

Simulation of Electric Vehicle Drive with Matlab/Simulink

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ABSTRACT-This paper shows the simulation of a basic electric vehicle motor-drive system which is used for investigation of power flow in both regeneration and motoring. The simulation assumes a permanent magnet DC motor, an motor controller with ideal characteristics connected with a PI controller, and the electric battery. This model is to be used for evaluation of energy flow of electric drive and efficiency for specific speed and torque load conditions. Some of the system parameters were specified and others were modeled as ideal in this model. A Developed MATLAB/SIMULINK file is validated which is perfectly stable. Then the model is used to determine the system performance and flow of energy over a given set of regeneration and motoring speed/torque conditions. This model can be used to enlarge instruction in energy conversion or vehicle systems courses.

I. INTRODUCTION

These coming years, electric vehicles were largely produced for the first time in history, and it should include more learning thoughts and experiments that are related to that topic. "The 2010 – 2020 time periods have been declared as the forthcoming 'tipping point'...the changeover from the Internal Combustion Engine (ICE) as the prime mover of vehicles to electric propulsion systems." [1] "Education is really the imperative base for where the industry is headed in this field. [2] At present, there are no ABET ascribed Automotive Engineering or Technology degree programs that contain electric vehicle courses [3]. An Intelligent search for electric vehicle education exposed a few single-offering or unique topics courses. [4] [9] The Department of Energy has awarded funds under the Advanced Electric Drive Vehicle Education Program to sustain the progress of new courses for graduate, undergraduate, secondary students, teachers, technicians, emergency responders, engineers and the public. [10] [11] However, industry is largely training some of the engineers 'in-house', and educational experience in this technology are required now to start a well skilled and educated staff to support the progress of Smart Grid and Electric-Vehicle applications.

In addition to the development in new technology, the design process in most of the industries has also experienced noteworthy change in modern years. A design which is model-based is now commonly used in aeronautical, automotive and other industries for compound embedded systems [12-15] Traditional design workflow follows a sequential path that involves: a) Necessities, b) Design, c) Implementation and d) Test and justification or validation.

The proposed Model-Based Design uses models early in the practice to generate executable specifications that allow engineers to instantly justify and verify specifications against the Necessities. The Engineer then shares the model that can display the performance of the subsystems and components, and also engineer uses the automatic code generation capability of Simulink/Real Time and Embedded Coder to aid Hardware In the Loop (HIL) testing..

Simulation is a key tool that facilitates design while decreasing the price of product progress. As the design process develops the engineer can perform Model-In-The-Loop (MIL), Software-In-The-Loop (SIL), and Hardware-In-The-Loop (HIL) development modeling to model the design. By integrating simulation within the design process engineers can reduce both design costs and design time thus helping the companies to complete and test designed items.

Drive Cycle:

To aid in the design process, vehicle driving tests and simulations are finished to assist support the design process to determine if the design is suitable for the desired application.

A driving cycle is a set of second-by-second set of vehicle speed values that the simulated vehicle is to achieve during the simulation. The need of a drive cycle is to decrease the quantity of costly on-road tests, and also decrease both the time of test and tiredness of the test engineer. The drive cycle course brings the road to the dynamometer or to the computer simulation.

Drive cycles are utilized in vehicle simulations to model the drive system and forecast the performance of the drive system. There are many

standard driving cycles utilized for testing road vehicles for fuel economics and other purposes. Some driving cycles are grown theoretically, and others are direct measurements of a delegate driving pattern. A driving cycle can include regular speed changes or extended periods at constant speed. One example of vehicle simulator is ADVISOR created by AVL Engineering [16] and additional on-line road load and fuel economy simulations.

Speed and Torque Values:

The simulation that is offered in this paper assumes that torque and speed values are known. If speed values are considered then the torque values can be found if the wheel dimensions are available and the road load values met by the vehicle values are known.

The whole road load is the summation of the rolling resistance, air resistance, and gradient resistances that are known or can be calculated. Information on these calculations is available in literature.[18-20]

Electric Vehicle Drive train operation:

In a characteristic gasoline powered vehicle the gas tank need not be designed in the model. Gasoline is exhausted by the engine, but the engine doesn't put gasoline back into the gas tank. A model shift from internal combustion engines to electric vehicles is that the battery is a part of electric vehicle train as shown in Figure 1: Electric Vehicle Drive Train.

The drive train consumes energy from the battery throughout motoring. The drive train will also add charge to the battery when the motor is operated as a specific generator during regeneration. This can occur under braking condition or if the vehicle is being powered by an Internal Combustion Engine (ICE). In the diagram, the battery is mostly constructed of Lithium Ion cells, and supplies 300+ volts and high current to the power electronics. A battery controller continuously monitors the key battery parameters and controls the battery pack.

