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*Full Length Research Paper*

# Dynamic stability enhancement and voltage support using UPFC tuned genetic algorithms in a multi-machine environment

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**Unified power flow controller (UPFC) is one of the most important flexible AC transmission systems (FACTS) devices in power systems. It has many applications such as stability enhancement, power flow control, voltage support, etc. In this paper UPFC is used in order to control voltage. In this scope, UPFC is installed on a specified bus and the voltage of the proposed bus is controlled by using UPFC. In order to optimize performance, the parameters of UPFC controllers are tuned using genetic algorithms (GA) optimization method. Simulation results, which are carried out on a multi-machine electric power system, clearly show effectiveness and viability of UPFC in voltage control.**

**Key words:** Unified power flow controller, voltage Support, dynamic stability enhancement, multi-machine electric power system genetic algorithms

## 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). Unified power flow controller (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, that is, 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 oscillations (LFO) (Eghtedari et al., 2011; Ozturk and Dosoglu, 2010; Hassan et al., 2010; Farahani et al., 2011; Alasooly and Redha, 2010; Mehraeen et al., 2010; Jiang et al., 2010 a, 2010 b, 2010 c; Faried, 2009). As referred earlier, one of the applications of UPFC is LFO damping. 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, 2009; Taher et al., 2008; Al-Awami, 2007; Eldamaty et al., 2005) offer better

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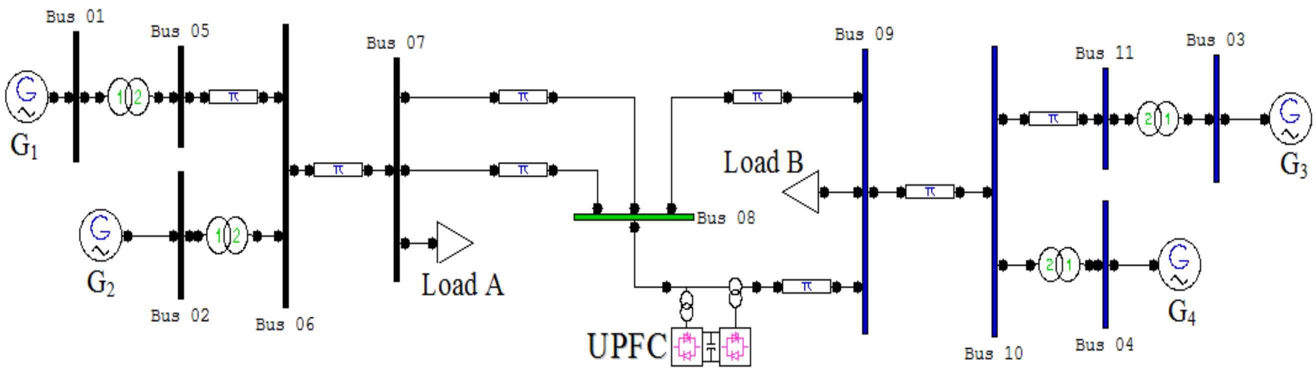


**Figure 1.** Four-machine eleven-bus power system.

dynamic performances than fixed parameter controllers.

In this paper the main objective is the application of UPFC for voltage control at a multi machine power system. In this paper the UPFC internal controllers (bus-voltage controller and DC link voltage regulator) are considered as PI type controllers. Genetic algorithms optimization method is used 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.

The rest of this paper is structured as follows: UPFC model and also dynamic model of multi-machine system containing UPFC is presented. A brief description about genetic algorithm (GA) technique is given, the adjustment of UPFC based on GA is discussed and simulation results are presented. Finally the conclusion follows.

## 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. Details of the system data are given (Kundur, 1993). To assess the effectiveness and robustness of the proposed method over a wide range of loading conditions, two different cases as nominal and heavy loading are considered and listed in Table 1.

