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ENERGY EFFICIENCY COMPARISON OF AC AND DC MICROGRIDS

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ABSTRACT

Base on the DC microgrid in the College of Energy, Xiamen University, we through three different power supply modes to compare the energy efficiency. This paper introduces the distribution situations of three power supply modes in detail, including components and loads, and calculates and evaluates the Xiamen typical daily loads, typical daily and annual power generation of photovoltaic array. Taking the college offices as the research objects, we test the overall efficiency, the results show that dc power distribution has more advantages than ac power distribution. The overall efficiency can be improved by 6.5-7.9%. Finally, the line loss and voltage drop are analyzed, and the maximum length of cabling is calculated under 380V DC power supply.

Keywords: efficiency; photovoltaic power generation; loads; voltage drop

1. INTRODUCTION

With the development of times, people consume more and more energy, among which building energy consumption accounts for a large part, and the Ministry of Housing and Urban-Rural Development points out that building energy consumption accounts for 27.5% [1]. In order to deal with the problem of energy consumption, various countries have carried out a series of research on energy-saving technologies. Voss K's concept of net zero energy building points out a good direction[2] (Subtask A-20110429 From Low Energy to NZNB-Status and Perspective). To study the feasibility of "net zero energy building", this paper takes some small offices as research objects and compares the efficiency of ac and dc microgrids by designing three different power supply modes. The traditional power supply mode is ac mode. For dc load, a rectifier is generally integrated inside the equipment to convert the grid ac power into dc, and then through the step-down or step-up circuit to obtain the voltage level. However, with the rise of dc power distribution mode, the rectifier link is omitted for dc load, but for ac load, the inverter module needs to be installed inside the equipment to convert the dc inverter into ac.

Fig. 1(a) shows a common ac power distribution system, among which many converters are used. Some systems have battery packs, which act as distributed energy and "backup supply". When only the battery packs supply the power, two or three conversions are often needed, this is inefficient. Fig. 1(b) shows a common dc power distribution system. The photovoltaic power generation system and battery packs can be directly connected to the dc bus. Obviously, dc power distribution saves some converters and improves the energy efficiency, but dc power distribution also has some disadvantages, such as large voltage drop when through low-voltage transmission.

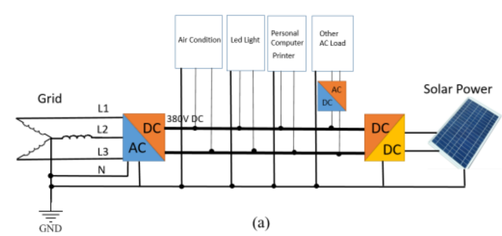

Fig. 1. (a) AC distribution system.

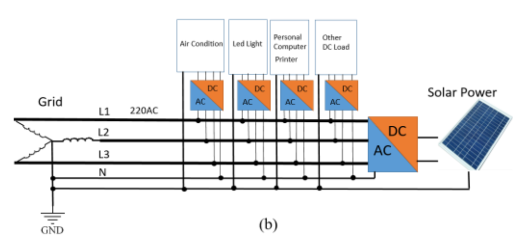

Fig. 1. (b) DC distribution system

Few studies consider the actual situations of dc microgrid and ac microgrid by designing several experiments, or the loads are dc loads basically. Base on the existing dc microgrid, office situation and sunshine situation in the College of Energy Xiamen University, this paper evaluates and calculates the typical daily load, typical daily power generation and annual power generation of photovoltaic system in Xiamen. And tests the energy efficiency under three different power supply modes under the same corresponding conditions exactly. Including (1) the only power supply of ac power grid (2) ac power grid + photovoltaic dc microgrid + distributed battery (3) photovoltaic dc microgrid + distributed battery. Finally, it is found that dc system distribution mode is indeed more efficient than ac distribution mode.

