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Development and Investigation of a modular stationary Second Life Storage System

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Abstract

Fig. 1: The developed second life stationary storage system (left) and its internals (right)

A growing market penetration of battery and hybrid electric vehicles is going to result in an increasing number of discarded batteries in the next years [1]. At the same time a growing trend towards renewable energies and decentralized generation like wind and photovoltaic (PV) raises the need for decentralized electrical storage capacities [2]. Combining these two trends, stationary battery storage systems built out of used vehicle batteries – so called Second Life Storage Systems – could potentially support to solve the storage problem for the energy sector but also stabilize the residual value of electric vehicles [3].
In order to investigate the applicability of used vehicle batteries for second life and to analyze the corresponding repurposing process, we developed a modular stationary storage system with 9 kWh energy content out of the battery pack of a 2010 Daimler Vito E-Cell. In this poster we present first results of the state determination of the used vehicle battery and second give an insight into the dimensioning of the final storage system for residential use. Finally, we take a look at the nowadays complex and cost-intensive repurposing process and present a new innovative approach to streamline the same.

End of life condition of the battery pack

For the investigations a battery pack of the 2010 Daimler Vito E-Cell with a total mileage of 30968 km was used. The pack consists in total of 16 modules connected in series which themselves are composed of 12 prismatic cells (50Ah) connected 6s2p. This way each module has a nominal voltage of 22,5V and a total initial energy content of 2,25kWh. In the development process of a stationary second life storage system you first of all need to know the actual state of the battery system (especially its remaining capacity). Since no data (e.g. from the battery management system) was available, measurements needed to be done. Depending on the intended reuse scenario of the battery pack, these measurements can be done on pack, module or even cell level (see figure 4). It has to be noted that with capacity tests on pack and module level only the remaining capacity of the weakest cell in each unit can be determined since charging or discharging has to be stopped when this cell reaches its voltage boundaries. Therefore, in order to quantify the remaining capacity of each cell and get an insight in the capacity dispersion within modules, for every single cell of the battery pack a capacity check was done separately. As a result the remaining capacity of all cells grouped in modules can be seen in figure 2.
As it can be seen, the capacity dispersion is relatively high not only within the modules (5,04% resp. 2,439Ah) but also in between the different modules of the pack (6,89% resp. 3,365Ah). The remaining capacity of the cells ranges from 45,460Ah up to 48,825Ah what means a SOH of 90,92% up to 97,65%. Although due to not knowing the history and the operating conditions (like temperature distribution) of the pack there can't be drawn any reasons for the high capacity dispersion, it nevertheless points out the importance of grouping modules homogeneously for a second life storage system on module level.

