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Multi objective Distributed Generators and D-STATCOM sitting and sizing by Modified Particle Swarm Optimization

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Abstract: This paper presents an algorithm based on Multi-objective modified Particle Swarm Optimization (MOMPSO) for determining optimal locations and optimal sizes of distributed generators and D-STATCOM units simultaneously. The problem has been solved by considering multiple objective functions of minimization of power loss, minimization of cost function and minimization of deviation of bus voltage. Sensitivity analysis is used to identify the candidate locations for installing DG and D-STATCOM units. The MOMPSO algorithm is used to find the optimal size of these units by considering the minimization of objective function subjected to practical constraints. The proposed algorithm has been tested on IEEE-33 and IEEE-69 test systems and results are presented.

Keywords: Distributed Generators (DGs), D-STATCOM, Multi objective function, modified particle swarm optimization, Sensitivity analysis.

I. INTRODUCTION

The distributed generators are considered as small scale electrical power generators, which generates active and reactive power and are going to be installed in the distribution systems itself where actually the need of electrical power. The addition of DGs in the distribution system relieves the generating stations and transmission and distributions systems from being additional electrical power because of load growth. Installing DG units helps to reduce the green house gas effects, improves the energy security, reduces the losses, and also improves the reliability and power quality [1]. The amount of power loss reduction is very much sensitive to the location and size of DGs. Therefore these loss can be minimized and better voltage profile can be obtained [2,3] by installing DGs which are operated with their optimal size.

Reactive power flow also plays very important role on portion of total power loss. The reactive power flow in the distribution system can also be controlled by connecting capacitors. The optimal allocation of shunt capacitor banks deals with determination of optimal locations, their sizes, type and number of capacitors so as to achieve maximum benefits [4]. In addition to the DG units, recently many researches [5-9] have dealt with the objective function of decreasing the loss and capacitor cost with proper capacitor placement. Distribution STATic Compensator (DSTATCOM) is the latest technology that can be connected in the distribution system to provide local reactive power generation. The connection of DSTATCOM in the distribution system regulates the bus voltage by providing the required amount of reactive power. Voltage source converter connected in parallel known as DSTATCOM can fix the power quality problems such as unbalanced nature of loads, voltage sag, fluctuation of voltage [10].

The process and concept of replacing the shunt capacitor with DSTATCOM is discussed in [11]. DSTATCOM is a power electronic based synchronous voltage generator which is capable of providing quick and uninterrupted lagging and leading reactive power supply.

The optimal location and optimal size of DG units as well as DSTATCOM in distribution systems reduces the total power loss with power quality improvement. In this work real power loss is reduced by connecting DG units and reactive power compensation is provided by connecting DSTATCOM. The optimal locations of DG units and DSTATCOM are fixed according to sensitivity analysis.

In this paper, modified particle swarm optimization technique is proposed as methodology for solving the optimal sizing of DG units and DSTATCOM units by considering the multiple objectives such as minimization of power loss, cost function and deviation of bus voltage subjected to a set of practical constraints. The results obtained through the approach are presented and analysed.

II. MODIFIED PARTICLE SWARM OPTIMIZATION (MPSO)

In general for basic PSO, the velocity update equation of an element of any particle is defined as

$$V_{id}^{k+1} = \omega . V_{id}^{k} + c1.rand * (Pbest_{id} - S_{id}^{k}) + c2.rand * (Gbest_{id} - S_{id}^{k}) \quad \ldots(1)$$

This above velocity update equation has three components:

i) The first component is referred to “Inertia” or “Momentum”. It represents the tendency of the particle to continue in the same direction it has been traveling. This component can be scaled by a constant or dynamically changing in the case of modified PSO.

ii) The second component represents local attraction towards the best position of a given particle whose corresponding fitness value is called the particles best (P_{best}) scaled by a random weight factor (C_1, *rand1*). This component is referred as "Memory" or "Self knowledge".

iii) The third component represents attraction towards the best position of any particle whose corresponding fitness value is called global best (G_{best}) scaled by another random weight factor (C_2, rand2). This component is referred to "cooperation" "social knowledge", "group knowledge" or "shared information".

