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Repurposing Second Life EV Battery for Stationary Energy Storage Applications

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Abstract—As global adoption of electric vehicles (EVs) increases, the need for sustainable solutions to manage end-of-life EV batteries becomes more pressing. This paper presents a battery energy storage system (BESS) that represents a novel approach to sustainable energy storage by repurposing end-of-life Tesla battery modules for stationary applications. The modules have been assembled and controlled in a robust and scalable design that offers versatile deployment options and economic benefits. Various use cases are described for these types of applications, such as energy management, backup power supply, demand response, grid support, and price arbitrage. An emphasis is placed on the grid services and benefits for end users. The system architecture is discussed in detail with a focus on the main components such as battery management system (BMS), the battery modules, and the inverter, and preliminary test protocols are outlined, including charge-discharge cycles and performance under different load conditions. These tests aim to evaluate the reliability, efficiency, and energy storage capabilities of the system, providing insight into its feasibility for real-world applications. The paper explore the capacity of the system of providing voltage stability between the series of the modules in low voltage conditions.

Index Terms—Second-life battery, Tesla modules, Battery energy storage system

I. INTRODUCTION

The exponential increase in EVs across Europe marks a significant shift in the region's transportation sector [1]. This change is driven by environmental imperatives, regulatory incentives, and technological advancements. The adoption of EVs is on an upward trajectory, reshaping not only the automotive sector but also the electrical grid. As the number of EVs increases, the demand for electricity to power these vehicles also increases. This surge in electricity consumption, particularly during peak charging periods, places a strain on the existing grid infrastructure [2]. Consequently, this requires upgrades and innovative solutions to ensure reliability and stability [3]. In this transition process, the adoption of a BESS appears to be a suitable solution [4]. These systems contribute to grid stability and, among others, can assist in peak shaving applications. The storage system can be installed at various levels, from large energy production plants to residential settings. As the EV market expands, so does the challenge of responsibly managing end-of-life batteries. In

the future, we will face an increasing need to dispose of EV batteries that are no longer suitable for mobility applications [5]. The recycling process of a lithium-ion EV battery involves significant energy costs and can represent a missed opportunity to repurpose the EV battery for other applications [6]. The concept of 'second life' applications for electric vehicles has gained global traction, aligning with the principles of a circular economy. By extending the lifespan of lithium-ion batteries beyond automotive use, we not only reduce the demand for raw materials, but also optimize the value chain of energy storage. As explained in [7] EV batteries are usually retired from automotive applications after the residual capacity drops below 80%. From this point on, battery reuse for a second life application is economically preferred to recycling [8]. EV batteries possess several characteristics that make them optimal for stationary applications, such as being designed to withstand i) high instantaneous currents and ii) rapid charge/discharge cycles [9]. Consequently, EV batteries tend to degrade at a slower pace and maintain more stable performance over time [5]. This inherent resilience makes them well-suited for stationary applications. Additionally, a battery for stationary application does not require a high-energy density level. Therefore, it is possible to arrange cells and modules to achieve better temperature management and more optimal environmental conditions.

Stationary storage systems based on batteries obtained from EVs are usually NMC or NCA cells [5]. These cells typically have an unclear but generally high number of cycles, which translates into a lower State-of-health (SOH). Several considerations about SOH estimation are explored in [10]. Furthermore, this system benefits users both as investors in storage systems for network services and as electric vehicle owners. Even when a vehicle battery reaches the end of its useful life, it can still be repurposed for stationary applications with minimal investment. The system described in this paper is a BESS composed of several Tesla Model S P85 modules, arranged in a two series eight parallel configuration for a total nominal capacity of 84.8 kWh. This BESS will be installed on the island of Samsø in Denmark. The installation site is a complex that includes several buildings equipped with solar panels, heatpumps and EV chargers. In this paper, we will explore various potential use cases of repurposed EV

batteries in residential energy storage systems. In Section II, we describe different scenarios and applications in which such a system can provide significant benefits, such as enhancing energy efficiency in homes, supporting the integration of renewable energy, and providing backup power during outages. Following this comprehensive exploration of use cases, in Section III, we present a detailed description of the system design, including its components, architecture, and integration of recycled batteries. In Section IV, we outline a series of tests that will be performed to evaluate the system performance. These tests include assessments of charge-discharge cycles, capacity, efficiency, and response to dynamic load conditions. Each test is designed to provide information on the reliability, durability and overall effectiveness of the system in real-world applications.

