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Original Article

Study and Investigate of DGs Units Effect on BINWALED 66 kV Sub-Transmission Network Considering Load Growth

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Abstract - *In this study, a Modified technique via Particle Swarm Optimization (MPSO) has been presented to find optimal sizing and siting of DGs units under different operating situations in the BINWALED 66kV sub-transmission system network in Libya, which has been used as a state to study the viability of distributed generation integration and its effect on sub-transmission system operation. Effects analysis of DGs units on the BINWALED 66 kV sub-transmission network in normal operation and load growth cases has been carried out to find the optimal solution of the penetration level of three DGs units to any changes in the loading of the network. Impacts of DG units have been studied on 29-bus and 47-bus sub-transmission networks using the two approaches, fitting and refurbishing of the three DGs. A comparative study shows that the optimal solution for the penetration level of three DGs units was increased by new optimal sizes, which vary directly with load growth, although the optimal locations of DGs units do not vary with load growth. Furthermore, results indicate that the optimal solution for DGs units' power factor was at a value of 0.87 lagging, which proves the integration of DGs units in controlling these losses and voltage deviations.*

Keywords - *MPSO technique, 29-bus and 47-bus sub-transmission system, Optimal refitting of DGs, Load growth, Optimal location, Optimal power factor.*

1. Introduction

Transmitting electrical energy from principal power stations to sub-transmission and distribution system networks through lengthy power transmission system networks may cause loss of electrical energy before reaching customers, but a major quantity of power losses occur in the sub-transmission and distribution system networks. The problem of system voltage failure in sub-transmission networks due to increased customer load demand and region load growth with network expansion can be processed via fitting of the DGs units at some network buses near the loads centre like hydro, wind, geothermal and photovoltaic. This alternative can decrease the power losses, and cost of the produced energy from main generation stations, furthermore, increase the reliability and efficiency of the network performance [1-4].

The techniques that have been applied to enhance the system performance are categorized as evolutionary and deterministic methods [5-7]. Evolutionary approaches include PSO (Particle Swarm Optimization) [8, 9], GA (Genetic Algorithm) [10, 11], DE (Differential Algorithm) [12], Ant Colony Algorithm (ACA) [2], the Dragonfly algorithm [13], and the Tabu search algorithms [14]. Deterministic approaches contain linear and nonlinear programming [15, 16]. Due to the limits of deterministic methods, evolutionary approaches were introduced to advance Optimal Power Flow Problems (OPFP) effectively [5-7, 16, 17].

On the other hand, some research has addressed the influence of shunt FACTS and STATCOM devices to decrease voltage deviation and power losses at critical states [4, 5]. In [18, 19], Particle Swarm Optimization (PSO) is applied to find the optimal size and location of Distributed Generation units (DGs) and DSTATCOM. In [20], an adapted MOPSO technique is used to find the multi objective sizing and siting of many DGs units and conventional capacitor banks. In [21], the JAYA process is examined to find the size of a conventional compensator to enhance the power factor in the 11 kV system networks.

Reducing the (PLoss) major power losses that occur in the sub-transmission networks is very important due to its effects on consumers and the economy. In addition, the future expansion of low voltage system networks, by increasing load growth, leads to a decrease in voltage level, an increase in flow power losses in the network, and transmission lines loading that leads to an outage, but blackouts of the system happen in the worst conditions. Furthermore, load growth has been applied to study the impact of using DG units in the sub-transmission system operation [22-27]. The main purpose of this research is to propose modifying approach (PSO) for finding the optimal siting and sizing of the DGs units that supply energy with two types of active and reactive power, with a suitable power factor for reducing total power losses and advancing the voltage profile in 66 kV sub-transmission system networks using the MATLAB (2020a) program.

This paper introduces a study and investigation of DGs influences on BINWALED 66 kV network performance considering normal operation cases and future load growth of the region. Additionally, investigates influences of load growth on optimal sizing and siting of DG units in 29-bus and 47-bus BINWALED sub-transmission networks. The MATLAP program using approach (MPSO) is adapted and applied to advance the test network performance and indicates the capability to reach the optimal solution more accurately and high faster, reducing the voltage deviation, as reductions in generation from main plants and total power losses [19, 23-25]. The contributions of this research are briefed as follows:

1. Modify the algorithm (MPSO) to discover the optimal sitting, sizing and optimum power factor (p.f) of multi DGs in 29-bus and 47-bus sub-transmission test networks in Libya.
2. Constraints of the total power losses (P_{LOSS}), the Margin Reserve (MR), and the Voltage Deviation (VD%) have been considered and enhanced at normal operation conditions and future load growth cases of the region.
3. Effects study of region load growth on optimal positions and sizes of DGs units in 29-bus and 47-bus BINWALED sub-transmission networks are investigated by algorithm (MPSO).

This paper is organized as follows: Section 2 introduces a brief description of the technology of distributed generation in the optimal planning of sub-transmission network expansion. Section 3 displays the problem formulation of optimization in this system. Section 4 introduces the suggested optimization approaches in this paper. The test system under study of the BINWALED 66 kV sub-transmission system network is informed in Section 5. Section 6 presents an effect study of DGs units on the 29-bus and 47-bus BINWALED sub-transmission networks performance considering future load growth. Furthermore, the change effects analysis of DGs power factor on 66kV practical network performance is introduced in this Section, and lastly, the most important investigation results are detailed in Section 7.

2. Distributed Generation (DGs)

DGs units can be joined directly to sub-transmission networks due to the wide range of capacities that range from 100 kW to 300 MW [1-3]. Moreover, it requires a short time to join and work; additionally, due to autonomous generation, it is mostly suitable for faraway loads.

The optimal design of DG unit sizing and siting reduces network power losses and improves its bus voltage profile; it furthermore increases security and voltage stability, power quality, network reliability, and load ability [2, 4]. As the DGs unit capacity increases in power rating at a network bus, the real power losses in the system network decrease. If the capacity of the DGs units increases additional, it is expected that network power losses will also increase. Therefore, to decrease the network power losses, the sizing and siting of DGs units must be optimally allotted in distribution and sub-transmission system networks [5-7].

Presently, the number of DGs units installed in sub-transmission system networks is rapidly increasing due to their ability to maximize the application of renewable energy. Mostly, four main categories of DGs units are considered based on their active and reactive power in delivering the ability [2-5].

DGs units that inject both active and reactive power via a power factor range of about $0.7 < PF_{DG} < 1$, like wind and steam power. DGs units that inject only real power, via $PF_{DG} = 1$, like a photovoltaic power. DGs units that inject real power and absorb reactive power, by power factor around $0 < PF_{DG} < 1$, like hydropower. DGs units that inject only reactive power, by $PF_{DG} = 0$, like FACTs and STATCOM devices.

The DG unit is suggested as a negative load (PQ) that supplies active and reactive power to the network buses. The number of DGs units to be used will be determined via the suggested technique, and one will be positioned per selected bus. [8-10, 14].

3. Optimization Problem Formulation

The problem formulation can mathematically be defined as the minimization or maximization of an exact function.

3.1. Objective Function

In this study, two objective functions are applied: the real Power Losses (P_{LOSS}) and the Margin Reserve (MR) of the test network.

3.1.1. Minimization of (P_{LOSS})

Choosing the optimal sizing and siting of the DGs are particular in this study in order to get the minimum real power losses in the test network. Therefore, the objective function indicates the total losses in the network [2, 4, 6, 11-13]:

$$\text{Obj (F1)} = \text{Minimize } \{P_{LOSS}\} = R_{bus} \,.\, I^{T}_{bus} .\, I^{*}_{bus} \qquad (1)$$

Where: R_{bus} is the real part of the bus impedance matrix, and I_{bus} implies the column direction of the injected bus currents.

3.1.2. Maximization of Margin Reserve (MR)

This objective function advances the reactive power flow (Q) in all sub-transmission networks to improve the margin reserve of the main transmission station and the isolated transformers in the network. This function is formulated as follows:

$$\text{Obj (F2)} = \text{MR} = \text{Maximize } (I_{real} / I_{imag})_{network} \quad (2)$$

Where, (MR) is the Margin Reserve, I_{real} and I_{imag} are the currents supplied to load at network buses [4, 6, 8, 14].

3.2. Constraints

The decreasing the objective function is subject to the following constraints [2, 4, 6, 11-13]:

1. The power balance at buses, as in Equation (3)

$$P_{DGk} - P_{Dk} - P_k = 0 \quad (3)$$

Where P_{DGk} is the power generated by DG unit (k), P_{Dk} is the load demand on bus k, and P_k is the power flow from bus k.

