

## APPLICATION OF SHUNT FACTS DEVICES FOR A SECURE AND EFFICIENT OPERATION OF THE ROMANIAN POWER SYSTEM

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*The paper presents the impact of the static VAr compensator over the voltage level and the transient stability limit of an electrical power system. Simulations are performed in the Eurostag software on a real database of the Romanian transmission system. The analysis is focused on the south-east area of the country, where a large amount of power was installed in wind power plants, this area becoming a strongly excess of power.*

**Keywords:** Static VAr Compensator (SVC), Transient Stability, Electric Power System

### 1. Introduction

Electric power systems are now becoming increasingly stressed and complex as a result of evolving demands for efficiency and reliability [1]. The integration of the renewable energy sources leaded to the power transfers increases and the power system becomes more insecure, more difficult to operate [2]. In addition, because of environmental and economic constraints, it is difficult to build new transmission line and consequently the power system is operated closer to its capability limits.

Secure and reliable operation is a fundamental requirement for an electric power system. Transient stability analysis is one of the basic analyses in the planning, design and operation of the power system [3]. To analyze the transient phenomena of the system, the time-domain simulation can be divided into three stages: pre-fault, fault-on and post-fault. Before any fault occurs, the pre-fault system is in normal steady state condition. During the fault occurrence, the system

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is said to be in the fault-on condition and it is cleared by the protective system operation. The transient stability problem consists in the study of the stability of the post-fault system after the opening of circuit breakers to isolate the fault. The transient analysis is required to ensure that the power system will survive large disturbances and move into an acceptable steady state condition [4].

The Flexible AC Transmission Systems (FACTS) offers many attractive advantages like voltage control and power flow control [5]. Once with the occurrence of the controlled thyristors devices based on power electronics, new perspective were opened in terms of power system stability improvement [6]. The paper aim is to underline the impact of the shunt FACTS device, SVC, over the voltage level and the transient stability limit in the south-east area of the Romanian power system.

The simulations were made using the Eurostag software [7]. The advantage of this software consists of the ability of modeling large power systems both in terms of load flow and dynamics.

## 2. Static VAr Compensator (SVC)

The Static VAr Compensator is a shunt FACTS device which is using the power electronic technology in order to control the voltage in the connection bus through the control of the absorbed or injected reactive power from the power system [5]. When the voltage level of the system bus is lower than the reference value, the SVC device is generating reactive power (capacitive behavior of the SVC); when the voltage in the system bus is bigger than the reference voltage, the SVC device is absorbing reactive power (inductive behavior of the SVC).

In Fig. 1 it is shown the simplified scheme of a Static VAr Compensator (SVC). The component elements are [8]:

- Thyristor Controlled Reactor (TCR), which is an inductance varied continuously between zero (when the thyristor is not conduction) and the maximum value (when the thyristor is in complete conduction).
- Thyristor-switched capacitor (TSC), which can introduce or not, depending on the necessities, the capacitive compensation. TSC is used together with the TCR in order to have a continuous control in the range maximum capacitive and maximum inductive.
- Electric filters – especially for low range harmonics emission filtering, caused by the TCR functionality. TCRs capacitors contribute to fundamental frequency and to the productivity of reactive power.

