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Research on Energy Efficiency of DC Distribution System

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Abstract

Energy efficiency of DC distribution systems is researched in this paper. Efficiency calculation models of feeders and loads are established, efficiencies of AC/DC, DC/DC and DC/AC are analyzed. Moreover, energy efficiencies of an AC system and two DC systems, monopole and bipolar, are calculated and compared. The efficiency improvement of office building supplied by DC power system compared to supply by AC power system is demonstrated. From analysis, it is showed that the energy efficiency is higher in DC distribution system than AC distribution system.

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Keywords: Energy efficiency ; DC distribution system; Calculation models

1. Introduction

With the rapidly development of new energy, information technology and power electrical technology and economic increasing, user demand for electricity and requirements of power quality, reliability, economy and environmental protection is continuing to increase. The power distribution system confront the problems that loads diversion, lack of power supply in city center, stress of power supply hallway and so on .

Compared to traditional AC distribution system, a series of advantages that large power supply capacity[1-3],small feeder loss[4-6], higher energy transmission efficiency[7-9],better power quality[10],higher power reliability[11] and access of renewable energy[12] are reflected in DC distribution system. If the AC distribution system is replaced by a DC distribution system, lots of rectifying and inverting links, along with the energy

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consumption of these parts can be reduced, and then achieve the purpose of energy conservation. In the paper[12],it is studied that as the feeder voltage value of DC distribution system is two times than it in AC distribution system, the feeder loss of DC distribution system account for about 15%~50% to it in AC distribution system.

In this paper, the energy efficiency of DC distribution system is treated. Firstly, the concept of DC distribution system is introduced, and the figure of DC distribution system is showed. Then, energy efficiencies of the feeder, the power electrical devices and the load are analyzed, and their calculation models are established. Finally, the total energy efficiency of DC distribution system is calculated and analyzed.

2. Energy Efficiency Analysis Of DC Feeder

2.1 Energy efficiency analysis models of DC feeder

Energy efficiency index of power feeder mainly include that active power loss, transmission efficiency, energy loss and loss rate of feeder. The calculation models of AC feeder, monopole DC feeder and bipolar DC feeder are compared as follows. The operating mode of DC feeder is metal loop operating mode.

Calculating model that active power loss of AC feeder is follow:

$$\Delta P = P^2 /(U_N{}^2 \cos^2 \varphi) \cdot rL \tag{1}$$

Where P is active power loss consumed by load, U_N is rated feeder voltage of feeder, $\cos\varphi$ is load power factor, r is feeder resistance every kilometre, L is feeder distance.

Calculating model that active power loss of monopole DC feeder is follow:

$$\Delta P = P^2 / U_N{}^2 \cdot RL \tag{2}$$

Where R is the total resistance of two feeders.

Calculating model that active power loss of bipolar DC feeder is follow:

$$\Delta P = P^2 /(2U_N{}^2) \cdot rL \tag{3}$$

Where r is the total resistance of two feeders.

Calculating model of transmission efficiency is follow:

$$efficiency = (P_2 / P_1) \times 100\% \tag{4}$$

Where P_1 is active power inputting at start, P_2 is active power outputting at end.

Calculating model of energy loss is follow:

$$\Delta W_z = \Delta P_{\max} \times \tau_{\max} \tag{5}$$

Where $\Delta P_{\max}$ is active power loss at maximum load, and $\tau_{\max}$ is time that energy loss in a year divide active power loss at maximum load.

Calculating model that loss rate of feeder is follow:

$$(\Delta W_z / W_1) \times 100\% = \Delta W_z /(W_2 + \Delta W_z) \times 100\% \tag{6}$$

Where W_1 is energy inputting at start, and W_2 is energy outputting at end.

2.2 Energy efficiency analysis of DC feeder

2.2.1 Assumed calculating conditions

The cable of YJV22 that single-phase cross-sectional area is 240mm^2 is selected in calculating, and the

distance of feeder is 3km.Then the active power consumed by load in the feeder is 3MW,and the power factor is set to 0.9.Finally,the cable voltages are set to five grade: 10kV、15kV、20kV、25kV、30kV.

