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IMPACT OF OPERATING DISPERSED GENERATORS ON THE OPERATION OF ELECTRICAL UTILITY WITH APPLICATION IN EGYPT

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Abstract- This work aims to assess the impact of dispersed wind generators (DWG) on the operation of distribution systems and determine the optimal location and penetration level (PL) of these generators with multi-system constraints to achieve a single and multi-objectives function. Genetic algorithm (GA) and SWARM are used as a modern optimization techniques, also the conventional linear programming (LP) technique also been employed to confirm the optimization results obtained by both GA and SWARM techniques, when they applied to assess the impact of DWG on an Egyptian utility operation. These impacts included active and reactive power losses and voltage profiles.

1. INTRODUCTION

Dispersed generators (DG) are, by definition, small size generators, which can come from traditional or some revolutionary technologies or it is an electric power source connected directly to the distribution network or on the customer side of the meter [1]. The increasing penetration DG added to the distribution power system creates new technical and economical challenges. Which can be classified into three main categories as technical, commercial and regulatory. The commercial side aspects are the cost of implementing, reward companies for connecting DG and the market mechanism. With the regulatory category, there is an absence of a clear policy and associated regulatory instruments on the treatment of DG. The reason for this are partly historical and related to the way distribution networks have been developed and operated as passive networks. The aspects referred to the technical side are presented as high financial costs, environmental protection, energy security, power quality, change in power flow and reactive power [2-5]

Therefore several benefits accrue by integrating DG with utility network. These benefits should be clearly understood, analyzed and quantified in order to increase the potential and value of DG penetration. It is proposed to classify the benefits into two groups technical and economic. The major technical benefits are, standby capacity or peak use capacity (peak shaving), reliability, security and power quality, grid support, climate, environmental, and health concerns [6-12].

While the economic benefits are the developments in DG technologies; which considered one of five major factors that contribute to the evolution of DG according to IEA (2002) [10]. As, the significant advances in several generation technologies that are much more environmentally benign (wind-electric generation, micro turbines, fuel cells, and photovoltaic) than conventional coal, oil, and gas-fired plants also contribute to the evolution of DG [10]. Furthermore, some DG technologies reduce operation and maintenance costs of the generation units.

As mentioned in [14], number of locations are suggested for dispersed wind generators on the distribution system of Mersi-Matrouh city. These locations are substation, the closed loop of all distribution feeders, one and two feeders of this distribution system. In this work, we will assess the impact of dispersed these wind generators (DWG) on the operation of the study distribution system and determine the optimal location and penetration level (PL) of these DWG with multi-system constraints to achieve a single and multi-objectives function.

2. PROPOSED TECHNIQUES

Different DWG penetration levels, considering the proposed DWG size limits and three proposed techniques are applied to obtain the optimal solution for the suggested location. These techniques are linear programming, genetic algorithm and swarm technique. The suggested techniques is programmed under MATLAB software.

2.1. Objective Functions:

The proposed techniques aim to determine the best location and PL for DWG by minimizing different functions. Two main goals are taken into considerations active/reactive power losses reduction and bus voltage improvement.

I) Single objective functions:

A. Voltage index (VI):

$$VI \% = ((V_{wo, DWG} - V_{w, DWG}) / V_{wo, DWG}) * 100 \quad (1)$$

where;

VI % : voltage index.

$V_{w, DWG}$: bus voltage of the system with DWG.

$V_{wo, DWG}$: bus voltage of the system without DWG (system as it is).

B. Active power-loss index (AP_{LI}):

$$AP_{LI} \% = (APL_{sec i w, DWG} / TAPL_{F wo, DWG}) * 100 \quad (2)$$

Where

$$APL_{sec i w, DWG} = 3 I_{sec i w, DWG}^2 (r_i L_i) \quad (3)$$

$$TAPL_{F wo, DWG} = 3 \sum_{i=1}^N I_{sec i wo, DWG}^2 (r_i L_i) \quad (4)$$

, and

$AP_{LI} \%$: active power loss index.

$APL_{sec i w, DWG}$: active power loss of section i of feeder F due to the presence of DWG.

$TAPL_{F wo, DWG}$: total active power losses of the feeder F that includes section i in case of DWG absence (system as it is).

r_i : line resistance of section i, ohm/km.

L_i : line length of section i, km.

$I_{sec i w, DWG}$: line current of section i in case of DWG presence, kA.

