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Energy Saving with D-FACTS in Distribution System Using Cuckoo Search Algorithm

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Abstract— In order to analyze the radial distribution system (RDS) for minimizing power losses, a meta-heuristic optimization technique named Cuckoo Search (CS) algorithm is applied for DG/D-STATCOM allocation. In this paper, an effort has been made to reduce RDS losses and energy cost by incorporating distributed generation (DG) and distribution static synchronous compensator (D-STATCOM). To verify the effectiveness of algorithm, it is tested on IEEE 33 and IEEE 69 buses for various situations of DG and D-STATCOM in RDS. Also the impact of minimization of power loss is observed on total annual energy saving cost (TAESC) and the total annual operating cost (TAOC). The accomplishment of the proposed algorithm is compared with a previously used method.

Keywords— Annual energy saving cost, Cuckoo search algorithm, DG, D-STATCOM, Power loss minimization.

I. INTRODUCTION

The electrical energy is one of the most important components of economic infrastructure. It is instrumental in ensuring the nation's welfare. The presence and development of appropriate infrastructure are essential for sustainable economic growth in India. The whole world is facing problems due to shortage of electricity and high cost of energy. So there is major attention on the saving of energy and its cost. Due to high $\frac{R}{X}$ ratio of distribution network, the power loss is nearly about 13% in Indian power system [1].

The generated electricity of renewable based DG is said to be green energy. This energy is most efficient and reliable for reducing environmental issues. DG is an ecological source of electricity which plays an indispensable job in the distribution of energy. DG generates and stores renewable energy from various sources for reducing environmental impact as well as for improving the safety and stability of the delivered energy [2]. But accurate location and size of DG and other compensation devices are the major issue in RDS. The integration of DG with appropriate allocation in RDS has various benefits viz. power loss reduction, energy saving, annual energy saving cost and environment protection from carbon emissions [3]. STATCOM is the most efficient and reliable reactive energy generation equipment of D-FACTS family. Joseph Sanam1 *et al*. [4] applied the Differential Evolution Algorithm (DEA) to minimize power loss and maximize the energy cost saving by placing D-STATCOM in RDS.

Despite the proper allocation of D-STATCOM in RDS, the various objective functions can be optimized viz. power loss minimization, annual cost saving maximization and minimization of the operating cost of compensation devices to improve the quality of electricity, power factor correction, load compensation, load balancing, harmonic and voltage regulation [5]. PV, Wind, Biomass, and CHP etc. are the types of DG. The practical implementations of these DGs are possible beneficial for the society. In the present scenario, the renewable energy

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resources or distributed generation (DG) plant viz. PV, wind and biomass etc. can solve the crises of electricity and its cost. M. A. Eldery *et al.* [6] described that the D-STATCOM capacity is reduced in presence of DG in the RDS.

However, the random placing of DG and D-STATCOM in RDS and the uncorrected size of these devices cause high I^2R losses dissipated in DG and D-STATCOM. The most appropriate allocation of these two devices in RDS can be obtained by mathematical techniques, sensitivity approaches, and several meta-heuristic optimization algorithms. Various exciting methods are available in literature for power loss reduction with various objective functions. Yet their appropriate capacity and location can be determined by various meta-heuristic algorithms to reduce power losses and solve the increased energy requirement.

Although many researchers are working on allocation of DG and D-STATCOM individually in the RDS, appropriate allocation of group combination of DG and D-STATCOM using meta-heuristic algorithms is addressed by limited researchers. K.R. Devabalaji *et al.* [7] applied Bacterial Foraging Optimization Algorithm and Loss sensitivity factor (LSF) to find the capacity and location of DG and D-STATCOM, respectively. BFOA is a swarm intelligence technique which is inspired by Stochastic Search Algorithm. Yuvaraj Thangaraj *et al.* [8] applied Lightning Search Algorithm (LSA) to calculate the appropriate allocation of DG with D-STATCOM and analyze multi-objective function viz. power loss minimization, minimization of TVD and maximization of VSI. T. Yuvaraj *et al.* [9] applied two different techniques viz. Voltage Stability Index (VSI) and Loss Sensitivity Factor (LSF) to obtain the capacity and position of DG and D-STATCOM respectively for analysis of RDS. Cuckoo Search Algorithm (CSA) is applied to obtain the capacity DG/D-STATCOM. Devi et al. [10] applied Particle Swarm Optimization to get the appropriate allocation of DG and D-STATCOM for minimization of power losses and enhancement of voltage profile. Kanwar *et al.* [11] proposed an improved Cat Swarm Optimization Algorithm (CSO) for the analysis of impact of allocation of DGs and D-STATCOM on distribution networks to alleviate the losses. Cat swarm optimization technique is inspired by mimicking the habitual behavior of cats. The proposed research outcome is compared with the PSO. Kiran Jasthi *et al.* [12] applied exact loss formula with reconfiguration to obtain the capacity of DG. A. R. Gupta *et al.* [13] applied two techniques for location and sizing of D-STATCOM respectively, Index Vector and Variational techniques to alleviate the total power loss, price of energy loss and annual energy saving in both condition viz. with and without D-STATCOM along with/without reconfiguration and cost of D-STATCOM. However, S. Ganguly *et al.* [14] explain that the significance of placing D-STATCOM with reconfiguration in RDS is a critical issue because of cost increment of this scheme.

