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Using of the Thyristor Controlled Series Capacitor in Electric Power System

The article deals with the use of thyristor controlled series capacitor (TCSC) in the power system. Aim of this work is to show the possibilities of using TCSC and its modelling in a simple electrical network from the perspective of power flow control by using MATLAB SimPowerSystem. Given the current pace of increasing electricity transmission and growth requirements for transit is to increase safety, capacity, controllability and flexibility of systems for the transmission of electricity, needed the implementation of certain measures and specialized equipment. Such specialized equipment is also TCSC from group of FACTS devices.

Keywords: TCSC, FACTS, power flow control, power system, modelling of TCSC, SimPowerSystem

I. INTRODUCTION

The electricity is an everyday, as it were an essential part of our life and need to get electricity to the consumer in reliable and specified quality. Transmission of electricity in the interconnected, cooperating electricity systems is steadily increasing due to increasing growth in consumption and electricity generation. While occur to excessive burden of transmission equipment, which leads ultimately to a disruption in electricity end-user. In addition, there are other unforeseen disturbances and situations of power system operation. Technical development, which is essential for electrical power engineering, brings in this area new trends and solutions to various problems in power system. In recent years in the world are getting to the fore so-called FACTS devices. It is modern semiconductor components control equipment, which have many potential uses. The issue of options for using these facilities to improve the performance and operation of power systems is therefore a hot topic.

Significant device from the group FACTS is a TCSC, which finds application in solving many problems in the power system. Its properties can increase the power lines transmission capacity and power flow control. It also provides a wide range of other uses to ensure effective, trouble-free and economical operation of power systems. Behaviours simulation of these devices is very important before the real deployment of these devices to the power system. Various computing and simulation programs, which help in understanding the activities and setting appropriate parameters of these devices, have found its application to modelling and simulating these devices.

II. TCSC

TCSC - Thyristor Controlled Series Capacitor compensator consisting of the series compensating capacitor, whereto is parallel connected thyristors controlled reactor (TCR), and it is one of FACTS devices which are mainly used to control active power flow in power system and increase the transmission power lines capacity.

TCSC is involved in a series to line (in terminal) and allows changing impedance of the transmission path and thus affecting the power flows. Control is fast, efficient and increased between the transmitted powers. Basic scheme of TCSC device is shown in the follows figure. [1]

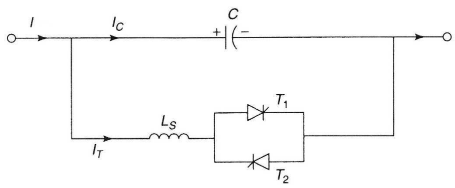

Figure 1 Basic diagram of TCSC

Change of impedance of TCSC is achieved by changing the thyristor controlled inductive reactance of inductors connected in parallel to the capacitor. The magnitude of inductive reactance is determined by angle switching thyristors α, which can also be controlled continuously flowing amplitude of current reactor from the maximum value to zero. Angle switching thyristors can change inductive reactance controlled choke from a minimum value (α = 0, $X_{TCR} = X_L$) theoretically to infinity ($\alpha = \pi/2$, $X_{TCR} = \infty$). [1][2]

Magnitude of inductance this compensator is given by:

$$X_{\text{TCSC}}(\alpha) = \frac{X_C \cdot X_{\text{TCR}}(\alpha)}{X_{\text{TCR}}(\alpha) - X_C}, \qquad (1)$$

where $X_C = 1/\omega C$ is capacitive reactance of capacitor and C its capacity. [1][2]

