

PMU PLACEMENT BASED FAULT LOCATION USING MULTI OBJECTIVES SHORTEST PATH ALGORITHM

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Abstract

The ability of the system to supply all kinds of loads during natural problems or fault has yet to be addressed. This work focuses on designing a wide-area measurement system to manage and control the power system during faults. IEEE 14 bus system and measurement of voltage and current were simulated by using PSCAD. In order to observe the effectiveness of measurement during a fault, multiobjective shortest path algorithm is considered in this paper. There are 19 fault cases have been simulated. Based on the calculation by utilizing multiobjective shortest path algorithm, a new path for the IEEE 14 bus system was obtained. All the section in the IEEE 14 bus system has been simulated with the fault in order to observe the performance of the multiobjective shortest path algorithm. The distance of the normal path (without fault) and the new path (with fault) have been recorded. From the data recorded the graph have been plot to show the performance of the algorith

1. INTRODUCTION

The monitoring of the system cannot show the dynamic phenomena of the power system based in the steady state with the SCADA system. The framework's practices are foreseen by utilizing the disconnected power framework simulation tool which is a vulnerability in exactness parameters and the generally estimate. The system workers need to know the consistent and detailed dynamic information to settle on the choice to deal with the system in certain cases. The framework can be observed and concentrate on the angle and phasors with time duration in dynamic state by using phasor measurement unit (PMU). PMU will demonstrate the dynamic information of the individual buses in the system for the system workers. This data will be helpful for reacting on the system circumstance reasonably. PMUs additionally can use as the system investigator apparatus on the activity of the hardware in the system, for example, the controller of the generator. The system workers need to manage the system as the wide area monitoring system by using PMU as the one of the smart grid routes to provide the data [1].

The operators need to understand the whole system behavior during dynamic phenomena based on wide area monitoring system as the monitoring system. The communication system, the data analyst and display the information are PMU function that contain on the wide area monitoring system. The placement of PMU installation over the power system to investigate the system phenomena and stability started on the system study on the system's constraint and the stability problem need the wide area monitoring system to face on these problems. The system workers will be concentrated on the detection and monitor the problem to show the idea of implementation in the wide area monitoring system. The planning, strategy and implementation including the experience on the dynamic behavior of the power system used by PMU for the wide area monitoring system. The system workers for supervising the event in the system as the dynamic view's point do not profit the workers only but also use to monitor and analyze the dynamic behavior of the power grid in assorted scenarios. The system protection, dependability and stability will be the development technique for wide area monitoring system of the power grid as an entire.

That is why the wide area monitoring system is important in power grid. This is to ensure the operation of power grid and system security. This will optimize the stability of the power system, reducing the cost and improve the technical indexes.

2. Related Work

The power system is a tremendous system because of the interconnections among each administrative region to enhance dependability and financial efficiency. The community system already for the most part created dependent on electrical energy for a superior life and financial development. Besides, the power system is always vulnerable to the natural atmosphere, thus, the system consumes some or vast unsettling influences, for instance, by lightning, tempest, and device deficiencies. Beneath these conditions, the framework must keep up steady process to keep away from power outages in the entire framework utilizing proper protection and manage plans. Besides, in a substantial scale interconnected system, there are a few challenges in assessing and keeping up the stability of the entire system. Lately, another issue in power systems has turned out, which is the infiltration of renewable energy sources, carrying further vulnerability that involves increasingly extreme operation. For energy security, the presentation of renewable energy source is fundamental subsequently, to keep up system dependability and utilize of endurable energy, power system monitoring ought to be a key innovation to accomplish the adaptable task in the system. Then again in recent years, the improvement of information and communication technology (ICT) has empowered greater adaptability in wide area monitoring of power system with quick and massive data transmission. Particularly, the wide-area monitoring system (WAMS) with phasor measurement units is a reassuring system as one of the smart grid innovations in the power grid.

