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Optimal Sitting and Sizing of Multi-Distributed Generation Units Considering Load Pattern Using Particle Swarm Optimization to Reduce Losses

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Abstract

Using distributed generation (DG) units in distribution systems for loss reduction is a pervasive factor. But inattention to measuring and establishing place of DGs, not only don't help to loss reduction, but also may be caused to increase of losses in network. Many ways and algorithms have represented to find for proper place and capacity of distributed generation sources which constant load pattern in many of them was assumed, but when the system load is diverse with time, using constant loads analyses would be misleading. In this paper optimal location and sizing of DGs, using particle swarm optimization (PSO) algorithm with attention to diversities of load efficacious toward time in period of one year is discussed for loss reduction in distribution system. The results were tested on an actual radial distribution system.

Keywords: Distribution System, Distributed Generation (DG), Loss reduction, Optimum Size and Location, Load Pattern, Load Index.

1. Introduction

Distributed generations have played a very important role in designing of distribution systems in these recent years. Nowadays, we utilize distributed generation principally in distribution systems for reduction of losses, improve of voltage profile, increase of reliability, and improve of power quality. Totally, distributed generation systems divide to two major groups which are based upon fuel and modern distributed generations, like distributed generations that are based upon renewable energies like photovoltaic, wind turbines and fuel cells. Dividing distributed generations have shown in Figure (1). Distributed generation's applications that we can point to them are such as supporting ready to work valence (standby), standalone application from lattice, and combined heat and power (CHP) cogeneration [1]. Although from economical and accessible viewpoint, it is economical and accessible issues as the first sources of energy, utilization of distributed generations based upon nonfuel energies and renewable sources are economical. But for the reason of lack of controllability and manageability and the conditions of dispatch, the executive companies of electric power energy generation have a tendency to utilization of normal distributed generations and based upon fuel that have more controllability and exploitation management. Although utilization of distributed generations in distribution systems have very advantages, but beside of these advantages, utilization of them have also some complexities, and it'll throw the distribution system in challenge, of course these complexities won't be considered

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as defect of distributed generation. The challenges and the complexities in front of the utilization of distribution systems have shown on [2].

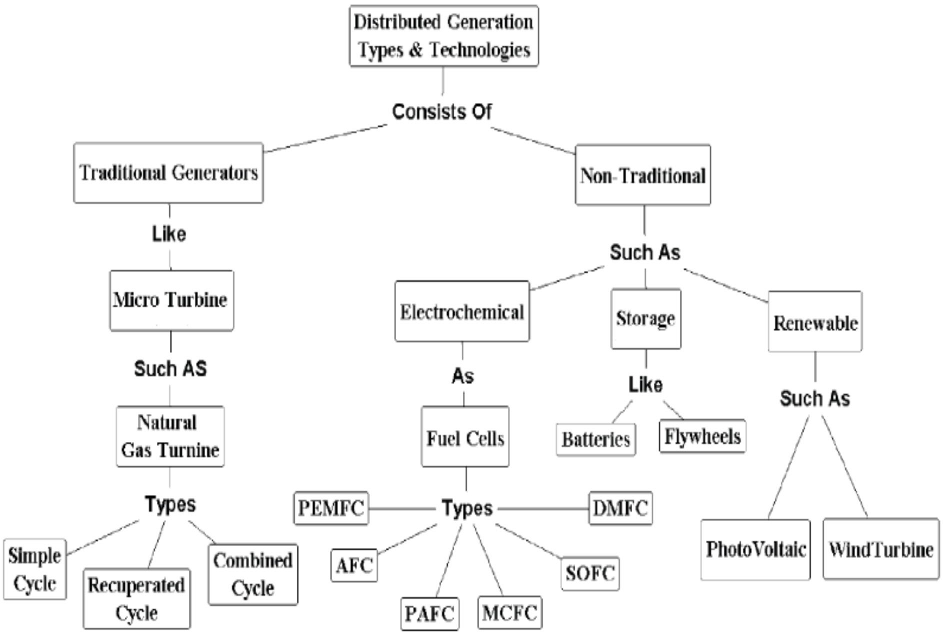

Figure 1: Distributed generation types and technologies [1]

