

the “optimum” state [12]. Recent research works on the real power loss minimization have been carried out by the use of various evolutionary techniques. The real power loss minimization has been mainly carried out to meet out the improvement of the voltage profile by GA technique [13].

This paper aims to solve optimal power flow without and with the presence of UPFC using BAT search algorithm for 5 bus test system and modified IEEE 30 bus system. Minimisation of real power losses is taken as objective function and simulation is carried out and placement of UPFC is done based on the less value of real power losses. The results are obtained for 5 bus test system and modified IEEE 30 bus system without and with the presence of UPFC. BAT Algorithm is implemented and the optimal power flow with the presence of UPFC is compared with Genetic algorithm based optimal power flow. The effectiveness of the proposed BAT algorithm based OPF with UPFC is done by varying its parameters like loudness and pulse rate. The improvement in voltage profile is achieved by placing multiple UPFCs and Convergence characteristics of BAT and Genetic algorithm are presented and analysed.

UPFC power flow model

The UPFC proposed by Gyugyi is used for real time control and dynamic compensation of the ac transmission system. The UPFC is simultaneously and selectively able to control all parameters affecting power flow in the transmission line i.e. voltage magnitude, line impedance and phase angle [14,15]. This multifunctional capability of the device justifies the term ‘unified’ in the UPFC. The UPFC consists of two voltage-source converters, one connected in shunt and the other connected in series. The series converter of the UPFC injects an AC voltage with the controllable magnitude and phase angle in series with the transmission line via a series connected coupling transformer. The shunt converter supplies or absorbs the real power needed by the series converter at the common DC link. It can also generate or absorb controllable reactive power and provide independent shunt reactive compensation for the line. The UPFC functions as an ideal ac to ac power converter where real power can freely flow in either direction between the ac terminals of two converters. Each converter can also independently generate or absorb reactive power at its own ac output terminals [16,17]. Thus, the UPFC can fulfil the task of reactive shunt compensation, series compensation and phase shifting.

UPFC voltage sources are written in Eqs. (1) and (2)

$$V_{vR}(\cos \delta_{vR} + j \sin \delta_{vR}) \quad (1)$$

$$V_{cR}(\cos \delta_{cR} + j \sin \delta_{cR}) \quad (2)$$

where V_{vR} and δ_{vR} are controllable voltage magnitude and phase angle of the voltage source representing the shunt converter. Similarly, V_{cR} and δ_{cR} are the controllable voltage magnitude and phase angle of the voltage source representing the series converter. Source impedance is considered [18] to be resistance less. (i.e. $R_{vR} = 0$, $R_{cR} = 0$).

The active and reactive power equations are given in Eqs. (3)–(10).

At bus k

$$P_k = [V_k V_m B_{km} \sin(\theta_k - \theta_m)] + [V_k V_{cR} B_{km} \sin(\theta_k - \delta_{cR})] + [V_k V_{vR} B_{vR} \sin(\theta_k - \delta_{vR})] \quad (3)$$

$$Q_k = V_k^2 B_{kk} - [V_k V_m B_{km} \cos(\theta_k - \theta_m)] - [V_k V_{cR} B_{km} \cos(\theta_k - \delta_{cR})] - [V_k V_{vR} B_{vR} \cos(\theta_k - \delta_{vR})] \quad (4)$$

At bus m

$$P_m = [V_m V_k B_{mk} \sin(\theta_m - \theta_k)] + [V_m V_{cR} B_{mm} \sin(\theta_m - \delta_{cR})] \quad (5)$$

$$Q_m = -V_m^2 B_{mm} - [V_m V_k B_{mk} \cos(\theta_m - \theta_k)] - [V_m V_{cR} B_{mm} \cos(\theta_m - \delta_{cR})] \quad (6)$$

At series converter:

$$P_{cR} = [V_{cR} V_k B_{km} \sin(\delta_{cR} - \theta_k)] + [V_m V_{cR} B_{mm} \sin(\delta_{cR} - \theta_m)] \quad (7)$$

$$Q_{cR} = -V_{cR}^2 B_{mm} - [V_k V_{cR} B_{km} \cos(\theta_k - \delta_{cR})] - [V_m V_{cR} B_{mm} \cos(\theta_m - \delta_{cR})] \quad (8)$$

