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Wind integrated power system to reduce emission: An application of Bat algorithmB

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Abstract: The trend of increasing demand creates a gap between generation and load in the field of electrical power systems. This is one of the significant problems for the science, where it require to add new generating units or use of novel automation technology for the better utilization of the existing generating units. The automation technology highly recommends the use of speedy and effective algorithms in optimal parameter adjustment for the system components. So newly developed nature inspired Bat Algorithm (BA) applied to discover the control parameters. In this scenario, this paper considers the minimization of real power generation cost with emission as an objective. Further, to improve the power system performance and reduction in the emission, two of the thermal plants were replaced with wind power plants. And also to boost the voltage profile, Static VAR Compensator (SVC) has been integrated. The proposed case study, i.e., considering wind plant and SVC with BA, is applied on the IEEE30 bus system. Due to the incorporation of wind plants into the system, the emission output is reduced, and with the application of SVC voltage profile improved.

Keywords: Bat algorithm, Emission, optimal power flow, SVC, Wind power.

1. Introduction

The electricity demand of the world keeps on increasing; this rises to a very high level by 2035. As most of the power generation depends on the fossil fuels in the present-day, the increase in load demand leads to an increase in the CO_2 emission into the environment [1]. To avoid this, renewable energy generation is the only possible solution to fulfil the electrical energy demand of the country. Current trends in the electricity industry is replace the thermal-based power plants with renewable energy-based plants, increasing rapidly to avoid the energy crisis [2]. Out of all renewable energy sources, the use of wind power has made significant progress in the last few years worldwide [3], [4]. The wind power generation of the world is expected to grow at an annual rate of 6%, and reach 2,800TWh by the end of 2035 [5].

A particular arrangement or design for power system is need for introducing various thermal and wind types of power plant. Any power imbalance will adversely affect the power system parameters. It may result in shut down or damaged the system, and it will also result in economic loss [6], [7]. Therefore, in a newly installed power system, it is necessary to study the power flow. Optimal power flow (OPF) can be used to achieve a technologically, feasible and commercially efficient solution [8].

Many approaches have been implemented in the recent past to address the OPF problem [9]. Conventional approaches, e.g., Newton's method, Evolutionary methods [10], Genetic algorithm (GA) [11], boosting algorithm [12], etc., are capable of solving the OPF problem effectively. However, due to the non-linearity of the system, it is more difficult to find a solution using the classical approach and might not be feasible with larger systems [13]. In recent days, enhanced algorithms [14], [15], and hybridized algorithms [16], [17] are getting popular in solving numerous engineering problems.

To avoid the above problems, various authors apply the different global optimization techniques like GA, ParticleSwarmOptimization Algorithm (PSO), DifferentialEvolution (DE) and Evolutionary Algorithm (EA) to solve the OPF problem. Bouktir et al. [18] uses GA to answer the OPF problem to reduce the fuel cost in IEEE30 bus system using soft limits.

Naresh et al. [19] use crow search algorithm, Serhat et al. [20] applied gravitational search algorithm, Khamees et al. [21] use the EA, Mostafa et al. proposed the Grey Wolf Optimizer [22].

Kahourzade et al. [23] propose the cost-based OPF containing loss and emission for solving IEEE30 bus system with evolutionary programming (EP), GA and PSO. A fuzzy choice constructed instrument is functional to obtain the finest solution. N.Ravi et al. [24] apply the differential evolution for solving OPF with emission to reduce the pollution. Six unit IEEE30 system has taken to solve the OPF problem. Sonmez et al. [25] propose artificial bee colony algorithm to answer economic, ecofriendly communication problem. It is applied on the six-unit generator system, and acquired results are matched with ABC algorithm. Some other authors also apply the Ant colony search algorithm [26], backtracking search optimization algorithm [27], firefly algorithm [28] to solve OPF with emission.

Mahmood Taha et al. [29] incorporates the Flexible AC Transmission Systems (FACTS) devices into the OPF problem. They review the use of OPF with FACTS devices, mentioning that using SVC, voltage profile of the system has been enhanced. B V Rao et al. proposes the incorporation of SVC [30] and TCSC [31] in OPF problem using Firefly algorithm. The obtained results indicate that with the insertion of FACTS devices, system performance has been enhanced.

Rambabu et al. [32] propose the renewable energy integrated OPF using Grey Wolf Algorithm. They also integrate the FACTS device called TCSC into the OPF problem. It is observed that after incorporating renewables and TCSC, the system performance has been enhanced. Ranjit et al. [33] applied the artificial bee colony to wind integrated OPF and tested its performance on IEEE30 bus system. It is observed that integration of wind power, generation cost and emission getting reduced. Ambarish et al. [34] use the bacteria foraging algorithm to solve the OPF problem with wind integration. Wind- thermal integration improves the voltage profile of the IEEE30 bus system.

