation Conference in Sevilla,* (2002).

Rehtanz, C. (2001). Wide Area Protection System and Online Stability Assessment based on Phasor Measurements. Bulk Power System Dynamics and Control - V, *Onomichi City, Japan,* (Augest 2001).

Zhang, N & Kezunovic, M. Verifying the Protection System Operation Using An Advanced Fault Analysis Tool Combined with the Event Tree Analysis. *Northern American Power Symposium, NAPS 2004 Moscow, Idaho,* (August 2004).

Lin, Y. L; Liu, C. W. & Chen, C. S. (2004). A new PMU-based fault detection/location technique for transmission lines with consideration of arcing fault discrimination—Part I: Theory and algorithms. *IEEE Trans. Power Del.,* Vol. 19, No. 4, (October 2004), pp. 1587–1593.

Yu, C. S; Liu, C. W; Yu, S. L. & Jiang, J. A. (2002). A new PMU-based fault location algorithm for series compensated lines. *IEEE Transaction on Power Deivery*, Jan. 2002, Vol. 17, No. 1, pp. 33–46.

Wang, et el. (2005). Design of a novel wide-area backup protection system, *Proceedings of IEEE/PES Transmission Distribution Conference Asia Pac. Dalian, China, (2005), pp. 1-6.*

Yan Wang; Yan-Xia Zhang; Song-Xiao Xu; (2008). Wide-area protection against chain over-load trip based on multi-agent technology, *Interntional Conference on Machine Learning and Cybernetics*, pp. 1548 – 1552, Volume: 3, Digital Object Identifier: 10.1109/ICMLC.2008.4620652, 2008.

Xiaoyang Tong; Xiaoru Wang; Li Ding (2008). Study of information model for wide-area backup protection agent in substation based on IEC61850, *Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies*, pp. 2212 – 2216, Digital Object Identifier: 10.1109/DRPT.2008.4523778

Yangguang Wang; Xianggen Yin; Dahai You; (2010). Agent-based wide area protection with high fault tolerance, *International Conference on the Modelling, Identification and Control (ICMIC)*, (2010), pp. 739 – 744

Hui Sun; Qianjin Liu (2009). Research of the Structure and Working Mechanisms of Wide-Area Backup Protection Agent. *1st International Conference on Information Science and Engineering (ICISE)*, (2009), Digital Object Identifier: 10.1109/ICISE.2009.926, (2009), pp. 5037 – 5042.

Zhiyuan Duan; Zhang, C.; Hu, Z.; Sun, Y. (2009). Design of Robust Controller of Interconnected Power System Considering Signals Transmission Delay. *International Workshop on Intelligent Systems and Applications*, (2009). ISA 2009. Digital Object Identifier: 10.1109/IWISA.2009.5072823, (2009), pp. 1 - 5

Zhiyuan Duan; Chengxue Zhang; Zhijian Hu; Yuanyuan Zhang (2009). Robust Control of Interconnected Power System Based on WAMS Considering Signals Transmission Delay, *Power and Energy Engineering Conference*, (2009). APPEEC 2009, Asia-Pacific, Digital Object Identifier: 10.1109/APPEEC.2009.4918729, (2009), pp. 1 – 4

Seong-Jeong Rim; Seong-Il Lim; Seung-Jae Lee (2008). Multi-agent based reliability enhancement scheme for IEC61850 substation, *Transmission and Distribution Conference and Exposition*, (2008), T&D. IEEE/PES, Digital Object Identifier: 10.1109/TDC.2008.4517294, (2008), pp. 1 – 6

Testa, S. & Chou, W. (2004). The distributed data center: front-end solutions, *IT Professional* Conference, Vol. 6, No. 3, Digital Object Identifier: 10.1109/MITP.2004.24, (2004), pp. 26 – 32

Begovic, M. (2004). Wide area protection and emergency control. *Power Systems Conference and Exposition*, (2004). IEEE PES Digital Object Identifier: 10.1109/PSCE.2004.1397488, (2004), pp. 1776 - 1777

Terzija, V.; Cai, D.; Valverde, G.; Regulski, P.; Vaccaro, A.; Osborne, M. & Fitch, J. (2010). Flexible Wide Area Monitoring, Protection and Control applications in future power networks Developments in Power System Protection (DPSP 2010), *10th IET International Conference on Managing the Change*, Digital Object Identifier: 10.1049/cp.2010.0361 (2010), pp. 1 – 5

Terzija, V.; Valverde, G.; Deyu Cai; Regulski, P.; Madani, V.; Fitch, J.; Skok, S.; Begovic, M. M. & Phadke, A. (2011). Wide-Area Monitoring, Protection, and Control of Future Electric Power Networks, *Proceedings of the IEEE*, Vol. 99, No. 1, Digital Object Identifier: 10.1109/JPROC.2010.2060450, (2011), pp. 80 - 93

Moxley, R. & Wronski, M. (2007). Using time error differential measurement in protection applications, *Power Systems Conference: Advanced Metering, Protection, Control, Communication, and Distributed Resources*, 2007. PSC 2007 Digital Object Identifier: 10.1109/PSAMP.2007.4740918, (2007), pp. 278 - 283

Phadke, A. G. & Kasztenny, B. (2009). Synchronized Phasor and Frequency Measurement Under Transient Conditions, *IEEE Transactions on Power Delivery*, Vol. 24, No. 1, Digital Object Identifier: 10.1109/TPWRD.2008.2002665, (2009), pp. 89 - 95

