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Optimal Location of STATCOM based Dynamic Stability Analysis tuning of PSS using Particle Swarm Optimization

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Abstract

Recent days in the field of power electronics are provided an appropriate place in order to using of Flexible AC transmission system in power system network. The FACTS devices have an ability to preserve the synchronism of generators under all kind of disturbance. The FACTS i.e static synchronous compensation (STATCOM) can play vital role to enhance dynamic stability in power system. In this paper introduces the concept of voltage stability and rotor angle improvement through tuning of PSS and optimal location of STATCOM is investigated. The performance of PSS with STATCOM has been carried out for Western Science Coordinated Council (WSCC) 9 bus system for the enhancement of dynamic stability using power system analysis tool box (PSAT) software. The effect of PSS with STATCOM is implemented in non-linear time domain simulation. The particle swarm optimization algorithm is developed for optimal location of STATCOM to improve voltage profile in the system.

Keywords: STATCOM, PSS,PSO,Dynamic stability;

1. Introduction

The first generations of FACTS devices have a common practice in power system. It is necessary required reactive power to compensate in the system. The compensation may be generated or absorbed by traditional capacitor or reactor banks. The FACTS i.e STATCOM is applied to improve power system function control and power transfer. So the STATCOM is one of the FACTS devices which are used to control the voltage by absorbing and injecting reactive power in the system [1] [2]. The major problem of voltage instability, the system enters state of voltage instability when a major disturbance occur i.e increase in load demand. Therefore the voltage instability can be avoided by tuning the power system stabilizer (PSS). The PSS is a controller which is used with automatic voltage regulator (AVR).

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Nomenclature

Q Reactive power
I_{sh} Shunt current
V Voltage
T_w Wash out time constant
K_w Wash out gain
T_1, T_2, T_3, T_4 & T_e Time constants
P_{best} Particle best value
G_{best} Global best of the particle
V_i^k Velocity of agent i at k^{th} iteration
V_i^{k+1} Velocity of agent i at $(k+1)^{th}$ iteration
W_k Inertia weight
C_1 & C_2 Individual and social acceleration constant
$rand_1$ & $rand_2$ Random numbers
S_i^k Position of agent i at k^{th} iteration
S_i^{k+1} Position of agent i
X_0 Constant
X Damping scale function

2. Dynamic stability with STATCOM

The power system has to maintain synchronism to avoid transient disturbance. The power system stability will be achieved by maintaining the dynamic stability. The main disturbance might be the system fault, loss of synchronism, identification optimal location and optimum capacity. The optimum capacity means the maximum power loss and minimum voltage deviation, rotor angle deviation and many variable of the system. The mainly a term dynamic stability has been used as a class of rotor angle stability. Here the role of static synchronous compensator (STATCOM) with 9-bus in power system, it absorbs or received reactive power [3] [4]. It is similar to synchronous condenser. The reactive power can be exchanged between AC system and STATCOM. The reactive current is controlled by firing angle control. It is executed by PSAT software. Hence the reactive power can be written as

$$Q = I_{sh}V \qquad \text{------------------------------} \qquad (1)$$

3. Power system stabilizer (PSS)

The multi machine power system, damping of oscillations has great importance. The rotor angle oscillations of the generators get decay in a well designed system [5] [6]. So the dynamic stability is achieved in that system. But, some systems could not achieve dynamic stability, because of high gain value of exciters, improper tuning of various controllers and inertia constant etc. To damp out these oscillations, auxiliary controllers are used. Hence PSS is one of the auxiliary controllers and its performance has been proved in many circumstances .In this paper, the gain of the PSS has been tuned by particle swarm optimization algorithm [7]. The performance of the PSS has been plotted using PSAT software. The PSS Type II is used from the PSAT software. Here, input signal is omega (w) i.e (rotor speed) and the output signal of PSS is the state variable V_s which changes the reference voltage of the AVR (Automatic voltage regulator). It is shown in figure 1.

