Application of particle swarm optimization technique for reactive power compensation using STATCOM with voltage stability enhancement

Bibek M. Shrestha[1], T. Murali Mohan[2], R. Srinivas Rao[3]

Department of Electrical and Electronic Engineering, Jawaharlal Nehru Technological University, Kakinada - 533003, India

Abstract

This paper presents a particle swarm optimization technique for multi-objective optimal reactive power dispatch problem. The objectives of the optimization problem are minimization of real power loss and enhancement of voltage stability. The proposed method achieves its objectives by determining a control strategy with continuous and discrete variables such as AVR operating values, OLTC tap positions and the amount of reactive power compensation equipment. This paper also presents the effective use of STATCOM to achieve above objectives. The proposed method is evaluated in IEEE 14-bus and IEEE 30-bus systems and the results show the effectiveness of the proposed methods.

Keywords: Mixed Integer Nonlinear Optimization Problem, Optimal Reactive Power Dispatch (ORPD) Problem, Particle Swarm Optimization (PSO), Reactive Power, STATCOM, Voltage Stability Index (VSI)

1. Introduction

Optimal reactive power dispatch (ORPD) problem is a mixed integer non-linear optimization problem. Reactive power could be supplied to the system by generators, synchronous condensers, static compensators, capacitors and tap changing transformers. The problem can be formulated as optimization problem by determining the optimal values of generator bus voltage magnitudes, transformer turns ratio and output of reactive sources for minimum real power loss. In recent years, voltage stability has been a major topic of discussion in power system planning and operation. Voltage magnitudes alone cannot reliably indicate whether a system is stable or not. Hence, this paper has formulated the ORPD as multi-objective optimization problem with enhancement of voltage stability index (VSI) as its objective along with minimization of real power loss [1,2]. Voltage stability evaluation using *L-index* is used as the indicator of voltage stability enhancement [3-5].

Particle swarm optimization (PSO) is an evolutionary computation (EC) technique. Both continuous and discrete variables can be handled by PSO, so it is applicable to ORPD problem which is mixed integer problem [6,7]. High quality solutions are generated within shorter calculation time. It shows stable convergence characteristics than other stochastic methods.

STATCOM is one of new generation flexible AC transmission systems (FACTS) devices. It has promising future applications and is considered to be one of the key advanced technologies of future power system [8]. It is one of the most commonly used shunt compensation FACTS devices and its output can be controlled independent of the system voltage. Its use significantly improves the voltage profile of the system.

This paper presents a PSO technique for ORPD problem formulated as mixed integer non-linear optimization problem considering voltage stability. This paper shows the use of STATCOM for significant improvement of voltage profile. The feasibility of proposed method is demonstrated in IEEE 14-bus and IEEE 30-bus systems with promising results.

2. Problem Formulation of ORPD

2.1 Objective Function

Mathematically, the ORPD problem can be formulated as following objective function [9-11]:

$$Min\ P_{loss} = \sum_{i=1, j\in i}^{N_B} G_{ij}[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)] \quad (1)$$

where,

[1] Bibek Man Shrestha, M.Tech. student, JNTU, Kakinada, Andhra Pradesh, India. Email bibekmanshrestha@gmail.com

[2]T. Murali Mohan, Senior Assistant Professor, Department of EEE, JNTUK, Kakinada, Andhra Pradesh, India. Email tmmohan2009@gmail.com

[3]R. Srinivas Rao, Associate Professor, Department of EEE, JNTUK, Kakinada, Andhra Pradesh, India.

P_{loss} is the active power loss in the system
N_B is total number of buses
G_{ij} is the mutual conductance between buses i and j
V_i and V_j are the voltage magnitudes of buses i and j
δ_i and δ_j are the voltage phase angles of buses i and j

2.2 Constraints

Above mentioned objective function is subject to following constraints:

2.2.1 Equality Constraints

$$P_{gi} = P_{di} - V_i \sum_{j \in N_i} V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) , i \in N_0 \quad (2)$$

$$Q_{gi} = Q_{di} - V_i \sum_{j \in N_i} V_j (G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}), i \in N_{PQ} \quad (3)$$

where,

P_{gi} and Q_{gi} are the specified active and reactive power supply at bus i
P_{di} and Q_{di} are the specified active and reactive power demand at bus i
B_{ij} is the susceptance between buses i and j
N_0 is total number of buses except slack bus
N_{PQ} is total number of PQ buses

