Journal of Green Engineering (JGE)

Volume-10, Issue-10, October 2020

D-STATCOM Allocation for Stabilization of Voltage in Multimachine Power System Using HBF-GWO

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Abstract

This paper represents an innovative algorithm to estimate optimum placement of Distribution Static Synchronous Compensator (D-STATCOM) in the multi-machine atmosphere. The main reason for the substantial loss of power in distribution devices is the voltage drop across the device. This shows that by increasing the voltage profile of the distributed device the entire loss of power is decreased. D-STATCOM was designed for satisfactory dynamic response and the control gains were normally tuned for trial-and-error method. The problem of tuning the D-STATCOM parameter is transformed into an optimization problem this is resolved by hybrid bacteria foraging and gray wolf optimization algorithm (HBF-GWO). Load flow analysis (LFA) is utilized for calculating the reactive power, voltage profile and active power in distributed systems. Also, IEEE 30-bus radial distribution devices are utilized to check this system. Performance of the proposed HBF-GWO algorithm with D-STATCOM is matched with a Genetic Algorithm (GA) with D-STATCOM under several operating conditions and instabilities.

Journal of Green Engineering, Vol. 10_10, 7360-7377.

Keywords: STATCOM Allocation for Stabilization, Voltage, Multimachine Power System, HBF-GWO

1 Introduction

In recent days, the complexity of the power system is increased. Increasing in population rapidly enlarge the power demand simultaneously. The need for power demand causes the incapability of a distribution system to supply or absorb reactive power. This, in turn, causes a voltage drop in the system. This leads to a loss of power in the radial distribution system. Flexible AC Transmission System (FACTS) devices are the electronics device utilized to solve many problems in distributed systems such a loss of power, increasing voltage profile etc [9]. It is the static equipment used for the transmission of AC in the circuits. Active power performs advantageous work in the device or load. Reactive power is caused by energy storage apparatuses. FACTS are the power electronics-based controller. The design of the controller connected in shunt is called Static Synchronous Compensator (STATCOM). STATCOM is a member of FACTS groups [25].

The optimal placement of the FACTS system in multi-machine is difficult and not perfect. For that many types of methods are utilized to do the process of allocation. The loss of power in the radial distribution device is reduced by the placement of D-STATCOM so that the energy can be saved. Improvement of voltage profile and decrease the loss of power is achieved to save energy in a distributed device and these systems are verified using IEEE 69-bus radial distribution devices [3]. Placement of DG and DSTATCOM is utilized to minimize the loss and enhanced the voltage profile in a device. However, only the placement of DG is not sufficient for the reactive power needs of the device. Therefore, to solve the voltage problem the optimal locations of D-STATCOM can be done through Loss Sensitivity Factor on the MATLAB platform. IEEE 33-bus is used to test the methodology [18]. To overcome the problems about the D-STATCOM design, artificial intelligence methods are developed [21, 8, 10, 22]. In the conventional method, the control process is done in the plant by the linguistic rules made by the human operator in the synthesis process [16, 13, 6]. When compared to the conventional techniques, the prior information of the controller device produces a superior response in FLC. In D-STATCOM design, different types of robust methods [14, 11, 19] are implemented. These techniques make the system complex and reduce its applicability.

The optimization techniques are done globally and locally. In the D-STATCOM design problem, the Global optimization method is applied. The Genetic Algorithm (GA) is implemented in [17, 15] but, this method needs long training time based on the size of the system. The D-STATCOM parameters are regulated using Particle Swarm Optimization (PSO) but, it is not working well in the scattering process [12, 20]. The performance of FA is tested using IEEE 16-bus system. Due to the slow convergence, local search ability the optimization algorithm is set up in local minimum solutions. The BAT optimization algorithm is used in the D-STATCOM. The feeder load is varied with 1% step size and the optimum allocations and size for D-STATCOM are calculated for each load step. Also, the optimum size of D-STATCOM per load levels is formulated by a curve-fitting algorithm. These optimization techniques are verified using IEEE 33-bus and 69-bus distributed systems [7]. Artificial Bee Colony (ABC) algorithm is implemented in the D-STATCOM. This optimization algorithm is very slow convergence process and the exploration and exploitation oppose with each other, so the two characters are balanced for reaching good optimization result. The Bacteria Foraging (BF) method can be recognized just by [1, 4, 5]. This algorithm based on the haphazard search ways which tend to interruption in attainment the global resolution. Cuckoo Search (CS) optimization procedure is developed in the optimum strategy of D-STATCOM constraints [2].

