Impact of TCSC on generator operation

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***Abstract*— This paper deals with the research of FACTS devices, specifically TCSC regulators. In the research, the NEPLAN program compiles a mathematical model of the TCSC system for the control of oscillations and the improvement of the dynamic stability of the transmission system. The TCSC element is implemented in the design in two places, namely in stations with generator outlets. The first outlet is the Mochovce nuclear power plant and the second on the outlet line of the Vojany thermal power plant. The height is mainly focused on reducing oscillations in short circuits. The result is the processing of dynamic stability data at a set short circuit with and without a TCSC device, as well as how this affects the CCT (Critical clearing time).**

Keywords*— FACTS, TCSC, controller, dynamic stability, stability, transient phenomenon, CCT (critical clearing time), NEPLAN, power system, power flow

I. INTRODUCTION

Strict requirements are placed on the transmission system operator or distribution system operators in the Slovak Republic. The main goal and their duty is to ensure a reliable, safe and economical supply of quality electricity to all consumers with the highest economic operation and the lowest possible losses or impact on the environment. FACTS (Flexible Alternating Current Transmission System) systems are increasingly being used to solve problems associated with the management of the operation of transmission and distribution systems. FACTS technologies have small dimensions and minimal impact on the environment. The project implementation time and the construction of this system are significantly lower than the choice of the construction of an alternative to the construction of new transmission lines or new power plants [18], [19], [20], [21], [22].

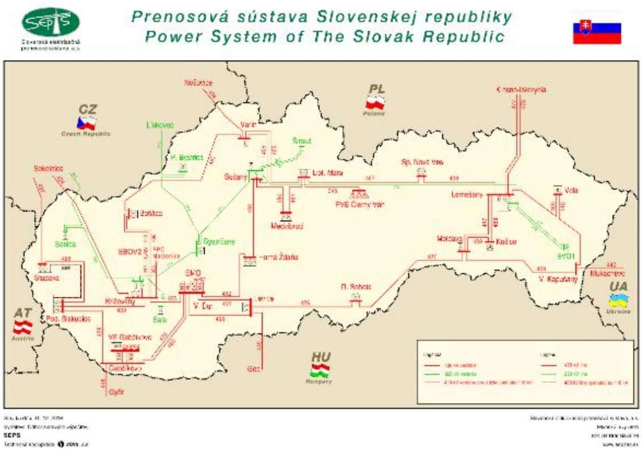

Fig. 1 Map of Slovak transmission system

On the basis of the diagram (Fig. 1) and the necessary parameters of individual lines, transformers, generators and other elements, a diagram of the entire electricity system of the Slovak Republic was compiled in the NEPLAN program. In the program, two FACTS systems were implemented in the transmission system, namely TCSC equipment, one of which was applied to the line "V071" at the outlet from the thermal power plant Vojany and at the outlet from the nuclear power plant Mochovce to the line "V047" in both cases in half management.

In the next subchapters, simulations of the active and reactive power of the fifth unit of the generator of the thermal power plant "TG5" at a three-phase short circuit on the 400 kV busbar in Spišská Nová Ves marked "SPNV_400_W1" will be plotted. The main result will be simulations that will point to the reduction of generator oscillations and faster stabilization of power using the FACTS technology of the TCSC (Thyristor-Controlled Series Capacitor) system. Emphasis on quality, reliability or so-called The dynamics of the power system is also positive for the CCT (Critical Clearing Time) indicator, which indicates the ability of the generator to remain in synchronism after a short circuit without its failure or disconnection from the network. The longer this time, the tougher the generator and thus the entire network or system and is more resistant to adverse effects, faults and short circuits. FACTS systems are able to slightly increase this time, which has a positive effect on the disconnection time of a damaged section, device or other element in the system. By increasing the CCT time, for example, we can provide protections with a higher time reserve to trip a fault, especially for backup protections that have a longer tripping time in case the primary protection that this protection was supposed to remove does not respond.

II. DYNAMIC MODEL OF TCSC CONTROLLER

For studies of dynamic stability and oscillating events, a TCSC device can be represented by a variable reactance, which is modeled as a variable reactance at the fundamental frequency due to a fault and during frequency fluctuations - the frequency remains constant [1], [2], [3].

