Indonesian Journal of Electrical Engineering and Computer Science
Vol. 5, No. 3, March 2017, pp. 502 ~ 507
DOI: 10.11591/ijeecs.v5.i3.pp502-507

Active Node Detection in A Reconfigurable Microgrid Using Minimum Spanning Tree Algorithms

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Abstract

Microgrids are the solution to the growing demand for energy in the recent times. It has the potential to improve local reliability, reduce cost and increase penetration rates for distributed renewable energy generation. Inclusion of Renewable Energy Systems(RES) which have become the topic of discussion in the recent times due to acute energy crisis, causes the power flow in the microgrid to be bi-directional in nature. The presence of the RES in the microgrid system causes the grid to be reconfigurable. This reconfiguration might also occur due to load or utility grid connection and disconnection. Thus conventional protection strategies are not applicable to micro-grids and is hence challenging for engineers to protect the grid in a fault condition. In this paper various Minimum Spanning Tree(MST) algorithms are applied in microgrids to identify the active nodes of the current topology of the network in a heuristic approach and thereby generating a tree from the given network so that minimum number of nodes have to be disconnected from the network during fault clearance. In the paper we have chosen the IEEE-39 and IEEE-69 bus networks as our sample test systems.

Keywords*: minimum spanning tree, microgrid protection*

1. Introduction

Microgrid is defined as a cluster of small sources, storage systems, and loads, which presents itself to the main grid as a single, flexible, and controllable entity [1], [2]. IEEE Std 1547.4-2011 states Distributed Resource (DR) island systems or micro-grids as electric power systems (EPS) that include:

a. DR and load,
b. The ability to disconnect from and parallel with the area EPS,
c. The local EPS and may include portions of the area EPS, and
d. Intentionally planned.

Microgrid structure is a more independent form than the grid network by using the concept of bi-directional power flow, on-site generation and storage. They are capable of acting in two modes, the grid connected mode and islanded mode [3].

The microgrid when operated in grid connected mode supplies or draws power to the utility grid depending on the generation and demand from the load side. But the microgrid can shift to an islanded mode in emergency situations or in situation of a power shortage [4]. In such a situation the DGs in the network supply power to the loads. The bi-directional power flow in a microgrid forbids the existence of any specified protocol for fault rectification due to continuously changing configuration of the microgrid.

The Central Protection Centre (CPC) monitors the status of the DGs, loads and the utility grid in a microgrid system. In view of creating a protection system for the microgrid various constraints have been considered. At first, if fault exists within a micro-grid the utility side consumers should remain unaffected. Secondly, backup protection has been enabled for both grid connected and islanded modes of operation. Lastly, the selectivity and speed should be in an acceptable level. Communication assisted protection strategies are a common solution to protect the microgrid [5-9]. Common issues like sympathetic tripping, false tripping, blind zone, variation in fault levels and unwanted islanding are caused due to the impact of distributed generations [10].

Since the microgrid changes its configuration at every instant of time based on the load condition, there has to be an automatic system to detect the active nodes present in the grid at

Received September 2, 2016; Revised January 25, 2017; Accepted February 11, 2017

that instant of time. This is done by graph theory algorithms, namely the Minimal Spanning Tree algorithm (MST). The MST converts a complex grid into its simpler derivative- a tree, which can be analysed to find out the shortest path between a particular node and the root node. This is particularly important in case of microgrids as because in case of a fault the current has to flow back to the main grid by disconnecting the minimum number of nodes in the network.

In this paper the performance of multiple MST algorithms are analysed by applying them to the standard microgrid networks (IEEE-39, IEEE-69), and thereby identifying the best suited algorithm for the purpose of fault detection and rectification.

2. Research Method

2.1. The Active Node Detection Problem

In a microgrid system which consists of renewable energy systems(RES) not all nodes are active at the same time. In such a reconfigurable structure the size and number of nodes in the grid does not remain constant. To cope up with such a problem, the minimum spanning tree algorithm is employed on microgrids [18].

A graph may contain a number of trees formed but this algorithm generates a tree in which the distance between the source and the nodes are minimum. Thus the MST converts a cyclic graph to an acyclic tree and also aids in finding the shortest distance between the fault node and the source (main grid). If a node with a fault is identified, then the traversal from the fault node to the source up the MST will be the shortest path to be followed.

This paper applies Boruvka’s, Prim’s and Kruskal’s algorithms to identify the active nodes of the network. The performance of the algorithms are analysed and the best suited algorithm is selected for fault clearance in microgrid systems.

2.2. Boruvka's algorithm

Boruvka's algorithm was first introduced to construct an efficient electricity network for Moravia [19]. Boruvka's algorithm takes a graph G = (V,E). For each vertex v, the algorithm adds the edge with the smallest edge into the tree. If the edge is already added, the algorithm moves on to the next vertex. The algorithm then joins these islands to form the minimum spanning tree.