Consequently, the above literature indicates that most authors applied two different optimization techniques for position and sizing of both compensation devices. However, to obtain the objective function in this paper, only one optimization algorithm, CSA, is applied. This paper includes five sections. In section I, a brief background of problem and literature survey is presented. In section II, the description of objective functions of power loss minimization, total annual energy cost saving, price of D-STATCOM and total operating cost (TOC) of DG and D-STATCOM are described. In section III, the optimization techniques of CSA are described; and a flowchart for the application of these techniques using load flow is presented. In section IV, the outcome of present research is compared to existing literature. In section V, the conclusion of the study is presented.

II. MATHEMATICAL MODEL DESCRIPTION

The main goals of the proposed research are the curtailment of total annual operating costs, maximization of total annual cost of energy saving, and alleviation of the power loss with appropriate allocation of single DG, single D-STATCOM and several DGs and D-STATCOM. The CS algorithm is used to optimize the location and size of DG and D-STATCOM and alleviate the power loss.

The load flow is the backbone of power system. Without load flow, the analysis and planning of power system are not possible. There are various methods to solve the load flow, but a conventional load flow method is not capable to calculate the branch current directly. To rectify this problem, Backward/Forward Sweep method is used for balanced RDS [15].

A two-bus system is considered as apart from RDS as exhibited in Fig.1. Here the loads ($P_i + jQ_i$) and ($P_{i+1} + jQ_{i+1}$) are connected at bus i & $i+1$ respectively in balanced RDS. The bus voltage V_i and V_{i+1} are at buses i and $i+1$ respectively. In this system, bus i and $i+1$ are sending and receiving end buses, respectively. The voltages at other buses are calculated by the forward/backward load flow method (1):

$$V_{i+1}\angle\theta_{i+1} = V_i\angle\theta_i - (R_i + jX_i)I_i\angle\delta \tag{1}$$

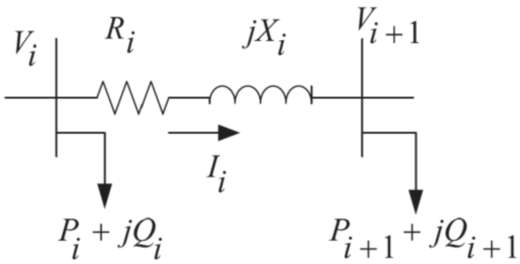

Fig. 1. Single line diagram of a two-bus distribution system

$P_{i,\ i+1}$ and $Q_{i,\ i+1}$ are respectively total real power and reactive power which flow between buses i and i+1as calculated by (2) and (3):

$$P_{i,\ i+1} = P_{\ sp} + P_{Loss(i+1)} \tag{2}$$

$$Q_{i,i+1} = Q_{\ sp} + Q_{Loss(\ i+1)} \tag{3}$$

Where $P_{\ sp}$ and Q_{sp} supplied real power and reactive power beyond the bus i+1 respectively.$P_{loss(\ i+1)}$ and $Q_{Loss(i+1)}$are the active and reactive power losses between buses i and i+1 respectively.

$$I_i = \frac{P_{i,\ i+1} - jQ_{i,\ i+1}}{V_{i+1}\angle\theta_{i+1}} \tag{4}$$

From (1)

$$I_i = \frac{V_i\angle\theta_i - (V_{i+1}\angle\theta_{i+1})}{(R_i + jX_i)} \tag{5}$$

The active and reactive power losses in the line section between buses i and $i+1$ are calculated

$$P_{Loss(i+1)} = I_i^{\,2}R_i \tag{6}$$

$$Q_{Loss(i+1)} = I_i^{\,2}X_i \tag{7}$$

In the whole distribution system, the total active and reactive power losses can be determined by the summation of losses in all line sections as given by:

$$P_{T,Loss} = \sum P_{Loss}\,(i, i+1) \tag{8}$$

A) Objective Functions

Power loss reduction using DG/D-STATCOM placement: the main purpose of DNO is to minimize the active power loss of the system by placing DG and D-STATCOM.

$$Min\ F = P_{T,Loss} = \sum_{i}^{N} P_{Loss}(i, i+1) \tag{9}$$

where *N* is the total number of branches.

To maintain the healthy condition of the power system network (PSN) and save energy, the power loss should be minimized.

B) Operational Constraints

B.1. Voltage Constraints

At each bus, the voltage should be kept within its minimum and maximum ranges with standard values.

$$V_i^{min} \leq V_i \leq V_i^{max} \tag{10}$$

where V_i is the voltage at bus *i*.

B.2. Power Balance

The generation of total electricity is equal to the total power demand and total power losses

$$\sum P_D^i + \sum P_{T,Loss} = \sum P_G^{DG} \tag{11}$$

$$\sum P_D^i + \sum P_{T,Loss} = \sum P_G^{DST} \tag{12}$$

where P_D^i is the power demand at bus *I*; and P_G^{DG} and P_G^{DST} are the power generation using DG and D-STATCOM.

B.3. D-STATCOM Capacity Limits

$$P_{i,DG}^{min} \leq P_{i,DG} \leq P_{i,DG}^{max} \tag{13}$$

$$Q_{i,D-STATCOM}^{min} \leq Q_{i,D-STATCOM} \leq P_{i,D-STATCOM}^{max} \tag{14}$$

where,

$P_{i,DG}^{min}$, $P_{i,DG}^{max}$, $Q_{i,RDSTATCOM}^{min}$ and $Q_{i,RDSTATCOM}^{max}$ are minimum active power limits of the compensated bus, maximum active power limits of the compensated bus, minimum reactive power limits of the compensated bus and maximum reactive power limits of compensated bus respectively.