The state-of-the-art controller is the optimized controller of D-STATCOM device for voltage regulation purpose. Optimization of controller gain is achieved by the help of HBF-GWO algorithm. In this paper D-STATCOM, a shunt connected regulator is utilized for the LFA and voltage stability improvement. The main goal of the proposed approach is to raise the voltage profile and minimizing the loss of device power by placing the D-STATCOM. LFA of the device is completed by radial distribution techniques which estimate the voltage and angle at each bus. Also, device performance is evaluated by the IEEE 30-bus structure.

The organization the further paper is given below: the mathematical modelling of D-STATCOM is given in part 2. The radial distribution system is explained in part 3, the bacteria foraging optimization techniques are described in part 4. In part 5, the experimental results are presented. In part 6, gives the paper conclusions.

2 Mathematical Modelling Of D-STATCOM

Mathematical modelling of the D-STATCOM is represented below. Here we consider radial distribution system, electric power is delivered from the particular sideways. Fitting of the D-STATCOM at bus n+1 is shown in Figure 1. Here the line resistance is represented as 'r_n' and the line reactance is represented as 'x_n' between the bus n and n+1. At bus n and n+1, $p_n + jq_n$ and $p_{n+1} + jq_{n+1}$ represents confined loads. The voltage at buses n and n+1 is represented as v_n and v_{n+1} respectively. Bus voltages in the conventional radial system are always less than 1 pu. For the enhancement of voltage profile, the D-STATCOM should be placed in the appropriate bus. Figure 2 presents the phasor graph for the two-bus system represents in Figure 1.

After D-STATCOM consideration of voltage at the bus n+1 is represented as $v'_{n+1} < \theta'_{n+1}$ and voltage at bus n is represented as $v_n < \theta_n$.

Similarly, after the D-STATCOM consideration, the flow of line current is $i_n < \alpha$ and injected current by D-STATCOM is given as $i_{D-STATCOM} < (\theta'_{n+1} + \pi/2)$.

Now,

$$v'_{n+1} < \theta'_{n+1} = v_n < \theta_n - (r_n + jx_n) i_n < \alpha - (r_n + jx_n) i_{DSTATCOM} < (\theta'_{n+1} + \pi/2) \quad (1)$$

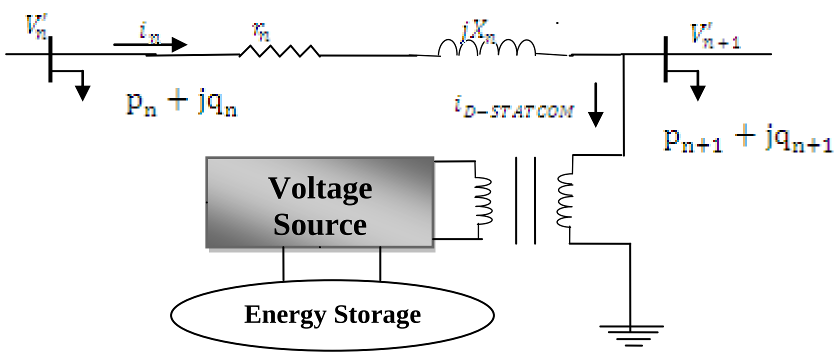

Figure: 1. Single line diagrams of 2 buses with D-STATCOM

Equating real and imaginary parts in equation 1

$$v'_{n+1} \cos\theta'_{n+1} = \mathrm{Re}(v_n < \theta_n) - \mathrm{Re}(r_n i_n < \alpha) + x_n i_{DSTATCOM} \times \sin\left(\theta'_{n+1} + \frac{\pi}{2}\right) - r_n i_{DSTATCOM} \cos(\theta'_{n+1} + \pi/2) \quad (2)$$

$$v'_{n+1} \sin\theta'_{n+1} = \mathrm{Im}(v_n < \theta_n) - \mathrm{Im}(x_n i_n < \alpha) - x_n i_{DSTATCOM} \times \cos\left(\theta'_{n+1} + \frac{\pi}{2}\right) - r_n i_{DSTATCOM} \sin(\theta'_{n+1} + \pi/2) \quad (3)$$

Considering the following representations:

P= $\mathrm{Re}(v_n < \theta_n) - \mathrm{Re}(r_n i_n < \alpha)$

Q= $\mathrm{Im}(v_n < \theta_n) - \mathrm{Im}(x_n i_n < \alpha)$

$R_1 = r_n$, $R_2 = x_n$, $S = v'_{n+1}$, V=$i_{D-STATCOM}$, X=θ'_{n+1}

At bus n+1,

The injected voltage is

$$v'_{n+1} = v'_{n+1} < \theta'_{n+1} \quad (4)$$

The injected current will be

$$i_{D-STATCOM} = i_{D-STATCOM}(\theta'_{n+1} + \pi/2) \quad (5)$$

The reactive power will be

$$jq_{D-STATCOM} = i^{*}_{D-STATCOM} v'_{n+1} \quad (6)$$

Here * denotes conjugate of a complex variable. Thus the added current, voltage and reactive power is found by equations 4, 5 and 6.

