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Performance Analysis of Data Centers Applying Hybrid Renewable Energy Power Systems

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ABSTRACT

Considering the current goal of energy-intensive industries such as data centers is mainly to reduce greenhouse gas emissions, a great effort is made to achieve sustainable operations by using renewable energy generation to meet power consumption. This paper proposes a hybrid power system based on a combination of a natural gas turbine, photovoltaic, wind energy, and battery storage, using a data center in Tianjin of China as a model. Technical and economic analyses are performed for each system configuration by comparing the renewable penetration and the Levelized Cost of Electricity. Taking into account renewable penetration and cost, the various types are ranked from best to worst as PV-wind-battery; PV-wind; PV only; and wind only. The results show that the larger the PV-rated power, the higher the renewable penetration. When considering using wind energy, 1,000 kW is the best solution. When battery storage is used, 3,000 kWh is optimal.

Keywords: Distributed Energy System; Renewable Energy; Data Center; Renewable Penetration; Levelized Cost of Electricity

1. INTRODUCTION

With the development of digital technologies such as artificial intelligence and blockchain, human society has started to enter the era of big data and the digital economy. As the physical foundation for realizing emerging digital technologies, the data center industry is developing rapidly, undertaking the functions of acquiring and storing, analyzing and processing, transmitting and exchanging various data. Due to its 24-hour operating nature, its energy consumption is much higher than general building. According to statistics, global data centers currently consume about 1.1-1.3% of the total electricity consumption. The energy consumption of a data center already accounts for 50 % of its operating costs. The most important issue facing data center development today is high energy consumption. Its energy-consuming equipment is generally including IT equipment, cooling system, and power supply and distribution system.

The cooling method of the data center consists of air cooling and liquid cooling. In the data center liquid cooling field, Li[1] et al. studied different placement strategies for liquid-cooled servers and found that has an impact on energy consumption. Thus, an intelligent placement algorithm named SmartPlace is proposed and its effectiveness is demonstrated. In addition, many scholars have conducted research in the field of air cooling. Yong-II Kwon[2] evaluated the performance of air-cooled data centers with different ventilation types and the results show that the ventilation system exhaust speed has a significant impact on energy consumption. On the premise of ensuring the stability and security of data centers, the rational planning and design of data center power supply and distribution systems, reducing power losses[3] and power carbon emissions have become the focus of researchers' attention. Xuehui Liu[4] et al. use natural gas as the energy supply, a data center energy scheduling model is constructed, and the results show that natural gas as a supplementary energy supply can effectively reduce the overall energy consumption of the data center. Soongeol Kwon[5] mainly concentrates on how to promote renewable energy utilization for data center operations considering the combination of solar power generation and battery energy storage.

Studies that have been conducted are mostly from the perspective of reducing energy consumption, and few people have studied energy supply systems at a level that ensures normal data center operations. There have been studies to apply renewable energy power systems to community buildings[6], isolated islands[7], rural residences[8], etc., while few relevant studies for data centers. Only a few studies have been conducted to configure hybrid power systems for data centers and compared the distinction between different types of renewable energy sources applied to data centers. Few articles quantify how data center costs and energy consumption change as the capacity of different energy types changes. Therefore, this paper proposes a distributed renewable energy system for data centers, configuring a natural gas (NG) turbine, photovoltaic power generation, wind power generation, and battery storage to meet the load requirements of data centers, using renewable energy instead of traditional energy to supply power to data centers, reducing carbon emissions and gradually realizing a green data center.

2. SYSTEM MODE

2.1 Mathematical models

Energy system modeling and simulation were based on OptiCE[9] with objective functions consisting mainly of renewable penetration (*RP*) and the Levelized cost of electricity (*LCOE*).

RP is one of the most important factors in a hybrid power system, which is defined as follows:

$$RP = \frac{H_{SL}}{8760} \times 100\%$$

where H_{SL} is the number of hours in a year that the load is met by renewable distributed energy (h).

The LCOE is defined as follows:

$$LCOE = \frac{LCC}{\sum_{n=0}^{N} \frac{Q_n (1-\delta)^n}{(1+d)^n}}$$

where *LCC* is the lifecycle cost of a project (US$); *N* is the lifetime of the project (year); Q_n is the annual production generated in year *n* (kWh), which is taken as 25 years in this case; δ is the degradation rate (%), which is taken as 1%; *d* is the depreciation rate (%), which is taken as 6.8%. Surplus energy is not considered in this study.

