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Research on converter control strategy in energy storage system of communication base station

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ABSTRACT

In the infrastructure of communication base stations, the power supply system is an important component. The bi-directional DC-DC converter of the energy storage system is important for maintaining system stability and ensuring safe operation of the load. In this paper, the mathematical model of lithium battery is studied, the topology and operating mode of the bi-directional converter for energy storage are analyzed, and the control strategy of the energy storage converter is summarized. The MATLAB/Simulink simulation results prove the effectiveness of the proposed strategy.

Keywords: Energy storage systems; DC-DC bi-directional converters; communication base stations; distributed energy sources

1. INTRODUCTION

With the full penetration of 4G networks and the continuous advancement of 5G network construction, the requirements of mobile communication networks for capacity and coverage continue to improve, and there will be more and more communication base stations[1].

Currently there are many base stations using distributed energy supply, and the base stations need to be in stable operation, should provide sufficient power to 5G base stations[2]. The distributed energy storage system composed of backup battery energy storage in communications base stations can participate in auxiliary power market services and power demand-side response, which will exert the superiority of distributed energy storage resources in power grid frequency regulation, energy capacity expansion and power quality improvement.

The bi-directional DC-DC converter is an important bridge between the DC bus and the energy storage medium. The charge and discharge state of the energy storage medium can be regulated by controlling the operating mode of the bi-directional DC-DC converter, thus achieving the purpose of stabilizing the DC bus voltage[3]. For a specific system with multi-source perturbations such as photovoltaic energy storage, the traditional double-loop control strategy based on PI controller cannot effectively suppress the large DC bus voltage fluctuations and shocks while improving the system dynamic response, resulting in poor system robustness and poor output performance[4]. To address this problem, this paper adopts a new DC-DC energy storage control strategy to ensure the stable operation of the base station.

2. ENERGY STORAGE BATTERY CHARACTERIZATION

The battery energy storage using electrochemistry is the mainstream energy storage method. Battery energy storage is electrochemical energy storage, which converts the stored chemical energy into electrical energy during the discharge process, while the charging process is the opposite. The main components of battery energy storage include the battery, controller and power conditioning system[5]. Batteries consist of cells that have series and parallel electrical connections to obtain the required voltage.

Due to the wide range of applications covering power system regulation, power system protection, rotating standby and power factor correction, battery energy storage technology can be a highly profitable energy storage technology for the distribution grid. Battery energy storage technologies that are widely used in the distribution grid include lead-acid batteries, lithium-ion batteries, and sodium-sulfur batteries[6]. Lithium-ion batteries are gradually gaining recognition in

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the market for their safety and economics and are the main form of rechargeable battery development.

(1) Lithium battery discharge model

The voltage expression for the discharge process of a lithium battery is

$$V_{\text{out}} = E_0 - K\frac{Q}{Q-\int_0^T i(t)dt}\times RI + Ae^{-B\int_0^T i(t)dt} - K\frac{Q}{Q-\int_0^T i(t)dt}\times i^* \tag{1}$$

where V_{out} is Discharge terminal voltage of lithium batteries; E_0 is constant voltage voltage source; K is Proportional polarization resistance; Q is Battery charge capacity; $\int_0^T i(t)dt$ is the actual charge charge, with constant current i at constant current charge and discharge. i can be simplified to it ; R is Battery internal resistance; i is Battery Current; A is Amplitude coefficient; B is time constant; i^* is Filter current, positive at this time.

(2) Lithium battery charging model

$$V_{\text{out}} = E_0 - K\frac{Q}{Q-\int_0^T i(t)dt}\times\int_0^T i(t)dt - RI + Ae^{-B\int_0^T i(t)dt} - K\frac{Q}{\int_0^T i(t)dt - 0.1Q}\times i^* \tag{2}$$

Where i^* is Filter current, negative at this point.

The amount of power and charge charge for charging and discharging an energy storage battery depends on the state of charge of the battery, which refers to the ratio of the remaining capacity of the energy storage battery to the capacity of the battery in a fully charged state.

$$SOC_{\text{t+1}} = SOC_{\text{t}} - \frac{P_{\text{t}}t}{E} \tag{3}$$

Where SOC_{t} is state of charge at moment t; $SOC_{\text{t+1}}$ is Next moment's state of charge; P_{t} is Charge and discharge power; E is Total battery capacity.

