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Fault detection in an interconnected power system using optimal number of phasor measurement unit

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ABSTRACT

Fault identification in a power system is crucial. In recent days, there have been multiple microgrids connected to the power system. And if many buses are connected, then there is a need for an increase in the phasor measurement unit. By using an optimization technique, the number of phasor measurement unit PMUs can be reduced by placing them optimally. In this paper, the fault detection algorithm is implemented using a reduced number of PMUs with the help of the particle swarm optimization (PSO) algorithm. The optimal locations of PMUs are identified using the PSO algorithm. Here, the reduction in the count of PMUs and the PMUs are designed in MATLAB as a model. This is done using the Simulink and dashboard block sets. The IEEE 9 and IEEE 30 test systems are used here for the analysis and tests. The IEEE 9 bus system is constructed in simulation and then the PMU is constructed using the data taken from the phasor measurement blocks. This data is used in the dashboard block set to represent the PMU-based fault detection system.

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1. INTRODUCTION

The broad adoption of new high-voltage transmission in today's power networks has demanded the development of a reliable wide-area protection system (WAPS). Because transmission lines cover such a broad region, the odds of a fault happening in them are likewise very significant, jeopardizing system reliability [1]. WAPS are used in modern power grid networks to monitor and detect anomalies across broad portions of the system, ensuring the system's dependable operation. As a result, transmission line fault analysis is an important aspect of power system functioning. In this way, this paper gives a strong method for finding, classifying, and locating transmission line faults based on the study of the symmetrical parts of voltage and current phasors.

The fundamental shortcoming of much of the earlier work [2]–[5] in fault analysis in power systems is the substantial reliance on network configuration. As mentioned in [6], [7], the wavelet transform is used in conjunction with soft computing approaches for fault analysis. These strategies, however, are extremely dependent on system parameters and cannot be used when the topology of the system changes. Soft computing approaches like neural networks and fuzzy logic [8], [9] have sparked a lot of interest in power system failure analysis because of their capacity to learn and recognize fault events. Neural networks have been used to improve real-time transmission line protection in many areas of power system operation [10]–

[13]. However, they depend on system parameters, and it is hard to train a neural network to recognize faults in large, interconnected power systems.

The introduction of phasor measurement units (PMUs) has transformed power system measurement and control studies are presented in [14]–[25]. Tshenyego *et al*. [14] have described a wide range of strategies for incorporating PMUs into power system protection. Phadke *et al*. [15] proposed a fault detection approach based on voltage and current phasor sequence components, but their work is limited to a two-bus system and does not include fault classification or localization algorithms. However, such strategies may be slow, and the suggested algorithm's correctness and durability in practical line models have not been verified. Other recent studies [25] have focused on the best location of PMUs in electric grids in order to reduce investment costs and measurement uncertainty. He *et al*. [23] performed adaptive fault analysis by partitioning the system into backup protection zones and then detecting the presence of a fault using the values of the zero and positive sequence current components. However, the study does not show that line faults can be distinguished from other transient events. But the study does not show that it is possible to tell line faults apart from other temporary events.

Rajaraman *et al*. [25] used data from a PMU device positioned on only one bus in the transmission system to achieve accurate fault analysis. This method is cost-effective and mitigates the effects of measurement errors. The fault analysis technique is implemented after the voltage and current phasors on all buses in the system are computed using data from a single PMU device.

There are no articles available with fault detection using a lower number of PMUs. In this paper, the IEEE 9 bus system is used for the implementation of a proposed fault detection algorithm using the reduced number of PMUs calculated from the particle swarm optimization (PSO) algorithm. The PMU location depends totally on the observability. Here the equations are given for the objective function where the cost of the PMU and whether the PMU is placed or not is decided by the decision variable. The formulation is given (1)-(4).

$$min \sum_{j=1}^{n} W_j Y_j \tag{1}$$

$$constrained\ to\ CY \geq D \tag{2}$$

$$Y = [Y_1, Y_2 \dots Y_n]^T \tag{3}$$

$$Y_j \epsilon [0,1] \tag{4}$$

Here,
W_j-weight value or cost value of PMU
Y_j-PMU placed or not decision variable
n-total number of bus
j-bus location

$$Y_j = \begin{cases} 1, & if\ PMU\ is\ placed\ at\ bus\ j \\ 0, & otherwise \end{cases} \tag{5}$$

The entries in C are defined as (6):

$$C_{i,j} = \begin{cases} 1, if\ 1 = j \\ 1, if\ i\ and\ j\ are\ connected \\ 0\ otherwise \end{cases} \tag{6}$$

And D is a vector whose entries are all ones as shown in (7):

$$D = [1\ 1 \dots 1]^T \tag{7}$$

Here, the objective function is taken as the minimization of the cost of the PMU. The particles are the binary number of the PMU placed or not. If it is placed, it will be one, and if not, it will be zero. The velocity function is modified with a weight function to make the iteration faster in convergence. The algorithm is as follows:

– Step 1: The PMUs are initialized with random function, which uses the uniform distribution
– Step 2: Calculate the fitness value from the (1) and evaluate the constraints from (2), by using the (3)-(7)

- Step 3: Take all the values of fitness for each particle as its own personal best. In that personal best check, which one is best in entire particles. Name it as global best
- Step 4: calculate the velocity using the given (8)
- Step 5: this velocity is added with the previous particle position to get near the solutions. It uses the (9)
- Step 6: now increment the iteration and proceed from step 2 till the end of the final iteration reached.

$$V_{k+1}=aV_k+b_1r_1\left(p_1\text{-}x_k\right)+b_2r_2\left(p_2\text{-}x_k\right) \tag{8}$$

$$x_{k+1}=cx_k+dv_{k+1} \tag{9}$$

Here Vk+1 is the current value of velocity, a is the weight factor, b1 and b2 are the learning factor which can be selected as 1 or 2 any random value. Then the r1 and r2 values are random values which is taken between 0 to 1. Here xk is the binary number taken in Y in (4).

