Design of Large-Capacity Battery Energy Storage System and Its Application in Coal Mine

Jianna Niu, George You Zhou, and Tong Wu
National Institute of Clean-and-Low-Carbon Energy, Beijing, China
Email: {niujianna, zhouyou, wutong}@nicenergy.com

***Abstract*—Battery energy storage technology is developing fast and has achieved widely application recently with the features of high reliability, less pollution, high flexible configuration and two-way flow of energy. This paper presents the characteristics, composition and architecture of the lead acid battery energy storage system. The design principle is also described in detail. The proposed Battery Energy Storage System (BESS) is composed of battery pack, Battery Management System (BMS), Power Conversion System (PCS) and monitoring system. According to the special safety requirements of electricity supply in coal mine, a battery energy storage technology based emergency power supply was proposed. The system will provide power support to coal mine ventilator to avoid accidents occur that caused by sudden power failure. The BESS also can be applied to hospital, communication base station and related areas where need stable and continuous power supply.**

***Index Terms*—battery energy storage system, PCS, BMS, coal mine, emergency power supply**

I. Introduction

Energy storage technology has been developing rapidly in recent years. Because of the characteristics of high reliability, less pollution, high flexible configuration and two-way flow of energy, battery energy storage technology got the most widely application [1]. It has been wildly applied in electric system to enhance the stability and reliability of power supply when a renewable energy generation system is incorporated. It can also be used to improve power quality for the industries which have high quality requirement or used as an emergency power supply in some special occasions such as hospital, communications base station etc.This paper describes the battery energy storage system including system design, component selection, system integration and architecture design. An application in coal system is also introduced in detail. The test results verify the correctness of BESS design.

II. Characteristics and Integration Process of Lead-Acid Battery Energy Storage System

Energy storage battery is the carrier to realize energy storage and release. When power grid have redundant energy, energy storage battery can absorb and storage it as chemical energy; When power grid need energy, energy storage battery can convert the energy into electricity and send back it to power grid. Fig. 1 shows the integrated process of a battery pack for BESS. It demonstrates the integration process of a battery pack: several cells connect in parallel forms a Battery Unit (BU); several battery units connect in series form a Battery Block (BB); several battery blocks connect in series form a Battery String (BS); several battery strings connect in parallel form a Battery Pack (BP).

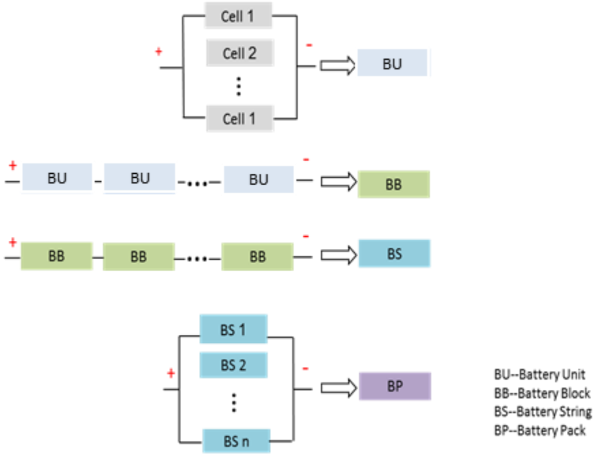

Figure 1. Integration process of a battery pack

Basic principle of battery pack design is as following:

For battery unit, the parallel quantity depends on the capacity, reliability of single battery and its connection. The number of single cells in parallel should minimize on the premise that battery performance can meet the application requirement.

For battery block, the battery module design should give priority to 8, 10, 12 units in series to keep consistent with the interface number of battery management system.

For battery string, the design should consider to match the PCS work voltage, the rated voltage of battery string is normally between 680~800V.

For battery pile, the design should consider total capacity of the system. System redundancy should also be taken into account.

Currently, various types of batteries are used to energy storage including lead-acid batteries, sodium sculpture batteries, flow cell and lithium-ion batteries etc. With the advantages of mature technology, low project investment,

Manuscript received December 31, 2015; revised June 1, 2016.

doi: 10.18178/ijoee.4.2.102-106

low manufacturing cost and rapid technology development of lead-carbon battery, lead-acid battery get more and more application in energy storage fields. Table I lists the performance parameters of four kinds of battery which are commonly used in energy storage field. The table shows that lead-acid battery has the advantages with low cost, long cycle life and high reliability [2], [3].