2.1. Optimal Placement of PMU

PMU become increasingly more appealing to power engineers since they can give synchronized estimations of real time phasors of voltage and currents. As the only system

monitor, state estimator plays a vital role in the security of power system operations. According to paper [3], an ideal PMU placement algorithm is developed to recover the bad data processing capability of state estimation by taking advantage of the PMU technology. Techniques for identifying placement sites for phasor measurement units in a power system based on incomplete observability are presented in [4], where simulated annealing method is used to solve the pragmatic communication-constrained PMU placement problem. The authors in [5] develop an optimal placement algorithm for PMUs by using integer programming. However, the proposed integer programming becomes a nonlinear integer programming under the existence of conventional power flow or power injection measurements. Besides, a similar formulation of optimal PMU placement problem is proposed by integer linear programming. According to [1], there is two proposed formulation which is without conventional measurements and with conventional measurements. Referring to [1], simulation results show that the proposed algorithm is computational efficiency and can be used in practice but due to space limitations, the simulation only use the IEEE 14 bus system. The authors in [6]-[7] developed an optimal placement algorithm for PMUs by using integer programming. However, the proposed integer programming becomes a nonlinear integer programming under the existence of conventional power flow or power injection measurements. Besides, a similar formulation of optimal PMU placement problem is proposed by integer linear programming. Paper [8] determine the PMU placement by considering Genetic Algorithm.

2.2. Dynamic Shortest Path Algorithm

Wide area monitoring system (WAMS) normally holds three element infrastructures named management, measurement and communication. For ideal activity of a power system, it is important to plan these foundations reasonably. According to [9], measurement and communication foundations in a wide area network are planned freely from an administration viewpoint, in view of a satisfactory level of system monitor.

Ideal positioning of phasor measurement units is decided utilizing an integer linear programming (ILP) arrangement procedure whereas considering into account zero-injection bus effects. The PMU position issue is illuminated utilizing integer linear programming (ILP) method with and without customary estimations and maximum estimation redundancy of all buses. According to paper [10]-[12] have tackled an ideal PMU position issue with the new decides on discernibleness limitations that could diminish the number of PMUs.

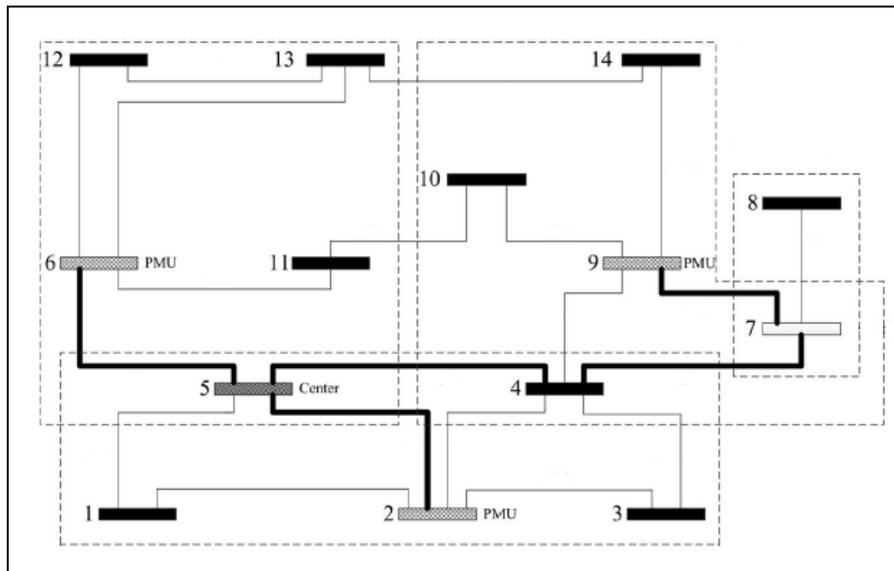


Fig. 1. Optimal design of wide area monitoring system for the IEEE 14 bus system.

