Research on Optimization of Distribution Network based on Power Electronic Transformer

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Abstract. As the core equipment of hybrid microgrid, power electronic transformer is a new type of multifunctional transformer which integrates power electronic technology, information communication technology and control protection technology. On the background of the Beijing Low-Carbon Winter Olympics Smart Grid Demonstration Project, this paper proposed an AC/DC hybrid microgrid topology with dual-end power supply based on power electronic transformer. Moreover, a coordinated optimization control for AC/DC hybrid microgrid based on power electronic transformer is studied. The content of the paper mainly includes: The common topology of power electronic transformer is studied, and a three stage four-port power electronic transformer is proposed according to the demand of demonstration project. The interface converter topology structure and control method of distributed generation and energy storage in hybrid microgrid are analyzed, and the system model of hybrid microgrid is established. Simulation results show that MPPT control can maximize the power output of distributed generation, and piecewise droop control can realize seamless switching between power control and voltage control in the grid-tied or autonomous mode.

Keywords: Hybrid Microgrid; Power Electric Transformer; Power Coordinated Control; Seamless Transfer.

1. Research Background and Significance

In 2016, the National Energy Administration promulgated the "Thirteenth Five-Year Plan for Energy Development", which pointed out that my country's clean energy replacement task is arduous, and the environmental carrying capacity of energy production and consumption in some areas is close to the upper limit. In order to cope with climate change and promote low-carbon, green and sustainable development, renewable energy (Renewable Energy, RE) is listed as the main energy source in the "13th Five-Year Plan" [1-2], and it is proposed that by the end of 2030, renewable energy will be The proportion of renewable energy consumption has increased to more than 20%. However, it is found in actual projects that the initial construction cost of renewable energy is too high, and the operation control is difficult [3], and its output power is subject to natural climate, which has certain volatility and uncontrollability [4]. Large-scale access to renewable energy can easily reduce the power quality of the grid [5], and even affect the stable operation of the power system under extreme conditions.

Since the hybrid microgrid has two power supply forms, AC and DC, and the power supply and load distribution are sometimes unbalanced, the power coordination control is particularly important in the hybrid microgrid, and the traditional AC/DC bidirectional converter has been difficult to meet the system requirements. With the rapid development of power electronics technology, a new type of multi-functional transformer that integrates power electronics technology, information communication technology and control and protection technology has become a research hotspot in the field of electrical equipment in recent years as the key equipment for building a smart grid. Power Electronic Transformer (PET) is mainly composed of power electronic equipment and high-frequency transformers. High-frequency transformers are used to achieve electrical isolation and voltage level conversion, and power electronic equipment is used to achieve power regulation, AC-DC conversion and fault isolation. and other functions. PET has excellent electrical properties such as small size, light weight, high controllability, and high power density, and is the core device for building new hybrid microgrids [6].

2. Research Status at Home and Abroad

2.1 AC-DC Hybrid Microgrid

The concept of microgrid was first proposed by CERTS in the United States, and many of its research results in the field of microgrid have been verified in the laboratory of the University of Wisconsin-Madison. In 2010, Professor Poh Chiang Loh of Nanyang Technological University in Singapore proposed the concept of AC-DC hybrid microgrid and gave a typical topology . The AC-DC hybrid microgrid can provide power for both AC and DC loads due to its AC bus and DC bus[7]. Compared with the pure AC microgrid, the special topology structure of the AC/DC hybrid microgrid makes it omit many converter links in the connection link of the DC power supply and the DC load, and simplifies the microgrid structure and distributed power supply mode. , which greatly improves the operation efficiency of the microgrid and the economy of the construction of the microgrid. Compared with the distribution network, the power supply form of AC-DC hybrid microgrid is complex and diverse, and its penetration rate of renewable energy is generally high. At present, the research on AC-DC hybrid microgrid has just started, and the research in the field of operation control can mainly be It is divided into two parts: control architecture and power coordination optimization[8].

2.2 Control System and Architecture of Microgrid

Microgrid control methods are complex and diverse, and there are different classification methods from different perspectives. In order to better study the microgrid control strategy and clarify the relationship between different control methods, some scholars summarize its systematic classification as the Hierarchical Control method. According to the specific topology and control method of the microgrid, the hierarchical method has a certain flexibility[9]. Generally speaking, the microgrid control can be divided into four levels according to the different control objectives and time scales. They are Inner Control Loops, Primary Control, Secondary Control and Tertiary Control. From the lower level to the upper level, the time scale of each level of control gradually becomes larger. The overall schematic diagram is shown in Figure 1.

