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OPTIMAL POWER FLOW SOLUTION THROUGH HYBRID BAT OPTIMIZATION ALGORITHM WITH DIFFERENTIAL EVOLUTION STRATEGY

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ABSTRACT:

Power system operation involves some kind of optimization for ensuring economy, security and stability. Optimal power flow (OPF) is one such optimization problems and it is applied for minimizing the total fuel cost. Optimizing the fuel cost is done by properly setting the control variables such as real power generation from the generators, generator bus voltages, transformer tap settings and SVC settings in a power system. In this work, Optimal Power Flow is achieved by considering the general quadratic cost function. The bio inspired hybrid Bat optimization Algorithm with the Differential Evolution (BADE) is recently developed optimization algorithm used for optimally setting the values of the control variables. The BADE is a recently developed algorithm and is with less number of operators and easy to implement. The algorithm can be coded in any programming language easily. The proposed algorithm is to be tested on the standard IEEE-30 bus system and by comparison with other algorithm the results of the proposed algorithm was found to be better than that of the other algorithms in the literature.

Key words:

Optimal power flow, bio inspired algorithm, line flow limit and quadratic function

1. INTRODUCTION:

Optimal power flow (OPF) control in power systems has a direct impact on system security and economic dispatch. Optimal power flow (OPF) has become one of the most important problem and the main objective of the OPF problem is to optimize a chosen objective function through optimal adjustments of power systems control variables while at the same time satisfying system operating conditions with power flow equations and inequality constraints. The equality constraints are the nodal power balance equations, while the inequality constraints are the limits of all control or state variables. The control variables involves the tap ratios of transformers, the generator real power, the generator bus voltages and reactive power of sources. In general the OPF problem is a large-scale, highly constrained, nonlinear and non-convex optimization problem.

H.W.Dommel and W.F.Tinneyfirstly presented the solution of optimal power flow. In the past conventional methods such as interior point method, linear programming and nonlinear programming have been discussed by K.Deb. The disadvantage of these techniques is that it is not possible to use these techniques in practical systems because of nonlinear characteristics. Recently manypopulation-based methods have been proposed for solving the OPF problem successfully such as genetic algorithm(GA), particle swarmoptimization(PSO), differential evolution(DE), simulated annealing(SA), Intelligent search evolutionary algorithm(ISEA) etc.,. These techniques have been increasingly applied for solving power system optimization problems such as economic dispatch, optimal reactive power flow and OPF for decades.

R. Gnanadassdevoted an evolutionary programming algorithm to solve the OPF problem with non-smooth fuel cost functions. M.R.AlRashidiand M.E.EI.Hawary has reported a hybrid particle swarm optimization algorithm to solve the discrete OPF problem with valve loading effect. Russell Eberhartpresents the optimization of nonlinear functions using particle swarm methodology is describedM.Varadarajan and K.S Swarup presented differential evolution approach to solve OPF problem with multiple objectives. A.V.NareshBabu and S.Sivanagaraju proposed a new approach based on two step initialization to solve the OPF problem.All search intelligence techniques are population based and stochastic in nature and are applied to obtain quality solutions to optimization problems. Big-Bang and Big-Crunch (BB-BC) developed by Erol and Eksinfrom the concept of universal evolution,FireFly Optimization (FFO) also a heuristic algorithmdeveloped by Dr. Xin-she yang and cuckoo optimization algorithm proposedby X.S. Yang, S. Deb are also a population based search technique used to solve OPF problem. Fruit Fly Algorithm put forward by Taiwanese Scholar Panhas been applied to solve a number of complex optimization problems. In this work Hybrid Bat optimization Algorithm with differential evolution strategy was used.

After formulating the OPF problems, programming work is carried out in Matlab. A case study on an IEEE-30 bus system expresses some sound idea in a very positive result oriented manner directed towards the applicability of the proposed approaches in the practical electrical network system.

2. PROBLEM FORMULATION:

The main objective this work is to minimize the total production cost of real power for reasons of economics by controlling the design variables.