2.2.2 Inequality Constraints

$$V_{i\,min} \le V_i \le V_{i\,max}, i \in N_B \quad (4)$$

$$T_{i\,min} \le T_i \le T_{i\,max}, i \in N_T \quad (5)$$

$$Q_{gi\,min} \le Q_{gi} \le Q_{gi\,max}, i \in N_G \quad (6)$$

where,

T_i is the tap position of transformer i
N_T is total number of transformers
N_G is total number of generator buses

3. Particle Swarm Optimization (PSO)

PSO is one of the evolutionary computation techniques which is a population based stochastic optimization technique developed by Kennedy and Eberhart. The method has been developed through simulation of simplified social models. The features of the method are as follows [6]:

- ✓ The method is based on researches on swarms such as fish schooling and bird flocking.
- ✓ The computation time is short and since it is based on a simple concept, it requires little memory.
- ✓ It was originally developed for non-linear optimization problems with continuous variables. However, it can easily be expanded to treat problems with discrete variables. Therefore, it is applicable to mixed integer nonlinear optimization problems with both continuous and discrete variables such as ORPD problem.

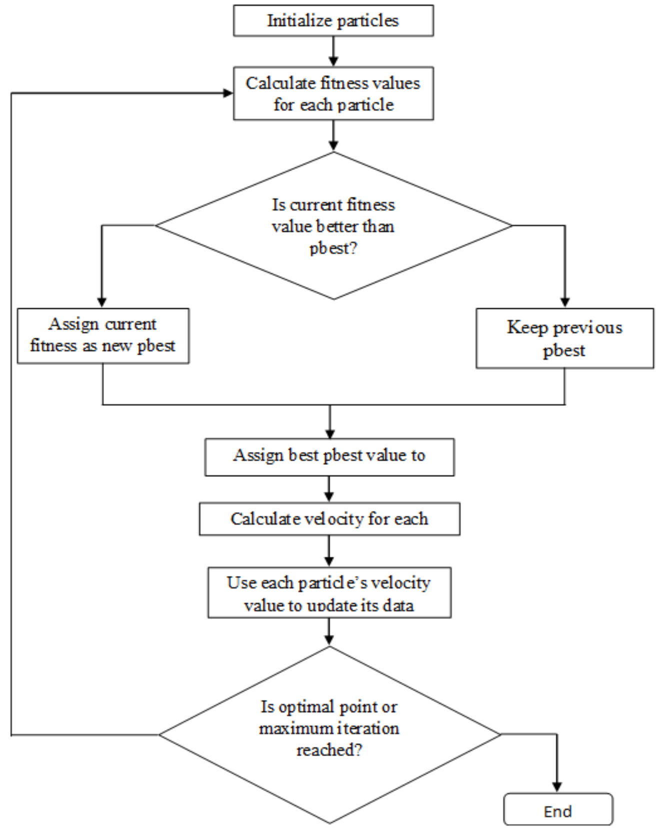


Figure 1 Flowchart for PSO

A population of particles exists in the n-dimensional search space. Every particle has a certain amount of knowledge, and moves about the search space based on this knowledge. The particle has some inertia attributed to it and so it will continue to have a component of motion in the direction it is moving. It knows where in the search space it might encounter with the best solution. The particle will then modify its direction such that it has additional components towards its own best position, pbest and towards the overall best position, gbest [1]. The modification can be represented by the concept of velocity. Velocity of each particle can be modified by the following equation [6]:

$$v_i = v_i + \text{rand} \times (pbest_i - s_i) + \text{rand} \times (gbest_i - s_i) \quad (7)$$

where,

v_i is velocity of particle i
rand is a random number between 0 and 1
$pbest_i$ and $gbest_i$ are the personal best and global best positions of particle i respectively
s_i the current position of particle i

Using (7), a certain velocity that gradually gets close to pbest and gbest can be calculated. The current position (searching point in the solution space) can be modified by the following equation:

$$s_i = s_i + v_i \tag{8}$$

PSO utilizes several searching points like Genetic Algorithm (GA) and the searching points gradually get close to the global optimal point using its pbest and gbest. The features of the searching procedure can be summarized as follows [6]:

- ✓ Initial positions of pbest and gbest are different. However, using the different direction of pbest and gbest, all particles gradually get close to the global optimum.
- ✓ The modified value of the particle position is continuous and the method can be applied to continuous problem. However, the method can be applied to the discrete problem using grids for XY position and its velocity.
- ✓ There are no inconsistency in searching procedures even if continuous and discrete state variables are utilized with continuous axes and grids for XY positions and velocities. Namely, the method can be applied to mixed integer non-linear optimization problems with continuous and discrete state variables naturally and easily.
- ✓ The above concept is explained using only XY axis (2-dimensional space). However, the method can be easily applied to n-dimensional problem.

