

Application of Particle Swarm Optimization for the Reactive Power Compensation using STATCOM in a Transmission System in the presence of Photovoltaic Integration

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ABSTRACT: The main aim of this paper is to implement the particle swarm optimization technique for finding the optimal location and sizing of the static synchronous compensator (STATCOM) in the system. The reactive power compensation in transmission systems is a serious problem, which can be solved by the use of Flexible AC Transmission Systems (FACTS). Of all the FACTS devices static synchronous compensator (STATCOM) is used for the enhancement of voltage profile of the transmission system. The particle swarm optimization (PSO) technique has been implemented for obtaining the optimal allocation of the FACTS device. An IEEE 14-bus test system has been considered for the implementation of the algorithm in order to obtain the required optimal solution. This paper also presents the optimal allocation of the STATCOM with and without presence of the PV integration in the considered test system. The results of the PSO technique have been obtained by using two objective functions separately. The objective functions are voltage deviation metric and real power loss of the system. The results are found to be promising. By using STATCOM in the transmission system, subjected to the constraints, the reactive power compensation is effectively done.

KEYWORDS: FACTS, STATCOM, Photovoltaic Integration, Optimal Location, PSO.

I. INTRODUCTION

In the power systems containing many components operating with generation, transmission and distribution purposes, there is a high priority for maintaining the voltage stability in limits. If the voltage stability is not maintained in the desired limits then the generators, various components of the transmission systems and loads may get exposed to several faults. The improvement of the voltage profile increases the transmission capacity of the transmission system. Hence for the improvement of voltage profile, flexible ac transmission system devices (FACTS) can be used. These devices can be used for the compensating the reactive power in the transmission system. By compensating the reactive power in the system, the voltage profile of the system can be efficiently controlled. Static synchronous compensator (STATCOM) has been considered for the reactive power compensation [1,2].

In these days, the transmission systems are integrated with the power generation from other sources like renewable energy sources. In the renewable energy sources available, photovoltaic energy and wind energy are the promising sources which generate a large amount of power. Several challenges and problems are being faced during the integration of PV with the existing transmission system [3-5].

Many traditional techniques are implemented for finding the optimal location and sizing of the FACTS devices. Later many evolutionary computation techniques such as Genetic Algorithms and Evolutionary Programming have been applied to solve this optimization problem. To find the optimal location and sizing of the STATCOM, another

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technique named Particle Swarm Optimization (PSO) can also be applied. Particle Swarm Optimization is an iterative evolutionary computation technique which provides an optimal solution based on the parameters given [6,7]. The particle swarm optimization techniques can be classified into different methods depending on the parameters provided. Classical PSO, PSO time varying inertia weight (PSO-TVIW) and PSO time varying acceleration coefficients (PSO-TVAC) are the different methods in PSO, as in [6].

II. RELATED WORK

Classical PSO method has been implemented for finding the optimal location and sizing of the STATCOM in [1,8]. The authors in [2], the improved particle swarm optimization method for finding the optimal allocation of FACTS device is used. The voltage deviation metric has been used as the objective function in [2,6,7]. The classical PSO technique was implemented using the multi-objective function which consists of individual functions such as real power loss, voltage deviation metric and inverse of maximum loadability, in [7].

The optimal allocation of STATCOM has been obtained in [9], for the improvement of voltage profile and total harmonic distortion (THD) reduction. The authors in [10], obtained the optimal sizing and location of the STATCOM by determining the weakest bus in the system, using eigenvalues and eigenvectors method. The effect of integration of wind farm with the existing system has been studied by the respective authors in [11]. The tuning of STATCOM has been done for the voltage control of the wind farm integrated system. Different load flow methods were conducted on different test systems, in order to study the load flow calculations in [13,14]. The difference between the effectiveness of the shunt and series compensation has been studied in [15]. A detailed study has been carried out about the STATCOM in the aspects of different operating modes and conditions in [16,17].

In this paper, classical PSO method is implemented for finding the optimal location and sizing of the STATCOM by considering both the power loss and voltage deviation metric as objective functions separately. The optimal allocation of STATCOM has also been found out in the presence of photovoltaic (PV) power generation. The real power and reactive power losses are compared before and after the placement of the STATCOM in the system. The comparison of voltage profile also been considered for knowing the effectiveness of the STATCOM compensator.

