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Use of PST in transmission system of the Slovak Republic

***Abstract**. The article deals with possibilities of phase shifting transformer to power flows control in transmission system. The main goal of the paper is to show results of the influence of the PST on power flows in the transmission system of the Slovak Republic.*

Streszczenie.** Artykuł omawia możliwości zastosowania transformatora PST do sterowania przepływami mocy w systemie przesyłowym. Głównym celem artykułu jest zaprezentowanie rezultatów wpływu transformatora PST na przepływy mocy w systemie przesyłowym Słowacji. **(Zastosowanie transformatora PST w systemie przesyłowym Słowacji)

Keywords: power flows, transmission system, phase shifting transformer
Słowa kluczowe: przepływy mocy, system przesyłowy, transformator PST

Introduction

Transmission system of the Slovak Republic is a part of European network of transmission system operators for electricity (ENTSO-E).

The operation and dispatch control of electric power systems requires resources for power flow control in networks. Due to the limitation of the paper, the paper shows only results of the simulations of the influence of the PST on the transmission system and very simple and basic principle of the PST.

PST

The main goal of the PST is to divide and control power among parallel transmission lines. Power, due to regulation by PST, is put to other lines and vice versa, the power is withdrawn from other lines, according to dispatcher and business needs in given area.

The principle of the PST is based on use of angle regulation of transformer ratio. PST is composed of series and regulation unit. Winding of the serial unit is placed directly into line (e.g. 400 kV), in which the phase angle is regulated. It means that the resulting voltage is composed of primary voltage and phase shifted regulation (additional) voltage. Regulating transformer with tap changer is supplied from serial unit. (Fig. 1)

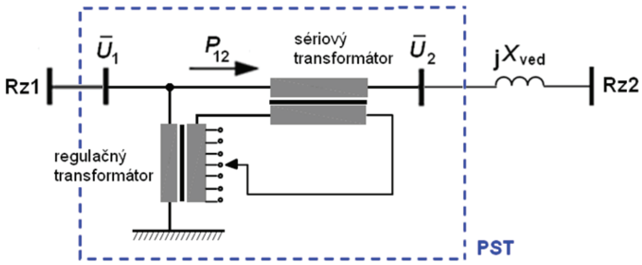


Fig. 1 Simple PST drawing

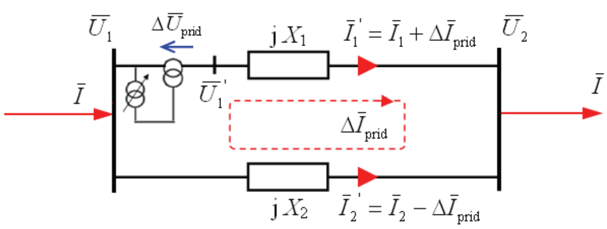


Fig. 2 Network with two parallel lines

The active power transferred between two nodes depends on voltage difference of these two nodes, difference of phasors, and indirectly in proportion to reactance of line between nodes, i.e.

(1) $$P_{12} = \frac{U_1 \cdot U_2}{X_{ved}} \cdot \sin(\vartheta_1 - \vartheta_2)$$

In case, the PST is used and put into line, the power flow can be calculated:

(2) $$P_{12}' = P_{12} \pm \Delta P = \frac{U_1 \cdot U_2}{X_{ved} + \Delta X} \cdot \sin(\vartheta_1 - \vartheta_2 + \Delta\vartheta)$$

where: ΔP – additional power flow caused by regulation, ΔX – additional reactance in line including PST, $\Delta\vartheta$ – angle between primary and secondary voltage of PST

In case the phase shit between primary and secondary winding equals zero ($\Delta\vartheta = 0°$), the power flow in the line with PST decreases and is limited due to its own reactance ΔX .

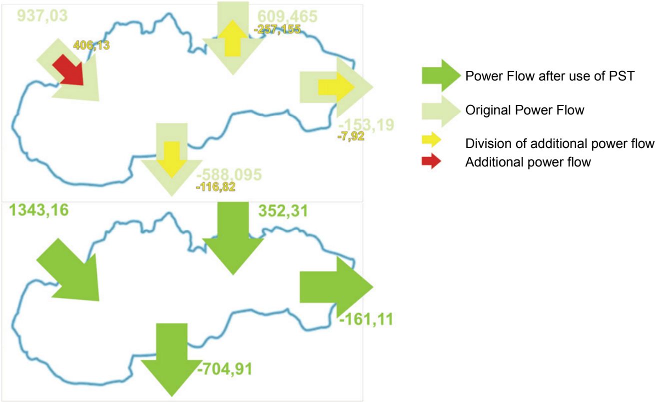
If angle difference between additional voltage and primary voltage equals zero, this is direct axis regulation. Because only network reactances are considered, additional current is delayed by 90^o behind additional voltage and has inductive character. From the above mentioned it is clear, that it is possible to influence mainly reactive power flows (the reactive part of currents is changing I_1 , I_2).