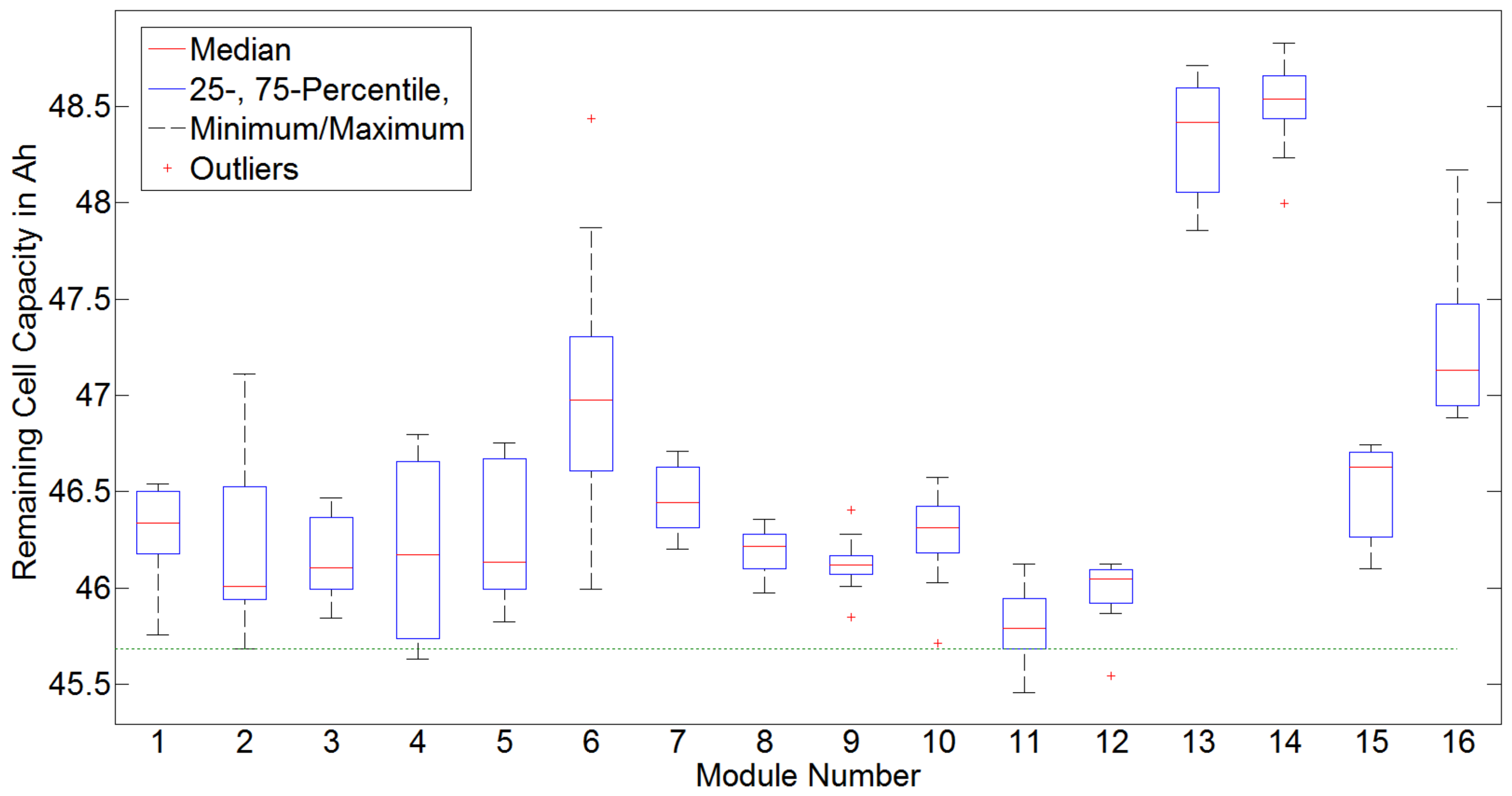

Fig. 2: Remaining cell capacity of every single cell of the battery pack grouped per modules

Acknowledgment

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Development of a modular storage system

The first step in the development of a storage system is the determination of the energy content and power for its intended purpose. Since our use case is self consumption enhancement of renewable energy in the residential area, a comparison of 230 state of the art home storage systems was done [4]. Thereby, the median for the useable energy could be found at 5,76 kWh and the one for power at 4,6 kW. To calculate the number of battery modules for an appropriate storage system, the following equation can be used

$$N = \frac{5{,}76kWh}{E_{Module} \cdot SOH_{minModule} \cdot DOD}$$

With E_{Module} as the modules nominal energy, $SOH_{minModule}$ as the lowest state of health of all modules used for the storage system and DOD as the intended depth of discharge. When using the most aged modules of the battery pack ($SOH_{minModule}$=0,9092) and setting the DOD to 80% N can be calculate to 3,52. Since Schröder et al. [5] showed that the largest increase in self consumption rate for households with up to 10 kWp Photovoltaik can be achieved with storage systems up to 10 kWh, N=4 was chosen. To minimize not useable module energy, modules 2, 4, 11 and 12 of the battery pack were selected for the storage since they are the ones with the lowest total SOH respectively.

As battery inverter the Sunny Island 6.0H from SMA with a nominal AC power of 4.6 kW was chosen. The advantage of this type with its DC input voltage range of 41-63 V is that additional high voltage safety components like an isolation monitor are not needed. To achieve the input voltage, four modules are connected 2s2p. Figure 3 shows the voltage operating range of the storage based on an equivalent circuit model (ECM).