At shunt converter:

$$P_{vR} = V_{vR} V_k B_{vR} \sin(\delta_{vR} - \theta_k) \quad (9)$$

$$Q_{vR} = V_{vR}^2 B_{vR} - V_{vR} V_k B_{vR} \cos(\delta_{vR} - \theta_k) \quad (10)$$

Using solid state controllers, the UPFC provides functional flexibility to practically handle all power flow control and transmission line compensation problems that are not generally obtained by variable impedance type thyristor-controlled controllers. Starting values of the UPFC voltage sources are taken as $V_{cR} = 0.04$ p.u., $\delta_{cR} = 87.13^\circ$, $V_{vR} = 1$ p.u. and $\delta_{vR} = 0^\circ$. Source reactance's are taken to be $X_{cR} = X_{vR} = 0.1$ p.u.

BAT algorithm and its parameters

A nature inspired metaheuristic method based on the echo location behavior of bats is used. This is called BAT algorithm which is developed by Yang [19]. Bats are fascinating animals. They are the only mammals with wings and they also have advanced capability of echolocation. Most of bats use echolocation to a certain degree; the capability of echolocation of micro bats is fascinating as these bats can find their prey and discriminate different types of insects even in complete darkness. Micro bats use a type of sonar, called echo location to avoid obstacles, to detect prey, and locate their roosting crevices in the dark. BAT algorithm is developed by idealizing some of the characteristics of micro bats. The approximated or idealized rules are [19]:

- All bats use echolocation to sense distance and they also know the difference between food, prey and barriers in some magical way.
- Bats fly randomly with velocity v_i at position x_i with a fixed frequency f_{min} , varying wavelength λ and loudness A_0 to search for prey. They can automatically adjust the wavelength (or frequency) of their emitted pulses and the rate of pulse emission $r \in [0, 1]$ depending on the proximity of the target.
- Loudness varies from a large positive A_0 to a minimum constant value A_{min} .

Population

The initial population i.e., number of virtual bats for BAT algorithm is generated randomly. The number of bats can be anywhere between 10 and 40. After finding the initial fitness of the population for given objective function, the values are updated based on movement, loudness and pulse rate.

Movement of virtual bats

The rules for updating the positions x_i and velocities v_i of the virtual bats are given as (12)

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (11)$$

$$v_i^t = v_i^{t-1} + (x_i^t - x_i^*)f_i \quad (12)$$

Table 1
Input parameters of BAT algorithm.

S.no	Parameters	Quantity
1	Population size	20
2	Number of generations	50
3	Loudness	0.5
4	Pulse rate	0.5

Table 2
Input parameters of Genetic algorithm.

S.no	Parameters	Quantity
1	Population size	20
2	Number of generations	50
3	Stall generation limit	100
4	Stall time limit	300

$$x_i^t = x_i^{t-1} + v_i^t \tag{13}$$

where $\beta \in [0, 1]$ is a random vector drawn from a uniform distribution. Here x_* is the current global best location (solution) which is located after comparing all the solutions among all the n bats. A new solution for each bat is generated locally using random walk given by Eq. (14)

$$x_{new} = x_{old} + \varepsilon A^t \tag{14}$$

where $\varepsilon \in [-1, 1]$ is a random number, while $A^t = \langle A_i^t \rangle$ is the average loudness of all the bats at this time step. Based on these approximations and idealization, the basic steps of the Bat Algorithm can be summarized as the pseudo code shown here [20].

Pseudo code of the BAT algorithm (BA).
 Objective function $f(x)$, $x = (x_1, \dots, x_d)^T$
 Initialize the bat population x_i ($i = 1, 2, \dots, n$) and v_i
 Define pulse frequency f_i at x_i
 Initialize pulse rates r_i and the loudness A_i
 while ($t < \text{Max number of iterations}$)
 Generate new solutions by adjusting frequency,
 and updating velocities and locations/solutions
 if ($\text{rand} > r_i$)
 Select a solution among the best solutions
 Generate a local solution around the selected best solution
 end if
 Generate a new solution by flying randomly
 if ($\text{rand} < A_i$ & $f(x_i) < f(x_*)$)
 Accept the new solutions
 Increase r_i and reduce A_i
 end if
 Rank the bats and find the current best x_*
 end while
 Post process results and visualization

Table 3
Comparison of OPF solution for 5 bus system using BAT-OPF without and with UPFC.