II. REVIEW OF APPLICATIONS

This proposed BESS opens up a spectrum of possibilities for residential use. In this section, we will describe the diverse range of functions and services that this type of system can offer within a residential setting. Generally, we can categorize the different applications into three distinct categories such as i) time control is a control method that instructs the BESS to absorb energy during times of relative surplus and to discharge stored energy during time of relative needing, ii) power control(peak shaving), involves the variable dispatch of energy in order to prevent the power level at a point of reference from exceeding a given threshold.iii) energy control is a common operating principle focused on maintaining a target state-of-charge (SOC) for the BESS, enabling it to execute some core functionalities. For example is used to maintain a BESS on average at the 70% of SOC to preserve it. These concepts are well described in [11].

A. Enhanced energy management

One of the primary functions of repurposed battery systems in residential settings is to optimize energy management [12]. These systems store surplus energy generated from renewable sources, such as solar panels [13], during periods of low demand. This enables homeowners to maximize self-consumption and reduce dependence on the grid [14]. In addition, intelligent energy management algorithms can dynamically adjust battery charging and discharging patterns based on electricity tariffs, peak demand periods, and weather conditions [15]. This further optimizes energy usage and cost savings.

B. Backup power supply

During blackouts or emergencies, these systems switch to battery power, ensuring uninterrupted electricity supply to critical appliances and systems, such as lighting, refrigeration, and communication devices. This improves the resilience of the residential infrastructure and provides safety for homeowners, particularly in regions prone to extreme weather events or grid instability [16]. This application seems to be particularly suitable for residential complexes located in remote islands,

where the connection to the power grid is usually made by means of a single land connection. This application is also suitable for off-grid solutions [17].

C. Demand response and grid support

Residential battery systems can participate in demand response programs that contribute to the stability and efficiency of the electric grid [18], [19]. Through demand response, homeowners can voluntarily adjust their energy consumption patterns in response to grid conditions or pricing signals. This alleviates strain during peak demand periods and potentially earns incentives or credits. Additionally, aggregated battery systems can offer ancillary services, such as frequency regulation and voltage support, enhancing grid reliability and facilitating the integration of renewable energy resources [20]. Practical examples of these types of applications include RES firming, where the BESS is employed to maintain the power output from a variable power source at a static value for a committed period. Another example is power smoothing, where BESS compensates for rapid changes in power level.

D. Electric vehicle charging integration

By leveraging surplus energy stored in the battery during off-peak hours, residents can charge their EVs more efficiently and economically, thus reducing the strain on the grid. This function performs better when used in synergy with photovoltaic (PV) or wind energy production systems, possibly by applying smart charging [4], [21]. This possibility is particularly appealing in Denmark due to the high penetration of renewable energy into the energy production mix, which results in periods of very cheap energy prices.

E. Price arbitrage

The BESS can engage in energy arbitrage by purchasing electricity from the grid during periods of low prices and selling it back during peak demand periods or when prices are higher. This allows homeowners to capitalize on fluctuations in electricity markets, potentially generating revenue or offsetting energy costs over time [22]. Additionally, participation in utility or aggregator programs, such as virtual power plants or capacity markets, can unlock additional revenue streams for residential battery owners, further incentivizing adoption and investment. This type of application is particularly appealing in scenarios where EV expired modules are used in residential applications, allowing the owner to fully exploit their potential and achieve a return on investment [23].

