MODELING AND DESIGN ANALYSIS OF TESLA MODEL S POWERTRAIN WITH A CONCENTRATION TOWARDS BATTERY MANAGEMENT SYSTEM AND REGENERATIVE BRAKING

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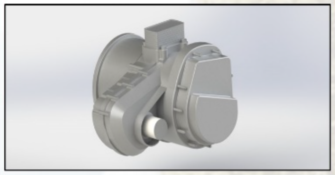
INTRODUCTION

From its first debut, the Tesla Model S powertrain has undergone numerous revisions that have improved its longevity, efficiency and power. The Model S can recoup the energy required to produce it in less than 10,000 miles. More than 60 kW of regenerative braking power is available from the drivetrain, which significantly lowers brake wear and energy consumption. Since there is an electronic power distribution between the two induction motors, there is no mechanical linkage between the front and back axles. As a matter of fact, accurate powertrain modeling and validation are paramount for critical design and control decisions of high performance electric vehicle. Described in this paper is a methodology for the design and description of Tesla Model S powertrain components. Justification of real-world vehicle system focusing on battery management system, CAN bus and regenerative braking is also provided.

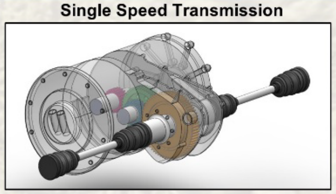
MAIN COMPONENTS

Inverter and Motor



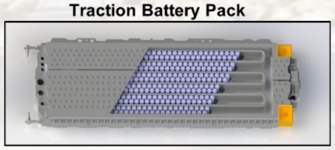
Motor type: Liquid-cooled, 3-phase, 4-pole, AC induction.
Inverter:
Type: Variable frequency drive with regenerative braking.
Energy storage: 40 kWh, 60 kWh or 85 kWh.
Charge rate (AC Charging) : 62%
Efficiency : 92%.
Maximum Charge Recovery : 30 mins

Single Speed Transmission



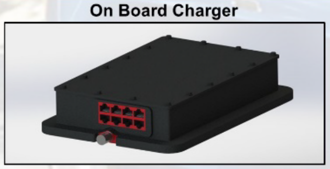
Front transmission:
Type : Single speed fixed gear
Ratio : 7.56:1
Overall Final Drive Ratio:
Front unit motor : 7.56:1
Rear unit motor : 9.04:1
Rear transmission:
Type : Single speed fixed gear
Ratio : 9.04:1

Traction Battery Pack



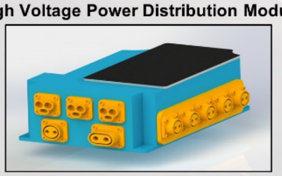
The battery pack includes 16 battery modules each consisting of 444 Panasonic 18650 lithium-ion battery cells. Glycol coolant is passed through metallic inner tubes between the cells.
Battery Pack Capacity: 85 kWh.
Battery Module:
Capacity : 5.3 kWh, 230 Ah.
Weight : 55 lbs.
Energy Density : 212 Wh/kg
Nominal Voltage : 22.8V (3.8V per cell)

On Board Charger



The onboard charger can provide up to 11.52 kilowatts of charge to the high voltage battery. There are two basic types of charging-direct current or alternating current. If AC power is used, from the outlet or from the AC charging station, the current passes through the charging cable to the on-board charger, which converts the AC current to DC and sends it to the battery via the Battery Management System (BMS).

High Voltage Power Distribution Module



High voltage in the case of an electric vehicle is approximately 400 volts. External input via the charge connector can be single or three phase of either 120 volts or 250 volts AC. This get boosted to a nominal 400 volts DC bus and get distributed around the various systems of the vehicle, including the motor, DC to DC converter etc.

DC-DC Converter

DC-DC converter transforms the high voltage and low current of the battery pack into low voltage and high current for charging the 12 V auxiliary battery. This liquid cooled converter works on buck or boost circuits and consists of power switches like MOSFETs, IGBTs or BJTs.
Input Voltage and Current : 400 V at 15 Amp
Output Voltage and Current : 9-16V at 180 Amp

