IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

# PARTICLE SWARM OPTIMIZATION (PSO) OF POWER SYSTEM STABILITY IMPROVEMENT USING STATIC SYNCHRONOUS SERIES COMPENSATOR

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**ABSTRACT**

A method for designing an SSSC-based stabilizer to damp inter-area oscillations is proposed in this paper. To reach this goal, a novel objective function was employed. The displacement of critical modes and the gain (control cost) of the stabilizer are taken into account in the given objective function. In order to have an SSSC-based stabilizer with minimum phase structure, appropriate constraints are calculated and appended to the objective function. For the robust design of an SSSC-based stabilizer, different operating conditions are simultaneously considered. A hybrid optimization algorithm (hGWO-GA) is proposed by combining the grey wolf optimizer (GWO) algorithm and the genetic algorithm (GA). The proposed method was tested on two standard test systems of 4 and 50 machines. The eigenvalues analysis and nonlinear simulations prove that the introduced approach can efficiently enhance the damping of inter-area oscillations. The obtained results show the superiority of the SSSC phase-based stabilizer compared to the magnitude-based stabilizer in damping inter-area oscillations. The results also show that the performance of the proposed hGWO-GA optimization algorithm is superior to the GWO, GA, ACO, and PSO algorithms. Considering the uncertainties in the design process is the future scope of this work.

Keywords: Particle swarm optimization, transient stability, power system oscillations, SSSC.

## INTRODUCTION

One of the critical problems that power system operators face is the mitigation of interarea oscillations [1]. With the advent of large-stressed power systems and interconnections between them, low-frequency oscillations between 0.2–2 Hz may be observed in power systems. The oscillations between a generator and an electrical power plant and the remaining part of the power system are named local oscillations. Local oscillations have frequencies of between 0.8 and 2 Hz. The frequency range of inter-area oscillations is 0.2–0.8 Hz, and they happen when the generators of one area oscillate with those of other areas. Because of weak damping, inter-area oscillations are more dangerous for power system stability [2].

The inter-area oscillations may not be damped effectively and can lead to system instability. Power system stabilizers (PSSs) are widely employed for mitigating low-frequency oscillations [3]; however, in some conditions, especially for interarea oscillations, PSSs may not provide adequate damping for the system [4]. The latest progress in the field of power electronics has made it incumbent to utilize flexible AC transmission system (FACTS) devices to solve power system problems.

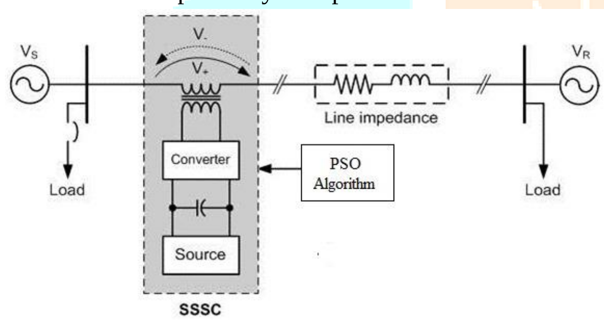


Fig 1: Block Diagram

These devices can control the network in different conditions quickly, and this feature allows their application to improve power system stability [5]. Furthermore, FACTS devices installed in suitable locations show a considerable potential for damping inter-area oscillations [6]. Hence, FACTS devices equipped with supplementary damping controllers (SDC) are used to reduce PSS limitations [7].

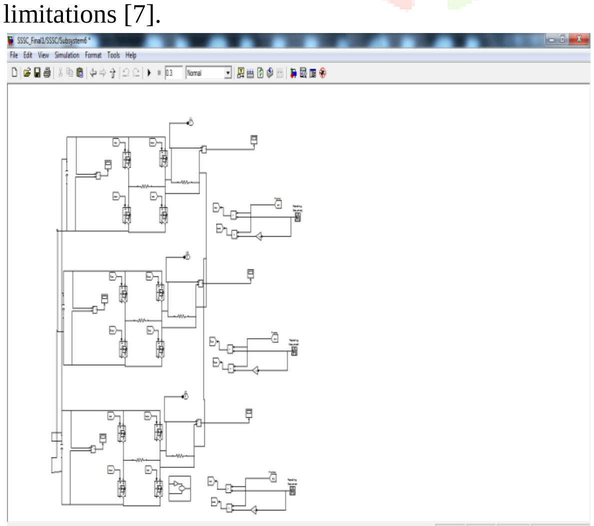

Fig 2: Without SSSC:

