Effects of UPFC for Transient Stability Improvment after a Fault in Power Systems

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Abstract

Nowadays, FACTS controllers are among the essentials of power systems. In this paper, one of the FACTS controllers (UPFC) is introduces and studied to improve the transient stability in power networks. So, the size and angle of the output terminal voltage of the existing generators in the network are studied in the two cases with and without UPFC. It is observed that to what extent these mentioned parameters improve in the presence of UPFC. PSAT software was used for simulation and IEEE 14-bus transmission network was used for study.

Key words: UPFC, FACTS controllers, transient stability, power system

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1. Introduction

The parts transferring electricity energy, sometimes some faults occur such as line-to-ground fault, line-to-line fault, etc. which cause oscillations, instabilities and such problems in the network. Energy decline, blackout and oscillations time in the network are among the most important tasks and concerns of electrical industry. When a fault occurs in the network, voltage amplitude, phase angle and power quality fall down which lead to the undesirable electricity and losses in the network and sometimes create damages. Nowadays, there are numerous synchronous generators in power networks which generate power. Output power of generators in transient condition is a function of relative angles of behind the transient reactance voltage of generators, size of these generators and line impedance; so, if relative angles of voltage sizes or line impedance could be changed rapidly to help power balance in system, economic utilization of the existing facilities would be feasible, in addition to system security increase.

2. Transient Stability

It shows a system ability to maintain the synchronous mode as a transient extreme disturbance occurs. System reaction includes great changes of generator rotor angle and is influenced by non-linear relationship of power-angle.

$$P = \frac{E_G E_M}{X_T} \sin\delta \qquad (1)$$

$$X_T = X_G + X_L + X_M \qquad (2)$$

Stability depends on system's initial operating point as well as disturbance intensity. System is usually subjected to change in this case, so that the operating point of stable system after disturbance is different from its operating point before disturbance. Disturbances with very different degree and probability of occurrence may occur in system. In spite of it, system is designed to remain stable against a series of selected events. These events mainly are phase to ground, phase to phase to ground and three phase short circuit. Short circuit is usually assumed to be on transmission lines, but sometime short circuit is also assumed in bus bar or transformer. The area affected by a fault is assumed to be separated from other areas of the system by required switching. In some conditions, fast recloser could be assumed. Figure (1) shows the synchronous machine behavior in stable and unstable situations. Rotor angle reaction for a stable and two unstable modes is shown in this figure. In stable mode (mode 1) the rotor angle first increases, reaches its maximum and then decreases and oscillations with a declining amplitude until reaches steady state. In mode (2), rotor angle increases continuously and uniformly till synchronous mode is lost. This instability is called first oscillation instability and is created because of shortage of synchronizing torque. In mode (3), system is initially stable during the first oscillation, but it gradually becomes unstable by oscillations amplitude increase. Such instability occurs as system's steady state conditions itself is unstable from the perspective of "small signal" and does not necessarily occur because of transient disturbance.

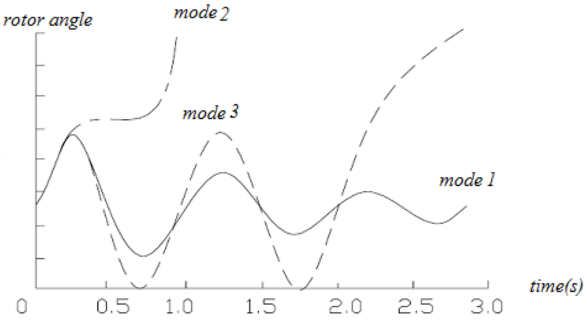


Figure 1. Rotor angle response to a transient disturbance

In large power systems, transient instability may not always occur as the first oscillation instability, but it may be the result of impacts of several swingings modes which lead to rotor angle's intensive changes after the first oscillation. In transient stability studies, time is usually limited to 3 to 5 seconds after disturbance, although it may also reach 10 seconds for the very large systems with dominant inter-regional swinging modes. "Dynamic stability" term is also mentioned as a kind of rotor angle stability in the published works. Despite this, different writers used this term for different aspects of this phenomenon. In northern America, this term was used in the sense of small signal stability with auto control equipments (mainly generator voltage regulators) versus stability without these equipments. In France and Germany, this term was used in the same sense of transient stability which was used here. As this term is so ambiguous, CIGRE and IEEE do not recommend its use. Nowadays, with the development of power electronic devices, controllers named FACTS entered power systems which can change power balance in the system to maintain stability. UPFC series compensators are a useful FACTS controller for damping of system oscillations.

