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Design of Facts Controller Using Genetic Algorithm Technique

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Abstract: The design objective is to enhance the power system stability. Phillips-Herffron model of a Single-Machine Infinite-Bus (SMIB) power system equipped with SSSC controller is used to model the system in these studies. The design problem is formulated as an optimization problem and GA optimization technique is employed to search for optimal controller parameters. To show the superiority of the proposed approach, the performance of GA optimization technique is compared with a recently published paper in which Phase Compensation Technique(PCT) has been applied for the SSSC-based controller design Simulation results are presented for various operating condition and parameter variation under various disturbances to show the effectiveness and superiority of the GA optimization technique over the recently published PCT technique for a SSSC-based controller design

Index Terms: FACTS Controllers, Artificial intelligence, power system stability.,Phillips Heffron model

I. INTRODUCTION

The drive towards deregulated environment may result in simultaneous installation of different FACTS controllers in power system. Different FACTS controllers have the potential to interact with each other which may lead to deteriorate or enhance system stability depending upon the chosen controls and placement of FACTS controllers. Hence there is a need to study the interaction between the FACTS controllers.

A stability improvement is very important for large scale power system. SSSC the important member of FACTS family which can be installed in series in the transmission lines [6]. Traditionally, fixed or mechanically switched shunt and series reactors, capacitors and synchronous generators were being used to damp out oscillation [7]. However, there are some restrictions as to the use of these conventional devices. For many reasons desired performance was being unable to achieve effectively [8]. A SSSC is an electrical device for providing fast-acting reactive power compensation on high voltage transmission networks and it can contribute to improve the voltages profile in the transient state [9]. A SVC/SSSC can be controlled externally by designing Power System controller which can improve the dynamic & steady state performance of a large scale power system [10]. The dynamic nature of the SSSC lies in the use of thyristor devices (e.g. GTO, IGCT) [9].Therefore, this paper presents thyristor based SSSC controllers to improve the performance of the multi-machine power system.

In [13] several methods are proposed for coordination of multiple FACTS controllers in multi-machine power systems from different operating conditions viewpoint. There are various other techniques such as a pole placement techniques, frequency response techniques, root locus techniques, projective control methods, non-linear feed control methods for coordination of FACTS controllers and PSS.

POWER SYSTEM STABILITY

Power system stability of modern large inter-connected systems is a major problem for secure operation of the system. Black Outs recently caused by system instability, even in highly secure system illustrate the problems facing secure operation of power systems. Earlier, stability was defined as the ability of a system to return to normal or stable operation after having been subjected to some form of disturbance. But in, modern power systems operate under complex interconnections, controls and extremely loaded conditions. Further, with increased automation and use of electronic equipment, the quality of power has gained utmost importance, shifting focus on to concepts of voltage stability, frequency stability, inter-area oscillations etc.

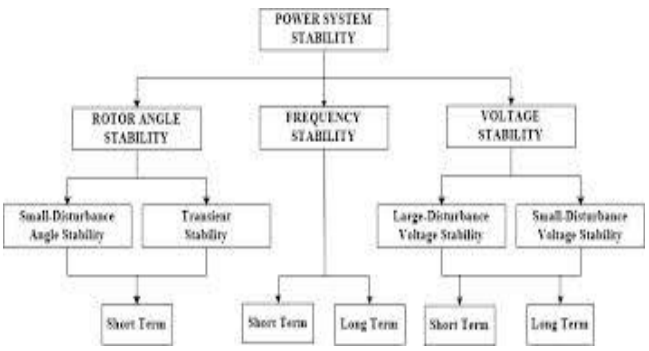

Fig1.1 Types of stability

- Rotor angle stability – ability of the system to maintain synchronism.
- Voltage stability – ability of the system to maintain steady acceptable voltage.
- Frequency stability – ability of the system to maintain frequency within an acceptable variation range.