TABLE I. PARAMETERS OF FOUR POPULAR ENERGY STORAGE BATTERY

Performance Index	Lead-acid Battery	Sodium-sculpture Battery	Flow Cell	Lithium Battery
Working Voltage (V)	2	2	1.4	3.6
Power Density (W/KG)	75~300	150~230	120~150	150~315
Cost (U.S./KW)	300~600	1150~2250	600~1500	1200~4000
Cycle Life (Y)	5~15	12~20	15~20	5~15
Safety	Relatively mature technology, security.	Ceramic membrane is fragile, easy to cause fire or explosion accidents.	Safety, even exchange membrane is damaged, the electrolyte can be restored.	Overcharge or severe internal short circuit temperature can lead to fire explosion.

Fig. 2 and Fig. 3 respectively show the maturity and cycle efficiency of difference energy storage batteries [4]. It can be seen that lead acid battery is a high technical mature product with high cycle efficiency, so it is ideal for market application.

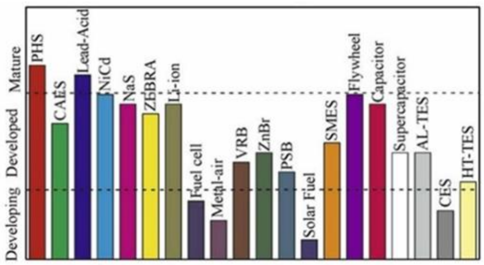

Figure 2. Technology maturity of different batteries

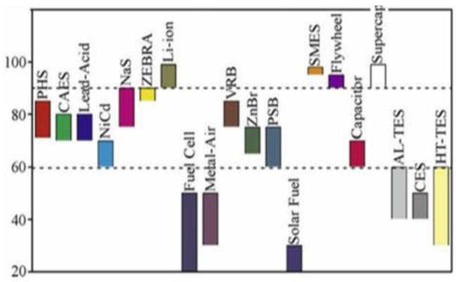

Figure 3. Cycle efficiency of different batteries

A. Structure and Composition of Battery Energy Storage System

There are three structure types of BESS to meet different applications scales. They are energy storage unit, energy storage branch and energy storage loop.

1) Energy storage unit

As shown in Fig. 4, an energy storage unit is a group with PCS, Battery Pack (BP) and BMS.

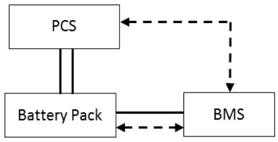

Figure 4. Energy storage unit

2) Energy storage branch

As shown in Fig. 5, the energy storage branch is composed of an energy storage unit and a low voltage switchgear cabinet. It is the basic unit of an energy storage loop; it can also be used as a complete energy storage system. The capacity of an energy storage branch is usually 250KW or 500kw when used as the basic element in a large capacity energy storage system.

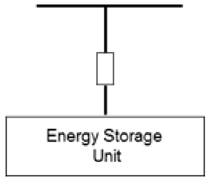

Figure 5. Energy storage branch

3) Energy storage loop

As shown in Fig. 6, energy storage loop is composed of a step-up transformer, several energy storage branches in parallel and a general monitor system, the typical power rating of an energy storage loop is 1MW~2MW.

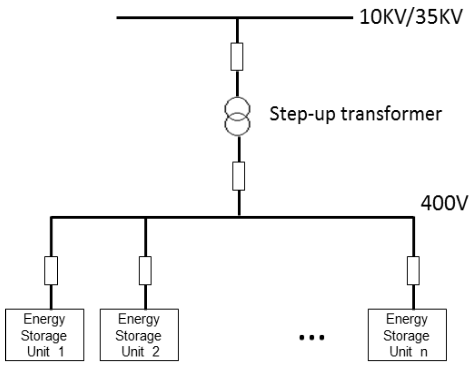

Figure 6. Energy storage loop

B. Battery Management System (BMS)

As an important part of energy storage battery system, BMS can monitoring and keep checking on the key operation parameters such as voltages, currents and the battery internal and ambient temperature during charging and discharging [5], [6]. Thus it can protect battery from over charge and discharge and then extend the battery service life; it can also provide status and parameter information to operators. Normally, there are three lays in BMS.

1) Battery Management Unit (BMU)

BMU can monitor and acquisition data including voltage, temperature, State of Charge (SOC) for single battery and battery module, it can manage the process during battery charge and discharge to ensure battery system can be used safely.

2) Master Battery Management System (MBMS)

Master battery management system is responsible for manage all the BMU used in a battery string. It can collect system current, system total voltage and detect electric leakage. MBMS can also provide protection to battery string by disconnect contactor to cut off batteries from grid when there is an unexceptional condition occur.