3. UPFC (Unified Power Flow Controller)

UPFC is created from the connection of SSSC and STATCOM, including two VSI inverters connected to the network in parallel and series via parallel and series transformers respectively. Series and parallel parts in UPFC are jointly fed by a DC capacitor. In terms of capability, UPFC performs series and parallel compensation together and can constantly control phase angle, impedance and voltage amplitude; therefore, it can directly control actual power and reactive power of transmission line. Figure 2 shows the equivalent circuit of UPFC. Considering figure 2, load distribution equations are described as below:

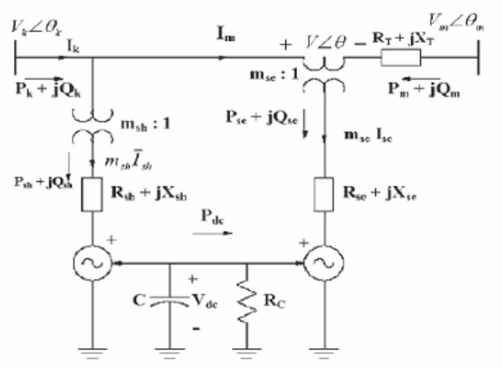


Figure2. UPFC equivalent circuit

$$P_K = P_{sh} + \sum\left\{\vec{V_k}\,\vec{I}^{*}{}_{m}\right\} \qquad (3)$$

$$Q_k = Q_{sh} + \sum\left\{\vec{V_k}\,I^{*}{}_{m}\right\} \qquad (4)$$

$$P_m = -\sum\left\{\vec{V_m}\,\vec{I}^{*}{}_{m}\right\} \qquad (5)$$

$$Q_k = -\sum\left\{\vec{V_m}\,\vec{I}^{*}{}_{m}\right\} \qquad (6)$$

$$K_{sh} = \sqrt{\frac{3}{8}msh} \qquad (7)$$

P_{sh} and Q_{sh} powers absorbed by parallel component are as below:

$$P_{sh} = V_K^2 = G_{sh} - K_{sh}V_{dc}V_kG_{sh}COS(\theta_k - \alpha) - K_{sh}V_{dc}V_kB_{sh}SIN(\theta_k - \alpha) \qquad (8)$$

$$\alpha_{sh} = V_k^2B_{sh} - K_{sh}V_{dc}V_kB_{sh}COS(\theta_k - \alpha) - K_{sh}V_{dc}V_kG_{sh}SIN(\theta_k - \alpha) \qquad (9)$$

The following differential equation is used for DC circuit:

$$V_{dc} = \frac{P_{sh}}{CV_{dc}} + \frac{\Sigma\left\{\vec{V}\, I_m^*\right\}}{CV_{dc}} = \frac{V_{dc}}{R_c C} - \frac{R_{sh}(P_{sh}^2 + Q_{sh}^2)}{CV_{dc}V_k^2} - \frac{R_{se}I_m^2}{CV_{dc}} \qquad (10)$$

5. Simulation

As it is shown in figure 3, the IEEE 14-bus transmission network is used. To simulate this network, PSAR software is used. Buses 1,2,3,6 and 8 enter power to the network and buses 2, 3, 4,5,6,9,10,12,13 and 14 are load buses. The results of simulation are divided to three parts in this paper; the first part is related to the results of system's normal state (without any fault and UPFC installation). The second part is related to system results with fault at the bus 2 and without UPFC installation, and finally the third part is related to the study and analysis of the occurred fault in the presence of UPFC. It should be mentioned that PSAT just stimulates the symmetrical three phase short circuit in the network in time domain and/or frequency domain (phasor). It should be noted that if we want to perform network short circuit calculations, there is no need to calculate the load distribution and its specific data such as slack bus and etc; in this case, PSAT assumes the voltage value a per unit before the fault.