2.2 Parameter settings

The Meteonorm[10] was used to retrieve the corresponding meteorological parameters in Tianjin of China, such as the hourly values of the wind speed, global horizontal radiation, and diffuse horizontal radiation. The hourly values of the data center selected in this study are shown in Fig.1. The load on the data center varies due to the amount of data and information stored and the needs of the users, with a maximum of 335 kW. According to this value, an NG turbine with a power of 400 kW was used in the study. The characteristic parameters of the PV modules and wind turbines used in the distributed energy system are listed in Tables 1 and 2. Considering the available area of the data center and the installation conditions of the renewable energy equipment, the PV-rated power was limited to 800 kW. Taking into account the urban landscape where the data center is located and the wind energy potential to avoid negative visual impact from the installation of wind turbines, 200, 500, 750, and 1,000 kW wind turbines have been configured for the system. When the wind-rated power is 1,000 kW, it can be achieved by using two Norwin 47-ASR-500 kW model wind turbines. In addition, battery capacity in the range of 0-6,000 kWh was considered for the configuration. Finally, the parameters relevant to the economic analysis of the system was listed in Table 3.

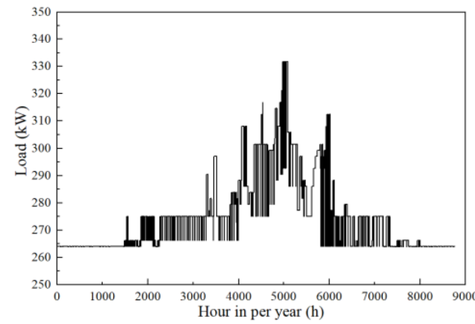

Fig. 1. Hourly values of load for a typical data center

Table 1 Feature parameters of photovoltaic modules[11]

Parameter	Value	Unit
Maximum module power	250	W
Efficiency	15.3	%
Module dimensions	990×1650	mm^2
Temperature coefficient of the output power	-0.06	%/℃
Standard test conditions temperature	25	℃
Nominal operating cell temperature	45	℃

3. SIMULATION RESULTS

This study presents simulations for three different renewable energy configurations: 1) only photovoltaic power; 2) only wind power; 3) combining photovoltaic and wind power. All of the above systems are considered to be configured with different battery capacities for energy storage.

3.1 Parametric analysis of system configurations with different PV-rated power

Fig.2 shows the trend of RP with PV-rated power, which varies from 0 to 800 kW. In general, without battery capacity, RP only reaches about 20%. With an increase in battery capacity, RP increases to 32%. It can be seen that the battery capacity has little effect on the RP when the PV-rated power is low, and only when it exceeds 400 kW does the RP change significantly with the battery capacity. And when battery capacity exceeds 1,000 kWh, the change in RP with increasing battery capacity is not significant.

Table 2 Feature parameters of wind turbines[12]

Parameter		Value		Unit
Series	Norwin 29-Stall-200kW	Norwin 47-ASR-500kW	Norwin 54-ASR-750kW	
Nominal power	200	500	750	kW
Cut-in wind speed	4	3	3	m/s
Cut-out wind speed	25	25	20	m/s
Rated wind speed	14	12	13	m/s
Hub height	30	50	50	m
Swept area	664	1735	2290	m^2
Wind turbine efficiency	76	76	76	%

Table 3 Main economic parameters of hybrid power system

Project	Specific initial costs	Lifetime	Operation and maintenance costs
PV power system	1.05[US$/W][13]	25 y	2% of initial costs
Wind power system	1.45[US$/W] [13]	25 y	4% of initial costs
Battery	0.50[US$/Wh] [14,15]	8 y	6% of initial costs
Inverter	0.10[US$/W]	10 y	
NG turbine	0.58[US$/W]	10 y	13% of initial costs

To find out about the economic efficiency and costs of the system, the LCOE is also analyzed in this study, and the trend of LCOE with PV-rated power is given in Fig.3. It can be seen visually that the LCOE changes very little with the change in PV-rated power. As the battery capacity grows in equal amounts from 0 to 6,000 kWh, the LCOE also keeps growing in equal amounts. With each 1,000 kWh increase in battery capacity, the cost increases about by 0.06 $.