The power electronics unit acts as inverter and inverts the DC battery voltage into three-phase AC voltage at the desired frequency and voltage for the motor to meet the requested speed and torque. The AC motor is normally a high efficiency Induction Motor (IM) or Permanent Magnet Synchronous Motor (PMSM). These motors can provide either acceleration torque or braking torque for both directions of rotation. If the vehicle's brakes are applied then the motor operates in regeneration mode and thus reversing both the current direction and torque direction. The reversed

torque direction will provide vehicle braking torque while serving to recharge the battery

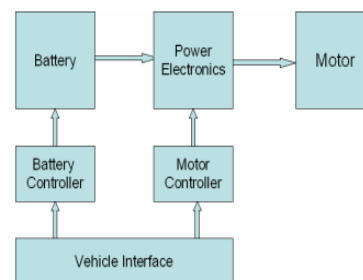


Figure 1: Electric vehicle Drive Train

The Vehicle Interface sends the signal and communicates with the Battery Controller and Motor Controller, and presents an interface with the vehicle-level controls and sensors. Communication between the separate units is done by Controller Area Network (CAN) communications system.

Model Development Process:

The model development process consists of 1) Finding how the model will be used, 2) Recognizing the key equations, parameters, and assumptions, 3) Creating and refining the model, and then 4) the actual model application, evaluation and justification.

This model can be used to calculate the energy flow of a DC motor drive train, and to find the ability of the system to meet specific drive cycle speed and torque necessities. The important components of the model are input road torque, input road speed, motor model, motor controller model, battery model, and PI controller.

A block diagram of the Drive model is presented below in Figure2: DC Drive Simulation Model. In this model the inputs are required Road Speed and Road Torque and the important model blocks are the Motor Model, Controller Model, Battery Model, PI Controller Model, and feedback which is connected from the PI Controller to the main power controller. The feedback contains a one-sample delay with an initial condition to avoid an algebraic loop in the Simulink model.

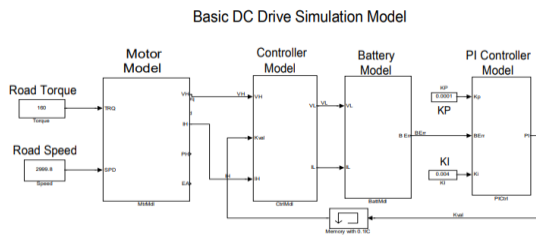


Figure 2: DC drive simulation model

Key Equations:

Finding the key equations and their equivalent variables and parameters is the first step required in model development. Each block in this simplified model symbolizes one or more major equations as listed below.

DC Motor:

Previously discussed, Battery Electric Vehicles (BEV) and Hybrid Electric Vehicles (HEV) mostly use special, high efficiency Permanent Magnet Synchronous Motors (PMSM). This type of motor may be considered as a brushless DC motor because it operates on DC voltage but have no brushes. PMSM motors now actually use AC voltage which is supplied by the Motor Controller. The motor controller acts as inverter and inverts the DC voltage to produce an AC voltage at the desired voltage and frequency. The motor voltage is frequently a 10-20 KHz PWM AC voltage where the voltage and frequency are tuned to provide the desired motor speed and magnetic field values.

The model presented below uses a DC permanent magnet motor. This type of motor is not efficient for BEV or HEV applications due to weight and efficiency considerations. This motor was used in the simulation because it is almost covered in undergraduate engineering education.

The motor model also includes some of the terms and parameters for power loss and time lag while other terms were deleted from the model. The model also accounts for loss of power in the winding resistance and time lag due to the energy storage in the magnetic field of the winding inductance. As it is a permanent magnet field there is no field power loss.

This model doesn't include power loss due to friction and other Iron losses(hysteresis and eddy current losses) and windage losses. The presented model also does not include the time lag due to energy storage in the inertia of the rotor. The motor model is based on the following equations which are given below.

The developed torque is directly proportional to the armature current of the DC motor which is given by the equation below.

$$T_D = K_M * I_A \text{ ----(1)}$$

The developed voltage is proportional to armature speed.

$$V_D = W_D(\text{rad/sec}) / K_m \text{ -----(2)}$$

Motor armature input or terminal voltage is equal to the summation of developed voltage, resistance and inductance voltage drops. In addition, the motor High Side voltage and current are clearly connected to, and therefore identical to, the motor controller High Side voltage and current.

$$V_H = (I_H * R_A) + L_H * (di/dt) + V_D(\text{motor voltage})\text{----(3)}$$

Motor controller:

The motor controller is considered to be an ideal controller with zero power loss and no time lag. The controller basically increases the battery voltage to meet the higher voltage needs of the motor. The dimensionless constant gain or K ratio of the output and input voltages is calculated in order to meet the motor's needs. The same K ratio is used to vary the current so that input and output power values are equal.

$$V_H = K * V_L \text{ ----(4)}$$

$$I_H = (1/K) * I_L \text{ ----(5)}$$

Battery:

The battery is modeled as a voltage source which has an internal resistance. The model has for internal power loss in the resistance of the battery. There is zero time lag in the model. The battery is considered to have a constant internal voltage, E_B . The battery terminal voltage V_B is equal to the summation of the internal voltage and resistance voltage drop. The battery current and battery voltage are equal to the controller current and low side voltage respectively.

$$V_B = (I_A * R_A) + E_B \text{ ----(6)}$$

$$V_L = (I_L * R_A) + E_B \text{ -----(7)}$$

This battery model utilizes the current and voltage information from the Motor Controller block to determine the required battery's internal voltage. This voltage is then compared with the actual E_B value to provide a battery voltage error, B_{ERR} , and that error is used by the Proportional Integral controller model to vary the loop gain.

$$B_{ERR} = E_B(\text{actual}) - E_B(\text{calculated}) \text{ -----(8)}$$

Proportional Integral Controller (PI):

The PI controller will accept the B_{ERR} signal from the Battery Model created and uses proportional constant (K_p) and integral constant (K_i) to determine the gain K value that is used by the Motor Controller block.

$$K = (K_p + s \cdot K_i) * B_{ERR} \text{ -----(8)}$$

Hence the Simulation includes eight equations and eight variables.