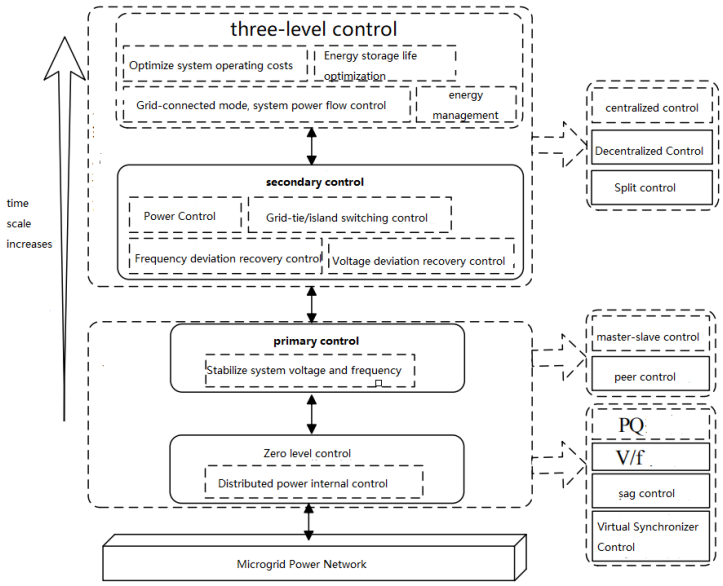


Figure 1. Microgrid layered control architecture

The four-level hierarchical control can be roughly divided into two layers in terms of function. The zero-level control and the primary control are the equipment layers, which are mainly responsible for the stable operation of the microgrid. The second-level control and the third-level control are the system layers, which are mainly responsible for the optimal operation control of the microgrid operation mode switching and energy management[10].

3. Topological Structure Design of AC-DC Hybrid Microgrid for Demonstration Project

Power electronic transformer refers to a new type of power electronic equipment that integrates power electronic technology and high-frequency transformer, and has functions such as voltage level conversion, electrical isolation and fault isolation between ports, reactive power compensation and harmonic control. It is called a smart transformer (Smart Transformer, ST) or a solid-state transformer (Solid-State Transformer, SST). The electrical port of the power electronic transformer has the real-time adjustment ability of voltage, current and power, which can realize the bidirectional flow of electric energy, and is generally used in the occasions of medium and high voltage and high power. Compared with traditional transformers, PET can be connected to different types of power supply, energy storage and load equipment, enriching system functions and improving system performance. In recent years, due to the rapid development of smart grids and the rapid popularization of new energy sources, the application scenarios of PET have become more and more abundant, and its topology structure has also become more and more complex. According to the series of power electronic devices used in PET, PET can be divided into single-stage, two-stage and three-stage.

Single-stage PET was first proposed by Professor Moonshik of Texas A&M University in 1999. The topology is based on direct AC/AC high-frequency conversion, as shown in Figure 2. Both the primary and secondary sides of the high-frequency transformer use matrix converters, which make the PET compact, light in weight and high in operating efficiency. However, because it does not include a DC link, its controllability is poor, and its application effect in power quality regulation and harmonic control is poor. Since there is a certain degree of coupling between the disturbances on both sides of the primary and secondary sides, this topology has certain advantages only when the volume and weight of the transformer are required.

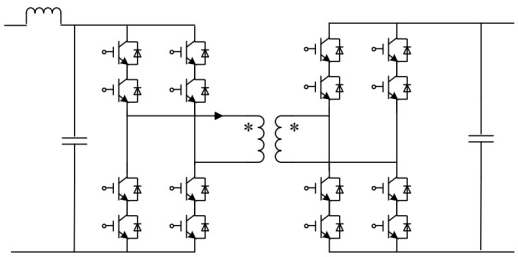


Figure 2. Schematic diagram of single-stage PET single-phase

In order to overcome the problem of poor controllability of single-stage PET, a first-stage DC link can be introduced at the output side to develop two-stage PET. The typical topology of two-stage PET is shown in Figure 3. It is a matrix converter, and the secondary side is converted into DC through the rectifier and then output through the inverter. Compared with single-stage PET, two-stage PET can integrate distributed power and renewable clean energy more conveniently due to the introduction of DC links, and can also better provide power support, adjust the power factor of the low-voltage side, and block the AC disturbance. Although two-stage PET can operate in four quadrants, it is less controllable when power is transferred from the low-voltage side to the high-voltage side.

