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Control Strategy of Energy Storage for Smoothing Photovoltaic Power Fluctuations

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Abstract: Taking the photovoltaic power generation with battery energy storage system (BESS) as research object, a charge-discharge control strategy considering charge-discharge depth and state of charge (SOC) of battery is proposed based on the low-pass filter principle. Simulation results show that the proposed control strategy not only can smooth the photovoltaic power fluctuations in real time, but also prolong the service life of the battery.

Keywords: renewable energy system, feedback signal, low-pass filter, energy storage, power control, state of charge, depth of charge and discharge.

1. INTRODUCTION

Photovoltaic (PV) generation is clean and environmental friendly and has become an important topic of research and application in the field of renewable energy generation nowadays [Michele, 2009]. However, photovoltaic output power is affected highly by natural conditions, such as the light condition, temperature, climate and so on, so its output power fluctuations are larger, which brings great challenges to the stable operation of power grid system [Li, 2011]. In recent years, the rapid development of energy storage technology provides a new way to solve the gird connection of photovoltaic generation. Integrating energy storage system with good regulation ability in photovoltaic generation, the active power output characteristics of photovoltaic-energy storage hybrid system is improved obviously and the security and stability of power system is enhanced [Ali, 2012].

At present, the active power control technology of renewable energy generation with BESS has been researched for a long time. In paper [Mohamed, 2013], an improved control strategy for a grid-connected hybrid PV/BESS for mitigating PV farm output power fluctuations is presented and an optimal feedback control method for BESS SOC is proposed using the genetic algorithm to solve the multi-parameter optimization to improve the dispatching performance while meeting the required operational constraints for BES. In paper[Ala, 2013], SOC is kept within certain limits to allow the storage to supply or sink any unexpected deficit or surplus in the DG power to overcome the limitations of renewable sources and forecasting models uncertainty. In paper [Baran, 2010], an open-loop optimal control scheme incorporating the state of charge limits, charge/discharge current limits, and lifetime operating constraints of the BESS is designed to make the wind farm dispatched on an hourly basis based on the forecasted wind conditions. In paper [Jia, 2011], a fuzzy-logic-based power smoothing method is presented for reducing output power fluctuations of wind/PV hybrid power generation systems and managing battery SOC within a specified target region while smoothing wing power and PV output power. In paper [Koshimizu, 2006], a washout filter -based scheme is adopted to smooth out short-term power fluctuations of a wind farm with vanadium redox-flow batteries (VRBs) as the energy storage.

In this paper, the photovoltaic-energy storage hybrid system is researched, and a control strategy considering charge-discharge depth of battery is proposed based on the principle of filter. Energy storage output power is adjusted dynamically through SOC feedback control, which ensures the SOC within its range and avoids the battery over-charged and over-discharged as far as possibly. Finally, validity of the proposed strategy is verified through simulation.

2. CHARGE-DISCHARGE CONTROL STRATEGY OF BESS

2.1 Power Control Strategy Based on Low-pass Filtering

In this paper, as to the photovoltaic generation with BESS, the output power of photovoltaic array is served as the control signal which is smoothed by filter. The difference between the expected photovoltaic power and the smoothed photovoltaic power is compensated by charging or discharging power of BESS. The topological structure of the system is shown in Fig.1. The system is made up of photovoltaic module, energy storage module and grid-connected DC/AC inverter. The photovoltaic module is composed of photovoltaic array and boost converter, the BESS module is composed of battery and a bidirectional DC/DC converter. In Fig.1, P_{PV} is the active power of photovoltaic array, P_{PO} is the expected active power of photovoltaic array smoothed by the low-pass filter, P_{ref} is the reference active power of BESS, P_{BESS} is the actual compensation power of BESS, and P_G is the output power of photovoltaic-energy storage hybrid system injected into the grid.

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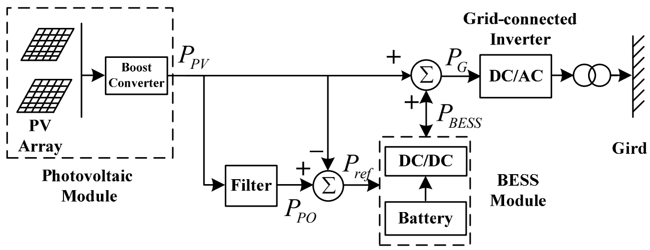

Fig. 1. Topological structure of photovoltaic-energy storage hybrid system.

