Solution of Optimal Reactive Power Dispatch by Flower Pollination Algorithm

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Abstract: This study presents an efficient and reliable evolutionary-based approach, termed as Flower Pollination Algorithm (FPA), to solve the optimal reactive power dispatch (ORPD) problem of power system. The performance of the proposed FPA is examined and tested, successfully, on standard IEEE-30 test power systems for the solution of ORPD problem in which control of bus voltages, tap position of transformers and reactive power sources are involved. The objective function considered is either minimisation of active power transmission loss or that of total voltage deviation or enhancement of voltage stability index. The results offered by the proposed FPA are compared with those offered by other evolutionary optimisation techniques surfaced in the recent state-of-the-art literature. Simulation results indicate that the proposed FPA yields superior solution over the other recently surfaced popular techniques in terms of effectiveness and convergence speed.

Keywords: Reactive Power Dispatch, Flower Pollination Algorithm, Loss minimization.

I. INTRODUCTION

Optimal reactive power dispatch problem is one of the difficult optimization problems in power systems. The sources of the reactive power are the generators, synchronous condensers, capacitors, static compensators and tap changing transformers. The problem that has to be solved in a reactive power optimization is to determine the required reactive generation at various locations so as to optimize the objective function. Here the reactive power dispatch problem involves best utilization of the existing generator bus voltage magnitudes, transformer tap setting and the output of reactive power sources so as to minimize the loss and to enhance the voltage stability of the system. It involves a non linear optimization problem. Various mathematical techniques have been adopted to solve this optimal reactive power dispatch problem. These include the gradient method [1-2], Newton method [3] and linear programming [4-7]. The gradient and Newton methods suffer from the difficulty in handling inequality constraints. To apply linear programming, the input-output function is to be expressed as a set of linear functions which may lead to loss of accuracy. Recently global optimization techniques such as genetic algorithms have been proposed to solve the reactive power flow problem [8, 9]. A genetic algorithm is a stochastic search technique based on the mechanics of natural selection. In this paper, genetic algorithm is used to solve the voltage constrained reactive power dispatch problem. The proposed algorithm identifies the optimal values of generation bus voltage magnitudes, transformer tap setting and the output of the reactive power sources so as to minimize the transmission loss and to improve the voltage stability. The effectiveness of the proposed approach is demonstrated through IEEE-30 bus system. The test results show the proposed algorithm gives better results with less computational burden and is fairly consistent in reaching the near optimal solution [10]. In this paper, FPA is applied for achieving enhanced computational speed and improved convergence profile of ORPD problem on standard IEEE-30 bus power system. The simulation results yielded by the proposed FPA technique are compared with those offered by the other computational intelligence-based techniques.

II. 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.

Minimisation of $P_{loss}$:
The general formulation of $P_{loss}$ minimisation problem may be expressed as follows:

$$\text{minimize } J_1(x_1, x_2) = \text{minimize } P_{loss} \sum_{k=1}^{N_L} \left[ G_k \left( V_p^2 + V_q^2 - 2V_pV_q \cos \delta_{pq} \right) \right]$$  \hspace{1cm} (1)
subject to
\[
\begin{align*}
 g(X_1, X_2 = 0) & \\
 h(X_1, X_2 \leq 0)
\end{align*}
\] (2)

where \( f_1(x_1, x_2) \) is the active power transmission loss minimisation function, \( x_1 \) is the vector of dependent variables consisting of load voltages \( \left(V_{L1}, ..., V_{LNpq}\right) \) generators’ reactive powers \( \left(Q_{G1}, ..., Q_{GNPV}\right) \) and transmission line loadings \( \left(S_{L1}, ..., S_{LN}\right) \). \( x_2 \) is the vector of control variables consisting of generators’ voltages \( \left(V_{G1}, ..., V_{GNpq}\right) \) transformers’ tap settings \( \left(T_1, ..., T_{Nt}\right) \) and reactive power injections \( \left(Q_{C1}, ..., Q_{CNc}\right) \). \( G_k \) is the conductance of branch \( k \). \( V_p, V_q \) are voltages of the \( p \)th and the \( q \)th buses, respectively and \( \delta_{pq} \) is the voltage angle difference between buses \( p \) and \( q \). Therefore \( X_1 \) and \( X_2 \) may be expressed as
\[
\begin{align*}
 X_1 & = [V_{L1}, ..., V_{LNpq}, Q_{G1}, ..., Q_{GNPV}, S_{L1}, ..., S_{LN}] \\
 X_2 & = [V_{G1}, ..., V_{GNpq}, T_1, ..., T_{Nt}, Q_{C1}, ..., Q_{CNc}]
\end{align*}
\] (3)

