FRAGARIA DALTONIANA ALGORITHM FOR SOLVING OPTIMAL REACTIVE POWER DISPATCH PROBLEM

Lenin **KANAGASABAI**

Prasad V.Potluri Siddhartha Institute of Technology, Kanuru, Vijayawada, 520007, Andhra Pradesh, India

gklenin@gmail.com

Keywords: optimization, reactive power, transmission loss, Fragaria Daltoniana plant

Abstract*: This paper projects Fragaria Daltoniana Algorithm (FDA) to solve optimal reactive power dispatch problem. Fragaria Daltoniana plant develops sprinter, roots for spread and pursuit for water resources & mineral deposit. In Fragaria Daltoniana plant sprinter, roots are whispered as implement for global and local searches. The planned Fragaria Daltoniana Algorithm (FDA) will replicate the computational agents at all iterations, revealing all agents to both minute and big movements from the begin to end & data exchange between agents. The proposed Fragaria Daltoniana Algorithm (FDA) has been tested on standard IEEE 30 bus test system and simulation results show evidently the better performance of the projected FDA in reducing the real power loss & enhancement of static voltage stability margin.*

1. INTRODUCTION

In recent years the optimal reactive power dispatch (ORPD) problem has received great attention as a result of improving in economy and security of power system operation. Solutions of ORPD problem aim to minimize object functions such as fuel cost, power system loses, etc. while satisfying a number of constraints like limits of bus voltages, tap settings of transformers, reactive and active power of power resources and transmission lines and a number of controllable Variables. Various numerical methods like the gradient method [1-2], Newton method [3] and linear programming [4-7] have been implemented to solve the optimal reactive power dispatch problem. Both the gradient and Newton methods have the intricacy in managing inequality constraints. The problem of voltage stability and collapse play a key role in power system planning and operation [8]. Evolutionary algorithms such as genetic algorithm have been already projected to solve the reactive power flow problem [9-11]. Evolutionary algorithm is a heuristic methodology used for minimization problems by utilizing nonlinear and non-differentiable continuous space functions. In [12], Hybrid differential evolution algorithm is projected to increase the voltage stability index. In [13] Biogeography Based algorithm is projected to solve the reactive power dispatch problem. In [14], a fuzzy based method is used to solve the optimal reactive power scheduling method. In [15], an improved evolutionary programming is used to elucidate the optimal reactive power dispatch problem. In [16], the optimal reactive power flow problem is solved by integrating a genetic algorithm with a nonlinear interior point method. In [17], a pattern algorithm is used to solve ac-dc optimal reactive power flow model with the generator capability limits. In [18], F. Capitanescu proposes a two-step approach to calculate Reactive power reserves with respect to operating constraints and voltage stability. In [19], a programming based approach is used to solve the optimal reactive power dispatch problem. In [20], A. Kargarian et al present a probabilistic algorithm for optimal reactive power provision in hybrid electricity markets with uncertain loads. This paper projects Fragaria Daltoniana Algorithm (FDA) to solve optimal reactive power dispatch problem. In the iteration's the capacity of computational agents is imitated in a suitable manner & prejudice the weakest agents. Computational agent is endangered to both minute and big movements repeatedly from begin to end & it conceivably achieve the local and global explorations synchronously. In the projected Fragaria Daltoniana Algorithm (FDA) the computational agents do not communicate with each other, and the above said duplication-elimination procedure are united with a kind of sifter that influence the agents on the path to the global best solution. The proposed Fragaria Daltoniana Algorithm (FDA) has been evaluated on standard IEEE 30 bus test system. The simulation results show that the projected Fragaria Daltoniana Algorithm (FDA) surpasses all the entitled reported algorithms in minimizing the real power loss and static voltage stability margin also enhanced.

2. VOLTAGE STABILITY EVALUATION

2.1. Modal analysis for voltage stability evaluation

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

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

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.

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

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

$$\Delta V = J^{-1} - \Delta Q \tag{3}$$

where:

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

J_R is called the reduced Jacobian matrix of the system.

2.2. Modes of Voltage instability

Voltage Stability characteristics of the system have been identified by computing the eigenvalues and eigenvectors.