III. SYSTEM OVERVIEW

The system consists of eight Tesla modules connected in parallel and BMS connected in series with the two parallel connections. The BMS is connected to both the positive and negative sides of the battery pack. This is because the contactor is connected to the positive side inside the BMS and the shunt resistance for the current measurement is connected to the negative side. Afterwards, BMS is connected to the inverter and the master controller. A system scheme and lab setup is

shown in Fig.1. For the laboratory setup, we included just two modules out of 16 modules.

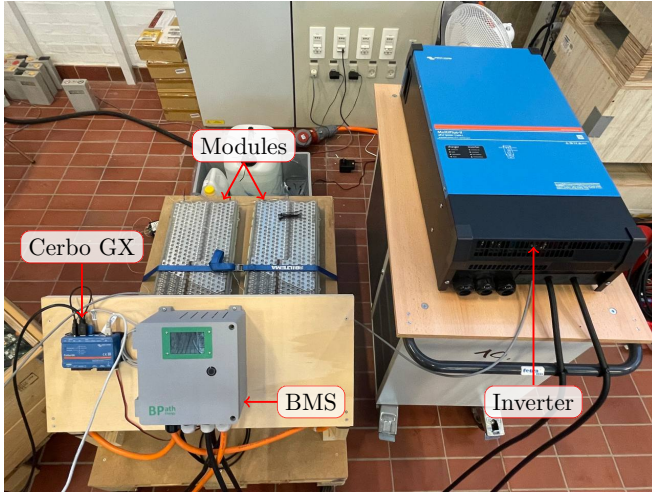
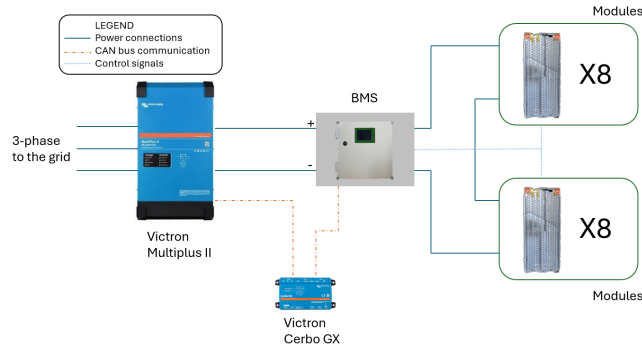


Fig. 1: Complete scheme of the system and the laboratory setup.

A. Battery modules

The battery modules (see table III-A) are connected in two series eight parallel configurations, for a total nominal capacity of 84.8 kWh. The modules were collected from Tesla Model S P85 which is no longer available to drive. However, the previous cycles of the modules and their life expectancy are unknown. In the laboratory setup, only two modules connected in series were included. Each battery module is equipped with a slave BMS, as shown in Fig.1, that is a board that acquires all the voltage, current, and temperature measurements and transmits them to the Tesla Master BMS or an analogue device.

B. Battery management system

The chosen BMS for this setup is the BPath Energy BATTERY MODULE CONTROLLER XL, shown in Fig.1. This device can connect both Tesla modules and Victron hybrid inverter through different CAN channels. All slaves BMS in each of the modules and BMS are connected through a single CANBUS channel to send all the collected information to the master BMS. As show in Fig.2 he BMS is equipped with a 400 A contactor and a current measurement sensor. It has the function of balancing the modules during the charge and discharge phases. It is also responsible for interrupting

TABLE I: Module characteristic

Quantity	Value	Measure unit
Original Capacity	5.3	kWh
Nominal Voltage	22.8	V
Maximum Voltage	25.2	V
Minimum Voltage	18	V
Module configuration	6s74p	
Discharge current	225	A(continuous)
	1000	A(10 s)
	1500	A(3 s)
Charge temp. range	0-45	°C
Discharge temp. range	-20- 60	°C