Jetti, S. R. & Venayagamoorthy, G. K. (2006). Real-Time Implementation of a Dual Function Neuron based Wide Area SVC Damping Controller, *Industry Applications Conference*, (2006), 41st IAS Annual Meeting. Conference Record of the 2006 IEEE, Vol. 2, Digital Object Identifier: 10.1109/IAS.2006.256598, (2006), pp. 672 - 678

Yi Hu & Novosel, D. (2006). Challenges in Implementing a Large-Scale PMU System Power System Technology, *International Conference on Power Con 2006*. Digital Object Identifier: 10.1109/ICPST.2006.321829, (2006), pp. 1 - 7

Wenxin Liu; Cartes, D. A. & Venayagamoorthy, G. K. (2006). Particle Swarm Optimization based Defensive Islanding of Large Scale Power System, *International Joint Conference on Neural Networks*, IJCNN, (2006), Digital Object Identifier: 10.1109/IJCNN.2006.246642
(2006), pp. 1719 - 1725

Xiupeng Guan; Yuanzhang Sun & Lin Cheng (2007). A load parameter identification method based on wide area measurement, *International Power Engineering Conference*, 2007. IPEC 2007, (2007), pp. 431 - 436

Zhang, G.; Lee, S.; Carroll, R.; Jian Zuo; Beard, L. & Yilu Liu (2010). Wide area power system visualization using real-time synchrophasor measurements, *Power and Energy Society General Meeting*, 2010 IEEE Digital Object Identifier: 10.1109/PES.2010.5588188, (2010), pp. 1 - 7

Moraes, R.; Volskis, H. & Yi Hu (2008). Deploying a large-scale PMU system for the Brazilian interconnected power system, Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, (2008), DRPT 2008, Digital Object Identifier: 10.1109/DRPT.2008.4523392, (2008), pp. 143 - 149

Sybille, G. & Hoang Le-Huy (2000). Digital simulation of power systems and power electronics using the MATLAB/Simulink Power System Blockset, *IEEE Power Engineering Society Winter Meeting*, (2000), Vol. 4 Digital Object Identifier: 10.1109/PESW.2000.847358, (2000), pp. 2973- 2981

De La Ree, J.; Centeno, V.; Thorp, J.S. & Phadke, A. G. (2010). Synchronized Phasor Measurement Applications in Power Systems, *IEEE Transactions on Smart Grid,* Vol. 1, No. 1, Digital Object Identifier: 10.1109/TSG.2010.2044815, (2010), pp. 20 - 27

Hall, I.; Beaumont, P.G.; Baber, G.P.; Shuto, I.; Saga, M.; Okuno, K. & Uo, H. (2003), New line current differential relay using GPS synchronization, *Power Tech Conference Proceedings, 2003 IEEE Bologna*, Vol. 3 Digital Object Identifier: 10.1109/PTC.2003.1304464, 2003

Naduvathuparambil, B; Valenti, M. C. & Feliachi, A. (2002). Communication delays in wide area measurement systems, *Lane Dept. of Comp. Sci. & Elect. Eng., West Virginia University, Morgantown, WV,* 2002. Avialble from
www.csee.wvu.edu/~mvalenti/documents/SSST_02.pdf

Klump R. & Wilson, R. E. (2005). Visualizing real-time security threats using hybrid SCADA/PMU measurement displays, *Proc. 38th Hawaii Int. Conf. System Sci.*, 2005, p. 55c.

Bhargava, B. & Salazar, A. (2008). Use of Synchronized Phasor Measurement system for monitoring power system stability and system dynamics in real-time, Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE Digital Object Identifier: 10.1109/PES.2008.4596963, 2008, pp. 1 - 8

Horowitz S. H. & Phake A. G. (2009). Power System Relaying, *Taunton Somerset, U.K.* Research Studies Press

Eissa, M. M. (2009). New principle for transmission line protection using phase portrait plane. *IET Generation Transmission Distribution*, (2009), Vol. 3, No. 1, pp. 49–56

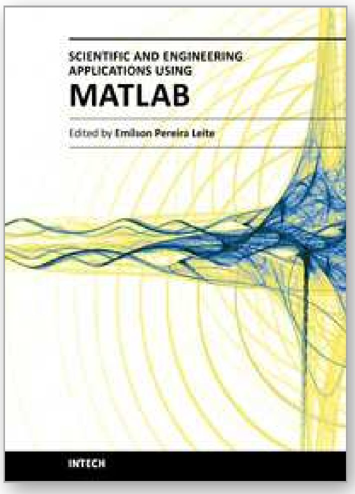
Tang J. & McLaren, P. G. (2006). A wide area differential backup protection scheme for Shipboard application, *IEEE Transaction on Power Delivery*, (2006), Vol. 21, No. 3, pp. 1121-1129

Eissa, M. M. (2008). Development and investigation of a new high-speed directional relay using field data, *IEEE Transaction on Power Delivery*, (2008), Vol. 23, No.3, pp. 1302–1309.

Eissa, M. M. (2009). A new digital feed circuit protection using directional element, *IEEE Transaction on Power Delivery*, (2009), Vol. 24, No. 2, pp. 531–537

Eissa, M. M. (2005). Evaluation of a new current directional protection technique using field data, *IEEE Transaction on Power Delivery*, (2005), Vol. 20, No. 2, pp. 566–572

Protection of Interconnected Electrical Networks Using Phasor Synchronized Measuring Technique, Ph.D. dissertation, Helwan University-Faculty of Engineering at Helwan, Cairo, Egypt, (2008)



ISBN 978-953-307-659-1
Hard cover, 204 pages
Publisher InTech
Published online 01, August, 2011
Published in print edition August, 2011