$I_{sec i wo, DWG}$: line current of section i in case of DWG absence, kA.

N : number of feeder sections.

C. Reactive power-loss index (RP_{LI}):

$$RP_{LI} \% = (RPL_{sec i w, DWG} / TRPL_{F wo, DWG}) * 100 \quad (5)$$

Where,

$$RPL_{sec i w, DWG} = 3 I_{sec i w, DWG}^2 (x_i L_i) \quad (6)$$

$$TRPL_{F wo, DWG} = 3 \sum_{i=1}^N I_{sec i wo, DWG}^2 (x_i L_i) \quad (7)$$

, and

$RP_{LI} \%$: reactive power loss index.

$RPL_{sec i w, DWG}$: reactive power loss of section i of feeder F due to the presence of DWG.

$TRPL_{F wo, DWG}$: total reactive power losses of the feeder F that includes section i in case of DWG absence.

x_i : line reactance of section i, ohm/km.

L_i : line length of section i, km.

$I_{sec i w, DWG}$: line current of section i in case of DWG presence, kA.

$I_{sec i wo, DWG}$: line current of section i in case of DWG absence, kA.

N : number of feeder sections.

II) Multi- objective functions:

Another technique that used to optimize more than one objective function simultaneously is the multi-objective technique, which can be solved by using weighting factors for maximizing benefits of DWG. The multi-objective function (MOF) of DWG can be formulated as:

$$MOF = W_1 VI \% + W_2 AP_{LI} \% + W_3 RP_{LI} \% \quad (8)$$

With $0 \leq W_i \leq 1$ $\sum_{i=1}^3 W_i = 1$

Where, W_1 , W_2 and W_3 are benefit weighting factors for VI%, AP_{LI} % and RP_{LI} % respectively. The choice of weighting factors depends on the objective that required to be maximized. However, if DWG is introduced to mitigate a certain objective to overcome a specific problem, the corresponding weighting factor is increased compared to other factors.

2.2 .System Constraints:

Number of constraints are stated and taken into consideration through carrying the objective function. These are:

1. Active and reactive power losses constraint:

The losses after locating DWG in the power grid should be less than or equal losses before locating DWGs.

$$PL \text{ with DWG} \quad PL \text{ without DWG} \quad (9)$$

$$QL \text{ with DWG} \quad QL \text{ without DWG} \quad (10)$$

2. The total number of DWGs:

Number of DWG units (N_{DWG}) must be less than or equal the maximum permissible number of DWG ($N_{DWG \max}$) to take into account the PL allowed in the electric utility study as:

$$N_{DWG} \leq N_{DWG \max} \quad (11)$$

3. Bus voltage constraints:

This constraint arise in order to maintain voltage profile at load bus and limiting the overload capacity. Here,

$$V_{i \min} \leq V_i \leq V_{i \max} \quad i = 1, 2, \dots, N \quad (12)$$

Where N represents the number of buses, V_i is the bus voltage,

$V_{i \min}$ is the bus minimum voltage and $V_{i \max}$ is the bus maximum voltage.

3. Proposed Optimization Techniques

3.1. Linear Programming (LP)

The conventional linear programming (LP) technique has the popular one may used due to the simplicity of system modeling and objectives. LP can be defined as an optimization of a linear objective functions and linear constraints. LP in the standard form can be written as [15]:

$$\text{Maximize or Minimize} \quad Z = cx$$

$$\text{Subject to :} \quad Ax = b$$

$$\text{Where} \quad x > 0, b > 0$$

We start LP by input system data (network and DWG data). A power flow study which is written in MATLAB for a system operating under normal operating conditions is called a base case. The results from the base case constitute a benchmark for comparison of changes in network flows and voltages under changing in network topology. After installation of the DWG units in the three proposed locations and with the proposed PLs, the power flow program is executed and then the single/multi-objective functions calculated. All obtained solutions that satisfy all constraints are registered and finally compared. The least solution which is less than the base case is considered the optimum solution for both the proposed location and the proposed PL. If no solution is less than the base case, the proposed location is considered unsuitable for adding DWGs. Then LP is repeated again to study the problem at the next suggested location. Then we compare all solutions to obtain the best solution by both single and multi-objective functions as illustrated below.

