Enhancing Stability and Management of Wind and Solar Energy Systems: Insights into Control and Storage Strategies

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Abstract. With the intensification of environmental problems and a large consumption of unable to renewable energy, clean energy has become increasingly important. The use of clean energy can reduce the pollution of atmospheric and greenhouse gas emissions and help relieve environmental problems such as climate change. Renewable energy has the advantages of rich resources, zero emissions and sustainability, so it has received more and more attention and attention. With the continuous progress of technology and the decrease in costs, the rapid development of renewable energy has become an important direction for global energy transformation. New types of coronary virus eruption and the Russian and Ukraine War have led to a sharp rise in global energy prices, which exacerbates people's attention to energy security and alternative energy. The development and application of renewable energy can reduce dependence on imported energy and improve the stability of energy supply. Wind energy and solar energy are the two most popular new energy sources. Their device costs are constantly declining, and efficiency continues to improve. At the same time, it has high renewable and adaptability. Therefore, they have been widely used globally and have become an important driving force for clean energy transformation.

Keywords: Wind and Solar New Energy; Energy Storage; Measurement and Control.

1. Introduction

Keeping the frequency and power of the power system is the key to ensuring the stable operation of the system within the acceptable range. Traditional generators have rotation inertia, which can help regulate the frequency and maintain system stability. However, the renewable energy system connected by the wind turbine and photovoltaic renewable energy system lacks rotation inertia, which makes the frequency dynamic faster, which has a greater challenge to frequency control and power system operation [1]. To solve the volatility and interval of renewable energy, the energy storage system has become increasingly important. By using the energy storage system, the excess energy can be stored and released when needed to balance the differences between supply and demand and maintain the stable operation of the power system. Wind energy and solar systems need to monitor and control in real time to ensure the normal operation of the equipment and maximize the energy utilization rate. Monitoring equipment such as pulse width modulation (PWM), maximum power point tracking (MPPT), and automatic generator control (AGC) can help optimize the performance and efficiency of the system. The instability of wind and solar has brought a series of challenges, but also prompted people to seek various solutions. In addition to energy storage systems, there are other technologies and strategies, such as flexible markets, smart micro -networks, and smart distribution networks, which can help improve the stability and reliability of the system.

In general, wind and solar energy, as free, renewable energy sources, have huge potential, but also faces some challenges. Through continuous technological innovation and system optimization, these challenges can be overcome, effective use of renewable energy, and promoting the development of power systems in a more sustainable and clean direction.

2. Stability and Energy Storage

The intermittency and instability of solar photovoltaic power generation lie in the alternation of day and night and changes in seasons and weather. The impact of the intermittency and volatility of wind power generation on the power grid. The corresponding impact of the intermittency of wind power generation on the transient stability of the power system depends to a certain extent on the specific operating conditions [2]. Energy storage can be Maintain efficiency when supply and demand are not balanced. For the above stability problems, energy storage is a solution to solve the stability problem. Three types of energy storage devices are introduced below.

2.1. Electrochemical Battery Energy Storage.

The first is lead-acid battery, which has low cost, simple process, and all parts can be recycled, but it has low energy, heavy weight, and limited number of charge and discharge times. In Applications of carbon in lead-acid batteries: a review, it is written that lead-acid batteries are still developing. During World War II, to prevent the formation of a passivating lead sulfate layer, carbon can be used as an additive for the negative active material. Wood is commonly used. barium sulfate, barium sulfate and activated carbon. It greatly improves the battery's cycle life, and carbon also increases the battery's available voltage during the final part of discharge. This research shows that carbon can also be used as a capacitor, and the lead-acid battery method with carbon electrodes is also used in supercapacitors [3].