2. METHOD

The current transformers (CT) and potential transformers (PT) are used to measure the three-phase current and voltage, respectively. Figure 1 shows conventional fault detection System single line diagram The connection to CT is on the line and the PT is one of the buses. The analogue values of currents and voltages are converted to phasors. This data is sent to the phasor data concentrator (PDC). The negative sequence component will be added if there is an asymmetric fault. In symmetrical faults, these sequence components are absent. In symmetric fault conditions, the positive sequence current phasor magnitude becomes higher. Both the faults are possible to detect. The PMU is not installed in all the buses here. So, the data is taken from the optimal PMU placement location. Then it is compared with the threshold value. If any one of the conditions is true, then the fault is confirmed. According to Rajaraman *et al.* [25], the value for is 1.5 pu.

Figure 1 show the conventional fault detection system used in [25]. Figure 2 shows the single line diagram of the proposed system. Figure 3 shows the IEEE 30 bus system. This is after placement of PMUs optimally using the PSO algorithm. So, it can be seen that after optimally placing the PMUs, the total number of PMUs is reduced from 9 to 3. So, there may be a significant cost reduction in implementing the fault detection algorithm. Figure 4 represents the proposed block diagram of fault detection system. Figure 5 shows the fault detection algorithm. The first stage is to check the negative sequence values. The Figure 4 shows the Fault detection algorithm implementation block diagram using PMU. Figure 5 shows the working algorithm of proposed fault detection using only 3 PMUs.

