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Comparison of UPFC, TCSC and SVC for Improving Voltage Stability

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***Abstract*—SVC, shunt device, performs voltage regulation of the bus by injecting reactive power into the system. TCSC, series device, which controls the impedance of the line in which it is connected. And UPFC, combination of series and shunt devices, can accomplish voltage support, power flow control and dynamic stability improvement. This paper deals with comparative analysis of SVC, TCSC, and UPFC. It consists to prove the coherence and effectiveness of these FACTS to improve voltage stability. The comparison will be based on voltage levels and powers transited through transmission lines. The implementation of dynamic models of various compensators was performed in the standard IEEE 14-bus network and simulations are carried out within the dynamic simulation software EUROSTAG.**

***Keywords*— EUROSTAG, SVC, TCSC, UPFC, voltage stability.**

I. INTRODUCTION

Power system must always operate in allowed stability margins. However, rapid growth of power demand due to industrialization and urbanization, appearance of contingencies of different origins such an increase in load or a short circuit etc ... lead the network to work much closer to its stability limits. As a result power system became more sensitive to the problem of instability. Voltage stability has been one of the major problems facing the electric power utilities in many countries. It relates to system ability to maintain all its buses voltage within permissible limits, after being subject of a disturbance. Effective control of reactive power can improve voltage profile and as a result enhance post-fault stability recovery. Conventional means such as automatic voltage and speed regulators and power system stabilizers [1] were used to improve voltage stability. In addition, there are many electromechanical devices such as tap changer transformer and capacitors which are devoted respectively to control active and reactive power. However they are very slow to ensure continuous power control [2]. Recently, the great evolution of power electronics, has given privilege to FACTS devices (Flexible AC Transmission Systems) in terms of rapidity, efficiency and flexibility to better exploit power system and improve its dynamic behavior.

Having acquired an epic popularity, Unified Power Flow Controller (UPFC) is able to act on all power system network parameters in order to control reactive and active power flow in a transmission line and adjust bus voltage where it is connected. Static VAR Compensator (SVC), as a shunt device, is mainly used to improve voltage profile by suitable control of reactive injections through its equivalent reactance. As for Thyristor Controlled Series Compensation (TCSC), it is designed to be connected in series to control power transfer through transmission line and protect it.

Reference [3] deals with enhancing power system stability using FACTS devices. It compared the performances of Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC) and UPFC during different disturbances. Results showed the efficiency of both SSSC and UPFC in damping oscillations rapidly and ensuring stability recovery.

G.P.Yuma *et al* [4] conducted a comparison between two combinations SVC-PID and SVC- STATCOM for the improvement of voltage stability and damping of oscillations by determining the optimal location of FACTS.

W.Hu, *et al.* [5] studied the impact of SSSC and STATCOM on power system stability. Comparative analysis showed that the two FACTS ensure the same oscillations damping. However authors considered SSSC as the proper controller in the study case for its lower cost compared to STATCOM.

This paper presents a comparative study between UPFC on one side and SVC coordinated with TCSC on the other side. Such a comparison once conducted, leads us to evaluate FACTS effects on the performance of power system in term of voltage stability. In addition, in this work, we will conclude if the combination between shunt and series compensators can replace the hybrid one in supporting voltage stability or compete it at least. Thus, we will adopt two comparison criteria: voltage magnitude and powers transmitted through transmission lines. In order to analyze the dynamic behavior of power system network, a simulation study on the effectiveness of FACTS devices is applied over an IEEE 14 bus system and their results are discussed. Two scenarios cases were considered; an increase in load and the appearance of a short circuit at bus 2.

All models of SVC, TCSC and UPFC are incorporated using Eurostag.

II. STABILITY

The study of power system stability constitutes a major concern for researchers. Reference [6] compared the potentiality of SVC, TCSC and TCPST (Thyristor Control Phase Shift Transformer) in improving voltage stability using dynamic simulations. In [7] the authors performed a comparative study between SVC, STATCOM, TCSC and UPFC to select the most efficient. Simulation results have demonstrated the indisputable contribution of UPFC in

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supplying reactive power at the weakest bus. As a result it ensures the best loading margin improvement. These performances were also evaluated in [8] for three different FACTS: TCSC, SVC and UPFC all introduced simultaneously into the network after being subjected to 200% increase in reactive load. Simulations obtained have shown that the integration of UPFC with the two other FACTS devices has contributed to a better reduction of active losses than in the case without UPFC.

