

Model Based System Design of Conceptual Drive-by-Wire ECU Functions for Electric Vehicle Conversion

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ABSTRACT

Development of conceptual drive-by-wire ECU for electric vehicle conversion (EVC) can be designed by means of a low cost and time saving model based process. This is done by employing MATLAB scripted programs to systematically compute the power flow regime of the electric vehicle propulsion and response to dynamic loads. In this particular design, vehicle data and modification of simplified federal urban driving cycle (SFUD) were the two main inputs for driving simulation. As a result, the simulation was capable to predict various EVC characteristics and design parameters, such as driving range, torque-speed characteristics, and motor power usage. Output obtained from simulation were employed as design criteria to set up drive-by-wire software and ECU hardware functions, which are driving modes, torque set point for EVC electric propulsion in all four quadrants. EVC functions also have potential benefits in the improvement of vehicle drivability to suit a driver's individual preference.

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INTRODUCTION

The clear environmental benefits of zero emission vehicle driving [4][5] have encouraged automotive engineers to design and develop electric vehicle (EV). Conversion of the internal combustion engine (ICE) vehicle to be driven by motor known as electric vehicle conversion (EVC) process is one of immediate solutions to produce zero emission vehicles, helping to lower amount of pollution in an urban or city area [6][7][12]. However, during pre-conversion process, all engine parts and theirs associated electronic components have to be taken apart. The dissembled parts include the electronic throttle controller connected to the accelerator pedal. To compensate the component, a potbox has been used to convert accelerator position into pulse width modulation (PWM) signals for motor drive. The device can be improved by implementing advanced driving functions, such as driving modes and torque setpoint generation in four quadrants, to support different driving conditions and preferences.

Therefore, current design effort is to focus on utilization of a design process to develop conceptual drive-by-wire ECU to replace existing electronic throttle controller for the converted EV. Drivability and driving preference of the EV can be improved as a result [15].

Model based process was selected as the primary ECU design tool [9][11][14]. Design criteria for software functions can be determined from simulation output parameters even

when some technical specifications are still unclear or unavailable. The design parameters could be updated as soon as additional specifications are available. Thus, the process help utilizing efficient design progress by reducing project time spending. It also helps avoiding the design cost from building range of actual prototypes.

MODEL BASED PROCESS FOR CONCEPTUAL DESIGN OF ECU

The overall process employed is shown in the flowchart below (Figure 1) where technical specifications were documented at the beginning of the design process. Then, EVC components and system models were built in mathematical equations based on physical laws governed. Subsequently, the models were programmed for simulation with vehicle data and driving cycles as programming inputs. Simulated outputs were then analyzed and selected as design criteria for the conceptual ECU function development. In this case, software function was designed as drive-by-wire algorithm for EVC, which comprises of driving modes, and torque setpoints command for four quadrants electric propulsion. Furthermore, all input/output variables, and parameters were established for ECU hardware and CAN bus interface. Details of each design process will be explained throughout the literature.

