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# KRUSKAL AIDED FLOYD WARSHALL ALGORITHM FOR SHORTEST PATH IDENTIFICATION IN MICROGRIDS

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**ABSTRACT**

Microgrids are indispensable at the distribution level network. Integration of Renewable Energy Systems (RES) with microgrid is the solution to effectively cater the need of customers. The dynamic behavior of microgrid poses a challenge while applying suitable protection strategies. In this paper, Floyd Warshall algorithm is employed to identify the shortest path to clear the fault in a microgrid network, taking into account its current topology. The Kruskal algorithm aids the Floyd Warshall algorithm in identifying the active nodes (Distributed Generators (DG), utility grid, loads and point of common coupling) of the current microgrid topology. The novel algorithm is tested on IEEE standard distribution test systems, with DGs included at certain buses. The proposed algorithm assists in adaptively setting the relay coordination for the microgrid.

**Keywords:** microgrid, distribution system, protection strategies, Floyd Warshall, Kruskal.

## INTRODUCTION

Renewable Energy Sources integrated with distribution network is the solution for the ever increasing power demand of the society. The depletion of conventional sources has increased the penetration of distribution generators (DG) in the distribution network. Microgrid is a distribution level network which is an aggregate of generators, including RES, loads and storage devices. It acts as a consolidated load or source with respect to the main grid. It operates in a grid connected mode or islanded mode. When there is a fault in the utility grid, the microgrid is said to act in islanded mode. In this scenario, the distributed energy resources (DER) supply the demand in the microgrid.

One major challenge in a microgrid is the bidirectional power flow due to the sources at the distribution end, where in the conventional protection schemes may fail [1]. Communication based digital relay scheme is used to protect the microgrid. This assists in detecting and clearing all faults instantly including high impedance faults (HIF) with current of at least 10% of the nominal current, at all feeders [2]. For microgrid protection, the IEC61850-7-420 communication protocol [3] and some data maps are efficiently used. For low-voltage microgrids, microprocessor-based relays are employed for handling protection issues by taking into account both the mode of operation and the magnitude of fault current. This protection strategy does not call for any communication devices [4]. A real time protection controller is used to identify two parameters namely the DG impact factor and relay hierarchy detection. This concept involves less human intervention and is robust [5]. Conflict in implementing the conventional distribution protection scheme in a microgrid is highlighted and the need for change in existing protection strategy to accommodate extensive penetration of DG is analyzed [6]. Decentralization is the key to current microgrid protection, since selectivity issues occur as the number of DG's increase in the microgrid network. The DG's are connected or disconnected frequently, which lead to false tripping and relay coordination issues. To overcome the selectivity issue which in unaddressed, a novel approach is suggested in this paper. However, graph theory algorithms [7-9] are used for various power system applications. In this paper, the proposed Kruskal aided Floyd Warshall algorithm, clears the fault in the microgrid by disconnecting a minimum faulted portion of the network. Kruskal algorithm helps to identify the active nodes of the microgrid network, which may vary due to the dynamic behaviour of network. Floyd Warshall algorithm identifies the shortest path that exists from the point of occurrence of fault to the nearest source. The proposed algorithm adaptively coordinates relays in the microgrid network.

Shortest path identification problem

Few common reasons that trigger the dynamic behavior of microgrids are adding new DG or load, occurrence of fault in the network, islanded operation and reconfiguration for reasons such as maintenance. The network topology of the microgrid changes due to its dynamic behavior. The relay coordination for each topology of the network must adapt itself to the changes.

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

$$\min d = \min (P) \tag{1}$$

subjected to the constraint that the shortest path identified from the network using the proposed algorithm should be a radial network. The proposed Kruskal aided Floyd Warshall algorithm, is a rigorous algorithm with mathematical proof in which the optimal solution is based on the conditions and assumptions that are applied. If the

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run-time is 't' and infinite, the time complexity of Kruskal algorithm is O ($t^2$). The algorithm incurs a worst-case runtime of O ($t^3$) for graphs with n vertices. The time complexity of this algorithm maybe overlooked because of its simple data structure. The shortest path problem may be solved using Dijkstra, the Double-Sweep and the Dantzig algorithms. But these are heuristic algorithms [10] that identify optimal solution based on some non-mathematical rules.

## METHODOLOGY

In this paper, the proposed Kruskal aided Floyd Warshall algorithm is used to identify the minimum spanning tree from the point of fault to the nearest operating source in the microgrid network. Floyd-Warshall algorithm is a graph theory algorithm that identifies the shortest path in a weighted graph with positive or negative edge weights. It assists in determining transitive closure of a relation R. The Floyd - Warshall algorithm derives all possible paths through the graph between each pair of vertices. It compares the paths that exist between each pair of vertices until an optimal shortest path between two vertices is achieved.

