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FLOWER POLLINATION ALGORITHM FOR SOLVING OPTIMAL REACTIVE POWER DISPATCH PROBLEM

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Abstract: **This paper proposes a Flower Pollination Algorithm for solving the multi-objective reactive power dispatch problem. Minimization of real power loss and enhancement voltage stability index margin is taken as objective. Flower pollination algorithm is a new nature-inspired algorithm, based on the characteristics of flowering plants. The simulation results demonstrate better performance of the FPA in solving an optimal reactive power dispatch problem. In order to evaluate the performance of the proposed algorithm, it has been tested on IEEE 30 bus system and compared to other algorithms. Simulation results show that FPA is better than other algorithms in reducing the real power loss and enhancing the voltage stability.**

Keywords: **flower algorithm, optimization, metaheuristics, optimal reactive power, Transmission loss.**

I. INTRODUCTION

Power system reliability is related to security, and safety criteria refer to continuity of service, stability of frequency and specified voltage limits. Main task is to maintain the voltage profiles within the limits for that the injection and removal of reactive power has great influence. The accurate management of reactive power resources is one of the main ways for the safe operation of transmission systems. The poor management of reactive power sources confines the active power transmission, which can cause unmanageable lows of voltage and tension fall down in the load buses. Optimal reactive power dispatch in power system is subject to reservations at least in the best case to uncertainty parameters given in the demand and the availability equivalent of shunt reactive power compensators. Optimal reactive power dispatch is a key factor for the operation and control of power systems, and should be carried out properly so that system reliability is not affected.The gradient method [1, 2], Newton method [3] and linear programming [4-7] suffer from the difficulty of handling the inequality constraints. Recently Global Optimization techniques such as genetic algorithms have been proposed to solve the reactive power flow problem [8.9]. In recent years, the problem of voltage stability and voltage collapse has become a major concern in power system planning and operation. This paper formulate the reactive power dispatch as a multi-objective optimization problem with real power loss minimization and maximization of static voltage stability margin (SVSM) as the objectives. Voltage stability evaluation using modal analysis [10] is used as the indicator of voltage stability. The meta-heuristic algorithms have impressive features that differs them from the gradient based methods. In the field of structural optimization, genetic algorithms (GA) [11-12], particle swarm optimization (PSO) [13-14] and Ant colony optimization (ACO) [15-16] are the most admired algorithms used to solve various optimization problems. Flowering plant [17] has been evolving for at least more than million of million years. It is approximate that there are over a section of a million types of flowering plants in Nature and that about 90% of all plant species are flowering species. In this paper the flower pollination algorithm (FPA) is used to solve the optimal reactive power problem. The performance of FPA has been evaluated in standard IEEE 30 bus test system and the simulation results shows that our proposed method outperforms all approaches investigated in this paper.

II. VOLTAGE STABILITY EVALUATION

A) Modal Analysis For Voltage Stability Evaluation

Modal analysis is one among best methods for voltage stability enhancement in power systems. The linearized steady state system power flow equations are given by.

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}J_{p\theta} & J_{pv}\\ J_{q\theta} & J_{QV}\end{bmatrix} \quad (1)$$

Where

ΔP = Incremental change in bus real power.

ΔQ = Incremental change in bus reactive

Power injection

$\Delta\theta$ = incremental change in bus voltage angle.

ΔV = Incremental change in bus voltage Magnitude

$J_{p\theta}$, J_{PV} , $J_{Q\theta}$, J_{QV} jacobian matrix are the sub-matrixes of the System voltage stability is affected by both P and Q. However at each operating point we keep P constant and evaluate voltage stability by considering incremental relationship between Q and V.

To reduce (1), let $\Delta P = 0$, then.

$$\Delta Q = \left[J_{QV} - J_{Q\theta}J_{P\theta^{-1}}J_{PV}\right]\Delta V = J_R\Delta V \quad (2)$$

$$\Delta V = J^{-1} - \Delta Q \quad (3)$$

Where

$$J_R = \left(J_{QV} - J_{Q\theta}J_{P\theta^{-1}}JPV\right) \quad (4)$$

J_R is called the reduced Jacobian matrix of the system.

B) Modes Of Voltage Instability

Voltage Stability characteristics of the system can be known by computing the Eigen values and Eigen vectors

Let

$$J_R = \xi\wedge\eta \quad (5)$$

Where,

ξ = right eigenvector matrix of J_R

η = left eigenvector matrix of J_R

$\wedge$ = diagonal Eigen value matrix of J_R and

$$J_{R^{-1}} = \xi\wedge^{-1}\eta \quad (6)$$

From (3) and (6), we have

$$\Delta V = \xi\wedge^{-1}\eta\Delta Q \quad (7)$$

or

$$\Delta V = \sum_I \frac{\xi_i\eta_i}{\lambda_i}\Delta Q \quad (8)$$

Where ξ_i is the ith column right Eigen vector and η the ith row left eigenvector of J_R.