2. The bus's voltage must be within the acceptable limits, i.e., it must not exceed (± 5%) of the nominal voltage of the network (1. p.u) as in Equation (4).

$$V_k^{\ min} < V_k < V_k^{\ max} \quad (4)$$

Where: $V_{k\ min,}$ $V_{k\ max}$ the lesser and the upper of buses voltage limits.

3. The output power of the DGs units is limited by lesser and upper limits. As a result, the DGs power addition in the distribution network must not exceed the power supplied from the main transmission station, as in Equations (5) and (6).

$$P_{DG}^{\ min} < P_{DG} < P_{DG}^{\ max} \quad (5)$$

$$\Sigma\,(P_{DGk}) < P_{ss} \quad (6)$$

Where: $P_{DG}^{\ min}$, $P_{DG}^{\ max}$ the minimum and maximum power generated via DGs units.

P_{ss} the power supplied by the main transmission station.

4. Optimization Algorithms

Two algorithms are used in this study to solve the optimization problem: the Distribution Load Flow Algorithm (DLFA) and the Improved Particle Swarm Optimization (MPSO).

4.1. Algorithm (DLFA)

The efficiency of the optimization depends on the choice of load flow methodology [28, 29]. In this study, the direct approach has been applied to the sub-transmission network. It introduces two matrices definitely, the Bus Injection to Branch Current [BIBC] and the Branch Current to Bus Voltage [BCBV] matrixes. The expression of this direct approach is formulated as in Equations (7-9).

$$[DLF] = [BCBV].[BIBC] \quad (7)$$

$$[\Delta E^{(k+1)}] = [DLF].[I^{\ (k)}]\ ; \quad Ii^{\ (k)} = (Si / Ei^{\ (k)})^* \quad (8)$$

$$[E^{(k+1)}] = [E^{o}] + [\Delta E^{(k+1)}] \quad (9)$$

Where: [DLF] is the Distribution Load Flow matrix, [BIBC] is the Bus Injection to Branch Current matrix, and [BCBV] is the Branch Current to Bus Voltage matrix, $Ii^{\ (k)}$ is the current injection of the i^{th} bus at the k^{th} iteration, S_i is the complex load for i^{th} bus as $(P_i + j\ Q_i)$, $Ei^{\ (k)}$ is the bus voltage of i^{th} bus at the k^{th} iteration, $[E^{(k+1)}]$ is the bus voltages matrix at the $k+1^{th}$ iteration, $[\Delta E^{(k+1)}]$ is the bus voltages correction matrix at the $k+1^{th}$ iteration, $[E^{o}]$ is the initial bus voltages matrix. A (DLF) matrix determines the complex radial construction of the sub-transmission system networks.

4.2. Improving Algorithm (PSO)

This proposed technique is a modified and Improved Particle Swarm Optimization (MPSO) for optimal planning of DGs unit's location and size. The DGs are sited within the buses on the sub-transmission network with the purpose of improving the voltage profile and decreasing power losses. The proposed algorithm (MPSO) is capable of making a choice quickly by decreasing the number of iterations. MPSO determines the position of the DGs based on sensitivity factors for active and reactive power controls [18-20, 30]. This means modifying the velocity in the following Equation (11) of particle j to the new velocity named (the modification velocity (Vj (k+1)) of particle j at the same iteration k+1 as in Equation (13).

This results in faster convergence of the optimal solution. Figure 1 includes the application steps showing how DGs units in the sub-transmission network are optimally allotted using MIPSO. Based on entire optimal solutions as in Equations (10-13).

$$W_j = W_{max} - (W_{max} - W_{min}) / K_{max}.\ K \quad (10)$$

$$S_j^{\ (k+1)} = Sj^{\ (k)} + V_j^{\ (k+1)\wedge} \quad (11)$$

$$V_j^{\ (k+1)} = w.V_j^{\ (k)} + c_1.rand_1(pbest_j^{(k)} - S_j^{\ (k)}) + c_2.rand_2(gbest_j^{(k)} - S_j^{(k)}) \quad (12)$$

$$V_j^{\ (k+1)\wedge} = w.V_j^{(k+1)} + c_1.rand_1(pbest_j^{(k)} - S_j^{(k)}) + c_2.rand_2(gbest_j^{(k)} - S_j^{(k)}) \quad (13)$$

Where W_j is the inertia weighting function, W_{jmin} and W_{jmax} are minimum and maximum inertia weight numbers reaching from 0.4 to 0.9, K_{max} and K are maximum and existing iterations, respectively.

- $V_j^{(k)}$ and $V_j^{(k+1)}$ are the old and new velocities of particle j at iteration k and k+1, respectively.
- $V_j^{(k+1)\wedge}$ the modification velocity of particle j at iteration k+1.
- $Sj^{(k)}$ and $S_j^{(k+1)}$ are the old and new positions of particle i at iteration k and k+1, respectively.

- Pbest is the finest solution attained via a single particle.
- Gbes,t is the finest solution attained in the whole swarm.
- c_1 and c_2 positive acceleration coefficients, their sum is from 2 to 4.
- $rand_1$ and $rand_{2,}$ the randomly made figures reaching from 0 to 1 [8,9,18-20,30].

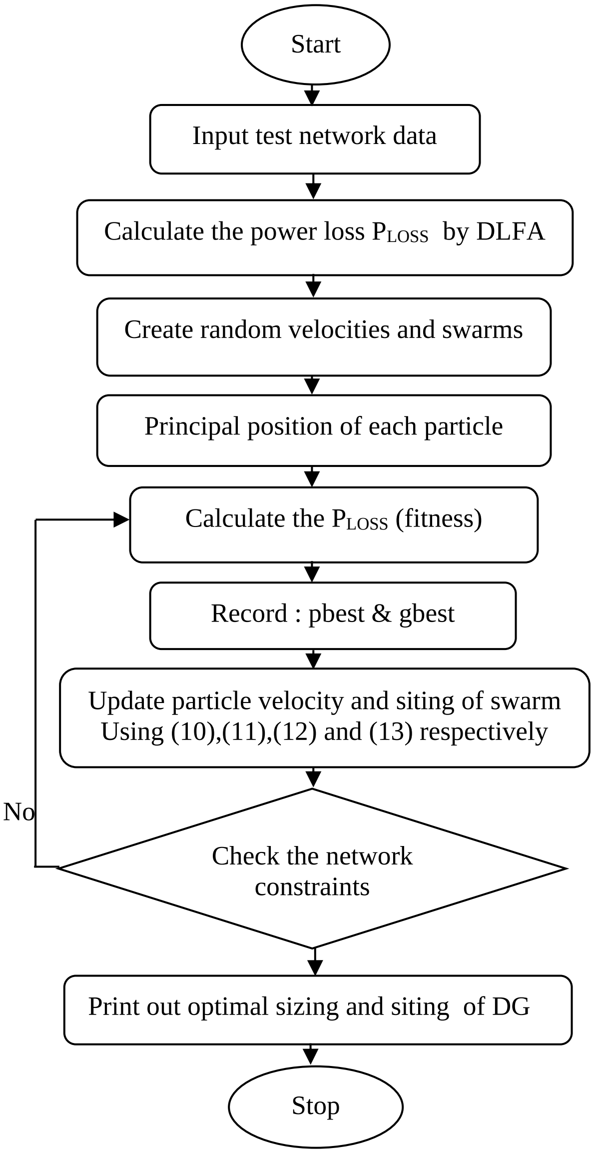

Fig. 1 Flowchart for optimal planning of DGs position and size using MPSO algorithm

5. System Model

BINWALED is the capital city of Libya's north; its region covers approximately 720,000 km2 and has a population of 95,000 people. The average loads are 75 MW, which are feds from the BINWALED 220 kV station. The substations have 29 (66/11 kV) power transformers and 28 feeders. Each transformer is committed to an isolated radial network via (11/0.4 kV) distribution transformers that cover region loads. The BINWALED 66 kV sub-transmission network suffers from large power losses, voltage drops, and lost loading. Hence, a network study was used in this paper. Figure 2 presents the 66 kV sub-transmission system network, which contains 29 buses and 28 feeders [31, 32]. The test network components are listed in Table 1, and cable and line parameters are given in Table 2.

