A MULTI CRITERIA DECISION IN OPTIMAL REACTIVE POWER DISPATCH THROUGHOUT SMART POWER GRID

Hosein Taji[1], Aliasghar Ghadimi[2]

1. Islamic Azad University, Arak Science & Research Branch, Arak, Iran
2. Arak University, Arak, Iran

Corresponding Author: t66taji@yahoo.com

ABSTRACT: *The undesirable voltage is the chief problem for connection of DGs in distribution systems, while excessive reactive power demand from transmission system is the major concern for Transmission System Operators (TSO). This paper presents a new sub-framework in the reactive power management for the optimal control of voltage in the appropriate range by decreasing the voltage deviation and obtain high voltage stability margin, simultaneously. In this research, the desirable voltage profile, by a set of controllable variables in power system such as a tap of transformers, value of capacitors is investigated. To determination the value of elements in the mentioned sub-framework, the Particle Swarm Optimization (PSO) method is employed to rapidly obtain the optimum parameters due to improvement of voltage profile. Finally, the proposed method is applied on standard IEEE- 24 bus and ARAK distribution system and the results are compared to each other.*

Keywords: Smart Grid, Distribution, Generation, Reactive Power Management, Voltage Stability Margin, Voltage Deviation, Particle Swarm Optimization.

INTRODUCTION

Growth of electric energy consumption continually, it is crucial to exploit system in a safe mode and providing economic, reliable and significant quality power for clients. Also, getting rid of fossil fuel resources and increment political tensions in the world, consequently increasing the price of fuels in the global energy market, many governments have to use the renewable energy resources. Further, they are obliged to decrease the amount of all Carbon emissions to 20 percent by 2050, as stated in the "Low Carbon Transition Plan", July 2009 [1]. These rationales are causing the electric power generation sources change from fossil fuels to sustainable resources. Among of them, the wind power plant and the solar energy have been taken into consideration more than other types due to economical, availability and operational matters. So that the 20% required energy of US will secured through wind energy [2]. These resources that are known to Distributed Generations (DG) s are connected to the grid directly in the local distributed grid.

In the case of DG's connection, a significant impact on the flow of power, voltage level and fault currents, could be acquired especially in rural distribution grid due to high impedance and low ratio of X/R [3-5].

In this work, according to capability of smart grid to control of variables in whole of power system due to using advanced metering infrastructure (AMI), and Phasor Measurement Unit (PMU), a novel framework in reactive power management is proposed [5-10].

The objective function in this paper is considered as a multi criteria decision function. In the proposed method, in the case of abnormal voltage condition, the DNO and TSO collaborate to each other. By using the voltage information of system gotten from PMUs and AMIs, the voltage deviation and voltage stability margin are calculated via software domains. Then, by using the Particle Swarm Optimization (PSO) method, the optimization process to find appropriate amount of variables instigates. In this work, tap of transformers and capacitors are the controllable variables in Optimal Reactive Power Dispatch (ORPD) problem.

As to the rest of the organization of the paper: Section.2 explains a new approach to analyze the voltage stability and voltage deviation, PMU and AMI fundamental. Section.3 indicates the implementation of PSO to online adjusting the controllable variables and finally in section. 4 the PSO is applied to a typical system and the obtained results are analyzed obviously.

METHODOLOGY OF OPTIMAL REACTIVE POWER DISPATCH (ORPD)

There are two main indices to determine the reactive power current in system: one voltage deviation and another voltage stability margin. The voltage deviation is the sum of voltage deviation of load buses from reference voltage value, 1 per unit. Indeed, this criterion can show the power quality which is important for customers. Also, in this paper to adapt the calculation process with smart grid aims, the L index formulation is determined as a voltage stability margin index.