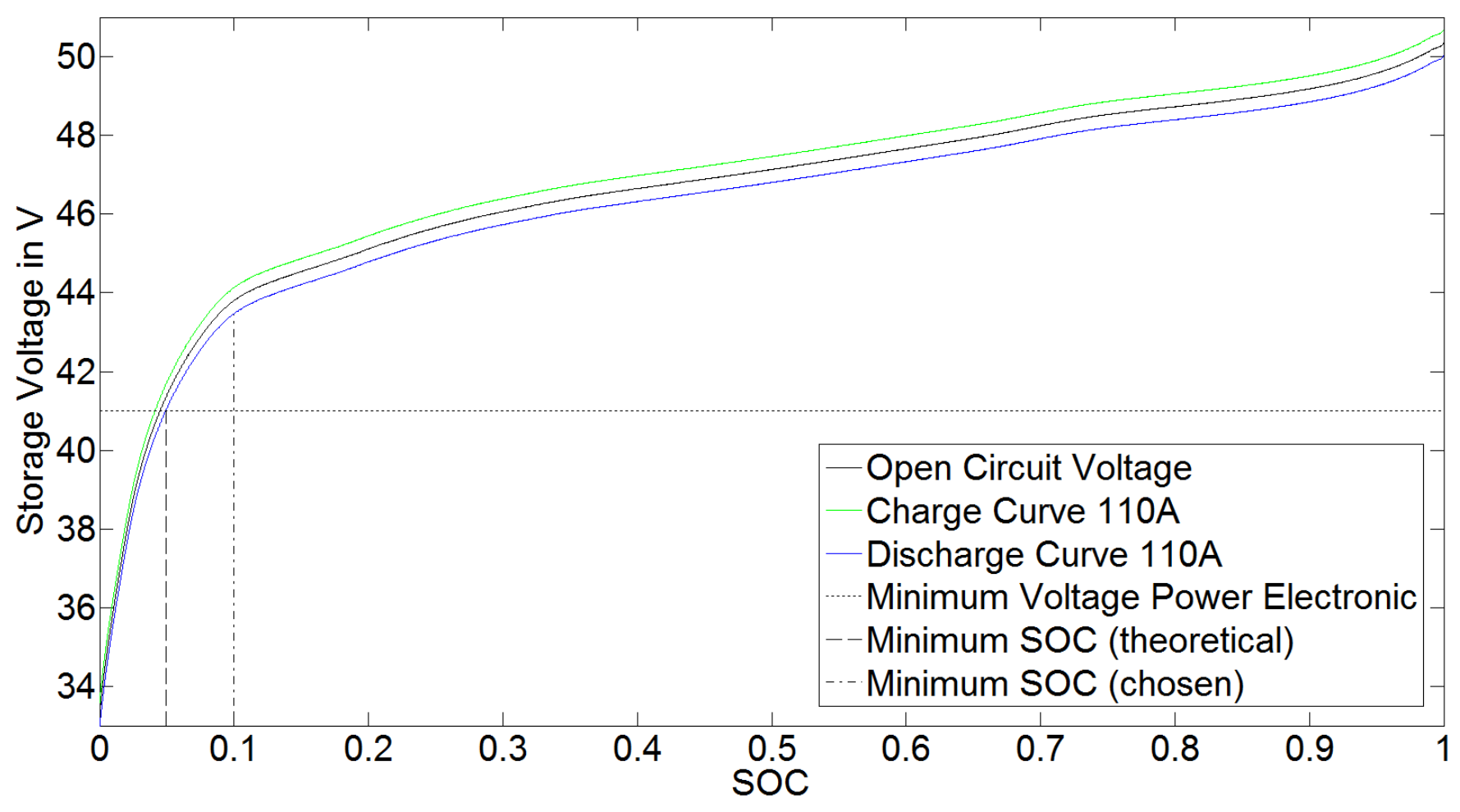

Fig. 3: Simulated charge and discharge voltage of the SL storage systems over the SOC

Analysis of the repurposing process

As previously detailed, the state of the art repurposing process to turn a vehicle's traction battery into a SL storage system consists of various steps as summarized in figure 4 [6]. Thereby, especially the electrical state estimation on pack and, if necessary on module level are very time and cost-intensive. Another drawback of current SL systems is the missing knowledge of the battery's history and parameter progression resulting in a high uncertainty about the remaining useful life of the batteries in second life applications [7].
Taking this into consideration, we suggest a server-coupled state and parameter estimation approach comprising a vehicle battery's usage history in a so called Battery Pass to provide the possibility for online battery residual value estimation and reuse decision making. Thereby the on-board battery management system (BMS) measures and determines relatively fast changing battery characteristics like e.g. cell voltage, current and SOC. This data gets pre-filtered and periodically transmitted to a server platform, where it is vehicle specifically stored. Based on that, parameters of an equivalent circuit model are calculated representing the actual state of the battery. Additionally, so called transaction data is generated which is a characteristic data set for the vehicle's battery use case (e.g. histograms for current, temperature, etc.). With these two data sets it is possible to keep track of the degradation process of electric vehicles' batteries as well as predict its future development by utilizing aging models like in [8]. Additionally custom-designed second-life storage systems can be planed and simulated with the data provided by the battery passes while the batteries are still in vehicle use. This not only minimizes the uncertainties of the batteries remaining useful life but also reduces value chain costs which arise for example from the necessary storage of dismantled but not yet to second life applications assignable batteries.