3.2. Genetic Algorithm (GA)

Genetic algorithm is a stochastic searching algorithm. It combines an artificial, i.e. The Darwinian Survival of the fittest principle with genetic operation, abstracted from nature to form a robust mechanism that is very effective at finding optimal solutions to complex-real world problems [16]. The LP results of our system of the proposed study cases is optimized using GA to get the best location and PL of DWG that achieve both system constraints and maximal benefits of DWG. Single objective function can be introduced including (VI%, AP_{LI} %, RP_{LI} %). Then, multi-objective function will be introduced to get the best solution too. The fitness function for multi-objective optimization is determined as following:

$$F = W_1 VI\% + W_2 AP_{LI}\% + W_3 RP_{LI}\% \quad (13)$$

Where :

VI% is the voltage index.

AP_{LI} % is the active power loss index.

RP_{LI} % is the reactive power loss index.

F is Fitness Function (multi-objective function).

W_1 , W_2 and W_3 are the objective function weights, subjected to:

$$W_1 + W_2 + W_3 = 1 \quad (14)$$

GA starts with a randomly generated initial population (chromosomes) based on the LP results previously obtained. Then the binary coded chromosomes are converted into decimal ones in the evaluation process to evaluate the fitness function (single/multi-objective function). After calculation of the fitness of each chromosome, chromosomes with the best fitness are selected for reproduction of the new generation by means of the roulette wheel. Two point crossover process is then performed and mutation to get the new generation. Then fitness function is evaluated again by the new values of new generation chromosomes. Number of iterations should be selected to obtain the needed convergence and accuracy. In this work crossover takes place with probability 0.5 and with 0.05 mutation probability.

3.3. Swarm Technique

Particle Swarm Optimization (PSO) is a relatively recent heuristic search method whose mechanics are inspired by the swarming or collaborative behavior of biological populations. The LP results of our system of the proposed study cases is optimized using SWARM to get the best location and PL of DWG that achieve both system constraints and maximal benefits of DWG. Single objective function can be introduced including (VI%, AP_{LI}%, RP_{LI}%). Multi-objective function will be introduced to get the best solution too. The fitness function for multi-objective optimization is determined as in equation (13) and (14). In PSO, chromosomes called particles change their positions with time. Particles are flown through the problem space by following the current optimum particles. PSO starts with initialize the swarm in the solution space based on the results obtained by LP to determine the bounds of each variable. Then, we evaluate fitness of each particle. The fitness of the initial position is set as pbest. Set the particle associated with the best evaluation value among pbests as the gbest. Then we modify gbest, pbest and velocity. Each particle is evaluated according to the updated position. If the evaluation value of each particle is better than the previous pbest, the current updated position is set to be pbest. If the best evaluation value among pbests is better than the previous gbest, we set the particle associated with it as the new gbest. Then velocity of each particle is modified according to the following equation:

$$v_i(t) = v_i(t-1) + \alpha_1 (x_{pbesti} - x_i(t)) + \alpha_2 (x_{gbest} - x_i(t)) \quad (15)$$

where α_1 and α_2 are random variables; $\alpha_1 = r_1 c_1$, $\alpha_2 = r_2 c_2$ with r_1 ,

$r_2 \sim U(0,1)$ and c_1 and c_2 are positive acceleration constants we choose $c_1 = c_2 = 2$. Then each particle will move toward a new position more closely the right direction, with the following equation:

$$x_i(t) = x_i(t-1) + v_i(t) \quad (16)$$

Then the fitness will be evaluated again with both the new modified position and velocity. Then the process is repeated until we get the best solution.

4. APPLICATION

Different wind generator modes had been optimized in reference [14], and concluded that 100 MW and 1500 MW wind generator modes are the superior ones to be installed at the considered distribution system of Mersin-Matrouh city, Figure 1. The test system consists of four feeders, each of four buses and five connecting lines (cables). Except the third feeder which contains only 3 buses and 4 connecting cables (cc). This system consists of one conventional supply (substation) located at bus A as illustrated in Figure 1. Resistances, reactances and the lengths of all lines are listed in appendix (I).

The power flows are solved using MATLAB program, while LP,

GA and SWARM techniques are used to assess the impacts of

varying the locations and PLs of DWG as the study network operation. In which 6 different cases of DWG locations are simulated.