III. STATCOM

Static Synchronous Compensator (STATCOM) is a shunt compensation device that improves the voltage profile by injecting current into the transmission line. The STATCOM can be applied for the generation of the reactive power into the transmission line and the absorption of the reactive power from the transmission line. The generation and the absorption of the reactive power of the line depend on the voltage difference between the system voltage and the generator voltage. When the generator voltage exceeds the system voltage, the generation of reactive power takes place and vice versa.

STATCOM is always connected at the load bus. Mostly STATCOM is considered as a synchronous generator with voltage at 1 p.u and zero real power output, having the reactive power output (VAR) instead. Here, in this paper, the STATCOM has not been modelled, but just reactive power generation of the STATCOM is added at the optimal location in the network found through PSO.

IV. PARTICLE SWARM OPTIMIZATION

Particle Swarm optimization is a stochastic optimization technique which was developed in 1995 by Dr.Eberhart, Dr.Kennedy and Dr.shi. The PSO mainly uses the swarm intelligence. The term swarm implies a flock of birds or a school of fishes. In this concept of bird flocking every bird changes its travelling path depending on both the group position and its own position. PSO also adapts the same principle in searching for the optimal solution. Here, a group of particles called population is used for searching the solution. Every particle has its own position and velocity.

x_n^i - particle position

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v_n^i - particle velocity

Where n denotes the particle and i denotes the iteration. The position and velocity of each and every particle will be updated further basing on their position and velocity in the previous iteration. The equations we use for updating the position and velocity are as follows

$$x_n^{i+1} = x_n^i + v_n^{i+1} \quad (1)$$

$$v_n^{i+1} = [w * v_n^i + c_1 * r_1 * (pbest_n^i - x_n^i) + c_2 * r_2 * (gbest^i - x_n^i)] \quad (2)$$

Where pbest and gbest are the best position of each particle and global best positions of the whole swarm respectively.

C_1 , C_2 - Acceleration coefficients

r_1 , r_2 - Random numbers between 0 and 1

w - inertia weight

x_n^{i+1} , v_n^{i+1} - updated position and velocity of the nth particle

After completing all the iterations, PSO provides the optimal solution by obtaining the global best position i.e., gbest value and calculating the fitness function by substituting the obtained gbest value or the position value in it. The fitness value will be minimized by these updated position and velocity. The values of the dimensions at which the fitness function gets its minimum value will be provided as the optimal solutions of the problem [7].

V. OBJECTIVE FUNCTION AND IMPLEMENTATION

A. OBJECTIVE FUNCTIONS

In power systems, the voltage profile of the network gets affected by the load variations. The main goal of this optimization problem is to get an optimal solution so that the voltage profile can be controlled as desired. This process can be done by using STATCOM (FACTS device) and thereby minimizing.

1. Voltage deviations in the system
2. Power system real power loss

Here in this paper, the optimal location and sizing of the STATCOM has been obtained by considering the above two objective functions separately. The PSO is made to run separately with the above objective functions.

Case A: Voltage deviation metric as objective function

In this case the voltage deviation metric is considered as the fitness function. The optimal solution is obtained by minimizing the objective function which is as follows [1].

$$F = \sqrt{\sum_{n=1}^{14} (V_n - 1)^2} \quad (3)$$

Where

$n=1, 2, 3, \dots, 14$ denotes the number of the bus
is the voltage of the nth bus

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Case B: Real power loss as objective function

In this case, the real power loss is considered as the fitness function. The optimal solution is obtained by minimizing the objective function which is as follows

$$F = P_{Ltotal} = \sum_1^{14} P_l \tag{4}$$

$$P_l = P_{sending} - P_{receiving} \tag{5}$$

Where P_l denotes the real power loss in each transmission line, P_{Ltotal} denotes the total real power loss of the IEEE-14 bus system, $P_{sending}$ and $P_{receiving}$ are the sending and receiving powers of each transmission line [6].