Artificial Intelligence (AI) Based Techniques

This section reviews the coordinated control of FACTS controllers based on various Artificial Intelligence based techniques such as genetic algorithm (GA), expert system (ES), artificial neural network (ANN), tabu search optimization, particle swarm optimization algorithm, and fuzzy logic based approach.

Genetic Algorithm (*GA*) [13].

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GA is a global search technique based on mechanics of natural selection and geneticsThis technique is a general purpose optimization algorithm that is distinguished from conventional optimization techniques by the use of concepts of population genetics to guide the optimization search. The advantages of GA over traditional techniques is that it needs only rough information of the objective function and places no restriction A major disadvantage of GA method is that it requires tremendously high time.

In [10], a genetic algorithm based on the method of inequalities has been addressed for the coordinated synthesis PSS parameters in a multi-machine power system in order to enhance overall system small signal stability. In [11], GA is applied for the simultaneously tuning multiple power system damping controllers in power system over a pre-specified set of operating conditions. Congestion in the transmission lines is one of the technical problems that appear particularly in the deregulated environment. The two types of congestion management methodologies to relieve are one is non-cost free methods and another is cost free method. Reddy et al. presented the congestion management is relieved using cost free methods for using FACTS devices, congestion can be reduced without disturbing the economic matters.

II. DYNAMIC MODEL OF SYSTEM

A nonlinear dynamic model of the system is derived neglecting, the resistances of all the components of the system (i.e. transmission lines , generator , transformer and series converter transformer).The transients related with the transmission lines, fixed series capacitor, synchronous generator stator and transformers.

The Nonlinear Equations

The non-linear differential equations of the SMIB system with TCSC are:

$$\dot{\omega} = \frac{(P_m - P_e - D\Delta\omega)}{M} \quad (1)$$

$$\dot{\delta} = \omega_\circ(\omega - 1) \quad (2)$$

$$\dot{E}_q' = \frac{(-E_q + E_{fd})}{T_{do}'} \quad (3)$$

$$\dot{E}_{fd} = \frac{-E_{fd} + K_A(V_{ref} - V_t + V_s)}{T_A} \quad (4)$$

$$\dot{V}_{dc} = \frac{m}{C_{dc}}(I_{t2d}Cos\psi + I_{t2q}Sin\psi) \quad (5)$$

where,

$$P_e = V_{td}I_{td} + V_{tq}I_{tq}$$

$$E_q = E_q' + (X_d - X_d')I_{td}$$

$$V_t = V_{td} + jV_{tq}$$

$$V_{td} = X_q I_{tq}$$

$$V_{tq} = E_q' - X_d' I_{td}$$

$$I_{td} = I_{t1d} + I_{t2d}$$

$$I_{tq} = I_{t1q} + I_{t2q}$$

$$I_{t1d} = \frac{(X_{Bv} - X_{CF})}{X_{ds}}E'_q - \frac{(X_{Bv} - X_{CF})}{X_{ds}}V_b Cos\delta + \frac{(X_d' + X_{tE})}{X_{ds}}mV_{dc}Cos\psi$$

$$I_{t1q} = \frac{(X_{Bv} - X_{CF})}{X_{qs}}V_b Sin\delta - \frac{(X_q + X_{tE})}{X_{qs}}mV_{dc}Sin\psi$$

$$I_{t2d} = \frac{X_{T1}}{X_{ds}}E'_q - \frac{X_{T1}}{X_{ds}}V_b Cos\delta - \frac{X_1}{X_{ds}}mV_{dc}Cos\psi$$

$$I_{t2q} = \frac{X_{T1}}{X_{qs}}V_b Sin\delta + \frac{X_3}{X_{qs}}V_{dc}Sin\psi$$

$$X_1 = X_d' + X_{tE} + X_T$$

$$X_2 = X_d' + X_{tE} + X_{Bv} - X_{CF}$$

$$X_3 = X_q + X_{tE} + X_T$$

$$X_4 = X_q + X_{tE} + X_{Bv} - X_{CF}$$

$$X_{ds} = X_1 X_2 - (X_{tE} + X_d')^2$$

$$X_{qs} = X_3 X_4 - (X_q + X_{tE}')^2$$

V_s = The stabilizing signal from PSS.