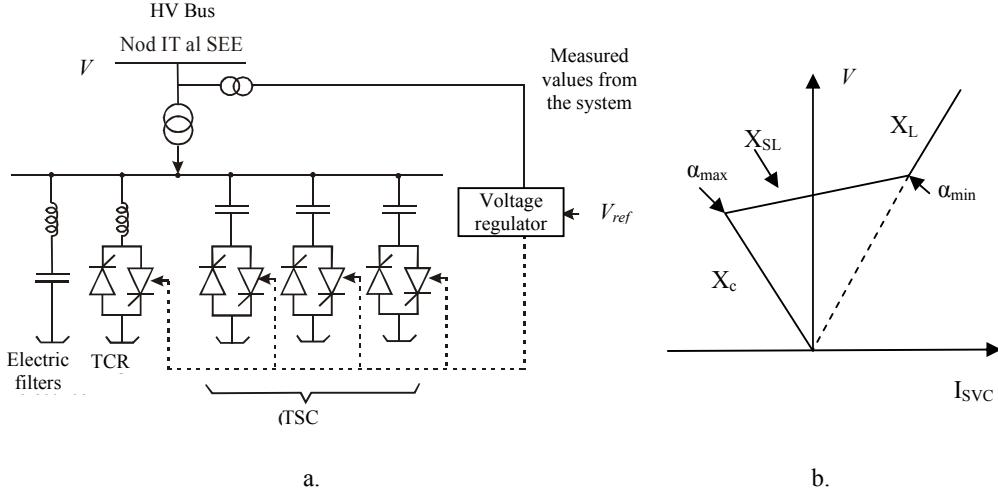


Fig. 1. Static VAr Compensator (a); typical steady state V-I characteristics of a SVC (b).

The steady state V-I characteristics of the SVC are depicted in Fig. 1, b. In steady state regime the SVC can be modeled as a variable susceptance [9]. The value of the  $B$  susceptance depends on the voltage level  $V$  of the connection bus with the system. Depending on the voltage deviation  $\Delta V$ , obtained as a difference between the reference voltage ( $V_{ref}$ ) and the bus voltage ( $V$ ), the control block (Fig. 2) command the modification of the  $B_{SVC}$  susceptance, until one of the limits  $B_{min}$  or  $B_{max}$  is achieved.

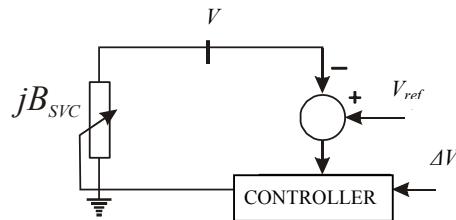


Fig. 2. Variable susceptance model of the SVC.

Considering Fig. 2, the current through the variable susceptance is given by the expression:

$$I_{SVC} = jB_{SVC}V_k \quad (1)$$

and the reactive power generated by the SVC in the connection bus  $k$ , becomes:

$$Q_{SVC} = -B_{SVC}V_k^2 \quad (2)$$

Considering as a state variable the equivalent susceptance  $B_{SVC}$  and having in mind the relation (2), it will be obtained the linearized equation system for the steady state calculation through the Newton Raphson method:

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \end{bmatrix}^{(i)} = \begin{bmatrix} 0 & 0 \\ 0 & Q^{(i)} \end{bmatrix} \cdot \begin{bmatrix} \Delta \theta_k \\ \Delta B_{SVC} / B_{SVC} \end{bmatrix}^{(i)} \quad (3)$$

At the end of iteration  $(i)$ , the variable susceptance  $B_{SVC}$  is updated according to the relation:

$$B_{SVC}^{(i)} = B_{SVC}^{(i-1)} + \left( \frac{\Delta B_{SVC}}{B_{SVC}} \right)^{(i)} B_{SVC}^{(i-1)} \quad (4)$$

The changing susceptance represents the total susceptance necessary to maintain the nodal voltage magnitude at the reference value.

The basic structure of the SVC dynamic model is shown in Fig. 3 [10].

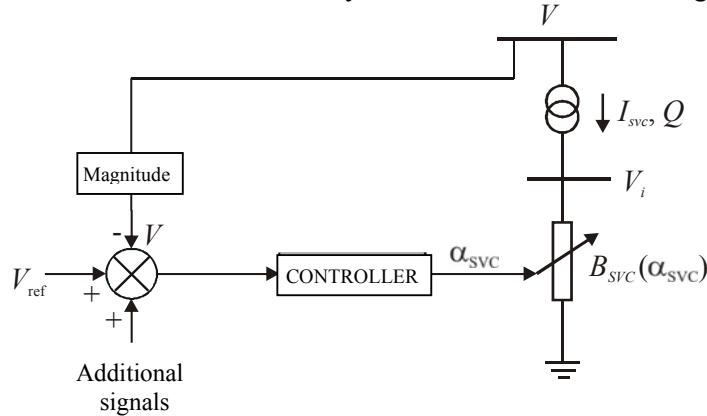


Fig. 3. Simplified dynamic model of the SVC.