A dynamic multiobjective shortest path (MOSP) routing method was displayed for the ideal structure of the communication framework. As such, the planned method first optimizes PMU position and after that improves communication ways that interface all phasor measurement units. The shortest path exploration algorithm is utilized to decide the shortest paths from phasor measurement units buses to the central control bus in the MOSP steering algorithm, which is utilized for ideal communication interface arrangement, hence, all the inspected PMU nodes, which have transferred into set S carried by Ghasemkhani on his paper [9], can be measured as original nodes. It could likewise be found that the closest phasor measurement units bus has dependably the shortest way to the central control bus between all the conceivable ways.

This paper also classified two diverse approaches to acquire the information transmission way from phasor measurement units bus to the central control bus as pursues:

1. Single objective shortest path.
2. Multi objective shortest path

On account of a Single objective shortest path, the most shortest way from each Single objective shortest path bus to the central control bus can be gotten freely utilizing shortest path algorithm such as Dijkstra, while in a multi objective shortest path algorithm directing calculation, overlapped ways are utilized to make information transmission ways for all phasor measurement units buses. At the end of day, on account of the multi objective shortest path algorithm, all phasor measurement units buses, with the exception of the closest one to the CCB, basically due to the overlapped ways that can be utilized as method for information transmission with decreased Optical fiber power ground wire coverage.

3. THE PROPOSED METHOD

Usually wide area monitoring system consist three element infrastructure named management, measurement and communication. The best operation of power system, it is required to create these infrastructures appropriately. The measurement and communication infrastructures in a wide area network area are planned freely from management perspective view, since a satisfactory level of system observability. So as to design the 14-bus system for this research, there are several steps that have been followed. The opening phase, ideal arrangement of measurement mechanism is decided to apply an integer linear programming referring to [5]. In the following phase, dynamic multiobjective shortest path is intended for the ideal proposal of communication infrastructure. The fault cases have been assigned to observer performance of multiobjective shortest path and compare the result for 19 fault cases. The distance of multiobjective shortest path algorithm for 19 cases has been taken and compare.

The multiobjective shortest path algorithm considering the optimal PMU placement and select one bus as central control bus (CCB) considering the lowest value for the communication coverage. Then, the shortest path exploration algorithm (SPEA) is connected to acquire minimum length from the central control bus to other buses, which are important to figure out matrix N. Matrix N are shortest path value for PMU buses. The example of the shortest path value for the main central bus in IEEE 14 bus system can be refer to table 2. The next step, the shortest path values between phasor measurement units buses obtained from the shortest path exploration algorithm is executed once again. Then, a new distance matrix (DM) is clarify for phasor measurement unit buses and the central control bus. Subsequently, the furthest phasor measurement units bus to main central bus is chosen dependent on the matrix N and measured as the assessing phasor measurement units buses.

$$\begin{array}{ccc}
 \text{No bus of PMU 1} & \text{No bus of PMU 2} & \text{No bus of PMU 3} \\
 \\
 N = [\text{distance shortest path 1} & \text{distance shortest path 2} & \text{distance shortest path 3}]
 \end{array} \tag{1}$$

Matrix N respect to shortest path value for PMU buses as follow:

$$DM = \begin{array}{l}
 \left[\begin{array}{l}
 \text{no bus of central control bus} \\
 \text{no bus of PMU 1} \\
 \text{no bus of PMU 2} \\
 \text{no bus of PMU 3}
 \end{array} \right] \left[\begin{array}{cccc}
 \text{matrix identity} & dsp1 & dsp2 & dsp3 \\
 dsp0 + dsp1 & \text{matrix identity} & dsp + dsp1 & dsp3 + dsp1 \\
 dsp0 + dsp2 & dsp1 + dsp2 & \text{matrix identity} & dsp3 + dsp2 \\
 dsp0 + dsp3 & dsp1 + dsp1 & dsp2 + dsp3 & \text{matrix identity}
 \end{array} \right]
 \end{array} \tag{2}$$

