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Application and comparison of computational intelligence techniques for optimal location and parameter setting of UPFC

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ABSTRACT

Unified power flow controller (UPFC) is one of the most effective flexible AC transmission systems (FACTS) devices for enhancing power system security. However, to what extent the performance of UPFC can be brought out, it highly depends upon the location and parameter setting of this device in the system. This paper presents a new approach based on computational intelligence (CI) techniques to find out the optimal placement and parameter setting of UPFC for enhancing power system security under single line contingencies ($N-1$ contingency). Firstly, a contingency analysis and ranking process to determine the most severe line outage contingencies, considering lines overload and bus voltage limit violations as a performance index, is performed. Secondly, a relatively new evolutionary optimization technique, namely: differential evolution (DE) technique is applied to find out the optimal location and parameter setting of UPFC under the determined contingency scenarios. To verify our proposed approach and for comparison purposes, simulations are performed on an IEEE 14-bus and an IEEE 30-bus power systems. The results, we have obtained, indicate that DE is an easy to use, fast, robust and powerful optimization technique compared with genetic algorithm (GA) and particle swarm optimization (PSO). Installing UPFC in the optimal location determined by DE can significantly enhance the security of power system by eliminating or minimizing the number of overloaded lines and the bus voltage limit violations.

1. Introduction

The secure operation of power system has become an important and critical issue in today's large, complex, and load-increasing systems. Security constraints such as thermal limits of transmission lines and bus voltage limits must be satisfied under all system operation conditions. Commonly, Power systems are planned and operated based on the $N-1$ security criterion, which implies that the system should remain secure under all important first contingencies. One solution to cope with this problem is to design the system to meet the $N-1$ security criterion which is somewhat conservative and costly. An alternative solution to improve the security of power system is the flexible AC transmission systems (FACTS) devices which is a concept proposed by Hingorani (1988).

FACTS devices can reduce the flows of heavily loaded lines, maintain the bus voltages at desired levels, and improve the stability of the power network. Consequently, they can improve the power system security under contingency situations. Unified power flow controller (UPFC) is a versatile FACTS's device which can independently or simultaneously control the active power, the reactive power, and the bus voltage to which it is connected (Gyugyi, 1992). However, to achieve such functionality of UPFC, it is highly important to determine the optimal location of this device in the power system with the appropriate parameter setting. Since UPFC can be installed in different locations, its effectiveness will be different. Therefore, we will face the problem of where we should install UPFC. For this reason, some performance indices must be satisfied. The following are some factors that can be considered in the selection of the optimal installation and parameter setting of UPFC: The stability margin improvement, the power transmission capacity increasing, and the power blackout prevention, etc. Therefore, conventional power flow algorithm (Puerle-Esquivel and Acha, 1997) should incorporate with UPFC and the optimization should consider one, two, or all of the above-mentioned factors. However, in this paper, we only consider blackout prevention, in other words, enhancing the security of power system under single line contingencies through installing UPFC in an optimal location with optimal parameter setting.

In the last decade, new algorithms have been developed for the optimal power flow incorporating with UPFC device as well as for the optimal placement of UPFC. Some of them are:

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A sensitivity-based approach which has been developed for finding suitable placement of UPFC (Singh and Erlich, 2005), an evolutionary-programming-based load flow algorithm for systems containing unified power flow controllers (Wang et al., 2003), a genetic algorithm which proposed for solving the optimal location problem of UPFC (Arabkhaburi et al., 2006), and a particle swarm optimization (PSO) for optimal location of FACTS devices (Saravanan, 2005).

Also a lot of work has been done in the contingency analysis research area. Operation scheme of FACTS devices to enhance the power system steady-state security level considering a line contingency analysis is suggested in Song et al. (2004). A method for contingency selection and security enhancement of power systems by optimal placement of FACTS devices using GA is presented in Sudersan et al. (2004).

Recently, a relatively new, easy to implement, reasonably fast, and robust evolutionary algorithms (EAs) technique, known as differential evolution (DE) has been developed (Storn and Price, 1995; Price et al., 2005). DE has shown great promise in several applications including the field of power system (Gamperle et al., 2002; Babu and Jehan, 2003; Ursem and Vadstrup, 2003; Onwubolu, 2004; Wong and Dong, 2005). To the best of the author's knowledge, the applications of the DE technique for optimal allocation of FACTS devices in general and UPFC in particular are not existed in the open literature.

In this paper, one of the newest EAs techniques, namely DE, is applied to find out the optimal location and parameter setting of UPFC device for enhancing system security under single line contingencies through eliminating or minimizing the overloaded lines and the bus voltage limit violations.

2. Problem formulation

2.1. UPFC power flow model

Fig. 1 shows the equivalent circuit of a UPFC power flow model, this circuit consists of two coordinated synchronous voltage sources represent the UPFC adequately for the purpose of fundamental steady-state analysis (Enrique et al., 2004), the UPFC voltage sources are:

$$E_{vR} = V_{vR}(\cos\delta_{vR} + j\sin\delta_{vR}) \tag{1}$$

$$E_{cR} = V_{cR}(\cos\delta_{cR} + j\sin\delta_{cR}) \tag{2}$$

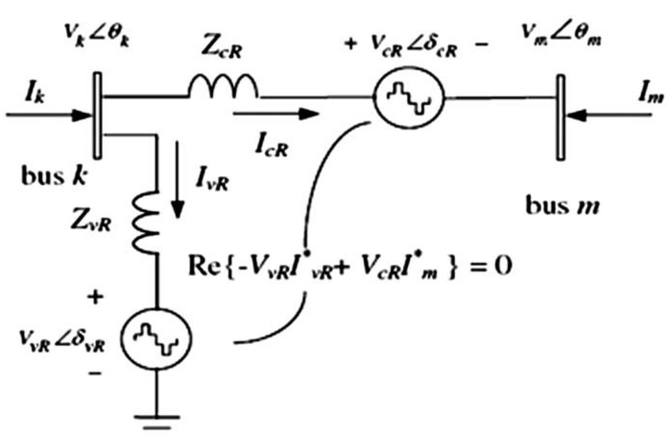

Fig. 1. Unified power flow controller equivalent circuit.

where V_{vR} is the shunt voltage source magnitude; δ_{vR} is the shunt voltage source angle; V_{cR} is the series voltage source magnitude; and δ_{cR} is the series voltage source angle.