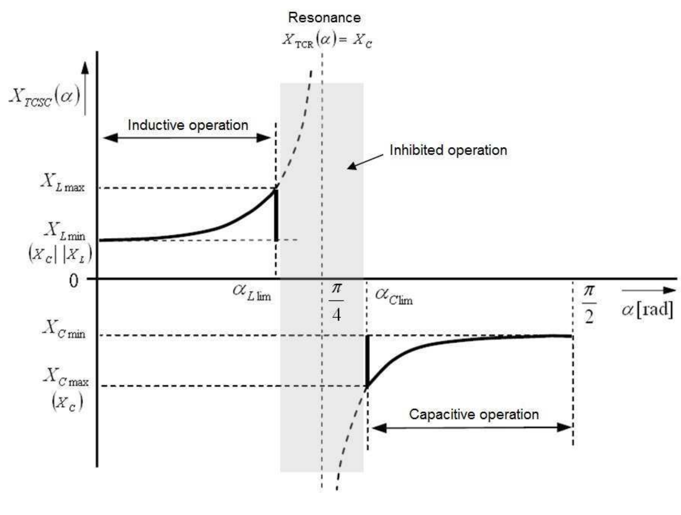

Figure 2. Operating diagram of TCSC [2]

For sufficiently small inductive reactance of reactor towards capcitive reactance of capacitor ($X_L < X_C$), the operating diagram of TCSC contains inductive and capacitive mode operation of TCSC and the transition between areas is the resonance region.

Under normal operating conditions TCSC can operate in four modes of operation, namely: blocked mode, bypassed mode, capacitive and inductive mode. [1][2][4]

III. ANALYSIS OF THE TCSC FROM THE VIEWPOINT OF POWER FLOW CONTROL IN POWER SYSTEM

TCSC compensator is no power source, but can changing the impedance of the transmission path, in which it is installed; affect the power flow in networks.

The following assumptions can be adopted to simplify the analysis:

- Since the active resistance of transmission lines is small due to their inductive reactance, in the following description it is not consider ($R = 0$).
- For simplification, at loaded lines in our transmission system we can ignore the cross admittance ($B = 0$).

Active power transmitted by line between nodes 1 and 2 is directly proportional to the voltages U_1 and U_2 also difference between load angles δ_1 and δ_2, and inversely proportional to the resultant reactance (impedance) of line X_{line}:

$$P_{12} = \frac{U_1 \cdot U_2}{X_{\text{line}}} \cdot \sin(\delta_1 - \delta_2) \quad (2)$$

From equation (2) is seen that is possible influence the power flow of power lines by change the resulting reactance (impedance) transmission path.

If TCSC is located in terminal, the transmitted power can be determined by the following equation:

$$P''_{12} = P_{12} \pm \Delta P = \frac{U_1 \cdot (U_2 \pm \Delta U)}{X_{\text{line}} \pm \Delta X} \cdot \sin(\delta_1 - \delta_2 \pm \Delta\delta) \quad (3)$$

Where:

ΔU is voltage change in node 2 caused by a reactance change of line,

ΔX is reactance change of the transmission path, which is decisive for effectiveness of the power flow control in networks by TCSC device.

$\Delta\delta$ is the angle of transmission change (load angle) caused by a change reactance of the transmission path. [1][2]

The diagram of contemplated the transmission path between two nodes:

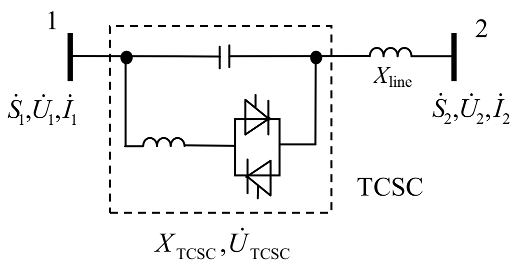

Figure 3 Diagram of transmission path with TCSC

IV. POSSIBILITIES OF USING TCSC

Using of the TCSC has many benefits that result from its substance, and for which its use is justified.

Possibilities and advantages of the TCSC are:

- increased dynamic stability of power transmission systems,
- improved voltage regulation and reactive power balance,
- improved load sharing between parallel lines,
- Elimination of subsynchronous resonance risks (SSR),
- damping of active power oscillations,
- improved stability,
- dynamic power flow control,
- minimizing system losses,
- reduction of loop flows,
- elimination of line overloads,
- optimizing load sharing between parallel circuits,
- reduction of the gap between commercial and physical flows.