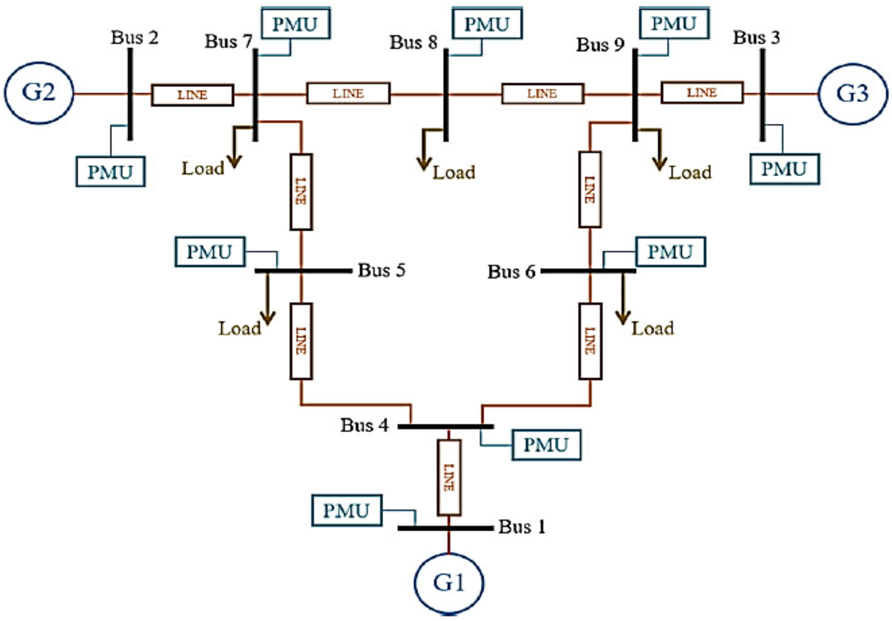


Figure 1. Conventional fault detection system single line diagram

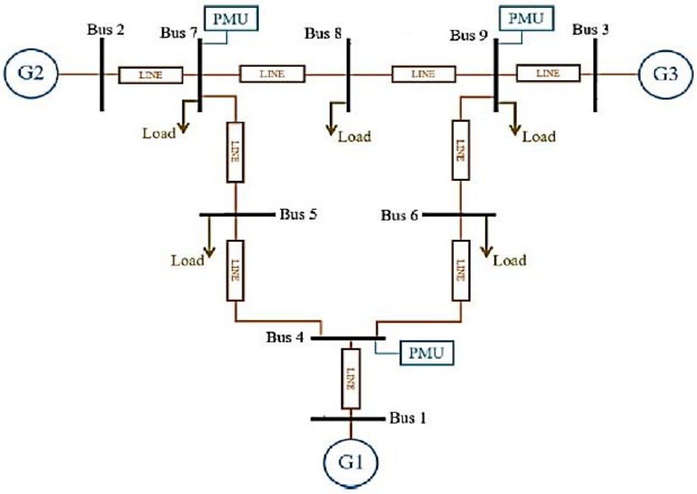


Figure 2. Proposed fault detection system IEEE 9 single line diagram

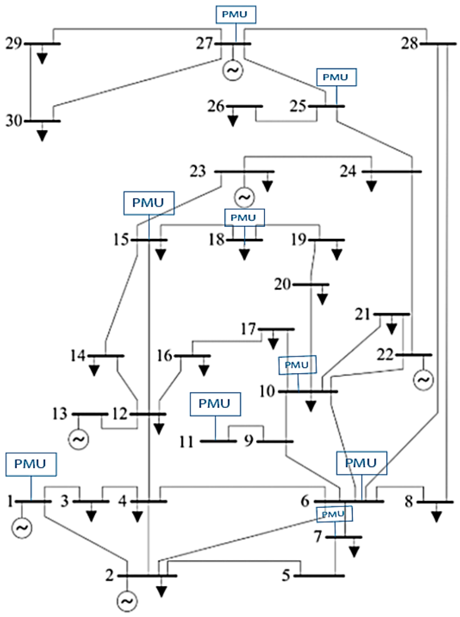


Figure 3. Proposed fault detection system IEEE 30 single line diagram

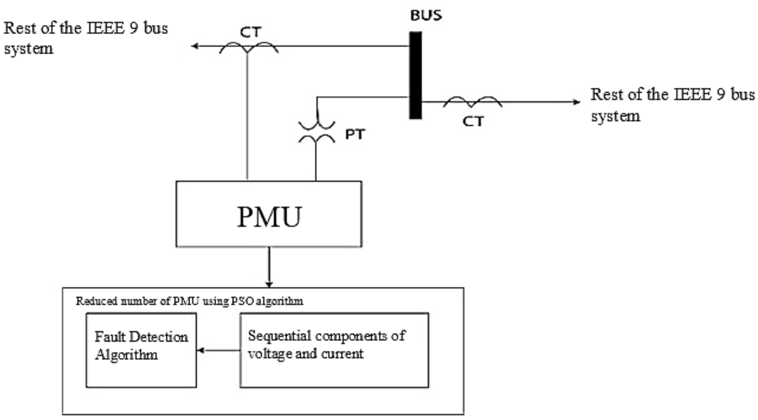


Figure 4. Proposed block diagram of fault detection system

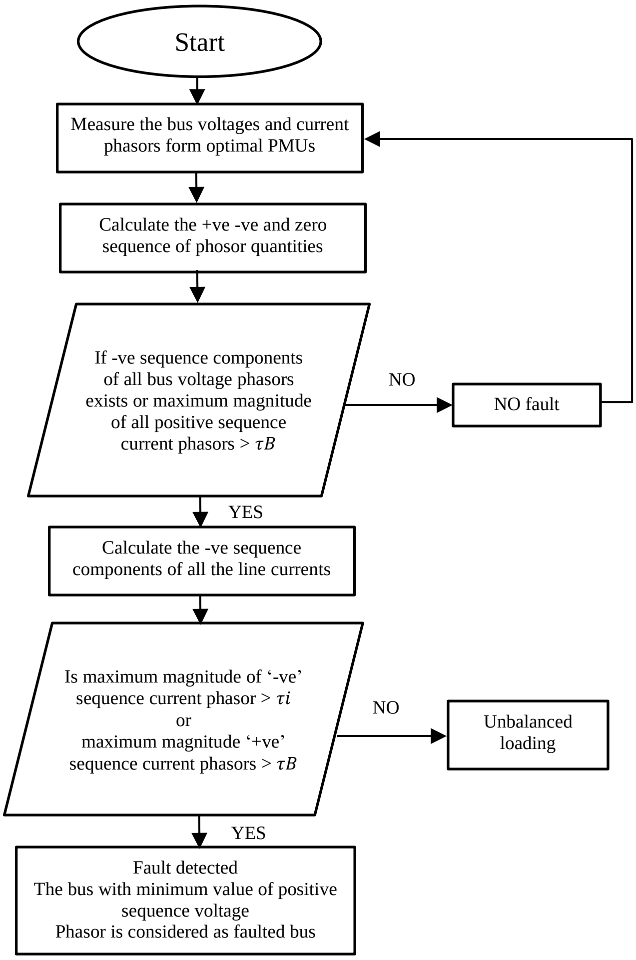


Figure 5. Proposed algorithm for fault detection

3. RESULTS AND DISCUSSION

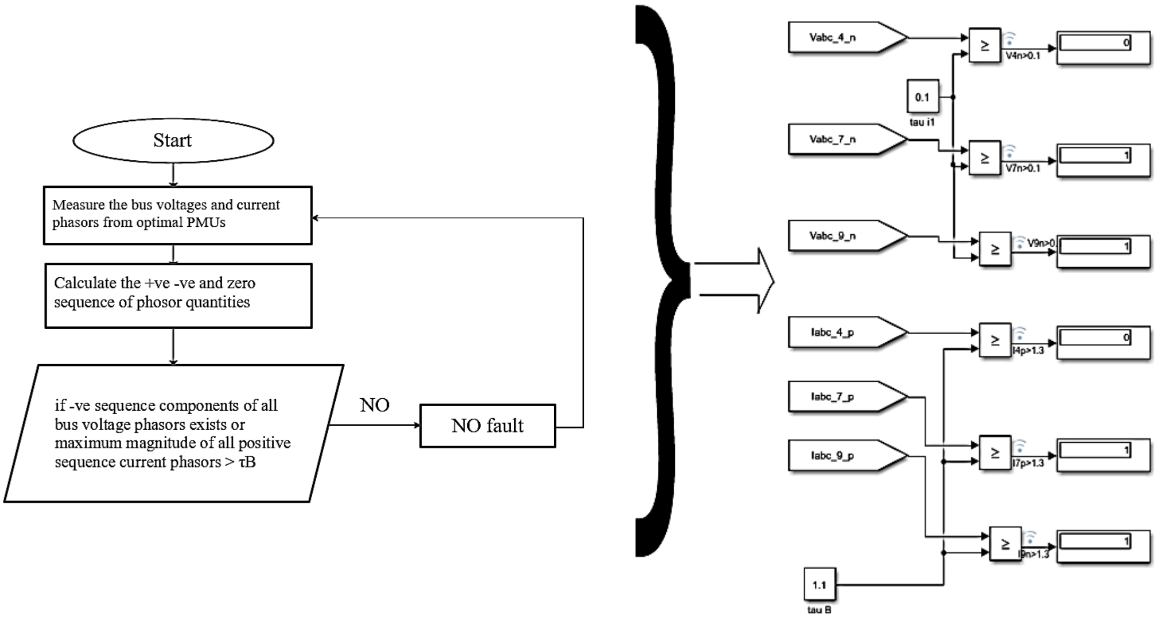
The optimal placement by using the algorithm presented the proposed solutions section. The IEEE 9 bus and IEEE 30 bus systems are used here for optimal placement of PMU and the Table 1 shows the results of the location of PMU placed. The Figure 6(a) shows the implementation of the algorithm in Figure 4. Then the continuation of the implementation is given in Figure 6(b). Then the simulation is figure is shown in Figure 6. It shows the simulation of IEEE 9 bus system implementation with fault. Validation of fault detection algorithm by using the optimal placement of PMU in IEEE 9 bus system. In the IEEE 9 bus system, 3 numbers of PMUs are connected. In Table 2 IEEE 9 and IEEE 30 bus system conventional fault detection technique used [25]. In this paper proposed a fault detection technique to reduce the PMU 3 and 10.

