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Research on Smooth Control of Wind Power Fluctuation with Hybrid Energy Storage

By Ding Yujie, Xu Bingxin, Zhang Hailong & Wang Enrong

Nanjing Normal University

Abstract- The output fluctuation of wind power system has brought huge hidden dangers to the grid. In recent years, the application of energy storage devices to stabilize the fluctuation has been greatly developed. In this paper, a control strategy for wind power fluctuation based on hybrid energy storage of battery and super-capacitor is proposed. Due to the performance characteristics of battery and super capacitor, a low-pass filter is designed to separate the output into low frequency for battery, and high frequency for super-capacitor. A voltage and current double closed-loop coordination controller is further designed to realize the frequency division mixed energy throughput of the battery and the super capacitor. The simulation results show that the proposed hybrid energy storage system effectively suppresses the power fluctuation of wind power system and prolongs the service life of the battery.

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Research on Smooth Control of Wind Power Fluctuation with Hybrid Energy Storage

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Abstract- The output fluctuation of wind power system has brought huge hidden dangers to the grid. In recent years, the application of energy storage devices to stabilize the fluctuation has been greatly developed. In this paper, a control strategy for wind power fluctuation based on hybrid energy storage of battery and super-capacitor is proposed. Due to the performance characteristics of battery and super capacitor, a low-pass filter is designed to separate the output into low frequency for battery, and high frequency for super-capacitor. A voltage and current double closed-loop coordination controller is further designed to realize the frequency division mixed energy throughput of the battery and the super capacitor. The simulation results show that the proposed hybrid energy storage system effectively suppresses the power fluctuation of wind power system and prolongs the service life of the battery.

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I. Introduction

In order to alleviate energy crisis and improve ecological environment, the development and utilization of new energy has been worldwide concerned, among which the wind power generation technology has been rapidly developed. However, wind energy, as a natural clean energy, has great volatility and randomness under the influence of weather. Large-scale wind power grid connection has a certain impact on the safe and stable operation of the power system. At present, matching corresponding energy storage devices is usually adopted in the wind power generation system to effectively smooth the power fluctuation of wind energy [1-3].

At present, the energy storage system based on battery and super capacitor is mainly used to smooth the wind power fluctuation. Literature[4] proposed an energy storage structure of dual battery pack that separated charging and discharging processes, and designed a control strategy for power fluctuation to keep the battery running within the optimum discharge depth, thus prolonging the service life of the battery. Sun G W[5] utilized storage battery to suppress the power fluctuation of the wind farm, and realized real-time system adjustment by studying the space vector modulation algorithm of PWM converter. However, a single energy storage device cannot fully meet the comprehensive performance requirements of the system, and the combination of super capacitors and battery can improve the power regulation capacity of the energy storage system[6]. In literature[7], super capacitor voltage low-frequency suppression method is adopted to distribute the smoothing power required by super-capacitor and battery respectively. The battery set is divided into three independent units to alleviate the current imbalance and reduce the loop current ripple. In literature[8], the sliding average filtering algorithm is adopted to separate the power required by the flat suppression of the battery, which effectively reduces The Times of charging and discharging of the battery and improves the operation economy of the energy storage system. Literature[9] proposed an energy storage technology based on wavelet packet decomposition to smooth power fluctuations. Power fluctuation signals are decomposed at multiple scales by wavelet packet decomposition theory. Low-frequency fluctuations are directly connected to the grid, while high-frequency fluctuations are further decomposed to different energy storage devices through wavelet packet decomposition for smoothing.

In this paper, for the combined wind storage system, a control strategy based on hybrid energy storage to smooth out wind power fluctuations is studied. Through a low-pass filter the fluctuation of power is separated into high frequency and low frequency, complying with the super capacitor and battery characteristics respectively, to enhance the control capacity and the service life of the battery energy storage system, proposing a voltage and current double closed-loop coordination controller where two kinds of energy storage devices share the voltage outer loop. Finally the validity of the proposed control strategy is validated by computer simulation.

