Hybrid Borůvka - Johnson’s Algorithm for Shortest Path Identification in Reconfigurable Microgrids

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Abstract—**The concept of microgrid is implemented on a large scale in the present distribution system. Reconfiguration in microgrid predominantly occurs due to connection and disconnection of the distributed generators (DG) and loads. Due to frequent topology changes, conventional protection schemes may not be applicable in microgrid for efficient fault clearance. This paper proposes a Hybrid Borůvkas - Johnsons’s algorithm which detects the shortest path between the fault and the point of common coupling. This ensures that minimum portion of network disconnection occurs during fault clearance. This algorithm is tested and validated on 30-bus standard microgrid network.**

***Index Terms*—Microgrid Protection; Johnson’s Algorithm; Borůvka's Algorithm.**

I. INTRODUCTION

Microgrids are smaller local grids with a number of distributed energy sources and loads. They may operate with the central power system or autonomously to avoid the grid disturbances from hindering supply to the customers [1-4]. These two modes of operation are called grid connected mode and islanded mode respectively [5]. In grid connected mode, the supply from the central utility grid is used to cater to the load demand of the users. The microgrid switches to the islanded mode of operation during the occurrence of a fault or major disturbance in the utility grid. In this case, the distributed energy sources operate to meet the current load demand. Such unpredictable change in the network causes reconfiguration of the microgrid system. Thus, at any instant of time, the system topology is dynamic and undeterminable. The nature of the power flow is bidirectional and in turn increases the complexity of the calculations and parameters to be considered for implementing the suitable protection schemes.

To overcome the dynamic nature of microgrid, a central protection controller which constantly monitors the parameters of the system and triggers the necessary control signals incorporated. Communication assisted protection strategies are a common solution to protect the microgrid [6-9]. Regular issues like false tripping, blind zone, deviation in fault levels and unwanted islanding are caused due to the impact of distributed energy sources in microgrid. The following points indicate the constraints that must be satisfied by the microgrid protection scheme [10]:

i. For low fault current levels, external and internal fault identification is possible.
ii. If fault prevails in the utility grid, the microgrid instantly operates in islanded mode.
iii. If faults exist within the microgrid, the utility side consumers are unaffected.
iv. Primary and backup protection is available for both grid connected mode and islanded modes of operation.
v. Selectivity and speed should be in acceptable levels.

A graph theory based algorithm is suitable for quicker shortest path identification in the microgrid. This paper proposes a novel hybrid Borůvka-Johnson’s algorithm that detects the current topology of the microgrid system. On occurrence of a fault at any point in the network, Johnson’s algorithm identifies the shortest path to isolate the fault. In the process of protecting the microgrid, this scheme ensures that minimum network disconnection is incurred.

II. SHORTEST PATH IDENTIFICATION PROBLEM

The main objective is to identify the distance from the point of fault occurrence to the nearest operating energy source, with minimum portion of load center disconnection. This can be formulated as a minimization problem:

$$min\, d = min\,(P) \qquad (1)$$

where:
d distance between faulted point to point of common coupling
P paths that exist between faulted point to point of common coupling

subjected to the constraint that the shortest path identified from the network using the proposed algorithm should be a radial network [11].

III. METHODOLOGY

Borůvka's algorithm is an old but effective graph theory concept based on the greedy algorithm to produce the minimum spanning tree by analyzing the network. A significant advantage of the Borůvka's algorithm is that it might be easily parallelized, enabling quicker detection and spanning of the network, considering its dynamic nature. The algorithm tries to determine the path for which the sum of weights of all the edges in the tree is the minimum.

It has a time complexity is $O\ (log\ V)$, where:
V number of vertices
E number of edges connecting the vertices

The algorithm begins by first examining each vertex and adding the least cost edge from that vertex to another in the graph, irrespective of the already added edges, and continues joining the grouped edges in a similar fashion until a tree spanning all vertices is formed.

In this paper, implementation of the Borůvka's algorithm to the microgrid network aids in identifying the current topology of the network. The Johnson’s algorithm is implemented on the current topology of the network to identify the shortest path from a faulted point to the point of common coupling. The Borůvka's algorithm generates all the possible paths between every node in the system. This network is further utilized by Johnson’s algorithm to produce the efficient and low cost path, affecting the minimum number of users.

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In this paper, implementation of the Borůvka's algorithm along with the Johnson’s algorithm to discover the shortest path to traverse from one node to other for immediate fault clearing is discussed. The Borůvka's algorithm generates all the possible paths between every node in the system. This network is further utilized by Johnson’s algorithm to produce the efficient and low cost path, affecting the minimum number of users.

For an electrical grid, loads (L), utility grid (UG), DG sources and the common point of coupling (PCC) are assumed to be the active nodes. Also we assume the edge weight as ‘1’. If ‘N’ is the number of active nodes in the network, then a dimension matrix of size N X N is built.