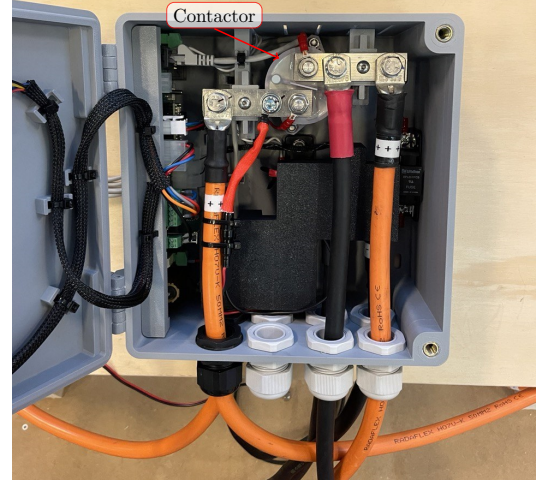
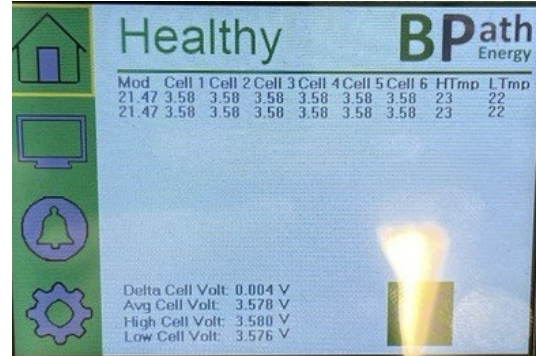


Fig. 2: Cell voltage measurement and internal view of BMS.

battery disconnection when SOC is too low or when it reaches maximum charge. The BMS is connected in series with the modules, enabling it to disconnect the circuit. It is also connected with every slave BMS in each module to acquire information about the battery cell.

C. Inverter

The system is equipped with the Victron Multiplus II inverter. It has a DC voltage port of 48 V and an AC voltage port between 187 and 265 VAC at 50 Hz. The maximum efficiency is 96% and comes with protection against short circuit of the output, overload, battery voltage too high or too

low, temperature too high, and input voltage ripple too high. The inverter is connected to the Cerbo GX control device. It is also possible to connect multiple inverters in parallel to compose a three-phase system.

D. Master control

The Cerbo GX is essentially a Victron-made management and monitoring device to control the entire system. It features a touchscreen and several communication ports, with the added capability of being controlled via an Internet (ethernet port) connection. The Cerbo GX can be connected to all devices in the system. It can show the SOC of the batteries and the different configurations of the inverter. It is also responsible for the inverter monitoring during the charge and discharge phase, the current limit control, and faults due to missed connection with one of the components.

IV. TEST CASES

The purpose of the tests is to confirm the reliability, efficiency and capacity of the BESS under various operating scenarios. In this paper the reliability part was more deeply explored while future works will focus more on the efficiency of the system.

A. Safety tests

To ensure that the system is operating as intended, a safety test is required. When the voltage hits the maximum allowed value, the BMS must stop the charging cycle; similarly, when the voltage hits the cutoff voltage, it must stop the discharge cycle. Software is used to insert each of these values. All safety features, such as the cell unbalancing fault and the high-temperature fault, have been tested, and their correct intervention has been verified. Every fault has two levels of intervention; when the fault level is approaching, a warning alarm is shown, and then when the fault level is reached the BMS reacts with the opening of the internal contactor and the disconnection of the system.

TABLE II: BMS fault test.

Fault description	Fault alarm event	Disconnection event
High temperature	verified	verified
Low temperature	verified	verified
High voltage	verified	verified
Low voltage	verified	verified
Cell imbalance	verified	verified

B. Battery tests

These tests are meant to confirm the current state of the module. The modules are tested individually to verify the SOH of the cells through a deep discharge cycle in which the residual capacity of the module is obtained and is tested the behaviour of the cells in low voltage conditions. Other tests that are performed measure the speed of the cells in changing the current supply in order to verify that they can perform service on the network. The single modules are tested through

a constant current discharge. The test presented in this paper has been performed in a single module discharged at a constant current of 40 A, subsequently raised at 50 A for technical reasons. Figures 3, 4 show the voltage, current, and maximum and minimum cell voltages, respectively. The purpose of the test was to verify the BMS behavior of a low-voltage module. In the last part of the discharge, the maximum and minimum cell voltages are more separate but still included within the safety parameters.

