Performance Analysis of Graph Algorithms for Microgrid Protection

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***Abstract*—Microgrids are energy systems that consist of distributed energy sources and loads, which can operate in parallel with or independently from the main grid. The integration of renewable Energy System (RES) into microgrid causes the power flow to be bidirectional in nature. Reconfiguration of the microgrid could occur due to RES, load or utility grid connection or disconnection. Thus, conventional protection strategies are not applicable to microgrids and it is challenging for engineers to tackle any faulty issues. This paper proposes graph algorithms, such as the Kruskals and the Prim which aid in identifying the shortest path from a faulted point to the point of common coupling(PCC). Algorithms, such as Floyd Warshall and Djiktra's algorithms ensure that only minimum portion of the network is disconnected during fault clearance.**

***Index Terms*—Microgrid; Kruskals Algorithm; Prims Algorithm; Djikstras Algorithms; Floyd-Warshalls Algorithm; Microgrid Protection.**

I. Introduction

A microgrid is a small network with consumers supplied a local source of supply, which is usually connected to a centralized national grid that can function independently [1 - 5]. The development of renewable energy sources, energy storage devices and distributed generation (DG), has attracted a lot attention on microgrid. Microgrid is capable of working in two different modes of operation, which are grid connected mode and the islanded mode. If a micro grid is connected to the main grid, it is seen as a single aggregate load or source, but when it is connected in island mode, it caters to considerably smaller loads and energy sources. As a distributed generator placed closely to the load, it has the advantage of reducing transmission losses and preventing network congestions. Varying load demands a DG that can be connected or disconnected from the microgrid.In this case, reconfiguration of microgrid is triggered due to its dynamic nature.

There are some constraints to be met when the microgrid protection schemes are to be designed:

i. If the current level is low, both external and internal fault can be identified.
ii. If a fault exists in the utility grid, the microgrid starts to operate in the islanded mode.
iii. If a fault exists in the microgrid, the utility side consumers are not affected.

A graph theory based on algorithm is employed for the shortest path identification and finding the minimum path to clear a fault. This paper proposes some algorithms, such as Kruskal, Prims, Floyd Warshalls and Djiktras that assist in protecting reconfigurable microgrids. This can be done by identifying the current topology of network. If a fault occurs on this network, the above mentioned algorithms identify the shortest path from the fault to the energy source. This scheme ensures that minimum network disconnection is incurred in the process of protecting the microgrid. It also calculates the minimum time required to find the shortest path. Different algorithms run time are compared as well.

II. Shortest Path Identification Problem

The aim is to identify the distance from the point of fault to the nearest operating source, with the least portion of load being disconnected [6-11]. This can be presented as a minimization problem.

$$\min d = min(p)$$

where: d = distance from the fault point to the PCC
p = paths that exist between the fault point to the PCC

The shortest path identified from the network, which is obtained using the proposed algorithm should be a radial network. The proposed algorithm is a heuristic algorithm, which is based on nonmathematical rules.

III. Methodology

Kruskals and Prims algorithm are the graph theory concepts to evaluate and form a minimum spanning tree. For a grid, it uses low cost considerations and transfers the data quickly. The objective of the algorithms is to achieve a path that minimizes the edge cost.

For a graph with V vertices and E edges, Kruskals algorithms run in O(E log V) time and Prims algorithm can run in O(E + V log V) time. Prims algorithm is considerably faster in the limit if a dense graph is considered. Kruskals performance is better in sparse graphs because simpler data structures are used.

A system having 'N' members is considered for the analysis. If at any point of time, only the first 'X' nodes are functional, then a network is developed using connected active nodes. These active nodes are directly or indirectly connected to other participating nodes for good communication among them.

The paper discusses how Kruskals and Prims algorithms are used for identifying active nodes of network and how Dijkstras and Floyd-Warshalls algorithm are used to determine the shortest path for traversal. Prims and Kruskals algorithm form a database of active nodes of the system that generates the network. For the network, further Dijkstras and Warshalls algorithms are used to produce a sequence of traversal in the network to obtain not just low cost but also an effective path for operation.

