Load Restoration in Distribution System Using Minimum Spanning Tree - Prim's Algorithm

H Mohamad, N Md Razali, N A Salim, Z M Yasin, B N S Rahimullah

***Abstract:** Power outage is detrimental to the grid system therefore solving the issue within a short amount of time is indeed compulsory. Load restoration is one the solution required in ensuring the load can be connected within short amount of time. This study proposes a methodology to solve the load restoration problem using minimum spanning tree by determining the switching sequence according to the Prim's algorithm. By using this algorithm, the switching is done based on the most minimum path which refer to the flow of power through the minimal value of weighted impedances. This method ensures that the losses is minimized and the voltage limit is not violated. The load restoration in this study focuses on reconfiguring the tie-lines in the 33-bus radial distribution network. Results obtained shows that Prim's algorithm is effective in restoring the loads by reconfiguring the network in a way that total active power losses are minimized. This algorithm is also compared with the Binary Particle Swarm Optimization (BPSO) to prove the effectiveness of this method thus enhancing the power system reliability.*

***Keywords:** Algorithm, Binary Particle Swarm Optimization, Distribution network, Load Restoration*

I. INTRODUCTION

In power distribution system, grid is connected to the loads like residential, commercial or industrial through the distribution transformer. There are three types of connection which are radial, loop and network. This paper focuses on the radial system which is where loads (customer) are powered only by one power source. Power outage occurred in the distribution line must be recovered as fast as possible due to possibility that there will be presence of vital loads that must be preserved. This problem should be taken seriously as the area that is isolated would affect the stability of the system. Thus, power system restoration should be conducted in order to solve this issue.

There are three phases in the power restoration which are black-start [1], network reconfiguration [2] and lastly load restoration. The most important part of the power system restoration is the load restoration stage which is the focus of this research.

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H Mohamad, Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450, Shah Alam, Selangor, Malaysia.

N Md Razali, Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450, Shah Alam, Selangor, Malaysia.

N A Salim, Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450, Shah Alam, Selangor, Malaysia.

Z M Yasin, Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450, Shah Alam, Selangor, Malaysia.

B N S Rahimullah, Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450, Shah Alam, Selangor, Malaysia.

The main objective of restoring the load is to stabilize the power system immediately after fault thus ensuring continuous power supply to the affected load [3]. Two main factors considered for load restorations are the restoration duration and the load size to be restored [3]. A good load restoration would have low restoration time interval with high amount of load to be restored. There are generally tie-lines (normally open switches) in the network which can be altered for optimal operation of the power system.

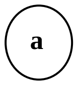
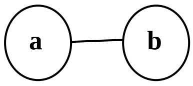
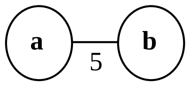
The existing load restoration technique can be categorized into two which are conventional and met heuristics techniques. Conventional method includes the application of ranking based method [4], mix integer programming [5] and also dynamic programming [6]. However, solving a load restoration problem by using mix integer programming is complicated as the power flow problem is a non-convex problem which also involve non-linear objective functions and constraints. Tabu Search [7], Genetic Programming [8], and Particle Swarm Optimization techniques [9][10] are the example of meta heuristics methods employed to solve the load restoration problem. The disadvantage of meta heuristics method is that there is no guarantee for optimality and different searching algorithm may result in different solution for the identical problem. Other methods are the Multi Agent System and the Minimum Spanning Tree (MST). Centralized controller for data process and decision making is applied in the load restoration problem in [11].

This paper discusses the application of MST technique through the Prim's algorithm in order to have a different approach to reconfigure the network for service restoration. Several case studies are carried out to find the minimal weighted path for power flow during load restoration service that contribute to minimum active power losses in distribution network .There are several cases which involve faults in the distribution system where Prim's algorithm is applied for the reconfiguration of the distribution lines. The effectiveness of this algorithm to solve the mentioned problem is justified by comparing the results obtained with the Binary Particle Swarm Optimization (BPSO) algorithm where both algorithms are applied on the IEEE 33-bus radial distribution network.

