Simultaneous Coordination and Tuning of PSS and FACTS for Improving Damping by Genetic Algorithm

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***Abstract*: In this paper is tried to coordinate and regulate the flexible ac transmission systems (FACTS) and power system stabilizer (PSS) to increase damping in multi-machine power systems. In multi-machine power system there are local and inter area modes. The inter area mode in multi-machine systems are undamped. The local modes can be damp by using PSS but inter area mode should be damp by using FACTS devices. Tuning and coordination together for several parameters is a complex work and we can not consider all conditions and limitations thus we have to use a global search algorithm to find the best solution. We have used modal analysis to improve damping. Damping ratio has been selected as the objective function. The loads have been modeled as constant impedance. GA has been selected as the optimization method to find the optimum point. IEEE 14 buses standard system has been chosen as the case study. Special conditions such as outage a transmission line considered and the stability of the system has been investigated in these conditions.**

Keywords-PSS; TCSC; Coordination; Tuning; GA; Damping.

I. INTRODUCTION

In these years using of FACTS devices and PSS has extended to improve stability. Considering that the PSS is one of important equipment to damp the mechanical oscillation of generators. Although PSS can relieve the mechanical oscillation of generators however there are some unstable inter area modes that we can not dispel them without using the FACTS devices. Moreover the PSS, FACTS devices have been used to enhance the damping [1]-[3]. In recent years due to competitive market created in the power industry and the necessity of optimal use of power system capacities, has been a tendency for the role of FACTS devices. While use both of FACTS devices and PSS coordination should be established between them to lead to not interfere with the performance [4] and not cause system instability. Many methods for coordination between FACTS devices and PSS has been presented in [5]-[7]. Nonlinear optimization method is one of ways that a lot of articles lean to this method [1]. The most important defect of the nonlinear optimization method is sensitivity to initial values and thereupon the final response depend on to initial values. In a multi-machine power system providing a good initial values to reach the global optimum point is very difficult otherwise the obtained optimized point may not be global optimum point. Hence we have applied a method that is independent of initial values and be able to find the global optimum point. For tuning and coordination between the FACTS devices and PSS we have linearized the system around different operating point. The damping ratio has been defined as the objective function. For design the parameters different conditions have been considered and system will remain stable for large disturbance. In reference [8] the equipments has been modeled with lowest order in this case inter area mode will survive stable for serious investigation, we have to consider system with details and all controller should be model because for this condition inter area oscillation will grow up Gradually.

This paper is organized as follows, In section II a explanation about basics of local and inter area mode will be presented. In section III the flow chat of the optimization is described. In section IV a explanation about the system and devices will be expressed. In section IV simulation habitude are presented. In section V the simulation results are submitted followed by the conclusions and future work.

II. LOCAL AND INTER AREA MODES

A. Local Modes

In interconnected power system, different type of oscillation can occur. Local mode is the name of oscillation that happen inside the area. The frequency of local mode is further than inter are mode. To stimulate the local mode, we should change two variable in an area. For example, we can change the governor power reference input of two generators, as equal and opposite of each other. With this act the local mode of area will be motivated.

B. Inter Area Modes

Inter area mode is the name of oscillation that happens among two areas. To excite the inter area mode we can change the governor power reference input of two generator that located in a different area. For correct investigation of inter area modes, the equipment should model with details and all controller of generator should be modeled. If the generators are modeled as classical model and controllers are ignored, the system behavior and inter area mode will not be correct because in these cases the inter area mode will not become unstable [9].

III. ALGORITHM AND IMPLEMENTATION

For tuning and coordination of PSS and TCSC parameters we have exerted the following flow chart, as shown in Fig. 1. GA is a search technique used in computing to find exact or approximate solutions to optimization and search problems. In this case the objective function is the summation of damping ratio of eigenvalues.

