

Effect of UPFC Tuned Based on Particle Swarm Optimization on Dynamic Stability Improvement in Power Systems

Shoorangiz Shams Shamsabad Farahani, Hossain Tourang, Behrang Yousefpour,
Mehdi Ghasemi Naraghi and Seyed Ali Mohammad Javadian

Department of Electrical Engineering, Islamshahr Branch, Islamic Azad University, Tehran, Iran

Abstract: This study presents the application of Unified Power Flow Controller (UPFC) in order to voltage support and also stability enhancement at a Multi-Machine electric power system installed with UPFC. PI type controllers are considered for UPFC control and the parameters of these PI type controllers are tuned using Particle Swarm Optimization (PSO). To show the ability of UPFC in voltage control and also stability enhancement, the results of the system with UPFC are compared with the results without UPFC. Nonlinear time domain simulation results emphasizes on the ability of UPFC in simultaneous control of voltage and also stability enhancement.

Key words: Dynamic stability enhancement, multi-machine electric power system, particle swarm optimization, unified power flow controller, voltage support

INTRODUCTION

The rapid development of the high-power electronics industry has made Flexible AC Transmission System (FACTS) devices viable and attractive for utility applications. FACTS devices have been shown to be effective in controlling power flow and damping power system oscillations. In recent years, new types of FACTS devices have been investigated that may be used to increase power system operation flexibility and controllability, to enhance system stability and to achieve better utilization of existing power systems (Hingorani and Gyugyi, 2000). UPFC is one of the most complex FACTS devices in a power system today. It is primarily used for independent control of real and reactive power in transmission lines for flexible, reliable and economic operation and loading of power systems. Until recently all three parameters that affect real and reactive power flows on the line, i.e., line impedance, voltage magnitudes at the terminals of the line, and power angle, were controlled separately using either mechanical or other FACTS devices. But UPFC allows simultaneous or independent control of all these three parameters, with possible switching from one control scheme to another in real time. Also, the UPFC can be used for voltage support and transient stability improvement by damping of low frequency power system oscillations (Alasooly and Redha, 2010; Mehraeen *et al.*, 2010; Jiang *et al.*, 2010a, b, c; Faried and Billinton, 2009). Low Frequency Oscillations (LFO) in electric power system occur frequently due to disturbances such as changes in loading

conditions or a loss of a transmission line or a generating unit. These oscillations need to be controlled to maintain system stability. Many in the past have presented lead-Lag type UPFC damping controllers (Zarghami *et al.*, 2010; Guo and Crow, 2009; Tambey and Kothari, 2003; Wang, 1999). They are designed for a specific operating condition using linear models. More advanced control schemes such as Particle-Swarm method, Fuzzy logic and genetic algorithms (Taher and Hematti, 2008; Taher *et al.*, 2008; Al-Awami, 2007; Eldamaty *et al.*, 2005) offer better dynamic performances than fixed parameter controllers.

The objective of this paper is to investigate the ability of UPFC for control voltage and also stability enhancement. In this paper the UPFC internal controllers (bus-voltage controller and DC link voltage regulator) are considered as PI type controllers. Particle Swarm Optimization (PSO) is considered for tuning the parameters of these PI type controllers. Different load conditions are considered to show ability of UPFC under different loading conditions. Simulation results show the effectiveness of UPFC in power system stability and control.

System under study: Figure 1 shows a multi machine power system installed with UPFC. The static excitation system, model type IEEE - ST1A, has been considered. The UPFC is assumed to be based on Pulse Width Modulation (PWM) converters. Detail of the system data are given in (Kundur, 1993). To assess the effectiveness and robustness of the proposed method over a wide