The aforementioned benefits are typically seen to increase transmission lines capacity. Benefits of TCSC are not subject only to newly built TCSC installation but they can also be achieved by upgrading existing series compensation on the thyristors controlled series compensation or only its part, thus considerably extended its influence and usefulness. [1][3][4][7]

The TCSC cannot reverse the power flow in a line, unlike HVDC controllers and phase shifters. [4]

V. MODELLING OF THE TCSC BY USING MATLAB SIMPOWERSYSTEM

The model of electrical network with TCSC device was prepared and simulated in Simulink version 7.2 and SimPowerSystem version 5.0 of program MATLAB version 7.7.0 (R2008b).

For demonstration of action TCSC device, from the viewpoint of active power flow control has been created a simple model of electrical network, in which was subsequently implemented TCSC device. The model of simple electrical network consists of a voltage source, load, two parallel lines and units for measuring and displaying measured electric variables.

The parameters of the model are as follows:

- *Ideal Three-Phase Voltage Source*
  Line to-line voltage $U_N = 400$ kV,
  Phase angle L1 $\varphi = 0°$,
  Frequency $f = 50$ Hz,
- *Three-Phase Parallel RL Load*
  Active power $P = 300$ MW,
  Reactive power $Q = 150$ MVAr,
  Configuration Y (grounded),
- *Three-Phase PI Section Line n.1 and n.2*
  Line resistance $R = 0.028$ Ω/km,
  Line inductance $L = 0.904$ mH/km,
  Line capacity $C = 0.012707$ μF/km,
  Line lenght $l = 100$ km,
  Maximum current of line $I_{\max} = 1200$ A.

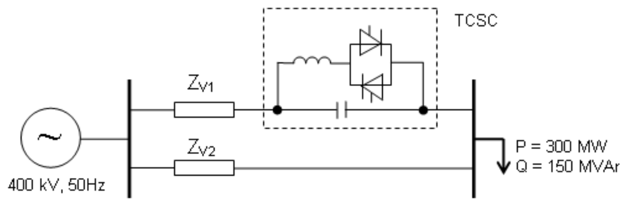

Figure 4. Block diagram of the model of electrical network with TCSC

The parameters of TCSC device are follows:

Inductance of TCR l_{TCR} = 6.71 mH,

Capacity of TCSC c = 203 μF,

Ratio X_l / X_c = 0.1343.

The parameters of TCSC model were designed so that the percentage of compensation of TCSC was approximately 55 % when switching thyristors angle α = 90 °, according to the following calculations:

Line series impedance No.1 is

$$Z_{V1} = R + j \cdot X_L = R + j \cdot \omega \cdot L = 2.8 + j \cdot \omega \cdot 0.0904 = 2.8 + j28.386\,\Omega \qquad (4)$$

From where line series reactance is $X_{LV1} = 28.386\ \Omega$

Capacitive reactance TCSC devices is

$$X_{C_{TCSC}} = \frac{1}{\omega \cdot c} = \frac{1}{\omega \cdot 203 \cdot 10^{-6}} = 15.688\ \Omega \qquad (5)$$

Percentage of compensation can be determined by the equation

$$\%comp = \frac{X_{C_{TCSC}}}{X_{L_{V1}}} \cdot 100 = \frac{15.688}{28.386} \cdot 100 = 55.27\,\% \qquad (6)$$

In Figure 5 is showed situation in the modelled electrical network without the use of TCSC. Since the parameter lines are the same, the flow of active and reactive power is distributed evenly on both lines, ie the power flows of the given lines are equal. The voltage at the load drops due to loss of voltage on lines.

Inclusion of TCSC device to one of the lines changes the power flow in given lines according to level desired. This change is achieved by changing the impedance of line, in which is installed TCSC device. With the entry values of angle switching thyristors α, TCSC can change the impedance of the line and thereby regulates the power flow as required. When such a change power flow, the power flow on lines is reallocated to another ratio, but the resulting flow performance remains unchanged.

