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# UPFC and SVC Devices for Transient Stability Enhancement

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*Abstract*— **Transient stability enhancement plays a significant role in ensuring the stable operation of power systems in the event of large disturbances and faults. This paper presents an approach to the implementation of the effect of UPFC and SVC devices in maintaining the stability of power system. A comparison study that highlighted the merits and demerits are given to assess the contribution of the UPFC and SVC. We performed the IEEE 14 bus system using well-known software EUROSTAG.**

*Keywords*— **Flexible ac transmission systems (FACTS), SVC, transient stability, UPFC.**

## I. INTRODUCTION

For many years, one of the major interests that power system should fulfill is satisfying sufficient conditions of stability. This interest is becoming a serious concern.

Following a major disturbance, disequilibrium between mechanical and electrical power can be instituted, this can affect rotor speed variations and can lead to a partial or total outage. It is well established that power system stabilizer is the first measure that has been used to improve damping oscillations of the power system during electromechanical transients [1-4]. Recently, researchers demonstrate that FACTS devices offer an alternative mean to mitigate power system oscillations [5-8].

Power electronic devices have had a revolutionary impact on the electric power systems around the world. The availability and application of thyristors have resulted in a new breed of thyristor-based fast operating devices devised for control and switching operations. Flexible AC Transmission System (FACTS) devices reveal a great interest during the last few years, which have found a wide spread application in the power industry for active and reactive power control. This paper deals with basic operating principles of FACTS devices and provides detailed discussions about the effectiveness of the SVC and the UPFC.

In recent decades, most researchers have attempted to study the problems of instability, especially transient. N. Hashim et al. [9] have analyzed the transient stability of IEEE 14 bus test system by analyzing the characteristics of the machine states, including machine speed, rotor angle, output electrical power and terminal voltage with respect to fault clearing time after the three-phase fault occurs in the system. The IEEE-14 bus system has been also studied in [10], where in both authors have studied the effect of fault location and critical clearing time on the system stability. In order to achieve this, the behavior of the synchronous machine has analyzed, in particular, the angular position of the rotor. Ref [11] provided a solution to the problem of transient stability. To test a constrained optimal power flow, and estimate critical clearing time and developed a new analytical function.

In [12], the author presents a comprehensive review of the research and developments in FACTS controllers and their contributions to improving system stability. He has highlighted several technical issues related to FACTS installations, and also discussed a comparison of different FACTS controllers. UPFC performance for the transient stability of power grid was studied in [13]. He showed through simulations under MATLAB / Simulink the viability of UPFC to damp oscillations in electrical power networks. Reference [14] deals with the comparison of various FACTS devices in enhancing power system stability. Comparative studies were carried out in the IEEE 5-Bus network and in a two-area power system. Compared to SSSC (Static Synchronous Series Compensator ), SVC and TCSC, it was concluded that UPFC is the better in regulating bus voltage, controlling power flows in addition to reducing the losses in lines. Reference [15] discussed the use of SVC, TCSC and UPFC in the improvement of dynamic and transient system stability. They compared the three FACTS based on their mathematical models and operation modes. It was found that UPFC provided the most rapid control and the highest performances in stabilizing the system.

Thus, the main idea of FACTS technology is to increase controllability and to optimize the utilization of the existing power system capacities using the reliable and high-speed power electronic devices instead of mechanical controllers. That is why in this paper, we confirm once again the need to integrate FACTS device like the UPFC and SVC in the power system to improve transient stability. SVC is the most used

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type in power systems, and UPFC the most powerful device in the present day transmission and control systems.

This paper aims at giving a contribution to improving the stability of power system using FACTS devices such as the UPFC and SVC based on simple heuristic method. Section II defines the FACTS devices. Mathematical formulations of each component of the system are given in Section III. The simulation results of the IEEE-14 bus system are presented in Section IV. Finally, the conclusion is given in Section V.