X is a state vector of the system with bus bar angles and load bus voltages VL.Control variables to optimize equation 1 are real power generation of generator loading units ( ), terminal voltages of generators ( ), tap-setting of transformers ( ) and switchable shunts ( ).

Equation (1) is considered as sum of quadratic cost functions of thermal generating real power loading units with usual cost coefficients.

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This objective is subjected to the following constraints.

2.1Equality constraints

(i) Active power balance in the network

(ii) Reactive power balance in the network

2.2Inequality constraints

(i) Active power generation of generator buses

(ii) Limits on voltage magnitudes of generator buses

(iii) Limits on switchable shunts

(iv) Limitsontap setting of transformers

Equation (3) has functional operating constraints which are as follows

(i) Limits on reactive power generation of generator buses

(ii) Limits on voltage magnitudes of load buses

(iii) Thermal limits of transmission lines

The limits on the control variables of real power generations, voltage magnitudes of generators, transformer tap settings and switchable shunt devices are implicitly handled while generating the parameters randomly. Due to inclusion of penalty terms, equation (7) transforms to a pseudo objective function (F)

Here , , , are penalty terms for slack bus generator MW limit violation, Load bus voltage limit violations, generator reactive power limit violations and violations for thermal limits of lies respectively.

3. HYBRID BAT ALGORITHM WITH DIFFERENTIAL EVOLUTION STRATEGY

Bats use echolocation to detect prey and discriminate different types of insects even in the dark. Hence bats are sensitive to the sounds. Bats usually feed on insects, which can emit sound. In a specific habitat, there exist a group of bats, some of which may simultaneously forage for food. Thus bats may be subjected to the noise and interference induced by their prey and their partners. For simplification of the bats behaviors, the other bats and insects interferences for the bats are not considered in the basic BA. In this algorithm, the living environments the bats inhabit would be integrated into the BA. Using the criteria, the virtual bats in the proposed algorithm can be more lifelike than the ones in basic BA, thus used in various optimization problems.

Through integration of the mutation operator in the DE/rand/1/bin scheme with the BA, the insects interferences for the bats can be visually simulated as a stochastic decision. The insects interferences for the bats only exists when rand (0, 1), a uniform random number in [0, 1], is smaller than *CR*. Here *CR* is the crossover rate in DE. Consider three different individuals interfere with the virtual bats. If the interference is strong enough that the virtual bats cannot distinguish the targets by themselves, they will follow the clues suggested by the interference. Otherwise, they will continue searching for their targets using their own strategies.

Using these criteria, the virtual bats in the proposed algorithm can be more lifelike than the ones in basic BA, thus helping them escape from the local optima.

4.1: ALGORITHM:

The main procedure of the BADE can be described as follows.

Step 1: Initialization

Step 1.1: Initialize *N bats* positions , velocities in a *D*-dimensional space, and initialize the associated parameters, such as frequency , pulse rates , and the loudness .

Step 1.2: Evaluate the fitness value of each bat by the objective function and the constraint value of each bat by the constrained functions.

Step 2: Update solutions.

While *t* < Max number of iterations (*M*)

Step 2.1: Generate offspring (solutions) using the equations

Step 2.2: If

Select a solution among the best solutions

Generate a local solution around the selected best solution using the equation

End if
Evaluate the fitness values and constraint values of the offspring .
Step 2.3: If
Generate offspring using the equation

Evaluate the fitness values and constraint values of the new offspring .
Select the final offspring by comparing the fitness value and constraint value of with those of according to the feasibility-based rules.
End if
Step 2.4: If
If is infeasible, but is feasible
Or both are feasible, but

Or both are infeasible, but constraint value of is bigger than Accept the offspring as the new solutions.
Increase and reduce using the equations

End if
Step 2.5: Rank the bats and find the current best .
Step2.6: If does not improve in *G* generations.
Reinitialize the loudness , and set the pulse rates , which is a uniform random number between [0.85, 0.9].
t=*t*+1. (8)
End while

Step 3: Update the best .

