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Optimal Source Placement in a DC Microgrid Considering Line Losses and Cables Weight

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Abstract—This research paper presents a methodology for optimizing the placement of an electric single source in a DC islanded microgrid mesh network with the aim of minimizing line losses while considering minimal cables weight. The paper utilizes the Dijkstra algorithm (a graph algorithm used in Google Maps) to identify the shortest path between a potential source node and all other variable loads in a predefined electric distribution mesh network topology. The resulting optimal placement of sources is ordered based on their corresponding line losses and optimal cables weight. Connected nodes in the mesh network are predefined, but lines optimal resistances are computed by the algorithm. The study only considers active power and provides insights into optimizing the placement of sources in DC microgrid mesh networks. The main contribution of this paper is to rank source node positions from least to highest line losses. The paper also provides a comparison of the mesh networks based on the optimal cables weight used when placing a source at a defined position. The proposed methodology can be useful for system designers and operators seeking to minimize line losses and optimize energy distribution in DC microgrids using a mesh network topology.

Index Terms—DC microgrid, mesh network, optimal electric single source placement, line losses and cables weight optimization, Dijkstra algorithm

I. INTRODUCTION

Distributed generation (DG) systems in microgrids (MG) have emerged as an alternative to centralized power generation systems due to their potential to enhance the power quality, improve energy efficiency, and reduce greenhouse gas emissions [1]. Various studies have tackled different aspects of MG design, mainly optimal sources sizing and energy management system while taking into consideration environmental and economic challenges [2]. Little attention has been given to the optimization of the network topology and the source placement to minimize line losses. In fact, the placement of DG in the distribution network requires a careful analysis to optimize the technical and economic benefits of the system. One of the main concerns in the placement of DG is to minimize the distribution losses, which can have a significant impact on the overall efficiency of the system. Therefore, an optimal DG placement strategy is crucial for maximizing the benefits of distributed generation systems.

Some recent papers studied the optimal placement of DG units in distribution networks to minimize distribution losses. In [3], authors used Particle Swarm Optimization (PSO) to find optimal distributed generation placement that reduces power losses in an AC microgrid. A radial distribution network is used where power flow is unidirectional. [4] determines the optimal location for injecting current into a power system in order to minimize power losses. The study uses an IEEE 33 bus system and examines the impact of current injection in multiple buses while considering first a constant load, followed by a variable load in the subsequent phase. A PSO algorithm is used to achieve this optimization. All mentioned papers identify a key challenge in microgrid operation, which is the optimization of power losses in a radial distribution system. This paper will propose the Dijkstra algorithm as an effective tool for optimizing power losses in microgrids using a mesh network distribution system. Due to their resilience and redundancy, mesh network topologies are commonly employed in microgrids to enhance communication and control capabilities, particularly in the face of equipment failures or grid disruptions. This is because mesh networks allow for decentralized communication, which enables devices within a microgrid to directly interact and coordinate with each other without requiring a centralized control center [5]- [6].

Dijkstra algorithm is a graph search algorithm that can be used to find the shortest path between two nodes in a graph [7]. In the context of optimizing power loss in an islanded microgrid, our paper considers the nodes of the graph as the different components of the microgrid, such as generators, loads, and energy storage systems, while the edges represent the distribution lines connecting them. Dijkstra Algorithm is already used in some applications related to microgrids. In [8], Dijkstra's algorithm is utilized to determine the hierarchy of the network components at any point in time and to calculate shortest paths in order to find relay hierarchy under fault conditions.

In our paper, a DC islanded microgrid with a mesh network topology is considered. The distribution network is not radial since multiple paths exist between nodes. The main contributions of this paper are the following:

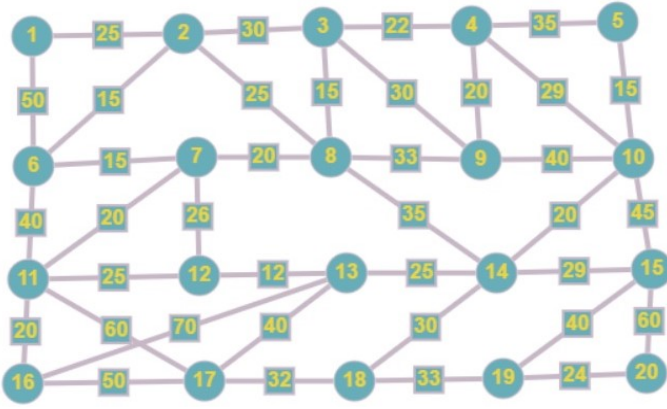


Fig. 1. DC Isolated Microgrid Network Representation

- The developed model allows to put in order the total line losses attributed to a source when placed in a defined node.
- The model used is dynamic. Cables resistance are not predefined and are computed using the Dijkstra algorithm.
- This study presents a new approach for comparing optimal topology of mesh networks based on the minimal cables weight used in the corresponding network.

