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Predicting Reliability, Improving Safety and Resiliency in Grid Connected Battery Energy Storage Systems

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I. Background and Objectives

- Energy storage deployments will grow 10-fold over the next 5 years.
- High string voltage affects both the potential for shock and the potential for arc-flash/blast [Sandia, 2015] – major concern at high penetration.
- Hence, objectives of this project are:
  - Investigate modular, transformer-less multilevel inverter topologies for grid connected battery energy storage systems (BESS).
  - Explore self – battery management system (BMS) and state of charge (SoC) balancing methods for battery/inverter modules interfaced to the grid to improve BESS flexibility as well as reliability.
  - Implement hardware test set-up to analyze device behavior (SiC MOSFET, battery, etc.) under different operating conditions.
  - Study Li-ion battery characteristics and fault tolerant operation through the interfacing converters and assess BESS resiliency.
  - Evaluate the component-level remaining useful life (RUL) index for SiC-FET and Li-ion batteries; then predict the system-level RUL for grid connected modular BES converter system through analytics.

Year	Milestones	Deliverables	Target
Year 1 (Done)	Develop a self – BMS and improved SoC balancing schemes for split battery architecture using Cascaded H-Bridge and Modular Multilevel Converters	A single phase 1kW laboratory scale hardware prototype using cascaded H-bridge to verify the proposed SoC balancing scheme	More than 50 % improvement in rate of SoC balancing using rated current operation compared to UPF operation
Year II (Ongoing)	Evaluate characteristics of Li-ion batteries for changes in internal impedance, capacity degradation, etc., due to effect of variations in depth of discharge, temperature, etc.	Characterization data of Li-ion batteries for BESS applications, with experimental profile	Identify key model parameters to implement component level reliability algorithm for Li-ion batteries
Year III (Upcoming)	Propose component -level reliability prediction algorithm to evaluate RUL of power devices and batteries, and to develop an integrated approach for predicting the BESS reliability.	Prediction algorithm to evaluate RUL of power devices and batteries for safe operation of BESS and model for overall reliability assessment.	Analytical capability of BESS RUL estimation with a prediction error of less than 500 hours

II. SOC Balancing Method

- For long life and reliable operation of BESS, the SoCs of battery modules need to be equalized through BMS.

❑ **We propose a self – BMS to perform SoC balancing among the battery modules using current controlled operation of cascaded H-bridge (CHB) interfacing converter.**

- Performs fast SoC balancing by operating the converter at rated current irrespective of the amount of power flow.
- Power transfer from a higher SoC battery module to a lower SoC battery module is achieved without compromising the amount of power flow among the BESS and the grid.

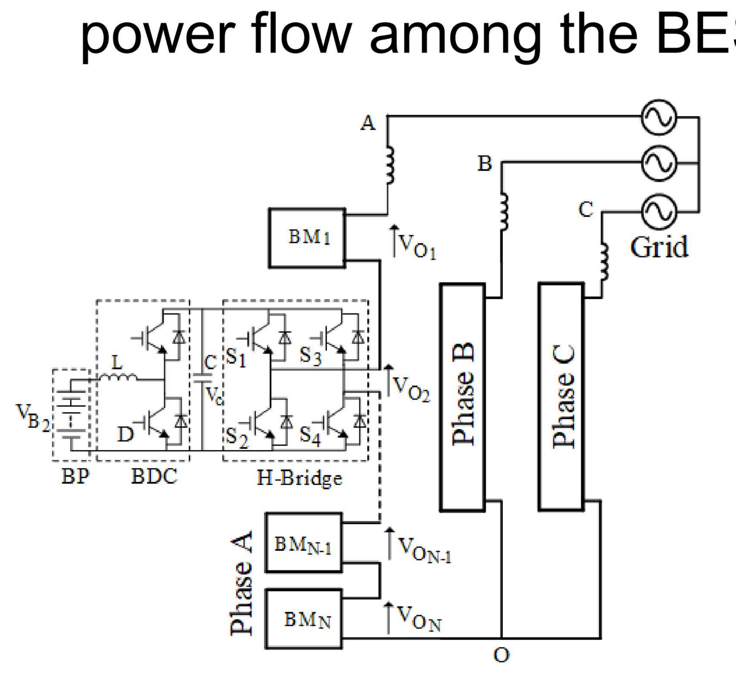
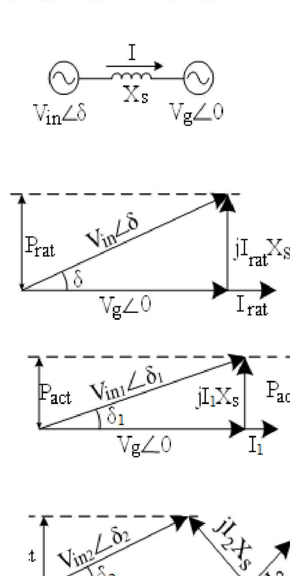


