Embedded Battery Energy Storage System for Diesel Engine Test Applications

Jianna Niu, George You Zhou, and Tong Wu

***Abstract*—As is known to all, components of locomotive will be abraded, deformed or damaged after a period of running. In order to ensure the locomotive running stably and extend its lifetime, periodic maintenance and testing must be performed. At present, as a means of load test, water resistance test has been widely used in locomotive diesel engine test field. According to conservative estimates, the static continuous test will accounts 15 ~ 30% of the energy production through the whole engine life. It will not only cause great waste of energy, but also cause severe corrosion of metal plate. This paper proposes a novel embedded energy storage system used in an energy harvesting demonstration project which is implemented to storage the energy produced during diesel engine test process. This paper also describes the project overall design and the function of key equipment. System simulation and experiment results show that this system is stable and reliable during energy harvesting.**

***Index Terms*—Energy harvesting, energy storage, battery, power conversion system, battery management system, diesel engine test.**

I. Introduction

Before putting into operation, diesel locomotive engine is required to go through a variety of performance testing: running-in, control test and acceptance test etc. Purpose of the test is to evaluate performance parameters of the diesel engine meeting all the operation requirements required by China Ministry of Railways locomotive maintenance. Generally, the repair cycle for diesel locomotive is 230000 ~ 300000 KM and the overhaul cycle is 700000 ~ 900000 KM [1].

Fig. 1 shows the layout of water resistance test system, which is the essential means of diesel locomotive testing and maintenance at present. The AC electricity power generated by diesel engine test system is converted into DC by rectifier, and finally consumed by the water resistance.

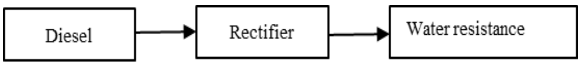

Fig. 1. Diagrammatic layout of water resistance test system for diesel engine test.

According to incomplete statistics, if all the power generated from a medium sized diesel engine testing process is converted to electrical power, which is about 1/3 power that used to manufacture the same diesel engine [2].

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Energy harvesting is a rapidly growing industry, storage devices applied in this field are various including capacitor, super capacitor and battery etc. Among them, capacitor is always used for adjusting spike power, super capacitor is used for high energy output with a fast recharge time, and battery is commonly used for sustained power distribution [3]. This paper proposed a novel embedded energy storage system (ESS) which can be applied to diesel engine test platform. As shown in Fig. 2, the system can harvest the energy produced during diesel engine test and charge the harvested energy into energy storage batteries through power conversion system (PCS). Besides, it can also feed the recycled energy to local power grid through a transformer.

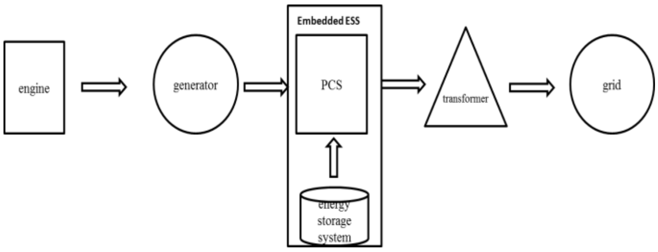

Fig. 2. The embedded energy storage system in energy harvesting demo.

II. Project Description

The overall system architecture is shown in Fig. 3. The embedded ESS consists of storage batteries, battery management system (BMS), power conversion system (PCS) and monitoring system. The whole scale of the project is 200KW/560KW·h, which is composed by two independent sets of 100KW /280 KW·h energy storage system.

III. Design and Functional of Embedded ESS

A. Battery Storage System

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 [4], [5], which match the project requirement exactly.

Two groups of lead-acid batteries (350 in series with the specification of single cell 2V / 400 Ah) is applied to harvest the energy that is produced during diesel engine test. Fig. 4 shows the layout of the battery pack in the container, each 280KW·h energy storage battery pack is placed inside a standard 20-foot container, 14 battery blocks are separately set on both side of the container. Enough space between the two rows of battery is reserved for later operation and maintenance. Battery management system (BMS) is located on the left side of container. Air duct is located at the back of battery holder; through that air can be conducted to each battery to guarantee batteries can be used at an optimum temperature.

