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Research on protection and control technology of power electronic transformers

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Abstract. As the key equipment in the modern power system, the power electronic transformer's performance and reliability play a vital role in the stable operation of the power system. This paper studies the soft switching technology, control technology and fault protection method of power electronic transformer. First, the soft switching technology of power electronic transformers is introduced, including zero voltage switching, zero current switching and so on. These soft switching technologies can effectively reduce the switching loss of the transformer, improve efficiency, and reduce electromagnetic interference and harmonic generation. Secondly, the control technology of power electronic transformer is introduced, including traditional proportional, integral, and derivative control (PID) control, model predictive control and direct power control. These control technologies can realize the precise control of the output voltage and current of the power electronic transformer, to meet the requirements of the power system for power quality and stability. In addition, this paper also introduces the fault protection methods of power electronic transformers, including short-circuit protection, over-voltage protection and over-medium current protection. These fault protection methods can effectively protect power electronic transformers from various faults and ensure their normal operation and safety.

Keywords: soft switching, control technology, fault protection.

1. Introduction

Recently, with the development of high-power electronic components and their control techniques, the Power Electronic Transformer (PET), which is used in power electronics, has been widely known as solid state transformer (SST) or intelligent transformer (intelligent transformer, ST). It is a new type of electric energy conversion power electronic equipment, which converts AC power into high-frequency AC power, and then transmits and distributes it through a high-frequency transformer. Unlike traditional iron-core-based power transformers, PET employs high-frequency conversion technology and semiconductor power electronics that can be used in a wide range of applications, and power electronic transformers have broad application prospects in the field of electric transportation. By transmitting high-frequency AC power to the vehicle side, fast charging and efficient power supply of electric vehicles can be achieved, thereby improving the convenience and reliability of electric transportation. Therefore, it is very important for the development of EV technology and to solve the problems of charging and power supply, such as RE, HV, DC, and intelligent grid. Because of its high efficiency,

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flexibility, reliability, etc., it has been widely applied in the energy field, but the traditional electric power system has some energy loss and environment pollution. Power transmission and distribution technology can reduce energy loss and environmental pollution in the power system, thus playing a positive role in solving energy crisis and environmental problems. Protection and control technology is a very important part of the PET system, including modulation and soft switching technology, control technology and fault protection technology [1, 2].

However, there are still some problems in the practical application of power electronic transformers, such as overcurrent, overvoltage, overtemperature, etc. These problems may cause failure and damage of power electronic transformers and affect the normal operation of the power system. Therefore, research on the protection and control technology of power electronic transformers has become particularly important. When it comes to power electronics transformer protection, researchers have taken various approaches. For example, model-based protection methods have been widely used in the protection of power electronic transformers. Kim et al. proposed a model-based overcurrent protection method that can detect and locate faults accurately and can adapt to different operating states of power electronic transformers. [3] In addition, artificial intelligence-based protection methods have also been widely used.

Liu et al proposed an overcurrent protection method based on artificial neural network, which can identify the fault types of power electronic transformers and has a high accuracy rate. [4] In terms of power electronic transformer control, researchers have also adopted various methods. For example, model-based control methods have been widely used in the control of power electronic transformers. Nakamura et al. proposed a control method for power electronic transformers based on model predictive control, which can achieve high efficiency and high stability of power electronic transformers. [5] In addition, artificial intelligence-based control methods have also been widely used. Zhang et al proposed a control method for power electronic transformers based on fuzzy control, which can adaptively control the output voltage and current of power electronic transformers. [6]

In short, the research on protection and control technology of power electronic transformers is an important direction for the application and development of power electronic transformers, which requires in-depth research and exploration.

2. Modulation and soft switching technology of PET

PET modulation technology is one of the key technologies for PET to achieve high efficiency and high precision. The main purpose of modulation technology is to convert the input voltage into a voltage suitable for PET output, and the commonly used modulation technologies include PWM modulation, Sinusoidal pulse width modulation (SPWM) modulation, Space vector pulse width modulation (SVPWM) modulation, etc. PWM modulation is a commonly used modulation technology, and its basic principle is to control the output voltage by changing the duty cycle of the PWM wave. SPWM modulation and SVPWM modulation are an advanced modulation technique, two commonly used modulation techniques in AC motor drive systems, used to generate three-phase voltage signals, control the voltage and frequency of the motor, and thus control the speed and torque of the motor. It can achieve higher voltage accuracy and lower harmonic distortion.