Figure (1)



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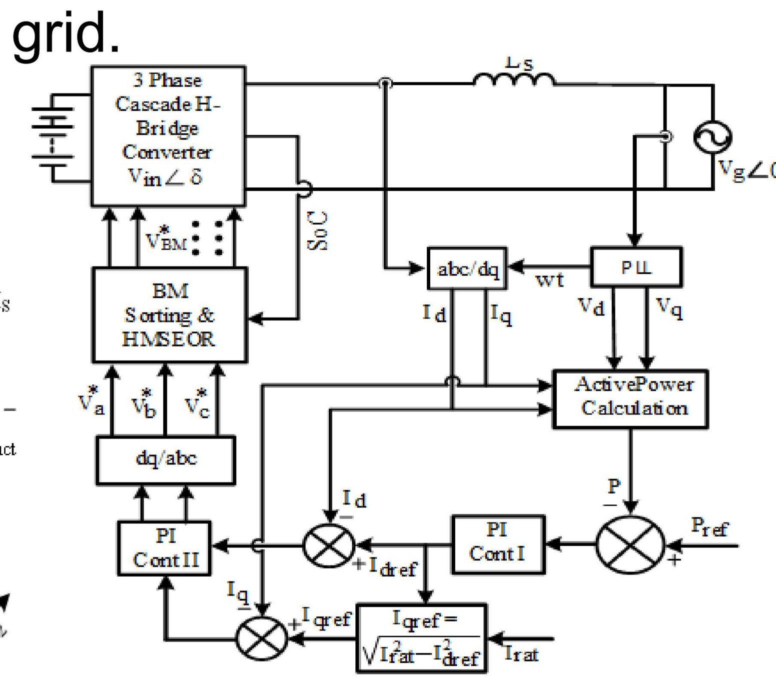
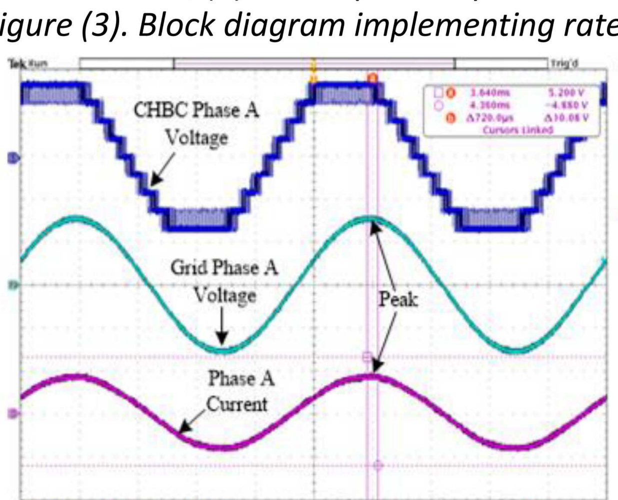


Figure (3)

Figure (1). Three-phase CHBC connected to the grid.

Figure (2). (a) Single line diagram of CHBC-grid system, (b) Rated power operation at UPF, (c) Actual power operation at UPF, (d) Actual power operation at rated current.

Figure (3). Block diagram implementing rated current operation of CHBC .



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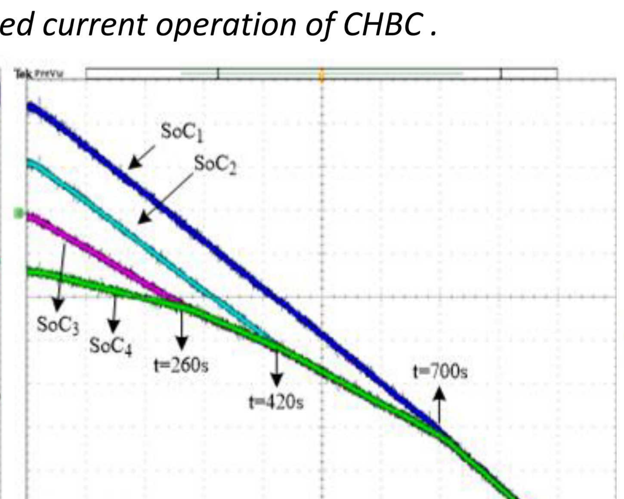