Pseudocode:

```
function borovka(G):
  T = forest of one-vertex trees (one for each vertex)
  while size of T > 1:
      for each tree t in T:
          S = {} (Empty set of edges)
          for each vertex in t:
             for each vertex v in t:
                  S union the cheapest edge originating from v which does not connect to any
vertex in the tree t
                      insert the cheapest edge of S in T
                      Merge all trees in T which are connected
  return T
```

Complexity: The outer loop of the algorithm runs O(log V) times. The inner loop runs at most once for each edge E. Therefore the algorithm runs in O(E log V). The algorithm however can be made to run in linear time for planar graphs by removing all but the cheapest edge between each pair of components after each stage of algorithm [20].

2.3 Prim’s Algorithm

Prim’s Algorithm is a greedy algorithm which starts with an empty spanning tree with an idea to maintain two sets of vertices. The first set contains the vertices already included in the MST, while the vertices not contained are included in the second set. At each step, the algorithm picks up the edges that connect the two sets and the minimum weight edge from these edges are picked. The end point of the edge picked is then moved to the set containing the MST.

Pseudocode:

```
function primMst(G)
        s = select a random node
        closed_set = {s}
        open_set = nodes adjacent to s
        n = number of vertices of G
        repeat n - 1 times
                u = node with least weight in open set
                remove u from open set
                add u to closed set
                add all neighbours of u to open set
        end
end
```

Complexity: Time Complexity of the above algorithm is O(V^2), where V is the number of vertices. If the input graph is represented using adjacency list, then the time complexity can be reduced to O(E log V).

2.4. Kruskal's Algorithm

Kruskal's Algorithm finds a safe edge to add to the growing forest by finding, of all the edges that connect any two trees in the forest, an edge (U,V), of least weight. It is a greedy algorithm as at each step it adds to the forest an edge of least possible weight [18]. Determining whether adding an edge is safe or not is done by checking whether it would form any cycles. This is done my recording the parent of each node in a tree of the forest. If the two nodes of the edge have the same root, then a cycle is formed.

Pseudocode:

```
function kruskalMst(G)
        E = set of all edges in G sorted according to weight
        n = number of vertices in G
        T = empty tree
        for each egde e in E
                if adding e does not cause a cycle in T then
                        add e to T
                end
        end
end
```

Complexity: O(ElogE) or O(ElogV).

3. Results and Analysis

3.1. Simulation Results

The Boruvka's, Prim's and Kruskal's algorithms are tested on a IEEE-39 bus and IEEE-69 bus distributed system. According to the concept of minimum spanning tree there can exist only one path from a particular node to the source [11-17]. This is possible only if the graph is converted to a tree. In the simulation result the shortest path is obtained by finding out only the predecessors of the fault node till the source node (1 in our case) is reached.

3.2. Experimental Results

Consider the IEEE 39 and 69 bus networks in Figure 1 and Figure 2. Let node 1 be the base node. Assume the fault occurs close to node 22 in both the networks. In the 39 bus network, the path length includes 11 edges, whereas in the 69 bus network it includes 20 edges. Table 1 shows the results for 100 iterations(in seconds) of the time taken to find the active nodes in the microgrid test systems.

In Figure 1 (the 69- bus system), the shortest path obtained after forming the MST is as shown in Figure 3. For a fault occurring close to node 22 the path is:

22->23->24->25->26->27->65->64->63->62->61->60->59->50->49->48->47->4->3->2->1

Weights :20 (assuming equal weights)

In Figure 2 (the 39- bus system), the shortest path obtained after forming the MST is as shown in Fig 4. For a fault occurring close to node 22 the path is:
22->23->24->16->15->14->4->5->8->9->39->1
Weights :11 (assuming equal weights)

Table 1. Empirical analysis of the various algorithms on 39 and 69 bus systems.

Algorithm	39 Bus Network		69 Bus Network	
	Time taken(ms)	Std. deviation(sec)	Time taken(ms)	Std. deviation(sec)
Prim	1.2	3.9936e-04	1.5	5.2912e-04
Kruskal	1.1	3.8664e-04	1.2	5.0328e-04
Boruvka	1.2	3.9566e-04	1.3	5.1299e-04

