Hybrid Electrical Energy Storage System (HEESS) for Battery Electric Vehicles (BEVs)

Introduction

In a typical BEV, LiPo/Li-ion batteries are used to drive the motors however from Fig.1 it can be seen that whilst batteries have high specific energy they have limited specific power. To combat this, a HEESS can be developed which relies supercapacitors as well as batteries. Supercapacitors have a much higher specific power, but limited specific energy (Fig.1). Through utilising 2 Electrical Energy Stores (EESs), a HEESS can be configured to exhibit characteristics of an ideal energy store, which has high specific energy and power. [1] A HEESS can be configured based on several different architectures of which there is significant literature available on. All of which rely on the EESs of the system, which may or may not be electrically isolated being interfaced with power electronics to supply the necessary voltage for a desired motor running speed. DC/DC converters are commonly used to ensure a regulated output voltage is provided to a load even with a change in input voltage. 4-switch DC/DC Buck-Boost converters are the most ideal choice for this application due to their low component count and cost of production. Furthermore through operating it as a buck, boost or buck-boost converter system efficiency can be maximised. This can be achieved by operating the system in Buck mode for recharging the EESs under braking when the motor acts as a generator, in boost for supplying energy to the motor when driving the wheels and in buck-boost when there is little difference between input and desired output voltage.

To exploit the strengths of each EES deployment modes will be integrated into the HEESS such that each buck-boost can provide a balanced or biased levels of voltage.

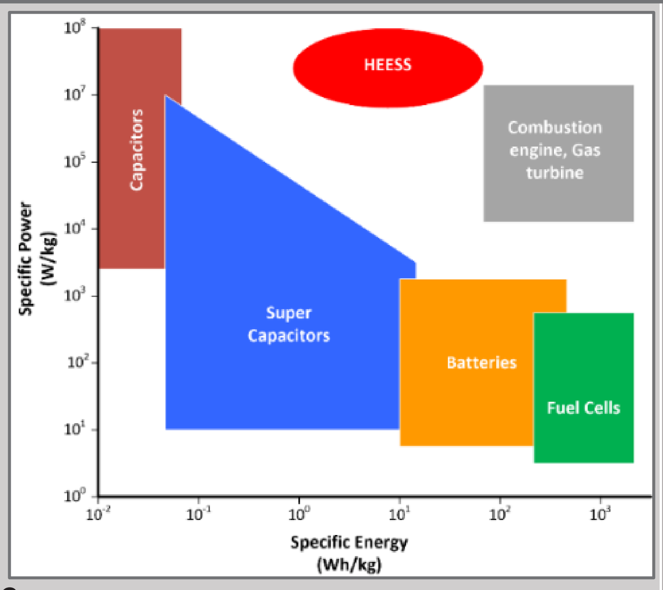

Figure 1 – Ragone plot

Aims & Objectives

- Identification of HEESS topology including relevant power electronic systems
- Definition of scaled deployment modes
- Design and simulation of power electronics and control systems
- Development of scaled test rig for proof of concept and to validate simulations
- Recommendations for further work for continued development of HEESS

Results

HEESS Block Diagram

Fig. 2 shows a block diagram of the proposed HEESS. It features the 2 EESs connected to a DC/DC Non-inverting Bi-directional Buck-Boost converter. Each converter relies on the switching of 4 MOSFETs based on the converters mode of operation. PI Control has been implemented to provide Pulse Width Modulation (PWM) to the 4 MOSFET gates. The PI control relies on voltage sensing from the EES and DC motor side of the converters to provide the necessary switching to the gates to ensure the desired output voltage is produced with the converters operating in Buck, Boost or Buck-Boost mode.