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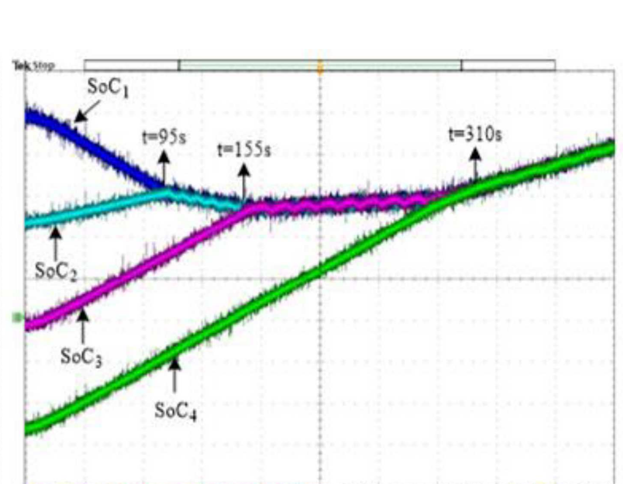


Figure (6)

Figure (4). Waveforms of CHBC voltage, grid voltage, and line current during 100kW power transfer from BESS to the grid at rated current operation

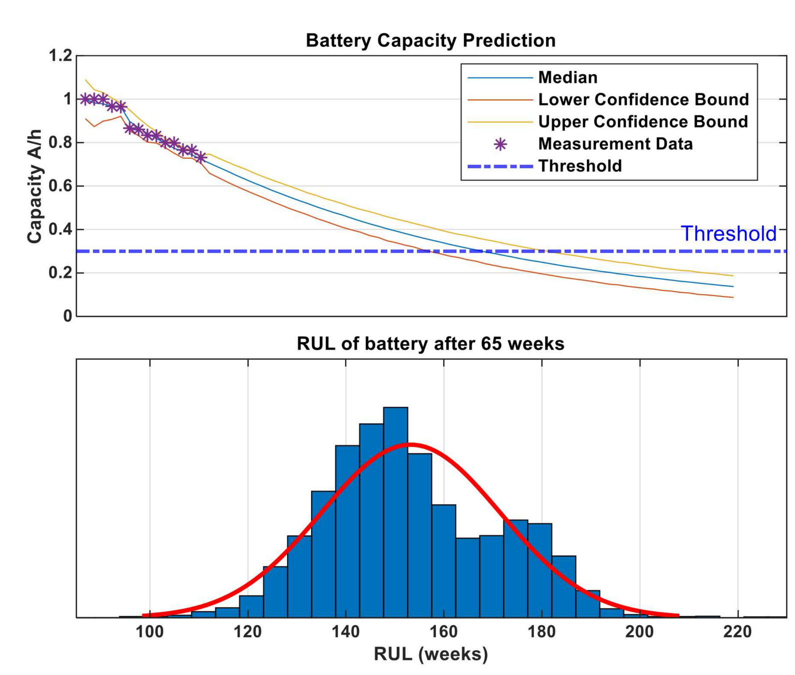
Figure (5). Variation of SoCs of the four BPs during 100kW power transfer from BESS to the grid at rated current operation.

Figure (6). Variation of SoCs of the four BPs during 50kW power transfer from the grid to BESS at rated current operation.

III. RUL Prediction for Li-ion Battery

- RUL prediction is critical to the implementation of condition based maintenance (CBM) and prognostics and health management (PHM) for battery system.
- A Particle Filter (PF) based algorithm for predicting the RUL of Li-ion battery to interface with converters for the safe operation of BESS is implemented.
- The estimated capacity of Li-ion battery is considered as the health condition indicator of Li-ion battery and used as the input of PF algorithm to predict the RUL of battery.

❑ **RUL estimation algorithm predicts the time to failure of BESS with certain probability to avoid unscheduled downtime.**



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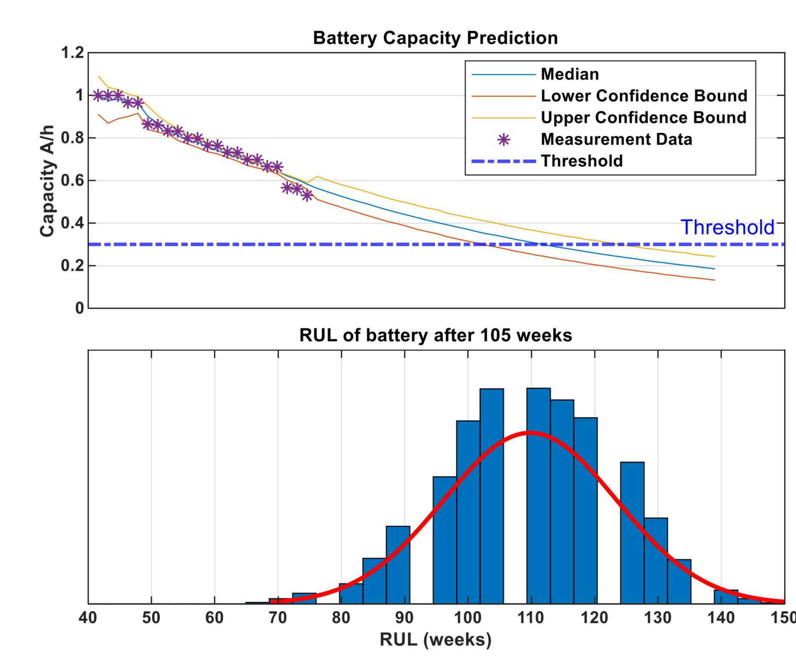