As an example, you must have attention that the utilization of distributed generation doesn't become cause of reduction of reliability, increase of losses, and voltage destruction. For achieve to these goals, and utilization of advantages of distributed generations then attention to selection of size and location is too important. The problem of optimum location and sizing of distributed generation for loss reduction is a complex mathematical problem that has presented for investigation of the kinds of heuristic and analytic optimization ways. Among the optimization ways that have presented in solve this problem we can mention to genetic algorithm (GA) [4, 6, 7], particle swarm optimization (PSO) [3, 5, 8, 9, 10], ant colony optimization (ACO) [11] algorithm, and simulated annealing (SA) [12]. In this article, it has utilized particle swarm optimization (PSO) for finding optimum size and location for distributed generation. This article is consisting of following sections. In section (2), we will embark on the formulation; in section (3), we will make a comment of particle swarm optimization; in section (4), we will mention to simulation and offering test algorithm on an actual distribution system; simulation results given in (5) and then, the conclusion is given in section (6).

2. Problem formulation

The real power loss in a system is given by (1). Popularly referred to as "exact loss" formula [13].

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - P_iQ_j)\right] \quad (1)$$

Where

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j) \quad (2)$$

$$\beta_{ij} = \frac{r_{ij}}{V_i V_j} \sin(\delta_i - \delta_j) \quad (3)$$

$$Z_{ij} = r_{ij} + jx_{ij} \quad (4)$$

Z_{ij} is the ij_{th} element of [Z bus] matrix with [Z bus] = [Y bus]-1. The mathematical formulation of objective function can be stated as:

$$\text{Minimize} \quad F = \sum_{j=1}^{N} P_{LOSS_j} \quad (5)$$

Where, P_{LOSSj} is total power losses in j_{th} line, N is number of lines in the distribution network. The minimization problem is subjected to both equality and inequality constraints as follows.

A. Equality Constraints

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n} |V_i||V_j|(Gi_j \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) = 0 \quad (6)$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{n} |V_i||V_j|(Gi_j \cos\theta_{ij} - B_{ij} \sin\theta_{ij}) = 0 \quad (7)$$

Where, n is number of buses, P_{Gi} and Q_{Gi} are injection powers of generators to the bus, P_{Di} and Q_{Di} are the loads , P_i and Q_i are the active and reactive power of the buses. And i=0, 1, 2... n

B. Inequality Constraints

$$|V_i|_{\min} \le |V_i| \le |V_i|_{\max} \qquad \text{i= 1, 2, 3... n} \quad (8)$$

$$P_{DGi,\min} \le P_{DGi} \le P_{DGi,\min} \qquad \text{i=1,2,3,.....,n} \quad (9)$$

$$Q_{Gi,\min} \le Q_{Gi} \le Q_{Gi,\max} \qquad \text{i= 1,2,3,.....,n} \quad (10)$$

3. Sitting and sizing of DG units using particle swarm optimization

A. Particle swarm optimization

Particle swarm optimization (PSO) is a population-based optimization method first proposed by Kennedy and Eberhart in 1995, inspired by social behavior of bird flocking or fish schooling [14]. The PSO as an optimization tool provides a population based search procedure in which individuals called particles change their position with time. In a PSO system, particles move around in a search space. During movement, each particle adjusts its position according to its own experience (P_{best}), and according to the experience of a neighboring particle (G_{best}), made use of the best position encountered by itself and its neighbor (Figure 3).

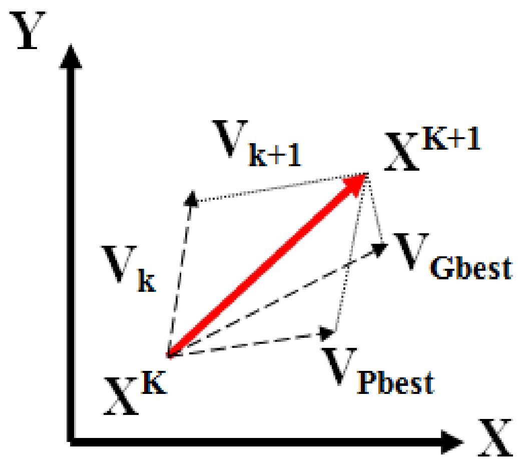

Figure 2: concept of a searching point by PSO [15]

This modification can be represented by the concept of velocity. Velocity of each agent can be modified by the equation (11):

$$v_{id}^{k+1} = \omega v_{id}^{k} + c_1 rand * \left(P_{best} - x_{id}^{k}\right) + c_2 rand * \left(g_{best} - x_{id}^{k}\right) \qquad (11)$$