2. SYSTEM CONFIGURATION

The configuration of system bases on 8 offices in the College of Energy, each office is equipped with 1 air conditioner, 12 led lights, 4 computers and 1 ceiling fan. The three schemes according to different power supply modes are shown in Fig. 2. Four offices are used for experiment of Fig. 2(a), and the other four are used for experiment of Fig. 2(b) and Fig. 2(c). A complete distribution system mainly includes converters, LED drivers and general power supplies, etc. These devices can be modified to connect to the corresponding bus. And ac bus uses 220V, and dc bus uses 380V.

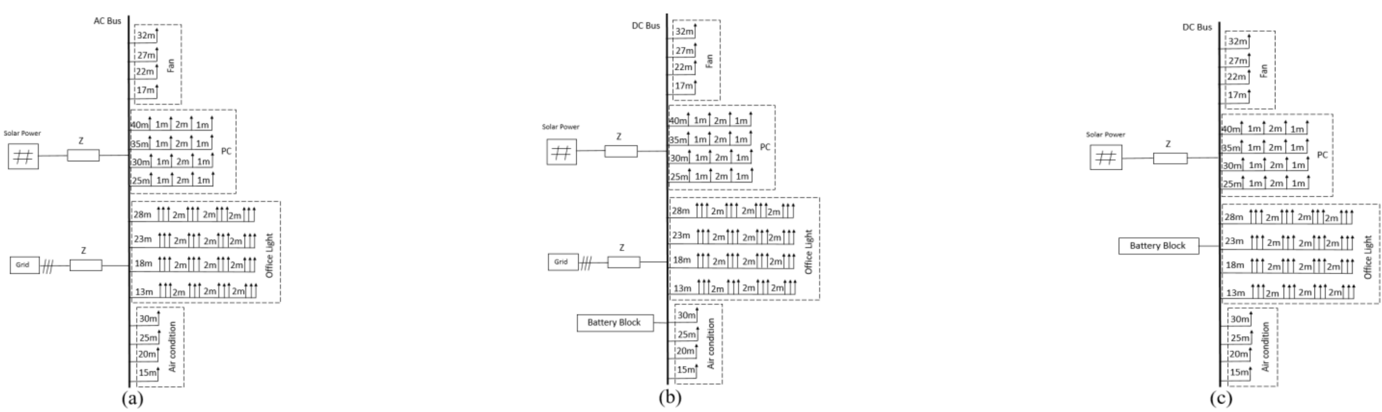

Fig. 2. (a) One-line diagram of only ac power grid (b) One-line diagram of AC grid + Photovoltaic dc microgrid + Distributed battery (c) One-line diagram of photovoltaic dc microgri + Distributed battery

In this experiment, the solar panels of photovoltaic power generation are arranged on the roof of building C (about 6 rows), College of Energy Xiamen University. The installed power is 30KW, as shown in Fig. 3 (a). The dc voltage generated by photovoltaic power generation fluctuates between 100V and 750V, and can be adjusted in the range of 380V±20V through bidirectional converter, as shown in Fig. 3 (c). The overall efficiency is 97.5%.

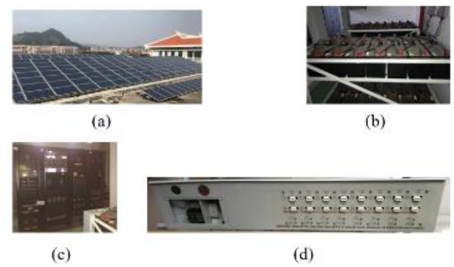

Fig. 3. (a) Photovoltaic array (b) Battery (c) Bidirectional converter (d) DC-DC converter

The bidirectional converter completes the bidirectional conversion of electric energy between ac grid and dc bus. When the photovoltaic power supply is insufficient, the converter works in rectifier state, and ac grid supplies power to dc bus and loads. When the photovoltaic power generation is in surplus, the converter works in inverter state and feeds part of the energy back to the power grid to prevent the dc bus voltage from being too high, the efficiency is 98.1%.

Batteries act as back-up for distributed energy, storing excess photovoltaic power, but also playing an important role in supplying energy when energy shortage and maintaining grid voltage balance. As shown in Fig. 3(b), 14 batteries are connected in series, and then two batteries of the same size are connected in parallel to the dc power grid through the controller, the efficiency is 91.8%. Each battery contains 6 basic units, with an output voltage of 12V and a capacity of 100Ah.