But in modified PSO in addition to the particles with best solution, particles with worst solution are also considered and the velocity update equation can be modified as

$$V_{id}^{k+1} = \begin{bmatrix} \omega . V_{id}^{k} + c1 \times r1 \times k1 \times (Pbest_{id} - S_{id}^{k}) \\ + c2 \times r2 \times k2 \times (Gbest_{id} - S_{id}^{k}) \\ + c3 \times r3 \times k3 \times (Pworst_{id} - S_{id}^{k}) \\ + c4 \times r4 \times k4 \times (Gworst_{id} - S_{id}^{k}) \end{bmatrix} \quad \ldots(2)$$

Where, C1 and C3 are the cognitive acceleration coefficients, C2 and C4 are the social acceleration coefficients, Gbest is the global best of the entire swarm, Gworst is the global worst of the entire swarm, K is the previous iteration number, K+1 is the current iteration number, K=[k1,k2,k3,k4] is switch matrix and its value is [1,1,0,0] for best particles and[0,0,1,1] for worst particles, Pbest is the particle's best, Pworst is the particle's worst, r1,r2,r3 and r4 are the random numbers between 0 to 1, S_{id}^{k} is the position of i^{th} particle, V_{id}^{k} is the velocity of i^{th} particle.

The position of any element in $(k+1)^{th}$ iteration can be modified according to

$$S_{id}^{k+1} = S_{id}^{k} + V_{id}^{k+1} \quad \ldots (3)$$

i = 1,2,……,n. d = 1,2,…..,m.

Where s^k is current searching point, s^{k+1} is modified searching point, v^k is current velocity, v^{k+1} is modified velocity of agent i, v_{pbest} is velocity based on Pbest, v_{gbest} is velocity based on gbest, n is number of particles in a group, m is the number of members in a particles, pbest is pbest of agent i, gbest is gbest of the group, ω_i is weight function for velocity of agent i, c_i is weight coefficient for each term.

The following weight function is used:

$$\omega_i = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{k_{max}} \times k \quad \ldots(4)$$

Where, ω_{min} and ω_{max} are the minimum and maximum weights respectively. k and k_{max} are the current and maximum iteration.

2.1 Generation of a particle:

Initialization: Following algorithm is used to generate a particle consisting of real and reactive power outputs of DG units and reactive power rating of D-STATCOM unit

Step 1: Set i=1

Step 2: Select the active power rating of first DG within the active power generation limits of the respective DG

Step 3: Repeat step 2 for all DG units

Step 4: Select the reactive power rating (if any) of first DG within the reactive power generation limits of the respective DG

Step 5: Repeat step 4 for all DG units

Step 6: Select the reactive power rating of D-STATCOM rating within the limits of its rating

Step 7: increment the particle number i.e., $i=i+1$

Step 8: If all particles are generated stop the initialization process, otherwise go to step 2.

The individual particle as created above is taken as list the initial optimal sizes.

2.2 Algorithm for optimal sizing

The algorithm to find the optimal sizes of DGs is:

Step 1: Read the line and load data of the system and DG units data

Step 2: Calculate the power loss using the distribution load flow based on backward and forward sweep algorithm for the original network

Step 3: Initialize the particles according to the algorithm given above

Step 4: For each particle find the objective function according to equation (8)

Step 5: If the objective function of each particle is better than the previous experience, then update its P_{best}

Step 6: Find the G_{best} by considering the fitness value of all the particles

Step 7: Find the velocity of each particle according to the equation (2)

Step 8: Update the velocity and position by using equations (3)

Step 9: If the iteration number reaches the maximum limit print the results,

Step 10: Otherwise set increase iteration count by one and go back to step 4.

Finally the optimal size (Real and reactive power outputs) of DGs can be observed from final G_{best}.

III. PROBLEM FORMULATION

The main goal of the proposed algorithm is to determine the optimal location and optimal size of the DG and DSTATCOM units by minimizing the different objective functions. In this section three objective functions and their practical constraints is presented.

Loss sensitive factors are used to decide the optimal locations of DG and DSTATCOM units and their size is obtained by solving multi-objective function with modified particle swarm optimization subjected to practical constraints.

3.1 Objective Functions:

3.1.1 Minimization of real power loss:

Minimization of power loss is considered as first objective function for the placement of DG.

$$f_1(x) = Min . \sum_{l=1}^{N_l} \left[|I_l|^2 \times R_l \right] \quad \ldots(5)$$

Where I_l is the current through branch 'l' and R_l is the resistance of branch 'l'.