Which are:

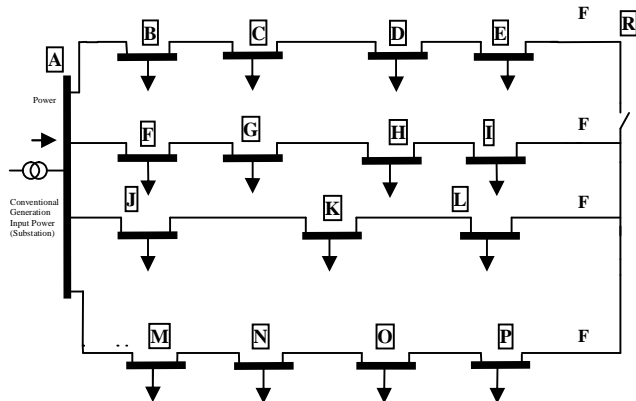


Figure 1. A line diagram of the study distribution system [17].

Case 1: DWG located at points [E&D] of feeder 1 with [5%, 10%, 15%, 20%] PL.

Case 2: DWG located at points [I & H] of feeder 2 with [5%, 10%, 15%, 20%] PL.

Case 3: DWG located at points [L & k] of feeder 3 with [5%, 10%, 15%, 20%] PL.

Case 4: DWG located at points [P & O] of feeder 4 with [5%, 10%, 15%, 20%] PL.

Case 5: DWG located at closed loop of all feeders with [5 %, 10 %, 15%, 20%] PL.

Case 6: DWG located at the substation, bus A, with [5%, 10%, 15%, 20%] PL. Which will results in a same load flow results as obtained in case of system as it is (base case).

5. Results and Discussion

After installation of the DWG units, the power-flow program is executed and then the single/mult-objective functions are calculated by means of the three proposed techniques (LP, GA and SWARM techniques). The results mentioned in [14] concluded that 1500 kW- wind generator (WG) is the optimum ones of the study wind generator modes (WGMs) to dispersed at the substation (bus A) and closed loop of the study distribution system, Figure 1. While, 100 kW-WGM is the most one to dispersed on feeders. Also, these results give the number of these generators at different penetration levels (PLs) of 1500 and 100 kW-WGMs.

5.1 Results of Voltage Index (VI%):

Table 1, gives the optimal location and PL of DWG to obtain the best VI% by using the proposed three optimization methods (LP, GA and SWARM). In this table, VI% has the minimum value using both GA and SWARM (1.5411) compared to the LP technique (1.5398). Therefore load point L of feeder 3 is the optimal location and 20% is the optimal PL to obtain the optimum

VI%. Figure 2 summerizes the results of both GA and SWARM

techniques. While Figure 3 shows the impact of DWG on VI% at Locating DWG with different PLs at load point L at feeder 3 using LP.

Table 1. Results for VI%

Results	LP	GA	SWARM
Optimal location	Load point L of feeder 3	Load point L of feeder 3	Load point L of feeder 3
Optimal penetration level	20%	20%	20%
VI%	1.5398	1.5411	1.5411

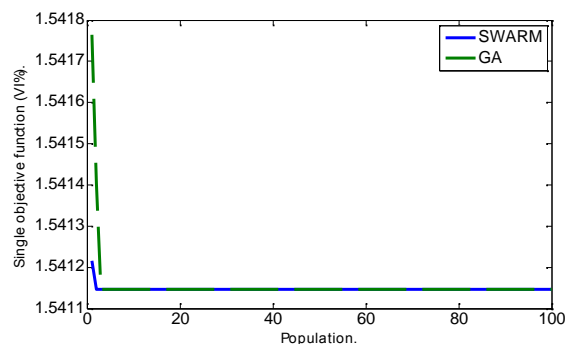


Figure 2. Performance of both GA and SWARM techniques to obtain minimum of VI% of case3 ($W_1=0.333$)

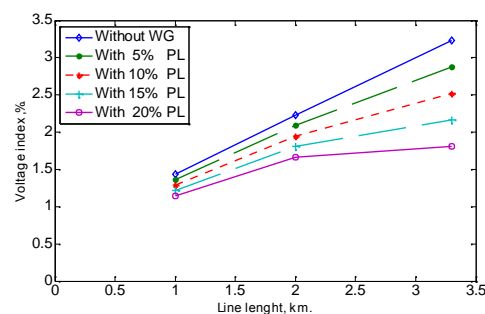


Figure 3. Impact of DWG on voltage index at Locating DWG with different PLs at load point L of feeder 3 using LP.

