Hindawi
Journal of Electrical and Computer Engineering
Volume 2024, Article ID 5395272, 11 pages
https://doi.org/10.1155/2024/5395272

Research Article

A Novel Technique for High-Performance Grid Integrated with Restricted Placement of PV-DG considering Load Change

Ayman M. Soliman, Safaa M. Emara, and Amir Y. Hassan

Department of Power Electronics and Energy Conversion, Electronics Research Institute, Cairo, Egypt

Correspondence should be addressed to Safaa M. Emara; safaa.mohamed@eri.sci.eg

Received 7 June 2023; Revised 26 December 2023; Accepted 19 January 2024; Published 6 February 2024

Academic Editor: Sheila Mahapatra

The distributed generation (DG) units' penetrations in power systems are becoming more prevalent. The majority of recent studies are now focusing on how to best position and size PV-DG units to further improve grid performance. In actuality, and as a result of ideal design requirements, the size and position of the PV are chosen and executed, and no luxury for a change. In this work, the PV-DG unit sizing and location were determined and placed beforehand. Also, load change is a fact and is to be highly considered in the grid. Studying the grid performance and how to enhance it under these conditions is the main objective of this study. This examination was executed using an IEEE 15 bus system in a MATLAB environment. Distribution lines were proposed to connect the PV-DG from its restricted location to the required bus. The purpose of this study is therefore to evaluate the grid's performance with various actual loads on each bus while connecting a PV-DG unit through a distribution line while taking the available transfer capacity (ATC) of the network into account to find the optimally connected bus. The results said that the optimally connected bus is changed by changing the load which is not doable on land. The results obtained indicate that breaking up PV-DG units into smaller units in the same location and connecting them to every bus was the best option for improving grid performance.

1. Introduction

There is no doubt that the electricity demand has reached a high mark due to the progress of human civilization. Therefore, the structure of the traditional electrical distribution network (EDN) has been modified by integrating the distributed generation (DG). Photovoltaic (PV), wind turbine (WT), and biomass (BM) are popular renewable DG technologies [1, 2]. Furthermore, there are technical, financial, and environmental advantages to integrating DGs into an already-existing EDN [3, 4]. Because of the many benefits of this technology, EDN was being integrated with DG technology. However, placing DG units, particularly large ones, in certain locations may have detrimental effects on the EDN, such as voltage increase, instability, and circuit breaker failure because of the bidirectional power flow [5]. Finding the ideal size and location of DG units is crucial for achieving the benefits of DG and avoiding any potential drawbacks [6]. Several researchers have presented efforts in literature with the main aim of harnessing the maximum benefits of optimal DG placement with a defined specific capacity in different scenarios with different techniques.

Numerous optimizations have been offered in literature, by optimizing their place with a definite specific capacity to obtain the main purpose of maximizing the profits expected from connecting DGs to EDN [7]. A Pareto optimal concept-based novel multiobjective quasi-oppositional grey wolf optimizer (MQOGWO) algorithm has been proposed in [8]. To find the optimal location and capacities of DGs, the stud krill herd algorithm has been implemented in [9]. The author in [10] used the self-adaptive levy flight-based black widow optimization algorithm to obtain the DG units' optimum location and size. The PV-DG sizing and locations using the loss reduction sensitivity factor and biogeography-based optimization algorithm in a distribution network are implemented in [11]. With the main objective of reducing the cost of connecting a new renewable DG unit to public medium voltage distribution systems, the author in [12] provided an analytical approach for effectively distributing renewable distribution generators and capacitor banks.

To improve a certain target or a grouping of purposes, the main advantages that have been researched in the literature include a reduction in power losses and grid performance enhancement [13–18]. A voltage sensitivity index and a voltage profile improvement indicator (VPII) were adopted for DG placement to minimize power loss [19]. In [20], a hybrid binary particle swarm optimization with ant lion optimizer (BPSO-ALO) is used to define ideal system reconfiguration while simultaneously allocating and sizing DGs to decrease power loss and enhance voltage profile. The author in [21] introduced a different optimization technique that combines the benefits of network reconfiguration options with the DG allocation to lessen technical losses and improve the bus voltage profile in EDN. In [22], the enhancement of the voltage profile by using a genetic algorithm is implemented. The equilibrium optimizer (EO) is used to realize the voltage profile enhancement by reconfiguring with DG placement in the distribution system [23]. Choosing the best placements and sizes for renewable DG units, considering the variation of load demand had been presented in works [24, 25]; a multiobjective optimization problem was constructed to identify the best locations and sizes of renewable DG units by considering the hourly change of load demand and the generation profile of renewable sources in [26]. The author in [27] introduced a methodology for DG unit placement in the distribution system that considers changes in the active power load. The evolutionary programming (EP) is used for finding the optimal placement and sizing of multidistributed generation (DG) units including different load models as presented in [28]. The grey wolf optimizer (GWO) and loss sensitivity factor (LSF) are used to determine the best location and size of DG in distribution systems at different load levels (light, nominal, and peak) [29]. A new imperialistic competitive algorithm ICA-based algorithm has been introduced in [30] to obtain the optimal location and size of DG units, reduce losses, and enhance voltage stability considering load variations. The authors in [31] proved that PV-DG fragmentation was one of the best solutions to enhance the grid performance under the restricted placement of PV-DG but without considering the load change in their study. In this research, DG grid integration was studied but with a predetermined PV placement and size which on the availability of the land plot, conditions of the proper location, cost budgetary, and a need for a modification considering the realistic change in load profile. The purpose of this study is to enhance the grid's performance with previously mentioned conditions using a novelty technique that breaks up PV-DG unit into smaller units and connects them to every bus of the grid through distribution lines. The paper is organized as follows. In Section 2, the proposed method is discussed using IEEE 15 bus system modeling based on the MATLAB environment. In Section 3, the research method is described. The results and discussion are presented in Section 3. Finally, the conclusion is presented in Section 4.