4. Voltage Stability Index (L-index)

Consider a system with n number of buses where g is total number of generator buses (including slack bus) and (n-g) is total number of load buses. For a given system, we can write [3]:

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \tag{9}$$

where, I_G, I_L, and V_G, V_L represent complex current and voltage vectors at the generator nodes and load nodes. $[Y_{GG}]$, $[Y_{GL}]$, $[Y_{LG}]$ and $[Y_{LL}]$ are corresponding partitioned portions of network *Y-bus* matrix.

Rearranging above equation, we get:

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \tag{10}$$

where, $F_{LG} = -[Y_{LL}]^{-1}[Y_{LG}]$ (11)

The elements of $[F_{LG}]$ matrix are complex and its column correspond to the generator bus numbers and rows correspond to the load bus numbers. Relation between load bus voltage and source bus voltages is given by this matrix. It also gives information about the location of load nodes with respect to generator nodes that is termed as relative electrical distance between load nodes and generator nodes.

For a given system operating condition, using the operational load flow (state estimation) results, the static voltage stability *L-index* is computed as follows [3]:

$$L_j = \left| 1 - \sum_{i=1}^{g} F_{ji} \frac{V_i}{V_j} \right| \tag{12}$$

where, j=g+1,……,n. The L-indices for a given load condition are computed for all load busses.

For stability, the maximum limit for the index L_j is 1 for any of the nodes j. Hence, the voltage stability index of total system is given by L = maximum of L_j for all j (load buses). An *L-index* value away from one and close to zero indicates an improved system security. When the system is near maximum power transfer condition, the voltage stability index L_j values for load buses gets close to one, indicating that the system is close to voltage collapse. The stability margin is obtained as the distance of L from a unit value, i.e. (1-L).

5. STATCOM

One of many FACTS devices, STATCOM is used to regulate the flow of reactive power in the system. Its characteristics is independent of bus voltage. It can exchange real power with the ac system but since it does not have a continuous source exchange of real power is not practical. In the transmission systems, STATCOMs primarily handle only the fundamental reactive power exchange and provide voltage support to buses by modulating bus voltages during dynamic disturbances in order to provide better transient characteristics, improve the transient stability margins and to damp out the system oscillations due to these disturbances [12].

STATCOM are based on current source converters and voltage source converters but voltage source based STATCOM are used more often due to its low cost and easy control. The converter constituting the STATCOM can be composed of GTOs or IGBTs.

6. Load Flow Equation Solution Methods

Among many methods for solving load flow equations, Newton-Raphson is one of them. This paper uses this method for load flow solution. The reason why this method is chosen in this paper is that this method is found to be more superior and efficient than other methods such as Gauss-Seidel method for large systems, from practical aspects of computational time and convergence characteristics. This method takes less number of iteration to converge and its convergence characteristics is not affected by selection of slack bus.

The linearized equation for this method is [12]:

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}\frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial V}\\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial \delta}\end{bmatrix}\begin{bmatrix}\Delta \delta\\ \Delta V\end{bmatrix} \quad (13)$$

where, ΔP and ΔQ are the real power and reactive power mismatch vectors. ∂P/∂δ and ∂P/∂V are the partial derivative vectors of real power with respect to voltage angles and voltage magnitudes. ∂Q/∂δ and ∂Q/∂V are the partial derivative vectors of reactive power with respect to voltage angles and voltage magnitudes. Δδ and ΔV are voltage angle and voltage magnitude mismatch vectors.

7. Formulation of ORPD Problem

For ORPD problem, the optimal values of following three quantities have to be determined [6]:

1. AVR operating values
2. Output of reactive power sources
3. Transformer tap settings

In load flow calculations, generator bus voltage magnitudes are treated as voltage specification values. Output of reactive power sources are treated as corresponding susceptance values. Transformer tap settings are treated as tap ratio of each tap position.

In PSO calculation, each initial values of above three quantities are generated randomly between upper and lower bounds. The values are modified in the search procedure between the bounds.

