Chapter 12

A Flower Pollination Algorithm Approach or Optimal Reactive Power Dispatch

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Abstract

This paper proposes an effective and robust evolutionary optimization technique, known as the Flower Pollination Algorithm (FPA), to address the Optimal Reactive Power Dispatch (ORPD) problem in power systems. The performance of the proposed FPA is evaluated using the standard IEEE 30-bus test system, where control variables include bus voltages, transformer tap settings, and reactive power sources. The objective functions considered are the minimization of active power transmission losses, total voltage deviation, and enhancement of the voltage stability index. The results obtained using FPA are compared with those from other recently developed evolutionary algorithms reported in the literature. Simulation outcomes demonstrate that FPA provides superior performance in terms of solution quality, effectiveness, and convergence speed, making it a promising tool for solving the ORPD problem.

Keywords Optimal Reactive Power Dispatch; Flower Pollination

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Algorithm; Loss Minimization; Voltage Stability; ORPD;

1. Introduction

The Optimal Reactive Power Dispatch (ORPD) problem is recognized as one of the more challenging optimization tasks in power system operation. Reactive power sources include generators, synchronous condensers, capacitor banks, static compensators, and tap-changing transformers. The primary goal in reactive power optimization is to determine the appropriate levels of reactive power generation at various locations in the system to optimize a given objective function.

In essence, the ORPD problem involves the efficient utilization of generator voltage magnitudes, transformer tap settings, and reactive power source outputs to minimize transmission losses and enhance the system's voltage stability. This results in a complex, nonlinear optimization problem.

Historically, several mathematical methods have been applied to address this issue, including the gradient method [1–2], Newton's method [3], and linear programming approaches [4–7]. However, these conventional techniques often encounter limitations, particularly in handling inequality constraints and maintaining accuracy. For instance, the gradient and Newton methods struggle with constraint handling, while linear programming requires linear approximation of nonlinear relationships, which may lead to reduced accuracy.

To overcome these limitations, global optimization techniques such as Genetic Algorithms (GAs) have been explored [8–9]. GAs, inspired by the process of natural selection, are stochastic search methods that have been effectively applied to solve the voltage-constrained reactive power dispatch problem. These algorithms determine the optimal settings of generator voltages, transformer taps, and reactive source outputs, aiming to reduce transmission losses and improve voltage stability. Test results using the IEEE 30-bus system have shown that GAs can achieve near-optimal solutions with lower computational burden and consistent performance [10].

In the present study, the Flower Pollination Algorithm (FPA) is employed to solve the ORPD problem with a focus on improving computational efficiency and convergence behavior. The algorithm is tested on the IEEE 30-bus standard power system. The performance of the proposed FPA approach is benchmarked against other computational intelligence techniques, and the simulation results demonstrate its superior performance in terms of convergence speed and solution quality.

2. Problem Formulation

ORPD problem is, mainly, concerned with either minimisation of PLoss or that of TVD or improvement of VSI, satisfying various equality and inequality constraints.

2.1. Minimisation of Ploss

The general formulation of Ploss minimisation problem may be expressed as follows

$$\text{minimize } J_1(x_1, x_2) = \text{minimize } P_{loss} = \sum_{K=1}^{NL}\left[G_k\left(V_p^2 + V_q^2 - 2V_pV_q\cos\delta_{pq}\right)\right] \quad (1)$$

subject to

$$\begin{Bmatrix} g(X_1, X_2 = 0) \\ h(X_1, X_2 \leq 0) \end{Bmatrix} \quad (2)$$

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where $J_1(x_1, x_2)$ is the active power transmission loss minimisation function, X_1 is the vector of dependent variables consisting of load voltages $\left(V_{L1}, \dots, V_{LN_{PQ}}\right)$ generators' reactive powers $\left(Q_{G1}, \dots, Q_{GN_{PV}}\right)$ and transmission line loadings $\left(S_{L1}, \dots, V_{LN_L}\right)$ X_2 is the vector of control variables consisting of generators' voltages $\left(V_{G1}, \dots, V_{GN_{PV}}\right)$ transformers' tap settings $\left(T_1, \dots, T_{N_T}\right)$ and reactive power injections $\left(Q_{C1}, \dots, Q_{CN_C}\right)$, G_k is the conductance of branch k, V_p, V_q are voltages of the pth and the qth buses, respectively and δ_{pq} is the voltage angle difference between buses p and q. Therefore X_1 and X_2 may be expressed as