The SVC dynamic model is generally described by the following set of algebraic-differential equations where  $x_c$  represents the control variables vector:

$$\begin{bmatrix} \dot{x}_c \\ \alpha \end{bmatrix} = f(x_c, \alpha, V, V_{ref}) \quad (5)$$

$$B_{SVC} - \frac{1}{X_C X_L} \left\{ X_L - \frac{X_C}{\pi} [\pi - 2\alpha_{SVC} - \sin(2\alpha_{SVC})] \right\} = 0 \quad (6)$$

$$I_{SVC} - V_k B_{SVC} = 0 \quad (7)$$

$$Q - V_k^2 B_{SVC} = 0 \quad (8)$$

The differential equations characterize the dynamics of the regulator and depend on its' particular structure. The algebraic equations represent the steady state operating conditions of the static VAr compensator.

### 3. Power system transient stability

Power system transient stability is defined as an ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subject to physical disturbances, with most system variables bounded so that practically the entire system remains intact. The system response to such disturbances involves large excursions of generator rotor angle, power flows, bus voltage and other system variables. The most practical available method of transient stability analysis is time-domain simulation in which the nonlinear differential equations are solved by using step-by-step numerical integration techniques [11, 13].

The mathematic model which describes the dynamic behavior of the power system is made up by [12]:

- a set of differential equations of the generators and the automatic systems of them, asynchronous and synchronous motors, FACTS device, etc.
- a set of algebraic equations composed of the stator equations of the synchronous generators, the power balance equations in the transmission network, etc.

This hybrid model can be described through the following compact form:

$$\dot{x} = f(x, y, \mu) \quad (9, a)$$

$$0 = g(x, y, \mu) \quad (9, b)$$

where:  $x$  is the dynamic variables vector;

$y$  - algebraic variables vector;

$\mu$  - parameters vector;

$f, g$  - vectors whose components are nonlinear and derivable functions.

### 4. Case studies and result analysis

In this section it is studied the impact of the SVC device on the operating conditions of the Romanian Power System. The analyzed area are located in the Dobrogea region, in the south-east part of Romania and this area is bounded by the 400 kV overhead lines Smârdan - Gutinas, Gura Ialomiței - Bucuresti Sud, Pelicanu - Bucuresti Sud, the 220 kV overhead line Barbosi - Focșani, the 110 kV overhead line Slobozia Sud - Dragos Vodă and the 400 kV interconnection overhead lines with Bulgaria, Rahmanu-Dobrudja and Stupina-Varna (Fig. 4). The power exchange between analyzed area and the rest of the Romanian power system and Bulgarian power system respectively quantifies a surplus of 1650

MW. In this moment 1870 MW are in operation in wind power plants, 1400 MW in nuclear power plant and more power will be installed in this region in the next years.



Fig. 4. South-east area of the Romanian transmission system.

The performed analysis consists of identification of the SVC impact on the voltage regulation and improvement of transient stability limit. In this purpose was simulated the functionality of a SVC device with the rated reactive power of 300 Mvar with  $Q_{min} = -200$  Mvar and  $Q_{max} = +100$  Mvar installed in the 400 kV bus Lacu Sărat.

The voltage of the 400 kV bus Lacu Sărat in the case without the SVC is 407,9 kV. In the case with SVC connected in the connection bus it was set as reference voltage the value of 410 kV. In order to maintain the voltage at the reference value the SVC is working in capacitive domain and is injecting in the connection bus 53,6 Mvar. In Table 1 are given the values of the voltages in the studied transmission network in the cases with and without SVC. Also, it can be observed from Table 1 that beside the fact that SVC maintain the voltage in the bus at a reference value it is also improving the voltage level in the nearest electric buses, Gura Ialomitei, Smardan, Isaccea.