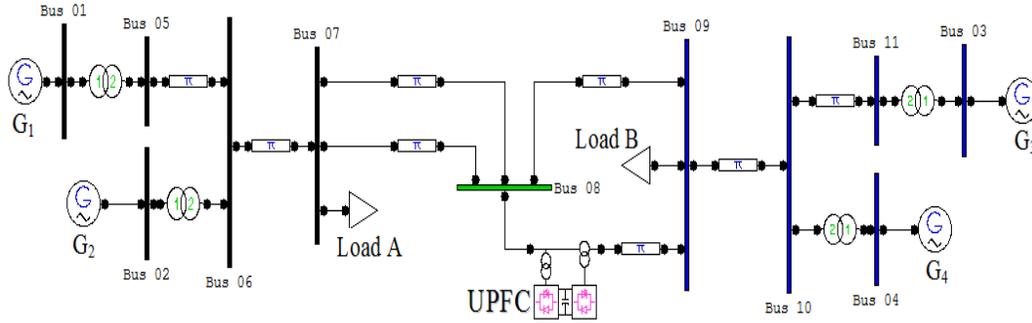


Fig. 1: Four-machine eleven-bus power system

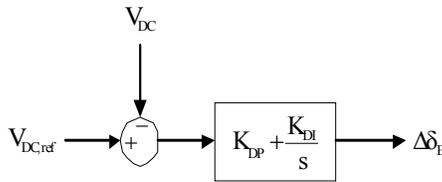


Fig. 2: DC-voltage regulator

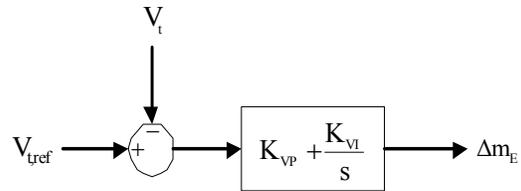


Fig. 3: Bus voltage controller

range of loading conditions, two different cases as nominal and heavy loading are considered and listed in Table Dynamic model of the system with UPFC:

The nonlinear dynamic model of the system installed with UPFC is given as (1). The dynamic model of the system is completely presented in (Kundur, 1993) and also dynamic model of the system installed with UPFC is presented in (Nabavi-Niaki and Iravani, 1996; Wang, 2000).

$$\begin{cases} \dot{\omega}_i = \frac{(P_m - P_e - D\omega)}{M} \\ \dot{\delta}_i = \omega_0(\omega - 1) \\ E'_{qi} = \frac{(-E_q + E_{fd})}{T_{do}} \\ E'_{fdi} = \frac{-E_{fd} + K_a(V_{ref} - V_t)}{T_a} \\ V_{dc} = \frac{3m_E}{4C_{dc}}(\sin(\delta_E)I_{Ed} + \cos(\delta_E)I_{Eq}) \\ + \frac{3m_B}{4C_{dc}}(\sin(\delta_B)I_{Bd} + \cos(\delta_B)I_{Bq}) \end{cases} \quad (1)$$

where, $i = 1, 2, 3, 4$ (the generators 1 to 4), δ , rotor angle; ω , rotor speed; P_m , mechanical input power; P_e , electrical output power; E_q , internal voltage behind x'_d ; E_{fd} , equivalent excitation voltage; T_e , electric torque; T_{do} , time constant of excitation circuit; K_a , regulator gain;

T_a , regulator time constant; V_{ref} , reference voltage; V_t , terminal voltage. m_B : pulse width modulation of series inverter. By controlling m_B , the magnitude of series-injected voltage can be controlled.

- δ_B : phase angle of series injected voltage
- m_E : pulse width modulation of shunt inverter. By controlling m_E , the output voltage of the shunt converter is controlled
- δ_E : phase angle of the shunt inverter voltage

The series and shunt converters are controlled in a coordinated manner to ensure that the real power output of the shunt converter is equal to the power input to the series converter. The fact that the DC-voltage remains constant ensures that this equality is maintained.