## II. FACTS DEVICES

FACTS concept includes all power electronics-based devices that improve system stability management. FACTS devices are used for the dynamic control of voltage, impedance, and phase angle of high voltage AC lines [16]. They are installed in the lines and critical regions to control the stability of the system. Thus, they provide strategic benefits for greater control of power; increased transmission system reliability and availability; greater ability to transfer power, prevention of cascading outages and damping of power system oscillations. There are many types of FACTS systems [17]. We will make a brief description of the main types:

1) Static Var Compensator (SVC)

It is important equipment of reactive compensation, which is compared in voltage supporting. SVC is used for improving the transient stability. It is considered as a continuous, shunt variable susceptance, which is adjusted in order to achieve a specified voltage magnitude while satisfying constraint conditions [18-20].

2) Thyristor Controlled Series Compensator (TCSC)

The adjustable series compensator is conventional series capacitor through adding a thyristor-controlled reactor. TCSC is one of the most popular FACTS controllers, which allows rapid and continuous modulation of the transmission line impedance [21-23]. The main benefits of TCSCs are increased energy transfer, dampening of power oscillations, and control of line power flow.

3) Static Phase Shifter (SPS)

SPS is a transformer that substitutes the mechanical tap-changer with thyristors. It is installed in transmission lines. Conventional applications of SPS are for steady-state, power flow regulation and voltage regulation [24].

4) Unified Power Flow Controller (UPFC)

UPFC can control three parameters either individually or in appropriate combinations at its series-connected output while maintaining reactive power support at its shunt-connected input device. The aim of UPFC is to enhance the usable transmission capacity of lines and control the power flow. UPFC is the most powerful and versatile device [25-28].

## III. MODELING OF TEST SYSTEM

### A. Model of Machine

The generator is represented by the four-order model comprising of the electromechanical swing equation and the generator internal voltage equation. The model can be written as follows [1]:

$$\begin{cases} \frac{d\delta}{dt}=\omega-1 \\ M.\frac{d\omega}{dt}+D.(\omega-1)=P_{m.pu}-P_{e.pu} \\ \frac{dE'_q}{dt}=\frac{1}{T'_{do}}(E_{fd}-E'_q+(X_d-X'_d).i_d) \\ \frac{dE'_d}{dt}=\frac{1}{T'_{qo}}(-E'_d-(X_q-X'_q).i_q) \end{cases} \tag{1}$$

Where:

$\delta$: rotor angle of the machine;

$\omega$: rotor speed ;

$M$: inertia coefficient of machine;

$D$ :damping coefficient of machine;

$P_m, P_e$: mechanical and electrical power of the machine;

$E'_d, E'_q$: voltage behind the direct and quadrature axis transient reactance $X'_d, X'_q$.

$T'_{d0}$: d-axis open circuit transient time constant.

$T'_{d0}$: q-axis open circuit transient time constant.

$E_{fd}$: field voltage

### B. Model of SVC

Fig. 1 shows the dynamic model of SVC. It can be modelled as variable shunt admittance with a thyristor controller. However, by neglecting the losses of SVC, we can consider it as ideal, so the admittance is purely imaginary and is described by the equations (2) and (3):

$$G_{SVC}=0 \tag{2}$$

$$y_{SVC}=jB_{SVC} \tag{3}$$

The susceptance $B_{SVC}$ can be capacitive or inductive. Indeed, in the case of reactive power excess, SVC absorbs the increased amount through the inductor and in the opposite case; the capacitor cover the reactive demand.

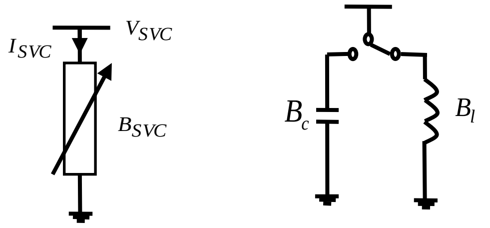

Fig.1. SVC model.

