Integrated wind energy storage microgrid stability research

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Abstract. With the ongoing advancement of new energy microgrid systems,the structure of microgrid systems is progressively evolving towards complexity and multi-functionality. The incorporation of new power electronic devices has brought forth new challenges to the stability of microgrid operation. This paper investigates the stability of the wind-storage-charging integrated microgrid. Through the simulation analysis of the impacts of minor and major disturbances on this microgrid,it is affirmed that the wind-storage-charging integrated system possesses certain static and dynamic stability attributes,offering theoretical backing for the subsequent research on new energy systems.

Keywords: microgrid system; wind-solar energy storage integration; small disturbance stability analysis; large disturbance stability analysis.

1. Introduction

With the advancement of the countrys carbon neutrality goals, new energy power generation systems are gradually becoming an important part of the power generation system. However, new energy power generation has uncertainty in power output, and charging piles, as power electronic devices, inevitably generate harmonic interference[1].The coordination degree of various modules in the microgrid system and other issues. These problems will pose challenges to the stable operation of the microgrid system. Because of these unstable factors,the integrated wind-storage-charging microgrid system is of great significance for the efficient utilization of new energy and the stable operation of the power system because it studies the stability of the integrated system including wind turbines, energy storage units, and charging piles under small disturbances and transient conditions[2].

2. Structure of wind storage and charging integrated microgrid system

2.1 General structure

The wind-charging integrated microgrid structure is shown in Figure 1, which consists of direct-drive wind turbines, energy storage units, charging piles and large power grids. Wind turbine is controlled by maximum power point tracking (MPPT). The energy storage unit realizes bidirectional charging and discharging through bidirectional DC/DC converter. Dc charging pile adopts CLLC bidirectional converter. The bidirectional charging pile can not only charge electric vehicles, but also serve as an energy storage unit when necessary to realize the bidirectional flow of electricity and further enhance the flexibility and adjustment ability of the microgrid [3].

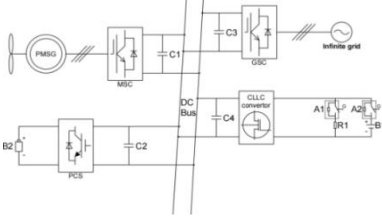

Figure. 1 Structure diagram of wind storage and charging integrated microgrid system

In the figure, A1 and A2 are controllable switches, R1 is the analog load, B1 is a DC voltage source, B2 is a storage battery, and C1, C2, C3, and C4 are filter capacitors.

2.2 Wind turbine model construction

This paper selects direct drive wind turbine is selected. The structure of direct drive wind turbine is relatively simple, which reduces the risk of failure caused by complex structure [4] .The basic principle of wind turbine is that when the wind blows over the blade surface, the airflow speed changes, thus generating the force to promote the rotation of the blade.mathematical modeling of the fan system is crucial, and according to aerodynamic principles, the wind energy captured by the fan can be expressed by the following formula:

$$\begin{cases} P_m = \frac{1}{2} C_p(\lambda, \beta) \rho \pi R^2 V^3 \\ \lambda = \frac{\omega R}{V} \end{cases}$$

In the formula, Cp(λ , β) is the power coefficient of the fan, ρ is the air density, R is the radius of the wind turbine, and ω is the rotational speed of the wind turbine. The power coefficient Cp is maximized when the optimal blade tip speed ratio λ_{opt} is achieved, expressed as:

$$\mathrm{P_{mmax}} = \frac{1}{2} \rho \pi \mathrm{R}^5 \frac{\mathrm{C_{pmax}}}{\lambda_{\mathrm{opt}}{}^{3^3}}$$

The optimal blade tip speed ratio is shown in Figure 2, with the pink dashed line indicating the maximum wind energy capture for a fan at different wind speeds under λ =8 conditions for the optimal blade tip speed ratio Cp. As can be seen from the above equation, when the wind turbine blades have a fixed pitch angle and the optimal blade tip speed ratio is ensured, the wind energy utilization coefficient is maximized and becomes a constant value, at which point the maximum power input of the fan is proportional to the cube of the wind speed.

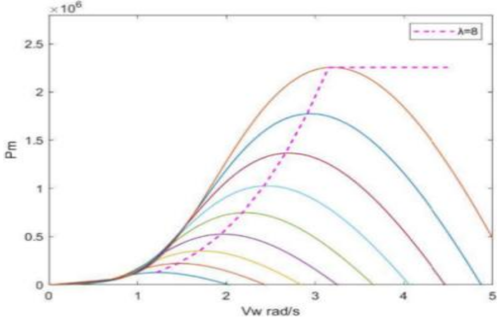

Figure. 2 Fan characteristics under different wind speed conditions

Power obtained by wind turbines from wind energy:

$$P_w = T_w \omega_w$$

The mathematical model of wind turbine system is as follows:

$$\frac{d\omega_r}{dt} = \frac{T_e - T_w - B_m \omega_r}{J}$$

In the formula, ω_r is the rotor speed of the generator; Te is the electromagnetic torque; B_m is the equivalent moment of inertia; J is the rotational viscosity coefficient.