The experiment involves some low-voltage dc loads, which need reduce voltage by dc-dc to meet the requirements of load power supply. A dc-dc converter was developed to accommodate multiple loads, as shown in Fig. 3 (d), the efficiency is 98.3%. Other loads are dc air conditioners, led lights, computers and ac ceiling fans. Their power and power factor are shown in Table 1.

Table 1. Load power and Power factor

Load type	Power(W)	Power factor
Air conditioner (refrigeration)	1030	0.9
Air conditioner (heating)	1450	0.9
Led light	10	0.98
Ceiling fan	78	0.8
Computer	300	0.92

3. COMPUTATIONAL EVALUATION

In the process of experiment, typical daily load, typical daily and annual power generation of photovoltaic array in Xiamen are calculated and evaluated through test, which can be used as a reference for actual project design. According to the actual situation, our research objects are eight offices of 20m^2. Cold and heat loads refer to the use of air conditioner, the total load is the power consumption of all loads used in this experiment. Due to the influence of air conditioner, we divide the total load into summer and winter situations. The transitional season in Xiamen is similar to summer, so it is not listed separately. The data are shown in Fig. 4 (a) and (b).

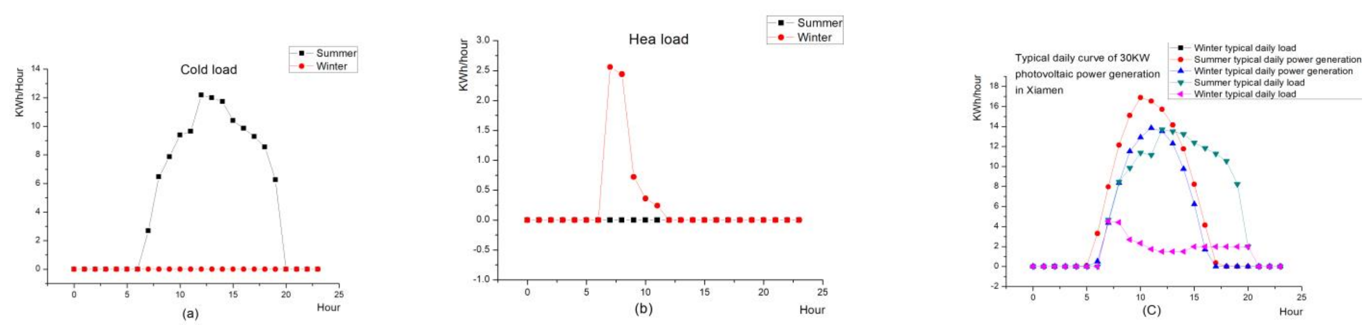

Fig. 4. Typical daily curve in Xiamen

The typical daily and annual power generation curves of 30KW photovoltaic power generation installed in the College of Energy Xiamen University are shown in Fig. 4 (c). It can be seen from Fig. 4 (c) that the photovoltaic power generation in winter is always greater than the daily load consumption, which can meet the equipment operation demand. However, in summer, photovoltaic power generation is not enough to maintain daily electricity demand, so it needs to rely on the power grid or energy storage unit for power supply. In scheme 2 and 3, the batteries with a capacity of 100AhX28 are set, they can supply 37.8KW ·h/ day, these electricity add with the summer daily generation is larger than the daily load, so it can meet the energy storage and power supply demand of the experiment. When running, the batteries can store the surplus electricity generated by photovoltaic power generation first, and then supply the power to the loads when system need. Therefore, all the three scheme can work well.

In order to compare the energy efficiency of the three schemes, we need to measure the power supply efficiency and load efficiency of offices under the same condition. Power measure use power meter, we use multiple measurements to calculate the average value to make the results more precise. Due to the sufficient power supply, the batteries in scheme 2 mostly play the role of energy storage and voltage regulation. According to the fitting curve of software simulation, solar power supply accounts for about 74.2% of the overall power supply, and other power supply is 25.8%.The intermediate link efficiency, power supply ratio and power supply side efficiency of the three schemes are shown in Table 2, and the ac/dc power supply efficiency and utilization rate of loads are shown in Table 3.