Table 1

Nodal voltages from Dobrogea area

Bus	$U_r$ [kV]	$U$ [kV]	$U$ [kV]
		Without SVC	With SVC
Lacu Sărat	400	407,9	410
Gura Ialomiței		405,7	406,6
Pelicanu		405,9	406,4
Cernavodă		403,9	404,4
Medgidia Sud		403,6	404,1
Constanța Nord		404,3	404,9
Tariverde		406,7	407,6
Tulcea Vest		407	408,3
Isaccea		409,3	410,7
Rahman		411,7	412,9
Stupina		411,2	412,4
Smârdan		407,9	409,5
Lacu Sărat	220	229,7	230,7
Filesti		228,5	229,3
Barbosi		228,4	229,1

Starting from the results of the steady state it was simulated in the presence of the SVC, disturbances represented by the variations of the load in the analyzed area ( $\pm 30\%$ ).

In Fig. 5 it can be observed that, after the increase, and the decrease of the load in the studied area, the SVC device is modifying the reactive power injected in the connection bus in order to maintain the voltage level at the reference value.

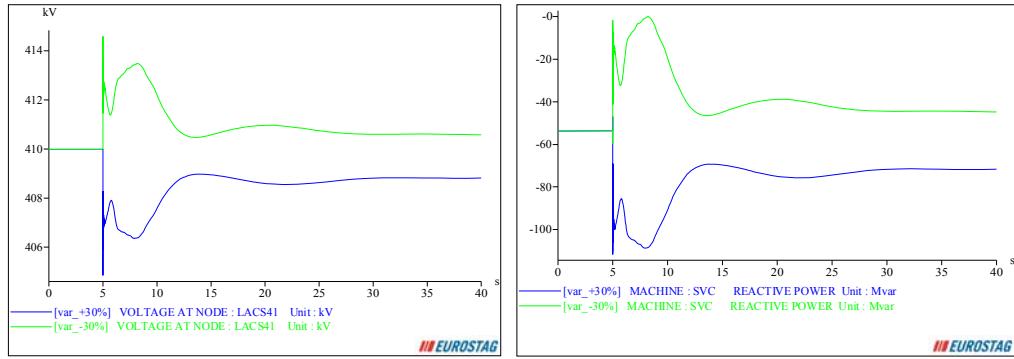


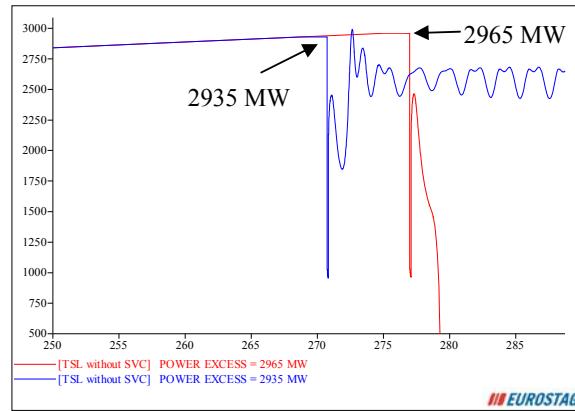
Fig. 5. Voltage in 400 kV bus Lacu Sărat (a) and reactive power of the SVC (b).

In order to identify the transient stability limit the generated active power of the area has been raised and were simulated three phase short circuits on all the overhead lines of the area. This limit was calculated on a network topology with

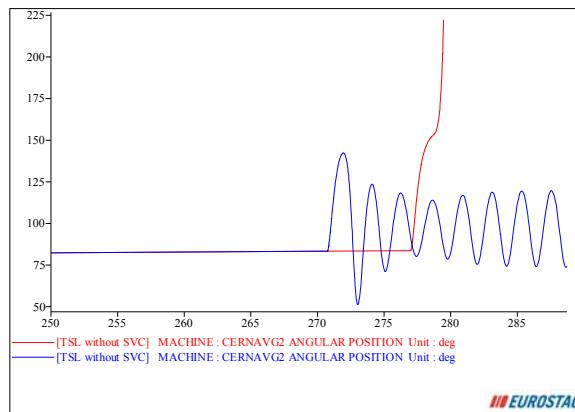
one element out of service. The disturbance which determined the transient stability limit of the generators of the area was the three phase short circuit on the 400 kV OHL Pelicanu-Bucuresti Sud.