7.1 ORPD algorithm using PSO

Proposed algorithm for ORPD problem using PSO is as follows:

Step 1. Perform the optimal power flow
Step 2. Initialize particles to random values within their operating limits
Step 3. Initial searching points and velocities are randomly generated within their limits
Step 4. pbest is set to each initial searching point
Step 5. The best evaluated values among pbest is set to gbest
Step 6. New velocities and searching points are calculated using (6) and (7)
Step 7. Check if the above values are within the limit
Step 8. Evaluate the fitness values for each particle and obtain the pbest and gbest values
Step 9. Perform load flow
Step 10. Repeat from step 6 until max iteration is reached or optimal point is reached

7.2 Integration of voltage stability index (VSI) in ORPD

Integration of VSI in ORPD problem is achieved by modifying the objective function by adding *L-index* to it. The objective function is now changed to:

$$New\ objective\ function = P_{loss} + L\text{-}index \quad (14)$$

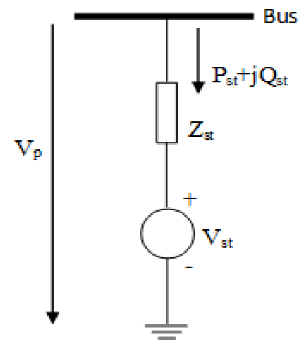


Figure 2 Single line diagram of STATCOM

7.3 Integration of STATCOM in load flow

The power flow constraints of the STATCOM is given by:

$$P_{st} = V_p^{\,2} g_{st} - V_p V_{st}\left(g_{st}\cos(\theta_p - \theta_{st}) + b_{st}\sin(\theta_p - \theta_{st})\right) \quad (15)$$

$$Q_{st} = -V_p^{\,2} b_{st} - V_p V_{st}\left(g_{st}\sin(\theta_p - \theta_{st}) - b_{st}\cos(\theta_p - \theta_{st})\right) \quad (16)$$

where, P_{st} and Q_{st} are active and reactive powers supplied by STATCOM to bus respectively. V_p is the voltage magnitude of the bus P and V_{st} is the voltage across STATCOM. g_{st} and b_{st} are transfer conductance and susceptance between bus and STATCOM respectively. Θ_p and Θ_{st} are the voltage angles of bus and STATCOM respectively.

One operating condition for STATCOM is that the active power exchange should be zero, i.e.

$$PEx = Re(V_{st} I_{st}^{\ *}) = 0 \quad (17)$$

where, PEx is the active power exchange between STATCOM and specified bus. I_{st} is the current flowing from the STATCOM to bus.

Another control function of STATCOM is that specified bus voltage and STATCOM voltage should be equal, i.e.

$$F = V_p - V_{sp} = 0 \quad (18)$$

where, F is voltage magnitude mismatch and V_{sp} is the specified voltage for the bus.

Considering (13), (17) and (18), the linearized equation for load flow including STATCOM is [8]:

$$\begin{bmatrix}\Delta P\\ \Delta Q\\ \Delta PEx\\ \Delta F\end{bmatrix} = \begin{bmatrix}\frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial V} & \frac{\partial P}{\partial V_{st}} & \frac{\partial P}{\partial \delta_{st}}\\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial V} & \frac{\partial Q}{\partial V_{st}} & \frac{\partial Q}{\partial \delta_{st}}\\ \frac{\partial PEx}{\partial V} & \frac{\partial PEx}{\partial V} & \frac{\partial PEx}{\partial V_{st}} & \frac{\partial PEx}{\partial \delta_{st}}\\ \frac{\partial F}{\partial V} & \frac{\partial F}{\partial V} & \frac{\partial F}{\partial V_{st}} & \frac{\partial F}{\partial \delta_{st}}\end{bmatrix}\begin{bmatrix}\Delta \delta\\ \Delta V\\ \Delta V_{st}\\ \Delta \delta_{st}\end{bmatrix} \quad (19)$$

where, ΔPEx and ΔF are active power exchange vector and voltage magnitude mismatch vector respectively. ΔV_{st} and $\Delta \delta_{st}$ are the STATCOM voltage magnitude and angle mismatch vectors.

