Analysis of Optimal Power Flow using Hybrid Fruitfly Algorithm

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ABSTRACT— In this paper, hybrid fruit fly algorithm is proposed to find the optimal solution for optimal power flow (OPF) problem in a power system. The proposed approach is applied to determine the optimal settings of control variables of the OPF problem. The performance of the proposed approach examined and tested on the himmelblau test function and 30-bus test systems with different objective functions and is compared to other heuristic methods reported in the literature recently. Simulation results obtained from the proposed approach indicates that HFFA provides effective and robust high-quality solution for the OPF problem.

Keywords— Generation fuel cost; Emission; Total power loss; fruit fly;

I. Introduction

Optimal power flow (OPF) has become one of the most important problems and commonly studied subjects for optimal operation and planning processes of modern power systems. Main objective of the OPF problem is to optimize a chosen objective function such as fuel cost, piecewise quadratic cost function, fuel cost with valve point effects, voltage profile improvement, voltage stability enhancement, through optimal adjustments of the power system control variables while at the same time satisfying various system operating such as power flow equations and inequality constraints [1,2]. In its most general formulation, the OPF is a nonlinear, non-convex, large-scale, static optimization problem with both continuous and discrete control variables. Even in the absence of non-convex unit operating cost functions, unit prohibited operating zones, and discrete control variables, the OPF problem is non-convex due to the existence of the nonlinear (AC) power flow equality constraints. The presence of discrete control variables, such as switchable shunt devices, transformer tap positions, and phase shifters, further complicates the problem solution.

Conventional optimization techniques can obtain acceptable results for the OPF problem, but when the dimension of the optimization problem is great, non-linear, and discontinuous, these techniques cannot reach the global optima easily. Therefore, these conventional methods cannot always reach the global optimal solution. In other words, they are not suitable for solving the complicated optimization problem. A literature survey reveals that various numerical optimization techniques have been used for the OPF problem, such as non-linear programming (NLP) [3], linear programming (LP) [4-6], Newton methods [7,8] (which minimizes a quadratic approximation of the Lagrangian function, but this method increases the number of problem variable in each iteration), quadratic Programming [9], integer programming [10], decomposition method [11,12] . Recent advances in computation have motivated the development of evolutionary algorithms; these methods can overcome all the above mentioned drawbacks of conventional methods. Some of the population-based methods have been proposed for solving the OPF problem successfully, such that genetic algorithm [13], improved genetic algorithm [14], tabu search, particle swarm, differential evolution algorithm [15], simulated annealing [16], evolutionary programming [17]. Anitha et al. presented a new variation of particle swarm optimization algorithm to solve the OPF problem with IEEE 30-bus system. The obtained results of proposed approach are compared with tabu search (TS), simulated annealing (SA), evolutionary programming (EP), improved evolutionary programming (IEP) and particle swarm optimization (PSO) methods [18].

In this paper, HFFA method is proposed to solve the OPF problem. The problem is formulated as a non-linear optimization problem with equality and inequality constraints. In this approach different objectives are considered such as minimizing the fuel cost, improving the voltage profile, and enhancing power system voltage stability in both normal and contingency conditions. The proposed is examined and tested on himmelblau test function standard and IEEE 30-bus test systems. The potential and effectiveness of the proposed approach are demonstrated. Additionally, the results are compared to those reported in the literature.

II. PROBLEM FORMULATION

The non linear constrained mathematical problem can be formulated as follows

$$\text{Minimize } [A_m(x,u)] \quad \forall\, m = 1,2,\ldots\ldots,J \qquad (1)$$

Subject to

$$g\,(x,u) = 0 \qquad (2)$$

$$h\,(x,u) \le 0 \qquad (3)$$

where 'g' and 'h' are the equality and inequality constraints respectively and 'x' is a control vector of dependent variables like slack bus active power generation, PQ bus voltage magnitudes and generator reactive powers and vector 'u' consist control variables like real powers and voltages of generators, transformer tap ratios and shunt compensation . 'J' is the number of objective functions.