METHODOLOGY

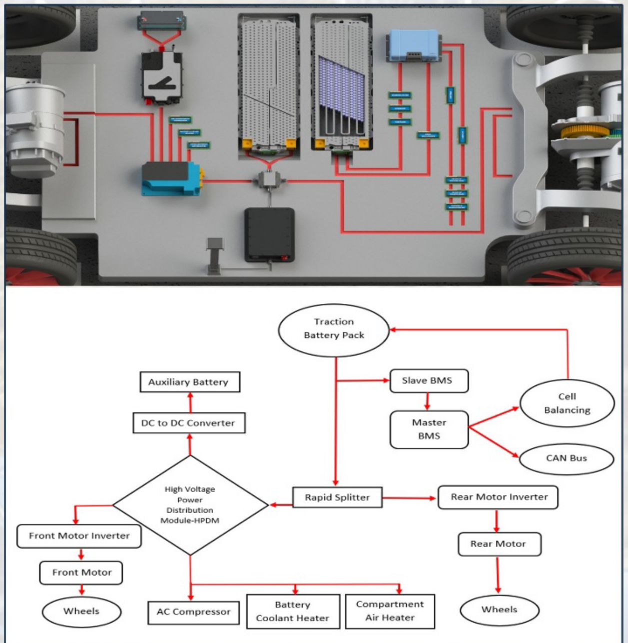


Fig: Flowchart of powertrain when vehicle is running

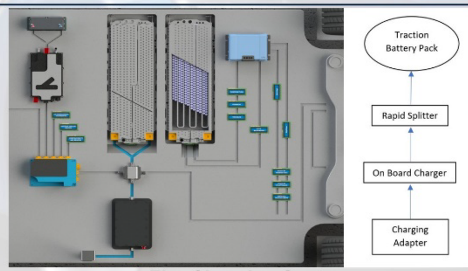


Fig: Charging System

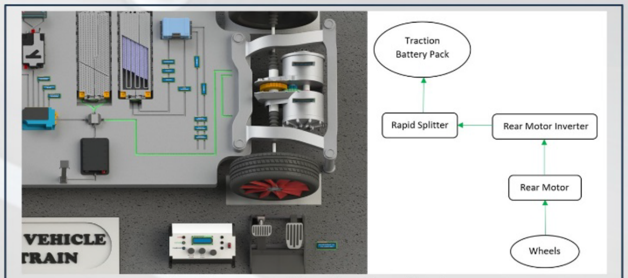


Fig: Regenerative Braking System

BATTERY MANAGEMENT SYSTEM AND CAN BUS

- Battery Management System (BMS) is one of the most crucial and essential components of an electric vehicle. The main feature of a BMS is to safeguard the battery and make the operation reliable and smooth.
- BMS monitors a range of parameters including the battery current, voltage, remaining travel range of the battery, State of Charge (SoC), State of Functioning (SoF) of a particular function or task and State of Health (SoH).
- The Controlled Area Network (CAN) is one of the most preferred communication protocols in modern vehicles. It is used for the communication between numerous control units and the BMS.
- In normal cases, the communication between the battery pack and the control units is done by wiring, which becomes bulky and does not allow for adding of extra components.
- In order to solve this problem, the implementation of CAN bus-based communication is essential as it reduces the wiring required between the control units. It uses a single serial bus which combines all the wiring into a single node using the controlled area network protocol.

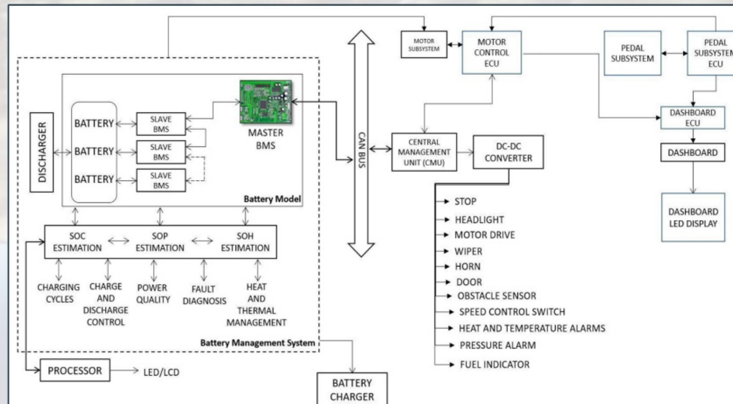


Fig: BMS integrated CAN bus control environment

REGENERATIVE BRAKING

- Regenerative braking uses the vehicle's electric motor to create resistance to slow down the vehicle. In addition to slowing the vehicle down without the use of brakes, the motor running in reverse acts as a generator and captures the kinetic energy that would typically be lost as heat and converts it into electrical energy.
- Power produced by the regenerative action is in AC format. The power converter circuit of the inverter transforms AC power into DC by rectification. This DC voltage is fed to the battery for charging.
- During regenerative braking, RMF speed of the induction motor is kept lower than the rotor speed. The direction of the induced current in the rotors is flipped and so rotor slows down instantly initiating braking action. This phenomenon takes place whenever driver releases the accelerator pedal.
- Regenerative braking can add 10 percent more range and extend the life of braking mechanisms by more than 50 percent.

CONCLUSION

Globally, electric vehicles have revolutionized the automotive industry for the future. Slowly, it is pacing towards the next generation of mobility that has unveiled itself as a replacement for the traditional IC engine vehicles. Battery performance is one of the key features of this development that substantially reduces the consumption of fuel. Automakers are continuously pushing their boundaries of powertrain modification to extract the best possible efficiency and sustainability out of their electric vehicles. Founded in 2003, Tesla is ranked as the most valuable automotive brand worldwide as of June 2023 and within the fourteenth most valuable brands across all industries in 2022. Globally, Tesla's vehicle deliveries reached a record 1.31 million units in 2022 and have been steadily growing year-over-year.