In this paper, authors propose the OPF based on Bat algorithm to express the finest values of regulated variables involved in OPF. In this OPF problem, shunt FACTS device, SVC used to advance the voltage profile, and wind plants are incorporated into the system to reduce emission and operating cost. To validate the proposed methodology, it is applied on IEEE30 bus system. It is also observed that incorporation of SVC into the system losses further reduced. Authors did this analysis because of it has not been considered previously in the literature, showing the effectiveness of Bat algorithm and apply the same for actual objective function considered in this paper.

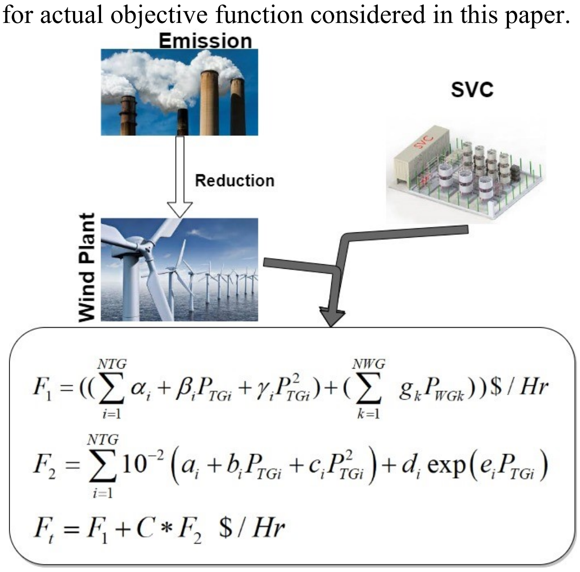

Fig. 1.Graphical representation

The main scientific novelties are summarized as:

- In this paper, a soft computing Bat algorithm is used to optimize the true power generation and SVC value.
- Emission constraint optimal power flow with wind power plants to reduce the emission has been proposed.
- Both renewable and FACTS device has been incorporated into the system to obtain better performance. It is graphically represented as shown in fig. 1.

The paper presented is organized as follow: Section2 introduces the formulation of OPF problem; Section3 describes the Bat Algorithm; The proposed technique is showed in Section 4; Section 5 displays the Static VAR Compensator; The Section6 describes the stochastic wind model; where the outcomes are investigated in Section 7; Finally, Section 8 offerings the key conclusions.

2. Mathematical Formulation of Optimal Power Flow Problem

OPF is expressed as eq. (1). The restrictions for are specified by eq. (2), (3).

$$Minimize\, F = (u, v) \tag{1}$$

Subject to:

$$G(u, v) = 0 \tag{2}$$

$$H(u, v) \le 0 \tag{3}$$

where: F is objective function; G and H are equality and inequality restrictions respectiveley, and; u, v are the dependent variables.

A. Objective function

Objective of this paper is to reduce the over-all cost and emission in the system. The over-all generation cost function (F_1) is given by eq. (4):

$$F_1 = ((\sum_{i=1}^{NTG} \alpha_i + \beta_i P_{TGi} + \gamma_i P_{TGi}^2) + (\sum_{k=1}^{NWG} g_k P_{WGk}))\$/Hr \quad (4)$$

Emission of adverse gases is designed in ton/Hr is obtained by eq. (5):

$$F_2 = \sum_{i=1}^{NTG} 10^{-2}\left(a_i + b_i P_{TGi} + c_i P_{TGi}^2\right) + d_i \exp\left(e_i P_{TGi}\right) \quad (5)$$

Emission control optimal power flow is used to condense both emission & generating cost simultaneously, calculated by eq. (6),

$$F_t = F_1 + C * F_2 \quad \$/Hr \quad (6)$$

where, F_t is the emission controlled OPF objective function in \$/hour; F_1 is in \$/hour, F_2 is in ton/hour; α, β, γ are cost coefficients of PV buses; a,b,c,d,e are the emission coefficients of PV buses; P_{TGi} is the true power of i^{th} thermal generator; NTG is the total n^o of thermal generators; Carbon tax, C, is the price consequence factor in \$/ton (C is considered as 20 \$/ton in this paper); NWG is n^o of wind generators; P_{WGk} is the true power of k^{th} wind generator, and; g_k is the k^{th} wind generator direct cost constant. Graphical illustration of proposed approach is displayed in Fig.1.