II. METHODOLOGY

Prim's Algorithm is one of the MST methods applied in load restoration problem to find the minimal weighted path for the power flow with minimum active power losses in the system. MST is the spanning weighted tree where it computes the cost between vertexes to be minimal among all of others spanning trees. It was reported that apart from this algorithm, others algorithm in MST such as Dijkstra [12], Kruskal [13] and Boruvka [14] were adopted for restoration of power supply. Table 1 show the symbols used in graph theory for the application of MST.

Table. 1 Symbols used in MST

Term	Meaning
	Node or Vertex (V)
	The joining line between these two vertices is called edges (E) and it is an undirected graph as there is no direction shown at the line.
	The edge carries what is called a weight, 7 between the two connected vertices.

Prim's Algorithm

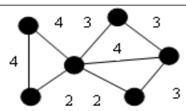
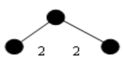
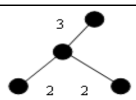
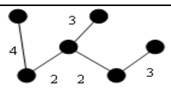
The Prim's algorithm was discovered by Vojtech Jarnik, a Czech Mathematician in 1930. After that, Robert C. Prim, a computer scientist further developed this algorithm in 1957 [15]. This paper uses one of the MST techniques and is applied using graph theory. Graph is formed by the edge that connects between two vertices [16]. A graph can be written as (V, E), whereby V is the set of vertices and E is the set of edges.

In this paper, the buses where the loads are installed symbolize the vertices and the line impedances that are connected between the buses symbolize the edges. The values of the line impedance represent the weight of the edges. The algorithm tends to choose the path that provide the minimum weight between the line impedances to restore the load. The restoration must consider the feeder to be the starting point without accounting the value of weight the line carries. The objective is to find the minimum losses for the power restoration. The constraints included are the system's voltage that must be within the acceptable range and the network must be radial at all time. Table 2 explains on the process required to obtain the MST.

The properties of the Prim's Algorithm are as follow:

1. A single tree must always be formed in the MST from the edges in thee subset.
2. All of the graph's vertices must be spanned and grow in the minimal path for the edges between the vertices.
3. In each step, new edges will be added to the tree if its weight is the minimum of any edge that is connected to the vertex of the graph.

Table. 2 MST techniques

Term	Meaning
	This is an example of a given network
	Firstly, choose any random vertex in the network
	Then, pick the shortest edge or lightest weight from the vertex.
	Choose nearest vertex that is not yet in solution
	Next, choose the nearest new vertex according to the choices of vertices.
	Lastly, repeat until minimum spanning tree is achieved.

Network Reconfiguration and Load Restoration

The Prim's and load flow algorithms are both written and integrated in MATLAB R201b script environment. Figure 1 show that the process initiates when the input data is obtained which consist of the test system's buses and lines data.