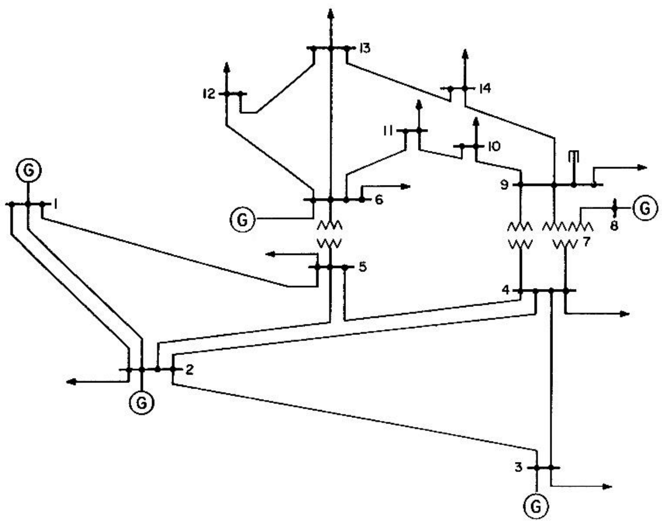


Figure 3 IEEE-14 bus system

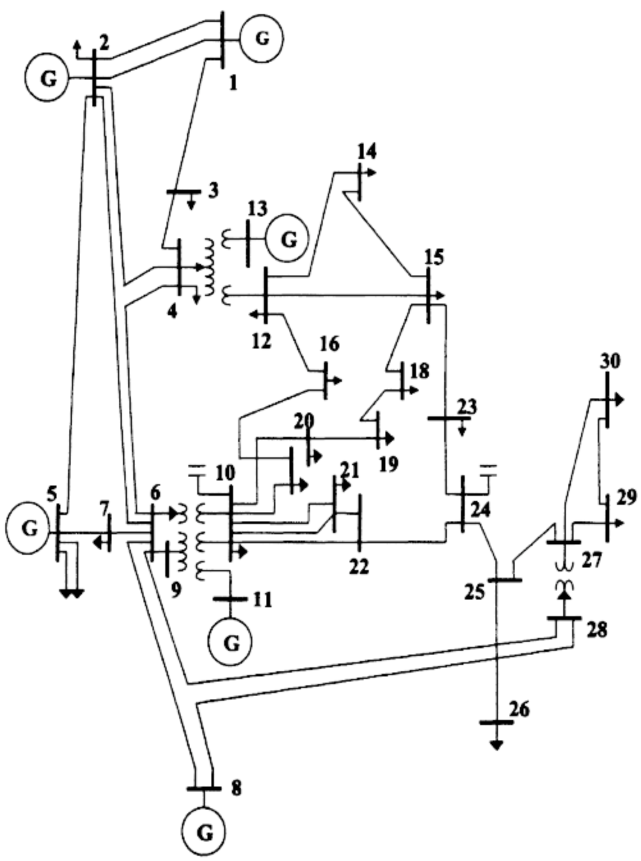


Figure 4 IEEE 30 bus system

Table 1 Lowest VSI for best location of STATCOM in 14 bus system

Bus	5	13
VSI	0.0353	0.0341

Table 2 Lowest VSI for best location of STATCOM in 30 bus system

Bus	26	30
VSI	0.063	0.0559

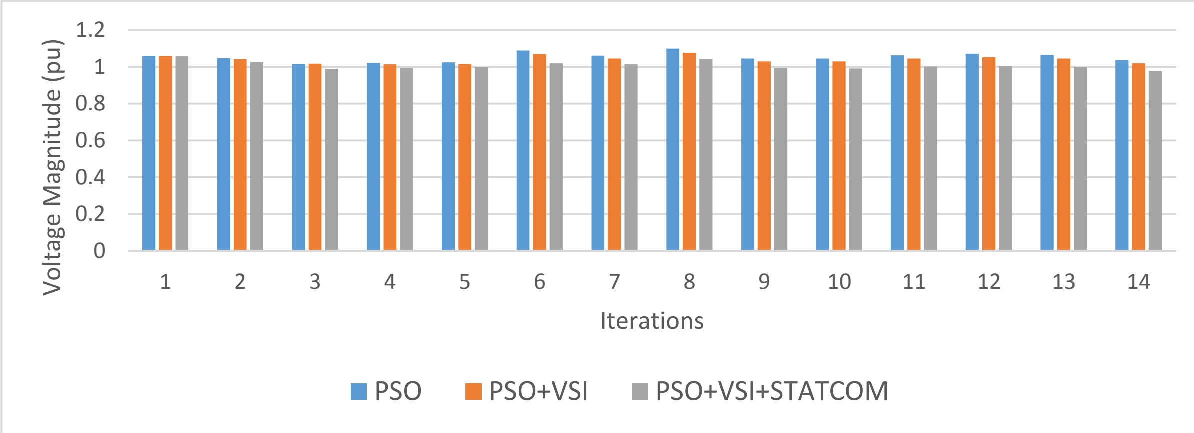
Table 3 Optimal values of control parameters for IEEE-14 bus system [pu]

Control variables	PSO	PSO with VSI	PSO and STATCOM with VSI
AVR 2	1.048	1.0414	1.026
AVR 3	1.0155	1.0176	0.9905
AVR 6	1.0882	1.0693	1.0201
AVR 8	1.1	1.077	1.0433
RPG 2	0.3293	0.1799	0.0088
RPG 3	0.0694	0.1745	0.083
RPG 6	0.2071	0.1518	-0.0429
RPG 8	0.2446	0.1973	0.1756
Tap 4-7	1.0409	0.95	0.95
Tap 4-9	1.0929	0.9595	0.9527
Tap 5-6	1.0334	1.25	1.25
Power Loss	0.1474	0.1512	0.1443
VSI	0.07	0.0568	0.0458