For the electric grid, the edge weight is assumed to be unity. With 'N' active nodes in the network, the dimension matrix of size N X N is formed. For connected or disconnected node, the shortest distance is changed accordingly.

For the problem, the following properties should be true:

i. For all the vertices (a,b€V) ,'p' can be taken as the shortest path for traversal from a to b which uses its weight function w, if it is true for w^ as well.
ii. For all the edges the newly calculated weights must be positive.

A. Minimum Spanning Tree Algorithms

a. Kruskals Algorithm

i. Create F (a set of trees), where each vertex is a separate tree
ii. Create a set S, which contains all the edges of the graph.
iii. While S is non empty and F is not spanning,
    - Delete an edge from S with a minimum weight.
    - If the deleted edge connects two separate trees, then add it to F, to combine two trees into a single tree.

b. Prims Algorithm

i. Initialize a tree with a vertex, which is chosen randomly from the graph.
ii. Increase the tree by one edge to connect the tree to the vertices that are not yet in the tree. Find the minimum-weight edge and put it into the tree.
iii. Repeat step two till all the vertices are present in the tree.

B. Shortest Path Algorithm

a. Dijkstras Algorithm

i. Assign to each node an approximate distance value: zero for initial nodes and infinity for all others.
ii. Set initial node as current node and mark all others as unvisited, create an unvisited set.
iii. For a current node, consider all the unvisited neighboring nodes and calculate approximate distance. Compare the newly calculated distance to the current assigned value and assign the lesser one.
iv. If all the neighboring nodes of the current node are done, consider marking the current node visited and remove it from the unvisited set.
v. If the destination node is already visited, all the smallest distance among the nodes of the unvisited set is infinity, then stop.
vi. Else, choose the unvisited node marked with the smaller distance, set it to a new current node and repeat step three.

b. Floyd-Warshalls Algorithm

i. Start with all single edge paths,
ii. For i=1 to n, j=1 to n, choose the best distance from vertex i to vertex j as the weight.
iii. For k(intermediate vertex)=1 to n, i=1 to n, j=1 to n, if distance between vertex i and vertex k added to the distance between vertex j and k is less than the distance between vertex i and j, then it is a shorter path.
iv. Otherwise, distance between vertex i and j is the summation of distance between vertex i and k and distance between k and j.

IV. SIMULATION RESULTS

This paper analyzes 39 bus networks as shown in Figure 1. If a fault is present between bus 15 and 16, the possible paths for fault clearance are:

i. 24-16-15-14-4-3-2-1 (Weight=7)

ii. 24-23-22-21-16-15-14-4-3-2-1 (Weight=10)

iii. 24-16-15-14-12-11-6-5-4-3-2-1 (Weight=11)

iv. 24-23-22-21-16-15-14-4-3-2-1 (Weight=10)

The shortest path identified using the algorithms-Dijkstras, Floyd-Warshalls, Prims and Kruskals is as indicated in Figure 2. The shortest path involves 8 nodes and the weight of its path is 7. Uninterrupted power supply to the highest number of connected nodes is obtained using the proposed algorithms.