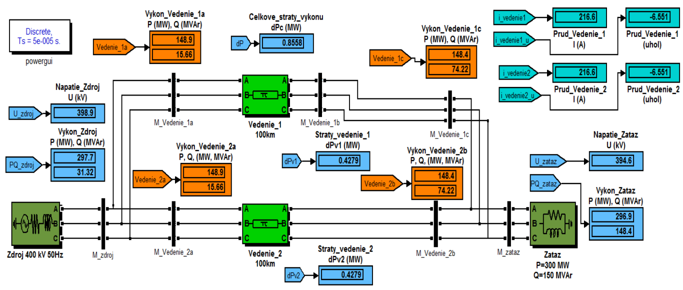

Figure 5. Model of electrical network without TCSC

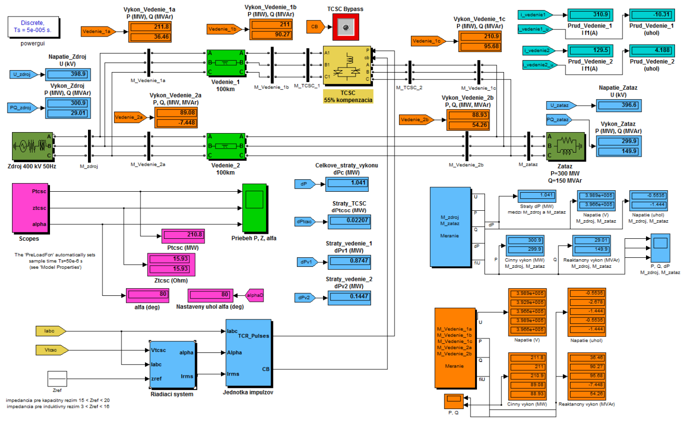

Figure 6. Model of electrical network with TCSC at adjusted angle α = 80°

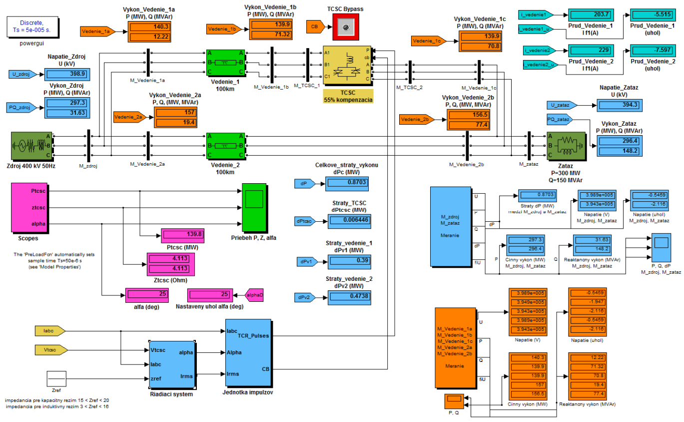

Figure 7. Model of electrical network with TCSC at adjusted angle α = 25°

In Figure 6 is showed situation in the modelled electrical network at adjusted angle α = 80 °. Impedance of TCSC is capacitive and therefore there is a change in power flow on lines No.1 and No.2. This value of the angle of switching leads to increase power flow on line No. 1, whose value has risen from the original value of P_{V1} = 148.4 MW to P_{V1} = 210.9 MW (measured at the load).

In Figure 7 is showed situation in modelled electrical network at adjusted angle α = 25 °. Impedance of TCSC is inductive and therefore there is a change in power flow on lines No.1 and No.2. This value of the angle of switching leads to decrease power flow on line No. 1 from the original value of P_{V1} = 148.4 MW to P_{V1} = 139.9 MW (measured at the load).

In the case of inductive action of the TCSC to impedance of line No.1 will increase, resulting in a decrease in the flow of power on line No.1 and increase the flow on line No.2. In the case of capacitive operation, when capacitance TCSC acts on impedance of line No.1, will decline impedance of line No.1 and thereby will increase the power flow through the line No.1 and reduced the power flow through the line No.2. When is setting the appropriate parameters of TCSC and correct regulation, it may increase the extent of change in power flow in the electrical network, or to introduce another application of TCSC in the power system.