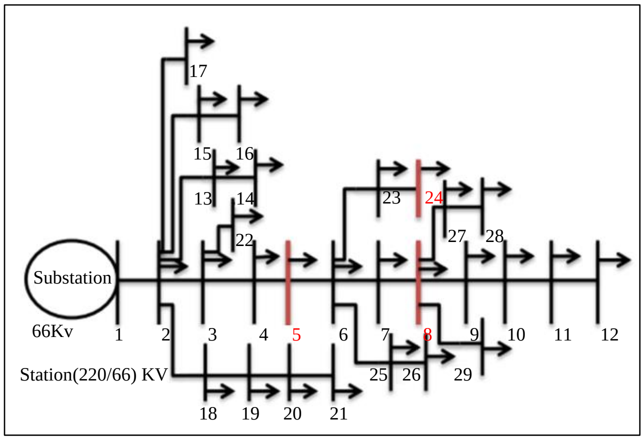

Fig. 2 Single diagram of BINWALED 66 kV sub-transmission network

Table 1. The BINWALED 66 kV network components

Type	Slack Bus	Load Bus	Control Bus
Substation kV	1x (220/66)	20 x (66/11)	1x(11/66)
Transformer MVA	2 x (63MVA)	11x(20MVA) 13x(10MVA), 5x(5MVA)	1x(20MVA) 1x(10MVA)
Overhead line ($326mm^2$) Km	1 Km	600 Km	3 Km
Cable Type. ($630 mm^2$) Km	1 Km	20 Km	1.2 Km

Table 2. Line and cable parameters of the BINWALED network

Parameter / Type	R (Ω/Km)	X (Ω/Km)	Yc (µ℧/Km)	Qc (Mvar/Km)
Line. Type. A.C.S.R (Bear ($326.5mm^2$)).	0.1093	0.3818	2.996	0.01305
Cable. Type. ($630mm^2$)	0.0436	0.07	129.8	0.567

6. Simulation Results and Discussion

In this study, a BINWALED 66 kV sub-transmission network by 29 buses and 28 feeders was surveyed via the suggested techniques (MPSO) and coded in MATLAB (2020a) computing the different cases of refitting DGs units to maximize system performance efficiency are given as follows:

- Case-1: System without DGs units.
- Case-2: Multiple installations of DGs units operating at optimal PF.
- Case-3: Load growth compensation by using DGs units in 29-bus and 47-bus sub-transmission networks.
- Case-4: Change effect of DGs power factor on 47-bus sub-transmission network performance.

6.1. Case 1: Pre-Fitting DGs

In the pre-fitting case, the BINWALED 66 kV sub-transmission network was surveyed by the proposed methods (MPSO) computing state without fitting any DGs units. The results indicate that the overall real power loss in the practical network is about 1.72 MW, which shows that about 2.3% of the energy is lost in the BINWALED sub-transmission network. Furthermore, the voltage deviation achieved is 6.47 %, which is high, as shown in Figure 5 and Table 3, which shows the results of the pre-fitting case.

6.2. Case 2: Installing of Multi DGs Units

In this case, the algorithm (MPSO) is applied to limit the optimal size and location of a single DGs unit linked to the network buses. Figures 3 and 4 show the convergence of the proposed approach (MPSO) and approach (PSO) to find the optimum solution for the 29-bus test network. Where the approach (MPSO) requests to create 3 iterations in order to discover the optimal siting and sizing of a single DG unit by a less total power loss of 0.377 MW, while the traditional technique (PSO) requests to create 6 iterations in order to discovery same the optimum solution, which means that technique (MPSO) best than the technique (PSO) by reducing 3 iterations.

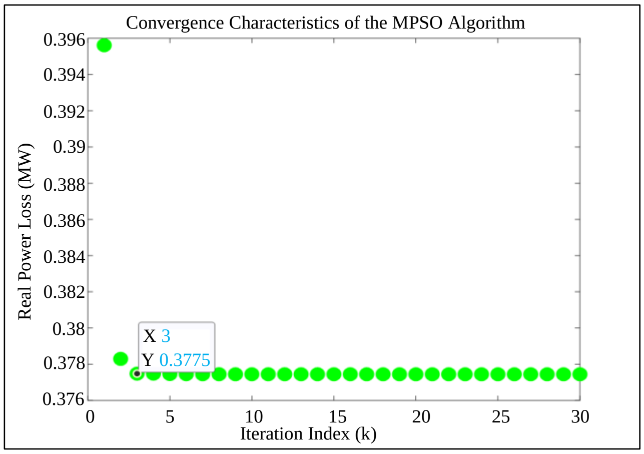

Fig. 3 Convergence characteristics of the MPSO algorithm

The results indicate that the optimized DG unit position was at node 6, with an optimal size of 41 MW and a power factor of 0.82 lagging. The total real power losses were reduced to 0.377 MW, which institutes a 78.3% reduction in network losses. In addition, the voltage deviation index decreased from 6.47% to 1.43%, as shown in Figure 5.

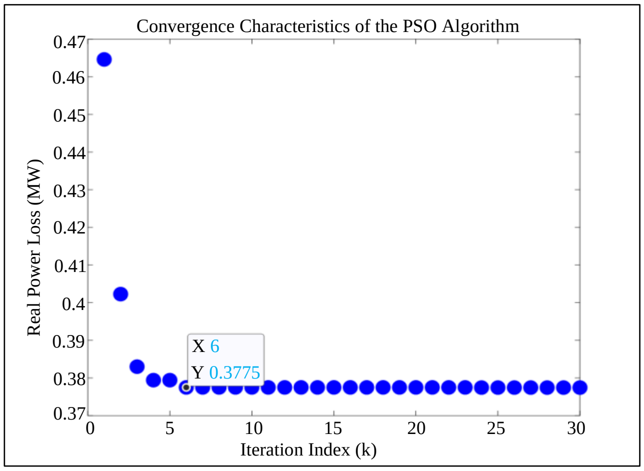

Fig. 4 Convergence characteristics of the PSO algorithm

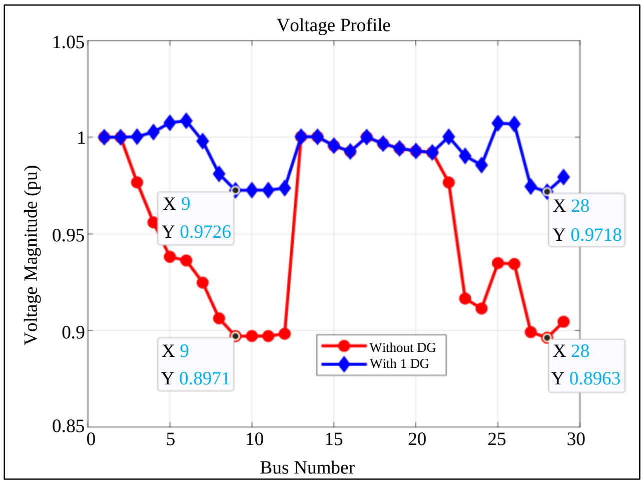

Fig. 5 Voltage profile of 66 kV network at fitting single DGs

From Figure 5, the minimum voltage, in this case, is increased from 0.8963 pu to 0.9718 pu recorded on node 28, leading to the voltage deviation index reduced from 6.47% to 1.43%, which indicates an enhancement in the system performance. In the second case, two DGs units are used in network buses. The technique (MPSO) chose buses 6 and 8 as optimal locations for DG units based on optimal capacities of 27.59 MW and 12.1 MW, respectively, with a power factor of 0.811 lagging. Fitting the two DGs units decreased the power loss to 0.21 MW, and the VD % index improved from 6.47 % to 0.77 %. In the final case, three DGs units were connected to the test network buses. Figures 6 and 7 show the convergence of the MPSO algorithm and PSO algorithm to find the optimum solution of the 29-bus test network, which show the results that the MPSO-algorithm requests to create 41 iterations in order to discover the optimal sites and sizes of three DGs units by a less active power loss of 0.132 MW, while the PSO-algorithm requests to create 60 iterations in order to find the solution with a less active power loss of 0.148 MW, which means that the MPSO-technique best than the PSO-technique by reducing 20 iterations, additionally, an enhancement in the test network performance by reducing 0.016 MW of the power losses.

Results illustrate that the optimized positions were at nodes 5, 8, and 24, by DGs unit sizes of 22.3 MW, 12.3 MW, and 5.4 MW, respectively, with an optimal (p.f) of 0.83 lagging. The total (PLoss) was 0.132 MW, representing a lessening of 92 %. The voltage Deviation (VD%) was 0.64 %. Therefore, the fitting of three DGs units at optimized sites caused reduced total power losses and enhanced voltage profiles. Figure 8 shows the voltage profile improvement of the 66 kV network caused by adding three DGs units. Figures 9 and 10 illustrate the comparative results of the total power loss and the Voltage Deviation index (VD%) for all cases.

