Overview of High-voltage Large-capacity DC Transformer

Meng Chen, Yan Li, Jinyang Bai*, Gang Feng, Yujin Peng, Jiangzhen Guo
State Grid of China Technology College, Jinan, Shandong Province, 250002, China
Email: 1019854711@qq.com

Abstract. DC transformer is the core equipment to realize the convergence and transmission of new energy such as solar energy, wind energy, etc. It also plays a key role in the construction of large-scale DC power grid in the future. Therefore, DC transformer has a broad application prospects in the future energy Internet era. This paper briefly summarizes the current research on DC transformer at home and abroad, and also summarizes the current research on DC transformer in the future. On the basis of the basic principle of decomposing DC transformers, the characteristics and applications of common DC transformers are classified and the problems to be solved are summarized.

Keywords: DC transformer; DC/DC converter; DC power grid; high voltage and large capacity

1. Introduction

Based on the current crisis of traditional fossil energy, it is an inevitable choice for human society to embark on the road of sustainable development to efficiently develop and fully utilize renewable energy in order to get rid of the heavy dependence on traditional fossil energy. Therefore, many scholars at home and abroad put forward the concept of "wide area network", which integrates new economy, information and energy to promote the efficient conversion between various renewable energy sources. In the energy Internet, it takes the UHV large power grid as the "backbone network", that is to say, in the era of future energy Internet, the power system is the hub of all kinds of energy conversion [1]. With the proposal of energy Internet, the electric power construction in China has appeared new characteristics in recent years, including: a large number of DC loads represented by electric vehicle charging stations and data centers are connected to the power grid, and new energy sources represented by wind, solar and energy storage are connected to the power grid year by year [2]. In order to meet the power demand of dc load of different voltage levels and the collection and application of large-scale renewable energy, it is necessary to transform through different DC voltage levels in the energy Internet, thus, the DC transformer will play an important role in the energy Internet. In different application scenarios, DC transformers need to meet different technical requirements. For example, the transformer is required to be relatively high in order to reduce the loss generated in the process of transmission To bring new energy together and send it out; in the case of multistage DC voltage conversion, the DC transformer is required to have high transmission efficiency and achieve bi-directional power transmission, and can play the role of fault isolation. Furthermore, in the scenario of DC system interconnection and power flow control, the dynamic response speed of DC transformer is required to be higher, so that the power flow of the system can be accurately controlled.
2. Principle of DC Transformer

DC transformer is also called DC/DC converter, the basic principle of it is to use the power electronic device on and off the continuous DC voltage is intermittently applied to the load, through the power electronic device on and off time namely duty cycle change to control the average value of the output voltage, so as to achieve the purpose of DC voltage conversion. Similar to ac transformer, DC transformer is also divided into primary side and secondary side in structure. Its basic circuit structure is shown in figure 1 [2]. In the figure, the primary and secondary circuit structures of the DC transformer have a variety of combination forms. For example, the circuit topology of the primary side is generally half-bridge, full bridge and push-pull structure, etc., while the secondary side circuit topology is commonly half-wave and full-wave rectifier circuit.

3. Research Status of DC Transformer

When the traditional DC converter is used for the interconnection of HVDC power grid, the capacity and voltage requirements of the system can be met generally through the insulated gate bipolar transistor (IGBT) with a large number of series and parallel connections. However, the use of a large number of IGBT will bring high switching loss, and also exist the problem of voltage and current equalization. This is a major reason that restricts the application of traditional DC/DC converter to high voltage and large capacity applications. Traditional DC/DC converters mainly focus on low and medium power applications. Research on DC/DC converters applied in high voltage and high power situations is in the stage of circuit topology, simulation calculation and principle prototype, and no industrial prototype has been reported [3]. In DC power grid, DC transformers not only need to have bidirectional power flow ability, but also need to provide electrical isolation to ensure safety. At present, the main way is to achieve high frequency conversion through power converter, and achieve voltage conversion and electrical isolation through high frequency isolation transformer [4]. There are many classification methods for DC transformers. Two simple and common classification methods are introduced in literature [2]. One is to divide the range of transformer ratio k, and divide transformers with k belonging to (0, 1.5), [1.5, 5) and [5, +∞) respectively into three types, high, medium and low ratio, as shown in table 1. The other is to divide dc transformers into isolated and non-isolated dc transformers based on the internal structure of dc transformers. Furthermore, according to the topology of DC transformer, the isolated type is divided into three types: Dual Active bridge dc transformer (DAB), MMC-based face-to-face DC transformer (F2F-MMC) and Flyback/Forward transformer. The non-isolated transformers are divided into DC auto-transformer, resonant DC-DC transformer and MMC-DC transformer, as shown in table 2.
Table 1. DC transformers are classified according to voltage variation ratio.

| Dc transformer classification | ratio       |
|-----------------------------|-------------|
| Low ratio                   | k<1.5       |
| Middle ratio                | 1.5≤k<5     |
| High ratio                  | k≥5         |

Table 2. Topology classification of DC transformers.

| Isolated transformer                                   | Non-isolated transformer                     |
|--------------------------------------------------------|-----------------------------------------------|
| Dual Active bridge dc transformer (DAB)                 | DC auto-transformer (DC AUTO)                 |
| MMC-based face-to-face DC transformer (F2F-MMC)        | resonant DC-DC transformer                    |
| Flyback/Forward transformer                            | MMC-DC transformer                            |

Figure 2. Topology of DAB DC transformer.