B. Constraints

1) Equality limits:

Equality limits which are characterized in eq. (7,8) hold load flow equations.

$$P_{Gi} - P_{Di} = \sum_j \left(V_i V_j Y_{ij} \cos\left(\theta_{ij} + \delta_j - \delta_i\right)\right) \quad (7)$$

$$Q_{Gi} - Q_{Di} = -\sum_j \left(V_i V_j Y_{ij} \sin\left(\theta_{ij} + \delta_j - \delta_i\right)\right) \quad (8)$$

2) Inequality limits

Inequality limits characterized by eq. (3) are given now by the generator limits according to eq. (9-11).

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \quad (9)$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \quad (10)$$

$$V_{Gi}^{\min} \le V_{Gi} \le V_{Gi}^{\max} \quad (11)$$

here $i = 1...., N_G$

3. Bat algorithm

Bat is motivated by the echolocation of bats. Yang presented this algorithm [35]. It is recycled for answering the optimization problems. Bats accomplish the echolocation to renovate their position. It is in a sequence structure of lurid ultra-sound waves are prepared to make echoes. These waves are reverted with interruptions and unlike sound, level to help the bats to notice a specific search. It has a persistent frequency typically among 25 to 150 kHz peers to the wavelengths amid 2 to 14 mm. For all bat i, its position x_i and velocity v_i must be distinct and modernized throughout the optimization process. The novel elucidations x_i^t and rates v_i^t at interval step t deliberate by subsequent equations given by eq. (12-14):

$$z_i = z_{\min} + \left(z_{\max} - z_{\min}\right)\beta \quad (12)$$

$$u_i^t = u_i^{t-1} + \left(y_i^{t-1} - y^*\right) z_i \quad (13)$$

$$y_i^t = y_i^{t-1} + u_i^t \quad (14)$$

For the local search a novel result for every bat is generated by means of an arbitrary home-produced walk according to eq. (15).

$$X_{new} = X_{old} + \varepsilon A^t \quad (15)$$

Loudness (A_i) and pulse emission rate (r_i) renovated.

For effortlessness, $A_0 = 1$ and $A_{\min} = 0$ to be recycled according to eq. (16,17).

$$D_i^{t+1} = \alpha D_i^t \quad (16)$$

$$r_i^{t+1} = r_i^0 \left[1 - \mathrm{e}\left(-\gamma t\right)\right] \quad (17)$$

Obtained D using eq. (18) for different 0<α, γ<1.

$$D_i^{t+1} \to 0, \; r_i^t \to r_i^0 \quad as \; t \to \infty \quad (18)$$

Bat algorithm pseudo code given in Fig.2.

Objective function as defined in Eq. (6)

Start

Initialize the bat population x_i and velocity v_i

While t<maximum iteration

Generate new solutions by adjusting frequency and update velocities using eq. (12-13)

update positions using eq. (14)

Fitness function is calculated using (6) for all bat positions

Loudness and pulse rate updated using eq. (17-18).

Rank the bats in each iteration and obtain the best positions

End while

Output the best solution

End

Fig.2. Bat algorithm pseudo code

4. Proposed Method

The implementation of Bat algorithm in OPF is designated as follows:

Step 1. Reset the parameters.

Step 2. Random control variables are generated in between the given limits.

Step 3. Fitness function is calculated.

Step 4. Loudness and pulse rate updated using eq. (17-18).

Step 5. Update these values and repeat the steps 3 and 4 till the iterations are satisfied.

The flowchart of BA for resolving the OPF problem is revealed in Figure 3.

