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VORTEX OPTIMIZATION ALGORITHM FOR SOLVING OPTIMAL REACTIVE POWER DISPATCH PROBLEM

Dr.K.Lenin [*1]
[*1] Professor, Prasad V.Potluri Siddhartha Institute of Technology, Kanuru, Vijayawada, Andhra Pradesh -520007, India

Abstract

In this paper, a new Vortex Optimization (VO) algorithm is proposed to solve the reactive power problem. The idea is generally focused on a typical Vortex flow in nature and enthused from some dynamics that are occurred in the sense of Vortex nature. In a few words, the algorithm is also a swarm-oriented evolutional problem solution methodology; since it comprises numerous techniques related to removal of feeble swarm members and trying to progress the solution procedure by supporting the solution space through fresh swarm members. In order to evaluate the performance of the proposed Vortex Optimization (VO) algorithm, it has been tested in Standard IEEE 30 bus systems and compared to other standard algorithms. Simulation results reveal about the best performance of the proposed algorithm in reducing the real power loss and static voltage stability margin index has been enhanced.

Keywords: Reactive Power, Transmission Loss, Swarm Intelligence, Evolutional Computation, Vortex Optimization.

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1. Introduction

Main objective of the Optimal reactive power dispatch problem is to minimize the real power loss and to enhance the voltage stability index.A variety ofnumerical techniqueslike the gradient method [1-2], Newton method [3] and linear programming [4-7] have been adopted to solve the optimal reactive power dispatch problem. Both the gradient and Newton methods has the complexity in controlling inequality constraints. If linear programming is applied, then the input-output function has to be articulated as a set of linear functions which predominantly lead to loss of accuracy. Thedifficulty of voltage stability and fall down, play a major role in power system planning and operation [8]. Global optimization has received wide-ranging research responsiveness, and enormousnumber of methods has been applied to solve this problem. Evolutionary algorithms such as genetic algorithm have been already proposed to solve the reactive power flow problem [9,10].Evolutionary algorithm is a heuristic approach used for minimization problems by utilizing nonlinear and non-differentiable incessant space functions. In [11], Genetic algorithm has been used to solve optimal reactive power flow problem. In [12], Hybrid differential evolution algorithm is proposed to perk up the voltage stability index. In [13],Biogeography Based algorithm is planned to solve the reactive power dispatch problem. In [14], afuzzy based method is used to solve the optimal reactive power scheduling method. In [15],an improved evolutionary programming is used to solvethe optimal reactive power dispatch problem. In [16], the optimal reactive power flow problem is solved by integrating a genetic algorithm with a nonlinearinterior point method. In [17], apattern algorithm is used to solve ac-dc optimal reactive powerflow model with the generator capability limits. In [18], proposes a two-step approach to evaluate Reactive power reserves with respect to operating constraints and voltage stability. In [19], a programming based proposed approach used to solve the optimal reactive power dispatch problem. In [20], presents aprobabilistic algorithm for optimal reactive power requirementin hybrid electricity markets with uncertain loads. In this paper, Vortex Optimization (VO) algorithm is proposed to solve the reactive power problem. Goal of this paper is to initiate the idea of a new artificial intelligence based optimization algorithm, which is enthused from the nature [21-22] of Vortex. As also a bio-inspired computation algorithm, the proposal is commonly focused on a typical Vortex flow in nature and enthused from some dynamics that are happened in the sense of Vortex nature. From a common perception, the algorithm is also a swarm-oriented evolutional problem solution methodology; because it includes many methods related to removal of feeble swarm members and trying to perk up the solution procedure by supporting the solution space by means of fresh swarm members. In order to evaluate the performance of the proposed Vortex Optimization (VO) algorithm, it has been tested in Standard IEEE 30 bus systems and compared to other standard algorithms. Simulation results reveal about the best performance of the proposed algorithm in reducing the real power loss and static voltage stability margin index has been 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.

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

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 Eigen values and Eigen vectors.
Let

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

Where,
ξ = right eigenvector matrix of JR
η = left eigenvector matrix of JR
∧ = 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 ξi is the ith column right eigenvector and η the ith row left eigenvector of JR.
λi is the ith Eigen value of JR.

The ith modal reactive power variation is,

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

where,

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

Where
ξji is the jth element of ξi
The corresponding ith modal voltage variation is

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

If | λi | =0 then the ith modal voltage will collapse.