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3.1.2 Minimization of cost function

Minimization of cost of function is considered as second objective function for the placement of DG and it can be modeled as

$$f_2(x) = Minimizing \sum_{i=1}^{N_{DG}} C(DG_i) + P_{sub} \times T \times price_{sub} + C(E_L) + \sum_{i=1}^{N_{DS}} C(DS_i) \quad \ldots(6)$$

Where N_{DG} is the number of dg units used, $C(DG_i)$ is the cost of energy generated by the i^{th} DG units ($) [13], $C(E_L)$ is the cost of energy loss, P_{sub} is the real power at the substation bus(kW), $Price_{sub}$ is the price of active power at substation in ($/kWh), T is the time period in hours. The above cost function is calculated for 15 years.

3.1.3 Minimization of deviation of bus voltage (D.V.B)

Minimization of deviation of bus voltages is considered as third objective function of reconfiguration problem.

$$f_2(x) = Minimizing \sum_{i=1}^{N_b} |V_r - V_i| \quad \ldots(7)$$

Where Nb is the number of buses or nodes, V*i* is the voltage magnitude at i^{th} bus, Vr is the rated voltage magnitude at i^{th} bus (1 p.u.)

3.2 Constraints:

The above multi-objective function is solved by onsidering a set of practical constraints.

3.2.1 Voltage magnitude constraint:

Voltage magnitude at each bus should be within the specified limits even after placing a DG i.e., it should be greater than V_{min} and less than V_{max} and is represented as

$$V_{min} \le V_j \le V_{max}$$

3.2.2 Feeder capability constraint:

The magnitude of the current through all the line sections should be within the tolerable limits of the respective section i.e.

$$I_k \le I_k^{max}, k \in \{1,2,3 \ldots\ldots l\}$$

Where I_k^{max} is maximum current capability of branch k

3.2.3 Distributed generator constraint:

If a DG unit is installed at bus *'i'*, its active and reactive power generations should be within the DG unit's capacity limits; otherwise these values should be equal to zero. Mathematically, this constraint can be developed as:

$$W_i.P_{G,i}^{min} \le P_{G,i} \le W_i.P_{G,i}^{max} \quad i \in N \ \& \ i \ne Sub$$

$$W_i.Q_{G,i}^{min} \le Q_{G,i} \le W_i.Q_{G,i}^{max} \quad i \in N \ \& \ i \ne Sub$$

W_i is a binary variable used to describe the installation of DG on bus *'i'*. When a DG unit is installed at bus *'i'*, $W_i = 1$ other wise $W_i = 0$

3.2.4 D-STATCOM constraints:

If a DSTATCOM is installed at bus 'i', its reactive power generations should be within the range of its kVar. Mathematically this constraint can be represented as:

$$W_i.Q_{DSi}^{min} \le Q_{DSi} \le W_i.Q_{DSi}^{max} \quad i \in N_b \ \& \ i \ne Sub$$

Finally multi-objective function can be developed as

$$f(X) = Min.\left[W_1 \times \sum_{l=1}^{N_l} \left[|I_l|^2 \times R_l \right] + W_2 \times \left(\sum_{i=1}^{N_{DG}} C(DG_i) + P_{sub} \times T \times price_{sub} + C(E_L) + \sum_{i=1}^{N_{DS}} C(DS_i) \right) + W_3 \times \sum_{i=1}^{N_b} |V_r - V_i| \right] \quad ..(8)$$

W_1, W_2 and W_3 are the weighing factors subjected to a condition that $W_1+W_2+W_3=1$

IV. DISTRIBUTION STATIC COMPENSATOR (D-STATCOM)

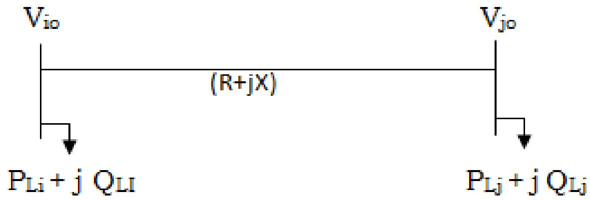

Fig. 1 Sample line section of a distribution system

By considering the fig.1 the following relationship between voltage and current can be developed as

$$V_{jo} \angle \alpha_o = V_{io} \angle \delta_o - (R + jX) \times I_{Lo} \angle \theta_o \quad \ldots(9)$$

