VORTEX OPTIMIZATION ALGORITHM FOR SOLVING OPTIMAL REACTIVE POWER DISPATCH PROBLEM

Dr. K. Lenin

*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 evolutilional 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.

Cite This Article: Dr. K. Lenin. (2018). “VORTEX OPTIMIZATION ALGORITHM FOR SOLVING OPTIMAL REACTIVE POWER DISPATCH PROBLEM.” International Journal of Research - Granthaalayah, 6(1), 266-276. 10.29121/granthaalayah.v6.i1.2018.1614.

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 of numerical techniques like 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. The difficulty 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 enormous number 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], a fuzzy based method is used to solve the optimal reactive power scheduling method. In [15], an improved evolutionary programming is used to solve 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], 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 a probabilistic algorithm for optimal reactive power requirement in 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 evolitional 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.

\[
\begin{bmatrix}
\Delta P \\
\Delta Q
\end{bmatrix} = \begin{bmatrix}
J_{p\theta} & J_{pV} \\
J_{q\theta} & J_{qV}
\end{bmatrix} \begin{bmatrix}
\Delta \theta \\
\Delta V
\end{bmatrix}
\]

(1)

Where
\[
\Delta P = \text{Incremental change in bus real power.}
\]
\[
\Delta Q = \text{Incremental change in bus reactive Power injection}
\]
\[
\Delta \theta = \text{incremental change in bus voltage angle.}
\]
\[
\Delta V = \text{Incremental change in bus voltage Magnitude}
\]
\[
J_{p\theta}, J_{pV}, J_{q\theta}, J_{qV} \text{ jacobian matrix are the sub-matrixes of the System voltage stability}
\]
\[
is affected by both P and Q.
\]
To reduce (1), let \(\Delta P = 0\), then.
\[
\Delta Q = J_{qV} - J_{q\theta} J_{p\theta} J_{pV} \Delta V = J_R \Delta V
\]

(2)
\[ \Delta V = J^{-1} - \Delta Q \]  

Where

\[ J_R = (J_{QV} - J_{Q\theta}J_{P\theta}^{-1}J_{PV}) \]  

\( J_R \) 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

\[ J_R = \xi \Lambda \eta \]  

Where,
- \( \xi = \) right eigenvector matrix of \( J_R \)
- \( \eta = \) left eigenvector matrix of \( J_R \)
- \( \Lambda = \) diagonal eigenvalue matrix of \( J_R \)

\[ J_{R}^{-1} = \xi \Lambda^{-1} \eta \]  

From (5) and (8), we have

\[ \Delta V = \xi \Lambda^{-1} \eta \Delta Q \]  

Or

\[ \Delta V = \sum \xi_i \eta_i \lambda_i \Delta Q \]  

Where \( \xi_i \) is the ith column right eigenvector and \( \eta \) the ith row left eigenvector of \( J_R \).

The ith modal reactive power variation is,

\[ \Delta Q_{m_i} = K_i \xi_i \]  

where,

\[ K_i = \sum \xi_{ji}^2 - 1 \]  

Where
- \( \xi_{ji} \) is the jth element of \( \xi_i \)
- The corresponding ith modal voltage variation is
\[ \Delta V_{mi} = [1/\lambda_i] \Delta Q_{mi} \]  

(11)

If \( |\lambda_i| = 0 \) 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,

\[ \Delta V = \sum \frac{\eta_{1k} \xi_1}{\lambda_1} \]  

(12)

\( \eta_{1k} \) \( k \)th element of \( \eta_1 \)

\( V-Q \) sensitivity at bus \( k \)

\[ \frac{\partial V_k}{\partial Q_k} = \sum \frac{\eta_{1k} \xi_1}{\lambda_1} = \sum \frac{P_{kd}}{\lambda_1} \]  

(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.

\[ P_{loss} = \sum_{k=1}^{n} g_k (V_i^2 + V_j^2 - 2 V_i V_j \cos \theta_{ij}) \]  

(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 \( \theta_{ij} \) 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.