2. Proposed Method

2.1. Problem Definition. Grid performance enhancement is expected using DG integration. PV-DG grid integration is used in this research considering realistic conditions that represent the problem of this research. These conditions are predetermined PV size and placement based on land plot availability, proper site conditions, cost budgetary, and available transfer capacity (ATC) of the existing EDN for how far the existing transmission lines can bear the PV-DG surpluses. The research also considers the change in the load profile.

2.2. IEEE-15 Bus System. The IEEE 15-bus, 11 kV redial distribution system was selected to be the test bed in this study. The test bed is selected because it has characteristics of a long grid lightly loaded requiring the application of voltage regulators to satisfy voltage standards, which is similar to structures of medium voltage systems in Egypt. The total load of the IEEE-15 bus system is 1226.4 KW and 1251.11 KVAR. The distribution line and load data of the test system are given in [25]. The IEEE-15 bus system is simulated in MATLAB/Simulink environment to obtain all buses per unit voltages, power flow data, and system efficiency for performance judgment.

2.3. PV-DG Connected to the System. The PV-DG unit is integrated into the IEEE-15 bus system test bed with a restricted specific size and location to study the grid performance and how to enhance it as shown in Figure 1. The size of the PV-DG unit 400 kW is selected to be in the range of 25% of the system load which represents a huge percent value of the system under this study. Also, the PV-DG unit location is selected to be beside Bus 1 as a restricted placement in which there is high incident solar radiation and the least weather factors.

2.4. Proposed Techniques. This research proposes two techniques. First, by connecting the whole size selected PV-DG unit through the transmission line to the optimum bus considering the available transfer capacity (ATC) of the test bed and load change, this technique is called here through the paper "PV-DG without fragmentation." Second, by breaking up PV-DG unit into smaller units to be connected to all buses together overcoming the problem of the ATC of the network, this novelty technique is called "PV-DG with fragmentation."

3. Research Methods and Results

3.1. First Technique: Optimal Bus Connected to PV-DG Unit without Fragmentation. The PV-DG unit without fragmentation adjacent to Bus 1 is connected to each bus to determine the optimum bus taking the existing EDN's available transfer capacity (ATC) into account. Only the available buses 1, 2, 3, 4, 6, and 11 can be connected to the PV-DG unit using distribution lines as indicated in Figure 2. These buses have interconnected distribution lines that can support the PV-DG surpluses.

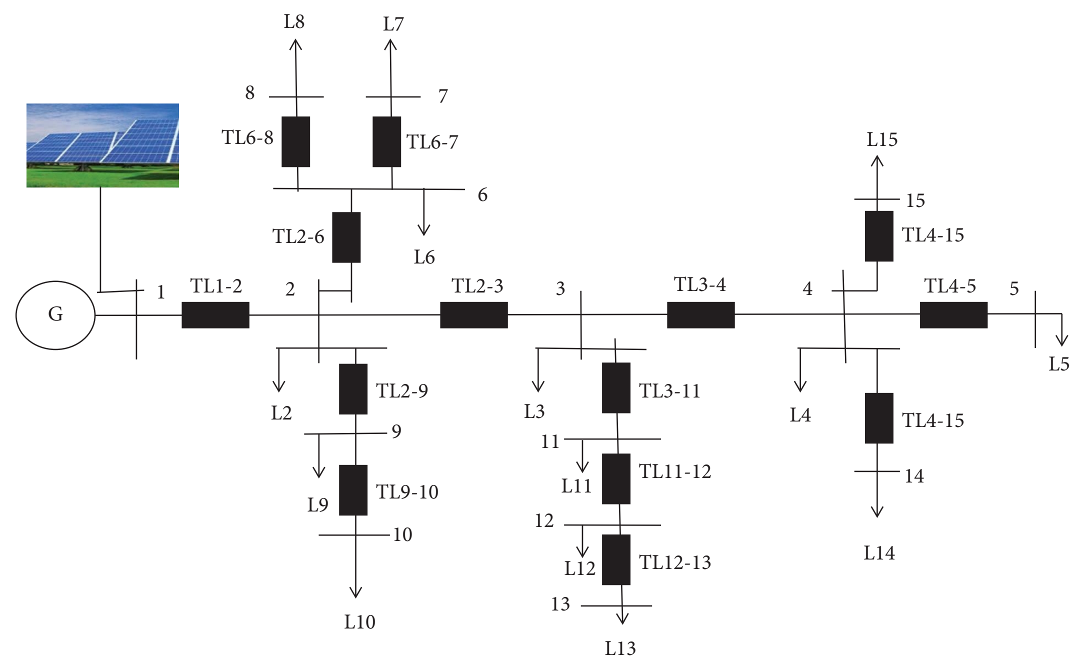

Figure 1: PV-DG unit connected to the IEEE-15 bus system.

