Electrical Power and Energy Systems 68 (2015) 81–88

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes



# Optimal power flow by BAT search algorithm for generation reallocation with unified power flow controller

B. Venkateswara Rao, G.V. Nagesh Kumar *

*Department of EEE, GITAM University, Visakhapatnam, Andhra Pradesh, India*

ARTICLE INFO

*Article history:*
Received 8 May 2013
Received in revised form 12 December 2014
Accepted 17 December 2014

*Keywords:*
BAT algorithm
FACTS device
Optimal power flow
UPFC

ABSTRACT

Optimal power flow with generation reallocation is a suitable method for better utilization of the existing system. In recent years, Flexible AC Transmission System (FACTS) devices, have led to the development of controllers that provide controllability and flexibility for power transmission. Out of the FACTS devices unified power flow controller (UPFC) is a versatile device, capable of controlling the power system parameters like voltage magnitude, phase angle and line impedance individually or simultaneously. The main aim of this paper is to minimize real power losses in a power system using BAT search algorithm without and with the presence of UPFC. Minimization of real power losses is done by considering the power generated by generator buses, voltage magnitudes at generator buses and reactive power injection from reactive power compensators. The proposed BAT algorithm based Optimal Power Flow (OPF) has been tested on a 5 bus test system and modified IEEE 30 bus system without and with UPFC. The results of the system with and without UPFC are compared in terms of active power losses in the transmission line using BAT algorithm. The obtained results are also compared with Genetic algorithm (GA).



## Introduction

Power systems are becoming increasingly more complex due to the interconnection of regional system, deregulation of the overall electricity market and increased in power demand. So power engineers are looking for ways to better utilize their existing transmission systems. Optimal power flow with generation reallocation is a suitable method for better utilization of the existing system. Optimization is a process of getting the best output under given conditions. However optimized the power system is on account of power generation reallocation is not sufficient and further refinement in the system is also needed. It is usual practice in power systems to install shunt capacitors to support the system voltages at satisfactory levels. Series capacitors are used to reduce transmission line reactance and thereby increase power transfer capability of lines. Phase shifting transformers are applied to control power flows in transmission lines by introducing an additional phase shift between the sending and receiving end voltages. In recent years, advances in the power electronic devices, have led to the development of controllers that provide controllability and flexibility for power transmission. Flexible AC Transmission System (FACTS) controllers have been developed and their usage in controlling power transmission is seen to be increasing nowadays [1]. The variables and parameter of the transmission line, which include line reactance, voltage magnitude and phase angle are able to be controlled using FACTS controllers in a fast and effective way [2,3]. Hsmmns and Lim [4] presented a review literature, which addresses the application of FACTS, concepts for the improvement of power system utilization and performance. Recent developments involving deregulation and restructuring of the power industry is feasible only if the operation of AC transmission systems is made flexible by introducing FACTS devices. Among FACTS controllers, UPFC is a versatile device that plays the vital function of controlling all power system parameters simultaneously. The primary function of the UPFC device is to control the load flow of the power system.

The Optimal Power Flow (OPF) is a power flow problem in which certain variables are adjusted to minimize an objective function such as cost of the active power generation or the losses. Over the last three decades, many successful OPF techniques have been developed such as, the generalized reduced gradient method [5], linear programming solution, quadratic programming, the Newton method [6,7], the Interior Point Method (IPM), Genetic algorithm (GA) [8,9], Evolutionary Programming [10], and Differential Evolutionary [11] algorithm. After obtaining the OPF solution, the implementation of the optimal control variables will bring the system to

* Corresponding author at: Department of EEE, GITAM University, Visakhapatnam 530 045, Andhra Pradesh, India.
*E-mail address:* gundavarapu_kumar@yahoo.com (G.V. Nagesh Kumar).

http://dx.doi.org/10.1016/j.ijepes.2014.12.057
0142-0615/

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)

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

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

where $V_{vR}$ and $\delta_{vR}$ are controllable voltage magnitude and phase angle of the voltage source representing the shunt converter. Similarly, $V_{cR}$ and $\delta_{cR}$ 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 $k$

$$P_k = [V_kV_mB_{km}\sin(\theta_k - \theta_m)] + [V_kV_{cR}B_{km}\sin(\theta_k - \delta_{cR})] + [V_kV_{vR}B_{vR}\sin(\theta_k - \delta_{vR})] \tag{3}$$

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

At bus $m$

$$P_m = [V_mV_kB_{mk}\sin(\theta_m - \theta_k)] + [V_mV_{cR}B_{mm}\sin(\theta_m - \delta_{cR})] \tag{5}$$

$$Q_m = -V_m^2B_{mm} - [V_mV_kB_{mk}\cos(\theta_m - \theta_k)] - [V_mV_{cR}B_{mm}\cos(\theta_m - \delta_{cR})] \tag{6}$$

