Hybrid BatAlgorithm for solving reactive power problem

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***Abstract*—**Real power loss reduction plays a significant role in power system operation and control. Ahybrid bat algorithm (HBA)is proposed to reduce the real power loss. Swarm Intelligence based bat algorithm has been hybridized with differential evolution strategyto solvethe problem. The main objective of the problem is to minimize the real power loss. HBA algorithm is used to find the optimal settings of generator bus voltage, transformer tap settings and reactive power of shunt compensator. The proposed HBA algorithm has been validated on standard IEEE 30 bus system. The results have been compared to other heuristics methods and the proposed algorithm converges to best solution.

***Keywords*—**swarm intelligence, bat algorithm, differential evolution, optimization, optimal reactive power, Transmission loss.

I. INTRODUCTION

Reactive power optimization plays a key role in optimal operation of power systems.

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Many numerical methods [1-7] have been applied to solve the optimal reactive power dispatch problem. The problem of voltage stability plays a strategic role in power system planning and operation [8]. So many Evolutionary algorithms have been already proposed to solve the reactive power flow problem [9-11]. In [12, 13], Hybrid differential evolution algorithm and Biogeography Based algorithm has been projected to solve the reactive power dispatch problem. In [14, 15], a fuzzy based technique and improved evolutionary programming has been applied to solve the optimal reactive power dispatch problem. In [16, 17] nonlinear interior point method and pattern based algorithm has been used to solve the reactive power problem. In [18-20], various types of probabilistic algorithms utilized to solve optimal reactive power problem.Echolocation is a key feature of bat behaviour. Bats emit a sound pulse and listens to the echo bouncing back from obstacles whilst flying. This phenomenon has been inspired Yang [21] to develop the Bat Algorithm (BA).The differential evolution [22] is a typical evolutionary algorithm was successfully applied to continuous function optimization problems. In this paper original bat algorithm has been hybridized with differential-evolution strategy to reduce the real power loss. This algorithm (HBA) is applied to obtain the optimal control variables so as to improve the voltage stability of the system. The performance of the proposed method has been tested on IEEE 30 bus system and the results are compared to other heuristics methods.

II. PROBLEM FORMULATION

The Optimal power flow problem is well thought-out as common minimization problem with constraints, and can be written in the following procedure:

Minimize $f(x, u)$ (1)

Subject to $g(x,u)=0$ (2)

and

$h(x, u) \leq 0$ (3)

Where f(x,u) is the objective function. g(x.u) and h(x,u) are respectively the set of equality and inequality constraints. x is the vector of state variables, and u is the vector of control variables.

The state variables are the load buses (PQ buses) voltages, angles, the generator reactive powers and the slack active generator power:

$x = \left(P_{g1}, \theta_2, .., \theta_N, V_{L1}, ., V_{LNL}, Q_{g1}, .., Q_{gng}\right)^T$ (4)

The control variables are the generator bus voltages, the shunt capacitors/reactors and the transformers tap-settings:

$u = \left(V_g, T, Q_c\right)^T$ (5)

or

$u = \left(V_{g1}, ..., V_{gng}, T_1, .., T_{Nt}, Q_{c1}, .., Q_{cNc}\right)^T$ (6)

Where Ng, Nt and Nc are the number of generators, number of tap transformers and the number of shunt compensators respectively.

III. Objective Function

A. Active power loss

The objective of the reactive power dispatch is to minimize the real power loss in the transmission network, which can be defined as follows:

$F = PL = \sum_{k \in Nbr} g_k \left(V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij}\right)$(7)

or

$$F = PL = \sum_{i \in Ng} P_{gi} - P_d = P_{gslack} + \sum_{i \neq slack}^{Ng} P_{gi} - P_d$$

(8)

Where gk : is the conductance of branch between nodes i and j, Nbr: is the total number of transmission lines in power systems. Pd: is the total active power demand, Pgi: is the generator active power of unit i, and Pgsalck: is the generator active power of slack bus.