Based on the literature mentioned above, our work focuses on the study of FACTS performances in restoring voltage stability of power system. Among different types of FACTS, there are three which are most common systems in the world namely UPFC, SVC and TCSC. Comparison between hybrid, shunt and series compensators is unobvious due to large differences in the models as well as in main functions [9], for this reason we will examine the action of UPFC compared to that of SVC and TCSC installed together in the study network. Indeed, we will study the response of power system after a considerable increase in total load and then when a three-phase short circuit affects network stability and stimulates the intervention of our compensators.

III. FACTS

Control of compensating reactive power in weak zones of power system ensures the improvement of voltage stability. Traditional means such as capacitor banks are a source of reactive power. There are similarly numerous universal controllers such as tap changer transformer [10] which are capable to stabilize power system. Nonetheless, the limitation and the slow response of such means, give FACTS devices the opportunity to be most used universally in stability study.

A. SVC

SVC which is one of the most installed FACTS systems in world networks [11] is able to provide adjustable reactive power in order to improve voltage profile. Indeed, in case of reactive power excess, SVC absorbs the increased quantity, which decreases bus voltage where it is connected. Otherwise, it acts like a capacitor and produces the reactive required to increase voltage magnitude.

B. TCSC

TCSC is an important device in the FACTS family. It can be modeled as an integrated adjustable reactance in series with transmission line. This structure allows it to adjust line impedance and therefore control powers transmitted through lines. In contrast to shunt compensators, TCSC will be more effective because thyristors can offer flexible adjustment, and more advanced control theories can be easily applied.

C. UPFC

UPFC is a hybrid compensator. It can control the three control parameters (phase angle, line impedance and bus voltage) either individually or in appropriate combinations at its series-connected output while maintaining reactive power support at its shunt-connected input device to enhance the transmission capacity of lines and control the power flow.

IV. SIMULATION

A. Studied model

IEEE 14-bus network is used to assess FACTS equipments capacities. It contains five generators each one has voltage and speed regulators, three of them are synchronous compensators and are connected to buses 3, 6 and 8. It also has two transformers with two windings, a three-winding transformer, fifteen transmission lines and eleven loads. Production in active power of this network is about 272.4 MW and 107.72 MVAR of reactive power. All data relating to this test network are extracted from reference [12].

The proposed test system was carried out in the dynamic simulation environment EUROSTAG. Within this program, loads and transformers are modeled as constant impedance. The generators were modeled as synchronous machines according to PARK's classical theory [13]. It includes four equivalent models, which are the exciter winding, the damper winding in the direct axis with magnetic coupling with the exciter winding, and two dampers in the quadrature axis. As for the shunt compensator, SVC is modeled as a current injector connected to a bus. Fig. 1 illustrates the dynamic model of SVC on EUROSTAG. Dynamic modeling of TCSC is realized by a variable admittance. This can be feasible on EUROSTAG by inserting into fictive buses S and R, two current injectors as shown in fig.2. The initial compensation level is provided by a fixed reactance XSC. Fig.3 shows the model of UPFC. Its interface is realized by two current injectors controlled by four macroblocks provided by software library [14].

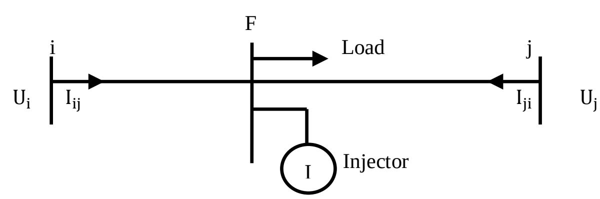

Fig. 1. SVC model on EUROSTAG

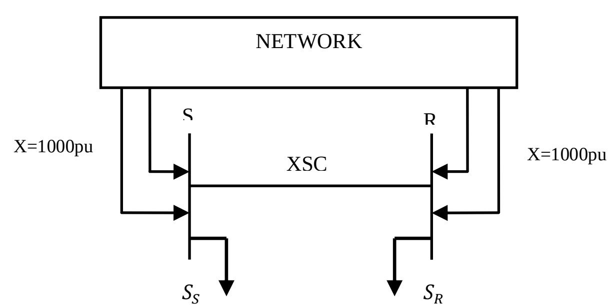

Fig. 2. TCSC model on EUROSTAG

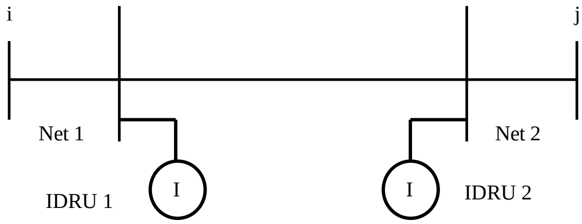

Fig. 3. UPFC model on EUROSTAG

B. Simulation results

The dynamic behavior of the system was studied for two types of scenarios. In the first scenario, the total load on the system was evenly increased by 30% at all the buses without any topological changes in the system. In the second scenario, a bolted three-phase short circuit was applied at bus 2.