2.2.2 Analysis of calculating results

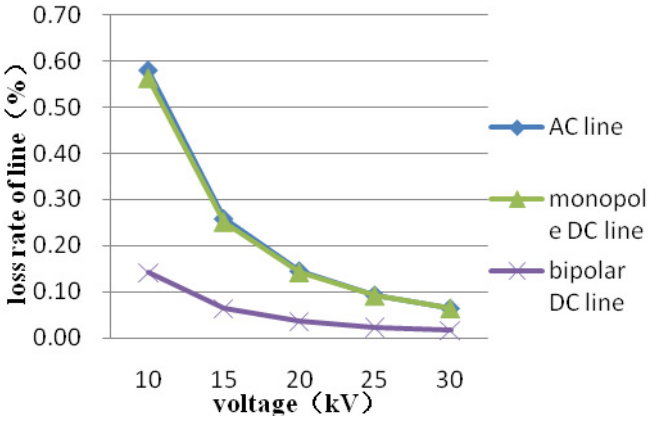

Fig.1 The comparison of loss rate between AC feeder with DC feeder

From Fig.1, it is reflected that the curves of transmission efficiency and loss rate in cable of YJV22, single-phase cross-sectional area is 240mm^2.We can compare the loss rate of AC feeder, monopole DC feeder and bipolar DC feeder according to these figures. By analyzing the result of the graph, efficiency of the power cable in a bipolar DC feeder that voltage level within a range from 10kV to 30kV is always optimal, and its advantage is obviously compared to AC feeder when the voltage level is 10kV. As the voltage level rises, the efficiency advantages of bipolar DC to feeder AC feeder is narrowing. Therefore, it has the highest efficiency to supply power in bipolar DC feeder.

3. Energy Efficiency Analysis Of AC/DC, DC/AC And DC/DC

The losses of AC/DC, DC/DC and DC/AC are not used to calculate, and cannot be computed simply by formula. Their energy efficiency is ascertained through table of power electrical devices efficiencies.

Tab.1 The efficiencies of AC/DC, DC/DC and DC/AC

Power rating(W) / The conversion	10	100	1000	10000	100000	1000000
AC/DC	69%	75%	81%	87%	93%	99%
DC/DC	86%	90%	92%	96%	97%	99%
DC/AC	90%	92%	92%	95%	95%	98%

The operation efficiencies of AC/DC, DC/DC and DC/AC interact with the capacity intimately. According to the survey for these power electrical devices in the market, the efficiencies are showed in Tab.1[13].

4. Energy efficiency analysis of office building

4.1 The power supplies of loads in the office building

4.1.1 The server

From the power systems of the server in data center mentioned above, the difference of energy efficiency between AC power supply and DC power supply is the power conversion devices and feeder losses. The power conversion devices include UPS, transformers and converters, etc. Figure.2 made it clear that within the server, the data switching equipment and other core IT equipments operate at the same voltage of DC. So whether in AC or DC power supply system, the energy consumption of the core device inside the server is the same in the same operating environment.

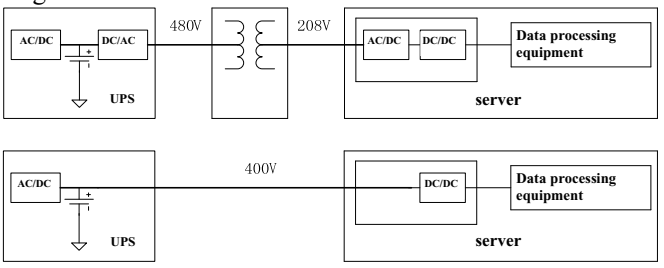

Fig.2 (a)AC power supply system of the server ;(b)DC power supply system of the server

If the servers used to be supplied by traditional AC power system, its power efficiency is following:

$$\eta_{AC} = \eta_{\mathrm{UPS}} \cdot \eta_{\mathrm{T}} \cdot \eta_{\mathrm{AC/DC}} \cdot \eta_{\mathrm{DC/AC}} \cdot \eta_{feeder} \tag{7}$$

If the servers used to be supplied by DC power system, so the power efficiency is following:

$$\eta_{AC} = \eta_{\mathrm{UPS}} \cdot \eta_{\mathrm{DC/DC}} \cdot \eta_{feeder} \tag{8}$$

Where η_{UPS} is the power efficiency of UPS, η_{T} is the power efficiency of transformer, $\eta_{\mathrm{AC/DC}}$ is the power efficiency of AC/DC, $\eta_{\mathrm{DC/DC}}$ is the power efficiency of DC/DC, η_{line} is the power efficiency of feeder.

4.1.2 Other loads

Like the server, energy efficiency models of air-conditioner, fluorescent lamp, LED lamp and laptop are showed by formula (9)~(13).

