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Research on frequency modulation application of flywheel energy storage system in wind power generation

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Abstract

Wind energy, characterized by randomness and intermittensity, leads to the grid-connection problem of wind power generation system, which makes the utilization rate of wind power extremely limited. Flywheel energy storage, as one of the energy storage technologies, has the characteristics of quick response ability, long life and no pollution, etc. It is especially suitable for solving the limitation of wind power consumption capacity when wind power is connected to the grid, improving the utilization rate of wind power in the power grid, especially in the wind farm, it can show the extraordinary primary frequency modulation ability. This paper mainly introduces the background of wind power generation frequency modulation demand, the main structure and principle of energy storage flywheel system and the application of energy storage flywheel system in wind power generation frequency modulation.

Keywords

Energy storage flywheel; Wind power generation; FM. Application; research.

1. Introduction

With the rapid development of renewable energy in China, the phenomenon of abandoning wind, light and water is getting worse. According to the survey, the amount of abandoned wind power nationwide only reached 49.7 billion KWH in 2016, mainly concentrated in less-developed regions such as Gansu, Inner Mongolia and Xinjiang. This has caused huge losses and negative effects on the utilization of renewable energy in China. Faced with the increasingly severe problem of wind power consumption, the abandonment of light and wind has gradually eased since 2019 under the national multi-party organization and coordination, but there is still a long way to go to increase the flexibility and schedulability of the power system in the long run. In addition to the limited local consumption capacity, the time of renewable power generation resources and the difficulty of power grid power delivery, a common reason leading to the abandonment of a large number of renewable energy sources is the limited peak and frequency modulation capacity of power sources.

Wind farms in China are generally built in regions far away from load centers, and large-scale centralized development is usually adopted in development mode. However, the construction period of transmission grid is usually longer than that of wind farm, so the synchronicity of network source construction will limit transmission line capacity. When the running state of the system cannot meet the regulation demand of wind power, the traditional solution is wind abandoning and power limiting in order to maintain the stability of the system operation, which causes a great waste of energy. At present, the wide application of doubly-fed fan can relieve the peak and frequency modulation pressure of the system. However, limited by the

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characteristics of the fan itself, its regulation ability is restricted by wind speed, and in some cases, it can not fully meet the requirements of the system's frequency regulation ability. Therefore, energy storage technology can be used in the system's frequency regulation process to participate in the work of frequency regulation. Energy storage technology can not only smooth the fluctuation of wind farm output, reduce the problem of wind abandoning caused by wind farm output not meeting system requirements, but also further reduce the pressure faced by peak and frequency modulation of the power grid [1]. Current energy storage methods can be divided into electrochemical energy storage, electromagnetic energy storage and mechanical energy storage. Table 1 compares several common energy storage modes in the current industrial field.

Table 1 Comparison of characteristics of various energy storage modes

Energy storage category	Specific power（W/kg）	Energy density（Wh/kg）	Charging speed	cycle index	environmental implication
Lead-acid Cell	150-200	30-40	Slow	500-700	Maximum
NI-MH battery	160-230	50-60	Fast	>2000	Larger
Lithium battery	>200	>102	Fast	>500	Smaller
Super capacitor	>104	5-10	Slower	>105	Larger
Energy storage flywheel	103-104	20-30	Faster	>10年	Minimum

Different energy storage methods have their own advantages and disadvantages. Table 1 compares various characteristics of various energy storage modes. The table shows that although chemical batteries are widely used because of their advantages of small size and low cost, they also have disadvantages such as small power and less cycle times. Especially, lead-acid batteries do great harm to the environment, so their application is limited. Ultra capacitor energy storage batteries have high specific power and many cycles, but their disadvantages are high cost, and the energy storage density is difficult to increase due to the limitations of volume and process. The flywheel energy storage battery system has the advantages of long life, high absolute energy density and power density, high charging and discharging efficiency, strong adaptability, fast start-up speed, no pollution, low maintenance cost and modularization, which is bringing a revolution to energy storage and showing a broader development prospect of green energy storage technology.

2. Flywheel storage battery system

Flywheel energy storage battery systems are a very old technology, but they have gained new life thanks to recent developments in rotary motors, including non-contact magnetic bearings and permanent magnet motors/generators using new strong magnetic materials (NdFeB and SmCo). The flywheel energy storage battery system is mainly composed of an electric/generator and its controller, flywheel body, various magnetic bearings and mechanical components, and vacuum device, etc. The system model of a flywheel energy storage product is shown in Figure 1. The flywheel energy storage battery system stores the electrical energy in the flywheel rotor at high speed, and realizes the conversion between electrical energy and

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mechanical energy by the flywheel speed up and down. Its working principle block diagram is shown in Figure 2. During charging, the energy provided by the power grid drives the flywheel to run at a high speed through power electronic devices to complete the conversion of electric energy to kinetic energy of the flywheel. Keep the flywheel at a constant speed, reduce the speed when discharging, determine the discharge depth according to the requirements of the load, and then convert the kinetic energy of the flywheel into electrical energy to provide the load.