If additional voltage is in quadrature to basic voltage (α = 90°), it is called quadrature voltage control. Because only network reactances are considered, additional current is delayed by 90^o behind additional voltage and has active character.

Application of the PST in transmission system

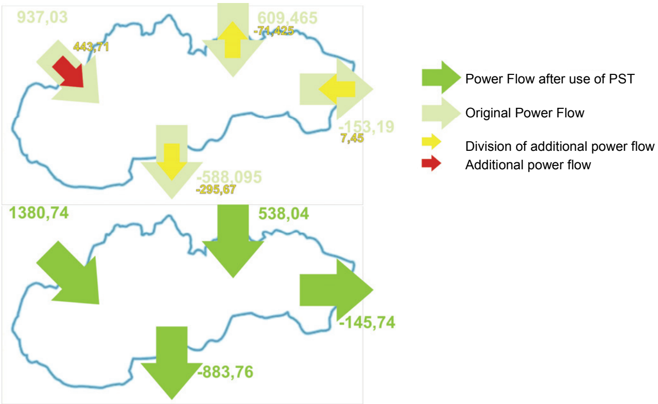
In order to simulate power flows in the Transmission system of the Slovak Republic, it is necessary to have a model of the whole transmission system of UCTE. In this simulation the model of UCTE (29th November 2007 at 12.30 o'clock) was used to simulate power flows on boundary lines. This model contains 5784 nodes (from this 982 generators, 3262 loads), 7798 lines, 1102 transformers [7].

Transformer PST was added separately into each of international 400 kV lines of Slovak transmission system (Fig. 3). After individual simulation, the regulation effect and losses was calculated, see Fig. 3 - Fig. 10.



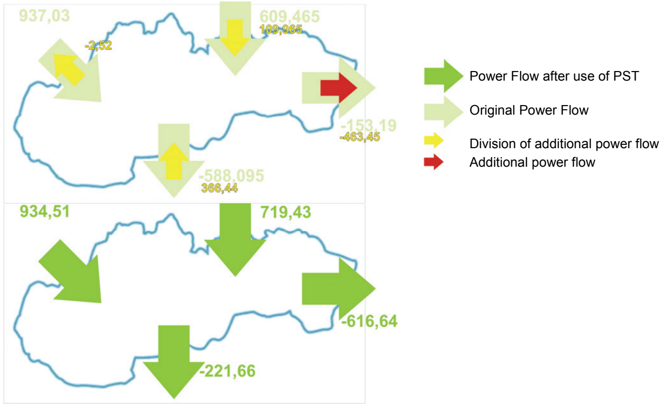
Profil	SK-CZ	SK-PL	SK-HU	SK-UA	Profile
Toky [MW] pôvodné	937,03	609,465	-588,095	-153,19	Original power flow [MW]
Toky [MW] pre Uhol PST= -25 °	1343,16	352,31	-704,91	-161,11	Power flow for angle -25° of PST
Rozdiel tokov pre uhol PST = -25 ° a pôvodných	406,13	-257,155	-116,82	-7,92	Difference between power flows for -25° angle and original power flows
Saldo pôvodné [MW]				805,21	Original balance [MW]
Saldo pre uhol PST= -25 °				829,45	Balance in case o PST Angle = -25°
Straty vplyvom PST pre uhol = -25 °				23.78	Losses caused by PST
Rozdiel (Saldo pre uhol = -25 ° - Straty vplyvom PST)				781,71	Difference (Balance for angle = -25° - losses caused by PST)

Fig. 3 Graphical visualisation of the PST regulation influence on profiles, in case of use of PST in line V404