$$X_1 = [V_{L1,} \dots \dots . V_{LN_{PQ},} Q_{G1,\dots\dots} Q_{GN_{PV},} S_{L1\dots\dots,} S_{LN_L} \quad (3)$$

$$X_{2=}\left[V_{G1,\dots\dots} V_{GN_{PV},} T_{1,\dots\dots} T_{N_T,} Q_{C1\dots\dots\dots} Q_{CN_C}\right] \quad (4)$$

where NPV is the number of generator buses, NPQ is the number of load buses, NL is the number of transmission lines, NT is the number of tap setting transformer branches and NC is the number of capacitor banks.

2.2. Minimisation of TVD

The general formulation of TVD minimisation objective may be stated as in (5)

$$\text{minimize } J_2(x_1, x_2) = \text{ minimize TVD} = \sum_{P=1}^{N_{PQ}} \left|V_{P-} V_P^{ref}\right| \quad (5)$$

where J2(x1, x2) is the TVD minimisation objective function, Vp is the voltage at bus p and V_P^{ref} is the desired value of the voltage magnitude of the pth bus, taken as 1 pu.

2.3. Improvement of VSI

The general objective of VSI improvement problem may be stated as in (6)

Minimise $J_3(X_1, X_2)$ = Minimise (Lmax)

$$= \min[\ \max(LK)],\quad K=1,2\ N\ P\ Q \tag{6}$$

where Lk is the voltage stability indicator (L-index) of the kth node. The value of Lk may be written as

$$L_k=\left|1-\sum_{P=1}^{NPV} m_{qp}\frac{Vp}{Vq} < \{\lambda pq + (\theta_p - \theta_q)\}\right| \tag{7}$$

where Mqp are the (p, q)th components of the sub-matrices obtained from partial inversion of Ybus matrix.

The value of Mqp is given by (8)

$$M_{qp} = -[Y_{qq}]^{-1}[Y_{qp}] \tag{8}$$

where λpq is the phase angle of Mqp, θp, θq are phase angles of the pth and the qth bus voltages, respectively, Yqq is the self-admittance term of the qth bus and Yqp is the mutual admittance between the qth and pth buses.

2.4. Equality constraints

Constraints representing the load flow equations given by (9)

$$\begin{cases} P_{G_P} - P_{L_P} = \sum_{q=1}^{NB} V_p\,||V_q(G_{pq}\cos\delta_{pq} + B_{Pq}\sin\delta_{pq}) \\ Q_{G_P} - Q_{L_P} = \sum_{q=1}^{NB} Vp||Vq(\,G_{pq}\sin\delta_{pq} - B_{pq}\cos\delta_{pq} \end{cases} \tag{09}$$

where PGp, QGp are injected active and reactive powers, at the pth bus, respectively, PLp , QLp are active and reactive power demands,

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at the pth bus, respectively, Gpq, Bpq are transfer conductance and susceptance, between the pth and the qth buses, respectively and NB is the number of buses.

3. Inequality constraints

3.1. Generator constraints

For all the generator voltages (including slack bus), real and reactive power outputs (including slack bus) must be restricted within their lower and upper limits as stated in (10)

$$\begin{cases} V_{G_P}^{Min} \leq V_{G_P} \leq V_{G_P}^{Max}, p = 1,2, \dots \dots . N_{PV} \\ V_{G_P}^{min} \leq Q_{G_P} \leq Q_{G_P}^{max}, P = 1,2 \dots \dots \dots N_{PV} \end{cases} \tag{10}$$

3.2. Transformer constraints

Transformer tap settings must be within their specified lower and upper limits as presented in (11)

$$T_{G_P}^{min} \leq Q_{G_P} \leq Q_{G_P}^{max}, p = 1,2 \dots \dots . . N_T \tag{11}$$

3.3. Shunt VAR compensator constraints

Reactive power outputs of shunt VAR compensators must be restricted within their lower and upper limits as written in (12)

$$Q_{C_P}^{min} \leq Q_{C_P} \leq Q_{C_P}^{max} \; p = 1,2 \dots \dots N_C \tag{12}$$

