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Power System Observability and Fault Detection Using Phasor Measurement Units (PMU)

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Abstract: ***The increasing demand of load without considerable increase in transmission resources has posed numerous constraints and challenges in the power system monitoring and performance. The issues of deregulation trend in the industry and the requirement of better network monitoring, leads to the development of the solutions for wide area monitoring(WAM), protection and control, than the currently used methods which are mostly good for local area monitoring, protection and control. The purpose is to increase the overall system efficiency and reliability for all power stages via significant dependence on WAM as distributed intelligence agents with improved monitoring, protection, and control capabilities of power networks. The necessity for WAM has gained worldwide acceptance, and a number of WAM systems have been established, or initialized, in different power utilities throughout the world. Phasor Measurement Unit (PMU) is enabler of time-synchronized measurement, it communicate the synchronized local information to remote station. Wide-area monitoring, protection, and control require communicating the specific-node information to a remote station but all information should be time synchronized so that to neutralize the time difference between information. It gives a complete simultaneous snap shot of the power system.***

Keywords: Wide Area Monitoring(WAM),. Phasor Measurement Unit (PMU) ,Global Positioning System (GPS) ,Phasor Data Concentrators (PDCs) ,Energy Management System (EMS)

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. 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, protectionand optimization platform by means of new communication systems (GPS),andintegrated application design. When the system operates in extreme conditions, load shedding, generation shedding, or system islanding must occur to prevent total system collapse. 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.

2. Phasor Measurement Units

A phasor is a vectorial representation of an ac signal with sinusoidal waveform as shown in figure. It is well known that a sinusoid can be written using the equation,

$$X(t) = X_m \sin(\omega t + \Phi)$$

where ω being the frequency of the signal in rad/sec. Φ is the phase angle in radian and Xm is the peak amplitude.

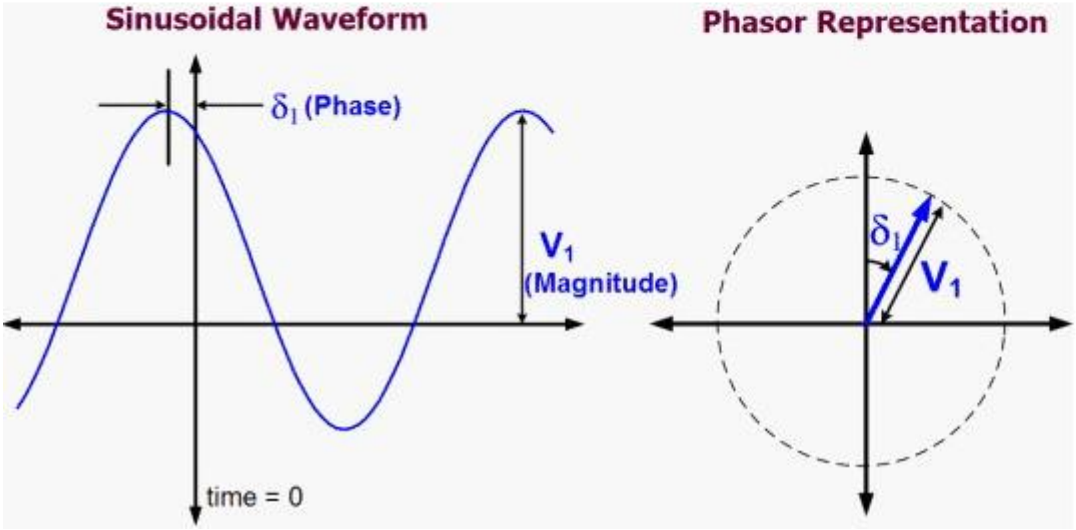

Figure 1: Phasor representation of sinusoidal signal

A phasor representation corresponds to a pure sinusoid. However, in realworld situations, ac signals are typically distorted by the presence of harmonics. As the analysis of a signal is always focused on specific frequency components, the extraction of the component of interest is important. A phasor is a complex number that represents both the magnitude and phase angle of the sine waves found in electricity. Phasor measurements that occur at the same time are called synchrophasors, as are the PMU devices that allow their measurement. In typical applications phasor measurement units are sampled from widely dispersed locations in the power systemnet work and synchronized from the common time source of a global positioning system (GPS) radio clock. Synchrophasor technology provides a tool for system operators and planners to measure the state of the electrical system and mange power quality.

PMUs are devices able to sample high speed, time-stamped snapshots of voltage and current in phasor format, frequency and rate of change of frequency. Being synchronized to Coordinated Universal Time (UTC) through Global Positioning System(GPS) signal, these devices are able to provide real time measurements recorded from different parts of the system, giving this way the potential to time-align these measurements and have a precise and representative view of the power system.

