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Studying the Performance of UPFC Tuned Based on Tabu Search for Voltage Regulation in Power System

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Abstract: This paper 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 Tabu search (TS). 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 emphases on the ability of UPFC in simultaneous control of voltage and also stability enhancement.

Key words: Unified Power Flow Controller; Voltage Support; dynamic stability enhancement; Multi-machine Electric Power System; Tabu search

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, 2010 a; Jiang et al, 2010 b; Jiang et al, 2010 c; Faried, 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 tabu search (Taher and Hematti, 2009; 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. Tabu search optimization method 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.

The Rest of paper is structured as follows: In section 2, UPFC model and also dynamic model of multi-machine system containing UPFC is presented. In section 3, a brief description about TS technique is given.

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In section 4, adjustment of UPFC based on TS is discussed. In section 5, simulation results are presented. And finally, the paper is concluded in section 6.

2. 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 range of loading conditions, two different cases as nominal and heavy loading are considered and listed in Table 1.

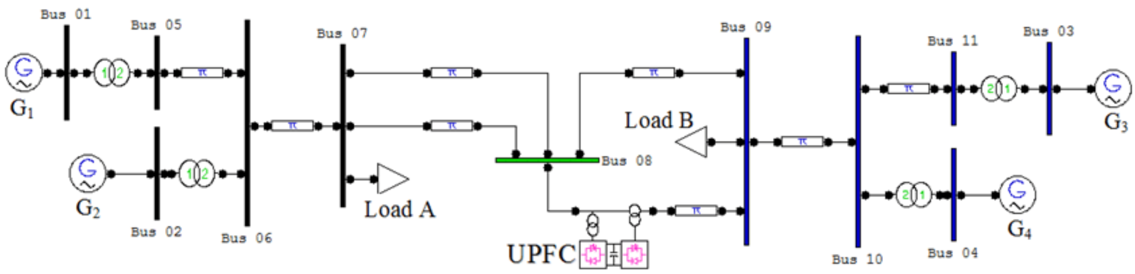

Fig. 1: Four-machine eleven-bus power system.

Table 1: System loading conditions.

Load	Nominal		Heavy	
	P	Q	P	Q
A	18.5535	-2.625	20.4089	-2.63
B	10.1535	-1.05	11.1689	-1.055

2.1. 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).

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

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; 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.

2.2. 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.

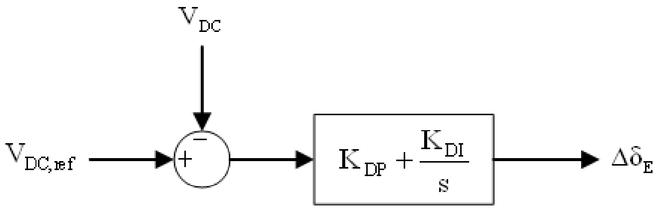

Fig. 2: DC-voltage regulator.

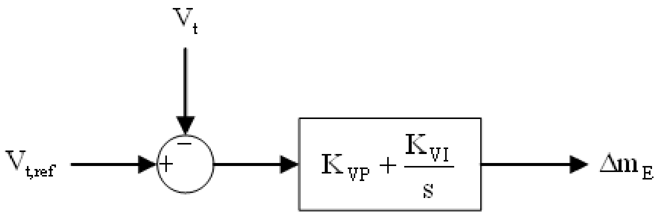

Fig. 3: Bus voltage controller.

The most important subject is to tuning the UPFC controller parameters K_{DP}, K_{DI}, K_{VP} and K_{DI}. 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 TS is considered for tuning UPFC parameters. In the next section an introduction about TS is presented.

3. Tabu Search:

Tabu search (TS) was first presented in its present form by Glover [Glover, 1986]; Many computational experiments have shown that TS has now become an established optimization technique which can compete with almost all known techniques and which - by its flexibility - can beat many classical procedures. Up to now, there is no formal explanation of this good behavior. Recently, theoretical aspects of TS have been investigated [Faigle and Kern, 1992].