Using the above equation, a certain velocity, which gradually gets close to p_{best} and g_{best} can be calculated. The current position (searching point in the solution space) can be modified by the equation (12):

$$x_{id}^{k+1} = x_{id}^{k} + v_{id}^{k+1} \quad i= 1, 2, 3..., n \;\&\; d=1, 2, 3....m \qquad (12)$$

where x_k is current searching point, xk+1 is modified searching point, vk is current velocity, vk+1 is modified velocity of agent i, p_{best} v is velocity based on p_{best}, g_{best} v is velocity based on g_{best}, n is number of particles in a group, m is number of members in a particle, pbesti is pbest of agent i, g_{besti} is g_{best} of the group, ω_i is weight function for velocity of agent i, c_i is weight coefficients for each term. The following weight function is used from equation (13):

$$\omega_i = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{k_{\max}} . k \qquad (13)$$

Where, ω_{min} and ω_{max} are the minimum and maximum weights respectively. K and k_{max} are the current and maximum iteration. Appropriate value ranges for C1 and C2 are 1 to 2, but 2 is the most appropriate in many cases. Appropriate values for ω_{min} and ω_{max} are 0.4 and 0.9 [14, 15] respectively.

B. Application of PSO in sitting and sizing of DG units

The PSO-based approach for finding optimum size and location problem to minimize the loss takes the following steps:

Step 1: Input line and bus data, and bus voltage limits.

Step 2: Calculate the loss using distribution load flow.

Step 3: Randomly generates an initial population of particles with random positions and velocities on dimensions in the solution space. Set the iteration counter k = 0.

Step 4: For each particle if the bus voltage is within the limits, calculate the total loss in equation (1). Otherwise, that particle is infeasible.

Step 5: For each particle, compare its objective value with the individual best. If the objective value is lower than P_{best}, set this value as the current P_{best}, and record the corresponding particle position.

Step 6: Choose the particle associated with the minimum.

Individual best P_{best} of all particles, and set the value of this P_{best} as the current overall best G_{best}.

Step 7: Update the velocity and position of particle using (11) and (12) respectively.

Step 8: If the iteration number reaches the maximum limit, go to Step 9. Otherwise, set iteration index k= k+1, and go back to Step 4.

Step 9: Print out the optimal solution to the target problem. The best position includes the optimal locations and size of DGs, and the corresponding fitness value representing the minimum total losses.

These steps are illustrated in Figure (3), [15].

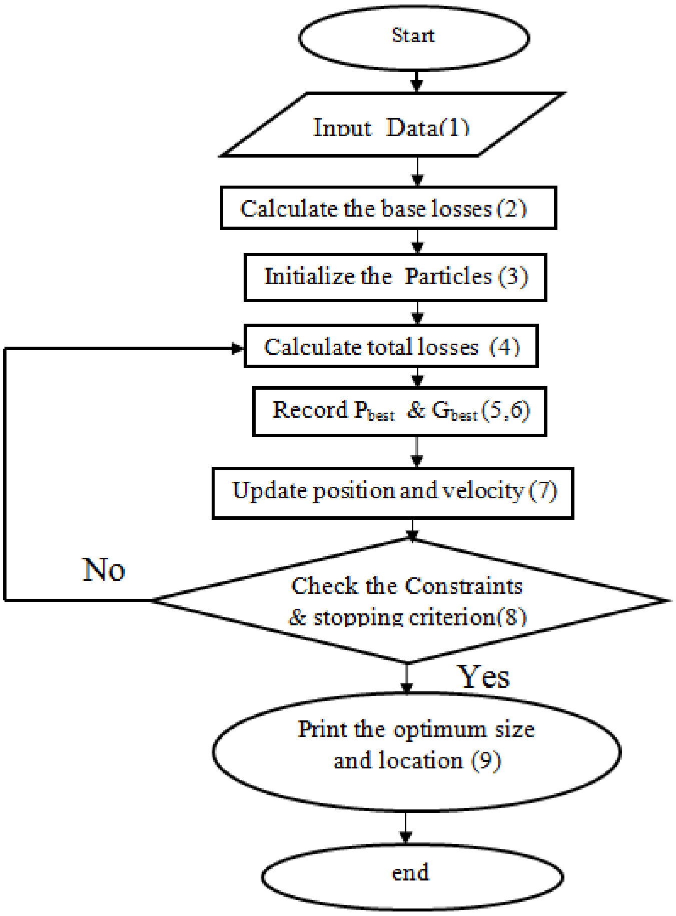

Figure 3: PSO Procedure

4. Proposed method to determination of optimum location and size of DGs

A. Load pattern

As it was represented, pattern of consuming is diverse toward time, and as it should be remarked to diversities of load rate toward time in this paper, then it is necessary that be studied on consuming patterns, and consuming rate and valence losses determine in each working cycle. Load pattern at one year in Iran for global network is shown in Figure (4).

