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Efficiency Limits of SVC in Improving Voltage Stability

H.Jmii, A.Meddeb, and S.Chebbi

Abstract—**Voltage stability is considered as an important problem for safe system operation. With the development of power system structure and the growing of power demand, this problem became more and more significant. Therefore, researches are always looking for methods for the improvement of voltage stability. In this context, the application of FACTS devices can improve voltage profile, reduce reactive losses and control power transmission. This paper evaluates the capability of SVC in maintaining voltage stability after a small and a heavy load variation. The implementation of the dynamic model of SVC was applied to the standard IEEE 14-bus network and simulations are carried out in the dynamic simulation software EUROSTAG.**

***Index Terms*— EUROSTAG, FACTS, SVC, voltage collapse, voltage stability.**

I. Introduction

Worldwide, one of the main interests of researchers and engineers is maintaining power system stability under satisfactory conditions, which is an ineluctable challenge. Increasing power demand is considered as the major cause threatening power system stability particularly voltage stability. Voltage instability is characterized by a progressive and uncontrollable decrease in bus voltages, which can lead to a total collapse of power system. In this situation, providing a source of reactive power can be an efficient solution [1]. Capacitor banks are traditional measures that have been used to compensate the reactive power.

Recently, the great development of power electronics technology, gives FACTS devices (Flexible AC Transmission System) such as SVC (Static VAR Compensator) more efficiency, rapidity and flexibility to stabilize power system and improve its dynamic behavior when subjected to disturbances. SVC has the ability to control reactive power where it is connected in order to enhance voltage profiles.

Reference [2] presents a new method including an SVC and a TCSC (Thyristor Controlled Series Compensation) to evaluate the voltage stability of interconnected systems represented by equivalent model. G.Yuma *et al* [3] performed a comparative study between two combinations SVC-PID and SVC-STATCOM (Static Synchronous Compensator), to improve voltage stability and damping of oscillations by determining the optimal location of FACTS.

H.Jmii, A. Meddeb and S. Chebbi are with Research Laboratory of Technologies of Information and Communication & Electrical Engineering (LaTICE) at the University of Tunis, Tunisia (e-mail: hajerjmii@yahoo.com, meddebasma@yahoo.fr, souad.chebbi@yahoo.com).

The main purpose of this work is to study the impact of SVC in enhancing voltage stability of perturbed system. The reaction of SVC during major disturbances is also studied. For this reason, we performed load increases of various ranges to analyze the dynamic behavior of the network in presence and absence of SVC. The software EUROSTAG contributed as a dynamic simulation environment where we established the test network IEEE 14-bus.

II. Stability

As it is an important issue, researchers accord a considerable attention to the study of power system stability that is why many works relative to this topic are carried out until now.

Reference [4] studied the maximum load capacity of the Bangladesh power system network, which once reached can lead to voltage collapse. In this case, injection of necessary reactive energy can be a support to the network. It improves voltage profile at various buses. Therefore power system is away from the point of voltage collapse. It was for this reason that authors inserted an SVC in the most vulnerable bus of the Bangladesh network.

The application of FACTS devices to enhance voltage stability was also proposed in [5]. This work focused on the study of voltage stability. To do this, authors proceeded by a gradual increase in system load, which led to a progressive drop in voltage but still always conform to EN50160 [6]. This standard specifies the interval [0.94 pu; 1.06 pu] for MV grid as an allowable range. Nevertheless, writer was talking about voltage collapse situation while voltage level has a permissible value. S.Maram *et al.* [7] were interested also in voltage stability. A large part of their work was earmarked for investigating the positive effect of SVC on the network and its ability to prevent voltage collapse. After being subject of two simultaneous faults: an opening of one line and an increase of 5% in all loads, power system network lost its stability. However, thanks to the action of FACTS device, the system recovered its stable state and voltage stability margins were improved.

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Considering the previous literature, our vision will focus on the study of voltage stability. Indeed, we will examine the response of power system after different load variations. This perturbation is classified in the category of small disturbances [8], nonetheless it can lead to a critical situation when the maximum load capacity of power system is exceeded. The study of the impact of FACTS on voltage stability is also an essential part of our vision; however, according to works that we have referred to, most consider only the positive side of these compensators. Hence, it seems interesting for us to give attention to their operation limits. SVC is widely used in supporting voltage stability [9] that is why; we chose to introduce its model on the side of production network. Throughout dynamic simulations, we will determine to which extent this compensating element is able to restore voltage stability.

