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Optimal Allocation of Multiple Distributed Generators and Shunt Capacitors in a Distribution System Using Political Optimization Algorithm

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Abstract- To meet the increasing real & reactive power demand of a distribution system (DS), it is essential to allocate the Distributed Generators (DGs) and Shunt capacitors (SCs) optimally. In this article, multiple DGs and SCs are allocated simultaneously in the DS aiming minimal power loss (P_L), improved voltage stability index (VSI) and voltage profile of the system. A combined approach considering loss sensitivity factor (LSF) and political optimization algorithm (POA) is proposed to solve the allocation and sizing of DGs and SCs. The analysis is performed on an IEEE 33 bus system considering 9 different scenarios and results are compared with other Meta heuristic techniques. The analysis is extended for a 24-hour case study to prove the efficacy of the proposed combined approach. From all the performed simulations it can be observed that the combined approach helps in minimizing power loss and improving voltage profile and VSI for dynamic load variations effectively.

Keywords Political Optimization algorithm (POA), Distributed Generators (DGs), Distribution System (DS), Shunt Capacitors (SCs), Power Loss (P_L), Voltage Stability Index (VSI), Loss Sensitivity Factor (LSF).

1. Introduction

The usage of electricity throughout the globe is increased drastically. Therefore it is necessary to escalate the power generation. In this perspective, more generating stations are constructed to fulfill the load and generation gap. These generating stations are centrally located and the generated power is transmitted over long distances using existing transmission lines, which creates congestion problems. To resolve this issue it is vital to connect DGs and suitable compensating devices in the DS. Developing nations and industries are initiating investment in sustainable energy resources like solar, wind-based DGs, because of their zero-emission. These DGs have the ability to supply desired active power to the loads, whereas the reactive power support can be supplied by the shunt capacitors. Suitable placement of DGs & SCs in DS plays a significant part in augmenting the VSI, voltage profile and minimizing the P_L. Else, the overall performance of the DS will be degraded. In recent years some of the authors solved DG, Capacitor allocation problems separately and combined. The different methods with and without DGs and SCs are summarized in Table 1.

In [1-7] authors implemented the DG allocation problem and studied various test systems. In most of the works, it is observed that the objective function considered is to minimize the PL alone. In [8-13] authors considered reactive power generation sources integration to the DS. Few authors considered both DGs and SCs simultaneously integrated to DS [14-20]. The combined integration of DGs and SCs proved to be successful when compared with their individual allocation. In all the mentioned works the authors considered a single load level to assess the performance of DS. This method doesn't yield appropriately installed capacities of DGs as well as SCs with dynamic changes in load levels. Therefore, a combined approach (LSF and POA) is proposed to solve DGs and SCs allocation problem with static and dynamic load variations. The remaining sections of the article are as follows. In section 2 problem formulations along with constraints are given. A combined approach (LSF and POA) for the determination of DGs and SCs locations and sizes is explained in section 3. Results and important findings followed by a conclusion of the article is given in section 4 and 5.

Table 1. Summary of various methods with and without allocation of DGs and SCs in DS.

Reference	Author	Year	Objective	Methodology	Test System
DG to DS					
[1]	U. Sultana, A. B. Khairuddin, A. S. Mokhtar, N. Zareen, and B. Sultana.	2016	Real Power Loss reduction and Voltage Profile improvement	GWO, GSA, BA	69-Bus
[2]	M. Saleh, Y. Esa, N. Onuorah, and A. A. Mohamed.	2017	Power Loss minimization, Voltage stablity improvement	MGs, CDG	IEEE 30
[3]	W. M. da Rosa, J. C. Teixeira, and E. A. Belati.	2018	Power Loss	SA, OPF	34-Bus, 70-Bus
[4]	E. O. Hasan, A. Y. Hatata, E. A. Badran, and F. M. H. Yossef.	2019	Reducing Power Loss and Voltage Deviation	MOPSO, MILP	IEEE 33
[5]	A. Gad and H. A. Gabbar.	2020	Power Loss minimization	PPA	70 bus
[6]	T. T. Nguyen	2021	Power Loss Reduction	ESFO, SFO	33-Bus
[7]	A. M. Shaheen, A. M. Elsayed, R. A. El-Sehiemy, and A. Y. Abdelaziz.	2021	Power Loss Reduction, Voltage Profile Improvement	IEOA	33, 69 and 137 Buses
SC to DS					
[8]	A. A. Abou El-Ela, R. A. El-Sehiemy, A. M. Kinawy, and M. T. Mouwafi.	2016	Power Loss reduction, Voltage Profile Enhancement	BFS, LSIs	34-Bus, 85-Bus
[9]	M. S. Javadi, A. Esmaeel Nezhad, P. Siano, M. Shafie-khah, and J. P. S. Catalão.	2017	THD and Power Loss Minimization	NSGA-II	85-Bus
[10]	K. Muthukumar and S. Jayalalitha.	2018	Power Loss reducing and improving Voltage Stability	HSA-PABC	69-Bus, 118-Bus
[11]	A. A. Z. Diab and H. Rezk	2019	Improving voltage profile, decreasing total cost	GWO, DFO, MFA	33, 69 and 118 buses
[12]	A. Selim, S. Kamel, and F. Jurado.	2020	Reduce Power Loss and Energy Cost	SSA_SCA, LSF, Fuzzy	15-Bus, 69-Bus, 85-Bus, EDN 30-Bus
[13]	K. Mahmoud and M. Lehtonen.	2021	Minimizing Power Loss and Total Cost	ACFE	69-Bus
DG + SC to DS					
[14]	K. Muthukumar and S. Jayalalitha.	2016	Power Loss Decrement	HAS, PABC	33-Bus, 119-Bus
[15]	P. P. Biswas, R. Mallipeddi, P. N. Suganthan, and G. A. J. Amaratunga.	2017	Reducing Active- Reactive Power Loss	MOEA/D	IEEE 33-Bus, 69-Bus, 119-Bus
[16]	A. A. A. El-Ela, R. A. El-Sehiemy, and A. S. Abbas.	2018	Decreasing Power Loss, Voltage stability Improvement	WCA	IEEE 33-Bus, 69-Bus
[17]	A. Bayat and A. Bagheri.	2019	Active and Reactive Power Loss Minimization	GS, PSO, IA, HAPSO,TLBO,QOTLBO, CTLBO	33-Bus, 69-Bus, 119-Bus
[18]	E. A. Almabsout, R. A. El-Sehiemy, O. N. U. An, and O. Bayat.	2020	Decreasing Power Loss, Improving Voltage Stability	EGA	IEEE 33, 69 and 119 buses
[19]	A. M. Shaheen and R. A. El-Sehiemy.	2021	Decreasing operational cost and power loss, Improving Voltage profile	EGWA, GWA	TDRF 37 and EDDR real test systems
[20]	A. Naderipour.	2021	Reducing Energy Losses, cost, and Power Loss	SHO, GWO, GA	24-Bus