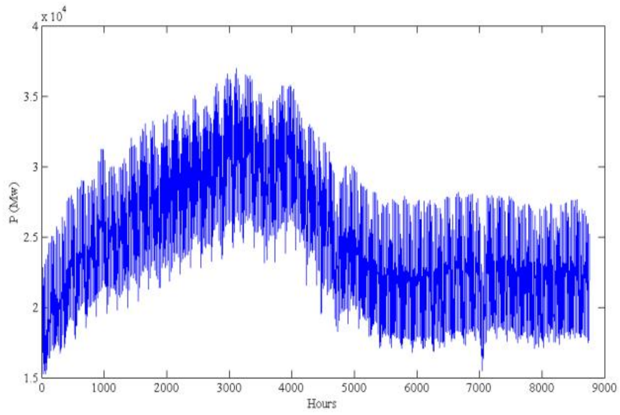

Figure 4: Load pattern at one year

As it is shown in Figure (4), load pattern is diverse toward time. If we arrange cycloid of Figure (4) in arrangement of the most consuming rate to the least consuming rate, it will be in result of Figure (5). In the next section, it will be settled to calculate of load indexes with use of this diagram.

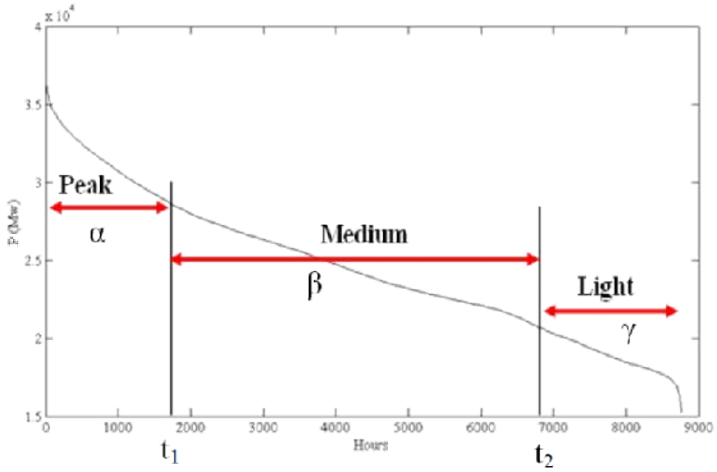

Figure 5: arranged load pattern

With attention to this notice that consuming rate and losses of consumers are different in light (L), balanced (M), and peak (P) working cycles, then it is necessary that it become determine in consuming rate and losses. For this reason, it is reproduced of load indexes in this paper. As the load pattern is exist for global network, and they inseparably are not available for each Bus, then it is necessary that load pattern become determine for each Bus in every year. In this paper, it is assumed that the load pattern in each Bus follow load pattern of global network. Also, rate of nominal load in each Bus is considered as a balanced load, and indexes of light load and peak load is selected in base on load pattern of global network. As it was represented before and it was shown in Figure (5), load pattern divides into three working cycles that include light load, balanced load, and peak load that for each of these cycles was determined an average index. Average index of medium of consumption is a surface of under cycloid in the time period. According to Figure (5), we can say:

$$M_n = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} P_t \, dt \tag{14}$$

$$L_n = \frac{1}{8760 - t_2} \int_{t_2}^{8760} P_t \, dt \tag{15}$$

$$P_n = \frac{1}{t_1} \int_{0}^{t_1} P_t \, dt \tag{16}$$

Where:

In the same way, for light and peak loads we use of equations (18) and (19) representatively, that in there, it is determined for indexes of light and peak loads .L_n: is average indicator of light load of global network that is equal with 18694/26 Mw.

M_n: is average indicator o of balanced load of global network that is equal with 24299/3 Mw.

P_n: is average indicator of peak load of global network that is equal with 31365/17 Mw.

