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Modified Flower Pollination Algorithm Constrained Optimal Power Flow

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ABSTRACT

In power systems, the power flow must satisfy a set of operational and safety requirements. It is a highly nonlinear problem to optimize the power flow. In this paper, the flower pollination algorithm (FPA) is modified and applied to optimize the power flow. Firstly, the author set up a mathematical model for power flow optimization problem, and formulated all the constraints. Next, the FPA was introduced in details, including the self-pollination, cross-pollination and other operations. After that, the local search strategy of the FPA was modified to replace the worst individuals in the current population with the best individuals in the previous population. Finally, the modified FPA (MFPA) was proved more efficient and better in convergence than standard algorithms like the firefly algorithm.

1. INTRODUCTION

The optimal power flow (OPF) problem has been studied for decades, and determining the settings of control variables for economic and secure operation of a power system has been the main purpose of all OPF programs. Due to recent complexity of the operating conditions, new mathematical models have been created and they have been used to solve this problem.

For many years, classical programming methods are used to solve OPF such us Gradient method [1, 2] linear programming (LP) and non linear programming (NLP) [3, 4], in the literature we find also Newton methods [5-10] and quadratic programming (QP) [11, 12]. As these methods have proven their efficiency,

They have been vastly applied to several Optimal Power Flow problems. However, the efficiency of these methods is limited, when the situations encountered in practice involve one or more complications: for example, the objective function can be non-linear, or even not express itself analytically as a function of the parameters; or the problem is multi objective [13].

Through the huge improvements in the capacity of the computers and the arrival of a new class of methods, called meta-heuristics, marks a reconciliation of this area: Indeed, they apply to all kinds of problems. These methods include genetic algorithms [14], Evolutionary Programming (EP) [15, 16], taboo search method [17], ant colony algorithms [18, 19], Particle Swarm Optimization (PSO) [20-22] etc. these methods appeared with a common goal: face out to the difficult optimization problems.

It is worth the mention that other techniques are used to solve the OPF, such as Cuckoo Search Algorithm (CSA) [23-25] and firefly optimization algorithm [26-29].

Developed by X. S. Yang in 2012, Flower Pollination Algorithm, it is one of the most modern optimization techniques that targeted optimization issues [30].

This algorithm, as stimulated from nature, simulates the features of flowering plants and the important aspects that lead to find the global and the local feasible space. As for these features, it has been used to solve the optimal power flow problem [31-34].

The main goal of this work is the minimization of fuel cost, voltage deviation and power losses (PL) using a modified flower pollination algorithm. where the IEEE 30-bus system is taken as test system.

This work is structured as follows: Firstly, the mathematical formulation of OPF is given; followed by the presentation of the FPA. Afterwards, a description of the Modified FPA technique is presented then applied to OPF.

A presentation of a comparative study, consisting of a comparison of results from the literature against FPA, Firefly Algorithm (FFA) and MFPA using three objective functions is given; at the end, some comments about the achieved results.

2. MATHEMATICAL FORMULATION

The OPF is a nonlinear optimization problem where its main objective is to obtain the optimum power system operating conditions. In general, the OPF problem is formulated as follows [1]:

$$\begin{aligned} &\min\ f(x,u) \\ \text{Subject to: } & g(x,u)=0 \\ & h(x,u)\le 0 \end{aligned} \tag{1}$$

where, $f(x,u)$ is the objective function, in general given by:

Fuel Cost Function [1]

$$f(P_g)=\sum_{i=1}^{ng}(\alpha_i+\beta_i P_{gi}+\gamma_i P_{gi}) \tag{2}$$

where, α_i, β_i and γ_i are the cost coefficients of ith unit.

Active power losses function [36, 36]

$$f = \min(PL) \tag{3}$$

Voltage deviation function [37, 39]

$$f = \sum_{k=1}^{Lnpq} \left| V_{l1} - 1 \right| \tag{4}$$

State variables are shown in Eq. (5).

$$x^T = \left[V_{L1},..., V_{Lnpq}, P_{G1}, Q_{G1},..., Q_{Gnpv}, S_{L1},..., S_{Lntl} \right] \tag{5}$$

where, V_L the load bus voltages; P_{G1} is the slack bus active power; Q_G the reactive power generation of the units; S_l the transmission line loading; *NPQ* the number of load bus, *NPV* the number of controlled bus; and *NTL* the number of transmission lines.