5.2 Results of Active Power (AP_{LI} %):

Table 2, gives the optimal location and PL of DWG to obtain the best AP_{LI} % by using the proposed three optimization methods. In this table, AP_{LI} % has the minimum identical value using GA, SWARM and LP of (10.368). Therefore, load point I of feeder 2 is the optimal location and 20% is the optimal PL to obtain the optimum AP_{LI} %. Figure 4 summerizes the results of both GA and SWARM techniques. While Figure 5 shows the impact of DWG on AP_{LI} % at Locating DWG with different PLs at load point I at feeder 2 using LP.

Table 2. Results for AP_{LI} %

Results	LP	GA	SWARM
Optimal location	Load point I	Load point I	Load point I

	of feeder 2	of feeder 2	of feeder 2
Optimal penetration level	20%	20%	20%
$AP_{L1}\%$	10.368	10.368	10.368

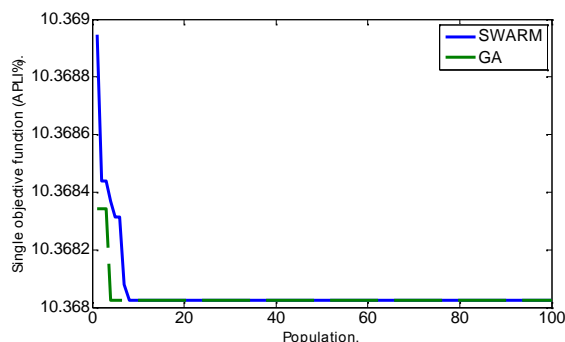


Figure 4. Performance of both GA and SWARM techniques to obtain minimum of $AP_{L1}\%$ of case2 ($W_2=0.25$).

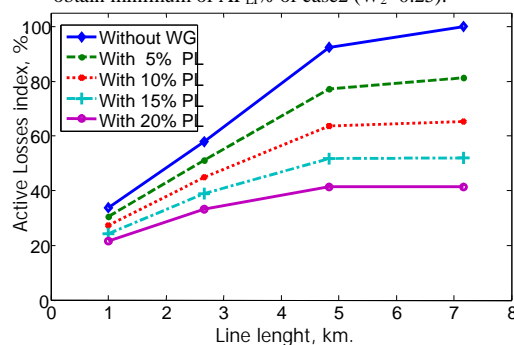


Figure 5. Impact of DWG on active power loss index at Locating DWG with different PLs at load point 1 of feeder 2 using LP.

5.3 Results of Reactive Power ($RP_{L1}\%$):

Table 3. gives the optimal location and PL of DWG to obtain the best $RP_{L1}\%$ by using the proposed three optimization methods. In this table, $RP_{L1}\%$ has the minimum value using LP of (12.1059), GA of (12.0828) and SWARM of (12.0769). Therefore, load point E of feeder 1 is the optimal location and 20% is the optimal PL to obtain the optimum $RP_{L1}\%$. Figure 6 summarizes the results of both GA and SWARM techniques. While Figure 7 shows the impact of DWG on $RP_{L1}\%$ at Locating DWG with different PLs at load point E of feeder 1 using LP.

Table 3. Results for $RP_{L1}\%$

Results	LP	GA	SWARM
Optimal location	Load point E of feeder 1	Load point E of feeder 1	Load point E of feeder 1
Optimal penetration level	20%	20%	20%
$RP_{L1}\%$	12.1059	12.0828	12.0769

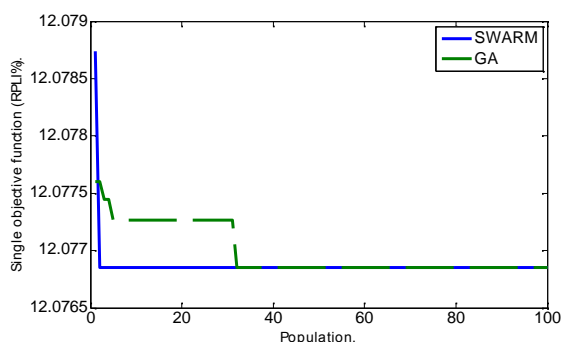


Figure 6. Performance of both GA and SWARM techniques to obtain minimum of $RP_{L1}\%$.

obtain minimum of $RP_{LI}\%$ of case1 ($W_3=0.25$).