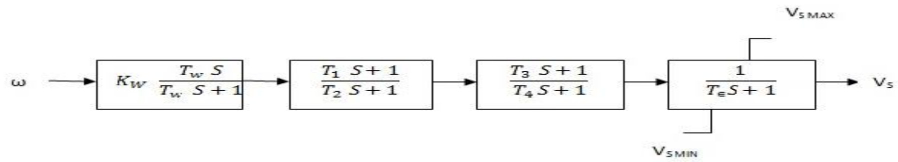

Fig. 1 A mathematical model of PSS type-II system

Where
T_w = wash out time constant, K_w = wash out gain, T_1, T_2, T_3 & T_e = time constants

4. Particle swarm optimization (PSO)procedure

The main objective of this research paper is to design and simulate 9-bus western science coordinated council (WSCC) system in STATCOM to improve voltage stability and rotor angle with PSS tuned by PSO technique. The PSO algorithm is a simple and robust method. The PSO places the particles in the search space with initial velocities. The particles positions can be assumed containing values within the limits specified in the input data. The function parameters will be minimized in the PSO algorithm which is defined as grades. The grades are defined as the arithmetic mean of the buses apparent power. Each particle has a local grade [8] [9]. This value is obtained by its local best value. Similarly the global grade is the grade related to the best global of all the particles. The first step of the PSO algorithm is to generate the initial values to the particles positions, velocities, local best parameters and global best parameters. The velocities are assigned to the particles randomly. Each particle in search space will find optimal solution with the help of two parameters. The two parameters are velocities and position. By the help of two parameters, the fitness function of the particle has been calculated. Each particle in the problem space would have its best solution. The best value is called as P_{best} when a particle completes its population, then the best value is global best G_{best} . After finding the two best values, the particle updates its velocity and position according to the following equations.

$$V_i^{k+1} = W_k \times V_i^k + C_1 \times rand_1 (P_{best} - S_i^k) + C_2 \times rand_2 (G_{best} - S_i^k) \quad \text{-------------------- (2)}$$

$$S_i^{k+1} = S_i^k + V_i^{k+1} \quad \text{--------------------------- (3)}$$

4.1 Objective function

Here an Eigen value based objective function is used to design the gain of PSS. The damp scale function is used. The damping scale function is

$$X = \frac{-(\sigma - \sigma_0)}{\sqrt{(\sigma - \sigma_0)^2 + \omega^2}} \times 100\% \quad \text{--------------------------- (4)}$$

Now the fitness value can be calculated, hence

Fitness value = X_0 -minimum value of X

Here the complex pair of the Eigen value is $\lambda = \sigma + j\omega$ --------------------- (5)

Where σ is real part of Eigen value and jω is the imaginary part of the Eigen value, σ_0 is damping factor constant i.e (-1). According to this objective function, it relocates the oscillation modes from right side to left side of the s- plane within the fan shaped region. Because of that, the optimal values of the objective function are less than zero. Here the parameters $T_1, T_2, T_3, T_4 and T_\omega$ are required for PSS which can be used to tune the system. Here the gain K_ω is only selected to tune as per algorithm procedure: Population size = 100, Gain lower bound = 20 and Gain upper bound = 100.

4.2 Constraint

The constraint can be written as

$T_{\omega(\min)} \prec T_\omega \prec T_{\omega(\max)}$ ---- (6), $T_{1(\min)} \prec T_1 \prec T_{1(\max)}$ ---- (7), $T_{2(\min)} \prec T_2 \prec T_{2(\max)}$ ---- (6)

Where T_1, T_2 and T_w are time constants. The time constant values have lower bound and upper bound as shown in table 1.

4.3 Table1

Table 1. Time constant values per unit

Time constant values	K_ω	T_ω	T_1	T_2
Lower bound	20	0.01	0.01	0.01
Upper bound	100	20	20	20

5. Algorithm procedure

Step 1: Initialize each particle's velocity and position.

Step 2: Calculate the fitness value using the objective function and determine the $P_{best.}$

Step 3: Determine G_{best} from the $P_{best.}$

Step 4: Update the velocity and position.

Step 5: Check the solution is feasible or not.

Step 6: If the solution is feasible, check the iteration count.

Step 7: If the iteration count reaches the maximum, stop the process.

Step 8: If the iteration count does not reach the maximum, then continue the process from 2-7.

