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Towards an extended power system stability: An optimized GCSC-based inter-area damping controller proposal

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ABSTRACT

Due to the crucial importance of the FACTS based damping controllers in mitigation the deteriorative impacts of the power system low frequency oscillations, particularly the inter-area modes, improving the system stability margins seems indispensible. This paper proposes an optimization approach to effectively carry out the multi-machine based stabilization function of the Gate-Controlled Series Capacitor (GCSC) in providing a robust damping to the power system low frequency oscillations. It is aimed to provide a reliable damping framework by means of an optimized GCSC based supplementary damping controller. Thus, to attain the most efficient set of the damping controller parameters, Particle Swarm Optimization algorithm as a proficient optimum hunter is employed to explore for the global stabilization solution in accordance to a vast range of power system operating conditions. Moreover, as a weighty assessment, the eigenvalue analysis is taken into account as the cornerstone of the performed studies in order to investigate the damping methodology in which the unstable or lightly damped inter-area modes are scheduled to effectively shift to some predominant stability zones in the s-plane. Meanwhile, derived results through the nonlinear time domain simulation as well as two dynamic performance evaluators manifestly demonstrate the impressiveness and verify the robustness of the proposed GCSC based damping scheme in enhancing the power system stability, especially regarding to the inter-area modes.

1. Introduction

Power system ever increasing demand for the secure and reliable electricity asks for intensified stability margins to be provided with an emergency priority in the system operation. On the other hand, regarding to the market restructuring and environmental constraints, power system stable performance especially fronting to the inherent low frequency oscillations (LFOs) is critical to the system operators. LFOs concerning to the mutuality of the system dynamic components lie in two major oscillatory modes. Inter-area modes with the frequencies in the range of 0.1–1 Hz and local modes having frequencies of 1–3 Hz ordain the power system low frequency oscillations [1,3]. Due to invaluable impacts of the steadily performance of the zonal tie lines in sustaining the system integrity and providing an incessant electrification, therefore, damping the inter-area modes appearing principally in large scale power systems has more preference to the local ones. The significance of damping the inter-area modes are when revealed that the conventional Power System Stabilizers (PSSs) are lacking in giving adequate relaxation to these modes, particularly in the case of heavy loading of the long transmission lines [1]. On the other hand, recently, Flexible AC Transmission System (FACTS) technology brings about a more universal stabilizing factor to the power systems. One of most utilities of the FACTS devices is the rapid controllability to provide a dynamic security limit in which at least the system inherent low frequency oscillations are mitigated guardedly. Hence, employing the FACTS controllers in such emphatic power systems is crucial to the system stability improvement [2,4]. Gate Controlled Series Capacitor (GCSC) treated as a new contribution of the FACTS series category is a potent power modulator producing dependable series compensation [5]. A single module of a GCSC comprises a capacitor connecting in shunt with a pair of anti-parallel gate-commutated switches. Wide range of controllability is the direct result of the gate-commutated based scheme. Furthermore, the GCSC by a structural-based restraining of the resonant frequencies unlike that occurs in the case of TCSC,[1] provides a continuous stabilizing signal standing to offer a more beneficial power system operation. For the sake of comparison to especially the TCSC and SSSC,[2] simplicity [6], extensive controllability [7] inexpensiveness [8] and high efficiency [9] are the main features led the

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[1] Thyristor Controlled Series Capacitor.
[2] Static Synchronous Series Compensator.

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GCSC to be considered as a powerful option in enhancing the system dynamic stability. Although considering to the further practical background of the TCSC and its more familiar operative aspects, referring to the overall controllability of the gate commutated switches, the GCSC, at least from the theoretical viewpoint, has more profitableness to its elder scheme, i.e. TCSC. It should be noted that all the aforementioned comparisons are valid only using the mathematical hypotheses, and in the operational phases, at this time, the GCSC may be a risky choice, however it seems erelong to have an appropriate potential to be adopt in the real experiences. Consequently, it could be said that the GCSC may be soon replaced by the TCSC or even SSSC in most of series compensation scopes. As reported in the literature, to improve a better damping to the power system, some commonly modern control methodologies such as fuzzy set [10] and neural networks [9] are developed to design a GCSC based damping controller. Although these algorithms are impressive, but they are on the basis of the trial and error efforts especially in the initialization stages and in some cases, may cause to reach improper solutions. Although, the investigation the power system dynamic performance has been performed in some literatures [6,9,10], the lacuna of a detailed and thorough study on the GCSC, as an appropriate series compensator, efficient dynamic modeling and damping performance analysis, especially regarding to the low frequency oscillations is still evident. In order to fill this gap out, the main contribution of the paper is in the light of proposing a detailed proper dynamic modeling of the GCSC to investigate perfectly the capability of the GCSC in providing a robust damping framework to the power system LFOs.