2. Problem Formulation

The developed approach for DG and SC allocation problem in DS is discussed in this section. The real, reactive P_L and voltage magnitude equation are represented as follows.

$$P_{m+1} = P_m - P_{Li+1} - R_{i,i+1}.\frac{P_m^2 + Q_m^2}{|V_m|^2} \quad (1)$$

$$Q_{m+1} = Q_m - Q_{Li+1} - X_{i,i+1}.\frac{P_m^2 + Q_m^2}{|V_m|^2} \quad (2)$$

$$|V_{m+1}|^2 = |V_m|^2 - 2\left(R_{m,m+1}.P_m + X_{m,m+1}.Q_m\right) + (R_{m,m+1}^2 + X_{m,m+1}^2).\frac{P_m^2 + Q_m^2}{|V_m|^2} \quad (3)$$

At bus m → P_m, Q_{m}- represents active & reactive power

At bus m + 1 → P_{Lm+1}, Q_{Lm+1}- real & reactive power loads

$R_{m,\,m+1}$, $X_{m,\,m+1}$ are resistance and reactance at m+1^th^

m^th^ bus voltage magnitude $|V_m|$

Equation 1, 2 satisfies power balance.

Equation 3 satisfies sending and receiving end bus voltage magnitude

The below equation represents real P_L equation

$$min \sum_{m=1}^{24} P_{loss}(m) \quad (4)$$

where

$$P_{loss}(m) = \sum_{m=1}^{24} I^2.R_m \quad (5)$$

Where, P_{loss}- real P_L, Adding all line losses getting total P_L

TP_{Loss} is represented in Eq. (6).

$$TP_{loss} = \sum_{k=0}^{N-1} P_{loss}\ (m, m+1) \quad (6)$$

2.1 Objective Function

P_L in the presence of DG and SC:

Simultaneous allocation of DGs and SCs decreases P_L enhances voltage profile and VSI of the system. Actual P_L in the presence of DGs & SCs optimally placed between buses m and m + 1 is

$$P_{DGSC,loss(m,m+1)} = R_{m,m+1}.\left(\frac{P_{DGSC,m,m+1}^2 + Q_{DGSC,m,m+1}^2}{|V_m|^2}\right) \quad (7)$$

The total P_L after allocating DGs and SCs in a DS

$$P_{DGSC,TLoss(m,m+1)} = \sum_{m=1}^{nbm} P_{DGSC,loss(m,m+1)} \quad (8)$$

$$Objective\ Function = w_1 \times y_1 + w_2 \times y_2 \quad (9)$$

Where w_1, w_2 are weighting factors y_1 and y2 are P_L and VSI objectvies respectively.

P_L minimization (y_1):

$$y_1 = \Delta P_{DGSC\ Total\ loss} = \frac{P_{DGSC,Tloss}}{P_{Total\ loss}} \text{ (or) } y_1 = \text{minimize } (P_L) \quad (10)$$

VSI enhancement (VSI) y_2:

$$y_2 = maximize(VSI) = minimize\left(\frac{1}{VSI}\right) \quad (11)$$

The value of VSI (12) is determined by

$$VSI = |V_m|^4 - 4\left[P_{m+1.eff}X_m - Q_{m+1.eff}R_m\right]^2 - 4\left[P_{m+1.eff}R_m + Q_{m+1.eff}X_m\right]|V_m|^2 \quad (12)$$

The multi objective function is a combination of y1 and y2.