B. IMPLEMENTATION

The sizing criterion of the STATCOM is determined by a value that partially compensates the reactive power, while the voltage at any bus of the system does not exceed the allowable limit. Hence, for simplicity the maximum limit of the STATCOM size is considered to be 30% of the reactive power load of the system.

The placement criterion depends on the location of the bus at which the objective function gets its minimum value. The generator buses in the system are eliminated from the search process of the optimal location of the STATCOM, as the voltages of the generator buses are already get controlled by the automatic voltage regulators (AVR) and other controlling equipment. Hence only load buses are considered for the searching process of the STATCOM placement.

The proposed algorithm has also been tested in the IEEE 14 bus system with the presence of photovoltaic (PV) integration. As the power generation over PV systems has been increasing with growing demand in these days, PV integrations into the transmission system are gaining significance. For simplicity, it is assumed that the capacity of integrated PV generation be 20% of the total real power generation of the existing system without PV integration.

VI. RESULTS

Case with PV Integration: In this case, it is assumed that PV generation is added to the system. As said earlier, in the above section, PV generation of size equal to 20% (approximately) of the real power generation of the considered system is added at bus no. 14. The comparison of the load flow results of the IEEE 14 bus system with and without PV integration are as follows.

Table 1 Loss profile

	Without PV integration	With PV integration	Decrement of Losses
Real Power Loss (MW)	19.075	14.117	25.99%
Reactive Power Loss (MVar)	85.555	51.715	39.55%

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The comparison of the voltage profile without and with PV integration is as follows.

Table 2 Voltages without and with PV integration

Bus Number	Voltages without PV integration (p.u)	Voltages with PV integration (p.u)
1	1.0600	1.0600
2	1.0450	1.0450
3	0.9800	0.9800
4	0.9772	0.9904
5	0.9874	0.9991
6	1.0400	1.0300
7	1.0080	1.0198
8	1.0500	1.0600
9	0.9846	0.9944
10	0.9833	0.9898
11	1.0061	1.0047
12	1.0156	1.0113
13	1.0061	1.0136
14	0.9669	1.0300

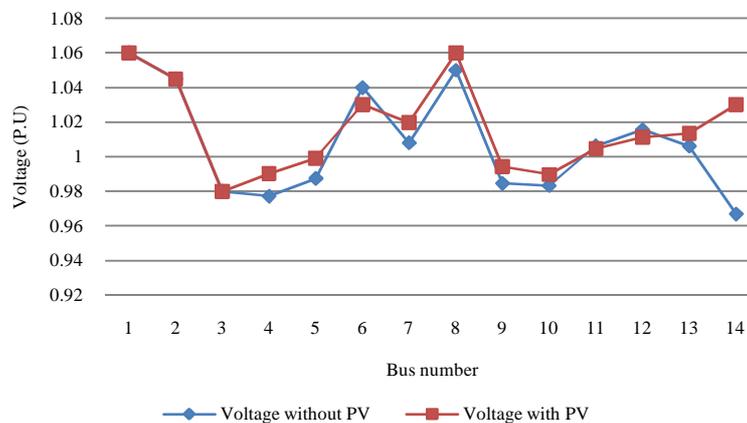


Fig. 1 Voltage profile comparison of base case with PV

The above figure shows that the voltage profile of the PV integrated case is better compared to that of the base case without any integration. As PV is integrated at bus number 14, a noticeable change in the voltage magnitude at bus number 14 has been observed.

The results of the proposed algorithm with two objective functions, voltage deviation metric and real power loss, are shown separately as follow.

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Case A: Voltage deviation metric as objective function

Case 1A: With STATCOM

In this case, optimal location and sizing of the STATCOM is obtained for the test system without any PV integration.

Table 3 Optimal solution for STATCOM

Location (Bus number)	14
Size (MVar)	3
Convergence Rate (%)	60

Table 4 Loss profile

	Without STATCOM	With STATCOM	Decrement of Losses
Real Power Loss (MW)	19.075	18.882	1.01%
Reactive Power Loss (MVar)	85.555	85.274	0.32%

The comparison of voltage profile with and without STATCOM is as shown in the figure below.

