



# Research on Smart Grid Optimization Based on Wind-Solar-Storage Integration

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**Abstract.** With the acceleration of energy transition, wind and solar energy are widely utilized due to their cleanliness and low carbon emissions. However, their intermittency and volatility pose challenges to the stability of the power grid. This paper focuses on the research of the integrated wind-solar-storage power generation system, which introduces energy storage technology to achieve energy regulation and balance. The paper elaborates in detail on the main components and principles of the wind turbine, photovoltaic modules, and energy storage devices in the system. It further analyzes the impact of wind-solar-storage integration from technical, economic, environmental, and social perspectives. The research conclusion of this paper holds that the wind-solar-storage system can not only achieve clean and low-carbon development but also bring significant economic and social benefits. However, the current application practice also faces challenges such as high energy storage costs, safety, and environmental impacts. In the future, through further policy support and technological innovation, the wind-solar-storage system will play a key role in building a low-carbon, safe and efficient energy system.

**Keywords:** Wind-Solar-Storage System, Component, Principle, Impact

## 1 Introduction

With the acceleration of the global energy transition from high-carbon to low-carbon, renewable energy generation technologies have become the core development goal of power systems. Among them, wind and solar energy have been widely used and developed worldwide due to their abundant resources and clean, low-carbon characteristics [1]. However, the inherent intermittency and instability of wind power generation and photovoltaic power generation have posed severe challenges to the operation of power grids. To address this issue, the system that can preserve wind and solar energy has emerged. The volatility of generating wind power and generating photovoltaic power has been solved by the characteristic of energy storage in storing electricity. The integration of these three power generation systems has enhanced the stability of power generation in the grid and significantly improved efficiency [2].

This paper mainly studies the structure and characteristics of the system that can generate and maintain the wind and solar power. The system which used for maintaining the wind and the solar energy mainly consists of wind turbine generator

sets, solar photovoltaic panels, energy storage devices, power conversion and remote control terminals. It is a new type of power generation system that combines wind energy, solar energy and energy preserving technology. The energy maintaining system can store the excess energy from wind power generation and photovoltaic power generation and use it when energy is in short supply.

The system of generating photovoltaic power mainly constitutes of solar panels, inverters and control systems. Solar panels convert solar energy into direct current, and inverters then convert direct current into alternating current for household or industrial use. Due to the advantages of being a clean and renewable energy source as well as having simple maintenance, photovoltaic power generation has been widely applied. Wind power generation mainly consists of wind turbines and towers. It converts wind energy into clean electricity by using the wind to rotate the wind turbine, then increasing the low rotational speed to a high one through a speed-increasing gearbox to drive the generator. Moreover, it is clean, renewable, has low generation costs and does not occupy too much land resources. Therefore, wind power generation has been widely applied both on land and at sea. The battery pack of the energy storage system can store electrical energy. The battery management system monitors the status of the battery to ensure its safe and efficient operation. The power conversion system is responsible for converting the direct current in the battery into alternating current for household and industrial use. Energy storage technology is an important part of the wind-solar-storage power generation system. It stores electrical energy for future use, which greatly improves energy utilization efficiency and grid stability. Due to its ability to store electrical energy, energy storage power generation systems have been widely applied.

## **2 Analysis of the Basic Characteristics of Wind-Solar-Storage**

### **2.1 Wind-Solar-Storage System**

The wind energy and solar energy storage power generating system is a new type of power system that combines wind energy, solar energy and energy storage technology. It can store the excess energy generated by wind power and photovoltaic power for future use, thereby enhancing the stability and utilization efficiency of the power grid. The system that combines wind energy and solar energy and maintaining power mainly consists of wind power generation units, solar photovoltaic panels, energy storage devices, and power conversion and remote-control systems [3].

Wind turbines and solar panels convert the wind energy and solar energy in nature into electrical energy. Energy storage devices can store excess or unused electrical energy and release the stored energy when needed. The power conversion system mainly controls the operation of the entire system. This system ensures the storage and release of electrical energy, guarantees its efficient use and ensures the reliable operation of the power grid.

Nowadays, the wind and solar power generation system has been widely applied and developed on a global scale. It has been better utilized and developed in regions rich in wind and solar energy resources, and the wind-solar-storage power generation

system has become one of the most important sources of electricity. Moreover, with the advancement of technology in reducing costs, the system that generates wind, solar and storage energy will have a better development.

