Analysis on Grid-connection Characteristics of Wind/Photovoltaic/Energy Storage Hybrid Station

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Grid-connection characteristics of renewable energy, such as wind farm (WF) and PV plants often have the negative influence on the security and stability of power system. To smooth the active power, energy storage (ES) system was presented. The model presented of wind/photovoltaic/energy storage (W/PV/ES) hybrid station was simulated, and the grid-connection characteristics of W/PV/ES hybrid station were analyzed in Dig SILENT Power Factory. Simulation results show that it is positive and effective for ES to smooth the output fluctuation, and to improve the controllability of active power. Moreover, the electric power quality can be improved and the capacity of low voltage ride through (LVRT) can be raised for renewable energy station.

Keywords: Grid-connection Characteristic; Dig SILENT Power Factory; W/PV/ES Hybrid Station; Intermittence Renewable Energy Generation

1. Introduction

The characteristics of wind speed and solar irradiance, namely, randomness and intermission, can cause the outputs of the wind farm and PV plant to fluctuate frequently, and further lead to the poor reliability of the renewable energy station. With the rapid development of renewable energy, one can hardly ignore that the proportion of photovoltaic power and wind power is being large, the fluctuating outputs of renewable energy station will impact on the peak regulation and frequency regulation of the power grid [1]. Under this background, the battery energy storage system (BESS) is introduced to smooth the fluctuation of renewable energy station [2]. The coordination of BESS and renewable energy can guarantee the reliability of power supply and decrease the impact on power
system caused by the fluctuating outputs of renewable energy station. Meanwhile, it can also be used to reduce the reserve capacity of power grid, and improve the operation economy and the power system’s ability of acceptance of renewable energy [3].

Traditional research work of W/PV/ES hybrid generation station mainly focus on the energy management and application of ES [4-7]. To achieve tracking the power grid’s dispatching instructions, the research of the energy management focus on how to adjust the outputs among wind farm, PV plant and ES, which can make wind energy and solar energy converted to high quality electricity. Moreover, the application of ES technology mainly focus on the control strategy of ES system in different control modes, which can be useful for ES system to smooth the fluctuating output of wind power and PV power. Meanwhile, the ability can be improved for power grid to accept renewable energy. For energy management, the economy of W/PV/ES system is considered, and a model is established to comprehensively consider the minimization cost between generation and operation. Finally, a power control method is presented to solve this model [4]. The feasibility of multi-agent mode control used in a W/PV/ES system is tested and verified [5]. Different coordination control strategies are proposed and used in multiple operating conditions; note that smooth output can be achieved [6-7]. For the application of energy storage, when a W/PV/ES hybrid generation station works in off-grid or grid-connected mode, its key problems in the operation control of the ES device are analyzed [8]. It is noted that the ES capacity in a W/PV/ES hybrid generation station can affect the stability of ES system active power’s output, so an optimal model and a control strategy to charge and discharge for ES device are proposed to minimize the fluctuation of active power [9]. In [10], ES device is used to smooth the fluctuating outputs which are generated by the W/PV/ES hybrid generation station. The two layers distributed control framework is proposed, and the control strategy in each layer is analyzed specifically.

This paper will focus on the negative influence on power system’s security and stability of active power, which is caused by the fluctuating active power of renewable energy station. Firstly, a control strategy employing ES system is proposed to smooth the fluctuating active power. Secondly, a model of W/PV/ES hybrid station is built in Dig SILENT Power Factory. Finally, the grid-connected characteristics of the model are analyzed in the simulation.
2. Model Frame

At present, the modeling methods of W/PV/ES hybrid station mainly consist of direct modeling method and indirect combination modeling method [11-12]. The former method belongs to the non-mechanism model in which the hybrid renewable energy station is considered as a whole. However, using the direct modeling method, the physical structure of the power plant cannot be described and the model parameters are also difficult to identify, only the input/output characteristics are described. The latter method divides the system based on the physical structure firstly, then establishes mechanism model according to the operating characteristics of each section, and finally forms the overall model via the connection of data interface. This method not only reflects the entirely and partly operating characteristics of hybrid renewable energy station, but also has a good expansibility. In this paper, hybrid renewable energy station is modeled by using the indirect combination modeling method and the framework of the model, which is shown in Fig. 1.

