13AE-0054

Model Based System Design of Conceptual Drive-by-Wire Software Function for Electric Vehicle Conversion

Author, co-author (Do NOT enter this information. It will be pulled from participant tab in MyTechZone)

Affiliation (Do NOT enter this information. It will be pulled from participant tab in MyTechZone)

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. The EVC functions also have potential benefits in the improvement of the vehicle drivability to suit driver's preferences.

INTRODUCTION

The clear environmental benefits of zero emission vehicle driving [4][5] have encouraged automotive engineers to design and develop electric (EV) vehicle. 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 build zero emission vehicles, helping to reduce pollution in urban or city area [6][7][12]. However, in 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 does not have functions, such as driving modes by means of torque set points generation in four quadrants to support different driving conditions and preferences. Therefore, current design effort is focusing on utilization of model based design process to develop drive-by-wire ECU to replace existing electronic throttle controller from pre-converted ICE vehicle. As a result, drivability and driving preference of EVC can be improved [15].

Model based process were served as the primary conceptual ECU design tool [9][11][14]. Design criteria for software function 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 a range of actual prototypes.

MODEL BASED DESIGN PROCESS FOR CONCEPTUAL FUNCTIONAL DESIGN OF ECU

The overall process employed is shown in the flowchart below (figure 1) where technical specifications were documented to start the design. Then, EVC components and system models were built in mathematical forms 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 ECU parameters were conceptually established for ECU hardware functional design and CAN bus interface. Details of each design process will be explained throughout the literature.

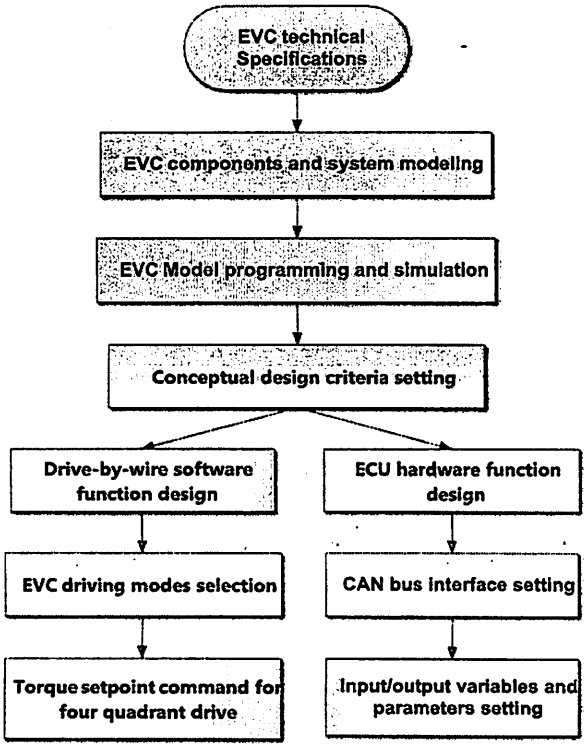


Figure 1.Model based process employed in the conceptual design of ECU.

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 $(F_{\omega a})$, 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 efficiency about 90 percent. Traction model is divided into two phases due to the motor traction characteristics. Motor is operated at maximum torque and then torque is declined with constant motor power. The point where motor characteristics start to change is known as motor critical speed.

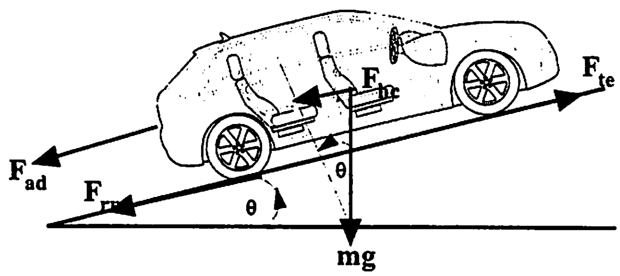


Figure 2.The force components involved in the electric vehicle traction [10].

Battery dynamic behavior can affect EV performance and autonomy or range. Lithium ion battery type will be chosen as the power source for EV. 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.