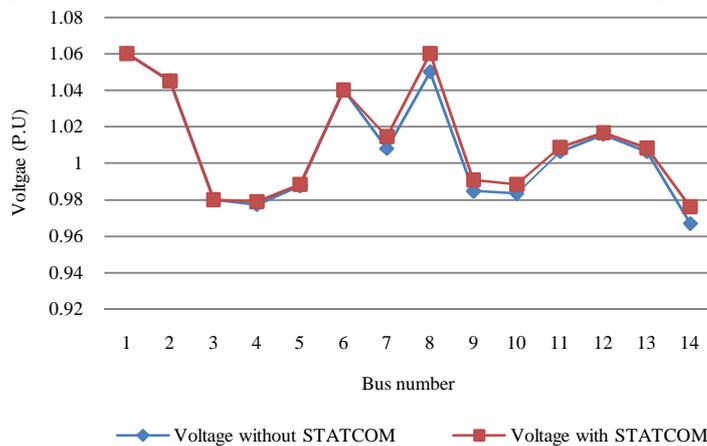


Fig. 2 Voltage profile comparison of base case with STATCOM

The above figure shows that the voltage profile with the integration of STATCOM into the system is more efficient than the voltage profile of the base case without any source for compensation.

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Case 2A: With PV integration and STATCOM

In this case, the optimal location and sizing of the STATCOM is obtained by PSO for the considered test system in the presence of PV integration at bus number 14 of the system.

Table 5 Optimal solution for STATCOM

Location (Bus number)	4
Size (MVar)	4
Convergence Rate (%)	96.67

Table 6 Loss profile

	Without PV and STATCOM	With PV and STATCOM	Decrement of Losses
Real Power Loss (MW)	19.075	13.978	26.73%
Reactive Power Loss (MVar)	85.555	51.003	40.38%

The comparison of voltage profile with and without PV and STATCOM is as shown in the figure below.

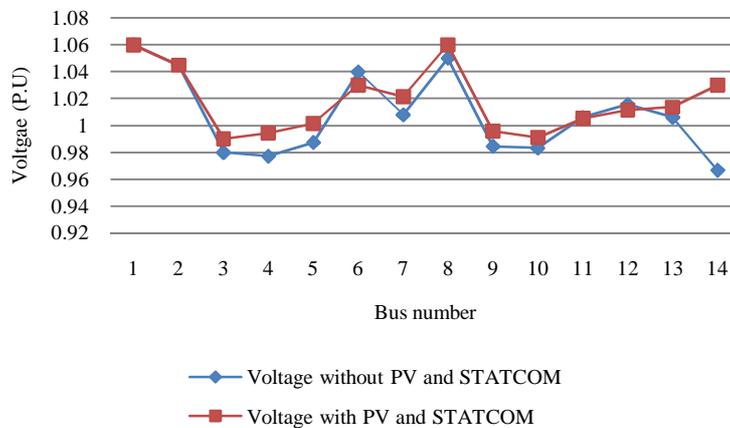


Fig. 3 Voltage profile comparison of base case with PV and STATCOM

The above figure shows that the voltage profile of the system with PV integration and STATCOM is better compared to that of the base case. Considerable improvement has been observed in the case with the STATCOM.

Case B: Real power loss as objective function

Case 1B: With STATCOM

In this case, the optimal location and sizing of the STATCOM is obtained by using PSO for the considered test system without any PV integration.

Table 7 Optimal solution for STATCOM

Location (Bus number)	9
Size (MVar)	35
Convergence Rate (%)	100

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Table 8 Loss profile

	Without STATCOM	With STATCOM	Decrement of Losses
Real Power Loss (MW)	19.075	18.344	3.83%
Reactive Power Loss (MVar)	85.555	83.636	2.24%

The comparison of voltage profile with and without STATCOM is as shown in the figure below.