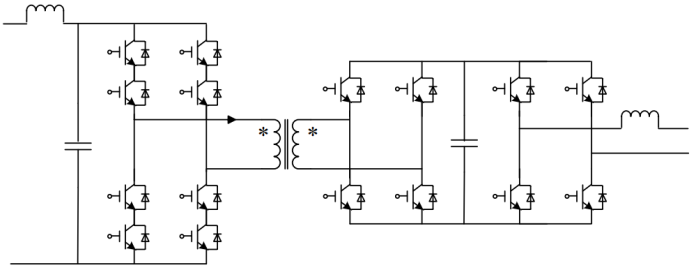


Figure 3. Schematic diagram of two-stage PET single-phase

Compared with two-stage PET, a DC link is also introduced in the original side of three-stage PET, which is composed of an input stage H-bridge, an isolation and transformation stage DAB and an output stage VSI, as shown in Figure 4. VSI converts the low-voltage DC inverter output by DAB into AC, which is connected to the AC bus through LC filter. Compared to the two levels of PET, level 3 type PET despite the introduction of more and more power electronic links, but as the former vice edge contains the dc link, make its can easily run in four quadrant, even when power delivers can convenient adjusting reactive power and power factor of the high pressure side, greatly convenient for energy storage, such as two-way access dc power supply. Because the components of the three-stage PET can be very convenient to use modular technology cascade, and the three-stage PET often has higher switching frequency and power density than the two-stage PET, so the three-stage PET is mainly used in high-voltage high-power occasions.

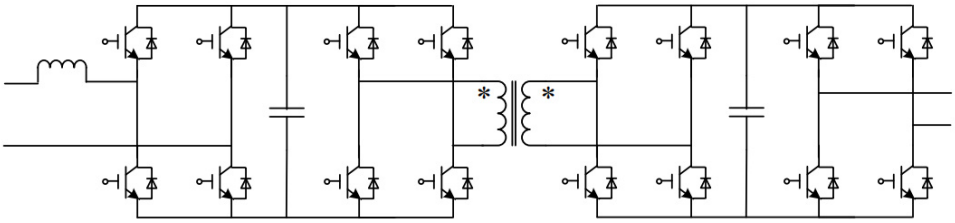


Figure 4. Three-phase PET single-phase diagram

Generally speaking, the topology of PET can be adjusted according to the actual application situation, such as the need to adopt the form of cascade in high-voltage and high-power occasions. Considering the application scenarios and engineering requirements of the demonstration project, three-stage PET is selected in order to improve the controllability of bidirectional power transmission in the hybrid microgrid. Furthermore, in order to improve the power supply reliability of the hybrid microgrid and increase the redundancy of the equipment, the input stage of the three-stage PET is expanded into two groups of H-bridges which are standby to each other, so as to form a three-stage four-port power electronic transformer with input stage, isolation transformation stage and output stage, as shown in Figure 5. The rated power of the 10 kV AC port is 2.5mVA, the rated power of the 750 V DC port is 1.2MW, and the rated power of the 380 V AC port is 0.6mVA.

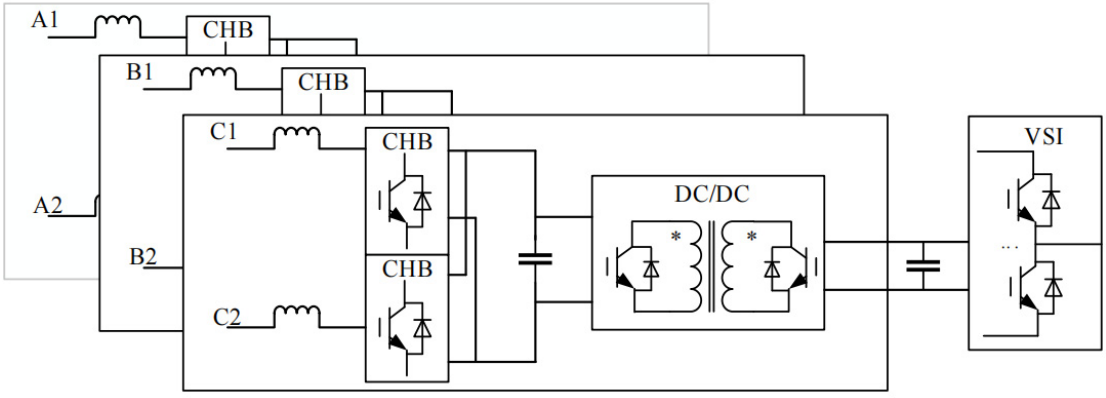


Figure 5. PET topology

The isolation transformation stage adopts the isolated bidirectional DC/DC topology based on DAB. The front stage is connected to the output capacitor of the CHB, and the rear stage is connected to the DC bus in parallel to facilitate fault isolation and energy control. As the power transmission stage of power electronic transformer, dual active bridge converters belong to isolated converters, whose working principle is DC-AC-DC transformation. The basic circuit is shown in Figure 6.