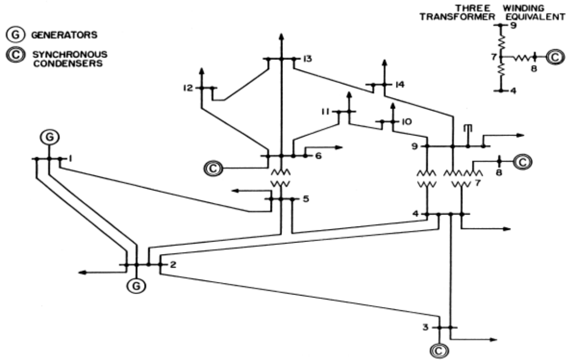


Figure 3. IEEE 14-bus system

5.1. Simulation Results without any Fault and UPFC Installation

In this stage, the results are studied in the case that no fault exists in the network. Since buses 1,2,3,6 and 8 produce power and voltage in the network, they are more important and the simulation results are focused on these buses. Figure 4 represents voltage waveforms of buses 1,2,3,6 and 8. And also, Figure 5 shows the output terminal voltage angle waveforms of generators 1,2,3,6 and 8.

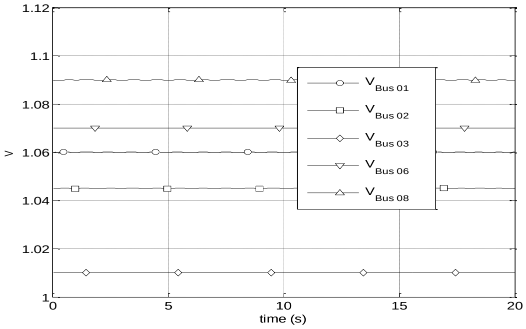


Figure 4. Voltage waveforms of buses 1,2,3,6 and 8 without any fault and UPFC installation in the network

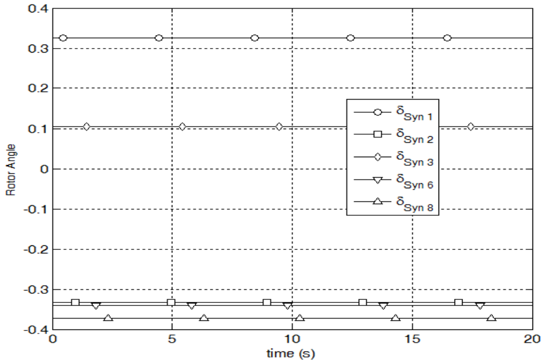
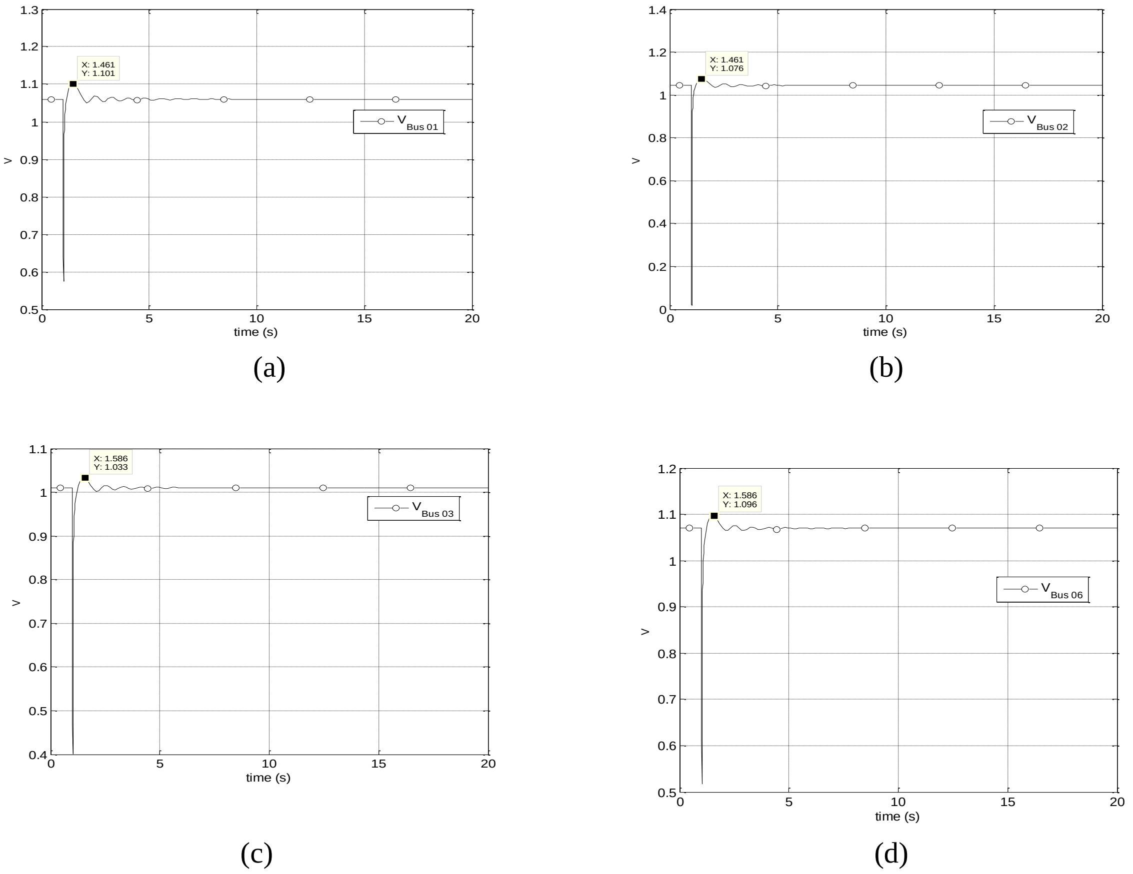