1) Fuel cost objective

The optimal allocation of the real powers generated by the generating units at power stations should be organized in a most economic way to meet the existing load on a give system can be considered as economic load dispatch problem. The simplified quadratic cost expression for ith unit for real power output of subjected to different constraints can be expressed as [8]

$$F_i(P_{G_i}) = a_i P_{G_i}^2 + b_i P_{G_i} + c_i$$

where are the fuel cost-coefficients of generators. The total generation fuel cost ( ) of all ' ' number of units can be mathematically expressed as

$$A_1 = min\ (F_T) = \sum_{i=1}^{N_G} F_i(P_{G_i}) \qquad \$/h \qquad (4)$$

2) Emission objective

In practical, minimizing generation cost is not only sufficient but also it is necessary to decrease the pollutions caused by the emission of polluted gases (SOX, NOX, COX) becoming mandatory for generation units. The emission generated can be approximated as [19]

$$A_2 = \min\left(E(P_{G_i})\right) = \sum_{i=1}^{N_G} \left(\alpha_i + \beta_i P_{G_i} + \gamma_i P_{G_i}^2 + \xi_i \exp^{(\lambda_i P_{G_i})}\right) \quad ton/h \qquad (5)$$

where are emission coefficients of the generator.

3) Transmission loss objective

The system active power loss in transmission lines must be less to get safer operation. This objective can be expressed as

$$A_3 = \min(TPL) = \sum_{i=1}^{N_{line}} P_{Loss,i} \qquad (6)$$

where is the real power loss in ith line.

While minimizing the objectives it must satisfy the following equality and inequality constraints along with the ramp-rate and POZ limits. These constraints can be expressed as

i). Equality constraints

$$\sum_{i=1}^{N_G} P_{G_i} - P_{Demand} - P_{Loss} = 0$$

$$\sum_{i=1}^{N_G} Q_{G_i} - Q_{Demand} - Q_{Loss} = 0$$

where P_l and are total real and reactive power demands and its corresponding total power losses.

ii) In-equality constraints

The self restricted constraints satisfied within OPF are

Generator bus voltage limits:

$$V_{G_i}^{min} \le V_{G_i} \le V_{G_i}^{max}; \qquad \forall$$

Generator real power limits:

$$P_{G_i}^{min} \le P_{G_i} \le P_{G_i}^{max}; \qquad \forall$$

Transformers tap setting limits:

$$T_i^{min} \le T_i \le T_i^{max}; \quad i = 1,2,3, \dots n_t \text{ (total number of taps)}$$

Capacitor reactive power generation limits:

$$Q_{C_i}^{min} < Q_{ci} < Q_{C_i}^{max}; \quad i = 1,2 \dots\dots n_c \text{ (total number of VAr sources)}$$

Transmission line flow limit:

$$S_{l_i} \le S_{l_i}^{max}; \qquad i = 1,2,3, \dots\dots\dots l$$

Generator reactive power limits:

$$Q_{G_i}^{min} \le Q_{G_i} \le Q_{G_i}^{max};$$

Bus voltage magnitude limits:

$$V_i^{min} \le V_i \le V_i^{max}; \qquad i = 1,2,3, \dots\dots\dots N_{load}$$

III. HYBRID FRUITFLY ALGORITHM (HFFA)

Fruit fly algorithm is the meta-heuristic method suitable for solving continuous non linear optimization problems. This algorithm was developed from the lifestyle of fruitfly family. Fruit flies live in the temperate and tropical climate zones. They have very sensitive osphresis and vision organs which are superior to other species. They feed on rotten foods, it smells all kinds of scents in the air through their organs, then fly towards the corresponding food location for searching food.