This paper is organized as follows: the Dijkstra algorithm model applied to a DC microgrid is presented in Section II. Simulation results showing optimal line losses and their total line weight, corresponding to a source placed in a specified node, is exposed in Section III. The Section IV concludes this paper.

II. DIJKSTRA MODEL OF THE MICROGRID NETWORK

A. Microgrid and Distribution Network Representation

In islanded microgrids, line losses in the distribution network can have a significant impact on the overall system efficiency. Therefore, it is essential to find the optimal placement of a source to minimize these losses. Dijkstra algorithm is used in this paper as an optimization technique to find the optimal placement of a single source in DC islanded microgrids using a mesh network while considering optimal line losses and cables weight.

The microgrid studied in this paper is composed of 20 residential loads and one source (e.g. a fuel cell that is supposed to always meet the load). The load power profile is taken from [9]. This study seeks to identify the ideal placement of a source by evaluating and ranking each node's position based on the level of line losses incurred, starting from the location with the least losses to the one with the highest losses. The power profile of four representative days (each day representing a season) is chosen to conduct the optimization study. Figure 1 shows the microgrid distribution network. Each node (circles from 1 to 20) represents a load. Some of these loads are connected with branches which length is defined in a rectangle (Figure 1). Although the connection structure of the distribution network is predefined, the resistance and weight of the lines are calculated based on the position of the source, which can be placed in any predefined node. A new approach of evaluating networks configuration based on their optimal line losses and minimal cables weight is developed in this study.

B. Initial Dijkstra Graph

The first step is to define the Dijkstra graph through a matrix. The initial matrix size (Figure 2) is 20 x 20 (since there are 20 source nodes). It shows distance (in *meters*) between source nodes (i, j) directly connected. For example, if distance between source node 1 and 2 is 25 meters, then position (1,2) and (2,1) is equal to 25 in the Dijkstra graph matrix. If node i and j are not connected, the value assigned to position (i, j) in the matrix is 0. The value in a position (i, i) of the initial matrix is also 0.

C. Computing Optimal Source Placement

An algorithm is designed in this study in order to assess the line losses associated to placing electric source in corresponding nodes. Since multiple paths exist from a source to a load, Dijkstra algorithm calculates the shortest path connecting these nodes. The algorithm designed in this paper uses the following steps:

- Step 1: Compute the current needed for each load. The microgrid studied is DC. Knowing the loads active power profile P and the DC voltage U (considered to be 120 V), the DC current I absorbed by each load is calculated using the formula $P = UI$. Average current for the 4 representative days is used to compute line losses while maximum current is considered for cable sizing.
- Step 2: Run iteration 0. In this iteration, all branches are supposed to have equal linear resistance. Consider separately each node as the source node supplying all other loads. Set dijkstra graph matrix as per Figure 2. Run dijkstra algorithm to find shortest path between a source and all other loads. The current circulating in each branch is then calculated (using the formula in step 1). Cable datasheet is taken from [10] to calculate cable resistance (in Ohm/km) and the cable weight (in kg/km) corresponding to the computed current. The line losses allocated to a branch connecting 2 nodes are calculated using the following equation:

$$P_{\text{loss}}(i, j) = R(i, j) \times d(i, j) \times \left(\sum I(i, j) \right)^2 \quad (1)$$

Where $P_{\text{loss}}(i, j)$ are the line losses in the connected branch (i, j) in Watt, $R(i, j)$ is line (i, j) resistance in Ohm/km, $d(i, j)$ is the distance between node i and j (in km) if connected, $\sum I(i, j)$ is the sum of all currents circulating in the branch (i, j).

For a defined source location, branches lines losses, lines resistances, lines weight and lines current are stored each in a corresponding matrix. Line losses and weight are then summed for each possible source position.