3. TOPOLOGY OF ENERGY STORAGE BI-DIRECTIONAL CONVERTERS

The basic circuit structure of an energy storage device bi-directional converter consists of a DC-DC converter for bi-directional energy transfer. A bi-directional current converter enables the bi-directional flow of current without changing the voltage. If the voltage is the vertical coordinate and the current is the horizontal coordinate in a planar Cartesian coordinate system, the converter can operate in quadrant 1 and quadrant 2. If the bi-directional converter can change the polarity of the voltage without changing the polarity of the current, the converter can operate in quadrant 1 and quadrant 4. In this study, a bi-directional converter that shares the main circuit, also known as a bi-directional converter, operates in quadrants one and two. Fig 1 shows the circuit diagram of the stored bi-directional converter.

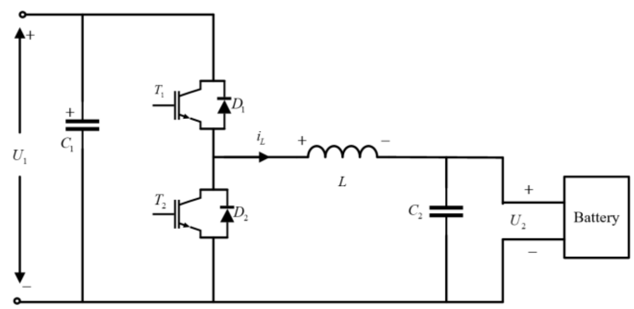

Fig 1 Circuit diagram of an energy storage bidirectional converter

The bi-directional energy storage converter shown in Fig 1 contains two switches T_1 and T_2, two diodes D_1 and D_2, and two filter capacitors C1 and C2. That is, when T_1 is in an on state, T_2 is in a cut-off state; conversely, when T_2 is in an on state, T_1 is in a cut-off state. In order to prevent control disorder caused by two tubes T_1 and T_2 conducting at the same time, it is necessary to set the dead time, so as to ensure that one of the tubes can be effectively turned off before the other tube can be conducted.

If the duty cycle is constant, when $U_1>U_2$, the power transmission direction flows from U_1 to U_2, and the power supply at U2 becomes charged; on the contrary, when $U_1<U_2$, the power transmission flows from U_2 to U1, and the power supply at U_2 becomes discharged.

4. CONTROL STRATEGIES FOR ENERGY STORAGE CONVERTERS

With the development of renewable energy and distributed generation, Energy Storage System (ESS) is getting more and more attention, which has different ways of optimizing the operation in the field of energy management: when the photovoltaic cells are subjected to insufficient solar light intensity, the energy storage system begins to release the active power, if the light intensity becomes stronger, the energy storage system's The mode of operation is transformed into absorption of active power as a way to stabilize the grid-connected power of distributed power supply and realize the optimization process of power control. According to the various functions of the energy storage system in a three-phase grid-connected PV system, there exist two general control strategies for bi-directional energy storage converters: one is the energy storage control strategy used to meet the grid power dispatch needs to achieve the stability of the grid-connected power of PV generation; the other is the energy storage control strategy used to meet the grid-connected power suppression of PV generation.

This model employs a second control strategy for smoothing the grid-connected output power and achieving reduced grid-connected power fluctuations. The storage bi-directional converter uses a dual-loop control algorithm, which is characterized by a power loop for the outer loop control and a current loop for the inner loop control.

The grid-connected PV power value is set to PPV and passed through a filter to obtain a grid-connected power given value of PPV* after removing burr spikes. The difference between the actual battery power Pb and Pb* is compared, and the error is sent to the power external loop PI regulator, the output of the PI regulator through the limiting link to get the inductance current given value IL*. The actual sampling of the inductance current IL and IL* to compare and make the difference, the error is passed to the current inner loop regulator, the output of the PI regulator is the PWM carrier. Finally, the PWM carrier is compared with the modulating wave to obtain the PWM pulse signal of the upper and lower bridge arms.