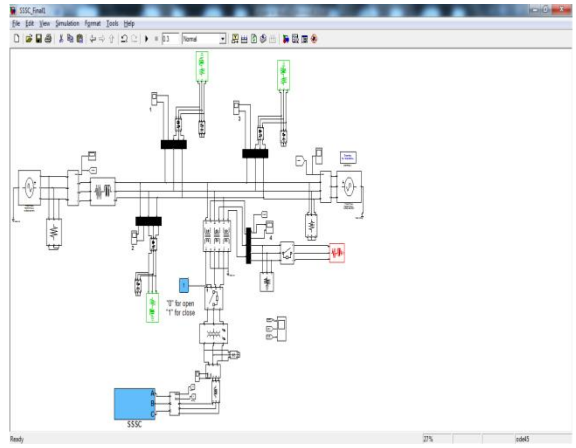

Fig 3: With SSSC:

The static synchronous series compensator (SSSC), as a member of the FACTS device family, can control power flow in power systems by changing its characteristics from capacitive to inductive [8].

Considering the advantages, mentioned above, the SSSC can be a suitable solution for relaxing the capacities of transmission lines and active and reactive power controls in long transmission lines by having a low cost and appropriate control capability. Similar to other FACTS devices, it is possible to damp low-frequency oscillations, especially inter-area oscillations, by using a supplementary damping controller installed in an SSSC. [9,10].

## LITERATURE REVIEW

The SSSC-based stabilizer is more reliable and effective in damping inter-area oscillations than other FACTS-based stabilizers such as TCSC and STATCOM [11]. The flower pollination algorithm is suggested in this article for the robust tuning of a static VAR compensator to mitigate power system oscillations [12]. Two independent control channels are used to control the magnitude and phase of the voltage in voltage source converters (VSCs) [13,14]. When an SSSC stabilizer is employed to damp oscillations, it can be applied to both the magnitude and phase control channels. In a single-machine infinite bus (SMIB) power system, an SSSC-based stabilizer can be applied to the magnitude control channel [15] or to the phase control channel to improve the stability of the system [16]. Moreover, in the case of a multimachine power system, one can use an SSSC-based stabilizer on the magnitude control channel to damp electromechanical oscillations [17]. Many methods have been presented in the literature for designing stabilizer parameters. Conventional methods for tuning the controller, such as the relocation of poles [18], phase compensation [19], quadratic mathematical programming [13], fuzzy logic [20], and modern control methods, have been proposed in the studies thus far [2]. The disadvantages of most of these methods are their complexity and computational burden with a high volume of calculations, low convergence speeds, and the possibility of reaching local solutions. Today, some intelligent methods, including meta-heuristic methods, such particle swarm optimization(PSO) [2], real coded genetic algorithm (RCGA) [3], differential Evolution-

Pattern Search(DE-PS) algorithm [4], gravitational search optimization (GSA) Algorithm [5,6], seeker optimization algorithm(SOA) [7], evolutionary differential(ED) algorithm [9], shuffled frog-leaping Algorithm(SFLA) [8], Ant Colony Optimization Algorithm extended to real-variable optimization (ACOr) [9] and hybrid particle swarm and bacteria foraging algorithm(hPSO-BFO) [20], have been widely employed for a SSSC-based stabilizer design in order to reduce the available problems in classic design methods.

In [1], a new optimization method based on genetic algorithm is used to coordinate a SSSC based stabilizer and a PSS to improve stability of a power system. A coordinated controller for SSSC and PSS considering time delay in remote signals is presented in [2] and a new hybrid particle swarm optimization and gravitation search algorithm is used to find the stabilizer parameters. In [3,4], a multi-input single output (MISO) controller has been proposed as a SSSC-based stabilizer to improve stability of a power system. In [5], a optimization method based on genetic algorithm is presented to the tuning parameters of a lead-lag SSSC-based stabilizer to improve stability of a power system has been proposed.

The GWO is the most popular optimization algorithm based on swarm intelligence, which has some suitable features, including easiness, resilience, deviation-free mechanism, and avoiding local optima. In addition, it has features of simple implementation, fewer tuning parameters, and fast convergence. Many engineering problems have used this algorithm for many problem-solving cases. The GWO algorithm has been investigated for exploration, exploitation, convergence, and crossing local minima. It has been tested on unimodal, multimodal, and multimodal with fixed dimensions and combined functions [4]. One can easily see that it gives similar results to the other distinguished meta-heuristic algorithms. The algorithm was also successfully applied to innovative tuning approaches in fuzzy control systems (CSs) [12]. Reference [15] investigated the application of the GWO in surface wave data for estimating near-surface S-wave velocity and profile parameters in surface waves. It has also been used for a subset feature selection problem [16]. The efficacy of the GWO for training multilayer perceptron (MLP) has been studied in [7]. In [18], the GWO algorithm was employed to solve the economic load dispatch problem. It was used for designing a wide-area PSS (WAPSS) [19]. It has also been used for the economical design of combined heat and power economic dispatch (CHPDE) [50]. This algorithm has been utilized for optimal reactive power dispatch [11].

