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Application of Fuzzy Control in PV- Storage Distributed Generation System

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ABSTRACT

In allusion to the output power fluctuation of intermittent energy source in the photovoltaic (PV)-storage distributed generation system, the fuzzy control strategy based on the hybrid energy storage system between battery and super capacitor (SC) is established in PV-storage distributed generation system. In view of the power management and energy distribution between the battery and SC two energy storage units, the output of fuzzy control of present charging/discharging capability of the hybrid energy storage system is utilized. Target power value is determined firstly, according to the battery and SC charged state synthetically, the deviation value beyond the target power value is allocated according to the fuzzy control theory between the two kinds of energy storage medium. The effectiveness of the proposed strategy is validated by results of the case study.

Keywords: Fuzzy control, Photovoltaic-storage, Distributed generation.

1. INTRODUCTION

The PV-storage distributed generation system system is becoming an important development direction in many countries and regions along with our country economy development fleetly, electric power requirement advance year after year and energy sources & environment contradiction looming large. However, the distributed renewable energy power generation intermittence and randomicity characteristics restrict its power generation capability and its running stabilization [1-8].

The distributed generation system can join the distributed generation, burthen, energy storage equipment together through advanced control system. It not only run with distribution power system connection grid, but also run without grid [9-12]. The distributed generation system can bring remarkable value into the power supply department and user. The hybrid storage system as the power tame unit of micro power supply and grid has a crucial role for the stable operation of the whole system and the effective use of power [13-15].

In view of the PV and energy distribution between the battery and SC two energy storage units. Target power value is determined firstly, according to the battery and SC charged state synthetically, the deviation value beyond the target power value is allocated according to the fuzzy control theory between the two kinds of energy storage medium. The simulation results validated that hybrid storage system fuzzy control is viable and effective for the PV-storage distributed generation system.

2. THE REALIZATION OF THE FUZZY CONTROL STRATEGY

Define $\Delta P(t)$ is smooth target external power value. The smooth target external power value is needed for the optimal power allocation between SC and battery. But the hybrid energy storage system is difficult to establish control model for charging and discharging accurately. In order to obtain the SOC when processing power allocation between SC and battery easily, the method based on fuzzy control theory is used for power allocation between SC and battery of energy storage system reasonably. The specific control optimization goal is as follows:

(1) The target external power is minimized after smoothing.

$$\min\left|\Delta P(t)-P_{HESS}(t)\right| \quad (1)$$

(2) In order to the power fluctuations is smoothed at next moment, SC is needed to save maximum energy.

$$\min\left|S_{SOC\_SC}(t)-S_{SOC\_SC}(0)\right| \quad (2)$$

(3) In order to the power fluctuations is smoothed at next moment, battery is needed to save maximum energy.

$$\min\left|S_{SOC\_B}(t)-S_{SOC\_B}(0)\right| \quad (3)$$

In the above formula, $P_{HESS}(t)$ is the charge and discharge power of hybrid energy storage system at t moment, the unit is MW; $S_{SOC\_SC}(t)$, t $X_1(t)$ $S_{SOC\_SC}(0)$ is the charged state(SOC) of SC at moment and initial moment respectively, %; $S_{SOC\_B}(t)$, $S_{SOC\_B}(0)$ is the charged state of battery at t moment and initial moment respectively, %.

The optimize power allocation for SC and battery hybrid energy storage system should be combined with the size of the $S_{SOC\_SC}(t)$, $S_{SOC\_B}(t)$ and $\Delta P(t)$. Two fuzzy control input and $X_2(t)$ is set up in this paper:

$$X_1(t) = S_{pd\_SC}(t) \tag{4}$$

$$X_2(t) = S_{pd\_B}(t) - S_{SOC\_B}(0) \qquad (5\ X_2(t))$$

$X_1(t)$ is the SOC predicted value of the SC; $X_2(t)$ is The SOC deviation predicted value of the Battery. i

Figure 1 shows the membership function $X_1(t)$, $X_2(t)$ and output membership function at $\Delta P(t) \ge 0$. Table 1 shows the fuzzy control rules used in the fuzzy control method. Figure 2 shows the input membership function of the SC at $\Delta P(t) < 0$, the output membership function and the battery input membership function are the same as $\Delta P(t) \ge 0$. Fuzzy control rules as shown in table 2.

