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Reactive power dispatch in Distribution System for Power Loss Minimization and Voltage Control

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ABSTRACT: In the distribution system, due to large resistance and lower reactance of lines, the voltage control and power loss became a crucial issue. In this context,to find the size and location of compensating devices for the reactive power and voltage control devices became the essential need.In this paper, the multi-objective optimisation problem is solved for the sizing and location of reactive power compensating devices in the distribution system. The main contributions of the proposed work are (i) to address the hybrid algorithm to determine the location and size of Distribution Static Synchronous Compensator (D-STATCOM). (ii) The power loss and voltage deviation are minimised. (iii) The impact of D-STATCOM with minimum voltage growth is analysed. The results are verified, tabulated and compared with other methods.

Keywords: Power loss minimisation, voltage deviation, D-STATCOM.

I. INTRODUCTION

The optimal operation of the distribution network operator is comprised of the better voltage profile at each node, minimum power loss and higher cost of energy saving. The flat voltage profile, is therefore expected to distribution system at each node, minimum power loss, the maximum cost of saving and maximum efficiency.One of the operations is to reactive power compensating devices which aims to manage the voltage control and reactive power control for minimisation of power loss.

The reactive power has been compensated using the capacitor banks, synchronous condenser, tap changers and voltage regulators etc, in the earlier distribution system.

The power loss has been reduced using the capacitor bank for power factor improvement also[1]. The active and reactive powerhave been compensated using the distribution generations and capacitor bank [2]. The meta-heuristic techniques are used to solve the reactive power dispatch problems [3]. In this context, the two-archive multi-objective grey wolf optimizer [4], modified differential evolution technique [5], multi-objective strategy [6], a combined swarming algorithm [7], gravitational search algorithm [8], learning based technique [9] etc., have been used for the reactive power dispatch. The uncertainty in renewable based generation has been implemented for reactive power dispatch, although the compensating devices were not used [10]. Apart from this, the distribution D-FACT devices has used to avoid the switching problem in capacitor bank for the reactive power dispatch and voltage control. The reactive power dispatch has been determined using the sitting of capacitor banks, tap position of tap changing transformers and generator voltage[11]. However the penalty based optimization problem has also been considered for the reactive power dispatch [12]. Apart from the above literature, the D-STATCOM has been used instead of capacitor bank for the reactive power dispatch and voltage control. In this context, the probabilistic assessments has been used for the D-STATCOM installation [13]. The D-STATCOM has been installed for the economic load sharing also [14]. The D-STATCOM has been installed to mitigate the low voltage fluctuations in the distribution system [15]. The voltage instability problem has also been mitigates using the D-STATCOM [16]. The various optimization techniques have been implemented for the installation of the D-STATCOM [17],lightning search algorithm (LSA)[18], the direct load flow (DLF) approach in [19], cuckoo search algorithm (CSA)[20], Levy flights algorithm [20] etc.

As evidenced by the literature review, the proposed work aims to determine the size and location of D-STATCOM for minimising the power loss and voltage deviation. The key contribution of this work is as follows:(i) determine the location and size of D-STATCOM to obtain the optimal reactive power dispatch. (ii) to propose the GAMS algorithm for solving the multi-objective

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problem, (iii) The rating of D-STATCOM has also been considered with the multi-objective problem.The present work has been tested in IEEE-33 bus test system of radial distribution (RDS). The results have been tabulated and compared with the other existing methods and techniques also.

In this paper, the total of five sectionsis represented. In section 2, the problem formulation and system modelling is represented. In section 3, the proposed algorithm is explained. In section 4, the results part is discussed. In the last section 5, the paper is concluded.

II. PROBLEM FORMULATION AND MATHEMATICAL MODEL

In this section, the problem formulation and the mathematical model has been explained as follows;
The multi-objective function has been carried out for the analysis. In objective 1: power loss has been determined.
Objective 2: the voltage deviation has been minimised.
The optimal location of D_STATCOM is determined to minimise the cost of energy loss and voltage deviation, as explained in equation (1) and (2).

$$\min\{f_1\} = \sum_k^T \sum_i^{nb} \sum_j^{nl} \left|P_{Loss,ij}^k\right| \quad (1)$$

$$\min\{f_2\} = \sum_k^T \sum_i^{nb} \left|\frac{(V_o - V_i^k)}{V_o}\right| \times 100 \quad (2)$$

The following constraints are considered;
Power balance constraints are represented in eq. (3) and (4).