Air-conditioner:

The efficiency when the AC power system supply:

$$\eta_{AC} = \eta_{\mathrm{AC/DC}} \cdot \eta_{DC/DC} \cdot \eta_{\mathrm{DC/AC}} \cdot \eta_{feeder} \tag{9}$$

The efficiency when the DC power system supply:

$$\eta_{DC} = \eta_{DC/DC} \cdot \eta_{\mathrm{DC/AC}} \cdot \eta_{feeder} \tag{10}$$

Fluorescent lamp:

The formula (11) is the efficiency of traditional fluorescent lamp supplied by AC power, and the formula (10) is it supplied by DC power.

$$\eta_{AC} = \eta_{feeder} \tag{11}$$

LED lamp:

The efficiency when the AC power system supply:

$$\eta_{AC} = \eta_{\mathrm{AC/DC}} \cdot \eta_{DC/DC} \cdot \eta_{feeder} \tag{12}$$

The efficiency when the DC power system supply:

$$\eta_{DC} = \eta_{DC/DC} \cdot \eta_{feeder} \tag{13}$$

Due to that distribution system supply power to laptop through power adapter as LED supply system, the power losses are produced in power adapter and several losses are produced in feeders. So the laptop efficiencies supplying by AC system and DC system are showed with formula (12) and (13).

4.2 Energy efficiency analysis of the office building

4.2.1 Classification of office buildings

In this paper, a large office building which area is 10000m^2 is analyzed. Common loads in the office building include that air-conditioner, laptop, lighting, IT device and so on.Tab.2 lists several loads in the office building.

Table.2 Statistics of loads power in the office building

No.	Loads	Power(W)	Quantity	Total(W)
1	Air conditioner	40000	5	200000
2	Fluorescent lamp	40	600	24000
3	LED	150	100	15000
4	Laptop	60	1000	60000
5	Printer	200	100	20000
6	IT device	5000	6	30000

4.2.2 Load curve in the office building

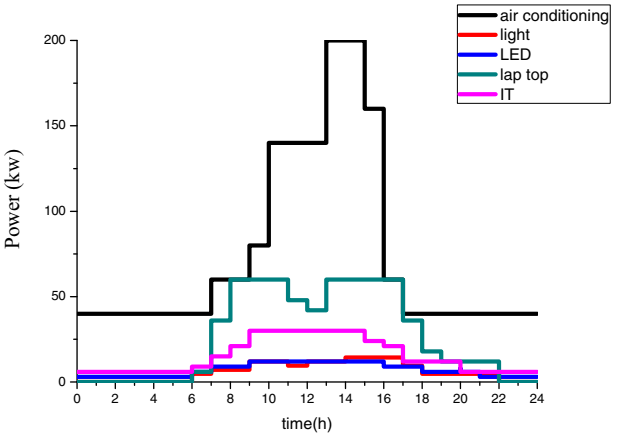

Fig.3 Loads curve in the office building

In this paper, the working time ranging from 8:00 to 17:00 is set to by us, and the load curve in the office building is showed as Fig.3.

4.2.3 The calculating results analysis of energy efficiency in the office building

In calculating, it is assumption that the losses of feeders in the building are neglected. On the basis of calculating models of loads and loads daily curves, the energy loss of building and main loads on one day can be calculated, the results are presented by Tab.3.

Table.3 Calculating result for energy efficiency in office building

Loads	Power consumption （kWh/d）	Energy loss by AC （kWh/d）	Energy loss by AC（kWh/d）	Efficiency by AC （%）	Efficiency by DC （%）
Air-conditioner	1800	589.27	255.39	75.34%	87.57%
Fluorescent lamp	148.8	0	41.24	100%	78.3%
LED	171	84.03	19	67.05%	90%
Laptop	642	343.87	87.55	65.12%	88%
IT device	366	259.18	109.44	58.54%	76.98%
Total	3127.8	1276.35	512.61	71.02%	85.92%

It is clear that efficiency of office building supplied by DC power increase 14.90% than it supplied by AC power from the Table.3.When DC power supply, air-conditioner can save the most electrical energy about 333.88kWh every day, and its supply efficiency can increase 12.23%.And laptops in the building can save electrical energy about 256.32kWh, its efficiency can raise 22.88%.The statistic of other loads are showed by Tab.3.

5. Conclusion

In this paper, calculation models of DC feeder and DC system for the supply of office building have been established. Power losses and efficiencies have been calculated for AC power supply system, and compared with the results given from DC power.

Compared to AC feeder and monopole DC feeder, bipolar DC feeder has the highest efficiency through calculating the models. And the efficiency of office building is higher when supplied by DC power than supplied by AC power. The efficiency of office building has ascended about 14.90%. Furthermore, the theoretical basis that DC supply system replaces AC supply system in office building is provided.

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