

Development and Analysis of an Electric Vehicle Controller for LCV

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ABSTRACT

This paper describes the system architecture together with control and diagnostics features of an indigenously developed electric vehicle controller for Light Commercial Vehicle. The key functions of vehicle controller include power management, driveline controls, regeneration and vehicle mode controls. In particular this paper presents vehicle's operational strategy in economy, normal and performance modes based on the vehicle speed and SOC. It also has feature to enable vehicle operation in reduced performance mode at low battery voltages. The battery fault predictor algorithm is also described in detail that is used to control discharge current to prevent sudden dip in SOC and to increase battery life. The vehicle control strategy is modeled & simulated using MATLAB™ environment and results for a specific test case are validated with embedded controllers-in-the-loop in a test-bench environment. The electric vehicle controller is implemented with a fully integrated Battery Management System, motor controller and other auxiliary subsystems. The test-track results of electric vehicle driven in different operating modes are analyzed for the performance metrics. The results of three stages of development namely the simulation, test-bench validation and vehicle performance are presented.

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INTRODUCTION

The environmental impact of the petroleum-based transportation infrastructure, along with the depletion of fossil fuels, has led to renewed interest in an electric transportation infrastructure. The stringent emission norms keep pushing the vehicle manufacturers to move towards the sustainable electric mobility.

The electric vehicle controller is the crucial element of the electric vehicle design, as it influences vehicle operation and performance [2]. Since this also function as power management module, its proper design helps in improving the energy efficiency of the vehicle.

It acts as a supervisory unit to control all modules in the vehicle. It has the intelligence to make logical decisions for better control and safety of the vehicle.

The main two functions are vehicle level controls such as vehicle sequencing control, power distribution control, diagnostics, Motor controller sequencing, instrument cluster controls etc., and propulsion control functions such as regeneration, shifter safety logics, acceleration control etc.

The paper describes in detail the vehicle controller strategy model developed in MATLAB™ environment and the simulation results are compared with the test bench setup results for a standard drive cycle.

The vehicle controller validated in test bench environment is installed in the LCV and tested for vehicle's performance measurement. The vehicle level test results are presented. It also discusses different operating modes of the vehicle such as performance mode, energy efficient mode, and reduced performance mode.

VEHICLE CONTROLLER ARCHITECTURE

The overall architecture of vehicle controller is shown in Figure 1. The vehicle controller gets driver inputs (like accelerator pedal, brake pedal and shifter inputs), feedback signals from modules such as analog & digital inputs, etc. It communicates via CAN to modules such as Battery Management System (BMS), motor controller, Universal Cluster (instrument) Controller (UCC) and Electronic Shifter Control.

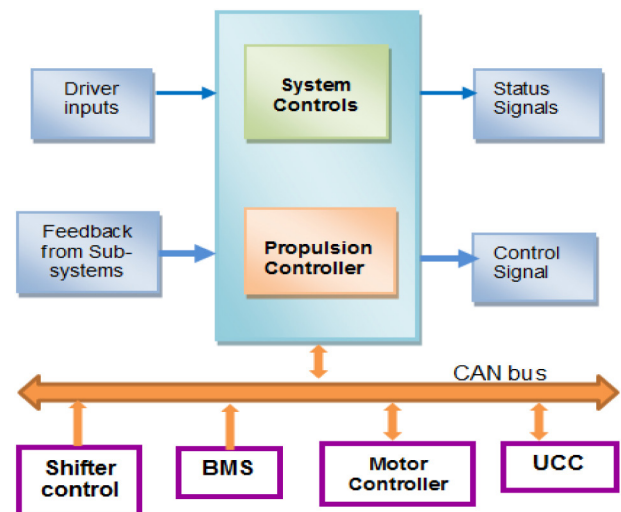


Figure 1. Overall architecture of vehicle controller

System Controls

The system control module is responsible for vehicle level functions such as vehicle start sequencing, controlling high-voltage power distribution, system diagnostics, Motor controller sequencing and other small functions like chime, reverse buzzer etc. Here motor control sequencing, stop-start feature and shifter safety logic are discussed in detail.

Vehicle Power ON Sequencing and Diagnostics

Vehicle sequencing ensures the proper powering up the vehicle to ensure the safety. Before enabling the modules health of the modules should be ensured. For example, before power up the DC-DC convertor, the BMS system should be healthy. If not the diagnostic LED will blink in pattern to indicate the cause for the fault.

Motor Controller Sequencing

The state machine as in Figure 2 shows proper enabling of motor controller in sequence. The system operates in different operating states such as disabled, ready, enabled and power down. The sequencing also involves intermediate wait states to account for CAN command delay or hardware delays. (T0-T10) are state transition conditions.