**METHODS**

In most research, as mentioned above, relating to the SSSC-based stabilizer, the stabilizer is applied to the magnitude control channel. In [13], using quadratic mathematical programming, parameters of an SSSC stabilizer in the two control channels for mitigating inter-area oscillations have been tuned. However, assuming that the variation in eigenvalues in the iterations is sufficiently small, this method provides good performance. Also, the stabilizer is not robust against changes in operating conditions. On the other hand, according to the no free lunch (NFL) theory [17], it can be said that there is no single accurate simulation method to solve all available optimization problems. That is, although a specific optimization algorithm may have suitable results for some given problems, it can, however, give a weak performance against some other problems. Also, the aforementioned cases are merely a part of the GWO algorithm applications in power systems and optimization problems. Comparing the GWO algorithm's performance with other algorithms proves its superiority with much better results. However, when the current leader in this algorithm is in the local minimum, the entire group may fall into the local minimum. In this situation, access to a global minimum may not be possible.

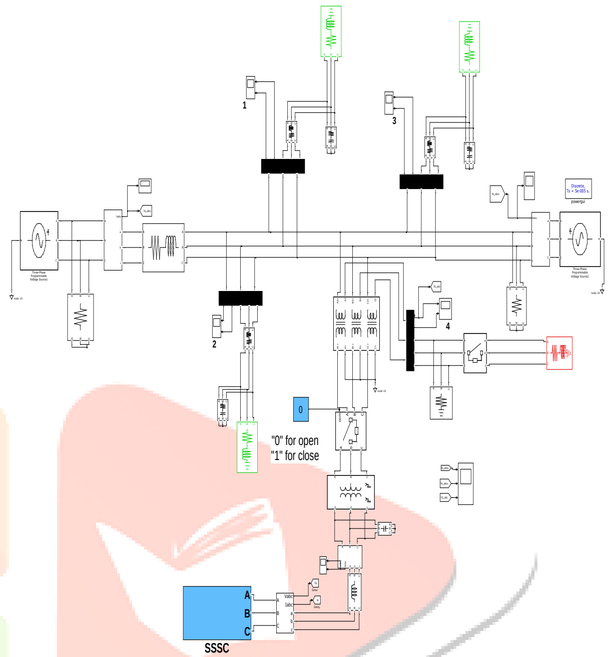


Fig 4: SSSC circuit

In this new method, several objective functions have been considered for optimal design and the optimal selection of the best control channel (phase or magnitude) for the installation of an SSSC-based damping controller. These objective functions are, respectively, reducing the gain of the controller to reduce the control costs, the second and third objective functions of displacement of critical and unstable modes, and the fourth objective function are also considered as a constraint for designing the controller in the form of the minimum phase. These objective functions are calculated as a single objective function using the sum of weighted coefficients method. Further, to design the robust stabilizer to load changes, different operating conditions have been used simultaneously. To solve this optimization problem, the combined method of the gray wolf algorithm and the genetic algorithm (hGWO-GA) has been used. This combined method has advantages such as crossing local minima and high convergence. To show the effectiveness of the proposed method, eigenvalues analysis, and nonlinear simulations have been used on two power systems of 4 and 50 machines. By examining the results of the eigenvalue analysis, it is possible to choose a resistant control channel with low control gain and high damping.

**RESULT ANALYSIS**

The SimPowerSystems (SPS) toolbox is used for all simulations and SSSC-based damping controller design. SPS is a MATLAB-based modern design tool that allows scientists and engineers to rapidly and easily build models to simulate power systems using Simulink environment. The SPS's main library, powerlib, contains models of typical power equipment such as machines, governors, excitation systems, transformers, lines and FACTS devices. The library also contains the Powergui block that opens a graphical user interface for the steady-state analysis of electrical circuits. The Load Flow and Machine Initialization option of the Powergui block performs the load flow and the machines initialization.

