

Research and Application on Multi-mode Energy Storage System Smart Control

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Abstract— The smart control of energy storage system is always the hot and difficult topic of the smart grid. From the view of power distribution and utilization, we can make the original almost completely 'rigid' power system become the 'flexible' one through the establishment of the energy storage system. Also, the energy storage system can improve the power supply reliability and self-healing ability. In this paper, we study chemical energy storage system and its operating mode. In addition, we propose the architecture of multi-mode lithium-ion battery energy storage system based on on-grid and off-grid mode and the strategy of smart energy input and output switch control. Finally, we apply our achievement into the practical project. Our energy storage system provides the smart building sustained energy supply and plays an important role in cutting the power peak to fill the power valley.

Keywords— Control, Energy Storage System, Multi-mode, Lithium-ion Battery, Battery Management System

I. INTRODUCTION

Energy storage technology has been regarded as an important part of the grid operation process, which includes Power-Generation, Power-Transmission, Power-Transformation, Power-Distribution, Power-Utilization and Power-Scheduling. After adding energy storage technology to the original power system, we can make the original almost completely 'rigid' power system become the 'flexible' one. Further, we enhance the security, economy and flexibility of the grid operation process. Not only can energy storage technology achieve the effective management of the power utilization side, eliminate the peak-valley difference between day and night, smooth the load, make more efficient use of electrical equipment and reduce the power costs, but also it can improve the power system stability, adjust the frequency of the power system and compensate for the load fluctuations. Therefore, the application of the energy storage technology is bound to bring about the great changes to the traditional power system design, plan, scheduling and control [1]–[3].

The energy storage system is mainly comprised of on-grid mode and off-grid mode. The on-grid system is a self power generation system onto the grid, which can generate the power for self-use and supply the excess power to the grid. The off-grid system is an independent self-generating power system which can generate the power only for self-use. The energy storage system in this paper is designed to support the function to achieve the smooth switch between on-grid and off-grid mode.

With the changes in power consumption, the price of the general industrial and commercial electricity fluctuates periodically during a day. The price is high during the power peak and low during the power valley. In addition, there is certain regularity during the daily power consumption in buildings. Therefore, this paper will develop energy storage system control strategy, based on four switching conditions, which are Grid-bus (i.e. commercial power) voltage condition, periodic price of electricity, state of charge (SOC) and priority of loads.

This paper is structured as follows: Chapter 2 introduces the architecture of the energy storage system; Chapter 3 presents the implementation of the energy storage system, including operation mode and control strategy; Chapter 4 verifies the control strategy through the practical project; Chapter 5 summarizes the full text.

II. ARCHITECTURE

The research objective in this paper is the chemical energy storage system [10]. The main parts of the chemical energy storage system involve Integrated Energy Management System, Battery Management System, Battery Module, Load Controller, Inverter Controller, Inverter and Grid-bus, as shown in Figure 1.

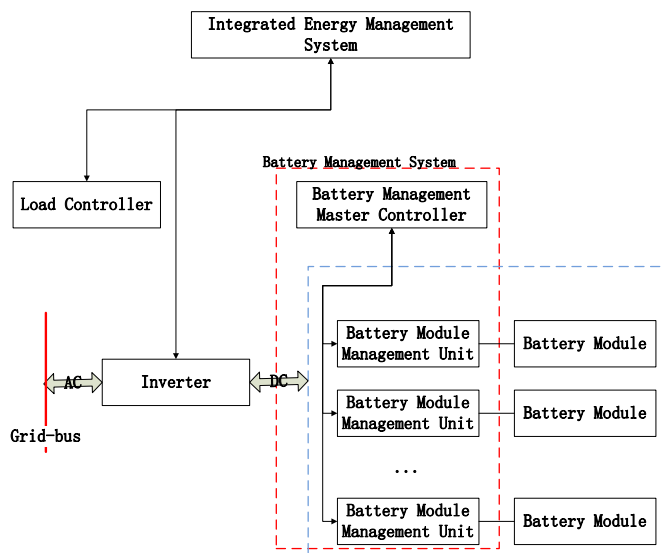


Figure 1. Architecture of the chemical energy storage system

Integrated Energy Management System monitors Inverter and Battery Management System comprehensively, collects and analyses the data from these equipments. Further, with the information of the entire system, Integrated Energy Management System can carry out power-scheduling, monitoring, prediction, power balancing and data services. The function of power-scheduling is to achieve the automatic switch between on-grid and off-grid mode on the base of the control strategy, mainly including Mode Controller Unit; the function of monitoring is to collect data from Battery Management System, Inverter and Load Controller; the function of prediction is to forecast the electricity consumption of the loads; the function of power balancing is to achieve the balance between active power and reactive power through regulating the grid, energy storage and load, to realize the smooth switch between on-grid mode and off-grid mode, and to maintain the safe operation of the entire grid system; the function of data services is to provide data services to remote calls.