The success with TS implies often that a serious effort of modeling be done from the beginning. In TS, iterative procedure plays an important role: for most optimization problems no procedure is known in general to get directly an "optimal" solution.

The general step of an iterative procedure consists in constructing from a current solution x_i a next solution x_j *and* in checking whether one should stop there or perform another step.

In other hand, a neighborhood $N(x_i)$ is defined for each feasible solution x_i, and the next solution x_j is searched among the solutions in $N(x_i)$.

In this part we summarize the discrete TS algorithm in four steps. Assume that X is a total search space and x is a solution point sample and f (x) is cost function:

1- Choose $x \in X$ to start the process.
2- Create a candidate list of non-Tabu moves in neighborhood. (x_i, i=1,2,...,N)
3- Find $x_{winner} \in N(x)$ such that $f(x_{winner}) < f(x_i)$, $i \neq winner$.
4- Check the stopping criterion. If satisfied, exit the algorithm.

If not, winner $x = x_{winner}$, update Tabu List and then go to step 2.

In order to exit from algorithm, there are several criterions that are considered in our research.

1- by determining a predetermined threshold: If the value of cost function was less, algorithm would be terminated.
2- Determination of specific number of iterations.
3- If the value of the cost was remained invariable or negligible change for several iterations, algorithm would be terminated.

A didactic presentation of TS and a series of applications have been collected in [Glover et al., 1992; Randy and Sue, 2004].

4. UPFC Tuning Based on TS:

In this section the parameters of the UPFC controllers are tuned using TS. The optimum values of K_{DP}, K_{DI}, K_{VP} and K_{DI} which minimize different performance indices are accurately computed using TS. In optimization methods, the first step is to define a performance index for optimal search. In this study the performance index is considered as (2). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (ITAE).

$$ITAE = \int_0^{\tau} t\left|\Delta\omega_1\right|dt + \int_0^{\tau} t\left|\Delta\omega_2\right|dt + \int_0^{\tau} t\left|\Delta\omega_3\right|dt + \int_0^{\tau} t\left|\Delta\omega_4\right|dt \qquad (2)$$

Where, Dw 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 TS. 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.

Table 2: Optimal parameters of UPFC using TS.

Parameter	Optimal value
K_{DP}	20.7712
K_{DI}	1.051
K_{VP}	74.9
K_{VI}	0.08

5. Simulation Results:

In this section, the TS-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 3 and bus 11 by breaker
Scenario 2: 10% load change

It should be noted that, in scenario 2, the load has two step changes. In first it is increased at 1 second and then driven back to the nominal load at 2th second; then the load is reduced at 10th second and driven back to the nominal load at 11th second It should be noted that this tuning have been done for the nominal operating condition. The simulation results are presented in figures 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 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 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.

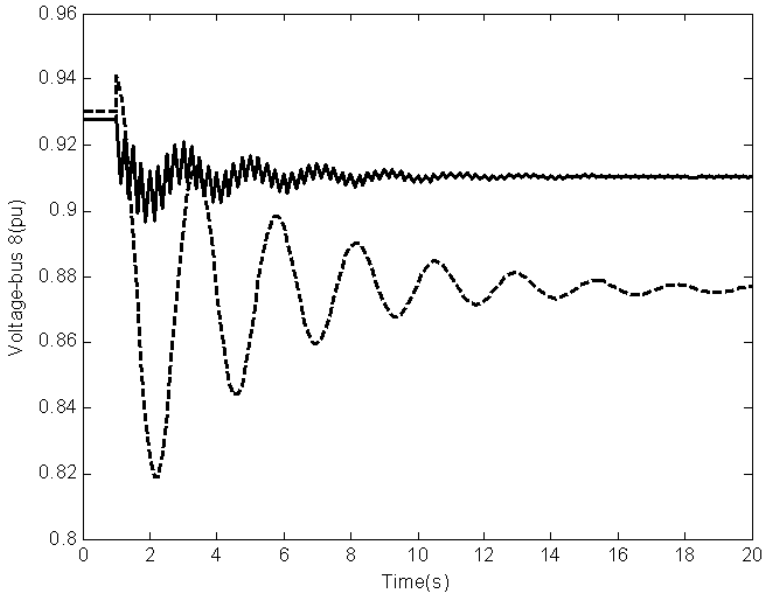

Fig. 4: Voltage of bus number 8 under scenario 1 in nominal load condition Solid (with UPFC); Dashed (without UPFC).