The filter in Fig.1 is a first-order low-pass, whose transfer function is

$$H(s) = 1/(1+sT_f) \tag{1}$$

T_f is filter time constant and is the key factor that determines the smoothing effect of power fluctuations, and its value is bigger, the smoothing effect is more obvious. The reference active power of BESS P_{ref} can be defined as follows:

$$P_{ref}(s) = (-sT_f/(1+sT_f))P_{PV}(s) \tag{2}$$

The relationship between SOC and the rated capacity of BESS is shown as below:

$$SOC(s) = -P_{BESS}(s)/(sE_{BESS}) \tag{3}$$

In the ideal condition that the battery capacity is large enough, then the actual output power of BESS P_{BESS} equals to the expected power P_{ref}, and the output power of BESS can meet the expected photovoltaic output power completely. And then

$$SOC(s)\cdot E_{BESS} = T_f P_{PO}(s) \tag{4}$$

Equation (4) shows that the actual charge-discharge capacity of BESS $SOC(s)\cdot E_{BESS}$ is T_f times the expected photovoltaic output power P_{PO}. The rated capacity of battery E_{BESS}, average output power of photovoltaic array $\bar{P}_{PV}$, and filter time constant T_f are different and then the actual charge-discharge capacity of BESS is different. We conclude three cases here:

Case 1: when $T_f < E_{BESS}/\bar{P}_{PV}$, the actual charge-discharge capacity of BESS is less than the battery rated capacity;

Case 2: when $T_f = E_{BESS}/\bar{P}_{PV}$, the actual charge-discharge capacity of BESS is equal to the battery rated capacity;

Case 3: when $T_f > E_{BESS}/\bar{P}_{PV}$, the actual charge-discharge capacity of BESS is bigger than the battery rated capacity.

Three curves about the charge-discharge capacity of BESS with different filter time constants are shown in Fig.2 whose X-axis means time t and Y-axis means battery capacity E and SOC.

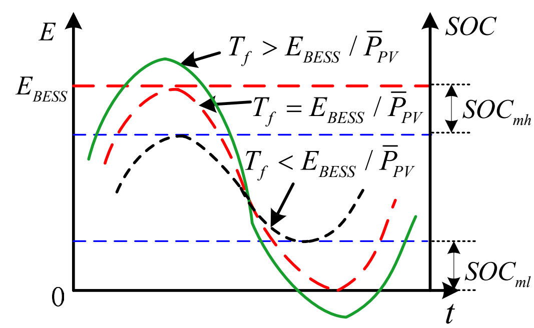

Fig. 2. Curves of capacity of BESS with different filter time constants and depth of charge and discharge.

2.2 Power Control Strategy Considering the Charge and Discharge Depth of Battery

The Fig.2 shows that when $T_f > E_{BESS}/\bar{P}_{PV}$, the actual charge and discharge capacity of energy storage system is beyond its rated capacity. In actual operation, the battery capacity could not be infinite. In order to avoid the battery over-charged and over-charged, the zoom coefficient k ($0 \le k \le 1$) of the filter time constant is introduced here, and then $T_f' = kT_f \le E_{BESS}/\bar{P}_{PV}$, which means that certain degrees of power fluctuations smoothing effect is sacrificed selectively because the rated capacity of the batteries is limited. Taken the depth of charge and discharge into consideration means that certain capacity margin is set, and then the zoom coefficient k can be further optimized.

As shown in Fig.2, the upper and lower margins of SOC are assumed to be SOC_{mh} and SOC_{ml} respectively, according to the (3) and (4), the margin capacity of battery is

$$(SOC_{mh} + SOC_{ml})\cdot E_{BESS} = E_{BESS} - kT_f\bar{P}_{PV}(s) \tag{5}$$

At time t, the discharge power of battery is $P_{BESS}(t)$, then the output capacity of photovoltaic generation expected by BESS is

$$E_{PV}(s) = kT_f P_{PO}(s) \tag{6}$$

The feedback control of SOC is introduced here to adjust the target output power of battery. The difference between the real charge and discharge capacity and the sum of expected photovoltaic capacity and margin capacity of battery is calculated and then the adjusted power of battery is

$$\begin{aligned} P'_{BESS}(s) = \{&SOC(s)\cdot E_{BESS} - (kT_f/(1+sT_f))\cdot P_{PV}(s) \\ &-(E_{BESS} - kT_f\bar{P}_{PV}(s))\}/T_f \end{aligned} \tag{7}$$

Then the feedback control of SOC is developed, which is shown in the dashed lines in Fig.3.