DSP = Distance shortest path

The distance matrix respect to shortest path value for PMU buses. Subsequent, the closest bus to the assessing phasor measurement units bus is chosen from the distance matrix and measured as an original commencement point in the shortest path exploration algorithm. On the chosen start point is equivalent to the CCB, acquired edges from past consequences are added to set E and this stage is applied for the following phasor measurement units bus. Set E

describe as $\ell(v_1, v_2, \dots, v_k) = \int_{i=0}^{i=k-1} \ell(v_i, v_{i+1})$, where $\ell(v_i, v_{i+1})$ is the geographical distance among nodes v_i and v_{i+1} . If not, the shortest path exploration algorithm is executed for the original commencement point besides this bus is set as another assessed phasor measurement unit bus until a complete path is formed from the phasor measurement units to the central control bus. These steps are performed until all the PMU buses are considered and the communication spanning tree is created. The communication spanning tree is formed and all the PMU need to be considered as illustrate in figure 3. To form the communication spanning tree and reviewed all the PMU all the step needs to be executed.

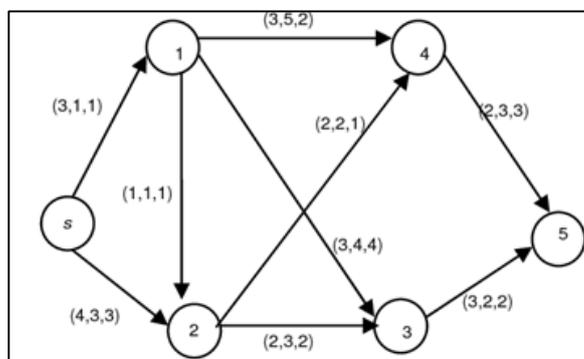


Figure 2. multiobjective shortest path routing

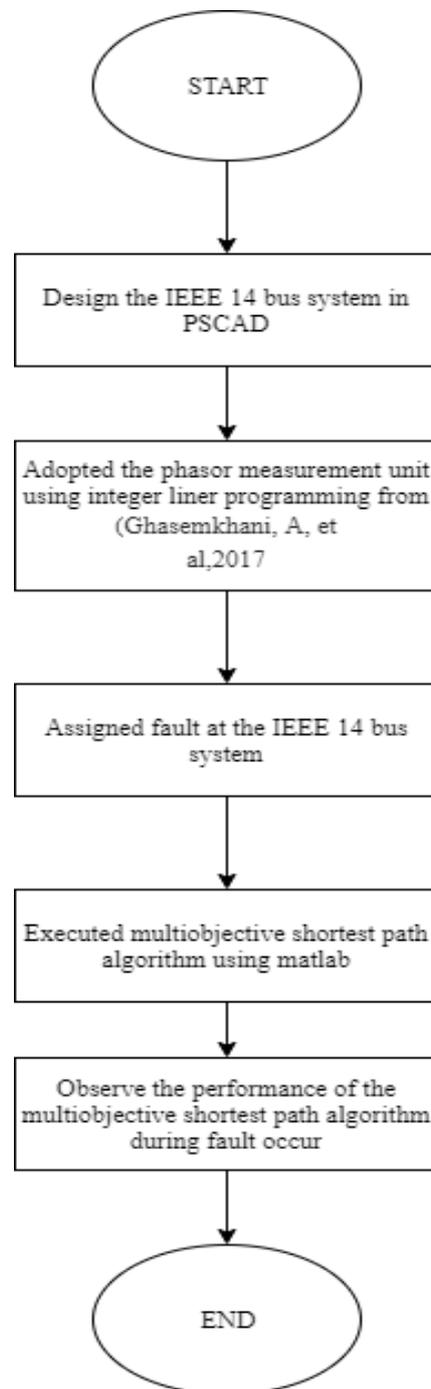


Figure 3. Flowchart of research process

Figure 3 is described about the flow to complete this research based on the objective of this study. The objective to design the network of IEEE 14 bus system. The IEEE 14 bus system will be design on the PSCAD.