Figure 5. The output terminal voltage angle waveforms of generators 1,2,3,6 and 8 without any fault and UPFC installation in the network

5.2. Simulation Results with Fault and without UPFC Installation in the Network

In this stage, protective relay acts after 0.04 second by creating fault at the bus 2. In this case, the created transient oscillations in the generators in question are studied. Value and angle of the output terminal voltage of the generators are shown in figure 6 and 7 respectively.

Figure 1 a, b, c, d and e show voltage waveforms of buses 1,2,3,6 and 8 respectively. As it is seen, some noises and oscillations affect the voltage waveforms of the buses in question, which indicate that by creating fault in the network, an intensive voltage drop occurs at the buses; this drop decreases during short time and its oscillations are damped.

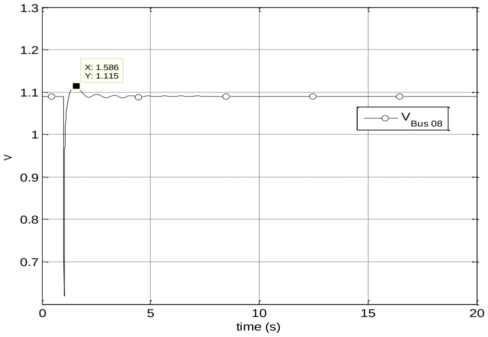


(a)

(b)

(c)

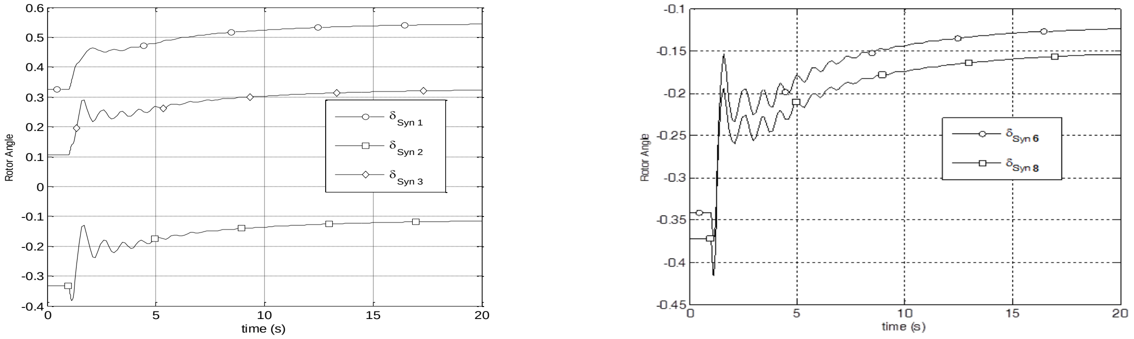
(d)



(e)

Figure 6. Voltage waveforms a, b, c, d, and e of buses 1,2,3,6 and 8 respectively with creating fault at the bus 2 and without UPFC in the network

Figure 7 a and b show output terminal voltage angle waveforms of generators 1,2,3 and 6,8 respectively which indicate generator's output terminal voltage angle tends toward instability after 0.04 second from the creation of fault in the network.