5. ENERGY STORAGE MODEL SIMULATION ANALYSIS

The main circuit of the energy storage model mainly consists of a lithium-ion battery and a bi-directional Buck/Boost circuit. Considering the output voltage of photovoltaic power generation, the parameters of the lithium-ion battery are set to the rated voltage of 400V and rated capacity of 200Ah. In order to prevent the damage to the battery due to over-discharge, the depth of discharge (DOD) in the parameters of the energy storage battery is used to measure the degree of discharge of the battery. Considering the energy storage battery used in the grid-connected photovoltaic system, the demand for frequent charge and discharge cycles is very low, and after each discharge of the battery, the battery can be floated through the grid to charge the battery, when needed it can usually be discharged to a deeper level, so its DOD value can be relatively large, relatively speaking, the battery charge state can also be relatively small. The initial charge state is set to 50% because factors such as battery losses are ignored in the simulation. This not only takes into account the discharge depth of the energy storage battery, but also leaves a certain margin for the charging or discharging process of the energy storage battery at the beginning of the simulation. The main circuit model of the energy storage device is shown in Fig 2.

The control circuit of the energy storage device is shown in Fig 3.

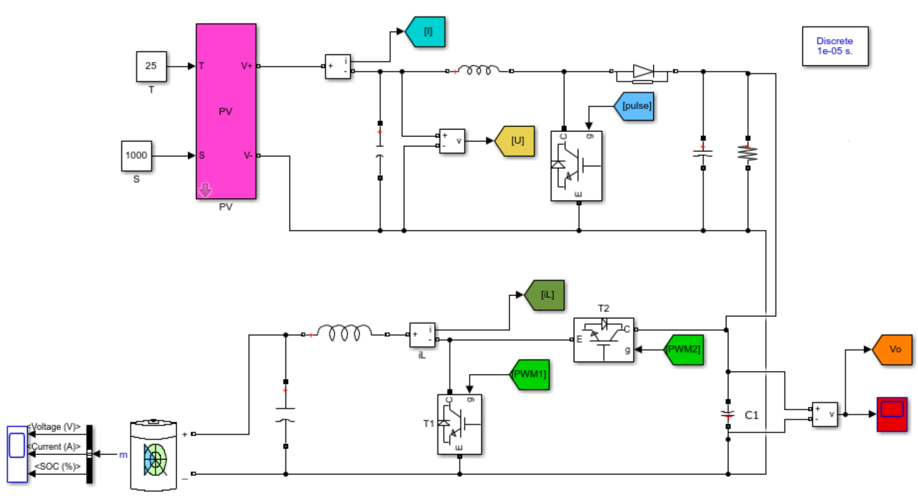

Fig 2 Model of the energy storage device

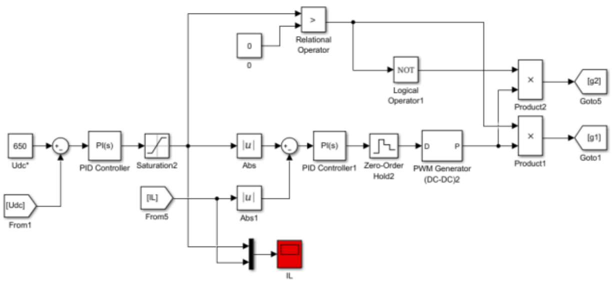

Fig 3 Control circuit of the energy storage device

The energy storage system adopts dual closed-loop control of voltage and current, and the control circuit is divided into five modules, which are DC voltage outer loop module, inductance current inner loop module, PWM generation module, energy storage operating mode judgment module, and display module (to display the reference and actual values of energy storage charge and discharge current). The input signal of the energy storage device is adjusted to simulate the changing process of external conditions. The simulation results are shown in Fig 4 and Fig 5.

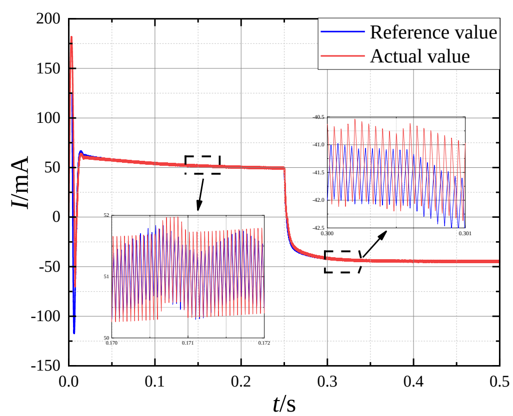

Fig 4 Reference and actual values of energy storage charge and discharge currents