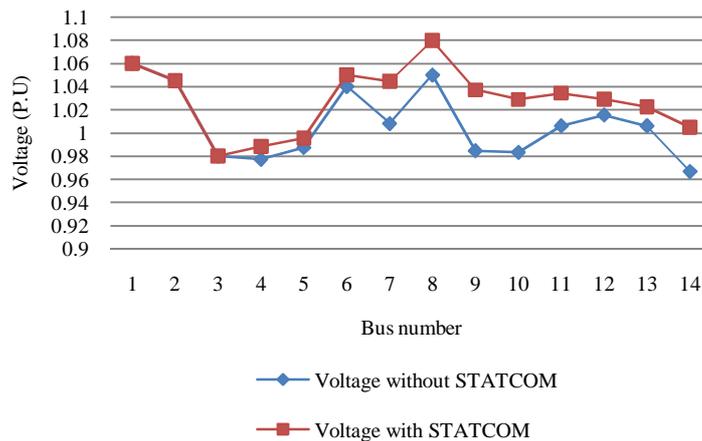


Fig. 4 Voltage profile comparison of base case with STATCOM

The above figure shows the improvement of the voltage profile from the base case to that of the case with the integration of only STATCOM. The real power loss objective function yields better results compared to that of the voltage deviation metric objective function as shown in the above figure.

Case 2B: With PV integration and STATCOM

In this case, the optimal location and sizing of the STATCOM is obtained by using PSO for the considered test system with PV integration at bus number 14.

Table 9 Optimal solution for STATCOM

Location (Bus number)	4
Size (MVar)	35
Convergence Rate (%)	100

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Table 10 Loss profile

	Without PV and STATCOM	With PV and STATCOM	Decrement of Losses
Real Power Loss (MW)	19.075	13.5275	29.08%
Reactive Power Loss (MVar)	85.555	49.269	42.41%

The comparison of voltage profile with and without PV and STATCOM is as shown in the figure below.

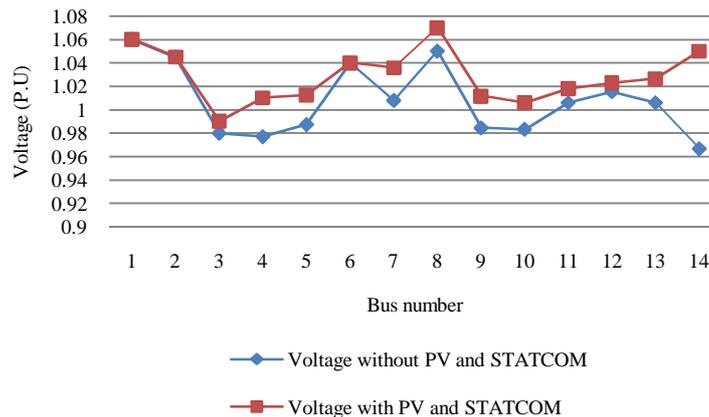


Fig. 5 Voltage profile comparison of base case with PV and STATCOM

The above figure shows the considerable improvement of the voltage profile in the case of PV and STATCOM compared to that of the base case without any integration.

VII. DISCUSSION

In this paper, IEEE 14 bus system has been considered for the testing of the proposed algorithm. The line data and bus data are adapted from [6]. As the PSO is a randomization process, it cannot be said that the solution obtained in the first run of the algorithm is appropriate. Hence the PSO is made to run for 30 trails for each case. In each of the 30 trails, PSO converges to a feasible solution. These feasible solutions may or may not get repeated in all the trails, which determines the convergence of that solution. Simply, convergence rate is the rate at which a feasible solution got repeated over all the trails been done.

Of all 30 feasible solutions, the solution with highest convergence rate is considered as the optimal solution. The location of the PV is not computed by the algorithm. For simplicity, it is assumed that the PV is integrated at the bus which has lowest voltage in the existing system. Here in this case bus number 14 has the lowest voltage in the existing system. Hence the prescribed size (20% of the real power generation of the system) is integrated at bus number 14.

The results of the PSO technique for optimal allocation of STATCOM are found reliable both in the cases of the test system with and without PV integration. Therefore, in these cases, the effectiveness of STATCOM on voltage profile and load flows of the system has been studied.

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VIII. CONCLUSION

In this paper, the test system with and without STATCOM, before and after the integration of PV in the network has been analyzed. The improvement is more significant, when real power loss is considered as objective function rather than voltage deviation metric. However, the performance of the test system in terms of real power losses, reactive power losses and voltage profile has been improved compared to that of the base case. Even for the future expansion of power systems, the use of PSO will result in more flexibility in the solution.

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