WIDE AREA BACK UP PROTECTION TECHNIQUE ON POWER SYSTEM USING PHASOR MEASUREMENT UNIT

1BHAGYASHRI BHARAT KHANDARE, 2B.T.DESHMUKH
1M.E.(PS), JAWAHARLAL NEHRU COLLEGE OF ENGINEERING, Aurangabad, Maharashtra, India.
2Assistant Professor, JAWAHARLAL NEHRU COLLEGE OF ENGINEERING, Aurangabad, Maharashtra, India.

ABSTRACT- This paper deals with PMU based wide area backup protection scheme for transmission lines is developed to identify the faulted line by PMUs. Current differential protection relays are widely applied to the protection of electrical plant due to their simplicity, sensitivity and stability for internal and external faults. To protect large power transmission grids the proposed method has the feature of unit protection relays based on phasor measurement units. After a fault arises in the transmission network, zero and positive sequence currents entering the faulted backup protection zone highly increase, and faulted backup protection zone can be determined. The new technique depends on synchronized phasor measuring technology with high speed communication system and time transfer GPS system. The goal of the protection scheme is to estimate a new wide area backup protection system to maintain the power system stable by isolating only faulty components from the healthy part of system. The new technique can successfully distinguish between internal and external faults for interconnected lines. The new protection scheme works as unit protection system for long transmission lines. The purpose is to boost the overall effectiveness and consistency of the power structure for all power stages via significant dependence on WAPS as distributed intelligence agents with improved monitoring, control and protection capabilities of power network.

Keywords- Phasor measurement unit(PMU), Wide area measurement system(WAM), Global positioning system(GPS).

1. INTRODUCTION

Nowadays, power systems become very tough and challenging to manage due to fast development to satisfy enormous boost in load demands which leads the power system arrangement to become more complex. So, Electrical networks with adequate power quality and high reliability are preferred. The principle of the protection scheme depends on comparing positive sequence voltage magnitudes at each bus during fault conditions inside a system protection center to detect the nearest bus to the fault and the absolute differences of positive sequence current angles for all lines. System-wide disturbances in power systems are a challenging problem for the utility industry because of the large scale and the complexity of the power system. The present control actions are not designed for a fast developing disturbance and may be too slow. Further, dynamic simulation software is applicable only for off-line analysis.

In this paper an optimization model is developed to minimize the number of PMUs required for this scheme. This overcomes the problems of data storage, Limitations and requirements of extensive communication facilities and infrastructures. The suggested technique can see all the power system area and can deal with the transmission lines as unit protection. 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.

The recent enlargement and increased complexity of power system configurations has led to adjacent arrangements of short and long distance power transmission lines, both connected to the same bus bar in a substation. 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. This causes difficult situations when relay engineers coordinate reach or operate time among distance relays. In this area, an adaptive Phasor Measurement Unit (PMU) based protection scheme for both transposed and un-transposed parallel transmission lines is given.

This paper proposes protection scheme 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 paper will cover all fault events. The technique uses the time synchronized phasor measurements. This provides a dynamic view of the power system. The measurements are processed in a system protection central (SPC). The development of the scheme is based on the distributed line model and the synchronized phasor measurements at both ends of lines. The proposed arcing fault discriminator can discriminate between arcing and permanent faults within four cycles after fault inception. This
capability is used to set up a wide area control, protection and optimizing the platform by means of new fast communication system and (GPS).

II. 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.

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. The distance relays are based on standalone decision, while each relay operates independently according to three different zone of operation, see Fig. 1.

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.

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. 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, in this paper a novel wide-area backup protection system is proposed.

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. 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 Fig. 2. 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.