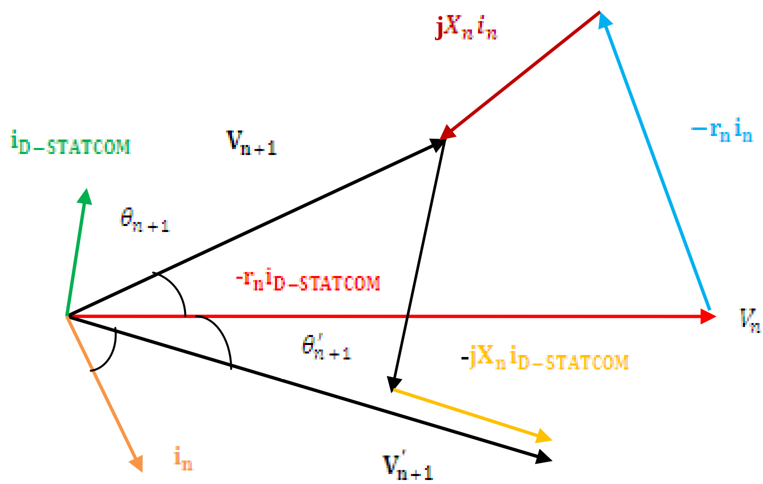

Figure: 2. Phasor diagrams of current and voltages of the system with DSTATCOM

3 Radial Distribution System

The distribution transformers are placed close to consumer location, where the voltage power is carried through the main distribution lines. The secondary distribution line is used to carry the voltage to the household items, which is also connected to distribution transformers. In a radial distribution system, distributors are feed in the single substation from that radiation take place. The basic structure of the radial system contains no loop configuration but all buses are directly linked to source through a single path. The network structure has least reliable but cheapest network.

Some factors are considered while numbering the node and line:

- In the ascending order, every node is consecutively numbered from layer to layer also from the root node to a terminal node.
- From the sending bus, every branch is began and denoted by a unique number.

4 Problem Formulations

In the distribution system, the flow of power is calculated using the basic recursive equations obtained using single-line structure represented in Figure. 3. Analysis of the flow of power is utilized to attain the voltage magnitude, loss of power in a device with 30 buses. The power flow calculation is the objective function. Figure 3 shows Single Line diagram.

$$p_{m+1} = p_m - p_{Ls,m} - p_{Lm+1} \quad (7)$$
$$q_{m+1} = q_m - q_{Ls,m} - q_{Lm+1} \quad (8)$$

Where p_m Real power of bus flow; q_m Reactive power of bus flow; p_{Lm+1} Real power of bus load m+1; q_{Lm+1} Reactive power of bus load m+1. Buses m and m+1, the Power loss will be estimated from the fixed-line section is given in equation (9) & (10).

$$p_{ls}(m, m+1) = r_m \frac{p_m^2 + q_m^2}{v_m^2} \quad (9)$$
$$q_{ls}(m, m+1) = x_m \frac{p_m^2 + q_m^2}{v_m^2} \quad (10)$$

Where, $p_{ls}(m, m+1)$ loss of Real component power in buses m and m+1; $q_{ls}(m, m+1)$ loss of Reactive component power in buses m and m+1.