In the above equation

$V_{io} \angle \delta_o$ is the voltages at bus '*i*' before connecting DSTATCOM, $V_{jo} \angle \alpha_o$ is the voltages at bus '*j*' before connecting DSTATCOM, $(R + jX)$ is the impedance of the branch connected between buses '*i*' and '*j*', $I_{Lo} \angle \theta_o$ is the current through the branch connected between buses '*i*' and '*j*'

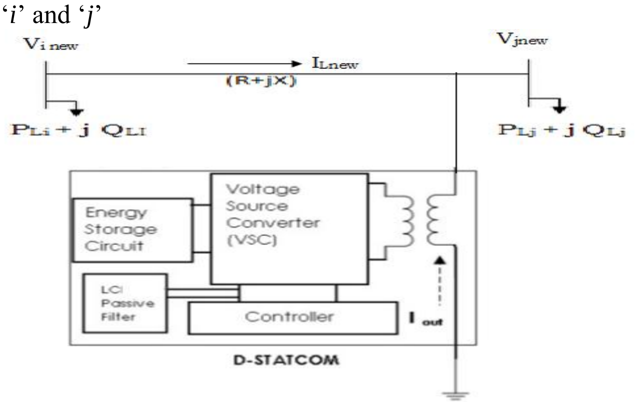

Fig.2 Distribution system connected with D-STATCOM

After connecting DSTATCOM as shown in fig.2, the voltage at bus *'j'* changes from its previous value $V_{jo} \angle \alpha_o$ to a new value $V_{jnew} \angle \alpha_{new}$ and is given by

$$V_{jnew} \angle \alpha_{new} = V_{io} \angle \delta_o - (R + jX) \times I_{Lnew} \angle \theta_{new} - (R + jX) \times I_{D-STATCOM} \angle ((\pi/2) + \alpha_{new}) \quad \ldots(10)$$

Where

$I_{D-STATCOM} \angle((\pi/2)+\alpha_{new})$ is the current injected by D-STATCOM and α_{new} is the angle of corrected voltage, $V_{jnew} \angle \alpha_{new}$ is the voltage at bus 'j' after connecting D-STATCOM, $I_{Lnew} \angle \theta_{new}$ is the current through the branch after connecting D-STATCOM and is given by

$$I_{Lnew} \angle \theta_{new} = I_{oL} \angle \theta_o + I_{D-STATCOM} \angle((\pi/2)+\alpha_{new}) \quad \ldots(11)$$

V. RESULTS AND ANALYSIS

The proposed MOMPSO is tested on two test systems viz., IEEE 33, IEEE 69 bus radial distribution systems and results are presented. For these test systems two cases are considered:
Case-1: Optimal sitting and sizing of DG units without DSTATCOM
Case-2: Optimal sitting and sizing of both DG units and DSTATCOM

Based on the sensitivity analysis, D-STATCOM is installed at bus 6 for IEEE-33 bus system and bus 61 for IEEE-69 system. DG units are placed at bus numbers 11, 29 and 31 for IEEE-33 bus system and for IEEE-69 system bus numbers 60, 63 and 62 are selected. To show the effect of distributed generator and D-STATCOM placement and its size, the single objective optimal placement of DG for power loss, cost function and deviation of bus voltage are tabulated in table 1. From these table it is observed that, due to the presence of both distributed generator and D-STATCOM units the values of objective functions are better when compared to the objective functions with D-STATCOM units only. Further it is also identified that, minimization of one of the objectives increases the values of other objective function values. For example, minimization of cost function increases the power loss and deviation of bus voltage.

It is also observed that, installing D-STATCOM units along with DG units reduces the losses, cost function and deviation of bus voltage. This is because, the addition DG units provides the real and reactive power injections into the system and D-STATCOM provides reactive power decreases the current through various line sections thereby reduces the power loss and decreases the cost and improves the voltage profile.