### C. Model of UPFC

UPFC is capable of both supplying and absorbing real and reactive power. The model of UPFC implemented in a transmission line is shown in Fig.2. The main features are two converters, one connected in series with the line through a series insertion transformer, and one connected in shunt with the line through a second transformer. The DC terminals of the two converters are connected together, and their common dc voltage is supported by a capacitor bank. A mathematical model of the UPFC is well-detailed in [29].

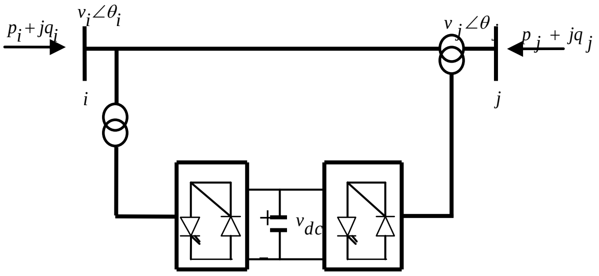

Fig.2. UPFC model

## IV. SIMULATION

### A. Case Study

A 14-bus test system as shown in Fig. 3 is used for transient stability studies. The test system consists of five generators and eleven load bus. The simulations use software EUROSTAG. It is a powerful simulator, which in particular allows the user to build dynamic models of his own, integrated into the simulation. Process and control phenomena are implemented by means of such editable block diagrams, called macroblocks. A library of standard models is provided, and the user may adapt them or create quite new instances [30]. The behaviour of the test system with and without FACTS devices under different fault conditions is studied.

The generators are modelled as an ideal voltage source behind the synchronous reactance of the machines. The model adopted for the transmission lines considers the resistance and the reactance, neglecting the shunt capacitance. The transformer model includes the short-circuit impedance. The loads are modelled as constant impedance. The all data for simulation were selected from [31].

Two types of fault are simulated; a bolted three-phase fault at bus 14 with duration of 100ms and the total load on system was evenly increased by 25%, without any modification to the network configuration. We will connect SVC at bus 9 and UPFC between the two buses 1 and 2. Power dimension of SVC is ± 60 MVAR. UPFC sized to ± 200 MVAR.

### B. Case 1 : Three-phase fault at bus 14

Variations of rotor angle of the generator G1 is reported in Fig.4. The first oscillation of the rotor angle δ1 without FACTS is almost 16 degrees. Indeed, the increase in the first oscillation is a consequence of triggering and on clearing the fault. Results of simulation without FACTS show a low damping of the oscillations of rotor angle after almost 9s. With the presence of UPFC, angle oscillations are damped more quickly. After integrating SVC, oscillations dampen less rapidly.