II. Structure of the Wind Storage System

The energy storage system can cut the peak load, fill the valley load and reduce the power fluctuation when wind power is connected to the power system, which is conducive to large-scale access of wind power, improving the stability of the grid, and carrying out planned dispatching of wind power generation[10]. For

Author α σ ρ Ѡ: School of Electrical and Automation Engineering, Nanjing Normal University, Nanjing 210042, China.
e-mail: zhl_chosenone@163.com

the current mainstream doubly fed induction generator, adopting a centralized hybrid energy storage system which is directly connected to the ac bus in parallel. Its structure is shown in figure 1.

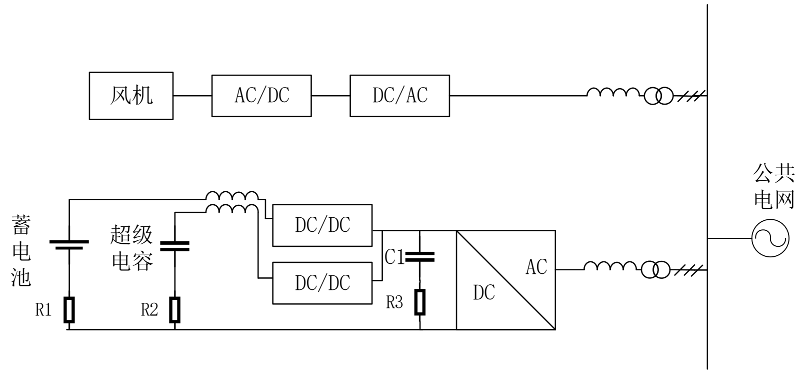

Fig. 1: Structure of wind turbine-energy storage system

The energy storage devices are all connected to the dc bus of the energy storage converter through bi-directional DC-DC Converter, as shown in figure 2.The circuit has a Boost state and a Buck state. When the wind energy is insufficient, the energy storage device is required to provide energy. Energy flows from the energy storage device to the dc bus. When there is surplus of wind energy, the energy storage device is required to absorb energy. Energy flows from the dc bus to the energy storage device. Meanwhile T1 tube is turned on and T2 tube is turned off, the converter works in Buck state, and the energy storage device is charged.

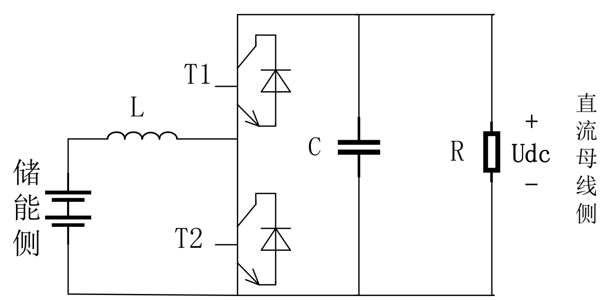

Fig. 2: Bidirectional DC-DC convertor

The energy storage converter is connected between the dc bus and the common ac bus, and PQ control is adopted to obtain the active power and reactive power required by the system (where the reference value of reactive power is set as 0). When there is surplus of wind energy, the energy storage system absorbs energy, and the energy storage converter is in the rectifying state. When there is short of wind energy, the energy storage system releases energy, and the energy storage converter is in the state of inverter. Its circuit structure diagram is shown in figure 3.

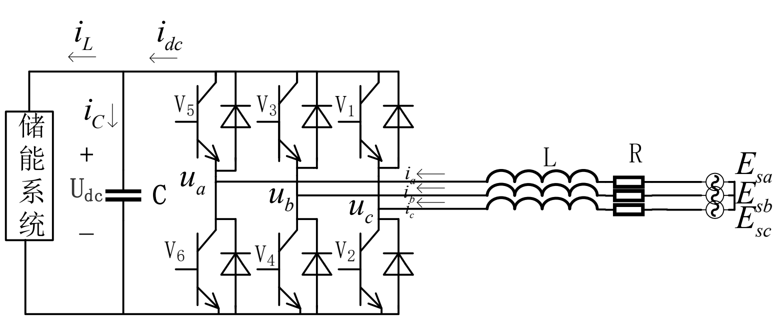

Fig. 3: Equivalent circuit model energy storage convertor

The expressions of active power and reactive power of the energy storage converter are as follows [11]