For a node connected or disconnected, the shortest distance is updated accordingly. For the problem under consideration, we consider the utility grid as the base node and for any alterations in the grid, the change is directed to the base node. For the problem, there are two properties that must hold true in order to evaluate the shortest path for a network.

i. For all vertices a,b ϵ V, ‘p’ can be considered as the shortest path for traversal from a to b using its weight function w, only if it holds true for w^ as well.
   Where $w^\wedge(a,b) = w(a,b) + Dist[a] - Dist[b]$
ii. For all edges (a, b), the new calculated weights must be non-negative.

Johnson’s algorithm is ideally employed in sparse, edge weighted, directed graphs. The Bellman-Ford algorithm is first used to transform the input graph in order to remove all the negative weights. The Johnsons algorithm incurs a time complexity of $O\ (|V|2\ log\ |V|\ +\ |V||E|)$.

The proposed hybrid Borůvka-Johnson’s algorithm is tested on 30 bus microgrid network shown in Figure 1. The microgrid is assumed to be in grid connected mode. The active nodes of the network include utility grid, distributed generators and loads at any instant of time. Let all the nodes be connected in the microgrid after a reconfiguration. Let the edges assume a value of ‘1’.

The Borůvka algorithm generates the list of active nodes of the network to be:

Utility Grid:
  UG
Distributed Generators:
  DG1, DG2, DG3, DG4, DG5, DG6, DG7, DG8, DG9
Loads:
  L1, L2, L3, L4, L5, L6, L7, L8, L9, L10, L11, L12, L13, L14, L15, L16, L17, L18, L19, L20, L21, L22, L23, L24, L25, L26, L27,L28 ,L29, and L30.

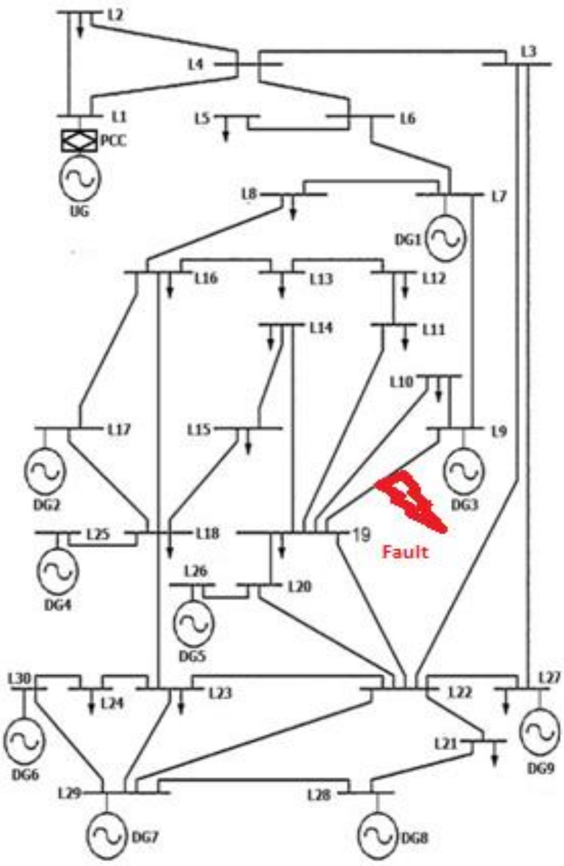

Figure 1: 30 bus microgrid network

IV. SIMULATIONS RESULTS

Table 1 gives the shortest path from a faulted point to the utility grid, assuming that the microgrid is in grid connected mode.

Let a fault be initiated as indicated in Figure 1. The shortest path from faulted point to UG is identified using Johnson’s algorithm as Node 19-9-7-6-4-1.

The same is indicated in Figure 2.

Table 1
Shortest path between faulted point to UG

Node closer to fault	Distance	Shortest path
DG2	6	17-16-8-7-6-4-1
DG4	7	25-18-16-8-7-6-4-1
DG6	9	30-24-23-18-16-8-7-6-4-1
DG7	4	29-22-3-4-1
DG8	5	28-21-22-3-4-1
DG9	3	27-3-4-1
L1	1	L1-UG
L2	2	L2-L1-UG
L4	2	L4-L1-UG
L3	3	L3-L4-L1-UG
L5	3	L5-L4-L1-UG
L6	3	L6-L4-L1-UG
L7	4	L7-L6-L4-L1-UG
L8	4	L8-L6-L4-L1-UG
L16	5	L16-L8-L6-L4-L1-UG
L27	4	L27-L3-L4-L1-UG
L22	4	L22-L3-L4-L1-UG
L21	5	L21-L22-L3-L4-L1-UG
L28	6	L28-L21-L22-L3-L4-L1-UG
L29	5	L29-L22-L3-L4-L1-UG

V. CONCLUSIONS

Conventional protection schemes are not suitable for microgrid due to bi-directional power flow, changes in topology of network and variation in fault current magnitude in the system. This paper proposes hybrid Borůvka-Johnson's algorithm that identifies active DGs, loads and utility grid (if any) in the network. In the event of fault occurrence in the microgrid network, the algorithm provides the shortest path from the faulted point to the utility grid to clear the fault effectively. Thereby effective isolation of faulted segment from the healthy portion of network is attained. The proposed algorithm is tested and validated on a 30-bus microgrid network. It is witnessed that only minimum portion of network disconnection occurs during fault clearance. Thus this novel hybrid Borůvka-Johnson's algorithm maybe extended to larger microgrids conveniently.

