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Full Length Article

Damping of power system oscillations by a novel DE-GWO optimized dual UPFC controller

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ABSTRACT

This work presents a novel dual optimized controller to damp intra plant and inter area oscillations in power system. The parameters of controllers are tuned by a novel hybrid Differential Evolution-Grey Wolf Optimizer (DE-GWO). The dual optimized controller simultaneously controls two independent variables of UPFC there by maximizing the efficacy of controller and UPFC. The effectiveness of proposed algorithm is justified by testing with standard benchmark functions. The dual controller is applied to single and multi machine system for small signal stability assessment. A broad comparison is performed between single and dual controllers employing other standard algorithms prevailing in recent researches. Different objective functions are verified with this controller and ITAE was found to provide best response and selected here for minimization. The oscillation peaks, settling time and eigen values of system response show that proposed dual controller damps oscillations to a large extent in contrast to other single and dual optimized controllers.

1. Introduction

One of the major research areas for a modern power system network is stability pertaining to different disturbances like changes in prime mover power, random load variations and variations in system operating conditions. Due to inter connections of different power grids, small signal stability has become a challenging issue for safe operation and control of power system. The Indian power grid has suffered by these oscillations, when new and SR grids are synchronized after 29th June 2014. This has been reported by POSOCO in the report of March-2016. In this work the stability issues is centralized to local and inter area oscillations in power system. So many major black outs in grid system are contributed by inter area oscillations like in Western Australia (1982, 1983), Ghana Ivory coast (1985), DE–Ontario hydro-Hydro Quebec (1960, 1985), Scotland-England (1978) etc. as reported by internet resources. So these oscillations have to be damped out effectively otherwise there may be loss in synchronism. A wide area measurement system for estimating these oscillations are reported in [1]. PSS has been used for so many years for this purpose but, large changes in voltage profile, leading operation at severe disturbances are its drawbacks [2]. Now a day's FACTS based PSS are gaining more popularity in contrast to traditional PSS [3,4], which may employ SVC, SSSC, TCSC [5–11]. But, UPFC is more versatile as it has three degrees of freedom and can affect both real and reactive power in the line [12]. It can inject any amount of series voltage and can provide more security and flexibility to the system [13]. For dynamic stability assessment the Heffron- Phillips model has been a very successful since so many years [14]. The main problem now is tuning of parameters of UPFC based PSS. In power system the lead-lag controller is very much popular due to its simplicity and effectiveness and easy tuning and also dual controller is more efficient as compared to single lead-lag controller [15]. But, tuning of dual controller is an uphill task and modern optimization tools can be employed to tune parameters of this controller, which has not been reported significantly in researches. So a powerful tuning technique can increase the efficacy of dual controller to a large extent. As per current researches, the meta-heuristics optimization techniques are much more preferable as they are inspired by simple natural phenomenon, nature of animals and concept of evolution. This techniques may be of SI (swarm intelligence) or EA (evolutionary algorithm) type. These techniques like PSO, DE, adaptive PSO, GA, GA-GSA etc, have been utilized for design of damping controller [16–21].

The SI methods have lots of merits like less parameters to tune, easy implementation, use of memory for saving best solution. On

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the other hand EA methods have lots of advantages like increase in participation of best individual during iterations and continuously getting more superior population [22]. The grey wolf optimizer (GWO) recently revealed [22] is a powerful SI technique, which is inspired by the way the grey wolfs hunt for a prey. GWO has straight forward property and does not need specific input parameters. It has simple computation and also this concept can be easily transferred to programming language. This has been used for wide area PSS in [23].For economic load dispatch in [24] and for AGC in [25] with advanced features. On the other hand DE is very fast and robust technique being derivative free. It has very good characteristics of convergence as compared to other popular EAs [26]. DE has two prime factors, crossover and mutation and choice of these factors has been explained in [27,28]. DE has good global search capability and the advancements in DE has been reported in literature, like with fuzzy inference system in [29], with cultural algorithm hybridization in [30] and with adaptive feature for reactive power management in [31]. Advances in DE techniques have been reported in [32]. Keeping in view of the researches obtained so far, a new hybrid technique is proposed here, where advantages of both techniques are retained and combined without modifying DE algorithm. This is a hybridization of GWO (SI) and DE (EA) type algorithms, where GWO and DE are helping each other to tune the parameters of dual UPFC controller. This technique has been verified with some standard benchmark functions [33], prior to optimize UPFC based dual controller parameters. Four different objective functions as taken in [34] to tune PID controller are taken here and the best one is selected to design the dual controller. Dual controller optimizes the utility of UPFC by simultaneously controlling two of its variables, which are modulation index of one VSC and phase angle of another VSC.

