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POWER SYSTEM TRANSIENT STABILITY IMPROVEMENT USING SERIES FACTS DEVICES

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The paper presents the impact of the thyristor controlled series capacitor and the static synchronous series compensator over the power flows in a transmission network 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: power system, transient stability, thyristor controlled series capacitor, static synchronous series compensator

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 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

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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 or voltage-source converters 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 series FACTS devices, Thyristor Controlled Series Capacitor (TCSC) and Static Synchronous Series Compensator (SSSC), over the power flows and the transient stability limit in the south-east area of the Romanian power system.

The simulations were made using the Eurostag software [7].

2. Thyristor Controlled Series Capacitor

The Thyristor Controlled Series Capacitor is a FACTS device which consists of a series capacitor bank connected in parallel with a thyristor-controlled reactor in order to provide a variable series capacitive reactance and thus continuous control of the power flow on the transmission line [5]. The TCSC power flow model presented in this section is based on the simple concept of a series reactance that can be automatically varied so that to allow more or less power to flow across the line, as required by the operating conditions. The value of this variable reactance is determined efficiently using Newton-Raphson method. The reactance X_{TCSC}, shown in Fig. 1, represents the all element that are part of the TCSC, when operating in either the inductive or the capacitive regions [8].

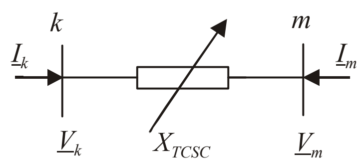


Fig. 1. Thyristor controlled series compensator equivalent circuit

Applying the Kirchhoff theorems on the circuit, the nodal equations result:

$$\underline{I}_k = (\underline{V}_k - \underline{V}_m)\frac{1}{jX_{TCSC}}$$
$$\underline{I}_m = (\underline{V}_m - \underline{V}_k)\frac{1}{jX_{TCSC}} \tag{1}$$

Equations (1) can be written in matrix form:

$$\begin{bmatrix} \underline{I}_k \\ \underline{I}_m \end{bmatrix} = \begin{bmatrix} -j\dfrac{1}{X_{TCSC}} & j\dfrac{1}{X_{TCSC}} \\ j\dfrac{1}{X_{TCSC}} & -j\dfrac{1}{jX_{TCSC}} \end{bmatrix} \begin{bmatrix} \underline{V}_k \\ \underline{V}_m \end{bmatrix} \tag{2}$$

From the matrix equation (2), the nodal admittance matrix is obtained:

$$\left[\underline{Y}_{nn}\right] = \begin{bmatrix} jB_{kk}^{TCSC} & jB_{km}^{TCSC} \\ jB_{mk}^{TCSC} & jB_{mm}^{TCSC} \end{bmatrix} \tag{3}$$

For inductive operation we have:

$$\begin{aligned} B_{kk}^{TCSC} = B_{mm}^{TCSC} &= -\frac{1}{X_{TCSC}} \\ B_{km}^{TCSC} = B_{mk}^{TCSC} &= \frac{1}{X_{TCSC}} \end{aligned} \tag{4}$$

whereas for capacitive operation the signs are reversed.

The active and reactive power equations at bus *k* are:

$$\begin{aligned} P_k &= V_k V_m B_{km} \sin(\theta_k - \theta_m) \\ Q_k &= -V_k^2 B_{kk} - V_k V_m B_{km} \cos(\theta_k - \theta_m) \end{aligned} \tag{5}$$

3. Static Synchronous Series Compensator

The Static Synchronous Series Compensator uses a shunt capacitor which is connected to the transmission line via a voltage-source converter and a series transformer in order to produce a controllable voltage, in quadrature with the line current.

The steady-state model of the SSSC device in series with a transmission line *i-j*, can be represented by a voltage source which has the voltage magnitude V_{SSSC} and the voltage phase γ (Fig. 2) [9], [10].