## 2.2 Photovoltaic Power Generation

The technology of generating photovoltaic power involves directly converts sunlight into electricity using solar cells. When the solar panels received the sunlight, photons excite the current, thereby generating electricity. The photovoltaic power generation system mainly consists of solar panels, inverters and control systems.

First, solar panels convert sunlight into direct current. The basis of this process is the photoelectric effect, and the core is the solar cells in the solar panels, mainly made of silicon. First, countless photons in sunlight are absorbed by semiconductor materials (such as silicon) [4]. After receiving the energy of photons, electrons in the semiconductor are excited into free electrons, leaving positively charged "holes" in their original positions. When manufacturing solar cells, two different impurities are doped into the silicon material (because ordinary silicon material has poor conductivity). At this time, P-type semiconductors (rich in holes) and N-type semiconductors (rich in electrons) are formed. When they combine, a region called a PN junction is formed. In this region, electrons from the N region diffuse to the P region, and holes from the P region diffuse to the N region, forming an internal electric field pointing from the N region to the P region. The force of the internal electric field will push the negatively charged electrons to the N region and the positively charged holes to the P region. If the electrodes on both sides of the solar cell are connected by a wire at this time, the separated charges will form direct current under the drive of the electric field force [5].

Secondly, the inverter converts direct current into alternating current. First, the boost circuit inside the inverter can increase the DC voltage to a stable level that is higher than the peak value of AC (311V). Then comes the inversion process, which is accomplished by an H-bridge circuit composed of a group of high-power switching tubes. These switches are turned on and off in an orderly manner at an extremely high frequency of tens of thousands of times per second to change the direction, thereby converting DC into AC. Among them, AC is mainly supplied for household or industrial use. Finally, the control system ensures the efficient and safe operation of the entire system.

Photovoltaic power generation has many advantages. First, it is a clean and renewable energy source that does not produce greenhouse gases that exacerbate the greenhouse effect. Secondly, its construction and operation costs are relatively low and maintenance is simple. In addition, photovoltaic power generation systems can be installed on rooftops, open land, etc., and do not occupy a large amount of land resources. It can develop well in some urban or rural areas. Moreover, with the advancement of technology and the reduction of costs, the application and development of photovoltaic power generation are global, and it has an important influence in promoting energy transformation and mitigating the greenhouse effect.

### **2.3 Wind Power Generation**

Wind power generation refers to the process of converting the kinetic energy of wind into mechanical energy through wind turbine generators and then into electrical energy. The wind power generation system mainly consists of wind turbines and towers. It rotates the wind wheel by wind power, and then increases the low speed to a high speed through a speed-increasing gearbox to drive the motor to generate electricity [6]. In this way, wind energy can be converted into clean electrical energy.

Nowadays, onshore wind power has become one of the lowest-cost power generation methods and is making progress and being widely applied on a large scale. The cost of generating electricity from onshore wind power is even lower than that of fossil fuels [7]. The prospects for offshore wind power are also quite broad. Offshore wind energy resources are more available and stable, and avoiding conquer any land resources.

### **2.4 Energy Storage**

The energy system is mainly composed of a battery pack, a battery management system and an electrical conversion system. The battery pack can store electrical energy. The battery management system monitors the battery's status to make sure that it can work in a safe condition and work more efficiently. The power conversion system is responsible for converting the direct current in the battery into alternating current for household and industrial use [8].

Energy storage technology is a very important part of wind-solar-storage power generation systems. It stores electrical energy for future use, which greatly improves energy utilization efficiency and grid stability. Energy storage technologies mainly include various forms such as battery energy storage, pumped storage, and compressed air energy storage. Battery energy storage is one of the most common energy storage methods and also the most flexible form. It stores electrical energy in batteries and releases it when needed.

Energy storage can store electrical energy in batteries, thus solving the intermittency of wind and solar power generation. Secondly, its characteristic of storing electrical energy enhances the safety and reliability of the power system, significantly reducing the failure rate of the power system [9]. Moreover, with the advancement of technology, energy storage technology has been widely applied globally, becoming an important force in promoting energy transformation and addressing climate change.