C) Cost of D-STATCOM

The total annual cost of D-STATCOM can be determined by the following expression:

$$DST_{cost,\ year} = DST_{cost} \times \frac{(1+B)^{n_{DST}} \times B}{(1+B)^{n_{DST}} - 1} \tag{15}$$

where,

DST_{cost} = Cost of Investment in the Year of Allocation

$DST_{cost,\ year}$ = Annual cost of D-STATCOM

n_{DST} = Life of D-STATCOM in years

B = Asset rate of return

D) Total Annual Cost of Energy Saving (TACES)

TACES is the difference between total energy loss without D-STATCOM and energy loss with D-STATCOM and annual installation cost of D-STATCOM by (11) [16]

The total annual energy cost saving can be obtained:

$$(TACES) = (K_p \times T \times P_{loss}^{without}) - (K_p \times T \times P_{loss}^{with}) - \left(K_c \times\ DSTATCOM_{cost,\ year}\right) \tag{16}$$

E) Total Operating Cost (TOC) of DG and D-STATCOM

The total operating cost of DG and D-STATCOM [9] can be determined by (12) [17]:

$$\mathrm{TOC} = \left\{ \begin{array}{c} \mathrm{TOC_{DG}} = \beta_1 \times \mathrm{P_{loss_{DG}}} + \beta_2 \times \mathrm{P_{D_{DG}}} \\ \mathrm{TOC_{D-STATCOM}} = \beta_1 \times \mathrm{P_{loss_{DSTATCOM}}} + \beta_2 \times \mathrm{P_{D_{DSTATCOM}}} \end{array} \right\} \tag{17}$$

$\beta_1$and $\beta_2$are the cost coefficients; and their values are 4\$/kW or kVAr and 5\$/kW or kVAr, respectively.

III. OPTIMIZATION TECHNIQUES

Consequently, optimization is seen as the main task in the analysis of such a technical problem as the entanglement of these problems and the profitability necessity to achieve an appropriate increase at the same time. Two main types of goals should be investigated: minimization of costs, energy consumption and time, and maximization of power quality and efficiency [18]. The various optimization techniques are used to obtain appropriate results of the problem such as minimization and maximization.

As per literature, there are various methods of optimization. However, many existing traditional optimization methods are applied to the actual world's problems. The traditional optimization methods are not capable to solve numerical difficulties related to computing second or higher order derivatives [19]. However, various heuristic and metaheuristic algorithms, which are nature-inspired, are applied to overcome this critical issue. Consequently, many meta-heuristic algorithms viz. Kalman Filter Algorithm, Hybrid PSO, Genetic Algorithm (GA), Tabu search, Evolutionary Programming (EP), Ant Colony Search Algorithm, GA-Fuzzy, Search Algorithm (SA), Stochastic Search Algorithms, Analytic Hierarchy Process, Conventional, Artificial Intelligence Algorithm, Particle Swarm Optimization Algorithm, Probabilistic Approach, Pattern Recognition Techniques, Graph Search Algorithm, Discrete Genetic Algorithm, Adaptive Hybrid Genetic Algorithm, Simulated Annealing, Constrained Decision Problems Approach, Differential Evolution (DE), Harmony Search Algorithm, Monte Carlo based techniques, Krill Herd Algorithm, Shuffled Bat Algorithm, Invasive Weed Optimization Algorithm, Bacterial Foraging Optimization Algorithm, Lightning Search Algorithm, Gravitational Search Algorithm, Elephant Algorithm and sensitivity based approach etc. are widely used in various applications of power system. In the current scenario, the applications of CSA are used in every engineering field. Because of the excellent features of this CS algorithm, the CSA is used to solve optimization problems in real applications to get encouraging results.

Cuckoo search (CS) algorithm: Xin She Yang and Sush Deb developed Cuckoo search optimization algorithm in 2009 [20]. Many authors tested CS algorithm in some known reference functions. Researchers tested this algorithm in some known reference functions and compared it to PSO and GA; and it was obtained that the CS algorithm achieved better results. Xin She Yang, Sush Deb and many other authors also applied CSA to various engineering optimization problems; and they found that the results of the CS algorithm are encouraging [21]. The CS algorithm is a population-based optimization technique which is inspired by the bird cuckoo species in nature. In CSA, the purpose of Lévy flights is to create a new solution for a new nest [22]. The CS Algorithm is a fast, secure and effective algorithm for optimization. For optimization, we can follow three rules of CSA [23] as:

- Each cuckoo puts an egg every time; and kills his egg in a nest chosen randomly.
- The distinguished quality of the eggs (better solutions) passes to the next generations.
- A host bird can discover a foreign egg with a chance, *pa* = 0.25; and it builds a new nest in a new position or completely abandon its nest or throw the eggs.

CSA generates a random host nest using levy flight for a new solution X_{pq}^{gen+1}. The cuckoo chooses the nest position to lay egg randomly:

$$X_{pq}^{gen+1} = X_{pq}^{gen} + S_{pq} * Levy(\lambda) * \alpha \tag{18}$$

where α>0, denotes the step size,

$$Levy(\lambda) = \left| \frac{\Gamma(1+\lambda) * sin(\pi * \frac{\lambda}{2})}{\Gamma\left(1+\frac{\lambda}{2}\right) * \lambda * S^{(\lambda-1)/2}} \right|^{1/\lambda} \tag{19}$$

where λ = constant $1 < \lambda \leq 3$; α = random number [-1 to 1].