Let

$$J_R = \xi \wedge \eta \tag{5}$$

where,
ξ = right eigenvector matrix of JR
η = left eigenvector matrix of JR
Λ = diagonal eigenvalue matrix of JR
and

$$J_{R^{-1}} = \xi \wedge^{-1} \eta \tag{6}$$

From (5) and (8), we have,

$$\Delta V = \xi \wedge^{-1} \eta \Delta Q \tag{7}$$

or

$$\Delta V = \sum_I \frac{\xi_i \eta_i}{\lambda_i} \Delta Q \tag{8}$$

where ξ_i is the ith column right eigenvector and η the ith row left eigenvector of JR and λ_i is the ith eigenvalue of JR.

The *i*th modal reactive power variation is,

$$\Delta Q_{mi} = K_i \xi_i \tag{9}$$

where,

$$K_i = \sum_j \xi_{ij^2} - 1 \tag{10}$$

with ξ_{ji} is the *j*th element of ξ_i.

The corresponding *i*th modal voltage variation is

$$\Delta V_{mi} = [1/\lambda_i]\Delta Q_{mi} \tag{11}$$

If | λ_i | = 0 then the *i*th modal voltage will collapse.

In (10), let $\Delta Q = e_k$, where e_k has all its elements zero except the *k*th one being 1. Then,

$$\Delta V = \sum_i \frac{\eta_{1k}\ \xi_1}{\lambda_1} \tag{12}$$

η_{1k} being the kth element of η_1 .

V –*Q* sensitivity at bus *k*,

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

3. 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).

3.1. Minimization of Real Power Loss

Minimization of the real power loss (P_{loss}) in transmission lines is mathematically stated as follows:

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

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 θ_{ij} is the voltage angle difference between bus *i* and bus *j*.

3.2. Minimization of Voltage Deviation

Minimization of the voltage deviation magnitudes (*VD*) at load buses is mathematically stated as follows:

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

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

3.3. System Constraints

Objective functions are subjected to these constraints shown below.
Load flow equality constraints:

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

$$Q_{Gi} - Q_{Di} - V_{i \sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \sin\theta_{ij} \\ +B_{ij} & \cos\theta_{ij} \end{bmatrix} = 0, i = 1,2 \ldots., nb \tag{17}$$

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 (VGi) inequality constraint:

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max}, i \in ng \tag{18}$$

Load bus voltage (VLi) inequality constraint:

$$V_{Li}^{min} \leq V_{Li} \leq V_{Li}^{max}, i \in nl \tag{19}$$

Switchable reactive power compensations (QCi) inequality constraint:

$$Q_{Ci}^{min} \leq Q_{Ci} \leq Q_{Ci}^{max}, i \in nc \tag{20}$$

Reactive power generation (QGi) inequality constraint:

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max}, i \in ng \tag{21}$$

Transformers tap setting (Ti) inequality constraint:

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

Transmission line flow (SLi) inequality constraint:

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

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

4. FRAGARIA DALTONIANA PLANT

Fragaria Daltoniana plant (*fig. 1*) which promulgates through runners will do to augment its survival. If it is in an upright spot of the ground, with enough water, nutrients, and light, then it is sound to undertake that there is no stress on it to leave that spot to promise its survival. So, it will propel numerous short runners that will give new Fragaria Daltoniana plant and inhabit the locality as greatest they can. If, on the other hand, the mother plant is in a spot that is meagre in water, nutrients, light, or any one of these essential for a plant to endure, then it will try to find a healthier spot for its offspring. So, it will propel few runners further afield to explore distant areas. One can also assume that it will propel only a limited, since sending a long runner is a large venture for a plant which is in a meagre spot. We may further assume that the class of the spot (abundance of nutrients, water, and light) is imitated in the development of the plant.

Fig. 1. Fragaria Daltoniana plant

A plant p_i is in spot X_i in dimension n. This means $X_i = \{x_{i,j}, for\ j = 1, . . . , n\}$. Let NP be the number of Fragaria Daltoniana plant to be used initially:

i. Fragaria Daltoniana plant which are in noble spots propagate by engendering numerous short runners.
ii. Those in poor spots promulgate by producing few long runners.

It is clear that, in the above explanation, exploitation is applied by sending many short runners by plants in noble spots, while exploration is applied by sending fewlong runners by plants in meagre spots.

The parameters used in Fragaria Daltoniana plant are the population size NP which is the number of Fragaria Daltoniana plant, the maximum number of generations $g_{\max}$, and the maximum number of possible runners $n_{\max}$ per plant. $g_{\max}$ is effectively the stopping criterion.