- Step 3: Run a new iteration to make sure that new shortest paths are not created (since cables linear resistances are not anymore constant as in iteration 0). Line resistances are updated according to the current circulating in the corresponding branch (computed in the previous iteration). This implies that new potential paths connecting nodes, calculated as $R(i, j) \times d(i, j)$, are generated. New Dijkstra matrix representing new paths between connected nodes is generated. Run dijkstra algorithm to find shortest path between a source and all other loads. The position of the source goes from node 1 to node 20. New current values might circulate between connected nodes in case new shortest paths are identified. Therefore lines resistance and weight are again updated. Source placement could

0	25	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	30	0	0	15	0	25	0	0	0	0	0	0	0	0	0	0	0	0
0	30	0	22	0	0	0	15	30	0	0	0	0	0	0	0	0	0	0	0
0	0	22	0	35	0	0	0	20	29	0	0	0	0	0	0	0	0	0	0
0	0	0	35	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0
50	15	0	0	0	0	15	0	0	0	40	0	0	0	0	0	0	0	0	0
0	0	0	0	0	15	0	20	0	0	20	26	0	0	0	0	0	0	0	0
0	25	15	0	0	0	20	0	33	0	0	0	0	35	0	0	0	0	0	0
0	0	30	20	0	0	0	33	0	40	0	0	0	0	0	0	0	0	0	0
0	0	0	29	15	0	0	0	40	0	0	0	0	20	45	0	0	0	0	0
0	0	0	0	0	40	20	0	0	0	0	25	0	0	0	20	60	0	0	0
0	0	0	0	0	0	26	0	0	0	25	0	12	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	12	0	25	0	70	40	0	0	0
0	0	0	0	0	0	0	35	0	20	0	0	25	0	29	0	0	30	0	0
0	0	0	0	0	0	0	0	0	45	0	0	0	29	0	0	0	0	40	60
0	0	0	0	0	0	0	0	0	0	20	0	70	0	0	0	50	0	0	0
0	0	0	0	0	0	0	0	0	0	60	0	40	0	0	50	0	32	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	32	0	33	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	33	0	24
0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0	0	0	24	0

Fig. 2. Dijkstra Graph Matrix Showing Distances in meters Between Directly Connected Nodes

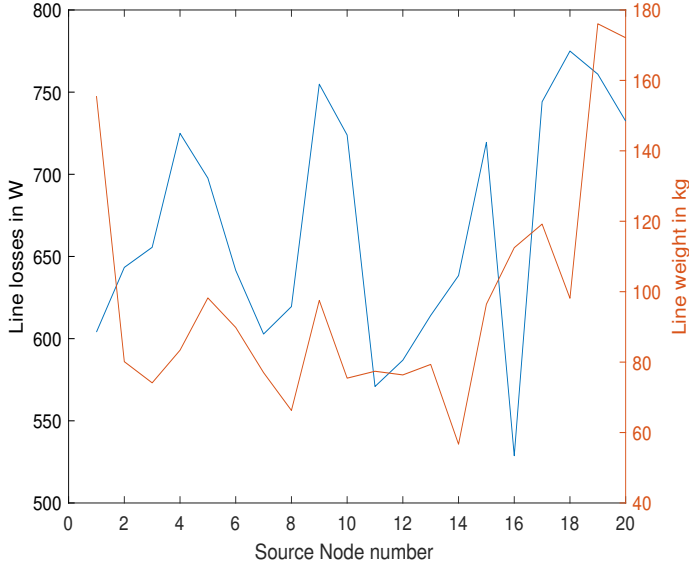


Fig. 3. Total Line Losses and Lines Weight while varying source node position

be ranked from the position with lowest line losses to the highest line losses.

- Step 4: Repeat step 3 until cables resistances converge to a constant value.

In the following section, we will present the results of applying Dijkstra Algorithm to compute the optimal line losses of a DC islanded microgrid distribution network.

III. SIMULATION RESULTS

In this section, a DC islanded microgrid composed of 20 residential units is studied. A mesh network is implemented. The average total load power is 34 kW. Connected nodes are presented in the Dijkstra matrix (Figure 2). The Dijkstra algorithm computes the shortest path between a source placed in a defined node and all other load nodes. It is important

to use this algorithm since several paths exist from one node to another in a mesh network. When the algorithm is run, the current circulating in each line connecting two nodes is computed (knowing the active power of each load and the optimal path connecting the source to the load). It is important to remind that average current value is used when computing line losses and maximal current when sizing cables.

A. Dijkstra function implementation

In our study, we used the Dijkstra function applied to Mathworks from [11]. Reference [11] contains Matlab M-files to implement Dijkstra algorithm.