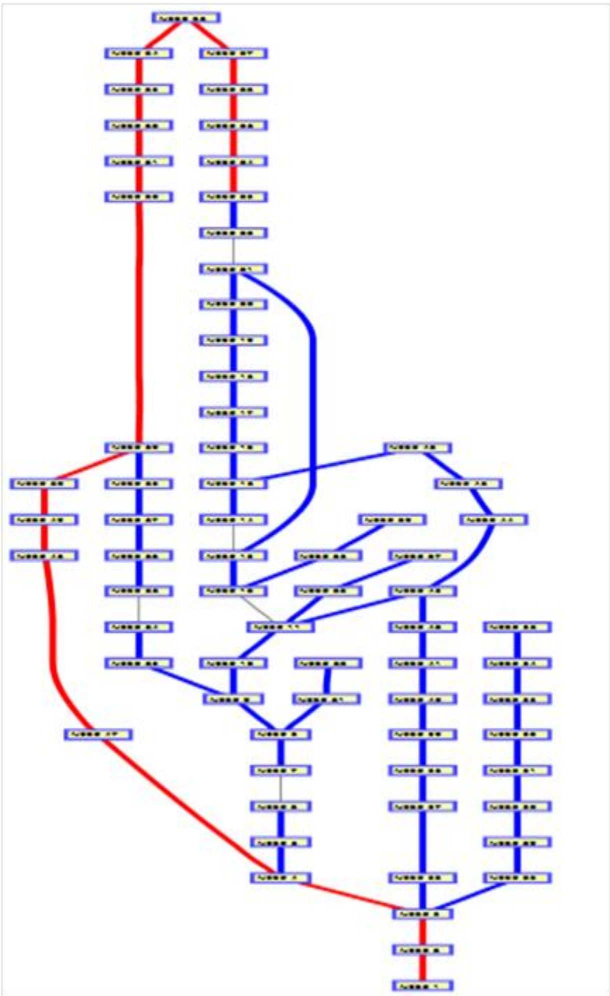

Figure 1. IEEE 69 bus distributed network

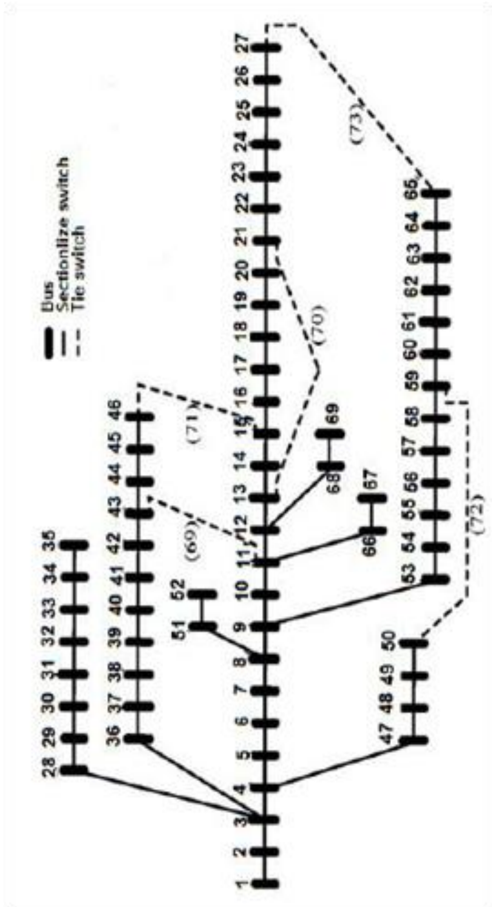

Figure 3. Simulation Result for shortest path identification on 69 bus network

The application of algorithms to microgrids thereby aids in identifying the active nodes of the reconfigurable network at that instant of time. From the results in Table 1 it is identified that application of Kruskal's algorithm takes minimum time to find the MST and in turn identifies the shortest path for fault clearance which may cause minimum load disconnections in