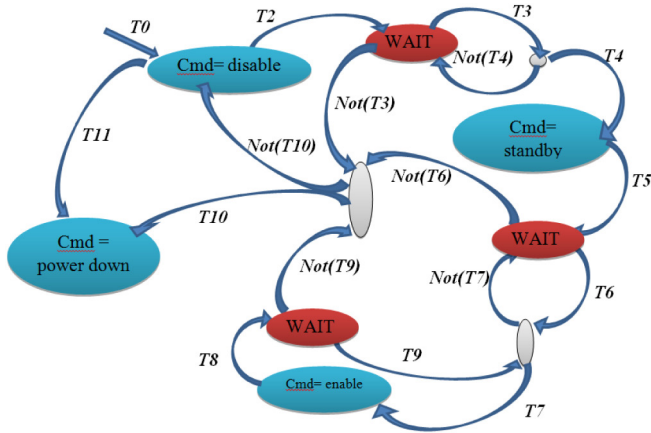


Figure 2. State diagram of motor controller sequencing

Shifter Safety Feature

The Shifter safety logic feature enables safety functions like Brake pedal must be pressed for changing state of the shifter. It also forbids the fault case inputs like reverse shift while vehicle is moving in forward direction and vice versa. The shifter logic model is developed in Simulink/State flow.

Stop-Start Feature

The stop-start feature enables the system to save the energy during idling. It switches off the auxiliary subsystem during idling. The conditions for idling being shifter in neutral and vehicle is standstill. Power during idling without stop-start is 1.02kW. With this feature, the auxiliaries consume 510 W during idling. Thus the stop-start feature saves 48% of energy compared to idling without stop-start.

Propulsion Controls

The propulsion control is the sub module of vehicle controller. It is responsible for calculating the motor torque commands to the motor controller. Figure 3 shows the overall block diagram of the Propulsion control. The mode selector is responsible for selecting the mode of the vehicle. It assigns high priority for brake pedal to ensure safety.

The acceleration control module takes care of accelerator pedal input from the driver. The brake control module takes care of accelerator pedal input from the driver.

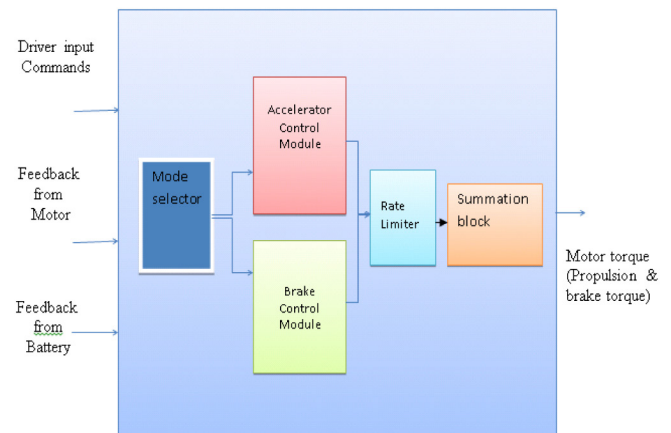


Figure 3. Block diagram of propulsion controller

Accelerator Control Module

The Accelerator Control Module (ACM) commands the motor controller for propulsion torque based on driver input through accelerator pedal and feedback signals from drive (speed, torque signals) and battery system (SOC, discharge limits, etc.).

It is pre-programmed with the motor speed torque curves to calculate the available torque from the motor at any instant. This module operates the vehicle in different optimized modes such as performance mode, energy efficient mode and reduced performance mode etc. The detailed functionalities of the operating modes and its results will be explained in later section of the paper.

The instantaneous battery power limit is calculated based on the available state of charge (SOC), discharge current limit (DCL), and pack voltage of the High Voltage Battery (HVB). The torque is calculated considering both HVB limit and drive system limit.

Figure 4 shows the Simulink model of the Accelerator control module.

Figure 6 shows the torque limit of motor and battery limited torque, for a part of standard urban LCV drive cycle. The overlap of the torque request and battery limit shows the hitting of battery limits and at these instants the controller will limit the command to battery limits.

