

Use of Specialized Devices to Power Flow Control in Power Systems

Beňa Ľubomír¹⁾, Jakubčák Roman²⁾, Kolcun Michal³⁾

¹⁾Technical university in Košice/Department of electrical power engineering, Košice, Slovakia, Lubomir.Bena@tuke.sk

²⁾Technical university in Košice/Department of electrical power engineering, Košice, Slovakia,
Roman.Jakubcak@tuke.sk

³⁾Technical university in Košice/Department of electrical power engineering, Košice, Slovakia, Michal.Kolcun@tuke.sk

Abstract—This article discusses specialized devices for the power flow control in power systems. Today it is an actual topic because of permanent increasing power flow in the transmission lines. This trend can lead to overloading of transmission lines and can endanger the security of electric energy supply.

Keywords— power flow control, FACTS, phase shift transformer.

I. INTRODUCTION

Most of the world electric power systems are widely interconnected. These connections include also international connection. This is done for economical reason, to reduce the cost of electricity and to improve reliability of the power supply. Today we are witnessing a continuous increase of electricity demand. This trend along with market liberalization causes problems in management of power systems. These problems can lead to overloading of transmission lines and in the worst scenario lead to disconnection of these lines. The tools for the power flow control in the Slovak transmission system are insufficient from the point of view of increasing demand. For this reason we need specialized devices that are able to control the power flow in transmission lines. Between these devices belong FACTS (Flexible Alternating Current Transmission System) and PST (Phase Shift Transformer). These devices provide the ability to manage the power flow in power systems and are able to prevent creation of power system transmission lines overloading [4], [6].

II. THE CURRENT MEANS FOR CONTROLLING THE ACTIVE POWER FLOW

Present tools for the power flow control in the Slovak transmission system are:

1. *Change of the source operation* – The distribution of power plants and support services generally remove a transmission element overloading. Usability is practicable during normal operating situations as well as in emergency critical states of the power system when a state of emergency is declared.
2. *Consumption control* – In this case power is adjusted in distribution networks supplied from the transmission system. It depends mainly on the possibilities of the distribution network.
3. *Electrical network reconfiguration*—For example, the restriction during maintenance work and switching temporarily disabled elements. This is

possible in the case when the off lines are available. If a line is overloaded it can be turn off. As the result of this action is redistribution of the power flow in the power system but this action can lead to overloading of another transmission line and in the worst scenario to outage of the transmission line.

The above mentioned way offers insufficient options to the power flow control and for this reason we are looking for specialized devices for the power flow control in a power system.

III. SPECIALIZED DEVICES FOR POWER FLOW CONTROL

The need for greater control of the power flow requires use of specialized equipment, which includes FACTS devices and specialized transformer PST.

FACTS devices—According the IEEE FACTS devices are: Alternating Current Transmission Systems incorporating power electronics-based and other static controllers to enhance controllability and power transfer capability. They open new opportunities for controlling the power flow and enhancing the capability of present as well as new lines. Controlled parameters are current, voltage, line impedance and phase angle.

The FACTS devices for control the active power flow can include, among others:

A. TCSC

The basic Thyristor-Controlled Series Capacitor is shown in Fig. 1.

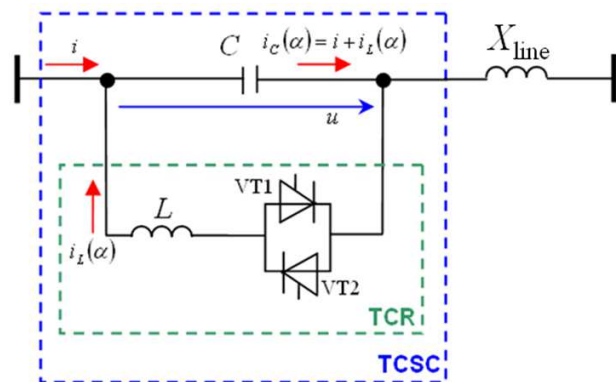


Fig. 1. Thyristor-Controlled Series Capacitor

It consists of the series compensating capacitor shunted by a Thyristor-Controlled Reactor (TCR). In a practical

TCSC implementation, several such basic compensators may be connected in series to obtain the desired voltage rating and operating characteristics. The basic idea behind the TCSC is to provide a continuously variable capacitor by means of partially cancelling the effective compensating capacitance by the TCR. The TCR at the fundamental system frequency is continuously variable reactive impedance, controllable by the delay angle α , the steady-state impedance of the TCSC is a parallel LC circuit, consisting of a fixed capacitive impedance X_C , and a variable inductive impedance $X_L(\alpha)$ [1].

