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Transmission Line Fault Detection and Identification in an Interconnected Power Network

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Abstract: This paper proposes a novel hybrid technique to detect and identify transmission line faults in an Interconnected Network using the measurements from Phasor Measurement Units (PMUs). The proposed fault detection and identification technique is based on Positive Sequence voltage and current measurement from PMUs. The proposed algorithm for fault detection and identification is deployed in two stages: First stage is the detection of fault using Positive Sequence Voltage Magnitude (PSVM) and second stage is the fault-location identification through Positive Sequence Current Angle Differences (PSCADs). Sometimes, both of these condition might fail to detect and identify the fault, then another condition based on Positive Sequence Current Magnitude (PSCM) is employed. The proposed hybrid technique for fault detection and fault line identification is tested on a five area interconnected transmission network that employs PMUs at its buses/nodes. During fault, the sequence of PSVM near the faulty line changes or its value drops to minimum, thus detecting the fault. If the PSVM condition fails, then fault is detected by observing sequence and magnitudes of PSCM at all the buses. Fault identification is performed by comparing the PSCAD (Positive Sequence Current Angle Difference) of corresponding node with PSCADs of remaining nodes and maximum PSCAD identifies the faulty line. Simulations are carried out in MATLAB/SIMULINK and results are given for the five area power system. The results verify the proposed fault detection and identification algorithm.

Keywords: Phasor Measurement Units (PMUs), Positive Sequence Voltage Magnitude (PSVM), Positive Sequence Current Magnitude (PSCM), Positive Sequence Current Angle Difference (PSCAD).

1. INTRODUCTION

The largest part of power system is transmission network. For reliable transmission of electric power through transmission network, its protection is of prime importance for power engineers. For this reason, researchers have paid much attention to the protection schemes of transmission lines. The literature survey reveals that protection schemes for transmission lines can be divided into two broader classes, that is, 1) techniques involving Phasor measurement units (PMUs) and 2) techniques that do not involves PMUs. Due to advantages associated with PMUs, they are preferred over non-PMU based techniques. Non-PMU based techniques include: 1) Technique based on Superposition principle, which is based on Fourier transform and Laplace transform methods. It involves single end measured data which has less accuracy as compared to both end measured data. This approach has also assummed several assumptions regarding fault resistance and current ratios, moreover the accuracy of obtained results also depends on the underlines assumption (Takagi *et al.* 1981 & 1982); 2)Both end measured data technique, in which lump-model is used to represent the short line and made compensation for long lines. The described scheme is suitable only for offline post-fault analysis (Novosel *et al.* 1996); 3)The wavelet technique, proposed as detection of fault based on lifting wavelet but it detects only short circuited fault and other faults are not detected (Zhou *et al.* 2008); 4)Technique based on traveling wave, proposed to clear the faults very rapidly on transmission lines (Chaudhary *et al.* 1994, Lian 1994, Elangovan 1998). Although Fault location is independent of network configuration and devices installed in the network, but algorithm is somewhat frequency dependent, unless auxiliary cross-correlation function is utilized. Besides, it is a rigorous task to identify the local maximum of cross-correlation function for calculating fault location. It requires very high sampling rates and their implementations are more costly than implementations of impedance techniques (Hashim *et al.* 2009); 5) Distance protection techniques for parallel lines are proposed in recent years; they have been discussed in (Karishna *et al.* 2014, Eissa *et al.* 2010, Dash 2016, Chen *et al.* 2002).These techniques possess some errors inherently due to the assumptions taken in during the development process of the algorithms. All the aforementioned techniques reveal that they have no synchronized real-time measurements of different system parameters. The parameters like voltage and current etc. can not be compared over wide area due to lack of common time base. This problem is addressed using PMU based protection schemes which utilize GPS time-syncing in the Wide Area Measurement Systems (WAMS). PMUs are normally installed at remote sites to measure phasors then stamp these phasors with GPS based time and transmitit to Phasor Data Concentrators (PDCs). PDCs transfer the data to central station to monitor and control theparameters on remote sites (Phadke 2009)(Rauhala *et al.* 2011)(Karishna *et al.* 2014).

Considering the importance of PMUs, various techniques have been proposed in literature. These include; 1) An adaptive protection scheme, which includes the detec- tion, classification, and direction discrimination of faults. This method adopts the parameter estimation based on lumped model and differential equation algorithm used in distance protection. This method is only valid for short transmission lines because of neglecting the line charging current (Jiang *et al.* 2002); 2) An adaptive PMU based protection scheme is proposed (Chen *et al.* 2002, (a)Jiang *et al.* 2000, (b)Jiang *et al.* 2000), which has very high accuracy for detecting fault location, but valid only for balanced system. The algorithm is complex and different for both transposed and untransposed networks. The transmission line is based on distributed model and synchronized data from its both ends is utilized; 3) Synchronized sampling technique(Kezunovic *et al.* 1994), adopted a time domain model of transmission line for developing fault location/detection algorithm. The accuracy of the proposed algorithm is well within 1 percent error, but the data must be acquired at a sufficiently high sampling rate to provide adequate approximation of the derivatives; 4) Sequence based technique(Eissa *et al.* 2010, Dash 2016), in which protection scheme compares positive sequence voltage magnitudes at each bus and minimum voltage gives the nearest bus to the fault. Furthermore, finding the positive sequence current angle differences identifies the faulty line. This is a simulation based technique in which an interconnected transmission network is considered.