2.1.1 Constraints

To achieve the above multi objective, the proposed technique must satisfy inequality & equality constraints of DS.

Equality Constraints:

Power Balance:

$$\sum_{m=1}^{24} P_G(m) = \sum_{m=1}^{24} P_D(m) + P_{SC}(m) + P_{loss}(m) \quad (13)$$

In Equality Constraints:

Bus Voltage:

$$V_{m,min} \le |V_m| \le V_{m,max} \quad (14)$$

DG Capacity Range:

$$P_{m,min}^{DG} \le P_m^{DG} \le P_{m,max}^{DG} \quad (15)$$

Where

$$(P_{m,min}^{DG} = 0.1 \sum_{m=2}^{n} P_m^{DG}, P_{m,max}^{DG} = .8 \sum_{m=2}^{n} P_m^{DG})$$

Capacitor Capacity Ranges:

The accessible capacity of the shunt capacitor should be in particular ranges given below it's not exceeds those limits.

$$\sum_{m=1}^{nc} Q_{cl} \le 1.0 \sum_{m=1}^{n} Q_c^L \quad (16)$$

$Q_{cl} = KQ_0$ k = 1, 2 …..n_c

Q_0 = minimum capacitor capacity, k = integer number

3. Combined approaches for optimal location and sizing of DGs

Combined approach considers LSF method for suitable locations for DGs and SCs, passes the obtained locations to Meta heuristic optimization technique (POA). This POA determines the suitable quantity of active and reactive powers to be supplied to the load from the available limit.

3.1. LSF method for obtaining the suitable location of DGs and SCs

LSF method is mainly used to find the possible locations for placement of DGs and SCs. The P_L Equation is given below. From that equation calculate real and reactive P_L sensitivities. The buses with minimum sensitivities should be considered as best locations for placement of DGs and SCs.

$$P_{line\ loss} = \left(\frac{P_{m+1,eff}^2 + Q_{m+1,eff}^2}{|V_{m+1}|^2}\right).R_{m,m+1} \quad (17)$$

Sensitivity analysis of actual & reactive power loss is determined by partial derivative of real power loss while injecting real and reactive power.

$$APLSF = \frac{\partial P_{line\ loss}}{\partial P_{m+1,eff}} = \frac{2P_{m+1,eff} \cdot R_{m,m+1}}{|V_{m+1}|^2} \quad (18)$$

$$RAPLSF = \frac{\partial P_{line\ loss}}{\partial Q_{m+1,eff}} = \frac{2Q_{m+1,eff} \cdot R_{m,m+1}}{|V_{m+1}|^2} \quad (19)$$

3.2. Political Optimization Algorithm (POA)

Askari developed the latest meta-heuristic technique that is a political optimizer (PO). This method influenced by several phases of politics. POA is mainly a human behaviour-based approach. This method cracks applied mathematical problems, and it is terrific in the performance of convergence speed, quality investigative capacity in fast iterations. Mathematical modelling of PO covers all main stages of politics. “PO consists of five stages 1. Party formation, 2. Constituency allocation, 3. Election campaign, 4. Party switching, 5. Parliamentary affairs” [24 - 26].

All citizens categorized into n political parties

$$P = \{P_1, P_2, P_3, \dots\dots P_n\} \quad (20)$$

Each party include n members, as showing below eq

$$P_i = \{P_i^1, P_i^2, P_i^3, \dots\dots P_i^n\} \quad (21)$$

Every member of the party considers dimension d, following eq

$$P_i^j = [P_{i,1}^j, P_{i,2}^j, P_{i,3}^j, \dots\dots P_{i,d}^j]^T \quad (22)$$

n number of electoral districts demonstrated below

$$C = \{C_1, C_2, C_3 \dots\dots C_n\} \quad (23)$$

Every constituency n members is considered

$$C_j = \{P_1^j, P_2^j, P_3^j, \dots\dots P_n^j\} \quad (24)$$

Head of the party determine with good fitness

$$q = \underset{1 \le j \le n}{argmin}\ f(P_i^j),\ \forall i \epsilon \{1, \dots\dots, n\} \quad (25)$$

$$P_i^* = P_i^q$$

Champion of every individual constituency called member parliament demonstrated below

