Research and Analysis of Phase Modulation Method of Standby Power Transmission Line Based on TSPST

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Abstract. When the power plant fails, in order to reduce the excessive inrush current generated by the switching of the backup power supply to the electrical equipment, the backup power supply was unable to switch quickly. This article mainly studies and analyzes a power supply method based on TSPST to adjust the phase of the standby power transmission line and make corresponding design and calculation for the theory and structure of the process. According to the actual parameters of the project, the power supply method is simulated and analyzed. According to simulation experiments, the feasibility and reliability of the proposed power supply method are verified.

1. Introduction

In order to ensure the safe and stable operation of the auxiliary power system of the power plant, when the main power supply side fails, it is necessary to disconnect the main power supply side and switch to the backup power supply. Usually, a quick switching device is used to switch to a backup power source to continue powering the equipment. However, the cause and location of the failure in the power plant are different. The failure of the electrical system will cause the switching conditions of the backup power supply to change, resulting in unsuccessful quick switching. Reduce the impact of excessive inrush current generated when switching backup power to cause damage to the auxiliary power system equipment or lead to unsuccessful rapid switching. To reduce the time of switching power supply and the time of power failure of electrical equipment, improve the reliability of power supply. This article chooses to use TSPST to adjust the phase switching power supply method of the standby power transmission line.

2. TSPST working principle and topological structure

TSPST consists of parallel transformer (ET), series transformer (BT) and thyristor valve group. TSPST obtains the standby line voltage from the parallel transformer, gets the required injection voltage through the thyristor valve group, and injects the voltage into the standby power line by the series transformer, so as to change the standby power voltage and phase angle.

According to the different adjustment methods and results of the line voltage amplitude and phase angle, the phase shifter is generally divided into three adjustment methods: longitudinal adjustment, horizontal adjustment and diagonal adjustment. In order to adjust the difference between the phase angle of the standby power voltage and the residual voltage of the busbar, improve the success rate of rapid switching, and ensure that the impact current to the electrical equipment after the switching is within the equipment’s acceptable range.
2.1. Working principle

The power supply method is to connect an additional potential (∆U) with a suitable phase in series on the backup power transmission line, superimpose the voltage on the backup power line to adjust the voltage amplitude and phase of the backup power to obtain the backup power output voltage (U_a2). The structure diagram of the power supply system for seamless switching of standby power based on TSPST hierarchical adjustment is shown in Figure 1.

![Figure 1. Structure diagram of power supply system based on TSPST hierarchical adjustment of standby power seamless switching.](image_url)

When the factory power system is working normally, the factory load is powered by the main power source. When the main power supply system fails, after the protection device operates, the voltage amplitude and phase angle difference between the load side and the backup power supply side are measured. According to the analysis of the measurement results, adjust the opening and closing of the thyristor valve group by changing the trigger pulse of the thyristor valve group. Adjust the phase and amplitude of the additional potential ∆U to make the output voltage of the standby power supply close to the phase of the bus voltage on the load side. Switch to the backup power source to continue supplying power to the load, and then continue to control the opening and closing of the thyristor valve group, and gradually decrease the injection voltage levels until it is adjusted to the 0 level, Then switch to the bypass switch to complete the seamless switching of the backup power supply of the power supply system.

2.2. Topology

The TSPST circuit structure diagram is shown in Figure 2(a), the thyristor valve group is composed of four groups of double inverted thyristors connected in parallel. The thyristor valve group is composed of four groups of double inverted thyristors in parallel, which are connected in parallel with the secondary winding of the parallel transformer. The secondary side of the parallel transformer adopts a 3^k connection method to ensure that the phase difference between the standby power supply and the residual voltage of the busbar is within the safe closing range. In this paper, k=3, then the secondary side adopts a three-winding with a turns ratio of 1:3:9. Therefore, the secondary voltage should be ∆U, 3∆U, 9∆U. After being controlled by the thyristor valve group, a total of 27 voltage levels can be obtained from -13∆U to 13∆U. The transformation ratio of the primary side and the secondary side of the parallel transformer is 1:1, so the value of ∆U is 444V.

The voltage vector relationship diagram is shown in Figure 2(b). The phase of the standby power supply voltage produces a phase change of ±θ.
The corresponding state of the output voltage and the thyristor valve group is shown in the table, + means the winding is connected in the forward direction, - means the winding is connected in the reverse direction, and × means the winding is not connected.