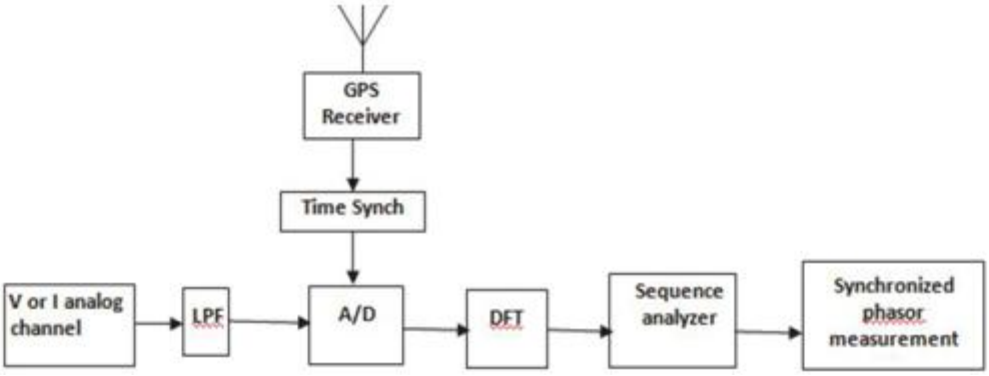

Figure 2: Block diagram of the Synchronized Phasor Measurement System (PMU)

Phasor Data Concentrators(PDCs) are devices able to concentrate measurements from different PMUs, time-align them and communicate them as a single stream to other PDCs or to monitoring and control devices. Using theabo-mentioned devices, a synchrophasor network can be developed which can which can derive measurements from different parts of the power network through PMUs. These measurements can be aggregated and time-aligned through PDCs and sent as a single stream of data through the communication network to Supervisory Control and Data Acquisition Systems (SCADA) or Energy Management System (EMS).

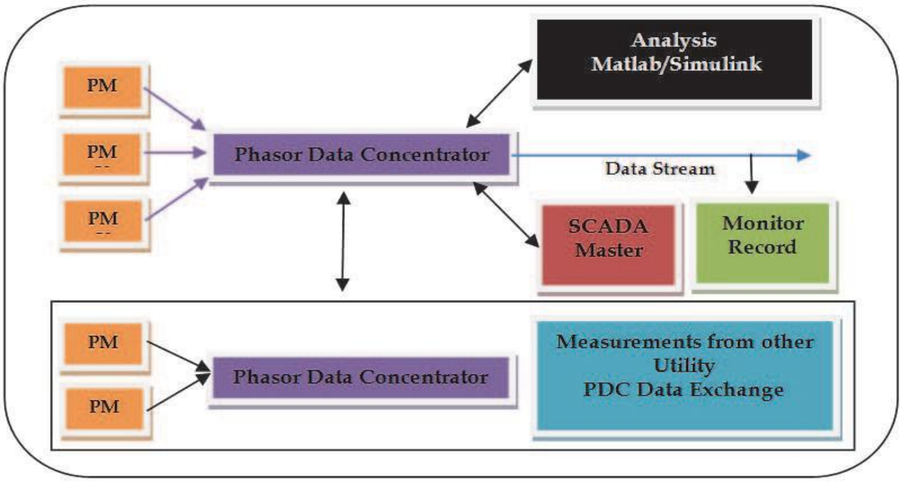

Figure 3: Phasor data concentrator

Synchronised Phasor Measurement Units (PMUs) were first introduced in early1980s, and since then have become a mature technology with many applications which are currently under development around the world. The occurrence of major blackouts in many major power systems around the world has given a new impetus for large-scale implementation of Wide Area Measurement Systems (WAMS) using PMUs and Phasor Data Concentrators (PDCs) in a hierarchical structure. Data provided by the PMUs are very accurate and enable system analysts to determine the exact sequence of events which have led to the blackouts, and help analyse the sequence of events which helps pinpoint the exact causes and malfunctions that may have contributed to the catastrophic failure of the power system. As experience with WAMS is gained, it is natural that other uses of phasor measurements will be found. In particular, significant literature already exists which deals with application of phasor measurements to system monitoring, protection, and control.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 systems 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.