Table 1. Results of optimal placement

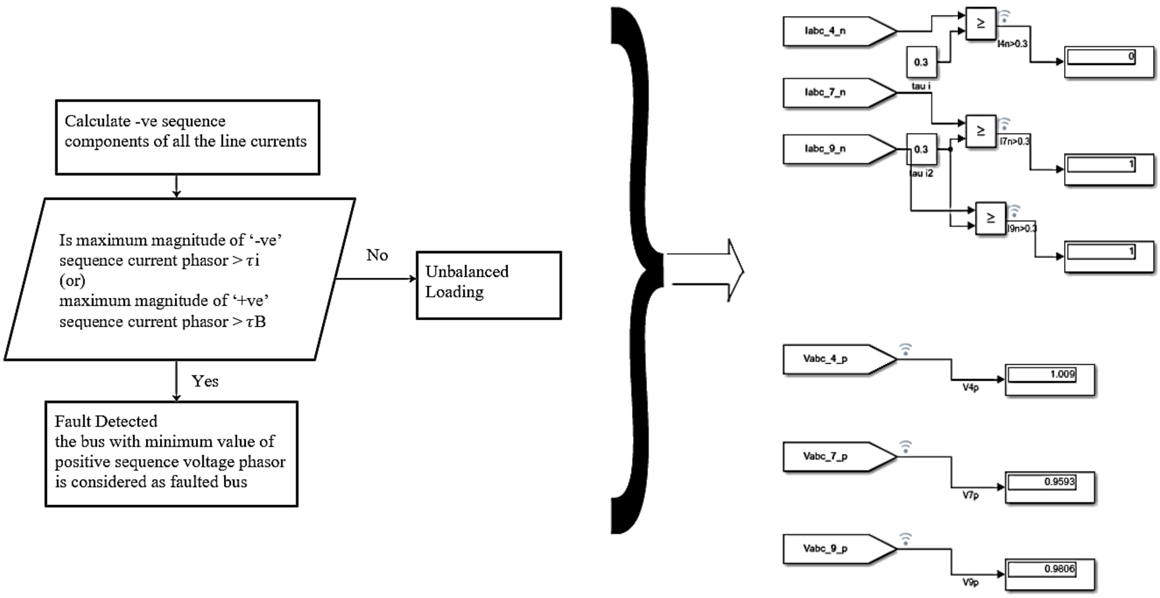
Test system	Optimally placed PMUs (Bus numbers)
IEEE 9 Bus	4,7,9
IEEE 30 Bus	1,6,7,10,11,12,15,18,25,27

Table 2. Comparison with conventional method

System under consideration	Technique used	Number of PMUs used
IEEE 9	Conventional fault detection technique [25]	9
	Proposed fault detection technique	3
IEEE 30	Conventional fault detection technique [25]	30
	Proposed fault detection technique	10



(a)



(b)

Figure 6. Implementation of algorithm to find fault detection: (a) for no fault condition and (b) for unbalanced condition

The IEEE 9 bus system is implemented in Simulink shows in Figure 7. The optimal PMU locations identified from PSO algorithm are buses 4, 7, and 9. In the paper [25] they used 9 PMU to detect the fault. In this paper only three PMUs to detect the fault. Case study: 1) Fault near bus 4, 2) Fault near bus 7, and 3) Fault near bus 9. Each case study carries three scenarios. Scenario 1 shows the AG (LG) type fault. The scenario 2 shows the ABG (LLG) fault and scenario 3 shows the AB fault (LL) fault.

The results of phasor values from the algorithm and the results of voltage and current for each case are shown in Figures 8–25. Figures 8, 10, and 12 show the result of phasor values from the algorithm for cases 1, scenario 1, 2, and 3. It shows that the neutral current of buses 4, 7, and 9 is high, and then the lowest voltage is on the 4^{th} bus. So, the fault is identified at bus 4.