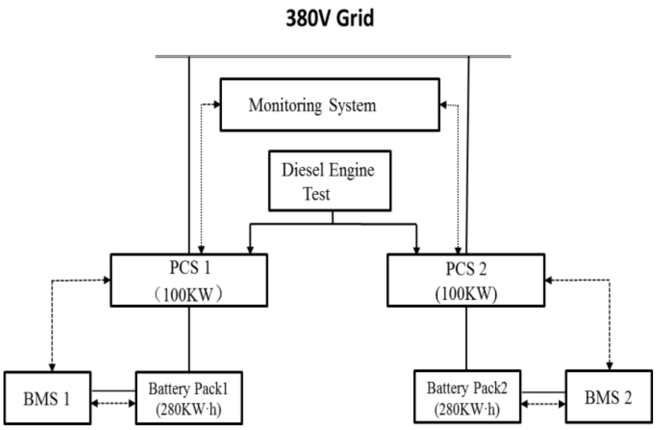

Fig. 3. Architecture of energy harvesting demo.

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.

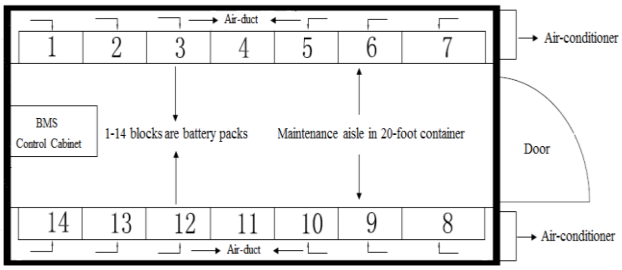

Fig. 4. Layout of 280KW·h energy storage battery system

B. Battery Management System (BMS)

1) BMS architecture design

The structure of BMS applied in the project is divided into two layers: battery management unit (BMU) and energy system management unit (ESMU). BMU is used to acquire sing battery information including voltage, current, temperature etc. As top layer, ESMU can collect all batteries running data. Besides that, it can also control & manage BMU to ensure all the single batteries can be used fairly. As shown in Fig. 5, there are totally 14 sets of BMU and 1 set of ESMU is applied. Every single BMU module is able to collect up to 25 battery cell's parameter information. All the information of battery will be send to PCS periodically for the control and protection purposes.

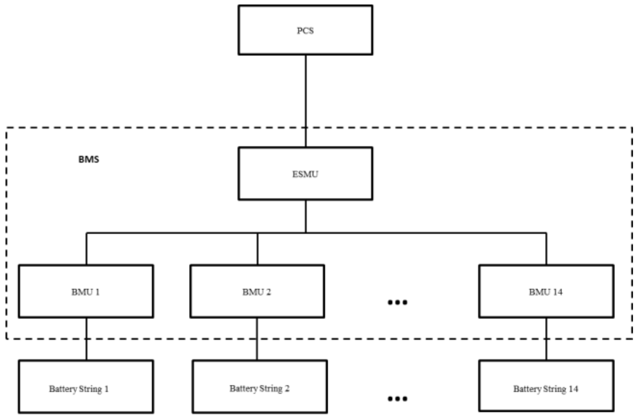

Fig. 5. Architecture of BMS.

2) The function of BMS

The battery management system (BMS) controls how a storage system will be used. In addition, the application of BMS will also offer better robustness for the storage system [6]. As an important part of energy storage battery system, BMS is used to monitor, evaluate, and protect the energy storage batteries [7]-[10].The major functions of BMS are:

1) Collect battery working data real-timely and upload the information to PCS and energy storage monitoring system;
2) Protect the security of energy storage batteries during charging and discharging;
3) Emergency alarm;
4) Accept monitoring system's operation scheduling and conduct actions accordingly.

C. Power Conversion System (PCS)

1) PCS architecture design

The characteristic of diesel engine test is intermittent as the schedule of test plan and requirement of debugging and repairmen, which require PCS must be extremely durable and can running for months without breaking down. The existing standard PCS will cause much higher voltage ripple when directly interface with storage battery, which will eventually create higher current ripple to shorten the battery life. Fig. 6, Fig. 7 and Fig. 8 embody three possible architectures of PCS combining with energy storage system connecting to AC grid.

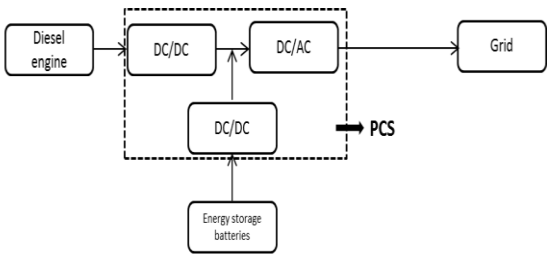

Fig. 6. Architecture of PCS with DC connected energy storage battery.