The active power transported over a transmission line is given by the following equation:

$$P = \frac{U_1 U_2}{X_{line}} \sin(\delta_1 - \delta_2) \quad (1)$$

P is the transmitted active power, U_1 and U_2 are the voltages at the beginning and end of line, X_{line} is the line reactance, the angles δ_1 and δ_2 are the voltage angles at the line beginning and end. After addition TCSC:

$$P = \frac{U_1 (U_2 \pm \Delta U)}{X_{line} \pm \Delta X} \sin(\delta_1 - \delta_2 \pm \Delta \delta) \quad (2)$$

ΔU , ΔX and $\Delta \delta$ are changes of the voltage, line reactance and phase angle due to insertion of TCSC into the power system. From above mentioned equations it is clearly seen that we can control the power flow through the line by a change of the line impedance..

B. SSSC

The SSSC (Static Synchronous Series Compensator) is a series connected synchronous voltage source that can vary the effective impedance of a transmission line by injecting a voltage containing an appropriate phase angle in relation to the line current [2].

In the principle, an SSSC is capable to interchange active and reactive energy in the power system. The injected voltage could be controlled in magnitude and phase if sufficient energy source is provided. For the reactive power compensation function, only the magnitude of the voltage is controllable since the vector of the inserted voltage is perpendicular to the line current. The SSSC can be smoothly controlled at any leading or lagging value within the operating range of voltage source converter (VSC) [3].

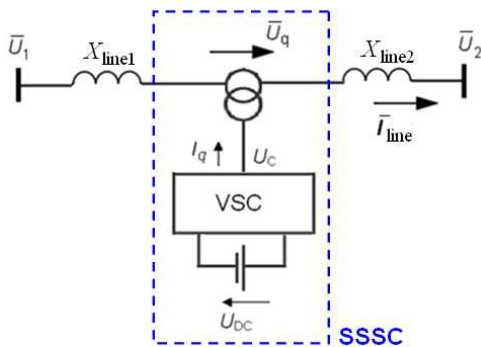


Fig. 2. Basic configuration of an SSSC

The behaviour of an SSSC can be similar to a controllable series capacitor and controllable series reactor. The basic difference is that the voltage injected by SSSC is not related to the line current and can be independently controlled. The SSSC is effective for both low and high loading [3].

The application of SSSC:

- *Power flow control* – The SSSC can be used both for increasing and decreasing the power flow through the transmission line.
- *Voltage and angle stability enhancement* – The SSSC gives a better possibility for damping electromechanical oscillations.

The SSSC can be represented as series connected voltage source.

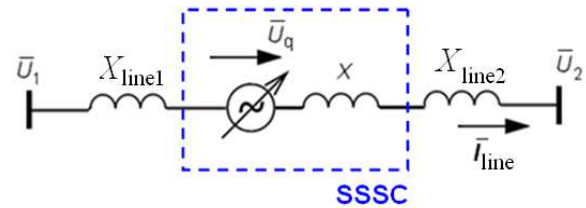


Fig. 3. Representation of a series connected voltage source

Phase shift transformer (PST)– Phase shift transformer consists of two units that create phase shift. PST is a device for controlling the power flow through specific lines in a complex power transmission network. The basic function of PST is to change the effective phase displacement between the input voltage and the output voltage of a transmission line, thus controlling the amount of active power that can flow in the line [3].

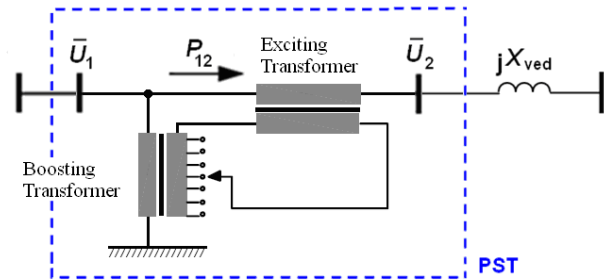


Fig. 4. Phase shift transformer

The PST consists of:

- exciting transformer – it provides input voltage to the phase shifter.
- boosting transformer – it injects a controlled voltage in series in the system.

PST's have many different forms. They can be classified into four classes:

1. Direct PST's – based on one three phase core. The phase shift is obtained by connecting the windings in an appropriate manner.
2. Indirect PST's – based on a construction with two separate transformers, one variable tap excited to regulate the amplitude of the quadrature voltage

and one series transformer to inject the quadrature voltage in the right phase.

3. Asymmetrical PST's – create an output voltage with an altered phase angle and amplitude compared to the input voltage.
4. Symmetrical PST's – create an output voltage with an altered phase angle compared to the input voltage, but with the same amplitude [4].

Conventional PST includes mechanical tap changer. In TCPST (Thyristor Controlled Phase Shift Transformer) classical mechanical switches in conventional PST were replaced by thyristors. They are able to emulate mechanical switches. Advantage is that they offer continuously phase angle control.

IV. USING PST FOR ACTIVE POWER FLOW CONTROL

According to data from international exchanges of electricity, the most loaded interstate profile transmission system of the Slovak Republic is the profile of SK-HU. According to SED Žilina, power flow on the profile is between approximately 400 – 1800 MW.