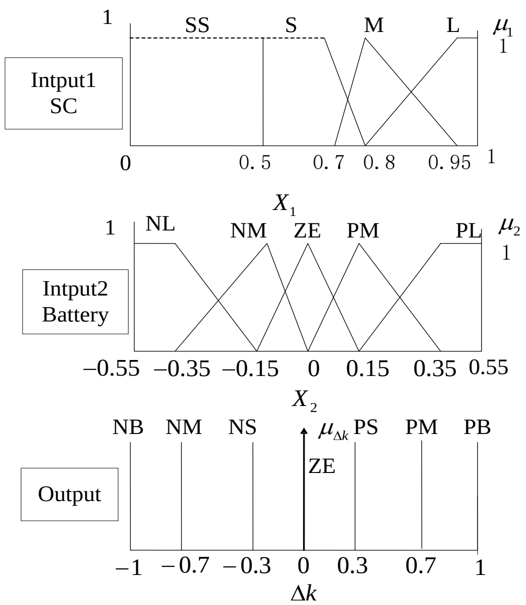


Figure 1. Membership functions of $X_1(t)$, $X_2(t)$ and output $(\Delta p(t) \ge 0)$

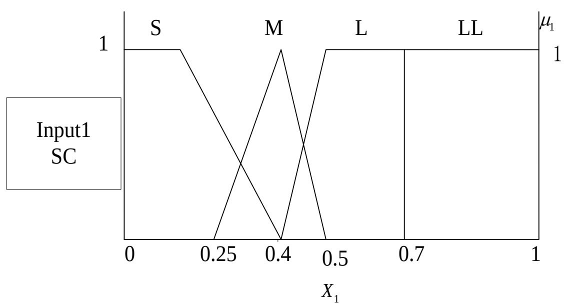


Figure 2. SC input membership functions $(\Delta p(t) < 0)$

Table 1. Fuzzy control rules at $\Delta p(t) \ge 0$

$X_1(t)$	NL	NM	ZE	PM	PL
SS	ZE	ZE	ZE	ZE	ZE
S	ZE	ZE	ZE	ZE	NS
M	NL	NL	NL	NL	NL
L	NM	NL	NL	NL	NL

Table 2. Fuzzy control rules at $\Delta p(t) < 0$

$X_1(t)$	$X_2(t)$				
	NL	NM	ZE	PM	PL
S	PL	PM	PL	PL	PL
M	PM	PS	PL	PL	PL
L	ZE	ZE	ZE	PS	ZE
LL	ZE	ZE	ZE	ZE	ZE

The power correction coefficient $b(t)$ of SC and battery hybrid energy storage system is obtain at t moment via making the solution fuzzy calculation for input $X_1(t)$ and $X_2(t)$ used weighted average method.

$$b(t) = \frac{\sum_i \sum_j \mu_{1i}(X_1(t))\mu_{2j}(X_2(t))\Delta k_{ij}}{\sum_i \sum_j \mu_{1i}(X_1(t))\mu_{2j}(X_2(t))} \tag{6}$$

In the above formula, $\mu_{1i}(X_1(t))$ and $\mu_{2j}(X_2(t))$ is the membership value for the of $X_1(t)$ and the j of $X_2(t)$. The set of i is $\{S, M, L, LL\}$, the set of j is $\{NL, NM, ZE, PM, PL\}$. Δk_{ij} is the corresponding output value of input $\mu_{1i}(t)$ and $\mu_{2j}(t)$.