At series converter:

$$P_{cR} = [V_{cR}V_kB_{km}\sin(\delta_{cR} - \theta_k)] + [V_mV_{cR}B_{mm}\sin(\delta_{cR} - \theta_m)] \tag{7}$$

$$Q_{cR} = -V_{cR}^2B_{mm} - [V_kV_{cR}B_{km}\cos(\theta_k - \delta_{cR})] - [V_mV_{cR}B_{mm}\cos(\theta_m - \delta_{cR})] \tag{8}$$

At shunt converter:

$$P_{vR} = V_{vR}V_kB_{vr}\sin(\delta_{nR} - \theta_k) \tag{9}$$

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

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, $\delta_{cr} = 87.13°$, $V_{vr} = 1$ p.u. and $\delta_{vr} = 0°$. 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]:

(a) All bats use echolocation to sense distance and they also know the difference between food, prey and barriers in some magical way.
(b) Bats fly randomly with velocity $v_i$ at position $x_i$ with a fixed frequency $f_{min}$, varying wavelength $\lambda$ 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.
(c) 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)

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

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

**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 $f(x)$, $x = (x_1, \ldots, x_d)^T$
Initialize the bat population $x_i$ ($i = 1, 2, \ldots, n$) and $v_i$
Define pulse frequency $f_i$ at $x_i$
Initialize pulse rates $r_i$ and the loudness $A_i$
while ($t <$ Max number of iterations)
Generate new solutions by adjusting frequency,
and updating velocities and locations/solutions
if (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 (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

*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 $\alpha$ and $\gamma$ are constants.

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

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

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:

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

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

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

**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 |

*Inequality constraints:*
Voltage limits for generator buses:

$$V_{Gi}^{min} \leqslant V_{Gi} \leqslant V_{Gi}^{max} \tag{21}$$

Real power generation limits:

$$P_{Gi}^{min} \leqslant P_{Gi} \leqslant P_{Gi}^{max} \tag{22}$$

Reactive power generation limits:

$$Q_{Gi}^{min} \leqslant Q_{Gi} \leqslant Q_{Gi}^{max} \tag{23}$$

where $i = 1, 2, \ldots, N_g$, $P_L$ 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

$$V_{vr}^{min} \leqslant V_{vr} \leqslant V_{vr}^{max} \tag{24}$$

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

$$V_{cr}^{min} \leqslant V_{cr} \leqslant V_{cr}^{max} \tag{25}$$

$V_{cr}$ 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.

