Using TCSC to improve the dynamic stability of the power system

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***Abstract*— The article deals with the research of devices used to improve the transient stability of the power system. It refers to current global electricity trends, leading to ever-increasing electricity transmission. This is due both to the increase in consumption and production of electricity, as well as to the creation of a single electricity market. Recently, there is an increasing problem of the operation of renewable resources with unpredictable production, which also often contributes to the creation of unplanned transit flows and to the deterioration of system stability.**

***Keywords*— TCSC, transient stability, FACTS**

I. INTRODUCTION

For many years, power engineering has been characterized as an integrated structure, consisting of electricity generation, transmission and distribution and trading. The process of liberalization results in the division of this structure. Nowadays, production and trading are organized in a separate organizational structure that are subject to competition, while transmission and distribution remain a natural monopoly.

As electricity trading takes place at two levels: physical and contractual. However, we must recognize that these two levels are completely different from each other. If we want the electricity market to be understood as a network trade, we need to consider and understand basic electrical properties such as:

- Electricity needs a transmission and distribution network.
- Electricity cannot be stored in large quantities.
- Physical transmission of electricity has nothing to do with contracts for electricity trade.

The role of the power grid is essential in the context of electricity business. Its operation is governed by physical laws. Each network element has a final capacity, which limits the amount of electricity that can be transferred. This means that the electricity market, together with the increasing demand for electricity, leads to a strain on transmission systems. This requires operation closer to their stability limit. The operation of power grids is affected by the stability problem, leading to unpredictable behaviour of the system. More cost-effective solutions are getting more and more pre-emptive before network expansion. In many countries, opportunities for significant network expansion are limited, which means that the existing network has to withstand changing requirements. Flexible AC Transmission Systems, so-called FACTS, are already known for several years.

In general, FACTS devices are used to increase transmission capacity, improve stability, or increase electrical power. Their main functions are: reactive power compensation, voltage control and power flow regulation. Due to their control via the power electronics, FACTS provide fast and fine regulation compared to conventional devices.

II. FACTS

A. Flexible AC Transmision Systems

Flexible AC Transmission Systems has proved to be an excellent means of controlling and managing power systems in recent years. Worldwide, many FACTS have been put in place for various applications, and many new devices are still waiting for their first application. Many FACTS devices have been installed in the world mainly because of their ability to regulate various quantities in power systems as well as a replacement for the construction of new lines. Installing a FACTS device that can increase the transmission capability of surrounding lines is cheaper and much faster than the construction of new lines while still offering many other advantageous features in one device such as:

- Power flow regulation
- Improving the transmission capabilities of existing lines
- Voltage control
- Reactive power compensation
- Improved stability (static and dynamic)
- Improving the quality of electricity
- Flicker mitigation

For all FACTS apps, consider investing and choosing a new device [14].

B. TCSC

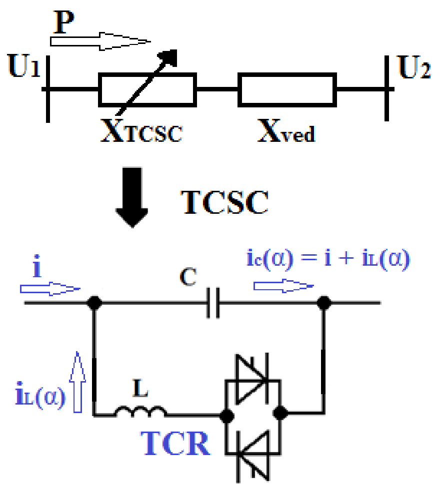

Fig. 1. Connection scheme of TCSC

A thyristor-controlled serial capacitor is designed to troubleshooting of dynamic stability issues in the transmission system. First, oscillation is decreased in interconnected systems and, as a further aid, overcomes the sub-synchronic resonance of SSR that occurs when two series-compensated systems are interconnected. Quick TCSC control allows you to control flow performance allowing to increase the transmission capacity management. The series compensators offer considerable advantages over parallel compensators. When using serial capacitors, the reactive power increases quadrature with current flowing through the line, while using parallel capacitors the reactive power is generated adequately with respect to the voltage quadrant in the node. Another disadvantage of parallel capacitors is that they should be installed in the middle of the line, but with serial capacitors this problem is avoided.