![Model frame of W/PV/ES hybrid station.](image)

In Fig. 1, note that the W/PV/ES hybrid renewable energy station can be divided into four parts, such as wind farm, PV plant, ES and collection system. The energy transfer and information exchange between the renewable energy station and power grid are achieved by grid-connected bus. The modeling process of hybrid renewable energy station mainly consists of three parts:

Establish the model of wind turbine, photovoltaic power generation system and ES system.

Employ the double multiplication to achieve the equivalent unit of whole wind farm and PV plant.

Collect the output of equivalent unit and storage energy system in the grid-connected node.
For the power grid, the grid-connected characteristics of hybrid renewable energy station are reflected by the dynamic characteristics in the grid-connected node.

3. Coordinated Control Strategy

When the output of renewable energy system is larger than the reference value, ES system is charging, and vice versa. The fluctuation in output of wind farm and PV plant is caused by the random variations of wind speed and solar irradiance, and its output frequencies are widely distributed among the high frequency (1Hz and above), middle frequency (0.01~1Hz) and low frequency (0.01Hz and below). The power component in low frequency region is generally larger than that in high frequency region, and its rate of changing is also smaller. For this part, the power grid has a relatively long time to respond. However, for the power component in high frequency region, its amplitude is generally small and the rate of changing is large, so its impact on the power grid is also quite serious. Therefore, to stabilize the output of hybrid renewable energy station, ES system is employed and its function is to remove fluctuations in the high frequency part and middle frequency part, which is in outputs of the wind farm and PV plant.

To design the coordinated control strategy of hybrid renewable energy station, the key point is to design the charge and discharge controller of ES system. While, the key point in the charge and discharge controller of ES system is to get the power reference value. Note that the controller used in ES system for stabilizing the combined output fluctuation of hybrid renewable energy station is similar to the controller used in the low-pass filter can reflect the long-term trend of signal. Therefore, the combined method of low-pass filter and spectrum analysis can be adopted to control active reference value of ES system. In Fig. 2, Pwp is the combined output of wind farm and PV plant; Pg is the target output of W/PV/ES hybrid renewable energy station; Pref is the active reference value of ES system; oL is the cutoff frequency of low pass filter, and oL is determined according to the analysis result of the power spectrum of the hybrid renewable energy station.

![Figure 2. Control method for active power reference in energy storage.](image-url)
The rest part of ES system can be referred in [15], and the equivalent models of wind farm and PV plant are shown in [13-14].

4. Modeling and Grid-connected Characteristic Analysis

In a W/PV/ES hybrid renewable energy station, there are two ways to stabilize the combined fluctuation in outputs of wind farm and PV plant for the ES system [12]:

For wind turbine and photovoltaic unit, equipped with ES systems, respectively;

Centralized equipped with ES systems in the grid-connected node of hybrid renewable energy station.

There exists a complementarily between wind and solar irradiance, for example, during the day, irradiance is strong while wind is deficient, but at night, irradiance is inexistent while wind is strong; in summer, the irradiance strong and the wind is weak, but in winter, conditions are opposite. As a result, it can be indicated that the scheme (2) is better than the scheme (1), and the ES capacity configured in (2) is less than (1). According to the model frame of W/PV/ES hybrid station, which is shown in Fig.1, a hybrid renewable energy station frame based on Dig SILENT Power Factory is established, which is shown in Fig. 3. To facilitate the realization of model, and to reduce the impact of the analysis results as far as possible, which is caused by the difference between the model and the fact, note that the outputs of wind power and PV power converge to the same bus, which are converged with ES system in the grid-connected node through a very short line.