3) Battery Array Management System (BAMS)

As a top controller, battery array management systems is responsible for control & manage all the MBMS; it can monitor all the status information including voltage, current, temperature and SOC for all single batteries and battery modules. It will ensure all batteries in the system working in a safe and optimal state. BAMS will send battery real-time information to PCS periodically for control and protection purposes.

Based on the functional of each component in BMS, The typical design of BMS in a BESS is shown in Fig. 7.

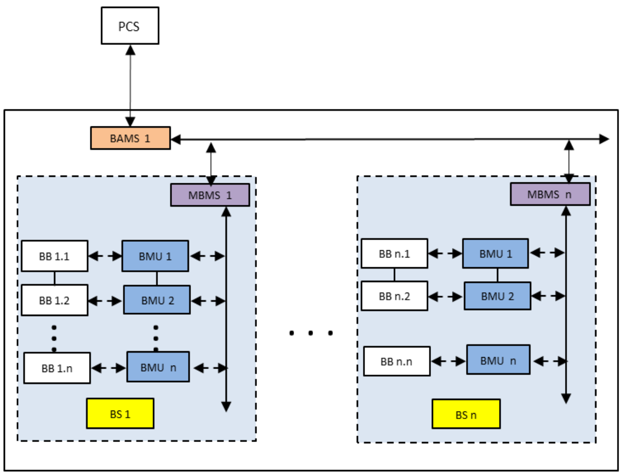

Figure 7. The typical architecture of BMS in a BESS

C. Power Conversion System (PCS)

PCS is an important part of an energy storage system; it can realize two-way energy conversion between grid and battery. PCS can work as a rectifying device to transfer current from AC to DC and storage the power into energy storage battery; as an inverter, it can transfer the energy that stored in battery into AC current and then send back to power grid. PCS have two types: single-stage circuit topology and bi-directional circuit topology, which is separately shown in Fig. 8 and Fig. 9. It can be seen from the two figures that bi-directional PCS has additional DC/DC converter compared with single-stage PCS.

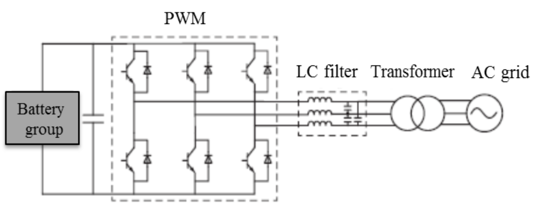

Figure 8. Single-Stage PCS circuit topology

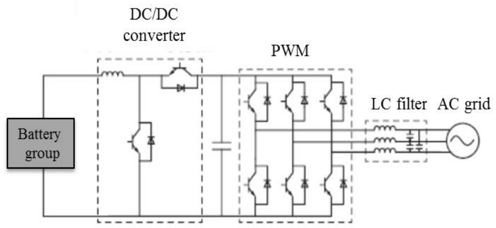

Figure 9. Bi-Directional PCS circuit topology

The characteristic of single-stage PCS is simple configuration, high efficiency and small size, but it will cause poor consistency between different batteries. For bi-directional topology PCS, the efficiency will be decreased, but the reliability will be improved and it can permit batteries configure in a more flexible way to compose a large scale system [7]-[9]. PCS has communication interface with BMS and monitoring system, which can receive battery status data and alarm information from BMS and send them to monitoring system.

D. Monitoring System

The functional of energy storage monitoring system is monitoring operation status of the whole energy storage system. It can not only collect dynamic operation information including energy storage batteries, BMS, PCS, but also can make demand accordingly to ensure energy storage system in the best working condition [10]-[13].

III. The Application of Battery Energy Storage System for Emergency Power in Coal Mine

In the past years, gas explosion accidents have been occurred frequently in many of the China's coal mines. The main reason is that local ventilator and main ventilator will both stop work when power is failure so that the fresh air can't be transported to underground coal mine, this will lead to gas accumulation and then the gas explosion accident will inevitably occur. Although China's policy requiring coal mines must be equipped with "dual-power and dual-fan", but there is only one power supply substation in most China's coal mine. Add an independent emergency power supply to local grid becomes an effective method to give a solution to prevent or reduce the accident that caused by power sudden failure. Battery energy storage system is very suitable for coal mine emergency power system application for the features of high reliability, quick response and flexible configuration [14]. Based on the design described, a 2MW/2MWh lead-acid BESS battery energy storage power station was designed combined with the emergency power supply demands from coal mine in Wuhai of Inner Mongolia. The system will provide power supply to important loads at least 30 minutes when local power is failure.