Dependency of TCSC impedance change from thyristor switching angle:

Given that the overall impedance of TCSC is possible to change by changing the impedance of TCR (Thyristor Controlled Reactor), so there are first explained the principle of regulation of TCR.

Current value flowing through the choke $i_L(\alpha)$ we can continuously control its maximum value up to zero by controlling the thyristor switching angle.

If we consider the value of the harmonic waveform of the voltage on coil:

$$u(t) = U_m \cdot \cos \omega \cdot t \tag{1}$$

the instantaneous current value at the time of the flowing impedance is determined according to the following relationship:

$$i_L(t) = \frac{1}{L}\int u(t)dt = \frac{U_m}{\omega \cdot L} \cdot \sin \omega \cdot t \tag{2}$$

When considering the angle of thyristor switching α from the interval $\langle 0, \pi/2 \rangle$ so the current value $i_L(t)$ flowing by single-phase TCR device is given by the following relationships:

$$i_L(t,\alpha) = \frac{1}{L}\int_{\alpha}^{\omega t} u(t)dt = \frac{U_m}{\omega \cdot L} \cdot (\sin \omega t - \sin \alpha) \tag{3}$$

for

$$\alpha \leq \omega \cdot t \leq \pi - \alpha \tag{4}$$

$$i_L(t,\alpha) = \frac{1}{L}\int_{\alpha}^{\omega t} u(t)dt = \frac{U_m}{\omega \cdot L} \cdot (\sin \omega t - \sin \alpha) \tag{5}$$

for

$$\pi + \alpha \leq \omega \cdot t \leq 2\pi - \alpha \tag{6}$$

The relationship (3) represents the flow of the current in the positive half-plane, and the relationship (5) represents the flow of the current in the negative half-plane.

The amplitude of the fundamental harmonic current depending on the angle can be determined after applying the Fourier analysis by the following relation:

$$I_{L1}(\alpha) = \frac{U_m}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right) \tag{7}$$

where U_m is amplitude of the voltage on coil, L is the inductance if the coil and ω is the circular frequency of the voltage. As a result, it is possible to continuously control the amplitude of the current flowing from the maximum value to zero by angular control of the thyristors.

Using relationships

$$I_{L1} = U \cdot B_{TCR}\,,\ B_L = \frac{1}{\omega \cdot L} \tag{8}$$

$$\text{a } I_{L1}(\alpha) = \frac{U_m}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right) \tag{9}$$

it is possible to directly determine the inductive susceptibility of the TCR device (considering only the basic harmonic current flowing through the device) as an α angle function as follows:

$$B_{TCR}(\alpha) = \frac{1}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right) = B_L \cdot \frac{\pi - 2\alpha - \sin 2\alpha}{\pi} \tag{10}$$

Inductive susceptibility of the device TCR $B_{TCR}(\alpha)$ will vary depending on the angle in the same way as the amplitude of the fundamental harmonic current $I_{L1}(\alpha)$, that is, it is possible to change it by the angle of thyristor switching from the maximum value ($\alpha = 0$, $B_{TCR} = B_L$) to zero ($\alpha = \pi$, $B_{TCR} = 0$)

From the equation (10) for the TCR induction reactance

$$X_{TCR}(\alpha)=\frac{1}{B_{TCR}(\alpha)}=X_L\cdot\frac{\pi}{\pi-2\alpha-\sin 2\alpha},\qquad (11)$$
$$X_L\leq X_{TCR}(\alpha)\leq\infty$$

where $X_L=\omega\cdot L$.

From the relation (11) it follows that the inductive reactance of the controlled coil can be varied by the thyristor switching angle from the minimum value ($\alpha=0$, $X_{TCR}=X_L$) theoretically up to infinity ($\alpha=\pi$, $X_{TCR}=\infty$).

III. Model of Power System and TCSC Conntrollers

In the following section, we show the dynamic models of the Slovak Republic transmission system in NEPLAN.

Two models were created in NEPLAN.

- Complete model of Slovak power system (SR PS) without FACTS devices.

This model contains all the elements (nodes, lines and generators, power switches, disconnectors) at voltage levels of 220 kV and 400 kV. All generators contained in this model are controlled by the combined controller shown in the figure Fig. 2. This controller includes the AVR controller as well as the PSS.