Table 1: Results of IEEE-33 bus system for single objective functions

S.No.	Control Parameter	Original System	Minimization of power loss		Minimization of Cost function		Minimization of Deviation of bus voltage	
			Case-1	Case-2	Case-1	Case-2	Case-1	Case-2
1	P_{DG1}(kW)	-	-	146.32	-	132.47	-	140.26
2	P_{DG2}(kW)	-	-	54.98	-	58.14	-	59.21
3	P_{DG3}(kW)	-	-	714.32	-	571.26	-	638.39
4	Q_{DG3}(kW)	-	-	451.32	-	474.11	-	521.21
5	Q_{DS1}(kVar)	-	642.38	684.23	541.36	457.84	648.11	681.36
6	Losses (kW)	211.48	154.62	126.31	167.21	142.67	156.16	128.14
7	Cost function *(Million $)*	31.4111	29.1465	27.6426	29.1145	27.4246	29.0942	27.7829
8	D.V.B	1.806	0.926	0.821	0.932	0.842	0.916	0.811

Table 2: Results of IEEE-33 bus system for two objective functions in three combinations for different weight factors

Set No.	Weight factors		Combination-1				Combination-2				Combination-3			
			Case-1		Case-2		Case-1		Case-2		Case-1		Case-2	
	W1	W2	T.P.L (kW)	Cost function (Million $)	T.P.L (kW)	Cost function (Million $)	Cost function (Million $)	D.B.V	Cost function (Million $)	D.B.V	T.P.L (kW)	*D.B.V*	T.P.L (kW)	D.B.V
1	0.1	0.9	147.38	29.1677	142.44	27.3272	29.9451	0.920	27.9951	0.813	146.77	0.918	141.37	0.812
2	0.2	0.8	147.38	29.1677	142.44	27.3272	29.9451	0.920	27.9951	0.813	146.77	0.918	141.37	0.812
3	0.3	0.7	142.66	29.2246	134.76	27.6456	29.6425	0.924	27.9504	0.827	142.41	0.925	135.17	0.825
4	0.4	0.6	142.66	29.2246	134.76	27.6456	29.6425	0.924	27.9504	0.827	142.41	0.925	135.17	0.825
5	0.5	0.5	139.24	29.3171	128.37	27.9478	29.4114	0.930	27.6466	0.834	139.01	0.925	127.91	0.833
6	0.6	0.4	139.24	29.3171	128.37	27.9478	29.4114	0.930	27.6466	0.834	139.01	0.929	127.91	0.833
7	0.7	0.3	136.55	29.9477	124.23	27.9949	29.4114	0.930	27.6466	0.834	139.01	0.929	123.74	0.842
8	0.8	0.2	136.55	29.9477	124.23	27.9949	29.1549	0.935	27.3281	0.844	135.87	0.934	123.74	0.842
9	0.9	0.1	136.55	29.9477	124.23	27.9949	29.1549	0.935	27.3281	0.844	135.87	0.934	123.74	0.842

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Table 3: Results of IEEE-33 bus system for three objective functions for different weight factors

S. No.	Weight Factors			Case-1			Case-2		
	W1	W2	W3	T.P.L (kW)	Cost function *(Million $)*	D.B.V	T.P.L (kW)	Cost function *(Million $)*	D.B.V
1	0.1	0.1	0.8	148.67	29.9481	0.9172	145.74	27.9994	0.8134
2	0.1	0.8	0.1	148.67	29.1679	0.9330	145.74	27.3290	0.8416
3	0.8	0.1	0.1	137.57	29.9481	0.9330	124.68	27.9994	0.8416
4	0.5	0.3	0.2	139.21	29.5671	0.9301	134.79	27.5874	0.8344
5	0.5	0.2	0.3	139.21	29.7749	0.9286	134.79	27.7142	0.8291
6	0.3	0.5	0.2	142.44	29.3457	0.9301	137.22	27.4467	0.8344
7	0.3	0.2	0.5	142.44	29.7748	0.9244	141.46	27.7142	0.8187
8	0.2	0.5	0.3	146.89	29.3456	0.9287	143.27	27.4467	0.8291
9	0.2	0.3	0.5	146.89	29.5671	0.9245	143.27	27.5876	0.8187