We simulated the system without facts, we noticed that it suffers from voltage collapse under a heavy load, and also it cannot resist for a bolted three-phase short circuit. For that reason, we decided to integrate FACTS in the test network to study their impact on voltage stability.

UPFC was connected to the system in the middle of line 9-14 with a capacity of 60 MVA for each one of its two injectors; the choice of this location is based on the critical node in the network. From a series of simulation, we define the node 14 as the weak bus. Thus, compensation of reactive power in this bus, gives a better improvement of voltage stability compared to other buses in the system. Then, we repeated the same simulation replacing UPFC by TCSC and SVC. TCSC is inserted in the same line with a total power of 60 MVA and SVC connected at bus 9 having a capacity of [-60 MVAR, +60 MVAR].

We adopted a comparison criteria based on voltage amplitude as well as active and reactive powers transmitted through lines.

1) First scenario: In this simulation case, we have increased the total load of test system from 259 + j 81.4 MVA up to 336.7 + j105.82 MVA which corresponds to a variation of 30% of initial load, at time t = 250 s.

Fig.4 shows network voltage profiles with and without FACTS devices. We clearly observe a great improvement in voltage level after the intervention of UPFC as well as with the coupled action of SVC and TCSC. This is observable in particular for buses 9, 10, 11, 12, 13 and 14 situated in the same zone where FACTS equipments are installed. However, voltage levels obtained using UPFC are much more increased, in addition buses 2, 3.6, and 8 which are producer buses have exactly recovered their imposed voltage values while this was not the case with TCSC and SVC.

Fig.5 shows the temporal evolution voltage of bus 2 with and without the intervention of FACTS. It is clear that the hybrid compensator was able to restore the same voltage level pre-fault. It should also be noted that with UPFC, voltage drop just at the moment of disturbance is less important than the other case; furthermore oscillations are less severe and more damped. We note also that we obtained similar results for the other buses.

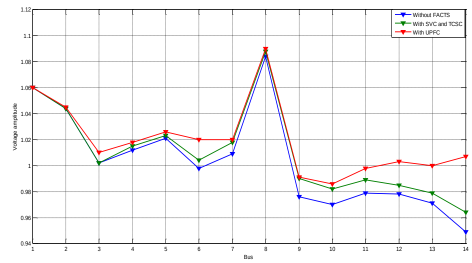

Fig. 4. Voltage profiles of IEEE 14-bus network for 30% load with and without FACTS

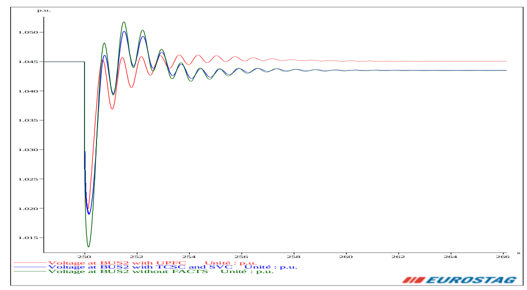

Fig. 5. Temporal evolution of voltage at bus 2 for 30% load increase with and without FACTS.

Fig.6 shows active power transmitted through line 9-10 before and after the action of FACTS. From this figure, it is clear that at time of disturbance, active power has augmented significantly, it increased from 6.45 MW to 8.3 MW for a period of 2.5s and then it continued to oscillate severely to return after 10s to a fixed value corresponding to 8 MW. The implementation of the hybrid compensator has considerably increased the level of active power compared to the case without FACTS, which reached a value of 9.1 MW after some oscillations. However, as we can see in the same figure, the coordinated action of TCSC and SVC has also been successful, in fact these two compensators could increase the active power transmitted through line 9-10 from 6.5 MW to 8.3 MW after 11s, but still lower than that obtained with UPFC.

