Drivetrain Integrated DC Fast Charging for Electric Vehicles

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Abstract

- **Interest in Electric Vehicles (EV) has soared in recent years**
- **Reduced environmental impact, improved efficiency are strong motivation for EV research**
- **Charging infrastructure cost, range anxiety impose important challenges to rapid EV adoption**
- **Integrated charging has shown promising results as it leverages existing drive inverter and machine inductance to reduce component count, weight, volume, and cost**
- **This work presents a search for an optimal integrated drivetrain/charging station and proposes two topologies, boasting a flexible, cost effect design**

Theoretical Background – Park Transformation

Three-phase current sets can be expressed using Park transformation

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin(\theta) & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

- In this reference frame, i_d and i_q are field producing currents while i_0 is an extra degree of freedom which can be used for charging purposes.
- Since i_0 does not produce any field, it does not produce any torque, allowing a parked car to charge without accelerating and without requiring engagement of the breaking system
- Additionally, i_0 is fully decoupled from torque production. As a result, i_0 does not interfere with driving controls, providing systems with simultaneous driving and charging capabilities

Theoretical Background – Fault Blocking

- Standard UL2231 requires either galvanic isolation or bidirectional fault blocking capability, in order to prevent faults in one side of the system to propagate to the other
- Buck-boost topologies present inherent semiconductor powered bidirectional fault blocking capability
- Additionally, it allows to charge with voltages higher than the battery facilitating fast charging and meeting the central ground standard requirement

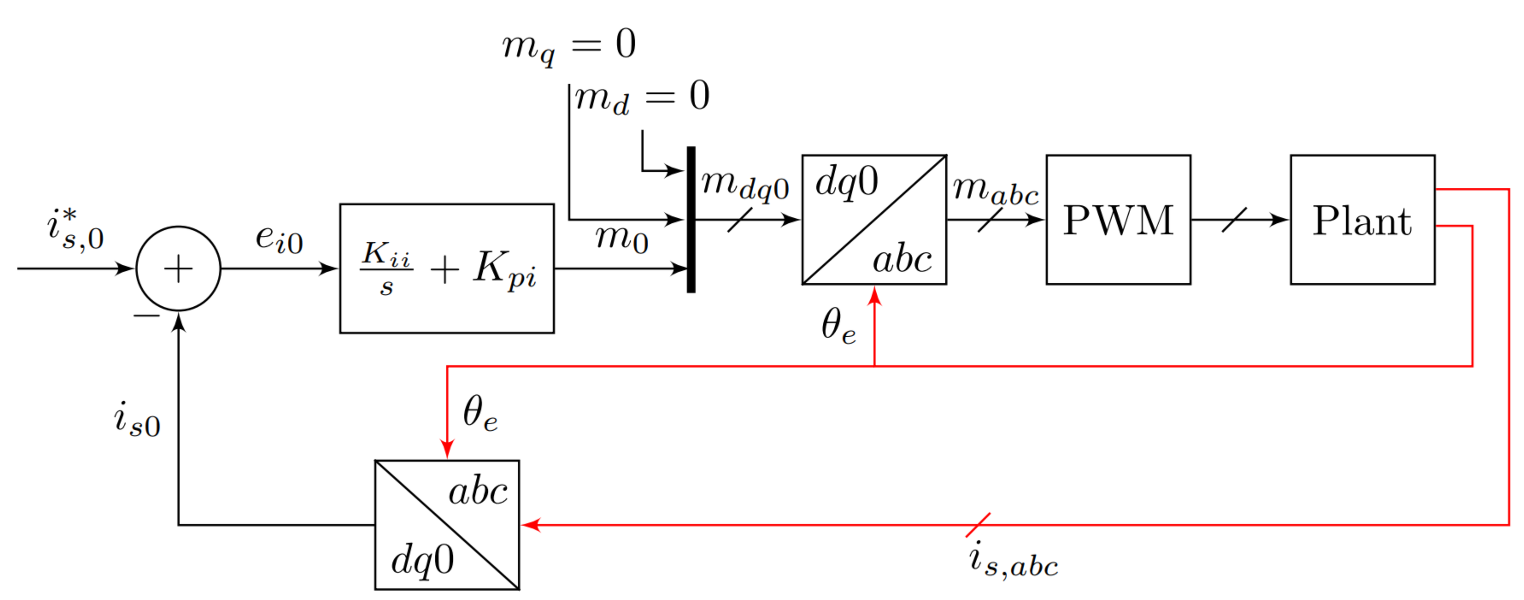
The Search for an Optimal Integrated Fast Charger