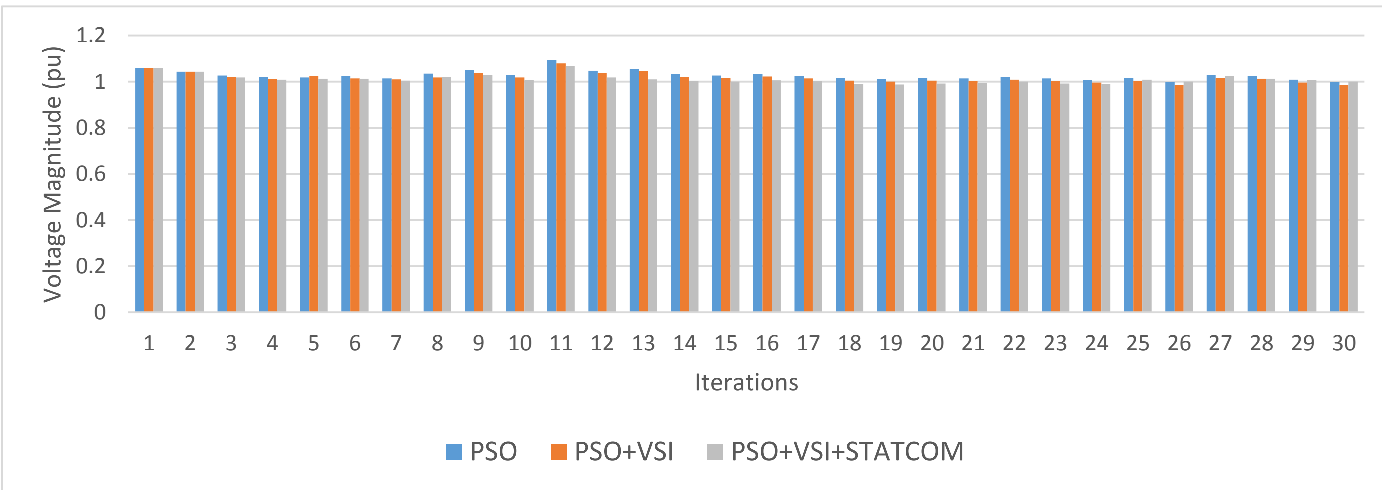
Table 3 Optimal values of control parameters for IEEE-14 bus system [pu]

Control variables	PSO	PSO with VSI	PSO and STATCOM with VSI
AVR 2	1.044	1.0433	1.0437
AVR 5	1.0188	1.024	1.0123
AVR 8	1.0348	1.0181	1.0214
AVR 11	1.0941	1.0802	1.0667
AVR 13	1.0552	1.0459	1.0098
RPG 2	0.2331	0.284	0.3811
RPG 5	0.1908	0.302	0.1848
RPG 8	0.3765	0.1842	0.3094
RPG 11	0.232	0.2177	0.1902
RPG 13	0.0584	0.0604	-0.0586
Tap 4-12	0.9952	1.1205	1.0079
Tap 6-9	1.0471	0.85	1.1911
Tap 6-10	1.1656	1.1884	1.0893
Tap 27-28	1.009	1.0296	0.9729
Power Loss	0.1849	0.1916	0.1879
VSI	0.1572	0.0759	0.0716

AVR 2: Automatic Voltage Regulator value of Bus 2
RPG 2: Reactive power generation of Bus 2
Tap 4-12: Tap setting of transformer between 4 and 12

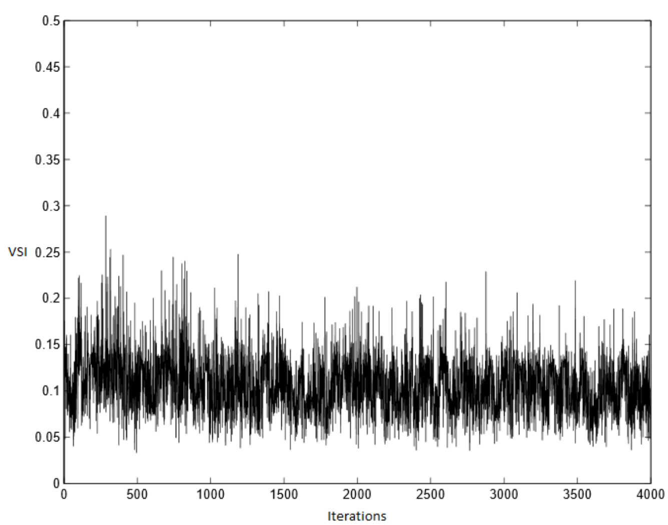


(a)