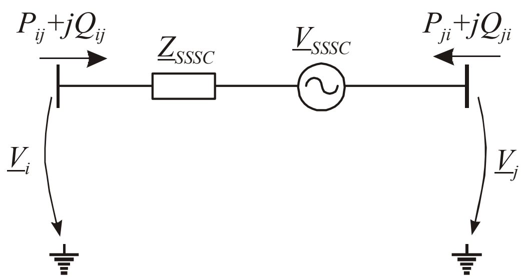


Fig. 2. Representation of the SSSC device in series with a transmission line

The active and reactive power equations which flow between the nodes *i* and *j* are:

$$P_{ij}^{SSSC} = V_i^2 G_{SSSC} - V_i V_j \left[G_{SSSC} \cos(\theta_i - \theta_j) + B_{SSSC} \sin(\theta_i - \theta_j)\right]$$
$$- V_i V_{SSSC} \left[G_{SSSC} \cos(\theta_i - \gamma) + B_{SSSC} \sin(\theta_i - \gamma)\right]$$
$$Q_{ij}^{SSSC} = - V_i^2 B_{SSSC} - V_i V_j \left[G_{SSSC} \sin(\theta_i - \theta_j) - B_{SSSC} \cos(\theta_i - \theta_j)\right]$$
$$- V_i V_{SSSC} \left[G_{SSSC} \sin(\theta_i - \gamma) - B_{SSSC} \cos(\theta_i - \gamma)\right]$$

where:

$$G_{SSSC} + jB_{SSSC} = 1/\underline{Z}_{SSSC} \tag{6}$$

Because the SSSC device can modify the power flow on the transmission line which connects the *i* node with *j* node, in the Newton-Raphson method the power values forced by the device will be added to the nodal powers of these two nodes:

$$\begin{aligned} P_i^{new} &= P_i + P_{ij}^{SSSC} \\ Q_i^{new} &= Q_i + P_{ij}^{SSSC} \end{aligned} \tag{7}$$

4. 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:

$$\dot{x} = f(x, y, \mu) \quad (8, a)$$

$$0 = g(x, y, \mu) \quad (8, b)$$

where: x is the dynamic variables vector;
y - algebraic variables vector;
μ - parameters vector;
f,g - vectors whose components are nonlinear and derivable functions.

4. Case studies and result analysis

Currently, the total capacity in the Romanian Power System installed in wind power plants is 1940 MW, of which 1870 MW are located in the Dobrogea region, in the south-east part of Romania (Fig. 3).

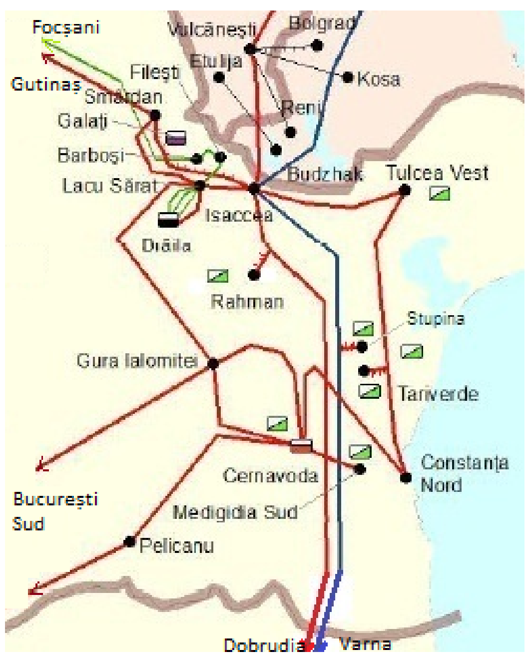
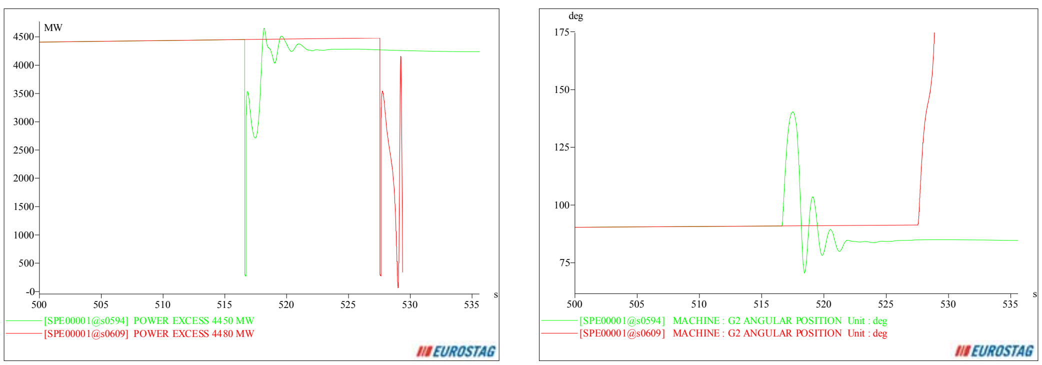


Fig. 3. South-east area of Romanian transmission system

This region encounters today a power surplus that is, sometimes, very difficult to control by the system operator. As more power will be installed in this region in the next two year, an efficient solution should be identified in order to manage the power transfer. One solution for this problem is to build new electric transmission lines, but due to the complex legislation, he high costs of the land, and the duration of construction, new solutions should be quickly identified.