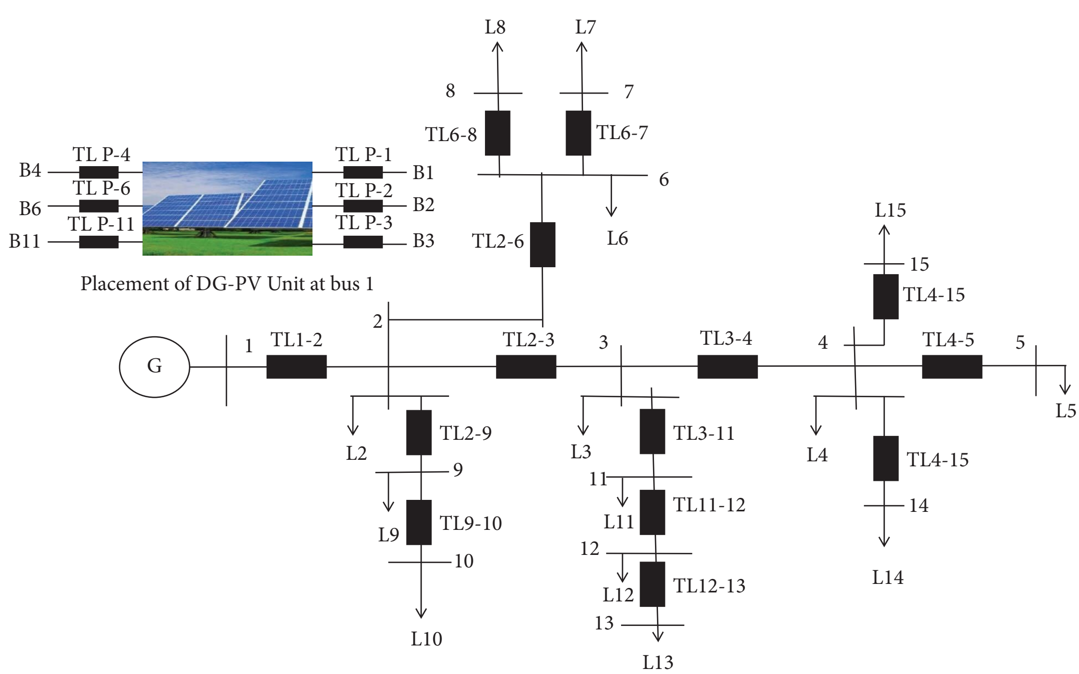

Figure 2: PV-DG unit available connected buses without fragmentation.

Three different scenarios were considered to study the EDN performance of integrating the PV-DG without fragmentation and determination of the optimum bus in which it is to be connected through a distribution line with different load schemes:

The performance analysis of the EDN is carried out in this study by studying the voltage deviation obtained from each bus when the PV-DG unit without fragmentation is inserted and by determining the resulting efficiency of the EDN. The equations used to obtain the two parameters are as follows:

$$V_{\text{dev}} = V_{\text{max}} - V_{\text{min}}, \tag{1}$$

where V_{dev} = voltage deviation, V_{max} = maximum voltage obtained when PV-DG unit was at bus i, and V_{min} = minimum voltage obtained when PV-DG unit was at bus i. And the reason for using equation (1) to minimize the voltage dip percent.

$$\gamma = \frac{1 - P\_L}{P\_\text{in}}, \tag{2}$$

Table 1: Standard load data (scheme 1).

Bus no.	Load data	
	Active power (KW)	Reactive power (KVAR)
1	0	0
2	44.1	44.99
3	70	71.41
4	140	142.82
5	44.1	44.99
6	140	142.82
7	70	71.41
8	140	142.82
9	70	71.41
10	44.1	44.99
11	70	71.41
12	44.1	44.99
13	140	142.82
14	140	142.82
15	70	71.41

Table 2: Distribution line data for PV-DG without fragmentation connected to grid-available buses.

From PV-DG unit to bus no.	Transmission line data TL P	
	Resistance (Ohms)	Inductance (Henry)
1	0	0
2	0.841110	0.00218
3	1.051387	0.00272
4	1.177554	0.00305
6	1.135498	0.00294
11	1.219609	0.00316

Table 3: Bus voltages when connecting PV-DG without fragmentation to available buses through T.L. (scheme 1).

Voltage at	PV-DG at					
	Bus 1	Bus 2	Bus 3	Bus 4	Bus 6	Bus 11
Bus 1	0.846077	0.844828	0.844075	0.843534	0.843235	0.843056
Bus 2	0.823860	0.827533	0.826743	0.826175	0.825864	0.825672
Bus 3	0.812657	0.816281	0.819815	0.819217	0.814633	0.818690
Bus 4	0.808226	0.811829	0.815344	0.817881	0.810191	0.814226
Bus 5	0.807466	0.811067	0.814578	0.817112	0.809429	0.813462
Bus 6	0.813712	0.817341	0.816559	0.815997	0.825065	0.815501
Bus 7	0.812849	0.816473	0.815692	0.815131	0.824188	0.814635
Bus 8	0.811729	0.815349	0.814569	0.814008	0.823054	0.813512
Bus 9	0.821227	0.824888	0.824103	0.823538	0.823228	0.823037
Bus 10	0.820375	0.824032	0.823249	0.822685	0.822376	0.822184
Bus 11	0.807551	0.811151	0.814663	0.814071	0.809512	0.820213
Bus 12	0.802519	0.806098	0.809589	0.809011	0.804467	0.815104
Bus 13	0.799377	0.802942	0.806420	0.805834	0.801315	0.811916
Bus 14	0.804722	0.808311	0.811811	0.814336	0.806675	0.810697
Bus 15	0.807282	0.810882	0.814392	0.816926	0.809244	0.813276
V_{Max}-V_{Min}	0.046701	0.041886	0.037655	0.037701	0.041920	0.032358

Table 4: Total demand, losses, and generation with PV-DG without fragmentation connected to bus 11, (scheme 1).

Total generation (in KW)	845
Total demand (in KW)	816.3
Total losses (in KW)	28.7
γ, efficiency (%)	96.6

where γ = efficiency, P_L = power losses when the PV-DG unit was at bus i, and P_in = power demanded when the PV-DG unit was at bus i.

3.1.1. Case A: At Standard Load (Scheme 1). A MATLAB/Simulink environment is used to simulate the IEEE-15 bus

Table 5: Change in load data (scheme 2).

Bus no.	Load data	
	Active power (KW)	Reactive power (KVAR)
1	0	0
2	35	35
3	70	71.41
4	5	5
5	2	2
6	2	2
7	40	40
8	80	80
9	70	71.41
10	1	1
11	1	1
12	1	1
13	5	5
14	70	70
15	20	20

Table 6: Voltages buses when connecting PV-DG without fragmentation to available buses through TL, (scheme 2).