Table 1. Correspondence table of TSPST output additional potential ΔU and state of thyristor valve group.

| Adjustment level | ΔU | 3ΔU | 9ΔU | Phase shift angle |
|------------------|----|-----|-----|------------------|
| 0                | ×  | ×   | ×   | 0                |
| 1(-1)            | +(-)| ×   | ×   | ±4.4             |
| 2(-2)            | +(-)| +(-)| ×   | ±8.8             |
| 3(-3)            | ×  | +(-)| ×   | ±13.2            |
| 4(-4)            | +(-)| +(-)| ×   | ±17.6            |
| 5(-5)            | +(-)| -(+)| +(-)| ±22              |
| 6(-6)            | ×  | -(+)| +(-)| ±26.4            |
| 7(-7)            | +(-)| -(+)| +(-)| ±30.8            |
| 8(-8)            | -(+)| ×   | +(-)| ±35.2            |
| 9(-9)            | ×  | ×   | +(-)| ±39.6            |
| 10(-10)          | +(-)| ×   | +(-)| ±44              |
| 11(-11)          | ×  | +(-)| +(-)| ±48.4            |
| 12(-12)          | +(-)| +(-)| +(-)| ±52.8            |
| 13(-13)          | +(-)| +(-)| +(-)| ±57.2            |

3. TSPST main parameters and control strategy selection

3.1. Selection of main technical parameters of TSPST

According to the actual parameters of a thermal power station project, the voltage level of the high voltage side in the plant is 10kV, the design transmission capacity of the standby power side is 28MW, and the rated current of the line is 2.5kA. In this paper, the parameter technology selection of TSPST is considered according to the transmission voltage level and transmission capacity of the standby power line.

Suppose the transformation ratio of the primary and secondary sides of the parallel transformer is $1:k_E$, and the reactance percentage is $X_E$. The transformation ratio of the primary and secondary sides of the series transformer is $1:k_B$, and the reactance percentage is $X_B$. Let $\theta$ be the phase shift angle when TSPST is running at full load, and let $\psi$ be the phase shift angle when TSPST is running at no load. According to Figure 2(b),

\[
\sqrt{3}U_{Ma}(1 - X_E)k_E(1 - X_B)/k_B = \Delta U_a
\]

\[
\tan\frac{\theta}{2} = \frac{\Delta U_a}{2U_{Ma}} = \sqrt{3}(1 - X_E)k_E(1 - X_B)/2k_B
\]
\[
\tan \frac{\psi}{2} = \frac{\Delta U_{a}'}{2U_{Ma}} = \frac{\sqrt{3}k_E}{k_B} \tag{3}
\]

\[
\frac{\tan \frac{\theta}{2}}{\tan \frac{\psi}{2}} = (1 - X_E)(1 - X_B) \tag{4}
\]

Assuming that the reactance percentage of series and parallel transformers is 4%, the phase shift angle \(0\) is \(\pm 57.2^\circ\) at full load, and the phase shift angle \(\psi\) is \(\pm 62.03^\circ\) at no load.

The parallel secondary winding adopts the thyristor valve group as the switch, and the calculation result of the phase difference between the load side line voltage and the standby power side voltage is used as the on-off condition of the thyristor valve group. A simulation model is built based on the above-mentioned parameters, and the phase shift angle of the TSPST after different gear shifts is simulated when the standby power transmission line is empty and compared with the theoretical calculation value. The simulation results of phase-shifting simulation angle under different gears when TSPST is no-load are shown in Figure 3 and Figure 4.

![Figure 3](image3.png)

**Figure 3.** The simulation diagram of the phase shift angle during the switching process of TSPST from 0 gear to +1 gear, +4 gear, and +13 gear when the line is no-load.

![Figure 4](image4.png)

**Figure 4.** The simulation diagram of the phase shift angle during the switching process of TSPST from 0 gear to -1 gear, -4 gear, and -13 gear when the line is no-load.

According to the above simulation results, when the standby power transmission line is no-load, and the TSPST is adjusted to the +1 (-1) gear, the phase shift angle of the output voltage of the phase shifter is \(\pm 4.77^\circ\). When TSPST is adjusted to +4 (-4) gear, the phase shift angle of the output voltage of the phase shifter is \(\pm 19.1^\circ\). When TSPST is adjusted to +13 (-13), the phase shift angle of the phase shifter output voltage is \(\pm 62.1^\circ\). The simulation results are basically consistent with the calculated values.