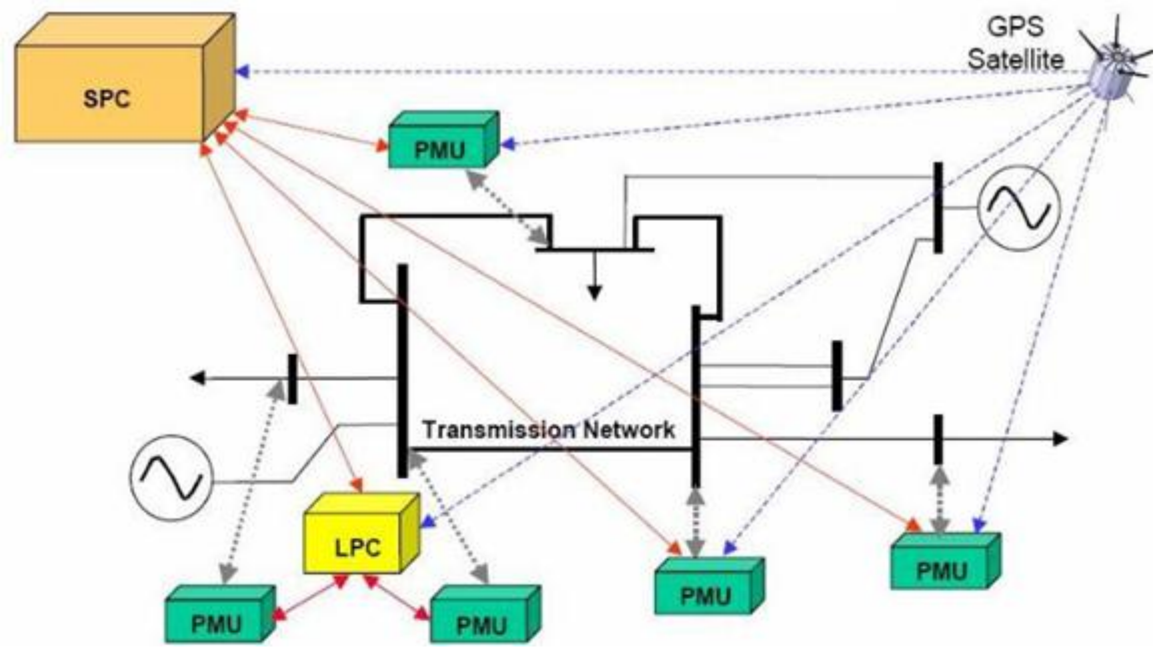

Figure 4: An integrated application design based on Phasor measuring units

Figure. 4shows an integrated application design of a transmission network based on phasor measuring units. Here we have phasor measurement units dispersed on different key buses in the transmission network. The time synchronized measurements are available with the help of GPS satellite. The data from different phasor measurement units are communicated with System Protection Center (SPC). And this SPC can control all the circuit breakers in the transmission network by sending control pulses, and also we have a LPC for local control applications.

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. 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.This study proposes a novel technique based on wide-area measurements for a power system. This 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.

3. Simulation Results

The system here under consideration, was simulated using MATLAB Simulink.

