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A New Algorithm for TCSC- Based Controller Design by Using Differential Evolution Method

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Abstract. Design of an optimal controller requires the optimization of differential evolution performance measures that are often no commensurable and competing with each other. Being a population based approach; Differential Evolution (DE) is well suited to solve designing problem of TCSC – based controller. This paper investigates the application of DE-based multi-objective optimization technique for the design of a Thyristor Controlled Series Compensator (TCSC)-based supplementary damping controller. The designing objective is to improve the power system stability with minimum control effort. The proposed technique is applied to generate Pareto set of global optimal solutions to the given multi-objective optimization problem. Further, a fuzzy-based membership value assignment method is employed to choose the best compromise solution from the obtained Pareto solution set. Simulation results are presented to show the effectiveness and robustness of the proposed approach.

Keywords: multi-objective optimization, differential evolution algorithm, pareto solution, thyristor controlled series compensator, power system stability.

1. Introduction

Real world problems often have multiple conflicting objectives competing with each other. For example, while designing a control system, we would usually like to have a high-performance controller, but we also want to achieve desired performance with little control efforts (cost). Optimization of multiple performance measures which are no commensurable and competing with each other is in reality a multi-objective optimization problem. In multi-objective optimization problems generally there is no single solution that is the best when measured on all objectives. Hence several trade-off solutions (called the Pareto optimal set) are usually preferred [1]. Control systems optimization problems involving the optimization of multiple objective functions require high computational time and effort [2, 3]. As conventional techniques are difficult to apply, modern population based heuristic optimization techniques are preferred to obtain Pareto optimal set [4].

Recent development of power electronics introduces the use of Flexible AC Transmission Systems (FACTS) controllers in power systems [5]. Thyristor Controlled Series Compensator (TCSC) is one of the important members of FACTS family that is increasingly applied with long transmission lines by the utilities in modern power systems [6-10].Power System Stabilisers (PSS) are now routinely used in the industry to damp out power system oscillations**.** Unfortunately, the conventional techniques are time consuming as they are iterative and require heavy computation burden and slow convergence. In addition, the search process is susceptible to be trapped in local minima and the solution obtained may not be optimal. DE differs from other Evolutionary Algorithms (EA) in the mutation and recombination phases. . In view of the above, DE optimization technique has been employed to design a power system stabilizer and a TCSC-based controller.

2. Problem Formulation

The commonly used lead–lag structures are chosen in this study as a PSS and TCSC-based controller as shown in Fig. 1 and Fig. 2 respectively. Each structure consists of a gain block, a signal washout block and two-stage phase compensation block. The washout acts as high-pass filter and eliminates the low frequencies that are present in the input signal and allows the controllers to respond only to changes in the input. Without it steady changes in input would modify the output. The phase compensation block provides the appropriate phase-lead characteristics to compensate for the phase lag between input and the output signals.

The input signal to these controllers is the speed deviation ($\Delta\omega$). The output signal of the PSS is the signal V_S which is used as an additional input to the excitation system block. The output signal of the TCSC-based controller is the reactance offered by the TCSC, $X_{TCSC}(\alpha)$. In Fig. 2, σ_0 represents the initial conduction angle as desired by the power flow control loop. The steady state power flow loop acts quite slowly in practice and hence, in the present study, σ_0 is assumed to be constant during large disturbance transient period. The desired value of line reactance is obtained according to the change in the conduction angle $\Delta\sigma$. This signal is put through a first order lag representing the natural response of the controller and the delay introduced by the internal control which yields the reactance offered by the TCSC, $X_{TCSC}(\alpha)$.