This research work proposes a novel sequence based technique for detection and identification of short circuit faults on transmission lines. The proposed framework makes use of the Positive Sequence based technique for fault detection. The fault detection process is carried out intwo-stages. In the first stage, the detection of fault using Positive Sequence Voltage Magnitude (PSVM) is carried out and the then identification is completed through Positive Sequence Current Angle Differences (PSCADs). Some faults in power system are not detectable using the first stage, then second condition is used which is based on Positive Sequence Current Magnitude (PSCM). By employing this algorithm, detection and identification of faulty lines is carried out in an interconnected transmission network. Voltage and currents are gathered using PMUs. PMUs are installed on buses/nodes; when the fault occurs, the bus nearest to faulty line will either change the sequence of PSVM or will have minimum magnitude of PSVM. Fault is identified by comparing the PSCAD of corresponding node with PSCADs of remaining nodes and maximum value PSCAD identifies the fault. If this technique fails, then fault identification is completed by either the change in sequence of PSCM or based on its maximum value. It is worth noticing that the proposed techniques is more reliable as compared to the sequence based techniques mentioned in wherein fault detection is carried out using only PSVM which fails at some points (Eissa *et al.* 2010, Dash 2016). The proposed framework can detect short circuit faults for both balanced and unbalanced systems.

The rest of the paper is organized as follows: In the section 2 methodology of fault detection is described. Section 3 give the results of simulation of network in Matlab/Simulink and section 4 concludes the research findings.

2. DEVELOPMENT OF METHOD

2.1 Principle of the technique

The proposed technique for fault detection and identification is a two-step process based on two conditions. In the first condition, first step is to detect the fault using PSVM and second step is to identify the fault by com-paring the PSCADs. The two-step process is elaborated as follows: 1) During fault, measured values of PSVM are compared at main bus for each area. The area for which the sequence of PSVMs changes is the nearest area to the fault. If sequence of PSVM remains constant but the value of PSVM changes, then minimum value of PSVM indicates the area nearest to fault. 2) In second step, Absolute values of PSCADs for all the areas with respect to faulty bus are calculated. These PSCADs are compared to each other. The maximum absolute PSCAD value identifies the faulted line. During fault, if the magnitude of PSVM remains same then detection using PSVM fails and second condition of PSCM is utilized to detect the fault. The second condition of PSCM to detect the fault is satisfied by comparing the measured values of PSCM at main bus for each area. The area for which the sequence of PSVCMs rapidly change, indicates the nearest area to the fault. If there is no change in sequence of PSCM but the magnitude of PSCM changes during fault, then maximum PSVM indicates the area nearest to fault. Fault is again identified by comparing the PSCADs.

This method of fault detection and identification is represented by flowcharts as represented in Fig. 1, Fig. 2 and Fig. 3.

2.2 Simulation Network Arrangement

Fig. 4 shows the electrical network of five interconnected areas with PMUs installed on buses. The PMU is represented by a discrete phase sequence analyzer block which converts 3 phase signals (Vabc or Iabc) to positive, negative and zero sequence component magnitudes and angles. Each phase signal (Va, Vb and Vc) is converted to real and imaginary component using Discrete Fourier Transform (DFT). In this research work, positive sequence component(voltage or current) is measured using sequence analyzer in MATLAB/Simulink. In Simulink model, no filter and no analog-to-digital conversion is performed.