## **3 The Impact of Wind-Solar-Storage Integration on Grid Integration**

The integration of wind, solar and energy storage into the power grid can be analyzed from multiple perspectives, including technical, economic, environmental and social aspects. The following is a detailed analysis of these impacts.

### **3.1 Technological Impact**

Energy storage addresses the intermittency and volatility of wind and solar power generation. The integration of wind, solar and energy storage into the power grid can enhance its stability.

### **3.2 Economic Impact**

As wind and solar power generation is a clean energy source and the construction and maintenance deteriorate of the wind and the solar energy projects costs relatively low, and the generation cost of wind power is even lower than that of fossil fuels, in the long run, the integration of wind and solar power can reduce fuel costs, alleviate the greenhouse effect, and bring environmental benefits [10].

With technological progress, the cost of wind, solar and storage power generation has gradually decreased. The government can greatly reduce energy consumption by enacting relevant preferential policies or providing subsidies to encourage development.

### **3.3 Environmental Impact**

All wind, solar and storage generating systems are clean power generation systems. They reduce the use of fossil fuels and the emission of greenhouse gases or other pollutants, which is of great benefit to the environment and helps mitigate climate change and improve air quality.

Wind-solar-storage projects may have an impact on land and ecosystems. For instance, the rotating blades of wind turbines may affect birds, and photovoltaic power stations may occupy a large amount of land resources and interfere with ecosystems. Therefore, rational planning and environmental protection measures are particularly important [11].

### **3.4 Policy and Technological Support**

The government can encourage developing the wind, solar and energy storage power generation by formulating or promulgating relevant policies, such as subsidies and tax incentives. Alternatively, the government can implement mandatory energy storage policies, clearly requiring wind, solar and energy storage power generation to generate electricity in accordance with a certain proportion or for a certain period of time [12].

The power generation capacity can be enhanced by applying AI technology, providing a reliable basis for it.

### **3.5 Social Impact**

The development of wind-solar-storage projects is highly likely to affect local communities. Photovoltaic power generation will occupy land resources, and wind power generation may generate a large amount of noise. Therefore, communication with the public is necessary to ensure that the project is at least not opposed by the public.

The vigorous development of the wind-solar-storage power generation system undoubtedly provides a large number of job opportunities, promoting economic development while reducing costs and improving the environment.

## 4 Conclusion

The wind-solar-storage power generating system is an integrated energy system which combines wind turbines, photovoltaic arrays, and energy maintenance technologies. By addressing the intermittency and volatility of different renewable energy sources, this system can play a significant regulatory role, effectively overcome the intermittency and volatility of renewable energy, and significantly enhance the stability of power grid operation and the efficiency of energy utilization.

Nowadays, the system has been widely scaled up globally, and wind and solar energy have become the main power supply methods in resource-rich regions. The advantages it brings include three aspects: First, the environmental benefits brought by the wind-solar-storage power generation system are significant. It can be said that zero carbon emissions can be achieved through this system, which plays an important role in promoting resource transformation and mitigating the greenhouse effect. Second, the economic benefits continue to grow. The advancement of technology and the large-scale application of this system have made its cost lower than that of traditional fossil energy. Moreover, the large-scale application of this system has provided many job opportunities and benefits, bringing many benefits to economic growth and showing significant long-term benefits. Third, it drives the development of the industrial chain. To vigorously develop this power generation system, more equipment manufacturing, project construction, operation and maintenance are needed, all of which provide a large number of job opportunities.

However, the wind-solar-storage power generation system still faces many challenges. The operating cost, service life and safety of the energy storage system need to be further improved. The development and operation of wind power generation and photovoltaic power generation will have certain impacts on the ecological environment or land resources of the surrounding areas. It is necessary to select the development site through scientific discussion and adopt environmentally friendly designs to reduce the harm to the surrounding environment.

The future development of the wind-solar-storage power generation system may rely on the simultaneous progress of government policy support and technological innovation. In terms of government policy, it is necessary to implement subsidy policies and improve the market that is conducive to the development of this system. In terms of technological development and progress, it is necessary to focus on coordinated control technology, improve the integrity and coordination of the system, and various cost-effective technologies. Moreover, it is necessary to develop batteries that are more difficult, safer, and can store more energy. Through continuous optimization in the future, the wind-solar-storage system may play a very important role in providing key support for building a cleaner, lower-carbon, safer and more efficient energy system.

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