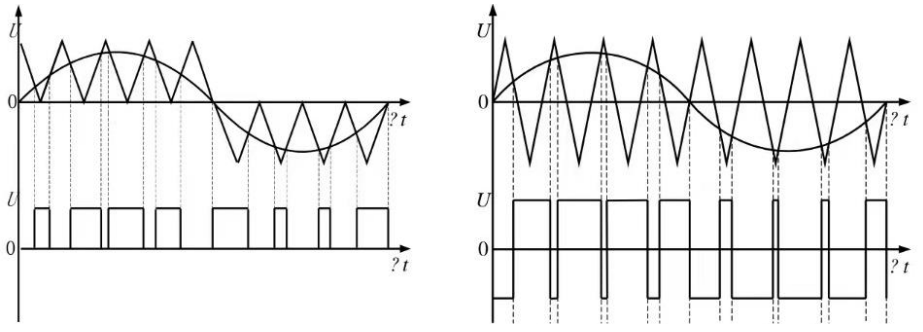

Figure 1. SPWM control [3].

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SPWM is a sine wave-based pulse width modulation technique that controls the voltage and frequency of the motor by adjusting the pulse width of the output signal (Figure 1). The principle of SPWM modulation is to compare a fixed-frequency three-phase sine wave signal with an adjustable DC voltage to generate a PWM signal with adjustable pulse width. This PWM signal converts the DC voltage into a three-phase AC voltage through the inverter to drive the power supply. SPWM is easy to realize, but it may produce harmonics in low speed operation, and the output voltage waveform is not ideal. SVPWM is a pulse width modulation technology based on vector control, which controls the voltage and frequency of the motor by generating a synthesized voltage vector in a specific vector space. The principle of SVPWM modulation is to compare a reference vector with two recent effective vectors to determine the composite vector, and to generate a PWM signal by adjusting the pulse width of the composite vector. SVPWM can generate ideal sine wave output voltage with lower harmonics and higher voltage utilization. Due to the precise control of voltage and frequency in vector space, SVPWM is widely used in high-performance AC motor drive systems.

She Xu et al put forward a novel 3D space modulation technique, which is used in three level PET, and uses the 7-level rectifier as the interface to the 7.2 kV power distribution system. The results of simulation and experiment show that the proposed method is effective, and the voltage equilibrium can be obtained at the same time as the harmonic content [7].

Zhao Tiefu and his colleagues put forward a new technique which is based on the combination of a cascade H bridge converter and a power equilibrium controller. This technique is based on the single phase dq model, and it uses a new control strategy of voltage and power. This control strategy balances rectification by connecting DAB modules in parallel. The voltage of the capacitor and the actual power. By using this control method, the DC link voltage and the actual power of each module can be balanced. The results indicate that this control strategy is effective in achieving voltage and power equilibrium [8].

Li Zixin and others proposed a new topology control strategy design for the PET circuit of the medium and high voltage intelligent distribution network. Compared with traditional PET, this design significantly reduces the number of high-frequency transformers, and at the same time, this design improves the quality of DC output voltage [9].

The soft switching technology of PET is an important technology for realizing high-efficiency and low-loss switching operation of switching devices, which can effectively improve the efficiency and reliability of PET. Lu, D et al proposed a soft switching technique for dual active bridge converters isolated from intermediate frequency transformers, and introduced a control strategy with DC fault protection. By controlling multiple switching devices in the topology, soft switching operations in different operating modes are realized, thereby reducing the loss of the switching devices. At the same time, a DC fault protection strategy is also introduced to detect and deal with possible fault conditions to protect the safe operation of the converter and its surrounding systems. The main purpose of soft switching technology is to reduce switching losses and voltage fluctuations during the switching process of the switching tube. Commonly used soft switching technologies include Zero Voltage Switching (ZVS) technology, zero-current switching (ZCS) technology, and common-mode voltage suppression technology. ZVS technology is a commonly used soft switching technology, and its basic principle is to reduce switching loss and voltage fluctuation by realizing zero-voltage switching during the switching process of the switching tube. ZCS technology is an advanced soft switching technology that can achieve higher efficiency and lower electromagnetic interference. Common-mode voltage suppression can be achieved by using technologies such as common-mode voltage suppression circuits and three-level converters. For example, in a three-level converter, by controlling the operation timing and voltage polarity of the switching devices, the common-mode voltage drops to zero or keeps a small value, thereby reducing the voltage stress and loss of the switching devices [10].

3. Control technology for PET

The PET control technology is the core technology in the PET system, which can realize the efficient and stable operation of the PET. The main purpose of the control technology is to convert the input signal into a control signal to achieve the stability and controllability of PET. The commonly used

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control technologies include PID control, fuzzy control, neural network control, etc. PID control is a commonly used control technology. Its basic principle is to generate a control signal by comparing the difference between the output signal and the reference signal, thereby controlling the stability and accuracy of the output signal. Fuzzy control and neural network control are advanced control techniques that can achieve higher control precision and better robustness.

Ji Zhendong et al. proposed a three-phase cascaded topology PET and its control strategy. In the high-voltage stage, a simple three-phase DC side balance was proposed based on the double closed-loop PI control of the traditional H-bridge rectifier. Control method: In the low-voltage stage, based on DAB phase-shift control, a multi-DAB current sharing control strategy with parallel output is proposed. Through experimental verification, the phase-to-phase and phase-to-phase balance of the DC side and the PET units are well realized. Power balance, with better dynamic response and steady-state performance [11].

