Optimal Placement and Sizing of STATCOM Using PSO

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Abstract*: Voltage collapse is usually occurs when reactive power demand on load side is not being met in electric power transmission. Reactive power compensation is important for maintaining voltage to deliver real power through power lines. The flexible AC transmission system (FACTS) are now recognized as a viable solution for controlling transmission voltage, power flow, etc. and represent a new era for transmission systems. STATCOM is a member of FACTS family and is connected in shunt with system. However, owing to the considerable cost of the FACTS device involved, it is important to find the optimal location and sizing (rating) of the device in a power system to obtain maximum benefits of the devices. The main purpose of this research is to implement the Optimum Reactive Power Delivery (ORPD) to "optimally" set the values of control variables such as generator reactive power output (generator bus voltages), transformer tap ratios and reactive power outputs for the shunt trimmed equipment. This research work proposes an effective heuristic optimization technique known as the Particle Swarm Optimization (PSO). The objective function is formulated to minimize total power loss (TPL) and to enhance the Voltage stability. For load demand levels location and sizing (rating) of the device is determined. The whole work is simulated in MATLAB

***Keywords*: ORPD, FACTS, Sizing of STATCOM, PSO.**

1. Introduction

The techniques of reactive power compensation are found to be efficient in a stressed transmission network for the better utilization of existing facilities of the network without sacrificing desired stability margin. The VAR compensation improves the stability of ac system by increasing the maximum active power that can be transmitted Voltage magnitude is important factor that affect power supply quality. Voltage sag or swell prove problematic to customer as it leads to production downtime. Reactive power compensation improves the performance of ac system. It is important for maintaining voltage to deliver real power through power lines. By reactive power compensation we can control the power factor and reduce the consumption of electricity. Reactive power compensation has two aspects. Voltage support means voltage fluctuation reduction at the given terminal of transmission line. Load compensation involves power factor improvement, balance of active power drawn from supply improvement in voltage regulation and elimination of current harmonics etc. There are mainly two types of compensation in use: Series compensation and shunt compensation. System parameters are modified by these to enhance VAR compensation. This results in improvement of stability of the ac system by raising maximum active power to be transmitted. The flexible AC transmission system (FACTS) are now recognized as a viable solution for controlling transmission voltage, power flow, dynamic response, etc. and represent a new era for transmission systems. These adjust parameters like governing the power system like voltage, current, phase angle, impedance and frequency. Although primary purpose of the shunt FACTS devices is supporting bus voltage by injection (or absorption) of reactive power, they also have capability of improving transient stability by increasing (or decreasing) power transfer capability as machine angle increases (or decreases), that is achieved by operation of shunt FACTS devices in the capacitive (or inductive) mode. STATCOM is a member of FACTS family and is connected in shunt with system. it is capable of enhancing voltage security. However, owing to the considerable cost of the FACTS device involved, it is important to find the optimal location and sizing (rating) of the device in a power system to obtain maximum benefits of the devices.

A. Karami and Galougahi [3], Discussed in their paper, an auxiliary controller is employed for the STATCOM (static synchronous compensator) to improve transient stability limit of the multi machine power systems.

Nitish Rawat et. al. [4] In his research discussed about facts devices that are used in the power system. The facts devices are used to maintain and enhance different parameters such as, transmission losses, generation cost, voltage stability and system security in the power system

Esmaeil Ghahremani; Innocent Kamwa [8] Discussed in their paper Flexible AC transmission systems, known as FACTS devices, can assist decrease power flow on the overloaded lines, resulting in enhanced power system load ability lower transmission line losses, enhanced stability and safety, and ultimately, transmission system with more energy-efficiency. To make it easier and more flexible to locate appropriate FACTS locations, they introduced graphical user interface (GUI) based on a genetic algorithm (GA) in their paper

Rahul Dubey et. al. [10], has presented in their paper literature survey on shunt connected Flexible Alternating

Current Transmission Systems (FACTS) applications such as Static VAR Compensator (SVC), Static Synchronous Compensator (STATCOM) for enhancing power system efficiency parameters such as compensation of reactive power, minimizing real power losses, improving voltage stability, and also providing flexible operation and improved controllability.