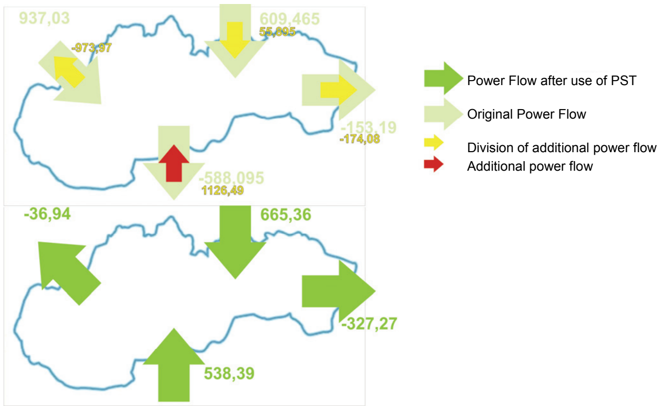
Profil	SK-CZ	SK-PL	SK-HU	SK-UA	Profile
Toky [MW] pôvodné	937,03	609,465	-588,095	-153,19	Original power flow [MW]
Toky [MW] pre Uhol PST= -40 °	1380,74	538,04	-883,76	-145,74	Power flow for angle -40° of PST
Rozdiel tokov pre uhol PST = -40 ° a pôvodných	443,71	-71,425	-295,67	7,45	Difference between power flows for -40° angle and original power flows
Saldo pôvodné [MW]				805,21	Original balance [MW]
Saldo pre uhol PST= -40 °				889,28	Balance in case o PST Angle = -40°
Straty vplyvom PST pre uhol = -40 °				83.78	Losses caused by PST
Rozdiel (Saldo pre uhol = -40 ° - Straty vplyvom PST)				781,82	Difference (Balance for angle = -40° - losses caused by PST)

Fig. 4 Graphical visualisation of the PST regulation influence on profiles, in case of use of PST in line V424



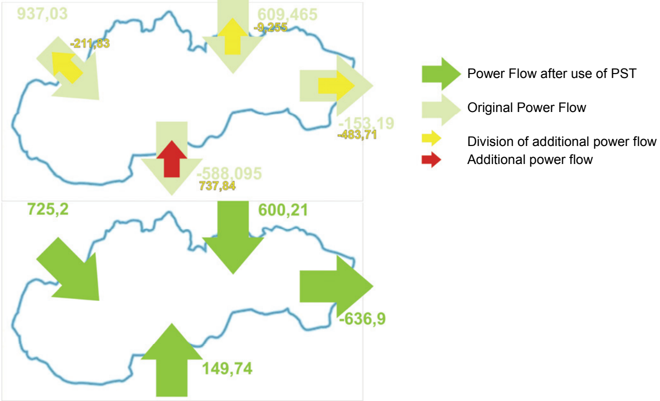
Profil	SK-CZ	SK-PL	SK-HU	SK-UA	Profile
Toky [MW] pôvodné	937,03	609,465	-588,095	-153,19	Original power flow [MW]
Toky [MW] pre Uhol PST= -20 °	934,51	719,43	-221,66	-616,64	Power flow for angle -20° of PST
Rozdiel tokov pre uhol PST = -20 ° a pôvodných	-2,52	109,965	366,44	-463,45	Difference between power flows for angle -20° and original power flows
Saldo pôvodné [MW]				805,21	Original balance [MW]
Saldo pre uhol PST= -20 °				815,64	Balance in case o PST Angle = -20°
Straty vplyvom PST pre uhol = -20 °				13.78	Losses caused by PST
Rozdiel (Saldo pre uhol = -20 ° - Straty vplyvom PST)				778,2	Difference (Balance for angle = -20° - losses caused by PST)

Fig. 5 Graphical visualisation of the PST regulation influence on profiles, in case of use of PST in line V440



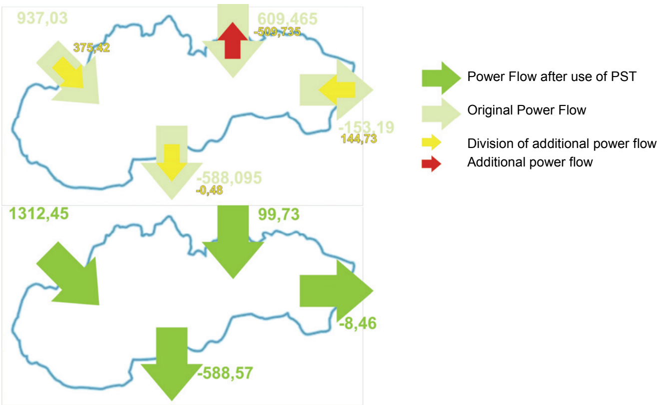
Profil	SK-CZ	SK-PL	SK-HU	SK-UA	Profile
Toky [MW] pôvodné	937,03	609,465	-588,095	-153,19	Original power flow [MW]
Toky [MW] pre Uhol PST= -40 °	-36,94	665,36	538,39	-327,27	Power flow for angle -40° of PST
Rozdiel tokov pre uhol PST = -40 ° a pôvodných	-973,97	55,895	1126,49	-174,08	Difference between power flows for -40° angle and original power flows
Saldo pôvodné [MW]				805,21	Original balance [MW]
Saldo pre uhol PST= -40 °				839,54	Balance in case o PST Angle = -40°
Straty vplyvom PST pre uhol = -40 °				34.78	Losses caused by PST
Rozdiel (Saldo pre uhol = -40 ° - Straty vplyvom PST)				780,93	Difference (Balance for angle = -40° - losses caused by PST)