$$P^* = \{P_1^*, P_2^*, P_3^*, \dots\dots P_n^*\} \quad (26)$$

$$C^* = \{c_1^*, c_2^*, c_3^*, \dots\dots c_n^*\} \quad (27)$$

$$P_{i,k}^j(t+1) = \begin{cases} if\ P_{i,k}^j(t-1) \le P_{i,k}^j(t) \le m^*\ or\ P_{i,k}^j(t-1) \ge P_{i,k}^j(t) \ge m^*, \\ \quad m^* + r\left(m^* - P_{i,k}^j(t)\right); \\ if\ P_{i,k}^j(t-1) \le m^* \le P_{i,k}^j(t)\ or\ P_{i,k}^j(t-1) \ge m^* \ge P_{i,k}^j(t), \\ \quad m^* + (2r-1)|m^* - P_{i,k}^j(t)|; \\ if\ m^* \le P_{i,k}^j(t-1) \le P_{i,k}^j(t)\ or\ m^* \ge P_{i,k}^j(t-1) \ge P_{i,k}^j(t), \\ \quad m^* + (2r-1)|m^* - P_{i,k}^j(t-1)|; \end{cases} \quad (28)$$

$$P_{i,k}^j(t+1) = \begin{cases} if\ P_{i,k}^j(t-1) \le P_{i,k}^j(t) \le m^*\ or\ P_{i,k}^j(t-1) \ge P_{i,k}^j(t) \ge m^*, \\ \quad m^* + (2r-1)|m^* - P_{i,k}^j(t)|; \\ if\ P_{i,k}^j(t-1) \le m^* \le P_{i,k}^j(t)\ or\ P_{i,k}^j(t-1) \ge m^* \ge P_{i,k}^j(t), \\ \quad P_{i,k}^j(t-1) + r\left(P_{i,k}^j(t) - P_{i,k}^j(t-1)\right); \\ if\ m^* \le P_{i,k}^j(t-1) \le P_{i,k}^j(t)\ or\ m^* \ge P_{i,k}^j(t-1) \ge P_{i,k}^j(t), \\ \quad m^* + (2r-1)|m^* - P_{i,k}^j(t-1)|; \end{cases} \quad (29)$$

λ Utilized as an adaptive parameter and it is reduced from 1 to 0 throughout the iterative process. Every member is nominated as per probabilityλ.

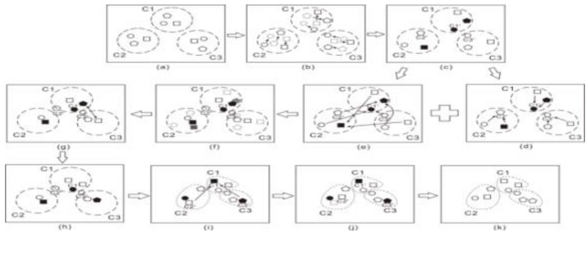

Fig. 1. POA mechanism [26]

$$q = \underset{1 \le j \le n}{argmax}\ f(P_i^j) \quad (30)$$

Champion of constituency determined with the following eq.

$$q = \underset{1 \le j \le n}{argmax}\ f(P_i^j) \quad (31)$$

$$c_j^* = p_q^j$$

3.2.1 Steps for calculating best sizes of DGs and SCs using POA

Step 1: Read the DS data (Line and Bus data)

Step 2: Run the base case load flow

Step3: Find a suitable locations for DGs and SCs with the LSF method

Step 4: Best locations of DGs and SCs determined using LSF should be given as input to POA

Step 5: As per eq. 20 all citizens categorized into ‘n’ political parties, each party include ‘n’ member by using eq. 21.

Step 6: Chief of the party determined with good fitness in eq. 25, champion of every individual constituency called a member of parliament by using eq. 26

Step 7: Compared present values with the previous position values

Step 8: At the beginning of algorithm loops, fitness values and positions are created temporarily.

Step 9: Eq. 28, 29 represents 2nd phase election campaign, using this eq's all political parties’ member’s values and positions updated

Step 10: Eq. 30 represents the election campaign after phase, every individual member of the switching phase runs

Step 11: Champions of constituency calculated with eq. 31.

Step 12: In this step, the algorithm shows all the champions of parliamentary locations, called the parliamentary affairs phase

Step 13: This is the final step, upgrading all fitness values (Power loss) and positions such as best DG and Capacitor sizes.

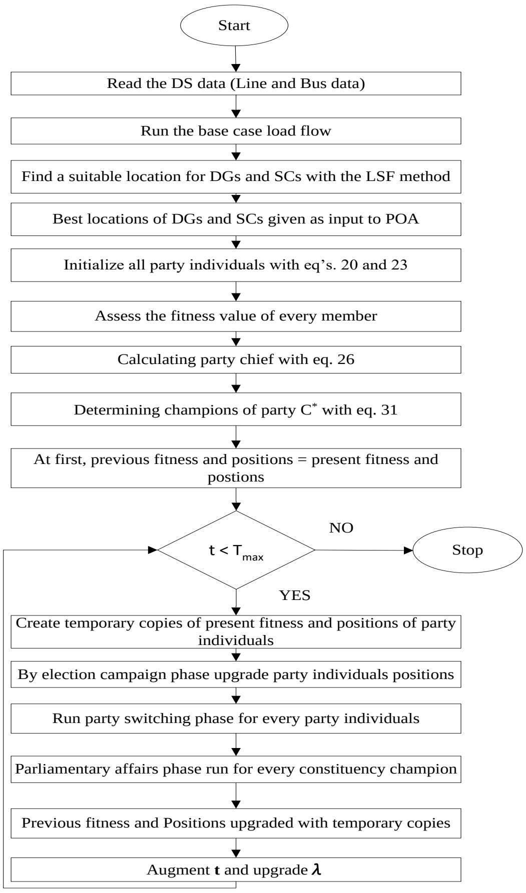

Fig.2. Flow Chart of POA

4. Result and Discussion

In this section the results obtained using the proposed combined approach are presented. The analysis is implemented on IEEE 33 bus system [21 - 23] in MATLAB (R2017a) environment. Before implementing the combined approach for dynamic loading conditions, a general static method of DG and SC allocation are simulated and the results are compared with existing methods in the state of art. The various case studies to show the efficacy of the proposed approach are given below.