According to the above formula, the model of direct drive wind turbine can be built by using MATLAB/Simulink.

2.3 Energy storage unit modeling

There is uncertainty in wind power generation due to uneven wind speeds, so battery energy storage units are added to the microgrid to supplement or absorb fluctuating power on the bus. A non-isolated Buck/Boost converter with simpler control circuits and higher efficiency was selected. In the boost mode, the electric energy flows from the battery to the DC bus to maintain a stable DC power level. In buck mode, the energy storage unit absorbs excess active power. The control unit uses a double loop to control voltage and current [5]. When the power supply on the DC side of the bus is unbalanced, the converter will control the bus voltage according to the difference between the set value and the actual bus voltage.

2.4 Charging pile module construction

Charging piles must consider minimizing the impact on the electrical equipment connected to them in the event of a grid failure, so isolated CLLC bidirectional converters with electrical isolation characteristics are used. When the CLLC converter works in forward mode, the converter realizes forward transmission by controlling the frequency of the switching device. The working principle of the reverse mode is similar to that of the forward mode, but the switching frequency of the switching devices on both sides is changed to achieve the reverse power transmission.

2.5 Wind-storage-charging microgrid model

The wind-storage-charging microgrid model composed of the above-mentioned wind turbine generator units, energy storage units and charging pile modules is shown in Figure 3. This model achieves optimal control through back-to-back PWM converters[6].

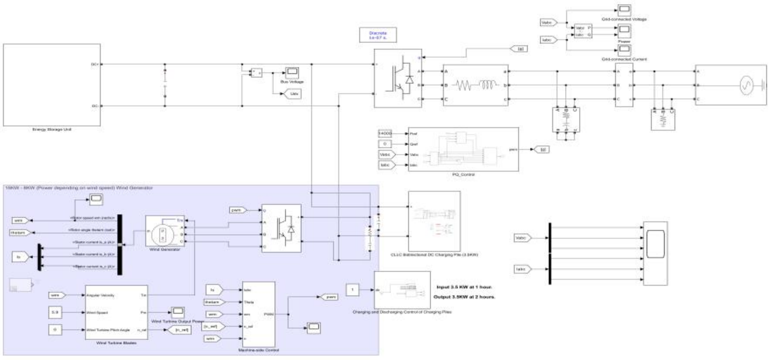

Figure.3 Wind Storage Charging Integrated Microgrid Modeling Model

3. Analysis of stability of wind storage and charging integrated microgrid

3.1 Factors affecting the stability of microgrid

3.1.1 Wind turbine output power fluctuation

Due to the fact that wind turbines derive their energy from renewable wind power, the randomness and intermittency of wind energy can lead to frequent adjustments of rotor speed in wind turbines, resulting in significant fluctuations in power output. The fluctuation in power can directly affect the bus voltage level of the microgrid, thereby impacting the power quality and stability of the power system[7].

3.1.2 The coordination of each module in the microgrid system

Because there are many power electronic converters in the system, and the control mode adopted by the converter is different. Therefore, the previous mutual coordination is particularly important.

3.2 Microgrid simulation parameters

In order to verify the stability of the wind storage and charging integrated microgrid, the MATLAB/simulink software was used to build it. The parameters are shown in Table 1.

Table 1.Simulation parameters

Parameter	Value and unit
Busbar voltage	400V
Target power for grid connection	12kW

Accumulator voltage	240V
Accumulator capacity	20A·h
Charging pile load	3.5kW

After the above model is built, the operating state of the system under simulated small and large disturbances is tested.

3.3 Small interference stability analysis

The sudden change in wind speed makes wind power generation systems frequently susceptible to disturbances caused by small perturbations, thus the stability study of wind-storage-charging integrated microgrids when encountering sudden changes in wind speed is particularly important. Using a step signal module to simulate the sudden change in wind speed at a certain moment, the stability of the microgrid is analyzed by observing the bus voltage fluctuations after the sudden change in wind speed. As shown in Table 2, the wind speed suddenly changes from 7.6m/s to 5.9m/s at 1.5s, during which the output of the wind turbine decreases, and the power output from the machine-side converter does not meet the grid-connected set power, with the missing power being provided by the energy storage unit.

Table 2.Power variation during sudden change of wind speed

Wind speed	Wind turbine power
7.6m/s	15kW
5.9m/s	8kW

The voltage waveform of the DC bus after small interference disturbance is shown in Figure 4.

