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Research on AC & DC hybrid power supply system with high-proportion renewable energy of data centre

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Abstract: In the background of the energy Internet, the number of data centres is increasing, aiming at the shortcomings of power supply and reliability in power supply system of traditional data centre and the development trend of green data centres. This article proposes an AC & DC hybrid power supply system with high-proportion renewable energy. The system includes photovoltaic generation, wind power generation, photothermal power generation, thermal utilisation system, power storage system, and different types of loads. Therein, a multi-port power electronic transformer is used to realise AC & DC multi-level mixing system with high proportion of variety of distributed renewable energy. Thereafter, the power supply, power grid, and the load can efficiently complement each other by using the integrated energy storage system such as electricity storage and heat storage. In detail, the rationality and functionality of the AC & DC hybrid power system are analysed through the system simulation and power supply reliability calculation. Moreover, the results show that the proposed hybrid power supply can effectively improve the impact of high-proportion renewable energy access to the grid and provide a new design scheme for the green data centre.

1 Introduction

The power supply system of data centre is the basis for the normal operation of the information system. It is well known that the engineering design of data centre is to provide a stable, reliable, safe, environmentally friendly, and energy-saving power supply [1]. However, the current data centre power supply system is in a different form than other systems. The problem of high AC–DC energy conversion loss, poor power consumption, and low matching power consumption has become increasingly prominent in the traditional AC power distribution. To overcome the drawbacks of the traditional AC power distribution, the AC & DC power distribution technology was well developed, which can reduce the intermediate links of AC–DC conversion in power distribution and improve the economic efficiency, reliability, and flexibility of power distribution. Therefore, it is very important and valuable in the power distribution [2–5]. At the same time, the establishment of a unified DC power supply system and DC power supply architecture in the data centre is conducive to save energy and efficient use green energy. Additionally, the AC & DC hybrid power system has many advantages, such as saving investment, improving energy efficiency, and reducing pollution. Therefore, obtaining a high proportion of renewable energy is the development trend in data centre.

The literatures [6, 7] introduced the 240 V DC power supply scheme of data centre, which has obvious advantages in improving system reliability and availability, reducing power grid pollution, improving power supply efficiency, reducing construction and maintenance costs, improving management intelligence etc. On this basis, the applicability of the 240 V DC power supply system in the data centre was analysed, and a new data centre power supply scheme was explored. The literature [8] expounded the application of high-voltage DC power supply system in the data centre and compared it with the traditional UPS power supply scheme, indicating the direction for the subsequent design of the data centre power supply scheme. The literature [9] proposed a power supply system of the green data centre, analysed the shortcomings of the existing power supply scheme, designed the power supply system including renewable energy, and verified the rationality and feasibility of the above scheme through simulation. The literature [10] introduced the design concept of the AC & DC hybrid power supply system and analysed the advantages of the system. To a certain extent, it has met the current industrial demand for high-power AC uninterrupted power supply.

The existing literatures mostly study how to improve the UPS power supply system and the traditional AC and DC power supply system of data centre. There are few studies on renewable energy and AC & DC hybrid power supply systems. Under such backdrop, this paper proposes a novel AC & DC hybrid power supply system of data centre which contains photovoltaic power generation and energy storage devices. In detail, the shortcomings of traditional power supply have been analysed, and the system power quality and reliability have been simulated and calculated. Finally, the simulation and calculation results verify the rationality and functionality of the proposed system.

2 Traditional power supply scheme

The traditional data centre power supply system structure is shown in Fig. 1. Most of the equipment in the data centre need DC power supply. The front end of the DC equipment needs a rectifier to convert the AC voltage to the DC voltage. The electrical energy conversion from the power grid to the DC load is converted to the 380 or 220 V first through the AC–AC transformation, and then the DC voltage used by the server is completed by the multi-stage conversion of AC–DC and DC–DC transformation. Each transformation has power loss which results in low efficiency, and the increase in the intermediate links will reduce the reliability of the system [9]. The distribution network is the system that is connected with the whole power system and the user. It is an important link of power supply to the whole power system. Once the fault or overhaul of the distribution network occurs, the interruption of the power supply will be caused in the power system. So, the reliability of the distribution network plays a very important role in the reliability of the power system [11]. Therefore, the redundancy of the power transformation link is the main problem of the traditional data centre AC bus power supply system structure. At the same time, although the energy storage