UPFC controllers: In this paper two control strategies are considered for UPFC. These controllers are Bus voltage controller and DC voltage regulator. The real power output of the shunt converter must be equal to the real power input of the series converter or vice versa. In order to maintain the power balance between the two converters, a DC-voltage regulator is incorporated. DC-voltage is regulated by modulating the phase angle of the shunt converter voltage. Fig. 2 shows the structure of the DC-voltage regulator. Also fig. 3 shows the structure of the bus voltage controller. The bus voltage controller regulates the voltage of bus during post fault in system. The most important subject is to tuning the UPFC controller parameters K_{DP} , K_{DI} , K_{VP} and K_{VI} . The system stability and suitable performance is guaranteed by

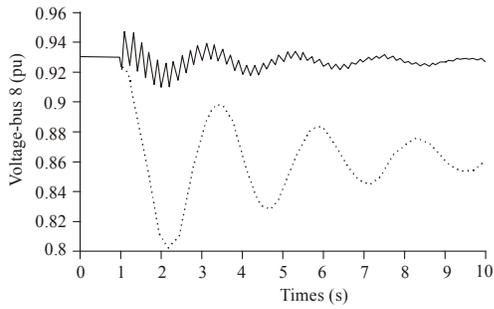


Fig. 4: Voltage of bus number 8 under scenario 1 in nominal load condition Solid (with UPFC); Dashed (without UPFC)

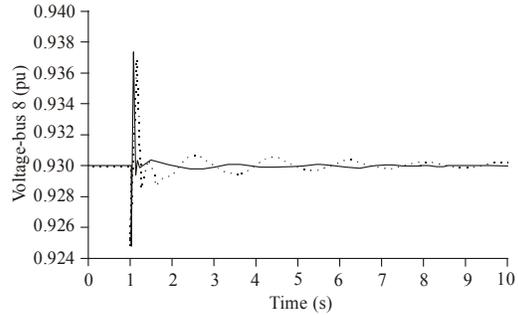


Fig. 8: Voltage of bus number 8 under scenario 2 in nominal load condition Solid (with UPFC); Dashed (without UPFC)

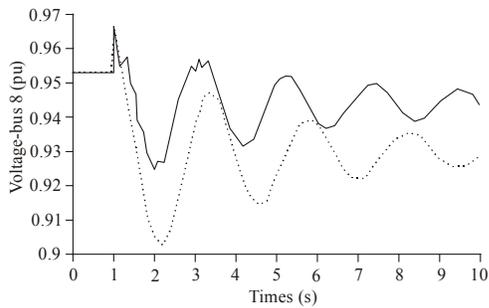


Fig. 5: Voltage of bus number 7 under scenario 1 in nominal load condition Solid (with UPFC); Dashed (without UPFC)

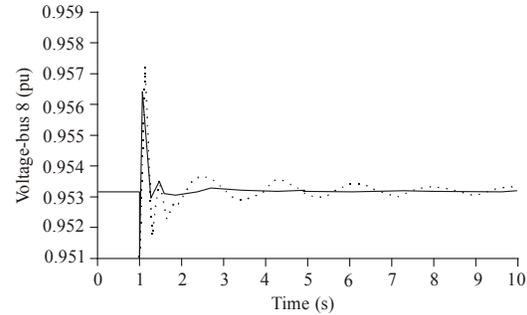


Fig. 9: Voltage of bus number 7 under scenario 2 in nominal load condition Solid (with UPFC); Dashed (without UPFC)

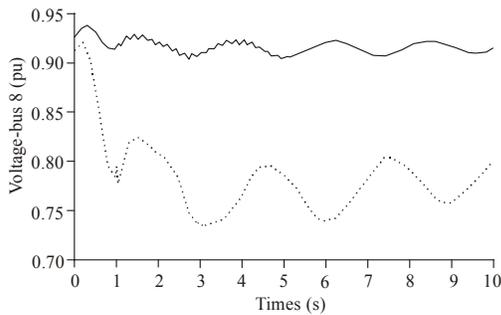


Fig. 6: Voltage of bus number 8 under scenario 1 in heavy load condition Solid (with UPFC); Dashed (without UPFC)