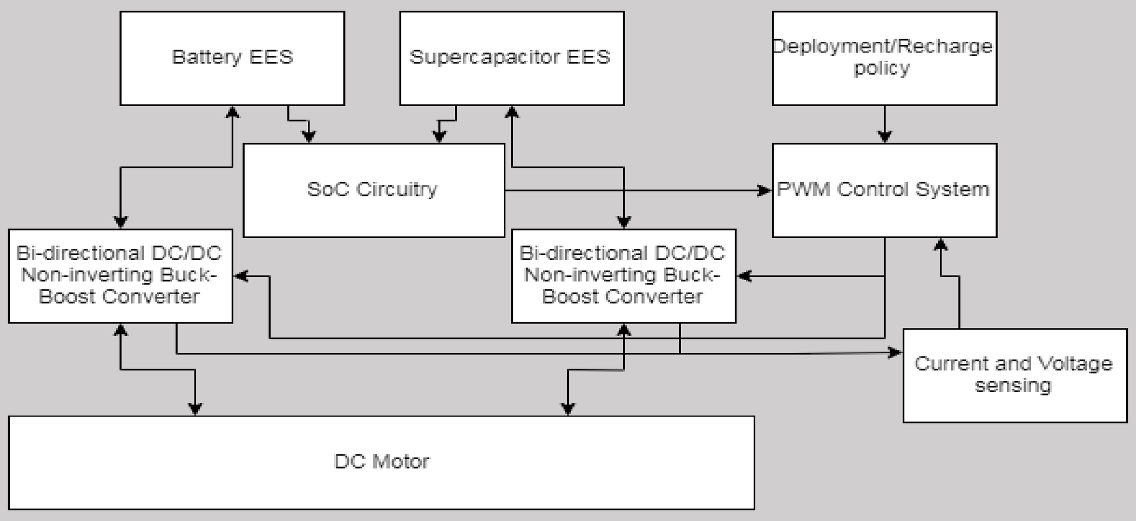

Figure 2 – HEESS System Diagram

Operation of 4-Switch DC/DC Non-inverting Buck-Boost Converter

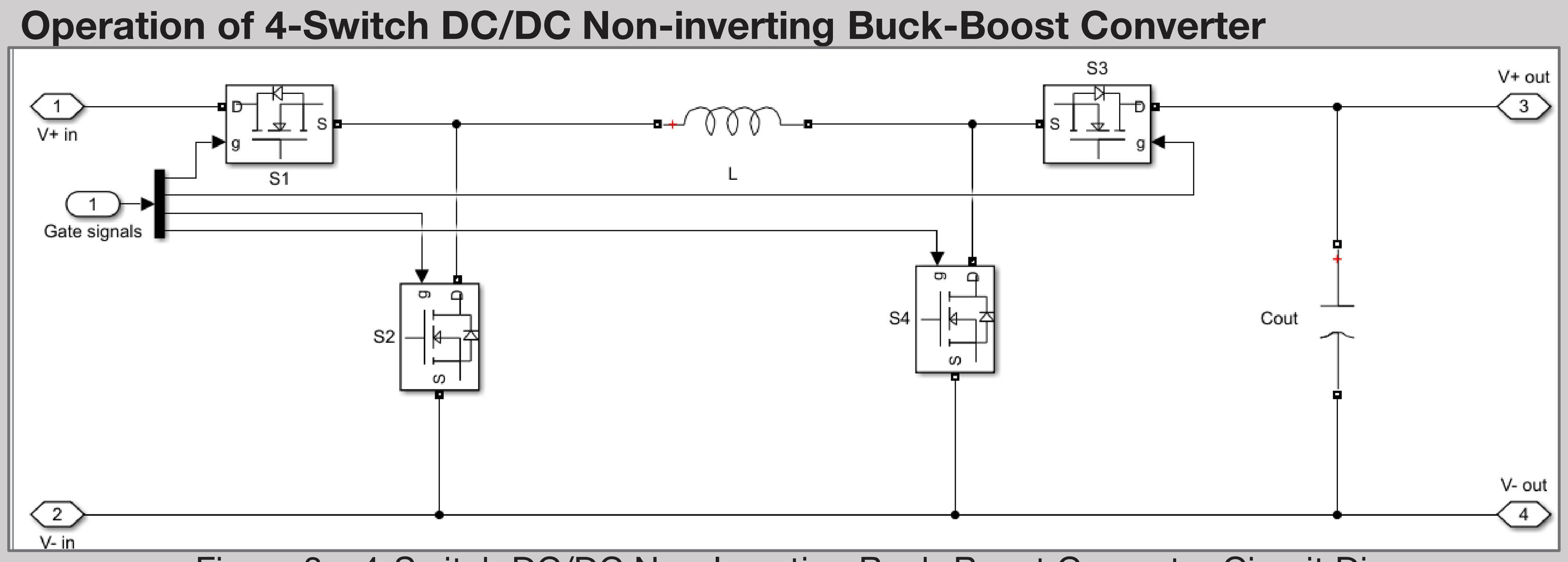

Figure 3 – 4-Switch DC/DC Non-Inverting Buck-Boost Converter Circuit Diagram

Mode	S1	S2	S3	S4
Buck	PWM	PWM invert	On	Off
Boost	On	Off	PWM invert	PWM
Buck-Boost	PWM	PWM invert	PWM invert	PWM