The simplified IEEE Type-ST1A excitation system is considered in this work. The diagram of the IEEE Type-ST1A excitation system is shown in Fig. 1.2.

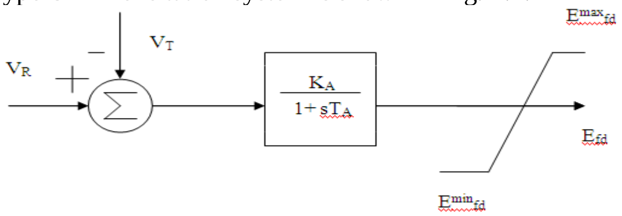

Fig. 1.2 Simplified IEEE type ST 1A excitation system

THE LINEARIZED MODEL

A linear dynamic model (Modified Heffron-Phillips model of a SMIB System including SSSC) is obtained by linearizing the non-linear model around a nominal operating condition. The linearized model is described below:

$$\Delta\dot{\omega} = \frac{(\Delta P_m - \Delta P_e - D\Delta\omega)}{M} \quad (6)$$

$$\Delta\dot{\delta} = \omega_\circ \Delta\omega \quad (7)$$

$$\Delta\dot{E}_q' = \frac{(-\Delta E_q + \Delta E_{fd})}{T_{do}'} \quad (8)$$

$$\Delta\dot{E}_{fd} = \frac{-\Delta E_{fd} + K_A(\Delta V_{ref} - \Delta V_t + V_s)}{T_A} \quad (9)$$

$$\Delta\dot{V}_{dc} = K_7\Delta\delta + K_8\Delta E_q' + K_9\Delta V_{dc} + K_{cm}\Delta m_E + K_{c\delta m}\Delta\psi + K_{cb}\Delta m_B\Delta\psi \quad (10)$$

where,

$$\Delta P_e = K_1\Delta\delta + K_2\Delta E_q' + K_{pm}\Delta m + K_{p\delta m}\Delta\psi + K_{pb}\Delta m_B + K_{pd}\Delta V_{dc}$$

$$\Delta E_q = K_3\Delta E_q' + K_4\Delta\delta + K_{qm}\Delta m + K_{q\delta m}\Delta\psi + K_{qd}\Delta V_{dc}$$

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$$\Delta V_t = K_5\Delta\delta + K_6\Delta E_q^{'} + K_{vm}\Delta m + K_{v\delta e}\Delta\delta_E + K_{vdm}\Delta\psi + K_{vd}\Delta V_{dc}$$

The K_{pu}, K_{qu}, K_{vu} and K_{cu} are row vectors defined as:

$$K_{pu} = [K_{pm} \quad K_{p\delta m}] \qquad (11)$$

$$K_{qu} = [K_{qm} \quad K_{q\delta m}] \qquad (12)$$

$$K_{vu} = [K_{vm} \quad K_{v\delta m}] \qquad (13)$$

$$K_{cu} = [K_{cm} \quad K_{c\delta m}] \qquad (14)$$

The vector **u** is defined as:

$$u = [\Delta m \quad \Delta\psi]^T \qquad (15)$$

Δm =Deviation in modulation index of series converter. Magnitude of the series injection voltage can be modulated, by modulating m.

$\Delta\psi$ = deviation in the phase angle of series injected voltage $\overline{V_q}$.

The voltage on the dc link can be regulated, by modulating ψ.

ΔP_m = Deviation in mechanical power input to the generator.

ΔV_{ref} =Deviation in AVR reference voltage. The constants of the model are functions of the system parameters and operating condition. The modified Phillips-Heffron model of the single-machine infinite-bus (SMIB) power system with SSSC is obtained using linearized equations (6)-(15). The corresponding block diagram model is shown in Fig. 1.3.