$$P_i^k = \left(Pg_i^k - Pd_{ZIP,i}^k\right) = V_i^k \sum_{j=1}^n V_j^k \left(G_{ij} \cos(\delta_i^k - \delta jk + Bijsin\delta ik - \delta jk \quad (3)$$

$$Q_i^k = \left(Qg_i^k - Qd_{ZIP,i}^k\right) = V_i^k \sum_{j=1}^n V_j^k \left(G_{ij} \sin(\delta_i^k - \delta jk - Bijcos\delta ik - \delta jk \quad (4)$$

$$\forall\, i \in S_B \,\&\, k \in S_T$$

where the generated power Pg_i^k and Qg_i^k is represented in (5) and (6)

$$Pg_i^k = Pgrid_i^k + \sum_j^{nl} P_{Loss,ij}^k \quad (5)$$

$$Qg_i^k = Pgrid_i^k + Q_{DST,i}^k + \sum_j^{nl} Q_{Loss,ij}^k \quad (6)$$

D-STATCOM limits: this includes the maximum and minimum limits.

$$Q_{DSTmin,i}^k \le Q_{DST,i}^k \le Q_{DSTmax,i}^k \quad (7)$$

Power loss equation represents in (10): this includes the maximum power limit.

$$\left|P_{Loss,ij}^k\right| = \left|\sum_k^T \sum_i^{nb} G_{ij}^k \{(V_i^k)^2 + (V_i^k)^2 - 2V_i^k V_j^k \cdot \cos\delta ik - \delta jk \le Plmaxk \quad (8)$$

Limits for the generation: this includes the maximum and minimum limits.

$$P_{Gi}^{min} \le Pg_i \le P_{gi}^{max},\ i \in S_G \quad (9)$$

$$Q_{gi}^{min} \le Qg_i \le Q_{gi}^{max},\ i \in S_G \quad (10)$$

Voltage and load angle limit

$$V_{i,k}^{min} \le V_i^k \le V_{i,k}^{max},\ i \in S_B \quad (11)$$

$$\delta_{min\,i}{}^k \le \delta_i^k \le \delta_{max\,i}{}^k, \quad (12)$$

$$\forall i = 1,2 \ldots .\, nb$$

Power factor limit of the system is limited by (15)

$$pf_i^{lo} \le pf_i \le pf_i^{up},\ i \in S_B \quad (13)$$

III. ALGORITHM USED

In this section, the proposed algorithm has been explained as follows;
The MATLAB and GAMS have been carried out for solving the problem. The location and size of D-STATCOM is determined using NLP solver in GAMS. The following steps are used to solve the multi-objective problem.
Step1
(a) Read the test system bus and line data.
Step 2
(a) Run the load flow program for 24-hrs and obtain the candidate node having the highest power loss and voltage deviation for D-STATCOM location. Save the candidate node.
Step 3. After obtaining the location of the candidate node, the size of D-STATCOM has determined. Transfer the all control parameter from MATLAB to GAMS.
(a) Solve the objective function (1) and (2). Solve the constraints equation from (3) to (13).
Step 4 Transfer the objective variables form GAMS to MATLAB.
Step 5 Save and Print the results.
The flow chart of the proposed algorithm is shown in Figure 1.