In (10), let ΔQ = ek where ek has all its elements zero except the kth one being 1. Then,

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

η_{1k} k th element of η_1
V –Q sensitivity at bus k

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

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 (Ploss) in transmission lines is mathematically stated as follows.

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

Where n is the number of transmission lines, gk is the conductance of branch k, Vi and Vj are voltage magnitude at bus i and bus j, and θij 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 Vk is the voltage magnitude at bus k.

3.3. System Constraints

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

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

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

where, nb is the number of buses, PG and QG are the real and reactive power of the generator, PD and QD are the real and reactive load of the generator, and Gij and Bij are the mutual conductance and susceptance between bus i and bus j.

Generator bus voltage (VGi) inequality constraint:

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

Load bus voltage (VLi) inequality constraint:

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

Switchable reactive power compensations (QCi) inequality constraint:

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

Reactive power generation (QGi) inequality constraint:

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

Transformers tap setting (Ti) inequality constraint:

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

Transmission line flow (SLi) inequality constraint:

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

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

4. Vortex Optimization (VO) Algorithm

Foremost facts concerning to usage of Vortex behaviours for optimization approach has appeared when the following experiences in terms of communications with the nature world:

1) Vortex flow comes into sight in water when the plug hole is opened.
2) Vortex flows produced by the passageway of plane wing or by an engine of a plane.
3) Vortex shapes come into view in the nature; because of dissimilar environmental conditions.

After having information to form a solution methodology for optimization problems, there has been a need for employing some intelligent methods in order to have effectual solution steps based on the power of the artificial intelligence.

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Step 1: Describe preliminary parameters (*N* for number of particles; initial *vorticity* (*v*) values of each particle; max. and min. limits (min. limit is the negative of the max. one) for vorticity value (*max_v* and *min_v*) and other values associated to problem; and finally *e* for the elimination rate.

Step 2: Establish the particles arbitrarily within the solution space and compute fitness values for each of them. Modernize the *v* value of the particle with the most excellent fitness value by using an arbitrary value as equation below. Spot this particle as a 'Vortex' and keep its values as the finest one so far.

$$The\_Best\_particle\_at\_first\_V\_(new) = The\_Best\_particle\_at\_first\_V\_(current) + (arbitrary\_value * The\_Best\_particle\_at\_first\_V\_(current)) \quad (24)$$

Step 3: Replicate the sub-steps below in the logic of the stop criteria:

Step 3.1: Spot each particle, whose fitness value is equal to or below the common fitness of all particles (minimization problem), as the 'Vortex'. The other particles are in the 'normal' particle position.

Step 3.2: Modernize *v* value of each particle (*i*) by using the following equations:

$$Particle_i\_V\_(new) = Particle_i\_V\_(current) + (arbitrary\_value * (global\_best\_V / Particle_i\_V\_(current)) \quad (25)$$

Step 3.3: Update the *v* value of each Vortex particle (except from the best particle so far) by using an arbitrary value by equation below,

$$Particle_i\_V\_(new) = arbitrary\_value * Particle_i\_V\_(current) \quad (26)$$

Step 3.4: Modernize position of each particle (excluding from the best particle so far) by using the following equation:

$$Particle_i\_position\_(new) = Particle_i\_position\_(current) + (arbitrary_{value} * (Particle_i\_V\_(current)) * (global\_best\_position - Particle_i\_position\_(current)) \quad (27)$$

Step 3.5: compute fitness values according to fresh positions of each particle. Spot the particle with the best value as a 'Vortex' (if it is not a Vortex yet) and keep its values as the finest so far.

Step 3.6: If number of non-Vortex particles is equal to or under the value of *e*, remove all non-particles from the solution space and produce fresh particles according to number of separated particles. Establish these new particles arbitrarily within the solution space. Return to the Step 3.1, if the stopping criterion has not been reached.

Step 4: The most excellent values obtained within the loop are the near to global optimum solution.

The operational method of the Vortex Optimization (VO) algorithm can be envisioned briefly as in Figure 1.