The algorithm uses the objective function value at different plant positions X_i, $i = 1, . . . , NP$, in a regularized form N_i, to rank them as would a fitness function in a standard genetic algorithm.

The number of plant runners n_α^i, calculated according to (24), has length dx^icalculated using the regularized form of the objective value at X_i, each giving a $dx^i \in (-1,1)^n$, as calculated with (25). Afterward all plants in the population have sent out their apportioned runners, new plants are appraised and the whole increased population is sorted. To keep the population continuous, individuals with lower growth are eradicated.

The number of runners allocated to a given plant is proportionate to its fitness as in:

$$n_\alpha^i = [n_{max} N_i \alpha], \alpha \in (0,1) \tag{24}$$

Each solution X_i engenders at least one runner and the length of each such runner [21-24] are contrariwise proportionate to its growth as in (25) below:

$$dx_j^i = 2(1 - N_i)(\alpha - 0.5), for\ j = 1, .., n \tag{25}$$

where n is the problem dimension.

Having calculated dx_j^i, the extent to which the runner will reach, the exploration equation that finds the next area to discover is as follows:

$$y_{i,j} = x_{i,j} + (b_j - a_j) dx_j^i\ , for\ j = 1, .., n \tag{26}$$

If the bounds of the exploration domain are desecrated, the point is accustomed to be within the domain $[a_j,\ b_j]$, where a_j and b_j are lower and upper bounds demarcating the exploration space for the jth coordinate.

5. FRAGARIA DALTONIANA ALGORITHM (FDA)

In application of Fragaria Daltoniana Algorithm (FDA), the preliminary population is vital. We run the algorithm number of times from arbitrarily produced populations. The finest individual from each run forms a member of the preliminary population. The amount of runs to produce the preliminary population is NP; so, the population size is$r = NP$. When this number is greater than a definite threshold, the variables are fixed for the rest of the run. Let pop be a common matrix containing the population of a given run. Its rows correspond to individuals. The following equation is used to produce an arbitrary population for each of the preliminary runs:

$$x_{i,j} = a_j + (b_j - a_j)\alpha \, , j = 1, .., n \tag{27}$$

where $x_{i,j} \in [a_j, b_j]$ is the jth entry of solution X_i and a_j and b_j are the jth entries of the lower and upper bounds defining the exploration space of the problem and $\alpha \in (0, 1)$.

In the chief frame of the algorithm, before updating the population we produce a provisional population Φ to clutch new solutions produced from each individual in the population. Then we implement three rules with fixed amendment parameter P_m, chosen here, as $P_m = 0.789$.The first two rules are applied if the population is initialized arbitrarily.

Regulation one uses the following equation to modernize the population:

$$x_{i,j}^* = x_{i,j}(1 + \beta), j = 1, .., n \tag{28}$$

where $\beta \in [-1, 1]$ and $x_{i,j}^* \in [a_j, b_j]$.

The produced individual $X_i^*$is calculated according to the objective function and is stored in Φ.

In regulation two another individual is produced with the same modification parameter$P_m = 0.789$ as in the following equation:

$$x_{i,j}^* = x_{i,j} + (x_{l,j} - x_{k,j})\beta \, , j = 1, .., n \tag{29}$$

where $\beta \in [-1, 1]$, $x_{i,j}^* \in [a_j, b_j]$. l, k are conjointly special indices and are different from i.

The created individual X_i^* is appraised according to the objective function and is stored in Φ. The first two regulations are valid for $r \leq NP$ the number of runs. For $r > NP$ the algorithm also attempts to identify entries which are settling to their ultimate values through a counter IN. If the jth entry in existing population has a low IN value, then it is adapted by implementing (23); or else it is left as it is. The following equation is used when modification is essential:

$$x_{i,j}^{*} = x_{i,j} + \left(x_{i,j} - x_{k,j}\right)\beta \text{ }, j = 1, .., n \tag{30}$$

where $\beta \in [-1, 1]$, $x_{i,j}^{*} \in [a_j, b_j]$, and k is different from i.

To preserve the size of the population constant, the extra plants at the bottom of the organized population are eradicated.