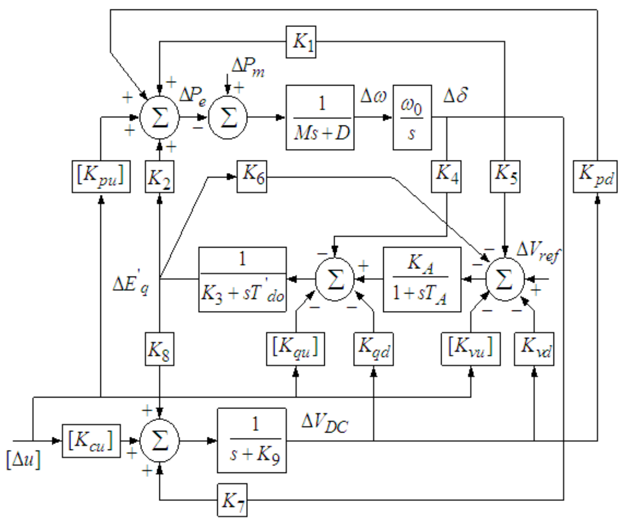

FIG. 1.3 MODIFIED LINER DYNAMIC PHILLIPS-HEFFRON MODEL OF SMIB WITH

III. SSSC DESIGN OF SSSC-BASED CONTROLLER STRUCTURE OF THE SSSC CONTROLLER

The commonly used lead–lag structure is chosen in this study as a SSSC-based controller. The structure of the SSSC controller is shown in Fig.1 3. It consists of a gain block with gain K_T, a signal washout block and two-stage phase compensation block. The phase compensation block provides the appropriate phase-lead characteristics to compensate for the phase lag between input and the output signals. That signal washout block serves as a high-pass filter, with the time constant T_{WT}, high enough to allow signals associated with oscillations in input signal to pass unchanged. Without it steady changes in input would modify the output. From the viewpoint of the washout function, the value of T_{WT} is not critical and may be in the range of 1 to 20 seconds. In this structure, the washout time constants T_{WT} is usually pre specified. In the present study, T_{WT} =10s is used. The controller gain K_T and the time constants T_1, T_2, T_3 and T_4 are to be determined.

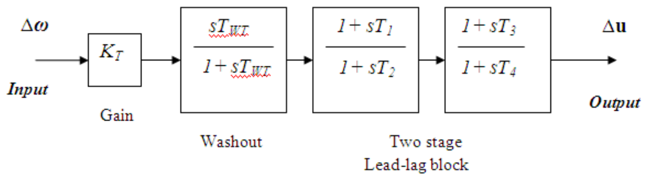

Fig. 1.4 Structure of the SSSC-based damping controller

IV. OBJECTIVE FUNCTION

It is worth mentioning that the SSSC-based controller is designed to minimize the power system oscillations after a disturbance so as to improve the stability. These oscillations are reflected in the deviation in the generator rotor speed ($\Delta\omega$). In the present study, an integral time absolute error of the speed deviations is taken with *J* as the objective function, which is expressed as:

$$J = \int_{t=0}^{t=t_1} |\Delta\omega| \cdot t \cdot dt \qquad (16)$$

In the above equations, $|\Delta\omega|$ is the absolute value of the speed deviation and simulation time controller parameters. For objective function calculation, the time-domain simulation of the power system model is carried out for the simulation period aiming to minimize this objective function in order to improve the system response in terms of the settling time and overshoots. Tuning a controller parameter can be viewed as an optimization problem in multi-modal space as many settings of the controller could be yielding good performance. Traditional method of tuning doesn't guarantee optimal parameters and in most cases the tuned parameters need improvement through trial and error. In modern heuristic optimization technique based methods, the tuning process is associated with an optimality concept through the defined objective function and the time domain simulation. Hence these methods yield optimal parameters and the methods are almost free from the curse of local optimality. In modern heuristic optimization techniques, the designer has the freedom to explicitly specify the required performance objectives in terms of time domain bounds on the closed loop responses. In view of the above, in the present study, modern heuristic optimization techniques are employed to solve this optimization problem and search for optimal