Step-1: Initialization of fruit fly swarm location

Generate randomly 'ps' number of populations

$$\delta_j = \delta_j^{min} + rand\ (0,1) \times (\delta_j^{max} - \delta_j^{min})$$

Where,

ps=Number of populations, n=Number of control variables

δ_j^{min} and δ_j^{max} are minimum and maximum limits of control variable

Step-2: Start loop: Set Generation=1

Perform operations on randomly generated population vector to get best [PV] vector. Operations to be performed are listed below.

Step-3: Osphersis foraging phase

In this phase a population of 'ps' food sources are generated randomly around the current fruit fly swarm locations.

where Δ is set of the randomly initialized swarm location

$$\Delta = (\delta_1, \delta_2 ----\delta_n)$$

Let $x_1, x_2, -- x_{ps}$ are the generated food sources

$$x_{ij} = \delta_j \pm \lambda.rand\ () \quad , j = 1,2,-------n$$

In osphersis foraging food sources generated around its swarm location within a radius equal to one. This radius is fixed and cannot be changed during iterations. For optimal solution this search region is too small and considerable increase needed in iterations. Hence search radius can be changed dynamically with iteration number.

$$\lambda = \lambda_{max}.\exp[\log\left(\frac{\lambda_{min}}{\lambda_{max}}\right).\frac{itr}{itr_{max}}]$$

Step-4: Crossover

It is an efficient recombination operator has been used to search swarm food location in certain long range. Recombination crossover generates new swarm locations by using the following crossover equation.

$$x_{i,j} = (1-\lambda) \times x^{(11)}_{(1,j)} + \lambda \times x_{(i,j)} \qquad i = 1,2----ps$$
$$j = 1,2---n$$

After getting new values of control variables for total number of food sources, whose limits has to check. New population vector is obtained its fitness vector is evaluated.

Step-5: Vision foraging phase

In this phase FFO carries a greedy selection procedure. Finding best food source with lowest fitness as given by

$$X_{best} = \arg(\min\ f(X_i)) \qquad , i = 1,2,---- ps$$

If X_{best} is better than the current fruit fly swarm location. Swarm will replace the new position. Otherwise swarm location will not change.

Step-6: Stopping criteria

The stopping criteria is the number of generations equals to the specified maximum number of generations.

IV. RESULT ANALYSIS

In order to demonstrate the effectiveness and robustness of the proposed method, two examples namely Himmelblau function and IEEE 30 bus system results are presented.

Example-1

To test the effectiveness of proposed method a standard Himmelblau function given in Eq.7 is used and the corresponding results are tabulate in Table.1.

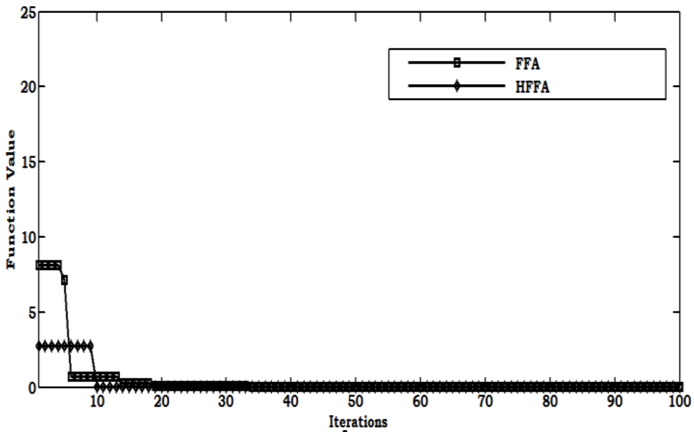
$$f(x_1,x_2) = (x_1^2 + x_2 - 11)^2 + (x_1 + x_2^2 - 7)^2 \qquad (7)$$

Table.1. OPF solution obtained for test function

S.No	Parameters	Existing GA[19]	FFA	Proposed HFFA
1	x_1	3.003	2.9912	3.0011
2	x_2	1.994	2.0078	1.9999
3	Function value	1.000e-3	0.0039	3.95644E-05
4	Computational time (sec)	-	0.865	0.423

The first example is Himmelblau function given by Eq. (13). The solution for this function was obtained using Genetic Algorithm (GA) [19]. But, in this paper, the solution for this function has been obtained using existing fruitfly algorithm (FFA) and proposed Hybrid fruitfly algorithm (HFFA). The solution obtained using existing FFA method and proposed method is compared with the solution given in [19].

