Study on Operational Tests for FACTS Thyristor Valves

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***Abstract*—Developed synthetic test circuits for thyristor valves of flexible ac transmission systems (FACTS) are established in this paper. By controlling the thyristor valves of synthetic test circuits, it can reproduce test stresses, including, but not limited to, the forward high voltage before the thyristor valve withstanding overcurrent and reverse recovery voltage after thyristor valves withstanding overcurrent, on thyristor valves in FACTS equipment equal to or greater than those that appear in commercial projects. With corresponding test circuits and control strategies, the temperature-rise test, overcurrent test, and the synthetic test for thyristor valves can be performed, respectively. Then, a protection method of synthetic test circuits is presented. Finally, a temperature-rise test platform, overcurrent test platform, and synthetic test platform for thyristor valves have been set up, respectively. The test results show that the developed circuit and proposed control and protect strategies are available to test for thyristor valves used in FACTS.**

***Index Terms*—Break over diode (BOD), controllable high-voltage shunt reactor (CSR), flexible ac transmission systems (FACTS), operational tests, static var compensators (SVC), synthetic test circuits, thyristor valve, thyristor-controlled series compensation (TCSC).**

I. Introduction

THE operation performance of long distance and inter-regional ac transmission system is usually limited by various factors. The power system stability and economy have been improved remarkably over the past 10 years, thanks to the application of flexible ac transmission systems (FACTS) equipment, such as static var compensators (SVC) [1]–[3] and thyristor-controlled series compensation (TCSC) [4]–[7]. FACTS controllers can also effectively mitigate the subsynchronous resonance (SSR) caused by an induction generator. For most FACTS equipment, the thyristor is the most critical semiconductor device. However, the thyristor is sensitive and vulnerable to voltage stress; current stress; $dv/dt, di/dt$; and its junction temperature. To enhance the reliability of FACTS, it is necessary to carry out test research and equipment development for the high-voltage (HV) thyristor valve.

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Since the capacity of FACTS equipment is continuously increasing, a direct test for the HV thyristor valve can hardly be realized. Currently, a synthetic test circuit is the preferred choice to test the valve section, which consists of several series-connected thyristor levels [9]–[12]. In the synthetic test setup, the large current and the high voltage (HV) are generated, respectively, by different power supplies. This method is an economical alternative, since it remarkably decreases the installed capacity of test facilities [11].

In the 1990s, several international companies proposed respective test circuits of various ratings for different test objectives. For example, the HV and large current of the synthetic test setup in ABB Company Switzerland are rated at 50 kV (peak) and 4500 A (rms), respectively [13]. It can be applied to the thyristor valves of SVC. However, its voltage rating is slightly low, and the synthetic test cannot reproduce the forward HV before the thyristor valve withstanding overcurrent. The HV and large current of the synthetic test setup in ABB Company Sweden are 70 kV (peak) and 4000 A (peak), respectively [10]–[12]. However, it can be applied for the HVDC thyristor valve. The HV and large current of the synthetic test setup in Siemens Company are 60 kV (peak) and 2600 A (rms), respectively [9]. Although the test setup is fit for thyristor valves of FACTS and HVDC, its resonance frequency is fixed. What is more, it can't reproduce the reverse recovery voltage of thyristor valves after withstanding overcurrent. In 2004, the China Electric Power Research Institute (CEPRI) developed their synthetic test facility, with voltage and current rating at 80 kV (peak) and ac 4000 A (rms)/dc 5000 A, respectively. The test facility can reproduce the forward HV before the thyristor valve withstanding overcurrent and reverse recovery voltage after thyristor valves withstanding overcurrent. It is fully capable of performing an operational-type test for the thyristor valve of FACTS and HVDC per IEC/IEEE standards [14], [15]. The test facilities had been successfully used for the type test of more than 100 projects, such as the Dunhuang 750 kV controllable HV shunt reactor (CSR) project in 2011, Taoxiang 500 kV SVC project in 2010, and the Yimin-Fengtun 500 kV TCSC project in 2007 in China.

In this paper, the main circuits of the temperature-rise test, overcurrent test, and synthetic test have been improved by referring to the design of synthetic test setup of ABB Company, Siemens Company, and [16], [17]. The low-voltage (LV) continuous trigger for the control of the thyristor valve has been proposed. Then, the overvoltage of the large current test mode and the protection method are analyzed, respectively. Finally, three kinds of test of the thyristor valve have been carried out, respectively.

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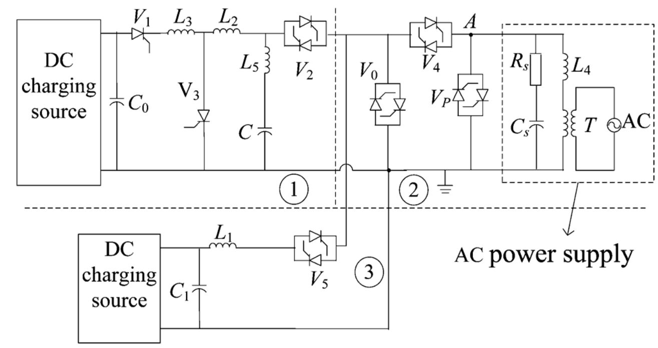

Fig. 1. Schematic diagram of the MIST circuit.