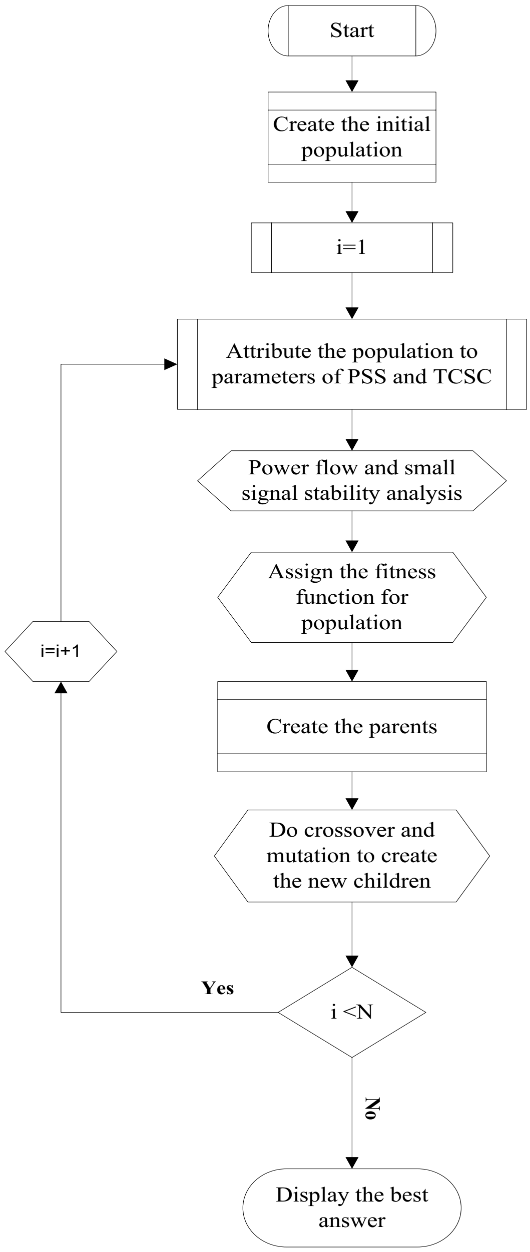

Figure 1. The flow chart of tuning and coordination of PSS and TCSC parameters.

The implementation of GA is as follow steps.

1) We have generated the initial populations by using of random generation function then they apply to the parameters of PSS and TCSC.
2) The power flow and small signal stability analysis have been accomplished respectively then The eigenvalues associated to the initial populations have attained.
3) The sum of damping ration for each population is calculated then they will be sorted as large to small.
4) The better half of population that their damping ratio summation has been greater will be selected and the rest will be eliminated. The parameters of selected values will be converted to binary value.
5) By using the random function will be determine, the point of crossover and two parents that should be cut with each other. In this step, the mutation will be done in random points too.
6) The produced children binary values in step 5 will be transformed to integer values. The obtained children and parents will be substitute to PSS and TCSC parameters. This process will continue until the repetition number reaches to its limit.

These steps have depicted in Fig. 2.

IV. System and Device Description

A. Case Study

In this study, IEEE 14 buses system has been used. This system has five synchronous generators and 21 transmission lines. The TCSC has placed between 1 and 5 buses. The PSS located on Generator 1. A one-line diagram of the IEEE 14-bus test system with the addition of controllers is given in the Fig. 3.

B. Synchronous Generators Model

Generator 1 has been modeled as fifth order differential equation and the rest generators have been modeled as sixth order differential equation. The state vector of generator 1 is as

$$X = [\delta \quad \omega \quad E_q^{'} \quad E_q^{''} \quad E_d^{'}]$$

where

δ rotor angle.
ω rotor speed.
$E_q^{'}$ q-axis transient voltage.
$E_q^{''}$ q-axis subtransient voltage.
$E_d^{'}$ d-axis transient voltage.

The rest generators have a excess state variable where is
$E_d^{''}$ d-axis subtransient voltage.

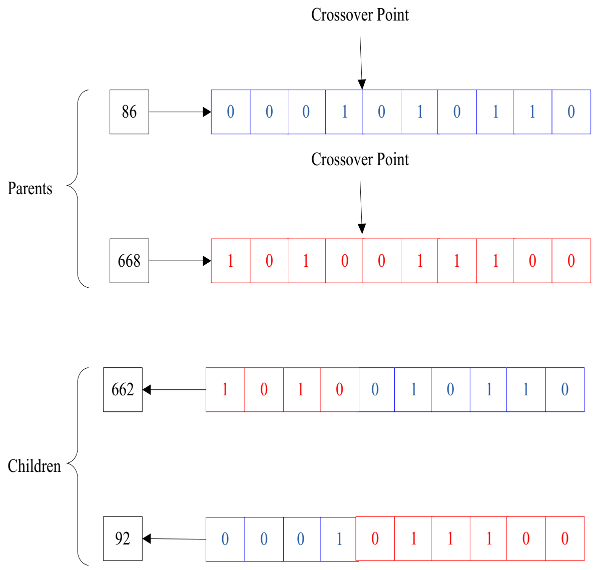

Figure 2. Implementation of GA.