From Table 1, it can be observed that the parameter values (x1 and x2) obtained using FFA and proposed HFFA is better than GA. The function value is less in the proposed method compared to existing FFA and GA. Further, the computing time in FFA method is 0.865 s, whereas in proposed method it



is 0.423 s, which is 0.442 s less in comparison with FFA.

Fig. 1 Comparison of convergence characteristics of Himmelblau function

It is observed from Fig.1 is that the convergence of the proposed HFFA method starts with good function value and final best value is obtained within less number of iterations when compared with other methods. It is also observed that the existing FFA method starts with high initial value and take more number of iterations to reach final value and where as proposed method start at less initial value and time taken to reach final value is less.

Example-II

We consider the IEEE-30 bus test system with forty-one transmission lines to extend the features of the proposed HFFA technique to solve single objective OPF problems and proposed HFFA for single-objective optimization problems. There are eighteen control variables for this system, which include six active power generations and respective voltage magnitudes, two shunt compensators and four tap setting transformers.

Table 2 OPF solution for IEEE 30 Bus system for the existing and proposed methods

Control variables	Existing methods			Proposed method
	PSO [20]	**CSA [20]**	**FFA**	**HFFA**
PG1(MW)	178.5558	170.7789	176.742	174.297
PG2(MW)	48.6032	48.3696	46.142	48.123
PG5(MW)	21.6697	18.3135	20.040	22.026
PG8(MW)	20.7414	32.6057	24.543	20.833
PG11(MW)	11.7702	10	13.016	12.741
PG13(MW)	12	12	12.000	14.027
VG1(p.u.)	1.1	1.1	1.097	1.099
VG2(p.u.)	0.9	1.0567	1.075	1.082
VG5(p.u.)	0.9642	1.0912	1.036	1.055
VG8(p.u.)	0.9887	1.0725	1.049	1.054
VG11(p.u.)	0.9403	1.0465	1.055	1.069
VG13(p.u.)	0.9284	1.1	1.000	1.091
TAP,6-9(p.u.)	0.9848	1.0531	1.099	0.948
TAP,6-10(p.u.)	1.0299	1.007	1.050	1.009
TAP,4-12(p.u.)	0.9794	1.0395	0.962	0.987
TAP,28-27(p.u.)	1.0406	0.9707	1.038	0.996
QC10(MVAr)	9.0931	30	12.519	22.848
QC24(MVAr)	21.665	6.7556	14.307	10.427
COST($/h)	**803.4548**	**802.7283**	**801.447**	**800.212**
P LOSS(MW)	9.9403	8.6677	9.0835	8.6462
Severity value	---	---		

Time (sec)	30.2301	23.3948	18.4307	10.0286

The OPF results with generation fuel cost as an objective are tabulated in Table 2 for the existing and proposed methods. The proposed HFFA method produces the best generation fuel cost compared to the existing methods. The time to convergence is also less in the proposed method. This confirms that lower generation fuel cost is obtained with the proposed method. Convergence for the existing and the proposed methods are shown in Fig. 2. The proposed method starts with a good initial value and reaches the final best value in less iteration than existing methods.

V. Conclusions

With the proposed HFFA, the important power system objectives like generation fuel cost, emission and total power loss objectives are optimized. The result shows that effectiveness of the proposed method even in the presence of all constraints. Since this method works independent of the nature of the objectives, and can be applied to solve any type of the objectives. The proposed method is tested on standard Himmelblau function and IEEE-30 bus test system with supporting numerical results.

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