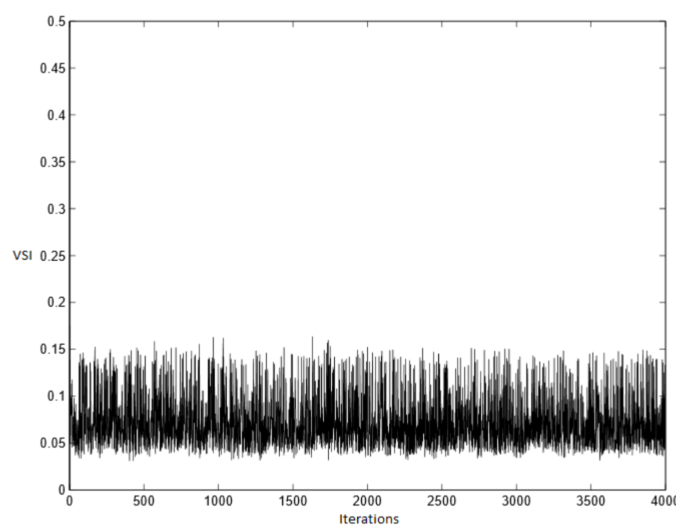


(b)

Figure 5 Comparison between voltage magnitudes of buses under different conditions (a) 14-bus system (b) 30-bus system



(a)



(b)

Figure 6 Variation of voltage stability index with iteration (a) without STATCOM (b) with STATCOM, in 30 bus system

8. Simulation Results and Discussion

In order to demonstrate the effectiveness of the proposed method, minimization of real power loss was considered under three conditions; without voltage stability enhancement, with voltage stability enhancement, and with both voltage stability enhancement and STATCOM. MATLAB code has been developed for this ORPD optimization problem and the validity of the proposed method is demonstrated on IEEE-14 bus and IEEE-30 bus systems.

IEEE-14 bus system

Figure 3 shows IEEE 14 bus test system. The control variables are:

1. AVR operating values of buses 2, 3, 6 and 8
2. Reactive power generators of buses 2, 3, 6 and 8
3. Tap settings of transformers between buses 4-7, 4-9 and 5-6

IEEE-30 bus system

Figure 4 shows IEEE-30 bus test system. The control variables are:

1. AVR operating values of buses 2, 5, 8, 11 and 13
2. Reactive power generators of buses 2, 5, 8, 11 and 13
3. Tap settings of transformers between buses 4,12, 6-9, 6-10 and 27-28

Two STATCOMs are used in both the test systems and the best locations for STATCOMs were obtained using VSI as shown in Table 1 and Table 2. MATLAB programs for both the systems, IEEE-14 bus and IEEE-30 bus systems were executed and data obtained are shown in Table 3 and Table 4.

All the results illustrated in this paper are the best among many results obtained from multiple execution of the Matlab program with following different cases

8.1 Case 1: PSO

For both the systems, first ORPD problem was solved using only PSO i.e. without considering voltage stability and STATCOM. In this case, the objective function F is considered as real power loss i.e.

$$F = P_{loss} \qquad (20)$$

For IEEE-14 bus system, real power loss obtained was 0.1474 pu i.e. 14.74 MW and the VSI obtained was 0.07. For IEEE-30 bus system, real power loss obtained was 0.1849 pu i.e. 18.49 MW and the VSI obtained was 0.1572.

8.2 Case 2: PSO and VSI

In second case, ORPD problem was solved considering voltage stability using PSO. The new objective function F for this case is considered as real power loss in addition to the VSI i.e.

$$F = P_{loss} + VSI \qquad (21)$$

For IEEE-14 bus system, real power loss obtained was 0.1512 pu i.e. 15.12 MW and the VSI obtained was 0.0568. For IEEE-30 bus system, real power loss obtained was 0.1917 pu i.e. 19.17 MW and the VSI obtained was 0.0759. Now, since voltage stability is considered, VSI in this case decreases for both the systems while power loss increases.