S.no	Parameter		GA-OPF without UPFC	GA-OPF with UPFC	BAT-OPF without UPFC	BAT-OPF with UPFC
1	Real power generation (MW)	PG1	94.8591	92.9324	87.8893	88.0179
		PG2	57.1972	58.1972	63.1972	62.3488
2	Total real power generation (MW)		152.0562	151.1296	151.0865	150.3667
3	Real power loss (MW)		7.0562	6.1296	6.0865	5.3667
4	Real power generation cost (\$/h)		1786.56	1781.2	1779.2	1770.8

Loudness and pulse emission

The loudness A_i and the rate of pulse emission r_i are updated accordingly as the iterations proceed. The loudness decreases and rate of pulse emission increases as the bat closes on its prey i.e., the equations for convergence can be taken as Eq. (15)

$$A_i^{t+1} = \alpha A_i^t \tag{15}$$

$$R_i^{t+1} = r_i^0 [1 - \exp(-\gamma t)] \tag{16}$$

where α and γ are constants.

For any $0 < \alpha < 1$ and $\gamma > 0$, we have

$$A_i^t \rightarrow 0, r_i^t \rightarrow r_i^0 \text{ as } t \rightarrow \infty \tag{17}$$

The initial loudness A_0 can typically be (1,2), while the initial emission rate r_i^0 can be (0,1).

The step by step implementation of BAT algorithm can be described as follows:

- i Step I. Initialize the load flow data, and BAT parameters such as the size of population (N), the maximum number of generations (N_{gen}), Loudness (L), Pulse rate (PR) and the number of variables to be optimized (D).
- ii Step II. Generate the initial population of N individuals randomly in the feasible area. Consider the optimized variables. Therefore, all the solutions are practicable solutions and the object is to find the best possible one.
- iii Step III. Evaluate the fitness for each individual in the population according to the objective function.
- iv Step IV. Generate a new resident.
- v Step V. Stop the process and print the best individual if the stopping criterion is satisfied, else go back to step IV.

Problem formulation

The losses that occur in a power system have to be minimized in order to enhance its overall performance. In this paper, the BAT algorithm attempts to minimize the real power losses. The objective function is loss function. It is minimize the total real power loss subjected to the constraints. Mathematically, the objective function can be written as:

$$F_{P_{Loss}} = \min(P_{Loss}) = \min \left(\sum_{k=1}^{ntl} \text{real}(S_{ij}^k + S_{ji}^k) \right) \tag{18}$$

where ntl = no. of transmission lines.

S_{ij} is the total complex power flow in line $i-j$ (i is the sending end and j is the receiving end).

Equality constraints:

$$\sum_{i=1}^N P_{Gi} = \sum_{i=1}^N P_{Di} + P_L \tag{19}$$

where $i = 1, 2, 3, \dots, N$ and N = no. of buses.

$$\sum_{i=1}^N Q_{Gi} = \sum_{i=1}^N Q_{Di} + Q_L \tag{20}$$

Inequality constraints:

Voltage limits for generator buses:

$$V_{Gi}^{\min} \leq V_{Gi} \leq V_{Gi}^{\max} \quad (21)$$

Real power generation limits:

$$P_{Gi}^{\min} \leq P_{Gi} \leq P_{Gi}^{\max} \quad (22)$$

Reactive power generation limits:

$$Q_{Gi}^{\min} \leq Q_{Gi} \leq Q_{Gi}^{\max} \quad (23)$$

where $i = 1, 2, \dots, N_g$, P_L is the real power loss in the system, P_{Gi} is the real power generation at bus i , P_{Di} is the power demand at bus i , N and N_g are the number of buses and number of generators in the system respectively. The limits of UPFC add to the above constraints in determining generation reallocation and optimal sizing of the UPFC device with optimization technique.