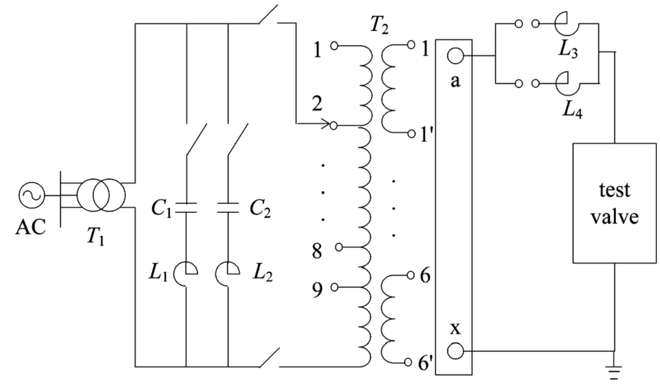

Fig. 2. Schematic diagram of the temperature-rise mode.

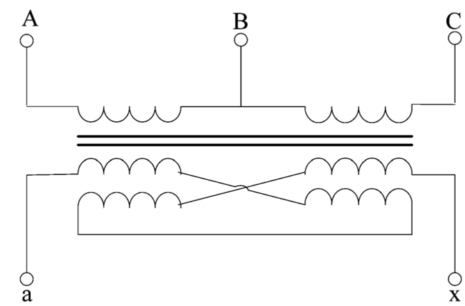

Fig. 3 Wiring of the conversion transformer.

II. Test Circuits

The synthetic test circuit for the operational tests of the FACTS thyristor valve is shown in Fig. 1. It consists of three subsystems, which are the double injection voltage circuit ①, the large ac current injection circuit ②, and the resonance injection circuit ③. The mechanical switches between the circuits can realize the switching of test circuits as well as mechanical isolation. The double injection voltage circuit consists of the LV charging circuit (which comprises the dc charging power supply, the capacitor C_0), auxiliary valve V_1, reactors L_2 and L_3, the oscillatory voltage boost circuit (which includes the resonance reactor L_5 and resonance capacitor C). The large ac current circuit comprises the ac power supply, the charging transformer T, auxiliary valve V_4, snubber circuit $R_{\rm s}$ and $C_{\rm s}$, protection valve $V_{\rm p}$, and lead inductance L_4. The resonance injection circuit consists of the capacitor C_1, resonance inductor L_1, auxiliary valve V_5, and dc charging power supply. By controlling thyristor valves V_5, V_2, V_4 and the test object V_0, the temperature-rise test, overcurrent test, and synthetic test of V_0 can be realized. The synthetic test circuit for the operational tests of the HVDC thyristor valve can refer to Fig. 1 (only replace the large ac current injection circuit with the large dc current injection circuit).

III. Operating Principle and Testing Methods

A. Operating Principle of the Temperature-Rise Mode

The circuit of the temperature-rise mode is shown in Fig. 2. Since the load of the conversion transformer T_1 is a single-phase load, the structure of T_1 shown in Fig. 3 can distribute the single-phase load to A phase, B phase and C phase primary windings in the proportion of 25%: 50%: 25%. And the unbalance of the single-phase load for the ac power can be mitigated effectively. Taking into account the requirement for adjusting the voltage and current to the test valve, the secondary winding of the temperature-rise transformer T_2 is designed as 6 windings (mutually isolated) so that the output voltage can be regulated by series and/or parallel windings. Moreover, the output current can be controlled by selecting different limiting reactors, which are adjustable. In Fig. 2, C_1 and L_1, C_2 and L_2 constitute different filtering circuit for the power supply, respectively, and L_3 and L_4 are adjustable reactors which are capable of wide-range regulation for the large current.

B. Operating Principle of Overcurrent Mode

The test circuit mainly comprises subsystems ② and ③ shown as Fig. 1. The test procedures are as follows:

1) Fire the isolating valve V_4 and the test valve V_0 before the instant t_1 so that the test valve carries large current. The procedure simulates the normal current of V_0 in service.
2) Block V_4 and V_0 when the test valve reaches thermal equilibrium and the junction temperature reaches the test requirement.
3) Continuously fire the control valve V_5 at the instant t_2 so that the forward HV applies to the test valve V_0. The procedure simulates the forward HV before the test valve withstands overcurrent.
4) Fire the test valve V_0 at the instant t_3 to keep it under the overcurrent state.
5) When the voltage of capacitor C_1 (Fig. 1) reverses after half a resonance period, block the test valves V_0 to keep V_0 under reverse HV. Then, continuously fire V_5, so that the test valve V_0 is exposed to negative HV. The procedure simulates the reverse recovery voltage after thyristor valves withstand overcurrent. The current and voltage waveforms of the test valve are shown in Fig. 4.

C. Operating Principle of Synthetic Test Mode

The test circuit mainly comprises subsystems ① and ② as shown in Fig. 1. The current circuit verifies the current-carrying and temperature-rise capabilities of SVC and TCSC thyristor valve. Also, the current test is a precondition for the voltage-current synthetic test. The voltage circuit includes the LV charging circuit and the oscillatory voltage boost circuit, which is an actual HV oscillation generator.

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