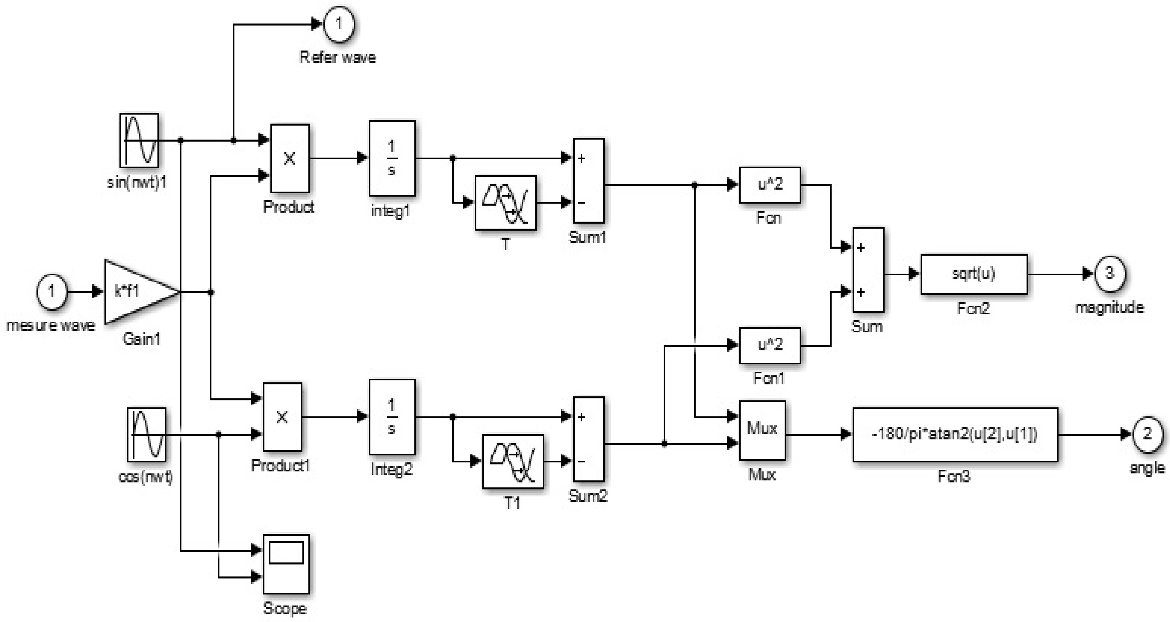

Figure 5: Basic Simulink Model of PMU

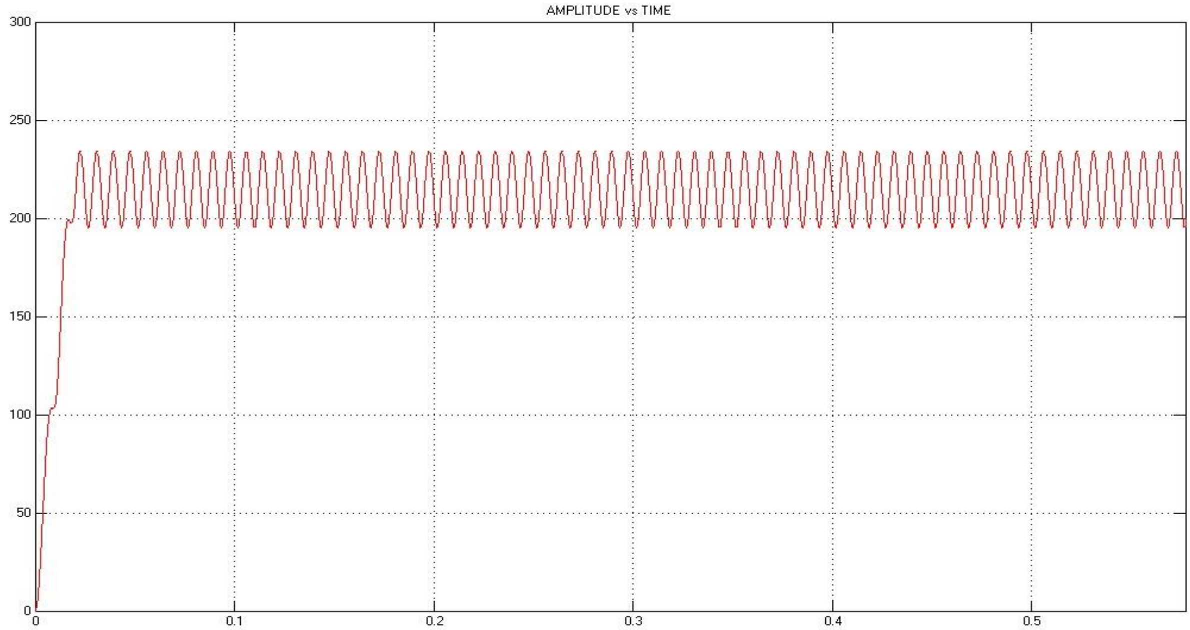

Figure 6: Basic Simulink model output voltage Waveform

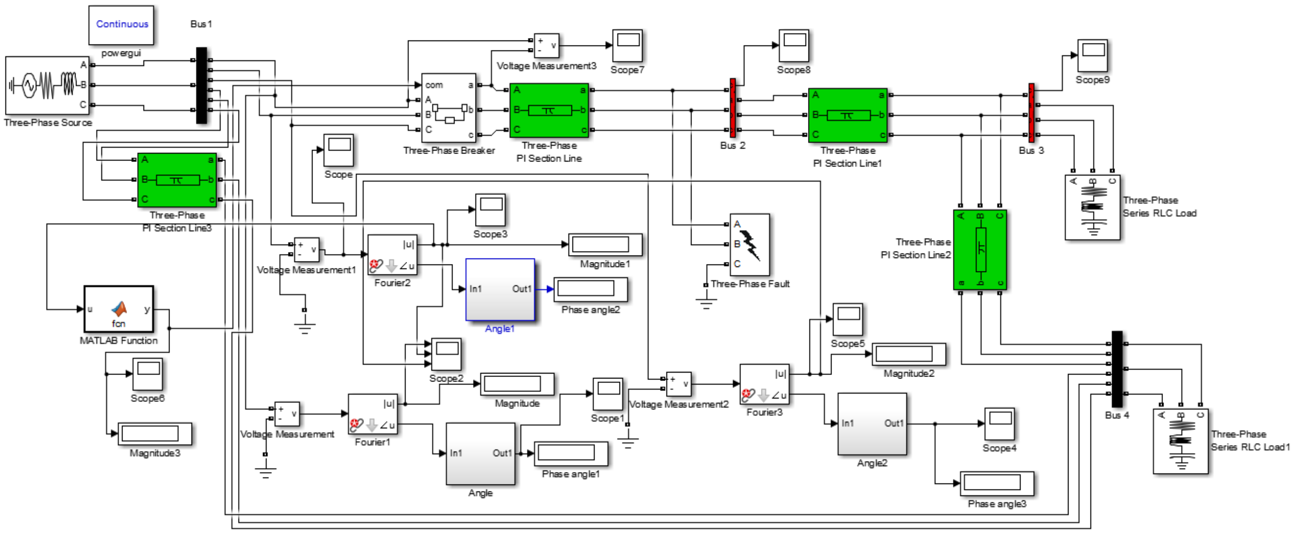

Figure 7: Single PMU on the test system

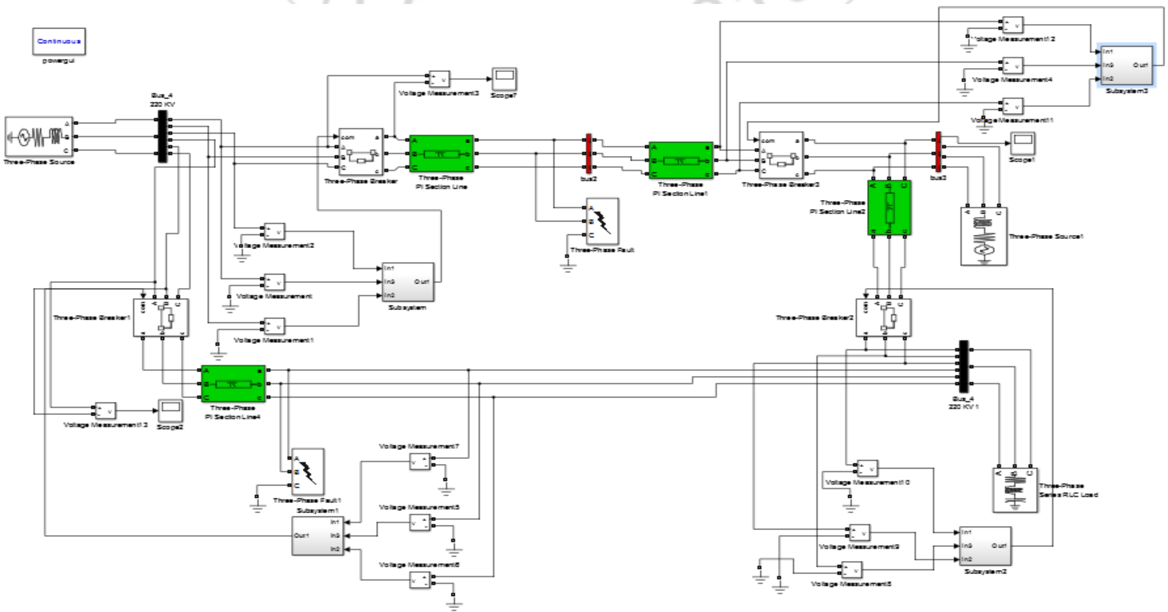

Figure 8: PMUon all buses of the test system

The following results were obtained to validate the considered system.