UPFC Limits

$$V_{vr}^{\min} \leq V_{vr} \leq V_{vr}^{\max} \quad (24)$$

V_{vr} is the shunt converter voltage magnitude (p.u).

$$V_{cr}^{\min} \leq V_{cr} \leq V_{cr}^{\max} \quad (25)$$

V_{cr} is the series converter voltage magnitude (p.u).

Results

In this paper, a 5-bus test system and modified IEEE 30 bus system have been considered to demonstrate the effectiveness and robustness of BAT algorithm without and with UPFC. The input parameters of BAT algorithm and Genetic algorithm for the test systems are given in Tables 1 and 2 respectively.

Case 1: For 5 bus test system:

In 5-bus test system, bus 1 is considered as slack bus, while bus 2 is taken as PV bus and other buses are PQ buses. To include a unified power flow controller an additional node 6 is added in between buses 3 and 4 in the network. It maintains the active and reactive powers leaving the UPFC towards the bus 4. The UPFC shunt converter is set to regulate bus 3 nodal voltage magnitude at 1 p.u. A MATLAB program is implemented for the test system. Five runs have been performed for the test system. The optimal solution results over these five runs have been tabulated. Initially, the optimal power flow solution i.e. active power generation, real power generation cost and power loss for 5-bus system are calculated using proposed BAT algorithm method without UPFC. Next, for the same system the optimal power flow solution is obtained using BAT algorithm with UPFC.

The active power generation, cost and power loss for 5 bus test system without and with UPFC is shown in Tables 3 and 4 represents the bus voltage of the network without UPFC and with UPFC.

Table 4

Comparison of bus voltages and its angles for 5 bus system without and with UPFC.

Bus no	GA-OPF without UPFC		GA-OPF with UPFC		BAT-OPF without UPFC		BAT-OPF with UPFC	
	Voltage magnitude (VM) (V)	Voltage magnitude (V)	Voltage magnitude (V)	Voltage angle (deg)	Voltage magnitude (V)	Voltage angle (deg)	Voltage magnitude (V)	Voltage angle (deg)
1	1.06	0	1.06	0	1.06	0	1.06	0
2	1	-0.943	1	-0.867	1	-0.837	1	-0.743
3	0.9523	-3.856	1	-4.875	0.9619	-3.329	1	-4.216
4	0.9512	-3.982	0.9712	-3.853	0.9631	-3.674	0.9853	-3.598
5	0.9589	-4.976	0.9624	-4.654	0.9629	-4.522	0.9706	-4.376
-	-	-	0.9854	-3.103	-	-	0.9896	-3.172

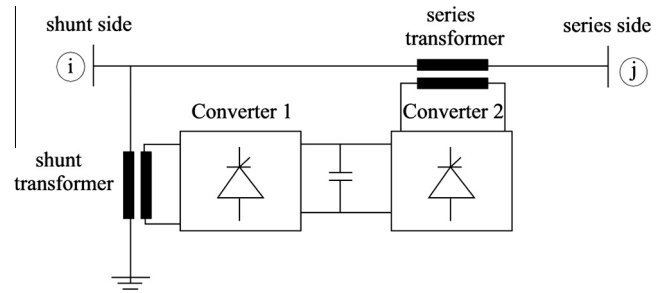


Fig. 1. Schematic arrangement of the unified power flow controller.

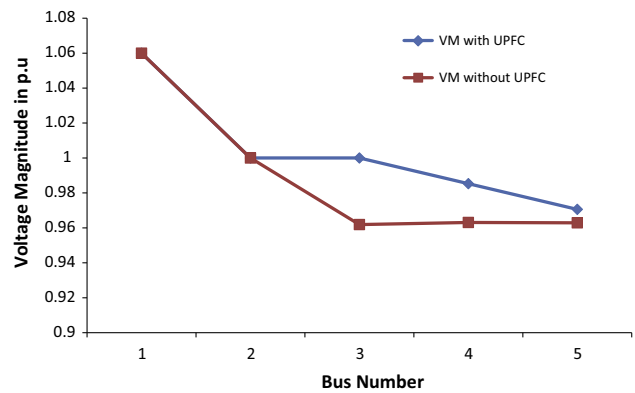


Fig. 2. Comparison of voltage profile with and without UPFC using BAT-OPF.

Table 5

Line flow with and without UPFC for the 5-bus system.