In load pattern of each Bus, nominal amounts of active and reactive valence are considered as an average indicator of balanced load pattern of each Bus. This amount is shown in (17) according to M_{LF}.

$$M_{LF} = \frac{M_n}{M_n} \tag{17}$$

In the same way, for light and peak loads we use of equations (18) and (19) representatively, that in there, it is determined for indexes of light and peak loads.

$$L_{LF} = \frac{L_n}{M_n} \tag{18}$$

$$P_{LF} = \frac{P_n}{M_n} \tag{19}$$

So with use of gained load indexes of equations of (17) to (19), we can say that medium of peak, light, and balanced loads in each Bus will gain of equations of (20) and (22) representatively.

$$L_b = (L_{LF})P_r \tag{20}$$

$$M_b = (M_{LF})P_r \tag{21}$$

$$P_b = (P_{LF})P_r \tag{22}$$

Where P_r in above equations is nominal network valence.

In fact, medium indexes of light, balanced, and peak loads will multiply in nominal amounts of active and reactive matrix of system load that, Bus losses rate of system determine in each one of three working cycles before sitting and sizing of DG. So according to everything that has been said, average indexes of load pattern of light, balanced, and peak are:

$$L_{LF} = 0.7693 \tag{23}$$

$$M_{LF} = 1 \tag{24}$$

$$P_{LF} = 1.2907 \tag{25}$$

On the other hand we will minimize equation of (26).

$$f = \alpha P_{Loss,L} + \beta P_{Loss,M} + \gamma P_{Loss,P} \tag{26}$$

Where:

α, β, γ are weighted factors of peak, balanced, and light loads. $P_{Loss,L}$,$P_{Loss,M}$, $P_{Loss,P}$ are losses in light, balanced and peak conditions respectively. For the next time, the first, we will try to find the optimum answers, in the condition of balanced load, in the second time, in the condition of light load, and finally, in the condition of peak load. Then for prevent of three different answer, we use of weighting factors of 0.4, 0.2, 0.4 for the peak load, balanced load, and light load respectively.

5. Simulation results

The system that is presented it in this investigation is an actual 14 Bus distribution system that its relevant data have existed in Appendix (I) and Single line diagram of the network is shown in Figure (6). The results of simulation are in following explanation: The number of population is: 100 particle and Maximum generation (k_{max}) is 20. Considering that the capacity of DGs is limited, the boundaries for active and reactive power generated by DOs in the present simulation will be as following.

$$0.05 \sum P_D \leq \sum P_g \leq 0.35 \sum P_D \quad (27)$$

$$0.05 \sum Q_D \leq \sum Q_g \leq 0.35 \sum Q_D \quad (28)$$

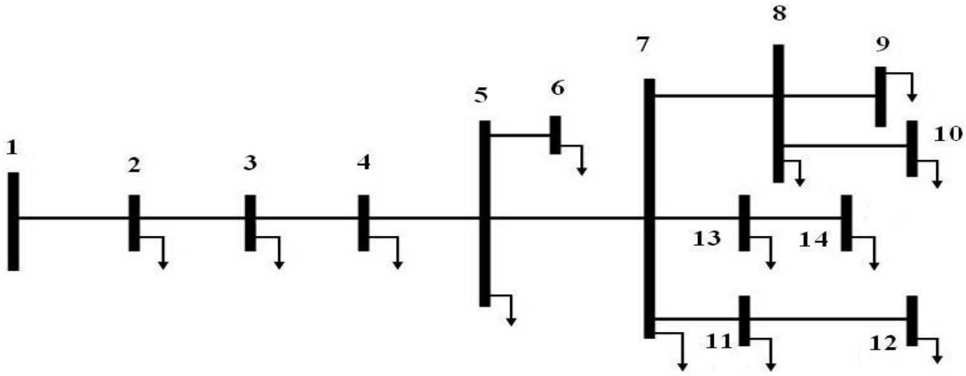

Figure 6: arranged load pattern

A. Optimum size and location of DGs in the balanced load condition

In this section, we will try to find optimum size and location of DGs under the balanced load condition. With understanding this explanations that total losses in this state before settlement of DG is equal 493.743 KW that was derived from run of load flow. The results of simulation are shown in table¬ (1). As it is represented, putting of 3 DGs with total capacities of 4733.75KW and 2693.69 KVAR in Buses No 13 and 12 and 7 are cause to decrease of 52.97 percent of total losses. The results of table (1) are gained with use of 20 generation and quantity of 100 particles that state of convergence answers is shown in Figure (7).

