Reactive Power Contribution of Multiple STATCOM using Particle Swarm Optimization

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***Abstract*—Reactive power is vital for reliability, power quality, transmission line loss and voltage stability. Rapid industrial development makes the power system is stressed. This stressed power system has more loss and low voltage profile, generator has its limitation and could not generate sufficient reactive power, to overcome this situation Flexible AC Transmission System (FACTS) devices are used. This paper makes use of one such FACTS device namely STATCOM to relief power system stress by injective adequate reactive power. Particle Swarm Optimization (PSO) technique is used to optimize the STATCOM location and reactive power injection. Test case IEEE-30 bus system is considered for the simulation.**

Keyword-PSO, STATCOM, Reactive Power

I. INTRODUCTION

Power system is a non linear and dynamic system which requires ample generation of real and reactive power to supply its loads or consumer and losses in the system. When the generation of real and reactive power is insufficient to meet its load and losses, it may not provide reliable and stable power supply. Without changing existing power system infrastructure increased demand may satisfy with the help of FACTS devices [1]. Some of these devices are connected in series, parallel, series-series and parallel-series with transmission lines. One of parallel connected, efficient reactive power and voltage support device is STATCOM [2], [3]. These devices may connect near to demand and reduce transmission line loss and provide reliable power supply. More stress on power system requires more than one STATCOM to meet its demand [6]. This multiple STATCOM has to locate in such a way to reduce loss and minimum amount of reactive power injection [9].

Traditional optimization methods such as mixed integer linear and non linear programming have been investigated to address this issue; however difficulties arise due to multiple local minima and overwhelming computational effort. In order to overcome these problems, Evolutionary Computation Techniques have been employed to solve the optimal allocation of FACTS devices. Different algorithms such as Genetic Algorithms (GA) [7], [8], tabu search [5], and Evolutionary Programming [10] have been tested for finding the optimal placement as well as the types of devices and their sizes, with promising results. Particle Swarm Optimization (PSO) is an evolutionary computation technique that has been applied to other power engineering problems [4], giving better results than classical techniques and with less computational effort. This paper use PSO technique to find location of the STATCOM and value of reactive power injection of individual STATCOM. IEEE-30 bus test case is used for the simulation.

II. PARTICLE SWARM OPTIMIZATION

Kennedy and Eberhart developed PSO through simulation of birds flocking in a two-dimensional space. The position of each agent is represented by its x, y axis position and also its velocity is expressed by Vx (Velocity in x-axis) and Vy (Velocity in y-axis). Modification of the agent position is realized by the position and velocity information.

Bird flocking optimizes a certain objective function. Each agent knows its best value so far (Pbest) and its x, y position. This information is an analogy of the personal experiences of each agent. Moreover, each agent knows the best value so far in the group (Gbest) among Pbests. This information is an analogy of the knowledge of how the other agents around them have performed. Each agent tries to modify its position using the following information

- The current position (x, y)
- The current velocities (Vx, Vy)
- The distance between the current position and Pbest
- The distance between the current position and Gbest

This modification can be represented by the concept of velocity (modified value for the current position). Velocity of each agent can be modified by the following equation

$$v_i^{k+1} = wv_i^k + c_1 rand_1.(pbest_i - s_i^k) + c_2 rand_2.(gbest_i - s_i^k) \tag{1}$$

Where v_i^k is velocity of agent *i* at iteration *k*, *w* is weight function, c_j is weight coefficients, *rand* is random number between 0 and 1, s_i^k is current position of agent *i* at iteration *k*, $pbest_i$ is pbest if agent *i*, and *gbest* is gbest of the group. The velocity is usually limited to a certain maximum value. PSO using equation (1) is called Gbest model, for this following weight function is used

$$w = w_{\max} - (\frac{w_{\max} - w_{\min}}{iter_{\max}}).iter \tag{2}$$

Where $w_{\max}$ is initial weight, $w_{\min}$ is final weight, $iter_{\max}$ is maximum iteration number, and *iter* is current iteration number. Right Hand Side (RHS) of equation (1) has three terms or vectors. First term is previous velocity of the agent. Second and third terms are utilized to change the velocity of the agent. Without the second and third terms, the agent will keep on flying in the same direction until it hits the boundary. Namely it tries to explore new areas and therefore, the first term corresponds with diversification in the search procedure. On the other hand, without the first term the velocity is flying agent is only determined by using its current position and its best positions in history. Namely, the agent will try to converge to their pbests and or gbest and therefore, the search procedure. Initial weight $w_{\max}$ is set to high value and $w_{\min}$ set to low value, so in the beginning it has diversification and finally it is intensification since pbest gets close to gbest. After calculating velocity current position is updated as follows

$$s_i^{k+1} = s_i^k + v_i^{k+1} \tag{3}$$

General flowchart of PSO is given in figure 1. Description of the flowchart is given below,