6. Flow chart

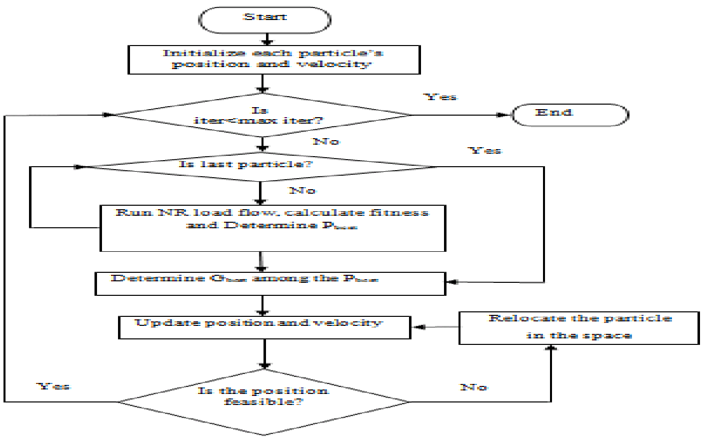

Fig.2 Flow chart development using PSO

7. WSCC 9-Bus system

A 9 bus system Western Science Coordinated Council (WSCC) with 6 transmission lines, 3 generators, 3 loads are considered to study as shown in figure 3.

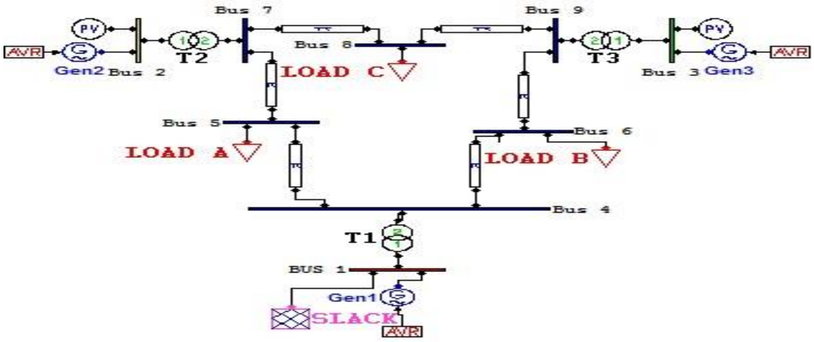

Fig.3 Structure of WSCC 9-bus system

In the above fig.3, it is assumed that the loading condition of the system for load A is the real power 2.40 p.u, reactive power 1.30 p.u. the load B is the real power is 2.20 p.u, reactive power 1.00 p.u. similarly load C is 2.00 p.u, reactive power 1.05 p.u.