Buses	Line flows without UPFC		Line flow with UPFC	
	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1–2	0.5287	0.8685	0.5078	0.8751
1–3	0.3502	0.3093	0.3723	0.1386
2–3	0.2759	0.1146	0.3076	-0.1022
2–4	0.3033	0.1007	0.2648	-0.0103
2–5	0.5626	0.1309	0.54020	0.0741
3–4	0.1544	-0.0963	0.2122	0.0601
4–5	0.0511	-0.0275	0.0723	0.0249

From Table 3, it can be seen that total active power generation required is reduced to 150.3667 MW from 151.0865 MW and power loss has been reduced to 5.3667 MW from 6.0865 MW because of UPFC. Further, it is observed that there is a significant reduction in the real power generation cost because of UPFC (see Fig. 1).

Table 6
Incorporation of UPFC in OPF with BAT algorithm in 5 different locations.

UPFC placed between bus no	Total real power generation (MW)	Total load (MW)	Total real power loss (MW)
2–3	150.663	145	5.663
2–4	150.9119	145	5.9119
2–5	151.3845	145	6.3845
3–4	150.3667	145	5.3667
4–5	150.8784	145	5.8784

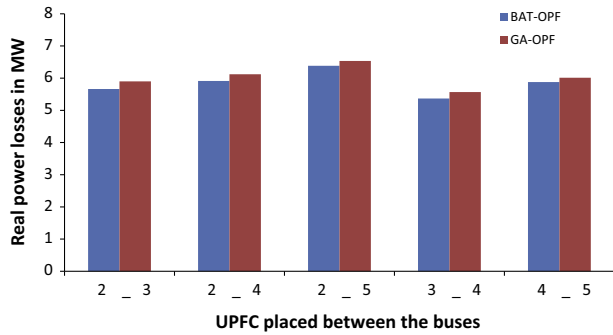


Fig. 3. Incorporation of UPFC at different locations in optimal power flow using BAT and Genetic algorithms.

From Table 4, it is observed that the voltage profile is improved for most of buses because of UPFC and the UPFC shunt converter is set to regulate bus 3 node voltage magnitude at 1 p.u. From Fig. 2 it is observed that by incorporating UPFC in this system voltage profile is improved. By placing the UPFC between bus no 3 and bus no 4, voltage at bus no 3 is increased from 0.9619 to 1 p.u. Table 5 represents the line flows calculated for with and without UPFC and line flow in the transmission line with the UPFC in between the bus 3–4 is increased from 0.1544 p.u to 0.2122 p.u. The increase is in response to the large amount of active power demanded by the UPFC series converter. From Table 6 it is observed that the active power losses are 5.3667 MW when the UPFC is placed between bus no 3 and bus no 4 which is the less as compared to

UPFC placed in other buses. From Fig. 3 it is observed that real power losses are less in BAT algorithm based optimal power flow as compared to Genetic algorithm based optimal power flow.

Case 2: For modified IEEE 30 bus system:

In modified IEEE 30 bus system bus no 1 is considered as a slack bus and bus no's 2, 5, 8, 11, 13, 30 are considered as a PV buses all other buses are considered as PQ buses. This system has 41 interconnected lines. By simulating the optimal power flow with BAT algorithm in MATLAB it is observed that voltage magnitude at bus no 26 is 0.8986 p.u which is less as compared to other buses so to improve the voltage profile at that bus it is required to place the UPFC between bus no 25 and 26. To include a unified power flow controller an additional bus 31 is placed in between bus no 25 and bus no 26 in the network. It maintains the active and reactive powers leaving the UPFC towards the bus 25. The UPFC shunt converter is set to regulate bus 26 nodal voltage magnitude at 1 p.u. A program in MATLAB is coded for the test system and five runs are performed for the test system and the optimal solution is given in below tables.

The active power generation, real power generation cost and real power loss for modified IEEE 30 bus system without and with UPFC is shown in Table 7. From Table 7, it can be seen that total active power generation required is reduced to 288.4386 MW from 289.2179 MW and power loss has been reduced to 5.0386 MW from 5.8179 MW because of UPFC. Further, it is observed that there is a significant reduction in the real power generation cost because of UPFC. Table 8 represents the total active power losses for different conditions those are NR method, NR method with UPFC, Genetic algorithm based optimal power flow without and with

Table 7
Comparison of OPF solution for 30 bus system using BAT-OPF without and with UPFC.