Desired Features:

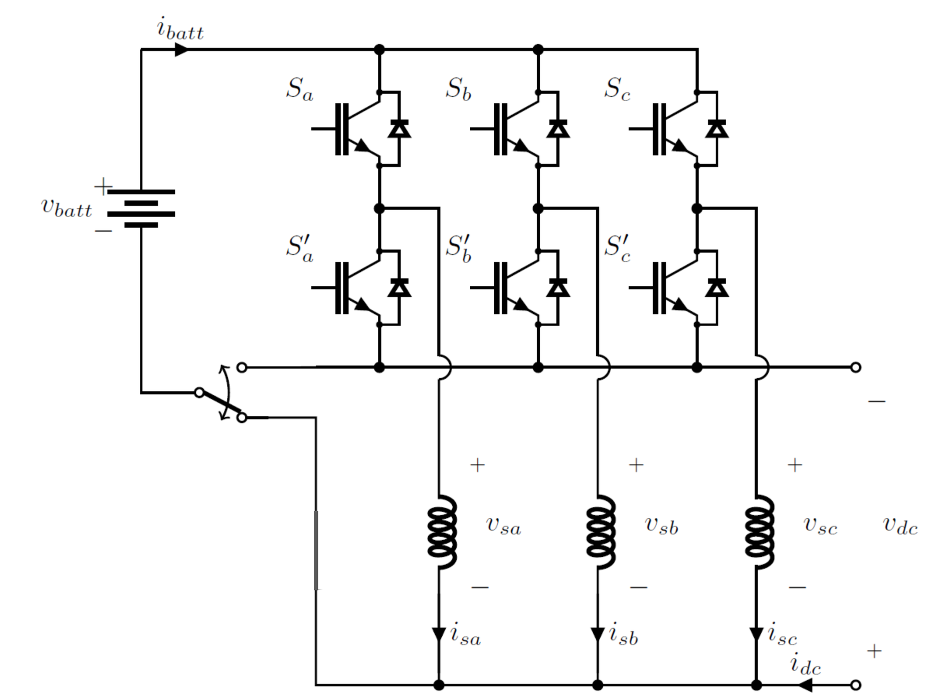
- Negligible added cost, volume and weight
- Zero torque production during charging mode
- Compliance with UL2231 Standard
- Fast charging to address rangy anxiety
- Bidirectional power transfer capability for V2G, G2V and V2V applications
- Bidirectional fault blocking capability without added components
- Low switch voltage stress
- Simultaneous driving/charging capabilities

Controller Design

- The system uses the i_0 for charging, leaving i_d and i_q free for torque control
- A control system example for topologies that follow this design principle is presented below