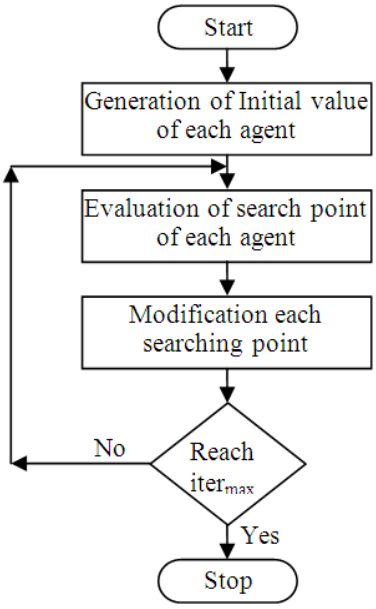

Fig. 1. PSO Flowchart

Step 1: Generation of initial conditions of each agent. Initial searching points s_i^0 and velocities v_i^0 of each agent are usually generated randomly within the allowable range. The current searching point is set to pbest for each agent. The best evaluated value of pbest is set to gbest, and the agent number with the best value is stored.

Step 2: Evaluation of searching point of each agent. The objective function value is calculated for each agent. If the value is better than the current pbest of the agent, the pbest value is replaced by the current value. If the best value of pbest is better than the current gbest, gbest is replaced by the best value.

Step 3: Modification of each searching point. The current searching point of each agent is changed using equation (1), (2) and (3).

Step 4: Checking the exit condition. The current iteration number reaches the predetermined maximum iteration number, then exit. Otherwise the repeat step 2 to step 4.

III. IMPLEMENTATION OF PSO ALGORITHM

For the implementation agent is a STATCOM attributes, there are two attributes for each STATCOM, one is location where it is connected and second one is value of reactive power injection. This device is to be connected in the load bus and not required to connect in generator bus. This condition is the constraint for the location. The size of the STATCOM is taken as 250 Mvar [2], so reactive power injection is bounded between 0 to 250 Mvar. The objective considered in the paper is minimizing voltage deviation, system losses and value of reactive power injection by the STATCOM.

Objective functions are,

$$\text{Min } J_1 = \sqrt{\sum_{1}^{nbus} (V_i - 1)^2} \tag{4}$$

$$\text{Min } J_2 = \text{STATCOM\_1}_{\text{MVAR}} + \dots + \text{STATCOM\_n}_{\text{MVAR}} \tag{5}$$

$$\text{Min } J_3 = P_{loss}, Q_{loss} \tag{6}$$

$$\text{Min } J = \alpha_1 J_1 + \alpha_2 J_2 + \alpha_3 J_3 \tag{7}$$

Where J_1 is total voltage deviation, nbus is number of buses in the considered power system, in this paper it 30 since IEEE 30 bus considered. Objective J_2 is to minimize MVAR injection by ‘n’ number of STATCOM. Objective J_3 is to minimize system real and reactive power loss. Final and main objective is included all these 3 objectives, in order to combine all objectives into single objective corresponding weight factor α is multiplied.

In this work a vector has two particles namely location and value of injected Mvar as follows

$$X_i = [\lambda_1, \lambda_2, \dots \lambda_n, Q_1, Q_2, \dots Q_n] \tag{8}$$

Where X_i is vector of i^{th} STATCOM λ_i and Q_i are location and value of injected Mvar of i^{th} STATCOM.

Another important constraint is, load bus not more than one STATCOM is connected to it.

$$\lambda_1 \neq \lambda_2 \neq \dots \neq \lambda_n \tag{9}$$

Parameter settings of simulation work are, initial weight w_{max} is 0.9, final weight w_{min} is 0.1, maximum iteration $iter_{max}$ is 100 in equation (2), social acceleration constants c1 = 2.5 and c2 = 1.5 in equation (1). α_1 value is 1, α_2 value is 1/(number of STATCOM x 250), α_3 is base MVA in objective function (7).