Aluminum titanate batteries (LTO) are very suitable for fast charge and discharge and NRMM applications. Compared with carbon, lithium has the characteristics of long cycle life, excellent safety, better low-temperature performance, and higher power density. The aluminum electrode of LTO is highly catalytic and easily reacts with the electrolyte to produce other composite materials and gases, forming a solid electrolyte interface (SEI). So, it is very important to protect the surface of LTO from impact. The mechanical stability of the SEI layers formed varies greatly, especially considering the use of various cell configurations and different operating conditions. These dielectric layers are composed of loosely bound materials that are deposited on the anode surface. At the same time, the SEI layer plays a very important role in the LTO anode system. The main disadvantage to LTO is the generated gas. At this time, carbon can be used to protect the electrode and build a carbon layer [4].

2.2. Flywheel Energy Storage

Flywheel energy storage (FESS) originates from aerospace technology. It has high power, fast response, large capacity, long life, almost no maintenance, and has very little effect on temperature. It can work between minus 20 and 50 degrees. According to A Review of Flywheel Energy Storage System Technologies and Their Applications, the energy stored in a FESS is determined by the shape and material of the rotor. Flywheels are usually made as solid or hollow cylinders and disks. In addition, the running speed of the flywheel is determined by the material strength of the rotor. Low-speed flywheels generally use heavier metals, while high-speed flywheels use lighter composite materials, but they are very expensive. Energy conversion in FESS is through electric motors and bidirectional power converters. The problems that FESS needs to solve are frequency regulation control and voltage sag control. The former can be solved by frequency modulation, which requires the generator to maintain reserve capacity to maintain the stability of power generation and consumption. The latter can be solved by other energy storage methods [5].

2.3. Supercapacitor

The reason why the supercapacitor (electrochemical double layer capacitor) has a large capacitance is that the space is large, and the distance is small. The large area is due to the sum of the carbon particle areas. The small distance means that the ionic distance between the electrolyte and the carbon particles is small. Fig 1. shows the simplified diagram of the internal principle of the super capacitor. Compared with traditional capacitors, no chemical changes occur inside supercapacitors. Its principle is the electric double layer principle (When charging, the electrode attracts electrons in the electrolyte, and when discharging, the electrons are released.)

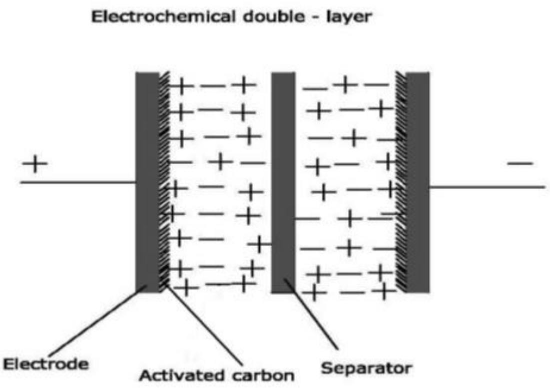

Fig. 1 Internal diagram of supercapacitor [6]

Because they offer high power density and low energy density, supercapacitors have a small output voltage (most available commercial products have a specific energy of less than 10 Wh/kg) but a long life, which can withstand hundreds of thousands of cycles. Discharge. Temperature has a greater impact on it. Among them, metal oxide electrodes have the characteristics of low resistance and high capacitance, which can build high-power and high-capacitance capacitors. Ruthenium oxide has been used in military applications, but due to its high cost and rarity, the academic community has been looking for other material alternatives [6].

3. Control Strategies

Subtle changes, such as solar radiation and shadows, wind speed and other factors, need to be controlled in real time. An example is a solar tracker, which is a device that points a solar collector device toward the sun or guides a reflector device so that it reflects maximum energy on the collector device [7]. There is also a wind power generation tracker.

Pulse width modulation (PWM) is an electronic control technology that regulates the power output of a circuit by periodically changing the pulse width of an electrical signal. It is commonly used in applications such as power converters, inverters and speed regulators and has the advantages of high efficiency and high reliability. In PWM, the pulse time of the signal changes periodically, thereby changing the average power of the signal. Generally, PWM can convert a continuous signal waveform (such as a sawtooth waveform) into a modulated waveform. In one cycle, PWM controls the power output of the signal by adjusting the width of the pulse. The duty cycle is the ratio of pulse width to period, usually expressed as a percentage ($D = W/T$, where W represents the pulse width and T represents the period). Fig. 2 shows one cycle after PWM adjustment.