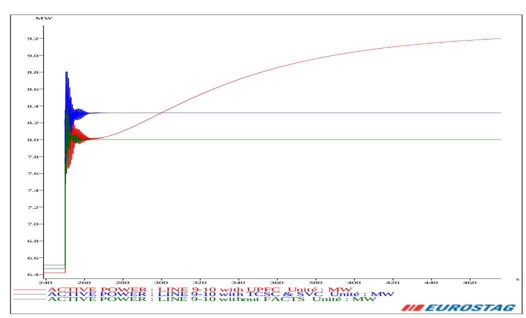

Fig. 6. Active power transmitted in line 9-10 for 30% load increase with and without FACTS.

The contribution of UPFC in controlling transmissible reactive power was also effective as we can see in fig.7. In fact reactive power transited across line 9-10 is reduced by

1.25MVAR. As for TCSC and SVC, they were able to rapidly restore the steady state but with a higher power level in comparison with other cases, about 6.2MVAR which corresponds to an increase of 45.88% compared to basic state.

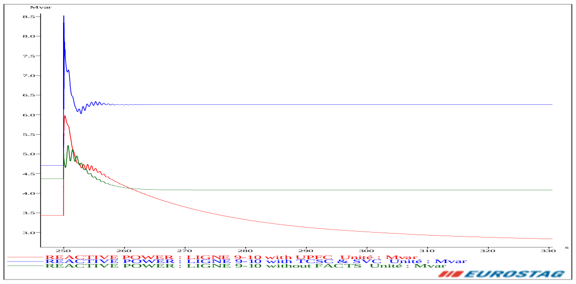

Fig. 7. Reactive power transmitted in line 9-10 for 30% load increase with and without FACTS

2) Second scenario : In order to examine the ability of FACTS in the improvement of power system stability, we chose to apply a permanent and bolted three-phase short circuit at producer bus 2 for a duration of 0.3 s at t = 250 s. Then we kept the same location of FACTS.

Fig.8 shows the temporal evolution of voltage at bus 2 with and without FACTS. We clearly distinguish a serious voltage drop due to fault that could reach 0pu. After some oscillations, voltage could return to its original position. However, the integration of FACTS was not really effective, with the exception of a slight attenuation of oscillations whether with UPFC or SVC-TCSC. As for temporal evolution of voltage at bus 14, presented in fig.9, FACTS were able to improve considerably voltage amplitude and damp oscillations. This is due to FACTS location which is very close to bus 14. Nevertheless the case with UPFC is much better than with SVC-TCSC, it could rapidly reach the steady state after some few oscillations and with the smallest peak just after the disturbance.

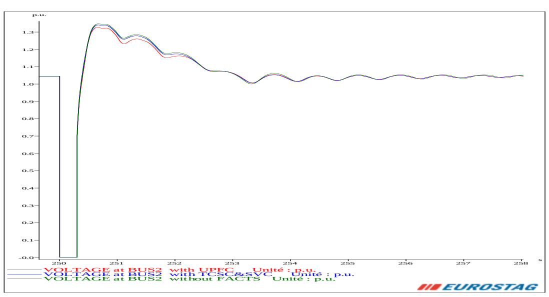

Fig. 8. Temporal evolution of voltage at bus 2 for three-phase short circuit with and without FACTS.

According to results presented previously, we can deduce that the combination SVC-TCSC can compete UPFC in improving voltage stability. It is noteworthy that the most important advantage of UPFC appears significantly in the case of increasing load. It is very efficient especially in supporting voltage levels which have taken exactly the same amplitude than before perturbation. Similarly, the hybrid FACTS could better control reactive power by minimizing its transfer through transmission lines as well as increasing active power transfer, however this was less notable in SVC-TCSC case.

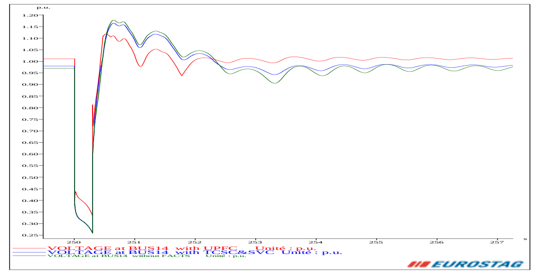

Fig. 9. Temporal evolution of voltage at bus 14 for three-phase short circuit with and without FACTS

V. Conclusion

In this paper, the main objective was to improve voltage stability of IEEE 14-bus system subjected to a disturbance. Simulation results confirm the contribution of FACTS devices to improve node voltage, active and reactive transited power. The comparison between UPFC and SVC-TCSC showed the effectiveness of UPFC. It is the most versatile FACTS controller with capabilities of voltage regulation, series compensation, and phase shifting. However, the response of these FACTS was not significant in short-circuit case, because it is a severe fault for the network and requires other protection devices.

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