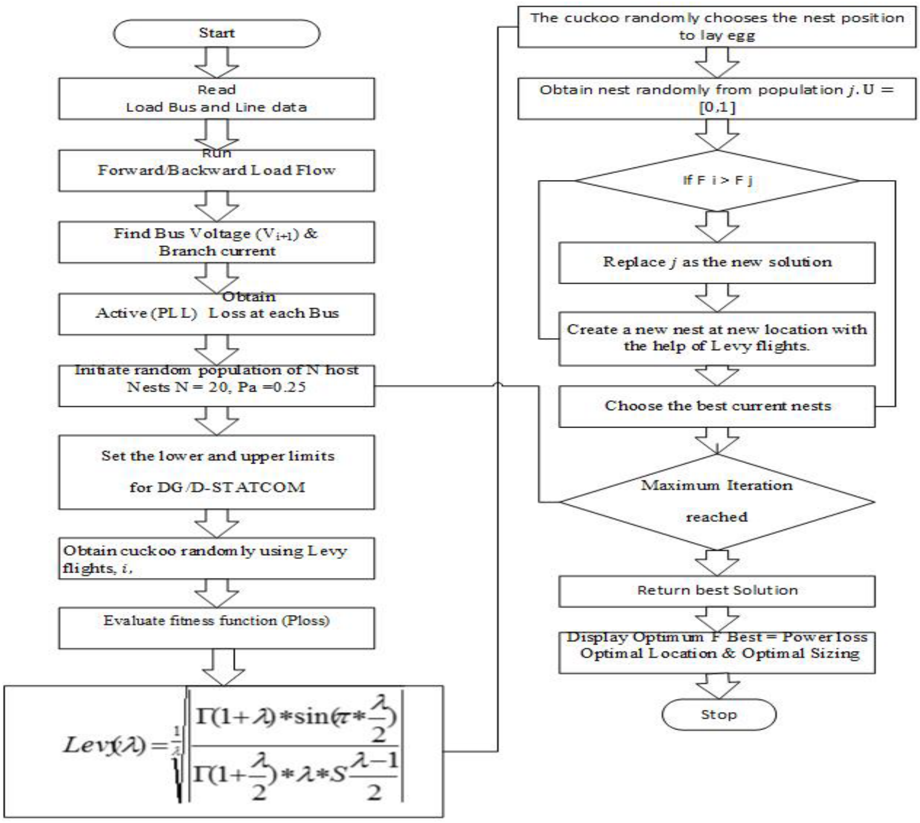

Fig. 2. Flowchart for optimization with CS algorithm embedded with load flow

pa= discovery rate of alien eggs/solutions
Γ = gamma function
S= step size
Where X_{pq}^{gen} is the current nest position; X_{pq}^{gen+1} is the next nest position; α is a random number in the range of -1 and 1; λ is a constant between 0.25 and 3; Γ is a gamma function; and S is the step size which has a great influence on the CSA. The flow chart of CSA with embedded load flow for appropriate allocation of DG and D-STATCOM is exhibited in Fig. 2.

IV. RESULTS AND DISCUSSION

The proposed optimization technique, CS algorithm, is executed through MATLAB 7.15 platform to determine the total annual energy saving cost and operating cost of D-STATCOM/DG with the accurate allocation of D-STATCOM /DG. To analyze the accomplishment of the proposed algorithm, it has been tested on IEEE 33-bus system and 69-bus system. The Backward/Forward Sweep load flow method is applied to determine the magnitude of the voltage and its phase angle and power losses at each bus.100 MVA and 12.66 kV are taken as base MVA and Base kV, respectively. The various cases are taken to analyze the effectiveness of the proposed method.

A) IEEE 33-Bus Test System

In this research, three cases are investigated to find out the accomplishment of the proposed optimization algorithm. Single line diagram of 33 bus radial distribution network is exhibited in Fig. 3. The meta-heuristic algorithms CSA are applied with Backward/Forward Sweep load flow method for the following cases:

- Case I: RDS with Position of Single DG
- Case II: RDS with Position of Single D-STATCOM
- Case III: RDS with Combined Position of DG and D-STATCOM

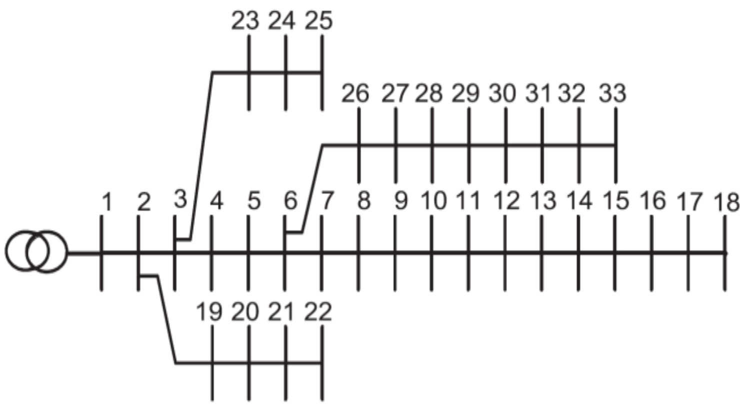

Fig. 3 Single line diagram of IEEE 33-bus of RDS

A.1. Case I: RDS with Position of Single DG

In this case, the CSA is applied to obtain the appropriate allocation of DG. The appropriate size and location are 2.57 MW and 6th bus respectively; and power loss is 111.03 kW. The total operating cost, annual energy saving and annual energy saving cost are 13294.0 \$, 875583.024 KWh and 38902 \$ respectively as exhibited in Table 1. Fig. 4 shows the power loss versus iterations with placing of 1- DG in RDS.