A. Demands and BESS Design

In the coal mine, the main ventilator power is 704 KW and local ventilator power is 222 KW (924KW in total). When a power failure happens, the main ventilator needs to recover within 10 minutes, but local ventilator must recover within 5 seconds, otherwise the gas concentration will rise quickly and a serious accident will possibly occur. Below content introduces the design of 2MW/2MWh energy storage unit and system.

1) Energy storage unit & branch design

Energy Storage unit's topology is shown in Fig. 10. The system is composed of 250KW PCS, 336KWh battery string and a set of BMS. Each battery string is designed with 2V/500Ah *336 cells in series. The total rated voltage of each battery string is 672V (the working voltage range is from 604.8V~789.6V). Every 12 battery is equipped with a set of BMU; in general, 336KWh battery system is composed of 28 energy storage blocks.

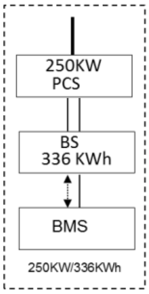

Figure 10. 250KW/336KWh energy storage unit topology

2) Energy storage system design

The architecture of 2MW/2MWh energy storage system is shown in Fig. 11. It is an energy storage loop which is composed of 8 energy storage branches (250KW/336KWh) in parallel. The 2MW/2MWh Energy storage system is connected to 6KV bus by a step-up transformer.

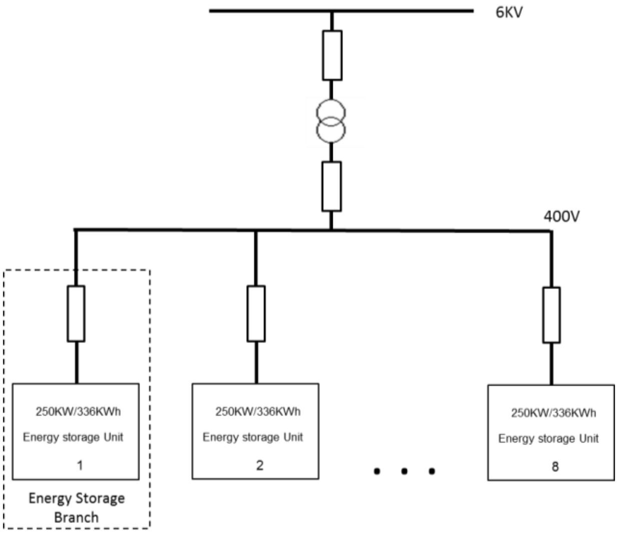

Figure 11. 2MW/2MWh energy storage system architecture

3) Monitoring system design

A monitoring system is designed to upload the operation information from energy storage battery system, BMS, PCS, interconnection switch and step-up transformer to the existed power station monitoring system; it will also conduct the commands from top monitoring system.

4) Major system Functions

When local grid works normally, BESS can play reactive compensation function; when a failure happens in local grid, BESS will play emergency power supply function and provide power to main ventilator and local ventilator to avoid accident occur. A modular design of control system allows the operator to enable and shift the different functions easily. The adding of all above functions and features makes the whole emergency power supply system more reliable, flexible and cost-effective.

B. Test

In order to verify the BESS design, ventilators in the coal mine was tested as load. The AC side current waveform of the BESS is shown in Fig. 12. It can be seen from the figure that system current is increasing gradually with the loads start and the curve is smooth and steady in whole process, it proves that the proposed BESS works very well when it plays the emergency power supply function. The experiment shows that the system current Total Harmonics Distortion (THD) is 3.21%, system working efficiency is 89.13%, which all meet the system performance requirement and product design specification.

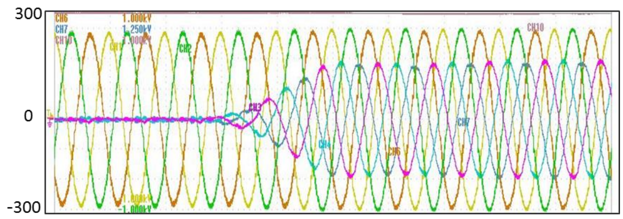

Figure 12. AC side current of BESS when running as emergency power supply

IV. Business Value and Conclusions

This paper gave the general design guide line of battery energy storage system and introduced the application of large-capacity battery energy storage system in coal mine area. With the increasing market demands from various industrial and fast development of material and power electronics technology, the large-capacity battery energy storage system will get more and more application in the near future.