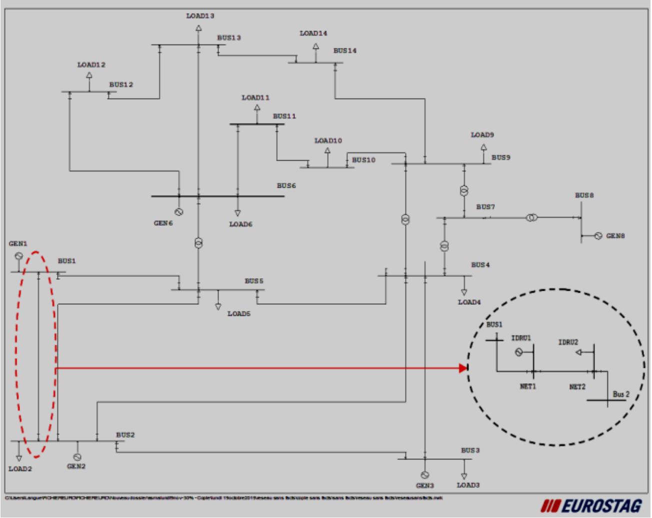

Fig. 3. Test model

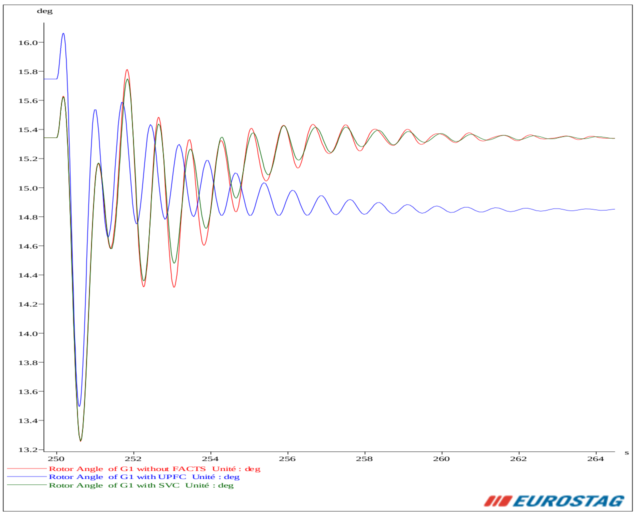

Fig. 4. Temporal evolution of rotor angle for machine G1without and with FACTS.

Fig.5 depicts the temporal evolution of voltage at bus 2. Let us note that a direct short circuit in the system causes the voltage drops which reach its minimum beyond a certain threshold value. On fault clearance, voltage regains its initial value after a few highly damped oscillations.

Despite the presence of SVC in the system, the voltage at bus 2 has a slight improvement; this is due to their location. But with UPFC, the evolution of voltage magnitude is well damped. For the same fault scenario, we have also followed the temporal evolution of rotor angle of machine G1 and the power generated by the two generators G1and G2.

In such scenario, the imbalance between mechanical and electrical power has resulted in increased angular deviations which are reduced to almost the pre-fault values.

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The deviations of the angles without facts and with SVC are more important than with UPFC. This simulation confirms the effectiveness of UPFC in the improvement of rotor angle behavior of critical generator. The oscillations of electrical power of generator G1 and G2 show an improvement in the damping with UPFC. The peak of electrical power is respectively for G1 and G2 approximately 0.5pu and 0.9pu following fault clearance. The addition of UPFC has remarkably improved damping of power oscillation compared to the action of SVC. Fig. 6 and Fig 7 illustrate this improvement in power level. Fig.8 displays the voltage at bus 14, where we applied short circuit. With UPFC action, the system exhibits an improvement for the evolution of voltage. Thus, a desired stable voltage profile was obtained compared to the action of SVC.

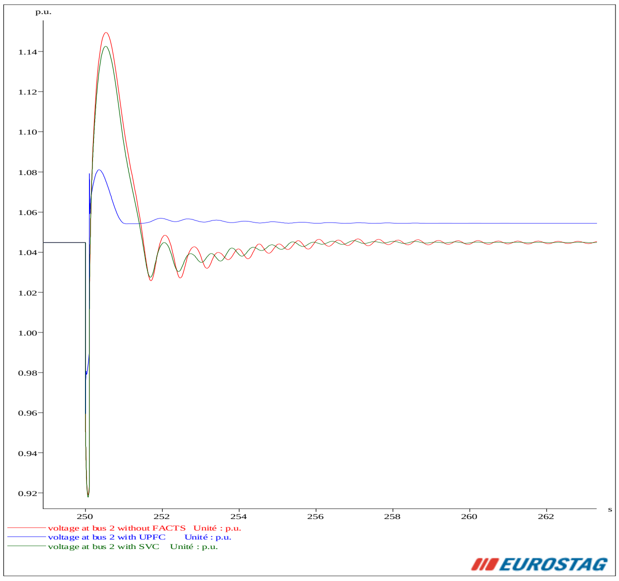

Fig. 5. Voltage magnitude at bus 2 without and with FACTS.