Voltage at	PV-DG at					
	Bus 1	Bus 2	Bus 3	Bus 4	Bus 6	Bus 11
Bus 1	1.071393	1.070719	1.070287	1.069945	1.069874	1.06979
Bus 2	1.061959	1.065188	1.064731	1.064371	1.064294	1.064203
Bus 3	1.058426	1.061645	1.064571	1.064191	1.060758	1.064013
Bus 4	1.057019	1.060233	1.063154	1.065208	1.059349	1.062597
Bus 5	1.056974	1.060188	1.063108	1.065162	1.059304	1.062551
Bus 6	1.057410	1.060616	1.060166	1.059808	1.067081	1.059640
Bus 7	1.056764	1.059978	1.059529	1.059171	1.066435	1.059003
Bus 8	1.055939	1.059151	1.058702	1.058344	1.065601	1.058177
Bus 9	1.059844	1.063066	1.062615	1.062256	1.062179	1.062088
Bus 10	1.059819	1.063041	1.062591	1.062231	1.062154	1.062063
Bus 11	1.058237	1.061454	1.064380	1.064001	1.060569	1.069011
Bus 12	1.058014	1.061232	1.064156	1.063777	1.060346	1.068784
Bus 13	1.057862	1.061079	1.064002	1.063623	1.060194	1.068628
Bus 14	1.054743	1.057951	1.060863	1.062909	1.057071	1.060308
Bus 15	1.056669	1.059882	1.062801	1.064854	1.058999	1.062245
Sum	15.88106	15.92542	15.94566	15.94985	15.93421	15.95311
Max	1.071393	1.070719	1.070287	1.069945	1.069874	1.069790
Min	1.054743	1.057951	1.058702	1.058344	1.057070	1.058177
V_{Max}-V_{Min}	0.016650	0.012768	0.011585	0.011601	0.012804	0.011614

Table 7: Total demand, losses, and generation with PV-DG without fragmentation connected to bus 3 (scheme 2).

Total generation (in KW)	459
Total demand (in KW)	453
Total losses (in KW)	6
γ, efficiency (%)	98

system using the standard load data shown in Table 1. Table 2 displays the distribution line parameters TL P for various connections between the PV-DG without fragmentation and available connected buses.

In this case, Table 3 shows the results of all bus voltages when the PV-DG unit was connected to each available bus. It is evident from the table that without PV-DG unit fragmentation, bus no. 11 gives the minimum voltage deviation and hence optimal voltage profile. Also, the results shown in Table 4 indicate a better enhancement in the system efficiency of 96.6% when connecting the PV-DG to bus no. 11.

3.1.2. Case B: At Load Change (Scheme 2). The load change information in Table 5 is used to simulate the IEEE-15 bus system. In this case, Table 6 displays the results of connecting the PV-DG without fragmentation to every available bus and displays that bus number 3 provides the best voltage profile. Additionally, the results in Table 7 show an improvement in system efficiency of 98.8% when the PV-DG is connected to bus number 3.

Table 8: Change in load data (scheme 3).

Bus no.	Load data	
	Active power (KW)	Reactive power (KVAR)
1	0	0
2	44.1	44.99
3	1	1
4	1	1
5	1	1
6	140	142.82
7	70	71.41
8	140	142.82
9	70	71.41
10	44.1	44.99
11	1	1
12	1	1
13	1	1
14	1	1
15	1	1

Table 9: Voltages buses when connecting PV-DG without fragmentation to available buses through T.L. (scheme 3).

Voltage at	PV-DG at					
	Bus 1	Bus 2	Bus 3	Bus 4	Bus 6	Bus 11
Bus 1	1.030371	1.029594	1.029081	1.02876	1.028332	1.028587
Bus 2	1.018583	1.021865	1.021322	1.020984	1.020541	1.020797
Bus 3	1.018424	1.021705	1.024686	1.024331	1.020383	1.024129
Bus 4	1.018367	1.021648	1.024628	1.026801	1.020326	1.024071
Bus 5	1.018345	1.021626	1.024606	1.026777	1.020304	1.024049
Bus 6	1.005793	1.009036	1.008499	1.008166	1.015379	1.007982
Bus 7	1.004705	1.007944	1.007409	1.007076	1.014281	1.006891
Bus 8	1.003288	1.006523	1.005988	1.005656	1.012849	1.005471
Bus 9	1.015331	1.018601	1.018061	1.017724	1.017289	1.017537
Bus 10	1.014277	1.017544	1.017004	1.016668	1.016235	1.016482
Bus 11	1.018346	1.021627	1.024607	1.024251	1.020305	1.029437
Bus 12	1.018275	1.021555	1.024534	1.024178	1.020234	1.029364
Bus 13	1.018245	1.021526	1.024504	1.024148	1.020204	1.029333
Bus 14	1.018335	1.021616	1.024595	1.026767	1.020294	1.024039
Bus 15	1.018351	1.021631	1.024611	1.026782	1.020309	1.024054
Min	1.003288	1.006523	1.005988	1.005656	1.012849	1.005471
V_{Max}-V_{Min}	0.027083	0.023071	0.023093	0.023105	0.015483	0.023966

3.1.3. Case C: At Load Change (Scheme 3). In this case, Table 8 shows another description of the load change which is used to simulate the system of the IEEE-15 bus. By carrying out the load flow analysis PV-DG without fragmentation is connected to every available bus. Table 9 gives the voltage profile of the system which presents that bus number 6 is the best voltage profile. The PV-DG unit's connection to bus number 6 results in a 98% increase in system efficiency as presented in Table 10.

Table 10: Total demand, losses, and generation with PV-DG without fragmentation connected to bus 6 (scheme 3).

Total generation (in KW)	546
Total demand (in KW)	539
Total losses (in KW)	7
γ, efficiency (%)	98

3.2. Second Technique: PV-DG with Fragmentation. The fragmentation here refers to the spread out of the small capacity of PV-DG unit installations across a larger area. This approach is more advantageous than a single large-capacity of PV-DG installation; which overcomes the problem of the available transfer capacities of the existing EDN. In this work, the PV-DG with fragmentation into small units had occurred by dividing the PV-DG unit into 14 equal parts each 28 kW approximately as shown in Figure 3, and connecting to each loaded bus with distribution lines parameters as described in Table 11.

Three different scenarios were considered to study the performance of the EDN when the PV-DG units were fragmented under different load schemes as presented when the PV-DG unit was not fragmented.