8.3 Case 2: PSO, VSI and STATCOM

In third case, STATCOM is integrated into the system. The objective function for this case is considered as (20), same as in previous case. For IEEE-14 bus system, real power loss obtained was 0.1433 pu i.e. 14.33 MW and the VSI obtained was 0.0458. For IEEE-30 bus system, real power loss obtained was 0.1879 pu i.e. 18.79 MW and the VSI obtained was 0.0716. This integration of STATCOM results in decrease in both VSI and power loss.

Figure 5 shows the comparison of voltage magnitudes of buses under different cases. For IEEE-14 bus system, Voltage magnitudes has the least deviation from 1 pu in the third case with standard deviation of 0.000257 while the deviation is highest in the first case with standard deviation of 0.001639. The deviation of voltage magnitude for the second case is in between the other two cases with standard deviation of 0.00096.

Similarly for IEEE-30 bus system, voltage magnitudes has the least deviation from 1 pu in the third case with standard deviation of 0.000482 while the deviation is highest in the first case with standard deviation of 0.001143. The deviation of voltage magnitude for the second case is in between the other two cases with standard deviation of 0.000741.

Figure 6 shows how VSI is varying with every iteration. Without integration of STATCOM, VSI mainly varies from 0.05 to 0.25 and reaches up to 0.28. On the contrary, with integration of STATCOM, VSI vary between 0.04 and 0.15. We can interpret from this that STATCOM enhances voltage stability in the system.

Results on both the test systems reveals that consideration of voltage stability index in the objective function decreases the index value i.e. make the system more stable even though the real power loss is increased. Integration of STATCOM helps decrease real power loss with further decrease in voltage stability index value.

9. Conclusion

In this paper, particle swarm optimization technique is used for optimal reactive power dispatch problem. The control used for the problem is minimization of real power loss. Voltage stability index is considered in the problem to enhance the voltage stability of the system. STATCOM is used in the system to minimize power loss and make the system more stable. IEEE-14 and IEEE-30 bus systems are used as test systems. The test results reveal that the proposed method is effective for reactive power optimization with voltage stability enhancement.

References

[1] P. A. Jeyanthy, D. Devaraj, Hybrid particle swarm optimization for multi-objective reactive power optimization with voltage stability enhancement, ACEEE International Journal on Electrical and Power Engineering, Vol. 1, No. 2, July 2010 16-21

[2] H. Tehzeeb-Ul-Hassan, R. Zafar, S. A. Mohsin, O. Lateef, Reduction in power transmission loss using fully informed particle swarm optimization, Electrical Power and Energy Systems 43 (2012) 364-368

[3] G. Yesuratnam, D. Thukaram, Congestion management in open access based on relative electrical distances using voltage stability criteria, Electrical Power Systems Research 77 (2007) 1608-1618

[4] K. Visakha, D. Thukaram, L. Jenkins, Transmission charges of power contracts based on relative electrical distances in open access, Electrical Power Systems Research 70 (2004) 153-161

[5] P. A. Jeyanthy, D, Devaraj, Optimal reactive power dispatch for voltage stability enhancement using real coded genetic algorithm, International Journal for Computer and Electrical Engineering, Vol. 2, No. 4, August 2010 1793-8163 734-740

[6] Hirotaka Yoshida, Kenichi Kawata, Yoshikazu Fukuyama, Yosuke Nakanishi, A particle swarm optimization for reactive power and voltage control considering voltage stability, IEEE International Conference on Intelligent System Applications to Power Systems (ISAP'99), Rio de Janeiro, April 4-8, 1999 1-6

[7] M. A. Abido, Optimal power flow using particle swarm optimization, Electrical Power and Energy Systems 24 (2002) 563-571

[8] F. Z. Gherbi, K. Merini, S. Hadjeri, K. F. Elatrech, Study of the best location of STATCOM to improve the voltage, Mediamira Science Publisher, Volume 51, Number 3, 2010 181-185

[9] M. Y. Ali, K. Raahemifar, Reactive power optimization based on hybrid particle swarm optimization algorithm, 25th IEEE CCECE 2012

[10] V. K. Jain, H. Singh, Hybrid particle swarm optimization based reactive power optimization, International Journal Of Computational Engineering Research/ISSN:2250-3005 464-469

[11] K. S. C. Mauryan, K. Thanushkodi, K. Sashikumar, M. Anandvelu, Optimization of reactive power based on improved particle swarm algorithm, European Journal of Scientific Research ISSN 1450-216X Vol. 72 No. 4 (2012) 608-617

[12] A. Barua, P. Kumar, Study of reactive power compensation using STATCOM, Department of Electrical Engineering, National Institute of Technology, Orissa, India, 2011, http://ethesis.nitrkl.ac.in/2243/