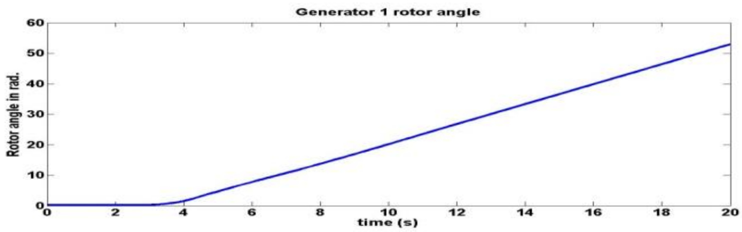

Fig.4 rotor angle of the generator 1 without PSS and STATCOM

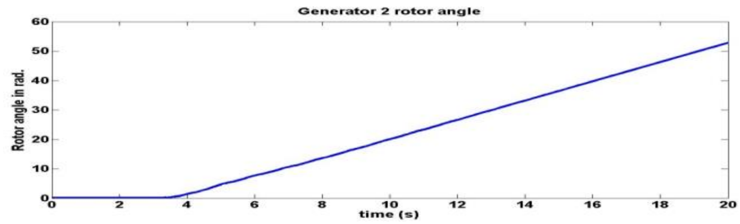

Fig.5 Rotor angle of the generator 2 without PSS and STATCOM

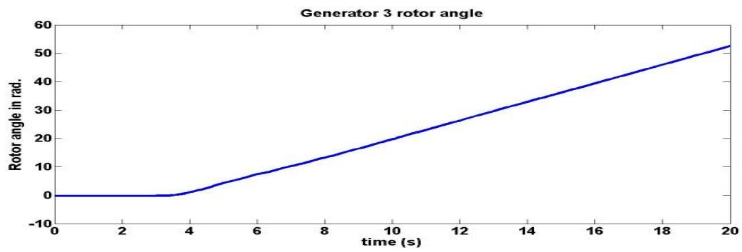

Fig.6 Rotor angle of the generator 3 without PSS and STATCOM

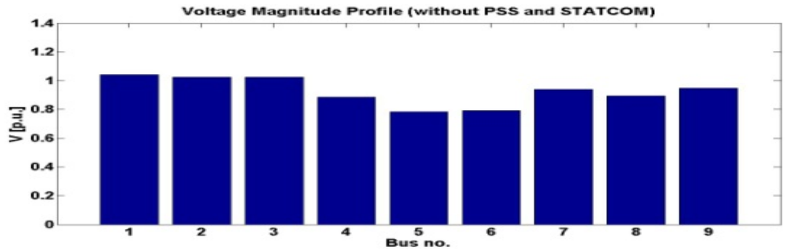

Fig.7 Voltage magnitudes profile without PSS and STATCOM

From the above figures, it is analyzed that without PSS and STATCOM, the rotor angle of the generator 1, generator 2 and generator 3 have been affected severely. It is going to unstable condition as shown in fig.5, 6 &7. According to voltage magnitudes profile, bus 5 has very low voltage profile. So the bus 5 is selected to apply STATCOM device to maintain constant voltage as shown in table 2.

7.1 Table 2

Table 2. Voltage profile per unit values without PSS and STATCOM

Bus	voltage	phase angle	real power	reactive power
Bus 1	1.0404	52.635	4.404	3.397
Bus 2	1.0251	52.238	1.630	1.480
Bus 3	1.0252	52.127	0.850	1.391
Bus 4	0.8867	52.357	-0.000	0.000
Bus 5	**0.7823**	**52.100**	**0.000**	**-0.000**
Bus 6	0.7923	52.084	0.000	-0.000
Bus 7	0.9402	52.131	0.000	-0.000
Bus 8	0.8931	52.023	0.000	0.000
Bus 9	0.9470	52.076	-0.000	0.000

8. WSCC 9 Bus with PSS and STATCOM

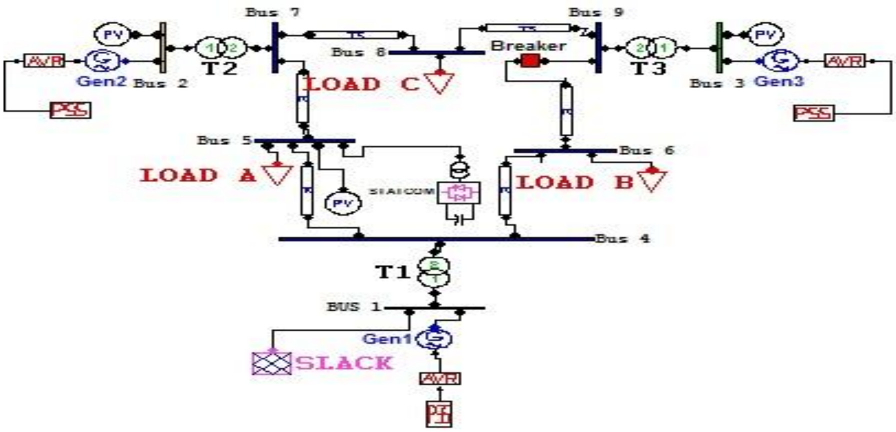

Fig.8 WSCC 9-bus system with PSS and STATCOM tuned by PSO

The arrangement of WSCC 9- bus with PSS and STATCOM tuned by PSO at bus 5 is shown in figure 8.

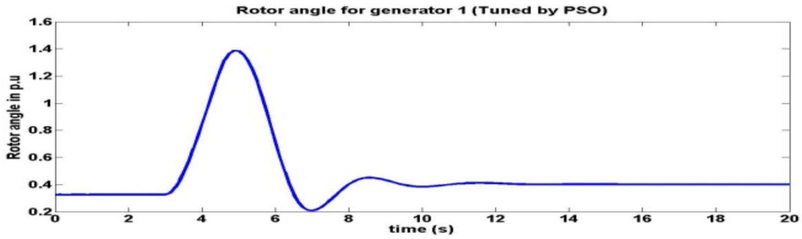

Fig .9 Rotor angle of the generator 1 with STATCOM and PSS (Tuned by PSO

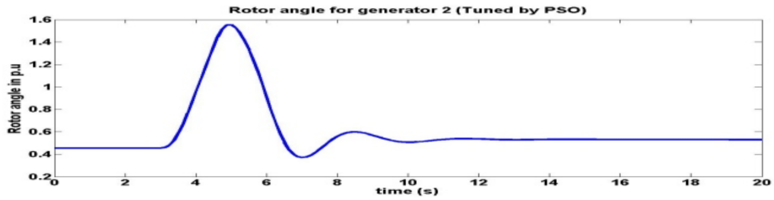

Fig .10 Rotor angle of the generator 2 with STATCOM and PSS (Tuned by PSO)