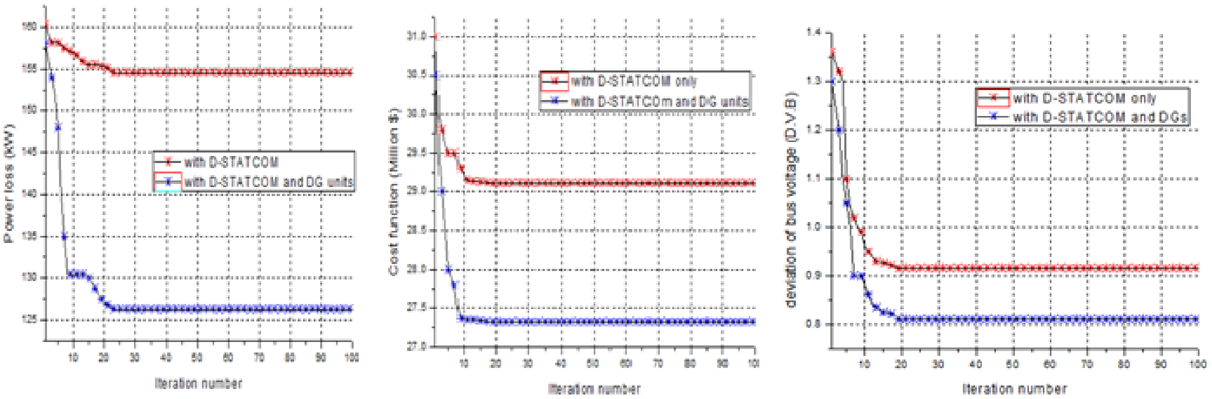

Fig. 3 Convergence characteristics of MPSO for IEEE-33 bus system
Single objective of Minimization of power loss, minimization of cost function, minimization of D.V.B

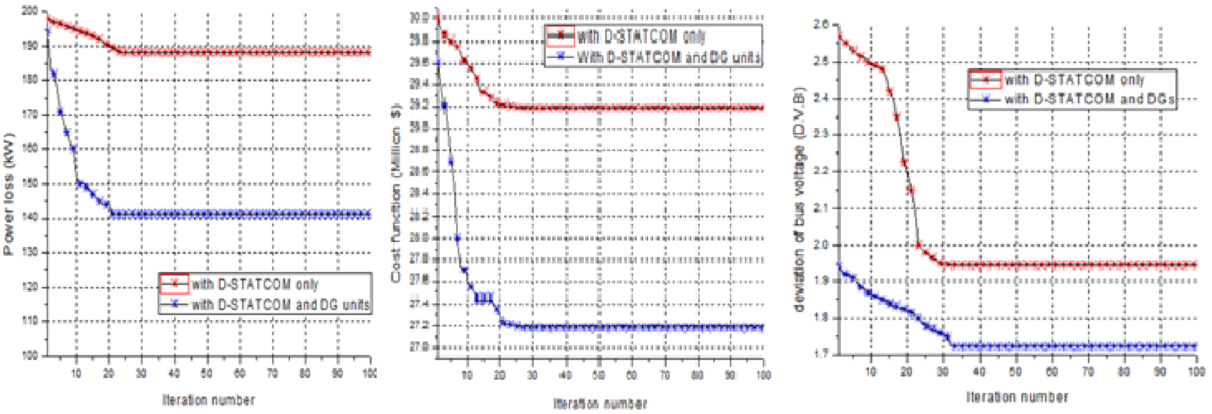

Fig. 4 Convergence characteristics of MPSO for IEEE-69 bus system
Single objective of Minimization of power loss, minimization of cost function, minimization of D.V.B

Table 4: Results of IEEE-69 bus system for single objective functions

S.No.	Control Parameter	Original system	Minimization of power loss		Minimization of Cost function		Minimization of Deviation of bus voltage	
			Case-1	Case-2	Case-1	Case-2	Case-1	Case-2
1	P_{DG1}(kW)	-	-	161.22	-	139.27	-	168.21
2	P_{DG2}(kW)	-	-	59.27	-	51.78	-	59.68
3	P_{DG3}(kW)	-	-	672.76	-	610.74	-	681.24
4	Q_{DG3}(kW)	-	-	581.22	-	435.39	-	501.22
5	Q_{DS1}(kVar)	-	651.33	711.38	578.32	492.34	721.44	754.18
6	Losses (kW)	224.68	188.21	141.32	192.47	149.47	191.32	143.39
7	Cost function *(Million $)*	30.7053	29.9416	27.3088	29.8816	27.2849	29.9468	27.3148
8	D.V.B	3.8377	1.9681	1.7444	1.9805	1.7892	1.9465	1.7233