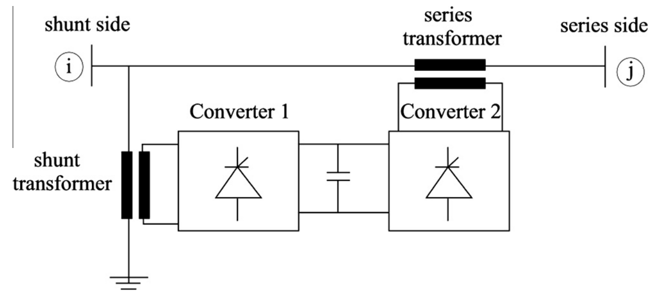


**Fig. 1.** Schematic arrangement of the unified power flow controller.

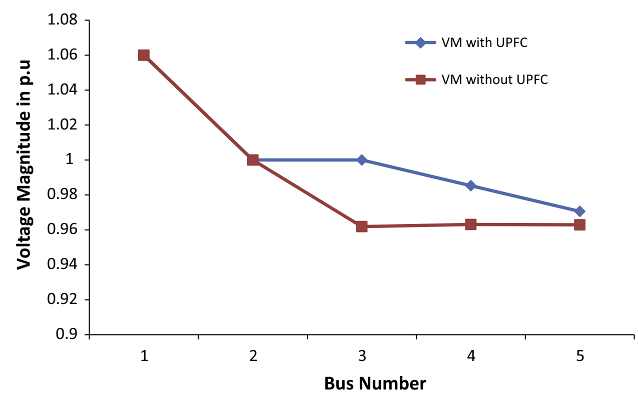


**Fig. 2.** Comparison of voltage profile with and without UPFC using BAT-OPF.

**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 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 |

**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 |

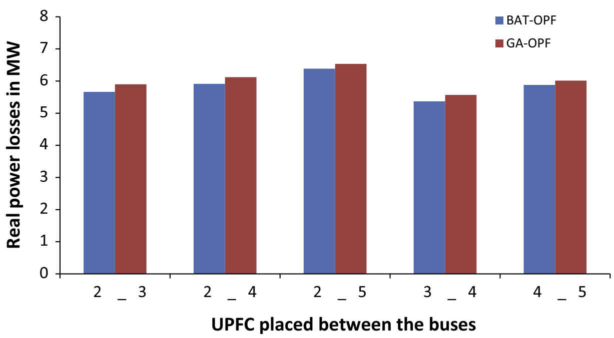


**Fig. 3.** Incorporation of UPFC at different locations in optimal power flow using BAT and Genetic algorithms.

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 | 50.000 |
| | | 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 | 6.3641 | 5.9323 |
| | | $\theta_{cr}$ | −87.1236 | | |
| | | $V_{vr}$ | 1.0106 | | |
| | | $\theta_{vr}$ | −14.4808 | | |
| BAT algorithm based optimal power flow | 25–26 | $V_{cr}$ | 0.1369 | 5.8179 | 5.0386 |
| | | $\theta_{cr}$ | −87.016 | | |
| | | $V_{vr}$ | 1.0105 | | |
| | | $\theta_{vr}$ | −8.3458 | | |

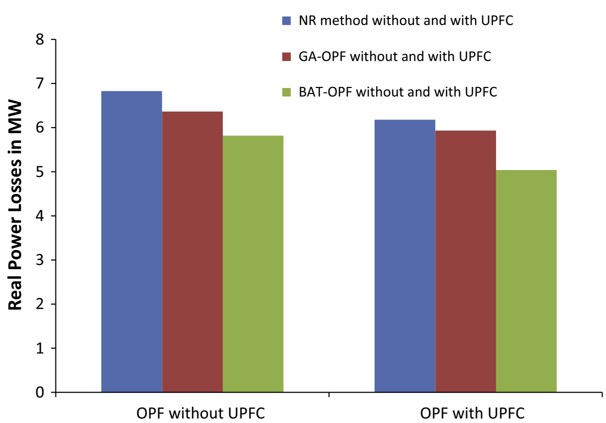


**Fig. 4.** Comparisons of real power losses.

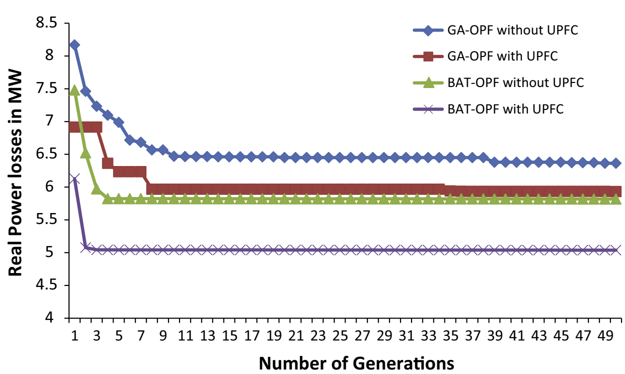


**Fig. 5.** Convergence characteristics of real power losses without and with UPFC device for modified IEEE-30 bus system.

**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 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 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

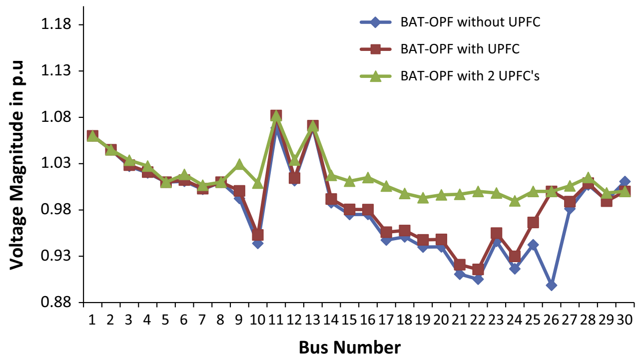


**Fig. 6.** Variation of voltage profile for different methods with and without UPFC.

**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 |

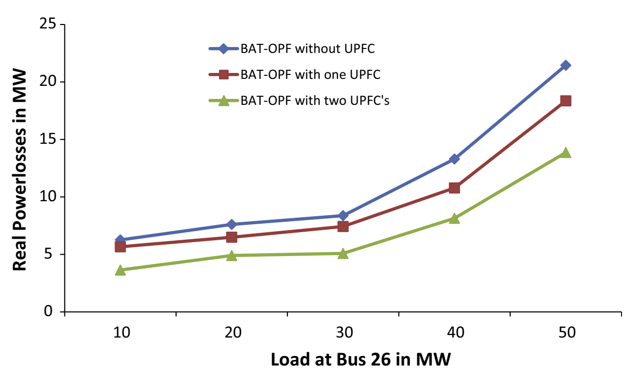


**Fig. 7.** Total losses comparison without and with UPFC's when bus 26 loaded.

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.