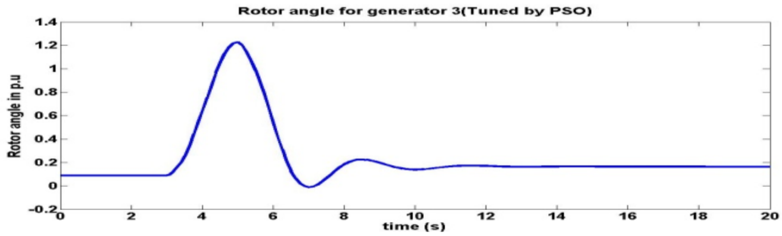

Fig.11 Rotor angle of the generator 3 with STATCOM and PSS (Tuned by PSO)

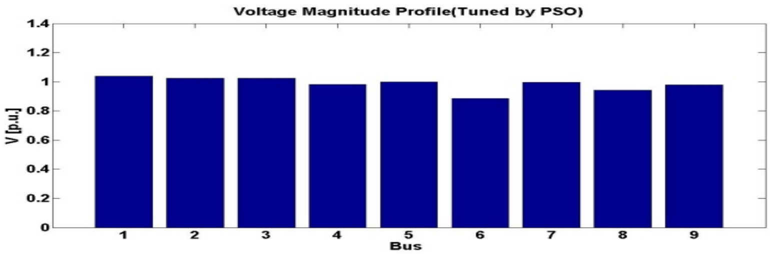

Fig.12 Voltage profile with STATCOM and PSS (Tuned by PSO

8.1 Table 3 & 4

Table 3: rotor angle without PSS &STATCOM

Machine	At 3.0 s	At 3.5 s	At 5 s	At 20 s
Gen 1	0.294	0.640	4.654	52.93
Gen 2	0.143	0.277	4.692	52.78
Gen3	-0.146	-0.002	4.334	52.49

Table 4: rotor angle with PSS &STATCOM tuned by PSO

Machine	At 3.0 s	At 3.5 s	At 5 s	At 20 s
Gen 1	0.32	0.48	1.39	0.4
Gen 2	0.45	0.58	1.52	0.53
Gen3	0.08	0.24	1.18	0.16

8.1 Table 5

Table 5. Voltage profile per unit values with PSS and STATCOM tuned by PSO

Bus	voltage	phase angle	real power	reactive power
Bus 1	1.0399	0.0748	4.300	1.556
Bus 2	1.0250	-0.2156	1.630	0.547
Bus 3	1.0250	-0.3162	0.850	0.799
Bus 4	0.9830	-0.1698	-0.000	-0.000
Bus 5	**1.0000**	**-0.3618**	**-0.000**	**1.802**
Bus 6	0.8867	-0.3788	0.000	0.000
Bus 7	0.9966	-0.3155	-0.000	0.000
Bus 8	0.9414	-0.4137	0.000	-0.000
Bus 9	0.9805	-0.365	-0.000	-0.000

The voltage profile of the system is improved, placed the STATCOM at optimum point and tuned to PSS as shown in fig 9, 10, 11 &12.

9. Conclusion

The performance of PSS and STATCOM has been investigated through the time domain through PSAT software. By selecting optimal location of STATCOM and tuning of the PSS, dynamic stability of the system is achieved. The results are obtained from non-linear simulation which is reflected in the PSO algorithm method. The PSS is tuned by PSO and selecting of optimal location for STATCOM contributes significantly to improve dynamic stability of the system. The performance of tuned PSS by particle swarm optimization has proved its effectiveness in achieving dynamic stability of the system. The other optimization techniques can also be used for tuning of PSS with STATCOM in order to improve the stability of the power system.

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