### 3.2. TSPST control strategy selection

The main function of TSPST used in this article is to inject the compensation voltage \(\Delta U\) to adjust the voltage amplitude of the backup power line and change the phase angle of the output line, adjust the phase angle difference between the backup power line voltage and the load side line voltage within the safe and fast switching range, The phase shifter input control flow chart is shown in Figure 5,
Figure 5. Control flow chart of thyristor valve group.

When the main power supply side fails, the phase angle and amplitude of the line voltage on the load side are monitored in real-time, and the phase angle and amplitude are calculated with the standby power voltage. When the phase angle difference is within the switchable range, the bypass switch on the standby power line is closed. When the error exceeds the allowable range, the phase shifter is automatically turned on and the appropriate voltage adjustment gear is selected, the compensation voltage $\Delta U$ is injected into the output circuit of the standby power supply to adjust the phase, to ensure quick cut timely action, and reduce the power-off time of the equipment. Reduce the impact current generated during power switching, making the switching process more stable, and the reliability of the power supply of the equipment is guaranteed.

4. TSPST adjusts the phase simulation model of standby power

Build a simulation model in Simulink, the simulation model diagram of TSPST adjusting standby power phase switching is shown in Figure 6, The thyristor valve group control module realizes the function of grading adjustment of the phase shifter voltage, and the output voltage of the thyristor valve group is injected into the backup power output line after the series transformer.

Figure 6. TSPST adjusts the simulation model of phase switching of standby power.

The voltage of the primary winding of the parallel transformer in TSPST is $10/\sqrt{3}$ kV, and the voltage of the secondary winding is 444V, 1332V and 3996V respectively, so the sufficient value of $\Delta U$ is 444V. The impulse current and voltage of a motor in the project are simulated and analyzed.
The rated voltage of the motor is 10kV, and the rated capacity is 2000kW, so the working current of the motor is 119A.

The simulation process is as follows. When \( t=0.43s \), a three-phase short-circuit fault occurs on the main power transmission line side. After 10ms, \( t=0.44S \) protection device action, load side main power circuit is disconnected. The detection device measures the magnitude and phase angle of the residual voltage of the load side busbar. After calculation, TCPST selects the appropriate voltage level to connect to the backup power circuit. When \( t=0.45-0.46s \), the phase difference between the output voltage of the backup transmission line and the voltage on the load side is within the safe closing range. When \( t=0.46s \), the backup power is closed, and the backup power is connected to the load side. When \( t=0.50s \), the voltage level is adjusted step by step every 10ms until it is adjusted to 0 gear, The bypass switch is closed, TSPST exits operation, and the standby power switch is completed. The simulation results are shown in figure 7.

![Figure 7. Three-phase current waveform diagram of the motor after switching the backup power supply.](image)

As shown in Figure 7, when \( t=0.46s \), After TSPST is put into use, the maximum inrush current of the standby power supply is about 590A, which is about 5.1 times of the rated current, and it only takes 0.03s or 30ms from the time of failure to the standby power input, which satisfies the seamless switching of the standby power and ensures the successful and rapid input of the standby power.

![Figure 8. Waveform diagram of comparison between backup power supply voltage and motor voltage.](image)

As shown in Figure 8, When \( t=0.43s \), a three-phase short circuit occurs on the main power supply side circuit, and the load side motor voltage value is basically 0, after the fault side protection device operates. TSPST starts when \( t=0.44s \), select the appropriate voltage gear according to the calculation result and put in the standby power. TSPST controls the thyristor valve group so that the voltage gear is decremented by one gear every 10ms until it reaches the 0 gear. The bypass switch is closed, the backup power supply is fully put into operation, and the waveforms of the two are completely overlapped. This method has less impact on electrical equipment and transmission lines, and the simulation effect is better.

5. Conclusion

This article mainly introduces the working principle and topological structure of TSPST used for backup power lines. On this basis, a fast switching power supply method of phase shifter based on thyristor switching is proposed, introduced the basic principle, structure and implementation of the way, and carried out the TSPST parameter design.
The model is built in Simulink, and the phase angle change of the proposed method is simulated and verified by simulation. By comparing the simulation results with the calculated results, it is further verified that the proposed method can achieve rapid switching of the standby power supply, reduce the impact on the equipment caused by the standby power switching, and has a good research significance for the insulation and durability of the equipment. The phase switching power supply method based on TSPST adjusting the standby power supply can be applied to the auxiliary power system of the power plant, which effectively improves the power supply reliability of the power plant.

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