➤ *Transient stability limit without SVC*

In Fig. 6 it can be observed that for an excess of active power of the area of 2965 MW the transient stability is lost at the occurrence of a three phase short circuit on the OHL 400 kV Cernavoda-Pelicanu. For an excess of the active power of 2935 MW the stability limit is not lost and is obtained a limit state with undamped oscillations.



a.



b.

Fig. 6. Power excess of the Dobrogea area (a) and angular position for a generator (b).

➤ *Transient stability limit with SVC*

The simulation for the determination of the transient stability limit in the presence of the SVC device has leaded at a limit of the power excess of the area of 3145 MW for which the same disturbance is producing a regime operation with

undamped oscillations (Fig. 7). In this case, other bigger values of the power excess lead to the instability of the generator groups of the studied area.

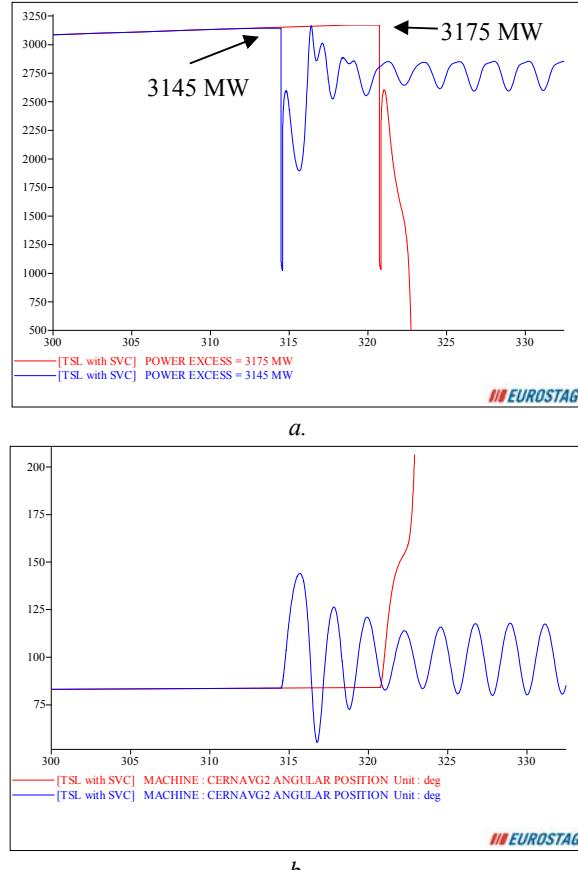


Fig. 7. Power excess of the Dobrogea area (a) and angular position for generator (b).

Comparing the two limit values for which the stability is maintained, it can be noticed that the SVC device installed in 400 kV Lacu Sărat bus increased the transient stability limit with 210 MW.

## 6. Conclusions

The paper underlines the impact of the SVC device over an area of the Romanian Electric Power System. For this purpose, the SVC device was modeled in the steady-state and dynamic database of a real network. Installing a SVC device in the 400 kV Lacu Sărat bus is improving the voltage level in the connection bus and in the nearest substations. By variation of the injection or the

absorption of reactive power, the SVC device maintains the voltage level at the desired value, also in the case in which a disturbance occurs and the device is operates in the linear domain. Regarding the impact over the transient stability limit, the SVC device increases this value with 210 MW. Having in mind the difficulties that appear in the case of other solutions for increasing the stability reserves, as the constructions of new overhead lines, the SVC is a good solution for increase the transient stability limit.

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