Acknowledgment

The authors would like to thank Dr. George You Zhou and Tong Wu for their instructions and suggestions. Also, many thanks to our technical team for the great help during my research work.

China HTRDP (The national high technology research and development program - 863). Project Number: 2014AA052302-1.

References

[1] Z. H. Wu, "Application of battery energy storage technology in the grid network of the renewable energy power plants," *Journal of Nantong Vocational University*, vol. 28, no. 2, Jun. 2014.

[2] M. Gavin and W. G. Hurley, "Battery management system for solar energy applications," in *Proc. 41st International Universities Power Engineering Conference*, Newcastle upon Tyne, 2006, pp. 79-83.

[3] S. Y. Liu and X. Zhang, "Survey on energy storage battery in renewable energy distributed generation system," *Chinese Journal of Power Sources*, vol. 36, no. 4, pp. 601-605, July 2012.

[4] The economic analysis of the main energy storage system technology. [Online]. Available: http://www.etp.ac.cn/hdzt/135zl/ghssdt/dgmkqcnjs/201210/t20121022_3665200.html

[5] S. Q. Zhou, L. Y. Kang, and B. G. Cao, "Optimization of energy storage system in solar energy electric vehicle," *Acta Energiae Solaris Sinica*, vol. 29, no. 10, pp. 1278-1282, Sep. 2008.

[6] J. G. Liu and J. H. Zhou, "Study on storage battery device used for consumer," *Electrical Application*, vol. 27, no. 13, pp. 65-68, Nov. 2008.

[7] X. Z. Wu and X. L. Shang, "A review of electrical energy storage technologies for renewable power generation and smart grids," *Energy Storage Science and Technology*, vol. 2, no. 3, pp. 316-320, Feb. 2013.

[8] W. L. Zhang, M. Qiu, and X. K. Lai, "Application of energy storage technologies in power grids," *Power System Technology*, vol. 32, no. 7, pp. 1-9, June 2008.

[9] S. L. Li and G. X. Yao, "Research on ultra-capacitor/battery energy storage in wind/solar power system," *Power Electronics*, vol. 44, no. 2, pp. 12-14, Sep. 2010.

[10] D. L. Chen and Y. H. Chen, "Comparison study of three kinds of AC-AC converters with high frequency link," *Advanced Technology of Electrical Engineering and Energy*, vol. 29, no. 2, pp. 1-4, April 2010.

[11] M. T. Lawder, *et al*., "Battery Energy Storage System (BESS) and Battery Management System (BMS) for grid-scale applications," *Proc. of the IEEE*, vol. 102, no. 6, pp. 1014-1030, May 2014.

[12] J. H. Xue, J. L. Ye, and F. B. Wu, "The application progress of energy storage power station monitoring system in the smart grid," *Electrical Application*, vol. 31, no. 21, pp. 53-59, 2012.

[13] F. Luo and X. X. Hao, "Study on different backup power supply schemes for important clients," *North China Electric Power*, no. 10, pp. 7-9, Oct. 2013.

[14] Y. G. Zhao, "The design and selection of emergency power supply for coal mine," *Science & Technology Information*, no. 27, pp. 91-92, Sep. 2012.

Jianna Niu was born in Luoyang, Henan Province, China, December 1981, received the M.S. degree from the Chemistry and Environmental Engineering School of Changchun University of Science and Technology University in 2007.

As a Lead Engineer, she is working for the New Energy Center of National Institute of Clean and Low Carbon Energy (NICE) since September 2012. Her research interests include energy storage system integration, energy storage battery and chemistry material R&D.

George You Zhou was born in Tangshan, China, May 1973. He received his PhD degree from Ryerson University in Canada in 2000, Master and Bachelor degree from the Department of Electrical Engineering of Tsinghua University in 1998 & 1995, major in power electronics and motor control.

As the Senior Principle Scientist and certified 1000-plan talent, he had been working for the New Energy Center of National Institute of Clean and Low Carbon Energy (NICE) since December 2011. Before joined NICE, he used to work for Honeywell in Canada as a Senior Principle Engineer more than 12 years.

Tong Wu was born in Beijing, China, November 1981, received the M.S. degree from the Electrical Engineering School of Beijing Jiaotong University in 2007 and major in power electronics and AC drives.

As a Lead Engineer, he is working for the New Energy Center of National Institute of Clean and Low Carbon Energy (NICE) since October 2012. Before Joined NICE, he used to working for ABB Drives and VESTAS more than 6 years.