III. SVC

Power system instability involves generally serious damages. It is the main cause of voltage collapse which can lead even to a system blackout where power system is unable to produce electric power. Hence, it is essential to equip the network with adequate means of control. Therefore, we resort in the compensation of reactive power in order to control voltage amplitude and as a result the transmission of active power, which improves system stability [10]. Capacitor banks were used to provide reactive compensation, however, when the network is severely disturbed, they become insufficient and unable to meet the reactive power demand. In this context, SVC, one of the most installed FACTS systems in the world networks [11], comes to fill this gap. It is able to provide adjustable reactive power in order to regulate 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.

IV. SIMULATION

A. Studied power system model

In this section, we adopt the standard IEEE 14-bus network as a test system. This network contains five generators each one has two regulators of voltage and speed, three of them are synchronous compensators, two transformers with two windings, a three-winding transformer, fifteen transmission lines and eleven loads. All data relating to our test system are taken from reference [12].

The implementation of the test network was performed via the environment EUROSTAG. This relevant and robust software has extensive modeling capabilities; it can model all the classical network elements such as loads and transformers which are represented by constant impedance. Synchronous machines are modeled by an emf in series with a reactance. SVC is modeled as a current injector incorporated in the middle of a line as shown in fig. 1

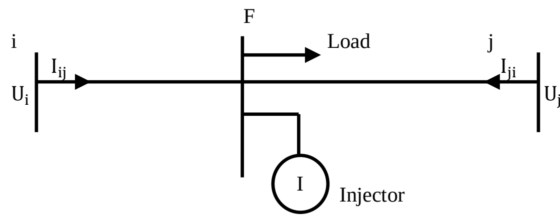

Fig. 1 SVC model on EUROSTAG.

B. Simulation resultats

In the test system, we created a gradual increase of all loads. We considered two ranges of increasing load. The first one consists in making proportionally small load variations not exceeding 40% of the initial load. As for the second method, percentages of load increase are very important, going up to 400%. These two different ranges of load increase will serve us first of all to study power system stability and on the other hand to analyze the ability of SVC in restoring stable state of the disturbed network. Results and discussions of the two simulations are presented in the following subsections.

1) Small load variation: In this simulation setup, we modified the data of all loads from 5% to 40% by a step of 5%, at t = 200 s.

Table I shows buses voltage of various load variation percentages. From one case of change in load to another, a progressive decrease about 0.002 pu is observed in voltage levels of all load buses, while those of generator buses (bus no: 1, 2, 3, 6 and 8) kept constant their amplitudes value, this returns to the role of voltage regulator that these buses are equipped with. It should be noted that up to 30% of load increase, voltage magnitudes remain within the allowable interval and the network remains stable. Starting from the case 35%, some buses are approaching their limit values such as bus10 and bus13, and others reach unacceptable levels in particular bus 14 which reached a value of 0.935 pu in the case of 40%. Thereby, power system loses stability which involves voltage collapse.

2) Large load variation: In this case, we carried out very large load variations; they vary from 100% to 400%. Even though this disturbance is classified as rare, once it takes place in the network, it leads to critical conditions, so it is very interesting to implement it.

Table II represents voltage profiles relative to diverse increases of load. According to this table, it is clear that for all situations the network is unstable, it collapsed dynamically as it is clearly observed especially in buses 9, 10, 13 and 14. From case 200 %, even generator buses could not hold their voltage amplitudes, particularly bus 2. We note as well that bus 14 is the weakest bus in the network, at 400% of load increase it reached the lowest value: 0.626 pu, while only bus 1 which has maintained its voltage level throughout all the simulations because it is the slack bus.