E. Ghahremani, I. Kamwa [11] discussed in his paper that power production costs have developed a need to find reliable, inexpensive and available power generation sources the optimization method is intended to minimize the losses of the transmission line and maximize power

K. Karthikeyana, P. K. Dhal [12] in this paper authors have thoroughly investigated transient stability enhancement through optimal location of STATCOM and its tuning. They have executed performance analysis of the STATCOM for the Western Science Coordinated Council (WSCC) nine bus system for enhancement of the transient stability using the Power System Analysis (PSAT) tool box software.

Majid Moazzami et. al. [14] discussed that by restructuring power systems, power plant companies improve power quality and the reliability of our distribution systems after using modern instruments. Also, using these distributed generation sources (DGs) and distribution static synchronized compensator (D-STATCOM) in the distribution systems are increased. The reduction of losses in the distribution systems and system energy losses costs is compared. In this article, to determine the optimal position of installation of instruments, used an objective function which consists of equipment's installation.

Bushra Weqar et. al. [15], used technique based on analytical approach in their work for finding optimized size and the location of distributed generations (DG) and the Distribution Static Compensator (D-STATCOM) in distribution network.

Garima Choudhary et. al. [13] investigated optimal placement of the Static Synchronous Compensators (STATCOMs) in order to enhance voltage stability limits and reduce the transmission losses. Continuous expansion of the power demands and the lack of supply have led to study on the Flexible Alternating Current Transmission System (FACTS) devices, as fascinated area for the research. Considering the benefits and applications of FACTS devices.

2. Reactive power compensation

Power which returns to source in each cycle having movement is in both directions in electric circuit or it reacts upon itself is called as Reactive Power. Reactive power supplies stored energy in reactive elements. Generation and transmission of the power is complex process, as it requires working of different power system components in tandem to maximize output. Main component among these is reactive power in power system. It is important for maintaining voltage to deliver real power through power lines. Inductive loads like motor transformer require reactive power for operating. For improving A.C power system performance management of reactive power in efficient way called as reactive power compensation is needed.

3. Implementation of PSO for ORPD

A. *Objective Function*

Optimum Reactive Power Delivery (OPRD) is a complicated optimization problem in which we try to "optimally" set the values of control variables such as generator reactive power output (generator bus voltages), transformer tap ratios and reactive power outputs for the shunt trimmed equipment such as capacities, etc. To minimize the following objective function, I used basic Particle Swarm Optimization (PSO).

The main objective function is:

$$min \sum_{k \in N_B} P_{kloss} = \sum_{k \in N_B} g_k \left(v_i^2 + v_j^2 - 2 v_i v_j \cos\theta_{ij} \right) \quad (1)$$

Where,

N_B = Total Number of Buses

$\sum_{k \in N_B} P_{kloss}$ = Total Active Power Losses in Transmission Line

g_k = Conductance of Branch k (pu)

v_i, v_j = Voltage magnitude (pu) of bus I and j respectively

θ_{ij} = Load Angle difference of bus I and j (rad)

B. *Equality Constraints*

So that Active power flow balance equations at all buses excluding slack bus is:

$$P_{gi} - P_{di} - v_i \sum_{j \in N_i} v_j \left(g_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right) = 0 \quad (2)$$

Reactive power flow balance equations at all PQ buses (load buses)

$$Q_{gi} - Q_{di} - v_i \sum_{j \in N_i} v_j \left(g_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right) = 0 \quad (3)$$

C. *Inequality constraints*

Reactive Power Generation limit for each generator bus is:

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max} \qquad i \in N_g \quad (4)$$

Voltage Magnitude limit for each bus

$$v_{gi}^{min} \le v_{gi} \le v_{gi}^{max} \qquad i \in N_B \quad (5)$$

Static penalty function is used to deal with the limitations of inequality. The increased objective (fitness) function would therefore be like

$$F_P = \sum_{k \in N_B} P_{kloss} + \text{Penalty Function} \quad (6)$$

$$\text{Penalty Function} = k_2 \times \sum_{i=i}^{N_g} f(Q_{Ri}) + k_2 \times \sum_{i=1}^{N_B} f(v_i) + k_3 \times \sum_{m=1}^{N_L} f(s_{lm}) \quad (7)$$

