Interest in Electric Vehicles (EV) has soared in recent years. 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

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

- 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.

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.

Desired Features:

- Negligible added cost, volume and weight.
- Zero torque production during charging mode.
- Compliance with UL2231 Standard.
- Fast charging to address range 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 \( i_d \) 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.

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.

Simulations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>( V_{bat} )</td>
<td>375 V</td>
</tr>
<tr>
<td>( V_{dc} )</td>
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</tr>
<tr>
<td>( L_s )</td>
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Battery is initially being discharged, by a 60 A current and at \( t = 10 \) s the current is reversed to show bidirectional power transfer.

Single Inverter Integrated Buck-Boost

- 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 \( v_{dc} < v_{bat} \) the no load switches can be turned into driving mode and the batteries can be charged at different rates, allowing for active charge balancing.

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Features

- The system fully leverages the existing drive inverter and machine 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.

Conclusion

- The system fully leverages the existing drive inverter and machine inductances, the only component addition is the no load switch.
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Future Work

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

Abstract

The Search for an Optimal Integrated Fast Charger

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