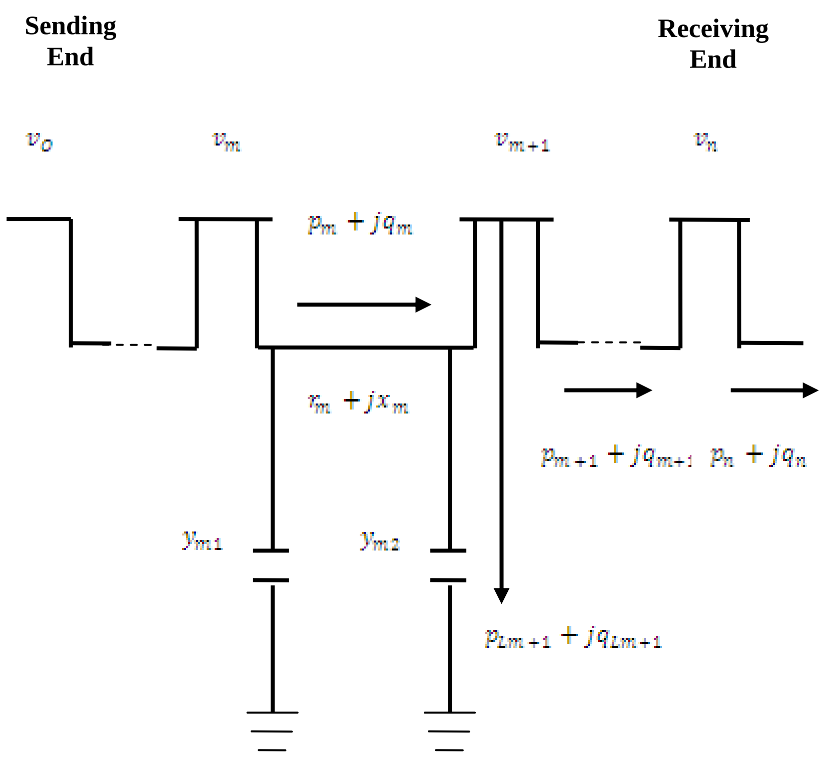

Figure: 3 Single Line diagram

5 Optimization Techniques

To find the optimum placements and size of the D-STATCOM, optimization techniques are utilized. Here hybrid bacteria foraging and gray wolf optimization algorithm (HBF-GWO) is used.

5.1 Bacteria Foraging Optimization (BFO)

To overcome the optimization problem, the bacteria foraging optimization can be used. The optimization technique is done through the running, chemotactic and tumbling activities of the bacteria are demonstrated below:

❖ The bacterium reaction will be running and tumbles alternate in the unbiased medium, which is just like a search.

❖ The bacterium swims larger distance or swims up gradients of nutrients its performance pursues gradually favourable atmosphere.

❖ The bacterium swims shorter distance or swims down gradients of nutrients its performance pursues gradually unfavourable atmosphere.

5.1.1 Algorithm of BFO

Step 1: Parameter initialization S, M_c, M_s, M_{rep}, M_{eld}, N_{eld} and the c (i), (i =1, 2,…, S).

- P: Optimization of total variables (p =2).
- S: Searching the entire area, total bacteria utilized (30).
- M_s: Iteration counts (50).
- M_c: Total chemotactic step (25).
- M_{rep}: Total reproductions step (4).
- M_{eld}: Total eliminations-dispersals procedures (2).
- N_{eld}: The possibility of the eliminations-dispersals procedure (0.5).
- c (i): In the random direction, changes of step size
- θ^i: Allocate position, least and extreme limits of the D-STATCOM.

Step 2: loop of iteration: p=p+1
Step 3: loop of Elimination-dispersal: q=q+1
Step 4: loop of Reproduction: r=r+1
Step 5: loop of Chemotaxis: s=s+1;

- Compute cost $m(i, q, r, s)$.

Let $m(i, q, r, s) = m(i, q, r, s) += m_c\left(\theta, p(q, r, s)\right)$

$$m_c(\theta, p(q,r,s)) = \sum_{i=1}^{s} m_c\left(\theta, \theta^i(q,r,s)\right) = \sum_{i=1}^{s}\left[-d_{attractant}\exp\left(-\omega_{attractant}\sum_{j=1}^{p}(\theta_j - \theta_j^i)^2\right)\right] + \sum_{i=1}^{s}\left[-h_{reppelant}\exp\left(-\omega_{reppelant}\sum_{j=1}^{p}(\theta_j - \theta_j^i)^2\right)\right] \quad (11)$$

Where $m_c(\theta, p(q,r,s))$ denotes biased functions which are combined to biased functions to represent timely biased functions, s denotes the number of bacteria, p denotes optimization of a variable in each bacteria, and $\theta = [\theta_1, \theta_2, \dots \theta_p]^T$ denotes search idea in the p-dimension area. $_{attractant}$, $h_{reppelant}$, $\omega_{attractant}$ and $_{attractant}$ are variable quantities which are chosen accurately.

- Let $m_{last} = m(i,q,r,s)$
- Tumble: This creates an arbitrary vector ∇ for every component $\nabla_j(i)$, j=1, 2, …p.
- Move: Consider

$$\theta^i(q+1,r,s) = \theta^i(q,r,s) + c(i)\frac{\nabla(i)}{\sqrt{\nabla^T(i)\nabla(i)}} \quad (12)$$

Where, $\theta^i(q,r,s)$ denotes jth chemotactic in the ith bacterium, lth elimination-dispersal stage and kth reproductive. In the random direction, changes of step size as c (i).