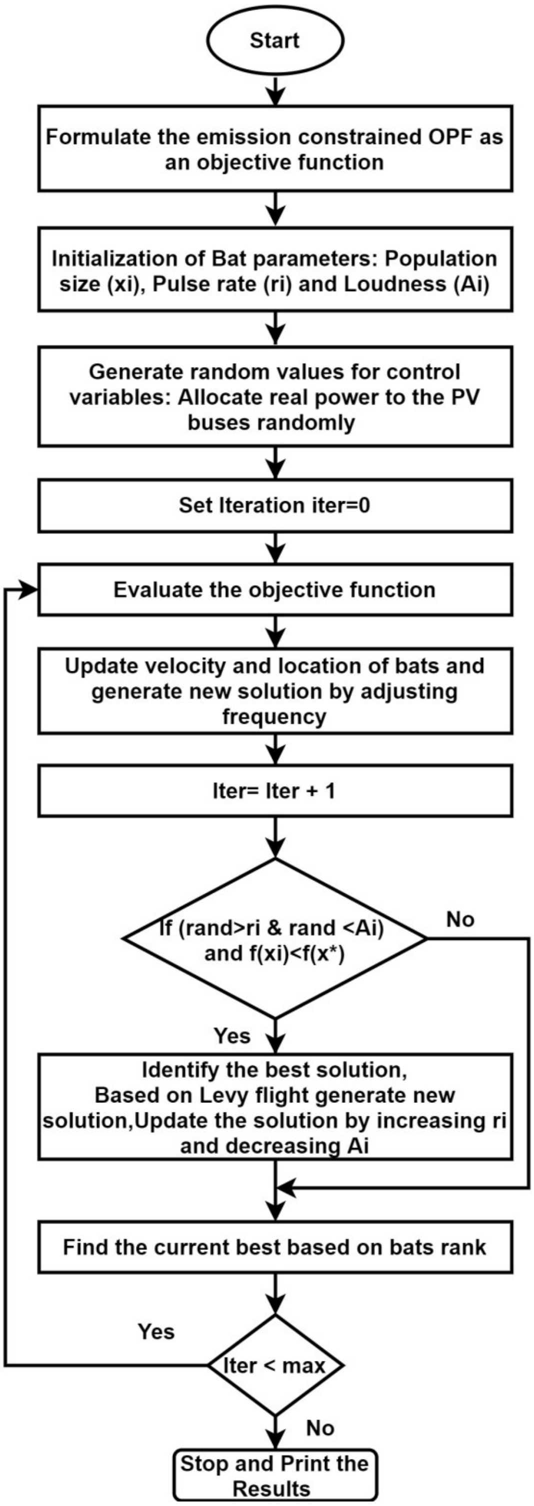

Fig. 3. Flow chart of Bat algorithm.

5. SVC Model

FACTS was announced in the late ’80s by the Electric Power Research Institute (EPRI). These devices are used to vary the angle, impedance and voltage based on injection or absorption of reactive power. [36]. These devices enhance the power system performance without modifying the physically existing transmission network.

SVC is a shunt coupled device, provide or absorber wattless power to regulate current to sustain definite considerations of the system [37]. It is demonstrated as a picture-perfect reactive power supporter at load ends. SVC value is varied between 0 and 0.2 p.u.

The current exhausted by the SVC is given by eq. (19)

$$I_{SVC} = jB_{SVC}V_k \quad (19)$$

Imaginary power drained by SVC, at bus k, is obtained by eq. (20)

$$Q_{SVC} = Q_K = -V_K^2 B_{SVC} \quad (20)$$

6. Stochastic Wind Model

This paper use the more practical approach to estimate the cost of wind generation[38]. In terms of scale factor (c) and shape factor (k), Weibull PDF is given by eq. (21) according to reference [39].

$$f_v(v) = \left(\frac{k}{C}\right)\left(\frac{v}{C}\right)^{(k-1)} e^{\left(\frac{-v}{C}\right)^k} \quad for \ 0 < v < \infty \quad (21)$$

Weibull scattering mean is calculated by eq (22).

$$M_{Wbl} = C * \Gamma\left(1 + k^{-1}\right) \quad (22)$$

Function of Gamma is given by eq. (23).

$$\Gamma(x) = \int_0^\infty e^{-t} t^{x-1} dt \quad (23)$$

In this paper, bus 11 and 13 of IEEE30 bus system are restored with wind power plants. Table1 shows the values of preferred wind speed for Weibull with different k & C parameters. Normal wind speed of 10 m/s considered for year. Wind plant placed at bus 11 consists of 10 turbines, and bus 13 consists of 13 turbines. Each turbine has rated output power of 3MW. Table1 shows the probability distribution function parameters for wind plant. Figures 4 and 5 show the wind speed probability distribution for C=9, k=2 & k=2, C=10.