$P_{SC\_ref}(t)$, $P_{B\_ref}(t)$ is the SC reference power and the battery reference power at t moment, which can be described as:

$$P_{SC\_ref}(t) = \Delta P(t) + b(t)|\Delta P(t)| \tag{7}$$

$$P_{B\_ref}(t) = -b(t)|\Delta P(t)| \tag{8}$$

The SC and battery hybrid energy storage system is sufficient capacity when $S_{SOC\_SC}(t) \le 0.5$ after absorbing the power and $S_{SOC\_SC}(t) \ge 0.7$ after outputting the power, the other situation is not enough capacity. The concrete model of optimizing energy allocation for SC and battery hybrid energy storage system as:

(1) If the SC has enough residual capacity, the output power of battery can be reduced. $\Delta P(t)$ is assumed by the SC independently. The SOC of SC can be recover soon, which make the tame results is better at next times.

(2) If the residual capacity of SC is insufficient, $\Delta P(t)$ is assumed by the SC and battery jointly. Which purpose is

preventing the smooth results from affecting due to SOC energy out-of-limit of SC.

When $\Delta P(t) \geq 0$, $-1 \leq b(t) < 0$;When $\Delta P(t) < 0$, $0 < b(t) \leq 1$. $S_{SOC\_B}(t)$ increased after absorbing the power when battery has enough residual capacity, then battery will be distributed $\Delta P(t)$ less in order to preventing the smooth results from affecting due to SOC energy out-of-limit of battery. If $S_{SOC\_B}(t)$ is decreased after absorbing the power, then battery will be distributed the more target external power value, and the reference power of battery is increased meanwhile.

According to the energy out-of-limit problem, the power fluctuation is smoothed by SC when SC appearing energy out-of-limit state firstly. The power fluctuation is smoothed by the battery firstly When the battery occurring energy out-of-limit problem. The hybrid energy storage unit of SC and battery energy optimization allocation management strategies is shown in figure 3.

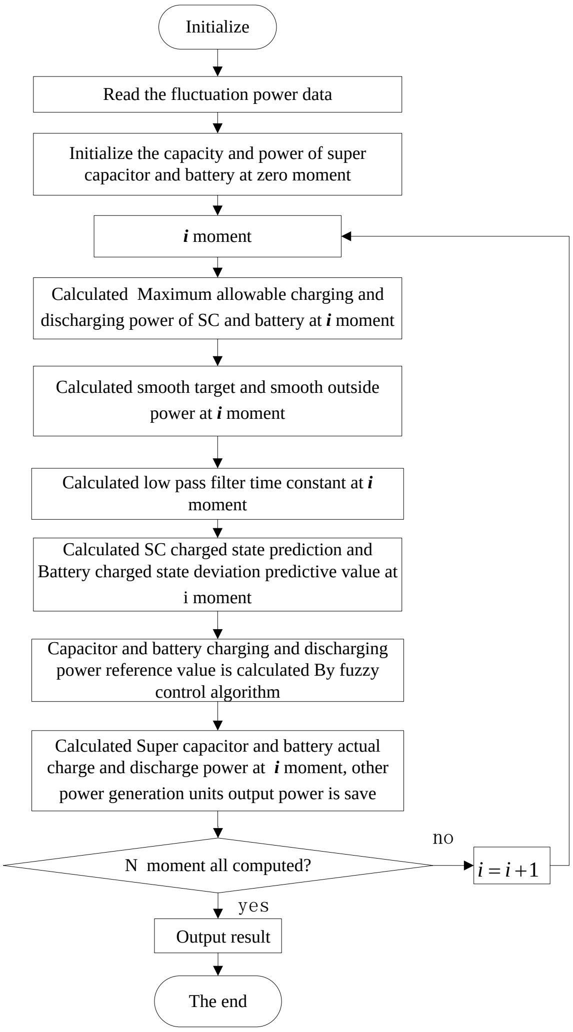


Figure 3. Hybrid energy storage unit management strategy structure

3. THE SIMULATION VERIFICATION OF FUZZY CONTROL IN PV- STORAGE DISTRIBUTED GENERATION SYSTEM

The control strategy will be validate by the 132 kW roof photovoltaic power generation system. That typical power curve is shown in figure 4. Maximum output power is 84 Kw, the minimum output power is 1 Kw, and the average power is 33.7 Kw.