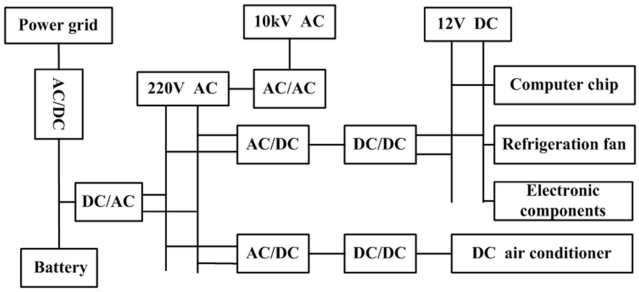

Fig. 1 *Traditional data centre supply system*

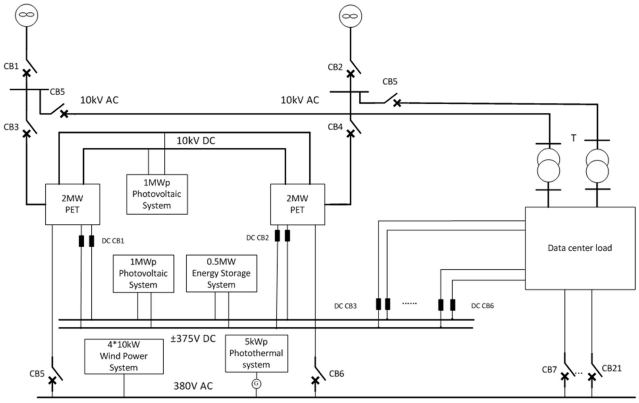

Fig. 2 *High proportion of renewable energy system grid structure*

device can provide a certain capacity of electricity, the traditional data centre network frame structure is single, the inverter failure will lead to the power failure directly, and the power supply reliability is not enough. In order to improve the efficiency and reliability of power supply system, a novel AC & DC hybrid power supply system suitable for data centre is proposed in this paper.

3 AC & DC hybrid power supply system

3.1 General situation of power supply system

A data centre needs to build two 10 kV power distribution stations which need two 10 kV electric lines. 10 kV bus uses single bus with sub-section connection. The total capacity of the transformer is 42 MVA, including four 2500 kVA transformers and sixteen 2000 kVA transformers. Therein, the main and standby power supply mode is adopted. The 0.4 kV bus also adopts single bus with sub-section connection. Each power supply in the data centre is required by each other and consists of two 10 kV power supply loops from different sub-stations. During normal operation, the rated load of each loop is 50%. When one of the power supplies fails or overhauls, the other transformer supplies power to all loads. M (1 + 1) hot standby mode of transformers is used in all data centre, and each of the two transformers provides 50% power.

3.2 AC & DC hybrid power supply scheme

Currently, IT loads with AC and DC inputs are both applied in data centres. This scheme is considered for the simultaneous power supply of 3 MW AC and DC load in the data centre. The data centre has three different types of loads. The primary load mainly includes IT cabinet and the air-conditioning refrigeration equipment. The other types of loads mainly include the power load and lighting load. The structure of the proposed power supply system is shown in Fig. 2. The transformer cluster scheme is adopted.

In this scheme, the dual 10 kV electric power lines are used to connect two 2 MW power electronic transformers, and two transformers are hot standby each other. The load capacity of the common power supply is 3 MW. The capacity of power supply system is 1.5 MW (50% load) at rated load. The transformer load rate is about 37.5%. The 2 MW power electronic transformers are with the functions of bidirectional and four ports, in which the 10 kV AC ports are the main power supply for the power grid. The 10 kV DC ports use a single bus connection to directly connect the two 2 MW power electronic transformers back to back, which can be used as the mutual support between the two 10 kV power supply ports, while the 10 kV DC bus is connected to the 1 MW remote distributed photovoltaic power generation system. The ± 375 V DC ports use single bus connection, and connect with 1 MW near distributed photovoltaic power generation system, 0.5 MW energy storage battery, and 1 MW DC load. The 380 V AC ports use single bus with sub-section connection, and connect with 40 kW wind generator, 5 kW photothermal generator system, and 2 MW AC load.

Considering the demand for power supply reliability, the AC & DC hybrid system can be used as one of the dual power sources to provide 240 V DC or 380 V AC for the data centre, and the other power source is the traditional AC distribution power supply. The two power sources supply normally with 50% loads on normal operation. When one power source fails or overhauls, the other one can operate at 100% full load.

4 System simulation analysis

The main DC load energy consumption of the data centre is high and requires extremely high-power quality and reliability. Multi-port and multi-function power electronic transformer cluster is used to realise high-proportional access of various distributed renewable energy sources and AC & DC power multi-stage hybrid. Through the comprehensive energy storage system, such as power storage and heat storage, the source, network, and load can be complemented efficiently. At the same time, the influence of the high proportion of distributed energy on the grid will be improved. In order to analyse the power quality of the power electronic transformer port, the system simulation model is built up in Power Systems Computer-Aided Design according to the system scheme. The system configuration, as shown in Table 1, is simulated and analysed. The system simulation model is shown in Fig. 3.