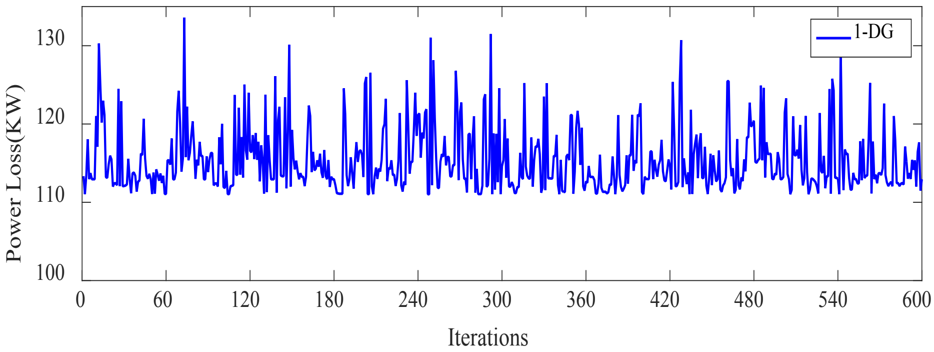

Fig. 4. Power loss versus iterations for one DG for 33 buses

TABLE 1
PERFORMANCE OF 33-BUS TEST SYSTEM FOR ONE DG

Comparison of the Proposed Technique with the Existing Technique		
	CSA (Proposed)	[7]
Base Case, kW	210.98	202.67
Power Loss, kW	111.03	111.17
DG Size, MW (Location)	2.57 (6)	2.69 (6)
TOC, $	13294.0	13,930
Loss Reduction, %	76	NA
Annual Energy Saving, kWh	875583.024	NA
Annual Cost of Energy Saving, $	38902	NA

A.2. Case II: RDS with Position of Single D-STATCOM

In this case, the CSA is applied to obtain the appropriate allocation of D-STATCOM. The appropriate size and location are 1.50 MVAr and 30th respectively; and power loss is 149.3262 kW. The total operating cost, annual energy saving and annual energy saving cost are 6816.5 $, 607527.024kWh and 29819 $ respectively. These results are exhibited in Table 2. Fig. 5 shows the power loss versus iterations with placing of 1 D-STATCOM in RDS.

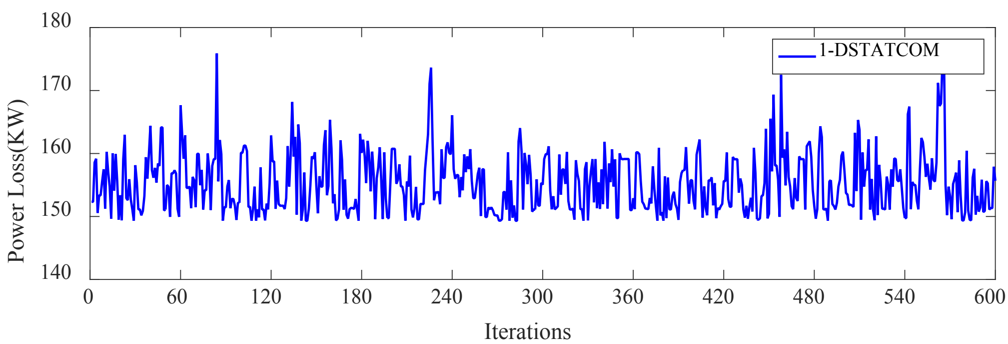

Fig. 5. Power loss versus iterations for one D-STATCOM for 33buses

TABLE 2
PERFORMANCE OF 33-BUS TEST SYSTEM FOR ONLY D-STATCOM

Comparison of the Proposed Technique with the Existing Techniques				
	CSA (Proposed)	[7]	[8]	[16]
Base Case, kW	210.98	202.67	210.98	171.79
Power Loss, kW	149.3262	144.38	151.37	0.962(12)
D-STATCOM Size, MVAr (Location)	1.25(30)	1.102 (30)	1.25 (30)	NA
TOC, $	6816.5	6091	NA	15.24
Loss Reduction, %	45	28.97	28.25	NA
Annual Energy Saving, kWh	607527.024		522183.6	NA
Annual Cost of Energy Saving, $	29,819	24,768	NA	11,120

A.3. Case III: RDS with the Combined Position of DG and D-STATCOM

In this case, one DG and one D-STATCOM are placed simultaneously in 33 bus RDS. The appropriate allocation is obtained through the CS algorithm. The appropriate size and location of both devices are 2.57 MW, 1.24 MVAr and 6th, 30th, respectively; and power loss is 51.18 kW. The total operating cost, annual energy saving, and annual energy saving cost are 13675$, 1399869.024 KWh and 69703 $ respectively. The results for the appropriate allocation of DG and D-STATCOM are exhibited in Table 3. Fig. 6 shows the power loss versus iterations with placing of 1 DG and 1 D-STATCOM in RDS.

TABLE 3
PERFORMANCE OF 33-BUS TEST SYSTEM FOR ONE DG AND ONE D-STATCOM COMBINATION

Comparison of the Proposed Technique with the Existing Technique		
	CSA (Proposed)	[7]
Base Case, kW	210.98	202.67
Power Loss, kW	51.18	70.87
DG Size, MW (Location)	2.57(6) 1.24(30)	1.23(10) 1.09 (30)
TOC, $	13675	11,955
Loss Reduction, %	135	NA
Annual Energy Saving, kWh	1399869.02	NA
Annual Cost of Energy Saving, $	69703	NA

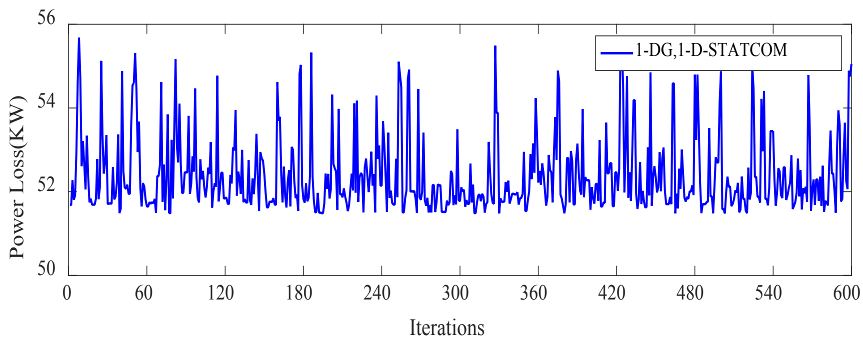

Fig. 6.Power loss versus iterations for one DG and one D-STATCOM for 33 buses

B) IEEE 69-Bus Test System

In this article, five different cases are considered to find out the accomplishment of the proposed optimization algorithm. Single line diagram of 69 bus radial distribution network is exhibited in Fig. 7.