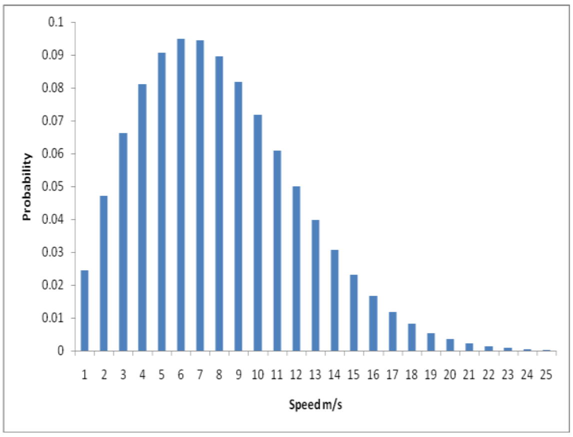

Fig. 4. Wind speed probability scattering for k=2 and C=9

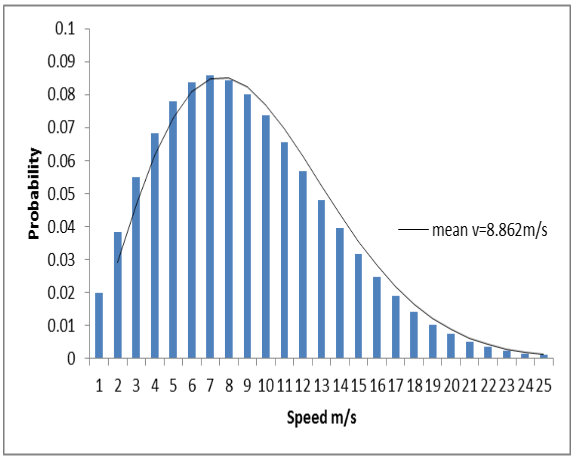

Fig. 5. Wind speed probability scattering for k=2 & C=10

Table 1
PDF parameters of wind plant

Wind plants	Number .of turbines	Assessed power, P_{Wr} (MW)	Weibull PDF parameters	Weibull mean, speed
1 (bus11)	10	30	k=2, C=9	v=7.976m/s
2 (bus13)	13	39	k=2, C=10	v=8.862m/s

7. Results

IEEE30-bus system considered for the study and it has 6 generators individually. Table2 shows the limits and cost coefficients of generators and Table 3 presents emission coefficients of generators.

Table 2
Generator Restrictions & Cost Quantities

Gen No	Restrictions of Real Power in MW		Cost Coefficients		
	Low	High	*α*	*β*	*Γ*
1	50	400	0	2	0.00375
2	20	80	0	1.75	0.0175
5	15	50	0	1	0.0625
8	10	35	0	3.25	0.00834
11	10	30	0	3	0.025
11(wg)	0	30	g1=1.6		
13	12	39	0	3	0.025
13(wg)	0	39	g2=1.75		

Table 3
Emission Coefficients of generators

Gen No	Emission Coefficients				
	a	b	c	D	e
1	0.4091e	-0.555e	0.649e	0.2e-3	0.2857e
2	0.2543e	-0.604e	0.5638e	0.5e-3	0.3333e
5	0.4258e	-0.509e	0.4586e	0.1e-5	0.8e
8	0.5326e	-0.355e	0.3380e	0.2e-2	0.2e
11	0.4258e	-0.509e	0.4586e	0.1e-5	0.8e
13	0.6131e	-0.555e	0.5151e	0.1e-4	0.6667e

For showing the effectiveness of Bat algorithm, initially, authors use only true power losses as an objective function and compare the obtained results with existing literature. The results are presented in Table4, which indicates that the obtained results with Bat algorithm superior to GA, PSO, DE and FA methods. It is also observed that incorporation of SVC into the system losses further reduced. Authors did this analysis because of other authors do not use the objective function considered in this, therefore, authors did the above analysis for showing the effectiveness of Bat algorithm and apply the same for actual objective function in eq. 06, considered in this paper.

Table 4
Comparison of true power generation and true power losses with various methods.

Method	Total true power generation (MW)	Total true power load (MW)	Total true power loss (MW)
NR method [30]	293.992	283.4	10.592
NR with SVC [30]	293.387	283.4	9.987
GA [31]	291.081	283.4	7.681
DE [31]	291.049	283.4	7.649
PSO [28]	290.125	283.4	6.725
FA [28]	290.041	283.4	6.641
BA	289.314	283.4	5.914
BA with SVC	289.265	283.4	5.865

In this paper three different case studies have been considered.

Case 1: Optimize generation cost through carbon tax lacking renewables
This case performs optimization of generation schedule by considering all generators as thermal generators to minimize the generation cost with carbon tax imposed on them. Generator real powers, overall generation cost & other intended system limits are provided in Table5.

Case 2: Optimize generation cost with carbon tax with renewables (wind energy)
This case performs optimization of generation schedule by replacing two of thermal generators at bus11 & bus13 with wind turbines, and other are thermal generators to minimize the generation cost with carbon tax imposed on them. Generator real powers, entire generation cost & other deliberate system considerations are provided in Table5.

Case 3: Optimize generation cost with carbon tax with renewables (wind energy) with SVC
This case performs optimization of generation schedule by replacing two of thermal generators at bus11 & bus13 with wind generators, and other are thermal generators to minimize the generation cost with carbon tax imposed on them with SVC. SVC is placed at bus number 30. Generator real powers, over-all generation cost and other considered system factors are provided in Table5.