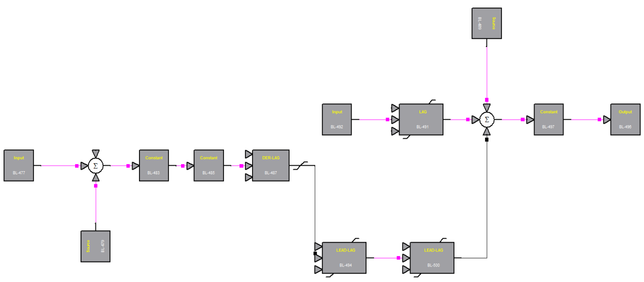

Fig. 2. AVR and PSS controller used fror simulation

- Complete model of SR PS with FACTS device.

This model is a superstructure for the complete model of SR PS without FACTS devices. This model includes a thyristor-controlled serial compensator (TCSC) controlled by the controller. The controller for the case where TCSC is installed on a single line is shown in the figure Fig. 3. The input parameters of this TCSC controller are the active power flowing through the line on which the TCSC is installed as well as the reference value of the TCSC reactance. The TCSC reactance value is different for each TCSC device and depends on the size of the capacitor and the coil from which the device is composed. The regulator output is the total TCSC reactivity value for the control step.

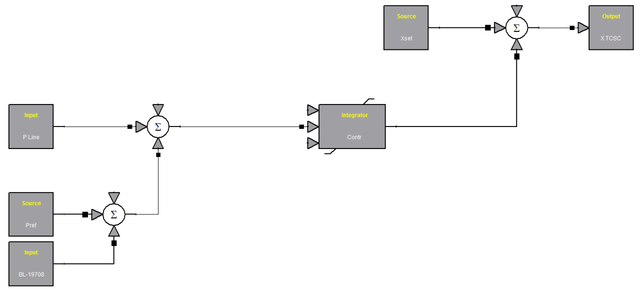

Fig. 3. TCSC controller for installation on single line.

The controller shown in Fig. 4 is used if TCSC is installed on one of the parallel lines. This controller monitors the operating parameters of both parallel lines. Its input parameters are the operating parameters of both parallel lines as well as the reference value of the TCSC reactance. The output of the regulator is the total TCSC reactance.
The controller monitors the maximum permitted load on both parallel lines. This means that the TCSC reactivity value during the TCSC operation must be such as to avoid overloading any of these lines. At the same time, care must be taken to avoid resonance.

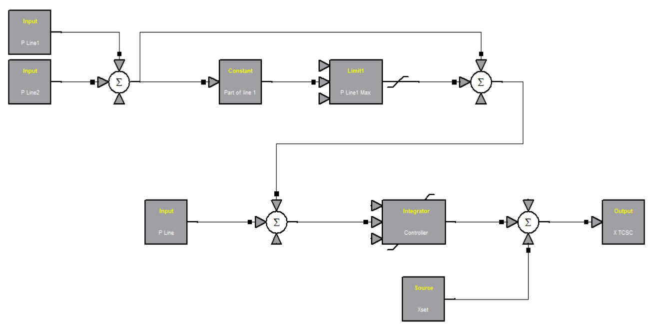

Fig. 4. TCSC controller for installation on double lines

IV. Calculations

A. Scenario 1: Three - phase short circuit on line V 490.

The transient stability simulation was aimed at monitoring the behaviour of the generators in the Mochovce nuclear power plant as well as at the Jaslovské Bohunice nuclear power plant during three-phase shortage on the V 490 line. Another focus of the simulation is the monitoring of the frequency fluctuation in the Križovany and Lemešany stations. In the SR PS, a 3f short circuit was simulated at the end of the V490 line at Levice station. The shorting duration was set according to the ENTSO-E instructions for simulating dynamic phenomena in the power system. The switch-off time for voltage levels 220, 330 and 400 kV is set to 0.150s. The clearing time consists of the following parts:

$$T_{total}=T_{protection}+T_{switch}+T_{security}=0{,}150\ s$$

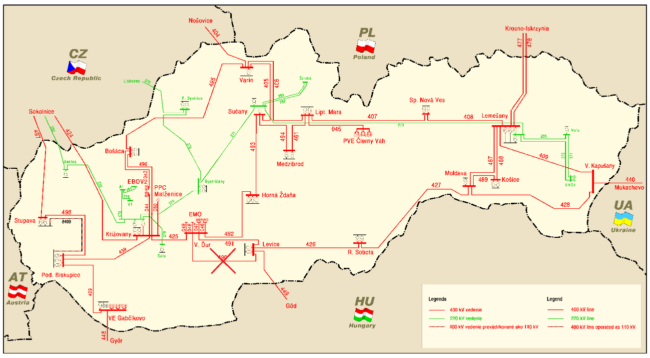

Fig. 5. Three-phase shortage on the V 490 line)