- Case I: RDS with Position of Single DG
- Case II: RDS with Position of Three DGs

- Case III: RDS with Position of Single D-STATCOM
- Case IV: RDS with Position of Three D-STATCOMs
- Case V: RDS with Combined Position of DG and D-STATCOM

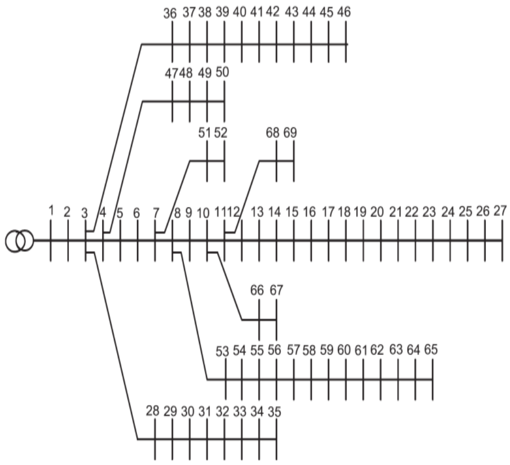

Fig. 7. Single line diagram of IEEE 69-bus distribution system

B.1. Case I: RDS with Position of Single DG

In this case, the CSA is applied to obtain the appropriate allocation of DG. The appropriate size and location are 1.76 MW and 60th respectively; and power loss is 63.13kW. The total operating cost, annual energy saving, and annual energy saving cost are 9602.5 $, 1081888.032 kWh and 54994.6 $. The results for the appropriate allocation of DGs are exhibited in Table 4. Fig. 8 shows the power loss versus iterations with placing of 1 DG in RDS.

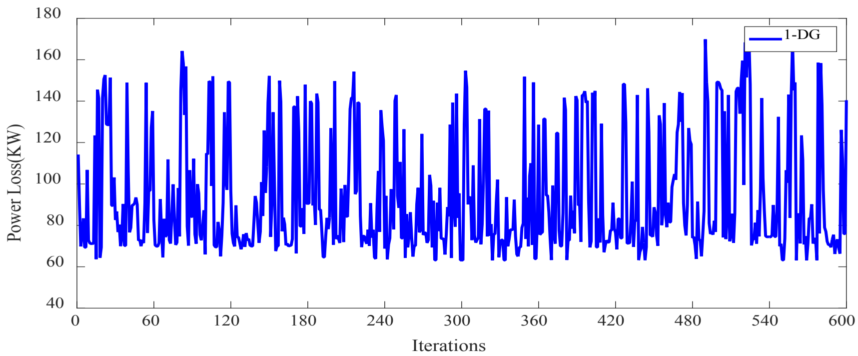

Fig. 8. Power loss versus iterations for one DG for 69 buses

B.2. Case II: RDS with Position of Three DGs

Similarly, when three DGs are placed simultaneously in RDS with capacities of 0.51 MW, 0.55 MW and 1.76 MW at location 49th , 66th and 60th respectively, the power loss, total operating cost, annual energy saving, and annual energy saving cost are 58.6227 kW, 14884$, 1121395.632 KWh and 51742 $. The results for the appropriate allocation of DGs are exhibited in Table 4. Fig. 9 shows the power loss versus iterations with placing of three DGs in RDS.

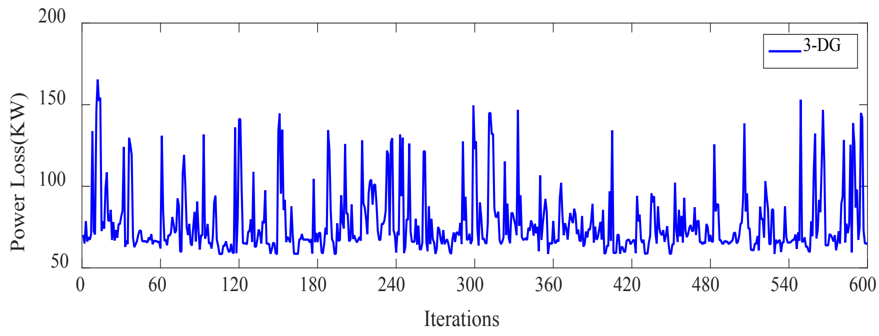

Fig. 9. Power loss versus iterations for of three-DGs for 69 buses

TABLE 4
PERFORMANCE OF 69-BUS TEST SYSTEM FOR THE DIFFERENT CONDITIONS OF DGS

	Comparison of the Proposed Technique with the Existing Technique			
		CSA (Proposed)	[9]	[19]
1-DG	Power Loss, kW	63.13	83.21	
	DG Size, MW (Location)	1.76 (60)	1.8727 (61)	
	TOC, $	9602.5	9696.3	
	Loss Reduction, %	195.63	NA	
	Annual Energy Saving, kWh	1081888.032	NA	
	Annual Cost of Energy Saving, $	54994.6	NA	
3-DG	Power Loss, kW	58.6227		70.7091
	DG Size, MW (Location)	1.76 (60) 0.55 (66) 0.51 (49)		0.6311 (11) 0.4263 (20) 1.8516 (61)
	TOC, $	14884		NA
	Loss Reduction, %	218.38		NA
	Annual Energy Saving, kWh	1121395.632		NA
	Annual Cost of Energy Saving, $	51742		NA