### Dynamic model of the system with UPFC

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

$$\begin{cases} \dot{\omega}_i = \dfrac{(P_m - P_e - D\omega)}{M} \\ \dot{\delta}_i = \omega_0(\omega - 1) \\ \dot{E}'_{qi} = \dfrac{(-E_q + E_{fd})}{T'_{do}} \\ \dot{E}_{fdi} = \dfrac{-E_{fd} + K_a(V_{ref} - V_t)}{T_a} \\ \dot{V}_{dc} = \dfrac{3m_E}{4C_{dc}}\left(\sin(\delta_E)I_{Ed} + \cos(\delta_E)I_{Eq}\right) + \dfrac{3m_B}{4C_{dc}}\left(\sin(\delta_B)I_{Bd} + \cos(\delta_B)I_{Bq}\right) \end{cases} \quad (1)$$

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; Te, electric torque; $T'_{do}$, time constant of excitation circuit; $K_a$, regulator gain; $T_a$, regulator time constant; $V_{ref}$, reference voltage and $V_t$, terminal voltage. $m_B$, pulse width modulation of series inverter. By controlling $m_B$, the magnitude of series-injected voltage can be controlled. $\delta_B$, 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. $\delta_E$, 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. Figure 2 shows the structure of the DC-voltage regulator. Also Figure 3 shows the structure of the bus voltage controller. The bus voltage controller regulates the voltage of bus during post fault in system.

**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 |

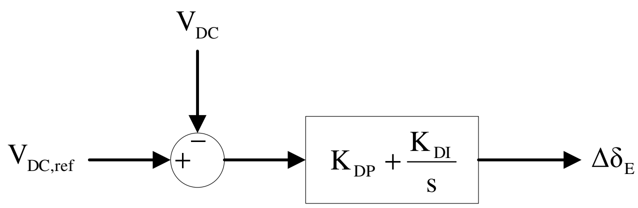


**Figure 2.** DC-voltage regulator.

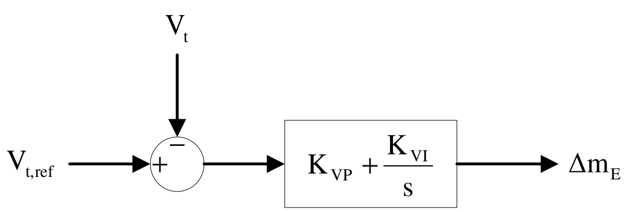


**Figure 3.** Bus voltage controller.

The most important subject is to tuning the UPFC controller parameters $K_{DP}$, $K_{DI}$, $K_{VP}$ and $K_{DI}$. Where, $K_{DP}$, $K_{DI}$, $K_{VP}$ and $K_{DI}$ are the proportional and integrator gain of controllers. The system stability and suitable performance is guaranteed by appropriate adjustment of these parameters. Many different methods have been reported for tuning UPFC parameters so far. In this paper, an optimization method named GA is considered for tuning UPFC parameters. Subsequently, introduction about GA is presented.

#### Genetic algorithms

Genetic algorithms (GA) are global search techniques, based on the operations observed in natural selection and genetics. They operate on a population of current approximations-the individuals-initially drawn at random, from which improvement is sought. Individuals are encoded as strings (chromosomes) constructed over some particular alphabet, such as the binary alphabet {0.1}, so that chromosomes values are uniquely mapped onto the decision variable domain. Once the decision variable domain representation of the current population is calculated, individual performance is assumed according to the objective function which characterizes the problem to be solved. It is also possible to use the variable parameters directly to represent the chromosomes in the GA solution. At the reproduction stage, a fitness value is derived from the raw individual performance measure given by the objective function and used to bias the selection process. Highly fit individuals will have increasing opportunities to pass on genetically

**Table 2.** Optimal parameters of UPFC using GA.

| Parameter | Optimal value |
|---|---|
| $K_{DP}$ | 21.932 |
| $K_{DI}$ | 1.022 |
| $K_{VP}$ | 75.01 |
| $K_{VI}$ | 0.05 |

important material to successive generations. In this way, the genetic algorithms search from many points in the search space at once and yet continually narrow the focus of the search to the areas of the observed best performance. The selected individuals are then modified through the application of genetic operators. In order to obtain the next generation, genetic operators manipulate the characters (genes) that constitute the chromosomes directly, following the assumption that certain genes code, on average, for fitter individuals than other genes. Genetic operators can be divided into three main categories: reproduction, crossover and mutation (Randy and Sue, 2004).

