New AC & DC hybrid power supply system and its reliability analysis in data centre

Jianzong He1, Xiang Xiao2, Rongfu Zhong3, Weixiong Huang1, Donghui Li2, Qingqi Chen1

1Dongguan Power Supply Bureau, Guangdong Power Grid Company, Dongguan 523000, Guangdong, People's Republic of China
2Electric Power Research Institute of Guangdong Power Grid Co., Ltd., Guangzhou 510080, People's Republic of China
3E-mail: zrf4832887@163.com

Abstract: This paper designs a new AC & DC hybrid power supply system for data centres, which includes photostatic power generation, wind power generation, solar thermal power generation, storage power systems, and different types of loads. According to the above-mentioned, the paper first presents the reliability evaluation indicators and analysis methods applicable to the new AC & DC hybrid power supply system for data centres, which are for solving the problem of the reliability evaluation under uncertain parameters and load parameters of the new data centre power supply system. The paper describes the new power supply system reliability indicators and evaluation methods in detail. The problem of the power supply reliability in the new AC & DC hybrid power supply system in the data centre is analysed in a targeted manner by adopting actual examples, then it is verified that the power supply reliability of the new AC & DC hybrid power supply system can perfectly meet the qualification of the A-class data centre power supply. The reliability of assessment index and analysis methods presented here will be two simple and superior analysing tools.

1 Introduction

In the past 30 years, with the rapid development of network technology, especially the area of cloud computing, big data, and mobile internet. The demand of network computing and network storage has been continuously expanding, and the quantity and scale of data centres have been rapidly developed [1]. It is estimated that the number of various data centres will reach 18.6 million by 2020 in the world, and energy consumption will account for 9% of global energy consumption [2, 3].

The power supply system of data centre equipment is the basis for guaranteeing the normal operation of the information system, which is a key issue to be considered for offering stable, reliable, secure and environmental-friendly power in engineering design of data centre [4]. Distributed renewable energy has been becoming an important way to promote energy transformation, and it is expected that non-water renewable energy generation will reach 43.44% by 2050 [5]. The distributed renewable energy, energy storage, and DC load access to traditional AC distribution networks, which requires multi-level conversion links, reduce the system energy efficiency [6]. Adopting AC & DC hybrid power consumption technology can effectively reduce the intermediate links of AC & DC conversion, which can promote the economical efficiency, reliability, and operational flexibility.

With the continuous expansion of the number and scale of data centres and the rapid growth of energy demand, it is of great advantage to design AC & DC hybrid distributed renewable energy system for power supply of data centres. From the perspectives of saving investment, improving energy efficiency, and reducing pollution, high income will be achieved. Therefore, the trend of the data centre must be connecting a high proportion of renewable energy, AC & DC hybrid power supply system [7–9].

This paper designs a new AC & DC hybrid power supply system for data centres. The system includes photovoltaic power generation, fan power generation, solar thermal power generation, power storage systems, and different types of loads. It ensure reliability for data centre traditional power supply systems and new AC & DC hybrid power supply systems. The analysis will provide a reference for the future use of the new AC & DC hybrid power supply system and its reliability analysis in the data centre.

2 Requirements of data center power supply reliability

The class of construction of data centres is divided into three classes in China: A, B, and C [10, 11]. A-class is the highest grade, and it requires the infrastructure be configured as a fault-tolerant system during the electronic information system operating. The infrastructure should ensure normal operation of the electronic information system after an accident or when the single system equipment is maintained or overhauled. With dual power supply, the availability of power needs to meet 99.99999% of requirement. The power availability ratio of B-class needs to reach 99.99 to 99.999%, while the C-class needs to reach 99 to 99.9%.

3 Power system of data centre

3.1 Traditional power supply system

Data centre load contains DC load and AC load. In the traditional power supply system, in order to ensure reliability of the power supply, two 10 kV AC power supplies are used to supply power and 10 kV/380 V transformer is used for step-down. The energy supply of DC load comes from 380 V AC/240 V DC converter. The wiring diagram of data centre traditional power supply system will be shown in Fig. 1.

3.2 New AC & DC hybrid power supply system

The data centre load is divided into three levels [10]. The first-level is the IT cabinet, the air-conditioner for the equipment room, the air-conditioning refrigerating equipment, and the air-conditioning main equipment. The second- level and third-level loads mainly include the power load and the lighting load.