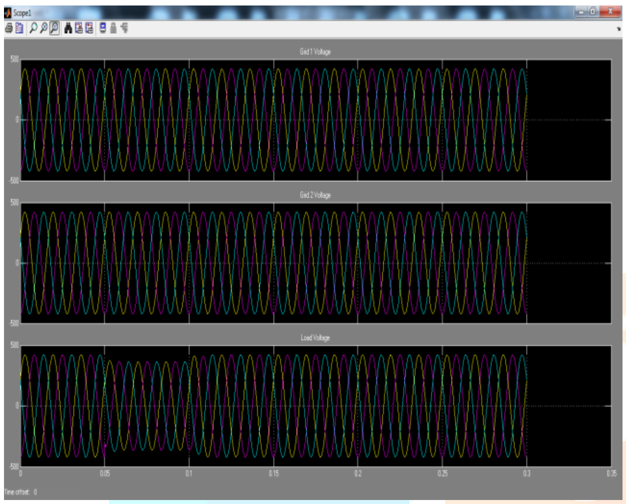

Fig 6: Without SSSC Load Voltage:

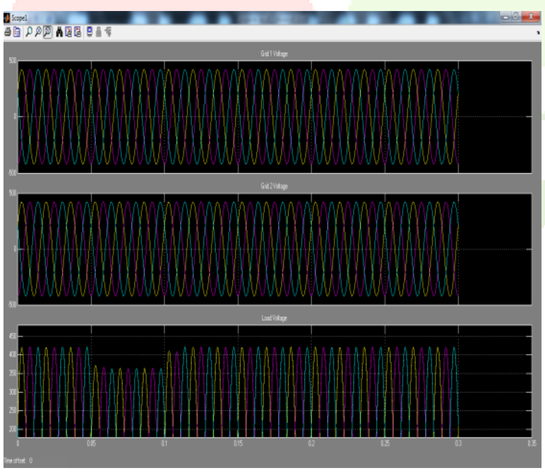

Fig 5: With SSSC voltage:

While applying PSO, a number of parameters are required to be specified. An appropriate choice of these parameters affects the speed of convergence of the algorithm. Table I shows the specified parameters for the PSO algorithm. Optimization is terminated by the prespecified number of generations. The optimization was performed with the total number of generations set to 50. The convergence rate of objective function J for gbest with the number of generations is shown in Fig. 6. Table II shows the optimal values of SSSC-based controller parameters obtained by the PSO algorithm.

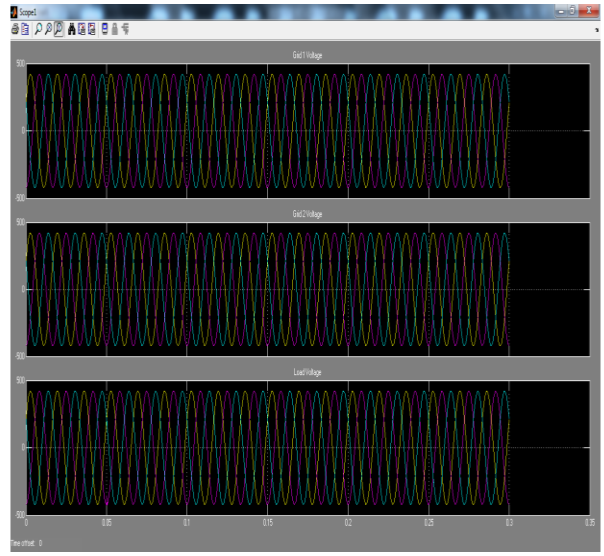

Fig 7: With SSSC:

To assess the effectiveness and robustness of the proposed controllers, simulation studies are carried out for various fault disturbances and fault clearing sequences. The behavior of the proposed controller under transient conditions is verified by applying a 6-cycle three-phase fault at t = 1 sec, at the middle of the one transmission line. The fault is cleared by permanent tripping of the faulted line. The system response under this severe disturbance is shown in Figs. 7 (a)-(f). The response without control (no control) and response with PSO optimized SSSC-based controller are shown in the figures with legends NC and PS respectively.

**CONCLUSION**

Improving the stability of power systems using FACT devices is an important and effective method. This paper uses a static synchronous series compensator (SSSC) installed in a power system to smooth out inter-area oscillations. A meta-heuristic optimization method is proposed to design the supplementary damping controller and its installation control channel within the SSSC. In this method, two control channels, phase and magnitude have been investigated for installing a damping controller to improve maximum stability and resistance in different operating conditions. An effective control channel has been selected. The objective function considered in this optimization method is multi-objective, using the sum of weighted coefficients method. The first function aims to minimize the control gain of the damping controller to the reduction of control cost, and the second objective function moves the critical modes to improve stability. It is defined as the minimum phase within the design constraints of the controller. A hybrid of two well-known meta-heuristic methods, the genetic algorithm (GA) and grey wolf optimizer (GWO) algorithm have been used to design this controller. The proposed method in this paper has been applied to develop a robust damping controller with an optimal control channel based on SSSC for two standard test systems of 4 and 50 IEEE machines. The results obtained from the analysis of eigenvalues and nonlinear simulation of the power system study show the improvement in the stability of the power system as well as the robust performance of the damping in the phase control channel.

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