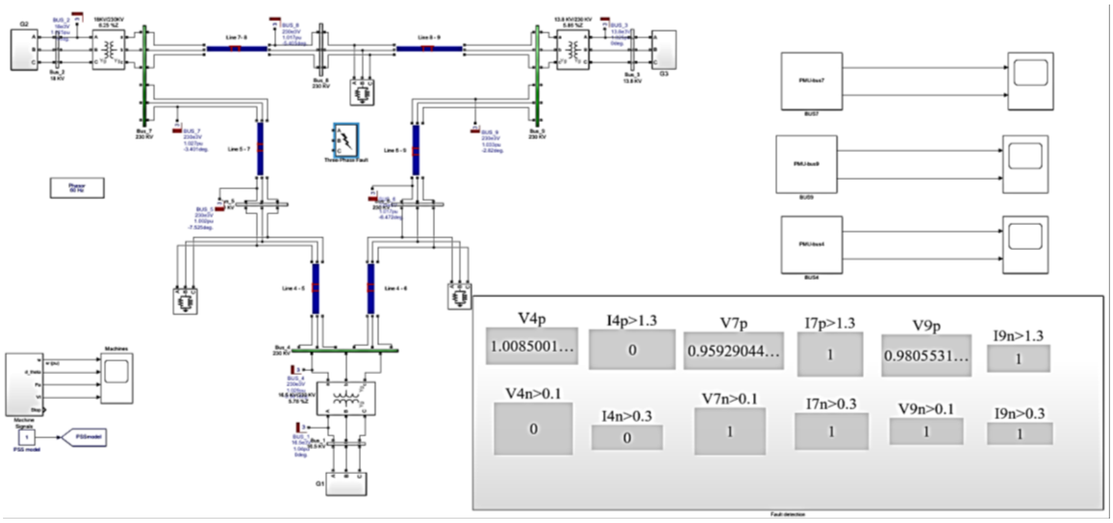


Figure 7. Proposed MATLAB simulation circuit using Simulink and dashboard

The Figures 9, 11 and 13 show the results of voltage and current for cases 1, 2, and 3 respectively. They show the effect of the fault after 0.5 sec. Figure 14, 16, and 18 shows the result of phasor values from the algorithm for case 2, scenario 1, 2 and 3. It shows that the neutral current of buses 4, 7, and 9 is high, and then the lowest voltage is on the 7th bus. So, the fault is identified at bus 7.

The Figures 15, 17, and 19 show the results of voltage and current for cases 2, 1, and 3 respectively. They show the effect of the fault after 0.5 secs. Figures 20, 22, and 24 depict the algorithm's phasor values for case 3, scenarios 1, 2, and 3. It shows that the neutral current of buses 4, 7, and 9 is high, and then the lowest voltage is on the 7th bus. So, the fault is identified at bus 7.

The Figures 21, 23, and 25 show the results of voltage and current for cases 3, 1, 2, and 3 respectively. They show the effect of the fault after 0.5 secs. Finally, the new fault detection algorithm with a reduced number of PMUs is working perfectly and the implementation is shown using the MATLAB dashboard blockset. Here,

V4p – positive sequence voltage value of 4th bus
V4n – Negative sequence voltage value of 4th bus
V7p – positive sequence voltage value of 7th bus
V7n – Negative sequence voltage value of 7th bus
V9p – positive sequence voltage value of 9th bus
V9n – Negative sequence voltage value of 9th bus
V4p – positive sequence voltage value of 4th bus
V4n – Negative sequence voltage value of 4th bus
V7p – positive sequence voltage value of 7th bus
V7n – Negative sequence voltage value of 7th bus
V9p – positive sequence voltage value of 9th bus
V9n – Negative sequence voltage value of 9th bus
I4p – positive sequence current value of 4th bus
I4n – Negative sequence current value of 4th bus
I7p – positive sequence current value of 7th bus
I7n – Negative sequence current value of 7th bus
I9p – positive sequence current value of 9th bus
I9n – Negative sequence current value of 9th bus