#### UPFC tuning based on GA

Here the parameters of the UPFC controllers are tuned using GA. The optimum values of $K_{DP}$, $K_{DI}$, $K_{VP}$ and $K_{DI}$ which minimize different performance indices are accurately computed using GA. In optimization methods, the first step is to define a performance index for optimal search. In this study the performance index is considered as Equation 2. In fact, the performance index is the integral of the time multiplied absolute value of the error (ITAE).

$$ITAE = \int_0^t t\,|\Delta\omega_1|dt + \int_0^t t\,|\Delta\omega_2|dt + \int_0^t t\,|\Delta\omega_3|dt + \int_0^t t\,|\Delta\omega_4|dt \quad (2)$$

Where, $\Delta\omega$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 GA. In order to acquire better performance, population size, number of chromosomes, number of iteration, mutation rate and crossover rate are chosen as 48, 4, 100, 0.05 and 0.5, respectively. The optimum values of parameters, resulting from minimizing the performance index is presented in Table 2. In this paper the mating is performed as follows:

$$Pnew = \beta.Pmn + (1-\beta)Pdn$$

Where, β is a random number and $P_{mn}$ and $P_{dn}$ show father and mother chromosomes, respectively. Also for mutation, 5% of the chromosomes are replaced with random ones.

## SIMULATION RESULTS

Here the GA-based UPFC is exerted to voltage support in the under study system. In order to study and analyse system performance under different scenarios, two scenarios are considered as follows:

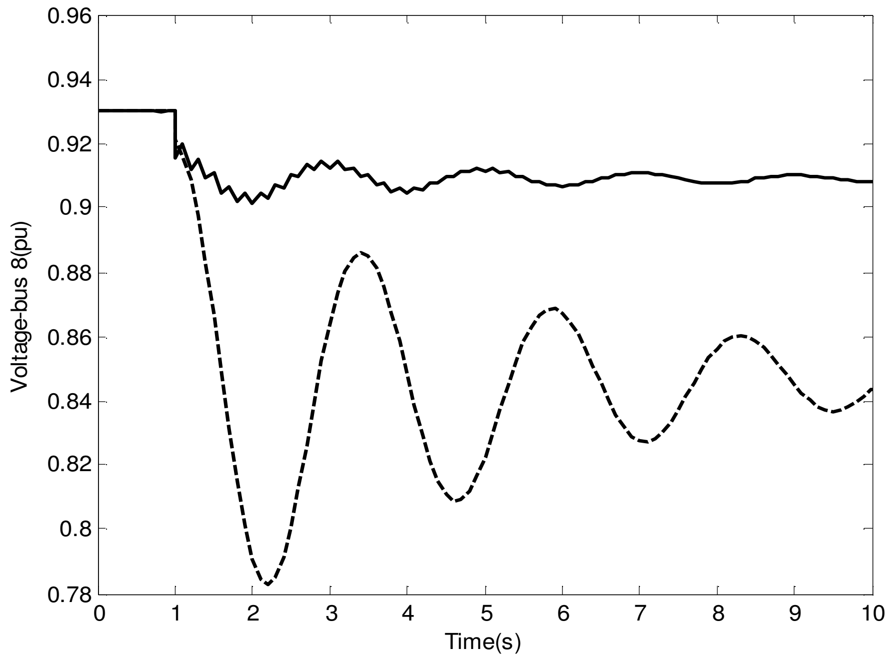


**Figure 4.** Voltage of bus number 8 under scenario 1 in nominal load condition. Solid (with UPFC); Dashed (without UPFC).

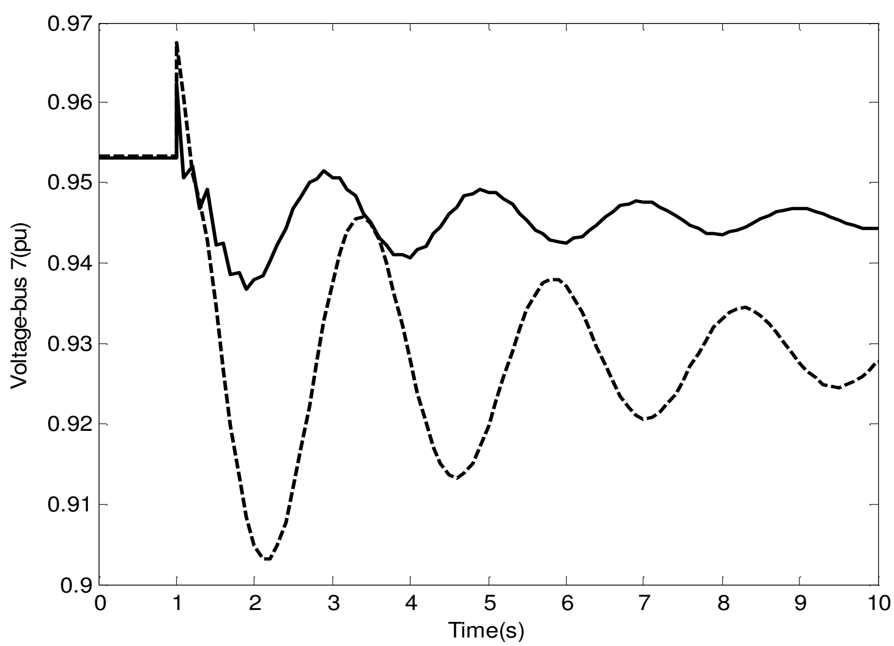


**Figure 5.** Voltage of bus number 7 under scenario 1 in nominal load condition. Solid (with UPFC); Dashed (without UPFC).

