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Dynamic stability enhancement of power system based on a typical unified power flow controllers using imperialist competitive algorithm

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Abstract This paper presents dynamic model of power system installed with a novel UPFC that consist of two shunt converters and a series capacitor. In this configuration, a series capacitor is used between two shunt converters to inject desired series voltage. As a result, it is possible to control the active and reactive power flow. The main advantage of the proposed UPFC in comparison with the conventional configuration is injection of a series voltage waveform with a very low total harmonic distortion (THD). In addition, a linearized Phillips–Heffron model is obtained and a supplementary controller for the modeling of proposed UPFC to damp low frequency oscillations with considering four alternative damping controllers is recommended. The problem of robustly novel UPFC based damping controller is formulated as an optimization problem according to the time domain-based objective function, which are solved using particle swarm optimization (PSO) and Imperialist Competitive Algorithm (ICA) techniques.

1. Introduction

Presently, power demand is growing considerably and the extension in transmission and generation is restricted with the rigid environmental constraints and limited availability of resources. Consequently, power systems of today are much more loaded than before. This brings about the essential for power systems to be operated near their stability limits. Moreover, interconnection between remotely located power systems gives rise to low-frequency oscillations in the range of 0.1–0.3 Hz. These oscillations may keep growing in magnitude, resulting in a loss of synchronism, if not well damped [1].

Power system stabilizers (PSSs) have been used to serve the purpose of increasing power system damping to low frequency oscillations. PSSs have proved to be efficient in performing their assigned tasks. A wide range of PSS tuning approaches has been recommended. These approaches have included pole placement [2], damping torque concepts [3], H_∞ [4], variable

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structure [5], and the different optimization and artificial intelligence techniques [6–8]. However, PSS may adversely affect voltage profile and may not be able to arrest oscillations resulting from severe disturbances, such as three-phase faults at generator terminals [9].

Recently FACTS controllers such as UPFC and STATCOM and IPFC have been applied for damping oscillations and improving dynamic stability of power systems [10]. FACTS devices, when used to improve power system steady-state performance, have shown very promising results. Through the modulation of bus voltage, phase shift between buses, and transmission line reactance, FACTS devices can cause a robust increase in power transfer limits during steady-state. Because of the extremely fast control action connected with FACTS-device operations, they have been very encouraging applicants for utilization in power system damping enhancement. It has been observed that employing a feedback supplementary control, in addition to the FACTS-device primary control, can considerably enhance system damping and can also improve system voltage profile, which is advantageous over PSSs [11].

Among them, UPFC is impressive for damping power system oscillations. This is obtained by regulating the controllable parameters of the system, line impedance, voltage magnitude and phase angle of the UPFC bus. The UPFC consists of two AC/DC converters. One of the two converters is connected to the transmission line via a series transformer and the other in parallel with the line via a shunt transformer. The series and shunt converters are connected via a large DC capacitor. The series branch of the UPFC injects an AC voltage with controllable magnitude and phase angle at the power frequency via an insertion transformer [12]. Recently researchers have presented dynamic models of UPFC in order to design suitable controller for power flow, voltage and damping controls [13–17]. Wang has presented a modified linearized Phillips–Heffron model of a power system installed with UPFC [18,19]. He has addressed the basic issues relating to design UPFC damping controllers, i.e., selection of robust operating conditions for designing damping controllers; and the election of parameters of UPFC (such as m_E, m_B, δ_E and δ_B) to be modulated for achieving desired damping. Wang has not presented a systematic approach for designing the damping controllers. Further, no attempt seems to have been made to identify the most suitable UPFC control parameters, in order to arrive at a robust damping controller and he has not used the deviation of active and reactive powers, ΔP_e and ΔQ_e as the input control signals. Abido has used the control PSO, for designing controller and this manner not only is an off-line procedure, but also depends strongly to selection of primary conditions of control system [20,7].

Recently, the intelligent techniques are used for optimal tuning of UPFC based damping controller. These techniques are used in multiple applications, such as PID controller designing, optimal placement of FACTS devices, economic load dispatch of power systems, power system stabilization, or harmonic omission in multilevel inverters. Among the intelligent algorithms PSO and ICA are used.

In [21] has been proposed a novel configuration of UPFC which consists of two shunt converters and a series capacitor. The injected series voltage waveform by this configuration has extremely low THD. The proposed UPFC is based on using only two 2-level 3-phase shunt converters and a series capacitor. So, the cost, volume and rated power of UPFC decrease and the control scheme becomes simpler than conventional UPFC configuration. In the proposed configuration, left shunt converter supplies to or absorbs from utility the necessary active power to regulate the voltage of dc link capacitor. It also exchanges reactive power with utility to control the sending end reactive power. It can be noted that the operation of this converter is same as shunt converter in conventional UPFC. On the other hand, right shunt converter tracks reference current to control the current of series capacitor to inject the desired series voltage, V_{se}. It should be noted that the proposed configuration is able to have all of the capabilities of conventional UPFC. Its reason is that the main functions of conventional UPFC are injecting the desired series voltage by series converter and tracking the reference current by shunt converter in order to exchange the active and reactive powers while both of these functions exist in proposed configuration of UPFC because it is possible to inject the series voltage with any desired amplitude and phase angle by combination of series capacitor and right shunt converter operation as well as to track the reference current by left shunt converter to have the same operation of shunt converter of conventional configuration.

In this paper, a connected single machine to infinite bus with novel UPFC, which consists of two shunt converters and a series capacitor installed, is used and a novel linearized Phillips–Heffron model for the mentioned power system is derived for design of the UPFC damping controller. In addition, the particle swarm optimization (PSO) and the Imperialist Competitive Algorithm (ICA) are used for the optimal tuning of the proposed UPFC based damping controller in order to enhance the damping of a power system's low-frequency oscillations and achieve the desired level of robust performance under different operating conditions, as well as different parameter uncertainties and a disturbance.

2. Description of case study system

Fig. 1 shows a SMIB power system equipped with the proposed configuration of UPFC which consists of two shunt converters and a series capacitor. The synchronous generator is transferring power to the infinite-bus through a transmission line and a UPFC. The UPFC consists of two excitation transformers, a series capacitor, two three-phase IGBT based voltage source converters, and a DC link capacitors.

First shunt converter, in the proposed configuration, supplies to or absorbs from utility the necessary active power to regulate the voltage of dc link capacitor. It also trades reactive

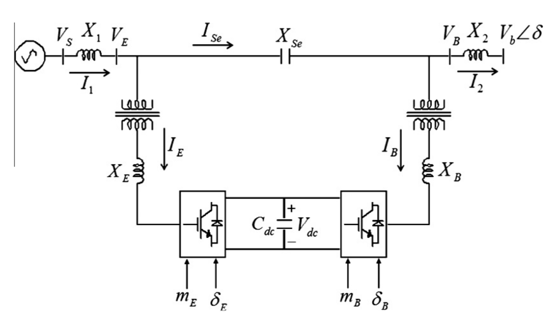

Figure 1 SMIB power system equipped with proposed UPFC.