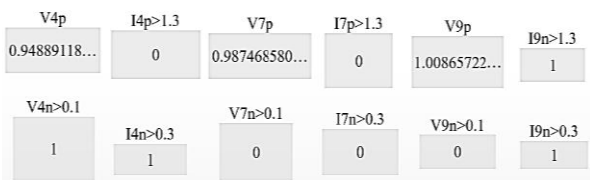


Figure 8. Results of phasor values from the algorithm for case 1, scenario 1

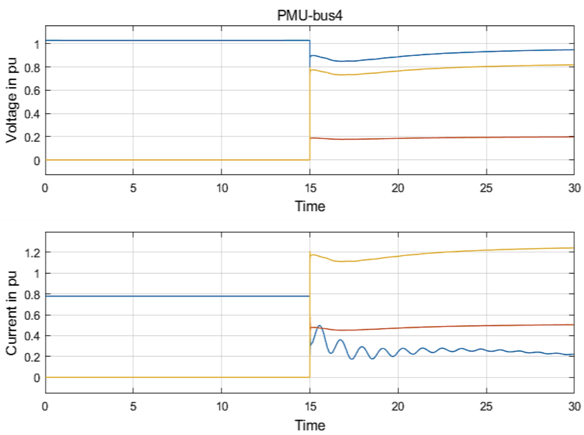


Figure 9. Results of voltage and current for case 1, scenario 1

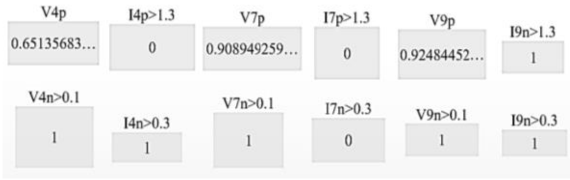


Figure 10. Results of phasor values from the algorithm for case 1, scenario 2

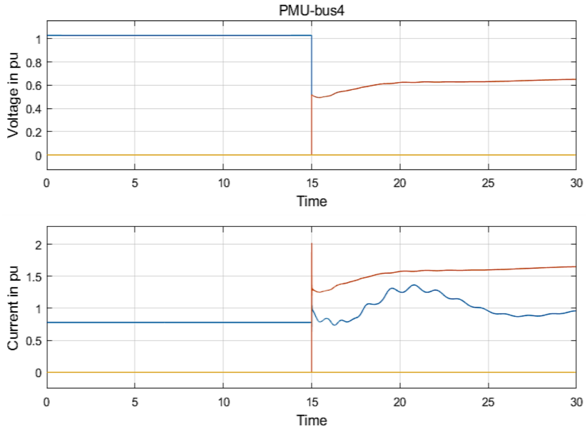


Figure 11. Results of voltage and current for case 1, scenario 2

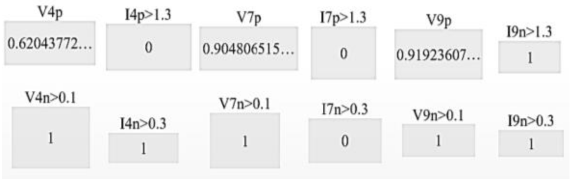


Figure 12. Results of phasor values from the algorithm for case 1, scenario 3

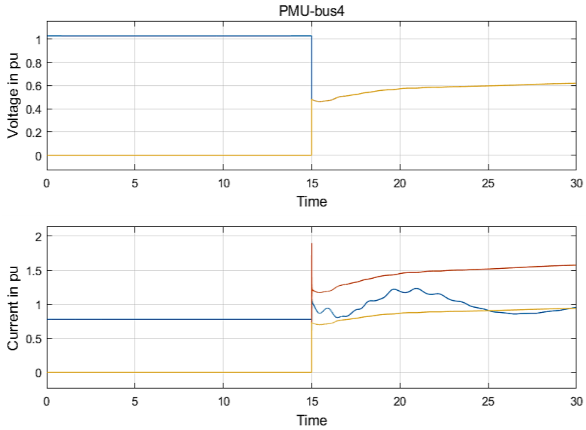


Figure 13. Results of voltage and current for case 1, scenario 3

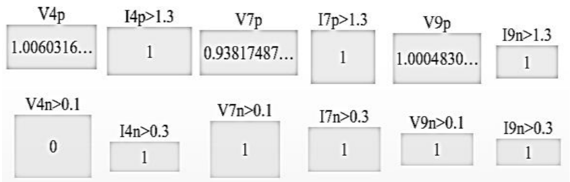


Figure 14. Results of phasor values from the algorithm for case 2, scenario 1

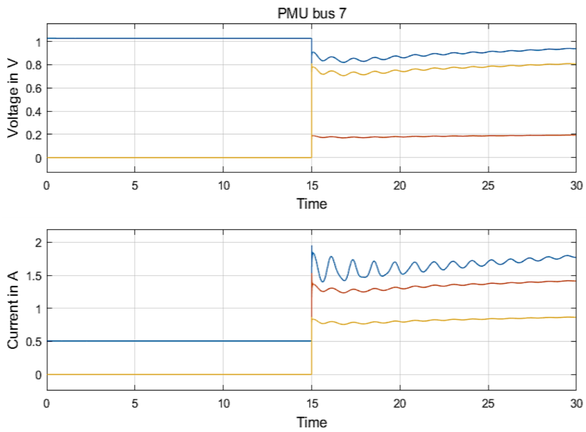


Figure 15. Results of voltage and current for case 2, scenario1

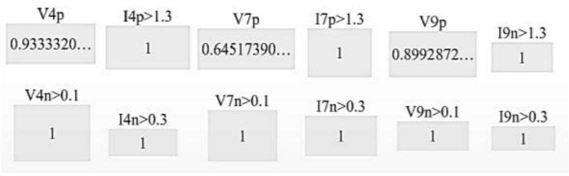


Figure 16. Results of phasor values from the algorithm for case 2, scenario 2

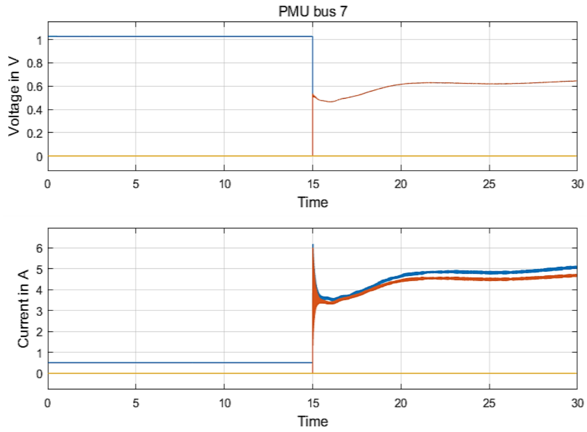


Figure 17. Results of voltage and current for case 2, scenario 2

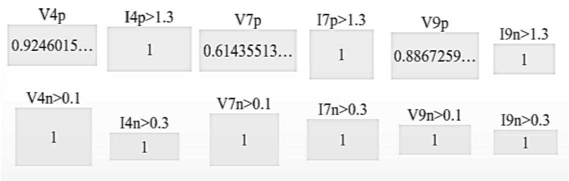


Figure 18. Results of phasor values from the algorithm for case 2, scenario 3

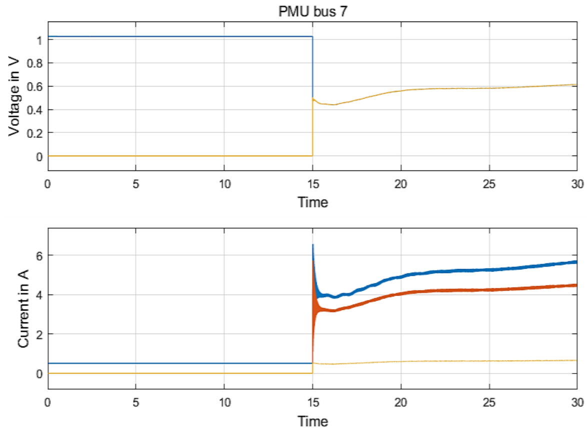


Figure 19. Results of voltage and current for case 2, scenario 3

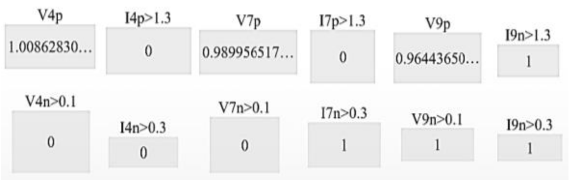


Figure 20. Results of phasor values from the algorithm for case 3, scenario 1

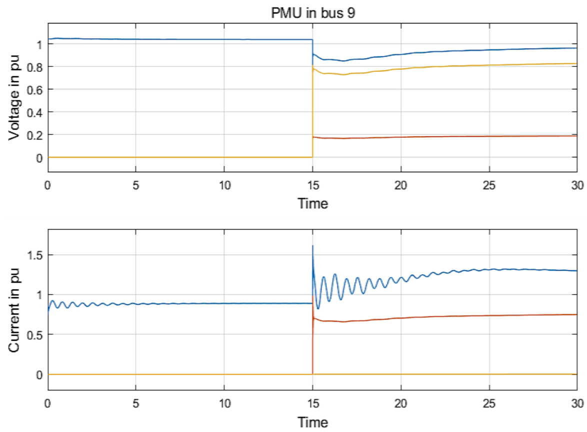


Figure 21. Results of voltage and current for case 3, scenario1

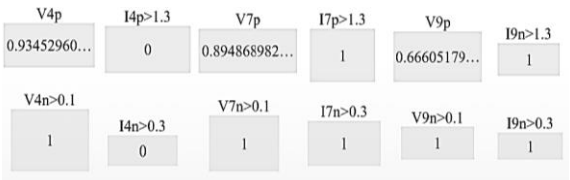


Figure 22. Results of phasor values from the algorithm for case 3, scenario 2

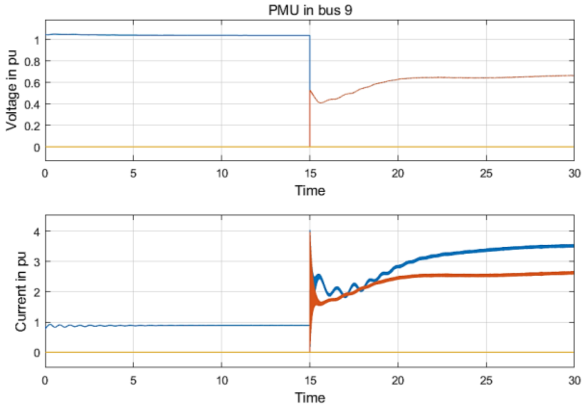


Figure 23. Results of voltage and current for case 3, scenario2

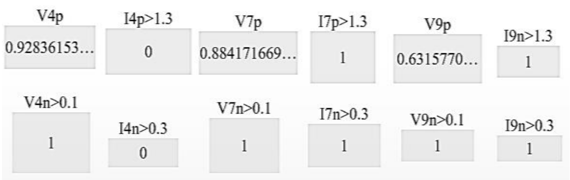


Figure 24. Results of phasor values from the algorithm for case 3, scenario 3

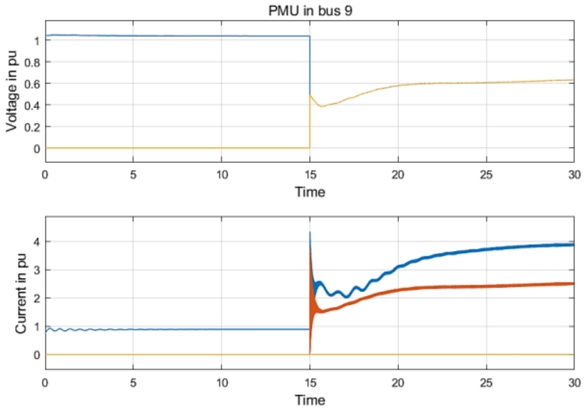


Figure 25. Results of voltage and current for case 3, scenario 3

