Management of a Modular Battery System for Shipboard Application

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***Abstract*—In the last two decades, the maritime industry has seen a strong technological development. In this process, shipboard power systems are developing to overcome the challenges of optimal use of energy sources and reduction of environmental impact, especially regarding pollutants and gas emissions. Shipboard developments aim to offer a higher energy efficiency by developing technologies, adding hybrid power generation systems with energy storage system to optimize performance. The goal of this thesis is to simulate in PLECS a distributed modular BESS with a hierarchical control where every single battery pack has a personal modular converter (MC) that takes care of battery State of Charge (SOC), state of health (SOH) and other parameters in order to protect battery from deep discharge or overcharging.**

I. INTRODUCTION

The battery energy storage system (BESS) is a popular solution for high power and long term load demands. Usually, lithium-ion battery is a good option due to its high energy density, low self discharge rate and long lifetime. A BESS can be integrated into the DC-SMG distribution throught a bidirectional converter. Normally, batteries are integrated by organizing multiple battery cells in series and parallel to built a storage unit in matrix. A centralized battery storage system checks the cell parameters such as SOC, temperature, voltage and manage the power flow. However, this type of configuration has problem in voltage sharing, over charge/discharge and efficiency iussies. To solve this problem, distributed BESS has been proposed in recent years, in which every battery cell has a dedicated dc-dc converter that regulate the output power. The goal of this Thesis is to study the control of this new structure.

II. DISTRIBUTED MODULAR BESS

In this section distributed BESS is presented. In this one the ESS is not connected with a full power dc-dc converter. The system is split into several ESSs which are connected to a lower power dc-dc converter rated at a fraction of the full power, depending on the number of of ESSs or Sub Modules (SMs). The output of every ESS module is connected in series in order to achive a higher dc-bus voltage, the resulting diagram is shown in Fig. 1. The control is guaranteed by a hierarchical control, where the Master controller, thanks to the information that it receives from the various slave in every string, will divide the power between the strings, following a special alghoritm.

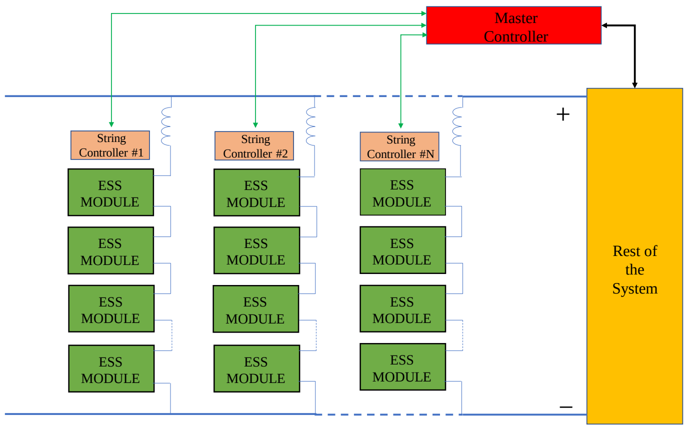

Figure 1: Simplified block diagram of the proposed BESS topology.

III. STRING CONTROL ALGORITHM

Consider a single string with n ESS module in series, two different control algorithms have been implemented:

- **Battery Wheights Implementation**
  Starting from an average duty d_{avg} computed by the current control, the duties of the various converters are computed through a proportional split to weights that take into account the characteristics of the batteries in the various modules. The control diagram is shown in Fig. 2.

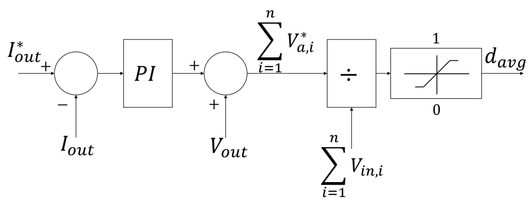

Figure 2: Master String Current Control.

- **Balancing Controller**
  This method monitors the SOC of the batteries and try to bring them to the same level. It consists of two control loops, the first internal control the current, the latter control the SOCs (see Figs. 3 and 4).