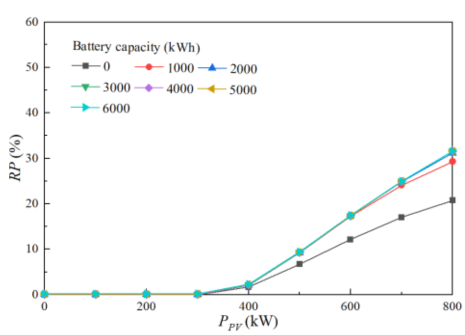

Fig. 2. RP of single solar renewable power system

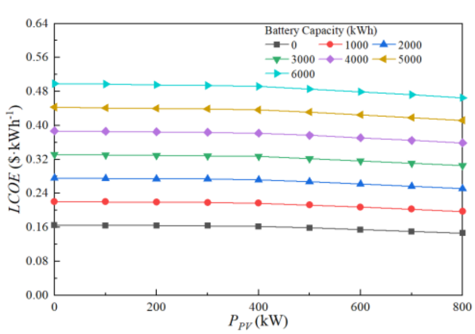

Fig. 3. LCOE of single solar renewable power system

3.2 Parametric analysis of system configurations with different wind-rated power

Due to atmospheric conditions, wind power is less stable than photovoltaic power. Fig.4 shows the trend of RP with wind-rated power. With a battery capacity of 0 and an increase in wind-rated power to 1,000 kW, the maximum RP is only 7%. As battery capacity increases, so does RP. However, when the battery capacity exceeds 1,000 kWh, the impact of battery capacity on RP can be negligible. Furthermore, even when equipped with a battery capacity of up to 6,000 kWh, the RP is still below 15%. These results show wind power lacks the ability to penetrate compared to photovoltaic power. With this hybrid power system, the LCOE is calculated and shown in Fig.5. It can be concluded that the LCOE increases rapidly with increasing battery capacity. For both PV-only and wind-only scenarios, system costs are essentially equivalent. However, for wind-only case, LCOE increases with wind-rated power increasing.

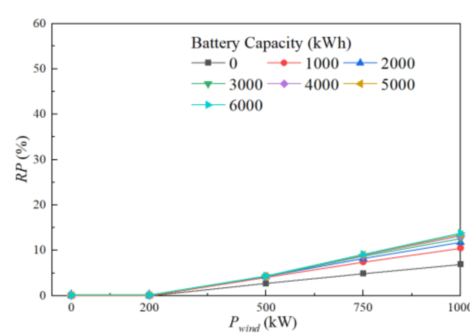

Fig. 4. RP of single wind renewable power system

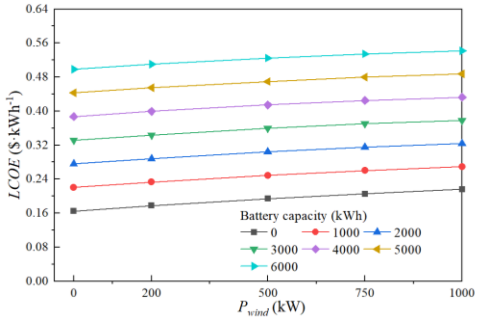

Fig. 5. LCOE of single solar renewable power system

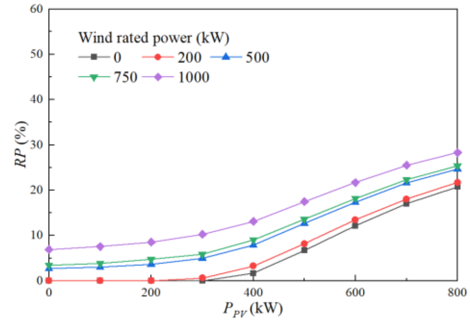

Fig. 6 RP of the hybrid power system(pv+wind)

3.3 Parametric analysis of system configurations with different hybrid power

For the system configuration with PV and wind generation, Fig.6 shows the trend of RP with PV and wind-rated power. It can be seen that RP increases with the increase of wind-rated power and PV-rated power. It starts to grow significantly when the PV-rated power exceeds 400 kW. The difference between the RP data for the wind-rate power selection of 200 kW and the PV-only case is not significant, and the same is true for the wind-rated power selection of 500 kW and 750 kW cases. The infiltration effect is better than in other cases when the wind-rated power is 1,000 kW. For this hybrid system, the trend of LCOE variation is shown in Fig.7. LCOE remains essentially constant with increasing PV-rated power and increases with increasing wind-rated power. Since the change of LCOE is not obvious with the increase of wind-rated power, but the RP increases significantly, it is recommended to choose the wind-rated power of 1,000 kW for simulation analysis when further combined with the battery.