4. CONCLUSION

The optimal placement of PMUs is done with the PSO algorithm. The test systems used here are IEEE 9 and IEEE 30. It shows that the algorithm works for lesser number of buses and higher number of buses. The construction of the IEEE-9 bus system is done using MATLAB/Simulink. The tests are carried out for faults on different buses like bus 4, 7, and 9. Different faults like LG, LL, and LLG faults are created. Then, only using three PMU, the faults are detected using the fault detection algorithm. Then the dashboard block set is used to display the results.

REFERENCES

[1] B. Ram and D. N. Vishwakarma, "Power system protection and switchgear," *New Delhi: Tata McGraw-Hill publication company limited*, pp. 6-9, 119-123, 2005.

[2] D. Spoor and Jian Guo Zhu, "Improved single-ended traveling-wave fault-location algorithm based on experience with conventional substation transducers," *IEEE Transactions on Power Delivery*, vol. 21, no. 3, pp. 1714-1720, 2006, doi: 10.1109/TPWRD.2006.878091.

[3] S. R. Samantaray, P. K. Dash, and G. Panda, "Distance relaying for transmission line using support vector machine and radial basis function neural network," *International Journal of Electrical Power & Energy Systems*, vol. 29, no 7, pp. 551-556, 2007, doi: 10.1016/j.ijepes.2007.01.007.

[4] K. Divyasri, S. S. Bhat and A. A. Reddy, "Traveling-wave distance proteAction using principal component analysis for a doubly fed system with synchronized measurements," *International Conference on Power and Embedded Drive Control (ICPEDC)*, 2017, pp. 254-259, doi: 10.1109/ICPEDC.2017.8081096.

[5] A. Prasad, and J. B. Edward, "Application of wavelet technique for fault classification in transmission systems," *Procedia Computer Science*,vol, 92, pp. 78-83, 2016, doi: 10.1016/j.procs.2016.07.326.

[6] M. Salehi and F. Namdari, "Fault classification and faulted phase selection for transmission line using morphological edge detection filter," *IET Generation, Transmission & Distribution*, vol. 12, no. 7, pp. 1595-1605, 2018, doi: 10.1049/iet-gtd.2017.0999.