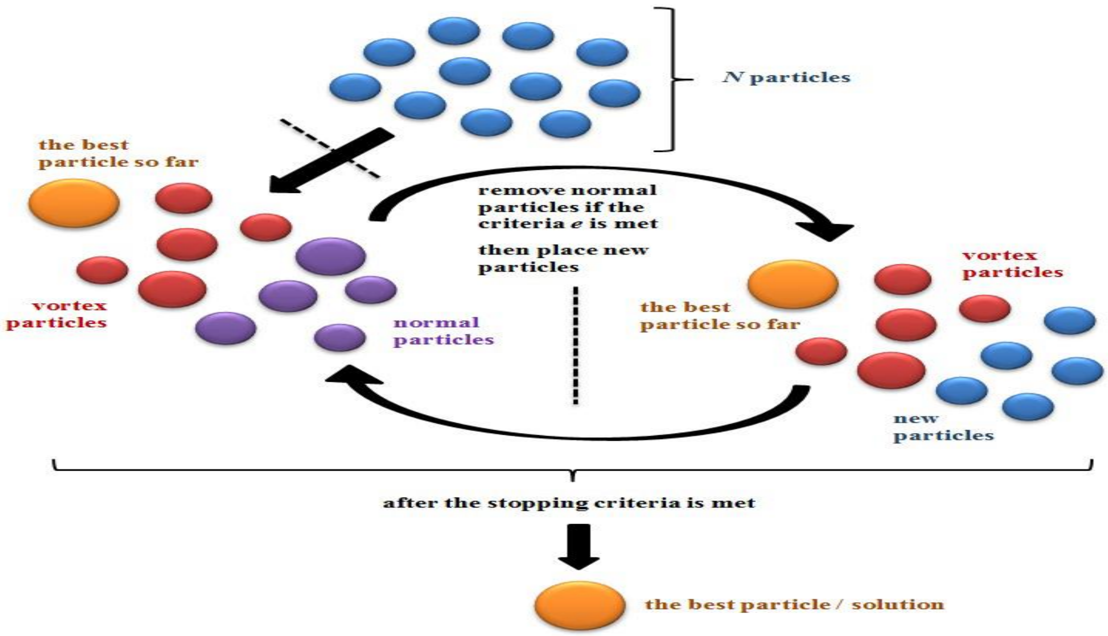

Figure 1: Operational method of the Vortex Optimization (VO) algorithm

5. Simulation Results

The efficiency of the proposed Vortex Optimization (VO) algorithm 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 VO – ORPD optimal control variables

Control variables	Variable setting
V1	1.040
V2	1.041
V5	1.042
V8	1.030
V11	1.000
V13	1.030
T11	1.00
T12	1.00
T15	1.00

T36	1.00
Qc10	2
Qc12	2
Qc15	2
Qc17	0
Qc20	2
Qc23	2
Qc24	3
Qc29	2
Real power loss	4.1426
SVSM	0.2478

Optimal Reactive Power Dispatch (ORPD) 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 0.2478 to 0.2482, 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 VO -Voltage Stability Control Reactive Power Dispatch (VSCRPD) Optimal Control Variables

Control Variables	**Variable Setting**
V1	1.045
V2	1.044
V5	1.043
V8	1.032
V11	1.002
V13	1.032
T11	0.090
T12	0.090
T15	0.090
T36	0.090
Qc10	3
Qc12	2
Qc15	2
Qc17	3
Qc20	0
Qc23	2
Qc24	2
Qc29	3
Real power loss	4.9880
SVSM	2482

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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
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

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Table 5: Comparison of Real Power Loss

Method	Minimum loss
Evolutionary programming [23]	5.0159
Genetic algorithm [24]	4.665
Real coded GA with Lindex as SVSM [25]	4.568
Real coded genetic algorithm [26]	4.5015
Proposed VO method	4.1426

6. Conclusion

In this paper Vortex Optimization (VO) algorithm has been successfully solved optimal reactive power dispatch problem. From a common perception, the proposed algorithm is also a swarm-oriented evolutional problem solution methodology; because it includes many methods related to removal of feeble swarm members and trying to perk up the solution procedure by supporting the solution space by means of fresh swarm members. In order to evaluate the performance of the proposed Vortex Optimization (VO) algorithm, it has been tested in Standard IEEE 30 bus systems and compared to other standard algorithms. Simulation results reveal about the best performance of the proposed algorithm in reducing the real power loss and static voltage stability margin index has been enhanced.

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*Corresponding author.
E-mail address: gklenin@ gmail.com