POWER FLOW CONTROL BY USE OF PHASE-SHIFTING TRANSFORMER

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ABSTRACT

The operation efficiency of electric transmission system can be increased using of appropriate tools for the control of electric powers flowing along the power lines. Phase - shifting transformers (PST's) rank among such tools. The purpose of this paper is to provide basic information about these transformers. The paper explains the function of PST and the meaning of PST application in electric transmission system. The influence of PST on power distribution is described using the model created in Matlab software.

1 INTRODUCTION

Usually transformers are used to transport electric power between different voltage levels of the electric grid. Transformers may also be used to phase angle control between the primary (source) and the secondary (load) side. Such special transformers are termed phase-shifting transformers (phase angle regulating transformers) or simply phase-shifters. These transformers create a phase shift between the primary side voltage and the secondary side voltage. The purpose of this phase shift is usually the control of power flow over transmission lines. Both the magnitude and the direction of the power flow can be controlled by varying the phase shift [1]. The principal use of phase shifters is at major inter-tie buses where the control of active power exchange is especially important [2].

2 FUNCTION OF PHASE-SHIFTING TRANSFORMER

Theoretically, the PST can be considered a sinusoidal ac voltage source with controllable amplitude and phase angle [3].

Function of PST can be described through the current distribution over parallel lines (Figure 1). The „natural" current distribution depends on the impedance of the lines. This distribution may be rather inefficient, if $\mathbf{Z}_{line1}$ and $\mathbf{Z}_{line2}$ are extremely different. With the introduction of an additional voltage source a circulating current can be generated, which equalizes the currents [4].

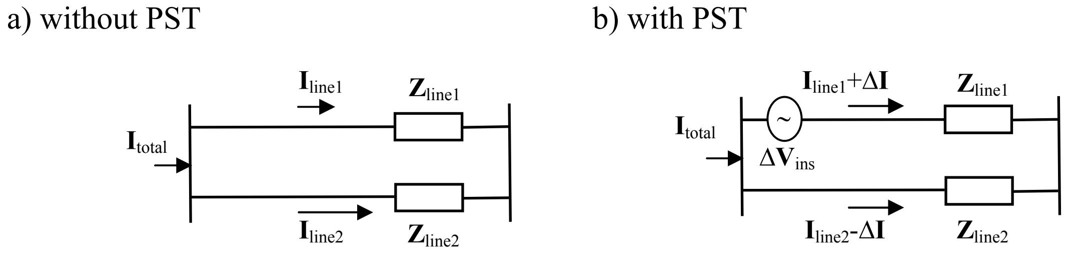

Fig. 1: *Current distribution over the parallel lines*

Because the mainly part of the line impedance (on high voltage levels) is inductive reactance, inserting a voltage in phase with or opposite to the line voltage (changing the magnitude of the voltage) will have an impact mainly on the reactive part of currents (reactive power flows). The boost voltage with a phase angle perpendicular to the line voltage (creating a phase shift) influences mainly the real part of currents (real power flows).

3 MAIN CATEGORIES OF PST'S

For the real power flow influence there are the most often used the quadrature symmetric or the quadrature non-symmetric PST's.

A quadrature type phase shifter is a unit where the boost voltage, which creates the phase shift between source and load terminals, is perpendicular to the line voltage at one terminal, or to a combination of the line voltages at source and load terminals [4].

The term „symmetric" means, that under no load condition the voltage magnitude at the load side is always equal to the voltage magnitude at the source side, independent from the phase angle [4].

Quadrature non-symmetric devices add a quadrature voltage to the input voltage. The output voltage is the vector sum of these two perpendicular voltages (therefore the output voltage is boosted by a small amount).

These transformers can be with a single (only series unit) or a dual core (series and exciting unit) design, and with a single tank or a dual tank design. In most cases a dual core design requires a dual tank design as well, but this is not a necessity [4].

There are shown the voltage phasor diagrams for different transformers in the Figure 2. There is shown the voltage control by classical regulating transformer (Figure 2a), the phase angle control by quadrature symmetric PST (Figure 2b) and the phase angle control by quadrature non-symmetric PST (Figure 2c).

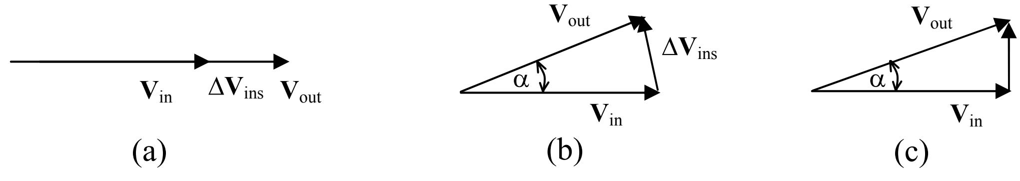

Fig. 2: *Voltage phasor diagrams for different transformers*

4 PST MODEL IN MATLAB SOFTWARE

It was created program for calculation of power distribution in the network with and without use PST. This program is developed in Matlab software and consists of simplified model of non-symmetric quadrature type PST and parallel connected lines. PST is used for the control of power flow over the lines.