- Calculate $m(i,q+1,r,s)$
- Swim: Consider j=0.
- However j < M_s, Consider j=j+1,

If $m(i,q+1,r,s) < m_{last}$, Let $m_{last} = m(i,q+1,r,s)$ and move $\theta^i(q+1,r,s)$

Equation. (12) & θ^i are utilized to estimate novel $m(i, q+1, r, s)$ otherwise, consider j=M_s, stop.

Step 6: Jump to subsequent bacteria (i+1) if i≠S:

Step 7: if m < M_c, back to step 5.

Step 8: Reproductions.

Step 9: If r < M_{rep}, back to step 4.

Step 10: Dispersal & elimination.

Choose the finest bacteria that consume minimum F and back to step 5. In the bacteria dispersal, the new D-STATCOM size will be obtained at a specific location.

Step 11: If s < M_{eld}, back to step 3.

Step 12: If p < M, back to step 2, or else stop.

In the last step population of bacteria, the F value can be estimated. In addition to that found which bacteria produce at least F and the optimum sizes of D-STATCOM. Lastly, execute the LFA with acquired D-STATCOM size in the specific place and finally shows the response.

5.2 Proposed Hybrid BF-GWO Algorithm

In the proposed HBF-GWO techniques, the local search procedure is done by BFO techniques and the global search process is done by GWO algorithm which is used to perform mutation in the BFO algorithm reproduction stage. The proposed algorithm almost very fastly gives an optimal solution. The GWO algorithm is characterized by the inability to capture local optimum, but have a higher rate of convergence, while BFO has disadvantages of very low convergence speed, but it is not capable of capturing local optimum. The novel Hybrid BF-GWO techniques accomplish a local search over the bacterial foraging chemotactic movement process while the global search across the search astronomical is accomplished through gray wolf optimization.

The modification made in the novel techniques in classical BFO which is emerged as proposed Hybrid BF-GWO algorithm.

i) In the HBF-GWO algorithm, local best values (pbest) is calculated through BFO techniques.

ii) In the HBF-GWO techniques, global best values (gbest) is calculated by GWO algorithm.

iii) The Step size c(i) is estimated in the turning step of the i^{th} bacteria. This is utilized to the movement of bacteria by a fixed step size in an arbitrary way in the limits of -1, 1. Due to the fixed step size, the reach of the global solution will be delayed. Thus, in the novel BFO, the fixed step size is altered to variable step size in the range from [0, 1] by random walk process to achieve optimum firefly techniques in which the earliest convergence is represented in the equation 13.

$$c(i) = \alpha\ (rand - ½) \quad (13)$$

Where α denotes a random variable, rand denotes generation of random number fluctuates 0.01.

6 Simulation Results and Discussion

In radial distribution networks, voltage profile and power loss are estimated through the LFA technique. Here radial distribution technique can be utilized to perform the LFA. The load models used in the radial distribution networks consists of the following assumptions:

- Reactive and real powers cannot be based on the voltage changes – constant power.
- Reactive and active powers can be related to bus voltage – constant current.
- Reactive and real powers can relational to voltage bus square– constant impedance.

In this study assume that all the loads are constant. The MATLAB software has been considered for modelling the LFA using radial distribution techniques. From this method, reactive and real power and the bus voltages values of the radial distribution network can be calculated. Also, the optimum placement of D-STATCOM can be obtained through optimization algorithm called as Hybrid BF-GWO. To estimate the effectiveness and proposed techniques performance, standard IEEE 30-bus system has been considered.

6.1 Case (1): Network without Compensation

Initial LFA is done through radial distribution techniques for an uncompensated IEEE 30-bus device. Here the minimum voltage is 0.9799pu and the minimum angle is -17.9030. The loss of active power in the device without recompense is 203.145kW. The system without compensation, the power loss is 250kW. Base network voltage is 11kV and the base apparent power is 100MVA.

6.2 Case (2): Network with DSTATCOM

In this case, D-STATCOMs have been optimally located at 18^{h} and 19^{th} buses. The active power loss can be minimized from 203.145kW to 42.4550kW after placing the D-STATCOM in the 18^{th} and 19^{th} buses. At 18^{th} and 19^{th} buses, the voltage profile before the installation of D-STATCOM is 1.0040pu and 0.9990pu. After the optimum placements of D-STATCOM 18^{th} and 19^{th} bus, the voltage profile has been increased from 1.0040pu to 1.0041pu and 0.9990pu to 1.0041pu respectively.