(4)

where \( N_{pq} \) is the number of generator buses, \( N_{pq} \) is the number of load buses, \( N_t \) is the number of transmission lines, \( N_l \) is the number of tap setting transformer branches and \( N_c \) is the number of capacitor banks.

**Minimisation of TVD:**

The general formulation of TVD minimisation objective may be stated as in (5)
\[
\text{minimize } J_2(x_1, x_2) = \text{minimise } \text{TVD} = \sum_{p=1}^{N_{pq}} |V_p - V_p^{\text{ref}}|
\] (5)

where \( J_2(x_1, x_2) \) is the TVD minimisation objective function, \( V_p \) is the voltage at bus \( p \) and \( V_p^{\text{ref}} \) is the desired value of the voltage magnitude of the \( p \)th bus, taken as 1 pu.

**Improvement of VSI:**

The general objective of VSI improvement problem may be stated as in (6)
\[
\text{Minimise } J_3(X_1, X_2) = \text{Minimise}(L_{max}) = \min \{ \max(L_k) \}, \quad K=1,2, \quad N \text{ P Q}
\] (6)

where \( L_k \) is the voltage stability indicator (L-index) of the \( k \)th node. The value of \( L_k \) may be written as
\[
L_k = \left| 1 - \sum_{p=1}^{N_{pq}} \text{M}_{pq} \frac{V_p}{V_q} \right| < \left\{ \lambda_{pq} + \left( \theta_p - \theta_q \right) \right\}
\] (7)

where \( \text{M}_{pq} \) are the \( (p, q) \)th components of the sub-matrices obtained from partial inversion of \( Y_{bus} \) matrix. The value of \( \text{M}_{pq} \) is given by (8)
\[
\text{M}_{pq} = -\left[Y_{qq}\right]^{-1}Y_{qp}
\] (8)

where \( \lambda_{pq} \) is the phase angle of \( \text{M}_{pq} \), \( \theta_p, \theta_q \) are phase angles of the \( p \)th and the \( q \)th buses voltages, respectively. \( Y_{qq} \) is the self-admittance term of the \( q \)th bus and \( Y_{qp} \) is the mutual admittance between the \( q \)th and \( p \)th buses.

**Equality constraints:**

constraints representing the load flow equations given by (9)
\[
\begin{align*}
 P_{Gp} - P_{LP} & = \sum_{q=1}^{NB} V_p |V_q (C_{pq} \cos \delta_{pq} + B_{pq} \sin \delta_{pq}) | \\
 Q_{Gp} - Q_{LP} & = \sum_{q=1}^{NB} V_p |V_q (C_{pq} \sin \delta_{pq} - B_{pq} \cos \delta_{pq}) |
\end{align*}
\] (9)

where \( P_{Gp}, Q_{Gp} \) are injected active and reactive powers, at the \( p \)th bus, respectively, \( P_{LP}, Q_{LP} \) are active and reactive power demands, at the \( p \)th bus, respectively, \( G_{pq}, B_{pq} \) are transfer conductance and susceptance, between the \( p \)th and the \( q \)th buses, respectively and \( NB \) is the number of buses.
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 cross-pollination. Cross-pollination means the 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, cross-pollination 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.
A. 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 \( p_a \in [0, 1] \). Due to the physical proximity and other factors such as wind, local pollination can have a significant fraction \( p_a \) in the overall pollination activities.