B. Voltage profile improvement

For minimizing the voltage deviation in PQ buses, the objective functions turn out to be as:

$F = PL + \omega_v \times VD$ (9)

Where ωv: is a weighting factor of voltage deviation.

VD is the voltage deviation given by:

$VD = \sum_{i=1}^{Npq} |V_i - 1|$(10)

C. Equality Constraint

The equality constraint g(x,u) of the ORPD problem is represented by the power balance equation, where the total power generation must cover the total power demand and the power losses:

$P_G = P_D + P_L$ (11)

This equation is solved by running Newton Raphson load flow method, by calculating the real power of slack bus to determine active power loss.

D. Inequality Constraints

The inequality constraints h(x,u) replicate the limits on components in the power system as well as the limits produced to make sure of system security. Upper and lower bounds on the active power of slack bus and reactive power of generatorsare:

$P_{gslack}^{min} \leq P_{gslack} \leq P_{gslack}^{max}$ (12)

$Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max}$, $i \in N_g$ (13)

Upper and lower bounds on the bus voltage magnitudes:

$V_i^{min} \leq V_i \leq V_i^{max}$, $i \in N$ (14)

Upper and lower bounds on the transformers tap ratios:

$T_i^{min} \leq T_i \leq T_i^{max}$, $i \in N_T$ (15)

Upper and lower bounds on the compensators reactive powers:

$Q_c^{min} \leq Q_c \leq Q_C^{max}$, $i \in N_C$ (16)

Where N is the total number of buses, NT is the total number of Transformers; Nc is the total number of shunt reactive compensators.

IV. Bat Algorithm

Bat algorithm has been developed by Xin-She Yang in 2010 [23]. Bats use sonar echoes to identify and evade obstacles. They use time delay from emanation to replication and utilize it for navigation. They classically emit short loud, sound impulse and the rate of pulse is usually 10 to20 times per second. Bats are in-bound to frequencies about 20,500kHz. Byexecution [25,26],Pulse rate can be simply determined from range 0 to 1, where 0 means there is no emanation and by 1, bats are emitting maximum [24], By utilizing above behavior new bat algorithm can be formulated. Yang [23] used three generalized rules for bat algorithm:

a) All bats use echolocation to sense distance, and they also guess the difference between prey and background barriers in some magical way.

b) Bats fly arbitrarily with velocity ϑ_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 of their emitted pulses and adjust the rate of pulse emission r ∈ [0; 1], depending on the proximity of their target.

c) Although the loudness can vary in many ways, we assume that the loudness varies from a large (positive) A_0 to a minimum constant valueA_{min}.

Original Bat Algorithm

a: Objective function $f(x), x = (x_1, .., x_d)^T$
b: Initialize the bat population x_i and v_i for i = 1…n
c: Define pulse frequency $Q_i \in [Q_{min}, Q_{max}]$
d: Initialize pulse rates r_i and the loudness A_i
e: while (t < Tmax) // number of iterations
f: Generate new solutions by adjusting frequency, and
g: updating velocities and locations/solutions
h: if(rand (0; 1) >ri)
i: Select a solution among the best solutions
j: Generate a local solution around the best solution
k: end if
l: Generate a new solution by flying randomly
m: if(rand(0; 1) < Ai and f(xi) < f(x))
n: Accept the new solutions
o: Increase ri and reduce Ai
p: end if
q: Rank the bats and find the current best
r: end while
s: Postprocess results and visualization

The generation of new solution has been performed by moving virtual bats according the following equations:

$$Q_i^{(t)} = Q_{min} + (Q_{max} - Q_{min}) \cup (0,1), \quad (17)$$
$$v_i^{(t+1)} = v_i^t + (x_i^t - best)Q_i^{(t)}, \quad (18)$$
$$x_i^{(t+1)} = x_i^{(t)} + v_i^{(t)} \quad (19)$$

Where U (0; 1) is a uniform distribution.