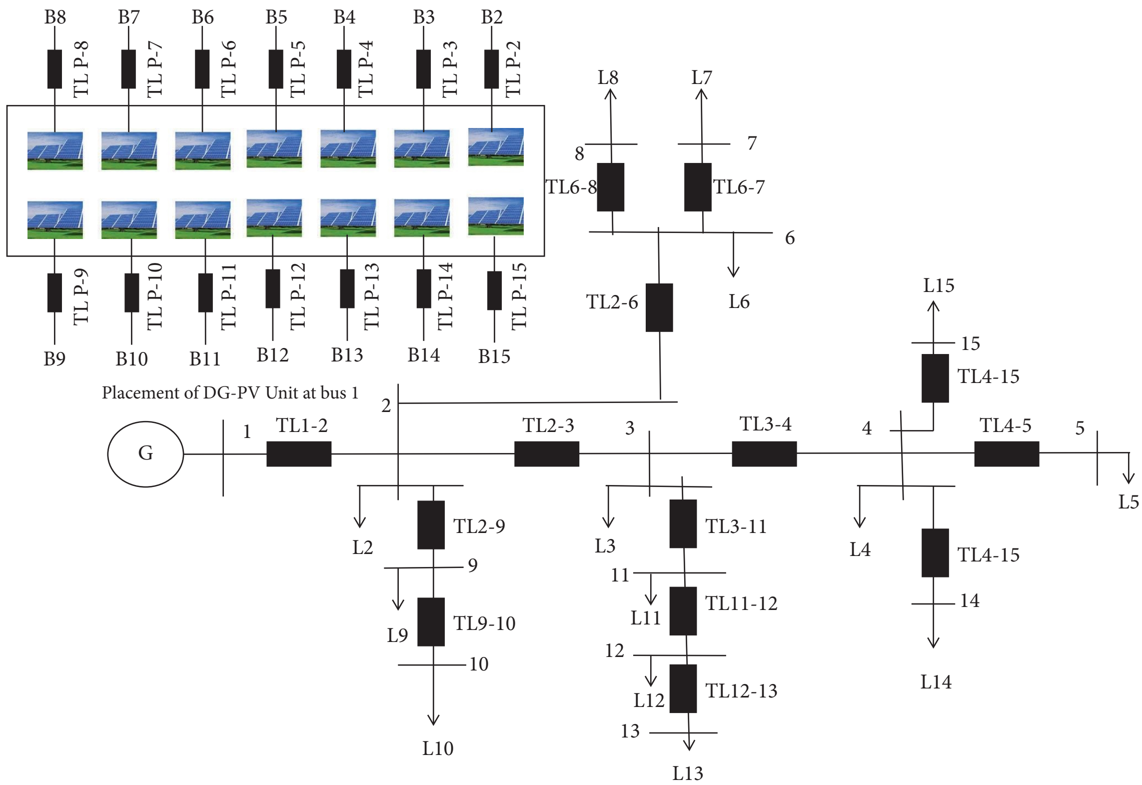

Figure 3: PV-DG with fragmentation.

Table 11: Transmission lines data for the PV-DG with fragmentation connected to the grid buses.

From PV-DG with fragmentation to bus no.	Line data T.L. P	
	Resistance (Ohms)	Inductance (Henry)
2	5.04666	0.01309
3	6.30832	0.01636
4	7.06532	0.01833
5	8.07465	0.02095
6	6.81299	0.01767
7	7.31765	0.01898
8	7.56999	0.01964
9	6.05599	0.01571
10	7.06532	0.01833
11	7.31765	0.01898
12	7.56999	0.01964
13	8.07465	0.02095
14	7.56999	0.01963
15	7.67092	0.01989

Table 12: PV-DG with fragmentation voltages buses compared to PV-DG without fragmentation optimum bus (scheme 1).

Voltage (P.U)	PV-DG	
	With fragmentation case A1	Without fragmentation optimum bus (bus 11) case A
Bus 1	0.858205	0.843055
Bus 2	0.841717	0.825672
Bus 3	0.833005	0.818689
Bus 4	0.829463	0.814226
Bus 5	0.829141	0.813461
Bus 6	0.834603	0.815500
Bus 7	0.834478	0.81463
Bus 8	0.832939	0.813512
Bus 9	0.840212	0.823036
Bus 10	0.839839	0.822184
Bus 11	0.829359	0.820212
Bus 12	0.825646	0.815104
Bus 13	0.823013	0.811915
Bus 14	0.826528	0.810697
Bus 15	0.828852	0.813276

3.2.1. Case A1: Fragmentation at Standard Load (Scheme 1). A MATLAB/Simulink environment is used to simulate the IEEE-15 bus system using the load data shown in Table 1. Table 12 displays voltages buses using "PV-DG with fragmentation" versus the "PV-DG without fragmentation" optimum bus through T.L. (Scheme 1). Results shown in Table 13 indicate a significant enhancement in the system efficiency of 99.4% in this case compared to the system efficiency of 96.6% when connecting the PV-DG without fragmentation to bus no. 11.

Figure 4 shows the simulation results of grid voltages buses' profile at load Scheme 1 when there is no PV-DG connection and when the two proposed techniques are applied: "PV-DG without fragmentation" finding the optimum bus to be connected and "PV-DG with fragmentation." Results show that the two proposed techniques enhance the performance more than no connection of PV-DG, while the second applied technique of PV-DG with fragmentation is the best.

Table 13: Generation, losses, and total demand with PV-DG with fragmentation (scheme 1).