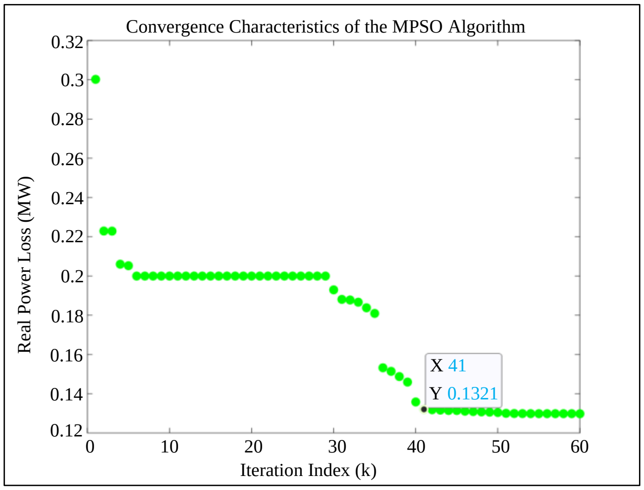

Fig. 6 Convergence characteristics of the MPSO-method at add 3 DGs

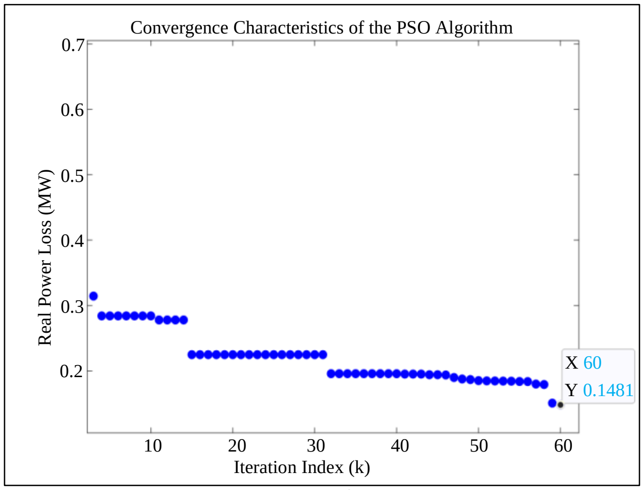

Fig. 7 Convergence characteristics of the PSO-method at add 3 DGs

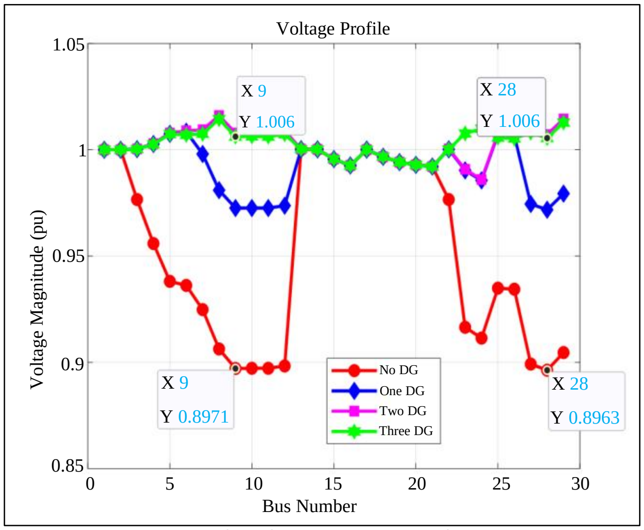

Fig. 8 Voltage profile of 66 kV network at fitting three DGs

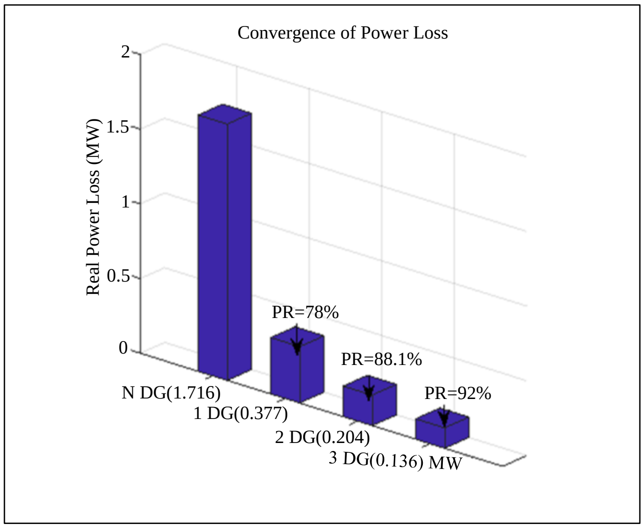

Fig. 9 A comparative results of power losses of 66 kV network -29bus

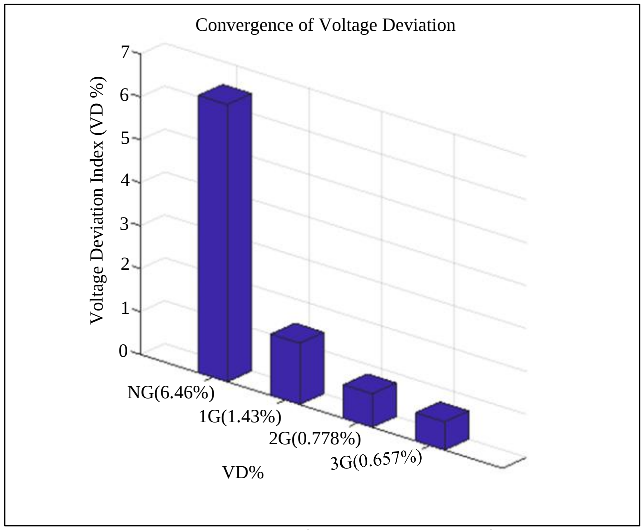

Fig. 10 A comparative results of voltage deviation of 66 kV network

Figure 8 shows the voltage profile for BINWALED's 66 kV network before and after the fitting of several DGs units. It is noticed that system voltage improves in all cases.

However, the best case is when refitting three DGs units to the system buses, where the minimum voltage in this case is improved from 0.89 pu to 1.006 pu by less deviation (VD%) of 0.64 %, and the real power losses are reduced to 0.132 kW at fitting a three DG units to buses 5, 8, and 24, which are the best results than results of the case fitting a two DG unit by reducing (VD%) of 0.13 % and power losses of 0.07 MW, which means an improvement in the grid performance. Table 3 shows the results in brief for all cases.

Table 3. Results of all cases

Cases	**DGs No.**	**DGs Site**	**DGs Size (MW)**	**Power Losses (MW)**	**PLR (%)**	**PF_{DG} (Lag)**	**VD (%)**
Case 1	Default	--	--	1.72	0	0.85	6.47
Case 2	DG1	6	41	0.377	78.3	0.82	1.43
Case 3	DG1 DG2	6 8	27.59 12.1	0.21	88.1	0.811 0.811	0.77
Case 4	DG1 DG2 DG3	5 8 24	22.3 12.3 5.4	0.132	92	0.83 0.83 0.83	0.64

Concerning Table 3, the results show that when installing a single DGs unit at the optimal location of bus 6, with an optimal size of 41 MW and a power factor of 0.82 lag, the voltage deviation is decreased from 6.47 % to 1.43 % and the active power loss is decreased from 1.72 MW to 0.377 MW by a power losses reduction ratio (PLR%) of 78.3 %.

In the second case, when installing two DGs units, the algorithm (MPSO) selected buses 6 and 8 as optimal locations for DG units with optimal sizes of 27.59 MW and 12.1 MW and a power factor of 0.811 lagging.

Furthermore, the voltage deviation is decreased to 0.77 %, and the power loss is decreased to 0.21 MW by a PLR of 88.1 %, which means an improvement in the network performance. In the last case, when re-installing the three DGs at optimal sites of 5, 8, and 24, they had optimal sizes of 22.3 MW, 12.3 MW, and 5.4 MW, respectively, and a power factor of 0.83 lagging.

The total power loss is reduced to 0.132 MW by a PLR of 92%; the VD% index was 0.64 %. Thus, installing the multiple DGs units at an optimized location leads to reduced active power losses and enhanced voltage profiles. Figure 11 shows the Optimal DGs siting and sizing of the 66 kV test network (29-bus) in the last case.