III. PHASOR MEASUREMENT UNIT

Synchronised Phasor Measurement Units (PMUs) were first introduced in early 1980s, 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. The technology of synchronized phasor measurements is well established. It provides an ideal measurement system with which to protect, monitor and control a power system, in particular during conditions of stress.
PMU measures positive sequence currents and voltages with accurate and exact time synchronization. The measurements are done by using GPS single pulse per second Synchrophasors, provide the phasor demonstration of voltage or current to complete time reference. This absolute reference is given in the form of a common timing signal by using high-accuracy clocks synchronized to corresponding universal time such as the universally used global positioning system (GPS). The synchronized clocks are used as a reference, so PMU creates the complex number of a constant sinusoidal signal phasor representation as presented in Fig. 3.

![Phasor representation](image)

Fig. 3. Phasor representation.

The essential feature of the technique is to measure positive sequence (negative and zero sequence quantities if needed) voltages and currents of a power system in a real time with precise time synchronization. This 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. In the suggested technique, a positive sequence voltage and phase angle of the positive sequence current is used. The DFT technique is a short-time variation of the Fourier analysis. 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.

Fig. 4 shows the analog power signal that 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 figure also shows a simple block diagram explaining the procedure of measured voltage or current analog signal. 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.

![Synchronized phasor measurement block diagram](image)

Fig. 4. Synchronized phasor measurement block diagram.

The main purpose is to improve the interruption monitoring and system event analysis. Synchronous phasor measurements gives all revelatory state measurements that are phase angle, frequency and voltage magnitude. PMU is used to evaluate bus voltages and all revealing line currents next these measurements are given to PDC at control centre.

![PMUs arrangement with phasor data concentration and system protection center](image)

Fig. 5. The PMUs arrangement with phasor data concentration and system protection center.

Fig. 5 shows the electric system with the location of the PMUs. The phasor measuring unit is represented by a discrete phase sequence analyzer block which convert 3 phase signals (Vabc or Iabc) to a positive, negative and zero sequence component magnitudes and angle. Each phase signal (Va, Vb and Vc) is converted to real and imaginary component using Discrete Fourier Transform.

The positive sequence component is calculated in sequences analyzer by the following equation:

$$V_1 = \frac{1}{3} (V_a + \alpha V_b + \alpha^2 V_c)$$
where, $\alpha = j \angle 120^\circ$ the overall process to calculate positive, negative or zero sequence component using Matlab Simulink

**IV. COMMUNICATION ISSUES AND BACKUP RELAYS**

The application of the wide area in the protection is not straightforward from the communication point of view. In such cases, the communication issues related to time delay is discussed. This proposed scheme is designed such that no single failure in either the ac circuits, the relays or in the dc control and trip circuits (except station battery failure) can nullify all protection. In essence, the proposed local back-up system provides two separate back-up functions: it provides relay backup with an entirely separate group of relays from that used for front-line protection, and it provides breaker backup with the necessary time delay and auxiliary relay components.

**A. Communication Options**

Available 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.

**B. Communication Delay Causes**

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 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.

**C. Delay Calculations**

Delay calculations form an important aspect of WAMS; these delays indicate the viability of a particular communication medium, since large communication delays amount to slower controller actions that can correct power grid instabilities and oscillations. Communication delay given can be expressed as

$$\tau = \tau_p + \frac{L}{R} + \theta$$

where is the total link delay, is the fixed delay associated with transducers used, DFT processing, data concentration and multiplexing, is the link propagation delay, is the amount of data transmitted, is the data rate of the link. The selected five different areas with buses are given in Table I.

**TABLE I**

<table>
<thead>
<tr>
<th>Area</th>
<th>Zone</th>
<th>Main Bus</th>
<th>Voltage (kV)</th>
<th>Main Bus Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Upper Egypt</td>
<td>Samalout</td>
<td>500</td>
<td>Substation</td>
</tr>
<tr>
<td>2</td>
<td>Kurimat</td>
<td>Kurimat</td>
<td>500</td>
<td>Generation</td>
</tr>
<tr>
<td>3</td>
<td>Cairo West</td>
<td>Cairo500</td>
<td>500</td>
<td>Substation</td>
</tr>
<tr>
<td>4</td>
<td>Cairo South</td>
<td>Tebben 500</td>
<td>500</td>
<td>Substation</td>
</tr>
<tr>
<td>5</td>
<td>Cairo East</td>
<td>Abo Zahal</td>
<td>500</td>
<td>Substation</td>
</tr>
</tbody>
</table>

We have assumed that media like fiber-optic cables, power lines, and telephone lines, on an average, have a propagation delay of around 25 ms. Reliability in this application includes both error rate and component failures. Such protection scheme suggested here needs to a very high media of communication system, the available data transfer can reach speed up to 2 Mpbs.