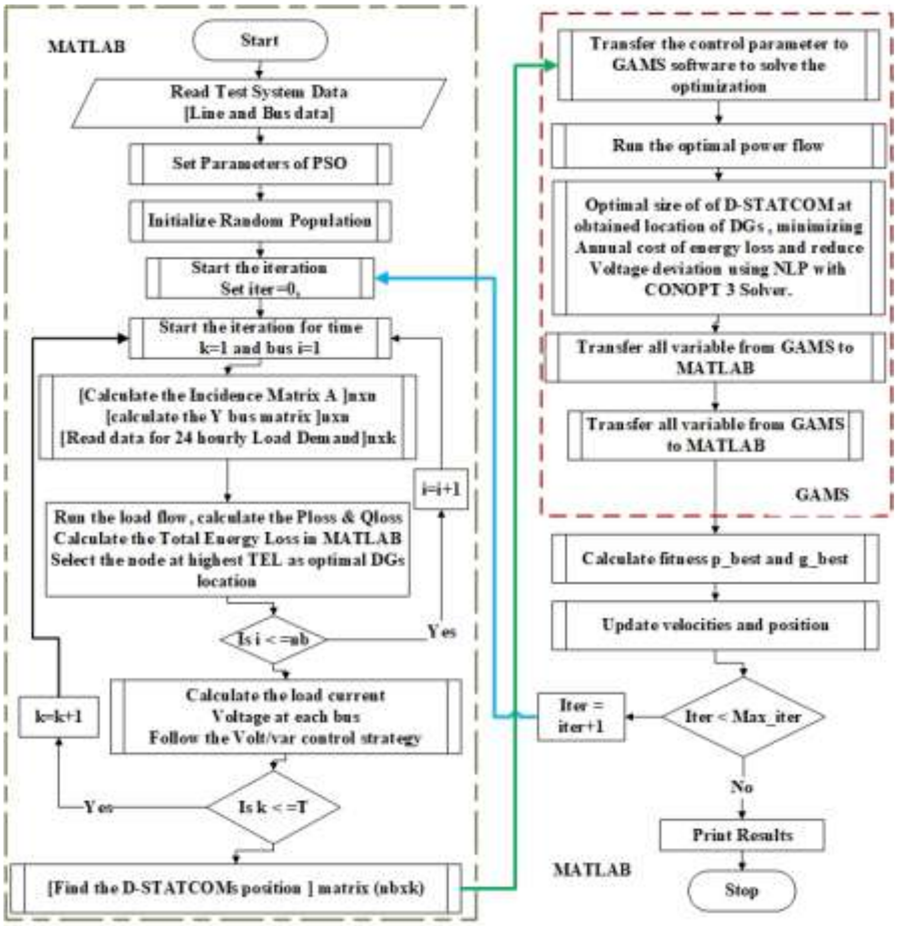

Figure 1 Flow chart for the proposed algorithm

IV. RESULT AND DISCUSSION.

In this section, the simulation results have been presented and discussed to study the D-STATCOMin distribution system. Furthermore, the proposed technique has been tested on distribution system: 100 MVA 12.66 kV IEEE 33 bus test system. Moreover, the rating of D-STATCOM has been determined with minimum voltage growth from 0.90 to 0.95 pu for better reactive power sources to minimise the power loss. The rating of multiple D-STATCOM, power loss, annual cost of energy loss, and saving of energy loss have been analysed.The following cases have been carried out for the analysis as follows;

Case 1: The impact of single D-STATCOM.
Case 2: The impact of multiple D-STATCOM.
Case 3: The impact of time-varying ZIP load with D-STATCOM.

The test system has been carried out with the above mentioned cases.

4.1 Result for Test system 1: IEEE 33 bus test system

In this section, the D-STATCOM rating and location have been determined to obtain the reactive power dispatch and maximum energy saving in IEEE 33-bus system.

In the base case, the peak demand of the distribution system is 3715 + j 2300 kVA. The base case power loss is $202.66 + j135.13$kVA annual cost of energy loss is \$106518.1, and the minimum voltage is 0.9047930pu.

4.1.1 Installation of D-STATCOM

The optimal location obtained for the single D-STATCOM is 30th bus, and the multiple D-STATCOM of two nodes are 12th and 30th, respectively. Furthermore, the rating of single D-STATCOM obtained is 1257.89kVAr at 30th busfor power loss saving.The power loss obtained after installation of D-STATCOM is 145.3001+j*98.07289kVA, the voltage profile has enhanced to 0.9245pu, and the annual cost of energy loss obtained is \$79365. Therefore, the

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saving in annual energy loss obtained is $23481.6 (28.303%).

In this context, the multiple D-STATCOMof464.98kVAr, and 1063.3kVArare installed at bus 12th and 30th, respectively. The power loss has been reduced to 136.1395+j*91.10344kVA with multiple D-STATCOM. Therefore, the annual cost of energy loss obtained is $74359, and the annual saving in energy loss obtained is $36338 (32.827%).In Figure 2the voltage profile with installation of D-STATCOM is shown.

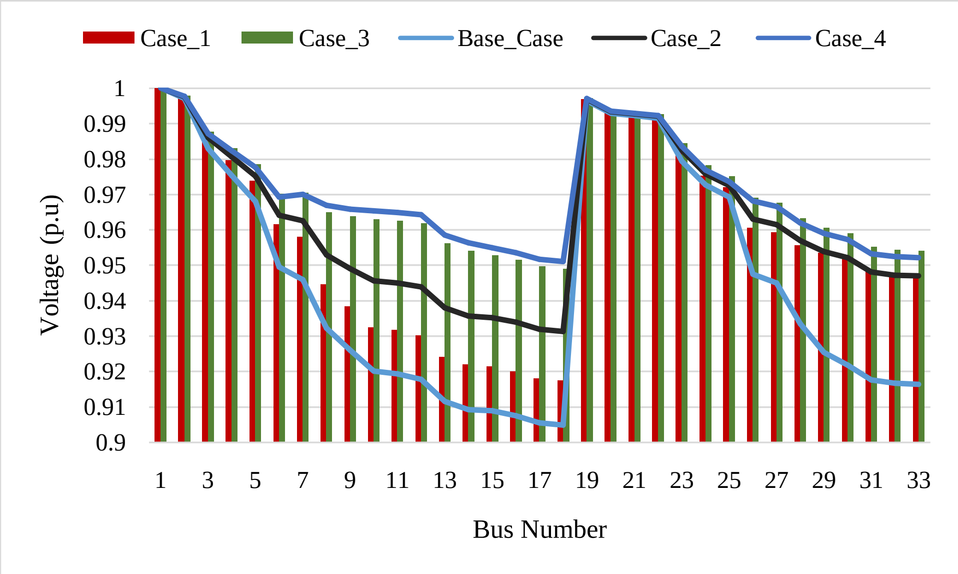

Figure 2 Minimum voltage profile with the installation of D-STATCOM in IEEE 33 bus system