B. Mathematical representation of Flower Pollination Algorithm.
The first rule plus flower constancy can be represented mathematically as
\[
x_i^{t+1} = X_i^t + L(X_i^t - g_*)
\]
(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.
Levy distribution is given by
\[
L \sim \frac{\lambda \Gamma(\frac{\lambda}{2})}{\pi} \frac{1}{S^{\frac{\lambda}{2} + 1}}, (S \gg S_0 > 0)
\]
(16)
where \( L \) is the strength of the pollination should be greater than zero, \( \Gamma(\lambda) \) is the gamma function and this distribution is valid for large steps \( S > 0 \).
The local pollination can be represented as
\[
x_i^{t+1} = X_i^t + \varepsilon(X_j^t - X_k^t)
\]
(17)
where, \( X_i^t \) and \( X_j^t \) are pollens from the different flowers of the same plant species. This essentially mimic the flower constancy in a limited neighbourhood. Mathematically, if \( X_i^t \) and \( X_j^t \) 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 \([0,1]\).

C. Switch probability or proximity probability (\( p_a \)).
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 \( p_a \) to switch between common global pollination to intensive local pollination. in this simulation we used \( p_a=0.6 \) and \( p_a=0.8 \) to analyse the simulation result.

D. Pseudo code of Flower Pollination Algorithm (FPA).
Objective min or max \( f(x) \), \( x = (x_1, x_2, ..., x_d) \)
Initialize a population of \( n \) flowers/pollen gametes with random solutions
Find the best solution \( g_* \) in the initial population
Define a switch probability \( p_a \in [0, 1] \).
while (\( t < \text{MaxGeneration} \))
for \( i = 1 : n \) (all \( n \) flowers in the population)
if \( \text{rand} < p_a \),
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 \( \varepsilon \) 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.
IV. SIMULATION RESULTS

FPA based results of the ORPD problem for Ploss, TVD and L-index minimization 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 minimization.

<table>
<thead>
<tr>
<th>Control variables</th>
<th>KHA [18]</th>
<th>CKHA [18]</th>
<th>Proposed FPA For Loss Minimization</th>
<th>Proposed FPA For TVD Minimization</th>
<th>Proposed FPA For L-index Minimization</th>
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<tr>
<td>V_{G1}</td>
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<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
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<tr>
<td>V_{G2}</td>
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<td>1.0473</td>
<td>1.0278</td>
<td>1.0256</td>
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<td>V_{G5}</td>
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<td>V_{G8}</td>
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<td>V_{G11}</td>
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<td>1.05</td>
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<tr>
<td>V_{G13}</td>
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<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
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</tr>
<tr>
<td>T_{11}</td>
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<td>0.9916</td>
<td>0.9686</td>
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<td>T_{12}</td>
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<td>1.9486</td>
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<tr>
<td>T_{15}</td>
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<tr>
<td>T_{36}</td>
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<td>0.967</td>
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<td>0.948</td>
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<td>Q_{C10}</td>
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<td>0.0097</td>
</tr>
<tr>
<td>Q_{C12}</td>
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<td>0</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q_{C15}</td>
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<td>0.0153</td>
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<td>Q_{C17}</td>
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<td>0.045</td>
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<td>Q_{C24}</td>
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<td>0.05</td>
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<tr>
<td>Q_{C29}</td>
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<td>Ploss, MW</td>
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<td>3.71</td>
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<td>1.3856</td>
<td>1.3256</td>
<td>1.3589</td>
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<td>L-index, pu</td>
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<td>0.1402</td>
<td>0.1416</td>
<td>0.1427</td>
<td>0.1389</td>
</tr>
</tbody>
</table>

Figure 1. Convergence characteristics of loss, TVD and L-index minimization

V. CONCLUSION

In this paper, FPA is proposed to solve the ORPD problem of power system having varying degree of dimensions and complexities. To check the superiority of the proposed FPA, it is tested on standard IEEE-30 bus power system. Simulation results, as offered by the proposed FPA is compared with other popular techniques recently reported in the recent state-of-the-art literatures and it is proved that this method having better efficiency, flexibility and good stability.
REFERENCES