Next, the location of the PMU is resolute using integer linear programming (ILP) apply on 14 bus system. The placement of PMU are use the binary integer programming of matlab to solve the problem but this research don't calculate the algorithm for the PMU placement due to the research limitation and just adopted from [6], for the PMU placement using ILP on the IEEE 14 bus system. There will be three PMU installed in buses 2, 6 and 9 regarding to the ideal phasor measurement units positioning problem.

Table 1. List of fault location

No. Fault	Location	No. Fault	Location
1	Bus 9 to 10	11	Bus 7 to 9
2	Bus 10 to 11	12	Bus 4 to 9
3	Bus 6 to 11	13	Bus 5 to 6
4	Bus 6 to 13	14	Bus 1 to 5
5	Bus 6 to 12	15	Bus 1 to 2
6	Bus 12 to 13	16	Bus 5 to 2
7	Bus 13 to 14	17	Bus 2 to 4
8	Bus 9 to 14	18	Bus 2 to 3
9	Bus 4 to 9	19	Bus 3 to 4
10	Bus 4 to 7		

The following step was assigned 19 fault cases at IEEE 14 bus system. Each fault has been assigned to different locations in order to observe the performance of the multiobjective shortest path algorithm. Figure 3 show the location of every fault cases has been assign on the IEEE 14 bus system.

After delegate fault on IEEE 14 bus system, each fault case has been simulated using Matlab. The algorithm has been designed to choose and consider every shortest path for every fault case. The result will show distance every fault case to connect with other buses.

Records every distance take for each fault case to connect between the other bus. The data from the 19 fault cases have been recorded and plot the graph to get more figures about the

performance of the multiobjective shortest path algorithm. Observer the performance of multiobjective shortest path algorithms during fault occurs.

4. RESULTS

In this section, all the data have been obtained from simulation and analyzed the data by obtained the graph for further discussion. 19 faults have been allocated on the line IEEE 14 bus system and has been tested to gather data from multiobjective shortest path algorithm simulation. All the fault has been allocated at different location on the line IEEE 14 bus system. Each fault will be simulated with multiobjective shortest path algorithm using matlab to get the distances shortest path and analyzed the data.

4.1. Fault Simulation Point

There are 19 fault cases have been simulated on the IEEE 14 bus system. Each fault has been simulated between buses and different locations. The detail of fault simulation points is show on table 2.

Based on table 2, it can be seen that in this research the fault point simulated in every section (between bus to bus). For example, fault 1 was simulated between 9 to 10 with the distance from bus 9 to 10 is 18.9 Km. All of the fault points were simulated in the middle of the section.

Table 2. Fault point

No of Fault	Location fault	Distance between bus (Km)	Distance of fault (Km)	No of Fault	Location fault	Distance between bus (Km)	Distance of fault (Km)
1	Bus 9 to 10	18.9	9.45	11	Bus 7 to 9	24.6	12.3
2	Bus 10 to 11	42.9	21.45	12	Bus 4 to 5	9.4	4.7
3	Bus 6 to 11	44.4	22.2	13	Bus 5 to 6	56.3	28.15
4	Bus 6 to 13	29.1	14.55	14	Bus 1 to 5	24.9	24.9
5	Bus 6 to 12	57.1	28.55	15	Bus 1 to 2	13.2	6.6
6	Bus 12 to 13	44.7	22.35	16	Bus 2 to 5	38.9	19.45
7	Bus 13 to 14	77.8	38.9	17	Bus 2 to 4	39.4	19.7
8	Bus 9 to 14	60.4	30.2	18	Bus 2 to 3	44.2	22.1
9	Bus 4 to 9	124	62	19	Bus 3 to 4	38.2	19.1
10	Bus 4 to 7	46.7	23.35				