**V THE TECHNIQUE COMPONENTS BASED ON WIDE AREA MEASUREMENT SYSTEM**

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. Most of these phasor measurement systems have been implemented as
real-time systems. With these systems, phasor measurement units (PMUs) installed at substations send data in real time over dedicated communications channels to a data concentrator at a utility control center.

PMUs measure the bus voltage(s) and all the significant line currents. These measurements are sent to a Phasor Data Concentrator (PDC) at the control center. The PDC correlates the data by time tag to create a system-wide measurement. The PDC exports these measurements as a data stream as soon as they have been received and correlated. System protection center (SPC) receive Data stream and make a wide area protection depending on wide area view. This principal of operation is used in this paper.

To accomplish this objective, an adequate back-up protective system must meet the following functional requirements:

1. It must recognize the existence of all faults which occur within its prescribed zone of protection.
2. It must detect the failure of the primary protection to clear any fault as planned.
3. In clearing the fault from the system, it must WAPS
   a. Initiate the tripping of the minimum number of circuit breakers.
   b. Operate fast enough (consistent with coordination requirements) to maintain System stability, prevents excessive equipment damage, and maintain a prescribed degree of service continuity.

WAPS depend on WAMs to take hieratical action depending on wide area monitor of the over all network.

VI. THE STUDIEDNET WORK

Synchronous phasor measurements gives all revelatory state measurements that are phase angle, frequency and voltage magnitude. PMU is used to evaluate bus voltages and all revealing line currents next these measurements are given to PDC at control centre. Fig. 6 shows the selected five areas from the overall network.

Table II defines each transmission line that connecting two neighboring areas. The lengths of the transmission lines are given in km. is defined as the absolute difference between positive sequence current angles measured at transmission line terminals.

![Table II](image)

| Line | Terminals | Length (km) | |Δ|Φ| |
|------|-----------|-------------|---|---|
| 1    | Samalout  | Karimat     | 145 | |12|21 |
| 2    | Samalout  | Cairo500    | 209 | |13|31 |
| 3    | Kurimat   | Cairo500    | 125 | |23|32 |
| 4    | Cairo500  | Basoos      | 22  | |35|53 |
| 5    | Kurimat   | Tebeen     | 160 | |24|42 |
| 6    | Tebeen500 | Abo Zabal   | 100 | |45|54 |

Fig. 6. Single line diagram of the studied network.

Fig. 7 shows the positive sequence current angles measured at transmission line terminals, from its area to the other connected area.

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. A sampling frequency of 20 kHz for a system operating at a frequency of 50 Hz is used in this paper.

VII. THE PROPOSED TECHNIQUE

To identify the faults on the transmission lines the proposed technique is based mainly on two components. Two components are very important to distinguish the faults on transmission line. One is the drop of voltage and other is due to fault occurrence the change in flow of power direction. The fault current way to be able to resolve by using phase angle through reference to a base quantity. 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. 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 $\pm \Phi$. When power lows in opposite direction, this angle become $(180 \pm \Phi)$. For the fault in reverse direction the phase angle of the current with respect to voltage will be $(180 - \Phi)$.

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 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.

When the fault take place on the network the output of positive sequence voltage magnitude becomes minimum. From this calculation the nearest faulted area can be determined. In this case this area is shown by “m”. 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:

$$\min \{ |V_1|, |V_2|, \ldots, |V_m|, \ldots, |V_n| \}$$  \hspace{1cm} (1)

where 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 (1) 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”.