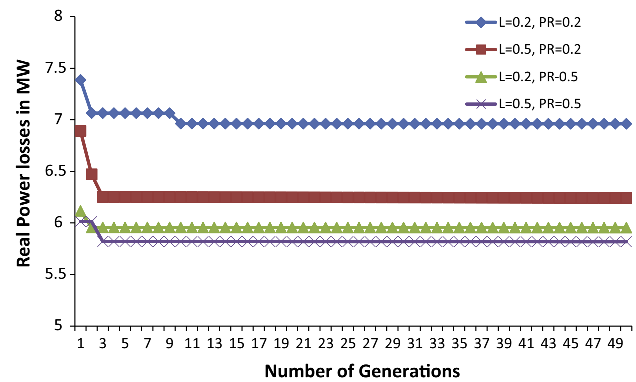


**Fig. 8.** BAT algorithm based convergence characteristics for modified IEEE-30 bus system.

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.

## References

[1] Hingorani NG. High power electronics and flexible AC transmission system. IEEE Power Eng Rev 1998.
[2] Hingorani NG, Gygyi L. Understanding FACTS: concept and technology of flexible AC transmission systems. In: Proc. IEEE Press; 2000. p. 18.
[3] Edris A. FACTS technology development: an update. IEEE Power Eng Rev 2000.
[4] Hsmmns TJ, Lim SK. Flexible AC transmission system (FACTS). Electr Mach Power Syst 1997;25:73–85.
[5] Stagg GW, El-Abid AH. Computer methods in power system analysis (Book). McGraw-Hill Book Co.; 1968.
[6] Carpentier J. Optimal power flows. Electr Power Energy Syst 1979;1:959–72.
[7] Sun DI, Ashley B, Brewer B, Hughes A, Tinney WF. Optimal power flow by newton approach. IEEE Trans Power Apparat Syst 1984;103(10):2864–80.
[8] Panda S, Padly NP. Comparison of particle swarm optimization and genetic algorithm for FACTS-based controller design. Appl Soft Comput 2007;8(4):251–9.

[9] Mahdad B, Srairi K, Bouktir T. Optimal power flow for large-scale power system with shunt FACTS using efficient parallel GA. Int J Electr Power Energy Syst 2010;32(5):507–17.

[10] Jumaat Siti Amely, Musirin Ismail, Mokhlis Hazlie. Transmission loss minimization using SVC based on particle swarm optimization. In: 2011 IEEE symposium on industrial electronics and applications (ISIEA2011), Langkawi, Malaysia; September 25–28, 2011. p. 419–24.

[11] Amrane Youcef, Boudour Mohamed, Ladjici Ahmed Amine, Elmaouhab Ali. Optimal VAR control for real power loss minimization using differential evolution algorithm. Int J Electr Power Energy Syst 2015;66:262–71.

[12] Chug TS, Qifeng D, Bomina Z. Optimal active OPF with FACTS devices by innovative load-equivalent approach. IEEE Power Eng Rev 2000;20(5):63–6.

[13] Hassan Lokman H, Moghavvemi M, Almurib Haider AF, Steinmayer Otto. Application of genetic algorithm in optimization of unified power flow controller parameters and its location in the power system network. Int J Electr Power Energy Syst 2013;46:89–97.

[14] Gyugi L. A unified power control concept for flexible AC transmission systems. IEE Proc C 1992;139(4):323–32.

[15] Gyugyi L, Schauder CD, IWilliams S, Rictman TR, Torgerson DR, Edris A. The unified power flow controller; a new approach to power transmission control. IEEE Trans Power Deliv 1995;10(2):1085–97.

[16] Padiyar KR, Kulakarni AM. Control design and simulation of unified power flow controller. IEEE Trans Power Deliv 1998;13(4):1348–54.

[17] Padiyar KR, Uma Rao K. Modeling and control of unified power flow controller for transient stability. Electr Power Energy Syst 1999;21(1):1–11.

[18] Zheng Sanbao, Tan Yoke Lin. Dynamic character study of UPFC based on detailed simulation model. In: IEEE power conference; 2000.

[19] Yang XS. Nature-inspired metaheuristic algorithms. Luniver Press; 2010.

[20] Yang XS. A new metaheuristic bat-inspired algorithm, nature inspired cooperative strategies for optimization (NISCO 2010), studies in computational intelligence, vol. 284. Berlin: Springer. p. 66–74.