λ_i is the ith eigen value of J_R.

The ith modal reactive power variation is,

$$\Delta Q_{mi} = K_i\xi_i \quad (9)$$

where,

$$K_i = \sum_j \xi_{ij^2} - 1 \quad (10)$$

Where

ξ_{ji} is the jth element of ξ_i

The corresponding ith modal voltage variation is

$$\Delta V_{mi} = [1/\lambda_i]\Delta Q_{mi} \qquad (11)$$

In (8), let $\Delta Q = e_k$ where e_k has all its elements zero except the kth one being 1. Then,

$$\Delta V = \sum_i \frac{\eta_{1k}\ \xi_1}{\lambda_1} \qquad (12)$$

η_{1k} k th element of η_1

V –Q sensitivity at bus k

$$\frac{\partial V_K}{\partial Q_K} = \sum_i \frac{\eta_{1k}\ \xi_1}{\lambda_1} = \sum_i \frac{P_{ki}}{\lambda_1} \qquad (13)$$

III. PROBLEM FORMULATION

The objectives of the reactive power dispatch problem is to minimize the system real power loss and maximize the static voltage stability margins (SVSM) index.

Minimization of Real Power Loss

It is aimed in this objective that minimizing of the real power loss (Ploss) in transmission lines of a power system. This is mathematically stated as follows.

$$P_{loss} = \sum_{\substack{k=1 \\ k=(i,j)}}^{n} g_{k}(V_i^2 + V_j^2 - 2V_i V_j \cos\theta_{ij}) \qquad (14)$$

Where n is the number of transmission lines, g_k is the conductance of branch k, V_i and V_j are voltage magnitude at bus i and bus j, and θij is the voltage angle difference between bus i and bus j.

Minimization of Voltage Deviation

The objective of minimizing the Deviations in voltage magnitudes (VD) at load buses is mathematically stated as follows.

$$\text{Minimize VD} = \sum_{k=1}^{nl} |V_k - 1.0| \qquad (15)$$

Where nl is the number of load busses and V_k is the voltage magnitude at bus k.

System Constraints

Objective functions are subjected to these constraints shown below.

Load flow equality constraints:

$$P_{Gi} - P_{Di} - V_{i\sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \cos\theta_{ij} \\ +B_{ij} & \sin\theta_{ij} \end{bmatrix} = 0, i = 1,2 \ldots., nb \qquad (16)$$

$$Q_{Gi} - Q_{Di} - V_{i\sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \cos\theta_{ij} \\ +B_{ij} & \sin\theta_{ij} \end{bmatrix} = 0, i = 1,2 \ldots., nb$$

(17)

where, *nb* is the number of buses, P_G and Q_G are the real and reactive power of the generator, P_D and Q_D are the real and reactive load of the generator, and G_{ij} and B_{ij} are the mutual conductance and susceptance between bus *i* and bus *j*.

Generator bus voltage (V_{Gi}) inequality constraint:

$$V_{Gi}^{min} \le V_{Gi} \le V_{Gi}^{max}, i \in ng \qquad (18)$$

Load bus voltage (V_{Li}) inequality constraint:

$$V_{Li}^{min} \le V_{Li} \le V_{Li}^{max}, i \in nl \quad (19)$$

Switchable reactive power compensations (Q_{Ci}) inequality constraint:

$$Q_{Ci}^{min} \le Q_{Ci} \le Q_{Ci}^{max}, i \in nc \ (20)$$

Reactive power generation (Q_{Gi}) inequality constraint:

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max}, i \in ng \quad (21)$$

Transformers tap setting (T_i) inequality constraint:

$T_i^{min} \leq T_i \leq T_i^{max}, i \in nt$ (22)

Transmission line flow (S_{Li}) inequality constraint:

$S_{Li}^{min} \leq S_{Li}^{max}, i \in nl$ (23)

Where, nc, ng and nt are numbers of the switchable reactive power sources, generators and transformers.

IV. 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 [18, 19]. 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 [20]. In the world of flowering plants, pollination can be achieved by self-pollination or crosspollination. 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, 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 [21], 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.

Flower Pollination Algorithm

Generally we use the following systems in FPA,

- System 1. Biotic and cross-pollination has been treated as global pollination process, and pollen-carrying pollinators travel in a way which obeys Levy flights.
- System 2. For local pollination, A- biotic and self-pollination has been utilized.
- System 3. Pollinators such as insects can develop flower reliability, which is equivalent to a reproduction probability and it is proportional to the similarity of two flowers implicated.
- System 4. The communication of local pollination and global pollination can be controlled by a control probability $p \in [0, 1]$, with a slight bias towards local pollination.