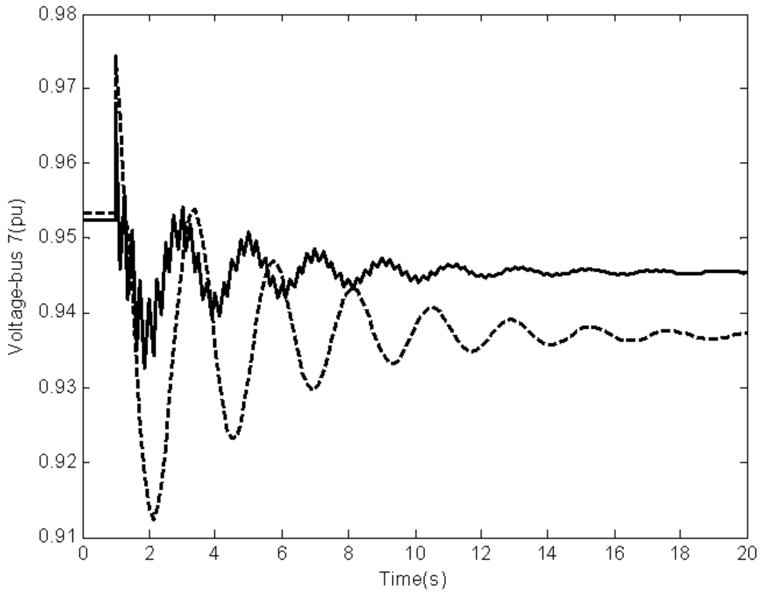

Fig. 5: Voltage of bus number 7 under scenario 1 in nominal load condition Solid (with UPFC); Dashed (without UPFC).

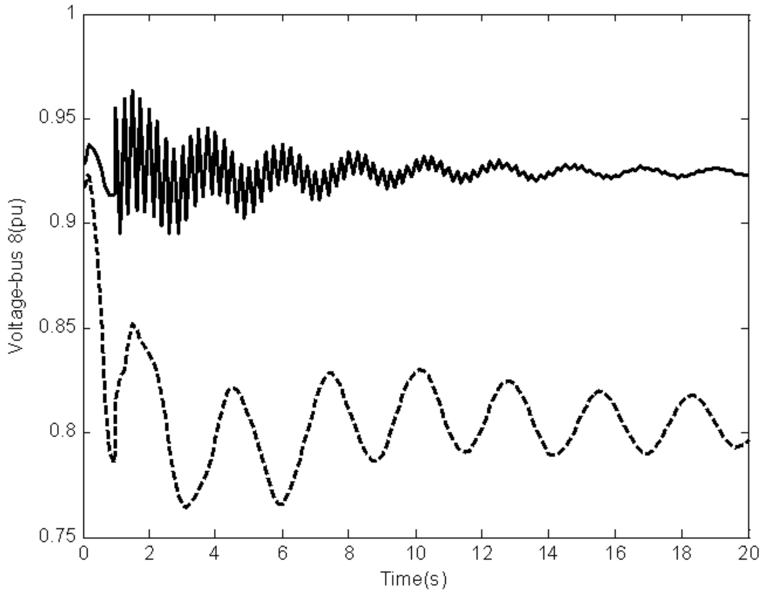

Fig. 6: Voltage of bus number 8 under scenario 1 in heavy load condition Solid (with UPFC); Dashed (without UPFC).