Total generation (in KW)	859
Total demand (in KW)	854.3
Total losses (in KW)	4.7
γ, efficiency (%)	99.4

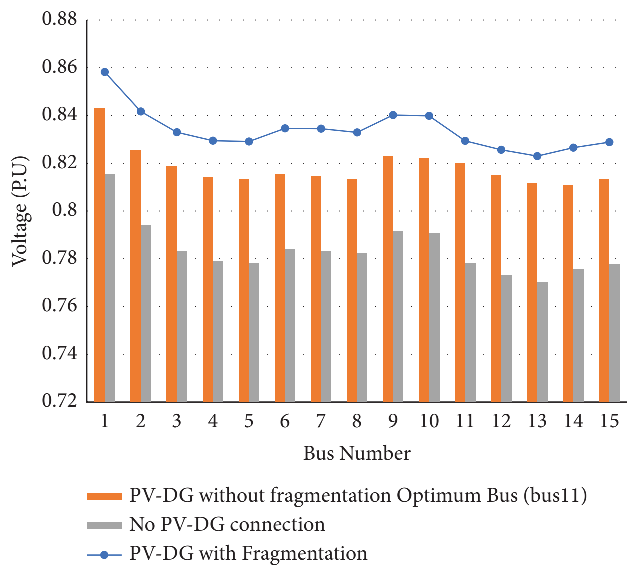

Figure 4: Voltages profile performance at different applied techniques, load scheme 1.

Furthermore, comparing the total losses in this standard load (Scheme 1) for the system without PV-DG penetration 35.6 KW [31], with optimal bus-connected unfragmented PV-DG penetration 28.7 KW, and with fragmented PV-DG penetration 4.7 KW, a very high performance can be noticed using PV-DG with fragmentation.

3.2.2. Case B1: Fragmentation at Load Change (Scheme 2). In this case, Table 14 shows all obtained bus voltages of "PV-DG with fragmentation" versus "PV-DG without fragmentation" optimum bus through T.L. (Scheme 2). Results shown in Table 15 also indicate a significant enhancement in the system efficiency of 98.9% in this case comparing the system efficiency of 98% when connecting the PV-DG without fragmentation to optimum Bus no. 3.

Figure 5 shows the simulation results of grid voltages buses' profile at load Scheme 2 when there is no PV-DG connection and when the two proposed techniques are applied: "PV-DG without fragmentation" finding the optimum bus to be connected and "PV-DG with fragmentation." Results show that the obtained optimum bus considering load change scheme 2 (Bus no. 3) when applying the first technique differs from load change scheme 1 (Bus no. 11), which is not doable in reality to change the connected bus. In the meantime, still, the two proposed techniques still enhance the performance more than no connection of PV-DG, while the second applied technique of PV-DG with fragmentation is the best.

Table 14: PV-DG with fragmentation voltages buses compared to PV-DG without fragmentation optimum bus (scheme 2).

Voltage (P.U)	PV-DG	
	With fragmentation case B1	Without fragmentation optimum bus (bus 3) case B
Bus 1	1.082788	1.070287
Bus 2	1.078197	1.064731
Bus 3	1.076726	1.064571
Bus 4	1.076042	1.063154
Bus 5	1.076350	1.063108
Bus 6	1.076420	1.060166
Bus 7	1.076529	1.059529
Bus 8	1.075176	1.058702
Bus 9	1.076974	1.062615
Bus 10	1.077338	1.062591
Bus 11	1.077772	1.064381
Bus 12	1.078672	1.064156
Bus 13	1.078979	1.064002
Bus 14	1.074183	1.060863
Bus 15	1.075956	1.062801

Table 15: Generation, losses, and total demand with PV-DG with fragmentation (scheme 2).

Total generation (in KW)	484
Total demand (in KW)	479
Total losses (in KW)	9
γ, efficiency (%)	98.9

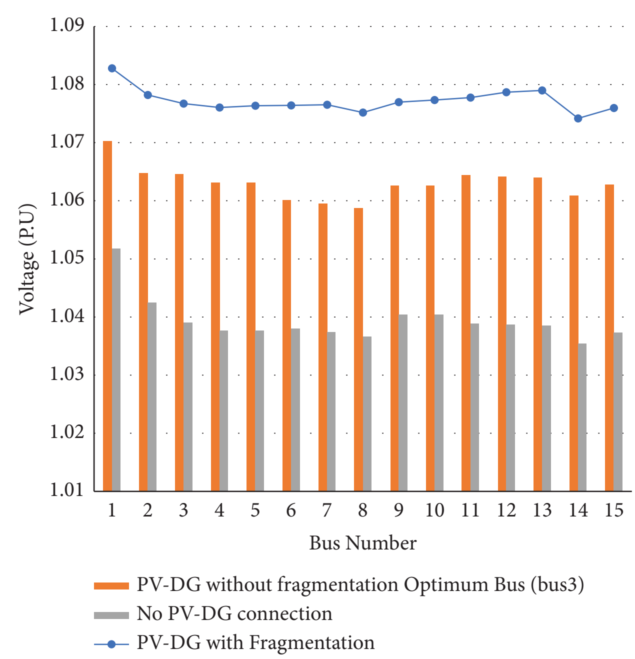

Figure 5: Voltages profile performance at different applied techniques, load scheme 2.

3.2.3. Case C1: Fragmentation at Load Change (Scheme 3). In this case, Table 16 shows all obtained bus voltages of "PV-DG with fragmentation" versus "PV-DG without

Table 16: PV-DG with fragmentation voltages buses compared to PV-DG without fragmentation optimum bus (scheme 3).

Voltage (P.U)	PV-DG	
	With fragmentation case C1	Without fragmentation optimum bus (bus 6) case C
Bus 1	1.043230	1.028332
Bus 2	1.036595	1.020541
Bus 3	1.038655	1.020383
Bus 4	1.039396	1.020326
Bus 5	1.039739	1.020304
Bus 6	1.026792	1.015379
Bus 7	1.026475	1.01428
Bus 8	1.024579	1.012849
Bus 9	1.034235	1.017289
Bus 10	1.033562	1.016235
Bus 11	1.039858	1.020305
Bus 12	1.040951	1.020234
Bus 13	1.041400	1.020204
Bus 14	1.039895	1.020294
Bus 15	1.039664	1.020309

Table 17: Generation, losses, and total demand with PV-DG with fragmentation (scheme 3).