Literature [4] introduces the basic structure and working principle of DAB DC/DC transformer, as shown in figure 2. It is concluded that DAB DC transformer has the advantages of reversible power transmission, significant reduction of switching loss and noise, and superior expansion performance. However, since the power transmitted by a single sub-module of DAB DC transformer usually cannot meet the requirements, if DAB DC transformer is to be used in high-voltage and high-power situations, it is necessary to adopt the structure of series and parallel connection of multiple modules, as shown in figure 3. This leads to transformer voltage and current equalization and the sub-module power imbalance problem, to deal with this problem at present only to increase the cost of investment to design additional circuits, which is the main reason to limit its promotion in high-voltage and high-power occasions. Literature [5] proposed various equalization control strategies, such as single-phase-shift (SPS) modulation method, to control input voltage sharing of each sub-module of DAB DC transformer. IVS or output current sharing (OCS) to achieve power balance.
Figure 3. Topology of multi module series parallel DAB DC transformer.

Literature [6] specifically introduces the most basic topology of Modular Multilevel DC/DC converter (Modular Multilevel DC/DC Converter) -- MMC-based Face to face DC transformer (F2F-MMC). As shown in figure 4, it is pointed out that its topology structure has the characteristics of excellent expansibility and high power transmission efficiency, and it is the most promising DC transformer for future high-voltage and high-power occasions. However, the most important problem to be overcome is the disadvantages of low power utilization and large transformer volume due to the use of two MMCS with the same power in the structure. Literature [7] improves its circuit topology on the basis of literature [6], and presents a new modular multilevel dynamic DC/DC Transformer (MMDT). Its basic idea is to use the transformer primary side and secondary side to use a capacitor to achieve the modular integration of the structure to achieve real-time, dynamic and rapid adjustment of dc transformer ratio, to achieve simple and efficient control system, mass volume greatly reduced, with significant economic advantages. The modular multilevel DC converter will be widely used in HVDC transmission in the future, so the theoretical analysis and control strategy research of such topology structure is an urgent research field.

Literature [8] specifically studied the resonant capacitor Converter (SCC) in resonant DC transformer. It first introduced a basic unit of resonant switched capacitor, on the basis of the circuit structure of existing resonant SCC and can realize the switch loss and noise significantly reduce working principle were analyzed, and points out its advantages are high efficiency, small volume, light weight, suitable for the current requirements of power density and efficiency of high dc load such as data center, electric cars, etc. However, the dc transformer is sensitive to the parameter difference of the floating switch, which leads to the voltage regulation ability can not meet the current requirements.
Literature [9] proposed a new type of primary side double-winding coupling DC transformer for electric vehicle wireless charging system. Without adding inductance windings, the bridge arm straight-through problem that has always existed in the gravity of traditional full-bridge DC transformer is solved, which greatly improves the utilization rate and service life of dc transformer. In addition, the power tube can realize zero current turn-on, and significantly reduce the influence of leakage inductance through the transformer parallel effect, and improve the transformer transmission efficiency. But the problem is that this advantage in the current high voltage large capacity need transformer with high strain ratio under the condition of a rapid decline or even disappear, as one of secondary side and electrical isolation has no direct electrical contact, so when the transformer is one side electrical fault occurs, would also be affected, on the other side will not well fault block.

4. Conclusion
At present, the research of circuit topology and control strategy of high voltage and large capacity DC transformer is still being explored and carried out. As the concept of energy Internet is put forward, HVDC transmission technology will develop to a new stage, and the research of HVDC transformer with large capacity will become a key direction. Based on the understanding of the basic principle of DC transformers, this paper summarizes the current research status of DC transformers through simple classification of transformers, and classifies the characteristics and application of common DC transformers and sums up the problems to be solved.

References
[1] Tian Sh M, Luan W P, Zhang D X, Liang C H, Sun Y J 2015 Technical forms and key technologies on energy internet Proceedings of the CSEE 35(14): 3482-3494.
[2] Wang Q T, Zhang Zh Y, Sun T, Wang X H 2020 A research review of dc transformer Hubei Electric Power 44(06): 18-26.
[3] YANG X F, Zheng T Q, Lin Zh Q, Xue Y, Wang Zh B, Yao L Zh, Chen B W 2016 Survey of high-power dc/dc converter for hvdc grid application Power System Technology 40(03): 670-677.
[4] Zhao B, An F, Song Q, Yu Zh Q, Zeng R 2021 Development and application of dc transformer based on dual-active-bridge Proceedings of the CSEE 41(01): 288-298+418.
[5] Sun Zh F, Xiao L, Wang Q 2021 Review research on control technology of output parallel dual-active-bridge-converters Proceedings of the CSEE 41(05): 1811-1831.
[6] Huang J W, An J Ch, Wen H Zh 2019 Electric Switcher 57(05): 1-5+10.
[7] Li B, Zhang W X 2018 A novel modular multilevel dynamic dc/dc transformer *Proceedings of the CSEE* 38(05): 1319-1328.

[8] Wu X Zh, Qi J J, Liu J D, Yang A N, Lyu G 2021 Review of topological research on resonant switched capacitor dc/dc converter *Proceedings of the CSEE* 41(02): 655-667.

[9] Zheng X X, Liu X T, He Y, Pan Y Sh, Zeng G J 2017 High efficiency dc transformer without dead-zone based on the double winding coupling of the primary sid *Proceedings of the CSEE* 37(15): 4503-4513+4592.