At 0.1s there will be 3 phase short circuit on line V490. Protective devices will disconnect the line in 0.15s. The impact of this failure on transient stability is analysed on the generator working in the first block of the Nuclear Power Plant Mochovce, on the generator working at the Jaslovské Bohunice nuclear power plant. Fig.6 shows the active power swings of generator at the Mochovce nuclear power plant during and after the 3 phase shunt on the V490 line at the Levice station. The red curve shows a generator swings with the TCSC implemented on the V424 line. The black curve shows the generator swings without TCSC installed. Fig.6 shows that the generator swings with the TCSC installed are smaller and the settling stabilization time is shorter. In this graph, the negative effect of TCSC can also be observed at the first swing, when active power exceeded with the installed TCSC is greater about 100 MW with respect to the swing without TCSC. Too large first swing of the generator can result in loss of synchronism of the generator.

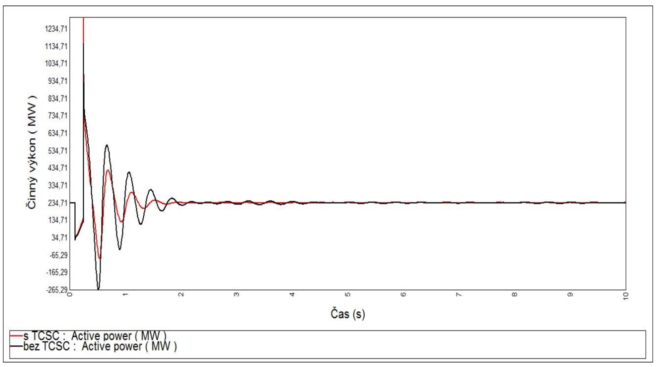

Fig. 6. Activ power swings of generator in Mochovce nuclear power plant during 3 phase short circuits on line V490.

The figure (FIG. 7) shows the generator bucket at the Bohunice nuclear power plant. The red curve shows a generator swings with the TCSC implemented on the V424 line. The black curve shows the generator swings without TCSC installed. The figure shows that the TCSC effect on the generator bucket is considerable. Stabilization of the active power oscillation on generator with installed TCSC has been for almost 2 seconds, whereby the generator swings without the TCSC installed lasts for more than 9 seconds. The first generator swing with TCSC installed is about 120MW smaller than the swing without TCSC installed. The difference in the influence of TCSC on generators at different power plants may be due to the location of the TCSC.

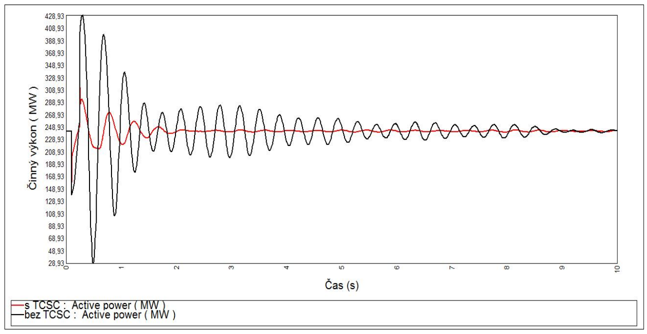

Fig. 7. Activ power swings of generator in Jaslovské Bohunice nuclear power plant during 3 phase short circuits on line V490.

B. Scenario 2: Turn off interconnection line V 448 between Slovakia-Hungary.

Transient stability simulation was aimed at monitoring generator behaviour at the Mochovce and Jaslovské Bohunice nuclear power plants, when there was shutting down interstate line V 448. In SK PS was in time 0,1s switched off interconnection line V448 from both sides.