This paper designs an AC & DC hybrid and renewable energy supply system for data center, as shown in Fig. 2. The system power comes from a double-circuit 10 kV power grid line, respectively, connected to two sets of 2 MW power electronic transformers. The two transformers are hot-standby power supply mode and supply the AC & DC load capacity 3 MW for the data centre together. During normal operating, the two transformers supply 1.5 MW (50% load) while the transformer load rate is ~37.5%.
With this consideration, the data centre needs high requirements for power supply reliability. This paper also designs a hybrid power supply system that combines a traditional power supply system with a new AC & DC hybrid power supply system. An ATS automatic switch box is added at the data centre AC UPS equipment and DC power distribution cabinets to reach automatic switching between the new AC & DC hybrid power supply system and the traditional power supply system. In normal operation, both types of power supply are operated with 50% load each. In the case of a single power supply failure or overhaul, the other power supply can be operated at 100% full load. As a result, the power supply reliability of the data centre has been further improved.

The hybrid power supply system uses four 10 kV lines to access the large power grid. It means that there is a three-way power supply for data centre AC load and DC load. The hybrid power supply system wiring is shown in Fig. 3.

4 Reliability assessment indicators and analysis methods

4.1 Reliability evaluation indicators

The reliability of the data centre power supply system is an indicator of the power supply system and the indicator of its ability to provide power to the data centre users to supply high-quality power to user [12]. Data centre power supply system reliability assessment must establish reliability assessment models and indicators to facilitate with the quantitative expression of data centre power supply reliability assessment. The model built should reflect the impact of the power supply system and its equipment on the reliability of the power supply to the user data centre [12].

For the reliability evaluation of the power supply system at the data centre load point, the following three basic indicators are proposed to evaluate: (1) the average failure rate $\lambda_i$; (2) the average duration of power outage for each failure $\gamma$; (3) the average duration of power outages per year $U$. The reliability indexes of the data centre power supply system include system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), and average service availability index (ASAI), average service unavailability index (ASUI) etc. The power supply system indicators can be calculated through the three basic indicators of the load point, and the calculation formula is as follows:

System average interruption frequency index (SAIFI)

$$R_{SAIFI} = \sum \lambda_i N_i (\sum N_i)^{-1}$$  \hspace{1cm} (1)

System average interruption duration index (SAIDI)

$$R_{SAIDI} = \sum U_i N_i (\sum N_i)^{-1}$$  \hspace{1cm} (2)

Average service availability index (ASAI)

$$R_{ASAI} = \frac{\left[ 8760 \sum N_i - \sum U_i N_i \right]}{\left( 8760 \sum N_i \right)^{-1}}$$  \hspace{1cm} (3)

Average service unavailability index (ASUI)

$$R_{ASUI} = 1 - R_{ASAI}$$  \hspace{1cm} (4)

where $U_i$, $\lambda_i$, and $N_i$ respectively, represent the average annual outage duration of the load point, the average failure rate and the number of users.

4.2 Analysis method of reliability

Various linking devices on the data centre power supply system can be viewed as a single independent component, which can be converted into the form of tandem and parallel connection of each
component. The three basic reliability indexes can be calculated according to the following expressions [13]. Tandem and parallel systems are shown in Figs. 4 and 5. The statistics of the key equipment failure rate of the AC & DC hybrid power supply system in the data centre are shown in Table 1. The annual failure rate of the power supply is 0.0642%, which is the 10 kV distribution network reliability data from the Dongguan Power Supply Bureau as of November 2017. The failure probability data of AC transformers, DC lines, AC circuits, DC/DC converters, and AC/DC converters are all from top industry journal articles and master's thesis [7, 8, 10]. The power electronic power supply system, and the hybrid power supply system in the data centre can be obtained, as shown in Figs. 6–8.

According to Figs. 1–3 and Table 1, the reliability evaluation index equivalent maps for the traditional data centre, the new power supply system, and the hybrid power supply system in the data centre can be obtained, as shown in Figs. 6–8.

A-class data centre power supply system must be dual power supply and above power supply, when a single device fails, it is called a first-order failure, when two devices fail at the same time, called a second-order failure, and so on. Under normal circumstances, the failure rate of the second-order fault in the power supply system is much smaller than the first-order fault. The higher the fault order, the lower the probability of failure. This article only considers first-order and second-order faults and does not consider the occurrence of third-order and above faults. A-class data centre power supply system uses dual power supplies for alternate design. When a first-order fault occurs, it will not affect the power load. Therefore, the probability of a power outage failure...

| Table 1 Equipment failure probability |
|--------------------------------------|
| Type of equipment | Code number | Average failure rate $\lambda$ (Times/Year) | Power outage for each failure $\gamma$, h | Annual failure probability $(\lambda \times \gamma)$ |
|-------------------|-------------|---------------------------------|---------------------------------|-----------------|
| power supply      | S1, S2, S3, S4 | 0.07811                         | 72                              | 0.000642        |
| AC transformer    | T1, T2      | 0.0167236                       | 11                              | 0.000021        |
| power electronic transformers | T11, T12 | 0.0249696                       | 72                              | 0.0002053       |
| 10 kV AC line     | L1, L2, L11, L12 | 0.0063534                      | 13.65                           | 0.000099        |
| 10 kV DC line     | L13         | 0.0039789                       | 13.65                           | 0.000062        |
| ±375 V DC bus    | L14, L16    | 0.0006417                       | 13.65                           | 0.000010        |
| 380 V AC bus      | L17, L18    | 0.0006417                       | 13.65                           | 0.000010        |
| DC/DC inverter    | L15         | 0.299665                        | 24                              | 0.0008210       |
| AC/DC inverter    | L3, L4      | 0.299665                        | 24                              | 0.0008210       |
| 240 V DC load     | F1          | /                               | /                              | /               |
| 380 V AC load     | F2          | /                               | /                              | /               |