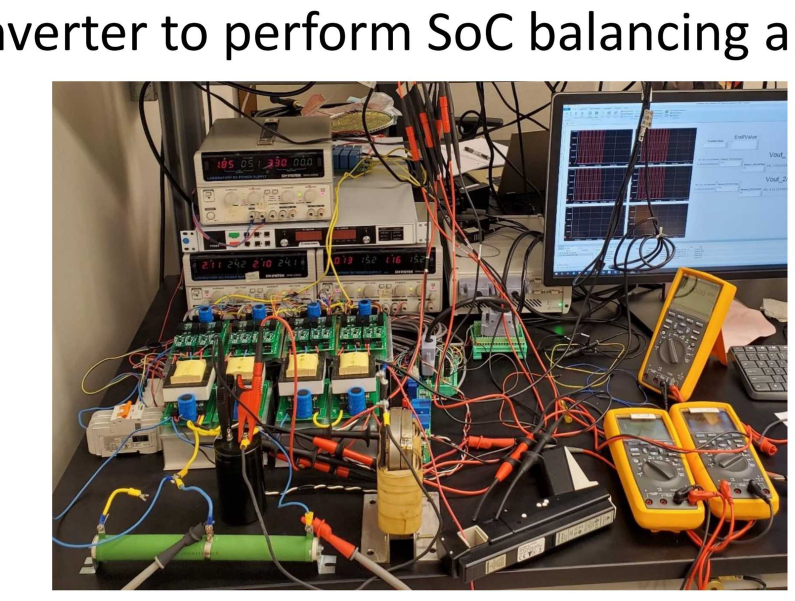
Figure (9)

Figure (8).The RUL distribution after the usage of battery for 65 weeks

Figure (9). The RUL distribution after the usage of battery for 105 weeks

IV. Ongoing Work – Hardware Evaluation

- Online SoC estimation through open circuit battery voltage calculation.
- Building hardware setup to implement rated current operation of CHB converter to perform SoC balancing among battery modules.



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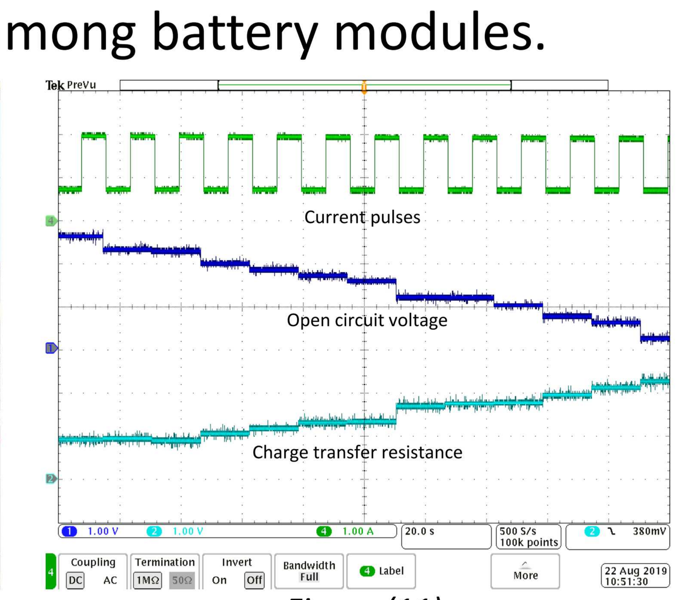

Figure (11)

Figure (10). Hardware set up for open circuit voltage calculation of a BM

Figure (11). The Waveform of open circuit voltage and charge transfer resistance of a BM.

V. Conclusion and Future Work

- Conventional battery systems use dedicated BMS for cell SoC balancing and module level balancing, which adds cost and control complexity. This can further affect the life of battery modules.
- Further, there is no existing technique to precisely predict the RUL of BESS, including the batteries and the power converters.
- In this project, we proposed a fast SoC balancing scheme with a self-BMS using interfacing modular converters for grid integration.
- We were able to achieve a **66 %** improvement in the rate of SoC balancing using rated current operation, when compared with conventional UPF operation at half the system power exchange.
- A 1 kW, 5-level hardware prototype is being set-up to implement the rated current operation for SoC balancing among BMs.
- A system-level health monitoring algorithm is being developed to predict BESS RUL with an error of less than **500 Hrs**. in about 20 years.

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