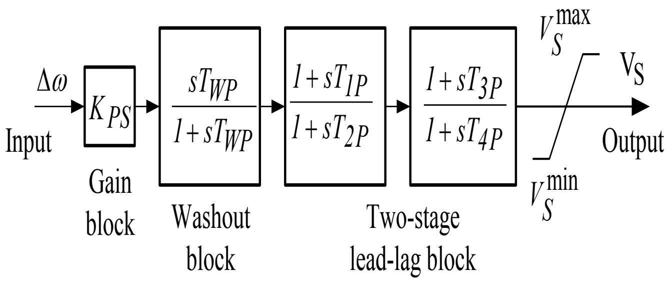


Fig. 1: Structure of power system stabilizer

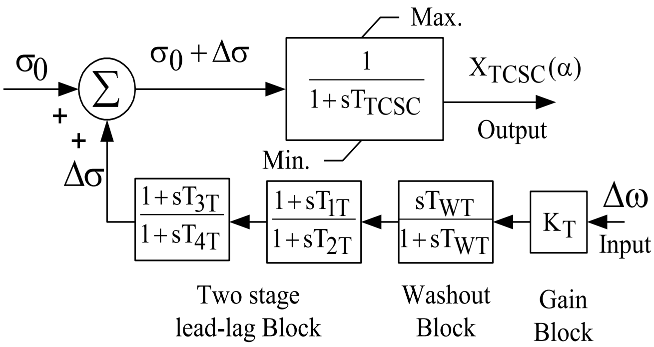


Fig. 2: Structure of TCSC-based controllers

3. Problem Formulation

The generator is represented by the third-order model comprising of the electromechanical swing equation and the generator internal voltage equation. The state equations may be written as (Yu, 1983):

$$\dot{\omega} = [P_m - P_e - D(\omega - 1)]/M$$

$$\dot{\delta} = \omega_b(\omega - 1) \qquad V_T = v_d + jv_q \quad I = i_d + ji_q$$

where, P_m and P_e are the input and output powers of the generator respectively; M and D are the inertia constant and damping coefficient respectively; ω_b is the synchronous speed; V_T is the terminal voltage; I is the current, δ and ω are the rotor angle and speed respectively.

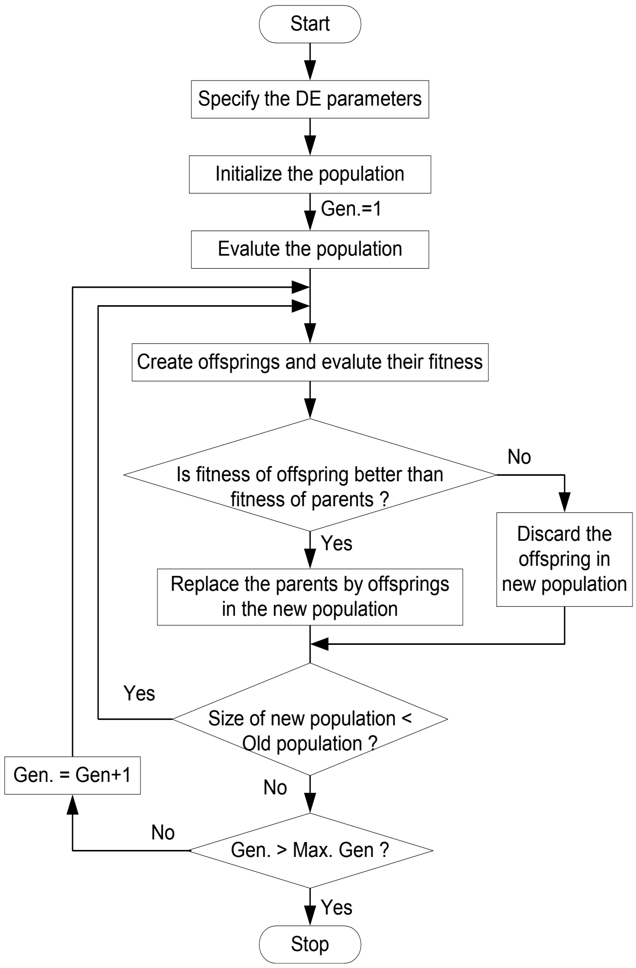
4. Overview of Differential Evolution

Differential Evolution (DE) algorithm is a stochastic, population-based optimization algorithm recently introduced (Stron and Price, 1997). DE works with two populations; old generation and new generation of the same population. The size of the population is adjusted by the parameter N_P. The population consists of real valued vectors with dimension D that equals the number of design parameters/control variables. The population is randomly initialized within the initial parameter bounds. The optimization process is conducted by means of three main operations: mutation, crossover and selection. In each generation, individuals of the current population become target vectors. For each target vector, the mutation operation produces a mutant vector, by adding the weighted difference between two randomly chosen vectors to a third vector. The crossover operation generates a new vector, called trial vector, by mixing the parameters of the mutant vector with those of the target vector. If the trial vector obtains a better fitness value than the target vector, then the trial vector replaces the target vector in the next generation.