Base Case: without DGs and SCs

This case study doesn't consider the allocation of DGs and SCs. From the base case load flow the following results are obtained. P_L=202.6666 kW, V_{min} = 0.9166 p.u, VSI_{min} = 0.7045 p.u

Case 1: **without SC, single DG placement**

Using LSF method bus 30 is identified for placement of single DG. This information is passed to POA and the DG size is determined as 1535.92 kW. The results are given in Table 2 and compared with recent methods. The combined approach helps in reducing the P_L by 42.1 % which is better than other optimization techniques (OTs). Further, the VSI_{min} and V_{min} are improved when compared to base case.

Case 2: without DG, Single SC placement

With LSF technique bus 30 is identified for placement of single SC. This is passed to POA and SC size is determined as 1252.726 kVAr. In Table 2 results are compared with latest techniques. Single SC approach reduced 29.2 % of P_L which is better than other OTs. V_{min}, VSI_{min} also improved compared to base case.

Case 3: Single DG + Single SC placement

In this case, applying the LSF technique, bus number 30 is identified for allocation of Single DG + Single SC. This detail is passed to POA and the DG and SC sizes are determined as 1532.027 kW, 1259.955 kVAr. In Table 2, P_L, V_{min}, VSI_{min} obtained by using POA. It is observed from the results, the combination of single DG and SC with POA algorithm gives better results with in minimum time. A reduction of 68.4% in P_L is observed which is better than other OTs. Finally, the efficacy of algorithm is tested wrt to convergence curve and illustrated in Fig. 3 POA convergences with best results in minimum number of iterations.

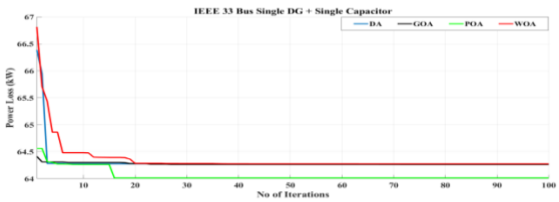

Fig. 3. Convergence Curve for Case 3

Table 2. Comparison of results for Base Case, Case 1, Case 2, Case 3 using POA

Case	OT	Bus No	DG Size in kW	SC (kVAr)	P_L (kW)	V_{min} (p.u.)	VSI_{min} (p.u.)	Time (Sec)
Base Case	NA	NA	NA	NA	202.6666	0.9166	0.7045	14.155
Case 1	DA	30	117.6416	NA	117.6409	0.9362	0.7621	15.669
	GOA	30	1535.92	NA	117.6295	0.9675	0.8747	18.401
	WOA	30	1535.931	NA	117.6409	0.9362	0.7621	17.327
	POA	**30**	**1535.92**	**NA**	**117.4095**	**0.9675**	**0.8747**	**15.501**
Case 2	DA	30	NA	1252.71	143.6016	0.9253	0.727	17.003
	GOA	30	NA	1252.725	143.5883	0.9465	0.8012	18.739
	WOA	30	NA	1252.71	143.6016	0.9253	0.7271	17.300

	POA	**30**	**NA**	**1252.726**	**143.5883**	**0.9465**	**0.8012**	**16.927**
Case 3	DA	30	1531.871	1257.795	64.2754	0.9483	0.8025	19.214
	GOA	30	1531.865	1257.796	64.2624	0.9872	0.8025	19.056
	WOA	30	1530.046	1259.955	64.2756	0.9482	0.8025	17.175
	POA	**30**	**1532.027**	**1259.955**	**64.0124**	**0.9971**	**0.9872**	**16.506**

Case 4: without SCs, two DGs placement

Utilizing LSF technique bus numbers 14 and 30 are determined for allocation of two DGs . The DG sizes are found to be 807.7966 kW, 1174.832kW using POA. In Table 3, results compared with other OTs. A reduction of 57.6 % P_{L} is observed with allocation of two DGs.

Case 5: without DGs, two SCs placement

The buses identified for case 5 are 14, 30. The best SC sizes obtained by POA are 385.6783 kVAr and 1091.63 kVAr. Results listed in Table 3 and compared results with other methods. In this case a reduction of 32.9% of P_L observed.