Table5
Optimized results of IEEE30-bus system

Control Variables and parameters	Case1	Case2	Case3
P_{TG1}(MW)	178.4125	141.0424	134.1201
P_{TG2}(MW)	48.1013	32.8409	45.6053
P_{TG5}(MW)	20.5352	15.0000	27.9065
P_{TG8}(MW)	26.2845	35.0000	15.7394
P_{TG11}(MW) (or) P_{wg1}	10.0000	30	30
P_{TG13}(MW) (or) P_{wg2}	12.0000	39	39
Total Power Generation P_G(MW)	295.3335	292.8833	292.3713
Thermal Generation cost ($/h)	811.0368	586.0582	581.7010
Wind Generation Direct cost	---	116.2500	116.2500
Emission (t/h)	0.3711	0.2021	0.1885
Emission Cost ($/h)	7.422	4.042	3.77
Ploss (MW)	11.9336	9.4833	8.9713
VD (p.u.)	1.2054	1.1620	0.7968
B_{SVC} in p.u	---	---	0.1179
F_t in ($/h)	818.458	706.35	701.7201

Cases 1-3 results are presented in Table5. It is observed that after incorporating the wind energy plants into the system, emission cost is reduced to 4.04$/h from 7.42$/h. It is further reduced to 3.77$/h by incorporating SVC into the system. It is also observed that to reduce the emission, in cases 2 and 3, thermal generators at buses 11 and 13 are replaced with wind plants. Emission cost is also part of the objective function, so in cases 2 and 3 maximum available wind power is utilized to minimize the emission. Figure 6 shows the generators allocation values for different case studies. It is observed that after incorporating wind and SVC into the system, generation values optimized effectively using Bat algorithm to reduce the total cost.

Figure 7 indicates the voltage magnitude values for cases 1-3 with Bat algorithm and case 3 with Genetic algorithm. It is observed that compared to case1, in case 2, with wind energy, the voltage improvement is less. In case3, the voltage profile enhanced is more compared to cases 1 and 2, because of reactive power support provided by SVC. It is also observed that in case 3, voltage magnitudes are improved by using Bat algorithm compared to Genetic algorithm. Figure 8 indicates the convergence characteristics of cases 2 and 3. It is concluded that after incorporating both wind plants SVC into the system, the total cost and voltage deviation are condensed to 701.7201$/h and 0.7968 p.u respectively. IEEE30 bussystem with wind plants and SVC is shown in Figure 9.

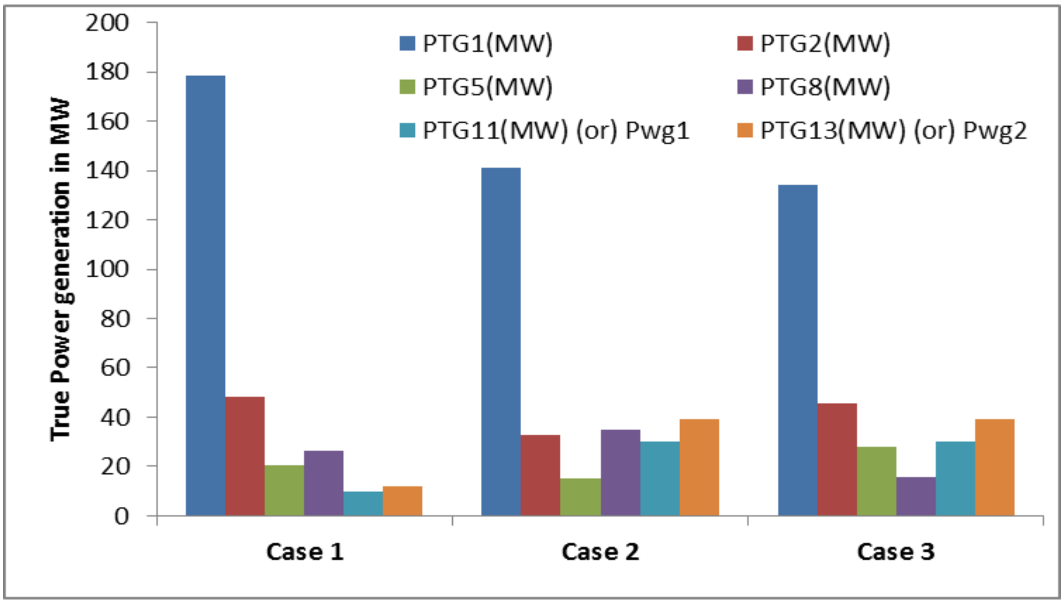

Fig. 6. True power generation for different cases.

