Power Flow Modeling and Simulation of TCPST Based on PSASP Program (Postprint)

Authors: Yang Yongqian, Chen Xi

Date: 2019-03-05T00:00:00+00:00

Abstract

This paper derives the injected power equations and injected current model for the dual-core symmetric thyristor controlled phase shifter (TCPST). For the two different models, utilizing the user-defined model functionality provided by the Power System Analysis Synthesis Program (PSASP) 6.2, two power flow algorithms suitable for PSASP are constructed to facilitate power flow analysis of power systems containing TCPST. A 3-machine 9-bus system is built based on PSASP 6.2 and simulations are conducted. The results demonstrate that both models established in this paper can effectively implement power flow calculation for TPCST-containing systems, which holds certain reference significance for the modeling of other power system components.

Full Text

Preamble

Modeling and Simulation of Power Flow for TCPST Based on PSASP

Yang Yongqian[1], Chen Xi[2]
(1. State Grid Jiangsu Electric Power Engineering Consulting Co., Ltd., Nanjing 210008, China)
(2. State Grid Jiangsu Economic Research Institute, Nanjing 210008, China)

Abstract

Based on the current-injection method and power-injection method, this paper proposes two distinct models for the two-core symmetrical thyristor-controlled phase-shifting transformer (TCPST). Leveraging the user-defined model interface of Power System Analysis Software Package (PSASP) version 6.2, we construct two corresponding models suitable for PSASP that enable power flow analysis of systems containing TCPST. To validate the effectiveness of both models, a 3-machine 9-bus test system is established as a calculation example. The results demonstrate that both models can effectively implement power flow calculations for TCPST-equipped systems, providing a valuable reference for modeling other power system components.

Keywords: Thyristor-controlled phase shifter, PSASP, modeling, simulation, power flow calculation

1 Introduction

As a type of FACTS device, the thyristor-controlled phase-shifting transformer (TCPST) not only fulfills the requirements of steady-state power flow control but also exhibits rapid response characteristics that positively impact power system transient stability. Reference [1] provides a comprehensive discussion of existing TCPST types and classifies them based on topological differences. Reference [2] introduces a novel two-core symmetrical discrete controllable phase shifter (TCSD-TCPST) and presents detailed mathematical modeling derivations. Although TCPST topologies vary widely and specific models differ accordingly, the mathematical model can be established by leveraging the coupling relationship between the series and parallel components through the TCPST phasor diagram. In power flow calculation modeling for controllable phase shifters, the power injection method is commonly employed. Reference [3] derives the node injection power model for an ideal phase shifter, while Reference [4] presents detailed derivations for phase shifter modeling and injection power models that consider impedance values.

To facilitate mathematical modeling of new power system components, PSASP 6.2 incorporates a user-defined (UD) modeling interface [5]. Reference [6] utilizes this UD module to construct a node injection power model for TCPST and validates its rationality within the IEEE 14-bus system. Reference [7] employs PSASP to establish a node injection power model for unified power flow controllers. In fact, besides the node injection power model, TCPST can also be modeled using the node injection current model. PSASP' s UD module conveniently provides an injection current interface for this purpose.

This paper extends the modeling analysis of the TCPST proposed in Reference [2], deriving detailed expressions for both node injection current and node injection power models that are suitable for power flow calculations. Using the UD module in PSASP, we model both approaches and validate them through simulation.

2 TCPST Power Flow Calculation Models

The equivalent circuit of TCPST is shown in Figure 1 [Figure 1: see original paper]. From the two-port network theory, the relationship between injection currents and node voltages can be expressed as:

$$\begin{bmatrix} \dot{I}_i \\ \dot{I}_j \end{bmatrix} = \begin{bmatrix} Y_T & -T^* Y_T \\ -T Y_T & Y_T \end{bmatrix} \begin{bmatrix} \dot{U}_i \\ \dot{U}_j \end{bmatrix}$$

where $T = e^{j\phi}$.

Equation (1) reveals that when a system contains a TCPST, the node admittance matrix becomes asymmetric, and the elements associated with the phase shifter nodes vary with the phase shift angle during power flow calculations. This necessitates handling variable matrix elements during iterations. However, using either the injection current model or injection power model for TCPST can effectively avoid this complexity and facilitate integration with PSASP’ s UD module for power flow components.