Battery Management System is the integrated system that improves the utilization of the battery, prevents battery overcharge and over discharge, extends battery life and monitors the status of battery. It is comprised of Battery Management Master Controller and Battery Module Management Unit. The function of Battery Management System involves state of charge (SOC) estimate, over voltage, over current, temperature protection, balance technology between battery modules and battery modules, balance technology between battery cells and battery cells, automatic alarm and communication. Further, it transmits the battery information to Integrated Energy Management System for the whole system decision criterion.

Battery Module is the energy storage device. Electrochemical energy storage involves lead-acid [6], nickel-hydride [7], nickel-cadmium [8], lithium-ion [4], sodium-sulfur [9] and flow redox batteries [5], etc. The energy

storage system described in this paper is used in commercial buildings and we should take into account the characteristics of each kind of battery. We use lithium-ion battery as the energy storage device, because the lithium-ion battery has the characteristics, such as high voltage, small size, high energy density, fast response, long cycle life and small resistance. And there are other obvious advantages in lithium-ion battery such as manufacturing cost, safety, cycle life and power output range.

Load Controller is monitoring and controlling each load. Its function is to collect data from loads, such as power consumption of loads, and control the on-off switch of loads.

Inverter is a large capacity voltage inverter essentially, which is an interface circuit between the battery and the grid. Inverter realizes the transformation between direct current (AC) and alternating current (AC). Inverter measures and controls the current, transforms the AC information, such as voltage, current, power factor and so on, into uniform communication format and sends data to Integrated Energy Management System.

Grid-bus is a line to connect with commercial power, to provide power for the energy storage system.

III. SYSTEM CONTROL

This chapter introduces operation modes and operation states of the energy storage system first and then develops the control strategy of operation modes switch for different situations.

A. Operation Mode and Operation State

There are three kinds of operation modes in the system: on-grid mode, mid-state mode and off-grid mode. Furthermore, there are five kinds of operation states, including on-grid charge state, on-grid discharge state, standby state, breakdown state and independent state. The operation modes and operation states is shown in Figure 2.

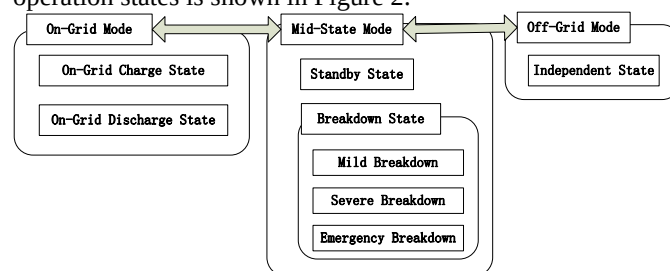


Figure 2. Structure of operation modes and operation states

1) On-grid Charge State: On-grid charge state is the state when the converter's AC side is connected to the grid and the converter controls the flow of energy from the grid side to the converter's DC side. Meanwhile the converter is using power control mode and the DC side batteries use the active balancing charge mode under the control of Battery Management System.

2) On-grid Discharge State: On-grid discharge state is the state when the converter's AC side is connected to the grid

and the converter controls the flow of energy from the converter's DC side to the grid. Meanwhile the converter is using power control mode and the DC side batteries use the active balancing discharge mode under the control of Battery Management System.

3) **Standby State:** Standby state is the state when the system is trouble-free installation, combined AC and DC circuit breakers are in place and the converter does not work in hot standby.

4) **Breakdown State:** Breakdown state is the state when the energy storage system breaks down. According to the severity of the breakdown, failures can be classified as mild breakdown, severe breakdown and emergency breakdown. In the mild breakdown state, the system is non-stop and only alarming such as overload alarm and over-temperature alarm, etc; in the severe state, the system is stopping pulse and alarming, the failures' flag resets automatically after failures disappearing and the state of the system turns into standby state; in the emergency state, the system is stopping pulse, shutting down and alarming, and both sides of AC and DC circuit breaker trips up. In addition, the failures' flag must be reset manually after removing failures. After the system detects a fault exception, the local and the remote display the failure type and the associated information.