Anarbitrary walk with direct exploitation is used for local exploration that modifies the existing best solution according to equation:

$$x^{(t)} = best + \epsilon A_i^{(t)}(2U(0,1) - 1), \quad (20)$$

Where ϵ is the scaling factor, and $A_i^{(t)}$ the loudness. The local exploration is launched with the proximity depending on the pulse rate ri and the new solutions accepted with some proximity depending on parameter.In natural bats, where the rate of pulse emissionri increases and the loudness Ai decreases when a bat finds a prey. The above characteristics can be written by the following equations:

$$A_i^{(t+1)} = \alpha A_i^{(t)}, r_i^{(t)} = r_i^{(0)}[1 - \exp(-\gamma\epsilon)], \quad (21)$$

Where α and γ and are constants.

V. DIFFERENTIAL EVOLUTION

Differential evolution (DE)[27] is a technique for optimization which was introduced by Storn and Price in 1995.DE supports a differential mutation, a differential crossover and a differential selection. In particular, the differential mutation arbitrarily selects two solutions and adds a scaled difference between these to the third solution. This mutation can be expressed as follows

$$u_{r0}^{(t)} + F.\left(\omega_{r1}^{(t)} - \omega_{r2}^{(t)}\right), \text{for } i = 1 \dots NP, \quad (22)$$

Where $F \in [0.1,1.0]$ denotes the scaling factor as a positive real number that scales the rate of modification while r0; r1; r2 are arbitrarily selected vectors in the interval 1… NP.

Uniform crossover is employed as a differential crossover by the DE.This crossover can be written as

$$z_{i,j} = \begin{cases} u_{i,j}^{(t)} rand_j(0,1) \le CR \vee j = j_{rand}, \\ \omega_{i,j}^{(t)} \quad \text{otherwise}, \end{cases} \quad (23)$$

Differential selection can be writtenas follows:

$$\omega_i^{(t+1)} = \begin{cases} z_i^{(t)} \text{ if } f(z^{(t)}) \le f(Y_i^{(t)}) \\ \omega_i^{(t)} \text{ otherwise} \end{cases} \quad (24)$$

VI. HYBRID BAT ALGORITHM

As we mentioned before, a new bat algorithm, called Hybrid Bat Algorithm (HBA) is proposed in this paper. That is, the original bat algorithm was hybridized using the differential evolution strategy.

Hybrid Bat Algorithm

a: Objective function $f(x), x = (x_1, .., x_d)^T$
b: Set the bat population x_i and v_i for i = 1…n
c: Outline pulse frequency $Q_i \in [Q_{min}, Q_{max}]$
d: Set pulse rates r_i and the loudness A_i
e: while (t <Tmax) // number of iterations
f: Create new solutions by adjusting frequency, and
g: modernizing velocities and locations
h: if (rand (0; 1) >ri)
i: Alter the solution using "DE Strategy"
j: Generate a local solution around the best solution
k: end if
l: Create a new solution by flying arbitrarily
m: if (rand (0; 1) < Ai and f(xi) < f(x))
n: Consent the new solutions
o: Upsurgeri and lessen Ai
p: end if
q: Rank the bats and find the current best
r: end while
s: Post process results

VII. IMPLEMENTATION OF HYBRID BAT ALGORITHM IN THE ORPD PROBLEM

The implementation of the proposed algorithm for the optimization problem must find the optimum value of generator bus voltages, the transformer tap setting and reactive power generation to minimize the object function while handling the constraints.

By adding the inequality constraints to the objective function, the augmented fitness function to be minimized becomes:

$$F_T = F + \lambda_s\left(P_{gslack} - P_{gslack}^{lim}\right)^2 + \lambda_v \sum_{i=1}^{NL}\left(V_i - V_i^{lim}\right)^2 + \lambda_P \sum_{i=1}^{nbr}(S_{li} - S_{li}^{max})^2 \quad (25)$$

Where λS, λV and λP are the penalty factors, these penalty factors are large positive constants. NL is a number of load buses (PQ buses) and Nbr: is the total number of transmission lines.

S_{li}, S_{li}^{max} are the apparent powers and maximum apparent powers in transmission line number i, respectively (line flow constraints).