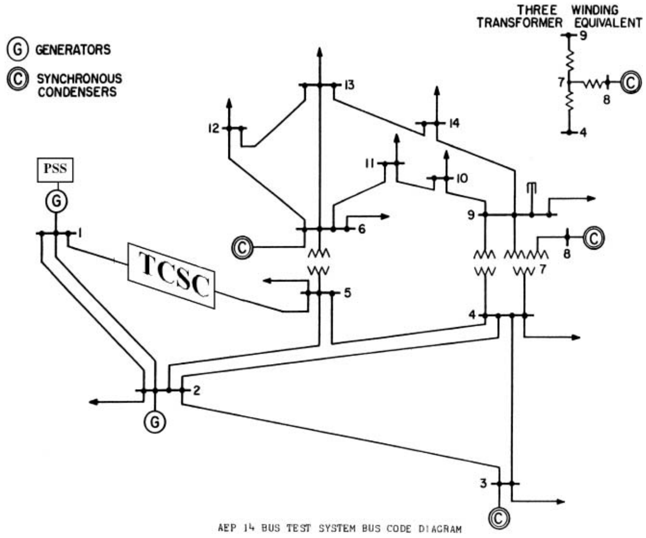

Figure 3. Test system additional power system controllers.

C. Exciter Model

Third order differential equation has used to model all exciters. The state vector of exciter is as the follow,

$$X = [v_f \quad v_m \quad v_r]$$

where

v_f The output voltage of field winding.
v_m The sampled voltage.
v_r The input voltage of field winding.

D. PSS Model

A PSS can be observed as a excess controller block on Automatic voltage controller (AVR). It improves the electromechanical oscillations. By using of PSS small signal stability performance of system gets better. Fig 4 depicts the PSS controller model used in this paper. The lead-lag controller has used for PSS. The input signal is speed variation ($\Delta\omega$). The first block was shown in Fig. 4, is an amplifier. The second block is a washout block, Its role is prevention of PSS performance in steady state conditions. And two next block are the lead-lag controllers.

E. TCSC Model

A TCSC is a controller specifically designed to be connected in series with transmission lines to control their impedance. These types of controllers can be utilized for oscillation damping (both subsynchronous and electromechanical) when suitably controlled. Its block diagram is similar to the PSS.

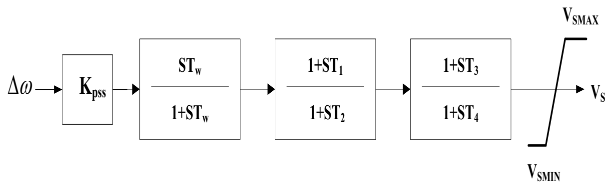

Figure 4. PSS block diagram.

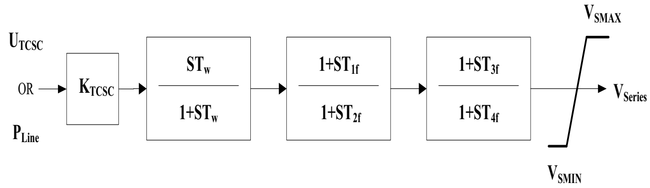

Figure 5. TCSC block diagram.

V. SIMULATION

One goal of installing TCSC is damping the inter area oscillations and the aim of installing PSS is damping the local mode and subsynchronous oscillations. By using of PSS and TCSC, we will be able to damp inter area and local oscillations and increase the overall system damping. The parameters setting for a multi-machine power system is a difficult problem, therefore we have applied GA to coordinate and adjust the parameters. At the first, system is linearized around the operating point then, state space equations will be solved.

