Optimization of TCSC with Multi Objective Genetic Algorithm for improving Stability of Single Machine Infinite Bus System.

Balasubramanyam Chiranjeevi K.B
Dept. Of ECE, University of Massachusetts Lowell, Massachusetts, USA.

Batlanki Sai Surya
Dept. Of Scientific Instrumentation, Ernst-Abbe Fachhochschule Jena, Germany,

***Abstract*— A power system is always prone to situations like faults causing oscillations and instability. To improve the stability of power system, techniques have been introduced and improving for the past few decades. One among them is using Power System Stabiliser (PSS), which damps the oscillations of power grid. But PSS is not sufficient enough to control all the problems. Therefore an additional stabiliser must be included in the Power system to improve its stability, reliability and utilization. In this paper we discuss about the FACTS device "Thyristor Controlled Series Compensator" (TCSC) and its application in damping the oscillations. The Genetic Algorithm (GA) is implemented to design the supplementary controller of TCSC. Its performance is compared with the phase compensation method of designing the controller and its effectiveness is demonstrated on Single Machine Infinite Bus (SMIB) power system.**

Keywords: TCSC, Genetic Algorithm (GA), Damping Oscillations.

I. INTRODUCTION

FACTS devices [1] are installed in power system to increase the power transfer capacity, to enhance continuous control over the voltage profile and/or to damp power system oscillations. They have the ability to control power rapidly, increase stability margins, minimize losses, work within the thermal limits range and as well as damping the power system oscillations. TCSC [1] is one of the FACTS devices which are used to improve the stability of the system. But the main challenge is in accurate tuning of its controller. One of the methods to design the TCSC controller is by phase compensation method [2]. In this method the controller is designed at one particular operating point and may not be robust. Genetic Algorithm (GA) [3, 4] is a popular method for solving optimisation problems in different fields of application. GA is utilised to design the parameters of the controller. It has the ability to obtain a near-optimal solution and is quite robust. The objective of the method used in this paper is to reduce the oscillations in less time with short peaks, to increase the damping of power system oscillations, TCSC based controller is utilized along with PSS thus improving power system stability. The TCSC controller is designed by two methods i.e., the conventional and proposed GA. These controllers are designed on linearized Phillips-Heffron model of Single Machine Infinite Bus (SMIB) [3, 4] power system and implemented on the same system. The performance of the controllers is compared.

The paper is organised as follows, in the following section the functioning of TCSC is explained. The third section gives the details about modelling of SMIB system followed by damping controller in the fourth section. The fifth section gives a general picture on Genetic Algorithm (GA) [5-10]. The sixth section depicts the implementation of GA in designing of controller. The results are displayed on the seventh section followed by conclusion.

II. FUNCTIONING OF TCSC

TCSC is an important FACTS device which makes it possible to vary the apparent impedance of a specific transmission line. TCSC consists of three components capacitor bank C bypass inductor L and bidirectional thyristors SCR1 and SCR2 as shown in Fig.1 [7, 8]. In Fig.1 I_C and I_L represents instantaneous values of the capacitor bank and inductor respectively I_S is the instantaneous current of the controlled transmission line, V is the instantaneous voltage across the TCSC. The firing angle (α) of the thyristors is controlled to adjust the TCSC reactance. The TCSC can be controlled to work in capacitive zone. The equation of reactance which is function of (α) is represented by equation (1).

$$X_{TCSC}(\alpha) = X_C - \frac{X_C^2}{X_C - X_L}\frac{\sigma + \sin(\sigma)}{\pi}$$
$$\frac{4X_C^2}{X_C - X_L}\frac{\cos^2(\sigma/2)}{K^2 - 1}\frac{(K\tan(K\sigma/2) - \tan(\sigma/2))}{\pi} \tag{1}$$

where, X_C =Nominal reactance of the fixed capacitor C. X_L = Inductive reactance of inductor L connected in parallel with C.

$\sigma = 2(\pi - \alpha)$ =Conduction angle of TCSC controller.

$K = \sqrt{\frac{X_C}{X_L}}$ =Compensation ratio.