Table 1 – MOSFET gate control for Buck-Boost converter operation [2]

Mode	Rated output Voltage (V)	Deployment Voltage split (Supercapacitor/Battery) (V)
1	48	30/18
2		24/24
3		18/30

Table 2 – HEESS Deployment Modes

Simulink Model and Simulation Results

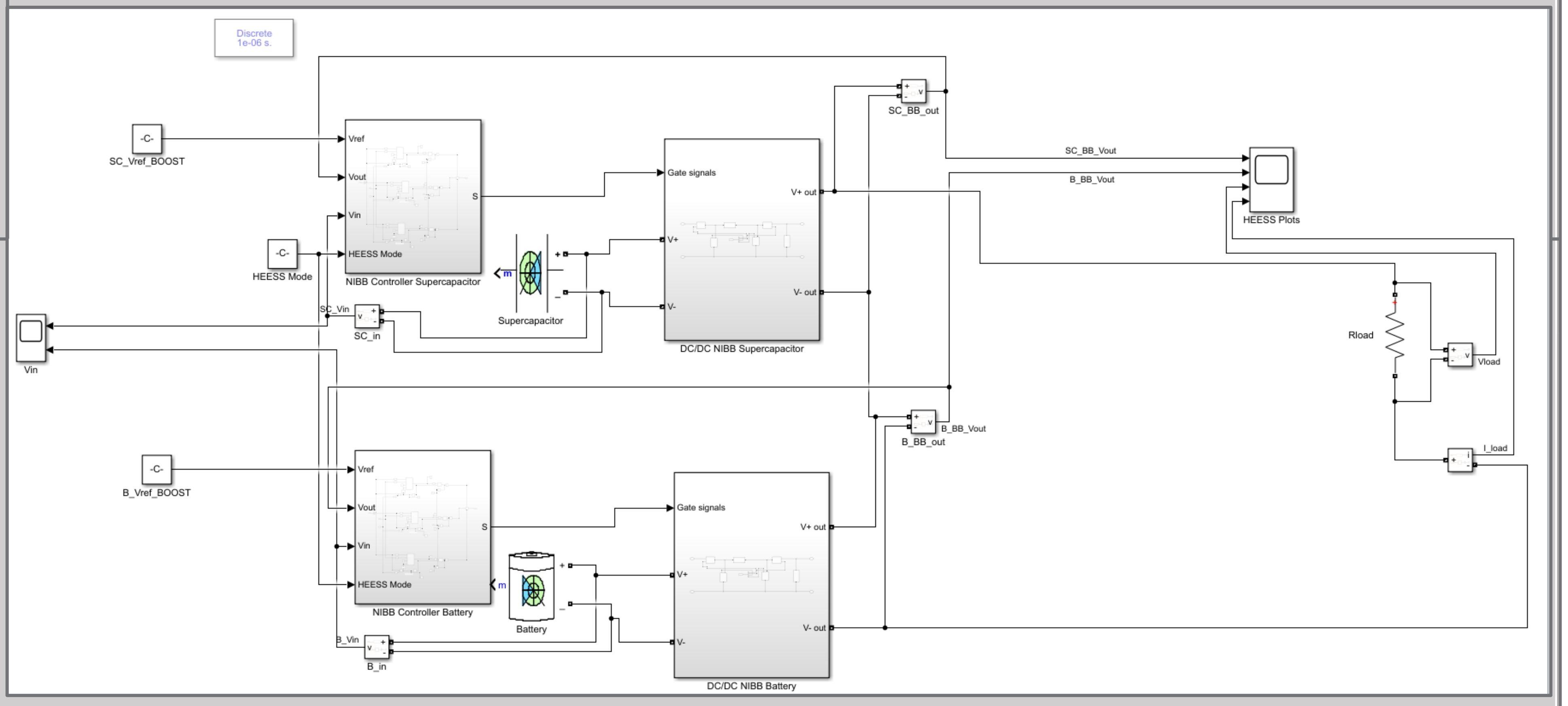

Figure 4 – HEESS Simulink Model

In Fig.4 it can be seen that both EESs have been connected to their respective Buck-Boost converters with inductor and capacitor values calculated based on the operating extremes of the system. Which are a function of nominal and minimum input voltages as well as desired output voltage ripple. [3]

Each Buck-Boost has its own dedicated controller capable of providing the necessary switching to the MOSFETs within the Buck-Boost to produce the required output voltage. Closed loop control is used with feedback from the output of each Buck-Boost being fed back into the controller to calculate the error voltage based on the following:

$$V_{error} = V_{reference} - V_{measured}$$

Where $V_{measured}$ is the feedback voltage from the output of the Buck-Boost and $V_{reference}$ is the desired output voltage set by the selected HEESS mode. V_{error} is then fed through the control loop to produce the switching signal for each gate as in table 1.