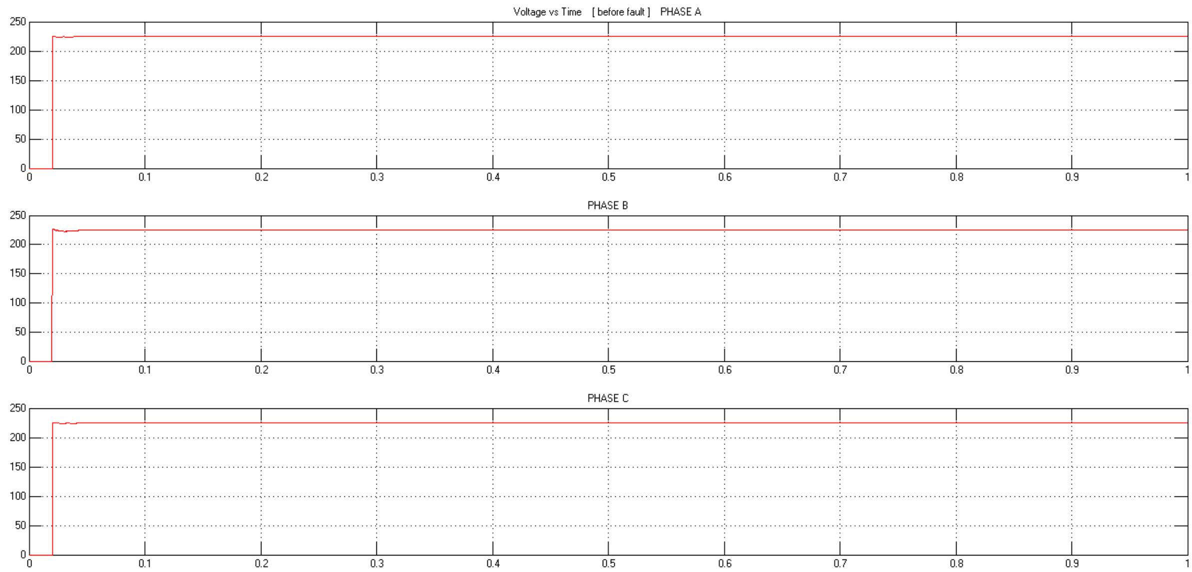

Figure 9: PMU Output Voltage at bus no:1before Fault

Now let us consider the complete test system. Here we have four different buses dispersed at different regions of the transmission network. Now all the buses are under the surveillance of PMUs, and we are applying a LLG fault on the transmission line between bus no: 1 and bus no: 4.During the without fault condition all the bus voltages are almost same. But during the faulted condition the voltage and phase angles at different buses will vary. The voltage waveforms of at different buses are obtained as shown below.

The final performance of the technique is identified by satisfying two criteria. The first criterion concerns the comparison of the voltage magnitudes at the bus and then selecting the minimum voltage value that indicates the faulted area. The voltage magnitude should go lower than setting value amounted by0.80 of the operating voltage. The second criterion is used to compare of the absolute difference of the angles and selecting the maximum one. A trip output is produced when the above two conditions are met. The final trip logic combines the decisions using the AND gate logic.