Table 3. Comparison of results for Case 4, Case 5, Case 6 using POA

Case	OT	Bus No	DG Size in kW	SC (kVAr)	P_L (kW)	V_{min} (p.u.)	VSI_{min} (p.u.)	Time (Sec)
Case 4	DA	14	807.7806	NA	86.0442	0.9677	0.8687	18.062
		30	1174.61					
	GOA	14	807.7843	NA	86.0429	0.9677	0.8756	18.690
		30	1174.747					
	WOA	14	779.9395	NA	86.0912	0.9683	0.8708	16.920
		30	1205.793					
	POA	**14**	**807.7966**	**NA**	**86.0129**	**0.9676**	**0.8753**	**16.834**
		30	**1174.832**					
Case 5	DA	14	NA	385.0071	135.9088	0.9383	0.769	19.705
		30		1092.678				
	GOA	14	NA	385.6629	135.8977	0.9464	0.801	18.941
		30		1091.668				
	WOA	14	NA	381.7745	135.9096	0.9382	0.7687	16.913
		30		1094.906				
	POA	**14**	**NA**	**385.6783**	**135.8977**	**0.9464**	**0.8009**	**16.721**
		30		**1091.63**				
Case 6	DA	14	811.5585	388.0327	28.6621	0.9802	0.9145	19.554
		30	1147.676	1053.448				
	GOA	14	803.1408	377.5508	28.6455	0.9961	0.983	19.532
		30	1155.939	1073.48				
	WOA	14	831.5043	345.1333	28.857	0.9801	0.9142	16.698
		30	1095.172	1129.015				
	POA	**14**	**814.5398**	**376.2026**	**28.4648**	**0.9962**	**0.9837**	**16.569**
		30	**1147.213**	**1084.299**				

Case 6: Two DGs + Two SCs placement

As per the LSF, 14 and 30 buses suitable for the placement of DGs and SCs. They inject both kW and kVAr into the system. Compared to without DGs and SCs, the combination of these sources provides the best results. A significant reduction of 86.0% P_L is observed as compared to base case. The POA convergence curve in this case is represented in Fig. 4 and it is evident that POA outperforms as compared to other methods.

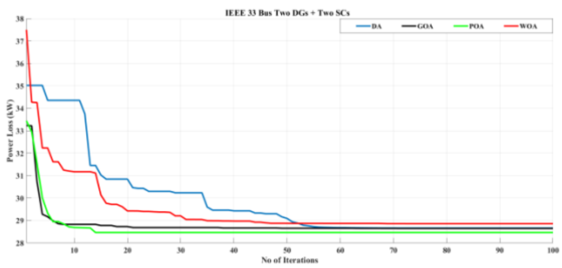

Fig. 4. Convergence Curve for Case 6

Case 7: Without SCs, three DGs placement

In this case allocating three DGs are considered and the results are given in Table 4. The suitable buses for DG allocation are 14, 24, and 30. Finally, 64.8%

P_L minimized, V_{min} and VSI_{min} maximized. The important finding from this placement of three DGs minimizes the losses to reasonable extent.

Table 4. Comparison of POA results with other methods (Three DGs + Three Capacitors) Case 7, Case 8, and Case 9.

Case	OT	Bus No	DG Size in kW	SC (kVAr)	P_L (kW)	V_{min} (p.u.)	VSI_{min} (p.u.)	Time (Sec)
Case 7	DA	14	753.3605	NA	71.4573	0.9679	0.8694	20.183
		24	1102.13					
		30	1070.822					
	GOA	14	754.091	NA	71.456	0.9679	0.8763	20.821
		24	1099.5					
		30	1071.406					
	WOA	14	675.3904	NA	71.8664	0.9685	0.8715	18.557
		24	1215.805					
		30	1106.958					
	POA	**14**	**753.2918**	**NA**	**71.316**	**0.9679**	**0.8762**	**18.321**
		24	**1100.695**					
		30	**1071.494**					
Case 8	DA	14	NA	361.2376	132.2102	0.938	0.9868	17.866
		24		547.3698				
		30		1043.461				
	GOA	14	NA	361.3258	132.1986	0.9462	0.8002	21.216
		24		547.3486				
		30		1043.449				
	WOA	14	NA	302.2056	132.4117	0.9363	0.7624	17.540
		24		599.3051				
		30		1074.713				
	POA	**14**	**NA**	**361.0949**	**132.2001**	**0.9461**	**0.800**	**17.025**
		24		**542.3353**				
		30		**1049.826**				
Case 9	DA	14	747.8706	349.7734	11.6317	0.9921	0.9641	23.872
		24	1087.021	514.3393				
		30	1045.312	1024.137				
	GOA	14	747.663	350.2579	11.6295	0.9956	0.9812	20.698
		24	1078.779	521.2622				
		30	1048.436	1020.977				
	WOA	14	844.129	393.1345	14.7278	0.9924	0.9611	17.075
		24	607.0614	601.0969				
		30	1012.829	1034.97				
	POA	**14**	**749.5181**	**351.0296**	**11.0829**	**0.9975**	**0.9887**	**16.921**
		24	**1084.281**	**620.4652**				
		30	**1012.481**	**1002.867**				

Case 8: without DGs, three SCs placement

In this case allocating three SCs are considered and the results are given in Table 4. Buses 14, 24, 30 suitable for placement of SCs as determined by LSF. Multiple SCs injects kVAr into the system. Around 34.8% of P_L reduction is observed along with enhanced V_{min} and VSI_{min}.