As shown in Fig. 6, in order to avoid the damage of high ripple to lead acid batteries, a general solution is to add DC/DC converter between battery system and common DC bus.

Fig. 7 shows the architecture of standard ESS which combining with energy storage system at AC grid system.

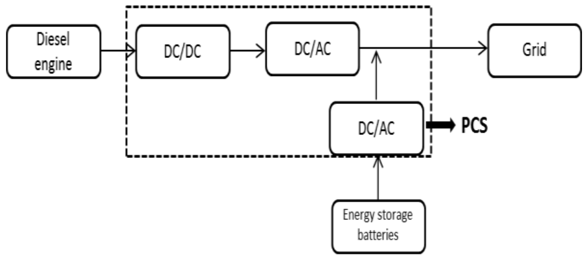

Fig. 7. Architecture of PCS with AC connected energy storage battery.

Instead of the above ESS architecture which combining with energy storage system at grid system by adding DC/DC module or DC/AC module, Fig. 8 presents a novel architecture that internally embedded with energy storage components. The obvious benefit of the proposed scheme is to save one third cost of power conversion system. The realization of the system only need minor software modification on the standard commercial product.

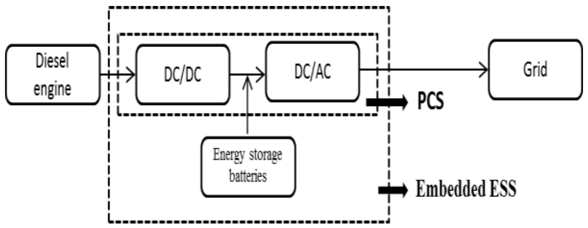

Fig. 8. Architecture of PCS with energy storage batteries embedded.

2) PCS working function

As a core equipment of the embedded energy storage system, PCS can harvest the energy produced during diesel engine test to large capacity energy storage batteries, beyond that, PCS can also feed the recovered energy back to 380Vpower grid.

PCS has four working modes:

1) Dispatch diesel engine energy to local load directly;
2) Dispatch diesel engine energy for battery charging;
3) Charge batteries from power grid;
4) Discharge batteries to power grid.

3) PCS communication function

PCS has communication interface with BMS and monitoring system, which can receive battery status data and alarm information from BMS and send to monitoring system. Besides that, PCS can exchange information with monitoring system and conduct user command from operator.

D. Monitoring System

1) Function of monitoring system

Energy storage monitoring system is responsible for supervise and control operation status of the whole energy storage system. It can collect dynamic operation information including diesel engine, energy storage batteries, BMS, PCS and local load, and then make demand accordingly to ensure energy storage system in the best working condition [11], [12].

The main function of monitoring system includes:

1) Display detailed information of measurement device, battery system, BMS and PCS;
2) Remote PCS to do four patterns of power control;
3) Record history operation data.

Fig. 9 shows the wiring interface diagram of monitoring system.

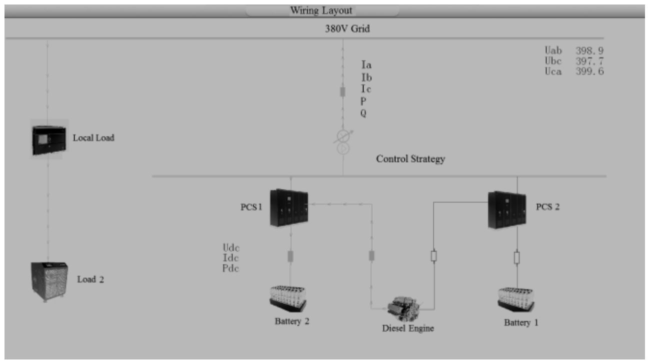

Fig. 9. Surface of wiring layout for monitoring system.