5) **Independent State:** Independent state is the state when the converter's AC side is disconnected to the grid and the converter controls the flow of energy from the converter's DC side to the load. Meanwhile the converter is using constant

frequency and constant voltage control mode and the DC side batteries control the voltage of DC bus and use the active balancing discharge mode under the control of Battery Management System.

B. Control Strategy

Reasonable energy storage system control strategy is the key to ensure that the energy storage system switch smoothly between different operation modes. The operation modes switch is done by Mode Controller Unit, which is involved in Integrated Energy Management System.

There are four kinds of switching conditions, i.e. Grid-bus voltage conditions, periodic price of electricity, SOC, priority of loads:

- We need to consider whether Grid-bus voltage condition is normal or not. If Grid-bus is out of power, the system must switch to the independent state immediately and Battery Module supplies power to the energy storage system. That Grid-bus voltage is abnormal may result from power cuts.
- Usually there are some preferential policies in electricity utilization. The price of the general industrial and commercial electricity will fluctuate periodically during a day. The price is high during the power peak and low during the power valley.
- We need to estimate SOC accurately, preventing permanent damage to battery because of battery's over-discharge.

TABLE 1. SWITCH BETWEEN MODES

Mode (From)	Condition			Equipment			Mode (To)
	Grid-bus voltage condition	Price of Electricity	SOC	Switch	Inverter	Others	
On-grid	normal	valley					On-grid
On-grid	normal	peak	low				On-grid
On-grid	normal	peak	high	selective cut off	DC		Off-grid
On-grid	abnormal			selective cut off	DC		Off-grid
On-grid						failure	Mid-state
Mid-state						failure clears	On-grid
Mid-state						failure clears	Off-grid
Off-grid		peak	high				Off-grid
Off-grid	abnormal	peak	low				Off-grid
Off-grid	abnormal	valley					Off-grid
Off-grid	normal	peak	low	selective cut off	AC		On-grid
Off-grid	normal	valley		selective cut off	AC		On-grid
Off-grid						failure	Mid-state

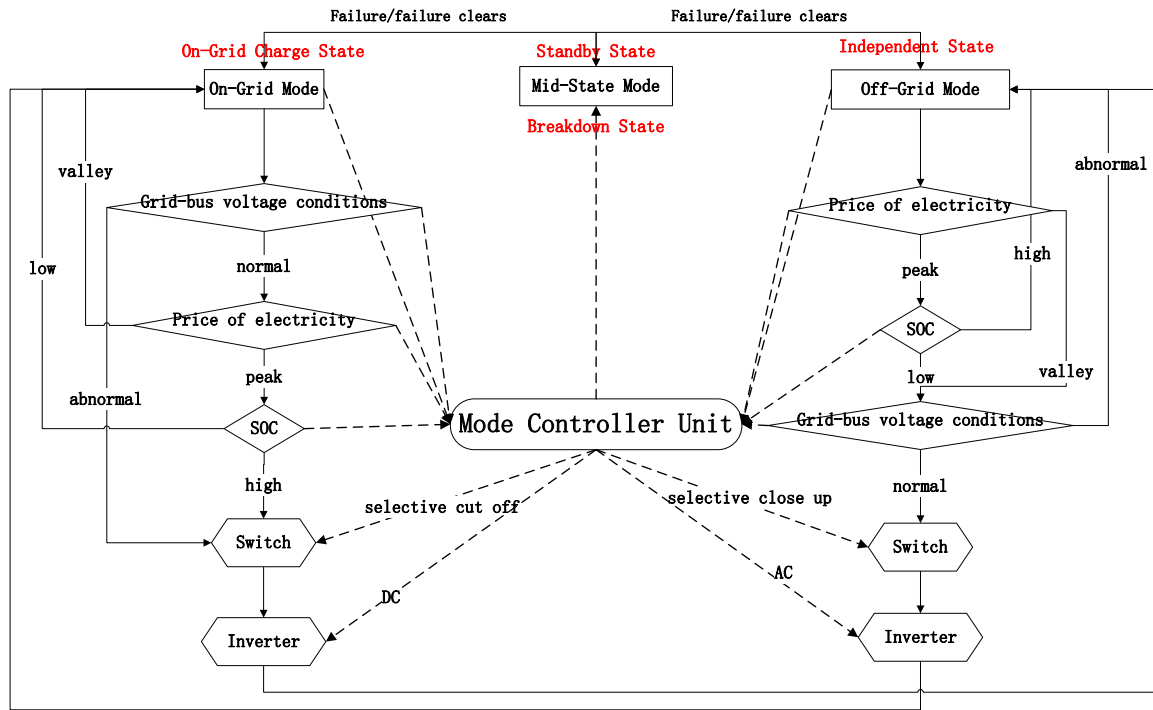


Figure 3. Flow chat of the control strategy

- In addition, we also take into account the priority of loads. There are three kinds of loads: sensitive loads, controllable loads, interruptible loads. The power of sensitive loads cannot be cut off, such as the server or emergency light; the power of controllable loads may be selective cut off, such as PCs; the power of interruptible loads should be cut off as soon as Grid-bus voltage condition is abnormal, such as common lighting equipments.