Scenario 1: disconnection of the line between bus 8 and bus 9 by breaker.
Scenario 2: 10 cycle three phase short circuit in bus 8.

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

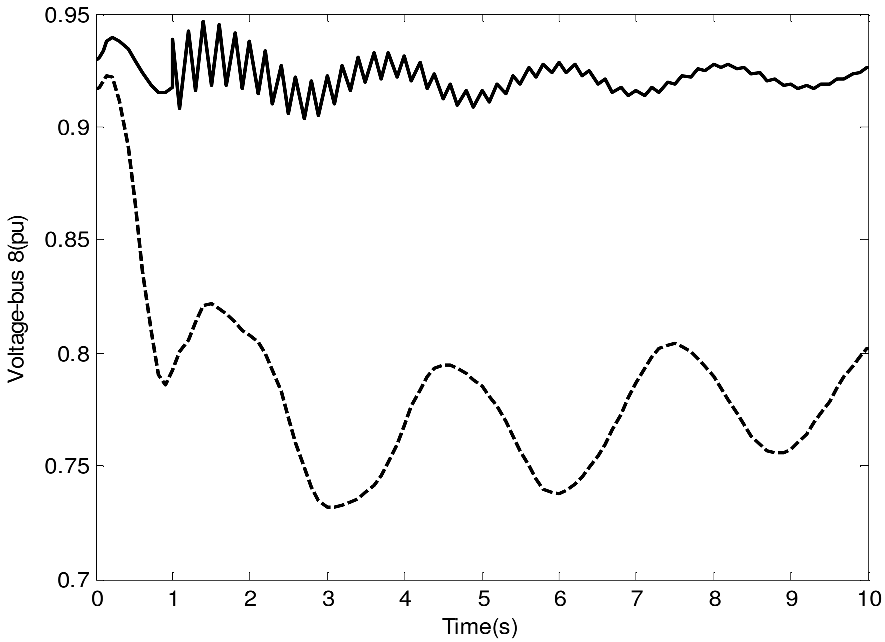


**Figure 6.** Voltage of bus number 8 under scenario 1 in heavy load condition. Solid (with UPFC); Dashed (without UPFC).

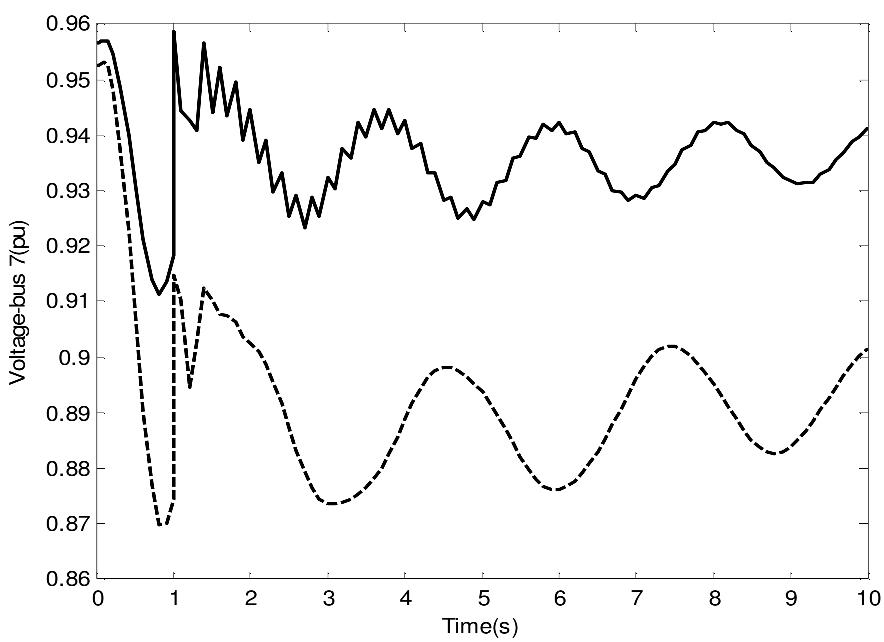


**Figure 7.** Voltage of bus number 7 under scenario 1 in heavy load condition. Solid (with UPFC); Dashed (without UPFC).