TABLE 1: OPTIMUM SIZE AND LOCATION OF DGS IN THE BALANCED LOAD CONDITION

BUS. NO	Size of DGs	
	P_G (KW)	Q_G (KVAR)
13	1319.547	672.91
12	1461.892	862.61
7	1952.311	1158.17
Total Size	4733.75	2693.69
Losses After DG Installation	232.16	

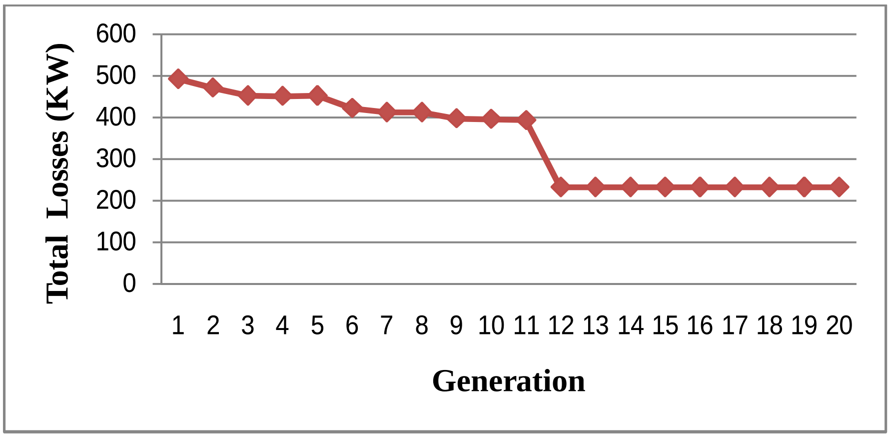

Figure 7: Convergence characteristic for optimum sitting and sizing of DGs in the balanced load condition

B. Optimum size and location of DGs in the light load condition

In this section, we will try to find optimum size and location of DGs under the light load condition. With understanding this explanations that total losses in this state before settlement of DG is equal 294.41 KW that was derived from run of load flow. The results of simulation are shown in table (2). As it is represented, putting of 2 DG with total capacities of 2125.393 KW and 1107.962 KVAR in Buses No 12 and 9 is cause to decrease of 41.94 percent of total losses. The results of table (2) is gained with use of 20 generation and quantity of 100 particles, that state of convergence answers is shown in Figure (8).

TABLE 2: OPTIMUM SIZE AND LOCATION OF DGS IN THE LIGHT LOAD CONDITION

BUS. NO	Size of DGs	
	P_G (KW)	Q_G (KVAR)
12	1352.054	645.832
9	753.339	462.13
Total Size	2125.393	1107.962
Losses After DG Installation	170.91	

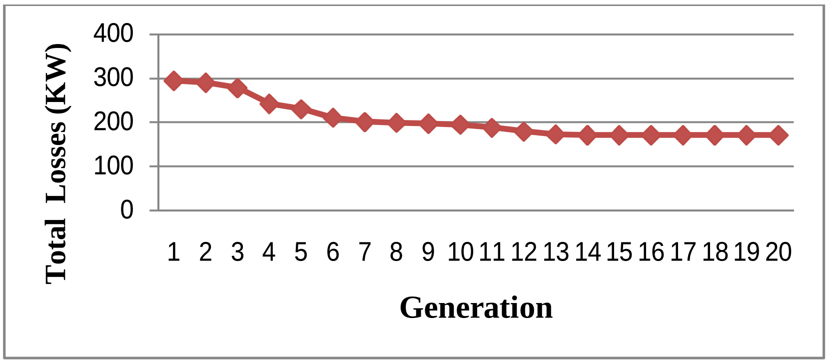

Figure 8: Convergence characteristic for optimum sitting and sizing of DGs in the light load condition

C. Optimum size and location of DGs in the peak load condition

In this section, we will try to find optimum size and location of DGs under the peak load condition. With understanding this explanations that total losses in this state before settlement of DG is equal 887.66 KW that was derived from run of load flow. The results of simulation are shown in table (3).

As it is represented, putting of 3 DGs with total capacities of 4422.58 KW and 2360.87 KVAR in Buses No 12 and 9 and 5 are cause to decrease of 58.86 percent of total losses. The results of table (3) is gained with use of 20 generation and quantity of 100 particles, that state of convergence answers is shown in Figure (9).