4.2. Path Analysis

In this section, path analysis discussed considering different fault simulation point. Every fault point will be discussed in the detail result and explanation. The result will be compared with normal path and the new path for every fault case. The normal path distance obtains from the multiobjective shortest path algorithm before the fault occur and the new path distance obtains from the multiobjective shortest path algorithm during fault occurs. Every fault case has 6 routes to connect the buses. Here the example of path analysis and discussion:

Table 3 shown route taken to connect to other buses and distance have been used for fault 1. Fault 1 occurs in the middle of the section between bus 9 and bus 10. When the fault occurs, the path to connect the phasor measurement unit and buses should be changed if the fault occurs at the path. In the normal condition (without fault), the path distance call as the main route which is shown in the table 3.

Table 3. Path Distance for Fault 1

Route	Main route	Normal path (Km)	Route after fault	New path (Km)
1	5 to 2	38.9	5 to 2	38.9
2	5 to 6	56.3	5 to 6	56.3
3	5 to 4 to 7 to 9	80.7	5 to 4 to 7 to 9	80.7
4	6 to 5 to 2	95.2	6 to 5 to 2	95.2
5	6 to 11 to 10 to 9	160.2	6 to 5 to 4 to 7 to 9	137
6	2 to 4 to 7 to 9	110.7	2 to 4 to 7 to 9	110.7

Table 3 consists of the 5 columns. The first column is the number of the route and follows by the main route (normal condition of the route). The third column is represented distance for the normal path (normal condition). Next, the fourth column is represented route after a fault and the last column is the distance of the new path. Based on table 4.2, in the main route between bus 5 to 2 bus for route 1 the distance is 39.8 Km. It was no changes when fault 1 occur. However, it can be seen the changes in route number 5, which is the main route path start from bus 6, continue to bus 11 to bus 10 and bus 9. The result simulated for the main path is 106.2 Km. So, finally the new path distance is 137 Km. This value has a different distance with the normal path is 30.8 km. It means that the multiobjective method to

determine the new path of the distance have a very significant impact on the effectiveness of path distance.

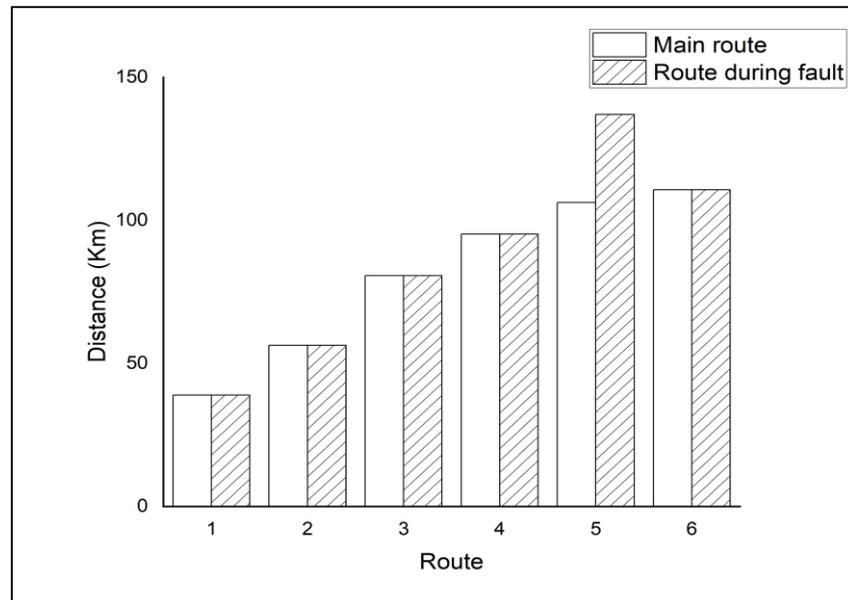


Figure 4. Alternative route during fault occurrence

Figure 4 shown that route 5 have a different distance between the main route and after fault occurs. The normal distance used for route 5 was 106.2 Km and after the fault occurs the distance has become 137 Km. It is because the fault 1 occurs between bus 10 and 11. The main route used bus 10 and 11 then the algorithm must calculate the shortest path to connect between bus 6 to 9. The algorithm considered all possible route and select the shortest path. The route 5 used buses 6, 5, 4, 7 and 9 as the path. The other route does not affect because the fault does not interrupt the path.