4. Application of Particle Swarm Optimization for ORPD

PSO was proposed by Eberhart and Kennedy, a quick, simple and efficient population-based optimization method. Each particle updates its position based on its own best position, best globally between the particles and its former speed vector in the following equations,

$$v_i^{k+1} = w \times v_i^k + c_1 \times r_1 \times \left(p_{best} - x_i^k\right) + c_2 \times r \times \left(g_{best} - x_i^k\right) \tag{8}$$

$$x_i^{k+1} = x_i^k + \chi v_i^{k+1} \tag{9}$$

Where,

v_i^{k+1} : The velocity of i^{th} particle at $(k+1)^{th}$ iteration

w : Inertia weight of the particle

v_i^k : The velocity of i^{th} particle at k^{th} iteration

$c_{1,} c_2$: Positive constants having values between [0, 2.5]

r_1, r_2 : Randomly generated numbers between [0, 1]

p_{best_i} : The best position of the i^{th} particle obtained based upon its own experience

g_{best} : Global best position of the particle in the population

x_i^k : The position of i^{th} particle at k^{th} iteration

χ : Constriction factor. It may help insure convergence.

Appropriate weight selection provides a good balance between global and local exploration.

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \tag{10}$$

Where,

W_{max} =Value of inertia weight at the beginning of iterations,

W_{min} = Inertia weight at the end of iterations,

5. Results of simulation

The whole code of the PSO is implemented on IEEE 30 bus test system in MATLAB. For running the simulation here we use MATPOWER 3.2 version. The results will be saved in the "diary" file. Because PSO is a stochastic optimization method, each simulation produces different optimized results. Figure 1 shows the IEEE-30 bus test system which is used in this work.

From the table 2 shows that the requirement of reactive power compensator is at bus no 3, 10 and 24. The estimated size of the compensator is also found that 10.788, 7.589 and 11.790 MVAR respectively. Table 1 shows the performance before and after compensation. From the figure 2 it is clearly seen that the total active power losses get decreases with increasing the iteration

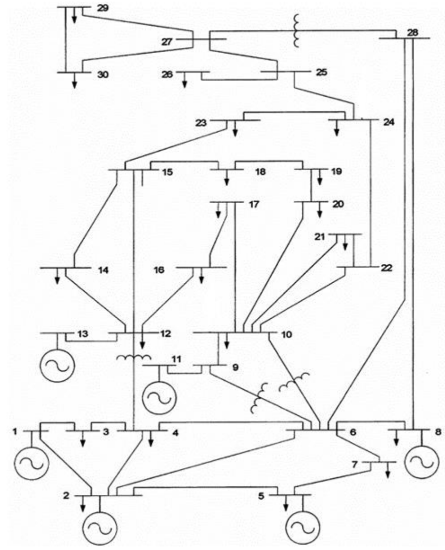

Fig. 1. IEEE-30 Bus System with 6 Generator

Table 1
Comparison of losses obtained before and after optimization

S. no.	Power	Losses before optimization	Losses after optimization	% reduction in losses
1	Active power losses (P_{loss}) MW	17.56	5.21	70.33
2	Reactive power losses (Q_{loss}) MVAR	67.69	15.61	76.94

Table 2
Values of Control variables after Optimization

Bus	Control variables	Optimized values (x_{min})
1	Vg1 (pu)	1.092
2	Vg2	1.073
5	Vg5	1.044
8	Vg8	1.051
11	Vg11	1.090
13	Vg13	1.066
6-9	T1	0.979
6-10	T2	1.015
4-12	T3	1.033
27-28	T4	0.982
3	QC3 (MVAR)	10.788
10	QC10	7.589
24	QC24	11.790

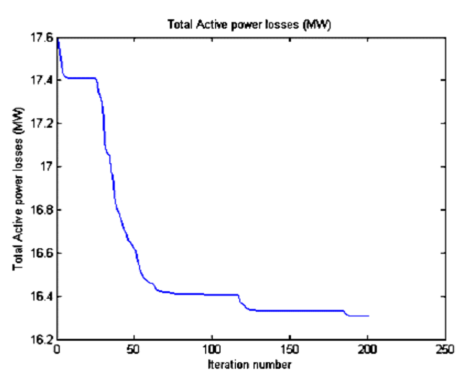

Fig. 2. Convergence characteristic of PSO

6. Conclusion

This paper presented the implementation of PSO algorithm for optimal placement of and sizing of STATCOM.

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