Total generation (in KW)	567
Total demand (in KW)	559
Total losses (in KW)	8
γ, efficiency (%)	98.5

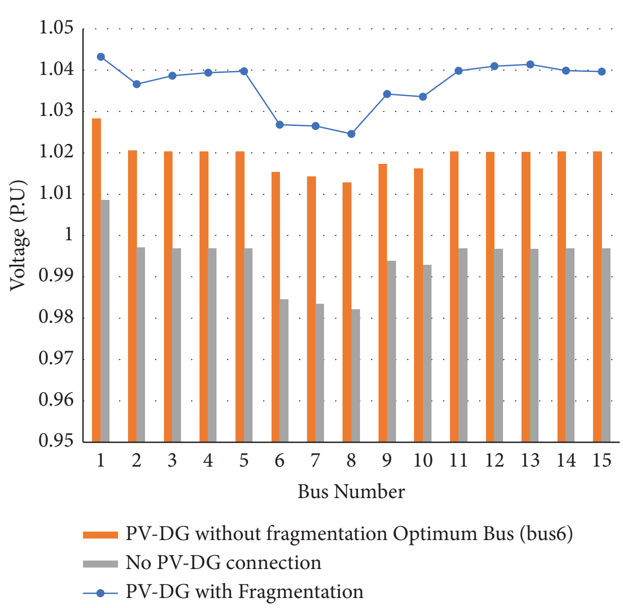

Figure 6: Voltages profile performance at different applied techniques, load scheme 3.

fragmentation" optimum bus through T.L. (Scheme 3). Results shown in Table 17 also indicate a significant enhancement in the system efficiency of 98.5% in this case comparing the system efficiency of 98% when connecting the PV-DG without fragmentation to optimum Bus no. 6.

Figure 6 shows the simulation results of grid voltages buses' profile at load Scheme 3 when there is no PV-DG connection and when the two proposed techniques are applied: "PV-DG without fragmentation" finding the optimum bus to be connected and "PV-DG with fragmentation." Results show also that the obtained optimum bus considering load change scheme 3 (Bus no. 6) when applying the first technique differs from load change scheme 1 (Bus no. 11) and scheme 2 (Bus no. 3), which is not doable in reality to change the connected bus. In the meantime, still, the two proposed techniques still enhance the performance more than no connection of PV-DG, while the second applied technique of PV-DG with fragmentation is the best.

4. Conclusions and Future Work

The main goal is to look into ways to increase grid performance while still adhering to the restrictions for PV sizing, PV location, and various realistic loads. The research applied two proposed techniques considering the available transfer capacity (ATC) of the EDN into account to find the optimally connected bus. Results show grid performance enhancement by applying the first technique where the optimal connected bus is changed by changing the load. Unfortunately, the validation of this action is not realistic. Simulation results indicate that the PV-DG with fragmentation into small units and connecting them to all buses as a novelty second technique was the best realistic action plan for improving grid performance. In future work, the authors will apply the proposed approach to various IEEE buses or any redial system and consider an economic analysis.

Abbreviations

ATC: Available transfer capacity
BM: Biomass
BPSO-ALO: Binary particle swarm optimization with ant lion optimizer
DG: Distribution generation
EDN: Electrical distribution network
EO: Equilibrium optimizer
EP: Evolutionary programming
GWO: Grey wolf optimizer
ICA: Imperialistic competitive algorithm
LSF: Loss sensitivity factor
MQOGWO: Multiobjective quasi-oppositional grey wolf optimizer
PV: Photovoltaic
RDS: Radial distribution systems
VPII: Voltage profile improvement indicator
V_{dev}: Voltage deviation
V_{max}: Maximum voltage
V_{min}: Minimum voltage
P_L: Power losses
P_in: Power demanded
WT: Wind turbine
γ: Efficiency.

Data Availability

The datasets used in the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The Electronic Research Institute funded the study.

References

[1] K. S. Sambaiah and T. Jayabarathi, "Optimal allocation of renewable distributed generation and capacitor banks in distribution systems using salp swarm algorithm," *International Journal of Renewable Energy Research-IJRER*, vol. 9, 2019.

[2] M. S. Eltohamy, M. S. A. Moteleb, H. Talaat, S. F. Mekhemar, and W. A. Omran, "Wind power ramps analysis for high shares of variable renewable generation in power systems," *Indonesian Journal of Electrical Engineering and Informatics*, vol. 8, 2020.

[3] M. Darfoun and H. Hosson, "Optimal allocation of distributed generation using genetic algorithm in houn 11kV distribution system," in *Proceedings of the Forth International Conference on Technical Sciences (ICST2021)*, Sion, Mumbai, India, May 2021.

[4] M. S. Eltohamy, H. E. A. Talaat, M. S. A. Moteleb, S. F. Mekhamer, and W. A. Omran, "A probabilistic methodology for estimating reserve requirement and optimizing its components in systems with high wind penetration," *IEEE Access*, vol. 10, 2022.

[5] M. Saber, F. M. A. Ghali, and E. E. Abou Elzahab, "The effect of DG penetration on short circuit currents level," in *Proceedings of the 2017 Intl Conference on Advanced Control Circuits Systems (ACCS) Systems & 2017 Intl Conference on New Paradigms in Electronics & Information Technology (PEIT)*, IEEE, Alexandria, Egypt, November 2017.

[6] A. S. Hassan, E. A. Othman, F. M. Bendary, and M. A. Ebrahim, "Optimal integration of distributed generation resources in active distribution networks for techno-economic benefits," *Energy Reports*, vol. 6, pp. 3462–3471, 2020.

[7] F. F. Amigue, S. N. Essiane, S. P. Ngoffe, and A. T. Nelem, "Optimal placement and sizing of distributed energy generation in an electrical network using the hybrid algorithm of bee colonies and Newton Raphson," *Journal of Power and Energy Engineering*, vol. 8, p. 6, 2020.

[8] S. Kumar, K. K. Mandal, and N. Chakraborty, "Optimal placement of different types of DG units considering various load models using novel multiobjective quasi-oppositional grey wolf optimizer," *Soft Computing*, vol. 25, pp. 4845–4864, 2021.