Voltage Stability Margin Index

Voltage stability problem has a close relationship with the reactive power of the system, and the voltage stability margin is inevitably affected in optimal reactive power flow (ORPF) [10]. Hence, the maximal voltage stability margin should be one of the objectives in ORPF [10], [11], [12]. For example, in two-bus power system shown in Fig. 2, voltage stability margin for bus i th can be evaluated as follows [13]:

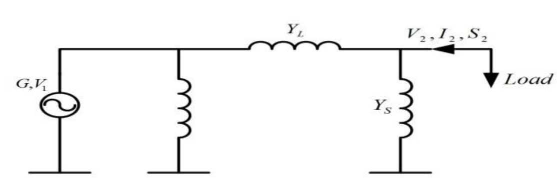

Fig.2. The two bus power system

By using the Kirchhoff Current Low (KCL) in Fig. 2:

$$I_2 = \overrightarrow{V_2}\overrightarrow{Y_S} + \left(\overrightarrow{V_2} - \overrightarrow{V_1}\right)\overrightarrow{Y_L} = \frac{\overrightarrow{S_2}}{\overrightarrow{V_2}} \quad (1)$$

Simplify the equation (1), the constraint for occurrence of voltage collapse is obtained as follows:

$$\sqrt{\frac{V_0^{\,4}}{4} + aV_0^{\,2} - b^2} = 0 \quad (2)$$

where

$$\overrightarrow{Y_{22}} = \overrightarrow{Y_S} + \overrightarrow{Y_L} \quad (3)$$

$$\frac{\overrightarrow{S_2}}{\overrightarrow{Y_{22}}} = a + jb \quad (4)$$

$$\overrightarrow{V_0} = -\frac{\overrightarrow{Y_L}}{\overrightarrow{Y_S} + \overrightarrow{Y_L}}\overrightarrow{V_1} \quad (5)$$

In other word, determinant of Jacobian matrix must be zero:

$$J = \begin{bmatrix} 2|V_2| + |V_0|cos\delta & -|V_0||V_2|sin\delta \\ |V_0|sin\delta & |V_0||V_2|cos\delta \end{bmatrix} \quad (6)$$

So, the voltage stability margin obtained as follows:

$$\left|1 - \frac{\overrightarrow{V_0}}{\overrightarrow{V_2}}\right| = \left|\frac{\overrightarrow{S_2}}{V_{22}^2 \overrightarrow{Y_{22}}}\right| = L_2 \quad (7)$$

Finally, it could be extended for a power system. By using the following equations and above results:

$$I_{bus} = Y_{bus} \times V_{bus} \quad (8)$$

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_1 & Y_2 \\ Y_3 & Y_4 \end{bmatrix}\begin{bmatrix} V_G \\ V_L \end{bmatrix} \quad (9)$$

$$\begin{bmatrix} I_G \\ V_L \end{bmatrix} = \begin{bmatrix} H_1 & H_2 \\ H_3 & H_4 \end{bmatrix}\begin{bmatrix} V_G \\ I_L \end{bmatrix} \quad (10)$$

WhereI_L, $V_L$are current and voltage of load buses and IG, VG are current and voltage of voltage controlled buses respectively. By using equations (9) and (10)

$$H_3 = -Y_4^{\,-1} \times Y_3 \quad (11)$$

So, the voltage of voltage controlled bus jth evaluated as follows:

$$V_{0j} = \sum_{i \in G} H_{3ji} V_i \quad (12)$$

WhereG is the number of generator buses. Finally the voltage stability margin of each bus calculated as follows:

$$L_j = \left|1 - \frac{V_{0j}}{V_j}\right| \quad (13)$$

where the $V_j$is the voltage of j th bus .In this work, we consider the global voltage stability margin for whole of power system as follows:

$$f_1 = L = \max(L_j) \quad (14)$$

By using the L index formulation, the operators in sub-framework could be informed of voltage stability of system permanently.