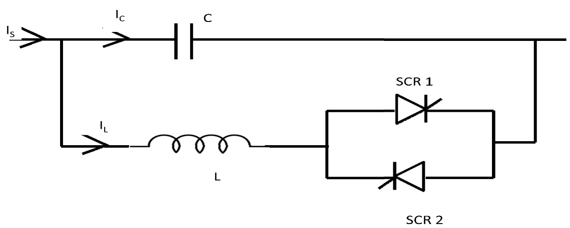

Fig.1 TCSC circuit diagram

III. MODELLING OF SMIB

Fig. 2 shows the SMIB power system with the FACTS device TCSC included in between the 2nd and 3rd bus. V_T and V_B are the generator terminal voltage and infinite bus voltage respectively, X_T and X_{Line} represent the transformer and transmission line respectively, X_{TCSC} is the reactance of TCSC given by Equation (1). The non-linear model given in [3], [4] has been linearized. The linearized Phillips-Heffron model has been established and given in equation (2). The block diagram of Phillips-Heffron model is shown in Fig.3.

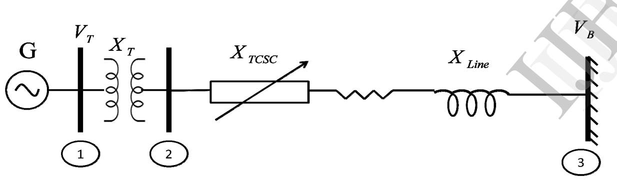

Fig.2 SMIB Power system with TCSC.

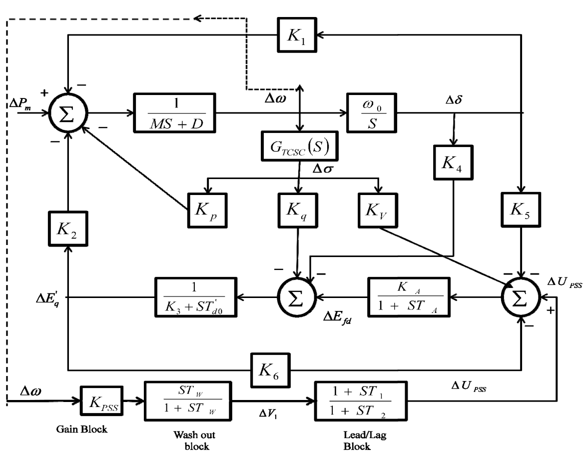

Fig. 3 Phillips-Heffron model of SMIB system with TCSC and PSS.

$$\Delta\dot{\delta} = \omega_b \Delta\omega$$
$$\Delta\dot{\omega} = [-K_1\Delta\delta - K_2\Delta E'_q - K_p\Delta\sigma - D\Delta\omega]/M$$
$$\Delta\dot{E}'_q = [-K_3\Delta E'_q - K_4\Delta\delta - Kq\Delta\sigma + \Delta E_{fd}]/T_{do} \quad (2)$$
$$\Delta\dot{E}'_{fd} = [-K_A(K_5\Delta\delta + K_6\Delta E'_q + K_v\Delta\sigma - \Delta U_{pss}) - \Delta E_{fd}]/T_A$$

The linearized system given by state equation (2) is used for eigenvalue analysis for observing the stability of the system. Further the TCSC controller parameters are designed based on the linearized system to increase the damping of lightly damped eigenvalues.

IV. MODELLING TCSC CONTROLLERS

The TCSC controller shown in Fig. 4. The controller block has a gain block followed by a washout block and two lead lag blocks as shown in the Fig. 4.The PSS is also of the same structure. The PSS damps out the oscillations at the generator side. For the PSS input for the controller is rotor speed deviation Δω and the output is V_{PSS} which is to be given to the excitation of the generator. Whereas the input for the TCSC Controller is rotor speed deviation and the output modulates Δσ which is the control input signal of TCSC.

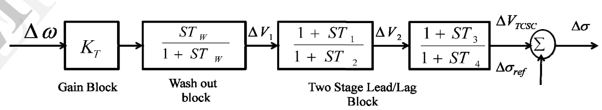

Fig. 4 Block Diagram of Controller.

The gain block determines the damping level; the phase compensation block compensates the lag between the input and output where as the washout block acts as a high pass filter to allow signals of only high frequencies. The PSS and TCSC controller are designed using phase compensation technique [2]. The value of T_w (the washout filter time constant) is chosen in the range of 10 to 20s. The reasonable choice of ζ is between 0.1 and 0.3. The alternate method i.e, GA is used for designing controller. This paper adopts GA from [5-12] for optimizing the controller parameters.

V. REVIEW OF GENETIC ALGORITHM

Genetic algorithms (GA) are computerised search and optimization algorithm based on mechanics of nature.(e.g.: nature of selection, survival of the fittest) and natural genetics. GA are good at taking large search spaces and then analysing them for optimal combinations of solutions which are very difficult to be computed by hand.