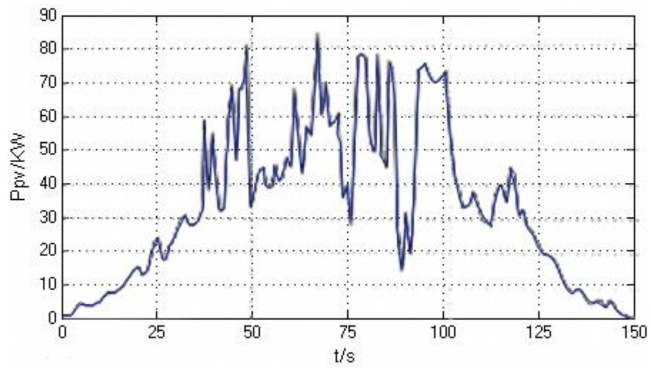


Figure 4. Output power waveform of PV power generation system

3.1 PV power spectrum analysis

As shown in figure 5, the power spectrum is obtained through the study of the Fourier transform of PV output power value. The figure shows that there are between 0.01 to 0.5 Hz frequency fluctuations, which correspond the time constant is 100-2s. And choice the filter time constant between Battery and SC in this period of time, the photovoltaic output power can be changed smooth waveform.

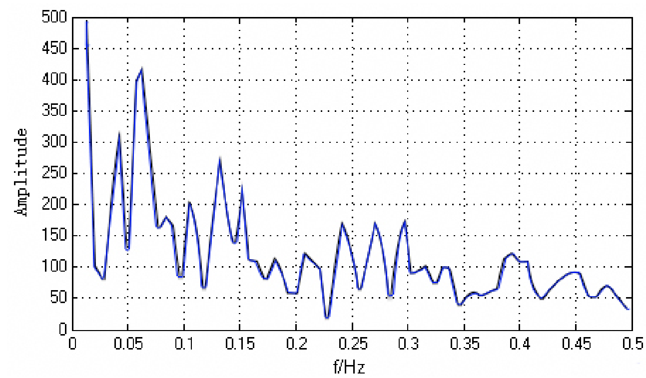
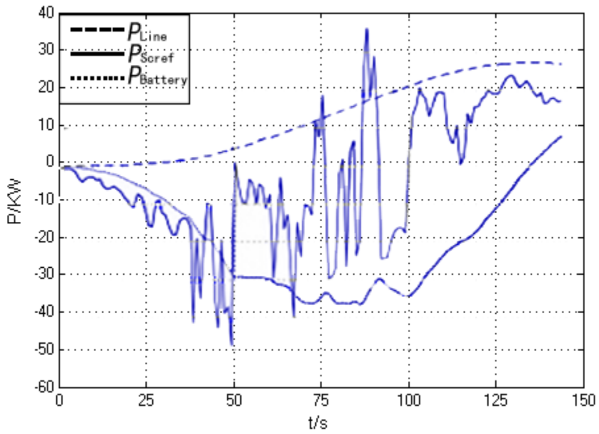


Figure 5. Output power spectrum of PV power generation system

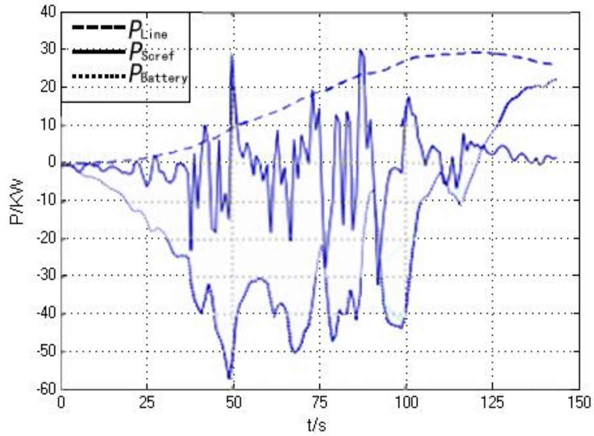
3.2 Energy storage power compensation

For the volatile components of SC and battery is process simulation analysis. The volatile components compensated the different spectrum respectively. After smoothing of the tie power line for SC and battery, and reference power respectively as shown in figure 6.