Voltage Deviation

Another purpose in smart grid related to reactive power management is voltage deviation. Treating the bus voltage limits as constraints in often results in all the voltages toward their boundary limits after optimization, which means power system lacks the required reserves to provide reactive power during contingencies. One of the effective ways to avoid this situation is to choose the deviation of voltage from the desired value as an objective function [13]:

$$f_2 = \Delta V_L = \sum_{i=1}^{N_L} |V_i - V_i^*| \quad (15)$$

where f_2 is the sum of voltage deviations and the NL is the number of buses in power system. Also the V_i, V_i^* are the actual voltage magnitude and desired voltage magnitude at bus ith.

Fitness Function to analyze voltage situation

In the proposed sub-framework of reactive power management in the smart grid, by using the information from AMI, the operator calculates the L index formulations and voltage deviation separately. To consider the two values in the one term, authors suggest the following fitness function:

$$F = w_1 \times f_1 + w_2 \times f_2 \quad (16)$$

Where w_1 and w_2 are the weight coefficients and the f1 and f_2 are L index value and sum of voltage deviations respectively.

Particle swarm optimization(PSO) method

Kennedy and Eberhart developed a PSO algorithm based on the behavior of individuals (i.e. particles or agents) of a swarm [14]. It has been perceived that members within a group seem to share information among them, a fact that causes to increased efficiency of the group. An individual in a swarm approaches to the optimum by its present velocity, previous experience, and the experience of its neighbors [14], [15].

In a physical n-dimensional search space, parameters of PSO technique are defined as follows:

$X_i = (x_{i1}, \dots, x_{in})$: Position individual i.

$V_i = (v_{i1}, \dots, v_{in})$: Velocity individual i.

$Pbest_i = (X_{i1}^{Pbest}, \dots, X_{ip}^{Pbest})$: Best position of individual i.

$Gbest_i = (X_{i1}^{Gbest}, \dots, X_{in}^{Gbest})$: Best position neighbors of individual i.

Using the information, the updated velocity of individual i is modified by the following equation in the PSO algorithm:

$$V_i^{k+1} = wV_i^k + c_1 rand_1 \times \left(Pbest_i^k - X_i^k\right) + c_2 rand_2 \times \left(Gbest_i^k - X_i^k\right) \quad (18)$$

where
V_i^k: velocity of individual i at iteration k.
c_1, c_2: weight factors
rand1, rand2: random numbers between 0 and 1
X_i^k: position of individual i at iteration k
P_{besti}^k: best position of individual i until iteration k
G_{besti}^k: best position of the group until iteration k
ω: weight parameter.
For more better operating of algorithm for find the best answer, this parameter can be updated by (19) for each iteration [16],[17]:
The individual moves from the current position to the next position by equation (19):

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (19)$$

The search mechanism of the PSO using the modified velocity and position of individual i based on equations (18) and (19) is illustrated in Fig.3.