According to the former analysis, the wind-rated power of 1,000 kW is the best selected for the PV-Wind hybrid power system. When the battery is taken, Fig.8 shows the trend of RP with PV-rated power and battery capacity in the tri-hybrid system. The RP increases with the increase of battery capacity, and when the battery capacity increases to 3,000 kWh, the change of RP with the increase of battery capacity is not obvious. Fig.9 shows the trend of LCOE in the tri-hybrid system. It is obvious that the cost increases when the system is equipped with battery energy storage. However, the LCOE does not change significantly with the increase in PV-rated power and remains basically the same. With each 1,000 kWh increase in battery capacity, the cost increases about by 0.06 $. It is the selection of the right battery capacity that has a significant impact on system cost.

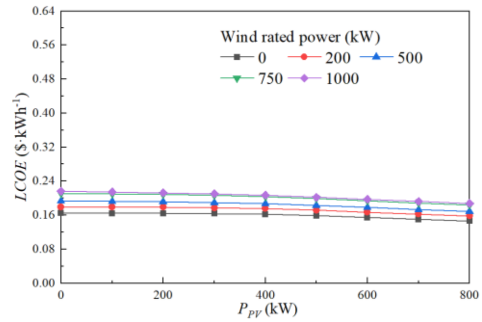

Fig. 7. LCOE of the hybrid power system(pv+wind)

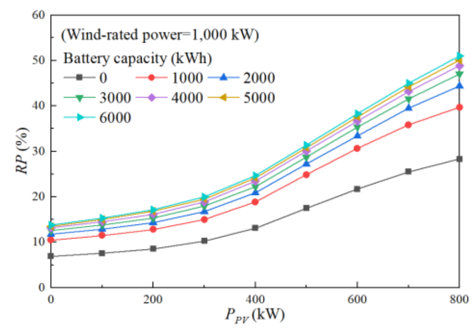

Fig. 8. RP of the hybrid power system(wind-rated power is 1,000 kW)

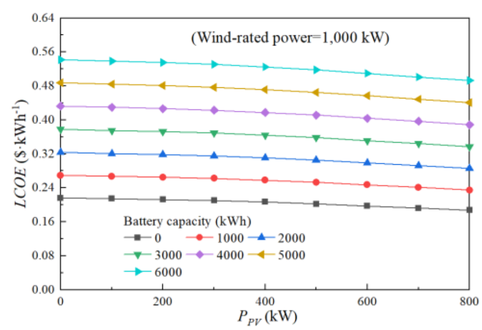

Fig. 9. LCOE of the hybrid power system (wind-rated power is 1,000 kW)

4. CONCLUSION

This study proposed a hybrid energy system for a data center and quantitatively analyzed how the technology and costs of the different systems changes with the change in energy capacity. Although a specific case study was used in this work, the model and methodology developed in this study can be replicated. The main findings of this study are summarized as follows:

(1) Using renewable energy and battery capacity as independent variables, their effects on RP and LCOE metrics of different systems were investigated. When using the PV-only system RP is up to 32% and the LCOE is 0.48 $/kWh at this time. When the energy configuration is wind only, the maximum RP is 14% and the penetration performance is poor, at which point the LCOE is 0.54 $/kWh. When the PV-wind system is used, the RP is 28% at maximum, and the cost is 0.22 $/kWh at this time. When the battery capacity is considered together, the maximum achievable RP for the tri-hybrid system is 50%, with the LCOE of 0.5 $/kWh.

(2) The performance differences between different multi-energy complementary systems were analyzed and compared under the conditions of using different system energy configurations. When the PV-rated power is less than 400 kW, the RP is small. The higher the PV and wind-rated power the better the RP and LCOE results of the system. The RP increases with battery capacity. When the battery capacity is increased to 1000 kWh there is less impact on the LCOE of PV only and wind only. When it increases to 3000 kWh it has little impact on the LCOE of the tri-hybrid system. PV-rated power has little effect on the change in LCOE. But the LCOE increases with wind-rated power and battery capacity. And with each 1,000 kWh increase in battery capacity, the cost increases about by 0.06 $.

(3) The design of the hybrid energy supply system can provide an effective reference for the actual operation of other data centers in Tianjin. The tri-hybrid system is the most recommended of all system configurations, while the wind-only system is the worst. When PV is considered in the system, it is recommended that use the maximum possible PV capacity. The rated wind power of 1000 kW is the best when the noise from wind power is acceptable at this time. It is recommended to use a battery of 3000 kWh when battery storage is considered for energy allocation.

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