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. In Fig. 4 it can be observed that for an excess of active power of the area of 4480 MW the transient stability is lost at the occurrence of a three phase short circuit on the OHL 400 kV Cernavoda-Pelicanu (red curve). For an excess of the active power of 4450 MW the stability limit is not lost and is obtained a limit state (green curve).



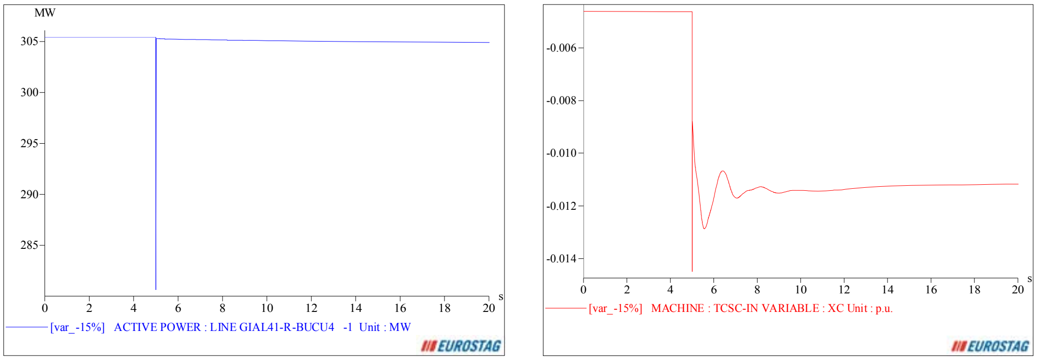
a. *b.*

Fig. 4. Power excess of the analyzed area *(a)* and angular position for a generator *(b)*

The impact of the TCSC and SSSC devices on the power flow control and transient stability has been analyzed in this paper.

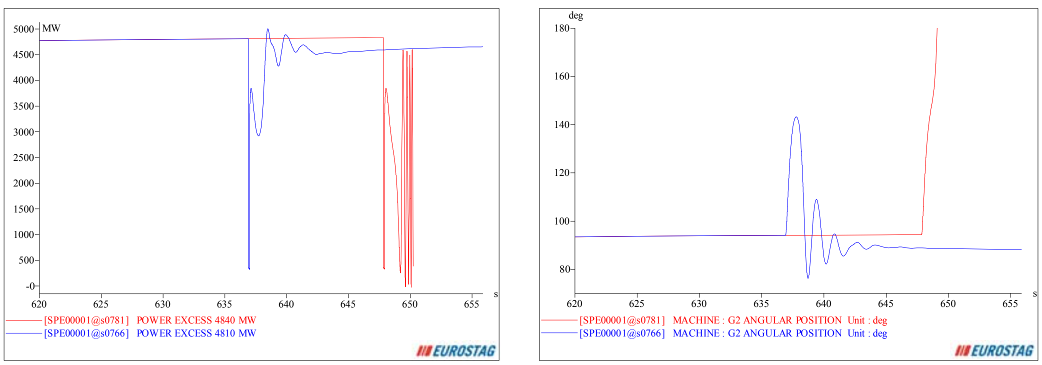
A. TCSC device in series with the 400 kV OHL Bucureşti S.- G. Ialomiței

The purpose is to increase the power flowing on the 400 kV OHL Bucureşti S. – Gura Ialomiței, and the TCSC device is set to operate in the capacitive domain. For a capacitive compensation of 30% of the inductive reactance of the line the active power will increase by 50 MW. In the case of a disturbance that leads to a change in the power flow on the studied line, the TCSC device will modify the compensation reactance in order to maintain the power at the desired value. Fig. 5 shows that for a decrease in the power flow, TCSC will command the modification of the compensation reactance from -0,0045 p.u. to -0,011 p.u. so that to force the power flow to reach the desired value.