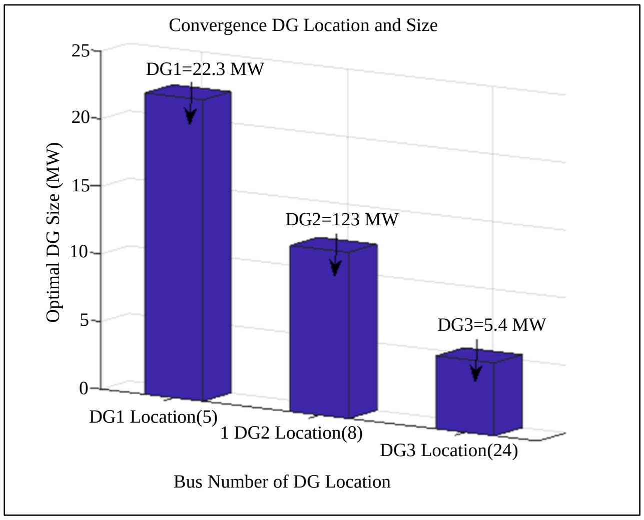

Fig. 11 Optimal DG position and size of (29-bus) network at add 3DGs

6.3. Case 3: Load Growth Compensation by Using DGs Units

This section contains the findings of the suitable load growth compensation (optimal siting and sizing) by using distributed generation units in the BINWALED 66 kV sub-transmission network. Where the two scenarios of the DGs units are used in this section, the first scenario will study the impact of DGs units on 66 kV practical network performance after load growth that contains 29 buses and 28 feeders.

The second scenario will study the impact of DGs units on 66 kV practical network performance after load growth that contains 47 buses and 46 feeders. The load growth (g %) to be taken into account in this paper is 8 % per year in the two cases. Therefore, the estimated loading for the next five years is 111 MW. This gives an estimate of the future load density. The next equation is used to approximate the growth load [31, 32].

$$PD_n = PD_o (1+ g)^n \tag{14}$$

$$PD_5 = 75\ (1+0.08)^5 = 111\ \text{MW}$$

Where PD_n is the future load density, PD_o is the now load density, g is the load growth ratio (g %) per year, and n is the number of years of load growth.

Estimating sub-transmission network performance was assessed by running the proposed method (MPSO) without fitting DGs units. The results show that P_{Loss} is around 4.359 MW, and the VD% is 11.2%, which is fairly high. There is an illustrious drop in the voltage profile below the satisfactory voltage limits, as shown in Figure 12.

6.3.1. Scenario 1: Effect Study of DGs Units on 29-bus Test Network after Load Growth

On this network, two DG unit methods are used.

The First Method: This method involves fixing or fitting the old three DGs units at their old optimal locations and sizes, then estimating the DGs unit's performance in the grid. In this method, the test network was surveyed by the MPSO algorithm to find the optimal solution. Figure 12 shows the voltage profile of the 66 kV sub-transmission network buses. There is a prominent drop in the voltage profile, particularly in buses between 8 and 12 and between 26 and 29. Figures 13 and 14 show that P_{Loss} in the network is about 0.668 MW, and the voltage deviation achieved is 3.2%, which is quite high.

The Second Method: This method is refurbishing or changing both old DGs sizes and locations, then performing grid analysis and evaluating network performance. In this method, the penetration level of three DGs units was increased to new sizes. Results show that the optimum solution is reached when buses of sizes 33.5 MW, 19.4 MW, and 8.5 MW with a power factor of 0.83 lagging are linked to buses 5, 8, and 24, respectively. Figure 12 illustrates the voltage profile improvement. Figures 13 and 14 illustrate the comparative results of the power loss (P_{Loss}) and the Voltage Deviation (VD%) indexes for all cases.

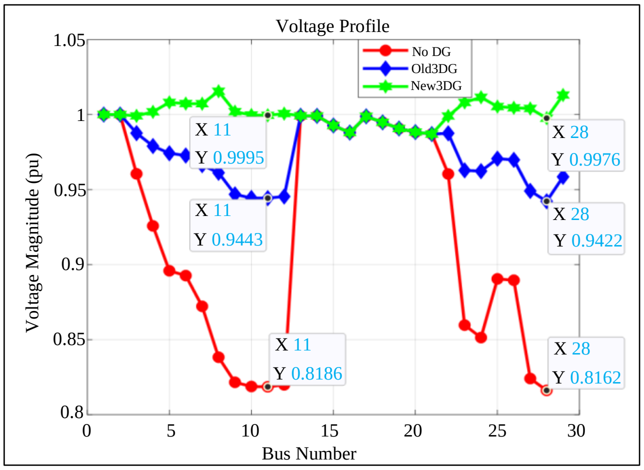

Fig. 12 Voltage profile of all cases using 29bus network

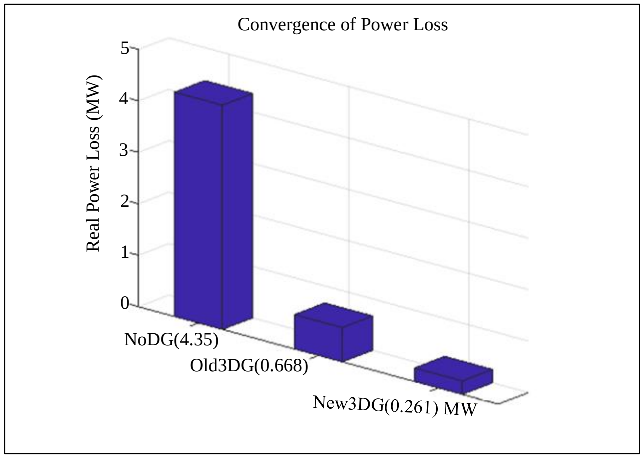

Fig. 13 A comparative results of test network power loss at fitting multiple DGs

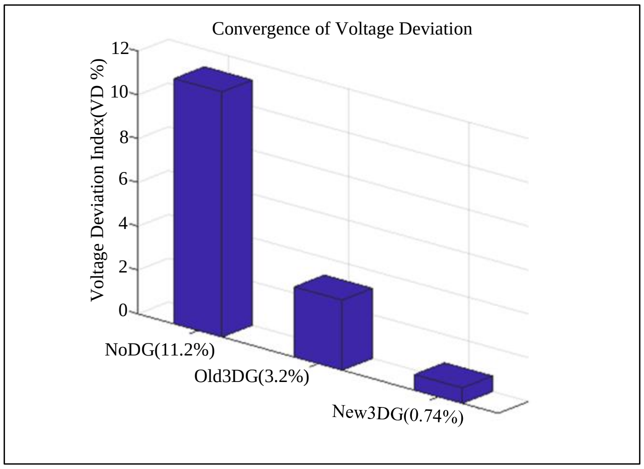

Fig. 14 A comparative results of voltage deviation (VD%) index

Table 4 shows the results of all the cases in brief, and Figure 15 shows the optimal DGs siting and Sizing of the sub-transmission network in case of fitting three new DGs.

Table 4. Results of cases

Cases	DGs No.	DGs Site	DGs Size (MW)	Power Loss (MW)	PLR (%)	PF_{DG} (Lag)	VD (%)
Case 1 NODG	--	--	--	4.359	0	0.84	11.2
Case 2 Old 3 DGs	DG1	5	22.3	0.668	84.6	0.83	3.2
	DG2	8	12.3				
	DG3	24	5.4				
Case 3 New 3 DGs	DG1	5	33.5	0.26	94	0.83	0.71
	DG2	8	19.4			0.83	
	DG3	24	8.5			0.83	

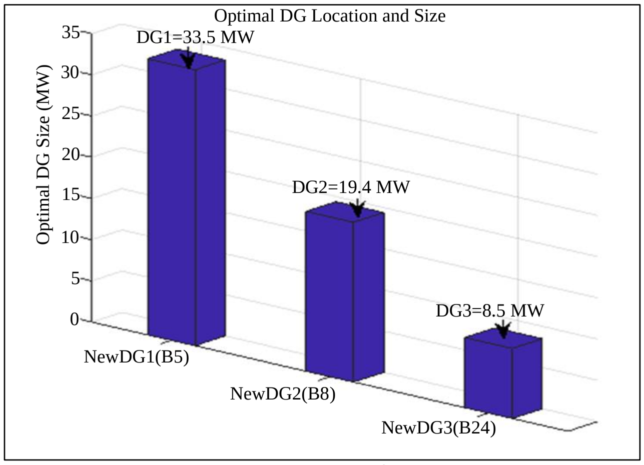

Fig. 15 Optimal DG location and size of (29-bus) sub-transmission network with load growth

Concerning Table 4, the results show that when re-installing the three DGs at optimal sites of 5, 8, and 24, with optimal sizes of 33.5 MW, 19.4 MW, and 8.5 MW, respectively, and a power factor of 0.83 lagging as shown in

Figure 15, The total power loss is reduced to 0.26 MW by a PLR percentage of 94%. Furthermore, the Voltage Deviation (VD%) index is reduced to 0.71%, which indicates an enhancement in the network performance. Thus, installing the new three DGs units at an optimized location leads to reduced active power losses and enhanced voltage profiles. As can be noted, optimal locations of DGs units do not change with load growth, while optimal sizes change directly with load region growth. Adding three DGs units of new sizes ensures that the voltage profile variations are within allowable limits, as the least voltage recorded is 0.987 p.u. on bus 21.