4.3. Distance Comparison Between Every Fault for Each Route

In this sub-section, distance comparison discussed about every fault case at each route. Every fault point will be been discussed in detail result and explanation for each route. Here the example of distance comparison between every fault for each route:

Route 1 is represent the condition of the phasor measurement unit which is placed on bus 2 and the center on the bus 5. When fault 1 occurs between bus 9 to bus 10, the path distance result is 38.9 Km. All the distance for route 1 is the same except distance for fault case 16. The distance for fault case 16 is 48.8 Km because the fault occurs on the bus 2 to bus 5. So, the bus 5 to bus 2 cannot be used as the path and the multiobjective shortest path algorithm have to calculate the new shortest path. Other fault cases do not affect because the path uses to connect bus 5 to bus 2 does not have an interruption.

Table 2. Distance for Route 1

No. of fault	Distance	No. of fault	Distance
1	38.9 Km	11	38.9 Km
2	38.9 Km	12	38.9 Km
3	38.9 Km	13	38.9 Km
4	38.9 Km	14	38.9 Km
5	38.9 Km	15	38.9 Km
6	38.9 Km	16	48.8 Km
7	38.9 Km	17	38.9 Km
8	38.9 Km	18	38.9 Km
9	38.9 Km	19	38.9 Km
10	38.9 Km		

Figure 5 shown the distance to connect bus 5 to bus 2 during fault occur. There are 19 faults that have been assigned on IEEE 14 bus system. Every fault case takes the same path to connect bus 5 to bus 2 and the path record 38.9 Km for that cases except during fault 16. During that fault occur to connect bus 5 to bus 2 the algorithm calculates the different paths for fault 16 because the fault occurs between bus 5 and 2. Then, the path between bus 5 and 2 cannot be used the algorithm assigns another path which is bus 5 to 4 and 2 as other options of path.