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There are two important aspects of GA wiz.,

- Defining the objective function
- Applying the genetic operators to obtain the required optimization.

For the given optimization function we need to determine chromosome size, population size, type of genetic operator, condition for convergence, crossover probability and points, mutation probability and point.

A) Chromosome representation:

Chromosome representation scheme determines how the problem is structured in GA and also the operators which are used. Each individual or chromosome id made up of a sequence of genes. Each chromosome can be represented in binary, decimal, floating, integer values, etc formats. In general binary coded chromosome structures are chosen for higher accuracy.

B) Selection Function:

The selection of individuals in the population is very important when GA is used. The selection function determines the individuals which survive and move on to next generation. A probabilistic selection is performed based upon the individuals fitness such that only the best individuals have the chances of being selected. Out of the all available selection processes, Roulette wheel selection is applied in this paper.

C) Operators of GA:

The two basic operators of GA i.e, cross over and mutation are used to produce the new solutions based on existing solutions in population. Crossover takes two individuals to be parents and produces two new individuals while mutation alters one individual to produce single new solution. in this paper uniform crossover and uniform mutation methods are chosen as GA operators.

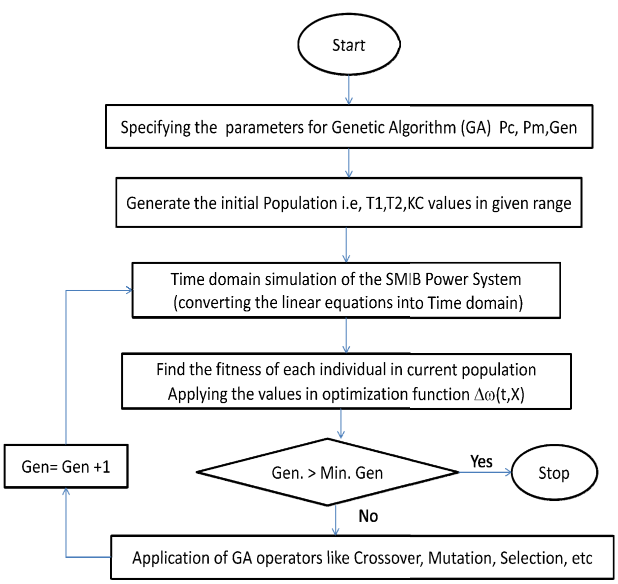

Fig. 5 Flow chart explaining GA

VI. OPTIMIZATION OF OBJECTIVE FUNCTION:

The term optimization is to improve or find the best possible output for a given system at particular instant. In SMIB system the oscillations are chosen to be observed in generator angle (ΔP_e) and rotor speed $(\Delta\omega)$. Since the oscillations have to be damped, the objective function is taken which is a function of the system parameters and controller parameters. The objective function can be formulated as minimization of the fitness function given by FIT.

i.e., $FIT = (f_1, f_2)$ where,

$$f_1 = \sum \int_0^{t1} (\Delta P_e(t, X))^2 dt \qquad (3)$$

$$f_2 = \sum \int_0^{t1} (\Delta\omega(t, X))^2 dt \qquad (4)$$

Here $'X'$ represents the TCSC parameters which should be minimised, t_1 is the time range of simulation. X Represents T_1, T_2, K_C which are TCSC parameters and $T_3 = T_1; T_4 = T_2$. Since the fitness function and the system generator parameters are dependent on T_1, T_2, K_C, the change in values of these parameters is reflected in control of oscillations. f_1 Measures the change in electrical power oscillations, f_2 measures the rotor oscillations in speed. Minimisation of FIT changes the system performance by damping the oscillations. For minimizing the FIT function we are adopting Genetic algorithm method which is fast and has a wide range of application. The parameters used in GA are given in Table 1 and 2.

TABLE 1:
PARAMETERS USED IN GA:

Parameter	Value/Type
Maximum Generations	1000
Population size	100
Type of Selection	Normal
Type of Crossover	Equal crossover (P_c=0.9)
Type of Mutation	Non uniform (P_m=0.1)
Termination Method	Convergence

TABLE 2:
BOUNDARIES OF UNKNOWN VARIABLES, OPTIMIZATION PARAMETERS:

Parameters	Gain (Kp)	Time constant (T_1)	(T_2)
Minimum Range	1	0	0
Maximum Range	10	2	2
Obtained Parameters	2.4144	1.4854	0.0419

VII. RESULTS:

The power system defined by equation (2) is simulated in Matlab with the system data and controller parameters given in the Appendix. The oscillations are created by giving in a three phase fault at the generator bus. The different controllers are placed in the system for respective cases and their performance is observed in Figs. 6-8. From these figures it is clear that by using Genetic Algorithm technique for controlling the TCSC is more effective and damps out the oscillations in the rotor speed and electrical power much earlier compared to the conventional phase compensation technique. This is due to the optimal tuning of TCSC while the other methods are poor in performance due to the multi objective function GA method is more robust. On the other hand the due to the operational sequence of GA, the initial shooing of the oscillations is also significantly damped for the given conditions compared to the conventional phase compensation method.