TABLE 3: OPTIMUM SIZE AND LOCATION OF DGS IN THE LIGHT LOAD CONDITION

BUS. NO	Size of DGs	
	P_G (KW)	Q_G (KVAR)
12	1855.42	864.33
9	1447.79	783.82
5	1119.37	712.72
Total Size	4422.58	2360.87
Losses After DG Installation	365.69	

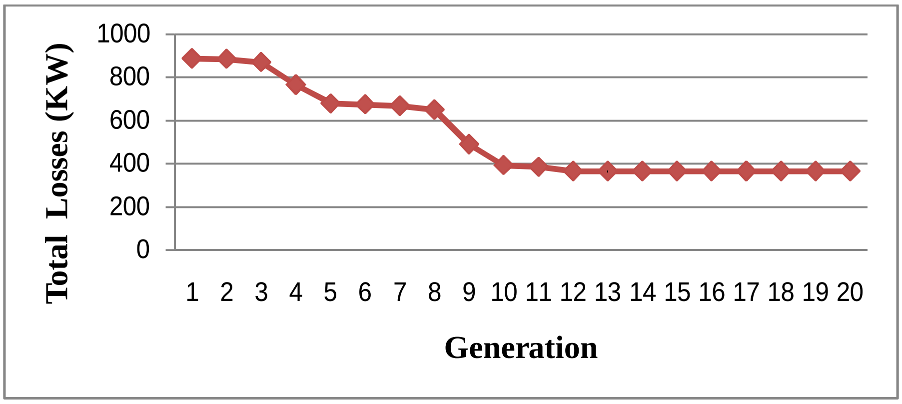

Figure 9: Convergence characteristic for optimum sitting and sizing of DGs in the peak load condition

D. Optimum sitting and sizing of DGs in the equivalent weighted load condition

In the before sections, it will be tried to proper determination of place and capacity of DGs in each one of the conditions of light load, balanced load, and peak load separately, and as it is shown, establishing place and optimum capacity of DGs would be changed with change of the conditions of loading. In this section, for prevent of suggestion of several different answers and to reach an overall optimum answer with definition of proper weighted factors, we will try to determination of optimum place and size of DGs with consider of simultaneous three state of loading of light, balanced, and peak. As it was represented in the before sections, weighted factors of 0.4, 0.2, and 0.4 are considered for the conditions of light load, balanced load, and peak load, representatively. The rate of decrease of total losses will investigate after the sitting and sizing of DGs. The results of stimulation are shown in table (4).

TABLE 4: OPTIMUM SIZE AND LOCATION OF DGS IN THE EQUIVALENT WEIGHTED LOAD CONDITION

BUS. NO	Size of DGs	
	P_G (KW)	Q_G (KVAR)
12	1571.41	993.68
9	1403.4	934.221
7	1792.53	1083.68
Total Size	4767.34	3011.581
Losses After DG Installation	224.73	

As it is shown, in this situation, algorithm suggests the use of 3 DGs, which these DGs units are with total capacities of 4767.34 KW and 3011.581 KVAR in Buses No. 12 and 9 and 7. As it shown in table (4), after DG installation, the total losses are equal with 224.73 KW in this state. For determination of gained losses decrease percent and gained total losses rate in this section will compare with three before section. As it is shown in Figure (10), the rate of total losses with presence of DGs in the way of suggested algorithm in the state of consider of three working cycle became (224.73KW) simultaneously. And in compare to the rate of total losses at the time of light load (294.41KW) is caused to decrease of about 23.66 percent in the rate of total losses.

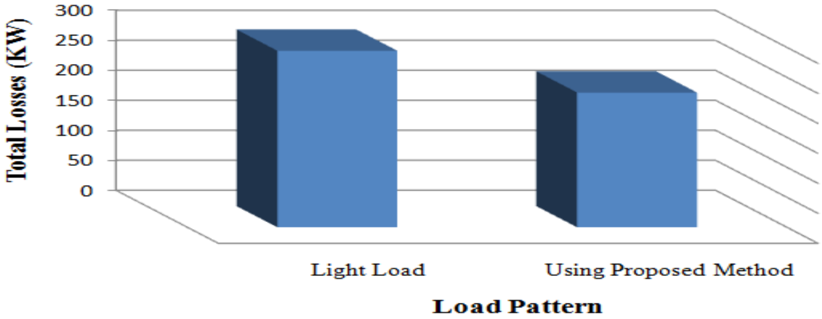

Figure 10: Comparison of total losses in the proposed method with the light load condition

On the other hand, As it shown in Figure (11), the rate of total losses with presence of DGs in the way of suggested algorithm in the state of consider of three working cycle became (224.73KW) simultaneously. And in compare to the rate of total losses at the time of balanced load (493.743KW) is caused to decrease of about 54.48 percent in the total losses.