Based on the frame shown in Fig.3, the simulation for W/PV/ES hybrid renewable energy station under the disturbance of wind speed and three-phase short circuit fault condition can be proceed. Analyzing the simulation results, a clear understanding of the grid-connected characteristics of the hybrid station can be obtained.
4.1. Wind Disturbance

The wind speed model is composed of basic wind and random wind. In order to observe the influence of wind speed disturbance on the grid-connected characteristics of W/PV/ES hybrid station, the variation range of random wind is enlarged. Therefore it should be noted that the random component in the actual wind speed is different from that in Fig. 4 (a). The simulation results of the hybrid renewable energy station under the wind speed disturbance condition are shown in Fig. 4.

It can be seen in Fig. 4 (a) and (b) that with the random change of wind speed, the output of wind generator presents stochastic fluctuations, thereby affecting the combined output of hybrid station. When the ES system does not exist, the combined output fluctuate randomly between 0.70 p.u. ~ 0.92 p.u.. With storage system configured, the output fluctuation is slow down, and this process is shown in Fig. 4 (c). The results show that when the combined output is larger than the output of the control target, the energy system charge and store energy; otherwise, ES system discharge and release the stored energy. In summary, for renewable energy station, ES system is an effective solution to reduce the output fluctuation of intermittent power, and thus conducive to the supply reliability protection of the renewable energy station.
Figure 4. Simulation results of W/PV/ES hybrid station under the condition of wind disturbance.

4.2. Three-phase Short-circuit Fault

Three phase short-circuit fault simulation is under the following condition. When the simulation time \( t \) equals to 3, the midpoint of the line 6 occurs a three-phase
short circuit fault, and 0.1 second later, the fault is cleared, and the simulation results are shown in Fig. 5.

It can be seen in Fig. 5 that, when three-phase short circuit occurs at the midpoint of line 6, the active power reference value of ES control system is increasing rapidly. However, since the short circuit process is very fast and ES system cannot fully respond to its changes, the actual active power absorbed by ES system is less than the control target. But due to the existence of ES system, the impact of the wind and PV power on the grid is alleviated, to a certain extent, in the condition of three-phase short circuit. Furthermore, besides of the reactive power provided by wind farm and PV plant, which is according to "GB/T 19963-2011 technology regulations of wind farm access to power system" and "GB/T 19964-2012 technology regulations of photovoltaic power station access to power system", respectively, in the period of three-phase short circuit fault occurring, ES system can also provide the grid with reactive power to support the voltage. Reactive power output provided by ES system in the period of three-phase short circuit can effectively contribute to promoting the ability of low voltage ride through, because ES system is installed in the power station, which is near the wind farm and PV plant.
The simulation results of the hybrid renewable energy station with the condition of wind speed disturbance and three-phase short circuit fault show that: due to the uncertainty of renewable energy, the intermittent power output represented by wind power and PV power is randomly fluctuating, which can have an easy impact on the power grid, and then affect the safe and stable
operation of the power system. For ES system, its characteristics of dynamic absorption energy and timely release can effectively stabilize the intermittency and fluctuation in outputs of renewable power. As a result, it can enhance the controllability in output of the active power and improve the power quality. Further improvement of the dispatching ability can be achieved for intermittent energy in power grid. Moreover, when the system is failure, ES system can maintain the voltage stability of the power grid by generating reactive power, so the introduction of ES system can improve the ability of the low voltage ride through in wind power and PV power.

5. Conclusion

The security and stability problems of power grid are commonly caused by the output fluctuation of the hybrid renewable energy station, this paper research on the solution that using ES system to solve the problems and smooth the renewable energy output. A model of W/PV/ES hybrid station based on Dig SILENT Power Factory is proposed to study the grid-connected characteristics of the renewable energy station. Note that the ES system can effectively stabilize the fluctuation of combined output, and reduce the output impact of renewable energy on the power grid. Moreover, the configuration of ES system has a positive influence on renewable energy station to improve its capacity of low voltage ride through.

References

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