6.3.2. Scenario 2: Effect Study of DGs Units on 47-bus Test Network after Load Growth

In this section, a single diagram of the BINWALED 66 kV sub-transmission network, as shown in Figure 16, will be used, which was increased from 29 buses to 47 buses and contains 47 (66/11 kV) power transformers and 46 feeders with the addition of overhead lines by length 40 Km, and addition of underground cable by length 10 Km. The average load of the new sub-transmission network (47 buses) is 111 MW.

The (Qc) charging capacity of the network (29-bus) was (15.44 MVAr), while the charging capacity of the network (47-bus) has been increased from 15.44 Mvar to 21.5 MVAr where Equation (15) is used to estimate the (Qc) charging capacity of overhead line (Qc_{OH}) and underground cable (Qc_{Cable}) [32].

$$Qc = Yc*V_{LL}^2 \qquad (15)$$

Then:

$$Qc_{OH} = 2.995*10^{-6} \text{ x } (66*10^3)^2 = 0.01304 \text{ Mvar/Km}$$

$$Qc_{Cable} = 129.99*10^{-6} \text{ x } (66*10^3)^2 = 0.566 \text{ Mvar/Km}$$

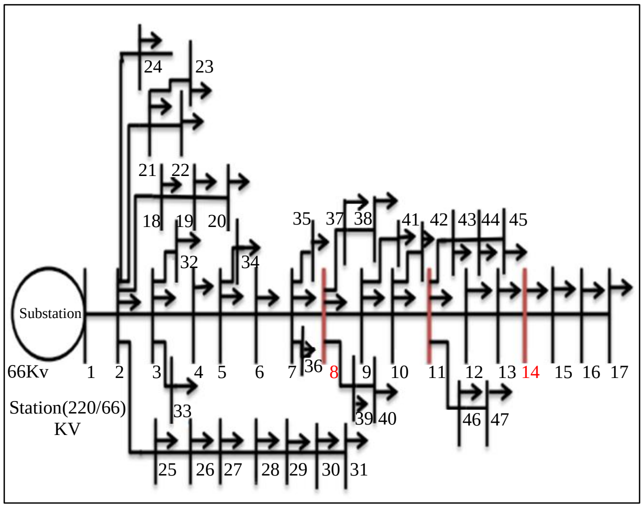

Fig. 16 Single line diagram of 47-Bus BINWALED sub-transmission network

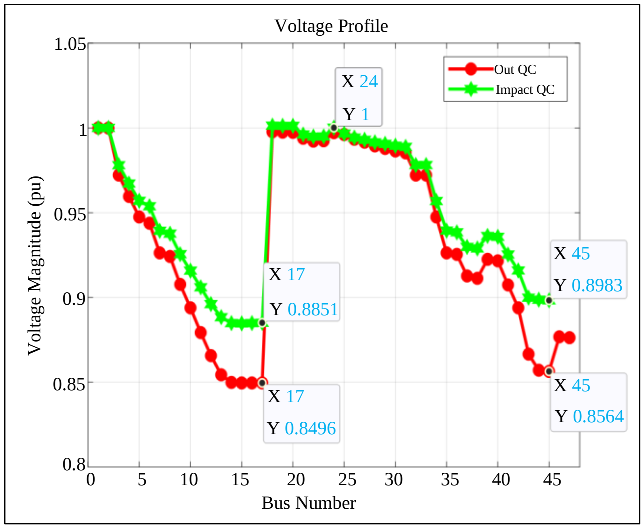

Fig. 17 Impact of line shunt admittance on voltage profile of 66kV network (47bus)

Figure 17, showed the impact of overhead line shunt admittance on the 66kV network performance. The total power loss was reduced from 2.06 MW to 1.71 MW. Moreover, the Voltage Deviation (VD%) index was reduced from 8.64 to 6.54, which indicates an enhancement in the network voltage profile.

Case 1: Estimating 47-Bus Network Performance before Load Growth

In this case, installing three DGs units at new optimal sites of 8, 11, and 14 results in optimal sizes of 28 MW, 10.5 MW, and 3.5 MW, respectively, and a power factor of 0.89 lagging, where the total power loss is reduced from 1.708 MW to 0.104 MW by a percentage PLR of 94%, which means an improvement in voltage profile of 47- bus network as shown in the Figure 18.

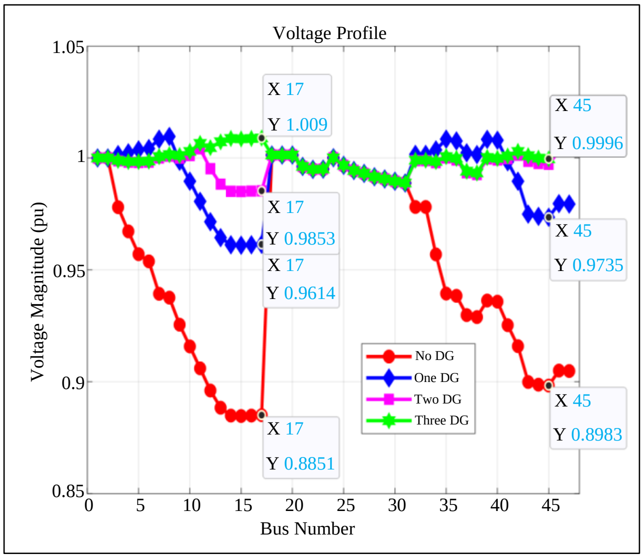

Fig. 18 Voltage profile of 47-bus network at installing three DGs

Case 2: Estimating 47-Bus Network Performance after Load Growth

Analysis results without fitting of DGs units show that the Power Losses (PLoss) of the new network are about 4.37 MW, and the Voltage Deviation (VD%) is 11.5%, which is not satisfactory since there is a voltage drop at the nodes.

Where two methods, fixing and refitting three DGs units, are used on the 47-bus network. Table 5 shows the results for the 47-bus test network when fixing and refitting the three DGs units, respectively. Results show that the optimum solution increased the penetration level of three DGs units from 28 MW, 10.5 MW, and 3.5 MW to new sizes of 40 MW, 15 MW, and 5 MW, respectively, with a power factor of 0.87 lagging, and linked them to new buses 8, 11, and 14 respectively, as shown in Figure 19. As can be noted, optimal locations and sizes of DGs units change directly with load growth in a region. After the refitting of three new DGs units in the network, the power losses decreased from 4.37 MW to 0.20 MW, which establishes a 95.5% reduction. Moreover, the VD% index was reduced from 11.5% to 0.65 %, which indicates improvement in the network voltage profile, as shown in Figure 20, and Table 5 shows the results of all the cases in brief.

Table 5. Comparison between cases at refitting of three DG units of 47-bus network

Cases	DGs No.	DGs Site	DGs Size MW	P_{Loss} MW	PLR (%)	PF_{DG} Lag	VD (%)
Case 1 NODG	--	--	--	4.37	0	0.85	11.5
Case 2 Fixing Old3DG	DG1 DG2 DG3	8 11 14	28 10.5 3.5	0.65	85.1	0.89 0.89 0.89	3.66
Case 3 Refitting 3DG	DG1 DG2 DG3	8 11 14	40 15 5	0.20	95.5	0.87 0.87 0.87	0.65

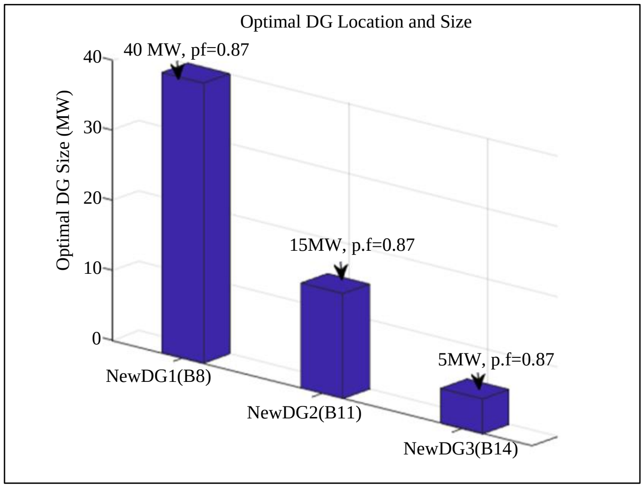

Fig. 19 Optimal DG location and size of 66 kV network (47-bus) with load growth

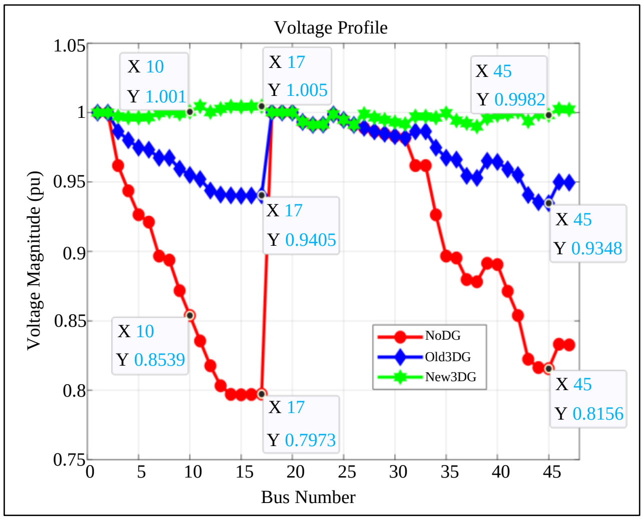

Fig. 20 Voltage profile of (47-bus) new sub-transmission network

Concerning Table 5, the results show that installing the new three DGs units at an optimized location leads to reduced active power losses and enhanced voltage profiles.