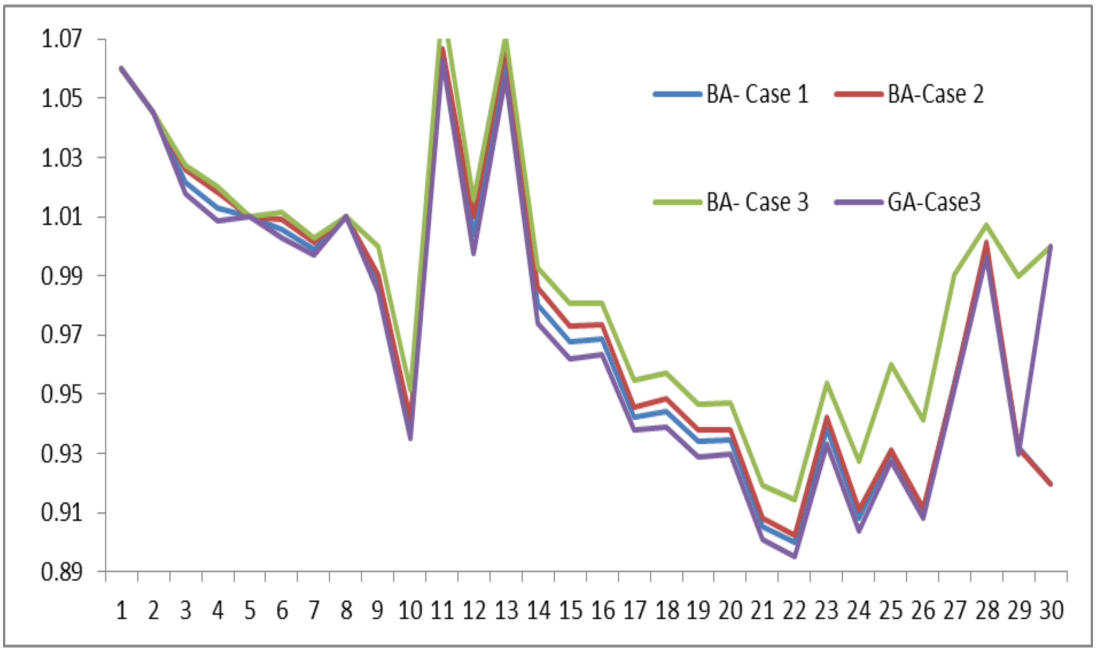

Fig. 7 Comparison of voltage magnitude for different case studies using BA and GA.