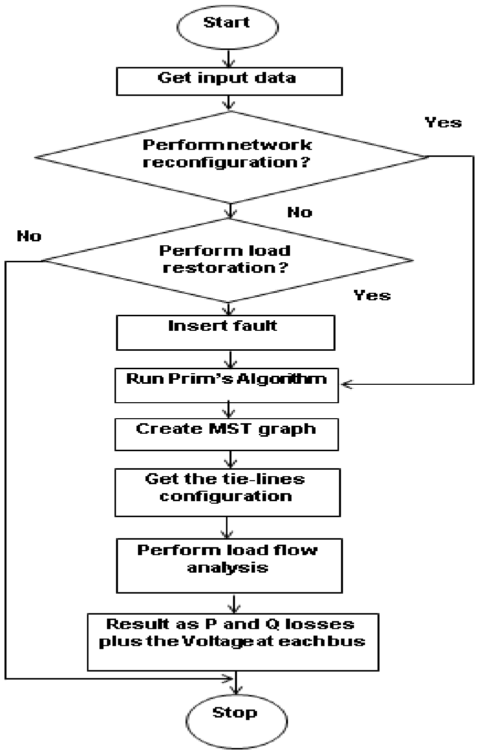


Fig. 1 Flowchart of network reconfiguration

The variables of the input data are set as such that the s (vertex 1-sending bus), t (vertex 2-receiving bus) and lastly the weights represents the line impedance value. Case studies in this research are the network reconfiguration and also the load restoration. If there is no requirement to perform the network reconfiguration, the step will be skipped to the load restoration case in which fault is inserted. Prim's algorithm is then executed to search for the minimal weighted path for both case studies with the objective to minimize the active power losses. The fault condition in this study is indicated by setting the value of weight which represents impedances of the lines to significantly high value [12].

The working principal of the algorithm is that it will choose the path that has the minimal total line impedance while a larger value is neglected by the algorithm. After faults have been inserted, the algorithm will create a MST graph showing the minimal path for the tie-lines configuration as shown in Figure 2. Lastly the load flow analysis is performed to analyse the active power losses, reactive power losses and the voltage at each buses.

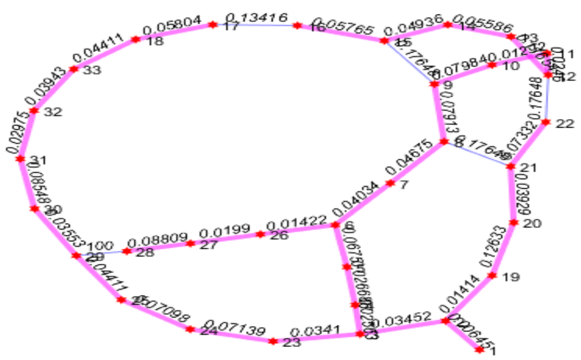


Fig. 2 Prim's algorithm switching configuration for S28

III. RESULTS AND DISCUSSIONS

The test system used in this study is the IEEE 33 bus radial distribution network as shown in Figure 3. The system's base voltage is 12.66 kV and base apparent power is 100 MVA [17]. In this system, there are 37 switches including 5 tie-lines with the amount of load is 3.715 MW and 2.295 MVar. The numbers of tie-lines are maintained before and after applying the algorithm. The bus network must also be maintained in the radial condition.

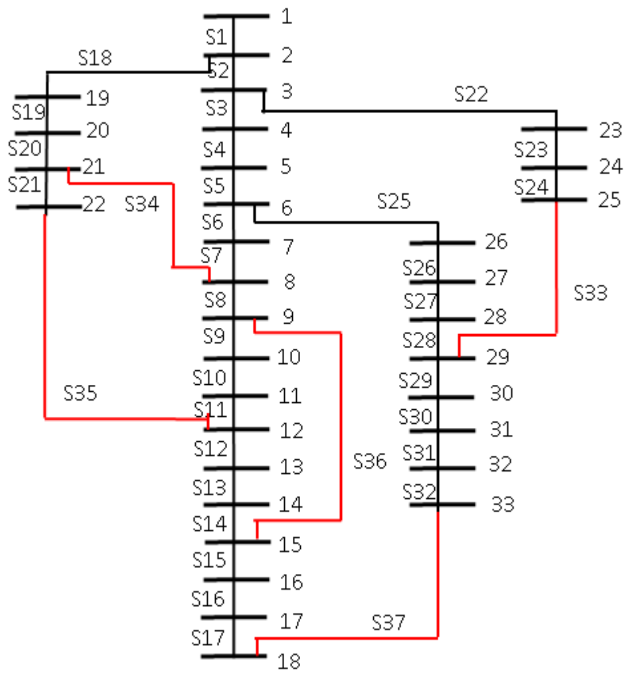


Fig. 3 33-bus network

Network Reconfiguration

The result for the network reconfiguration is as shown in Table 3. Comparison of result between the default tie-lines for the 33- bus network, Prim's algorithm configuration and BPSO algorithm is presented in the table. The default configuration has losses with the value of 0.202 MW and 0.135MVar which is higher than the other two methods.