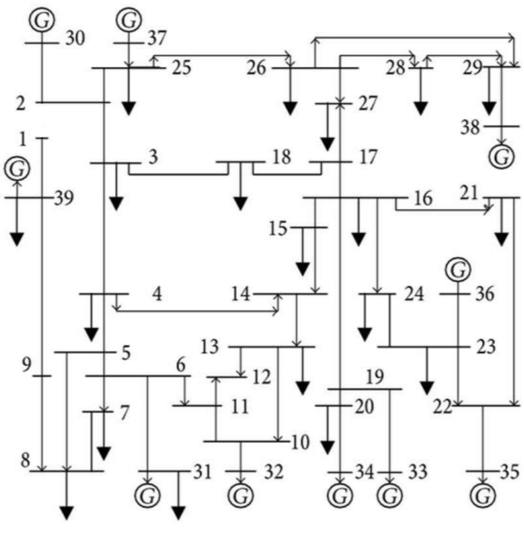

Figure 1: 39-bus distribution network

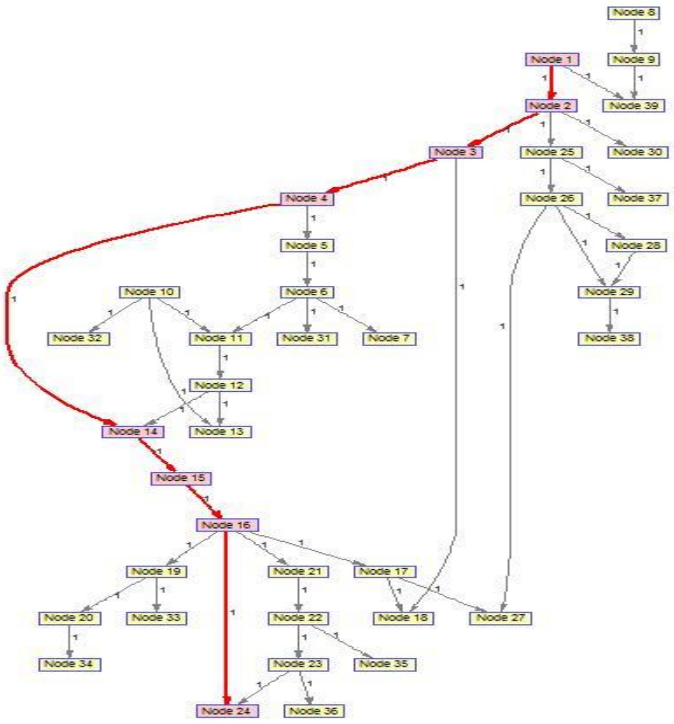

Figure 2: Shortest path identification

V. EXPERIMENTAL RESULTS

A generic code was developed using the proposed algorithms. Two different processors were used whose specifications are:

i. Intel(R) Core(TM) i5-4200U CPU @ 1.60GHz 2.30GHz, RAM 6.00GB, 64-bit operating system
ii. Intel(R) Celeron(R) CPU N2830 @ 2.16GHz 2.16GHz, RAM 4GB,64 bit operating system.

Table 1
Experimental results for active node algorithms using Intel i5 processor

Algorithm	Run Time (ms)
Kruskals	0.6661
Prims	0.6222

Table 2
Experimental results for active node algorithms using Intel Celeron processor

Algorithm	Run Time (ms)
Kruskals	1.6358
Prims	1.2572

In Table 1 and 2, the run time of spanning the tree algorithms-Kruskals and Prims are tabulated.

Table 3
Experimental results for shortest path algorithms using Intel i5 processor

Algorithm	Error Node	Run Time (ms)
Dijikstras	22	0.3201
Dijikstras	34	0.3383
Dijikstras	16	0.2930
Floyd-Warshalls	22	4.3686
Floyd-Warshalls	34	4.6399
Floyd-Warshalls	16	4.5474

Table 4
Experimental result for shortest path algorithms using Intel Celeron processor

Algorithm	Error Node	Run Time (ms)
Dijikstras	22	0.9030
Dijikstras	12	0.8016
Dijikstras	37	0.9231
Floyd-Warshalls	22	23.7663
Floyd-Warshalls	12	21.8058
Floyd-Warshalls	37	23.0790

In Table 3 and 4, the run time are tabulated for gthe shortest path algorithms -Dijkstras and Floyd-Warshalls for different fault locations.

VI. CONCLUSION

Conventional protection schemes are not applicable to the changing topology of a microgrid, which is a key challenge to protection engineers. Kruskals and Prims were used to determine the active nodes; Dijkstras and Floyd-Warshalls were used for identifying the shortest path from the fault point to the closest energy source. Due to this, the faulted segment was safely isolated from the healthy portion of the network, which may cause less number of consumer distribution. The proposed algorithms were tested on a 39 bus microgrid network. The results were validated using two different processors. For the chosen grid chosen, it is seen that for minimum spanning tree, Prims algorithm took less time compared to Kruskals algorithm. It was also observed that for shortest path, Dijskstra's algorithm took less time compared to Floyd-Warshalls algorithm. Only the minimum portion of the network is disconnected when the fault occurs. Thus, these algorithms may be used efficiently for larger microgrids.

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