Bifaretti et al put forward an advanced PET power conversion and control system, which is controlled by a new AC-DC-AC 7-level multi-level converter. Compared with the traditional large-scale line frequency transformer, this The system provides a flexible and modular power electronics interface capable of connecting different types of power sources and loads, including medium voltage grids, renewable energy and energy storage systems. The simulation results of MATLAB show that the control system can track the active and reactive power requirements in various power reference curves and grid operation conditions. The system makes the PET work efficiently, flexibly, and reliably with good performance [12].

4. PET's fail-safe technology

The fault protection technology of PET is the key technology in the PET system, and it is the key technology to ensure that PEPT can detect and deal with faults during normal operation, and protect PEPT and its surrounding systems from damage. Cuartas et al. studied the start-up, function and protection issues of PET based on cascaded H-bridge converters, and proposed a protection strategy based on current limiting and voltage limiting. The applied control ensures that the low-voltage side power supply has constant voltage and frequency, can effectively protect the safe operation of PET [13].

Zhang, Lei et al. proposed a fault detection and diagnosis method for modular multilevel converters in PET. The fault indicator-based method is adopted to detect and locate faults by monitoring the state parameters of capacitors, inductors and switching devices in the transformer. When a fault occurs, the system can identify the fault in time and take corresponding protective measures, such as shutdown protection or bypass operation of the faulty module, to ensure the normal operation of PET and protect the equipment from further damage [14].

Guillod et al. proposed a protection scheme suitable for AC-AC power distribution SST. By studying the design criteria and limitations of current and voltage stress, especially the robust operation effect in the medium-voltage grid, it was proved that the feasibility of the protection of the proposed scheme can effectively protect the safe operation of PET [15].

Fardoun, Ali et al. present a fault protection strategy for use in high frequency power electronic transformers. This paper proposes a multi-level fault protection method including current and voltage monitoring, short circuit detection, fault diagnosis and fault bypassing. A self-healing technique is also introduced, which bypasses the fault by reconfiguring the circuit when the fault occurs. This approach allows rapid detection and handling of failures, protecting PEPT and its surrounding systems from failures [16].

In short, the protection and control technology of PET is one of the important directions of PET research, which involves many aspects such as modulation technology, soft switching technology, control technology and fault protection technology. Different fault protection techniques applied in PET, including fault detection, diagnosis, fault-tolerant processing, etc., to ensure stable operation of PET and protect equipment from faults. The specific fault protection techniques may vary for different PET designs and applications. In practical applications, Suitable techniques must be chosen in accordance with the actual conditions, so that PET can be highly efficient, accurate, reliable, and safe.

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5. Conclusion

The modulation technique in the power electronic transformer is the key technology to control its output voltage and current waveform. Current research hotspots include modulation technology, hybrid modulation technology, high-area modulation technology and soft switching technology of multi-level power electronic transformers. These techniques can improve the conversion efficiency of power electronic transformers, reduce harmonic pollution, and reduce switching device losses and heat. Research on control technology includes traditional PID control, as well as new harmonic suppression technology. It is very important to study the fault protection technology of power electronic transformers to improve their reliability and stability. This includes the techniques for detecting, diagnosing, and dealing with failures. For example, applying current, voltage, and temperature sensors, fault diagnosis algorithms, and fault recovery techniques to enhance the reliability and stability of power electronics.

In summary, one of the key areas of study in PET is in the field's protection and control technologies, which spans a wide range of fields including modulation, soft switching, control, and fault prevention. Different fault prevention methods, including as fault detection, diagnosis, fault-tolerant processing, etc., are used in PET to assure stable operation and safeguard equipment from problems. For various PET designs and applications, several fault prevention strategies may be used. For practical applications, appropriate approaches must be used in accordance with the real circumstances in order for PET to be extremely effective, precise, dependable, and safe.

The development trend of PET technology is: 1. Increase power density: At present, the power density of PET technology is much higher than that of conventional transformers, but there is still room for further improvement. In the future, the energy density of PET materials will continue to increase to achieve smaller and lighter purposes. 2. Low cost: Since the production cost of PET is much higher than that of conventional transformers, its promotion in industry is limited. In the future, with the continuous development of PET technology, its production cost will continue to decrease, and it will be extended to more fields. 3. Increase reliability: Reliability is an important indicator of PET in actual production. In the future, PET will pay more attention to reliability in design and production, so as to improve its stability and reliability in the power grid. 4. Intelligence: With the development of smart grid, PET technology will gradually develop towards intelligence and integrate it into the smart grid to improve energy conversion efficiency and reliability. 5. Expand the application range of PET: In addition to traditional power systems, PET is also widely used in high-speed rail, electric vehicles and other fields. With the development of PET technology, its application range will become wider and wider, and its application range will become wider and wider.

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