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SSSC Controller parameter

For the implementation of GA, normal geometric selection, arithmetic crossover and non uniform mutation are employed in the present study. Also, random initialization and specified generations are used for initialization and termination process. Normal geometric selection is a ranking selection function based on the normalized geometric distribution is employed in the present study. Arithmetic crossover takes two parents and performs an interpolation along the line formed by the two parents. Non uniform mutation changes one of the parameters of the parent based on a non-uniform probability distribution. This Gaussian distribution starts wide, and narrows to a point distribution as the current generation approaches the maximum generation. A matrix of options where the first column represents the number of that crossover and mutation operations performed would be represented later in the form of a Table.

GA parameters
Population size: 20
Maximum number of generations: 100
Type of selection: Normal geometric [0.08]
Type of crossover: Arithmetic [2]
Type of mutation: Nonuniform [2 100 3]

A. For the purpose of optimization of equation (11), GA is employed. The objective function comes from time domain simulation of power system model shown in Fig. 3. Simulations were conducted on a Pentium 4, 3 GHz, 504 MB RAM computer, in the MATLAB 7.0.1 environment. Using each set of controllers' Optimization process is repeated 20 times for GA. The best, the average and the worst among the final fitness values and the related standard deviation obtained in the 20 runs of GA is shown in Table 1.2. The optimal SSSC-based controller parameters i.e. the best among the 20 runs of GA optimization technique are presented in Table 1

V. SIMULATION RESULTS

To assess the effectiveness and robustness of the controllers, different disturbances and parameters variations are considered.

A. VARIATION IN MECHANICAL POWER

In order to verify and compare the effectiveness of the optimized controllers, the performance of the both controller are tested for a disturbance in mechanical power input. A 10% step increase in mechanical power input at t =1.0 s is considered. The system responses for the above contingency are shown in Fig. In these Fig., the responses without control, response with proposed phase compensation technique tuned SSSC controller and proposed RCGA optimized SSSC controller are shown with legends WC, PCT and RCGA respectively. It can be observed from Fig. 1.5 that, without control the system is unstable and both PCT and RCGA tuned SSSC based controller maintains stability.

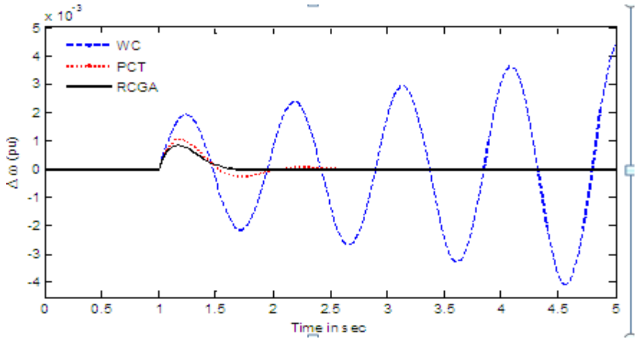

Fig. 1.5 Speed deviation response for 10% step increase in P_m

B. DISTURBANCE IN REFERENCE VOLTAGE SETTING

For completeness, the effectiveness of the proposed controllers is also tested for a disturbance in reference voltage setting. The reference voltage is increased by a step of 5% at t =1 s. Fig.1.6 show the system responses for the above contingency for all the three cases. These positive results of the proposed RCGA optimized SSSC based controller can be attributed to its faster response with less overshoot compared to that of PCT.