Control variables are presented in Eq. (6).

$$u^T = \left[V_{G1},..., V_{Gng}, P_{G2},..., P_{Gng}, Q_{c_1},..., Q_{cnc}, T_1,..., T_{nt} \right] \tag{6}$$

where, V_G is generator voltages, *NC* and *NT* respectively, are the number of shunt VAR compensators and number of taps changing transformers, T is the tap setting of the tap changing transformers and Q_C is the output of shunt VAR compensators.

2.1 Equality constrains

Power Flow Equations:

$$P_{gk} - P_{lk} - V_k \sum_{m=1}^{nb} \left[V_m \left[g_{km} \cos(\delta_k - \delta_m) + b_{km} \sin(\delta_k - \delta_m) \right] \right] = 0 \tag{7}$$

$$Q_{gk} - Q_{lk} - V_k \sum_{m=1}^{nb} \left[V_m \left[g_{km} \sin(\delta_k - \delta_m) - b_{km} \cos(\delta_k - \delta_m) \right] \right] = 0 \tag{8}$$

where,

P_{gk} is the active generation of the k^{th}

Q_{gk} is the reactive generation of the k^{th} unit, Q_{lk} and P_{lk} are reactive and active power demand on k^{th} bus,

V_k and V_m are the voltage value of k^{th} and m^{th} bus,

2.2 Inequality constrains

Generator limits:

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{9}$$

$$Pgimin \le Pgi \le Pgimax \tag{10}$$

$$Qgimin \le Qgi \le Qgimax \tag{11}$$

Compensators limits:

$$q_i^{\min} \le q_i \le q_i^{\max} \tag{12}$$

where, *i*=1 … nc, nc: number of compensators.

Tap limits transformer:

$$T_i^{\min} \le T_i \le T_i^{\max} \tag{13}$$

where, i= 1… nt, nt: number of transformers.

Voltages at loading buses:

$$V_j^{\min} \le V_j \le V_j^{\max} \tag{14}$$

where, j=1… npq, npq: loading buses.

Transmission line limits:

$$S_i^{\min} \le S_i \le S_i^{\max} \tag{15}$$

where, i =1,… ntl, ntl: number of transmission lines loading. In case of violation of control variables limits, the following variables are limited:

$$u_i = \begin{cases} u_i^{\max} & u_i > u_i^{\max} \\ u_i^{\min} & u_i < u_i^{\min} \end{cases} \tag{16}$$

In case of violation of state variables limits the penalty function is introduced in the objective function Where J is the new objective function:

$$J(x,u) = f(x,u) + \sum_{i=1}^{p} \left(x_i - x_i^{\lim} \right)^2 \tag{17}$$

3. THE FLOWER POLLINATION ALGORITHM

The reproduction in plants occurs by union of the gametes. The male gametes produce pollen grains and female gametes produce ovules; it is essential that the pollen has to be moved to the stigma for the union. Pollination is the process of transfer and deposition of pollen grains from anther to the stigma of flower. The process of pollination is ensured by an agent. In agriculture, the pollination is necessary to generate seeds and fruits [34]. There are two sorts of pollination.

3.1 Self-pollination

Self-pollination happens when a flower contains the male and the female gametes and the fertilization is done by pollen from the same flower or flowers of the same plant.

3.2 Cross-pollination

Cross-Pollination happens when pollen grains are moved to a flower from another plant. The procedure of cross fertilization results with the assistance of abiotic or biotic operators for example birds, bats, insects, ... etc.

When the fertilization happens without participation of external agents, this pollination is abiotic. Only about 10 % of plants fall in this category. Biotic Pollination is the process of pollination which needs external pollinators to move the pollen from the anther to the stigma.

The plants with strong odour and coloured petals attract honey bees, beetles, moths, ants, wasps and butterflies thus the insect pollination occurs. The availability of nectar attracts insects to flowers, edible pollen and when insect stands on the flower, the pollen grains stick to the body. When the insect visits another flower, the pollen is moved to stigma enabling pollination. The pollination is also facilitated by birds and bats.

Flower Pollination Algorithm (FPA) is developed by Xin-She Yang in 2012 the four rules of this algorithm are [34]:

• (Rule 1): Cross-pollination and the biotic are the global pollination and the pollinators pursue the Levy distribution.
• (Rule 2): Self-pollination and the abiotic are the local pollination.
• (Rule 3): The flower consistency property can be considered as a propagation ratio that is relative to the level of similarity between two flowers.
• (Rule 4): local fertilization has a slight favorable position over global fertilization. because of the physical proximity and wind.