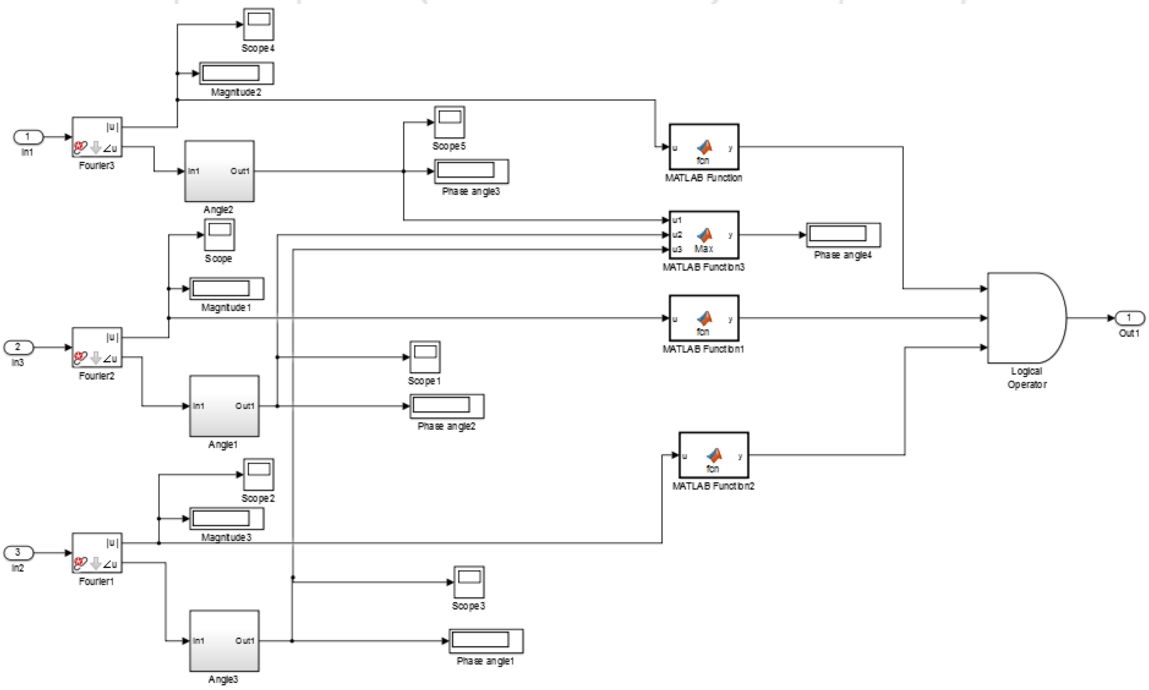

Figure 10: System Protection Center

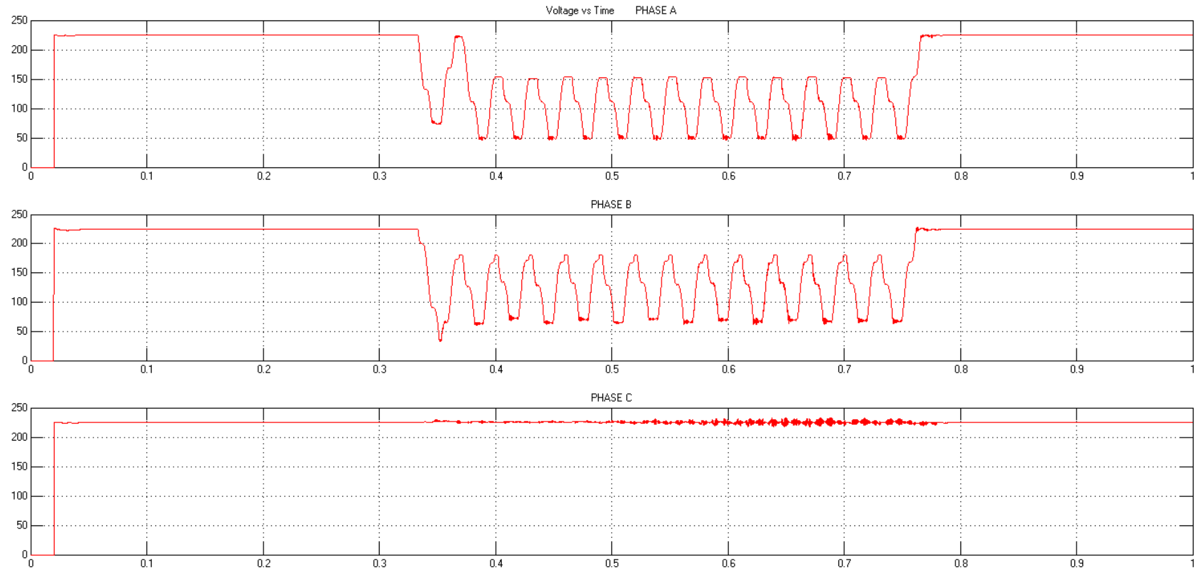

Figure 11: Voltage at bus no:1 during fault

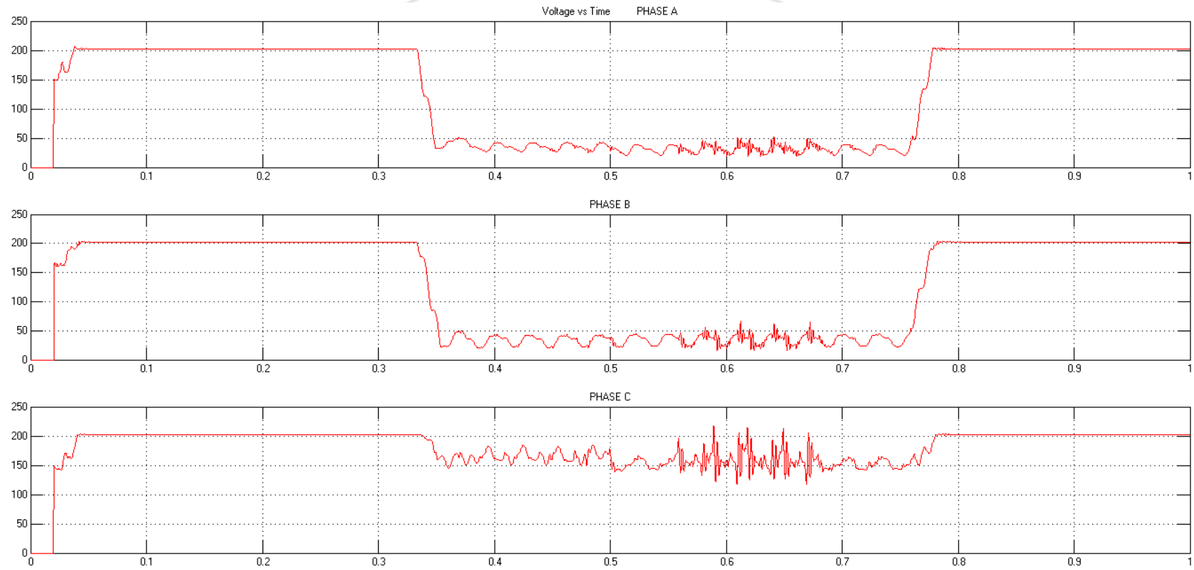

Figure 12: Voltage at bus no:2 during fault

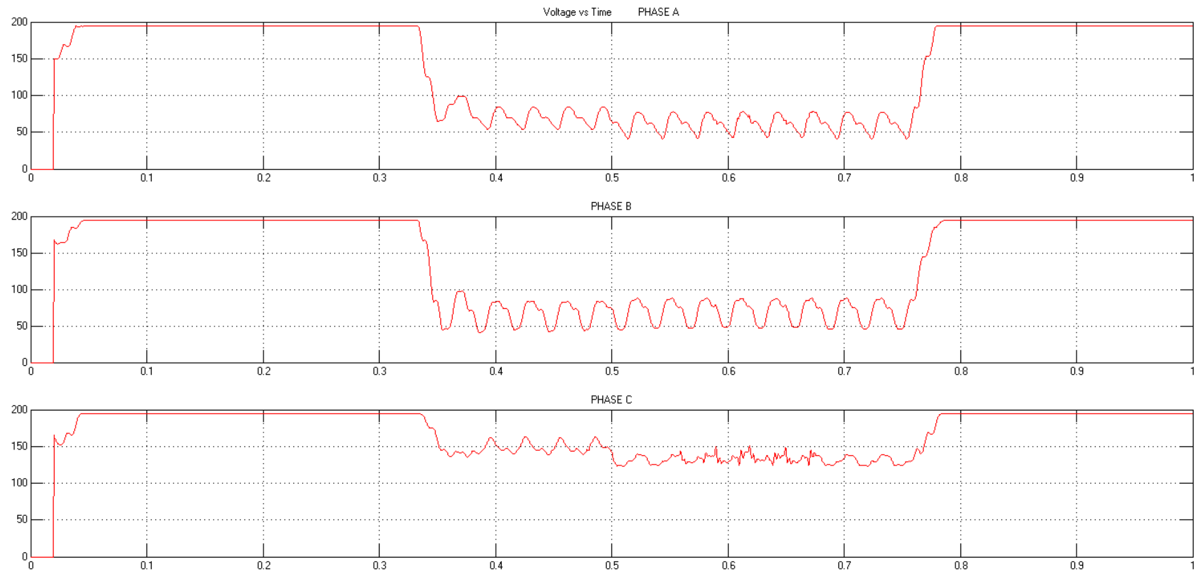