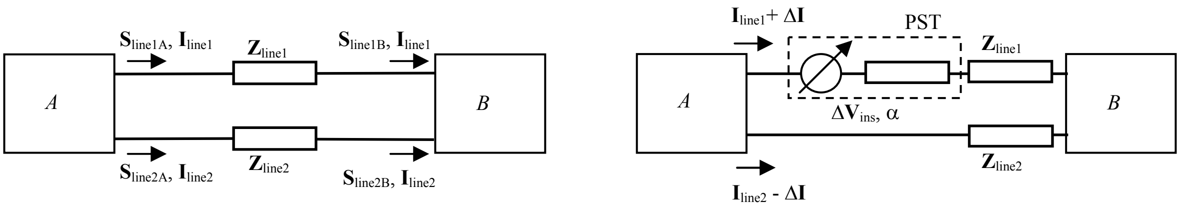

Fig. 3: *Models of power system used in the program*

A is the electric power undersystem, where it is defined voltage and the apparent power transmitted into the lines.

B is the electric power undersystem, where it is the voltage and power depended on the power flows over the lines. Phase-shifting transformer is represented by ideal transformer with a complex ratio in series with impedance. Power distribution over the lines depends on the voltage shift (α) between the voltages at transformer terminals as well as on the impedances (transformer impedance and line impedances).

4.1 NUMERICAL RESULTS

It was studied effect of real PST on the current and power distribution over two parallel 110 kV lines. The study was realized using of mentioned program. In the following tables are presented some results from this study.

I_{line1} [kA]	S_{line1A} [MVA]	S_{line1B} [MVA]
0.573-0.197i	109.08+37.52i	107.43+32.02i
I_{line2} [kA]	S_{line2A} [MVA]	S_{line2B} [MVA]
0.478-0.148i	90.92+28.22i	89.437+23.73i

Tab. 1: *Current and power distribution over the parallel lines without use of PST*

I_{line1} [kA]	S_{line1A} [MVA]	S_{line1B} [MVA]
0.525-0.167i	99.99+31.68i	98.55+24.6i
I_{line2} [kA]	S_{line2A} [MVA]	S_{line2B} [MVA]
0.525-0.179i	100.01+34.06i	98.17+28.53i

Tab. 2: *Effect of the phase-shifting transformer on the current and power distribution over the parallel lines after inserting voltage which equalizes the active currents*

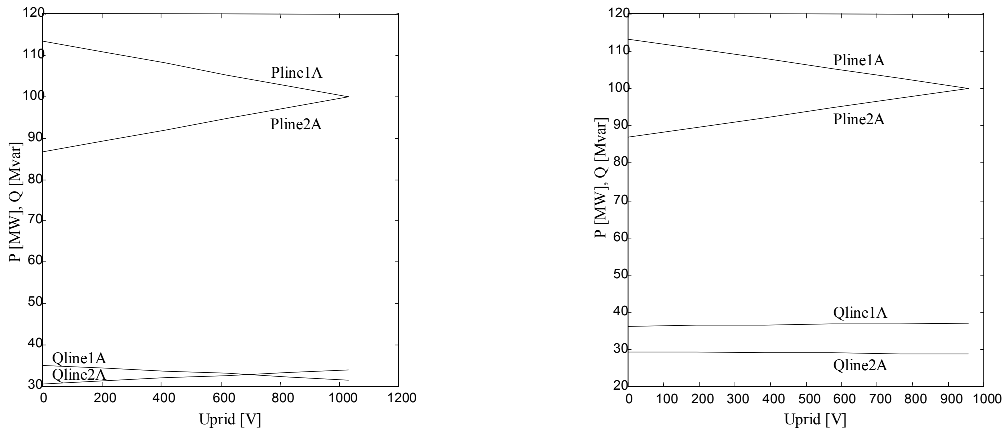

Fig. 4: *Effect of the PST on the power distribution over the parallel lines for the two alternatives of loop impedance*

Figure 4 shows impact of the PST equalizing the active currents on the power distribution for two alternatives of the line impedances. Figure 4a shows effect of the PST on the power distribution for $\mathbf{Z}_{line1}$=(1,5+j5)Ω and $\mathbf{Z}_{line2}$=(2+j6)Ω. Figure 4b shows effect of the PST on the power distribution for $\mathbf{Z}_{line1}$=(0,3+j5)Ω and $\mathbf{Z}_{line2}$=(0,4+j6)Ω.

It is clear that by increasing the ratio between reactance and resistance it is increased the PST effect on the active power flows and the other side it is decreased the PST effect on the reactive power flows.

5 CONCLUSIONS

From the results it is clear that PST can be used for the control of active power distribution over the lines. There is no phase-shifting transformer in Slovak republic therefore the results from the developed model are not verified. Developed program can be used to better understanding of function of PST and eventually for analysis of power distribution over two parallel lines without and with PST before PST application.

REFERENCES

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