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V. SVC Application

In this part, the limits of SVC in improving voltage stability are evaluated. So we inserted an SVC with a capacity of [-42 MVAr, 42 MVAr] in the middle of line 1-5 in three separate cases of load increase: 15%, 40% and 400%. Fig. 2, fig. 3 and fig. 4 show the temporal evolution of all buses voltage for these three simulations, in absence and presence of SVC. Based on these figures, we notice that the intervention of SVC has a significant impact for the case 15% (fig.2) where voltage profile is well improved. In case 40% (fig.3), the shunt compensator could not restore a tolerable voltage level for critical buses, however, voltage profile remains close to the stable state. In such a situation, an adequate sizing and a good location of SVC can solve this problem.

On the other hand, in case 400% (fig.4), voltage collapse situation is maintained as well as voltage levels of load buses which still below permissible limits, even with the action of SVC. In that case, if SVC is well-sized and well located, it can not restore voltage stability. This is clearly shown in fig. 5 where voltage of bus 5 is seriously collapsed and has had several oscillations even with the presence of SVC. In against part, fig. 6 illustrates the role of our equipment in the re-establishment of another stable voltage level of bus 5 after 40% of load increase.

Based on previous results, we conclude that the effectiveness of SVC in the improvement of voltage stability, degrades more and more as the disturbance happened in the network is accentuated, this proves the limiting operation of this device and its uselessness in the case of major disturbances.

TABLE I
Voltage Profile for Different Change in Load

Bus N°	Voltage(pu) 5% Change	Voltage (pu) 10%Change	Voltage (pu) 15% Change	Voltage(pu) 20% Change	Voltage(pu) 25% Change	Voltage (pu) 30% Charge	Voltage (pu) 35% Change	Voltage (pu) 40% Change
1	1.060	1.060	1.060	1.060	1.060	1.060	1.060	1.060
2	1.045	1.045	1.045	1.045	1.045	1.045	1.045	1.045
3	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009
4	1.022	1.020	1.019	1.017	1.016	1.014	1.012	1.011
5	1.028	1.027	1.025	1.024	1.022	1.021	1.019	1.018
6	0.986	0.986	0.986	0.986	0.986	0.986	0.986	0.986
7	1.014	1.013	1.011	1.010	1.008	1.007	1.005	1.004
8	1.081	1.081	1.081	1.081	1.081	1.081	1.081	1.081
9	0.982	0.980	0.978	0.975	0.973	0.971	0.969	0.966
10	0.974	0.972	0.970	0.968	0.966	0.963	0.961	0.959
11	0.976	0.975	0.974	0.972	0.971	0.970	0.968	0.967
12	0.970	0.969	0.968	0.967	0.966	0.965	0.964	0.963
13	0.965	0.964	0.963	0.962	0.960	0.959	0.958	0.957
14	0.954	0.952	0.949	0.946	0.944	0.941	0.938	0.935

TABLE II
Voltage Profile for Different Change in Load

Bus N°	Voltage (pu) 100% Change	Voltage (pu) 200% Change	Voltage (pu) 300% Change	Voltage (pu) 400% Change
1	1.060	1.060	1.060	1.060
2	1.045	1.040	1.003	0.928
3	1.009	1.008	0.990	0.886
4	0.989	0.941	0.857	0.741
5	0.996	0.945	0.857	0.745
6	0.985	0.970	0.900	0.773
7	0.984	0.944	0.881	0.794
8	1.080	1.080	1.075	1.055
9	0.938	0.883	0.801	0.692
10	0.931	0.877	0.792	0.679
11	0.950	0.913	0.833	0.712
12	0.952	0.921	0.840	0.711
13	0.941	0.904	0.821	0.693
14	0.902	0.840	0.747	0.626

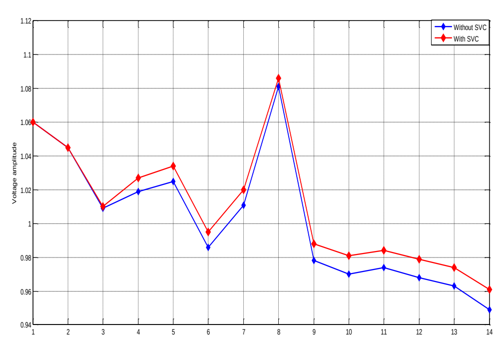

Fig. 2 Voltage Profile of IEEE 14-bus network with and without SVC for 15% load increase.