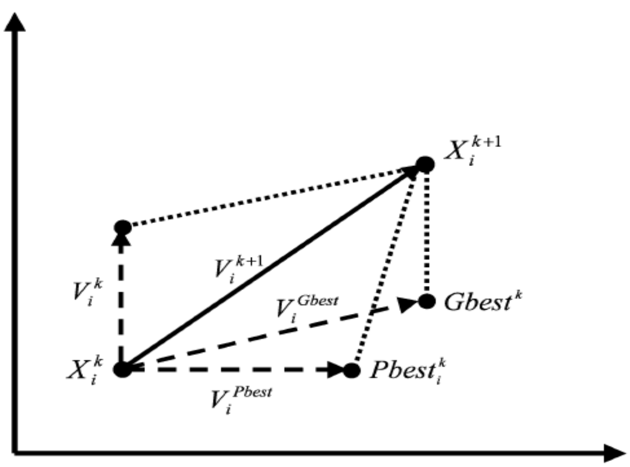

Fig.3. Mechanism of Particle Swarm Optimization

The solution algorithm can be briefly described as follows via the AMI and PMUobtained information:
Step 1- Generate particles from a set of uniformly random numbers ranging over the upper and lower limits of the optimization variables. Each particle includes two variables (i.e. value of transformer's tap and value of capacitor).
Step 2- By using the AMI information from the whole of transmission and distribution system, power flow equations are solved .Therefore, voltage stability margin (i.e. L index) and voltage deviation and fitness function could be calculated according to (14), (15) and (16).
Step 3- Using the global best (Gbest) and individual best (Pbest), velocity vector of particles is updated. Based on the updated velocity, each particle changes its position based on (18) and (19).
Step 4- Repeat calculations from step 2, until the stopping criterion is satisfied and the fitness function is the minimum possible value.

OBSERVIABILITY OF POWER SYSTEM IN ORDER TO REACTIVE POWER MANAGEMENT

Currently, one of the main problems in power system operation is chaotic system which not controlled by existed equipment. To avoid the problem, it is necessary to make a suitable monitoring structure for power system. In the ORPD, the Wide Area Measurement System (WAMS) tries to obtain the measured voltage data form the PMUs and AMIs. In this way operator can calculate the indices and make a decision on controllable variables. Fig. 3 illustrates the principle of WAMS in the smart power grid.

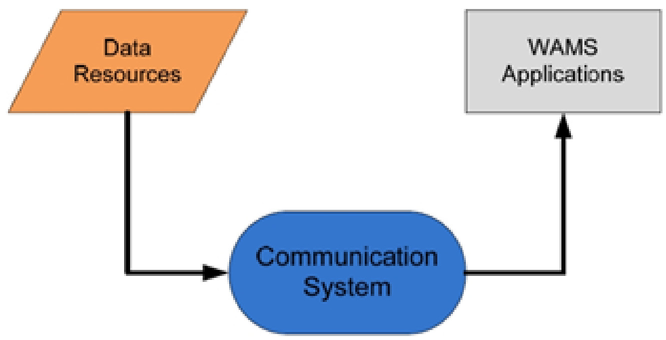

Fig. 3. Principle of WAMS

In the reactive power management framework, there are several entities which is responsible for voltage profile and stability of system. The smart entities are summarized as:

- Transmission Substation entity
- Transmission Field Device entity
- Plug-in Electric Vehicle (PEVs) entity
- AC and DC Loads
- Distributed Generation (DG)
- Distribution Field Device entity
- Distribution Substation entity

According to IEEE-2030 standard for smart grid, it is worth to say that by coordination of these entities, it is possible to achieve online reactive power control.

CASE STUDIES

To assess the proposed algorithm, it is applied to the IEEE 24-bus and a part of ARAK city's network as two test systems. The needed data for 24-bus network's simulations is given from [10] and all data related to the ARAK network are given from ARAK distribution utility. The capacitor banks steps and transformer tap-changer steps are considered as controllable variables. The tap-changer step value is considered 0.01 so that it can vary in range 0.9 to 1.1. All of simulations are calculated using Pentium V, 2.27 GHz and 4 G RAM.

Case study I: IEEE-24 bus test system

This system is a standard transmission network which its single diagram is illustrated in Fig. 4.

By applying the proposed algorithm for this system, the best state is obtained as given in Table .1. In this table, all variables with its value are provided.

The algorithm is simulated to problem for seven scenarios according to the objective functions described in previous section. The L index and active power losses for seven scenarios are shown in Fig. 5 and Fig. 6 respectively. The voltage profile of network for best states is illustrated in Fig. 7.