Based on the system simulation model of Fig. 3, the steady-state simulation analysis is carried out to obtain the voltage and current waveform of the four ports of 10 kV AC, 380 V AC, 10 kV DC, and ± 375 V DC, as shown in Fig. 4.

From the simulation results, when the system reaches steady state (each port reaches its designed power), the power quality of

Table 1 System simulation model configuration

Distributed renewable energy	Capacity	Access point
photovoltaic system	1 MWp	± 375 V DC Bus
	1 MWp	10 kV DC Bus
wind power system	40 kWp	380 V AC Bus
photothermal system	5 kW	380 V AC Bus

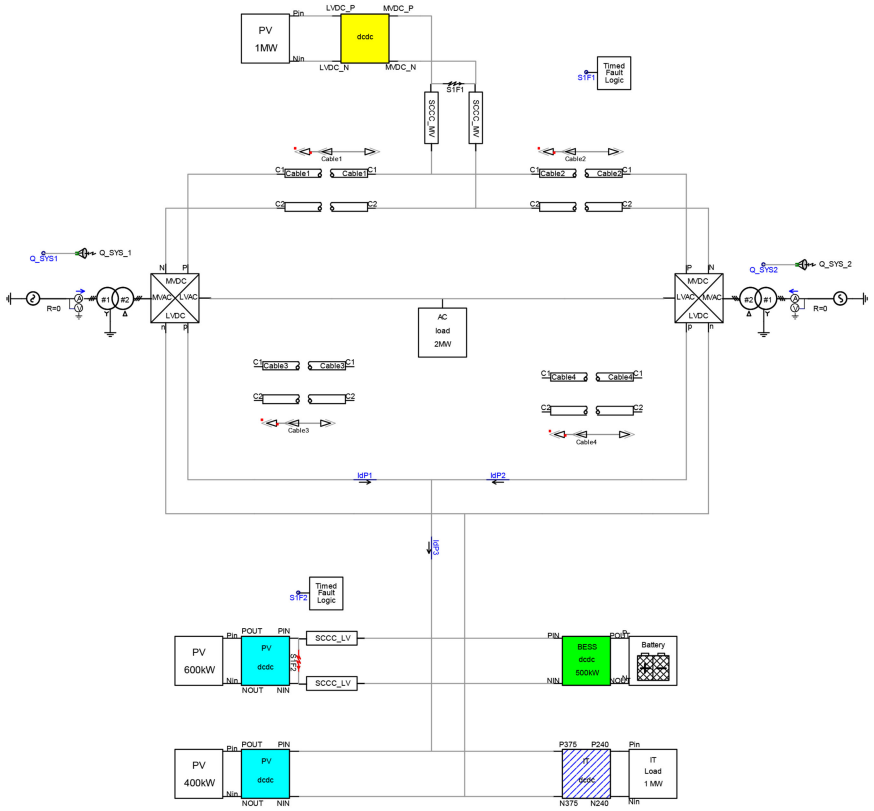

Fig. 3 *System simulation model*

each port of multi-port and multi-function power electronic transformer is as follows.

The voltage deviation of 10 kV DC port voltage, as shown in Fig. 4*a*, is −0.2 to + 0.8%. The national standard GB12325-2003 indicates that the voltage deviation of 10 kV is ±7%. It is obvious that the voltage deviation of the 10 KV DC port conforms to the national standard GB12325-2003. The voltage deviation of ±375 V DC port, as shown in Fig. 4*b*, is as follows: −1.67 to +1%. The state stipulates that the allowable deviation of single-phase power supply voltage is −10 to +7%. The total voltage harmonic distortion rate of 10 kV AC port, as shown in Fig. 4*c*, is 2.55%. The total current harmonic distortion rate of 10 kV AC port, as shown in Fig. 4*d*, is 1.87%. The national standard GB/T24337-2009 indicates that the power grid harmonic of 10 kV AC is about 4% and low-voltage power grid harmonic cannot exceed 5%. It is obvious that the harmonic of the 10 KV AC port conforms to the national standard GB/T24337-2009. The total voltage harmonic distortion rate of 380 V AC port, as shown in Fig. 4*e*, is less than 1%. The total current harmonic distortion rate, as shown in Fig. 4*e*, is 2.41%. In a word, the comparison of the simulation results with the national regulations shows that the voltage quality and the harmonic wave of each port conform to the national standard in the case of a high proportion of renewable energy.

5 Analysis of system operation reliability

The failure rate of the key equipment in the AC and DC distribution network system of the data centre is shown in Table 2. Thereafter, the failure rate of the power supply area is 0.0642%. The failure rate and repair time data of AC transformer and line are all from the industry's top journals and master's theses [12–14]. The fault probability of the power electronic transformer is calculated based on the 72 h annual power outage (diesel generators store fuel according to the 72 h continuous power supply). The 375–240 V DC/DC converter is calculated according to the fault probability of the power transformer.