3.4. Security constraints

These include the constraints on voltages at load buses and transmission line loadings. Each of these constraints must be within their lower and upper operating limits, as expressed in (13) and (14), respectively

$$V_{LP}^{min} \leq V_{LP} \leq V_{LP}^{max} , p = 1,2 \dots \dots .., N_{PQ} \quad (13)$$

$$S_{LP} \leq S_{LP}^{max}, p = 1,2 \dots \dots . . N_L \quad (14)$$

4. Nature-inspired Flower Pollination Algorithm

The flower reproduction is ultimately through pollination. Flower pollination is connected with the transfer of pollen, and such transfer of pollen is related with pollinators such as insects, birds, animals etc. some type of flowers depend only on specific type of insects or birds for successful pollination. Two main forms of pollination are A-biotic and biotic pollination. 90% of flowering plants are belonging to biotic pollination process. That is, the way of transferring the pollen through insects and animals. 10% of pollination takes A-biotic method, which doesn't need any pollinators. Through Wind and diffusion help pollination of such flowering plants and a good example of A-biotic pollination is Grass [10, 11]. A good example of pollinator is Honey bees, and they have also developed the so-called flower constancy. These pollinators tend to visit exclusively only certain flower species and bypass other flower species. Such type of flower reliability may have evolutionary advantages because this will maximize the transfer of flower pollen .Such type of flower constancy may be advantageous for pollinators also , because they will be sure that nectar supply is available with their some degree of memory and minimum cost of learning, switching or exploring. Rather than focusing on some random, but potentially more satisfying on new flower species, and flower dependability may require minimum investment cost and more likely definite intake of nectar [12]. In the world of flowering plants, pollination can be achieved by self-pollination or crosspollination. Cross-pollination means the

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pollination can occur from pollen of a flower of a different plant, and self-pollination is the fertilization of one flower, such as peach flowers, from pollen of the same flower or different flowers of the same plant, which often occurs when there is no dependable pollinator existing.

Biotic, crosspollination may occur at long distance, by the pollinators like bees, bats, birds and flies can fly a long distance. Bees and Birds may behave as Levy flight behaviour [13], with jump or fly distance steps obeying a Levy allotment. Flower fidelity can be considered as an increment step using the resemblance or difference of two flowers. The biological evolution point of view, the objective of the flower pollination is the survival of the fittest and the optimal reproduction of plants in terms of numbers as well as the largely fittest. The flower reproduction is done through pollination process. Flower pollination is connected with the relocation of pollen and such transfer of pollen is related with pollinators such as insects, birds, animals etc.

The major two pollination are A-biotic and biotic pollination. 90% of flowering plants are belonging to biotic pollination process. That is, the way of transferring the pollen through insects and animals. 10% of pollination takes Abiotic method, which doesn't need any pollinators. . Through Wind and diffusion help pollination of such flowering plants and a good example of A-biotic pollination is Grass. A very good example of pollinator is Honey bees, and they have also developed the so-called flower constancy. These pollinators tend to visit exclusively only certain flower species and bypass other flower species. Such type of flower reliability may have evolutionary advantages because this will maximize the transfer of flower pollen .

4.1. Rules for Flower Pollination Algorithm

1. Biotic and cross-pollination is considered as global pollination

process with pollen- carrying pollinators performing Levy flights.

2. Abiotic and self-pollination are considered as local pollination.

3. Flower constancy can be considered as the reproduction probability is proportional to the similarity of two flowers involved.

4. Local pollination and global pollination is controlled by a switch probability Pa∈ [0, 1]. Due to the physical proximity and other factors such as wind, local pollination can have a significant fraction pa in the overall pollination activities.

4.2. Mathematical representation of Flower Pollination Algorithm

The first rule plus flower constancy can be represented mathematically as

$$x_i^{t+1} = X_i^t + L(X_i^t - g_*) \qquad (15)$$

where X_i^t is the pollen i or solution vector X_i at iteration t, and g_* is the current best solution found among all solutions at the current generation/iteration.

4.3. Levy distribution is given by

$$L \sim \frac{\lambda\Gamma\sin\left(\frac{\pi\lambda}{2}\right)}{\pi}\frac{1}{S^{1+\lambda}}, (S \gg S_0 > 0) \qquad (16)$$

where L is the strength of the pollination should be greater than zero, Γ(λ) is the gamma function and this distribution is valid for large steps s > 0.