[7] A. Raza, A. Benrabah, T. Alquthami and M. Akmal, "A review of fault diagnosing methods in power transmission systems," *Applied Science*, vol. 10, no. 4, pp. 1-27, 2020, doi: 10.3390/app10041312.

[8] A. Prasad, J. B. Edward and K. Ravi, "A review on fault classification methodologies in power transmission systems: Part—I," *Journal of Electrical Systems and Information Technology*, vol. 5, no. 1, pp. 48-60, 2018, doi: . 10.1016/j.jesit.2017.01.004.

[9] M. Tasdighi and M. Kezunovic, "Preventing transmission distance relays maloperation under unintended bulk DG tripping using SVM-based approach," *Electric Power Systems Research*, vol. 142, pp. 258-267, 2017, doi: 10.1016/j.epsr.2016.09.024.

[10] D. Aborisade, I. Adebayo, and I. Akinola, "A comparative analysis of artificial neural network- based power transmission line fault classifiers," *American Journal of Engineering Research (AJER)*, vol. 10, no. 1, pp. 01-10, 2021.

[11] M. Fernandes, J. M. Corchado, and G. Marreiros, "Machine learning techniques applied to mechanical fault diagnosis and fault prognosis in the context of real industrial manufacturing use-cases: a systematic literature review," *Applied Intelligence*, 2022, doi: 10.1007/s10489-022-03344-3.

[12] A. Yadav, Y. Dash and V. Ashok, "ANN based directional relaying scheme for protection of Korba-Bhilai transmission line of Chhattisgarh state," *Protection and Control of Modern Power Systems*, vol. 1, pp. 1-15, 2015, doi: 10.1186/s41601-016-0029-6.

[13] A. Yadav and Y. Dash, "An Overview of Transmission Line Protection by Artificial Neural Network: Fault Detection, Fault Classification, Fault Location, and Fault Direction Discrimination," *Advances in Artificial Neural Systems, vol. 2014*, pp. 1-21, 2014, doi: 10.1155/2014/230382.

[14] O. Tshenyego, R. Samikannu and B. Mtengi, "Wide area monitoring, protection, and control application in islanding detection for grid integrated distributed generation: A review ," *Measurement and control,sage journals*, vol. 54, no. 5-6, pp. 585-617, 2021, doi: 10.1177/002029402198976.

[15] A. G. Phadke, M. Ibrahim and T. Hlibka, "Fundamental basis for distance relaying with symmetrical components," *IEEE Transactions on Power Apparatus and Systems*, vol. 96, no. 2, pp. 635-646, 1977, doi: 10.1109/T-PAS.1977.32375.

[16] J. A. Jiang, Y. H. Lin, J. Z. Yang, T. M. Too and C. W. Liu, "An adaptive PMU based fault detection/location technique for transmission lines. II. PMU implementation and performance evaluation," *IEEE Transactions on Power Delivery*, vol. 15, no. 4, pp. 1136-1146, 2000, doi: 10.1109/61.891494.

[17] C. W. Liu, T. C. Lin, C. S. Yu and J. Z. Yang, "A fault location technique for two-terminal multisection compound transmission lines using synchronized phasor measurements," *IEEE Transactions on Smart Grid*, vol. 3, no. 1, pp. 113-121, 2012, doi: 10.1109/TSG.2011.2171198.

[18] T. -C. Lin, P. -Y. Lin and C. -W. Liu, "An algorithm for locating faults in three-terminal multisection nonhomogeneous transmission lines using synchrophasor measurements," *IEEE Transactions on Smart Grid*, vol. 5, no. 1, pp. 38-50, 2014, doi: 10.1109/TSG.2013.2286292.

[19] Z. Y. He et al., "Dynamic fault locator for three-terminal transmission lines for phasor measurement units," *IET Generation, Transmission & Distribution*, vol. 7, no. 2, pp. 183-191, doi: 10.1049/iet-gtd.2011.0859.

[20] A. H. Al-Mohammed and M. A. Abido, "A fully adaptive PMU-based fault location algorithm for series-compensated lines," *IEEE Transactions on Power Systems*, vol. 29, no. 5, pp. 2129-2137, 2014, doi: 10.1109/TPWRS.2014.2303207.

[21] N. Kang and Y. Liao, "Double-circuit transmission-line fault location utilizing synchronized current phasors," *IEEE Transactions on Power Delivery*, vol. 28, no. 2, pp. 1040-1047, 2013, doi: 10.1109/TPWRD.2013.2246587.

[22] M. K. Neyestanaki and A. M. Ranjbar, "An adaptive PMU-based wide area backup protection scheme for power transmission lines," *IEEE Transactions on Smart Grid*, vol. 6, no. 3, pp. 1550-1559, 2015, doi: 10.1109/TSG.2014.2387392.

[23] Z. Y. He, R. K. Mai, W. He, and Q. Q. Qian, "Phasor-measurement-unitbased transmission line fault location estimator under dynamic conditions," *IET Generation, Transmission and Distribution*, vol. 5, no. 11, pp. 1183-1191, 2011, doi: 10.1049/iet-gtd.2011.0081.

[24] P. Gopakumar, M. J. B. Reddy, D. K. Mohanta, "Transmission line fault detection and localisation methodology using PMU measurements," *IET Generation, Transmission and Distribution*, vol. 9, no. 11, pp. 1033-1042, 2015, doi: 10.1049/iet-gtd.2014.0788.

[25] P. Rajaraman, N. A. Sundaravaran, B. Mallikarjuna, J. B. M. Reddy and D. K. Mohanta, "Robust fault analysis in transmission lines using Synchrophasor measurements," *Protection and Control of Modern Power Systems, vol.* 3, no. 14, pp. 1-13, 2018. doi: 10.1186/s41601-018-0082-4.

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