$$\begin{aligned} P &= E_{sd} i_d \\ Q &= -E_{sd} i_q \end{aligned} \tag{1}$$

Where i_d 、 i_q is the component of the three-phase current on the ac side in the d and q axis, and is the component of the three-phase voltage on the ac side in the d axis. Active power and reactive power can be controlled by controlling i_d and i_q. When the energy storage converter is connected to the grid, the phase and frequency of the ac side can be obtained through the phase-locked loop. Through the energy storage system to specify the throughput active power P_{HESS} and reactive power Q_{HESS}, the reference value of the current loop i_{dref} and i_{qref} can be obtained after calculation. u_d 、 u_q can be obtained by comparing and controlling the current loop with i_d 、 i_q, and u_{ref} can be obtained by Park transform in version, and then generating SVPWM wave to control the on and off of the switch tube.

III. Power Fluctuation Restrain based on Hybrid Energy Storage System

Current specification standards of wind power fluctuations is in accordance with Technical Provisions for Wind Farm Access to Power System issued by State Grid Corporation of China, in February 2009, This document clearly specifies the maximum variation of output power when the wind farm is connected to the grid, including the variation of 1min and 10mins. The specific data are shown in table 1 below.

Table 1: The recommendation value of the maximum variation rate of the wind farm

Capacity of Wind Farms(MW)	Maximum Change in 1 min(MW)	Maximum Change in 10 mins (MW)
<30	6	20
30-150	capacity/5	capacity/1.5
>150	30	100

a) Energy flow of wind storage system

The main output power of the wind storage system comes from the power generated by the draught fan, so the main factor affecting the wind storage system is wind speed. The power balance relationship of wind storage system is as follows

$$\begin{aligned} P_o &= P_w - P_{HESS} \\ P_{HESS} &= P_b + P_c \end{aligned} \tag{2}$$

Where P_{HESS} is the throughput power of the hybrid energy storage system, P_b and P_c is the throughput power of the battery and ultra-capacitor respectively, and P_o is the grid-connected power of the whole system. When the wind speed is relatively high, the energy storage system needs to absorb power to smooth the fluctuating power, while the wind speed is relatively low, the energy storage system emits power to stabilize the power fluctuation.

b) Low pass filter for frequency division

The first order low-pass filter is designed to separate the power frequency of the energy storage system into low frequency for battery and high frequency for super-capacitor. The circuit schematic diagram is shown in figure 4, where U_1 is the input signal, U_2 is the output signal, R is the filter resistance, and C is the filter capacitor.

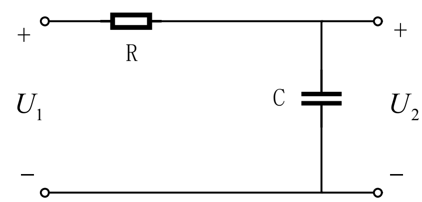

Fig. 4: Circuit diagram of one-order low pass filter

The differential equation of the circuit is shown in equation (3).

$$RC\frac{dU_2}{dt} + U_2 = U_1 \tag{3}$$

The transfer function is

$$H(s) = \frac{1}{1+\tau s} \tag{4}$$

Where s is the filter operator, τ is the filter time constant, $\tau = 1/2\pi f_c$, and f_c is the filter cut-off frequency. When the filter is applied to the power distribution of the energy storage system, the input signal U_1 is the expected power value of the energy storage through put P_{HESS}^*, and the output signal U_2 is the reference power value of the battery throughput P_b^*. The expressions are

$$P_b^* = \frac{1}{1+\tau s} P_{HESS}^* \tag{5}$$

$$P_c^* = P_{HESS}^* - P_b^* = \frac{\tau s}{1+\tau s} P_{HESS}^* \tag{6}$$

In the expression, P_c^* is the reference value of the power suppressed by super-capacitor. According to the characteristics of each energy storage device, the battery response time is the key factor. The power with a frequency higher than 0.1Hz and the power with a frequency lower than 0.1Hz is designed to be absorbed by a super-capacitor and a battery respectively, so take $f_c = 0.1Hz$, $\tau = 1.6s$.