In the case of the TCSC module controller (Fig. 2), two values are entered for the input, namely the reference value of the active power - entered in MW and the second input is the active power entered in proportional units. The controller reads both of these values directly from its module. These values, together with the value already entering the output member, which is fed back through the "SLACK" element, are connected to the summing member. It then enters the delay member, the integration-derivative member and again the delay member, which then enters the member needed to enter the control pulses for the transistors (thyristors). This value then travels to the summator via a constant, the other constant being connected separately and the output is then connected to the mathematical inverter and then to the output value that controls the TCSC module impedance Z (variable value inductance (XL). connected members that enter the TSCS resistance value. [10], [11]

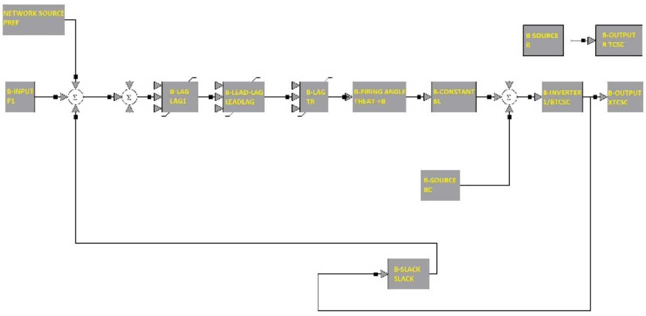

Fig. 2 Controller of TCSC system

Each of the FACTS devices is designed for the purpose of controlling or controlling the parameters in the system. Thus, the regulator may have entered different input values (voltage, current, power, etc.), which it monitors during operation and thereby controls the output value by means of the members included in the diagram, which may also differ from other regulators (susceptance - change of admittance, inductance - impedance change and others).

III. IMPACT OF THE TCSC SYSTEM IN THE TRANSMISSION SYSTEM OF THE SLOVAK REPUBLIC ON THE IMPROVEMENT OF DYNAMIC STABILITY IN THE NEPLAN PROGRAM

In Fig. 3 shows the busbar system of a 400 kV substation in Spišská Nová Ves drawn in the NEPLAN program, while a three-phase short-circuit is set on the busbar "SPNV_400_W1", which is removed in 0.25 s. With this short circuit, we can observe a transient event of active and reactive power on our selected generator (EVO TG5), which at the time supplied 33.4 MW and 11 MVAr (inductive). Since we deal with the implementation of FACTS systems and their ability to improve, for example, the dynamic stability of the generator, the FACTS component is built into the scheme. The result is a compared process without a FACTS compensation device and with a compensation technology of the TCSC system type. [12], [13].

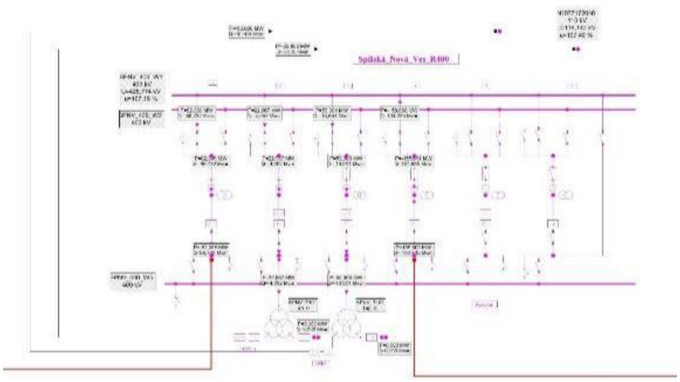

Fig. 3 Switchboard station ZVN - 400 kV with set short circuit in busbar W1

In the NEPLAN program, we start from the scheme shown in Fig. 4 modeled according to the current Slovak transmission system, which is supplemented by all transformers, busbar systems and generators working through block transformers directly into the transmission system.