The flow chart of the control strategy is shown in Figure 3. Rectangle denotes the mode; diamond denotes the condition; hexagon denotes the controllable equipment; real line denotes the transmission between processes; dash line denotes the process control of Mode Controller Unit. There are detailed explanations about switching from the first mode to the second mode in Table 1. Take the third row of Table 1 for example. On-grid mode will turn into off-grid mode when grid-bus voltage condition is normal, price of electricity is peak, SOC is high, switch is selective cut off and inverter is under DC mode.

IV. APPLICATION AND VERIFICATION

A. Introduction of Project

We plan to set up an energy storage system for a new office building in Beijing, to supply power to loads at 9th and 10th floor, like lights and computers, etc. The power of the loads is about 24kW and the capacity of the energy storage system that we designed is about 200kWh. This project is defined as a demonstration project.

B. Architecture of Project

The architecture of the project is shown as Figure 4.

As in Figure 4, we design the energy storage unit of which capacity is 200kWh as follows:

- The rated voltage of lithium-ion battery is 3.2V and the rated capacity is 10Ah;
- Paralleling 35 batteries of 3.2V10Ah become a 3.2V350Ah cell;
- Cascading 12 cells of 3.2V350Ah become a 38.4V350Ah battery module which is put into a battery box;
- Cascading 15 battery box of 38.4V350Ah battery box become 576V350Ah energy storage unit of which capacity is about 200kWh ($350\text{Ah} \times 3.2\text{V} \times 12 \times 15$).

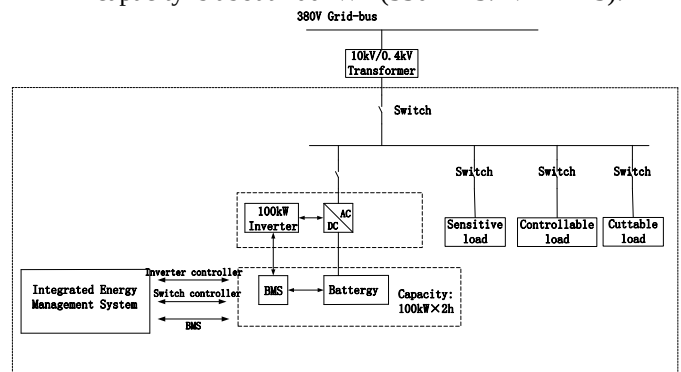


Figure 4. Architecture of project

C. Control Strategy of Project

In this project, we define SOC as follows: when the SOC of the energy storage unit is lower than 15%, we consider SOC is

low; when the SOC of the energy storage unit is higher than 95%, we consider SOC is high.

In addition, we refer to electricity price information in Beijing [4] as in Table 2. Therefore, the peak time of our system is 8:00-11:00 and 18:00-23:00 when battery is the main source of power and the valley time of our system is 23:00-7:00 when grid is the main source of power.

TABLE 2. TABLE OF ELECTRICITY PRICE

Power time	Range
peak	8:00-11:00 18:00-23:00
regular	7:00-8:00 11:00-18:00
valley	23:00-7:00

D. Operation

The operation result is fine and there are no problems temporarily.

V. CONCLUSIONS

In this paper, we have proposed the control strategy of the energy storage system comprehensively and the energy storage system that we designed runs very well.

The meaning of our work is as follows:

- This system can discharge during the peak time and charge during the valley time. Further it alleviate the daytime power pressure and cut the peak to fill the power valley;
- This system can be used as the emergency power supply when short interruption of the grid or low quality of power;
- This system realizes the energy economy.

In addition, the performance of battery, which is the core of the energy storage system, affects the operation of the battery energy storage system. On one hand, we should choose the battery of good adaptability to the environment, high energy density, small size and high efficiency. On the other hand, we still need that the battery manufacturers can develop much better batteries for us.

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