Selection: The target vector $X_{i,G}$ is compared with the trial vector $V_{i,G+1}$ and the one with the better fitness value is admitted to the next generation. The selection operation in DE can be represented by the following equation:

$$X_{i,G+1} = \begin{cases} U_{i,G+1} & \textit{if } f(U_{i,G+1}) < f(X_{i,G}) \\ X_{i,G} & \textit{otherwise.} \end{cases} \qquad \text{where } i \in [1, N_P]$$

5. Implementation of Proposed Approach



Flow Chart of Proposed Algorithm

6. Simulation and Results

The fitness function comes from time-domain simulation of power system model. Using each set of controllers' parameters, the time-domain simulation is performed and the fitness value is determined.

To assess the effectiveness and robustness of the proposed controller various loading conditions given in Table1. is considered. The response without controller is shown with dotted line with legend 'WC'; and the response with the proposed coordinated PSS and TCSC-based controller is shown with solid line with legend 'CC' respectively.

The Western Systems Coordinating Council (WSCC) 3-machine, 9-bus system has taken for designing of our model. The first stage in designing a FACTS-based controller in a multi-machine power system is the selection of the location of the controller. In the present study to find the location of TCSC controller, a 3-phase fault is applied near a bus at the end of a line.

For the critical clearing time (CCT) calculation machine equations are expressed in state variable form. The variation of the power angle difference for the above most severe case is shown in Fig. 3.

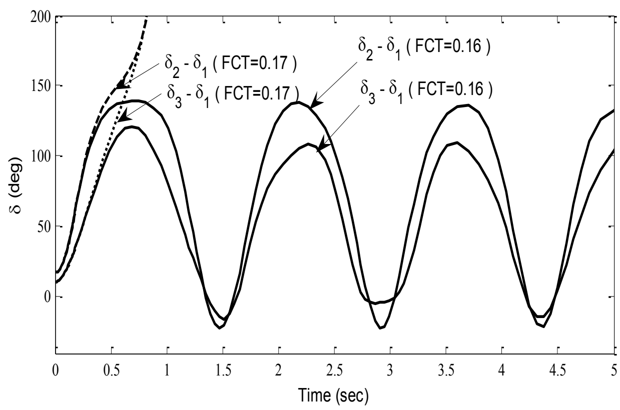


Fig. 3: Difference between power angle

Table 1: Loading conditions considered

Loading Conditions	P (pu)	Q(pu)	δ_0 (deg.)
Nominal Loading	0.9	0.1513	51.7963
Light Loading	0.5	0.0457	31.5689
Heavy Loading	1.1	0.2294	60.1850

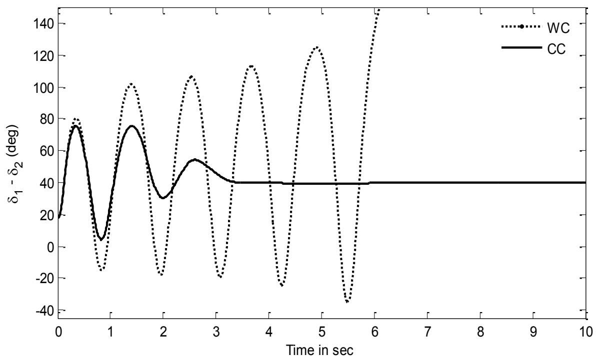


Fig. 4: System power angle response (δ_1-δ_2) for 100 ms three phase fault

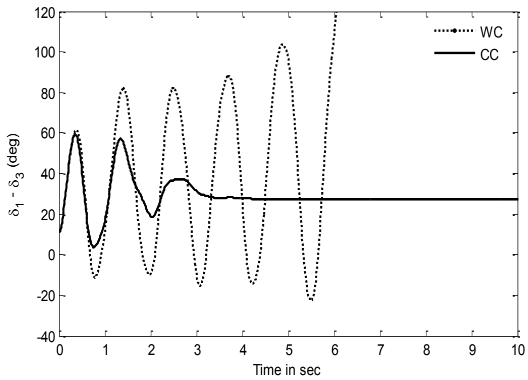


Fig. 5: System power angle response (δ_1-δ_3) for 100 ms three phase fault

8. References

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