The efficiency of load can be calculated through Table 3, the calculation formula is shown in formula (1), and the results are shown in Table 4.

$$\eta_{\text{load efficiency}} = \Sigma\, \eta_{\text{power supply efficiency}} * \varepsilon_{\text{usage rate}} \qquad (1)$$

Table 2. The intermediate link efficiency, power supply ratio and power supply side efficiency

Item	Intermediate link efficiency			Power supply ratio		Power supply side efficiency
Scheme 1	photovoltaic inverter	transformer		Photovoltaic power supply ratio	Ac power supply ratio	
Summer	97.500%	98.500%		74.200%	25.800%	97.758%
Winter	97.500%	98.500%		100.000%	0.000%	97.500%
Scheme 2	Dc transform	transformer	rectifier	Photovoltaic power supply ratio	Ac power supply ratio	
Summer	98.300%	98.500%	98.120%	74.200%	25.800%	97.874%
Winter	98.300%	98.500%	98.100%	100.000%	0.000%	98.300%
Scheme 3	Dc transform	Battery		Photovoltaic power supply ratio	Battery power supply ratio	
Summer	98.300%	91.780%		74.200%	25.800%	96.618%
Winter	98.300%	91.780%		100.000%	0.000%	98.300%

Table 3. AC/DC power supply efficiency and loads usage rate

Load	Ac power supply efficiency	Dc power supply efficiency	Usage rate (summer)	Usage rate (winter)
LED light	86.712%	97.282%	3.378%	14.944%
Air conditioner	83.735%	93.120%	81.847%	19.676%
Computer	95.354%	97.305%	11.820%	65.380%

Table 4. Load efficiency

Load ac power supply efficiency (summer)	Load dc power supply efficiency (summer)	Load ac power supply efficiency (winter)	Load dc power supply efficiency (winter)
85.171%	93.315%	91.776%	96.478%

Table 5. System efficiency

Scheme	System efficiency(summer)	System efficiency(winter)
Scheme 1	83.262%	89.482%
Scheme 2	91.331%	94.838%
Scheme 3	90.159%	94.838%

Finally, we can get the efficiency of the whole system through the data in Table 2 and Table 4. The calculation formula is shown in (2) and the results are shown in Table 5.

$$\eta_{\text{system efficiency}} = \eta_{\text{power supply efficiency}} * \eta_{\text{load efficiency}} \qquad (2)$$

From Table 5, we can see the distribution efficiency of scheme 2 and 3 is similar. The efficiency of scheme 1 in summer is 8.070% and 6.898% lower than scheme 2 and 3 respectively, and 5.356% lower in winter. This shows that dc power distribution is more efficient than ac power distribution. Scheme 3 also verifies the feasibility of the island operation mode, which provides a good evidence for the ultimate realization of net zero energy building. However, in order to achieve net zero energy building, the situations of line loss, voltage drop, loads and energy storage should be considered comprehensively. Here we mainly analyse the influence of line loss and voltage drop.

In the process of power distribution, due to the different distribution of rooms, long distance routing is often required, which will result in the loss of line power inevitably. Ignore the skin effect and proximity effect of wire, the circuit is equivalent to a resistance, and the loss power can be calculated according to the formula $P=I^2R$. Refer to GB/T 3956-2008 / IEC 60228:2004 < Conductor of insulated cables> [6] , Conductor resistivity select 0.0178 Ω / m, in this experiment we select two types of wires with cross-sectional area of 1.5mm^2 and 2.5mm^2. The formula of resistance is:

$$R = \rho \frac{L}{S} \tag{3}$$

For ac power distribution or dc power distribution, we focus on the load current, voltage drop and power loss, which can be calculated by formula (4) - (6).

$$I_{ac} = \frac{P_{load}}{U_{ac}\cos\varphi} \tag{4}$$

$$\Delta U_{ac} = 2\left(R_{line}\frac{P_{load}}{U_{ac}} + X\frac{P_{load}}{U_{ac}}\tan\varphi\right) \tag{5}$$

$$Ploss(ac) = Iac^2 R = \frac{P_{load}^2}{U_{ac}^2\cos^2\varphi} \times 2 \times R_{line} \tag{6}$$

Where, P_{load} is input power, U_{ac} is input voltage, Φ power factor angle, X is line reactance, R_{line} is line resistance.