Case 9: Three DGs + Three SCs placement

The suitable locations determined using LSF for allocation of DGs and SCs are 14, 24 and 30. Multi DGs and SCs inject kW and kVAr power into the system. In comparison with allocation of single or two DGs, SCs this method is more efficient which can be observed from the Table 4. An overall reduction of 94.5% P_L is observed in this case which can be treated as the best way of P_L minimization and voltage profile improvement. To prove the efficacy of POA the results are compared with other simulated OTs and compared in Table 4 and Fig. 5. It is proved that POA is superior to other compared methods and helpful in proceeding for dynamic case studies as well. Further in Table 5 the various metrics such as mean, median and standard deviation are compared with other OTs and it is found that POA outperforms in all aspects effectively. Finally a comparison between all case studies in terms of voltage profile, VSI and P_L are made in Fig's 6, 7 and 8. It is evident from the Fig's that using combined approach of LSF and POA, the overall system performance is improved drastically.

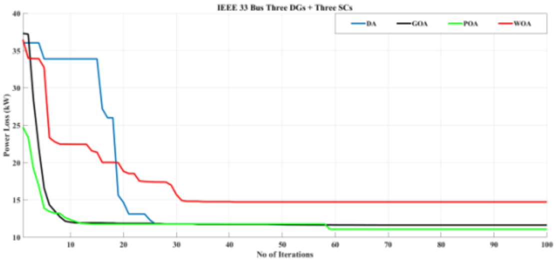

Fig. 5. 33Bus 3-DGs + 3-Capacitors Convergence Curve

Table 5. Comparison of various metrics for Ots

OTs	Mean	Median	Std Dev	Time(s)
DA	11.7691	11.6908	0.2341	23.872
GOA	11.6295	11.6295	0.0598	20.698
WOA	13.60938	13.4604	1.1388	17.075
PO	**11.6137**	**11.6031**	**0.0561**	**17.043**

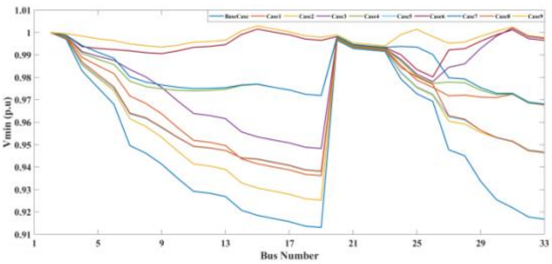

Fig. 6. Voltage Profile for 33Bus for different Cases

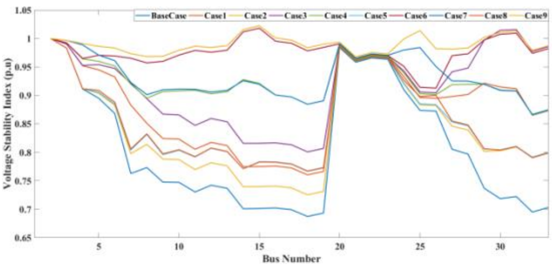

Fig. 7. VSI of IEEE 33Bus system for different cases

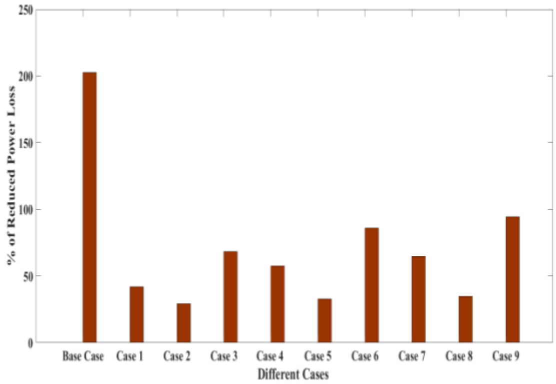

Fig. 8. Power loss reduction in all cases

Case 10: Dynamic analysis of IEEE 33 bus system with 3 DGs and 3 SCs

In this case, the analysis presented in Case 9 is extended for a typical 24-hour simulation using the combined approach of LSF and POA. As the load continuously changes from hour to hour, it is very important to analyze the dynamic changes in the system's voltage profile and power loss. The typical load curve for 24 hours is given in Fig 9. The load flow incorporating dynamic changes in system demand is simulated and the optimal locations of DGs and SCs for all the hours are identified using the LSF technique. In any system generally, the DGs and SCs will be immovable assets. Therefore the identified location should be unique for all dynamic changes in system demand. The best locations identified for all the dynamic load changes are 14, 24 and 30 respectively. The optimal DG and SC sizes for the dynamic cases are given in Table 6, Table 7, PL, Vmin and VSImin obtained using POA are presented. It is evident that Vmin and VSImin are within permissible limits for all 24 hours.