Now keeping in view of the researches for design of damping controller, it was found that there is no significant research on dual controller after 2003 [15] as per knowledge of author, though its performance was shown to be better than single lead-lag controller. In [12], it was presented that m_B and δ_E are the best controller actions to design damping controller based on UPFC. Again as per current researches [22–25,27–29] swarm and evolutionary algorithms like DE and GWO are shown as most effective techniques. This instigated to design the dual controller where both these control actions are taken simultaneously and whose parameters are optimized by a new powerful hybrid DE-GWO technique.

The major objectives covered in this work are: (i) a new DE-GWO optimization technique is proposed (ii) the proposed optimization technique is tested with standard unimodal and multimodal benchmark functions to justify its reliability and effectiveness, (iii) this technique is applied to optimize dual controller of UPFC (iv) this controller is tested with different objective functions (v) the proposed controller is applied to one machine system to damp intra plant mode oscillation and applied to multi machine system for a special negative power loading case to damp inter area oscillations. (vi) System eigen values are obtained for ensuring supremacy of the controller pertaining to power system stability.

2. The single machine system

The single machine system as shown in Fig. 1 has one generator connected to the infinite bus [14]. The generator has IEEE-ST1A type excitation system and the UPFC is connected in one of the line between generator and infinite bus. The UPFC has two VSCs, out of which one is series connected and other shunt connected to the line represented by VSC-B and VSC-E respectively. The UPFC has four parameters that can control the performance of power system. The modulation index and phase angle of VSC-E are m_E and δ_E respectively. If m_E is controlled, the voltage of bus where UPFC being installed can be controlled by compensating reactive power. The δ_E controls dc link voltage. So on the modulation index and phase angle of VSC-B are m_B and δ_B respectively. The m_B controls the magnitude of voltage injected in series to the line and there by controlling reactive power of system. The δ_B controls the exchange of real power with line.

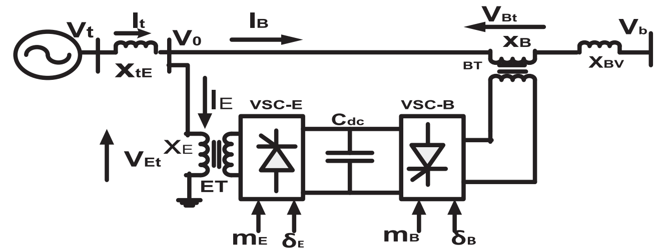

Fig. 1. The single machine system.

2.1. Non linear modeling

The non linear modeling can be obtained by following equations [14].

$$\dot{\omega} = \left(\frac{P_i - P_e - D\Delta\omega}{M}\right) \tag{1}$$

$$\dot{\delta} = \omega_0(\omega - 1) \tag{2}$$

$$\dot{E}'_q = (-E_q + E_{fd})/T'_{d0} \tag{3}$$

$$\dot{E}_{fd} = [-E_{fd} + K_a(V_{ref} - V_t)]/T_a \tag{4}$$

$$V_{dc} = \frac{3m_E}{4C_{dc}}(I_{Ed}\sin\delta_E + I_{Eq}\cos\delta_E) + \frac{3m_B}{4C_{dc}}(I_{Bd}\sin\delta_B + I_{Bq}\cos\delta_B) \tag{5}$$

The equation describing real power balance between shunt and series converters can be given in Eq. (6) as

$$Re(V_B I_B^* - V_E I_E^*) = 0 \tag{6}$$

2.2. Linear dynamic model

The linear model can be obtained by linearizing the model for dynamic stability assessment around an operating point.

$$\Delta\dot{\delta} = \omega_0\Delta\omega \tag{7}$$

$$\Delta\dot{\omega} = \left(\frac{-\Delta P_e - D\Delta\omega}{M}\right) \tag{8}$$

$$\Delta\dot{E}_q = (-\Delta E_q + \Delta E_{fd})/T_{d0} \tag{9}$$

$$\Delta\dot{E}_{fd} = [-\Delta E_{fd} + K_a(\Delta V_{ref} - \Delta V_t)]/T_a \tag{10}$$

$$\Delta V_{dc} = K_7\Delta\delta + K_8\Delta E'_q - K_9\Delta V_{dc} + K_{ce}\Delta m_E + K_{c\delta e}\Delta\delta_E + K_{cb}\Delta m_B + K_{c\delta b}\Delta\delta_B. \tag{11}$$

Where

$$\Delta P_e = K_1\Delta\delta + K_3\Delta E'_q + K_{pd}\Delta V_{dc} + K_{pe}\Delta m_E + K_{p\delta E}\Delta\delta_E + K_{pb}\Delta m_B + K_{p\delta b}\Delta\delta_B \tag{12}$$

$$\Delta E_d = K_4\Delta\delta + K_3\Delta E'_q + K_{qd}\Delta V_{dc} + K_{qe}\Delta m_E + K_{q\delta_E}\Delta\delta_E + K_{qb}\Delta m_B + K_{q\delta_B}\Delta\delta_B \tag{13}$$

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