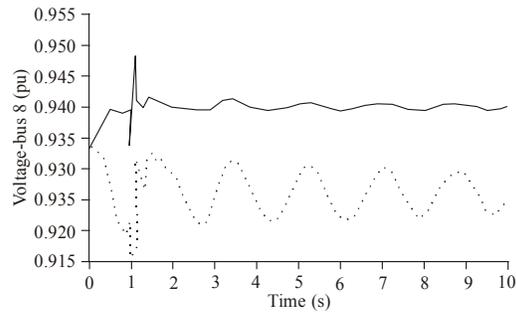


Fig. 10: Voltage of bus number 8 under scenario 2 in heavy load condition Solid (with UPFC); Dashed (without UPFC)

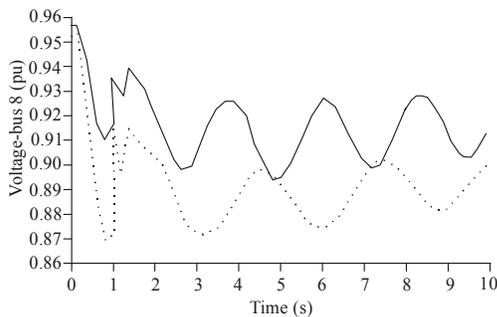


Fig. 7: Voltage of bus number 7 under scenario 1 in heavy load condition Solid (with UPFC); Dashed (without UPFC)

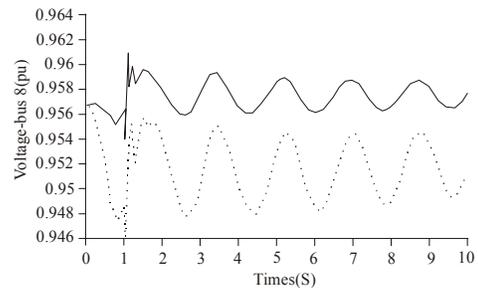


Fig. 11: Voltage of bus number 7 under scenario 2 in heavy load condition Solid (with UPFC); Dashed (without UPFC)

appropriate adjustment of these parameters. Many different methods have been reported for tuning UPFC parameters so far. In this paper, an optimization method named PSO is considered for tuning UPFC parameters. In the next section an introduction about PSO is presented.

Particle swarm optimization: PSO was developed in 1995. The thought process behind the algorithm was inspired by the social behavior of animals, such as bird flocking or fish schooling. PSO begins with a random population matrix. It has no evolution operators such as crossover and mutation. The rows in the matrix are called particles. They contain the variable values and are not binary encoded. Each particle moves about the cost surface with a velocity. The particles update their velocities and positions based on the local and global best solutions as shown in (2) and (3):

$$V_{m,n}^{new} = w \times V_{m,n}^{old} + \Gamma_1 \times r_1 \times (P_{m,n}^{local\ best} - P_{m,n}^{old}) + \Gamma_2 \times r_2 \times (P_{m,n}^{global\ best} - P_{m,n}^{old}) \quad (2)$$

$$P_{m,n}^{new} = P_{m,n}^{old} + \Gamma V_{m,n}^{new} \quad (3)$$

where, $V_{m,n}$: Particle velocity; $P_{m,n}$: Particle variables; W : Inertia weight; r_1, r_2 : Independent uniform random numbers; Γ_1, Γ_2 : Learning factors; $P_{m,n}^{local\ best}$: Best local solution; $P_{m,n}^{global\ best}$: Best global solution.

The PSO algorithm updates the velocity vector for each particle then adds that velocity to the particle position or values. Velocity updates are influenced by both the best global solution associated with the lowest cost ever found by a particle and the best local solution associated with the lowest cost in the present population. If the best local solution has a cost less than the cost of the current global solution, then the best local solution replaces the best global solution. The particle velocity is reminiscent of local minimizes that use derivative information, because velocity is the derivative of position. The advantages of PSO are that it is easy to implement and there are few parameters to adjust. The PSO is able to tackle tough cost functions with many local minima (Randy and Sue, 2004).