F is the total active power loss given by (8) or (9).

V_i^{lim} and P_{gslack}^{lim} are defined as :

$$V_i^{lim} = \begin{cases} V_i^{min} & \text{if } V_i < V_i^{min} \\ V_i^{max} & \text{if } V_i > V_i^{max} \end{cases} \quad (26)$$

$$P_{gslack}^{lim} = \begin{cases} P_{gslack}^{min} & \text{if } P_{gslack} < P_{gslack}^{min} \\ P_{gslcak}^{max} & \text{if } P_{gslack} > P_{gslack}^{max} \end{cases} \quad (27)$$

The equality constraint and generators reactive power inequality constraints are handling in Newton Raphson load flow calculation method.

The HBA approach takes the following steps

Step 1: Form the initial candidates.

Step2. Run Newton-Raphson power flow to calculate the fitness value of all the candidate solutions.

Step3. Generate new solutions – update velocities

Step4.Modify the solutions using DE strategy.

Step5. Rank the bats and find the current best.

Step 6.End, when stopping criterion reached.

VIII. Simulation Results

HBA algorithm has been tested on the IEEE 30-bus, 41 branch system. It has a total of 13 control variables as follows: 6 generator-bus voltage magnitudes, 4 transformer-tap settings, and 2 bus shunt reactive compensators. Bus 1 is the slack bus, 2, 5, 8, 11 and 13 are taken as PV generator buses and the rest are PQ load buses. The considered security constraints are the voltage magnitudes of all buses, the reactive power limits of the shunt VAR compensators and the transformers tap settings limits. The variables limits are listed in Table I.

TABLE I: INITIAL VARIABLES LIMITS (PU)

Control variables	Min. value	Max. value	Type
Generator: Vg	0.90	1.10	Continuous
Load Bus: VL	0.95	1.05	Continuous
T	0.95	1.05	Discrete
Qc	-0.12	0.36	Discrete

The transformer taps and the reactive power source installation are discrete with the changes step of 0.01. The power limits generators buses are represented in TableII. Generators buses are: PV buses 2,5,8,11,13 and slack bus is 1.the others are PQ-buses.

TABLE II: GENERATORS POWER LIMITS IN MW AND MVAR

Bus n°	Pg	Pgmin	Pgmax	Qgmin
1	98.00	51	202	-21
2	81.00	22	81	-21
5	53.00	16	53	-16
8	21.00	11	34	-16
11	21.00	11	29	-11
13	21.00	13	41	-16

TABLE III: VALUES OF CONTROL VARIABLES AFTER OPTIMIZATION AND ACTIVE POWER LOSS

Control Variables (p.u)	HBA
V1	1.0663
V2	1.0572
V5	1.0346
V8	1.0479
V11	1.0871
V13	1.0665
T4,12	0.00
T6,9	0.03
T6,10	0.93
T28,27	0.92
Q10	0.13
Q24	0.10
PLOSS	4.3052
VD	0.9119

Table III show the proposed approach succeeds in keeping the dependent variables within their limits. Table IVsummarizes the results of the optimal solution obtained various methods. Andit reveals better performance of the HBA method in reducing the real power loss.

TABLE IV: COMPARISON RESULTS (PLOSS) OF DIFFERENT METHODS

Methods	Ploss (MW)
SGA (28)	4.98
PSO (29)	4.9262
LP (30)	5.988
EP (30)	4.963
CGA (30)	4.980
AGA (30)	4.926
CLPSO (30)	4.7208
HSA (31)	4.7624
BB-BC (32)	4.690
HBA	4.3052

IX. Conclusion

In this paper, theHBA has been successfully implemented to reduce the real power loss. The main advantage of the HBA is easily handling of nonlinear constraints in reducing the real power loss. The proposed algorithm has been tested on the IEEE 30bus system. The simulation results reveal about the better performance of the proposed algorithm when compared to other heuristics methods. And real power loss has been considerably reduced and control variables are well within the limits.

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