MODEL BASED PROGRAMING AND SIMULATION

Vehicle Specification

The baseline vehicle data used for simulation is from specification of a commercial vehicle known as Honda Jazz (Fit) year 2010. The vehicle body is a hatchback type where the space behind passenger seats can be utilized for battery installation. All input data are listed in table 1as followed;

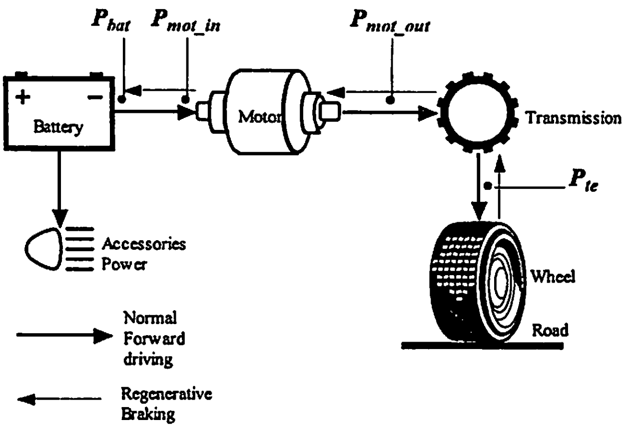


Figure 3. The diagram shows power flow in/out components within EV system for both normal forward driving and regenerative operations [10].

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 driving dynamics, a suitable driving cycle is required to be reasonably selected as another simulation input. For EV simulation, modification is made for simplified federal urban driving cycle (SFUD) [10] shown in figure 4. The maximum speed can now reach almost 90 km/hr (instead of 54 km/hr) since the vehicle is expected to be driven often in the city and urban area.

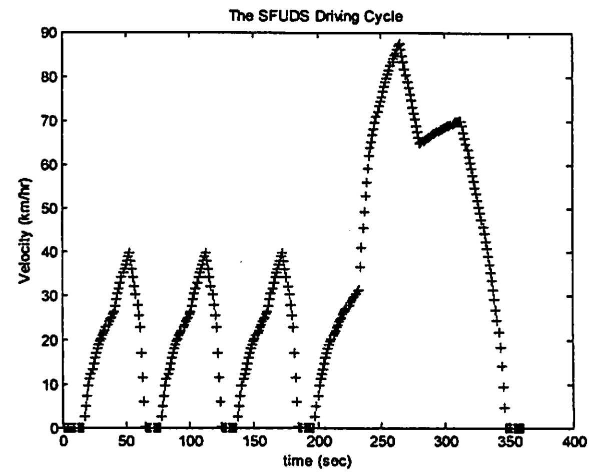


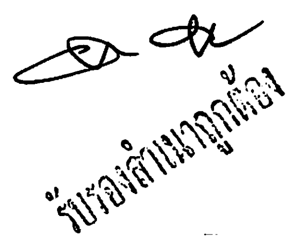
Figure 4. Modification of simplified federal urban driving cycle (SFUD) [10].

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. 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 urban and daily 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 be increased accordingly. Therefore, tradeoff between EV design parameters should be considered when EV conversion is considered.



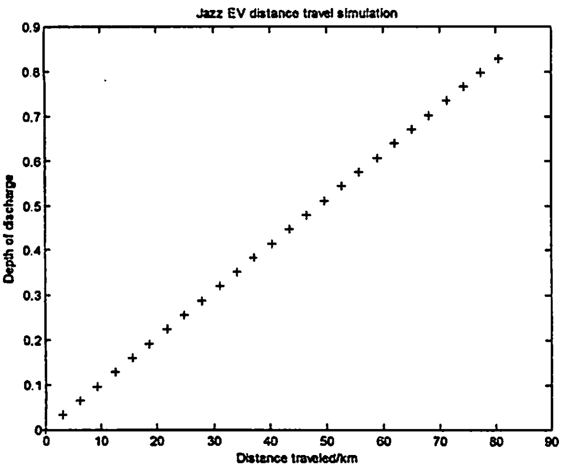


Figure 5.EV range simulation with modified SFUD cycle.

By adopting model based design, conceptual design criteria could be determined based on EVC simulation data. In this case, the motor power output is chosen as the information to set the power limit and pedal sensitivity for each driving mode.

The result shown in figure 6 indicates amount of motor power output based on SFUD cycle. The negative power regions are evidence of regenerative braking according to pre-specified regenerative ratio. Based on the power consumption limit, three EV driving modes were set to configure accelerator pedal sensitivity as specified in table 2. The power limit for city mode is chosen to match driving preferences in city area where there is frequent repetition of acceleration and braking at low speed. In commute mode, the power limit is set to cover the whole driving pattern, including more aggressive driving in the urban area. In power mode, the power limit is set at highest value, providing most responsive driving mode. The driving mode parameter sets were utilized in the drive-by-wire function design to determine power demand and the sensitivity of vehicle accelerator pedal.

Table 2.Driving mode criteria based on the power limit setting.

Driving mode	Power limit (kW)
City	15
Commute	35
Power	45

The torque speed map were also obtained from EVC simulation, and compared with specified EV motor characteristics mentioned in table 1. As presented in figure 7, the motor was capable of handling most of driving demand based on SFUD cycle.