Figure 13: Voltage at bus no:3 during fault

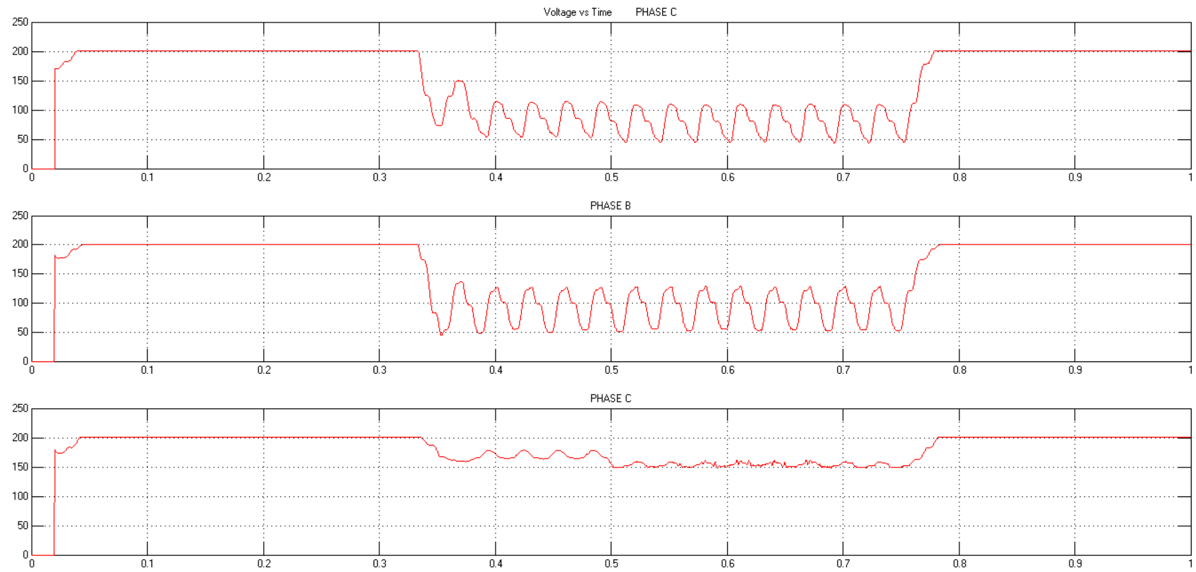

Figure 14: Voltage at bus no:4 during fault

Now the circuit breaker will remain opened during the fault interval and the voltage wave form is obtained as shown below.