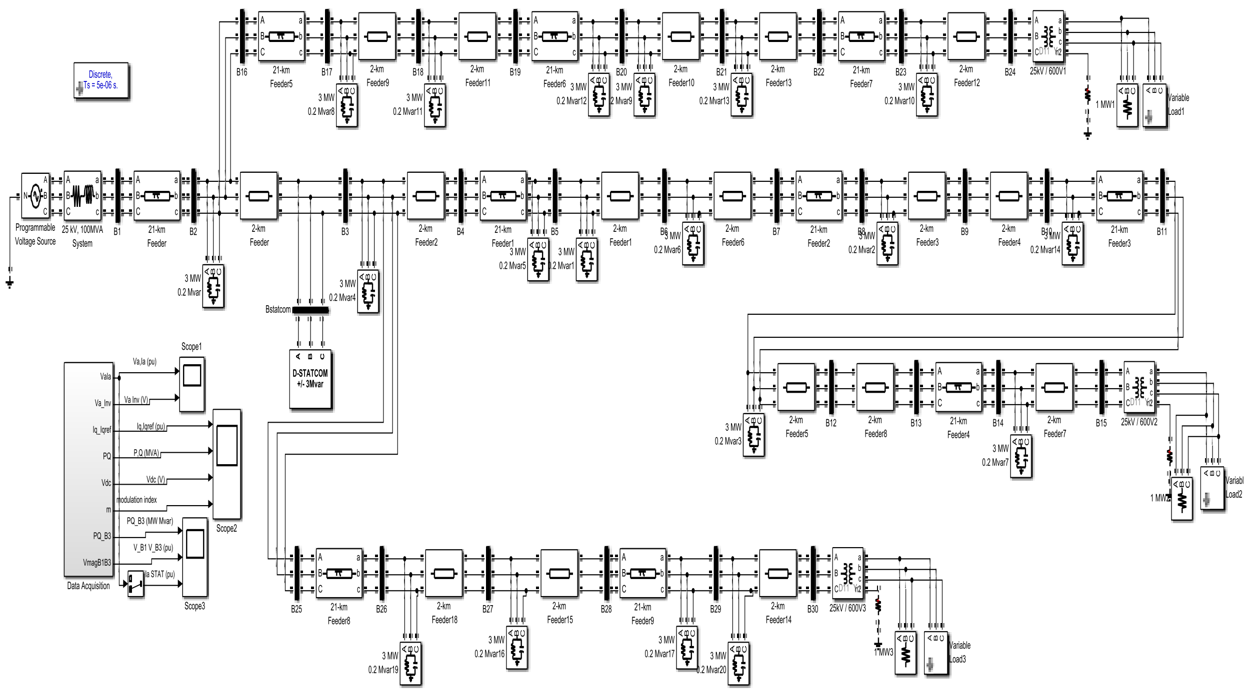

Figure: 4. D-STATCOM with IEEE 30 Buses

Figure 4 shows the Simulink diagram of the D-STATCOM with IEEE 30 Buses system.. Constant load is added at the end of each bus series. Bus 1-15 is linked in series and bus 16-24 is linked in series which is parallel to the first bus series of bus 2. The bus 25-30 is linked in series which is parallel to the first bus series of bus 3.

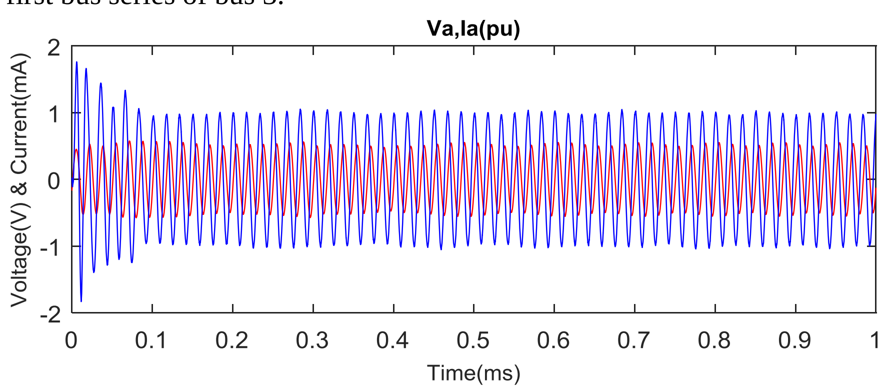

Figure: 5 D-STATCOM current and voltage (phase a)

Figure 5 shows the D-STATCOM current and voltage graphs. Here, the 3-phase device is implemented which is denoted as a, b, c. The voltage and current values of phase a are shown here. The Simulink running time is set as 1.