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

(15)

Where \( nl \) is the number of load buses 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:

\[ P_{Gi} - P_{Di} - V_i \sum_{j=1}^{nb} V_j \left[ G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij} \right] = 0, i = 1, 2, \ldots, nb \]  

(16)
Q_{Gi} - Q_{Di} = \sum_{j=1}^{nb} V_j \left[ G_{ij}\sin\theta_{ij} + B_{ij}\cos\theta_{ij} \right] = 0, i = 1, 2, ..., nb \tag{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 (V_{Gi}) inequality constraint:

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

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

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

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

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

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

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

Transformers tap setting (T_i) inequality constraint:

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

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

S_{Li}^{\text{min}} \leq S_{Li} \leq S_{Li}^{\text{max}}, i \in \text{nl} \tag{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.
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.

$$The\_Best\_particle\_at\_first\_V\_\left(new\right) = The\_Best\_particle\_at\_first\_V\_\left(current\right) + \left(\text{arbitrary\_value} \times The\_Best\_particle\_at\_first\_V\_\left(current\right)\right)$$

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:

$$Particle_i\_V\_\left(new\right) = Particle_i\_V\_\left(current\right) + \left(\text{arbitrary\_value} \times \left(global\_best\_V/\right.\ Particle_i\_V\_\left(current\right)\right)$$

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,

$$Particle_i\_V\_\left(new\right) = \text{arbitrary\_value} \times Particle_i\_V\_\left(current\right)$$

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

$$Particle_i\_position\_\left(new\right) = Particle_i\_position\_\left(current\right) + \left(\text{arbitrary\_value} \times \left(Particle_i\_V\_\left(current\right)\right) \times \left(global\_best\_position – Particle_i\_position\_\left(current\right)\right)\right)$$

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](image)

### 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.

| 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             |

Table 1: Results of VO – ORPD optimal control variables
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              | 0.2478          |
### 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  |
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 evolutilional 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.

References

[1] O.Alsac, B. Scott, “Optimal load flow with steady state security”, IEEE Transaction. PAS -1973, pp. 745-751.
[2] Lee K Y ,Paru Y M , Ortiz J L –A united approach to optimal real and reactive power dispatch , IEEE Transactions on power Apparatus and systems 1985: PAS-104 : 1147-1153
[3] A.Monticelli , M .V.F Pereira ,and S. Granville, “Security constrained optimal power flow with post contingency corrective rescheduling” , IEEE Transactions on Power Systems :PWRS-2, No. 1, pp.175-182.,1987.
[4] Deeb N, Shahidehpur S.M, Linear reactive power optimization in a large power network using the decomposition approach. IEEE Transactions on power system 1990: 5(2) : 428-435
[5] E. Hobson ,’Network constrained reactive power control using linear programming, ‘ IEEE Transactions on power systems PAS -99 (4) ,pp 868=877, 1980
[6] K.Y Lee, Y.M Park, and J.L Ortiz, “Fuel –cost optimization for both real and reactive power dispatches”, IEE Proc; 131C,(3), pp.85-93.
[7] M.K. Mangoli, and K.Y. Lee, “Optimal real and reactive power control using linear programming”, Electr.Power Syst.Res, Vol.26, pp.1-10,1993.
[8] C.A. Canizares , A.C.Z.de Souza and V.H. Quintana , “ Comparison of performance indices for detection of proximity to voltage collapse ,” vol. 11. no.3 , pp.1441-1450, Aug 1996.
[9] K.Anburaja, “Optimal power flow using refined genetic algorithm”, Electr.Power Compon.Syst , Vol. 30, 1055-1063,2002.
[10] D. Devaraj, and B. Yeganarayana, “Genetic algorithm based optimal power flow for security enhancement”, IEE proc-Generation.Transmission and. Distribution; 152, 6 November 2005.
[11] A.Berizzi, C. Bovo, M. Merlo, and M. Delfanti, “A ga approach to compare orpf objective functions including secondary voltage regulation,”Electric Power Systems Research, vol. 84, no. 1, pp. 187 – 194, 2012.
[12] C.-F. Yang, G. G. Lai, C.-H.Lee, C.-T. Su, and G. W. Chang, “Optimal setting of reactive compensation devices with an improved voltagestability index for voltage stability