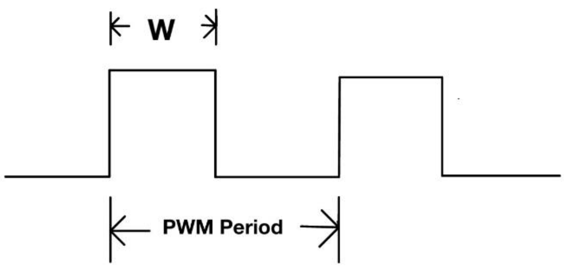

Fig. 2 PWM period

The output voltage after PWM modulation is equal to the product of the amplitude of the modulation wave and the duty cycle. Therefore, by adjusting the duty cycle, the output voltage can be adjusted, such as in motor speed control. However, it should be noted that the choice of frequency is also very important. A frequency that is too low may cause the device to fail to operate properly, while a frequency that is too high may damage the device. In practical applications, power switches usually use PWM control. Because PWM technology can achieve the integration of high current and high slew rate, as well as high-frequency conversion, it can achieve efficient energy conversion.

However, high-frequency conversion may also produce electromagnetic interference, causing damage to the converter or adjacent equipment, so appropriate electromagnetic interference suppression measures are required.

Maximum power point tracking (MPPT) is often used in solar and wind power generation devices. It can keep the power generation in the maximum working state. Especially at night or when there is no wind, the maintenance of voltage requires the battery not connected to the power grid to provide the required power. When the battery is not fully charged, the voltage currently is very different from the voltage during the day when there is light or strong wind. large (the voltage provided is relatively small), at this time MPPT can also enable the energy storage device to still output maximum power. In Hybrid, Optimal, Intelligent and Classical PV MPPT Techniques: A Review, it is written that classic MPPT technology includes constant voltage technology, increased conductance, open circuit voltage, short circuit current, disturbance observation, fluctuation-related control, etc., and intelligent MPPT includes fuzzy logic Controller, artificial neural network, Guass Newton Technique, Fibonacci series based MPPT, etc. Optimized MPPT includes Cuckoo Search, Particle Swarm Optimization, Gray Wolf Optimization, Ant Colony Optimization, and Artificial Bee Colony. Hybrid MPPT technologies include Fuzzy Particle Swarm, Optimization, Adaptive Neuro Fuzzy, Inference System, GWO-P & O, PSO-P & O, HC–ANFIS [8]. The principle of MPPT is very simple, and the algorithm is relatively simple, which makes MPPT versatile and widely used.

For solar power generation, the power output by MPPT mainly depends on objective factors such as temperature and irradiation amplitude. It maintains maximum power output from the solar cell by changing the resistance in the circuit. When $\frac{\mathrm{d}P}{\mathrm{d}U} = 0$, it means that the power has reached the maximum currently. When $\frac{\mathrm{d}P}{\mathrm{d}U} < 0$, the resistance needs to be reduced to reduce the power. On the contrary, the resistance needs to be increased. Fig. 3 is a schematic diagram of the photovoltaic system. The framework is composed of a solar-based photovoltaic array, a unidirectional DC/DC converter, and a DC/AC converter [8].

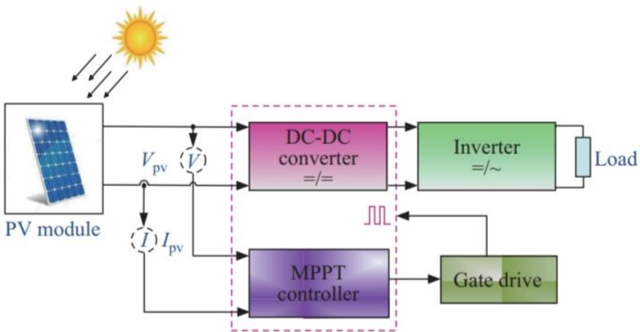

Fig. 3 MPPT controller - solar PV block diagram [8]

Likewise, MPPT can also monitor wind energy generation. The factors that determine power are wind speed and blade tip speed. The wind energy utilization coefficient (Cp) is the proportion of wind energy extracted, and the torque coefficient (Ct) represents the relationship between the wind turbine torque and wind speed. Under normal circumstances, when the wind speed is too fast or too slow, MPPT will automatically adjust the fan tip speed, that is, the rotation speed, so that the Ct value reaches the maximum, to always maintain the maximum power.