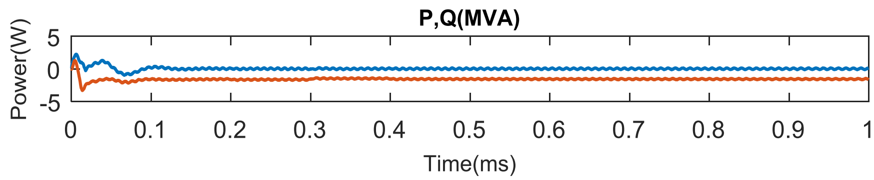

Figure: 6 Active and Reactive power

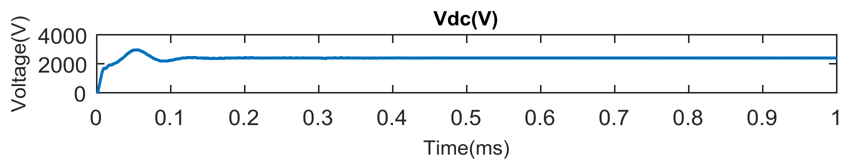

Figure: 7 DC capacitor voltage

The active and reactive power of D-STATCOM is represented in figure 6. In an electrical system, the reactive power consumes the capacity but does not complete real work. Figure 7 shows the capacitor voltage of the D-STATCOM device. DC capacitor supplies dc voltage to the VSC.

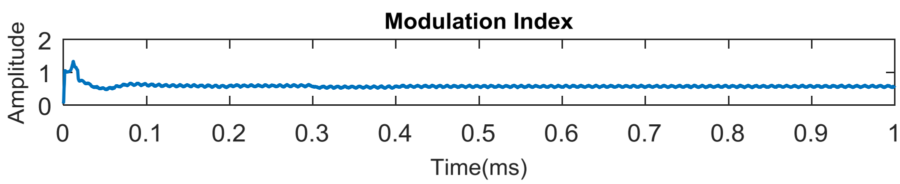

Figure: 8 Modulation Index

The modulation index of the device waveform is shown in figure 8. The width of the pulse is changed by PWM. Figure 9 shows the bus 1 and bus 2 voltage. The constant load is maintained at each bus system.

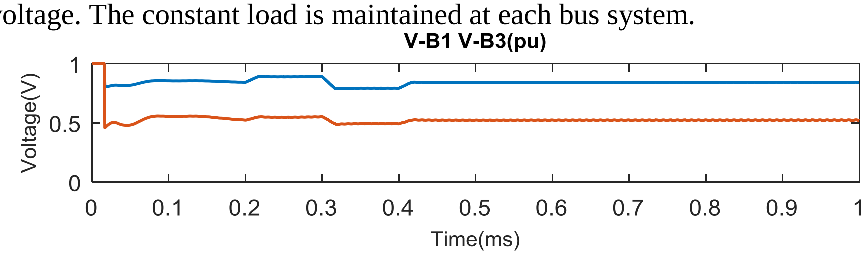

Figure: 9 Bus 1 and Bus 2 voltage

The number of searching agents used in this method is 30 and the maximum number of iteration utilized in this paper is 50. There are 23 test functions are available, among that 10^{th} function is used in this paper. Local best (pbest) process is done through the Hybrid Bacterial foraging optimization and the global best (gbest) process is through by the Gray wolf optimization.

Table: 1 Voltage profile and angle in each bus with and without D-STATCOM

Bus number	Without D-STATCOM		With D-STATCOM	
	Voltage (pu)	Angle (degree)	Voltage (pu)	Angle (degree)
1	1.0600	0.0000	1.0641	0.0000
2	1.0430	-5.3844	1.0471	-5.3853
3	1.0206	-7.5996	1.0246	-7.5994
4	1.0116	-9.3685	1.0156	-9.3683
5	1.0100	-14.2193	1.0141	-14.2213
6	1.0101	-11.1329	1.0141	-11.1346
7	1.0023	-12.9274	1.0063	-12.9293
8	1.0100	-11.8857	1.0141	-11.8884
9	1.0405	-14.2799	1.0445	-14.2857
10	1.0134	-15.5934	1.0173	-15.6000
11	1.0820	-14.5436	1.0861	-14.5501
12	1.0437	-15.0961	1.0471	-15.0927
13	1.0710	-15.3533	1.0751	-15.3564
14	1.0257	-15.9790	1.0287	-15.9689
15	1.0184	-15.9736	1.0210	-15.9459
16	1.0236	-15.5786	1.0272	-15.5799
17	1.0110	-15.8036	1.0148	-15.8088
18	1.0040	-16.5673	1.0041	-16.4647
19	0.9990	-16.7211	1.0041	-16.7639
20	1.0018	-16.4981	1.0066	-16.5314
21	1.0005	-16.1620	1.0041	-16.1616
22	1.0045	-15.9240	1.0083	-15.9288
23	1.0010	-16.1781	1.0046	-16.1753
24	0.9923	-16.2736	0.9960	-16.2754
25	0.9988	-16.1165	1.0026	-16.1201
26	0.9807	-16.5522	0.9846	-16.5560
27	1.0116	-15.7395	1.0155	-15.7438
28	1.0078	-11.7839	1.0119	-11.7858
29	0.9915	-16.9986	0.9954	-17.0034
30	0.9799	-17.9030	0.9838	-17.9082