Http://www.granthaalayah.com ©International Journal of Research - GRANTHAALAYAH [275]
enhancement,” International Journal of Electrical Power and Energy Systems, vol. 37, no. 1, pp. 50 – 57, 2012.

[13] P. Roy, S. Ghoshal, and S. Thakur, “Optimal var control for improvements in voltage profiles and for real power loss minimization using biogeography based optimization,” International Journal of Electrical Power and Energy Systems, vol. 43, no. 1, pp. 830 – 838, 2012.

[14] B. Venkatesh, G. Sadasivam, and M. Khan, “A new optimal reactive power scheduling method for loss minimization and voltage stability margin maximization using successive multi-objective fuzzy lp technique,” IEEE Transactions on Power Systems, vol. 15, no. 2, pp. 844 – 851, May 2000.

[15] W. Yan, S. Lu, and D. Yu, “A novel optimal reactive power dispatch method based on an improved hybrid evolutionary programming technique,” IEEE Transactions on Power Systems, vol. 19, no. 2, pp. 913 – 918, May 2004.

[16] W. Yan, F. Liu, C. Chung, and K. Wong, “A hybrid genetic algorithm interior point method for optimal reactive power flow,” IEEE Transactions on Power Systems, vol. 21, no. 3, pp. 1163 – 1169, Aug. 2006.

[17] J. Yu, W. Yan, W. Li, C. Chung, and K. Wong, “An unfixed piecewise optimal reactive power flow model and its algorithm for ac–dc systems,” IEEE Transactions on Power Systems, vol. 23, no. 1, pp. 170 – 176, Feb. 2008.

[18] F. Capitanescu, “Assessing reactive power reserves with respect to operating constraints and voltage stability,” IEEE Transactions on Power Systems, vol. 26, no. 4, pp. 2224–2234, Nov. 2011.

[19] Z. Hu, X. Wang, and G. Taylor, “Stochastic optimal reactive power dispatch: Formulation and solution method,” International Journal of Electrical Power and Energy Systems, vol. 32, no. 6, pp. 615 – 621, 2010.

[20] A. Kargarian, M. Raoofat, and M. Mohammadi, “Probabilistic reactive power procurement in hybrid electricity markets with uncertain loads,” Electric Power Systems Research, vol. 82, no. 1, pp. 68 – 80, 2012.

[21] Köse, U., “Design & Development of a Software System for Swarm Intelligence based Research Studies”. BRAIN. Broad Research in Artificial Intelligence and Neuroscience, (2012), 3(3), 12-17.

[22] Utku Köse, Ahmet Arslan, “On the idea of a new artificial intelligence based optimization algorithm inspired from the nature of vortex” arXiv:1704.00797 [cs.AI], 2017.

[23] Wu Q H, Ma J T. “Power system optimal reactive power dispatch using evolutionary programming”, IEEE Transactions on power systems 1995; 10(3): 1243-1248 .

[24] S.Durairaj, D.Devaraj, P.S.Kannan; “Genetic algorithm applications to optimal reactive power dispatch with voltage stability enhancement”, IE(I) Journal-EL Vol 87, September 2006.

[25] D.Devaraj, “Improved genetic algorithm for multi – objective reactive power dispatch problem”, European Transactions on electrical power 2007; 17: 569-581.

[26] P. Aruna Jeyanth and Dr. D. Devaraj “Optimal Reactive Power Dispatch for Voltage Stability Enhancement Using Real Coded Genetic Algorithm”, International Journal of Computer and Electrical Engineering, Vol. 2, No. 4, August, 2010 1793-8163.

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