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 4 to 11, in case with UPFC, the voltage of bus 8 which is installed with UPFC is controlled very well. Where, the bus voltage is driven

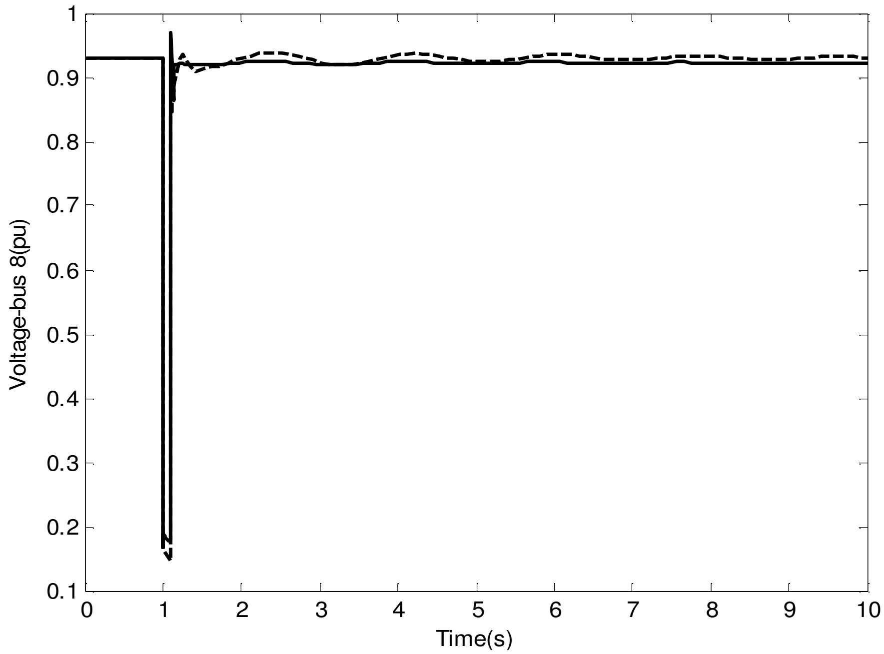


**Figure 8.** Voltage of bus number 8 under scenario 2 in nominal load condition. Solid (with UPFC); Dashed (without UPFC).

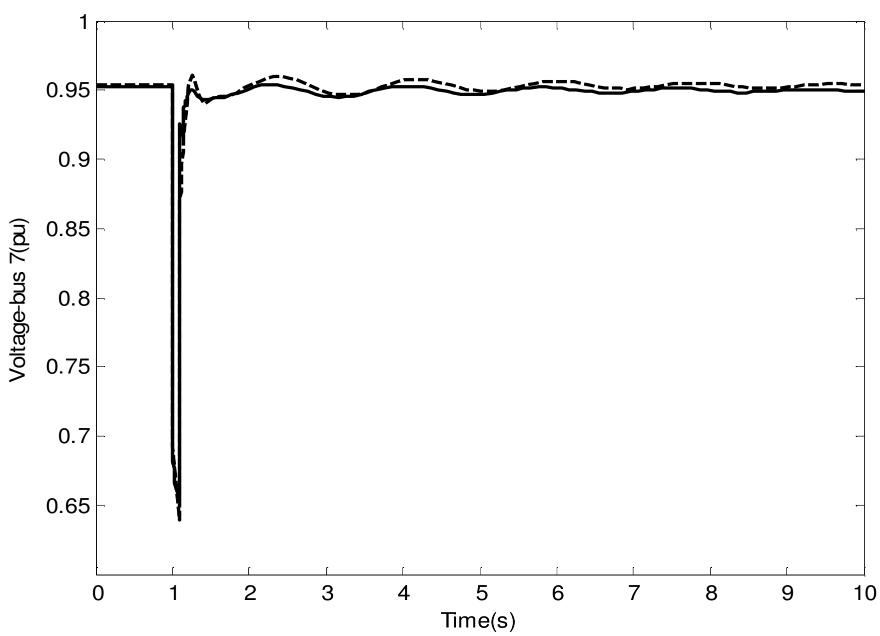


**Figure 9.** Voltage of bus number 7 under scenario 2 in nominal load condition. Solid (with UPFC); Dashed (without UPFC).