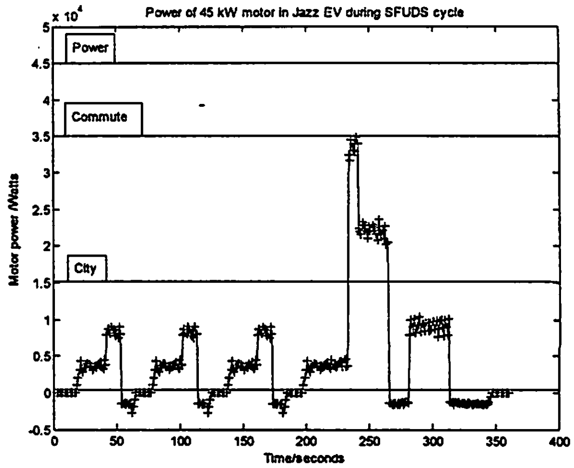


Figure 6.EV motor power output simulation results based on modified SFUD and power demand criteria for 3 different driving modes.

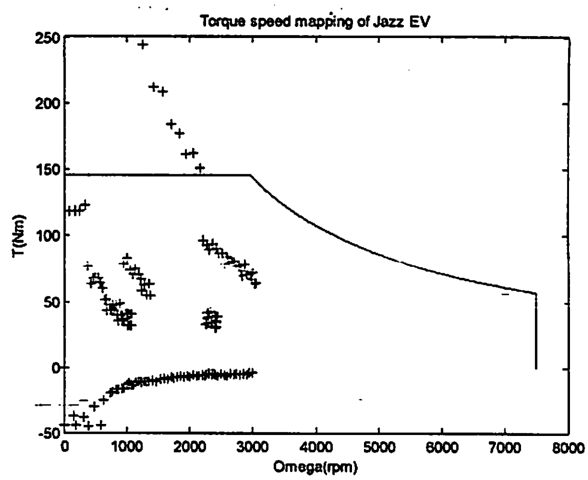


Figure 7.EV conversion torque-speed map simulation.

CONCEPTUAL DESIGN OF HARDWARE FUNCTION AND SIGNAL INTERFACE

The main function of drive-by-wire ECU is to determine power demand from the driver, through vehicle supervisory control ECU, based on pedal ratio in percentage and driving mode selection as shown in figure 8. After that, a torque setpoint or command for motor drive is calculated from the ratio power demand to motor speed. The command is sent to the drive unit and updated on control area network (CAN) bus with specified protocol configuration. The details of input and output commands for the ECU are presented in figure 9 below.

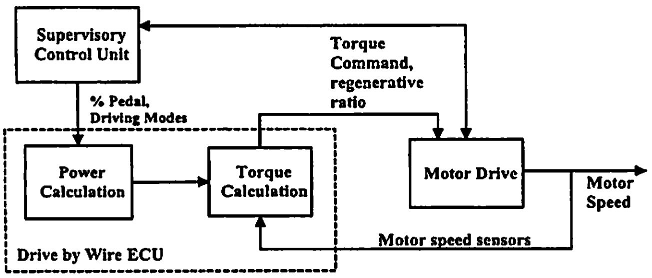


Figure 8.Drive-by-wire ECU functions and signal connection to the supervisory ECU and the motor drive unit.

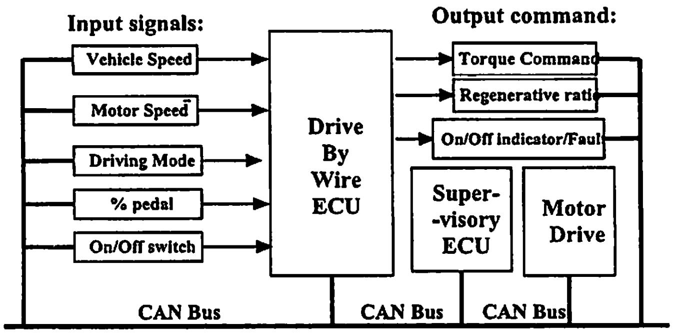


Figure 9.Input and output signal flow of the drive-by-wire ECU with CAN bus interface.

CONCEPTUAL DESIGN OF SOFTWARE FUNCTION

Torque setpoints for all four quadrants drive is determined from the power requested by the driver pressing on the pedal. Based on driver's preference or judgment, the vehicle could be handled in different road and traffic conditions.