System 1 and flower reliability can be represented mathematically as

$x_i^{t+1} = x_i^t + \gamma L(\lambda)(x_i^t - g_*)$ (24)

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. Here γ is a scaling factor to control the step size. $L(\lambda)$ is the parameter that corresponds to the strength of the pollination, which essentially is also the step size. Since insects may move over a long distance with various distance steps, we can use a Levy flight to mimic this characteristic efficiently. We draw $L > 0$ from a Levy distribution

$L \sim \frac{\lambda \Gamma(\lambda \sin(\Pi\lambda/2))}{\Pi} \frac{1}{s^{1+\lambda}}, (s \gg s_0 > 0)$ (25)

Here, $\Gamma(\lambda)$ is the standard gamma function, and this distribution is valid for large steps $s > 0$.

Then, to model the local pollination, for both system 2 and system 3 can be represented as

$x_i^{t+1} = x_i^t + \in \left(x_j^t - x_k^t\right)$ (26)

Where x_j^t and x_k^t are pollen from different flowers of the same plant species. This essentially mimics the flower reliability in a limited neighbourhood. Mathematically, if x_j^t and x_k^t comes from the same species or selected from the same population, this equivalently becomes a local random walk if we draw ∈ from a uniform distribution in [0,1]. Though Flower pollination performance can occur at all balance, local and global, neighbouring flower patch or flowers in the not-so-far-away neighbourhood are more likely to be pollinated by local flower pollen than those far away. In order to mimic this, we can effectively use a control probability (system 4) or proximity probability *p* to switch between common global pollination to intensive local pollination. To start with, we can use a raw value of *p* = 0.8 as an initially value.

The simplest method is to use a weighted sum to combine all multiple objectives into a composite single objective

$$f = \sum_{i=1}^{m} w_i f_i \quad \sum_{i=1}^{m} w_i = 1 \ , w_i > 0$$

Where *m* is the number of objectives and w_i(i = 1, ...,m) are non-negative weights.

FP Algorithm for solving optimal reactive power optimization

- *Step 1. Objective min of (x), x = (x_1, x_2, ..., x_d)*
- *Step 2. Initialize a population of n flowers*
- *Step 3. Find the best solution g_* in the initial population*
- *Step 4. Define a control probability p ∈ [0, 1]*
- *Step5. Define a stopping criterion (a fixed number of generations/iterations)*
- *Step6. while (t < Max Generation)*
- *Step6. for i = 1 : n (all n flowers in the population)*
- *Step7. if rand < p,*
- *Step8. Draw a (d-dimensional) step vector L which obeys a Levy distribution Global pollination through $x_i^{t+1} = x_i^t + L(x_i^t - g_*)$*
  - *else*
- *step9. Draw ∈ from a uniform distribution in [0,1]*
- *step 10.Do local pollination through $x_i^{t+1} = x_i^t + \in \left(x_j^t - x_k^t\right)$*
  - *end if*
- *step10. Evaluate new solutions*
- *step11. If new solutions are better, update them in the population*
  - *end for*
- *step12. Find the current best solution g_**
  - *end while*
- *Output - best solution has been found*

V. SIMULATION RESULTS

The validity of the proposed Algorithm technique is demonstrated on IEEE-30 bus system. The IEEE-30 bus system has 6 generator buses, 24 load buses and 41 transmission lines of which four branches are (6-9), (6-10) , (4-12) and (28-27) - are with the tap setting transformers. The lower voltage magnitude limits at all buses are 0.95 p.u. and the upper limits are 1.1 for all the PV buses and 1.05 p.u. for all the PQ buses and the reference bus. The simulation results has been presented in Tables 1, 2, 3 &4. And in the table 5 shows clearly that proposed algorithm efficiently reduces the real power losses when compared to other given algorithms. The optimal values of the control variables along with the minimum loss obtained are given in Table 1. Equivalent to this control variable setting, it was found that there are no limit violations in any of the state variables.

TABLE 1. RESULTS OF FPA – ORPD OPTIMAL CONTROL VARIABLES

Control variables	***Variable setting***
V1	1.045
V2	1.043
V5	1.042
V8	1.032
V11	1.011
V13	1.040
T11	1.09
T12	1.02
T15	1.1
T36	1.0
Qc10	3
Qc12	2
Qc15	4
Qc17	0
Qc20	3
Qc23	4
Qc24	3
Qc29	3
Real power loss	4.2445
SVSM	0.2455

ORPD including voltage stability constraint problem was handled in this case as a multi-objective optimization problem where both power loss and maximum voltage stability margin of the system were optimized concurrently. Table 2 indicates the optimal values of these control variables. Also it is found that there are no limit violations of the state variables. It indicates the voltage stability index has increased from 0.2455 to 0.2472, an advance in the system voltage stability. To determine the voltage security of the system, contingency analysis was conducted using the control variable setting obtained in case 1 and case 2. The Eigen values equivalents to the four critical contingencies are given in Table 3. From this result it is observed that the Eigen value has been improved considerably for all contingencies in the second case.