For dc power supply, we can also get load current, voltage drop and power loss through formulas (7) - (9):

$$I_{dc} = \frac{P_{load}}{U_{dc}} \tag{7}$$

$$\Delta U_{dc} = 2R\frac{P_{load}}{U_{dc}} \tag{8}$$

$$Ploss(dc) = I_{dc}^2 R = \frac{P_{load}^2}{U_{ac}^2} \times 2 \times R_{line} \tag{9}$$

Where, P_{load} is input power, U_{ac} is input voltage, R_{line} is line resistance.

The efficiency loss and voltage drop of each load can be obtained through the arrangement of formula (3) - (9), as shown in Table 6. Finally, we can get the system efficiency and efficiency loss of each scheme, as shown in Table 7.

Table 6. Load efficiency loss and Voltage drop

Load	Efficiency loss of ac	Efficiency loss of dc	Voltage drop of ac power supply(V)	Voltage drop of dc power supply(V)
LED light	4.43%	4.26%	2.744	2.671
Air conditioner	7.41%	6.09%	9.626	6.804
Computer	7.52%	6.44%	7.538	6.880
Ceiling fan	1.37%	0.88%	1.188	0.926

Table. 7 System efficiency and efficiency loss (considering line loss)

Scheme	System efficiency(summer)	System efficiency(winter)	System efficiency loss(summer)	System efficiency(winter)
Scheme 1	77.311%	83.163%	5.951%	6.319%
Scheme2	85.910%	89.107%	5.421%	5.731%
Scheme 3	84.808%	89.107%	5.352%	5.731%

From Table 7, we can see the distribution efficiency of scheme 2 and 3 is similar too. The efficiency of scheme 1 in summer is 8.599% and 7.497% lower than scheme 2 and scheme 3 respectively, and 5.944% lower in winter. Dc power distribution is still more efficient than ac power distribution. We also can find that line loss have a significant impact on the efficiency of the system obviously, on the other hand, we also need to pay attention to the voltage drop on the power supply system. Many devices have certain working voltage. If the voltage drop generated by the circuit is too large, the device may not work properly. The study in [3] points out that in power distribution, when the voltage loss exceeds 5%, the transmission efficiency will be greatly reduced. By checking against the table, we know the maximum current of 1.5mm^2 and 2.5mm^2 can thought are 14.5A and 22.5A respectively. We limit the maximum power according to two formulas, one is the limit of wire current, the other one is the limit of 5% voltage drop, the calculation formulas are as follows:

$$P_{1\max} = I_{max} U_{dc} \tag{10}$$

$$P_{2\max} = \frac{0.05 \times S \times U_{dc}^2}{2 \times \rho \times L} \tag{11}$$

Through formula (10) and (11), we can calculate the maximum distance of 1.5mm^2 and 2.5mm^2 cable transmission at the supply voltage of 380V is 55.2m and 59.3m respectively. Therefore, we must pay attention to the length of the cable when wiring, in case the device doesn't work.

4. CONCLUSION

This paper presents the comparative analysis experiment of energy efficiency under three different power supply modes carried out by the College of Energy Xiamen University. The efficiency comparison results of the three schemes are as follows: consider the line loss or not, the energy efficiency of scheme 2 and scheme 3 are similar and higher than scheme 1. According to the ratio of summer and winter weather in Xiamen is about 3:1, we can conclude that the efficiency of dc power distribution mode can improve by 6.5-7.9% compared with the ac power distribution mode. For dc power distribution, the influence of voltage drop must be considered. Once the voltage drop exceeds 5%, it is likely that the equipment cannot be used normally.

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