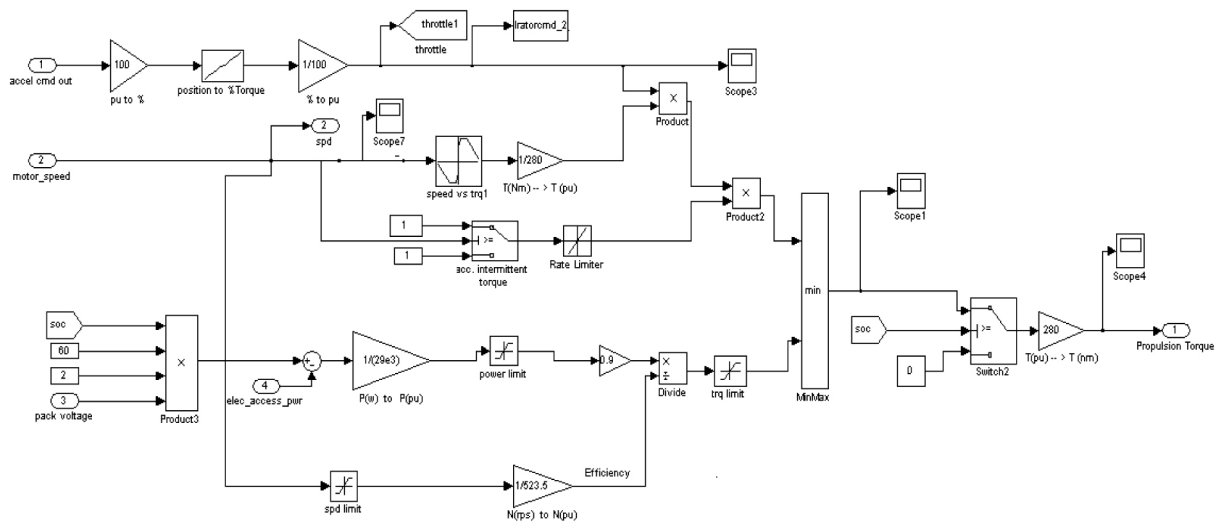


Figure 4. Simulink model of Accelerator Control Module

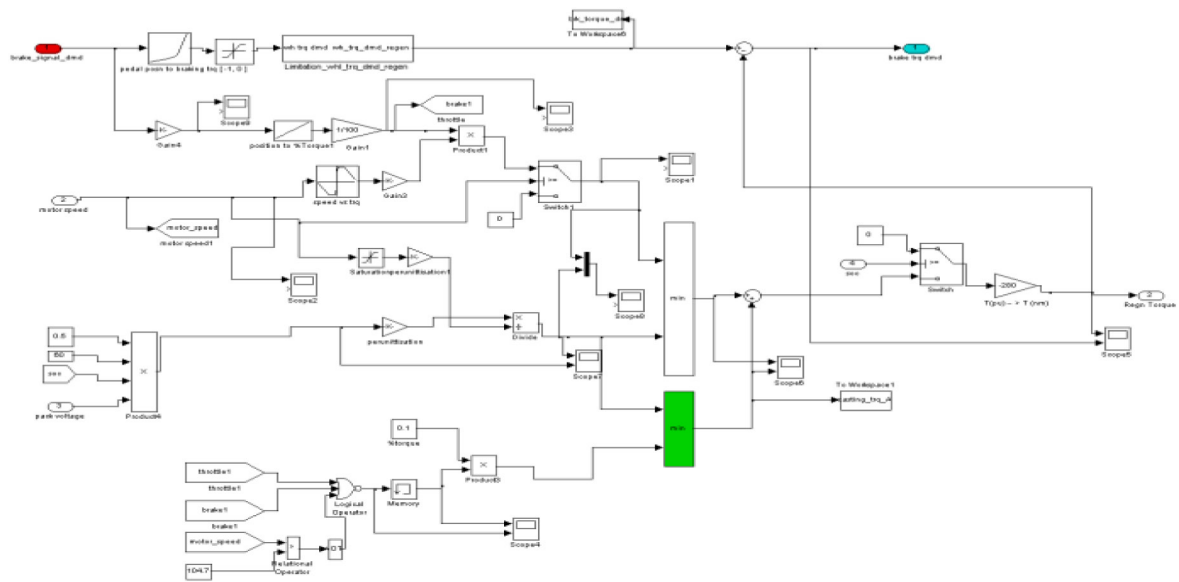


Figure 5. Simulink model of Brake Control Module

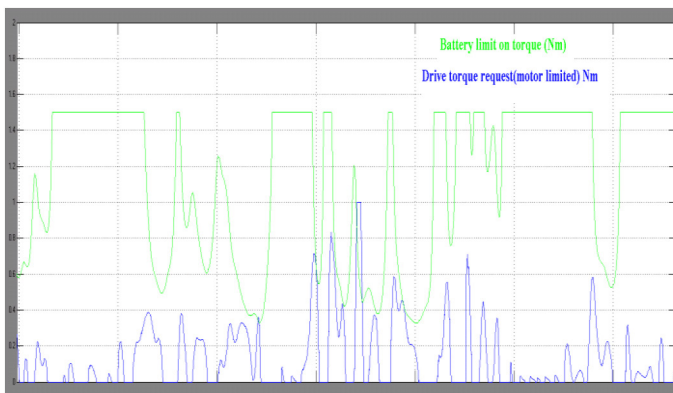


Figure 6. Torque limits of motor and battery

Brake Control Module

The brake control module (BCM) is a sub module of propulsion controller. It is responsible for recuperation of energy from wheels while braking or coasting.

The brake control module during braking mode does the regeneration based on brake pedal position, considering the motor and battery limits. But during the coasting mode it does constant torque regeneration.

Battery Charge Current Limit (CCL) is a factor to limit the current, which increases the life of the Li-ion battery used. BCM inherits the motor speed torque curve to find the maximum torque available from the motor. Figure 5 shows the Simulink model of the Brake Control Module (BCM).

Parallel braking strategy is adopted in the BCM. The frictional and electrical braking (regenerative braking) are applied simultaneously such that at any pedal position the braking effort is the summation of both.