**FLOYD WARSHALL ALGORITHM:**

A network N (V, A) is considered with 'i' and 'k' as any two nodes in the network N. The network has:

- node set V = {1, 2, . . . , n}
- arc set A = {(i, k) : i, k ∈ V, i != k} where |V| = n
- minimum of one cycle in the network

The square matrices $D_j$ and $R_j$ for j = 0. . . n are calculated, holding the shortest path weights and the shortest routes between 'i' and 'k', respectively.

Step 1. The network comprises of 'n' nodes and 'j' stage number. Two square n × n matrices, $D_j$ and $R_j$ are formed.

Step 2. For j = 0 calculate $D_0$ and $R_0$:

$D_0 = [d_{ik}]$, where

$$d_{ik} = \begin{cases} d_{ik} \text{ when a direct path connects node i and k} \\ \infty \text{ when no direct path connects node i and k} \\ 0 \text{ when i and k are the same nodes} \end{cases}$$

$R_0 = [r_{ik}]$, where

$$r_{ik} = \begin{cases} \text{k when a direct path connects i and k nodes} \\ \text{- when no direct path connects i and k node} \\ \text{- when i and k are the same nodes} \end{cases}$$

Step 3. For j = 1, . . . , n, $D_j$ and the $R_j$ matrices are computed as indicated. $D_j$ and the $R_j$ matrices are now derived on the basis of the entities of the last matrices computed, i.e. the $D_{j-1}$ and the $R_{j-1}$ matrices:

$D_j = [d_{ik}]$ where

$$d_{ik} = \begin{cases} d_{ik} \text{ when } i = k = j \\ \min(d_{ik}, d_{ij} + d_{jk}) \text{ otherwise} \end{cases}$$

$R_j = [r_{ik}]$ where

$$r_{ik} = \begin{cases} k \text{ when } i = k, i = j, k = j \\ k \text{ when } d_{ik} \leqslant d_{ij} + d_{jk} \\ j \text{ when } d_{ik} > d_{ij} + d_{ik} \end{cases}$$

Step 4. If $D_n$ and $R_n$ are not arrived, then Step 3 is performed again; else the algorithm terminates.

### Kruskal aided Floyd Warshall algorithm

Kruskal algorithm is a greedy graph theory algorithm. It aids in identifying a minimum spanning tree (i.e. active nodes) from a connected weighted graph. A tree, which is a subset of edges that traces through every node in the network, is found. The constraint involved is that the sum of weight of all the edges is minimized in the tree. In case of unconnected graph, this algorithm works on each connected component and defines its minimum spanning tree. This strategy is employed with Floyd Warshall algorithm for active node identification of the network. Consider the 5-bus microgrid network shown in Figure-1(a). Assume that all the loads, DG's, utility grid and point of common coupling are the active nodes. This network has 12 active nodes and 11 edges. The weight of each edge is assumed to be '1'.

The cost adjacency matrix of the graph acts as the input to the Kruskal algorithm. Based on the active nodes,

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the matrix dimension is 12 x 12. The shortest distance between any two nodes in the original network is denoted in this matrix, which is automatically updated at the microgrid protection centre, whenever a node is connected or disconnected from the network. The Kruskal algorithm generates the list of active nodes in the network as UG, PCC, DG1, DG2, L1, L2, DG3, L3 DG4, L4, L5 and DG5. If the microgrid is in the grid connected mode, then the utility grid is considered as the base node. The path and distance parameters from any node of consideration are derived with reference to the utility grid (UG). Once active nodes are identified, the Floyd Warshall algorithm is employed to identify the shortest path from faulted point to the utility grid. The shortest path from various faulted points to the utility grid of the 5-bus microgrid network shown in Figure-1(a) is indicated in Table-1.