c) Coordinated control strategy of voltage and current double closed loop

The following voltage and current double closed-loop frequency division coordination control strategy is further proposed, as is shown in fig 5. The super-capacitor and the battery share a voltage outer loop. The current inner loop reference value I_{ref} is obtained by the PI controller, and is subsequently divided into high frequency part and low frequency part, as the reference value of the battery current loop and the reference value of the super-capacitor current loop respectively.

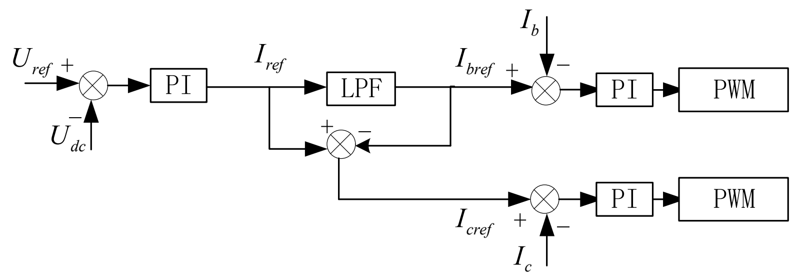

Fig. 5: Voltage and current double closed-loop coordination control strategy

When the circuit is in Boost state, T1 tube is turned off and T2 tube is working. The DC voltage is controlled by adjusting its duty cycle D, where $D = T_{on} / T$, and T_{on} is the conduction time of T2 tube in one cycle. Provided that the DC bus voltage is U_{dc}, the terminal voltage of the energy storage device is U_{bar}, and the current flowing into the energy storage side is I, when the T2 tube is working, the state equation can be obtained as follows:

$$\frac{d}{dt}\begin{bmatrix} I \\ U_{dc} \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1(1-D)}{L} \\ \frac{1-D}{C} & \frac{-1}{RC} \end{bmatrix} \begin{bmatrix} I \\ U_{dc} \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} U_{bar} \tag{7}$$

Thus, the circuit's current loop control equation and duty cycle adjustment equation under Boost state are:

$$L\frac{dI}{dt} = U_{bar} - (1-D)U_{dc} \tag{8}$$

$$D = \frac{(K_p + K_i / s)(I_{ref} - I) - U_{bar} + U_{dc}}{U_{dc}} \tag{9}$$

Where K_p and K_i are the proportional and integral current loop parameters of the PI controller.

Similarly, when the circuit is in Buck state, the current loop control equation and duty cycle expression are:

$$L\frac{dI}{dt} = -U_{bar} + D * U_{dc} \quad (10) \tag{10}$$

$$D = \frac{(K_p + K_i / s)(I_{ref} - I) + U_{bar}}{U_{dc}} \tag{11}$$

IV. Simulation Results

Based on Matlab / Simulink, an integrated wind and energy storage grid-connected system is established. The external system uses a single-machine infinite system. The main parameters of the fan are 100kW fan capacity and 690V rated voltage, and the main parameters of the energy storage system are 300Ah battery capacity, 0.5R battery internal resistance, 70F super-capacitor capacity and 800V DC bus reference voltage.

Assume that the active power output expectation of the system, namely the grid dispatch value, is constant within a second time scale, the reactive power is zero, and the wind speed is variable. The output power of the wind turbine and the power to the grid stabilized by the energy storage system are shown in Fig 6, which verifies that the power to the grid remains basically unchanged after smoothed by the designed hybrid energy storage stabilization system, meeting the grid dispatching requirements.