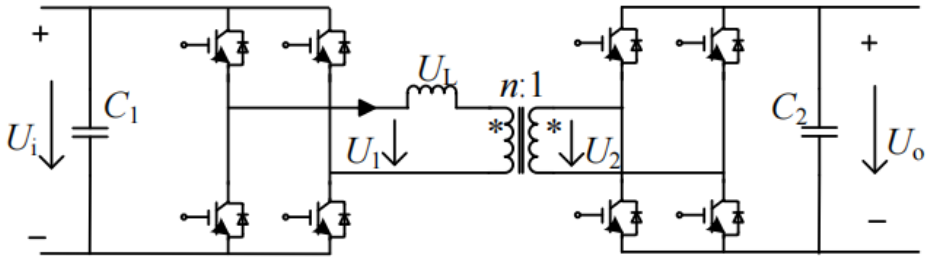


Figure 6. Topology of dual active bridge converters

In the figure, Ui is connected to the HVDC end, which is transformed into high-frequency AC U1 through the H-bridge on the left, which is reduced to high-frequency and low-voltage U2 through the high-frequency transformer, and is changed back to low-voltage DC U0 through the H-bridge on the right. C1 and C2 are voltage stabilizer capacitors, UL is the equivalent leakage voltage of the converter. DAB has the advantages of fewer passive components, high switching frequency and high power conversion rate. It has a large number of switching tubes and each switch tube needs to bear less voltage stress and current stress. Due to the low voltage and low power of the output stage, a three-phase PWM inverter is directly used to convert the low-voltage DC inverter output by IBDC into AC, which is connected to the AC bus through the LC filter. Figure 7 shows the three-phase voltage-type inverter with LC filter. The left side is the DC power supply and voltage regulator capacitor, the middle part is the inverter link, and the right side is the filter and AC bus.

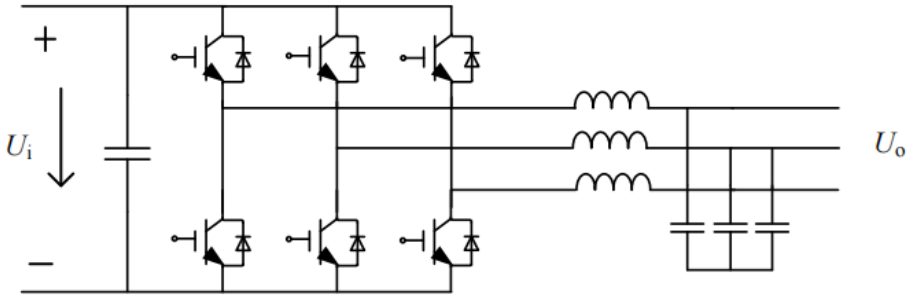


Figure 7. VSI topology

4. Power Coordination Control Strategy for Power Electronic Transformer in AC-DC Hybrid Microgrid

Microgrid has the characteristics of flexible operation, and its main control objectives are stability (voltage stability, frequency stability) and efficiency (improve clean energy consumption rate, reduce network loss rate). Since the microgrid system is composed of a large number of power electronic devices, its equivalent moment of inertia is small, and it contains a large amount of intermittent renewable energy, its control strategy is more critical, especially the power coordination control strategy of power electronic transformers, which is the key to the stable operation of the microgrid. According to whether the hybrid microgrid is connected to the large power grid, the hybrid microgrid can be divided into grid-connected operation state and islanded operation state. Based on the second chapter, this chapter mainly discusses the control methods of the four-port power electronic transformer in hybrid microgrid in grid-connected operation mode and islanded operation mode.

In parallel operation mode, because of the large power grid as a power support, generally USES the master-slave control, hybrid micro power grid by large power grid as the primary power supply, through the power electronic transformer for micro hybrid grid voltage and frequency reference, other distributed power supply, such as renewable energy and energy storage as power from running on power control. In islanding operation mode, due to the loss of power support from the superior power grid, the hybrid microgrid needs to balance power internally, otherwise it is difficult to maintain

voltage and frequency stability. In order to improve the power quality of hybrid microgrid under islanding operation mode, this chapter studies the AC-DC coordinated control method based on residual power droop, and uses power electronics transformer to coordinate the loads in AC-DC subnetwork, so as to achieve the purpose of mutual support of AC-DC.

5. Conclusion

In this paper, a novel three-level four-port power electronic transformer topology and a two-terminal ring network-based AC-DC hybrid microgrid topology are proposed. The equivalent circuit and control method of the AC-DC hybrid microgrid distributed power supply and energy storage interface converter are studied. Specifically, for distributed renewable energy, the disturbance observation MPPT algorithm is studied. By studying the cooperative power control technology of power electronic transformers in AC-DC hybrid microgrid, different control strategies are given according to different operation modes. For power electronic transformers, an AC/DC power coordinated control method based on residual power is proposed. The method is based on double closed loop control of inner current loop and outer power loop. By introducing the concept of residual power into the external power loop, the characteristic quantity of the AC/DC bus is standardized, which can provide a certain AC/DC mutual support and avoid the excessive coupling of the AC/DC bus. By introducing the rotor motion equation into the control structure, the power electronic transformer has a certain inertia.

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