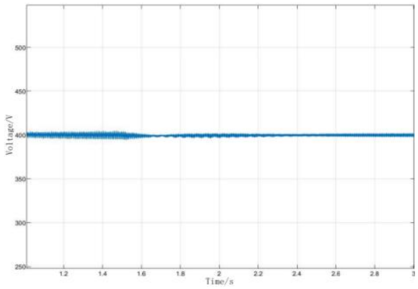

Figure.4 DC bus voltage waveform under small interference condition

As shown in Figure 4, the DC bus voltage will undergo a certain adjustment and then converge again under sudden wind speed changes, demonstrating that the wind-storage-charging integrated microgrid established in this paper has strong adjustment capability when encountering small disturbances. The energy storage units play a crucial role in the system when encountering small disturbances, serving to suppress peak and valley DC voltage levels, ensuring the stable operation of the DC microgrid and confirming the static stability performance of this integrated microgrid.

3.4 Transient stability analysis

Transient analysis mainly analyzes the dynamic stability performance of the system when it is subjected to large disturbances[8].Setting the wind speed to a constant value to simulate the transient stability of an integrated microgrid with wind and storage without receiving small disturbances but encountering large disturbances. The severe three-phase ground short-circuit fault at the grid connection point occurs when the 1.5s-2.5s, thus observing the fluctuation level of the DC bus voltage under large disturbances to analyze the transient stability of the microgrid system when encountering large disturbances.

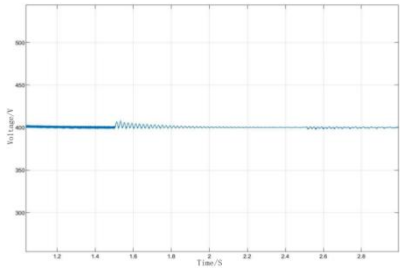

Figure. 5 DC bus voltage waveform under large interference condition

The simulation waveform is shown in Figure 5.When the connection point enters a severe three-phase-to-ground short-circuit fault, the DC bus voltage begins to show regular fluctuations and eventually tends to stabilize. The most intense moment of bus voltage fluctuation occurs at the instant when the grid connection point enters fault at 1.5s, but the fluctuation amplitude is not significant, having a minor impact on the power equipment connected to the system. The results show that the microgrid system has good transient stability and the ability to automatically restore to the predetermined operating state when encountering large disturbances.

4. Conclusion

In summary, as a promising new energy microgrid system with broad prospects for the future, conducting stability analysis of wind-storage-charging integrated microgrids has certain practical significance. Through simulation analysis, the dynamic stability performance of the wind-storage-charging integrated microgrid system built in this paper under common small disturbances, as well as the transient stability during major faults at the grid connection point, have been determined. The microgrid system did not exhibit spontaneous oscillations or asynchronous slip after experiencing small or large disturbances, confirming the high degree of integration among units in the system. The stability analysis of wind-storage-charging integrated microgrids provided in this paper offers practical reference value for future research on new energy microgrid systems[9].

References

[1] Yan Xiaomeng, Wang Peng, Wang Wei, et al. Study on the Adaptability of Electric Vehicle Charging Facilities to Power System [J]. Power Equipment Management, 2024, (17):179-181.

[2] Huang Xueliang, Liu Yongdong, Shen Fei et al. Interaction between Electric Vehicles and Power Grid: Review and Outlook [J]. Power System Automation, 2024,48(07):3-23.

[3] Wei Huang, CLLC Resonant Bidirectional Vehicle Charging DC-DC Converter Modeling and Design [D]. China University of Mining and Technology, 2022.

[4] Ma Wei and Bao Guangqing. Modeling and simulation of permanent magnet direct drive wind turbine [J]. Automation of Industry and Mining, 2010,36(08):49-53.

[5] Sun Sinan, Hao Zhenghang. Research on Battery Grid Connection Based on Dual Loop Control of Voltage and Current [J]. Electronic Science and Technology, 2023,36(02):13-21.DOI:10.16180/j.cnki.issn1007-7820.2023.02.003.

[6] Zhang Zhiming. Research on Converter Control of Permanent Magnet Direct-Drive Synchronous Wind Generator [D]. Northeast Petroleum University, 2018.

[7] Huang Zhichao. Research on Stability and Control Strategy of New Energy Microgrid [J]. Light Source and Lighting, 2024(03):219-221.

[8] Zhao Zhuoli, Yang Ping, Xu Zhirong, et al. Review on the Study of Transient Stability of Multi-source and Multi-transformer Microgrid under Large Disturbance [J]. Grid Technology, 2017,41(07):2195-2204.DOI:10.13335/j.1000-3673.pst. 2016.2557.

[9] He Fang. Exploration of the intrinsic potential of new energy industry development based on low-carbon economy [J]. Energy Storage Science and Technology, 2023,12(11):3583-3584.