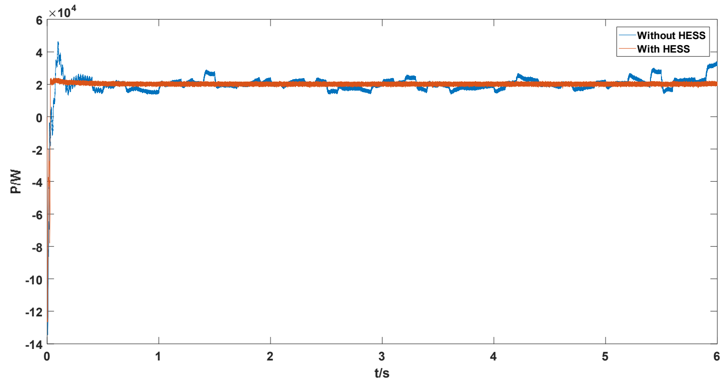

Fig. 6: Comparison of suppressing power under variable wind speed

Figures 7 and 8 compare the actual power and reference power of the battery and super-capacitor, illustrating that the energy storage device can be charged and discharged according to the reference value of power distribution, and the proposed hybrid energy storage system can well suppresses wind power fluctuations.

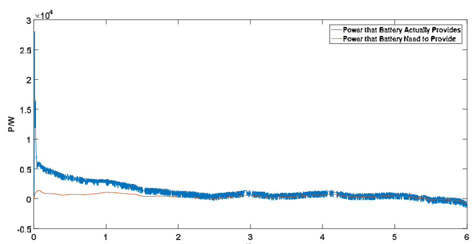

Fig. 7: Actual and reference power of battery

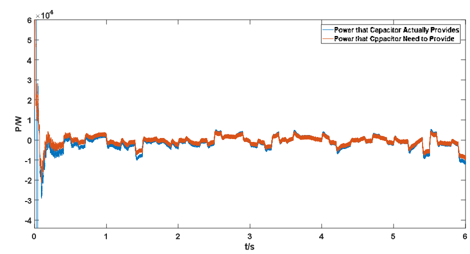

Fig. 8: Actual and reference power of capacitor

Fig 9 and 10 show the changes of SOC values of the battery and super-capacitor when the system is connected to the grid. It shows that the smooth battery SOC curve has a small amplitude variation range without repeated charge and discharge. The super-capacitor SOC changes rapidly with repeated charge and discharge for many times, and the charge and discharge depth is also larger than that of the battery. Therefore, the effectiveness of the hybrid energy storage control strategy is verified, which can effectively reduce the charging and discharging times of the battery and prolong its service life.

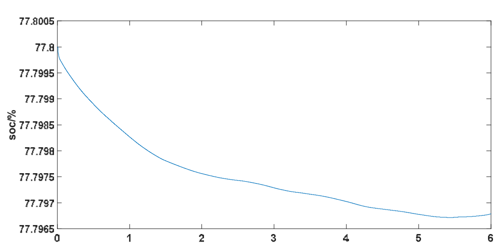

Fig. 9: SOC curve of battery

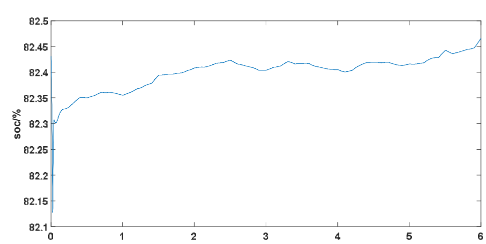

Fig. 10: SOC curve of super capacitor

V. Conclusion

In this paper, a wind power grid-connected system based on hybrid storage of battery and super-capacitor is established, and a power fluctuation smoothing strategy based on voltage and current double closed-loop frequency division coordinated control is proposed. The actual power characteristics and SOC change curve of the battery and super-capacitor are observed in the simulation under the conditions of constant wind speed and variable wind speed. The results verify that the control strategy can effectively smooth the fluctuation of wind power, reduce charging and discharging times of the battery, and prolong its service life.

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