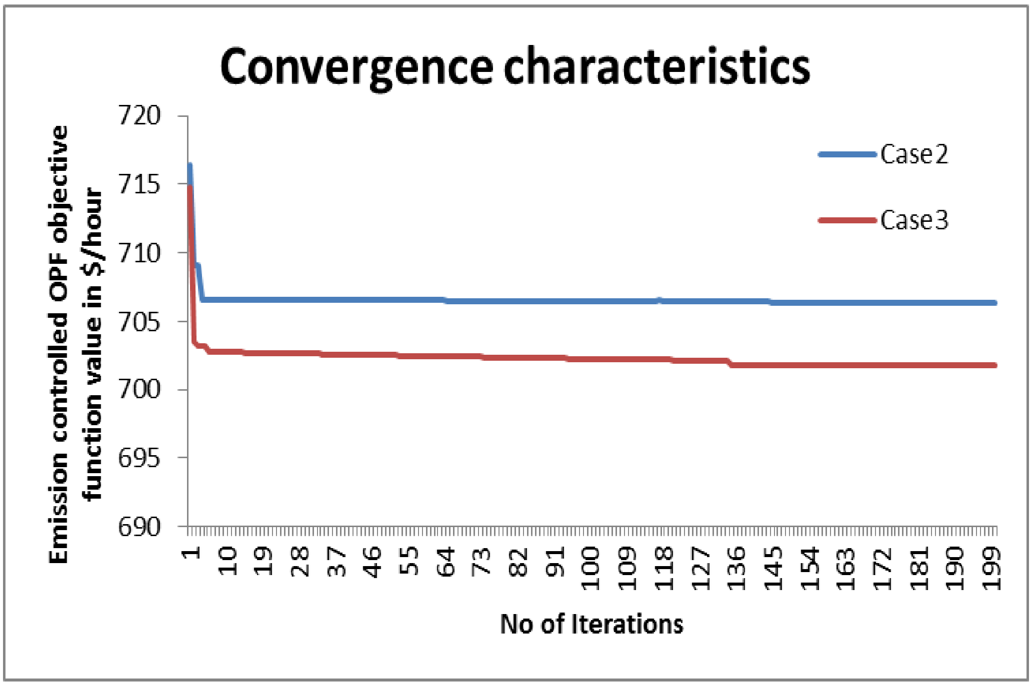

Fig. 8 Convergence characteristics of Case2 and Case3

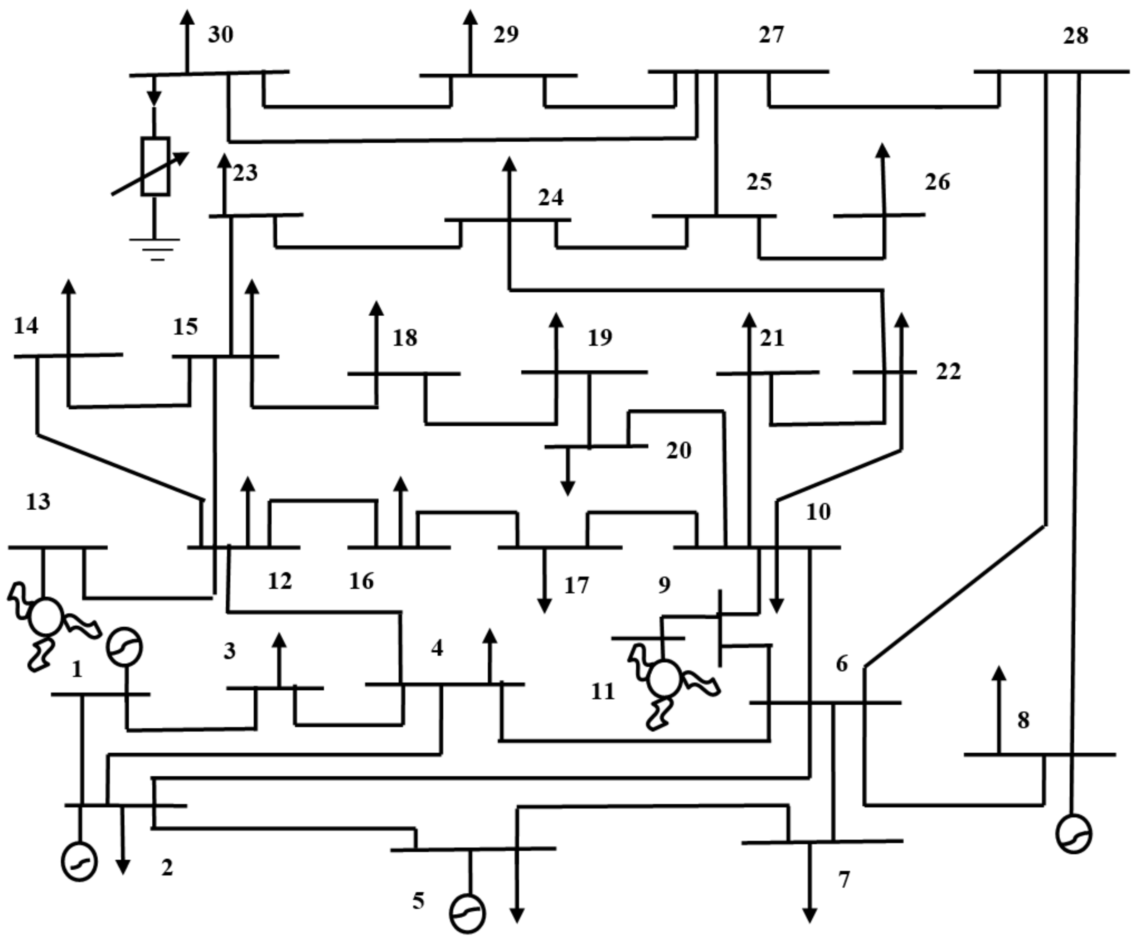

Fig. 9 IEEE30 Bus System diagram with wind power plants and SVC

8. Conclusions

In this paper, newly suggested meta heuristic, Bat algorithm was functional to resolve OPF problem. The BA approach was established to be worthy and generate superior results related to other methods by considering true power losses as an objective. This methodology was fruitfully and significantly fulfilled to catch the finest positions of the regulated variables of the IEEE30 bussystem.

To enhance the performance of the power network, wind power plant and SVC integrated to the system. Thermal generators at buses 11 and 13 are substituted with wind power plants, incorporation of wind power into the system emission getting condensed from 0.3711 t/h to 0.2021 t/h. But improvement in voltage deviation was less that is from 1.2054p.u to 1.1620 p.u. To advance the enactment of the system in terms of voltage deviation, SVC was placed at bus 30. Finally, it is witnessed that the over-all fuel cost, voltage deviation and emission are less with the combination of wind power and SVC. By incorporating SVC and wind power in Bat Algorithm established OPF, the system enactment has been upgraded.

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Nomenclature:

OPF	:	OptimalPowerFlow
SVC	:	StaticVARCompensator
BA	:	BatAlgorithm
FACTS	:	FlexibleAlternatingCurrent Transmission System
TCSC	:	ThyristorControlledSeriesCapacitor
GA	:	GeneticAlgorithm
PSO	:	ParticleSwarmOptimization
DE	:	DifferentialEvolution
EA	:	EvolutionaryAlgorithm
EPRI	:	Electric Power Research Institute

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