The main steps of FPA are illustrated below:

Objective min or max $f(x)$, $x = x_1, \ldots x_d$
generate population radomly
Find the current best solution g^*
Identify $p \in [0, 1]$ *a switch probability*
while *(i<maxGen)*
foreach flower
if *rand < p,*
Global pollination via $x_i^{t+1} = x_i^t + \gamma L(g_* - x_i^t)$
else
select two solution randomly
Local pollination via $x_i^{t+1} = x_i^t + \varepsilon(x_j^t - x_i^t)$
end if
Evaluate new solutions
Update solutions with better new ones
end for
Keep the current best solution g^*
end while

Figure 1. Pseudo code of the Flower Pollination Algorithm (FPA)

4. MODIFIED FLOWER POLLINATION ALGORITHM (MFPA)

The idea is if a no amelioration of solution is noticed during evaluations the modified algorithm select the best individuals from the previous population and replace the worsts individuals, as a result a new population is created.

The goal is to ameliorate the quality of solution by making a local search around the best individuals, the results show that this modification give a good result comparing with PSO and standard FPA.

5. RESULT

To demonstrate the attitude of the proposed algorithm the IEEE 30-bus system is considered as test system [36]. In order to find the global solutions to a different objective functions the algorithm was written in MATLAB and applied in HP Core i7 with a RAM of 8GB.

To see the superiority of proposed approach, all the parameters of FPA and MFPA are fixed and the number of evaluations is limited at 25000 evaluations.

Three functions are used to evaluate the performance of the proposed algorithm. The simulations results are shown in the following sections.

5.1 Evaluation of fuel cost function

The objective is to find the total fuel cost of active power of all generation units the minimum cost were obtained by MFPA 799.265 $/h and the Table 1 gives the comparison between proposed algorithm and the other algorithms.

Table 1. Best control variables (fuel cost minimization)

	Fuel Cost Minimization				
	EGA [40]	MSA [41]	FFA	FPA	MFPA
P1	177.285	177.21	177.03	178.09	177.30
P2	48.93	48.73	48.69	48.98	48.38
P5	21.29	21.45	21.30	21.05	21.31
P8	20.49	21.06	21.13	19.99	21.04
P11	11.93	11.96	11.94	11.97	11.96
P13	12.23	12.00	12.00	12.10	12.09
V1	1.098	1.0848	1.1000	1.1000	1.1000
V2	1.08	1.0653	1.0861	1.0855	1.0875
V5	1.053	1.0338	1.0588	1.0572	1.0610
V8	1.062	1.0382	1.0660	1.0653	1.0673
V11	1.08	1.0927	1.0991	1.1000	1.0876
V13	1.078	1.0453	1.0873	1.0864	1.0992
T11	0.975	1.0490	1.0132	0.9652	0.9565
T12	1.05	0.9387	0.9077	0.9996	0.9982
T15	1.0125	0.9701	0.9255	0.9316	0.9507
T36	1.0125	0.9749	0.9604	0.9619	0.9619
QC12	0.01	2.57	0.24	3.81	3.10
QC15	0.04	4.20	2.51	2.53	4.05
QC17	0.02	5	2.15	4.80	4.00
QC20	0.03	3.68	1.03	2.44	3.00
QC21	0.01	4.95	1.44	3.40	3.07
QC23	0.03	3.08	3.28	0.77	0.22
QC24	0.02	4.98	2.73	5.00	4.01
QC29	0.01	2.48	2.58	2.47	2.07
Cost ($/h)	799.56	800.5099	799.3268	799.285	**799.265**
Power losses (MW)	8.755	9.0345	8.6937	8.7729	8.6833
Voltage deviations	-	0.9035	1.9923	1.9890	1.9904
Number of evaluations	-	-	25000	25000	25000

5.2 Evaluation of active power losses function

The proposed algorithm was applied to minimize the active power losses of the system. The obtained results are compared to FFA and standard FPA, it is clear that the proposed algorithm gives the best result as mentioned in Table 2 2.928 MW.

5.3 Improvement of load buses voltage profile

To have a good voltage performance, the voltage deviation at each load bus must to be as small as possible. The minimization of total deviation by the proposed algorithm (MFPA) gives us butter result comparing with the result obtained from BBO [42], MDE [43], MFPA, FPA, and FFA all the results are shown in the Table 3.