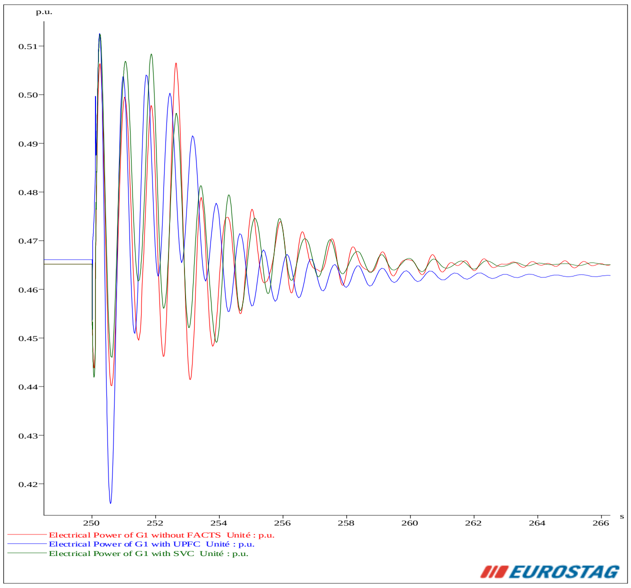

Fig. 6. Temporal evolution of power generated by machine G1without and with FACTS.

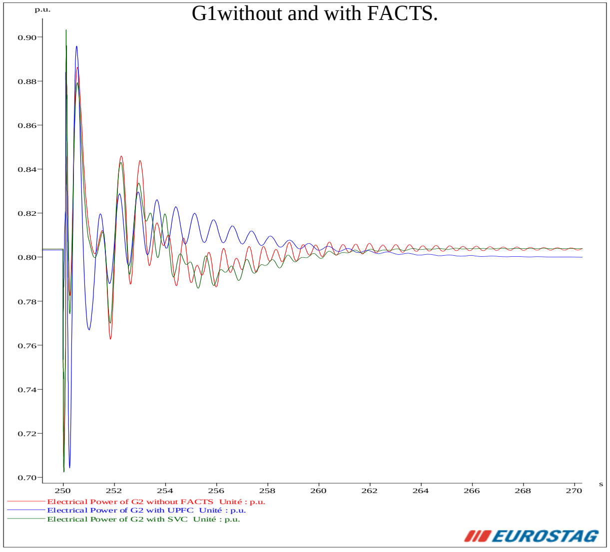

Fig. 7. Temporal evolution of power generated by machine G2without and with FACTS

The fact that the electrical power supplied is a function of the voltage, it decreases considerably, and high acceleration energy thus appears at the rotor, which causes an increase in the speed of rotation (Fig.8). We note that the variation of the speed and power of the generator as a result of this fault is to a regime damped oscillatory. Then we can say that the system is stable under these conditions. Generator speed and hence rotor angle varies according to a damped oscillatory pace around their initial equilibrium point. Therefore, these simulation results show that an effective damping of oscillations was achieved in the power of the two generators, rotor angle and buses voltages in the presence of UPFC.

Thus, there is a well improved transient stability with this device which allows the control active power, voltage magnitude and angle.

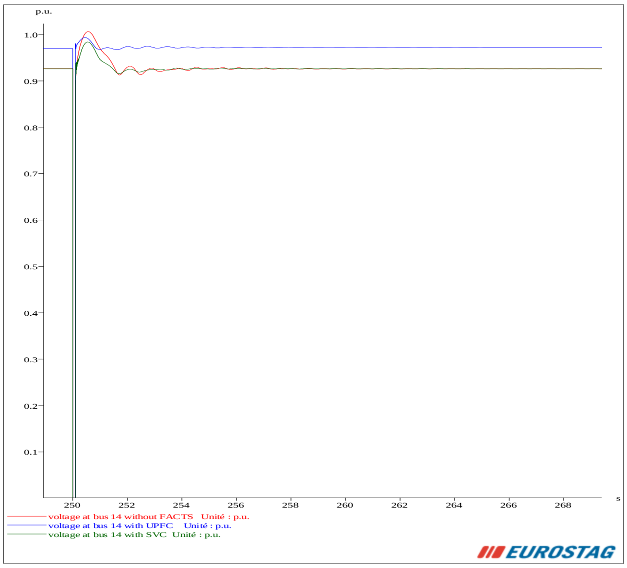

Fig. 8. Voltage magnitude at bus 14 without and with FACTS.