For parallel systems, there are

$$\gamma = \sum_{i=1}^{n} \lambda_i \gamma_i$$  \hspace{1cm} (7)

$$\lambda_i = \prod_{i=1}^{n} \lambda_i \times \sum_{i=1}^{n} \mu_i \times \left( \prod_{i=1}^{n} \mu_i \right)^{-1}$$  \hspace{1cm} (8)

$$U_i = \prod_{i=1}^{n} U_i$$  \hspace{1cm} (9)

$$\gamma_i = \left( \sum_{i=1}^{n} \mu_i \right)^{-1}$$  \hspace{1cm} (10)
Table 2  Reliability indicators of system

| Indicators | Traditional power supply system | New power system | Hybrid power supply system |
|------------|---------------------------------|-----------------|---------------------------|
| RₐSₐFᵢ    | 0.100213                         | 0.0473712       | 0.06962038                |
| RₐSₐDᵢ    | 3.2716409                        | 1.3705778       | 2.17102542                |
| RₐSₐUᵢ    | 1.3948 × 10⁻⁷                    | 6.0795 × 10⁻⁹   | 8.4797 × 10⁻¹⁶            |
| RₐSₐAᵢ    | 0.999998605                      | 0.999999994     | 0.999999999               |

... occurring during a first-order fault is zero. Therefore, this paper only analyses the probability a second-order fault.

According to the reliability assessment indicators and analysis methods proposed here, the probability of occurrence of equipment failure in Table 1 is factored into the calculation, and the results are reliability indices of the traditional power supply system, new power supply system, and hybrid power supply system can be obtained, as shown in Table 2.

According to the data in Table 2, compared with the traditional power supply system, the new power supply system has greatly improved the system reliability index. The average power outage frequency and the average power outage duration of the system are both lower than the traditional power supply system by >50%. The average power supply availability rate of the new power supply system reaches 99.9999994%.

Due to the complexity of the system and the large number of devices, the hybrid power supply system has caused the average power outage frequency and average power outage duration of the system become higher than that of the new power supply system. Although the average power supply availability of the system reached 99.9999999%, its investment cost is high, the redundancy is large, the economical cost performance is low, and the overall power supply system is relatively complicated.

According to the reliability requirements of the A-class in China, the availability of power supply must reach 99.9999999%. Therefore, the new AC & DC hybrid power supply system with a power supply availability rate of 99.99999994% can fully meet the power requirements of the A-class data centre. In the above calculation of the reliability index, the positive impact of the energy storage system on the power supply reliability has not been considered. The new AC & DC hybrid power supply system contains the use of renewable energy such as photostatic power generation, wind turbine power generation, and solar thermal power generation, which has advantages in energy conservation, emission reduction, and economical cost performance. Therefore, the new AC & DC hybrid power supply system has obvious advantages over traditional power supply system.

6 Conclusions

In the view of the traditional power supply system is not connected to renewable energy sources in the data centre. This paper proposes a new AC & DC hybrid power supply system and designs a hybrid power supply system of the new AC & DC hybrid power supply system and the traditional power supply system, and proposes a reliable power supply system of data centre. The evaluation indicators and analysis methods have solved the reliability evaluation problems of the uncertain parameters and load parameters of the new power supply system. By comparing the power supply reliability indicators of the three power supply systems, the following conclusions can be obtained:

(i) The power supply reliability index of the new AC & DC hybrid power supply system is significantly better than the traditional power supply system, and the average power supply availability rate of the system reaches 99.99999994%, which verifies that the power supply reliability of the new AC & DC hybrid power supply system can fully achieve the power supply reliability requirements of A-class data centre.

(ii) The new AC & DC hybrid power supply system is connected with a large number of renewable energy such as photostatic power generation, wind power generation, and solar thermal power generation, and it is connected to the storage battery. Therefore, the system not only has advantages in terms of energy saving and emission reduction, economical cost performance, but also further improves the power supply reliability of the system.

(iii) Although the power supply reliability of the hybrid power supply system designed here is higher than that of the new AC & DC hybrid power supply system, its investment and construction cost are higher and the redundancy is large, resulting in its low economic effect.

(iv) The reliability evaluation indicators and analysis methods of the data centre power supply system proposed here will be two simple and superior analysing tools.

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