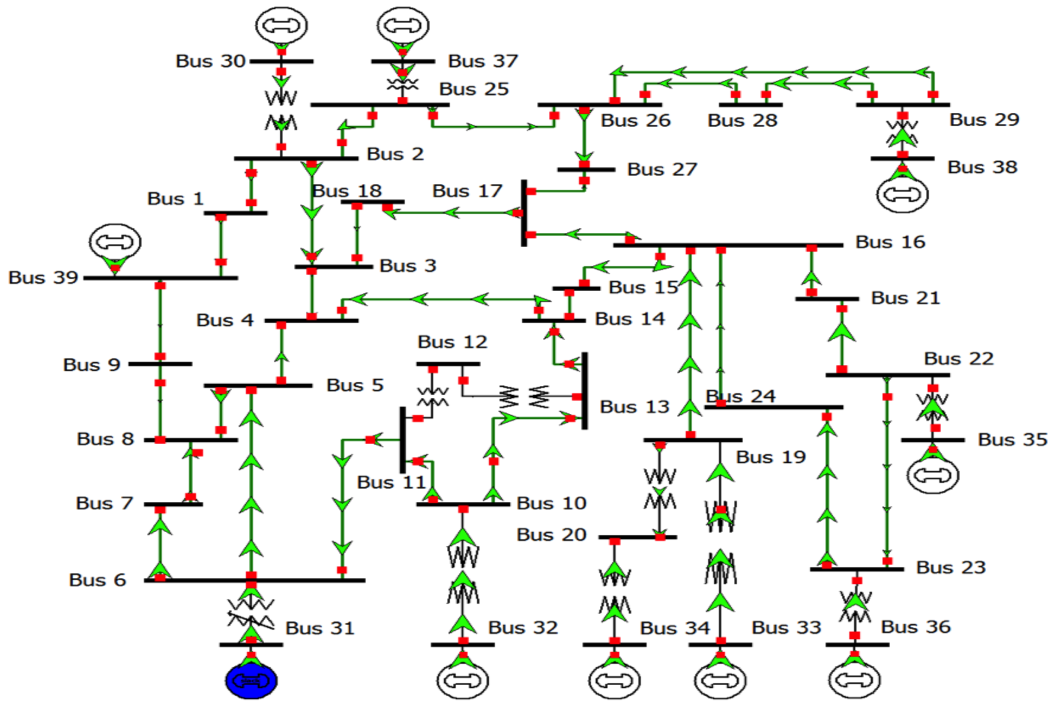

Figure 2. IEEE 39 bus distributed network

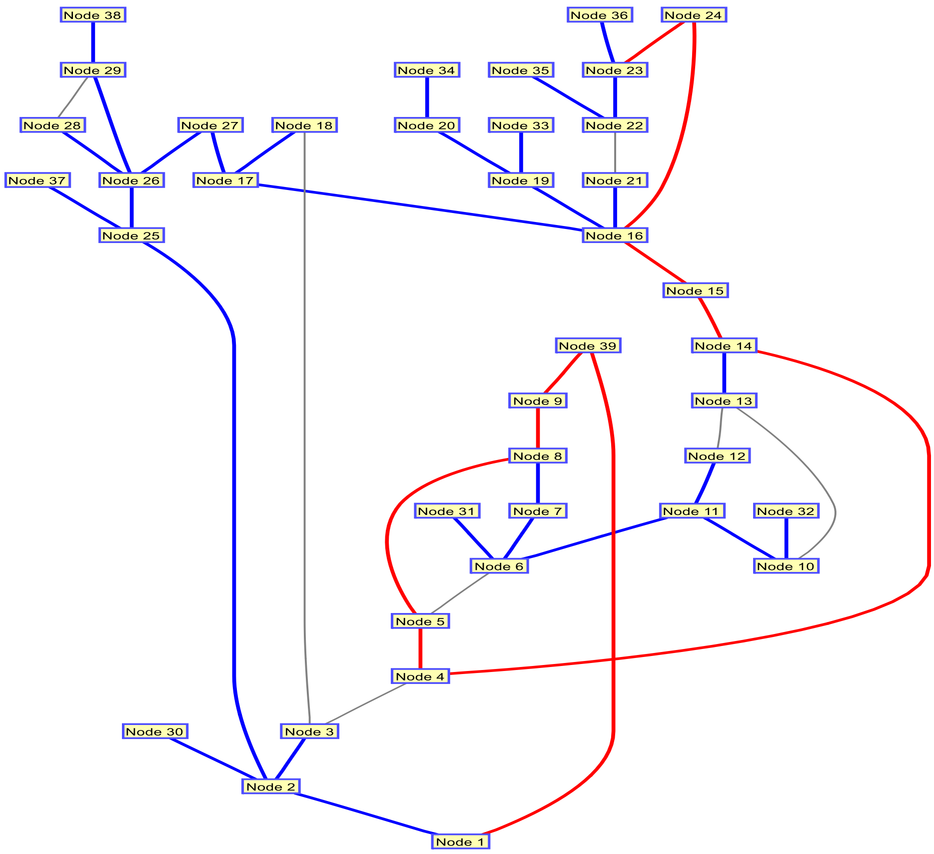

Figure 4. Simulation Result on the 39 bus network with fault at node 22

4. Conclusion

Fault clearance in a hybrid microgrid is quite a challenging task for protection engineers due to continuous reconfiguration of the grid. Thus it is necessary to rely on automatic computerised systems to solve such issues. This paper employs minimum spanning tree algorithms on IEEE-39 and IEEE-69 bus microgrid networks conveniently to identify the active nodes of the network which eventually generates the shortest path from the faulted point to the nearest operating source. The validations prove that the algorithms can be employed on any microgrid network and may cause minimum load centre disconnection. Based on the experimental results that have been employed it is confirmed that even microseconds of delay in disconnection of a faulted portion from the main grid can cause severe damage to appliances. Keeping this in mind Kruskal's algorithm can be suggested as a suitable algorithm for finding out the minimum spanning tree in a connected graph.

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