Automatic Generation Control (AGC) also mainly controls the output power by adjusting frequency, which is the basis of secondary frequency control. The AGC system controls the output power through the inverter by continuously detecting the grid load and generated power. AGC mainly includes two links: 1. Based on the real-time collected frequency and tie line power deviation, a centralized controller is used to approximate the real power fluctuation of the system and generate the total power command of the regional power grid; 2. According to a certain method, the total power is Instructions are distributed to each FM unit [9]. According to the discussion of Automatic Generation Control Strategies in Conventional and Modern Power Systems: A Comprehensive

Overview, AGC is classified into three categories based on controller organization: Centralized Controllers, Decentralized Controllers, Two-Level and Multi-Level Controllers. In the AGC service, two variables need to be continuously monitored, namely connection line swaps and frequency changes. For wind power, according to wind dynamics, the torque of the wind is first detected, and then the output is determined through the pitch angle of the turbine [10]. Fig. 4 shows the AGC control wind power generation system.

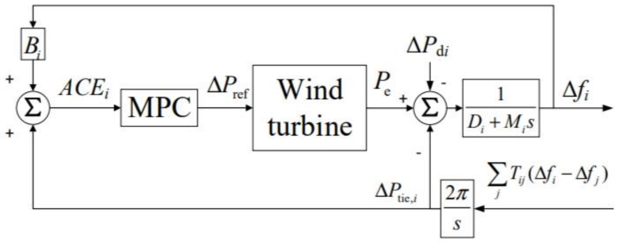

Fig. 4 the AGC control wind power generation system [9]

In photovoltaic power generation systems, AGC is used to adjust the fluctuations in the output frequency of the photovoltaic array caused by frequency fluctuations caused by solar radiation and weather changes.

4. Prediction

Using advanced prediction and optimization algorithms to regulate photovoltaic and wind power systems can achieve optimal support for the grid. By using meteorological data and advanced forecasting algorithms, accurate predictions of future weather conditions can be made. This includes factors such as solar radiation, wind speed and direction. Based on these predictions, photovoltaic and wind power systems can adjust their power output to suit future weather conditions. By combining weather predictions, photovoltaic and wind power systems can achieve intelligent regulation to maximize the stability and efficiency of the power grid, providing important technical support for the large-scale integration of renewable energy.

5. Conclusion

This article briefly introduces two main methods to solve the stability of wind energy and solar energy: energy storage (battery, capacitor, flywheel energy storage) and intelligent control (such as PWM, MPPT, and AGC), but there are no in -depth discussion of these methods Principles. As the proportion of renewable energy in energy supply continues to increase, ensuring that its stability and reliability will become more critical. Therefore, the continuous improvement and optimization of energy storage technology and intelligent control systems is crucial. This includes the improvement of the capacity, efficiency and reliability of the energy storage system, and the precision and flexibility of the intelligent control system to meet the changing needs and conditions in the power system. In addition, sustainable energy is an inevitable trend in the future, and it is pointed out that investment in this field is an important issue that every country is paying attention to. With the continuous increase of clean energy demand and the development of technology, it will indeed usher in a new energy stage. Among them, renewable energy will play a more important role and promote humanity towards more sustainable energy future. In the future, more complicated and smarter energy storage and adjustment equipment will be required to deal with more complex and subtle changes, and it is pointed out that renewable energy will become the leader of the future energy pattern. For the challenge of solving the stability of wind and solar energy, it is necessary to continuously improve and innovate to ensure the stable operation of the energy system and promote the widespread application and development of renewable energy.

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