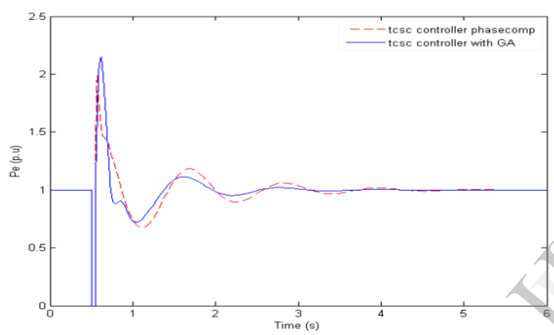

Fig.6 Response of electrical power to three phase fault

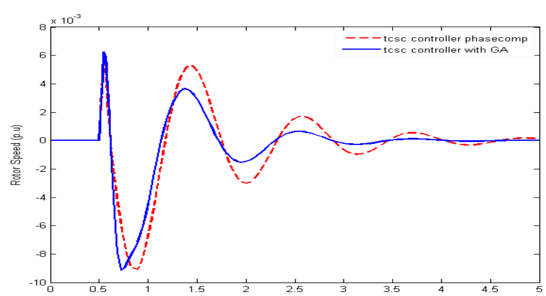

Fig.7 Response of rotor speed to three phase fault

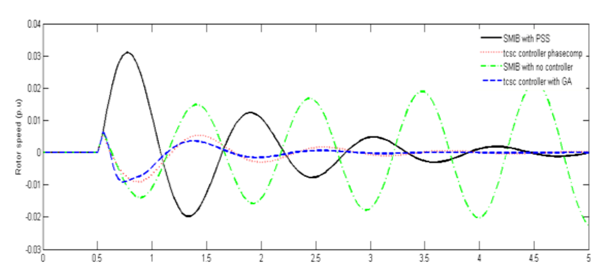

Fig.8 Response of rotor speed with different controllers to three phase fault

VIII. CONCLUSION

The problem of bringing the system back to synchronism in the shortest duration of time has been successfully achieved with the help of TCSC controller. The controller is designed by phase compensation and GA methods. The primary objective of this paper is to improve the stability of the system while reducing the overshooting of the oscillations at the earliest possible. This paper proves the contribution of improved method of GA termed as the multiobjective GA to meet the pre defined target. The response of SMIB power system with PSS, TCSC using phase compensation and genetic algorithm techniques are compared. The inclusion of TCSC controller along with PSS in the SMIB system improves its stability. The implementation of GA to design TCSC controller for dynamic stability showed significantly improved results by damping oscillations in minimum time possible compared to the conventional phase compensation based TCSC controller.

IX. FUTURE RESEARCH:

Advanced research can be implemented where the complexity of computation of the parameters could be decreased there by making it feasible for the user to narrow down the controller parameters reducing the duration of calculations and ensuring the correctness of the results. The new Evolutionary algorithms could be applied to observe the response of TCSC parameters and the system stability in the long run.

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APPENDIX:

System data: All data are in $p.u$
Generator: $H = 4.0$ s, $D = 0$, X_d =1.0, X_q =0.6;
$X_d{}'$ =0.3, $T_{do}{}'$ =5.044, f =50, R_a =0, Q_e =0.303,
P_e =1.0, δ_o =60.620. K_A =200, T_A =0.04 s.
Transmission line and Transformer:
(X_L = 0.7, X_T = 0.1) = 0. 0 + j0.8.
TCSC Controller: X_{TCSCo} =0.245, α_o =156.040,
X_C =0.21, X_L =0.0525.
PSS controller Parameters: K_{PSS} =7.0521, T_W =10,
T_1 =0.2875, T_2 =0.1272.(phase compensation method)
TCSC controller Parameters: K_C =0.4077, T_W =10,
T_1 =1.4510, T_2 =0.0202.(phase compensation method)
K_C =2.4144, T_W =10, T_1 =1.4854, T_2 =0.0419
(GA based method)