B.3. Case III: RDS with Position of Single D-STATCOM

In this case, the CSA is applied to obtain the appropriate allocation of D-STATCOM. The appropriate size and location are 1.32 MVAr and 60th respectively; and power loss is 123.21 kW. The total operating cost, annual energy saving, and annual energy saving cost are 7092.8 $, 555587.232 KWh and26334 $. The results for the appropriate allocation of D-STATCOMs are exhibited in Table 5. Fig. 10 shows the power loss versus iterations with placing of 1 D-STATCOM in RDS.

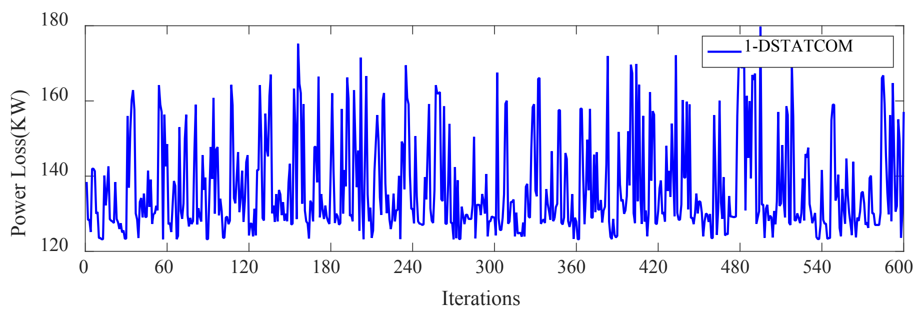

Fig. 10. Power loss versus iterations for one D-STATCOM for 69 buses

B.4: Case IV: RDS with Position of Three D-STATCOMs

Similarly, when three D-STATCOMs are placed simultaneously in RDS with capacities of 0.51 MVAr, 0..38 MVAr and 1.32 MVAr at location 11th , 49th and 60th respectively, the power loss, total operating cost, annual energy saving, and annual energy saving cost are 120.76kW**,** 11533 $, 577049.232 KWh and 22901 $. The results for the appropriate allocation of DGs are exhibited in Table 5. Fig. 11 shows the power loss versus iterations with the position of three D-STATCOMs in RDS.

TABLE 5
PERFORMANCE OF 69-BUS TEST SYSTEM WITH D-STATCOM

Comparison of the Proposed Technique with the Existing Technique				
		CSA (Proposed)	[16]	[8]
One D-STATCOM	Power loss, kW	123.21	157.5	
	D-STATCOM size, MVAr (Location)	1.32 (60)	1.70 (61)	
	TOC, $	7092.8	NA	
	Loss Reduction, %	51.48	30	
	Annual Energy Saving, kWh	555587.23	NA	
	Annual Cost of Energy Saving, $	26334	26,438	
Three D-STATCOM	Power loss, kW	120.76		145.16
	D-STATCOM size, MVAr (Location)	0.51 (11) 0.38 (49) 1.32 (60)		0.374 (11) 0.240 (18) 1.217 (61)
	TOC, $	11533		NA
	Loss Reduction, %	54.55		35.48
	Annual Energy Saving, kWh	577049.232		NA
	Annual Cost of Energy Saving, $	22901		NA

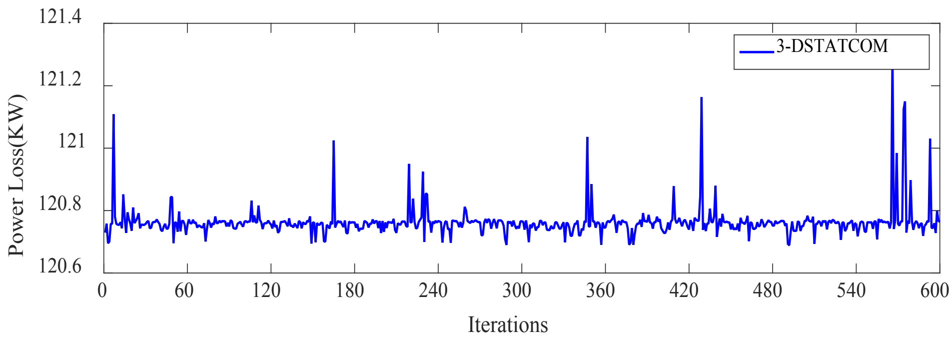

Fig. 11. Power loss versus iterations for three D-STATCOMs for 69 buses

B.5. Case V: RDS with the Combined Position of DG and D-STATCOM

In this case, one DG and one D-STATCOM are placed simultaneously in 69 bus RDS. The appropriate allocation is obtained through the CS algorithm. The appropriate size and location of both devices are 1.87 MW, 1.32MVAr and 60th, 60th, respectively; and power loss is 8.38 kW. The total operating cost, annual energy saving, and annual energy saving cost is 15984$, 1560797.232kWh and76769.5 $. The results for the appropriate allocation of DG and D-STATCOM are exhibited in Table 6. Fig. 12 shows the power loss versus iterations with placing of 1 DG and 1 D-STATCOM in RDS.