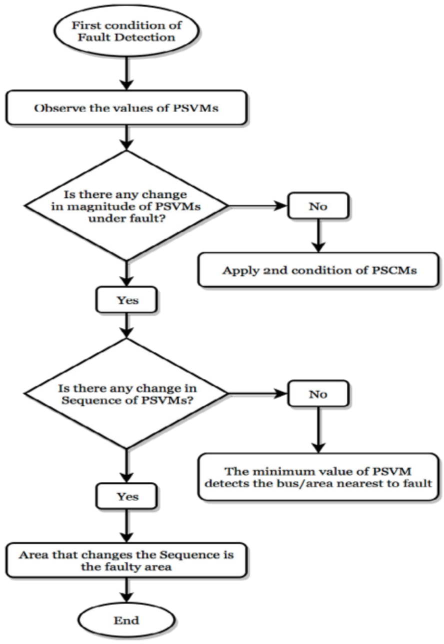

Fig. 1. Fault Detection - First Condition Flowchart

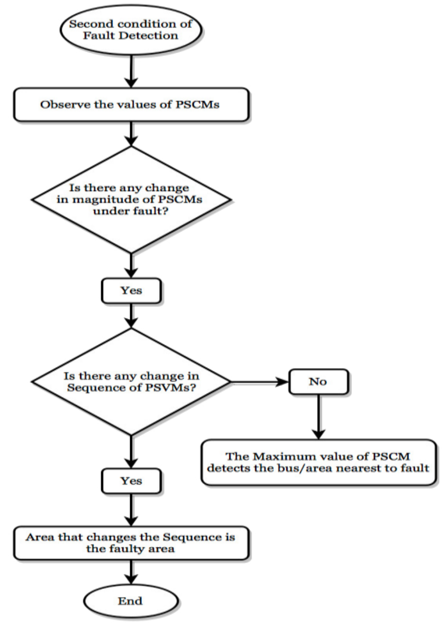

Fig. 2. Fault Detection - Second Condition Flowchart

Only sequence analyzer block is used which processes the analog signals to compute the required sequence values (PSVM, PSCM and PCADs).

Table 1. Five Areas, Data Table

Generator/ Load	Data
Generator 1	100MVA,220KV, 50 Hz Synchronous Generator
Generator 2	2000MW,-inf to +inf Var,220KV, 50 Hz Synchronous Generator
Generator 3	100MVA,220KV, 50 Hz Synchronous Generator
Load 1	220kv, 50MW, 24Mvar, RL load
Load 2	220kv, 80MW, 34Mvar, RL load
Load 3	220kv, 100MW, 48Mvar, RL load
Load 4	220kv, 120MW, 58Mvar, RL load

Table 2. Five Areas, Connection Table

Areas	Data
Area 1	Generator 1 and Load 1
Area 2	Generator 2
Area 3	Generator 3 and Load 2
Area 4	Load 3
Area 5	Load 4

The Five Areas Interconnected network in Fig. 4 is simulated in Matlab/Simulink. The details for areas, loads and generators are represented in the table 1 & table 2. The transmission lines used in simulation network are 3 Phase Distributed Parameter Lines with RLC parameters specified by 3x3 matrices.

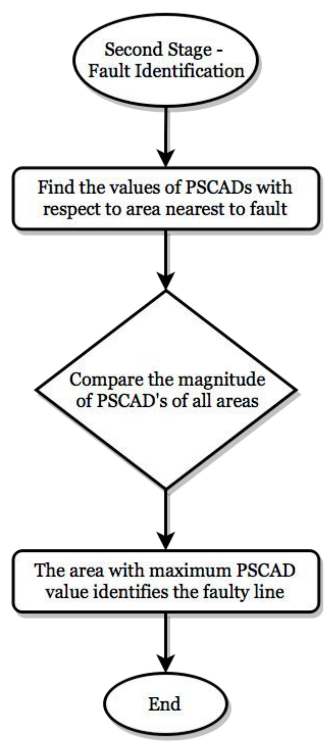

Fig. 3. Fault Identification Flowchart

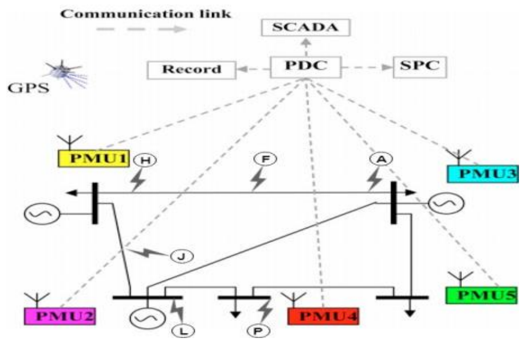

Fig. 4. 5-Area System diagram with PMUs arrangement, system protection center and fault locations (M.M Eissa *et al.* 2010)

The algorithm is tested by following short circuit faults:

- Phase A to Ground (AG) fault.
- Phase B to Ground (BG) fault.
- Phase C to Ground (CG) fault.
- Phases A & B to Ground (ABG) fault.
- Phases A & C to Ground (ACG) fault.
- Phases B & C to Ground (BCG) fault.
- Phase A to B (AB) fault.
- Phase A to C (AC) fault.
- Phase B to C (BC) fault.
- Phases A, B & C (ABC) fault.
- Phases A, B, C & Ground (ABCG) fault.

There are five fault locations as shown in Fig. 4. Fault A,H,L and P occur on nodes near generators while fault F and J occur on midpoint of transmission line from Area-1 to Area-3 and Area-2 to Area-3 respectively. Simulation results have been shown for these faults in next section.