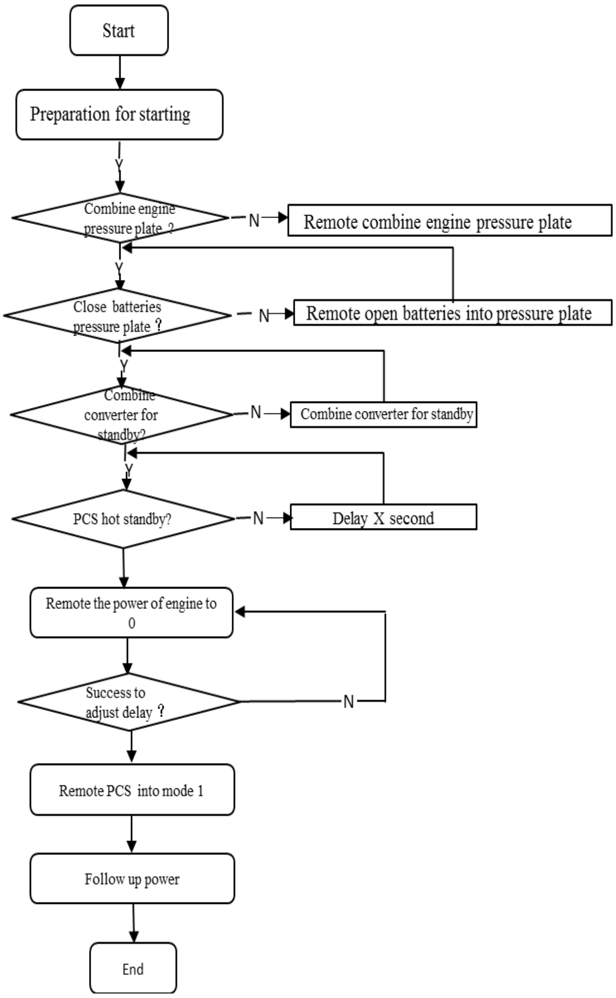

Fig. 10. One of the control strategies of monitoring system

2) Control strategy of monitoring system

Energy storage monitoring system will adopt different control strategies according to the amount of energy produced during diesel engine test and factory load to ensure the energy storage system can be operated stable and reliable. Fig. 10 shows the control strategies for PCS sending back power to power grid.

IV. Simulation and Experimental Results

A MATLAB simulation model and a 100kw prototype are built up and developed in order to verify the stability of the embedded energy storage system (ESS). The simulation and test results are shown as Fig. 11 and Fig.12. Fig. 11 shows the simulation waveform of the ESS running at 80 KW AC load, the results demonstrate that the system is stable and reliable.

1) Stage I: Grid provides 100% AC load current.
2) Stage II: With the increasing of ESS's output power, AC load get lower energy from grid.
3) Stage III: ESS provides 100% power to AC load.

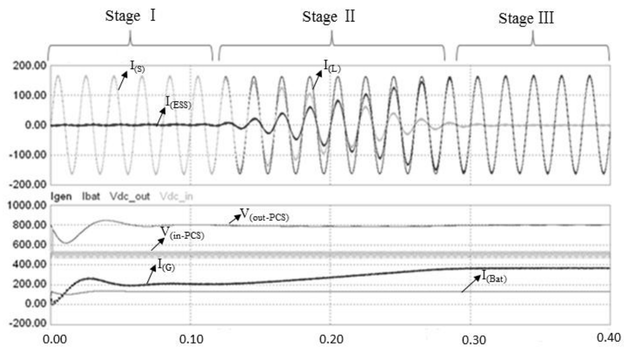

Fig. 11. Simulation waveforms of energy storage system.

In the above part of Fig. 11, $I_{(ESS)}$ is the AC side output current of ESS; $I_{(S)}$ is the current that power grid provides to local load; $I_{(L)}$ is the actual consumption current of AC load. In the figure below, $I_{(G)}$ is the output current of diesel engine; $I_{(Bat)}$ is the charging current of battery system; $V_{(out-PCS)}$ is input voltage of the battery system; $V_{(in-PCS)}$ is DC input voltage of the energy harvesting system.

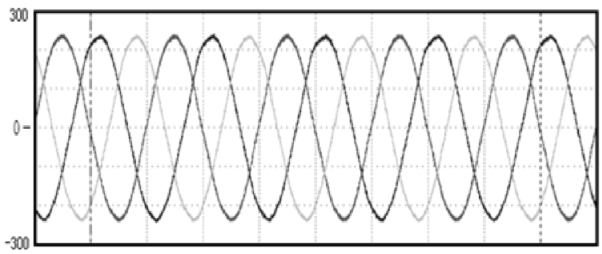

Fig. 12. The AC side current of 100KW prototype.

V. Conclusion

With the rapid development of economy, resource shortage and environmental pollution has become an important factor that will restrict the progress of human society. Since that, the development of efficient energy storage device for renewable energy harvesting is particularly urgent. This paper firstly proposed a novel embedded energy storage system applied to diesel engine test platform for energy recovery. Secondly, the system architecture, composition of equipment and its function are introduced. Finally, the simulation and experiment results demonstrate that the system runs stable and reliable in the energy harvesting process. The application of proposed system can effectively solve the energy waste problem during diesel engine test and benefit other similar industrial field.

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