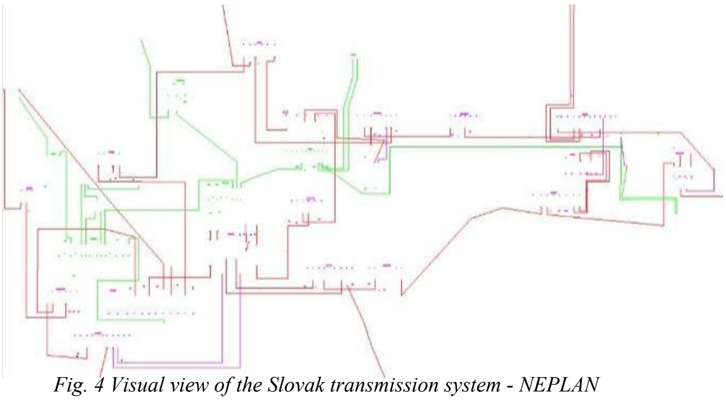

Fig. 4 Visual view of the Slovak transmission system - NEPLAN

When examining transients on the "EVO_TG5" generator, which opens into the Lemešany substation, the influence of the nearest TCSC plant will be most pronounced and is therefore located directly on the line that supplies power from the generator to the nearest substation (see Fig. 5). Also another location of the FACTS system, resp. of another kind, would be able to visibly improve the dynamic operation of the power system in case of adverse effects and the like. However, it should be noted that a poorly set controller can react incorrectly in certain faults, which could have fatal consequences for the operation of the system, limited power transmission, disconnection of customers and in the worst case, the so-called "Blackout" - falling into darkness.

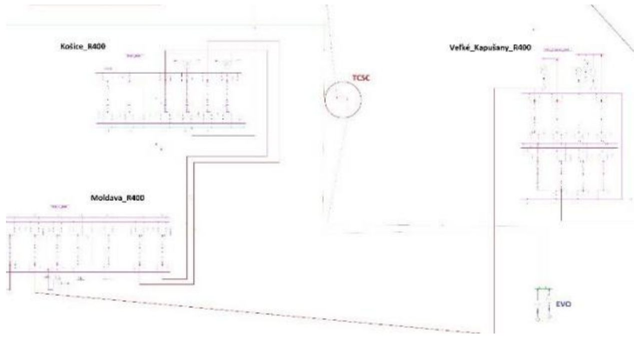

Fig. 5 Implemented TCSC regulator in the 220 kV line from the Vojany power plant

The second element of the FACTS system is located on the line that transfers power from the Mochovce nuclear power plant, specifically from units "22" and "21". The TCSC element is located in this line, which reacted to a small extent to the short circuit in the substation in Spišská Nová Ves and helped the generators to dampen and stabilize their oscillations faster. To a small extent, he was able to slightly reduce and help the remote generator we researched in the thermal power plant Vojany TG5.

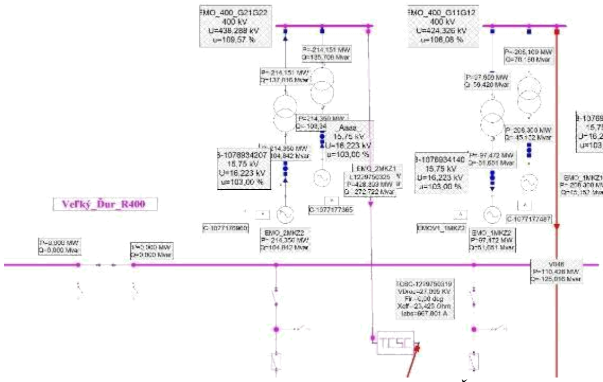

Fig. 6 Implemented TCSC controller in the Veľký Ďur station from the Mochovce power plant outlet

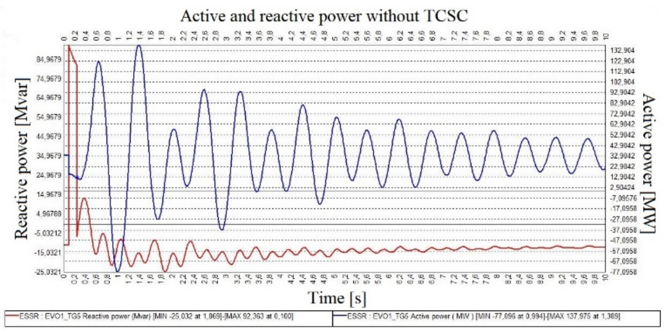

Fig. 7 The course of active and reactive power without the use of TCSC controller