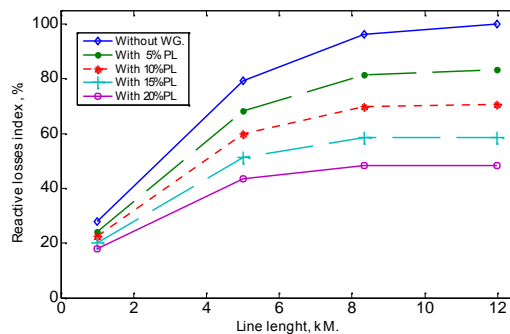


Figure 7. Impact of DG on reactive power loss index at Locating DG with different PLs at load point E of feeder 2 using LP.

5.5 Results of Multi-objective Function:

5.5.1 Optimization of Weighting Factors:

Weighting factors play a vital rule in determining the value of objective function. In this work our objective is to minimize $VI\%$, $AP_{LI}\%$ and $RP_{LI}\%$, which means bus voltage improvement and active/reactive power losses reduction. So we will choose the value of the weighting factors which will give the lowest multi- objective function by trial and error method. We give $VI\%$ the highest priority as voltage has the most important effect of system operation. So we let $W_1=0.55$, then we change the values of both $AP_{LI}\%$ and $RP_{LI}\%$ (W_2 and W_3) between 0 to 0.45. The resulted optimum weighting factors are.

$W_1=0.55$, $W_2=0.449$ and $W_3=0.001$ for feeder 1, 2 and 3.

$W_1=0.55$, $W_2=0.001$ and $W_3=0.449$ for feeder 4.

These results are taken for the best solution of the previous six study cases.

5.5.2. Multi-objective function results:

The multi-objective functions (MOF) for $VI\%$, $AP_{LI}\%$ and $RP_{LI}\%$ are achieved using the MOF which given in equation 13, using the optimum weights obtained in section 5.5.1, and applying the three proposed techniques (LP, GA and SWARM). Table 4 shows MOF for $VI\%$, $AP_{LI}\%$ and $RP_{LI}\%$ for the six study cases. Its obvious that MOF is nearly identical for the three proposed techniques. Also, Figure 8 summerizes both GA and SWARM optimization techniques results. While Figure 9 shows the variation of DG multi-objective function obtained by the three proposed optimization techniques with different DWG and PLs at different DWG locations. From previous tables we can illustrate that the best solution which has the minimum objective function is case 2 (locating DWG at load point I of feeder 2 with 20% PL).

Table 4. MOF of DWG for the study cases obtained by LP, GA and SWARM optimization techniques using the optimum selected weighting factors.

Cases	Multi-objective functions		
	Linear Programming	Genetic Algorithm	SWARM Technique
Case 1	24.2034	24.2033	24.2033
Case 2	23.1748	23.1747	23.1754
Case 3	25.2556	25.2556	25.2556
Case 4	37.5809	37.5509	37.55
Case 5	41.6147	41.6165	41.6146

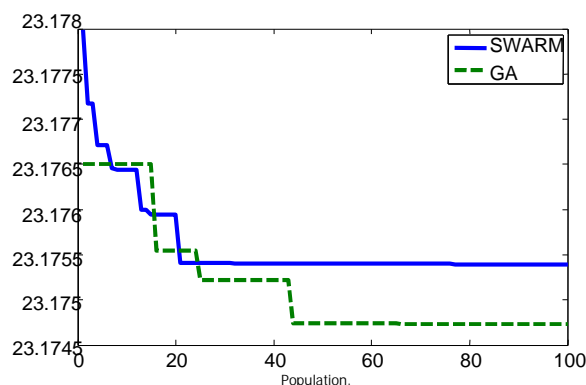


Figure 8. Performance of both GA and SWARM techniques to obtain minimum of MOF of case2 using the optimum

weighting factors ($W_1=0.55$, $W_2=0.449$, $W_3=0.001$).

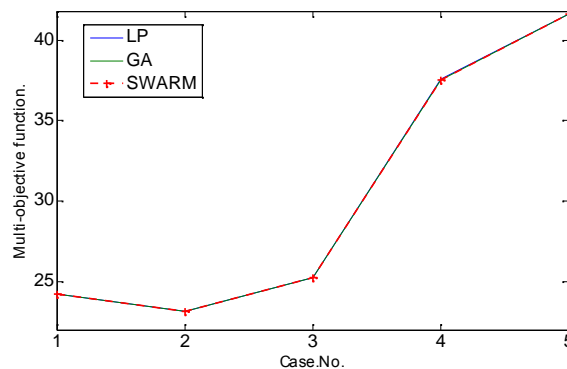


Figure 9. Variations of DWG multi-objective function obtained by LP, GA and SWARM optimization techniques with different DWG penetration levels and different locations.