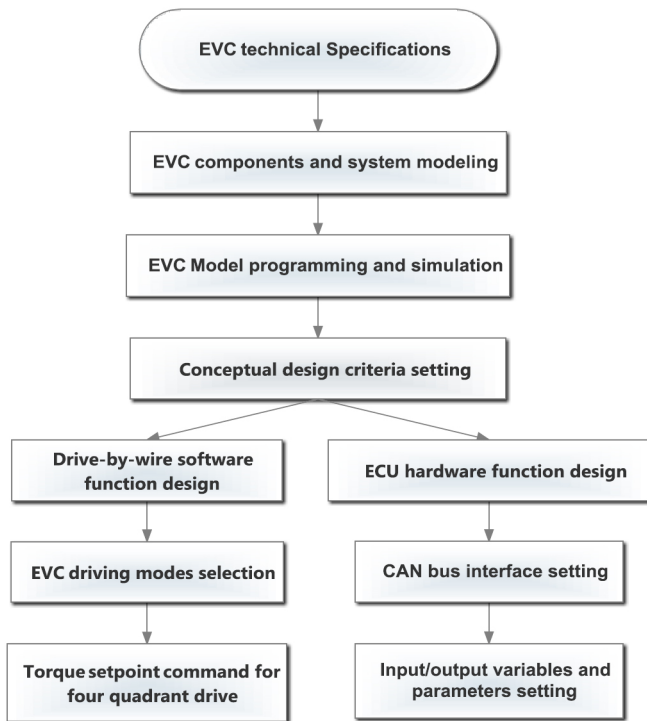


Figure 1. Model based process employed in the conceptual design of ECU.

EV COMPONENTS AND SYSTEM MODELING

Electric vehicle system modeling techniques employed in the current work are mainly based on Larminie and Lowry [10]'s physical based models where all mathematical models for EV dynamic system are generated from engineering principles and theories [3]. The core models are electric vehicle traction, motor, battery, and EV power flow models. Some model parameters, such as motor efficiencies and vehicle moment of inertias, are reasonably estimated.

For EV traction modeling, forces acting on the vehicle govern the traction equation as seen in Figure 2. Those forces comprised of tractive force (F_{te}), rolling resistance force (F_{rr}), aerodynamic force (F_{ad}), lateral acceleration force (F_{al}), wheel acceleration force (F_{wa}), hill climbing force (F_{hc}) [the component force of vehicle weight].

The relation is shown in equation (1) where traction needs to overcome the load is equal to five other forces;

$$F_{te} = F_{rr} + F_{ad} + F_{hc} + F_{la} + F_{wa} \quad (1)$$

The electric motor is installed to replace the internal combustion engine (ICE) in providing the torque to drive the wheels with the efficiency of approximately 90 percent. Traction model is divided into two phases due to the motor traction characteristics. The electric motor is operated at a maximum torque at low speed and then the torque value is

declined with constant motor power. The point where the torque characteristic starts to change is known as motor critical speed.

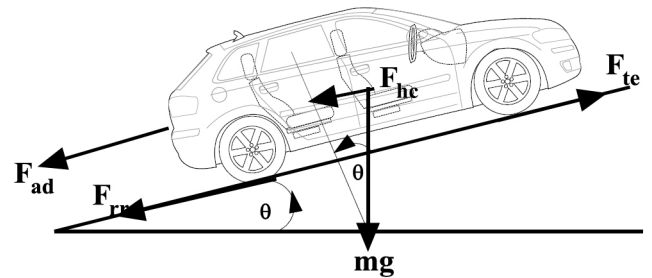


Figure 2. The force components involved in the electric vehicle traction [10].

Battery dynamic behavior can also affect EV performance and autonomy or range. Lithium ion battery type will be chosen as the power source for power source. Its open circuit voltage is known to be constant until 80 percent depth of discharge (DOD).

Figure 3 below illustrates schematic diagram of power flow model, which is transient forward facing type, to represent power flow within the EV system [3]. This particular modeling is preferred for control development and hardware in the loop testing [3]. It is, therefore, suitable for the present EV simulation.

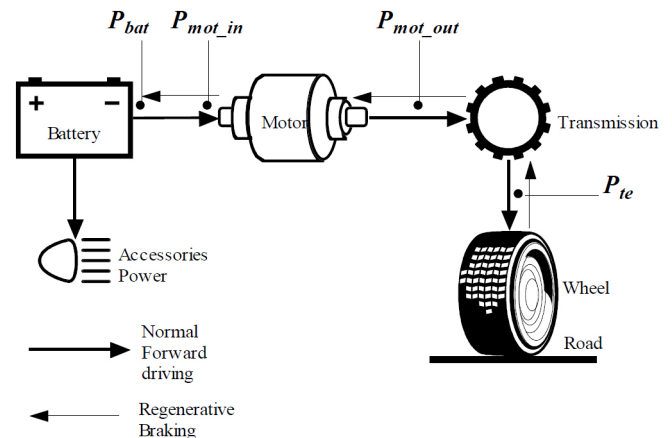


Figure 3. The diagram shows power flow in/out components within EV system for both normal forward driving and regenerative operations [10].