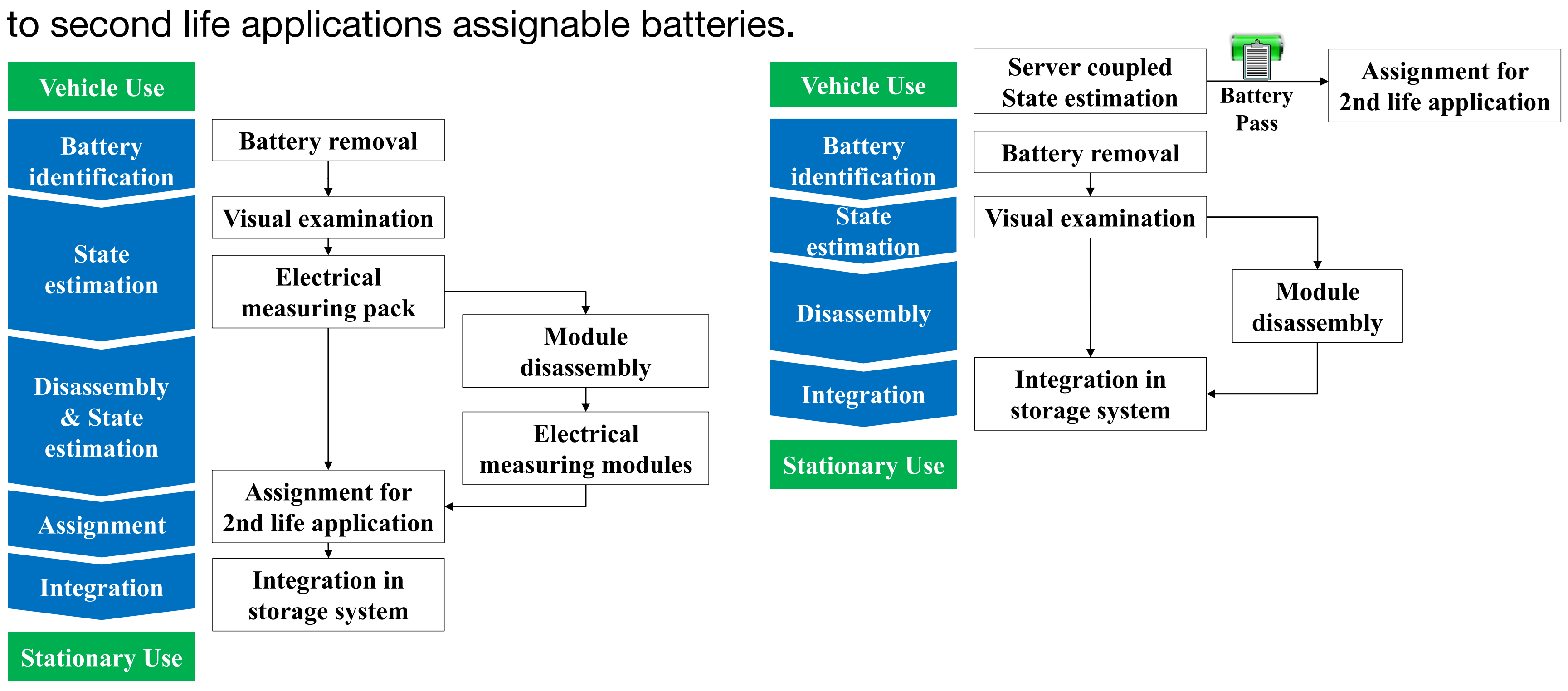

Fig. 4: Current Second Life repurposing process (left) and possible future repurposing process with the server-coupled state and parameter estimation approach

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