Table I Comparison of results for 33- bus system

Descriptions	Base Case	PSO [21]	BFOA [22]	LSF [19]	BAT [23]	IA [24]	GA [24]	Proposed with D-STATCOM
Optimal location at bus	------	30	30	30	30	12	12	30
Rating of D-STATCOM (kVAr)	------	1380	1102.7	3200	1150	962.49	1114.2	1257.89
Min. voltage (pu)	0.91309	0.92677	0.92422	0.9023	0.9244	0.9258	0.9236	0.9245
Total power loss (kW)	202.66	144.17	144.38	198.25	143.97	171.81	173.95	145.3
Loss reduction (%)	------	28.86	28.75	2.17	28.95	15.22	14.16	28.30
Total annual cost ($)	106518.1	83089.75	81730.44	121160.2	81765.63	95404.53	97333.38	83036.5
Cost of Compensation ($)		7314	5844.31	16960	6095	5101.197	5905.26	6666.817
Annual cost of energy loss ($)	106518.1	75775.75	75886.13	104200.2	75670.63	90303.34	91428.12	76369.68
Annual cost of energy loss saving ($)	0	23428.34	24787.66	-14642.1	24752.46	11113.56	9184.716	23481.6

The results have been compared with other existing methods and techniques as given in Table I the proposed method has shown better results with another method for the minimum power loss and voltage enhancement. Moreover, the power loss is reduced to 28.303%, and the

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minimum voltage is increased to 0.9245 pu with the proposed algorithm.Although, the size of D-STATCOM obtained is 1257.89kVAr for loss minimisation and voltage enhancement.

Table II Comparison of result of multiple D-STATCOM in 33 bus system

Descriptions	**Base Case**	**PSO**[21]	**BFOA**[22]	**BAT**[23]	**Proposed with D-STATCOM**
Optimal location at bus	------	12, 30	10, 30	10, 30	12, 30
Rating of D-STATCOM (kVAr)	------	472 (12) 1062 (30)	600 (10) 1200 (30)	450 (10) 995 (30)	464.98 (12) 1063.3 (30)
Total D-STATCOM (kVAr)		1534	1800	1445	1528.28
Min. voltage (pu)	0.91309	0.93636	0.9392	0.9356	0.9245
Total power loss (kW)	202.66	135.75	137.5	136.05	135.896
Loss reduction (%)	------	33.015	32.15	32.86	32.9438
Total annual cost ($)	106518.096	79480.4	81810	79166.38	79654.8052
Annual cost of energy loss ($)	106518.096	71350.2	72270	71507.88	71554.9212
Cost of compensation ($)	0	8130.2	9540	7658.5	8099.884
Annual cost of saving ($)	0	27037.696	24708.096	27351.716	26991.27

The power loss obtained is 135.896kW, the minimum voltage is 0.9245 pu, the annual cost of energy loss is $71554.92, with multiple D-STATCOM at bus 12 and 30, as given in Table II. Moreover, the D-STATCOM of 464.98 kVArat 12 bus, and 1063.3 kVAr at 30th bus. The power loss is reduced to 32.94 %, withthe proposed method is compared to another method.

V. CONCLUSION

The proposed hybrid technique is implemented for voltage enhancement and power loss minimisation to determine the optimal size and location of D-STATCOM successfully. It is observed that the proposed method has better results as compared with other techniques likewise PSO, LSF, BFOA, GA, and IA etc. The results are first analysed and compared with another technique considering D-STACOM only. In this context, the minimum voltage is obtained upto 0.95 pu with an optimal size of D-STATCOM and minimum power loss, by taking the D-STATCOM. Therefore, the following points concluded for the optimal solution of IEEE-33 bus test system are; the voltage deviation is reduced to 3.805 % form 5.456 % (base case), and power loss is reduced to 32.82% with multiple D-STATCOM.In the above-mentioned points the power loss and voltage deviation are reduced with D-STATCOM. Moreover, the voltage and power factor are remainedwithin the limits. In addition, the new concept of D-STATCOM Therefore, the proposed approach has better results with other methods.

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