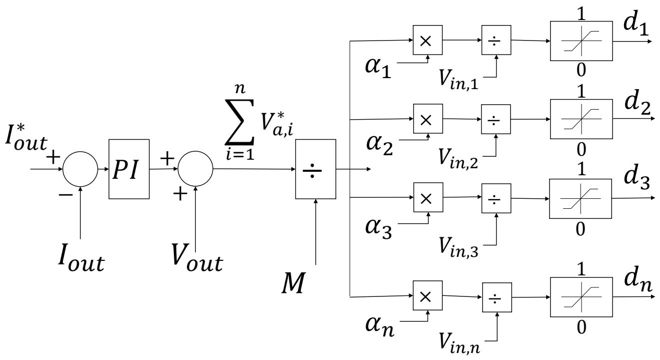

Figure 3: Current Control Loop for Balancing Control.

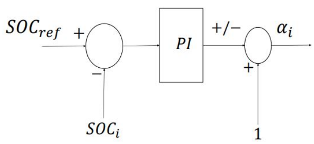

Figure 4: SOC Control Loop in charge/discharge mode.

IV. PLECS Simulation

Simulations were carried out to verify the two control algorithms. The first simulations were carried out on a scaled-up system of three modules and on a reduced time base due to the high simulation time required. Leading to good results regarding current control and SOC performance,as it can be seen from the results of Fig. 5 and 6. The controller is able to track the reference current and to equalize the SOCs of the batteries.

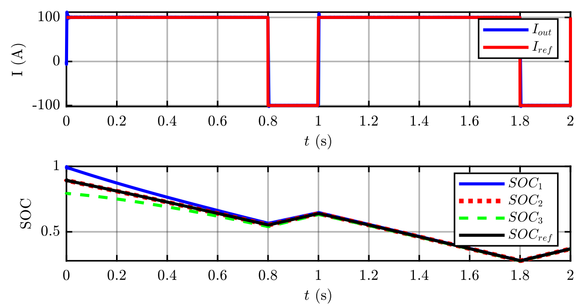

Figure 5: Current and SOC trends for SOC Balancing Controller.

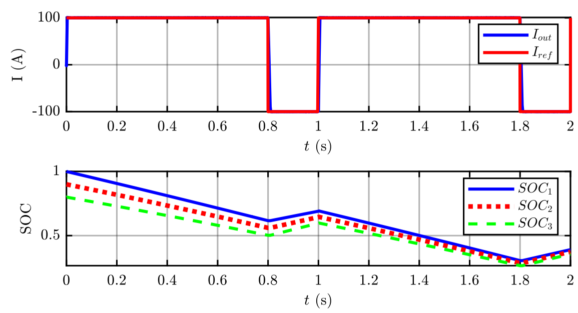

Figure 6: Current and SOCs trends for Battery weights Implementation.

Finally, to reduce the high computational time, a mean-value system was implemented to be able to simulate load diagrams of various naval applications with with various modules different from each other and with different initial SOCs. The results are shown in Figs. 7 and 8 for two representative vessels.

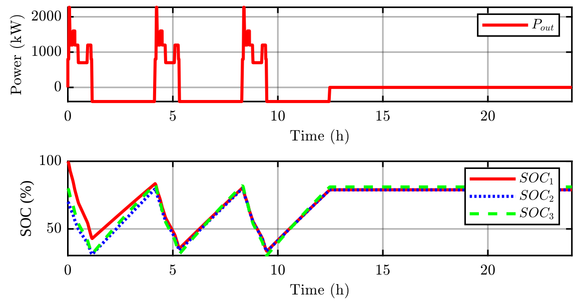

Figure 7: P_{out} and SOC for a Ro-Ro Ferry Vessel with different Modules.

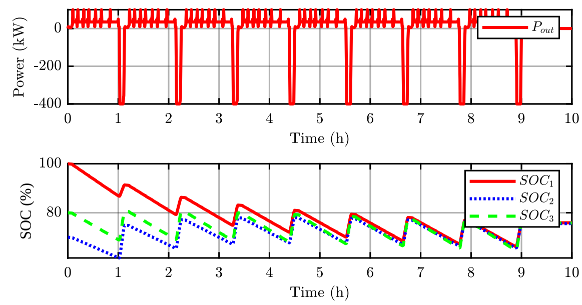

Figure 8: P_{out} and SOC for a Urban Ferry Vessel with different Modules.

V. Conclusion

In both implemented algorithms, the control works with excellent results. The reference is always maintained with adequate utilization of the various modules, with good response to various load situations and different SOC conditions. Both algorithms succeed in handling the various situations represented in an optimal manner. My personal contribution can be summarized as:

- Literature review about Energy Storage System and Ships Architecture and Modular Multilevel Converter.
- Implementation of the control algorithm in C language for a string of modules.
- Simulations of a scaled-up system to verify its operation