Prim's algorithm produces lower power losses compared to the default case while BPSO has the lowest power losses for the network reconfiguration case. Other than that, the generation for the BPSO is lower than Prim's algorithm with the value of 3.854 MW with 2.397 MVar and 3.893 MW with 2.416 MVar respectively. However, time taken using Prim's algorithm is only 0.8571 seconds, which is faster than BPSO which requires 34.63 seconds to solve the network reconfiguration problem. BPSO requires more times to identify the optimum value of power losses.

Figure 4 shows voltage profile for the test system. For all cases, voltages are maintained above 0.9 p.u which is within the voltage range for power distribution system[17]. The lowest voltage is recorded at bus 18 for all cases. However, among all cases, base case voltage at bus 18 is the lowest compared to Prim's and BPSO which is 0.91 p.u.

Table. 3 Comparison between PRIM and BPSO

Algorithm		Base case	Prim	BPSO
Tie switches		S33,S34,S35,S36,S37	S16,S27,S33,S34,S35	S7,S9,S14,S32,S37
Generation	P (MW)	3.916	3.893	3.854
	Q (MVar)	2.429	2.416	2.397
Ploss (MW)		0.2024	0.1786	0.1393
Qloss (MVar)		0.1349	0.1218	0.1022
Time (s)		-	0.8571	34.6300

In summary, even though BPSO shows better result in terms of voltage and minimization of power losses as compared to prim's algorithm, the time taken to solve the network reconfiguration problem is significantly shorter in Prim's algorithm. In addition, the Prim's algorithm results show that it is able to maintain the voltage within acceptable limit.

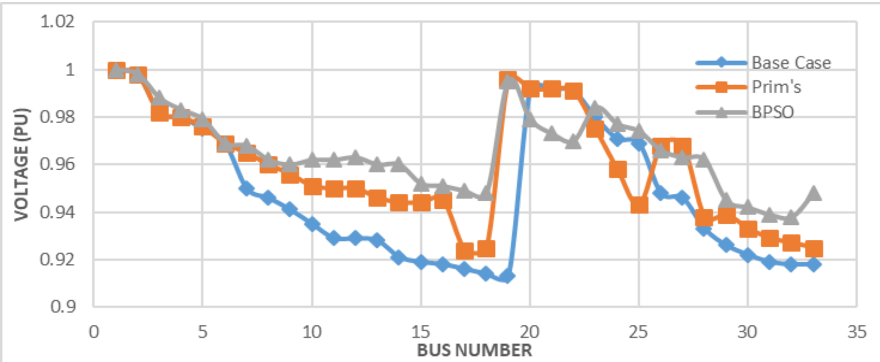


Fig. 4 Voltage profile at busses for network configuration using Prim's and BPSO

Load Restoration

Load restoration of a power distribution system is done by reconfiguring the tie-line when there is fault occurs in the system. The effective combination of opening and closing of the switches in the network results in different power losses and voltage magnitude.

Table. 4 Result for Single Line Outage

Outage line	Method	Switches				Power loss MW	Power loss MVar
S13	Prim	S27	S34	S35	S36	0.1971	0.1377
	Randomly switches	S25	S33	S34	S35	0.2072	0.1459
S21	Prim	S16	S27	S34	S36	0.1872	0.1275
	Randomly switches	S10	S27	S34	S36	0.2365	0.1701
S28	Prim	S16	S34	S35	S36	0.1757	0.1193
	Randomly switches	S8	S34	S35	S36	0.2415	0.1758

It is desirable to achieve the best combination of switches to be disconnected in order to have the minimum power losses while maintaining the system technical constraints. Table 4 shows the comparison in term of power losses between random switching combination and the combination produced by Prim's algorithm.