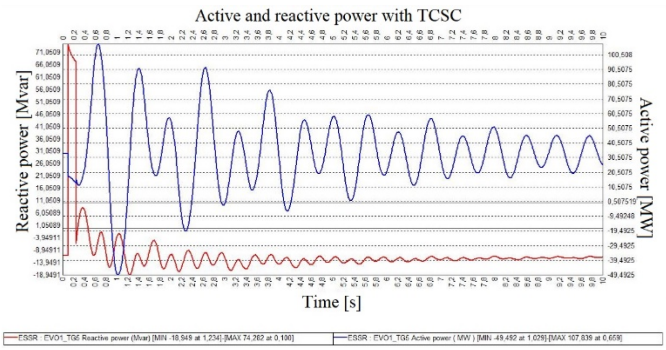

Fig. 8 The course of active and reactive power with the application of TCSC controller

From the courses of active and reactive power on the TG5 generator in the Vojany power plant, we can observe a significant influence of the TCSC device on the dynamic stability and the so-called oscillation of the generator, which are substantially damped using the FACTS system.

In the case without the use of TCSC systems, Fig. 7, the maximum amplitude of the active power on the "EVO_TG5" generator after a short circuit is approximately 138 MW, and subsequently all other oscillations oscillate and settle with a higher amplitude than in the case of using TCSC technology. After the application of the TCSC system to the power system, we can monitor the changes in the simulation (Fig. 8), and thus the effect of the FACTS device as it affects the oscillation of the generator, and thus the entire operation in the production and transmission of electricity. Using the TCSC element, which was able to reduce the oscillation of the generators and dampen their amplitudes, we achieved a change in the maximum amplitude to approximately 110 MW.

If we focus on the observation of reactive power, it may seem to us that the TCSC device had no effect on this component of power. However, if we notice, the maximum amplitude after short circuit was around +15 MVAr (capacitive) and -25 MVAr (inductive) without the use of FACTS technology and with the use of TCSC elements it is a value of approximately +9 MVAr (capacitive) and -19 MVAr (inductive). , which is a comparable difference and a visible improvement of dynamic (transient) processes using FACTS systems based on power electronics.

Table 1. Comparison of active power at the terminals of the EVO1_TG5 generator at short circuit

TCSC	**Active power EVO1_TG5**				
	Supply [MW]	Max eave [MW]	Time [s]	Min wave [MW]	Time [s]
Without	33,359	137,975	1,389	-77,096	0,994
With	33,361	107,839	0,659	-49,492	1,029
Difference	0,002	30,136	0,730	27,604	0,035

Table 2. Comparison of reactive power at the terminals of the EVO1_TG5 generator at short circuit

TCSC	**Reactive power EVO1_TG5**				
	Supply [MVAr]	Max wave [MVAr]	Time [s]	Min wave [MVAr]	Time [s]
Without	-12,346	92,363	0,100	-25,032	1,869
With	-12,425	74,282	0,100	-18,949	1,234
Differenc e	0,079	18,081	0,000	6,083	0,635

The reduction of generator oscillations and the improvement of dynamics for the entire power system can be realized by means of many other solutions using FACTS systems and the use of suitable regulators for a specific type of equipment. Implementation of such equipment in practice (for example, the Slovak Transmission Electricity System) requires a detailed study of what the equipment should correct, regulate or compensate. Thanks to these devices, the system is more durable, robust and flexible, whether in terms of power flows, its control and regulation or reducing adverse effects in the event of short circuits.

IV. IMPACT OF TCSC SYSTEM IN SLOVAK TRANSMISSION SYSTEM WITH REGARD TO CCT TIME

The critical CCT time depends on many factors in the network, such as the inertia of the turbines in the power plant, the parameters of the generator, the location of the short circuit, the initial conditions before the failure or the X / R ratio. From this title, we can conclude that the CCT time depends on the overall topology of the system. Transient stability studies are performed before planning projects for the construction of new power plants or individual power plant units, and therefore all installed circuit breakers are designed to withstand and trip the most severe "hardest" short circuit that can occur and have the shortest CCT. Thus, using circuit breaker data, we can conclude about the minimum critical time that can be present in a given network. However, there is no exact value for this time, as this is affected by all parameters in the system [26], [27], [28], [29].