4. Implementation of BADE algorithm:

Form an initial generation of NP swarms in a random manner respecting the limits of search space. Each bat is a vector of all control variables, i.e. [P_g, V_g, $T_{tap,}$ Q_{sh}]. There are 5 P_g's, 6V_g's, 9Q_{sh}'s and 4T_{tap}'sin the IEEE-30 system and hence a fly is a vector of size 1X15. Calculate the position, loudness and pulse rate function values of all bat solution by running the NR load flow. The control variable values taken by different bats are incorporated in the system data and load flow is run. The total line loss corresponding to different flies are calculated. The bats are arranged in the descending order and find the current best solutions (minimum cost). It should be ensured that the control variables are within their limits otherwise adjust the values. Repeat steps until the best solution has been achieved. It should be ensured that the control variables are within their limits otherwise adjust the values. Repeat steps until the best solution has been achieved.

Once the reconstruction operators have been applied and the control variables values are determined for each bat a load flow run is performed. Such flows run allow evaluating the branches active power flow and the total cost.

All these require a fast and robust load flow program with best convergence properties; the developed load flow process is upon the full Newton Raphson method.

BADE ALGORITHM APPLIED TO OPF MINIMIZATION:

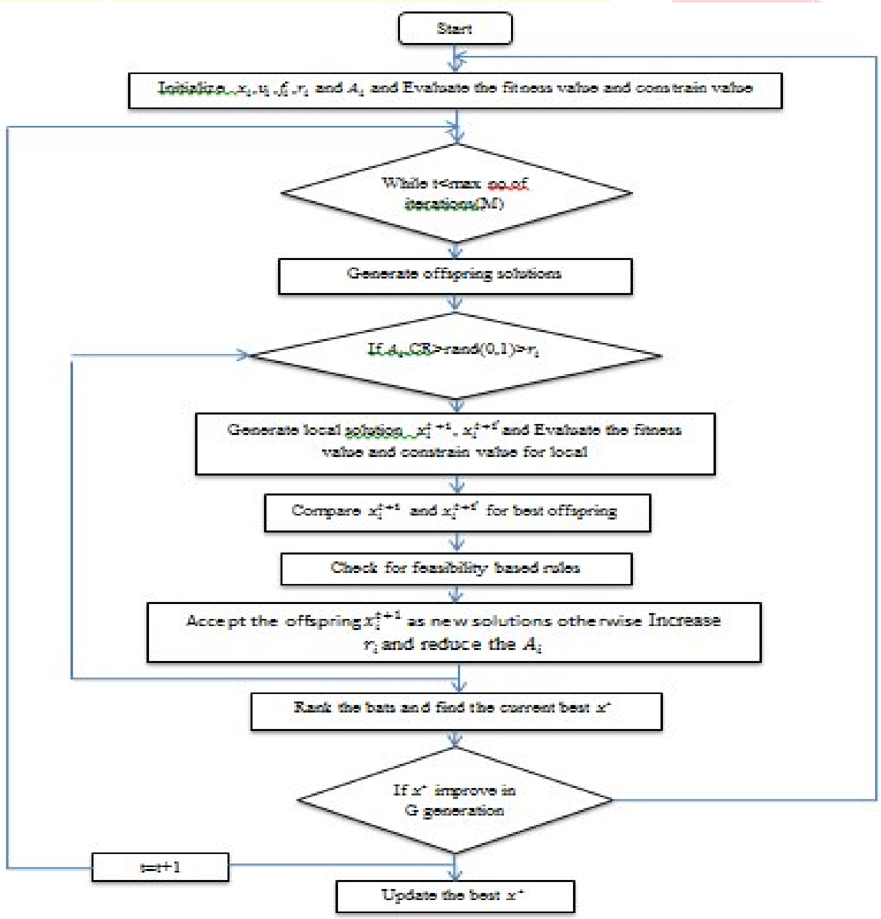
Step 1: Form an initial generation of NP bats in a random manner respecting the limits of search space. Each swarm is a vector of all control variables, i.e. [P_g, V_g,$T_{tap,}$ Q_{sh}]. There are 5 P_g's, 6V_g's, 9Q_{sh}'s and 4 T_k's in the IEEE-30 system and hence a bat is a vector of size 1X15.