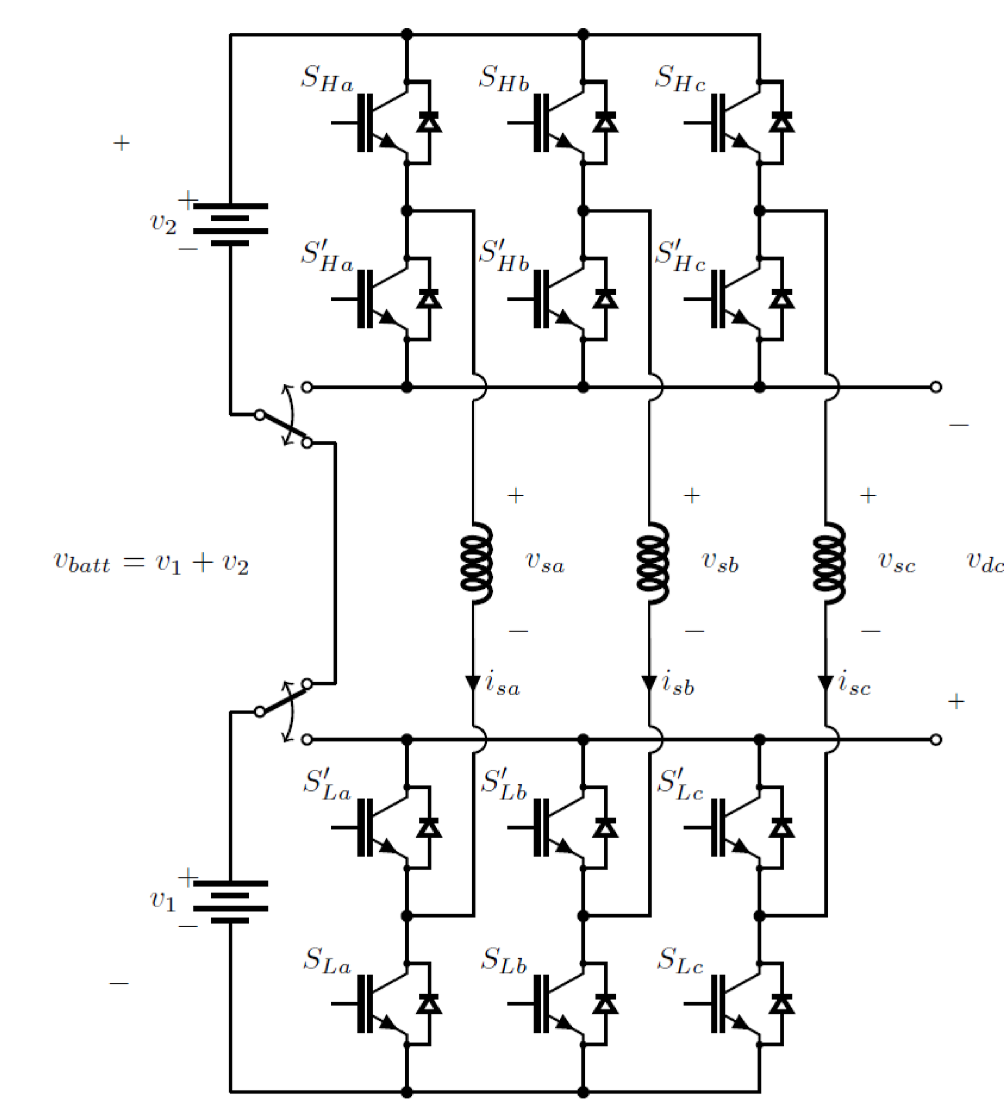
Single Inverter Integrated Buck-Boost



Features

- When the switch is flipped it implements an interleaved buck-boost topology from the dc input to the battery
- Higher voltage levels on the dc side allow for faster charging while keeping the current magnitude manageable for cabling purposes
- The battery current in this topology is proportional to the 0-sequence current through the motor (represented by the three phase inductances)
- When a source is connected to the dc port the converter is still able to control i_d and i_q for driving purposes
- If no source is connected, the no load switch can be used to put the system in the purely driving mode, and the system is equivalent to a regular driving system

Dual Inverter Integrated Buck-Boost



Features

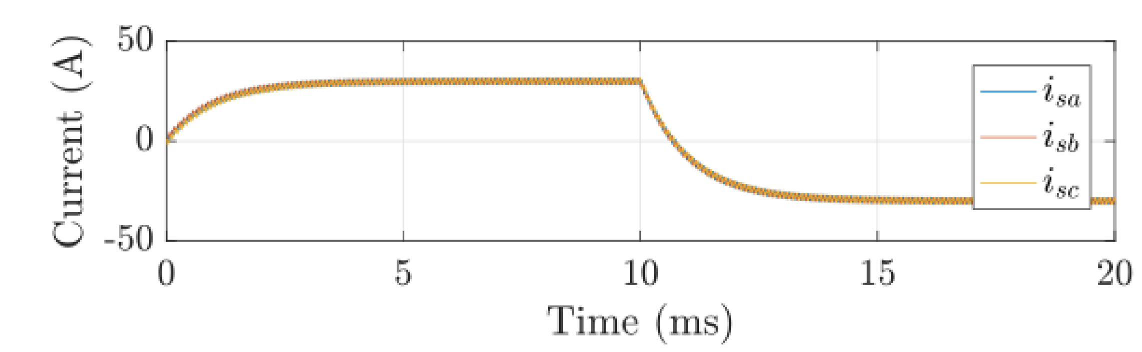
- With the voltages defined as shown in the picture, implements a buck-boost mathematically equivalent to the single inverter topology (shares all features)
- This system can be used with dual inverter drives
- If $v_{dc} < v_{batt}$ the no load switches can be turned into driving mode and the batteries can be charged at different rates, allowing for active charge balancing