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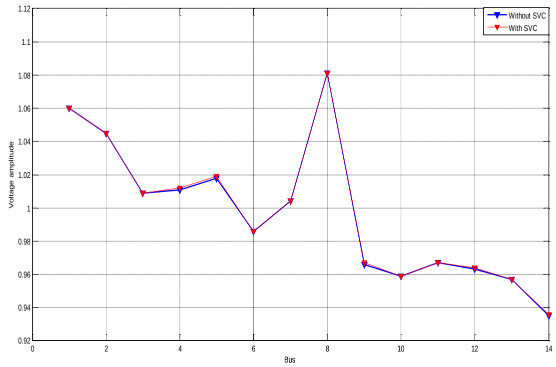

Fig. 3 Voltage Profile of IEEE 14-bus network with and without SVC for 40% load increase.

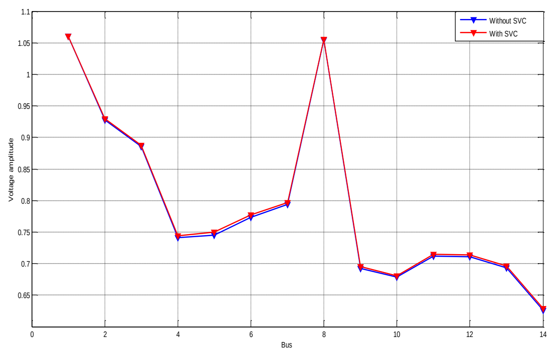

Fig. 4 Voltage Profile of IEEE 14-bus network with and without SVC for 400% load increase.

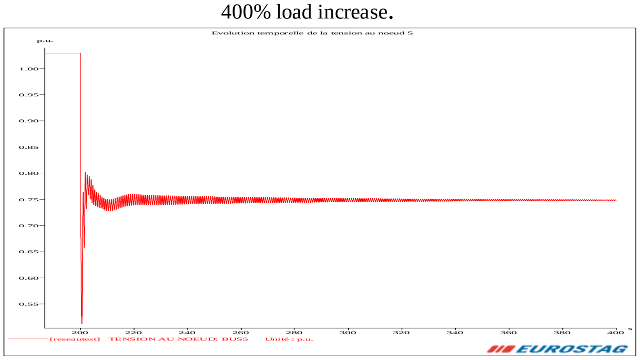

Fig. 5 Temporal evolution of voltage at bus 5 for 400% load increase with SVC.

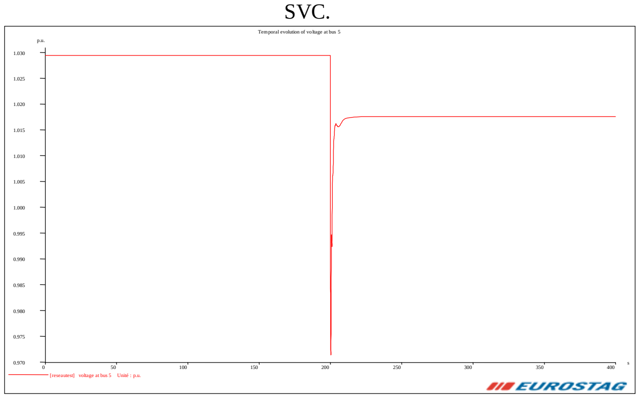

Fig. 6 Temporal evolution of voltage at bus 5 for 40% load increase with SVC.

VI. Conclusion

SVC is commonly used for voltage stability improvement. This paper examined the operation limits of this shunt equipment installed in the test system. Under different load conditions, it turned out that SVC is very efficient in increasing voltage levels of all network buses, not only the zone where it is connected. This, results in avoiding voltage collapse when it is about a relatively small load variation. Nevertheless, if the network is heavily loaded, reactive power provided by SVC becomes insufficient and as a result, power system is unable to withstand voltage collapse condition. Thus, according to this finding, it is essential to search for effective measures other than the incorporation of SVC in case of a rare disturbance with harmful effects. We propose in our earlier works to introduce other types of FACTS which can satisfy network requirements when it is seriously disrupted.

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