TABLE I
Power flows on lines and losses in the system during inductive operation of TCSC

	Without TCSC	α [°]						
		0	10	20	30	40	45	49
P_{V1} [MW]	148,4	141,8	141,1	140,5	139	134,3	128	117,3
P_{V2} [MW]	148,4	154,8	155,3	155,9	157,4	161,8	167,8	177,8
P_{SUM} [MW]	296,8	296,6	296,4	296,4	296,4	296,1	295,8	295,1
Q_{V1} [MVAr]	74,22	71,54	71,32	71,05	70,45	68,6	65,8	61,68
Q_{V2} [MVAr]	74,22	76,72	76,92	77,16	77,73	79,47	82,1	85,94
Q_{SUM} [MVAr]	148,44	148,26	148,24	148,21	148,18	148,07	147,9	147,62
P_{LOSS} [MW]	0,8558	0,859	0,8526	0,8578	0,8743	0,8748	0,8828	0,9601

TABLE II
Power flows on lines and losses in the system during capacitive operation of TCSC

	Without TCSC	α [°]					
		69	70	75	80	85	90
P_{V1} [MW]	148,4	229,2	226,1	215,5	210,9	209,7	209,5
P_{V2} [MW]	148,4	71,42	77,41	84,5	88,93	90,12	90,32
P_{SUM} [MW]	296,8	300,62	303,51	300	299,83	299,82	299,82
Q_{V1} [MVAr]	74,22	100,5	99,72	97,29	95,68	95,29	95,23
Q_{V2} [MVAr]	74,22	49,77	50,52	52,75	54,26	54,62	54,68
Q_{SUM} [MVAr]	148,44	150,27	150,24	150,04	149,94	149,91	149,91
P_{LOSS} [MW]	0,8558	1,133	1,118	1,093	1,041	1,019	1,011

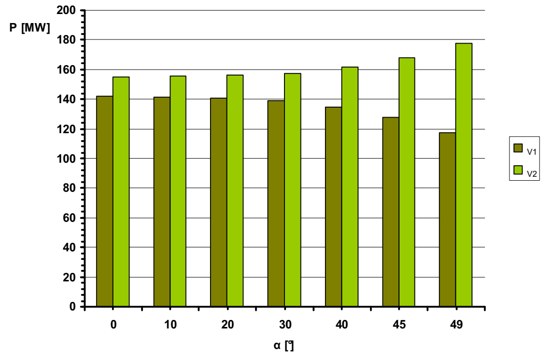

Figure 8. Variation of power flows through lines with angle α at inductive operation of TCSC

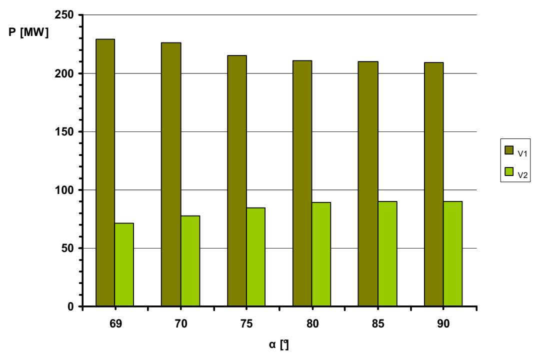

Figure 9. Variation of power flows through lines with angle α at capacitive operation of TCSC

VI. CONCLUSION

The article deals with the issue of using TCSC in the power system. The function of this device is the ability to change impedance transmission lines and thus increase the transmission capacity and power flow control. TCSC with his composition and capabilities allows widely using in power system. It can be used also for damping of active power oscillations, improve dynamic and voltage stability, eliminating SSR and other. Before the installation of TCSC is important to determine the parameters of TCSC, prepare power analysis and analysis of the behavior of TCSC at various cases. Thus the subject of analysis was on a simple model of electrical network with two parallel lines simulate the behaviour of TCSC in terms of use in power flow control through the lines. Based on simulations we can state the ability of TCSC to change power flows on lines. Since the TCSC has also wide usage, it just makes it suitable for deployment of the electricity system to ensure better operational parameters and safe power transmission. The benefits of TCSC show several installations of TCSC in many worldwide projects over the past 20 years.

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