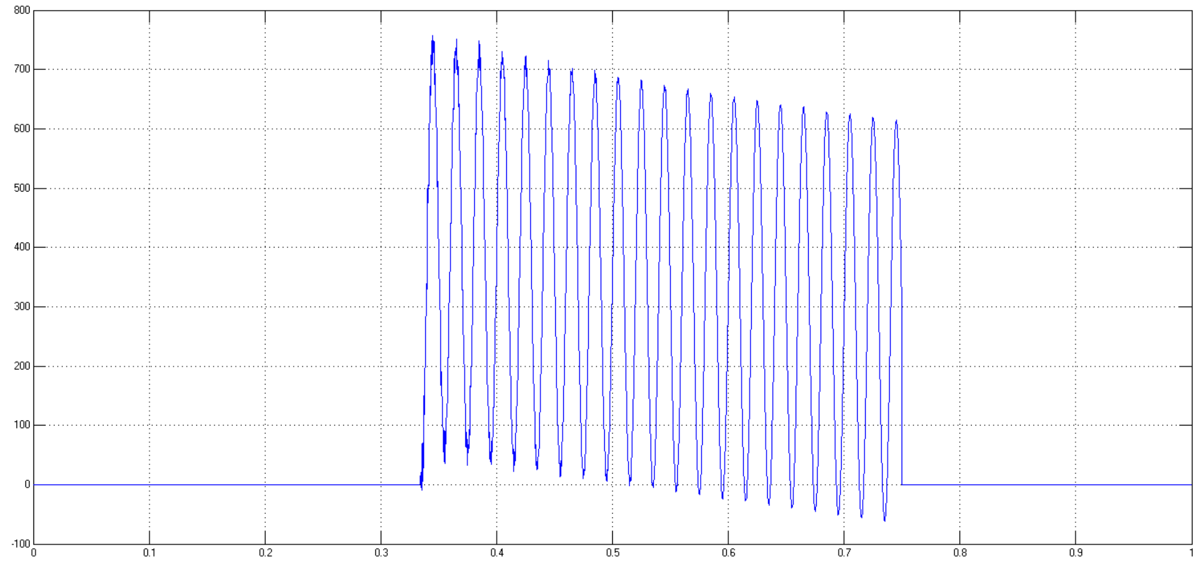

Figure 15: Voltage across the limb of the circuit breaker

BUS NO:1	BUS NO:2	BUS NO:3	BUS NO:4
94.9	10.31	126.8	115.5
145.1	130.3	113.2	124.5
25.1	109.7	6.83	4.482

Figure 16: Comparison of phase angle values at various buses during fault

The main idea of the proposed technique is to identify the faulted area. This can be achieved by comparing the measured values of the 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 angles are calculated for all lines connected with the faulted area. These angles are compared to each other. The maximum angle difference value is selected to identify the faulted line. From the above measurements we can observe that the phase angle differences between bus no 1 and bus no 4 is having largest value. Thus we can confirm that the fault is in the line connected between bus no 1 and 4.

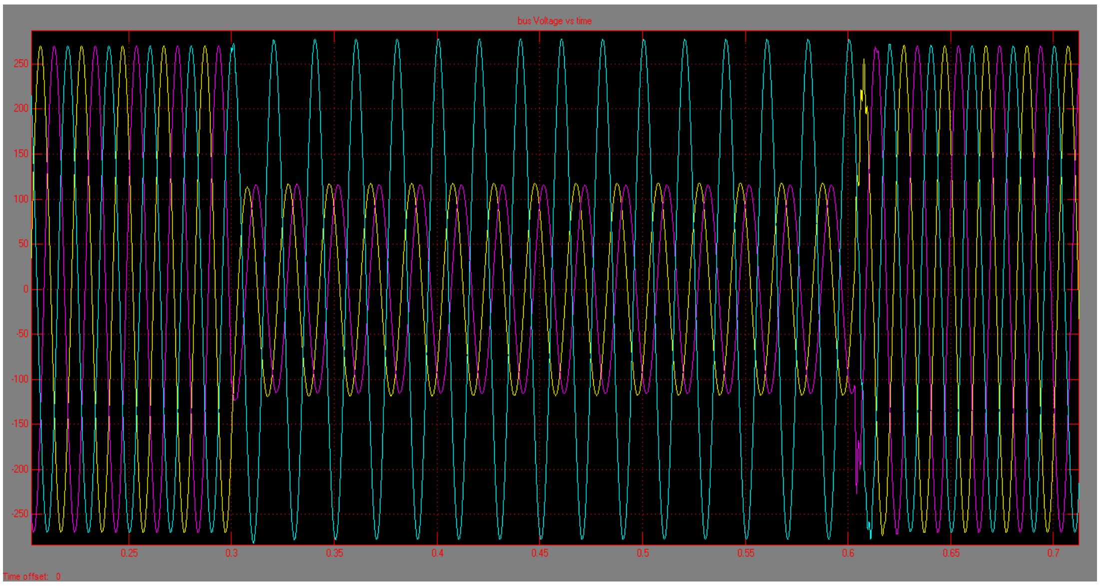

Figure 11: Three Phase Bus Voltage During Fault

4. Conclusion

The relevance of fault detection and classification using Phasor measurement units in a wide area system is studied. The idea has successfully identified the faulted line on a large power interconnected system. The idea described here 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 classified 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.

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