2.1 Node Injection Current Model

To derive the injection current model, the TCPST equivalent can first be represented as a controlled source model consisting of a controlled voltage source and a controlled current source, as shown in Figure 2 [Figure 2: see original paper]. In this figure, $\dot{U}_B$, $\dot{I}_E$, and K are expressed as:

$$\dot{U}_B = \dot{U}_j - \dot{U}_i = (e^{j\phi} - 1)\dot{U}_i = K\dot{U}_i$$

$$\dot{I}_E = \dot{I}_i - \dot{I}_j = (e^{-j\phi} - 1)\dot{I}_j = K^* \dot{I}_j$$

$$K = e^{j\phi} - 1 = (\cos\phi - 1) + j\sin\phi$$

As derived in Reference [2], a TCPST installed between nodes i and j can be represented by an ideal transformer with complex turns ratio and corresponding equivalent impedance, as shown in Figure 1. The complex turns ratio is $T = e^{j\phi}$ with impedance Z_T and admittance $Y_T = 1/Z_T = g_T + jb_T$. Typically, the resistance of TCPST is small and can be neglected for modeling convenience, i.e., $g_T = 0$.

Since PSASP’ s UD model injection current interface represents values through real and imaginary components, we must first derive the real and imaginary parts of injection currents at nodes i and j. Applying Norton’ s theorem, the series voltage source $\dot{U}_B$ in series with admittance Y_T can be converted to a parallel configuration of branch admittance and current source. This yields the injection currents $\dot{I}_i$ and $\dot{I}_j$ at nodes i and j in Figure 2b.

Combining equations (1) through (3), the real and imaginary components of TCPST injection currents at nodes i and j are:

$$I_{iR} = [g_T(\cos\phi - 1) + b_T \sin\phi]U_{jR} - [b_T(\cos\phi - 1) - g_T \sin\phi]U_{jI}$$

$$I_{iI} = [g_T(\cos\phi - 1) + b_T \sin\phi]U_{jI} + [b_T(\cos\phi - 1) - g_T \sin\phi]U_{jR}$$

$$I_{jR} = [g_T(\cos\phi - 1) - b_T \sin\phi]U_{iR} - [b_T(\cos\phi - 1) + g_T \sin\phi]U_{iI}$$

$$I_{jI} = [b_T(\cos\phi - 1) + g_T \sin\phi]U_{iR} + [g_T(\cos\phi - 1) - b_T \sin\phi]U_{iI}$$

where U_{iR}, U_{jR} are the real parts of node voltages; U_{iI}, U_{jI} are the imaginary parts; and $I_{iR}, I_{jR}, I_{iI}, I_{jI}$ are the real and imaginary components of TCPST injection currents at nodes i and j.

2.2 Node Injection Power Model

From Figure 2b, the TCPST injection power model is obtained as shown in Figure 3 [Figure 3: see original paper]. The injection powers ΔP_i and ΔP_j at nodes i and j are expressed as:

$$\Delta P_i + j\Delta Q_i = \dot{U}_i \dot{I}_i^*$$

$$\Delta P_j + j\Delta Q_j = \dot{U}_j \dot{I}_j^*$$

Since PSASP' s UD model injection power interface represents values through active and reactive power components, the real and imaginary expressions for TCPST injection powers at nodes i and j are:

$$\Delta P_i = U_i U_j \{g_T[\cos(\phi + \theta_{ij}) - \cos\theta_{ij}] + b_T[\sin(\phi + \theta_{ij}) - \sin\theta_{ij}]\}$$

$$\Delta Q_i = U_i U_j \{g_T[\cos(\phi + \theta_{ij}) - \cos\theta_{ij}] - b_T[\cos(\phi + \theta_{ij}) - \cos\theta_{ij}]\}$$

$$\Delta P_j = U_i U_j \{g_T[\cos(\phi - \theta_{ji}) - \cos\theta_{ji}] + b_T[\sin(\phi - \theta_{ji}) + \sin\theta_{ji}]\}$$

$$\Delta Q_j = -U_i U_j \{g_T[\sin(\phi - \theta_{ji}) + \sin\theta_{ji}] + b_T[\sin(\phi - \theta_{ji}) + \sin\theta_{ji}]\}$$

where $\Delta P_i, \Delta P_j$ are the injected active powers; $\Delta Q_i, \Delta Q_j$ are the injected reactive powers; U_i, θ_i and U_j, θ_j are voltage magnitudes and phases at nodes i and j; and $\theta_{ij} = \theta_i - \theta_j$, $\theta_{ji} = \theta_j - \theta_i$.

3 PSASP Custom Models

3.1 PSASP Custom Model Framework

The Power System Analysis Software Package (PSASP) is a comprehensive power system simulation software developed by the China Electric Power Research Institute. To accommodate evolving power electronics technologies and new system components, PSASP incorporates a user-defined modeling approach through its User Definition (UD) module.

The fundamental building block of a user-defined model is illustrated in Figure 4 [Figure 4: see original paper], where each functional block computes output y based on inputs (x_1, x_2). PSASP user-defined models are constructed by interconnecting these basic functional blocks, which can perform various operations including calculus, algebraic functions, basic mathematical functions, logical control, linear and nonlinear functions, and other computations. Complex power components can be modeled by combining sufficient basic functional blocks to achieve the desired functionality.