3. SIMULATION RESULTS FOR THE FAULTS AT DIFFERENT POINTS

All faults are applied between 0.2 to 0.4 sec in Mat-lab/Simulink and simulation runs for total of 0.5 sec.

3.1 Results for the Faults at Point A

- **Three Phase (ABC) Fault:**

In the Fig. 5, the PSVM of area 3 changes the sequence of PSVMs, so this indicates its proximity to the fault location and PSCADs of area-3 with other connected areas indicate that its magnitude is maximum for area-3 and area-1 in Fig. 6. So, the first condition is satisfied for this fault and there is no need to check the second condition.

The algorithm produce nearly same results for remaining faults at Points B, C, D and E because all are connected through ideal lines and for Matlab/Simulink these all are at the same point.

3.2 Results for the Faults at Point F

- **Phase A to Ground (AG) Fault:**

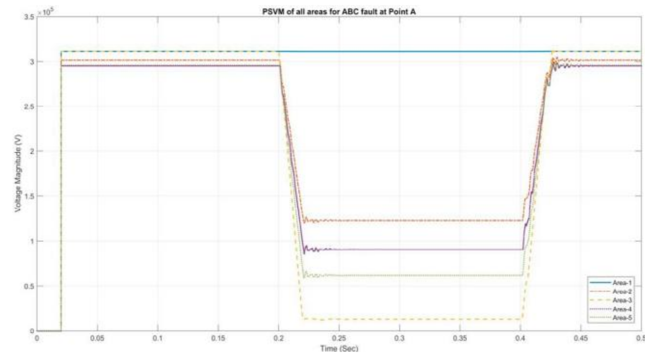

Fig. 5. PSVM for ABC Fault at Point-A

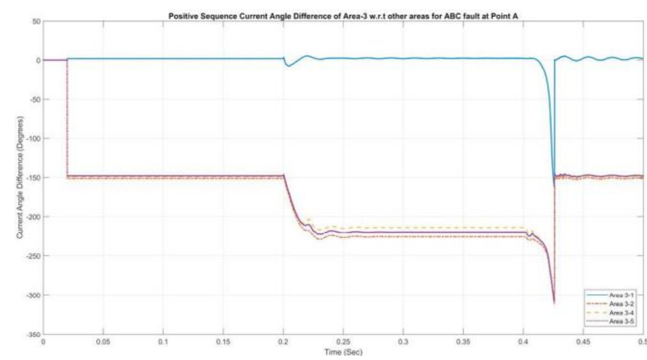

Fig. 6. PSCAD for Area-3 w.r.t other areas for ABC faultat Point-A

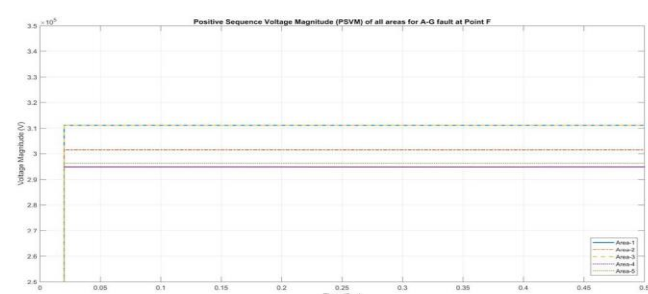

Fig. 7. PSVM of all areas for A-G Fault at Point-F

It can be observed in Fig. 7, that magnitude of PSVM before and during fault is same. So, the first condition fails to detect the fault and the second condition is used in this case. In Fig. 8, it can be seen that no change occurs in magnitude of PSCM for any area and its value is maximum for area 3 which indicates that area-3 is nearest to fault point.

Comparison of PSCADs of area 3 with other areas in Fig.9 show that transmission line between area 3 and area 1is under fault.

Similar results are obtained for remaining faults.

3.3 Results for the Faults at Point H

- **Phase A to Ground (AG) Fault:**

Detection of fault through PSVM is not possible as shown in Fig. 10 so we use PSCM in Fig. 11 to detect the fault.

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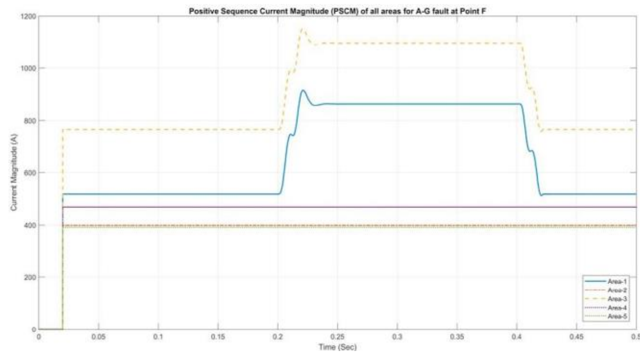