Based on the previous scheme, we will examine the critical time (angle) at which the generator cannot stabilize and return to the new required delivered power. We know from dynamic stability that if the braking area is smaller than the acceleration (one of the methods of determining the stability and instability of the generator), then the generator will fall out of synchronism. This time can be observed and in the English literature we know it under the abbreviation CCT (Critical Clearing Time).

In Fig. 9 shows the time when a short circuit occurred and when it was removed, but in the NEPLAN program it was simulated so that it is possible to observe the influence of the FACTS system as it can positively influence and prolong the critical time CCT. Thanks to this capability, FACTS systems help to build a more resilient, stable and robust system from production, transmission, distribution and consumption of electricity..

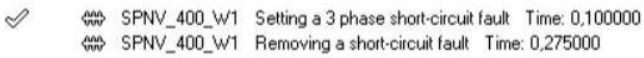

Fig. 9 Setting of short-circuit ratios in the NEPLAN program for observing the CCT indicator

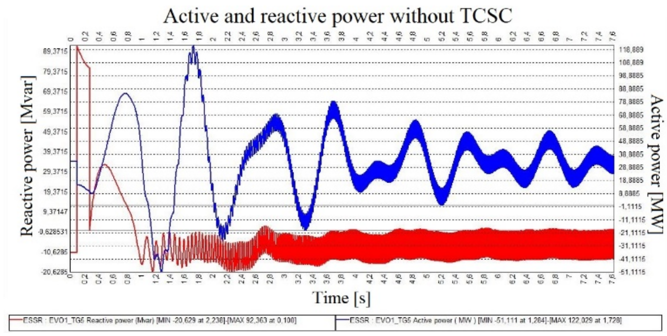

Fig. 10 The course of active and reactive power without TCSC system

At this set short-circuit duration, we can observe that the TG5 generator we observed at the Vojany power plant could not stabilize and would fall out of synchronism. From the course, we assume that the hard network, which supplies our electricity system of the Slovak Republic, helped the generator to stabilize, but as can be seen in Fig. 10 generators would continue to oscillate uncontrollably (sway) and subsequently it would be necessary to shut it down from this transmission system - there would be a failure from synchronism.

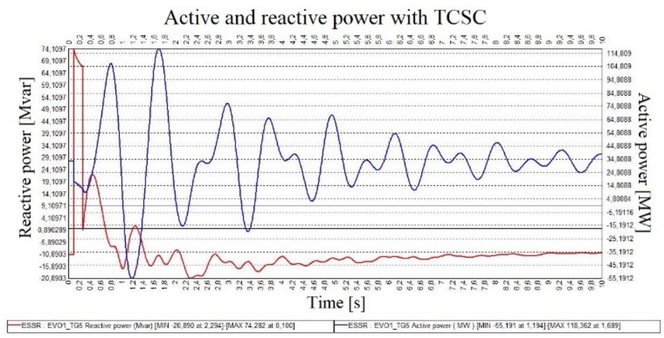

Fig. 11 The course of active and reactive power using the TCSC system

At this set duration of the short circuit, we can observe that the TG5 generator observed by us at the Vojany power plant could not stabilize and would fall out of synchronism. From the course, we assume that the hard network, which is fed by our electricity system of the Slovak Republic, helped the generator to stabilize, but as can be seen in Fig. 10 generators would continue to oscillate uncontrollably (sway) and subsequently it would be necessary to shut it down from this transmission system - there would be a failure from synchronism.

V. Analysis of Results

In order to observe the oscillation of the generator on the EVO_TG5 unit (turbogenerator of the Vojany power plant) at the set 3-phase short circuit in the SPNV_400_W1 substation, the influence of the TCSC device is observed. The output is processed the results of how the TCSC technology can dampen and stabilize the oscillation of the generator, and thus the whole system in real design. The TCSC system is able to eliminate generator oscillation (active and reactive power) in the event of a short circuit and thus help prevent the failure of a block or group of generator blocks operating into the system. The application of FACTS systems to the Slovak transmission power system also has an impact on the CCT (critical time), which gives a kind of time reserve for disconnecting the short circuit for protections. This analysis concluded that the FACTS system helps to improve the dynamic stability, reliability and increase the robustness of power systems.

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