Each custom model integrates with the power system through its input variables $X(x_1, x_2, ...)$ and output variables $Y(y_1, y_2, ...)$, as shown in Figure 5 [Figure 5: see original paper].

Equations (4) and (6) demonstrate that both TCPST node injection current and power models consist of fundamental algebraic calculations. Consequently, TCPST power flow calculation models can be readily constructed by interconnecting basic functional blocks in UD, enabling power flow simulation for systems with TCPST.

3.2 TCPST Node Injection Current Custom Model

Based on equation (4), the TCPST node injection current custom model can be built in PSASP using various functional blocks, as shown in Figure 6 [Figure 6: see original paper]. The parameters are defined as follows: B1 and B2 represent TCPST nodes i and j; VTR denotes the real part of node voltage; VTI denotes the imaginary part of node voltage; X(L) is the required line reactance (TCPST equivalent reactance); X0(B1) is the TCPST phase shift angle ϕ. The outputs ITR and ITI represent the real and imaginary parts of injected current at the corresponding bus. It is crucial to configure the A parameters in each functional block according to equation (4) to ensure model accuracy.

3.3 TCPST Node Injection Power Custom Model

Similarly, based on equation (6), the TCPST node injection power custom model can be constructed in PSASP using functional blocks, as depicted in Figure 7 [Figure 7: see original paper]. The parameters are: B1 and B2 as TCPST nodes i and j; VT as node voltage magnitude; X(L) as the required line reactance (TCPST equivalent reactance); X0(B1) as the TCPST phase shift angle ϕ. The outputs P and Q represent the injected active and reactive power at the corresponding bus. As with the current model, the A parameters must be set according to equation (6) to ensure correctness.

4 Case Study

The Anderson 3-machine 9-bus test system is employed to demonstrate the necessity of using detailed models that incorporate impedance. System power flow data is obtained from Reference [9]. The PSASP implementation is shown in Figure 8 [Figure 8: see original paper], with the phase shifter installed on line 8-9. Both the TCPST node injection current custom model and node injection power custom model are applied for power flow calculations. To verify accuracy, the Matpower software package described in Reference [10] is used for comparative calculations.

The calculation results demonstrate that both the TCPST injection current custom model and injection power custom model in PSASP yield results within 0.1% error compared to Matpower calculations for TCPST-equipped systems. This confirms that the models constructed in Figures 6 and 7 are effective and provide reliable UD models for analyzing TCPST systems in PSASP.

5 Conclusion

This paper abstracts the TCPST equivalent model into a controlled source model and derives detailed expressions for both TCPST node injection current and node injection power custom models. These injection models avoid the complexity of handling asymmetric admittance matrices in TCPST-equipped systems and enable effective interfacing with conventional power flow calculation programs. Based on PSASP interface characteristics, two distinct UD models are constructed for power flow calculations. Validation on the Anderson 3-machine 9-bus system confirms that both the TCPST node injection current custom model and node injection power custom model effectively represent TCPST behavior, offering a valuable reference for modeling other TCPST types or FACTS elements in PSASP.

References

[1] Iravani M R, Maratukulam D. Review of semiconductor-controlled (static) phase shifters for power systems applications[J]. IEEE Transactions on Power Systems, 1994, 9(4): 1833-1839.

[2] Yang Yongqian, Cui Yong, Yang Zenghui, et al. Modelling of two-core symmetrical discrete thyristor controlled phase shifting transormer[J]. Shanxi Electric Power, 2014, 42(11): 61-67.

[3] Han Z X. Phase shifter and power flow control[J]. IEEE Transactions on Power Apparatus and Systems, 1982, PAS-101(10): 3790-3795.

[4] Noroozian M, Andersson G. Power flow control by use of controllable series components[J]. IEEE Transactions on Power Delivery, 1993, 8(3): 1420-1429.

[5] China Electric Power Research Institute. Power System Analysis Software Package User Manual[M]. Beijing: China Electric Power Research Institute, 2005.

[6] Liu Qianjin, Li Xiong, Sun Yuanzhang. Power flow modelling of FACTS based on PSASP[J]. Power System Techonlogy, 2000(7): 6-9.

[7] Yao Shujun, Song Xiaoyan, Wang Yan. Power flow modelling of unified power flow controller base on power system analysis software pcckage(PASAP)[J]. Journal of North China Electric Power University(Natural Science Edition), 2011, 38(5): 11-16.

[8] Anderson P M, Fouad A A. Power system control and stability[M]. Wiley.com, 2008.

[9] Reference [9] citation (specific document not detailed in original text).

[10] Zimmerman R D, Murillo-Sánchez C E, Thomas R J. Matpower: steady-state operations, planning and analysis tools for power systems research and education[J]. IEEE Transactions on Power Systems, 2011, 26(1): 12-19.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv —Machine translation. Verify with original.