Fig. 8. PSCM of all areas for A-G Fault at Point-F

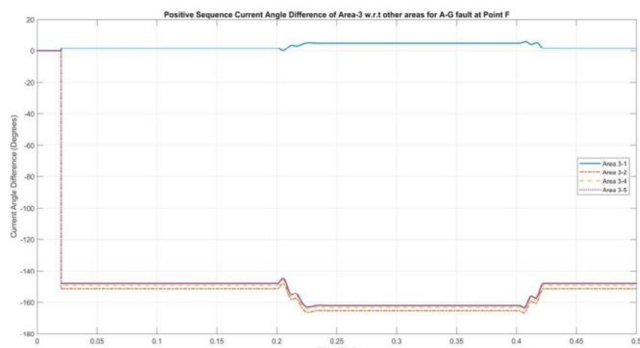


Fig. 9. PSCAD of Area-3 w.r.t other areas for A-G Faultat Point-F

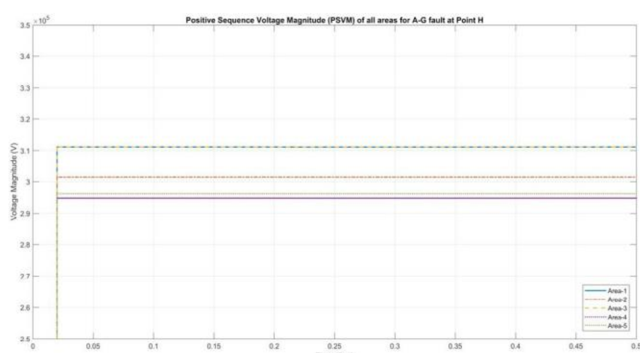
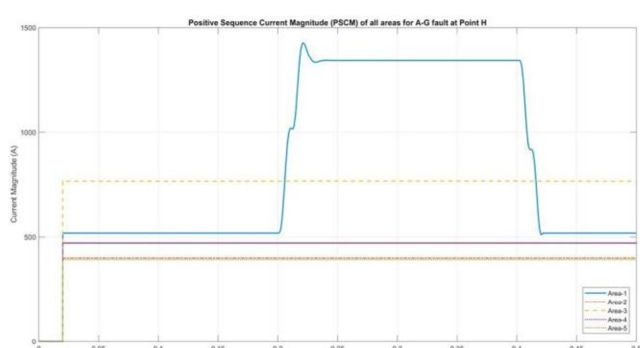


Fig. 10. PSVM of all areas for A-G Fault at Point-H



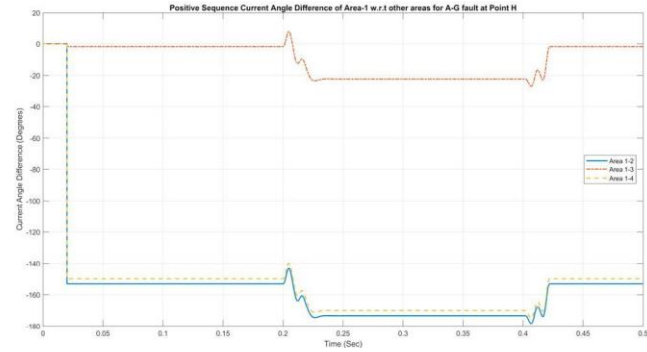


Fig. 11. PSCM of all areas for A-G Fault at Point-H

Fig. 12. PSCAD of Area-1 w.r.t other areas for A-G Fault at Point-H

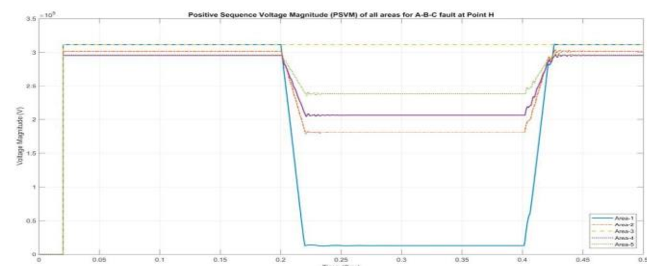


Fig. 13. PSVM of all areas for ABC Fault at Point-H

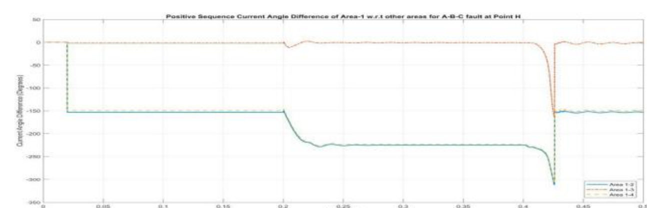


Fig. 14. PSCAD of Area-1 w.r.t other areas for ABC Fault at Point-H

This indicates that only PSCM of area 1 changes the sequence of PSCM under fault so it is nearest to fault and PSCAD is maximum for transmission line between area 1 and 3 as shown in Fig. 12; so fault exists between these areas.