Fragaria Daltoniana Algorithm (FDA) for solving optimal reactive power dispatch problem:

Initialization: g_{max}, *NP*, r

If $r \leq NP$ *at that juncture; Produce an arbitrary population of plants* $pop = \{Xi \mid i = 1, 2, . . . , NP\}$*, using (27) and collect the best solutions.*

End if

While $r > NP$ *do*

Use population pop_g *formed by congregation all best solutions from preceding runs. Compute* IN_j *value for each column* j *of* pop_g

End while

Estimate the population. In case of pop_g *the algorithm does not need to estimate the population,*

Set number of runners

While ($ngen < gmax$) *do*

Generate Φ:

for $i = 1$ *to NP do*

for $k = 1$ *to* n_r *do*

if $r \leq NP$ *then*

If rand $\leq P_m$ *then*

Produce a new-fangled solution $x_{i,j}^{*}$ *according to (28);*

Calculate it and store it in Φ;

End if

If rand $\leq P_m$ *then*

Produce a new-fangled solution $x_{i,j}^{*}$ *according to (29);*

Estimate it and store it in Φ;

End if

Else

For $j = 1$*:* n *do*

If (rand $\leq P_m$*) then*

Modernize the j*th entry of* X_i*,* $i = 1,2,..,NP$*, according to (30);*

End if

Calculate new-fangled solution and store it in Φ;
End for
End if
End for
Augment Φ to existing population;
Arrange the population in uphill order of the objective values;
Modernize current best;
End while
Revisit: updated population.

6. SIMULATION RESULTS

The efficiency of the proposed Fragaria Daltoniana Algorithm (FDA) is demonstrated by testing it on standard 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 have been presented in *Tables 1, 2, 3 &4*. And in the *Table 5* shows the proposed algorithm powerfully 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*. Corresponding to this control variable setting, it was found that there are no limit violations in any of the state variables.

Table 1. Results of FDA – ORPD Optimal Control Variables

Control variables	***Variable setting***
V1	*1.041*
V2	*1.046*
V5	*1.044*
V8	*1.030*
V11	*1.000*
V13	*1.030*
T11	*1.00*
T12	*1.00*
T15	*1.00*
T36	*1.00*
Qc10	*2*
Qc12	*3*

Table 2.Results of FDA -Voltage Stability Control Reactive Power Dispatch Optimal Control Variables

Control variables	***Variable setting***
V1	*1.049*
V2	*1.048*
V5	*1.045*
V8	*1.036*
V11	*1.002*
V13	*1.034*
T11	*0.090*
T12	*0.090*
T15	*0.090*
T36	*0.090*
Qc10	*3*
Qc12	*2*

Control variables	*Variable setting*
Qc15	*2*
Qc17	*0*
Qc20	*2*
Qc23	*2*
Qc24	*3*
Qc29	*2*
Real power loss	*4.2632*
SVSM	*0.2472*

Control variables	*Variable setting*
Qc15	*2*
Qc17	*3*
Qc20	*0*
Qc23	*2*
Qc24	*2*
Qc29	*3*
Real power loss	*4.9885*
SVSM	*0.2489*

Optimal reactive power dispatch problem together with 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 simultaneously. *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 0.2472 to 0.2489, 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 eigenvalues equivalents to the four critical contingencies are given in *Table 3*. From this result it is observed that the eigenvalue has been improved considerably for all contingencies in the second case.

Table 3. Voltage Stability under Contingency State

Sl.No	*Contingency*	*ORPD Setting*	*VSCRPD Setting*
1	*28-27*	*0.1419*	*0.1434*
2	*4-12*	*0.1642*	*0.1650*
3	*1-3*	*0.1761*	*0.1772*
4	*2-4*	*0.2022*	*0.2043*

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*

State variables	*limits*		*ORPD*	*VSCRPD*
	lower	*upper*		
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 [25]	*5.0159*
Genetic algorithm [26]	*4.665*
Real coded GA with Lindex as SVSM [27]	*4.568*
Real coded genetic algorithm [28]	*4.5015*
Proposed FDA method	*4.2632*

7. CONCLUSION

In this paper, the Fragaria Daltoniana Algorithm (FDA) has been successfully solved optimal reactive power dispatch problem. The planned Fragaria Daltoniana Algorithm (FDA) will replicate the computational agents at all iterations, revealing all agents to both minute and big movements from the begin to end & data exchange between agents. The proposed Fragaria Daltoniana Algorithm (FDA) has been tested on standard IEEE 30 bus test system and simulation results show evidently the better performance of the projected FDA in reducing the real power loss & enhancement of static voltage stability margin.

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