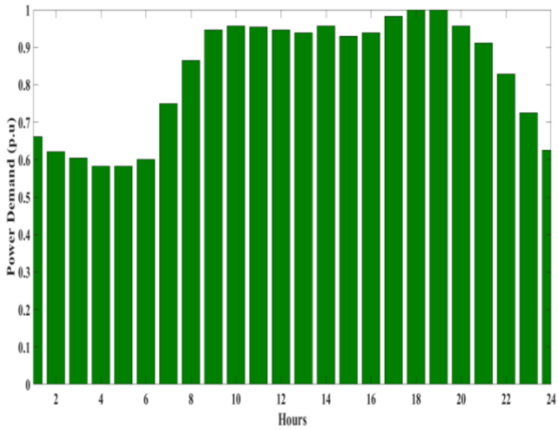

Fig. 9. power demand for 24hrs

Table 6. Hourly variation of DG and SC sizes using POA

Hour	DG1(kW)	SC1(kVAr)	DG2(kW)	SC2(kVAr)	DG3(kW)	SC3(kVAr)
1	563.3276	295.7301	585.8107	300.3281	530.7691	574.3089

2	537.8854	231.0691	584.2414	224.0634	620.0986	536.605
3	553.2491	220.7586	511.7908	247.9031	575.9157	531.2588
4	400.4083	293.1764	420.3128	388.6268	556.133	424.4145
5	400.4083	293.1764	420.3128	388.6268	556.133	424.4145
6	442.3535	202.9988	529.1288	404.4741	559.4524	556.1963
7	665.4528	361.0424	551.3651	422.0295	567.3573	656.4193
8	708.9445	398.6967	679.5026	249.8416	829.4645	766.4128
9	736.5187	298.164	706.1218	434.2542	965.2713	964.2441
10	838.2506	294.2359	635.4109	460.0538	839.9777	727.9987
11	608.4344	374.5878	566.2169	476.8513	950.7862	960.4156
12	736.5187	298.164	706.1218	434.2542	965.2713	964.2441
13	780.3559	383.2916	870.8675	430.0225	896.4321	836.3824
14	838.2506	294.2359	635.4109	460.0538	839.9777	727.9987
15	796.988	287.3726	750.5543	640.0192	862.0568	659.9935
16	780.3559	383.2916	870.8675	430.0225	896.4321	836.3824
17	710.1834	513.6347	729.3906	514.3394	839.7803	703.8495
18	856.9337	325.3341	949.7038	416.8063	814.6503	881.3532
19	750.6481	546.7182	693.7173	580.0011	968.9062	644.8762
20	838.2506	294.2359	635.4109	460.0538	839.9777	727.9987
21	684.1243	323.3497	663.2991	421.0336	929.1639	887.7124
22	703.8394	515.2928	766.2414	129.2874	660.3252	704.6708
23	587.4501	412.0113	563.1886	242.8181	694.768	573.3242
24	563.4805	379.4555	509.8164	411.7928	565.6295	459.7375

Table 7. Variation of P_L, V_{min} and VSI_{min} for 24 hours

Hours	P_L in (kW)	Vmin (p.u)	VSImin (p.u)
1	7.5707	0.9952	0.9779
2	6.6351	0.9951	0.9767
3	6.2348	0.9933	0.9683
4	6.0445	0.9947	0.9761
5	6.0445	0.9947	0.9761
6	6.3761	0.9959	0.9753
7	9.8874	0.9933	0.9679
8	12.6156	0.9917	0.9622
9	15.602	0.9918	0.9615
10	16.1574	0.9943	0.9692
11	15.9639	0.9869	0.9438
12	15.602	0.9918	0.9615
13	14.6798	0.9939	0.9689
14	16.1574	0.9943	0.9692
15	14.8536	0.9903	0.9611
16	14.6798	0.9939	0.9689
17	16.7948	0.9792	0.9115
18	17.4188	0.9891	0.9591
19	17.4188	1.0008	0.9554
20	16.1574	0.9943	0.9692
21	14.3946	0.9944	0.9702
22	11.7472	0.993	0.9649
23	9.5047	0.9936	0.9708
24	6.6787	0.9948	0.9743

5. Conclusion

In this article, a combination of LSF and POA method is utilized to solve the allocation and sizing of DGs and SCs in a DS. This method is capable of minimizing P_L and improving VSI & voltage profile of the DS significantly. LSF method determines the optimal locations for allocating DGs and SCs pass the values to POA for determine desired sizes. The analysis is performed on an IEEE 33 bus system considering 9 different scenarios and results are compared with other Meta heuristic techniques. From the simulated 9 different case studies it can be inferred that the chosen DS requires DGs and SCs in 3 locations for effective operation. In the identified 3 locations, POA will give suitable size of DG as well as SC. From the obtained appropriate size and location of DGs and SCs it is observed that PL is minimized by 94.5% which is prominent. The VSI and voltage profile are abruptly improved with the combined approach. The analysis is further extended for a 24 hour study and the results prove that P_L is minimized significantly throughout the period. The VSI and voltage profile are improved for entire simulation period. This shows that the proposed combined approach is effective in both static and dynamic load conditions.

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