Same is the result for AC and BC faults.

- **Three Phase (ABC) Fault:**

It can be seen that it is area 1 which changes the sequence of PSVM as shown in Fig. 13 and maximum PSCAD is for area 1 and 3, which is the faulty line as given in Fig. 14.

Same are results for remaining faults. Similar results are obtained for the faults at Point G and Point I for the aforementioned condition.

3.4 Results for the Faults at Point J

- **Phase A and Phase B to Ground (ABG) Fault:**

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Fig. 15. PSVM of all areas for A-B-G Fault at Point-J

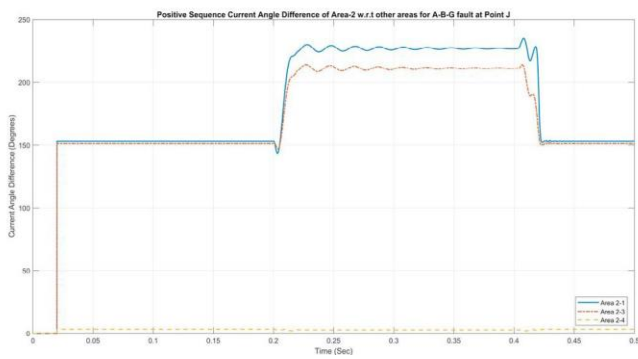

Fig. 16. PSCAD of Area-2 w.r.t other areas for A-B-GFault at Point-J

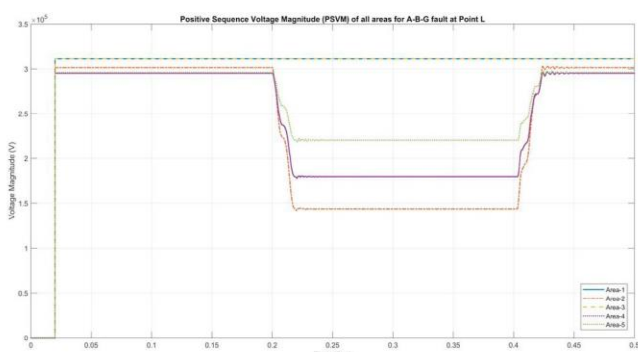

Fig. 17. PSVM of all areas for A-B-G Fault at Point-L

It can be seen that it is area 2 which changes the sequence of PSVM as shown in Fig. 15 so it is nearest to fault.

Maximum PSCADs of area 2 with other areas show that the fault lies between area 1 and 2 as given in Fig. 16. Similar results are obtained for the remaining faults.

3.5 Results for the Faults at Point L

- **Phase A and Phase B to Ground (ABG) Fault:**

In this case it is area 2 which changes the sequence of PSVMs because before fault occurrence it is above area 4 and area 5 but under fault it goes below both areas 4 and 5, so it changes the sequence as shown in Fig. 17. PSCADs of area 2 with others indicates that fault is either between areas 2 & 1 or area 2 & 3 is as both give the same values as shown in Fig. 18.

Again it can be observed that the PSCADs of areas 2 & 1 and areas 2 & 3 are approximately same so it shows that fault may be either between the areas 2 & 1 or areas 2 & 3. But the more accurate result is for areas 2 & 3. Similar results can be obtained for remaining faults.