Knowing the distance graph matrix of directly connected nodes, the shortest distance and its corresponding path used to go from a source node to a destination node are given as follows:

$$[distance, path] = dijkstra(Graph, source, destination)$$

In our case, the distance represents the minimal resistance between a source node and a destination node and the path corresponds to the optimal trajectory used from source to destination. Algorithms based on Dijkstra algorithm have been designed to compute matrices of currents circulating between nodes, losses, resistances and cables weight.

B. Optimal line losses and lines weight considering standard cable sizing

Source placement for optimal line losses could be seen in different perspectives. The first perspective is to place a source in a specified node, compute currents in each branch, size the cables using datasheet [10] and finally evaluate optimal line losses corresponding to the network configuration. When the current in each branch is calculated, the cable sizing and line resistances is defined. A new iteration is run where new optimal paths $R(i, j) \times d(i, j)$ could be generated. Once cables resistances of the mesh network converge, iterations are stopped and the network is defined.

In Figure 3, the source is placed at each node separately. Corresponding optimal line losses and total network cables weight are computed. In our case, lines resistance converged from iteration 1. Table 1 ranks the source placement from node position with least line losses to maximum line losses. As we

TABLE I
OPTIMAL SOURCE PLACEMENT RANKED WHILE CONSIDERING MINIMAL LINE LOSSES FOR OPTIMAL CURRENT DISTRIBUTION

Source Node Number	Total Line Losses in W	Total Lines Weight in kg	Lines Weight in kg per kW of Losses
16	529	112	213
11	571	77	136
12	587	76	130
7	603	77	128
1	604	156	258
13	614	79	129
8	620	66	107
14	638	57	89
6	642	90	140
2	643	80	125
3	656	74	113
5	698	98	141
15	719	96	134
10	724	75	104
4	725	83	115
20	732	172	235
17	744	119	160
9	755	98	129
19	761	176	231
18	775	98	127

TABLE II
OPTIMAL SOURCE PLACEMENT RANKED CONSIDERING TOTAL NETWORK CABLES WEIGHT PER 1 kW OF LOSSES

Source Node Number	Lines Weight in kg per kW of Losses	Total Line Losses in W	Total Lines Weight in kg
14	89	638	57
10	104	724	75
8	107	620	66
3	113	656	74
4	115	725	83
2	125	643	80
18	127	775	98
7	128	603	77
9	129	755	98
13	129	614	79
12	130	587	76
15	134	719	96
11	136	571	77
6	140	642	90
5	141	698	98
17	160	744	119
16	213	529	112
19	231	761	176
20	235	732	172
1	258	604	156

can see, the fuel cell considered as the main single source has minimal line losses if placed in node 16.

C. Optimal line losses considering optimal network cables weight

The assessment of optimal source placement and network optimization can be approached in a new perspective by considering the importance of cables weight in evaluating line losses. When two resistances are placed in parallel, the equivalent resistance is divided by 2, while the cables weight is multiplied by 2. This highlights the significance of cables weight as an essential parameter in assessing line losses. To better understand the importance of this ratio, a comparison is made between source placements at node 16 and node 14. From Table 1, we can see that placing source at node 16 leads to 529 W of line losses while placing source at node 14 incurs 638 W of losses. Placing the fuel cell (FC) at node 14, despite having higher total line losses compared to node 16, results in a lower optimal total lines weight (57 kg vs. 112 kg). This indicates that by doubling the cables weight while placing the FC at node 14, line losses can be reduced by half (319 W). This approach, which considers the minimal lines weight per kW of losses (as shown in Table 2), demonstrates the efficiency of placing the single source at node 14 in terms of optimal cables weight.

It is worth mentioning that in this study, the weight of the cables serves as a representation of their price. This approach offers a techno-economic perspective, as the price of copper used in the cables can fluctuate in the market. By considering the weight of the cables instead of the price, the study combines both technical and economic factors in the assessment of the optimal source placement and network optimization.

D. Optimal placement of multiple sources in a DC islanded microgrid with a mesh network configuration

The present study focused on determining the optimal placement of a single source in a mesh network topology for a DC islanded microgrid. However, future research aims to extend this analysis to include the optimization of multiple source placements within the mesh network. To achieve this, three strategies will be explored, building upon the findings of the current study.

The first strategy involves placing additional sources in the nearest nodes to the optimal node identified in this study (node 14). In this approach, all currents from the multiple sources will pass through node 14.