The selected HEESS mode switches in 1 of 3 PI controllers that are individually tuned using the Ziegler-Nichols method to produce optimal system response by minimising rise time, settling time and maximum % overshoot. 3 of many metrics that can be used to analyse system responses. [4]

Fig.5 shows the simulated results of the HEESS operating in mode 1 where the supercapacitor will provide 30V and the battery 18V to a simple resistive load.

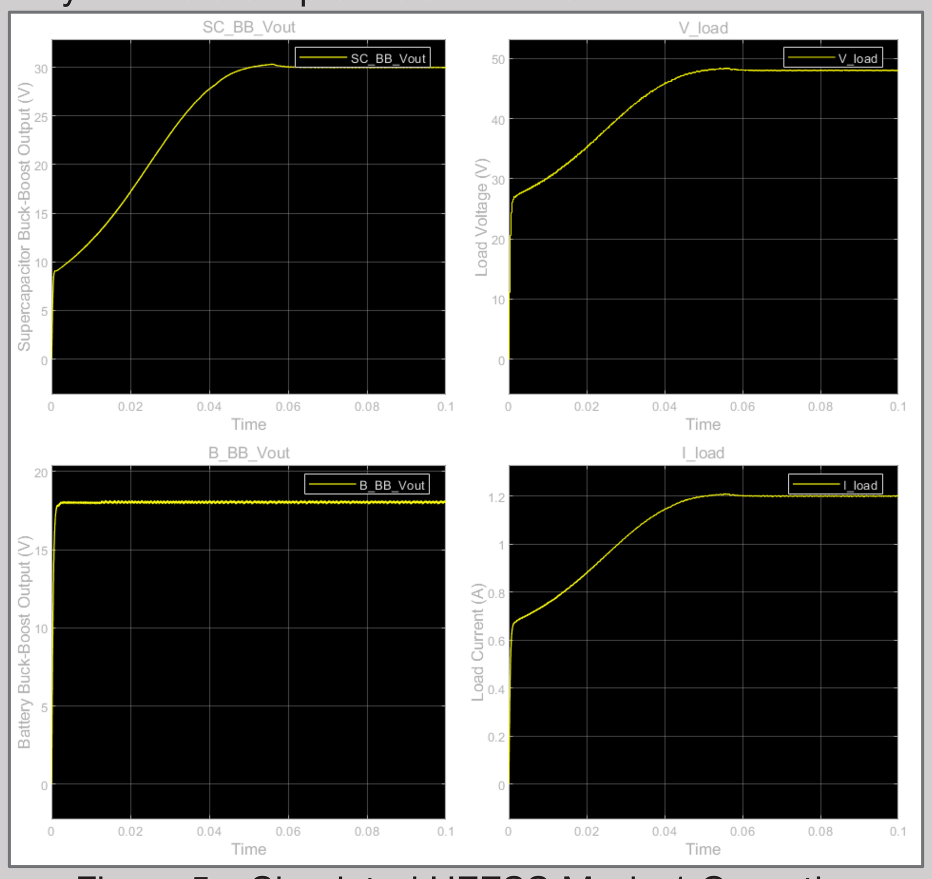

Figure 5 – Simulated HEESS Mode 1 Operation

Conclusion

This research has demonstrated the fundamental topology of a HEESS suitable use in the application of a BEV. The operating principles of such a system have been given extensive consideration with a system being developed and simulated to provide proof of concept. Fig.5 provides this proof of concept that such a system can be designed and configured to operate with deployment modes capable of splitting the desired load voltage.

A scaled test rig has also been built to investigate the practical performance of the system with further work being identified to enable the further development of the HEESS.

Further Work

Sliding mode control (SMC) is a nonlinear control method that will be implemented into the designed HEESS system. SMC can provide more robust control particularly with configured deployment modes.[5] The proposed SMC will be both simulated and integrated into a test rig to analyse full system performance. In addition to this, the HEESS can be further developed into a full unscaled test rig delivering voltages as high as 400-800V which would then be suitable for embedding within a chassis.

References

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