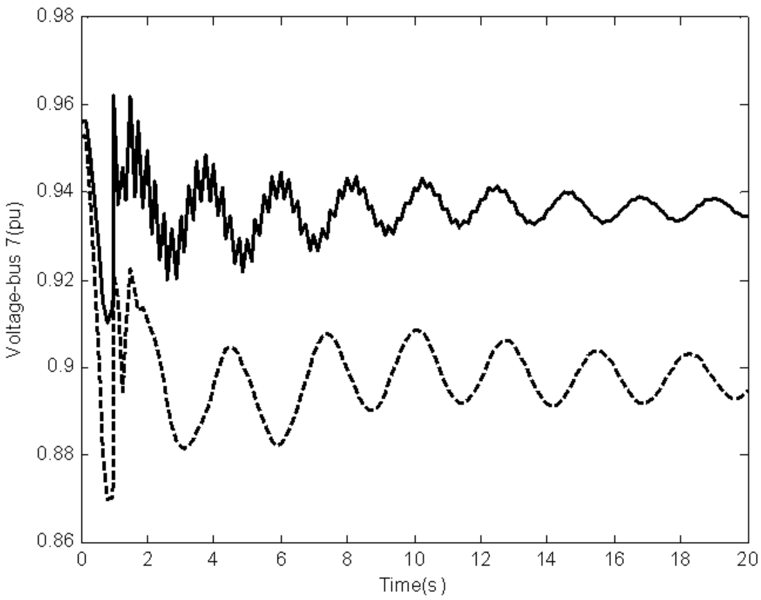

Fig. 7: Voltage of bus number 7 under scenario 1 in heavy load condition Solid (with UPFC); Dashed (without UPFC).

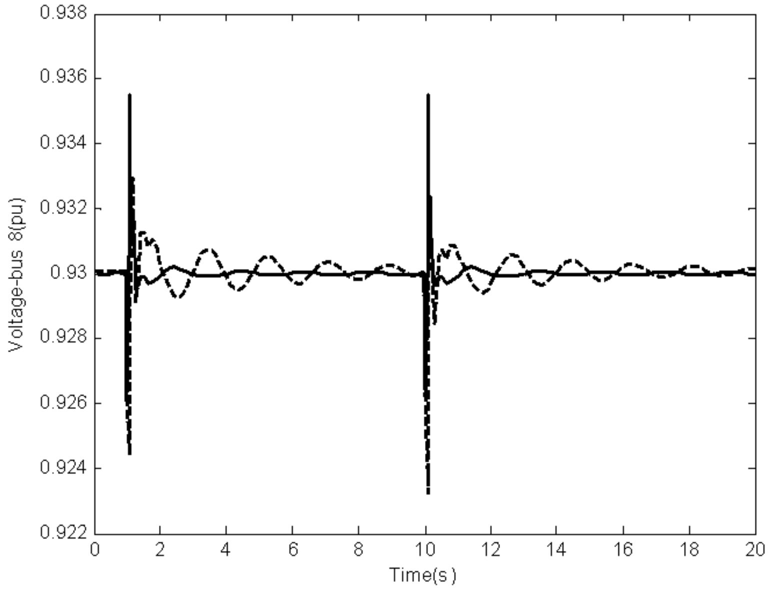

Fig. 8: Voltage of bus number 8 under scenario 2 in nominal load condition Solid (with UPFC); Dashed (without UPFC).