S.no	Parameter		GA-OPF without UPFC	GA-OPF with UPFC	BAT-OPF without UPFC	BAT-OPF with UPFC
1	Real power generation (MW)	PG1	51.0349	50.9129	50.9485	50.0000
		PG2	69.6610	80.0000	80.0000	80.0000
		PG5	50.0000	50.0000	50.0000	50.0000
		PG8	35.0000	35.0000	26.2693	35.0000
		PG11	30.0000	30.0000	30.0000	30.0000
		PG13	40.0000	28.3106	40.0000	28.9332
		PG30	14.0682	15.1088	12.0000	14.5053
2	Total real power generation (MW)		289.7641	289.3323	289.2179	288.4386
3	Total real power loss (MW)		6.3641	5.9323	5.8179	5.0386
4	Total real power generation cost (\$/h)		1118.6928	1066.1917	1055.1117	1042.5956

Table 8
Comparison of active power losses for different methods.

	Total power generation in MW	Load in MW	Total active power losses in MW
NR method	290.2286	283.4	6.8286
NR with UPFC	289.5793	283.4	6.1793
GA-OPF without UPFC	289.7641	283.4	6.3641
GA-OPF with UPFC	289.3323	283.4	5.9323
BAT-OPF without UPFC	289.2179	283.4	5.8179
BAT-OPF with UPFC	288.4386	283.4	5.0386

Table 9
Comparison of total real power loss by placement of UPFC in IEEE 30 bus system.

	UPFC location (from bus no to bus no)	UPFC parameters	Real power losses without UPFC	Real power losses with UPFC
Genetic algorithm based optimal power flow	25–26	V_{cr} 0.1428 θ_{cr} -87.1236 V_{vr} 1.0106 θ_{vr} -14.4808	6.3641	5.9323
BAT algorithm based optimal power flow	25–26	V_{cr} 0.1369 θ_{cr} -87.016 V_{vr} 1.0105 θ_{vr} -8.3458	5.8179	5.0386

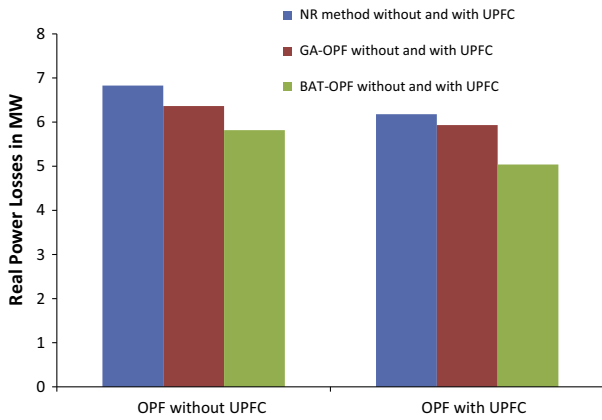


Fig. 4. Comparisons of real power losses.

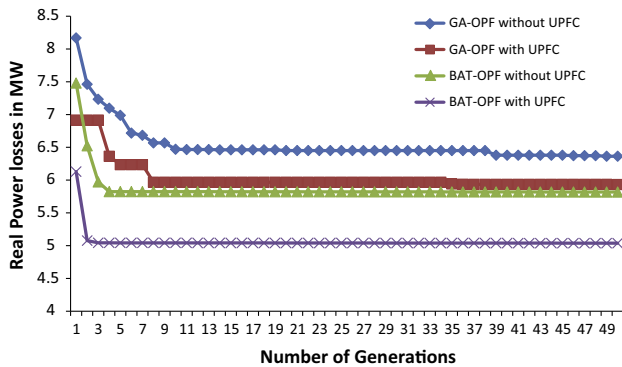


Fig. 5. Convergence characteristics of real power losses without and with UPFC device for modified IEEE-30 bus system.

UPFC and BAT algorithm based optimal power flow without and with UPFC. The real power losses obtained for the test systems using conventional NR method, GA method and proposed BAT algorithm based approach are given in Table 8. The optimal settings of the UPFC for various systems are given in Table 9.