As can be noted, optimal locations of DGs units do not change with load growth, while optimal sizes change directly with load region growth. Adding three DGs units of new sizes was better case-fitting old sizes.

6.4. Case 4: Change Effect of DGs Power Factor on 66kV Network Performance

In this case, the algorithm (MPSO) is applied to limit the optimal power factor of three DGs units linked to the 66 kV network buses. The results indicated that the optimized DGs units power factor was at a value (0.87) lagging, as shown in Figure 21, where improvement in the voltage profile of the 47-bus network, the real power losses were reduced from 0.31 MW to 0.2 MW, as shown in figure 22.

In addition, the voltage deviation decreased from 1.66% to 0.65%, which indicates an improvement in the system performance, as shown in Figure 23. Table 6 shows the results in brief for all cases of DGs power factor.

Table 6. Comparison between p.f change cases at refitting three DG units of the 47-bus network after load growth

Case	PF_{DG} (Lagging)	Total Power Losses (W)	VD (%)
Refitting.New3DG Site (8, 11, 14) Size(MW) (40, 15, 5)	0.80	0.31	1.66
	0.83	0.26	1.01
	0.85	0.24	0.71
	0.87	0.20	0.65
	0.89	0.24	1.41
	0.91	0.26	1.67

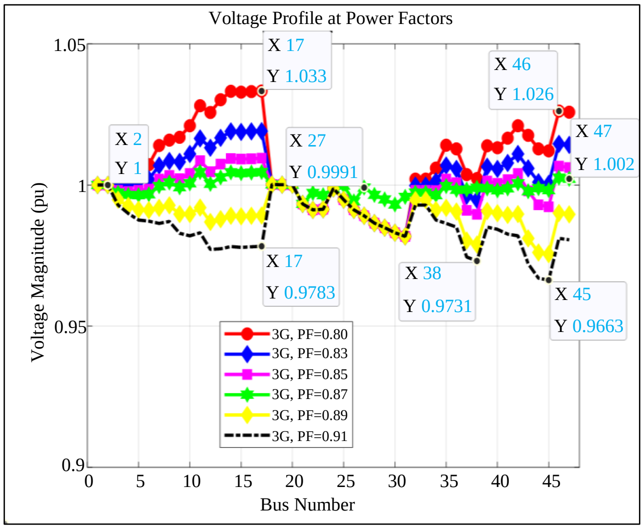

Fig. 21 Voltage profile of test network at change p.f. (47-bus)

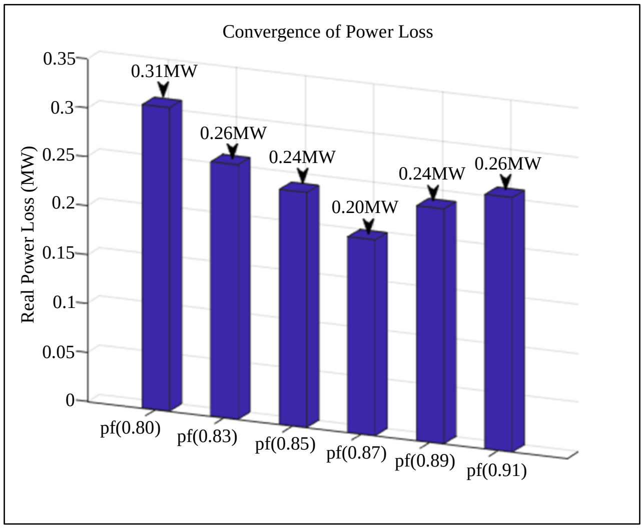

Fig. 22 A comparative result of system power loss (47bus)

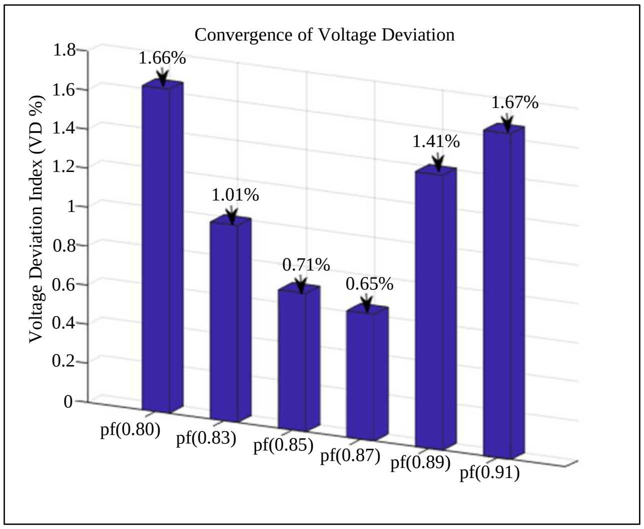

Fig. 23 A comparative result of the Voltage Deviation (VD%) index

Regarding Table 6, the results indicate that the optimized DGs unit's power factor was at a value of 0.87, lagging at optimal nodes of 8, 11, and 14, and optimal sizes of 40 MW, 15 MW, and 5 MW, respectively. The total real power losses are reduced to 0.20 MW. Moreover, the Voltage Deviation (VD%) index was 0.65%. Thus, the optimal power factor (0.87) caused a reduction in the real power losses and enhanced voltage profiles, which are better than the results of the other cases, by reducing 1.1 % of the voltage deviation and 0.11 MW of the power losses, which means more an improvement in the system performance.

Table 7 shows the brief results of the impact of refitting three DGs units on the network's performance of 29-bus and 47-bus after load growth in the region.

Table 7. Comparison between load growth cases at refitting three DG units of networks (29bus, 47bus)

Cases	Qc Mvar charging (Qc)	DGs Size MW	PEN LVL (%)	P.F DGs Lag	PLR (%)	Power Losses (W)	VD (%)
Case1 NO DG 29-bus	15.44	--	--	0.84	0	4.36	11.2
Case 2 Old 3DG 29 bus	15.44	40	36 %	0.83	84.6	0.67	3.2
Case 3 New 3DG 29-bus	15.44	61.4	55.4	0.83	94	0.26	0.76
Case 4 New 3DG 47-bus	21.5	60	54	0.87	95.5	0.20	0.65

Table 7 shows that the results of load growth compensation by using DGs units in the network (47-bus) are best compared to results of the network (29-bus), where the optimum solution for the penetration level of three DGs units was decreased from 55.4% to 54% with a lagging power factor of 0.87. As can be seen, the optimal sizes of DGs units increase directly with the region load growth. In the network (47-bus), the charging capacity (Qc) of the 66 kV network has increased from 15.44 MVAr to 21.5 MVAr. Thus, the total power loss is reduced from 0.26 MW to 0.20 MW. Moreover, the Voltage Deviation (VD%) index is reduced from 0.76 to 0.65, which indicates an enhancement in the network performance of 47-bus.

7. Conclusion

The study has suggested a modifying MPSO algorithm for determining the optimal sizing, siting, and optimal power factor of DGs units for improving the bus's voltage profile and decreasing real power losses in 66 kVsub-transmission networks. The proposed method has been applied and tested on the 66 kV BINWALED sub-transmission network in Libya. The effect study of DGs units on 29-bus and 47-bus BINWALED sub-transmission networks after load growth has been verified and achieved. The results show that the refitting of three DG units ensures the voltage profile variations are within allowable limits, as the least voltage noted is 0.998 p.u. on bus 22.

Furthermore, the Voltage Deviation (VD%) is reduced to 0.65% and (PLR%) by 96%. which indicates an improvement in the system performance, where the two approaches of the DGs units are used in this research. Fitting and refurbishing of three DGs units from both networks (29-bus and 47-bus) after region load growth.