(a) (b)

Figure 7. a and b are output terminal voltage angle waveforms of generators 1,2,3 and 6,8 respectively with fault at the bus 2 and without UPFC in the network

5.3. Stimulation Results with Creating fault at the Bus 2 and Presence of UPFC in the Network

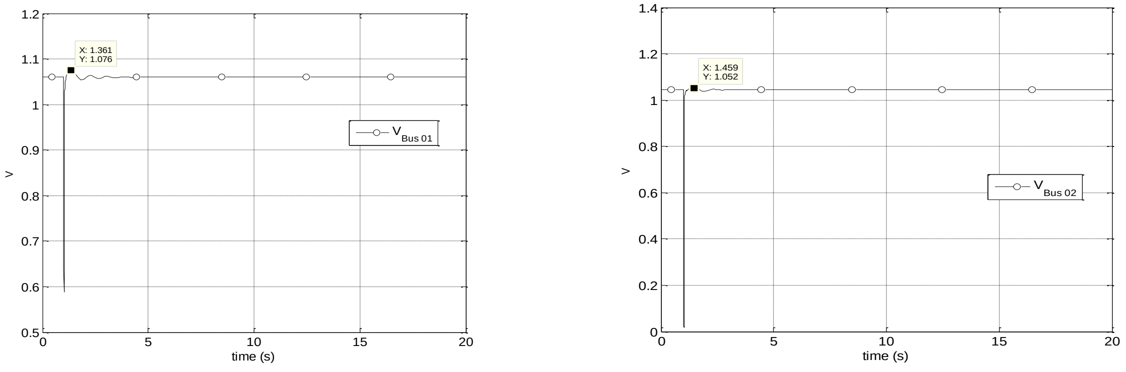
In this stage, an appropriate location should be found first for UPFC installation; the results of UPFC installation are shown in table 1. It is observed that by installing UPFC in line 11 connected to bus bar 1 and 2, the maximum value of its loading parameter equals 1.7713 per unit, which has the minimum loading point. By UPFC installation in the line 15 connected to bus bar 5 to 4, the maximum value of its loading parameter equals 2.0831 per unit, which has the maximum loading point.

Table 1. Results of UPFC installation in the lines

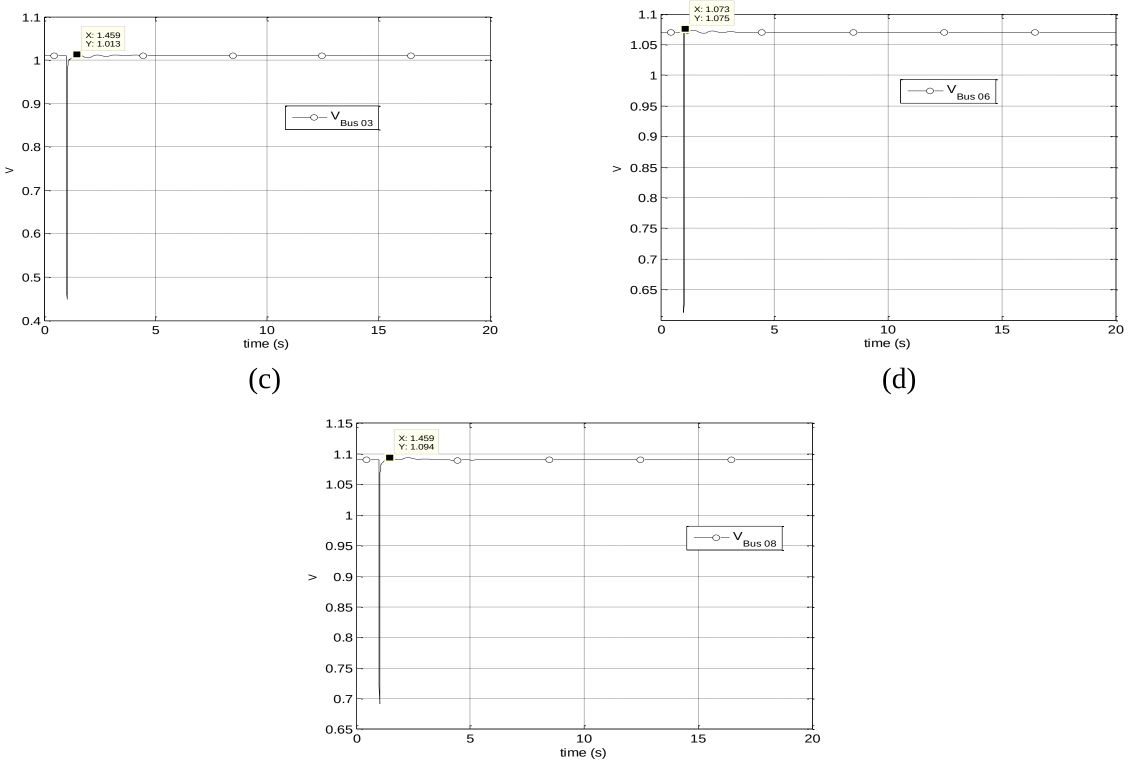
UPFC installation location in the line			Maximum loading point λ_{max} (p.u.)
Line	Bus		
	From	To	
1	2	5	1.9042
2	6	12	1.8922
3	12	13	1.8253
4	6	13	1.8987
5	6	11	1.8988
6	11	10	1.8592
7	9	10	1.9295
8	9	14	1.9341
9	14	13	1.8498
10	7	9	1.9176
11	1	2	1.7713
12	3	2	1.8146
13	3	4	1.7998
14	1	5	1.7717
15	5	4	2.0831
16	2	4	1.9229