From Fig. 4 it is observed that active power losses are reduced to 5.0386 MW from 5.8179 MW by placing the UPFC in BAT algorithm based optimal power flow. Fig. 5 shows that BAT algorithm takes less number of generations to converge as compared to Genetic algorithm. It is also observed that BAT-OPF with UPFC gives fewer losses as compared to GA-OPF with UPFC.

Table 10 represents the bus voltage of the network without UPFC and with UPFC. From Table 10, it is clear that the voltage profiles has been improved for most of buses because of UPFC and The

Table 10
Comparison of bus voltages for 30 bus system using BAT-OPF without and with UPFC.

Bus no	BAT-OPF without UPFC	BAT-OPF with one UPFC (UPFC placed between bus 25 and bus 26)	BAT OPF with two UPFC's one is placed between bus 25 and bus 26, another one is placed between bus no 21 and bus no 22
	Voltage magnitude (V)	Voltage magnitude (V)	Voltage magnitude (V)
1	1.06	1.06	1.06
2	1.045	1.045	1.045
3	1.0272	1.0284	1.0337
4	1.02	1.0209	1.0274
5	1.01	1.01	1.01
6	1.011	1.0123	1.0184
7	1.0023	1.003	1.0067
8	1.01	1.01	1.01
9	0.9924	1.0006	1.0295
10	0.9439	0.953	1.009
11	1.0686	1.082	1.082
12	1.0116	1.0144	1.0339
13	1.0692	1.071	1.071
14	0.9878	0.9918	1.0174
15	0.9751	0.9806	1.0111
16	0.9752	0.9804	1.015
17	0.9475	0.956	1.0058
18	0.9509	0.9578	0.9978
19	0.9399	0.9477	0.9932
20	0.9401	0.9482	0.9963
21	0.9106	0.9209	0.9969
22	0.9052	0.9158	1
23	0.9461	0.955	0.9983
24	0.9164	0.9299	0.9898
25	0.9424	0.9665	1
26	0.8986	1	1
27	0.9813	0.989	1.006
28	1.007	1.009	1.0151
29	0.9905	0.9895	0.9984
30	1.0107	1	1
UPFC node	-	0.9649	0.9985
UPFC node	-	-	0.9976

UPFC shunt converter is set to regulate bus 26 nodal voltage magnitude at 1 p.u. After incorporating the UPFC also still some of the bus voltages are less than 0.95 p.u. For further improvement of the bus voltages another UPFC is installed between bus no 21 and bus no 22. The second UPFC shunt converter is set to regulate bus 22 nodal voltage magnitude at 1 p.u. From Fig. 6 it is observed that by incorporating UPFC in BAT algorithm based optimal Power flow calculations voltage profile has been improved. By placing the UPFC between bus no 25 and bus no 26 its voltage at bus no 26 has been increased from 0.8986 p.u to 1 p.u. It is also observed that a flat voltage profile has been obtained by installing two UPFC's in the system. Table 11 represents the total Active power losses when

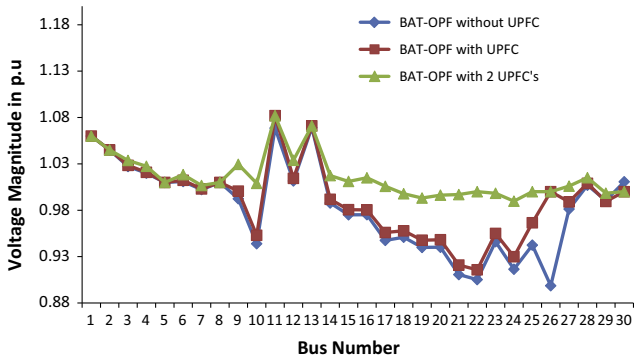


Fig. 6. Variation of voltage profile for different methods with and without UPFC.

Table 11
Total active power losses comparison with bus 26 loaded.