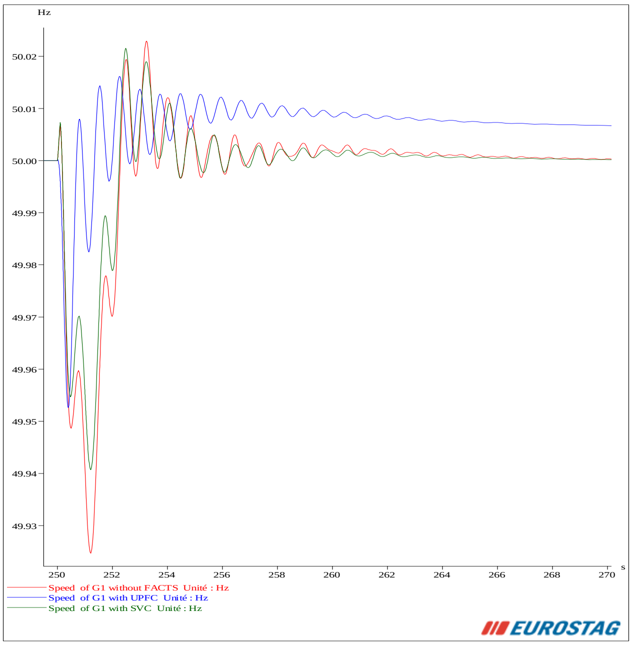

Fig. 9. Variation in the speed of machine G1 with and without facts.

### *C. Case 2: 25%-Load increase on the system*

Based on the results obtained from the short circuit at bus 14, we simulate the P and Q load over the network was evenly increased by 25%. Fig.10, 11 and Fig 12 show respectively oscillations of variation of rotor angle of generator G1, the temporal evolution of both voltages at bus 1 and bus 9 with and without FACTS. When the load increases electrical power as well as rotor angle δ1 is large, with a considerable voltage drop at different buses. As an example, the voltage at node 9 will drop from 0. 04pu and regain a value as 0.935pu, value below the threshold value, without the presence of FACTS. The system presents the same voltage profile even with the presence of SVC. With the integration of UPFC, the voltage reaches the value of 0.98pu with good damping of the oscillations.

The impact of SVC, on the variation of rotor angle, is almost negligible. Thus, it is difficult to improve network stability in the presence of a single SVC. For actions of UPFC, are the better, since it provides independent control of voltage, real and reactive power of the network. Lastly, note that in contingency cases, when the fault is cleared, SVC action is not very significant for stability improvement and oscillations dampening. Nevertheless, with UPFC an effective damping of these oscillations was achieved.

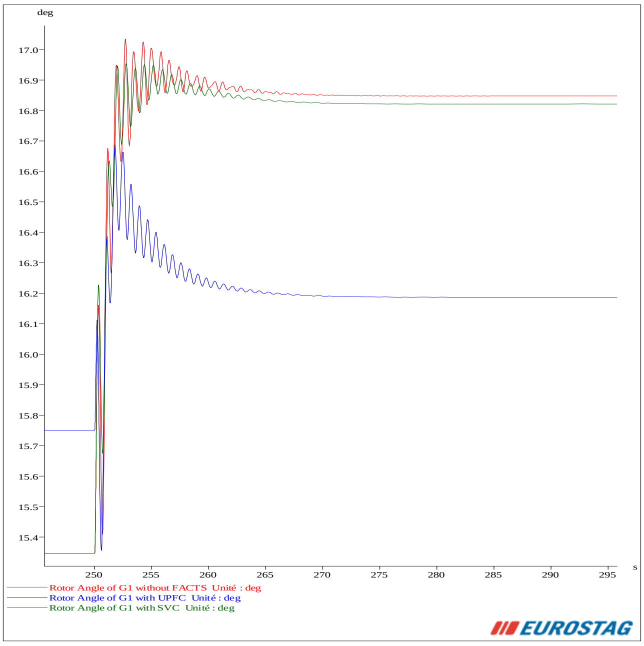

Fig. 10. Temporal evolution of rotor angle for machine G1 without and with FACTS.