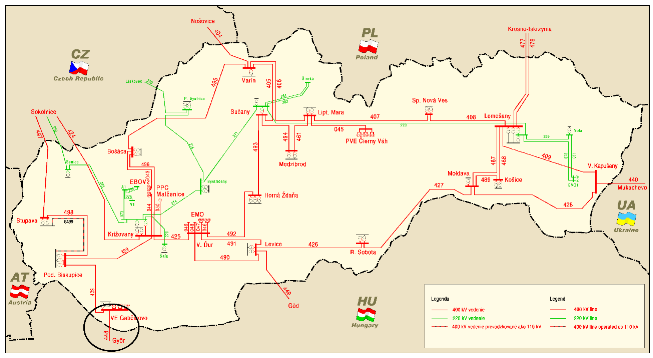

Fig. 8. Line V 488 at Slovak - Hungary interconection

The effect of switching off the interconnection line in the power system means a change in topology and power flows. The impact on transient stability is analysed on the generator working in the first block of the Nuclear Power Plant Mochovce, and generator working at the Jaslovské Bohunice nuclear power plant.

Fig. 9 shows the swings of generator at the Mochovce nuclear power plant. The active power swings on the generator is approximately 8 MW without TCSC. By installing TCSC, the active power swings decreased to 6 MW. This means that the line switching off does not pose a major risk to the stability of the operation.

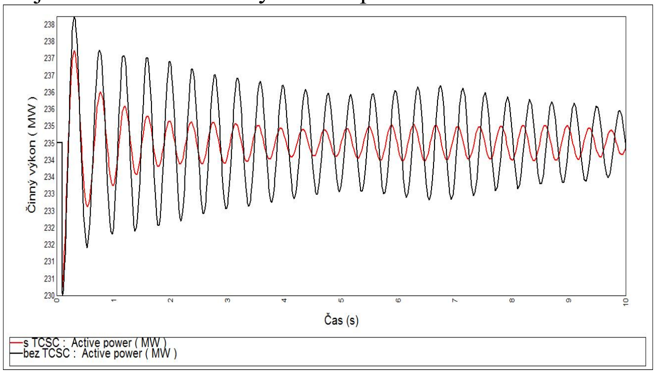

Fig. 9. Activ power swings of generator in Mochovce nuclear power plant during switching off line V448.

Fig. 10 shows the swings of active power of generator in a nuclear power plant Bohunice. Switching off the line from both sides will not cause a great swings of active power either to the generator at the Jaslovské Bohunice nuclear power plant. Swings of active power without installed TCSC is 10MW and without TCSC is 8 MW.

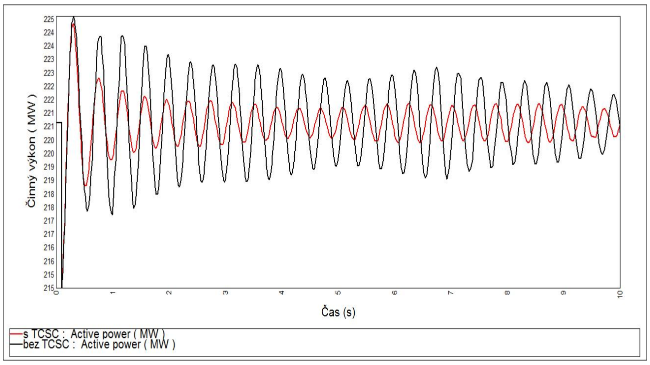

Fig. 10. Activ power swings of generator in Jaslovské Bohunice nuclear power plant during switching off line V448.

CONCLUSION

The paper refers to current global electricity trends, leading to ever-increasing electricity transmission. This is due both to the increase in consumption and production of electricity, as well as to the creation of a single electricity market. Recently, there is an increasing problem of the operation of renewable resources with unpredictable production, which also often contributes to the creation of unplanned transit flows and to the deterioration of system stability. A specific problem is then the so “narrow loops” in networks where, due to the above-mentioned transitions, the transmission capacities of the lines are exceeded, and thus the operational situations are unfavourable. Attention is paid to the TCSC device, which demonstrates a favourable impact on the dynamic stability of the power system.

The results of the analysis are essential when deciding where to install the FACTS devices in the power system. Of course, a financially demanding investment such as deploying, for example, TCSC requires a comprehensive analysis of the impact of TCSC on power system with a view to their development plan for several years ahead. The economic benefits to the Transmission system operators are expected to save electricity grid losses, improve system stability, increase electricity market opportunities for operators, and increase operational reliability of the power system.

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