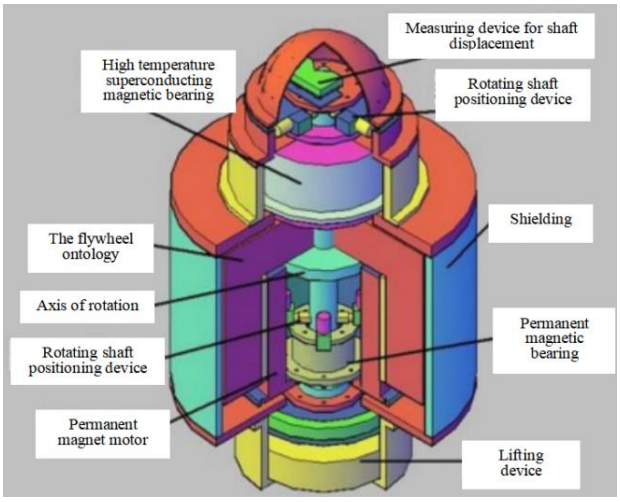

FIG. 1 Flywheel energy storage battery system model structure diagram

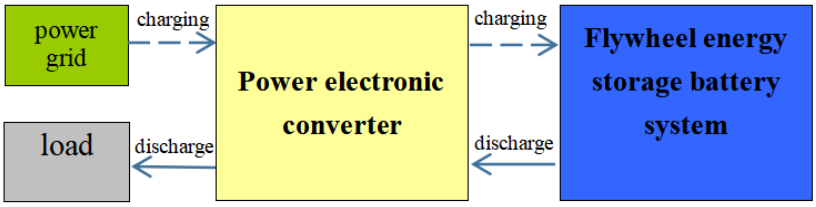

FIG. 2 Working principle of flywheel energy storage battery system

The energy stored in the flywheel energy storage battery system, namely the kinetic energy in the flywheel rotor, mainly depends on the rotational inertia and angular velocity of the rotor, as shown in Equation (1).

$$E = \frac{1}{2} I\omega^2 \tag{1}$$

Where E is the kinetic energy stored in the flywheel rotor, I is the moment of inertia of the rotor, and$\omega$is the angular velocity of the rotor. Another important factor to measure the flywheel energy storage battery system is the maximum energy density E_{sp}, which mainly depends on the tensile strength of the rotor material, rotor density and rotor shape of the flywheel energy storage battery system, which can be expressed in Formula (2).

$$E_{\mathrm{sp}} = K_{\mathrm{s}} \frac{\sigma_{\mathrm{m}}}{\rho} \tag{2}$$

Where, σ_m is the maximum tensile strength of rotor material in the motor/generator of the flywheel energy storage battery system, ρ is the density of rotor material in the motor/generator of the flywheel energy storage battery system, K_s is the rotor shape factor in the motor/generator of the flywheel energy storage battery system. Therefore, the energy storage capacity of flywheel energy storage battery is closely related to its rotor quality, speed and shape. At present, there are two kinds of rotor materials of flywheel energy storage battery, namely high-strength steel rotor and composite carbon fiber material. In theory, fibre-composite flywheels spin faster and store more kinetic energy than steel. However, the rotor of carbon fiber mainly lies in the weaving process, which requires very high demanding conditions. At present, the weaving process of carbon fiber in China is relatively backward, and it cannot meet the higher requirements of flywheel energy storage battery on its rotor material for the

time being. Therefore, flywheel energy storage batteries mostly use steel rotors. Although steel rotors have higher quality than carbon fiber rotors, they can achieve the same energy storage at a relatively low speed. In addition, under the same conditions, the contribution of slender rotor and flat rotor to energy storage is also very different, which is an important factor in the design. In particular, the rotor material strength of flywheel energy storage battery has high requirements, so the steel strength can reach 1700MPa by special forging process.

3. Application in wind power generation

At the same time as the country proposes the development goals of "carbon peak and carbon neutrality", the problem of new energy power generation represented by wind power is becoming increasingly prominent, especially the disturbance brought by its large-scale access to the power grid, which is not conducive to the stable and safe operation of the power grid. Therefore, the grid-connection problem of wind power generation systems urgently needs to be solved.