Fig. 6 Graphical visualisation of the PST regulation influence on profiles, in case of use of PST in line V448



Profil	SK-CZ	SK-PL	SK-HU	SK-UA	Profile
Toky [MW] pôvodné	937,03	609,465	-588,095	-153,19	Original power flow [MW]
Toky [MW] pre Uhol PST= -35 °	725,2	600,21	149,74	-636,9	Power flow for angle -35° of PST
Rozdiel tokov pre uhol PST = -35 ° a pôvodných	-211,83	-9,255	737,84	-483,71	Difference between power flows for -35° angle and original power flows
Saldo pôvodné [MW]				805,21	Original balance [MW]
Saldo pre uhol PST= -35 °				838,25	Balance in case o PST Angle = -35°
Straty vplyvom PST pre uhol = -35 °				36.78	Losses caused by PST
Rozdiel (Saldo pre uhol = -35 ° - Straty vplyvom PST)				777,95	Difference (Balance for angle = -35° - losses caused by PST)

Fig. 7 Graphical visualisation of the PST regulation influence on profiles, in case of use of PST in line V449



Profil	SK-CZ	SK-PL	SK-HU	SK-UA	Profile
Toky [MW] pôvodné	937,03	609,465	-588,095	-153,19	Original power flow [MW]
Toky [MW] pre Uhol PST= -20 °	1312,45	99,73	-588,57	-8,46	Power flow for angle -20° of PST
Rozdiel tokov pre uhol PST = -20 ° a pôvodných	375,42	-509,735	-0,48	144,73	Difference between power flows for -20° angle and original power flows
Saldo pôvodné [MW]				805,21	Original balance [MW]
Saldo pre uhol PST= -20 °				815,15	Balance in case o PST Angle = -20°
Straty vplyvom PST pre uhol = -20 °				9.78	Losses caused by PST
Rozdiel (Saldo pre uhol = -20 ° - Straty vplyvom PST)				781,91	Difference (Balance for angle = -20° - losses caused by PST)

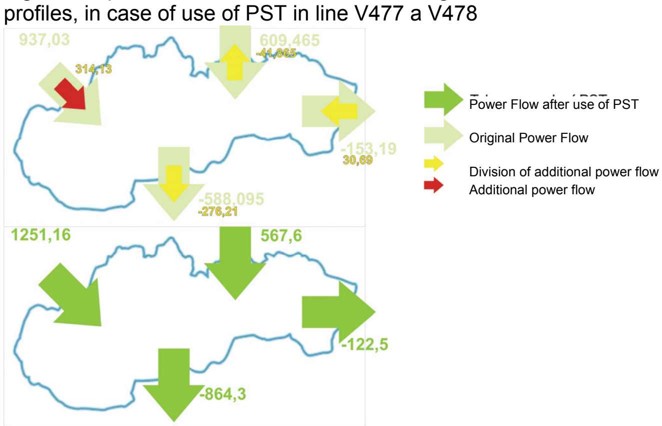
Fig. 8 Graphical visualisation of the PST regulation influence on profiles, in case of use of PST in line V477

It can be said, that:

- PST added into 404 affects mostly the power transmissions in profile SK-PL,
- PST added into 424 affects mostly the power transmissions in profile SK-HU,
- PST added into 440 affects mostly the power transmissions in profile SK-HU,
- PST added into 448 affects mostly the power transmissions in profile SK-CZ,
- PST added into 449 affects mostly the power transmissions in profile SK-UA,
- PST added into 477 (or 478) affects mostly the power transmissions in profile SK-CZ,
- PST added into 497 affects mostly the power transmissions in profile SK-HU.