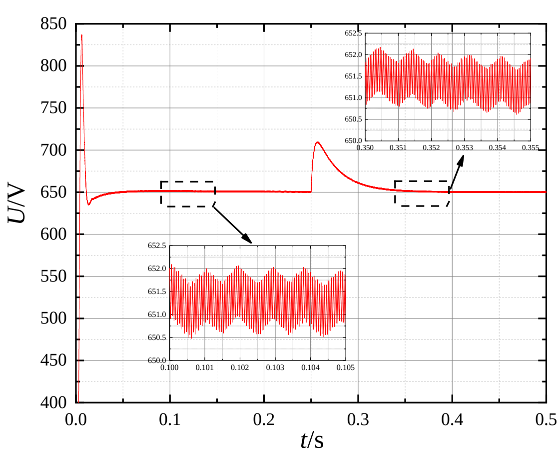

Fig 5 Variation of bus voltage

As can be seen from the waveform in Fig 4, if the current fluctuations generated when the system starts to operate are ignored, the reference value of the energy storage charge/discharge current and the actual value have a very good fit, with the reference value being the inductance current given by the output of the PI regulator through the limiting link, IL*. At 0.25s, when the external conditions change, the reference and actual values of the charge and discharge current of the energy storage system almost coincide with each other, which can meet the state transition requirements. The output current of the energy storage device is reduced from +50A to -50A, representing that the energy storage device changes from a charging state to a discharging state, thus enabling the energy storage system to better match the grid-connected power of PV, reducing the randomness and uncertainty of distributed power generation to the load of the communication base station, and improving the stability of the entire system.

CONCLUSION

In this paper, the mathematical model of lithium battery is studied, and the energy storage device is simulated in *MATLAB/Simulink* environment under the changing light conditions in a certain period of time. The simulation results show that the energy storage system can effectively adjust the charging and discharging state according to the changes of external conditions, so that it can cooperate with the grid-connected PV power to adjust the release power or absorption power state and improve the stability of the system.

At the same time, this paper is still worthy of further study in some places. Due to the limitation of the experimental conditions, the proposed control strategy is only verified by simulation, and no hardware experiment is carried out. The future research direction is to study the energy management and coordinated operation among different types of energy storage devices in the system.

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REFERENCE

[1] XU J, DUAN L, ZHANG R. Energy group buying with loading sharing for green cellular networks[J]. IEEE Journal on Selected Areas in Communications, 2016, 34(4): 786-799.

[2] SHI Y, ZHANG J, LETAIEF K B. Group sparse beamforming for green cloud-RAN[J]. IEEE Transactions on Wireless Communications, 2014, 13(5): 2809-2823.
[3] CI S, ZHOU Y, XU Y, et al. Building a cloud-based energy storage system through digital transformation of distributed backup battery in mobile base stations[J]. China Communications, 2020, 17(4): 54-62.
[4] Cai Yongxiang, Tang Wei, Xu Ouyang, et al. Review of voltage control research in LV distribution network with high proportion of residential PVs[J]. Power System Technology, 2018, 42(1): 220-229.
[5] Karamanakos P, Geyer T, Manias S. Direct voltage control of DC-DC boost converters using enumeration-based model predictive control[J]. IEEE Transactions on Power Electronics, 2014, 29(2): 968-978.
[6] Mei Yang, Li Xiaoqing, Qi Yuanyuan. Current predictive for bi-directional DC/DC converter of photovoltaic energy storage system[J]. Power Electronics, 2016, 50(5): 28-30.
[7] NIKNAM T, AZIZIPANAH ABARGHOOEER, NARIMANI M R. An efficient scenario-based stochastic programming frame work for multi-objective optimal microgrid operation[J]. Applied Energy, 2012, 99(6): 455-470.
[8] XIE YH, SUN J. Power flow characterization of a bidirectional galvanically isolated high power DC/DC converter over a wide operating range[J]. IEEE Transactions on Industrial Electronices, 2010, 25(1): 54-65.
[9] Jiaxin Yuan, Zhen zhao, Baichao Chen. An immune algorithm based dead time elimination PWM control strategy in a single phase inverter[J]. IEEE transaction on power electronics, 2015, 30(7): 3964-3975.