As one of the energy storage flywheel energy storage, and its rapid response ability, long service life, pollution-free characteristics, especially suitable for solving the problem of wind power grid wind power given ability limitation, improve the utilization rate of wind power in power grid, especially in wind farms can show more outstanding in the primary frequency control ability, in order to "smooth" the output power of wind turbines to produce [2]. According to the example given in literature [3], the capacity of flywheel energy storage battery system to participate in wind power frequency regulation is 1.7 times that of hydropower unit and 2.7 times that of gas unit. Therefore, some developed countries have taken the lead in the application of energy storage flywheels in wind power frequency modulation service. In 2011, the former Beacon Power company built a flywheel energy storage battery system FM Power station in Stephen Town, New York, which can provide 20MW FM service. Through practice tests, the flywheel energy storage battery system frequency modulation power station can provide local smart grid frequency regulation and peak adjustment. This is a historic leap for the development of the flywheel energy storage battery system, which marks the first time that the flywheel energy storage battery system has been used in the world's power grid. Literature [4] shows that Vista Tech Engineer company of The United States applied flywheel energy storage battery system for wind power generation, and the wind power frequency modulation service provided by the system improved the output characteristics of wind turbines to a certain extent, and achieved good economic benefits. A 350kKW flywheel energy storage battery system was applied to the wind farm in The Azores Islands of Portugal for joint power supply, which solved the unstable power supply frequency shock and other problems when the wind power with installed capacity of 630KW was connected to the grid [5].

Compared with western developed countries, the research on energy storage flywheel in China started late, especially the application of energy storage flywheel in wind power generation frequency modulation technology is still in the experimental stage. However, in recent ten years, there have been dozens of institutions engaged in key technology research of energy storage flywheel specialized in research and development and application of energy storage flywheel technology. The 60MJ/1MW energy storage flywheel based on composite rotor, permanent magnet unloading and mechanical bearing hybrid support developed by Professor Dai Xingjian from the Department of Engineering Physics of Tsinghua University has been applied in the drilling demonstration project of Zhongyuan Oilfield. At present, he is undertaking the key technology research and engineering prototype development of composite rotor and 25MJ/400kW energy storage flywheel supported by full active magnetic levitation bearing project of the Ministry of Science and Technology. Fang Jiancheng, academician of Beihang University, and Xu Yanliang, professor of Shandong University, jointly developed new satellite

attitude control and energy storage dual-purpose flywheel, composite rotor, high-strength alloy steel rotor, and fully suspended permanent magnet bias hybrid magnetic bearing energy storage flywheel, which won the first prize of National Technical Invention in 2007. The aerospace engineering model 20NM /100Wh/ 42KRPM ultra-low power consumption high-speed maglev attitude control dual-purpose flywheel and high-precision long-life maglev momentum wheel have been applied to shijian-9 satellite which has been in orbit for 8 years. Recently, two flywheel products, FW2550 and FW2503, have built 1WM flywheel array energy storage system, and conducted experimental tests in Tianjin and Qinghai Scenery Energy Storage Base respectively. The results show that the flywheel array has superior performance and fully meets the frequency modulation requirements of new energy [6]. Since 2004, the team of Weiming Ma, academician of NAVAL University of Engineering, has been devoted to the research and development of 120MJ/50MW flywheel with super power storage to meet the short-term high power load and peak adjustment requirements of the ship integrated power system. The flywheel prototype developed adopts sliding bearing and asynchronous motor/generator scheme. Beijing Qifeng Energy Polymer Technology Co., Ltd. was the first enterprise to study commercial flywheel in China. The 15kWh(54MJ)/300kW carbon fiber composite rotor and fully active magnetic levitation flywheel were developed and applied in cnooc's energy recovery engineering demonstration project in 2014. The single-machine 10.8MJ/250kW fully active maglev flywheel developed by Beijing Honghui International Energy Technology Development Co., Ltd. in 2017 was applied to the Chengdu Glofangde Project (the project was suspended due to the Sino-US trade war). The 144MJ/40kW hourly full magnetic levitation flywheel product developed by Huachi Energy (Beijing) Technology Co., Ltd. in 2020 has been applied to the emergency start-up power supply project of offshore drilling platform, and the 27MJ/500kW full magnetic levitation flywheel product has been applied to the FLYwheel UPS project of Tianrui Heavy Industry. The 500kW/125kWh product is currently being assembled and tested.