System eigenvalues are calculated as

$$|SI - A| = 0 \tag{1}$$

where

I unit matrix.
A state matrix.
S Laplace parameter.
| | matrix determine.

To find the parameter we need to investigate the eigenvalues with imaginary part as follows

$$\lambda = \sigma \pm j\omega \tag{2}$$

The real part (σ) relates to damping and the imaginary part (ω) relates to frequency of oscillation. We are more comfortable with damping ratio and frequency of oscillation in Hz. These are related to the eigenvalue by:

$$\zeta = -\frac{\sigma}{\sqrt{\sigma^2+\omega^2}} \tag{3}$$

$$f = \frac{\omega}{2\pi} \tag{4}$$

The fitness function can be defined as

$$F(Z) = \sum_{i=1}^{n}(\zeta_i) \tag{5}$$

Z a vector consist of PSS and TCSC parameters and percent of compensation.
n number of complex eigenvalue with $\sigma > -1$.

The range of PSS and TCSC parameters and percent of compensation are as

$$\begin{cases} T_{2min} \le T_2 \le T_{2max} \\ T_{4min} \le T_4 \le T_{4max} \\ K_{PSSmin} \le K_{PSS} \le K_{PSSmax} \\ \vdots \end{cases} \tag{6}$$

$$\begin{cases} \vdots \\ T_{2fmin} \leq T_{2f} \leq T_{2fmax} \\ T_{4fmin} \leq T_{4f} \leq T_{4fmax} \\ K_{TCSCmin} \leq K_{TCSC} \leq K_{TCSCmax} \\ K_{Cmin} \leq K_C \leq K_{Cmax} \end{cases}$$

Where, T_2, T_4 and K_{PSS} are time constants and amplification factor of PSS. T_{2f}, T_{4f} and K_{TCSC} are time constant and amplification factor of TCSC. K_C is percent of compensation and pay attention to subsynchronous oscillations and network restrain is specified.

To accede and find the parameters we need to shift all eigenvalues to the denoted area where has been depicted in Fig. 6.

VI. Simulation Results

At the first, the system without any FACTS and PSS devices has been investigated, by using modal method the eigenvalues of the system has obtained and shown in Fig. 7. Fig. 7 shows that, the system without any devices is unstable and two eigenvalues of the system have located on the right of eigenvalues' page.

After installation FACTS and PSS, system has been stable but the damping ratio is not enough yet. The system eigenvalues with coordinated and uncoordinated parameters has been shown in Fig. 8. After coordination process all eigenvalues have been transfer on the left page with $\zeta > 0.1$.

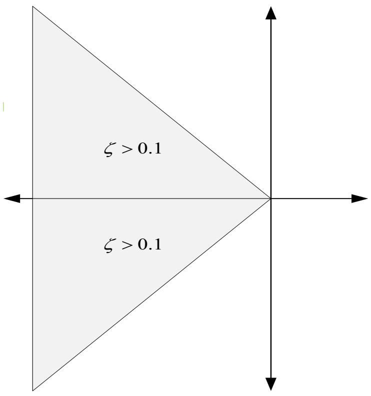

Figure 6. The area with $\zeta > 0.1$.

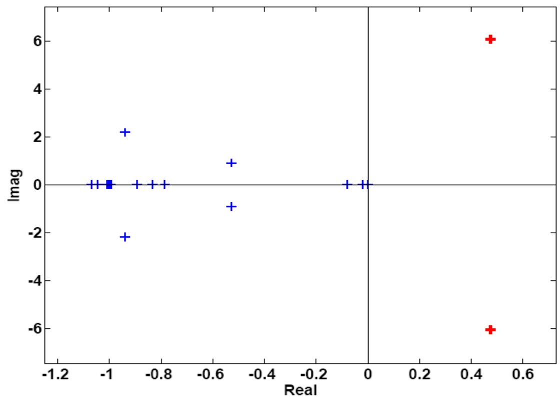

Figure 7. System eigenvalues without any FACTS and PSS.