Table 2. Best control variables (power losses minimization)

	Power losses Minimisation IEEE 30-Bus				
	EGA [40]	MSA [41]	FFA	FPA	MFPA
P1	51.674	51.50	51.31	51.55	51.39
P2	79.97	80	80	80	79.98
P5	50	50	50	50	50
P8	35	35	35	34.99	34.97
P11	30	30	30	29.95	30
P13	40	40	40	39.85	39.99
V1	1.0518	1.0618	1.0986	1.0994	1.0999
V2	1.0488	1.0576	1.0939	1.0948	1.0976
V5	1.0270	1.0381	1.0744	1.0762	1.0794
V8	1.0306	1.0442	1.0814	1.0835	1.0849
V11	1.0612	1.0720	1.0805	1.0818	1.0986
V13	1.0382	1.0590	1.0876	1.0976	1.0959
T11	1.0750	1.0907	0.9687	0.9662	0.9755
T12	0.9500	0.9000	0.9886	1.0072	1.0472
T15	0.9875	0.9978	0.9442	0.9591	0.9674
T36	1.0125	0.9765	0.9712	0.9665	0.9755
QC12	0.04	0.76	1.80	0.08	5
QC15	0.02	4.22	3.53	3.4	4.98
QC17	0.05	5	0.43	2.95	4.82
QC20	0.03	3.96	3.14	0.36	4.28
QC21	0.01	5	4.28	4.94	4.91
QC23	0	3.01	3.36	5	0.78
QC24	0.03	4.99	2.29	1.83	4.68
QC29	0.04	2.32	1.33	2.05	2.3
Cost ($/h)	967.9300	967.6636	967.2522	966.7892	967.1363
Power losses (MW)	3.244	3.1005	2.9404	2.9457	**2.9288**
Voltage deviations	-	-	2.0014	2.0425	2.0293
Number of evaluations	-	-	25000	25000	25000

Table 3. Best control variables (voltage deviation minimization)

	Voltage MinimisationIEEE 30-Bus				
	BBO [42]	MDE [43]	FFA	FPA	MFPA
P1	173.67	175.976	122.13	136.81	93.73
P2	049.06	49.5071	61.53	64.33	55.25
P5	021.77	21.8567	34.24	37.84	46.88
P8	023.27	21.4375	30.07	19.38	33.87
P11	013.84	12.4782	24.12	13.63	29.68
P13	011.98	12.0094	17.79	18.83	28.72
V1	1.0185	1.0420	1.0285	1.0366	1.0200
V2	1.0048	0.9849	1.0257	1.0309	1.0129
V5	1.0145	1.0144	1.0185	1.0174	1.0199
V8	1.0092	0.9988	1.0040	1.0047	1.0048
V11	1.0510	1.0516	1.0001	0.9806	0.9768
V13	1.0184	0.9876	1.0587	0.9960	1.0720
T11	1.0718	1.0718	1.0159	0.99348	0.9888
T12	0.9000	0.9000	0.9537	0.96259	0.9584
T15	1.0000	0.9410	1.0548	0.96932	1.0994
T36	0.9710	0.9706	0.9728	0.97439	0.9518
QC12	0.0370	1.2600	1.26	5.00	0.38
QC15	0.0500	4.9921	1.89	4.85	4.98
QC17	0.0000	0.0036	0.70	1.58	0.04
QC20	0.0500	5.0000	3.92	4.09	4.97
QC21	0.0500	4.9996	2.83	2.19	1.57
QC23	0.0500	4.9954	4.84	4.34	3.87
QC24	0.0500	4.9997	2.19	3.70	3.79
QC29	0.0300	2.6488	2.91	3.01	0.19
Cost ($/h)	805.75	803.79	835.09	833.21	892.17
Power losses (MW)	10.18	9.8653	6.4799	7.4373	4.7121
Voltage deviations	0.0951	0.0941	0.0975	0.0929	**0.0893**
Number of evaluations	-	-	25000	25000	25000

6. CONCLUSION

In this work, the application of MFPA method for solving optimal power flow problem has been presented. The fuel cost, the active power losses and the voltage deviation were minimized through optimization of control variable, the achieved results on IEEE 30 bus system test have been illustrated, the proposed algorithm gives as better results compared with standard FPA and FFA which confirm the robustness of proposed algorithm.

For the future researches it is recommended to use the proposed method to a multi-objective problem. to confirm the effectiveness of the proposed method.

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