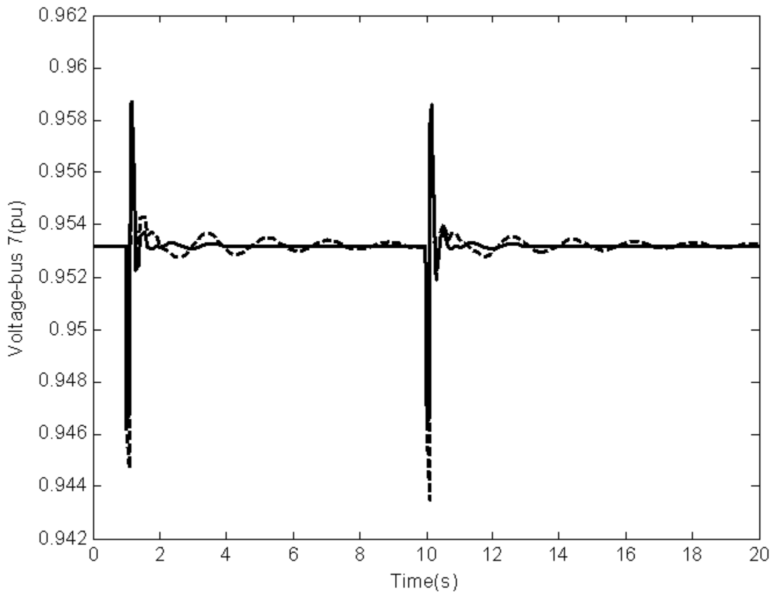

Fig. 9: Voltage of bus number 7 under scenario 2 in nominal load condition Solid (with UPFC); Dashed (without UPFC).

6. Conclusions:

In this paper Tabu search (TS) 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 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 TS 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.

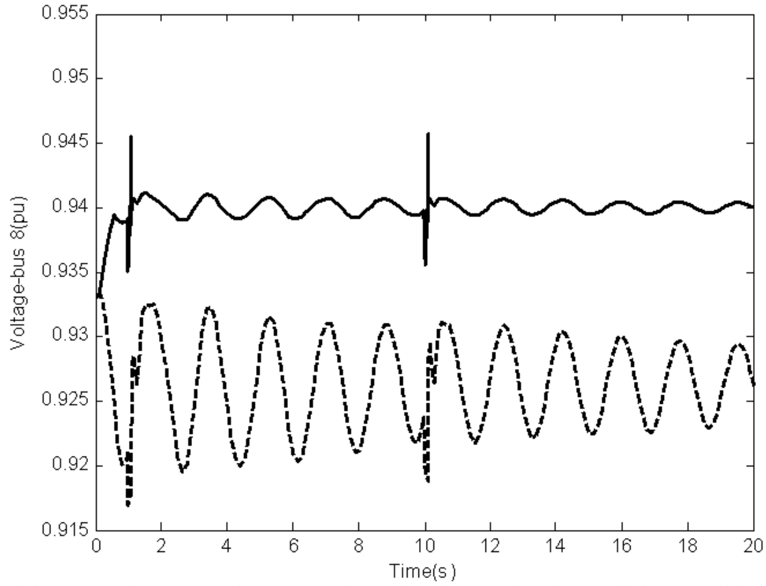

Fig. 10: Voltage of bus number 8 under scenario 2 in heavy load condition Solid (with UPFC); Dashed (without UPFC).

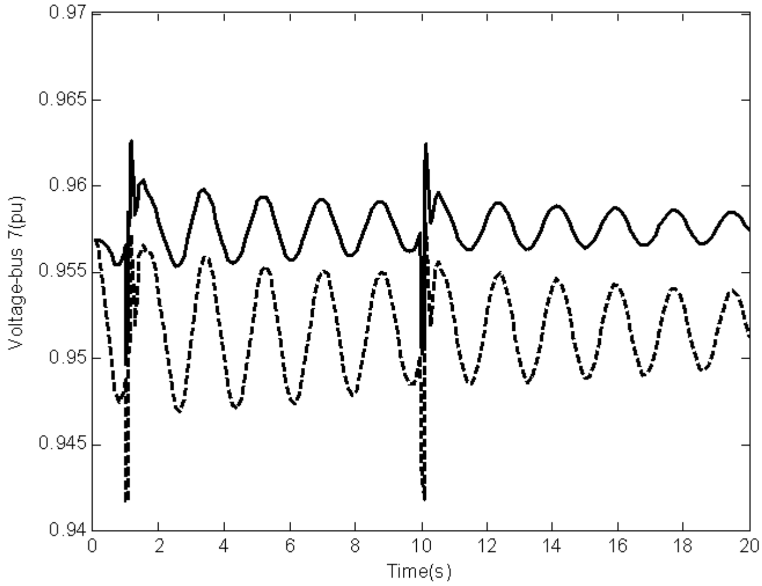

Fig. 11: Voltage of bus number 7 under scenario 2 in heavy load condition Solid (with UPFC); Dashed (without UPFC).

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