In order to match the four quadrants driving demand shown in figure 10, adequate torque setpoints are required. For example, some driving operation might require negative torque command for motor drive (i.e. reverse driving). Moreover, the driving modes introduced earlier need to be incorporated in the software function of the drive-by-wire ECU. To accomplish the development, linear conversion of power to torque command (figure 11) and driving schedule operation (table 3) are defined and implemented in the software function.

For the power to torque conversion, power demand by the driver is linearly calibrated with accelerator pedal position ratio where full press on the pedal or one hundred percent pedal ratio is equivalent to the maximum demand for each driving mode. Therefore, sensitivity of the pedal is configured according to each driving mode where power driving mode is the most sensitive and the city mode is the least.

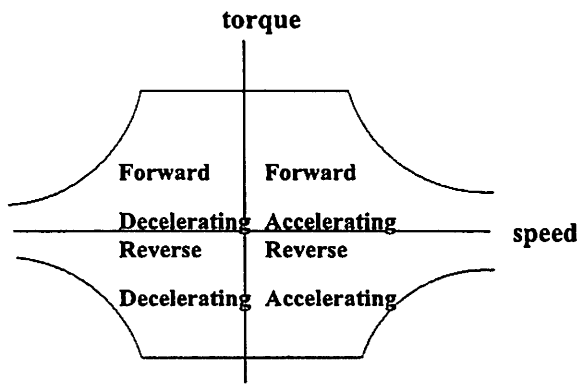


Figure 10.Four quadrants operation of converted EV driving.

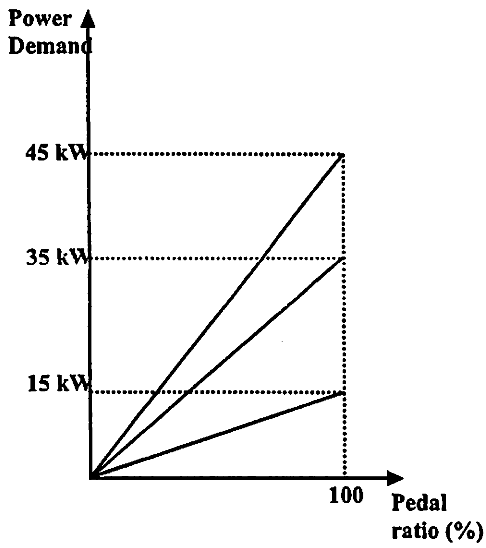


Figure 11.The pedal ratio is linear proportioned to the power demand for each driving mode.

Driving schedules were also defined to categorize the appropriate torque setpoint according to a particular driving operation and the selected driving mode. For a safety purpose, parking schedule was included in the software function where no torque is generated when parking the vehicle. Torque command (T) is calculated by dividing the power demand (P) with motor speed (ω) obtained from CAN bus. For vehicle reversing and decelerating operation, the toque command is defined as a negative value. The complete flowchart of drive-by -wire algorithm is presented in the appendix 1.

รับรองสำเนาถูกต้อง

Table 3.EV Driving schedules and torque setpoint calculation.

Driving Schedule	Pedal ratio (%)	Power Limit (kW)	Torque set point (N.m)
Parking	0	0	0
Forward Accelerating: City mode	0-100	15	$T = P/\omega$
Forward Accelerating: Commute mode	0-100	35	$T = P/\omega$
Forward Accelerating: Power mode	0-100	45	$T = P/\omega$
Forward Decelerating: City mode	0-100	15	$T = -P/\omega$
Forward Decelerating: Commute mode	0-100	35	$T = -P/\omega$
Forward Decelerating: Power mode	0-100	45	$T = -P/\omega$
Reverse Accelerating	0-100	15	$T = -P/\omega$
Reverse Decelerating	0-100	15	$T = -P/\omega$

CHALLENGES AND FUTURE CONTRIBUTION

In conceptual ECU design effort, amount of engineering assumptions had to be made in order to construct the hypothetical converted EV models for simulation since some variables (i.e. motor efficiency and accessories power) were unavailable, especially at the early system design level. The certain amount of variation between physical constructed and the simulated vehicle's data such as autonomy and performance would be expected [1]. Depending on detailed accuracy of vehicle modeling, tradeoff between amount of assumptions and runtime for simulation usually exist [3].

As common in the software development, software functions are required to be validated and calibrated by means of testing methodology [9][13][14]. The process will be applied to the present ECU development as well. For current design, in-vehicle test for rapid control development, EV system bench testing and hardware in the loop (HIL) testing system are being constructed for testing and calibrating conceptual drive-by-wire ECU [2][8] in upcoming scope of work. Track and road driving tests are also included for the long term development. Moreover, basic drive-by-wire algorithm could be further developed by incorporating braking and steering for more complex EV handling.