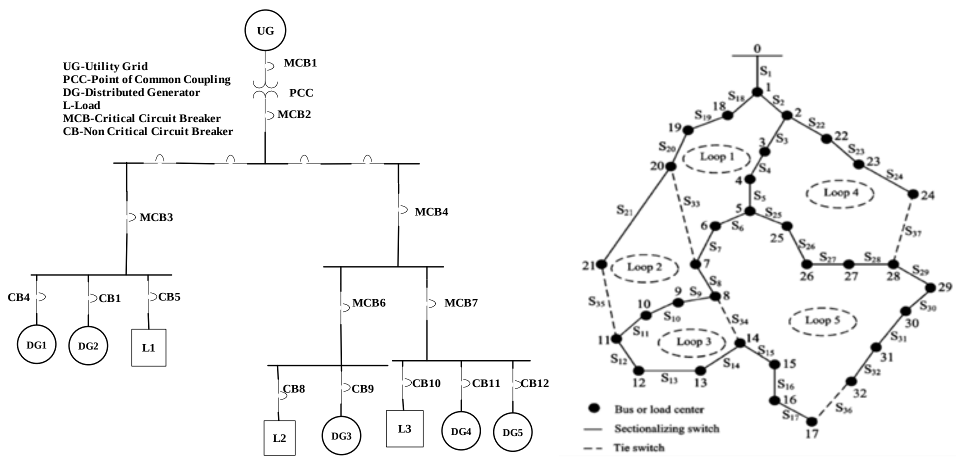


**Figure-1.** (a) Graph of grid connected 5-bus microgrid network; (b) IEEE 33-bus distribution network.

## SIMULATION RESULTS

A 33-bus IEEE standard distribution network is considered [11] in Figure-1b. DG's could be introduced at any node in the network. Assume a fault is triggered in feeder connecting bus 31 and bus 32. The paths that exist between the faulted point to utility grid are:

32-31-30-29-28-24-23-22-2-1-33(node 33 i.e. Utility Grid);
32-31-30-29-28-27-26-25-5-4-3-2-1-33;
32-17-16-15-14-8-7-6-5-4-3-2-1-33;
32-17-16-15-14-13-12-11-10-9-8-7-6-5-4-3-2-1-33;
32-17-16-15-14-13-12-11-21-20-7-6-5-4-3-2-1-33;
32-17-16-15-14-13-12-11-21-20-19-18-1-33.

The shortest path from bus 32 to the utility grid is identified using Floyd Warshall algorithm as shown in Figure-2. This path involves a total of 11 nodes. The path identified from bus 32 to the utility grid using conventional protection scheme is indicated with dotted lines in Figure-2. This path involves a total of 14 nodes. Hence the proposed algorithm is tested and validated to ensure that the smallest portion of network is disconnected when a fault occurs, unlike the conventional protection schemes which may cause discontinuity in supply for many consumers.

The topology of the IEEE 33-bus distribution network changes due to its dynamic behavior. For fault at any location, the shortest path for fault clearance with minimum load center disconnection is identified and validated using the proposed algorithm. The novel algorithm aids in adaptively setting the relay coordination of the network. The scalability of the algorithm is reflected by a time complexity ranging from O ($t^2$) to O ($t^3$).

## CONCLUSIONS

Decentralized energy eliminates the threat to protection issues in power system distribution network. The non-heuristic Kruskal aided Floyd Warshall algorithm is employed to identify the shortest path to clear the fault in a microgrid network, which may be reconfigured periodically. This novel algorithm is tested and validated on IEEE 33-bus distribution network and a 5-bus microgrid network with DGs connected at specific buses.]

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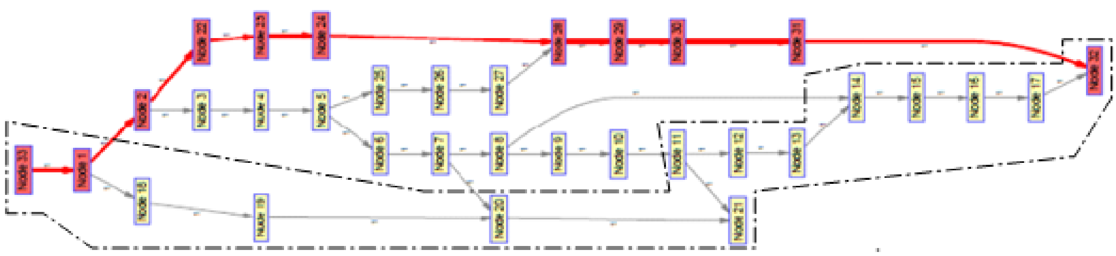
**Table-1.** Shortest path identification using Kruskal aided Floyd Warshall algorithm.

| Node closer to faulted point | Distance | Shortest path |
|---|---|---|
| PCC | 1 | PCC-UG |
| L1 | 2 | L1-PCC-UG |
| L2 | 2 | L2-PCC-UG |
| L3 | 2 | L3-PCC-UG |
| L4 | 3 | L4- PCC-UG |
| L5 | 3 | L5- PCC-UG |
| DG1 | 2 | DG1-PCC-UG |
| DG2 | 2 | DG2-PCC-UG |
| DG3 | 2 | DG3-PCC-UG |
| DG4 | 2 | DG4-PCC-UG |
| DG5 | 2 | DG5-PCC-UG |



Shortest path identification using proposed algorithm
Path identification using conventional protection schemes

**Figure-2.** Shortest path for fault clearance in an IEEE 33-bus distribution network.

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