So, the most appropriate location for line UPFC installation is line 15, which shows the maximum impacts on the system loading margin increase and static voltage stability improvement. After optimal displacement of UPFC, fault in the network is studied in the presence of UPFC, like stage 5.2.

Figure 8 and 9 respectively represents the size and angle of voltage on the buses in question, in the case of fault in the presence of UPFC in the network. Figure 8 a, b, c, d and e show voltage waveform for the buses 1,2,3,6, and 8 respectively; they indicate that after 0.04 second from the entrance of fault to the network, voltage oscillations of the buses in question are more damped in the presence of UPFC in comparison with the absence of UPFC; they are also get damped faster in this case.



(a) (b)

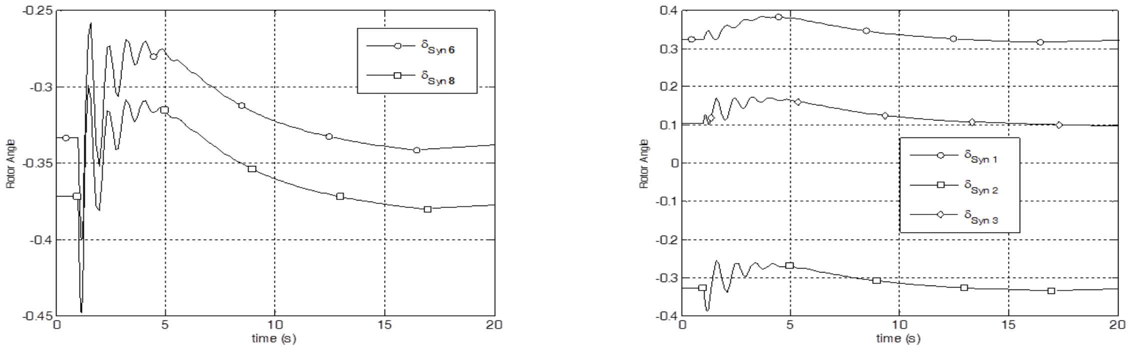


(c) (d)

(e)

Figure 8. Voltage waveforms a, b, c, d and e of the buses 1,2,3,6 and 8 by creating fault at the bus 2 in the presence of UPFC in the network

Figure 9 a and b show the output terminal voltage angle waveform of the generators 1,2,3 and 6,8 respectively by creating fault at the bus 2, in the presence of UPFC in the network; they indicate that what changes occurred in network's transient stability in the presence and absence of UPFC.



(a) (b)

Figure 9. a and b show output terminal voltage angle of the generators 1,2,3 and 6,8 respectively by creating fault at the bus 2 in the presence of UPFC

6. Conclusion

As it was seen, when a short circuit occurs in a line, that line is diverted from the circuit and if the remained line is not capable of transmitting the produced power of networks' generators, which feed the existing loads, the generators encounter sudden oscillations of power and voltage angle because of sudden decrease in the received load from the generators; this leads to the intensive sub transient and transient state in generators parameters, which may even lead to the generators' instability. In this paper, for simulation we used UPFC, which is a series FACTS controller, in a sample 14-bus system, where a fault occurs during 0.04 second, by means of PSAT software in two cases of with and without UPFC. Then, the created oscillations on the terminal parameters of the generators connected to the buses were studied. The achieved forms clearly show that UPFC has a great impact on rapid damping of the output terminal voltage angle of the generators, which is among the most important parameters of creating stability in them.

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