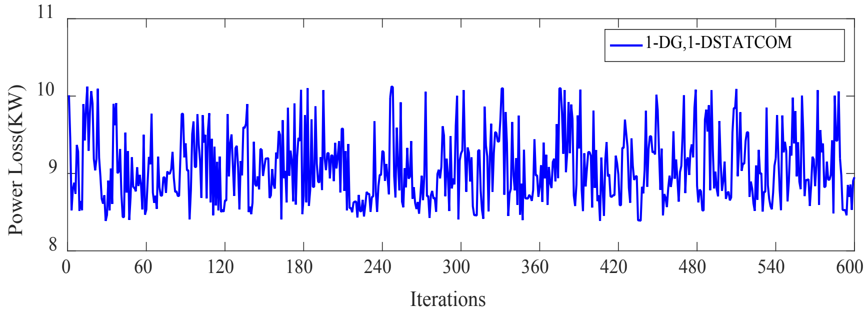

Fig. 12 Power loss versus iterations for one DG and one D-STATCOM for 69 buses

TABLE 6
PERFORMANCE OF 69-BUS TEST SYSTEM FOR SINGLE DG AND SINGLE D-STATCOM

Comparison of the Proposed Technique with the Existing Technique			
		CSA (Proposed)	[9]
1 DG with 1 D-STATCOM	Power Loss, kW	8.38	24.15
	DG size, MW (Location)	1.87 (60)	1.15 (61)
	D-STATCOM Size, MVAr (Location)	1.32 (60)	1.75 (61)
	TOC, $	15984	14596.6
	Loss Reduction, %	2106.07	NA
	Annual Energy Saving, kWh	1560797.2	NA
	Annual Cost of Energy Saving, $	76769.5	**NA**

TABLE 7
COMPARISON RESULT FOR 33 BUS SYSTEM PERFORMANCE FOR TOTAL ANNUAL ENERGY COST SAVING (TACES)

	Total Energy Loss Cost before Installation, $	Total Energy Loss Cost after Installation, $	Total Annual Cost of DG/D-STATCOM, $	Total Annual Energy Cost Saving, $
1-DG	110891	58357	13631	38902
1-D-STATCOM	110896	74441	6630	29819
1-DG+ 1-D-STATCOM	110892	26900	14289	69703
Existing Method				
1-DG [7]	110891	58430	13631	38830
1-D-STATCOM [8]	110891	79560	6630	24701
1-DG+ 1-D-STATCOM [7]	110891	37249	14289	59353

The total annual energy cost is calculated after the individual positioning of 1-DG, 1-D-STATCOM and combination of 1-DG and 1-D-STATCOM in IEEE 33 buses system of RDS. The TACES for different conditions are shown in Table 7. Similarly, for IEEE 69 buses system of RDS, TACES is calculated for the various conditions of DG and D-STATCOM as shown in Table 8. It is observed that the calculated TACES is maximized compared to an existing method in the literature.

TABLE 8
COMPARISON RESULTS FOR 69 BUS SYSTEM PERFORMANCE FOR TOTAL ANNUAL ENERGY COST SAVING (TACES)

	Total Energy Loss Cost before Installation, $	Total Energy Loss Cost after Installation, $	Total Annual Cost of DG/D-STATCOM, $	Total Annual Energy Cost Saving, $
1-DG	98094	33181	9918.4	54994.6
3-DG	98094	30812	15175	52107
1-D-STATCOM	98094	64759	7001	26334
3-D-STATCOM	98094	63471	11722	22901
1-DG+ 1-D-STATCOM	98094	4404.5	16920	76769.5
Existing Method				
1-DG [9]	98094	43735	9918.4	44440
3-DG [19]	98094	37164	15175	45755
1-D-STATCOM [16]	98094	82782	7001	8311
3-D-STATCOM [8]	98094	76296	11722	10,076
1-DG+ 1-D-STATCOM [9]	98094	12693	16920	68481

TABLE 9
PARAMETERS SETTING FOR OPTIMIZATION

D-STATCOM Cost US, $/kVAr	$n_{D-STATCOM}, Year$	B	K_p	K_c	T
50	30	0.1	0.06	1	8760

C) Price of D-STATCOM:

The investment price of the *D-STATCOM* per year can be calculated by using (10). Consider the following parameters to obtain the cost of the device:

$D-STATCOM_{cost}$ = Cost of Investment in the Year of Allocation=50 $/kVAr
$D-STATCOM_{cost,\ year}$ = Annual cost of D-STATCOM
$n_{D-STATCOM}$ = Longevity of D-STATCOM= 30Years
B = Asset rate of return= 0.1

After putting all values of the above parameters in (10), the annual cost of D-STATCOM is 6325 $.

V. CONCLUSION

In this research paper, cuckoo search algorithm is applied for various cases viz. the individual position of D-STATCOM and DG, combination of DG and D-STATCOM. By placing the combination of multiple DG and D-STATCOM, more reduction in power loss is achieved. It is obtained that the energy saving by applying CS algorithm for allocation of DG and D-STATCOM is more in RDS. The proposed research shows that the power loss is reduced; and the total annual cost of energy saving (TACES) is more than that in other existing techniques. Also, it is observed that the TACES is higher when placing one DG than when placing one D-STATCOM. But if both devices are placed simultaneously, TACES will be more enhanced. For IEEE 69 bus system, TACES for one DG is higher than that of three DG. Similarly one D-STATCOM is higher than three D-STATCOMs. But for the simultaneous placement of DG and-STATCOM, TACES is maximized. Therefore, it can be concluded that there is no significance of placing more than two DG/D-STATCOM in RDS. Also, it is observed that TOC for DG/D-STATCOM is minimized because the power loss is minimum compared to other existing methods in the literature. The power loss is minimized in each discussed case. So, the proposed algorithm is effective for getting a better outcome.

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