Next there is need of comparing the accurate differences of current angles of positive sequence of interrelated lines associated with this area “m” which is faulted with the interrelated close to area and then by selecting maximum one. This can be explained as

$$\max \{ |\Delta \phi_{m1}|, |\Delta \phi_{m2}|, \ldots, |\Delta \phi_{mn}| \}$$  \hspace{1cm} (2)

where is the absolute difference of positive sequence current angle for a transmission line connecting area “m” with area “n”. This can be described by the following equation

$$|\Delta \phi_{nm}| = |\phi_{mn} - \phi_{nm}|$$  \hspace{1cm} (3)

The above process can be implemented logically in Fig. 7. The output of the logic action is the faulted line. The following sub-sections will explain the stages of the proposed technique.

**VIII. OVERALL STAGES OF THE PROPOSED TECHNIQUE**

The studied configuration system is classified into 5 different areas. Fig. 9 shows more details about the elements used in the protection technique.

**A. Data Preparation (Bay Level)**

Each area contains one PMU which receives analog signals from (CTs) and (VTs) in bay level.

- Voltage transformers (VTs) on the main bus for each area receive 3 phase voltage (Vabc) to the PMU.
- Current transformers (CTs) on each line terminal receive 3 phase current (Iabc) to the PMU.
- PMU converts the analog voltage and current signals to digital samples synchronized in time of measuring, the Discrete Fourier Transform method inside PMU calculates the positive sequence voltage and current phasors.

**B. Output From PMU**

The output signal from the PMU is the positive sequence voltage and the positive sequence currents & nm nm respectively, For the proposed technique, only positive sequence voltage magnitudes and positive sequence current angles nm are selected.

**C. Phasor Data Concentrator PDC**

The PDC is considered as a computer database that contains data from five phasor measurement units (PMUs). Each PMU sends measuring data through fast communication system to PDC which correlates the data by time tag to create a system wide measurement.

**D. System Protection Center SPC**

The PMUs are strategically placed throughout a wide coverage area. The PMUs form part of local devices called system protection terminals (SPT). SPTs are able to run complete or parts of distributed control algorithms and can communicate directly with other SPTs, substation.
equipment and system protection centers (SPC) which is responsible for protection, monitoring and control of the power grid.

**E. Data Manipulation in SPC**

SPC receives data stream from PDC and provides a wide area protection depending on wide area view. In the SPC unit, the measuring values of positive sequence voltage magnitudes are compared, the minimum voltage magnitude is selected, and the nearest area to the fault is detected.

**SIMULATION RESULTS**

In this way in paper, the projected technique is tested. The simulation is performed by using the MATLAB Simulink software for five bus test system.

- line 1 connecting area 2 with area 1;
- line 3 connecting area 2 with area 3;
- Line 5 connecting area 2 with area 4.

---

**Fig. 10. Three phase voltage signals at LG fault.**

**Fig. 11. Three phase current signals for all lines connected to the LG faulted area.**

**Fig. 12. Positive sequence voltage magnitudes at LL faulted area.**

**Fig. 13. Block diagram of simulation.**

**Fig. 14. Positive sequence current angle absolute differences for all lines connected to the LL faulted area.**

**Fig. 15. Positive sequence voltage magnitudes measured at LLG faulted area.**

**Fig. 16. Positive sequence current magnitudes at LLG faulted area.**

**Fig. 17. Positive sequence voltage magnitudes measured at LLLG faulted area.**
CONCLUSION

The paper represents a new backup protection method for security of power system of smart grids using synchronized PMU in a wide area system. It has successfully recognized faulted area and faulted line all over the system. Main goal is to detect different fault locations, the fault type on system and clearance of that fault. This paper discovers a new state-of-art of relay in the field of interconnected grid because-

1) The relay is based on sharing data from all areas.
2) Instead of many stand alone relays with different Complexity coordination one relay is used.
3) The relay has the feature of unit protection in identifying the faulted zone.

REFERENCES