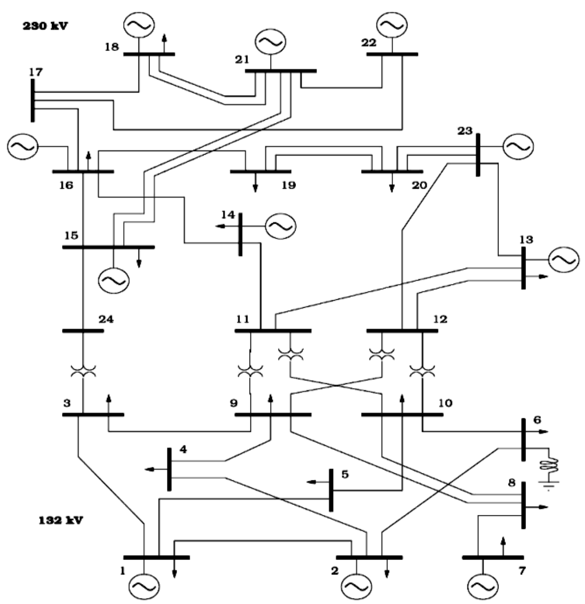

Fig. 4. IEEE 24-bus power system diagram

Table. 1. The value of controllable variables determining by operator

Controllable Variables	Location	Adjustable Value (%)
Tap1	Between 3 and 24 buses	6
Tap2	Between 9 and 11 buses	2
Tap3	Between 9 and 12 buses	4
Tap4	Between 10and 11 buses	5
Tap5	Between 10and 12 buses	-2
Capacitor1	Bus 4	10
Capacitor2	Bus 5	70
Capacitor3	Bus 9	70
Capacitor4	Bus 11	70
Capacitor5	Bus 12	40
Capacitor6	Bus 14	20
Capacitor7	Bus 16	80

Case study II: ARAK network

This system is a distribution network operated at 63 and 20 KV voltage level. This system contains three capacitor and three 63/20 KV transformers. The proposed ORPD algorithm is employed for this network and the obtained results are given in Table. 2.

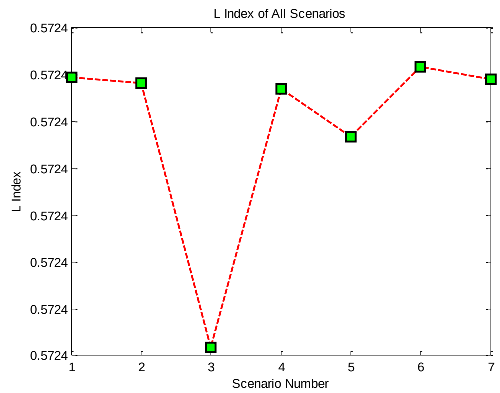

Fig. 5. L index values for different scenarios

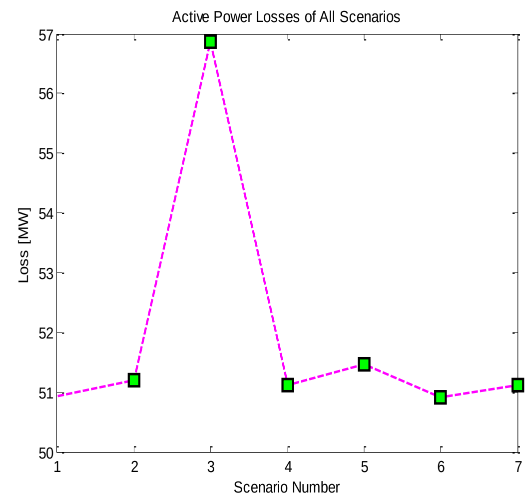

Fig. 6. Active power losses for different scenarios

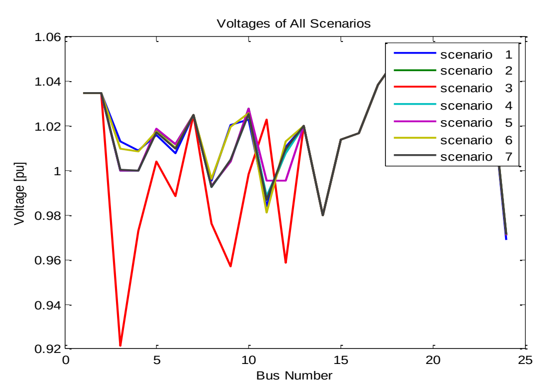

Fig. 7. The voltage profiles of 24-bus network for different scenarios

Table. 2. The value of controllable variables determining by operator

Controllable Variables	Location	Adjustable Value (%)
Tap1	Between 3 and 24 buses	10
Tap2	Between 9 and 11 buses	10
Tap3	Between 9 and 12 buses	10
Capacitor1	Bus 4	100
Capacitor2	Bus 5	100
Capacitor3	Bus 9	100

The convergence of PSO and profile voltage of the network for seventh scenario (all objective functions are considered) are illustrated in Fig. 8 and Fig. 9, respectively.