The second strategy also places multiple sources in the nearest nodes to node 14. However, in this case, the currents do not necessarily pass through node 14. Instead, the shortest path from each new source to the loads is determined. The distribution network is then overlaid, selecting the cables with the least resistance between the two network configurations (if two sources are used). Configuration 1 corresponds to the network used when the source is placed at node 14, while Configuration 2 represents the network defined in the current study when the source is placed nearest to node 14.

The third strategy involves placing the sources based on their positions ranked in Table 2, ranging from the least to highest line losses. Subsequently, the networks are overlaid, and the cable with the least resistance is chosen between each pair of nodes (i and j) when comparing the network topologies.

These three strategies expand upon the current study's findings and provide approaches for optimal source placement and network configuration in scenarios involving multiple sources.

IV. CONCLUSION

This paper focused on investigating the optimal placement of a source in an islanded DC microgrid with a mesh network topology, with the objective of minimizing line losses. The Dijkstra algorithm was utilized to determine the shortest paths between a source node and all other load nodes, considering the existence of multiple paths in the microgrid. It was observed that the network's line resistance is not predefined. Two perspectives were examined for optimal source placement. The first perspective involved ranking the source placements based on the line losses, while considering the resistance of the cables determined by the circulating current. The second perspective introduced a novel approach to assess the optimal network configuration by comparing different topologies based on the weight of cables used per kW of losses. The importance of this study lies in its ability to rank nodes according to their line losses and propose corresponding network structures for each source placement. Furthermore, future research will extend the investigation to include the optimal placement of multiple sources. Three strategies have been developed for this purpose, as discussed in the latter section of the paper. Overcoming the challenge of effectively overlaying distribution networks will be a key focus of these strategies. Additionally, the forthcoming study will examine voltage drop between nodes, PV hosting capacity, and the impact of injecting currents on overvoltage in defined positions. From a technical perspective, it aims to determine whether a node position can serve as a source.

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REFERENCES

- [1] L. Mehigan, J. P. Deane, B. Ó. Gallachóir, and V. Bertsch, "A review of the role of distributed generation (dg) in future electricity systems," *Energy*, vol. 163, pp. 822–836, 2018.
- [2] F. Boutros, M. Doumiati, J.-C. Olivier, I. Mougharbel, and H. Kanaan, "New modelling approach for the optimal sizing of an islanded microgrid considering economic and environmental challenges," *Energy Conversion and Management*, vol. 277, p. 116636, 2023.
- [3] S. Shaddiq, D. B. Santoso, F. F. Alfarobi, S. P. Hadi *et al.*, "Optimal capacity and placement of distributed generation using metaheuristic optimization algorithm to reduce power losses in bantul distribution system, yogyakarta," in *2016 8th International Conference on Information Technology and Electrical Engineering (ICITEE)*. IEEE, 2016, pp. 1–5.
- [4] R. R. Pallikunnan and M. Kumar, "Optimal location and sizing of distributed generation in a microgrid," in *2022 International Conference on Futuristic Technologies in Control Systems & Renewable Energy (ICFCR)*. IEEE, 2022, pp. 1–5.
- [5] L. Ren, Y. Qin, Y. Li, P. Zhang, B. Wang, P. B. Luh, S. Han, T. Oreskan, and T. Gong, "Enabling resilient distributed power sharing in networked microgrids through software defined networking," *Applied Energy*, vol. 210, pp. 1251–1265, 2018.
- [6] B. Zhou, J. Zou, C. Y. Chung, H. Wang, N. Liu, N. Voropai, and D. Xu, "Multi-microgrid energy management systems: Architecture, communication, and scheduling strategies," *Journal of Modern Power Systems and Clean Energy*, vol. 9, no. 3, pp. 463–476, 2021.
- [7] D. Rachmawati and L. Gustin, "Analysis of dijkstra's algorithm and a* algorithm in shortest path problem," in *Journal of Physics: Conference Series*, vol. 1566, no. 1. IOP Publishing, 2020, p. 012061.
- [8] T. S. Ustun, C. Ozansoy, and A. Zayegh, "Implementation of dijkstra's algorithm in a dynamic microgrid for relay hierarchy detection," in *2011 IEEE International conference on smart grid communications (SmartGridComm)*. IEEE, 2011, pp. 481–486.
- [9] [Online]. Available: <https://traces.cs.umass.edu/index.php/Smart/Smart>
- [10] [Online]. Available: <https://www.libancables.com/en/products/ENERGY-LOW-VOLTAGE-CABLES/Energy-LV-Copper/Unarmored,32007.html>
- [11] [Online]. Available: <https://fr.mathworks.com/matlabcentral/fileexchange/36140-dijkstra-algorithm>