S No	Bus 26 loaded (load in MW)	Active power losses in MW (BAT-OPF without UPFC)	Active power losses in MW (BAT-OPF with UPFC placed between bus 25 and bus 26)	Active power losses in MW (BAT-OPF with two UPFC's one is placed between bus 25 and bus 26, another one is placed between bus no 21 and bus no 22)
1	05	6.2659	5.6633	3.6431
2	10	7.6076	6.4984	4.9062
3	20	8.3760	7.4293	5.0879
4	30	13.3011	10.7811	8.1439
5	40	21.4532	18.3594	13.8684

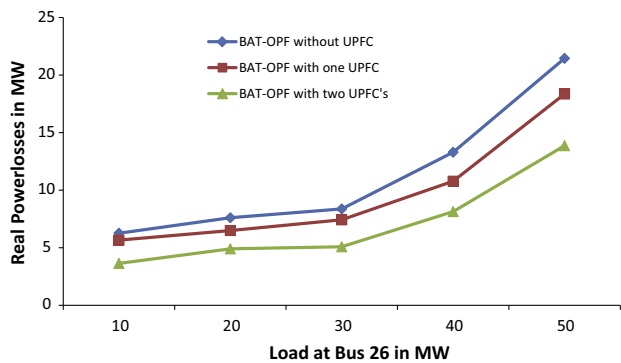


Fig. 7. Total losses comparison without and with UPFC's when bus 26 loaded.

the bus no26 is loaded. From the table it is observed that losses are increased by increasing load.

From Fig. 7 it is observed that by placing the UPFC in BAT algorithm based optimal power flow the losses are less. It is also observed that by placing two UPFC's in BAT algorithm based optimal power flow the losses are further reduced. Table 11 represents the total Active power losses when the bus no26 is loaded. From the table it is observed that losses are increased by increasing load. And it is also observed that by placing the two UPFC's the active power losses are further reduced.

Table 12 represents the objective function values with varying BAT algorithm parameters. Best, average and worst of the 20 solutions obtained by BAT algorithm are evaluated are given in table. It is observed that taking Loudness and Pulse rate at 0.5 in BAT algorithm gave better results compared to other values. Therefore, in

Table 12
Best, worst and average of objective function for IEEE 30-bus system using BAT algorithm.

Objective function value	L = 0.2 PR = 0.2	L = 0.5 PR = 0.2	L = 0.2 PR = 0.5	L = 0.5 PR = 0.5
Average	7.0451	6.3380	5.9813	5.9208
Worst	7.2483	6.5025	6.1200	6.0092
Best	6.9614	6.2413	5.9548	5.8179

L = Loudness; PR = Pulse rate.

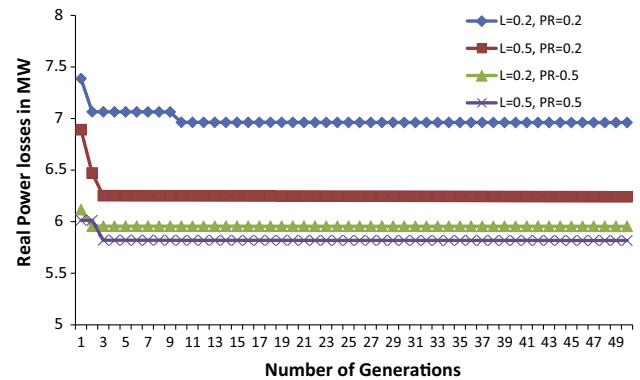


Fig. 8. BAT algorithm based convergence characteristics for modified IEEE-30 bus system.

this analysis BAT parameters are considered as 0.5. Fig. 8 shows the typical convergence characteristic of modified IEEE-30 bus system with varying BAT algorithm parameters.

Conclusion

In this paper, BAT algorithm has been proposed to solve optimal power flow problem in the presence of unified power flow controller. The results demonstrate the effectiveness and robustness of the proposed method with unified power flow controller. The results obtained for 5 bus test system and modified IEEE 30 bus system using the proposed method without and with UPFC are compared and observations reveal that the losses are less with UPFC. In 5 bus system UPFC is placed between bus 3 and bus 4 and in modified IEEE 30 bus system UPFC is placed between bus 25 and bus 26 the simulation results were taken and it was observed that the active power flow has been increased and active power losses were decreased. Optimal power flow based on BAT algorithm with UPFC the system performance has been improved. The obtained results indicate that BAT is an easy to use, robust, and powerful optimization technique compared with GA.

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