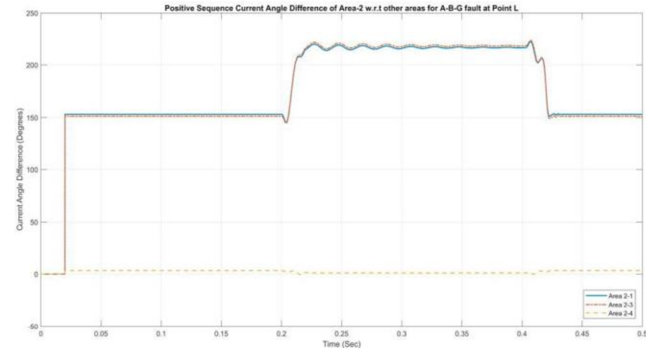

Fig. 18. PSCAD of Area-2 w.r.t other areas for A-B-G Fault at Point-L

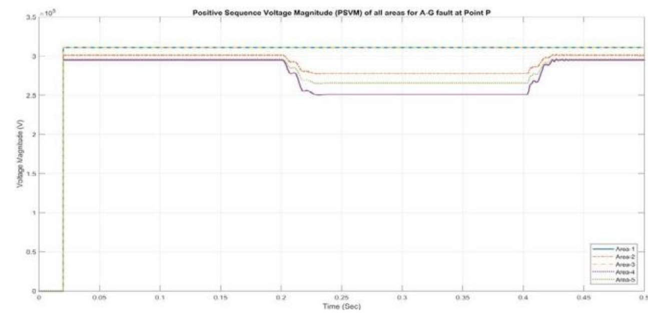

Fig. 19. PSVM of all areas for A-G Fault at Point-P

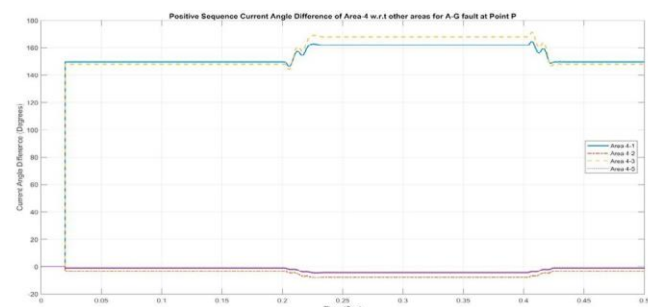

Fig. 20. PSCAD of Area-4 w.r.t other areas for A-G Faultat Point-P

3.6 Results for the Faults at Point P

- **Phase A to Ground (AG) Fault:**

It can be observed that no area changes the sequence of PSVMs under fault so we will take the minimum value of area 4 as point nearest to fault shown in Fig. 19, which is last condition of first step detection method. PCADs show that faulty line is between areas 4 to 3 as shown in Fig. 20.

Same is the result for the remaining faults.

Faults at points R, S, T, U and V are detected using PSVM.

3.7 Comparing Positive Sequence Voltage magnitude (PSVM)and Positive Sequence Current Magnitude (PSCM)

- **Phase A to Ground (AG) Fault at Point F:**

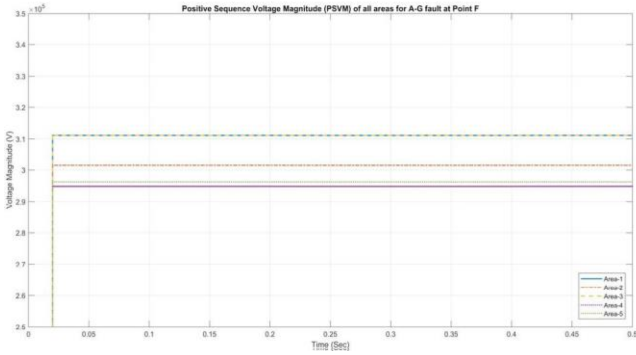

Fig. 21. PSVM of all areas for A-G Fault at Point-F

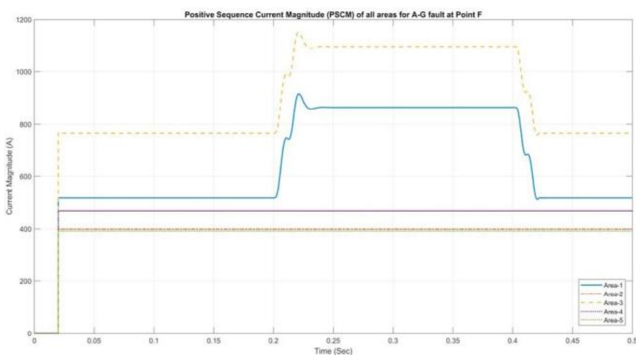

Fig. 22. PSCM of all areas for A-G Fault at Point-F

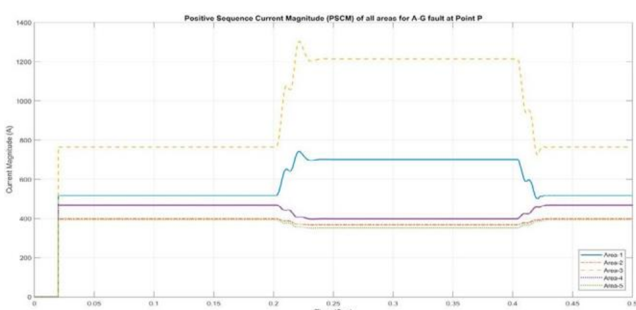

Fig. 23. PSCM of all areas for A-G Fault at Point-P

In Fig. 21 it is impossible to differentiate using PSVM that which TL is under fault because no voltage varies under fault. Using PSCM in Fig. 22 we can tell nearest point to fault is area 1.

So detection through PSVM is not possible at Point F.

- **Phase A to Ground (AG) Fault at Point P:**

Using PSCM in Fig. 23 it shows that area 3 is nearest to fault because of its maximum value as no other current changes the value under fault but actually area 3 is not nearest point to fault so it gives wrong result. But through PSVM in Fig. 24 it is possible to identify that nearest area to fault is area 4, which is correct.