Profil	SK-CZ	SK-PL	SK-HU	SK-UA	Profile
Toky [MW] pôvodné	937,03	609,465	-588,095	-153,19	Original power flow [MW]
Toky [MW] pre Uhol PST= -25 °	1390,06	1,36	-590,59	18,21	Power flow for angle -25° of PST
Rozdiel tokov pre uhol PST = -25 ° a pôvodných	453,03	-608,105	-2,5	171,4	Difference between power flows for -25° angle and original power flows
Saldo pôvodné [MW]				805,21	Original balance [MW]
Saldo pre uhol PST= -25 °				819,04	Balance in case o PST Angle = -25°
Straty vplyvom PST pre uhol = -25 °				13.78	Losses caused by PST
Rozdiel (Saldo pre uhol = -25 ° - Straty vplyvom PST)				781,9	Difference (Balance for angle = -25° - losses caused by PST)

Fig. 9 Graphical visualisation of the PST regulation influence on profiles, in case of use of PST in line V477 a V478



Profil	SK-CZ	SK-PL	SK-HU	SK-UA	Profile
Toky [MW] pôvodné	937,03	609,465	-588,095	-153,19	Original power flow [MW]
Toky [MW] pre Uhol PST= -25 °	1251,16	567,6	-864,3	-122,5	Power flow for angle -25° of PST
Rozdiel tokov pre uhol PST = -25 ° a pôvodných	314,13	-41,865	-276,21	30,69	Difference between power flows for -25° angle and original power flows
Saldo pôvodné [MW]				805,21	Original balance [MW]
Saldo pre uhol PST= -25 °				831,96	Balance in case o PST Angle = -25°
Straty vplyvom PST pre uhol = -25 °				26.78	Losses caused by PST
Rozdiel (Saldo pre uhol = -25 ° - Straty vplyvom PST)				781,79	Difference (Balance for angle = -25° - losses caused by PST)

Fig. 10 Graphical visualisation of the PST regulation influence on profiles, in case of use of PST in line V497

The regulation effect of the PST is shown in Fig. 11. Also energy loss was considered during the simulation and is presented in Fig. 12.

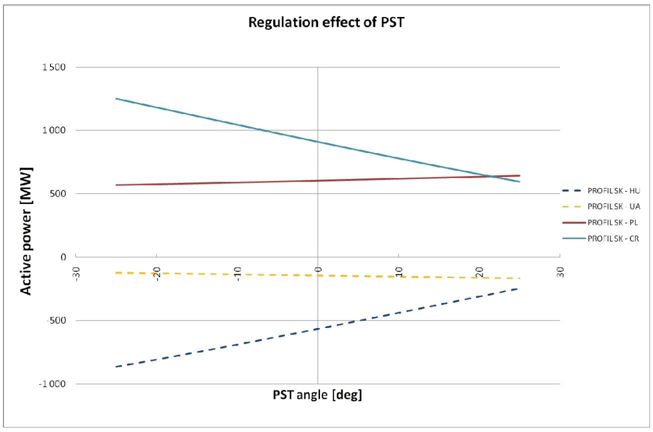


Fig. 11 The regulation effect of PST added into line 497

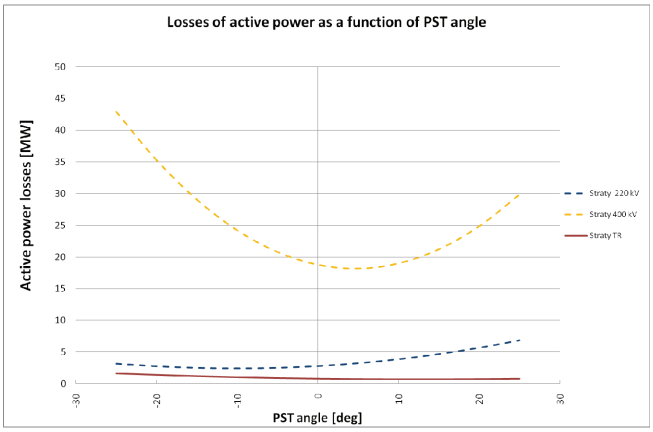


Fig. 12 Power losses in Slovak transmission system (PST in line 404, blue – energy losses for 220 kV level, yellow – energy losses for 400 kV voltage level, red - energy losses of transformers)

Conclusion

The main goal of this paper was to show and consider influence of the PST on power flows. The PST was used in international transmission lines, which are connecting the Slovak Republic to other countries. From the figures it is clear, that the PST has significant influence on power flows and also influences energy losses in the system.

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