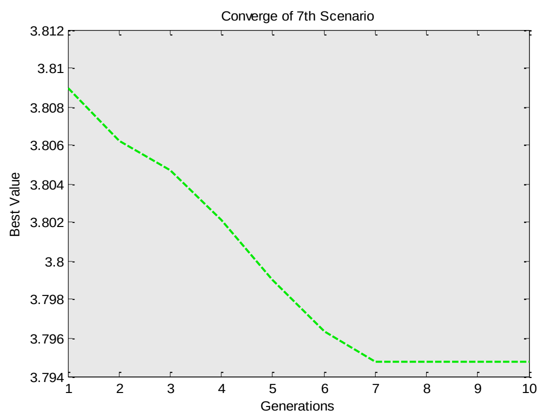

Fig. 8. The convergence of PSO algorithm for ARAK network at seventh scenario

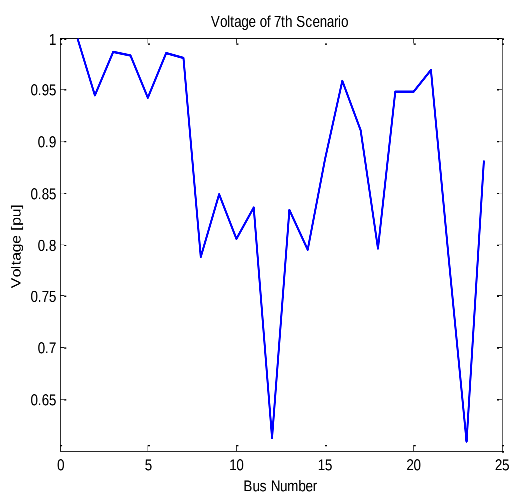

Fig. 9. The voltage profile of ARAK network at seventh scenario

CONCLUSION

This paper suggests a new framework in reactive power management to control the voltage profile in Smart Grids. Due to using the Distributed Generation (DG) in smart grid, the voltage rise and undesirable voltage condition is occurred in smart grid dramatically. In the proposed method, by using the received information from AMI and PMU, the Distribution Network Operator (DNO) and Transmission System Operator (TSO) could online adjusting the controllable variables and improve the voltage conditions in side of consumers. The parameters which determined by sub-framework are transformer's tap and capacitors in distribution system. The L index formulation is considered to analyse voltage stability margin. In the objective function sum of voltage deviations and voltage stability margin are investigated. To online adjusting the controllable variables, the PSO is successfully employed and applied on standard IEEE-24 bus distribution system and ARAK power system. By analysing the obtained results, one can find out that the proposed framework in the reactive power management section has powerful performance to controlling the voltage profile in desirable values. Also, in the mentioned method, by using the simplest devices the operators could obtain the voltage stability and lowest voltage deviation without extra equipment. Finally, the due to powerful performance of PSO in finding global optimum values for controllable variables in whole of trials, one could decreases the number of iteration which caused to decreases the time of running. This is a really important feature to implementation of smart grid section which the performance of each framework should be fast and straight off.

REFERENCES

[1] Department of Energy & Climate Change (DECC), "Smarter grids: the opportunity," Available online at http://www.decc.gov.uk.