Step 2: Calculate the position, loudness and pulse rate values of all bats solution by running the NR load flow. The control variable values taken by different bats are incorporated in the system data and load flow is run. The total line loss corresponding to different bats are calculated.

Step 3: Determine the best solution after check the feasibility conditions. The bats are arranged in the rank order and the first bat will be the candidate with best solution (minimum cost).

Step 4: Generate new solution around the global best bat solution by adding/subtracting a normal random number. It should be ensured that the control variables are within their limits otherwise adjust the values.

Step 5: Repeat steps by increasing t=t+1 until best solution has been achieved.



5. NUMERICAL RESULTS AND DISCUSSIONS:

The effectiveness of the proposed optimization method is tested on the standard IEEE-30 bus system. The necessary data of the system is taken from [13]. The dimension of this problem is 12 including 6 generator voltages, 4 transformer tap settings and 2 VAR compensators. The first bus is the slack bus and its real power generation is not controlled for OPF. System total load is considered(2.834pu+j1.2620pu) on 100 MVA basis.

5.1 IEEE 30 BUS SYSTEM

This test system is used to check the optimization of the power system

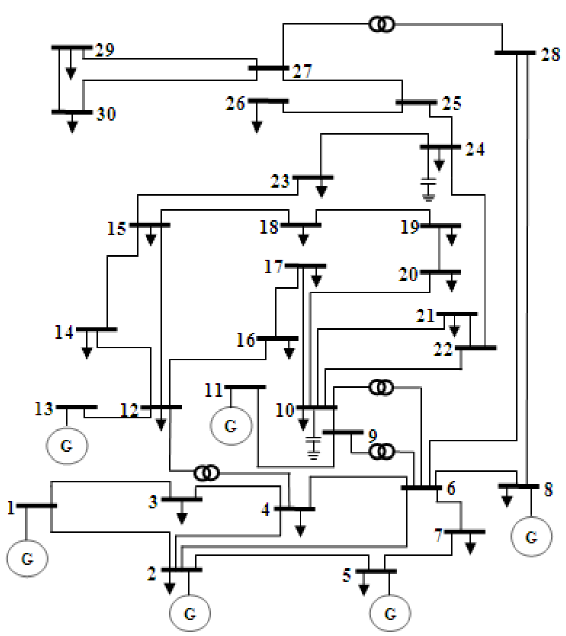


Figure 5.1: One line diagram of IEEE 30 bus system

The various parameters of the IEEE-30 bus was mentioned in the table follows

Table 1. Parameters of the IEEE-30 bus system

Sl.No.	Parameter	30-bus system
1	Buses	30
2	Branches	41
3	Generator Buses	6
4	Shunt capacitors	2
5	Tap-Changing transformers	4

Quadratic cost function is used for calculating the total fuel cost. The real power generation limits and three cost coefficients are given in table 2. By real power output and cost coefficients the fuel cost of the thermal plant is determined.

Table 2. Real power limits and cost coefficients of generators

Bus No	Real power output limit (MW)		Cost Coefficients		
	Min	Max	A	B	C
1	50	200	0	2.00	0.00375
2	20	80	0	1.75	0.01750
5	15	50	0	1.00	0.06250
8	10	35	0	3.25	0.00834
11	10	30	0	3.00	0.02500
13	12	40	0	3.00	0.02500

The control parameters are adjusted within their limits and the total fuel cost is minimized then other algorithms in the literature.