TABLE 2. RESULTS OF FPA -VOLTAGE STABILITY CONTROL REACTIVE POWER DISPATCH OPTIMAL CONTROL VARIABLES

Control Variables	***Variable Setting***
V1	1.043
V2	1.041
V5	1.039
V8	1.031
V11	1.008
V13	1.036
T11	0.091
T12	0.090
T15	0.092
T36	0.090
Qc10	2
Qc12	1
Qc15	3
Qc17	2
Qc20	0
Qc23	3
Qc24	4
Qc29	4
Real power loss	4.9901
SVSM	0.2472

TABLE 3. VOLTAGE STABILITY UNDER CONTINGENCY STATE

Sl.No	***Contigency***	***ORPD Setting***	***VSCRPD Setting***
1	28-27	0.1400	0.1420
2	4-12	0.1648	0.1661
3	1-3	0.1774	0.1753
4	2-4	0.2022	0.2031

TABLE 4. LIMIT VIOLATION CHECKING OF STATE VARIABLES

State variables	***limits***		***ORPD***	***VSCRPD***
	Lower	***upper***		
Q1	-20	152	1.3422	-1.3269
Q2	-20	61	8.9900	9.8232
Q5	-15	49.92	25.920	26.001
Q8	-10	63.52	38.8200	40.802
Q11	-15	42	2.9300	5.002
Q13	-15	48	8.1025	6.033
V3	0.95	1.05	1.0372	1.0392
V4	0.95	1.05	1.0307	1.0328
V6	0.95	1.05	1.0282	1.0298
V7	0.95	1.05	1.0101	1.0152
V9	0.95	1.05	1.0462	1.0412
V10	0.95	1.05	1.0482	1.0498
V12	0.95	1.05	1.0400	1.0466
V14	0.95	1.05	1.0474	1.0443
V15	0.95	1.05	1.0457	1.0413
V16	0.95	1.05	1.0426	1.0405
V17	0.95	1.05	1.0382	1.0396
V18	0.95	1.05	1.0392	1.0400
V19	0.95	1.05	1.0381	1.0394
V20	0.95	1.05	1.0112	1.0194
V21	0.95	1.05	1.0435	1.0243
V22	0.95	1.05	1.0448	1.0396
V23	0.95	1.05	1.0472	1.0372
V24	0.95	1.05	1.0484	1.0372
V25	0.95	1.05	1.0142	1.0192
V26	0.95	1.05	1.0494	1.0422
V27	0.95	1.05	1.0472	1.0452
V28	0.95	1.05	1.0243	1.0283
V29	0.95	1.05	1.0439	1.0419
V30	0.95	1.05	1.0418	1.0397

TABLE 5. COMPARISON OF REAL POWER LOSS

Method	***Minimum loss***
Evolutionary programming[22]	5.0159
Genetic algorithm[23]	4.665
Real coded GA with Lindex as SVSM[24]	4.568
Real coded genetic algorithm[25]	4.5015
Proposed FPA method	4.2445

VI. CONCLUSION

In this FPA algorithm is used to solve optimal reactive power dispatch problem by considering various generator constraints. The proposed method formulates reactive power dispatch problem as a mixed integer non-linear optimization problem and determines control strategy with continuous and discrete control variables such as generator bus voltage, reactive power generation of capacitor banks and on load tap changing transformer tap position. The performance of the proposed algorithm has been confirmed through its voltage stability evaluation by modal analysis and is effective at various instants following system contingencies. Also this method has a good performance for voltage stability Enhancement of large, complex power system networks. The effectiveness of the proposed method is demonstrated on IEEE 30-bus system. Simulation results shows that Real power loss has been considerably reduced and voltage profile index within the specified limits.

VII. NOMENCLATURE

NB number of buses in the system
Ng number of generating units in the system
tk tap setting of transformer branch k
Psl real power generation at slack bus
Vi voltage magnitude at bus i
Pi,Qi real and reactive powers injected at bus i
Pgi,Qgi real and reactive power generations at bus i
Gij,Bij mutual conductance and susceptance between bus i and j
Gii,Bii self conductance and susceptance of bus i
θij voltage angle difference between bus i and j

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