The active power demanded by the series converter is drawn by the shunt converter from the AC network and supplied to bus m through the DC link. The output voltage of the series voltage source (series converter) is added to the nodal voltage, let say at bus k, to boost the nodal voltage at bus m. The voltage magnitude of the output voltage V_{cR} provides voltage regulation, and the phase angle δ_{cR} determines the mode of power flow control. In addition to providing a supporting role in the active power exchange that takes place between the series converter and the AC system, the shunt converter may also generate or absorb reactive power in order to provide independent voltage magnitude regulation at its point of connection with the AC system.

Based on the equivalent circuit and on (1) and (2) the active and reactive power equations are:

At bus k:

$$\begin{aligned} P_k &= V_k^2 G_{kk} + V_k V_m[G_{km}\cos(\theta_k-\theta_m) + B_{km}\sin(\theta_k-\theta_m)] \\ &\quad + V_k V_{cR}[G_{km}\cos(\theta_k-\delta_{cR}) \\ &\quad + B_{km}\sin(\theta_k-\delta_{cR})] + V_k V_{vR}[G_{vR}\cos(\theta_k-\delta_{vR}) + B_{vR}\sin(\theta_k-\delta_{vR})] \end{aligned} \tag{3}$$

$$\begin{aligned} Q_k &= -V_k^2 B_{kk} - V_k V_m[G_{km}\sin(\theta_k-\theta_m) - B_{km}\cos(\theta_k-\theta_m)] \\ &\quad + V_k V_{cR}[G_{km}\sin(\theta_k-\delta_{cR}) - B_{km}\cos(\theta_k-\delta_{cR})] \\ &\quad + V_k V_{vR}[G_{vR}\sin(\theta_k-\delta_{vR}) - B_{vR}\cos(\theta_k-\delta_{vR})] \end{aligned} \tag{4}$$

At bus m:

$$\begin{aligned} P_m &= V_m^2 G_{mm} + V_m V_k[G_{mk}\cos(\theta_m-\theta_k) + B_{mk}\sin(\theta_m-\theta_k)] \\ &\quad + V_m V_{cR}[G_{mm}\cos(\theta_m-\delta_{cR}) + B_{mm}\sin(\theta_m-\delta_{cR})] \end{aligned} \tag{5}$$

$$\begin{aligned} Q_m &= -V_m^2 B_{mm} + V_m V_k[G_{mk}\sin(\theta_m-\theta_k) - B_{mk}\cos(\theta_m-\theta_k)] \\ &\quad + V_m V_{cR}[G_{mm}\sin(\theta_m-\delta_{cR}) - B_{mm}\cos(\theta_m-\delta_{cr})] \end{aligned} \tag{6}$$

Series converter:

$$\begin{aligned} P_{cR} &= V_{cR}^2 G_{mm} + V_{cR} V_k[G_{km}\cos(\delta_{cR}-\theta_k) + B_{km}\sin(\delta_{cR}-\theta_k)] \\ &\quad + V_{cR} V_m[G_{mm}\cos(\delta_{cR}-\theta_m) + B_{mm}\sin(\delta_{cR}-\theta_m)] \end{aligned} \tag{7}$$

$$\begin{aligned} Q_{cR} &= -V_{cR}^2 B_{mm} + V_{cR} V_k[G_{km}\sin(\delta_{cR}-\theta_k) - B_{km}\cos(\delta_{cR}-\theta_k)] \\ &\quad + V_{cR} V_m[G_{mm}\sin(\delta_{cR}-\theta_m) - B_{mm}\cos(\delta_{cR}-\theta_m)] \end{aligned} \tag{8}$$

Shunt converter:

$$P_{vR} = -V_{vR}^2 G_{vR} + V_{vR} V_k[G_{vR}\cos(\delta_{vR}-\theta_k) + B_{vR}\sin(\delta_{vR}-\theta_k)] \tag{9}$$

$$Q_{vR} = V_{vR}^2 B_{vR} + V_{cR} V_k[G_{vR}\sin(\delta_{vR}-\theta_k) - B_{vR}\cos(\delta_{vR}-\theta_k)] \tag{10}$$

where P_k and P_m are the active powers at bus k and bus m. Q_k and Q_m are the reactive powers at bus k and bus m. V_k and V_m are the voltage magnitudes at bus k and bus m. θ_k and θ_m are the power angles at bus k and bus m. P_{cR} and Q_{cR} are the active and reactive power of UPFC series converter. P_{vR} and Q_{vR} are the active and reactive power of UPFC shunt converter. G_{kk} and G_{mm} are the conductance at bus k and bus m. G_{mk} and G_{km} are the conductance of the line between bus k and bus m. B_{kk} and B_{mm} are the susceptance at bus k and bus m. B_{mk} and B_{km} are the susceptance of the line between bus k and bus m. G_{vR} and B_{vR} are the conductance and the susceptance of the shunt voltage source of UPFC.