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 a good effect on the voltage of other buses. For example, the

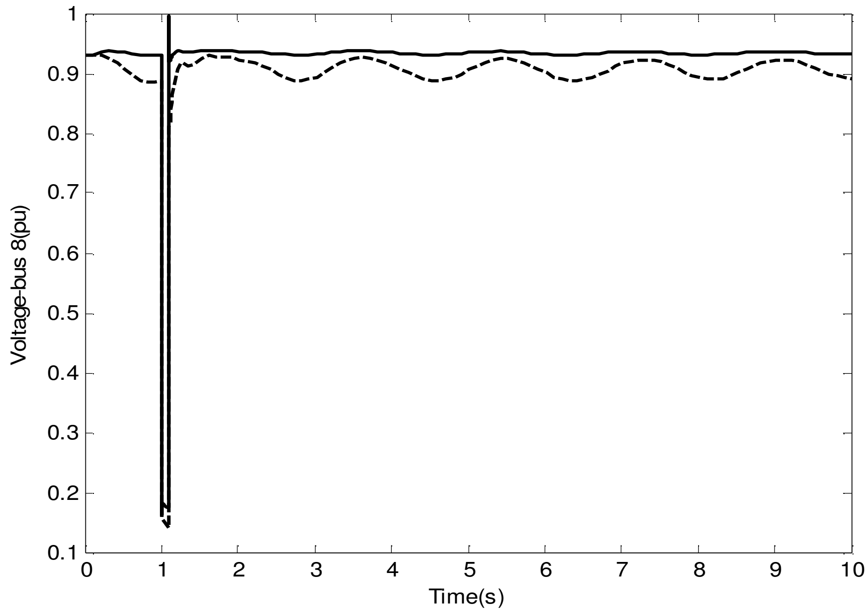


**Figure 10.** Voltage of bus number 8 under scenario 2 in heavy load condition. Solid (with UPFC); Dashed (without UPFC).

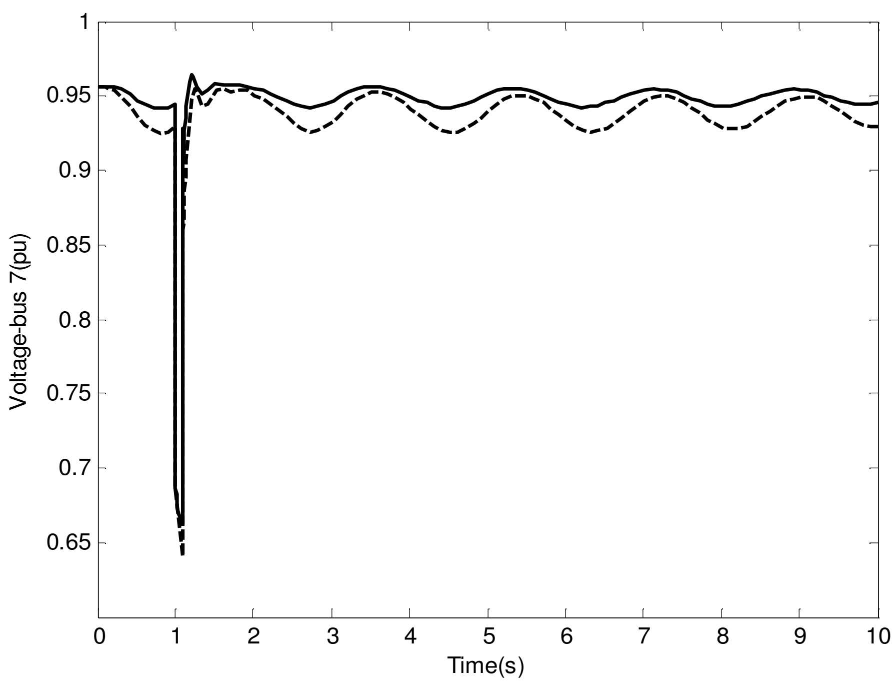


**Figure 11.** Voltage of bus number 7 under scenario 2 in heavy load condition. Solid (with UPFC); Dashed (without UPFC).

voltage of bus 7 in the case of having UPFC has less error when compared 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 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 Figures 8 to 11. In this scenario, a three phase short circuit fault occurs and then it is removed. So the system operation point does not 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.

## CONCLUSIONS

In this paper, genetic algorithms (GA) method 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 implement 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 GA 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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