From the table 1, the voltage profile improvement can be seen clearly. For each bus, the angle and voltage have been calculated and tabulated. Without D-STATCOM the voltage profile ranges from 0.9799pu to 1.0820pu. Thus, the minimum voltage in the base case is 0.9799pu. After the D-STATCOM locations, the voltage profile in most of the buses has enriched significantly. The normal range of voltage will be from 0.95 to 1.5pu.

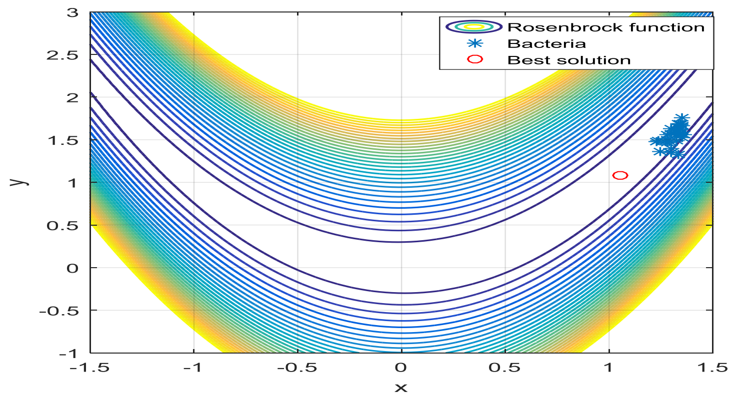

Figure: 10 Hybrid Bacterial Foraging Optimization

Figure 10 shows the hybrid BFO objective function. There are many benchmark function graphs are available but here the Rosen Brock function is used to plot the bacteria. From this method, the optimal location of the bus can be found.

Table: 2 Performance analyses with D-STATCOM

Parameters	Without D-STATCOM	With D-STATCOM
Total Power loss (kW)	250	51.37
Vmin (pu)	0.9799	0.9838
Active power loss (kW)	203.145	42.4550
Reactive power loss (kW)	2.354e+03	214.736
Optimal location	-	18, 19

The performance of the system with and without D-STATCOM placement in the distributed device is given in table 2. Without D-STATCOM placements the loss of real power has been estimated by Backward/forward sweep techniques. From that scheme, the calculated loss of real power and reactive power in radial distribution is 203.145kW and 2.354e+03 respectively. The minimum voltage without D-STATCOM placement is 0.9799pu. After the D-STATCOM placement at 18th and 19th bus, the loss of real power and reactive power is minimized from 203.145kW to 42.4550kW and from 2.354e+03 to 214.736 respectively. Also, the loss of power in the radial distribution device is minimized from 250kW to 51.37kW. Bus voltage has been improved from 0.9799pu to 0.9838pu.

Table: 3 Comparative analysis of the proposed method with the existing method

Algorithms	Real power loss (kW)	Optimal location (bus no.)	Vmin (pu)	Total power loss (kW)
Bat algorithm[7]	143.96	6	0.9244	143.97
BFO algorithm[5]	130.63	30	0.9430	111.17
LSF method[18]	113.577	30	0.9503	-
PSO method [20]	150.343	20	0.9123	153.34
Proposed method: HBF-GWO	42.4550	18, 19	0.9838	51.37

Table 3 represents the performance investigation of the IEEE 30 bus system with other approaches like BFO, bat algorithm PSO etc. To confirm the proposed LSA algorithm performance, voltage profile, total power loss and active power loss of the proposed method are equated with other techniques. The comparison table shows that the proposed algorithm has closely reached the objective conditions. The voltage stability has been reached by enhancing the voltage profile. Improvement in voltage profile proves the power loss reduction. Thus, the two main objective conditions were achieved through proposed techniques.

7 Conclusion

This paper gives an HBF-GWO technique for the optimum location of D-STATCOM and reduces the loss of power and improvements of voltage profile in radial distribution devices. Standard IEEE 30-bus system used to examine the effectiveness of the proposed techniques and LFA is done for obtaining the voltage and power loss in the radial distribution system. D-STATCOM is placed in 18^{th} and 19^{th} bus of IEEE 30-bus system. The result shows better voltage profile development and the minimization of power loss in the radial distribution system. This method is implemented in MATLAB 2016 which has coding and simulation results.

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