The optimal values of the control variables taken by the proposed algorithm in

OPF and its comparison with various algorithms are given in table 3

Table 3. Optimal variables for IEEE 30 bus

Variables Base	case	FFO [8]	BB-BC[8]	LTLBO[11]	BADE
Pg1(pu)	0.987014	1.765171	1.749672	1.7746	1.8073
Pg2(pu)	0.8	0.487865	0.481406	0.486837	0.480581
Pg5(pu)	0.5	0.214746	0.208195	0.213146	0.224622
Pg8(pu)	0.2	0.216439	0.222772	0.208867	0.192427
Pg11(pu)	0.2	0.11980	0.14110	0.118086	0.100000
Pg13(pu)	0.2	0.120276	0.12000	0.120000	0.120000
Vg1(pu)	1.06	1.085421	1.087797	1.1000	1.1000
Vg2(pu)	1.043	1.066785	1.065492	1.0817	1.0911
Vg5(pu)	1.01	1.034902	1.03551	1.0509	1.0501
Vg8(pu)	0	1.043234	1.04532	1.0555	1.0704
Vg11(pu)	1.082	1.069076	1.063822	1.0826	1.0153
Vg13(pu)	1.071	1.059076	1.010111	1.0574	1.1000
Qsh10(pu)	0.19	0.04	0.04	0.05	0.0050
Qsh12(pu)	0	0.03	0.01	0.05	0.0155
Qsh15(pu)	0	0.02	0.02	0.05	0.0500
Qsh17(pu)	0	0.04	0.02	0.05	0.0050
Qsh20(pu)	0	0.04	0.02	0.04	0.0050
Qsh21(pu)	0	0.04	0.05	0.05	0.0500
Qsh23(pu)	0	0.03	0.04	0.03	0.0364
Qsh24(pu)	0.043	0.03	0.04	0.05	0.0500
Qsh29(pu)	0	0.02	0.02	0.03	0.0050
t1(6-9)	0.978	0.9850	1.0950	1.0461	0.9000
t2(6-10)	0.969	0.9650	0.9600	0.9583	1.1000
t3(4-12)	0.932	0.9900	1.0100	0.9996	1.0336
t4(28-27)	0.968	1.005	1.015	0.9891	0.9620
Total Real power generation(pu)	2.887	2.9243	2.9231	2.9215	2.9250

Cost($/hr)	**900.5211**	**800.6803**	**800.8949**	**799.4369**	**799.2141**

The efficiency of the algorithm is proved by comparing its performance with that of other recently reported algorithms like FFO, LTLBO and BADE. It is obvious from table 4 that the reduction in the total fuel cost is quite encouraging. The cost obtained by other methods is about 802 USD/hr whereas BADE has achieved 799.21487 USD/hr and this is a great advantage.

Table 4 Total fuel cost obtained by different methods

IEEE-30 bus system	DE [14]	BB-BC [8]	FFO [8]	LTLBO [11]	BADE
Cost	802.230	800.894	800.680	799.4369	799.214

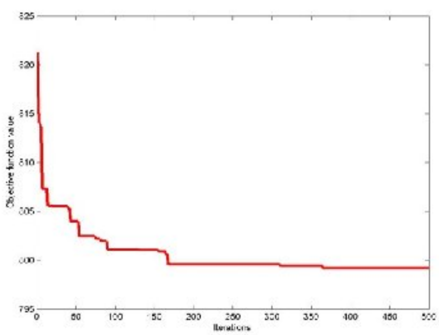


Figure 5.2 Convergence characteristics of OPF

Convergence efficiency of FOA is good in this case. It is clear from figure 5.2 that convergence occur at about 120th iteration. It is relatively less number of iterations.

6. CONCLUSIONS

BADE is new and bio inspired optimization algorithm mimicking the food searching behavior of Bats. Because of less number of operators and parameters, the algorithm is found to be simple in implementation. It is obvious from the test results than BADEoutperforms the other recently introduced optimization techniques in optimal power flow problem. The algorithm achieves the results in relatively less number of iterations. Speed of convergence of the algorithm is also examined to establish the strength of the algorithm. Therefore it is believed that this algorithm may be exploited for other power system operations like economic load dispatch, optimal power flow, voltage stability improvement etc.

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