a. *b.*

Fig. 5. Active power flow on the OHL *(a)* and TCSC reactance *(b)*



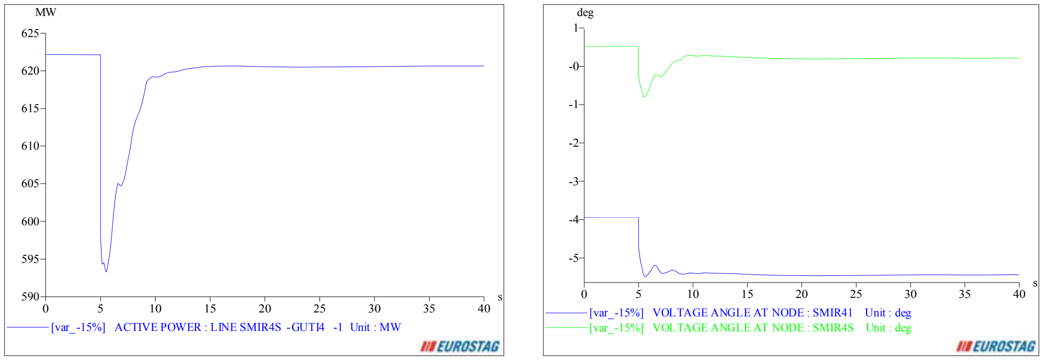
a. *b.*

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

The simulations for the determination of the transient stability limit in the presence of the TCSC device has leaded at a limit of the power excess of the area of 4810 MW for which the disturbance is producing a stable regime (Fig. 6). In this case, other bigger values of the power excess lead to the instability of the generator groups of the studied area (red curve).

B. SSSC device in series with the 400 kV OHL Gutinaş-Smîrdan

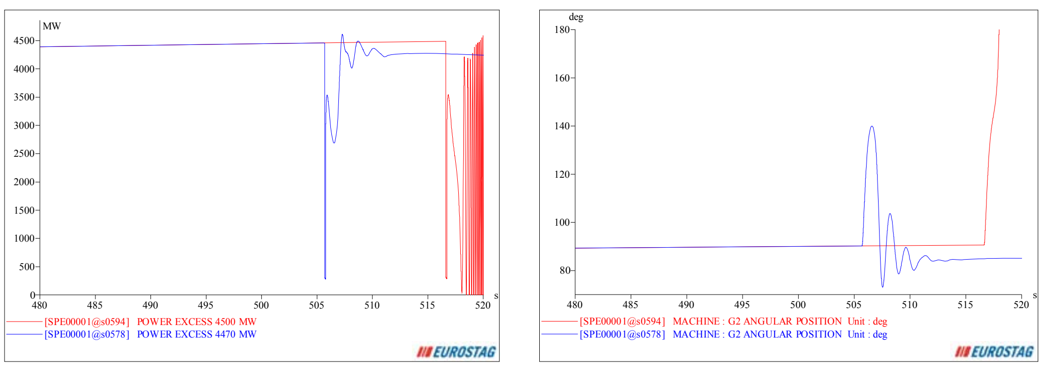
Assumes that the reference value of the active power flow on the OHL Gutinaş - Smârdan is 620 MW, with 100 MW bigger that in the case without the SSSC device. In order to maintain the power at the reference value, the phase shift between the voltages of the two sides of the SSSC is 4,48 degree. In the case of a disturbance which leads to a decrease in the power flow on the analyzed line, SSSC will command the modification of the voltage angle at 5.68 degrees (Fig. 7).



a. *b.*

Fig. 7. Active power flow on the OHL (a) and SSSC phase shift (b).

Regarding the transient stability, SSSC does not lead to a significant improvement of the stability limit. In Fig. 8 it can be observed that for a power excess of the area of 4500 MW the transient stability is lost at the occurrence of a three phase short circuit on the OHL 400 kV Cernavoda-Pelicanu (red curve).



a. *b.*

Fig. 8. Power excess of the analyzed area *(a)* and angular position for a generator *(b)*

6. Conclusions

The simulations have shown that the TCSC and SSSC devices represents effective solutions for active power flow control and may cope the problems about the power transfer from the Dobrogea region under the increasing installed power in wind power plants. The TCSC device is a good solution for increase the transient stability limit, in our case the limit increase with 360 MW while the

SSSC device cause an increase of only 20 MW. However, the optimal place should be performed in order to determine the most effective solution.

Acknowledgement

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