MODEL BASED PROGRAMING AND SIMULATION

Vehicle Specification

The baseline vehicle data used for simulation is from the specification of a commercial vehicle known as Honda Jazz (Fit) 2010 model. The vehicle body is a hatchback type where the cargo space behind passenger seat can be utilized for a

battery pack installation. All input data are listed in [Table 1](#) as followed;

Table 1. Vehicle technical data and EV components for simulation.

Vehicle body	hatchback
Mass	1490 kg
Passengers mass	140 kg (2 passengers)
Coefficient of drag	0.47
Frontal area	1525 x 1695 mm (H x W)
Tire radius	15 inches (0.381 m)
Moment of inertia	Add 20 kg to total mass
Rolling resistance	0.015 (radial)
Gear ratio	5:1
Gear efficiency	90% (approximation)
Motor	UQM: PowerPhase 75
Motor efficiency	90% (approximation)
Regenerative ratio	25%
Power	45 kW (nominal)
Battery	Thundersky
Type	Li-on
Peukert coefficient	1
Number of cell	100
Cell voltage	3.3 Volt
Capacity	60 Ah
Accessories loss	250 W
Limit discharge	80% (DOD)
Open circuit voltage	constant
Road condition	Long smooth surface
Driving cycle	Modified SFUD
Limit motor torque	145 N.m
Maximum motor speed	7500 rpm
Maximum vehicle speed	120 km/hr

Driving Cycle

To simulate EV driving, a suitable driving cycle is required to be a simulation input. For the EV simulation, modification was made for simplified federal urban driving cycle (SFUD) [10] shown in [Figure 4](#). The maximum speed reach almost 90 km/hr (instead of 54 km/hr in normal SFUD cycle) since the EV is expected to be driven often in the city and urban area.

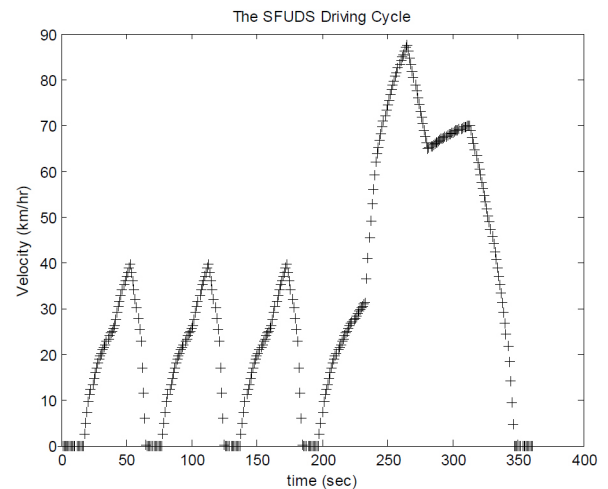


Figure 4. Modification of simplified federal urban driving cycle (SFUD) [10].

Driving Simulation Programming

To simulate EV driving range, one main program was written to incorporate and update all parameters, models, and driving cycle involved in the simulation. EV components in the electric vehicle conversion are all handcoded in MATLAB scripted m-files. The method is preferred since all codes are transparent and straightforward to write and correct the codes. Details of programming structures and procedures can be founded in [10].

SIMULATION STUDY AND ANALYSIS

The simulation result shown in [Figure 5](#) predicted that this hypothetical EV can travel with the range of approximately 80 km per charge based on 80 percent DOD. The result indicates that this electric vehicle is suitable for daily urban commute range limit. Nevertheless, the range can be increased with more Li-ion batteries, but then, the payload would also be increased and total cost of conversion will also be increased accordingly. Therefore, tradeoff between designed parameters needs to be considered for EV conversion.