The main affects on the SK-HU profile are :

1. Deficit of electricity production in southern part of Europe.
2. Export opportunities in Slovakia and neighbouring countries especially East Germany, Poland and the Czech Republic.
3. The actual configuration of the interconnected system. Export from Slovakia passes the profile SK-HU. In the case of Poland, the power flow passes through Poland-Czech-Slovakia-Hungarian profile. Energy export from the Czech Republic passes through Czech-Slovakia-Hungarian profile and also Czech-Austrian profile.

For these reasons the SK-HU profile is potentially the most suitable for PST deployment. Further is mentioned a depth analysis of PST deployment on this profile. The impact of PST on the active and reactive power flow control is shown in the following figures.

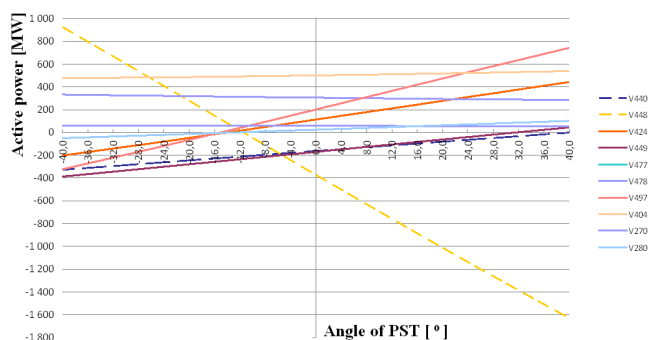


Fig. 5. Influence of PST on active power flows (PST is installed in line V448)

As we can see the profiles SK-HU and SK-CZ are particularly affected if PST is installed in the line V448. The profiles SK-HU and SK-UA are particularly affected if PST is installed in the line V449. The SK-HU profile control has no effect on the SK-PL profile.

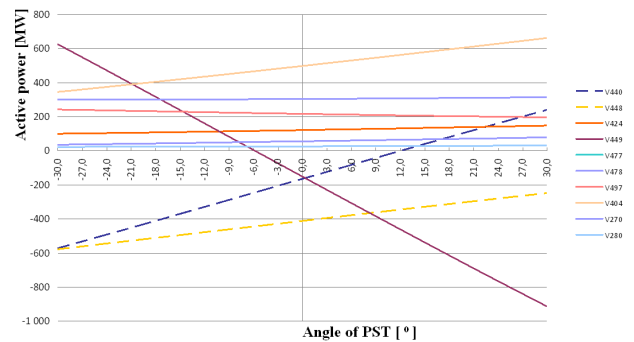


Fig. 6. Influence of PST on active power flows (PST is installed in line V449)

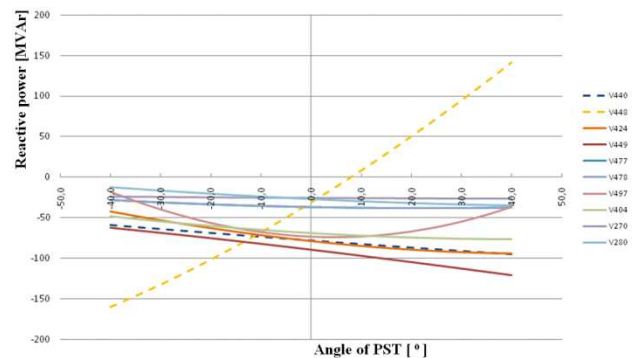


Fig. 7. Influence of PST on reactive power flows (PST is installed in line V448)

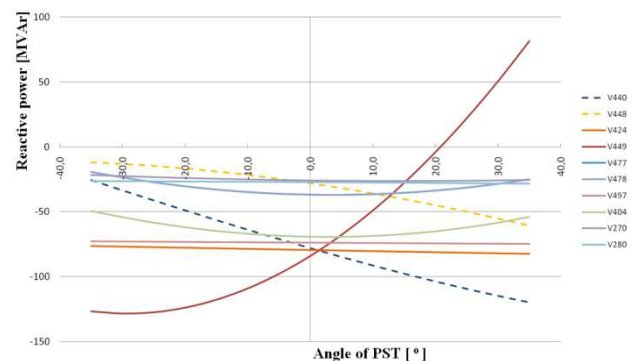


Fig. 8. Influence of PST on reactive power flows (PST is installed in line V449)

V. CONCLUSION

The article dealt with the analysis of the active power flow control on the common international lines of SK-HU using PST. This specialized device for the power flow control can be used for operational management of the loading lines, in fault conditions, but also for solving business cases.

The control has no affect only on the active power flow, but also on the active power losses in the power system. In some power systems due to control the active power losses can increase in other cases they can decrease. These losses have to be covered by increasing production.

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