IV. SIMULATION RESULTS

IEEE 30 bus test case is considered for the simulation, it has 6 generators, 41 transmission lines. This system is loaded than the base the load to induced voltage deviation in the test case and voltage of all buses are given below. For PSO 100 iteration is considered for each simulation run. For all 30 bus voltage magnitude for base case after additional loading is given in table I, second column. Column 3 gives voltage magnitude after 1-STATCOM connected, column 4 gives voltage magnitude after 2- STATCOM connected and column 5 gives voltage magnitude after 3- STATCOM connected to the system.

Objective 2 states that the injected Mvar should be less in order to get small size of STATCOM and to minimize STATCOM initial cost. In this simulation first one, then two and finally three STATCOM are connected to the power system. Table II illustrate the STATCOM connected bus and its corresponding Mvar injection. Column 1 provides information about number of STATCOM connected with the system. Column 2 indicates where the STATCOM is connected; column 3 gives individual Mvar injection of STATCOM and column 4 provide total Mvar injection by that configuration.

Objective 3 states that the system loss should be as low as possible. Table III provide information of losses before and after STATCOM is connected with the system. Main objective J is the combination all three sub objectives J_1, J_2 and J_3. From the simulation analysis for the test case IEEE 30 bus. 2 – STATCOM provides best compensation

TABLE I
Bus Voltages

Bus No	Base Case Voltage (pu)	After Number of STATCOM		
		One	Two	Three
1	1.05	1.05	1.05	1.05
2	1.013	1.013	1.023	1.013
3	0.9855	0.9899	1.0078	0.991
4	0.9728	0.9781	0.9998	0.9795
5	0.96	0.96	0.99	0.96
6	0.9684	0.9759	1.0066	0.9772
7	0.9528	0.9573	1.0069	0.958
8	0.97	0.98	1.01	0.98
9	1.0064	1.0126	1.0283	1.024
10	0.9958	1.0044	1.0199	1.0122
11	1.05	1.05	1.05	1.05
12	1.0235	1.0283	1.0385	1.0343
13	1.05	1.05	1.05	1.05
14	0.9982	1.0043	1.0152	1.0103
15	0.9887	0.9961	1.0074	1.0021
16	1.0008	1.0072	1.0197	1.014
17	0.9897	0.9976	1.0124	1.0052
18	0.9711	0.9791	0.9922	0.9858
19	0.9661	0.9744	0.9884	0.9816
20	0.9722	0.9806	0.995	0.9879
21	0.9773	0.9876	1.0026	0.9946
22	0.978	0.9887	1.0035	0.9955
23	0.9702	0.9819	0.9935	0.9868
24	0.9587	0.9762	0.9878	0.9794
25	0.9517	0.9876	0.9933	0.9824
26	0.9237	0.9607	0.9665	0.9553
27	0.9607	1.0076	1.0095	0.9972
28	0.963	0.9751	1.019	0.975
29	0.9238	1.0113	0.9748	0.976
30	0.9016	0.9745	0.9539	0.9706
J1=	0.2193	0.1397	0.1292	0.1428

TABLE II
Mvar Injection

No. of STATCOM connected	STATCOM Connected bus	Injected Mvar of STATCOM	Total MVar
1	29	13	13
2	7, 28	39, 40	79
3	9, 12, 30	14, 6, 8	28

TABLE III
System Losses

No. of STATCOM connected	Real Power Loss (MW)	Reactive Power Loss (Mvar)	Total Loss (MVA)
Not connected	34.9953	95.3765	101.5940
1	34.7240	93.0480	99.3161
2	34.3345	88.7963	95.2032
3	34.5136	91.9861	98.2478

V. CONCLUSION

Reactive power contribution of multiple STATCOM is analyzed. In the simulation one, two and three STATCOM are connected to the system and compared. To select the location and value on injected Mvar is found with the help of Particle Swarm Optimization (PSO). PSO is an efficient modern heuristic algorithm to solve non convex and complex problems. Its ability of better convergence is utilized to find location and reactive power contribution of individual STATCOM. In this work three objectives namely voltage deviation, amount of reactive power injection by STATCOM and system losses are considered. For combined effect of all three objectives, it is concluded that 2 – STATCOM connected in the system provide better result.

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BIOGRAPHIES

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