There are three cases of line outage which are at line S13, S21 and S28. In the first case, power loss for the Prim's algorithm is lower than randomly selected switches which is 0.1971 MW, 0.1377 MVar and 0.2072MW, 0.1459 MVar respectively. The configuration for Prim's are S13, S27, S34, S35 and S36 as the tie-lines while for the randomly selected switch are S13, S25, S34, S35 and S36. When fault occurs at S21, the configuration of switches for the Prim's algorithm is as shown in Figure 5(a) which provides lower power losses than in the randomly selected switches. Figure 5(b) shows the configuration for the randomly selected switch at fault S21. For the last case, the line outage at S28 result in the tie-lines combination of S28, S8, S34, S35 and S36 for the randomly selected switches with a higher losses value than Prim's algorithm i.e 0.2415 MW and 0.1758 MVar. Overall performances of these three cases of load restoration prove that the Prim's algorithm produce minimal path restoration with lower line losses compared to the randomly selected switches.

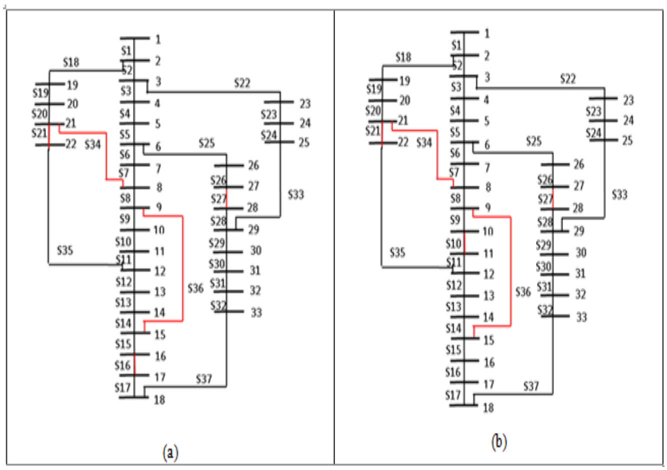


Fig. 5 Fault at S21: (a) Prim's configuration (b) Randomly selected configuration

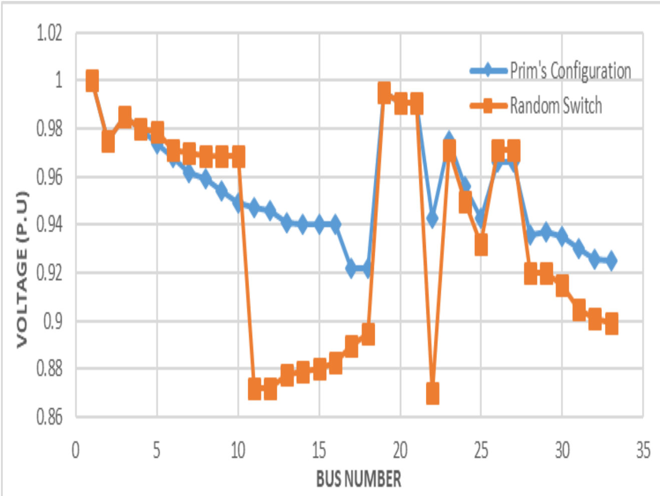


Fig. 6 Voltage profile at busses for network configuration using Prim's algorithm and random switch

The voltage profile for the fault case at S21 is shown in Figure 6. Randomly selected switch cause voltage to fall below 0.9 p.u while Prim's switching configuration is able to maintain the voltage above 0.9 p.u. In terms of overall voltage buses, Prim's configuration is identified to have a better voltage profile compared to randomly selected switches.

IV. CONCLUSION

Through this research, the minimal paths for load restoration have been identified by applying one of the MST techniques which is Prim's algorithm. The result showed that restoring a distribution network with minimal path lead to minimal power loss and also a more balanced voltage stability index. The time taken for the reconfiguration using Prim's algorithm was better than BPSO. In the load restoration part, Prim's configuration resulted lower power loss and also a better voltage profile when comparing with the configuration of randomly selected switch. This proved that this technique is indeed suitable for power system planning and operation to reduce switching and installation costs.

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