UPFC tuning based on PSO: In this section the parameters of the UPFC controllers are tuned using PSO. The optimum values of K_{DP}, K_{DI}, K_{VP} and K_{DI} which minimize different performance indices are accurately computed using PSO. In optimization methods, the first step is to define a performance index for optimal search. In this study the performance index is considered as (4). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (ITAE).

$$ITAE = \int_0^{\tau} t |\Delta \omega_1| dt + \int_0^{\tau} t |\Delta \omega_2| dt + \int_0^{\tau} t |\Delta \omega_3| dt + \int_0^{\tau} t |\Delta \omega_4| dt \quad (4)$$

where, Δ_∞ shows the frequency deviations. It is clear to understand that the controller with lower ITAE is better than the other controllers. To compute the optimum parameter values, a 10 cycle three phase fault is assumed in bus 1 and the performance index is minimized using PSO. To implement PSO, number of particle, number of iteration, Γ_1, Γ_2 , and Γ are chosen as 4, 50, 2, 2 and 1, respectively. Also, the inertia weight, w , is linearly decreasing from 0.9 to 0.4. It should be noted that PSO algorithm is run several times and then optimal parameters is selected respectively. The optimum values of parameters, resulting from minimizing the performance index is presented in Table 2.

SIMULATION RESULTS

In this section, the PSO-based UPFC is exerted to voltage support in the under study system. In order to study and analysis system performance under different scenarios, two scenarios are considered as follows:

Scenario 1: Disconnection of the line between bus 7 and bus 8 by breaker.

Scenario 2: 10 cycle three phase short circuit in bus 3.

It should be noted that this tuning have been done for the nominal operating condition. The simulation results are presented in Fig. 4-11.

Each figure contains two plots; solid line which indicates the system installed with UPFC and dashed line for system without UPFC. The UPFC is placed in bus 8.

As it is clear from the figures, in case with UPFC, the voltage of bus 8 which installed with UPFC is controlled very well. Where, the bus voltage is driven back to the nominal value during post-fault. However, bus voltage without UPFC is not driven back to nominal value and contains a steady state error. It should be noted that although UPFC has been used for the purpose of controlling the voltage of bus number 8, it has also a good effect on the voltage of other buses. For example, the voltage of bus 7 in the case of having UPFC has less error comparing with the case of lack of UPFC.

In general, UPFC not only controls the voltage of buses which installed on it, but also controls the voltage of the other buses and has direct good effect on the system stability.

Also, the system responses have fewer fluctuations when UPFC is included. Therefore UPFC is beneficial for the system stability.

System responses in heavy load condition have been demonstrated. As is clear these figures, by increasing

Table 1: System loading conditions

| Load | Nominal | | Heavy | |
|------|---------|--------|---------|--------|
| | P | Q | P | Q |
| A | 18.5535 | -2.625 | 20.4089 | -2.630 |
| B | 10.1535 | -1.050 | 11.1689 | -1.055 |

Table 2: Optimal parameters of UPFC using PSO

| Parameter | Optimal value |
|-----------|---------------|
| K_{DP} | 23.719 |
| K_{DI} | 1.046 |
| K_{VP} | 77.309 |
| K_{VI} | 0.042 |

system load and resultant heavier operation condition, UPFC has good performance in voltage control and cause the voltage to return to its nominal value.

The voltages of bus number 7 and 8 under second scenario have been shown in Fig. 8 to 11. In this scenario, a three phase short circuit fault occurs and then it is removed. So the system operation point doesn't change and voltages return to nominal value with and without UPFC. But it should be noted that UPFC has tremendous effect on damping of oscillations and make the system response faster.

CONCLUSION

In this study Particle Swarm Optimization (PSO) has been successfully exerted to adjust UPFC parameters. A multi-machine electric power system installed with a UPFC with various load conditions and disturbances has been assumed to demonstrate the ability of UPFC in voltage support and stability enhancement. Considering real world type disturbances such as three phase short circuit and line disconnection guarantee the results in order to implementation of controller in industry. Simulation results demonstrated that the designed UPFC capable to guarantee the robust stability and robust performance under a different load conditions and disturbances. Also, simulation results show that the PSO technique has an excellent capability in UPFC parameters tuning. Application to a multi-machine electric power system which is near to practical systems can increase admission of the technique for real world applications.

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