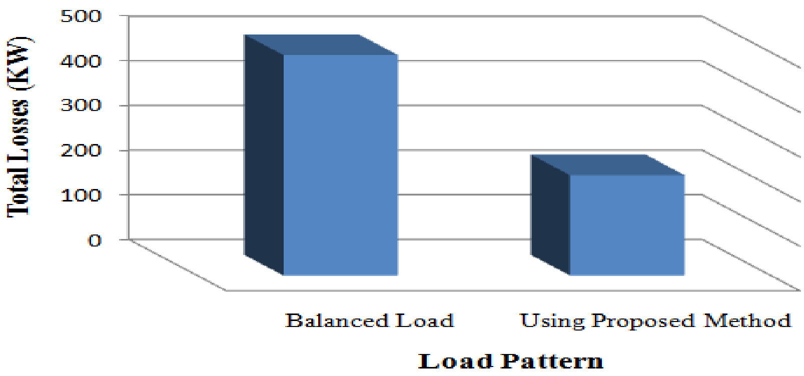

Figure 11: Comparison of total losses in the proposed method with the balanced load condition

On the another side, as it is shown in Figure (12), the rate of total losses with presence of DGs in the way of suggested algorithm in the state of consider of three working cycle became (224.73KW) simultaneously. And in the compare with the rate of total losses at the time of peak load (887.66KW) is caused to decrease of about 74.68 percent in the total losses.

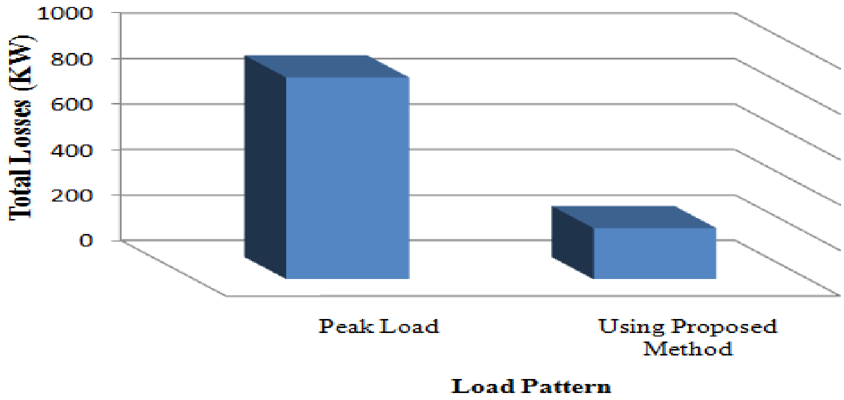

Figure 12: Comparison of total losses in the proposed method with the peak load condition

6. Conclusion

In this paper, it is paid with use of Particle Swarm Optimization (PSO) algorithm to determination optimum place and size of DGs with the purpose of loss reduction in one year period. The results was shown that the determination of place and size of DGs has regarded the rate of consuming load in the different periods, and it represents the importance of notice to the system load pattern. As an example, if the base of deciding in the select of place and the proper size become light load, demand of consumers will not comply at time of balanced load and peak load. And if the base of deciding becomes peak load, the rate of generated valence will be more than consume of consumers in the working light cycle. Also, if the base of deciding become balanced load, demand of consumers will not comply at the peak hours, and also generated valence will be more than consume of consumers at the light hours. For solving this problem and to reach the overall optimum answer, it was necessary to reach exact engineering Coordination between the different answers. For this reason, finally overall optimum answer was gained with the use of different weighted factors.

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APPENDIX I

TABLE A: BUS DATA (PARAMETERS OF THE SYSTEM IN FIGURE 6)

Bus Data		
Bus .No	P(Kw)	Q(Kvar)
1	0	0
2	890	468
3	628	470
4	1112	764
5	636	378
6	474	344
7	1342	1078
8	920	292
9	766	498
10	662	480
11	690	186
12	1292	554
13	1124	480
14	750	470

TABLE B: LINE DATA (PARAMETERS OF THE SYSTEM IN FIGURE 6)

Line Data			
From	To	R(Ohm)	X(Ohm)
1	2	0.176	0.138
2	3	0.176	0.138
3	4	0.045	0.035
4	5	0.089	0.069
5	6	0.045	0.035
5	7	0.116	0.091
7	8	0.073	0.073
8	9	0.074	0.058
8	10	0.093	0.093
7	11	0.063	0.05
11	12	0.068	0.053
12	13	0.062	0.053
7	14	0.076	0.076

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