Although no change of sequences of PSVMs occur under fault but minimum value of PSVM indicates the areas nearest to fault. So, it is not possible to distinguish the fault based on only PSVM or PSCM that is why both PSVM and PSCM are used for fault detection.

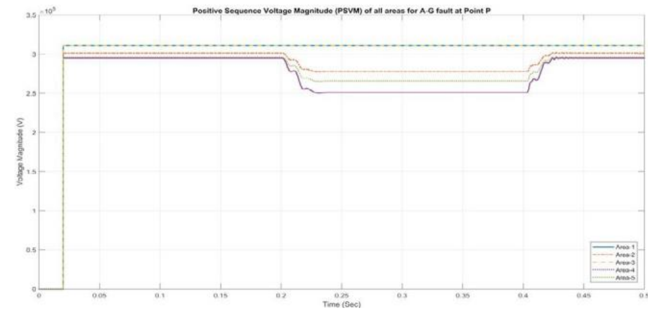

Fig. 24. PSVM of all areas for A-G Fault at Point-P

3.8 Reason for detection through PSVM and PSCM

- **Comparison at Point A for ABC fault:**

It is observed in Fig. 25 that voltage values of three phases are changed under fault from 0.2sec to 0.4sec and after applying sequence formula we can find the PSVM as shown in Fig. 5, so detection through PSVM is possible.

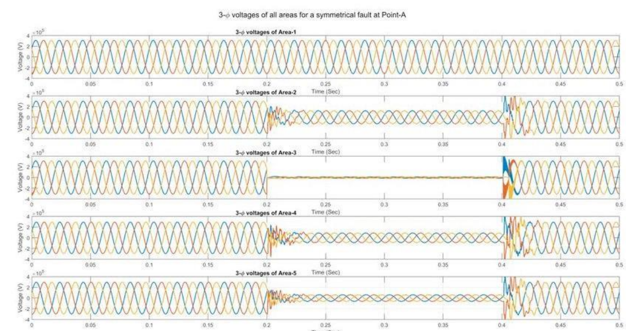

Fig. 25. 3-phase voltage wave-forms of all areas for sym-metrical (ABC) fault at Point-A

- **Comparison at Point F for ABC fault:**

It is observed in Fig. 26 that voltage values of three phases are not changed under fault from 0.2sec to 0.4sec but current values in Fig. 27 are changed and after applying sequence formula we can find the PSCM as shown in Fig. 27, so detection through PSCM is possible.

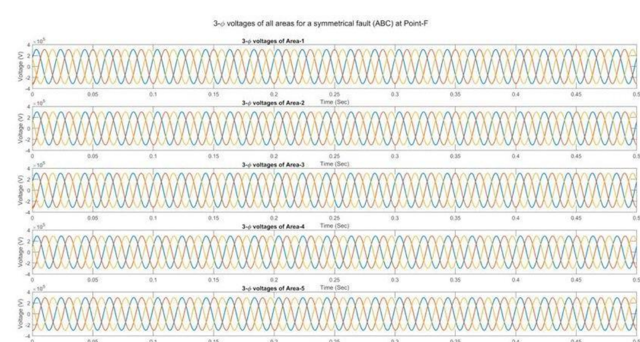

Fig. 26. 3-phase voltages of all areas for symmetrical (ABC) fault at Point-F

4. CONCLUSION

In this work, a novel sequence based technique for trans-mission line fault detection and identification has been

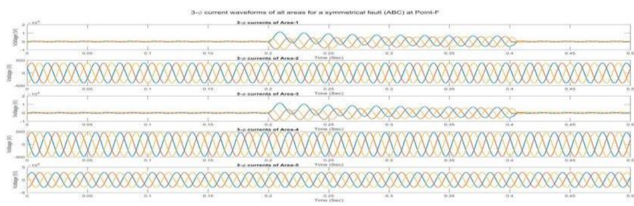

Fig. 27. 3-phase current wave-forms of all areas for symmetrical (ABC) fault at Point-F

proposed. The proposed framework is developed based on the use of the Positive Sequence based technique. The process of fault detection and identification is carried out in two-stages: 1)the detection of fault using Positive Sequence Voltage Magnitude (PSVM) and identification is completed through Positive Sequence Current Angle Differences (PSCADs). It is shown that in some cases detection and identification is unsuccessful then second stage is used which is based on Positive Sequence Current Magnitude (PSCM). The proposed method can only detect short circuit fault and it can not be used for open circuit faults without further modification. The proposed technique has been implemented on a 5-bus interconnected power network. By employing the algorithm, detection and identification of faulty lines is carried out for 11 type of faults at 6 different points in the network. Data for voltage and currents have been gathered using PMUs. Simulation results showed the effectiveness of the proposed framework and all types of faults have been detected for all faulty lines in the network.

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