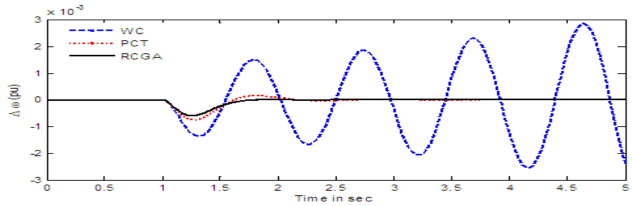

Fig. 1.6 Speed deviation response for 5% step increase in V_{ref}

C VARIATION OF SYSTEM PARAMETERS

In the design of damping controllers for any power system, it is extremely important to investigate the effect of variation of system parameters on the dynamic performance of the system. In order to examine the robustness of the damping controllers to variation in system parameters, a 25% decrease in machine inertia constant and 30% decrease of open circuit direct axis transient time constant is considered. The system response with the above parameter variations for a 5% step increase in mechanical power is shown in Fig. 1.7.

D. VARIATION CIRCUIT DIRECT AXIS TRANSIENT TIME CONSTANT

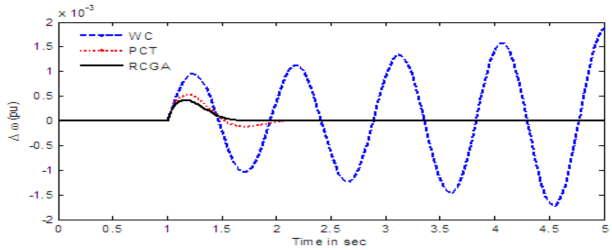

Fig.1.8 Power angle deviation response for 5% step increase in P_m with 30% decrease in T_{do}'

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VI. CONCLUSION

The work presented in this thesis mainly focuses on the aspects related to a Flexible AC Transmission Systems (FACTS)-based controller and evaluation of its contribution to system stability improvement ensuring secure and stable operation of the power system. In this context, modern heuristic optimization techniques have been employed to design the FACTS-based controllers. Investigations have been carried out considering a Static Synchronous Series Compensator (SSSC) which is a prominent series FACTS controller.The significant contributions of the research work presented in this paper are:

1. A systematic approach for designing a SSSC-based controller employing modern heuristic optimization techniques has been presented. It is observed that, in terms of computational time, the RCGA approach is faster compared to conventional phase compensation technique.
2. Studies show that the proposed controllers are robust and perform satisfactory under various disturbances with parameter variations.
3. The studies suggest that the damping produced in the power system is minimized by applying GA rather than PCT to SSSC based FACTS controller.

Table 1: SSSC based controller parameters in 20 run

Solution	K_T	T_1	T_2	T_3	T_4
1	75.8200	0.2787	0.3416	0.4168	0.3229
2	65.7484	0.1991	0.3658	0.4831	0.2185
3	83.6769	0.1442	0.4298	0.4766	0.1772
4	87.0707	0.4363	0.2402	0.2009	0.4062
5	85.7154	0.2476	0.2468	0.4876	0.3680
6	78.0890	0.4553	0.2617	0.1841	0.3405
7	80.9234	0.3192	0.2702	0.3492	0.3971
8	88.5404	0.2609	0.3485	0.4310	0.3432
9	67.0650	0.1561	0.2054	0.4527	0.3435
10	86.3079	0.4042	0.3742	0.2264	0.2565
11	86.8742	0.3450	0.3289	0.1338	0.1578
12	87.2629	0.3879	0.4607	0.3043	0.2444
13	77.4925	0.4498	0.2526	0.1086	0.2417
14	79.3984	0.1291	0.1485	0.3202	0.2730
15	88.4906	0.1651	0.2362	0.3126	0.2568
16	86.6889	0.3630	0.1456	0.1286	0.3547
17	89.7036	0.3114	0.1667	0.1093	0.2625
18	82.0820	0.4337	0.3419	0.2585	0.3328
19	89.6222	0.4087	0.3234	0.1822	0.2574
20	74.1568	0.1299	0.1981	0.4713	0.3528

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