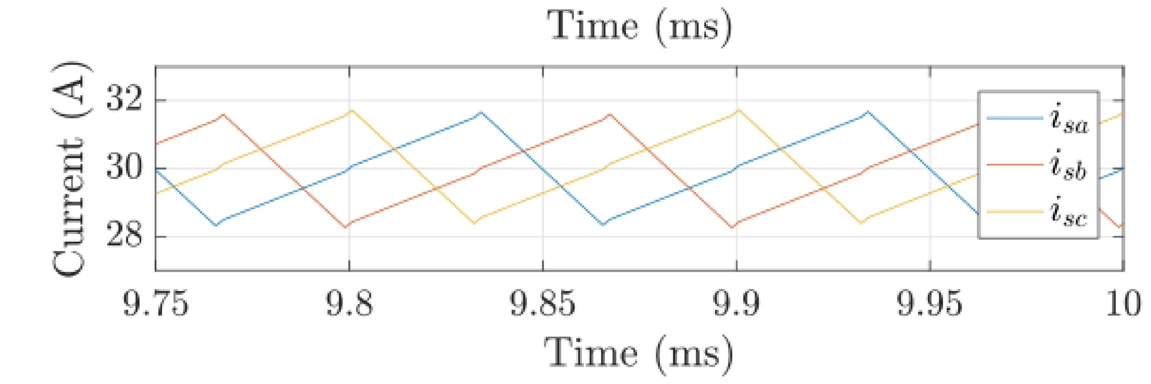
Simulations

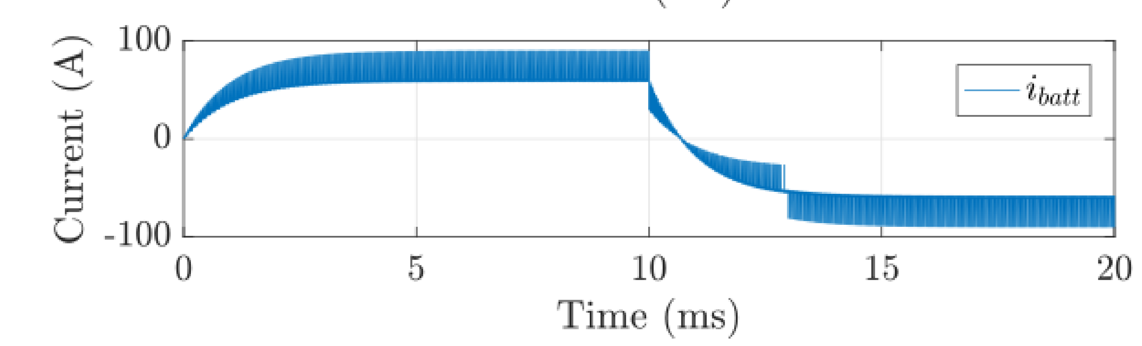
TABLE I: Simulation Parameters

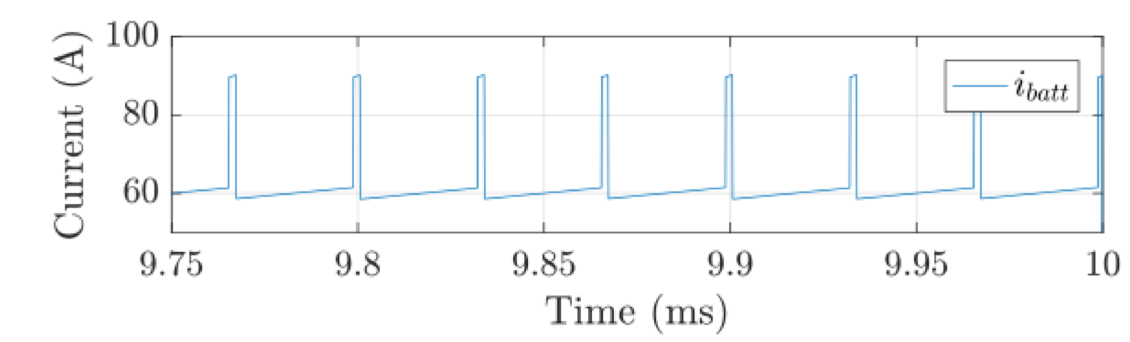
Parameter	Value
V_{batt}	$375\ V$
V_{dc}	$800\ V$
L_s	$0.8\ mH$
R_s	$0.1\ \Omega$
f_s	$10\ kHz$

Battery is initially being discharged, by a 60 A current and at t = 10 s the current is reversed to show bidirectional power transfer.









Conclusion

- The system fully leverages the existing drive inverter and motor inductances, the only component addition is the no load switch
- Only 0-axis current is produced (no torque)
- Fast charging
- Bidirectional power transfer
- Bidirectional fault blocking capability

Future Work

- Voltage stress decrease
- Simultaneous driving and charging optimization
- Multiphase generalization
- Battery current ripple decrease