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Table 5: Results of IEEE-69 bus system for two objective functions in three combinations with different weight factors

Set No.	Weight factors		Combination-1				Combination-2				Combination-3			
			Case-1		Case-2		Case-1		Case-2		Case-1		Case-2	
	W1	W2	T.P.L (kW)	Cost function (Million $)	T.P.L (kW)	Cost function (Million $)	Cost function (Million $)	D.B.V	Cost function (Million $)	D.B.V	T.P.L (kW)	*D.B.V*	T.P.L (kW)	D.B.V
1	0.1	0.9	192.44	29.2116	151.29	27.1844	30.0018	1.947	27.3158	1.724	191.26	1.982	148.38	1.722
2	0.2	0.8	192.44	29.2116	151.29	27.1844	30.0018	1.947	27.3158	1.724	191.26	1.982	148.38	1.722
3	0.3	0.7	189.49	29.3874	147.62	27.2578	30.0018	1.947	27.3158	1.724	188.69	1.978	145.29	1.746
4	0.4	0.6	189.49	29.3874	147.62	22.2578	29.7456	1.958	27.2946	1.748	188.69	1.978	145.29	1.746
5	0.5	0.5	184.38	29.5518	143.88	27.3124	29.7456	1.958	27.2946	1.748	188.69	1.957	145.29	1.746
6	0.6	0.4	184.38	29.5518	143.88	27.3124	29.4416	1.969	27.2619	1.769	183.47	1.957	142.33	1.768
7	0.7	0.3	184.38	29.5518	143.88	27.3124	29.4416	1.969	27.2619	1.769	183.47	1.957	142.33	1.768
8	0.8	0.2	179.27	29.9924	141.11	27.3477	29.3118	1.982	27.1977	1.791	177.22	1.945	139.84	1.789
9	0.9	0.1	179.27	29.9924	141.11	27.3477	29.3118	1.982	27.1977	1.791	177.22	1.945	139.84	1.789

Table 6: Results of IEEE-69 bus system for three objective functions for different weight factors

S. No.	Weight Factors			(Case-1) With D-STATCOM only			(Case-2) With D-STATCOM and DG units		
	W1	W2	W3	T.P.L (kW)	Cost function (Million $)	D.B.V	T.P.L (kW)	Cost function (Million $)	D.B.V
1	0.1	0.1	0.8	193.72	29.9647	1.9474	149.87	27.3156	1.7238
2	0.1	0.8	0.1	193.72	29.2114	1.9827	149.87	27.1855	1.7894
3	0.8	0.1	0.1	187.54	29.9647	1.9827	140.33	27.3156	1.7894
4	0.5	0.3	0.2	189.27	29.5481	1.9711	142.79	27.2918	1.7622
5	0.5	0.2	0.3	189.27	29.7948	1.9654	142.79	27.3043	1.7581
6	0.3	0.5	0.2	191.11	29.3676	1.9711	144.34	27.2451	1.7622
7	0.3	0.2	0.5	191.11	29.7948	1.9527	144.34	27.3043	1.7457
8	0.2	0.5	0.3	192.47	29.3676	1.9654	146.77	27.2451	1.7581
9	0.2	0.3	0.5	192.47	29.5481	1.9527	146.77	27.2918	1.7457

The convergence characteristic of MPSO for single objective of minimization of power losses, minimization of cost function and minimization of deviation of bus voltage are shown in fig. 3 and fig. 4 for IEEE-33 and IEEE-69 bus systems respectively.

The results of MOMPSO for IEEE-33 and IEEE-69 bus system that gives the optimal sizes and power losses and deviation of bus voltage by considering two objective function in three combinations for different weight factors is given in tables 2 and 3, for three objective functions MOMPSO for different weight factors are given in tables 4 and 5.

VI. CONCLUSION

In this paper, the optimal locations of DG units and D-STATCOM are found by sensitivity analysis and their optimal sizes are found by an algorithm based on multi objective modified particle swarm optimization (MPSO). The proposed algorithm has been tested on two test systems for single objective function, 3-combination of two objective functions and three objective functions for different weight factors and results are presented and analyzed. From these results it is observed that, including DG units and S-STATCOM with the distribution system optimally and operated with their optimal size will results in reasonable reduction of objective function values.

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