[2] U.S. department of energy, "20% wind Energy by 2030," 2008. [Online]. Available: http://www.nrel.gov/docs/fy08osti/41869.pdf

[3] T. Sansawatt , L. F. Ochoa and G. P. Harrison; "Integrating distributed generation using decentralized voltage regulation", *Proc. IEEE Power Energy Soc. Gen. Meet.*, 2010

[4] C. Masters, "Voltage rise the big issue when connecting embedded generation to long overhead 11 kV lines," *Inst. Elect. Eng. Power Eng. J.*, pp. 5-12, Feb. 2002.

[5] S. Repo, H. Laaksonen, P. Jarventausta, O. Huhtala, and M. Mickelsson, "A case study of voltage rise due a large amount of distributed generation on weak distribution networks," in *Proc. IEEE Bologna PowerTech Conf.*, Bologna, Italy, 2003.

[6] F. Viawan and D. Karlsson, "Voltage and reactive power control in systems with synchronous machine-based distributed generation," *IEEE Trans. Power Del.*, vol. 23, no. 2, pp. 1079-1087, Apr. 2008.

[7] F. Viawan and D. Karlsson, "Combined local and remote voltage and reactive power control in presence of induction machine distributed generation," *IEEE Trans. Power Syst*, vol. 22, no. 4, pp. 2003-2012, Nov. 2008.

[8] U.S.-Canada Power System Outage Task Force, "Final Report on the August 14, 2003 Blackout in the United States of America and Canada: Causes and

Recommendations," Apr. 2004. [Online]. Available: http://reports.energy.gov/BlackoutFinal-Web.pdf

[9] T. Van Cutsem, C. Vournas, "Voltage Stability of Electric Power Systems", Boston: Kluwer Academic Publishers, 1998.

[10] X. Hugang, C. Haozhong, L. Haiyu "Optimal reactive power flow incorporating static voltage stability based on multi-objective adaptive immune algorithm". Energy Convers. Manage. 49 (5) (2008), pp. 1175–1181.

[11] H. Yoshida, Y. Fukuyama, K. Kawata et al. A particle swarm optimization for reactive power and voltage control considering voltage security assessment IEEE Trans. Power Syst., 15 (4) (2001), pp. 1232–1239

[12] Chaohua Dai, Weirong Chen, Yunfang Zhu, XuexiaZhang,"Seeker optimization algorithm for optimal reactive power dispatch, "Power System", IEEE Trans.Vol 24, 1218-1231, 2009.

[13] N.G. Hingorani, Flexible AC transmission, IEEE Spectrum, April (1993) 40–45.

[14] J. Kennedy and R. Eberhart, "Particle swarm optimization," in Proc.IEEE Int. Conf. Neural Networks (ICNN'95), vol. IV, Perth, Australia, 1995, pp. 1942–1948.

[15] M. Ghazavi, J. Ansari and M. Kalantar "Economic Dispatch Incorporating Wind Power Plant Using Particle Swarm Optimization," in Proc.IEEE Int. Conf. ICREDG vol. II, Tehran, Iran, 2012, pp. 178-182.

[16] H. Yoshida, K. Kawata, Y. Fukuyama, S. Takayama, and Y. Nakanishi,"A particle swarm optimization for reactive power and voltage control considering voltage security assessment," IEEE Trans. Power Syst., vol. 15, pp. 1232–1239, Nov. 2000.

[17] K. Y. Lee and M. A. El-Sharkawi, Eds., "Modern Heuristic Optimization Techniques with Applications to Power Systems": IEEE Power Engineering Society (02TP160), 2002.

[18] P.M.Subcommittee, "IEEE reliability test system," *IEEE Trans. PowerApp. Syst.*,vol. PAS-98, no. 6, pp. 2047-2054, Nov. 1979.

[19] R. Srinivasa Rao, S.V.L. Narasimham and M. Ramalingaraju, "Optimization of Distribution NetworkConfiguration for Loss Reduction UsingArtificial Bee Colony Algorithm",International Journal of Electrical Power and Energy Systems Engineering,2008