Results show that the Penetration Level (PLV) of three DGs was increased via new optimal sizes which change directly with the region load growth. However, the optimal positions of DGs do not vary after load growth without increasing the system bus number. After the re-installing of three new DGs in the test network, the total real power losses were reduced from 4.36 MW to 0.20 MW, which institutes a 95.5% reduction in network power losses, and the voltage deviation was decreased from 11.2% to 0.65%, which shows enhancement in the system voltage.

Furthermore, the case refitting of the new three DG units in the 47-bus test network was better than the 29-bus test network due to the increased shunt admittance (Qc charging capacity) of the 47-bus test network from 15.44 MVAr to 21.5 MVAr and decreased power losses. Moreover, the effect of DGs power factor on 47-bus BINWALED network performance is studied.

Results show that the optimized DGs units power factor was at a value (0.87) lagging. In this power factor, the integration of DGs units reduced the losses and voltage deviations more than in the other cases.

References

[1] Rui Li et al., "A Review of Optimal Planning Active Distribution System: Models, Methods, and Future Researches," *Energies*, vol. 10, no. 11, pp. 1-27, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[2] Adeseye Amos Ogunsina et al., "Optimal Distributed Generation Location and Sizing for Loss Minimization and Voltage Profile Optimization Using Ant Colony Algorithm," *SN Applied Sciences*, vol. 3, pp. 1-10, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[3] Ahmed A. Raouf Mohamed, "A Multi-Objective Distributed Generation Allocation and Sizing Using Swarm Intelligence Based Algorithms," *19th IEEE Mediterranean Eletrotechnical Conference*, pp. 281-286, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[4] Mahdad Belkacem, "A Novel Tree Seed Algorithm for Optimal Reactive Power Planning and Reconfiguration Based STATCOM Devices and PV Sources," *SN Applied Sciences*, vol. 3, pp. 1-24, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[5] Zhichun Yang et al., "Review on Optimal Planning of New Power Systems with Distributed Generations and Electric Vehicles," *Energy Reports*, vol. 9, pp. 501-509, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[6] P. Pon Ragothama Priya et al., "Optimal Allocation of Distributed Generation Using Evolutionary Multi-objective Optimization," *Journal of Electrical Engineering & Technology*, vol. 18, pp. 869-886, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[7] Ankur Kumar et al., "Optimal Placement and Sizing of Distributed Generation in Power Distribution System: A Comprehensive Review," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 45, no. 3, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[8] Gafari Abiola Adepoju et al., "Optimal Placement and Sizing of Distributed Generation for Power Loss Minimization in Distribution Network Using Particle Swarm Optimization Technique," *European Journal of Engineering and Technology Research*, vol. 8, no. 1, pp. 19-25, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[9] Shreya Mahajan, and Shelly Vadhera, "Optimal Sizing and Deploying of Distributed Generation Unit Using a Modified Multi objective Particle Swarm Optimization," *2016 IEEE 6th International Conference on Power Systems (ICPS)*, New Delhi, India, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[10] Y. Alinejad-Beromi et al, "Using Genetic Algorithm for Distributed Generation Allocation to Reduce Losses and Improve Voltage Profile," *2007 42nd International Universities Power Engineering Conference*, Brighton, UK, pp. 954-959, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[11] K. Vinothkumar, and M.P. Selvan, "Fuzzy Embedded Genetic Algorithm Method for Distributed Generation Planning," *Electric Power Components Systems*, vol. 39, pp. 346-366, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[12] Soma Abdou Romeh et al., "Optimal Reconfiguration and Optimal Allocation of Distributed Generation Using Different Optimization Techniques," *Engineering Research Journal*, vol. 46, no. 1, pp. 1-9, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[13] M.C.V. Suresh, and Edward J. Belwin, "Optimal DG Placement for Benefit Maximization in Distribution Networks by Using Dragonfly Algorithm," *Renewables: Wind, Water, and Solar*, vol. 5, no. 4, pp. 1-8, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[14] Mlungisi Ntombela, Kabeya Musasa, and Moketjema Clarence Leoaneka, "Power Loss Minimization and Voltage Profile Improvement by System Reconfiguration, DG Sizing, and Placement," *Computation*, vol. 10, no. 10, pp. 1-24, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[15] M. Shahidehpour, and V. Ramesh, "Nonlinear Programming Algorithms and Decomposition Strategies for OPF," *IEEE/PES Tutorial on Optimal Power Flow*, 1996. [Google Scholar]

[16] Khaled Zehar, and Samir Sayah, "Optimal Power Flow with Environmental Constraint Using a Fast Successive Linear Programming Algorithm: Application to the Algerian Power System," *Energy Conversion and Management*, vol. 49, no. 11, pp. 3362-3366, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[17] Usama Khaled, Ali M. Eltamaly, and Abderrahmane Beroual, "Optimal Power Flow Using Particle Swarm Optimization of Renewable Hybrid Distributed Generation," *Energies*, vol. 10, no. 7, pp. 1-14, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[18] S. Devi, and M. Geethanjali, "Optimal Location and Sizing Determination of Distributed Generation and DSTATCOM Using Particle Swarm Optimization Algorithm," *International Journal of Electrical Power & Energy Systems*, vol. 62, pp. 562-570, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[19] A.A. Sadiq, S.S. Adamu, and M. Buhari," Optimal Distributed Generation Planning in Distribution Networks: A Comparison of Transmission Network Models with FACTS," *Engineering Science and Technology, an International Journal*, vol. 22, pp. 33-46, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[20] Arash Zeinalzadeh, Younes Mohammadi, and Mohammad H. Moradi, "Optimal Multi Objective Placement and Sizing of Multiple DGs and Shunt Capacitor Banks Simultaneously Considering Load Uncertainty via MOPSO Approach," *International Journal of Electrical Power & Energy Systems*, vol. 67, 2015, pp. 336-349, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[21] Walid Helmy, and Mohamed Abd Elhamid Abbas, "Optimal Sizing of Capacitor-Bank Types in the Low Voltage Distribution Networks Using JAYA Optimization," *2018 9th International Renewable Energy Congress (IREC)*, Hammamet, Tunisia, pp. 1-5, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[22] Chao Yang et al., "A Novel Partitioning Method for the Power Grid Restoration Considering the Support of Multiple LCC-HVDC Systems," *Energy Reports*, vol. 9, pp. 1104-1112, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[23] Ismail Alperen Ozlu et al., "A Heuristic Methods-Based Power Distribution System Optimization Toolbox," *Algorithms*, vol. 15, no. 1, pp. 1-14, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[24] Di Wu, and Jiacheng Guo, "Optimal Design Method and Benefits Research for a Regional Integrated Energy System," *Renewable and Sustainable Energy Reviews*, vol. 186, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[25] Ramin Cheraghi, and Mohammad Hossein Jahangir, "Multi-Objective Optimization of a Hybrid Renewable Energy System Supplying a Residential Building Using NSGA-II and MOPSO Algorithms," *Energy Conversion and Management*, vol. 294, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[26] Roman Bolgaryn et al., "Active Power Curtailment in Power System Planning," *IEEE Open Access Journal of Power and Energy*, vol. 8, pp. 399-408, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[27] R. Arulraj, and N. Kumarappan, "Optimal Economic-Driven Planning of Multiple DG and Capacitor in Distribution Network Considering Different Compensation Coefficients in Feeder's Failure Rate Evaluation," *Engineering Science and Technology, an International Journal*, vol. 22, no. 1, pp. 67-77, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[28] Jen-Hao Teng, "A Direct Approach for Distribution System Load Flow Solutions," *IEEE Transactions on Power Delivery*, vol. 18, no. 3, pp. 882-887, 2003. [CrossRef] [Google Scholar] [Publisher Link]

[29] G.W. Chang, S.Y. Chu, and H.L. Wang, "An Improved Backward/Forward Sweep Load Flow Algorithm for Radial Distribution Systems," *IEEE Transactions on Power Systems*, vol. 22, no. 2, pp. 882-884, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[30] Naveen Jain, S.N. Singh, and S.C. Srivastava, "Particle Swarm Optimization Based Optimal Siting and Sizing of Multiple Distributed Generators," *In Proceedings of the 16th National Power Systems Conference*, Osmania, India, pp. 669-674, 2010. [Google Scholar] [Publisher Link]

[31] Department of Control and Planning, "*Sub-Transmission Network Planning Technical Manual*," The Libyan Electric Power, Triply, Technical Report, 2022.

[32] Turan Gonen, *Electric Power Distribution Engineering*, 3rd ed., CRC Press, New York, 2014. [Google Scholar] [Publisher Link]