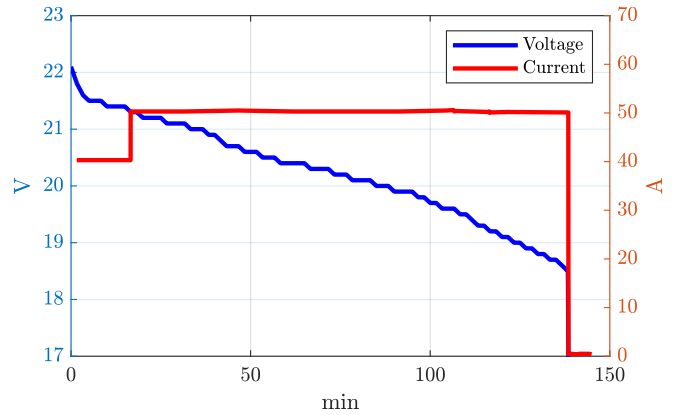


Fig. 3: Battery voltage and current during the discharge, when the low voltage limit is approached, the BMS opened the contactor and stop the discharge, taking the current to 0A.

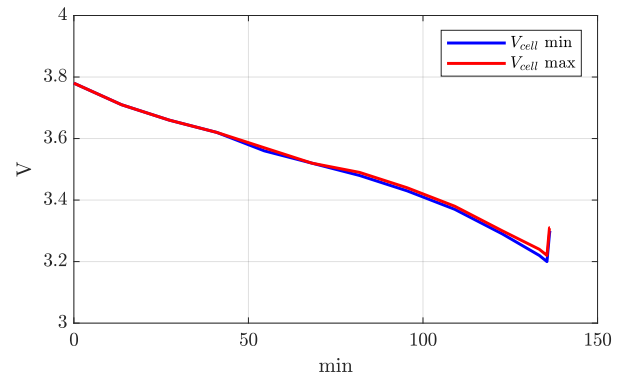


Fig. 4: Maximum (red) and minimum (blue) cell voltage during the discharge. The BMS keep them balanced, is possible to see a little difference in the end of the discharge, but is always under 0,01V.

C. Inverter tests

These tests confirm that the system's inverter can meet the requirements listed in TF3.3.1 in order to be connected to the grid [24]. The testing process will be similar to that described in [24], [25]. The system needs to handle several functions. It must respond to frequency deviations by adjusting the power at the point of connection when the grid frequency surpasses a certain threshold. Additionally, it sets an absolute

power limit for both absorbed and delivered active power. It also controls the rate of change in active power within a defined time frame. The system regulates the reactive power and adjusts the power factor, allowing independent control. Lastly, it can automatically activate the power factor control based on voltage levels.

V. CONCLUSION

This paper provides a general description of the state-of-the-art in the second-life batteries and gives a comprehensive overview of the applications for this type of system, covering functions ranging from grid services to end-user energy management. The system description focuses on individual components such as the BMS, inverter, master controller, and battery modules. The test case part pursued the evaluation of the technical and performance capabilities of this second-life battery application. The behavior of the module during a discharge in low voltage conditions has been tested as well as the BMS intervention for fault events. The tests conducted in the laboratory setup have shown that the system is able to intervene in case of fault events promptly and to maintain the voltage level between the series balanced even in low-voltage conditions. The primary goal of this experiment is to obtain a second-life battery system correctly functioning and able to be connected to the grid. Future tests in this system will explore cell degradation in this type of application and the test procedure to ensure the safety and correct operation of the system.

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