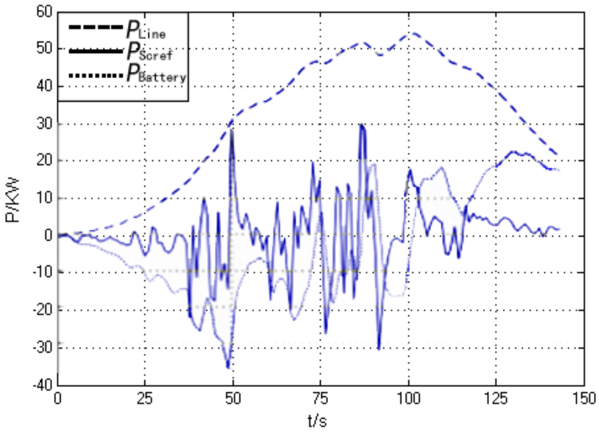
The figure 6(a) and figure 6(b) shows that when the time constant T_{bat} ia a constant value, T_{SC} changed small, the SC compensation wave frequency will be narrowed, the peak power will be smaller, focused on the zero value and the positive and negative switching, comply with the SC fast response and long cycle life characteristics.



（a） $T_{SC} = 20S, T_{bat} = 100s$



（b） $T_{SC} = 2S, T_{bat} = 100s$



（c） $T_{SC} = 2S, T_{bat} = 20s$

Figure 6. Battery, SC and tie line power waveforms with different filter time constant

The figure 6(b) and figure 6(c) shows that when T_{SC} is a constant value, T_{bat} is changed small, then the battery compensation band will be narrow, the tie line power peak is increased, battery charging and discharging power switching is very frequent, which is adverse to the battery life.

3.3 The improvement method consider battery power limitation

The figure 6 shows that photovoltaic power fluctuation range is larger in operation state. The reference power of battery also has a larger spike wave, which adverse to the battery. Using the figure 6 (b) parameters, assume that the battery charge and discharge power limit is 40 kW, then after limit value of the waveform power as shown in figure 7.

The figure 7 shows that the reference power of the battery shows more smoothly, the SC corresponding smooth space reference power is increased, that is to say, the peak power fluctuation is compensated via SC.

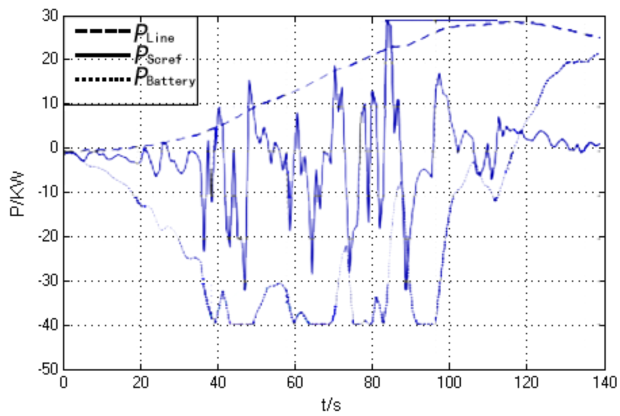


Figure 7. Reference power waveforms with limiting value

4. CONCLUSIONS

This study make the fuzzy coordinated control hybrid energy storage system apply to wind-solar-micro-storage microgrid system. The theoretical analysis and simulation research validate this method can stabilize the wind power and photovoltaic fluctuations very well. These controls let the wind-solar-micro storage microgrid system more conducive to realize the real time control and improve the efficiency of renewable energy in microgrid system.

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