In distribution network, it is called first-order failure when a single device fails. Similarly, when two devices fail at the same time, it becomes a second-order fault. Usually, the failure rate of the second-order fault in distribution network is much smaller than that of first-order fault. This paper only calculates the first- and second-order failures, and does not consider the occurrence of third- or high-order failures. Since the dual power supplies used in the system are designed in mutual backup mode, it will not affect the structure of the grid when first-order fault occurs. So, the failure probability of the power failure is 0%. The failure type of the power supply reliability is ignored. The reliability of the power supply system is more than 99.999% through calculation, which can meet the reliability index of the normal data centre.

6 Conclusion

In view of the fact that current data centre power supply system is not connected to a high-proportion renewable energy, a novel dual power supply circuit is proposed and designed, which reduces the construction cost to the maximum limit under the premise of guaranteeing the reliability of the power supply. The conclusions obtained from the simulation and calculation of the system are as follows:

1. According to the comparison of the simulation analysis results and the standard requirements, the voltage deviation and current harmonic distortion rate of the power electronic transformer are far better than the standard requirements. The

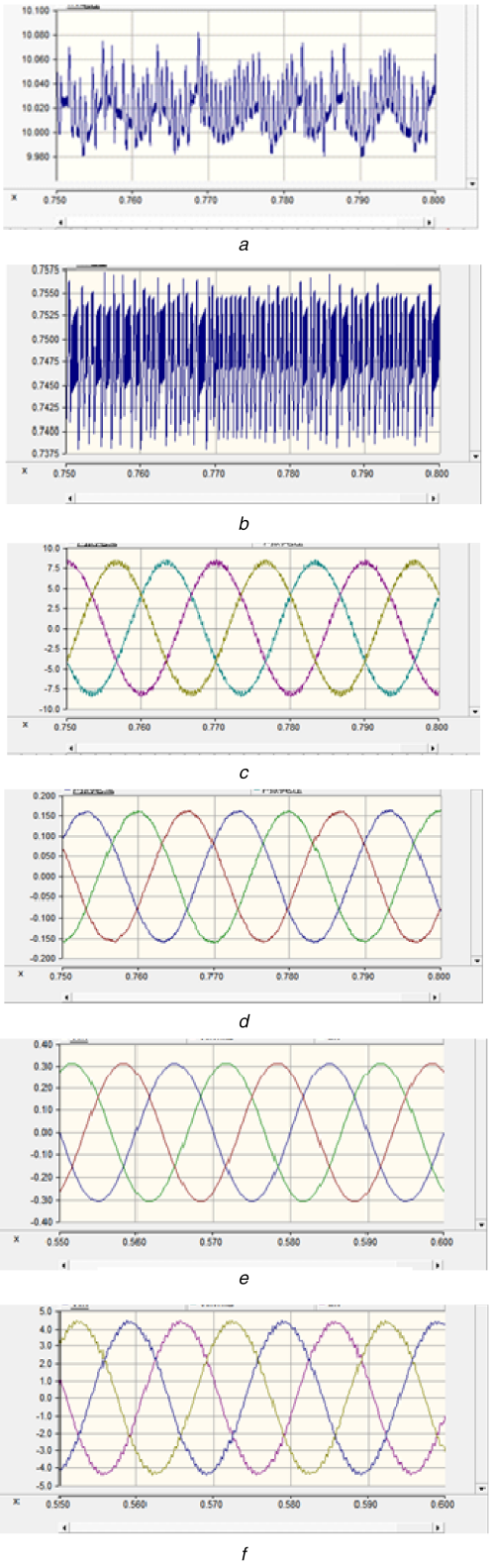

Fig. 4 *Power electronic transformer port voltage and current waveforms*
(a) 10 kV DC port voltage, ***(b)*** ± 375 V DC port voltage, ***(c)*** 10 kV AC port voltage, ***(d)*** 10 kV AC port current, ***(e)*** 380 V AC port voltage, ***(f)*** 380 V AC port current

power quality of the power supply well satisfies the requirements of the data centre.

Table 2 Equipment failure probability

Type of equipment	Average failure rate (times/year)	Power outage for each failure	Annual failure probability
power supply	0.0007811	72	0.000642
AC transformer	0.0167236	11	0.000021
power electronic transformers	0.0249696	72	0.0002053
10 kV AC line	0.0063534	13.65	0.0000099
10 kV DC line	0.0039789	13.65	0.0000062
± 375 V DC bus	0.0006417	13.65	0.0000010
380 V AC bus	0.0006417	13.65	0.0000010

2. The reliability of AC & DC hybrid distribution system satisfies the requirement of data centre.
3. The power supply system is with a high-proportion distributed renewable energy, which provides a demonstration for promoting the construction of green data centre.

7 Acknowledgments

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