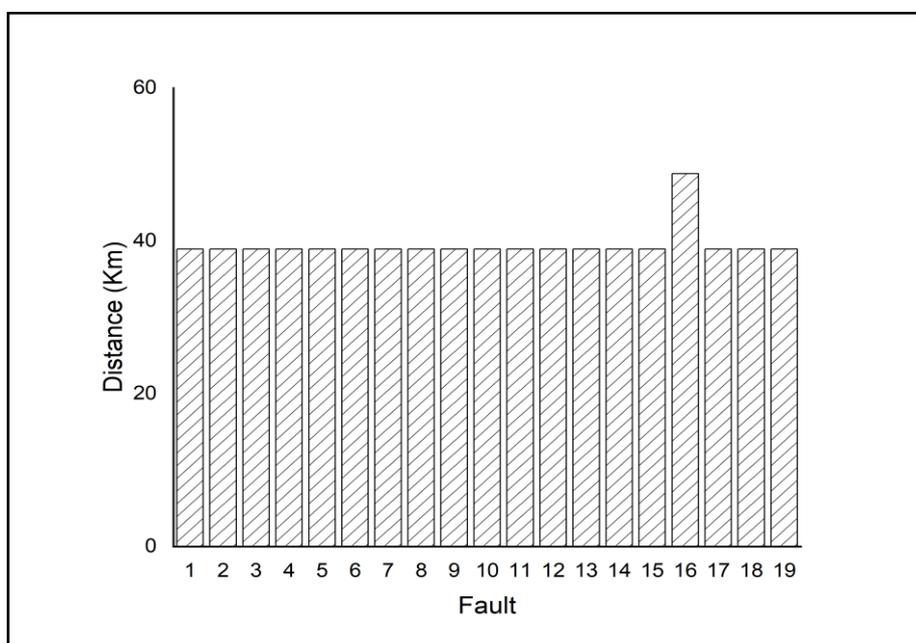


Figure 5. Alternative distance during Fault for Each Route

5. CONCLUSION

This research has been proposed the new path of the distance when the fault occur in the various of placed. The philosophy of the algorithm needs to understand in order to implement the algorithm in the research. The IEEE 14 bus test system has been designed to assign the fault on the IEEE 14 bus system. There are 19 faults has been assigned on the IEEE 14 bus system. The 19 faults also have been assigned in a different location. The performance of the multiobjective shortest algorithm during fault occur also observe in this paper. For that purpose, 19 faults have been assigned in a different location and the result of the distance path taken during fault occur have been a plot on graph.

Based on the obtained result has been shown that the location of the fault affected the shortest path for the buses to connected to each other. If the fault occurs at the route and the algorithm have to consider all route, then choose the new shortest path except old route because the old route cannot be used due to fault occurs.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

REFERENCES

- [1] Gou, B. (2008). Optimal placement of PMUs by integer linear programming. *IEEE Transactions on power systems*, 23(3), 1525-1526.
- [2] Gore, R., & Kande, M. (2015, March). Analysis of wide area monitoring system architectures. In *2015 IEEE International Conference on Industrial Technology (ICIT)* (pp. 1269-1274). IEEE.
- [3] Chen, J., & Abur, A. (2006). Placement of PMUs to enable bad data detection in state estimation. *IEEE Transactions on Power Systems*, 21(4), 1608-1615.
- [4] Nuqui, R. F., & Phadke, A. G. (2005). Phasor measurement unit placement techniques for complete and incomplete observability. *IEEE Transactions on Power Delivery*, 20(4), 2381-2388.
- [5] Xu, B., & Abur, A. (2004, October). Observability analysis and measurement placement for systems with PMUs. In *IEEE PES Power Systems Conference and Exposition, 2004.* (pp. 943-946). IEEE.
- [6] Xu, B., & Abur, A. (2004, October). Observability analysis and measurement placement for systems with PMUs. In *IEEE PES Power Systems Conference and Exposition, 2004.* (pp. 943-946). IEEE.

- [7] Korkali, Mert, and Ali Abur. "Placement of PMUs with channel limits." *2009 IEEE power & energy society general meeting*. IEEE, 2009.
- [8] Ahmadi, A., Alinejad-Beromi, Y., & Moradi, M. (2011). Optimal PMU placement for power system observability using binary particle swarm optimization and considering measurement redundancy. *Expert Systems with Applications*, 38(6), 7263-7269.
- [9] Ghasemkhani, A., Monsef, H., Rahimi-Kian, A., & Anvari-Moghaddam, A. (2017). Optimal design of a wide area measurement system for improvement of power network monitoring using a dynamic multiobjective shortest path algorithm. *IEEE Systems Journal*, 11(4), 2303-2314.
- [10] Rashidi, Farzan, et al. "Optimal placement of PMUs with limited number of channels for complete topological observability of power systems under various contingencies." *International Journal of Electrical Power & Energy Systems* 67 (2015): 125-137.
- [11] Abiri, E., Rashidi, F., & Niknam, T. (2015). An optimal PMU placement method for power system observability under various contingencies. *International transactions on electrical energy systems*, 25(4), 589-606.
- [12] Rashidi, F., Abiri, E., Niknam, T., & Salehi, M. R. (2015). On-line parameter identification of power plant characteristics based on phasor measurement unit recorded data using differential evolution and bat inspired algorithm. *IET Science, Measurement & Technology*, 9(3), 376-392.