6. Comparison Between Study Cases:

The optimum solution of the six suggested cases that have been studied according to the results we obtain from the load flow study can be identified directly by selecting the minimum value of our variables ($VI\%$, $AP_{LI}\%$ and $RP_{LI}\%$) between all cases. As the value of these variables is based on certain priorities of these three major variables, an assessment can be achieved by comparing all of these variables for each case and comparing the best case with respect to the base case without adding DWGs. Table 5 shows a comparison between the studied cases. While, Table 6 shows a comparison between the base case without DWG and with the best locating. Generally, the best case according to single/multi-objective function results is locating DWG units at load point I of feeder 2 with 20% PL.

Table 5. Comparison between the studied cases.

Case No	Case 1	Case2	Case 3	Case 4	Case 5
Optimal location	Bus E	Bus I	Bus L	Bus P	At closed loop of all feeders with 20% PL
Optimal penetration level (%).	20%	20%	20%	20%	
Total active power losses (MW).	0.0791 Saving 53.9%	0.094 Saving 58.5%	0.057 Saving 49.5%	0.3632 Saving 44.5%	0.0958 Saving 15.2%
Total reactive power losses (MW).	0.152 Saving 51.5%	0.1604 Saving 51.2%	0.1097 Saving 45%	0.2861 Saving 44.6%	0.1733 Saving 13.13%
Voltage improvement (%)	2.12	3.07	1.5	3.97	0.36

Table 6. Comparison between the base case without DG and with best case.

case	Base case	The best case	Notes
Total active power losses (MW)	0.2267	0.094	Saving 58.5%
Total reactive power losses (MW)	0.3288	0.1604	Saving 51%
Voltage improvement (kV)	$V_i=10.3836$	$V_i=10.7032$	Improvement 3.07%

7. CONCLUSION:

Two modern optimization techniques are proposed in this work to obtain the best location and PL of DWG units to be dispersed on the distribution system of Mersi- Matrouh city and achieve our system constraints. These optimization techniques are GA and SWARM technique. The results is confirmed by LP as a conventional technique. Multi-objective function is applied to achieve three objective functions simultaneously dependent on the

choice of their weighting factors which have been optimized by trial and error. The proposed techniques has applied to subsets of DG benefits, which are voltage improvement (VI%), active power loss reduction (AP_L%) and reactive power loss reduction (RP_L%).

It has been concluded that both DWG location and penetration level plays a vital role in determining VI%, AP_L% and RP_L%.

From multi-objective function results we can conclude that the best study case is the case 2 in which the DWG is located at load point I of feeder 2 with PL 20%.

From VI% results we can conclude that the best study case is the case 3 in which DWG is located at load point L of feeder 3 with 20% PL.

From AP_L% results we can conclude that the best study case is the case 2 as obtained from multi-objective function results.

From RP_L% we can conclude that the best study case is the case 1 in which the DWG is located at load point E of feeder 1 with 20% PL. These results concluded that the best study case is the case 2.

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APPENDIX (I)

Actual system data [17]:

Line No.	From Bus	To Bus	Length (km)	R (ohm/km)	X (ohm/km)
1	1	2	0.6	0.1683	0.3248
2	2	3	2.4	0.1683	0.3248
3	3	4	2.0	0.1683	0.3248
4	4	5	2.2	0.5448	0.4292
5	5	17	1.2	0.1683	0.3248
6	1	6	1.2	0.1683	0.3248
7	6	7	2.0	0.1683	0.3248
8	7	8	2.6	0.5448	0.4292
9	8	9	2.8	0.5448	0.4292
10	9	17	1.0	0.1683	0.3248
11	1	10	2.0	0.1683	0.3248
12	10	11	2.0	0.1683	0.3248
13	11	12	2.6	0.5448	0.4292
14	12	17	1.2	0.1683	0.3248
15	1	13	2.2	0.5448	0.4292

16	13	14	2.2	0.5448	0.4292
17	14	15	2.7	0.5448	0.4292
18	15	16	2.2	0.5448	0.4292
19	16	17	2.0	0.1683	0.3248