[9] S. A. Chithra Devi, K. Yamuna, and M. Sornalatha, "Multi-objective optimization of optimal placement and sizing of multiple DG placements in radial distribution system using stud krill herd algorithm," *Neural Computing & Applications*, vol. 33, no. 20, pp. 13619–13634, 2021.

[10] N. L. Gubbala Venkata, J. L. Askani, and V. Veeramsetty, "Optimal placement of distributed generation based on DISCO's additional benefit using self-adaptive levy flight based black widow optimization," *International Journal of Emerging Electric Power Systems*, vol. 22, no. 4, pp. 401–410, 2021.

[11] G. W. Chang and N. C. Chinh, "Optimal planning of PV-DG units in a distribution system by biogeography-based optimization," in *Proceedings of the 2020 IEEE Region 10 Symposium (TENSYMP)*, IEEE, Dhaka, Bangladesh, June 2020.

[12] S. Ouali and A. Cherkaoui, "Optimal allocation of combined renewable distributed generation and capacitor units for interconnection cost reduction," *Journal of Electrical and Computer Engineering*, vol. 2020, Article ID 5101387, 11 pages, 2020.

[13] M. Purlu and B. E. Turkay, "Optimal allocation of renewable distributed generations using heuristic methods to minimize annual energy losses and voltage deviation index," *IEEE Access*, vol. 10, pp. 21455–21474, 2022.

[14] M. Darfoun, "Improving the voltage profile and minimizing the power loss of the Houn (11kV) distribution network," in *Proceedings of the International Conference on Technical Sciences (ICST2019)*, Tripoli, Libya, March 2019.

[15] S. Shekarappa G, S. Mahapatra, and S. Raj, "A novel metaheuristic approach for optimal RPP using series compensated FACTS controller," *Intelligent Systems with Applications*, vol. 18, 2023.

[16] C. K. Shiva, S. S. Gudadappanavar, B. Vedik, R. Babu, S. Raj, and B. Bhattacharyya, "Fuzzy-based shunt VAR source placement and sizing by oppositional crow search algorithm," *Journal of Control, Automation and Electrical Systems*, vol. 33, pp. 1576–1591, 2022.

[17] C. K. Shiva, B. Vedik, S. Mahapatra, M. Nandi, S. Raj, and V. Mukherjee, "Load frequency stabilization of stand alone hybrid distributed generation system using QOHS algorithm," *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, vol. 35, p. 4, 2022.

[18] G. S. Shekarappa and S. Mahapatra, "A case study on influence of distributed generation in rural area," in *Proceedings of the International Conference on Power Electronics & Sustainable Development (ICPESD)*, Jamshedpur, India, January 2022.

[19] D. L. Yadav and S. C. Choube, "DG placement in distribution systems using analytical techniques," *International Journal of Engineering Trends and Technology*, vol. 69, no. 9, pp. 236–241, 2021.

[20] G. P. Rao and P. R. Babu, "Network reconfiguration and optimal allocation of multiple DG units in radial distribution system," *International Journal of Advanced Technology and Engineering Exploration*, vol. 8, p. 81, 2021.

[21] S. A. Romeh, S. M. Allam, S. R. Spea, and S. M. Nasr, "Optimal reconfiguration and optimal allocation of distributed generation using different optimization techniques," *Engineering Research Journal*, vol. 46, p. 1, 2023.

[22] J. E. A. Abutin, H. T. Jovena, Rpl Trinidad, M. C. Pacis, and G. V. Magwili, "Voltage profile enhancement by optimal placement of hybrid distribution generators using genetic algorithm," in *Proceedings of the 2021 IEEE Region 10 Symposium (TENSYMP)*, IEEE, Jeju, Republic of Korea, August 2021.

[23] S. Ma and N. V. Pl Mareddy, "Enhancement of voltage profile in the distribution system by reconfiguring with DG placement using equilibrium optimizer," *Alexandria Engineering Journal*, vol. 61, p. 5, 2022.

[24] M. S. Eltohamy, M. S. A. Moteleb, H. E. A. Talaat, S. F. Mekhamer, and W. A. Omran, "A novel approach for power ramps classification in wind generation," *Scientific Reports*, vol. 13, 2023.

[25] M. S. Eltohamy, M. S. Abdel Moteleb, H. E. A. Talaat, S. F. Mekhamer, and W. Omran, “A novel approach for the power ramping metrics,” *Indonesian Journal of Electrical Engineering and Informatics (IJEEI)*, vol. 9, no. 2, 2021.

[26] S. Saha and V. Mukherjee, “A novel meta-heuristic for optimal allocation of distributed generation in balanced distribution network considering hourly load variation,” in *Proceedings of the 2020 IEEE 9th Power India International Conference (PIICON)*, IEEE, Sonepat, India, February 2020.

[27] M. V. Kumar, S. K. Bilgundi, and H. Pradeepa, “Optimal allocation of DG units in distribution system considering variation in active power load,” *Archives of Electrical Engineering*, vol. 68, 2019.

[28] M. F. Mohammed, S. R. A. Rahim, A. Azmi et al., “Optimal allocation and sizing of multi DG units including different load model using evolutionary programming,” *Journal of Physics: Conference Series*, vol. 1878, 2021.

[29] I. M. Ahmed, S. Kamel, H. Abdel-Mawgoud, and J. Yu, “Optimal allocation of PV based DG in distribution networks at different load levels,” in *Proceedings of the 2018 Twentieth International Middle East Power Systems Conference (MEPCON)*, IEEE, Cairo, Egypt, December 2018.

[30] B. Poornazaryan, P. Karimyan, G. B. Gharehpetian, and M. Abedi, “Optimal allocation and sizing of DG units considering voltage stability, losses and load variations,” *International Journal of Electrical Power & Energy Systems*, vol. 79, pp. 42–52, 2016.

[31] A. M. Soliman, S. M. Emara, and M. N. F. Nashed, “Grid performance enhancement study under restricted placement and sizing of PV distributed generation,” *Journal of Electrical Engineering & Technology*, vol. 18, no. 1, pp. 229–237, 2022.