The local pollination can be represented as

$$x_i^{t+1} = X_i^t + \varepsilon\left(X_j^t - X_k^t\right) \qquad (17)$$

where, X_j^t and X_k^t are pollens from the different flowers of the same plant species. This essentially mimic the flower constancy in a limited

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neighbourhood. Mathematically, if X_j^t and X_k^t comes from the same species or selected from the same population, this become a local random walk if we draw from a uniform distribution in [0,1].

4.4. Switch probability or proximity probability (pa)

Most flower pollination activities can occur at both local and global scale. In practice, adjacent flower patches or flowers in the not-so-far-away neighbourhood are more likely to be pollinated by local flower pollens that those far away. For this, we use a switch probability (Rule 4) or proximity probability pa to switch between common global pollination to intensive local pollination. in this simulation we used pa=0.6 and pa=0.8 to analyse the simulation result.

4.5. Pseudo code of Flower Pollination Algorithm (FPA)

Objective min or max f(x), x = (x1, x2, ..., xd)

Initialize a population of n flowers/pollen gametes with random solutions

Find the best solution g_* in the initial population

Define a switch probability Pa∈ [0, 1].

while (t <MaxGeneration)

for i = 1 n (all n flowers in the population)

if rand < pa,

Draw a (d-dimensional) step vector L which obeys a Levy distribution

Global pollination via $x_i^{t+1} = X_i^t + L(X_i^t - g_*)$

else

Draw ε from a uniform distribution in [0,1]

Randomly choose j and k among all the solutions

Do local pollination via $x_i^{t+1} = X_i^t + \varepsilon(X_j^t - X_k^t)$

end if

Evaluate new solutions

If new solutions are better, update them in the population

end for

Find the current best solution g_*

end while

5. Simulation Results

FPA based results of the ORPD problem for Ploss, TVD and L-index minimisation objective of this test system is presented in Table 1. These results are compared with those offered by the algorithms such as KHA and CKHA.

Table 1: Best control variable settings for power loss, TVD and L-index minimisation

Control variables	KHA [18]	CKHA [18]	Proposed FPA For Loss Minimization	Proposed FPA For TVD Minimization	Proposed FPA For L-index Minimization
V_{G1}	1.05	1.05	1.05	1.05	1.05
V_{G2}	1.0381	1.0473	1.0278	1.0256	1.02389
V_{G5}	1.011	1.0293	1.0293	1.0238	1.0229
V_{G8}	1.025	1.035	1.028	1.016	1.012
V_{G11}	1.05	1.05	1.05	1.05	1.05
V_{G13}	1.05	1.05	1.05	1.05	1.05
T_{11}	0.9541	0.9916	0.9686	0.9548	0.9489
T_{12}	1.0412	0.9538	1.9538	1.9486	1.9369
T_{15}	0.9514	0.9603	0.9331	0.9327	0.9347
T_{36}	0.9541	0.967	0.948	0.948	0.946
QC_{10}	0.0089	0.0092	0.0092	0.0091	0.0097
QC_{12}	0	0	0	0	0
QC_{15}	0.0141	0.0153	0.0148	0.0139	0.0127
QC_{17}	0.0498 9	0.0497	0.0495	0.0492	0.0492
QC_{20}	0.0314	0.0302	0.0301	0.03	0.03

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QC_{21}	0.0345	0.05	0.045	0.033	0.041
QC_{23}	0.0241	0.0134	0.0234	0.0231	0.0238
QC_{24}	0.05	0.05	0.05	0.05	0.04
QC_{29}	0.0107	0.0121	0.0111	0.0118	0.0116
Ploss, MW	3.65	3.24	3.21	3.52	3.71
TVD, pu	1.3415	1.3364	1.3856	1.3356	1.3589
L-index, pu	0.1425	0.1402	0.1416	0.1437	0.1376

6. Conclusion

In this paper, the Flower Pollination Algorithm (FPA) is proposed as a solution to the Optimal Reactive Power Dispatch (ORPD) problem in power systems characterized by varying levels of dimensionality and complexity. To evaluate the effectiveness and robustness of the proposed approach, it is applied to the standard IEEE 30-bus power system. The simulation results obtained using FPA are compared with those produced by other well-known techniques recently reported in the literature. The comparison clearly demonstrates that the proposed FPA offers improved efficiency, greater flexibility, and enhanced stability, making it a promising tool for solving complex ORPD problems.

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