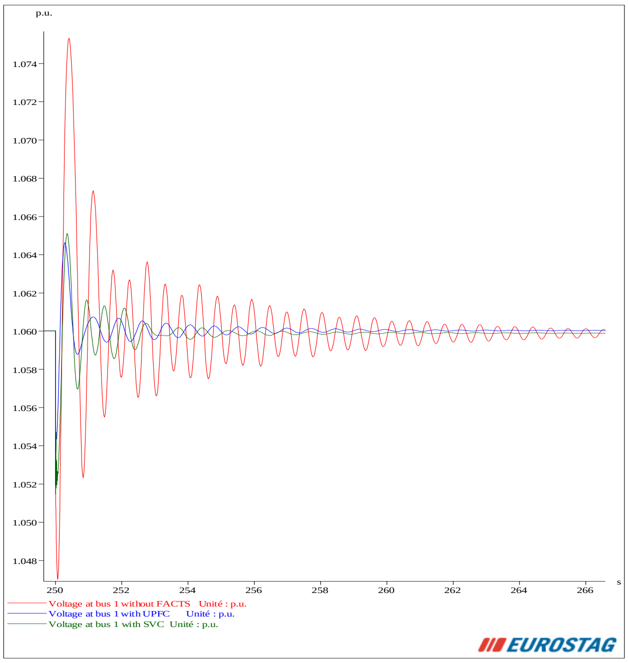

Fig. 11. Voltage magnitude at bus 1 without and with FACTS.

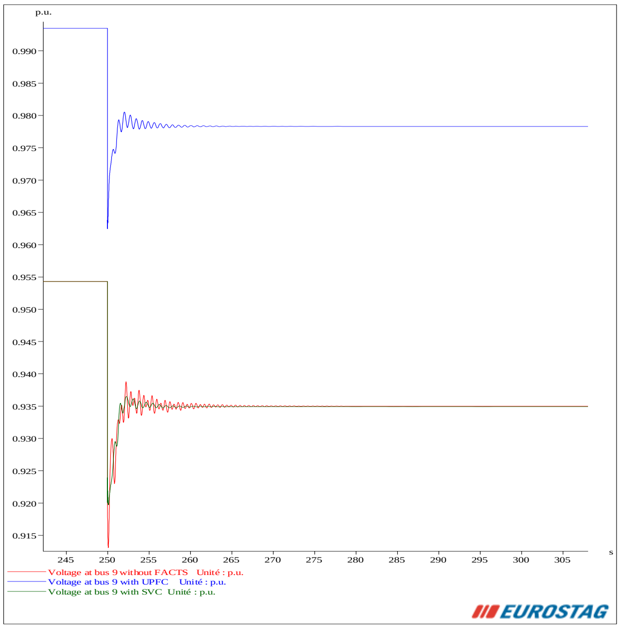

Fig. 12. Voltage magnitude at bus 9 without and with FACTS.

## V. CONCLUSIONS

This paper has presented an approach based on simple heuristic method to improving the stability of power system. Thus, a curative action using FACTS devices such as the UPFC and SVC are proposed. A comparison study that highlighted the merits and demerits, of each device, was given to assess their contribution. Simulation results have revealed an inefficient action of SVC to maintaining transient security and a good damping action of UPFC. Therefore, the effectiveness of UPFC in improving transient stability and reducing the harmful effects of the dangerous fault is proved.

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