CONCLUSIONS

The present work illustrates the capability and benefits of model based design methodology in design exploration of EVC system and conceptual ECU functions. EVC components and system were simulated and its output variables were analyzed. By adopting model based process, simulated EV characteristics were utilized as the design criteria in conceptual design of the drive-by-wire ECU without having to build range of actual prototypes. The ECU functions are capable of allowing drivers to select three EV driving modes, to suit their own driving preferences, by mean of adjusting pedal sensitivities. The drive-by-wire algorithm is also able to calculate torque setpoints for four quadrants motor operation to handle EV driving demand.

REFERENCES

1. Butler, K.L., Ehsani, M., and Kamath,P., "A Matlab-Based Modeling and Simulation Package for Electric and Hybrid Electric Vehicle Design," IEEE Tran. On Vehicle Tech.48(6):1770-1778,1999.
2. Cheng, L., and Lipeng, Z.,"Hardware-in-the-loop Simulation and Its Application in Electric Vehicle Development," presented at IEEE VPPC, China, September 3-5, 2008.
3. Gao, D.W., Mi, C., and Emadi, A., "Modeling and Simulation of Electric and Hybrid Vehicles," IEEE95(4):729-745,2009.
4. Hannan M.A., Azidin, F.A., and Mohamed, A.,"Multi-sources Model and Control Algorithm of an Energy Management System for Light Electric Vehicles," Energy Conv. Manag.62:123-130, 2012.
5. Jorgensen, K., "Technologies for Electric, Hybrid and Hydrogen Vehicles: Electricity from Renewable Energy Sources in Transport," Util. Policy16:72-79, 2008.
6. Jussani, A., Albertin, J., and Jussani, A., "Concept of an Urban Family Electric Vehicle," SAE Technical Paper 2011-36-0301, 2011, doi:10.4271/2011-36-0301.
7. Kaloko, B.S., Soebagio, Purnomo, M.H., "Design and Development of Small Electric Vehicle Using

Matlab/Simulink," Int. J. of Comp. App.24(6):19-23,2011.
8. Kohl, S., and Jegminat, D., "How to Do Hardware-in-the-Loop Simulation Right," SAE Technical Paper 2005-01-1657, 2005.
9. Lamberg, K., Beine, M., Eschmann, M., and Otterbach, M.,"Model-Based Testing Of Embedded Automotive Software Using Mtest," SAE Technical Paper 2004-01-1593, 2004.
10. Larminie, J., and Lowry, J., "Electric Vehicle Technology Explained," John Wiley & Sons, Ltd, UK, ISBN 0-470-85163-5, 2003.
11. Rousseau, A., Sharer, P., and Halbach, S., "Using Modeling and Simulation to Support Future Medium and Heavy Duty Regulations," presented at The 25th World Batteries, Hybrid and Fuel Cell Electric Vehicle Symp., China, Nov. 5-9,2010.
12. Terras, J. M. F., Neves, A., Sousa, D.M., and Roque, A., "Modeling and Simulation of Commercial Electric Vehicle," presented at The 13th Int. IEEE A. Conf. on Intel. Tran. Sys., Portugal, September 19-20, 2010.
13. Wewetzer, C., Lamberg, K., and Otterbach, R., "Creating Test Patterns for Model-Based Development of Automotive Software," SAE Technical Paper 2006-01-1598, 2006.
14. Zendri, F., Antonello R., Biral F., and Fujimoto, H., "Modeling, Identification and Validation of Electric Vehicle for Model-Based Control Design," presented at The 11th IEEE Int. Workshop on Adv. Motion Cont., Japan, March 21-24, 2010.
15. Zhan, W., McDermott, M., Zoghi, B., and Hassan, M., "Requirement Development for Electrical Vehicles Using Simulation Tools," presented at Proc. WCECS 2009 Vol II, USA, Oct. 20-22, 2009.

ACKNOWLEDGMENTS

The author would like to acknowledge the support of research under corporative electric vehicle research and development program from; Faculty of Engineering, Naresuan University, Cluster and Program Management Office (CPMO), National Science and Technology Development Agency (NSTDA), and Electric Generation Authority of Thailand (EGAT).

DEFINITIONS/ABBREVIATIONS

ABS	Anti-lock Braking System
CAN	Control Area Network
DOD	Depth of Discharge
ECU	Electronic Control Unit
ESP	Electronic Stability Program
EV	Electric Vehicle
EVC	Electric Vehicle Conversion
Li-ion	Lithium ion battery
SFUD	Simplified Federal Urban Driving
SOC	State of Charge

APPENDIX

Appendix 1. Flowchart for drive-by-wire software algorithm.