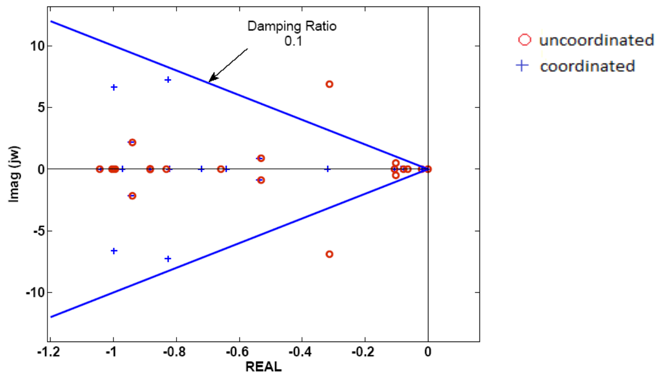

Figure 8. The system eigenvalues for coordinated and uncoordinated parameters.

For investigation of system with special condition, two cases has been considered. In the first case system the line between buses 4 and 9 is out of service, the eigenvalues of the system for this condition for coordinated and uncoordinated parameters have been shown in Fig. 9. Pay attention to eigenvalues of the system, system with coordinated parameters is more stable than uncoordinated parameters and the damping ratio for coordinated and uncoordinated parameters is nearly 0.05 and 0.02 respectively. In the second case, the line between buses 4-9 and 6-13 are out of service, the system eigenvalues for coordinated and uncoordinated parameters has been shown in Fig. 10. Pay attention to Fig. 10, the system with uncoordinated parameters is unstable.

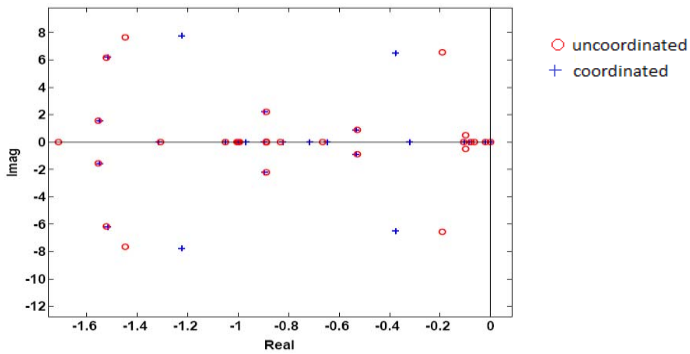

Figure 9. The system eigenvalues for coordinated and uncoordinated parameters, the line between bus 4 and 9 is out of service.

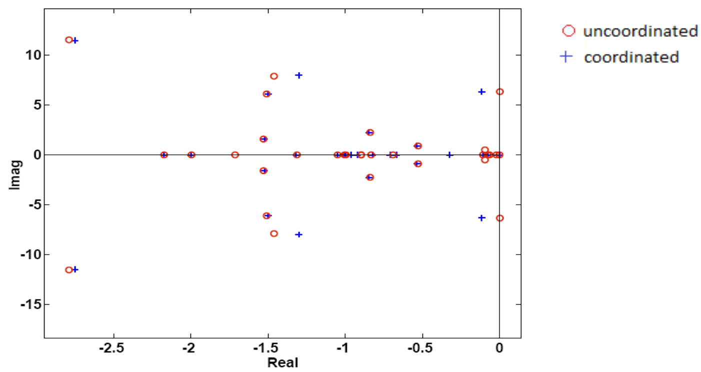

Figure 10. The system eigenvalues for coordinated and uncoordinated parameters, the line between buses 4-9 and 6-13 are out of service.

VII. Conclusion

In this paper tuning and coordination of parameters has been done simultaneously, In this paper PSS and TCSC parameters have been coordinated for stabilization the unstable system Tuning and coordination of several parameters with each other is a complex work, for tuning and coordination the parameters a computer program must be used. There are a lot of method to coordination parameters, one of these method is nonlinear optimization. The optimum point obtained by this method is depend on to initial values, for a power system with several buses providing a good initial value to reach a global optimum point is complex so for system with several parameters to find global optimum point, we have to use a method that, dose not have any relation with initial values. By this reason GA has been utilized in this paper, Summation of damping ratio of effective eigenvalues has been selected as the objective function. The selected case study is unstable at first after coordination the parameters system has been stable, we tset the system in special condition and was seen that, the system can maintain its stability in unforeseen conditions.

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