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JOHNSON'S ALGORITHM:

Step 1: A graph is considered G (V, E, w), where 'V' is number of vertices (nodes), 'E' is number of edges and 'w' is edge weight. A new vertex 's' is created. Now with 's' as the source, the distances for each vertex 'v' is:

$$\text{Dist}(v) = \begin{cases} 0 & \text{if V is source} \\ \infty & \text{If V is not a source} \end{cases}$$

Step 2: Taking D[i] as the distance matrix, I is iterated from 1 to (|V|-1), for each edge (a, b) with edge weight w

```
    if (Dist[a] +w<Dist[b]),
            update Dist[b] =Dist[a] +w
    else if (Dist[a] +w>Dist[b]),
            implies the graph contains negative weight cycle.
    return;
```

Step 3: The new weight for each edge (a, b) is updated as w + Dist [a]-Dist[b]

Step 4: Vertex 's' is then removed.

Step 5: Distances for each vertex 'v' are re-initialized as:

$$\text{Dist}(v) = \begin{cases} 0 & \text{if V is source} \\ \infty & \text{If V is not a source} \end{cases}$$

Step 6: A previously unvisited vertex 'k', with minimum distance value from the source vertex is then picked and the distance values of all adjacent vertices are then updated. For updating, iteration through all vertices is done with respect to every adjacent vertex 'm'.

```
    if (Dist[k] +w (k, m) < Dist[m]) then
        Dist[m] = Dist[k] +w (k, m)
```

Step 7: The above step is repeated till all the vertices are visited. The visited vertices are saved to get the shortest path.

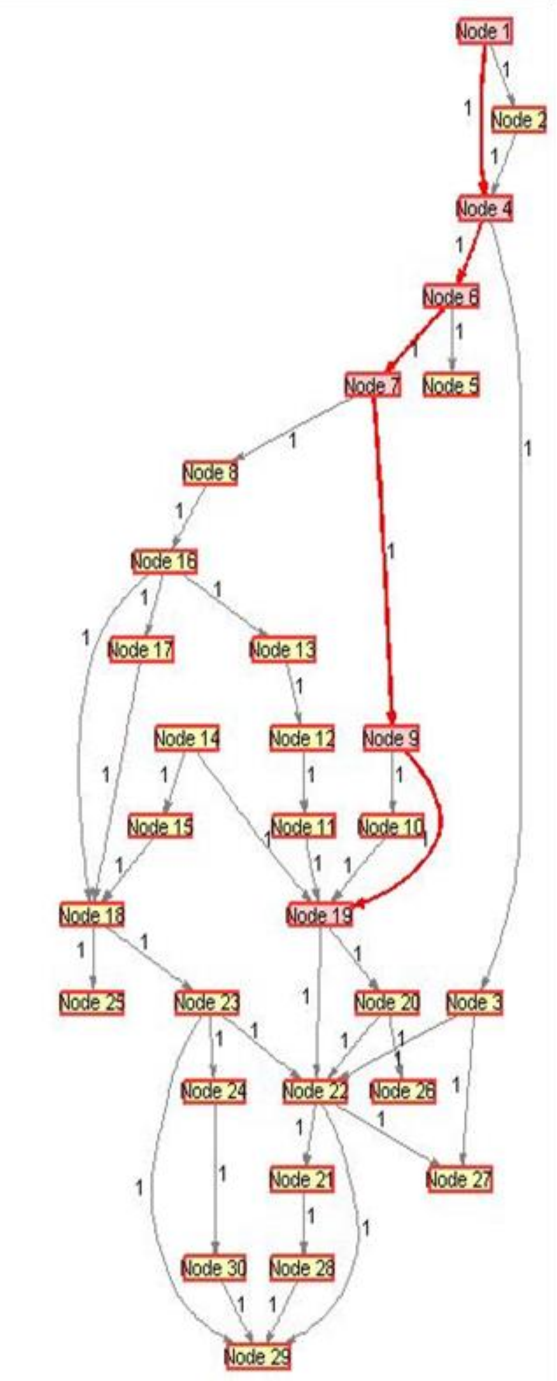

Figure 2: Shortest path identification for a fault between node 19 and node 9 in 30 bus microgrid network