Moreover, many famous colleges and universities in China have also participated in the research on frequency modulation technology of flywheel energy storage battery system applied to wind power generation. North China Electric Power University for flywheel energy storage array in the application of wind farms, adopt centralized access form, according to the ratio of 20% using consists of eight units of flywheel energy storage arrays simulation system of 10 mw wind power output power smoothly, through system modeling and simulation, the results show that the flywheel energy storage array system can effectively smooth the rapid fluctuations of wind power the fluctuation of wind farm output power is reduced within the required range [7].

Huazhong University of Science and Technology proposed a method of applying flywheel energy storage system to participate in AGC frequency regulation of power grid, and the experiment proved that it reduced the great influence of unstable output power of large grid-connected wind farms on the frequency of power system [8]. Advanced Flywheel Energy Storage Technology Research Center of North China Electric Power University adopts a 2MW flywheel energy storage array composed of 8 250kW /50 (kW·h) flywheel energy storage units to match 10MW wind power composed of 5 2MW wind turbines. Have put forward a kind of considering power allocation limit and can make each unit charged state of (SOC) tend to be more consistent power coordinated control strategy and control method of energy storage arrays can be grouped by parallel ac bus access to wind farm in the form of a smooth wind power output fluctuation, can significantly reduce the amount of wind power output fluctuation [9]. Han Yongjie et al from Harbin Engineering University designed an overall flywheel energy storage scheme matching the smooth output of 1.5MW fan, achieving a smooth power output of 150 kW and a maximum power of 200 kW[10]. Wang Yaonan et al., Hunan University [11] used flywheel energy storage to assist wind farm to participate in primary frequency control of

power grid, and achieved good results. Joint priorities in shandong province electric power company electric power research institute of shandong university put forward a kind of flywheel energy storage system aided thermal power unit a frequency modulation in power grid, power gap compensation and virtual droop control, combining to the flywheel energy storage system and the coordination of coordinated control strategy, the output of generating unit can inhibit the notorious problem; The strategy of optimal configuration capacity and charge state of energy storage is adopted to improve the charge state retention rate of energy storage and prolong unit life [12].

4. Conclusion and Prospect

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References

[1] WANG Mingyang. Research on Primary Frequency Modulation based on Energy Storage Wind Farm [D]. Shenyang Institute of Engineering, 2019.

[2] Howlader A M, Urasaki N, Yona A, et al. A review of output power smoothing methods for wind energy conversion systems[J].Renewable and Sustainable Energy Reviews, 2013,26 (oct.):135-146.

[3] Li Xinran, Huang Jiyuan, Li Peiqiang et al. High voltage technology, 2015,41 (07) : 2135-2141.

[4] Rounds R, Peek G. Design and Development of a 20MW flywheel-based frequency regulation power plant[R]. America: Sandia National Laboratories, 2009.

[5] Tang Changliang, Zhang Xiaohu, Meng Xiangliang. Research on flywheel energy storage technology abroad [J]. Chinese and foreign energy,2018,23(06):82-86.

[6] Li Shusheng, Wang Jialiang, Li Guangjun, Wang Dachun, Cui Yadong. Energy Storage Science and Technology, 202,11(02):583-592.

[7] Chen Yulong. Study on charge and discharge control of flywheel energy storage system applied to wind farm [D]. North China Electric Power University (Beijing),2021.

[8] Zhou Yujie, LIU Shilin, WEN Jinyu. Automatic Generation Control of Power System with Wind Power Assisted by Flywheel Energy Storage [A]. China Association for Science and Technology, Tianjin Municipal People's Government. Proceedings of the 13th China Association for Science and Technology Annual Conference, Beijing, China [C] / / Proceedings of the 13th China Association for Science and Technology Annual Conference, Beijing, China. China Association for Science and Technology, Tianjin Municipal People's Government: Academic Department of China Association for Science and Technology, 2011:60-65.

[9] Chen Yulong, Wu Xin, Teng Wei, Liu Yibing. Power Coordination Control Strategy for Flywheel Energy Storage Array for Wind Power Leveling [J]. Energy Storage Science and Technology, 202,11(02):600-608.

[10] Han Yongjie, Ren Zhengyi, Wu Bin, Li Chong. Application research of flywheel energy storage system on 1.5MW fan [J]. Energy storage science and technology, 2015,4(02):198-202.

[11] Sun Chunshun, WANG Yaonan. Integrated Power and Frequency Control of Wind Turbine System assisted by Flywheel [J]. Proceedings of the csee, 2008,28 (29) : 111-116.

[12] Yaodong Luo, Lijun Tian, Yao Wang, Jie Li, Jun Li, Tao Jiang. Flywheel energy storage participates in primary frequency modulation coordination Control Strategy and Capacity Optimization Allocation in power grid [J]. Automation of Electric Power Systems: 1-15.