To augment the modulated damping torque of the GCSC against the system uncertainties and nonlinear interactions and also attain a more techno-economical operation of the GCSC modules, a supplementary damping controller is proposed to be designed in a way in which the GCSC stabilizing signal is reinforced. In this study, an industrial preferable scheme of the damping controllers is proposed to be determined optimally. The present paper uses Particle Swarm Optimization (PSO) algorithm to search for the optimistic set of damping controller parameters. The PSO is known as a straightforward search conductor seeks intelligently for the near global optimal destination. Because of impassible nature of the PSO to the particularly nonlinear, differential and large scale problems [11], and further referring to the multi-modal fulfillment of the controller parameters, it is seemed to be an appropriate candidate to solve the problem of damping controller design. The problem of eliciting the optimistic set of controller parameters using the PSO algorithm is transmitted into a minimization an eigenvalue based fitness function. The purpose is to robustly shift the un-damped or lightly damped eigenvalues to some specified stable regions in the s-plane. It should be noted that due to more importance of the inter-area modes, only the dominant corresponded inter-area eigenvalues with frequencies in the range of 0.1–1 Hz are derived and be analyzed via the fitness function ruler. Hence, a multi-machine two area power system is considered to be equipped with the GCSC and then the stability issue is evaluated over the test system using the nonlinear dynamic equations. Owing to the capability of the current injection model in rendering a more detailed dynamic model of the FACTS devices, it is selected to be used in dynamic modeling of the GCSC. High compatibility, universality and easy implementation in the system dominant studies like OPF and stability analyses motivate to employ the current injected based model for GCSC in this contribution [21]. Besides, to guaranty the robustness and competency of the optimized damping controller, a wide range of operating points is assumed to be applied to the test power system. Moreover, to assure the controller performance a severe transient disturbance is imposed to the power system and the corresponding results are demonstrated in the framework of nonlinear time domain simulations.

The paper approach focuses on estimation the GCSC capability in providing a more robust stabilizer function for a multi-machine power system. Thus, a supplementary damping controller is assumed to be optimally designed in order to strengthen the GCSC modulating damping torque. The PSO algorithm is assigned to find the optimistic set of damping controller parameters through minimizing some eigenvalue based fitness functions over a wide range of operating conditions. Also, the nonlinear time domain simulation is employed to validate the eigenvalue analysis results. Assessment the derived results clearly show the efficiency of the GCSC in enhancement the system stability. Moreover, by calculation the numerical values of two performance indices defined on the basis of the power system dynamic response to the assumed disturbance, it can be deduced that all of the considered fitness functions provide a suitable stabilizing signal not only for the inter-area modes but also the local modes are damped aptly. To assure of the optimization results derived from the PSO, the performance of the PSO algorithm in the terms of the convergence rate and also the computational time is compared to the GA algorithm. The superiority of the PSO-based results validates the optimized tuning of the damping controller parameters and verifies the secure system stability improvements.

2. Description the system under study

2.1. Gate Controlled Series Capacitor

According to the substantial effects of the GCSC in increasing the power system available transfer capability (ATC) and thereby, providing more developed system stability margins, it is necessary to exploit a detailed and as well a compatible model to the nonlinear ingredients of a practical large scale power system. In this quest, the current injection model of the GCSC is drawn out through the variable impedance model. Truism, as represented in Fig. 1 for the GCSC installed between the buses *i* and *j*, the equivalent impedance is a variable capacitance changeable by the switch blocking angle variations. It is notable that the activate series compensation is produced when the blocking angle varies in range of 0–90° with respect to the line current maximum point [12].

Eq. (1) explains the relationship between the GCSC capacitive reactance and the blocking angle γ [2,12]. In Fig. 2 the equivalent impedance model of the GCSC is shown.

$$X_{GCSC}(\gamma) = X_C\left(1 - \frac{2\gamma}{\pi} - \frac{\sin(2\gamma)}{\pi}\right) \tag{1}$$

To attain the proposed current injection model, first the series current which flows through the compensated transmission line is considered to be calculated according to Fig. 2 as following:

$$\bar{I}_{se} = \frac{\overline{V}_i - \overline{V}_j}{r_l + j(x_l - x_{GCSC}(\gamma))} \tag{2}$$

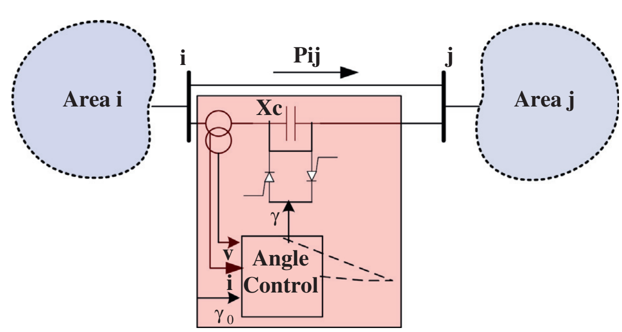

Fig. 1. The GCSC installed between buses *i* and *j*.