Simulation Model Blocks:

Motor model:

This model includes equations 1-3, the block is shown below Figure 3.

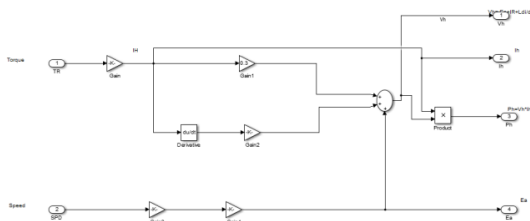


Figure 3: Motor model block

Motor Controller Model:

The block for motor controller includes equations 4 and 5. The block for motor controller is shown below Figure 4.

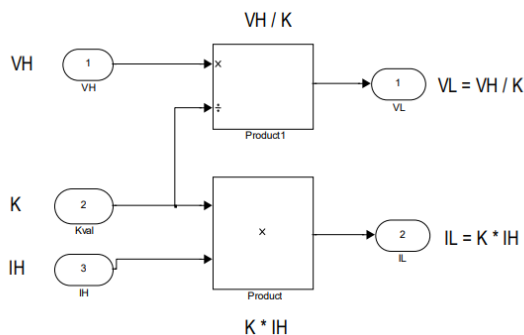


Figure 4: Motor Controller block

Battery Model:

The block for battery model includes equations 6 and 7. The block for battery model is given below figure 5.

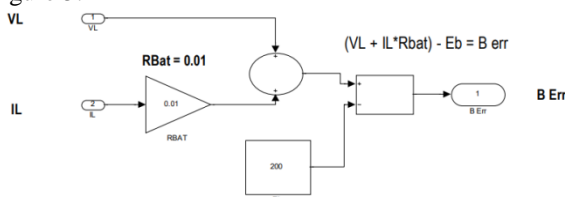


Figure 5: Battery Model block

PI Controller Model:

The model includes equation 8 for the PI controller (Figure 6)

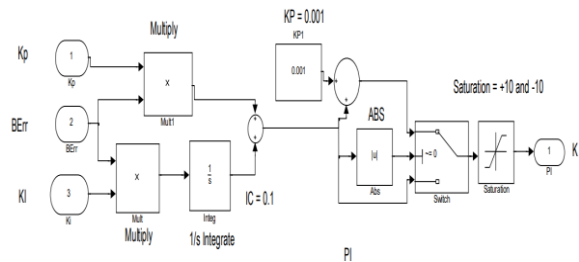


Figure 6: PI controller model block

Drive system model:

The Speed and Torque values were printed to the MATLAB Workspace and the values were then given into the model speed and torque look-up tables. The Clock input given to the look-up tables used the following time base values that were setup in the model parameters table: $T_{min} = 0$, $T_{step} = 0.01$, $T_{stop} = 100$ seconds.

The complete motor drive model is shown below in figure 7.

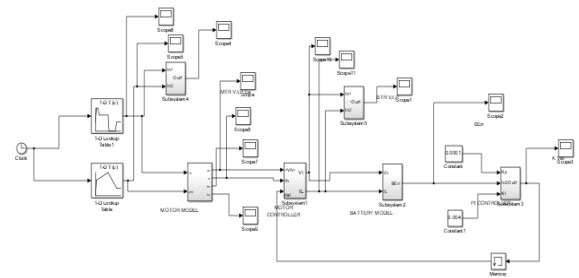


Figure 7: Motor Drive model

Simulation Road Torque and speed:

The first application of the model focused on processing a given set of Speed and Torque data to find evaluate the drive system's performance and also efficiency. The key Speed and Torque data was entered into the MATLAB Workspace using the section of MATLAB code shown below in Figure 8: Road Speed and Torque Data.

The data symbolize Speed-Time and Torque-Time values which match to transition times of their equivalent Speed and Torque curves. This data was then processed by the Simulink Speed Look-Up Table and Torque Look-Up Table.

```

% The key Speed and Torque values are loaded into the MATLAB Workspace
% for use by the Simulink Model.
%
% Load Speed vals and times into the Workspace
Swals = [ 0 2000 3000 1000 1000 ];
Stime = [ 0 5 50 85 100 ];

% Load Torque vals and times into the Workspace
Tvals = [ 0 330 330 160 160 -220 -220 0 0 ];
Ttime = [ 0 5 10 15 50 55 80 85 100 ];
    
```

Figure 8: Road speed and torque data

The plot Battery voltage error vs time is shown below in figure 9

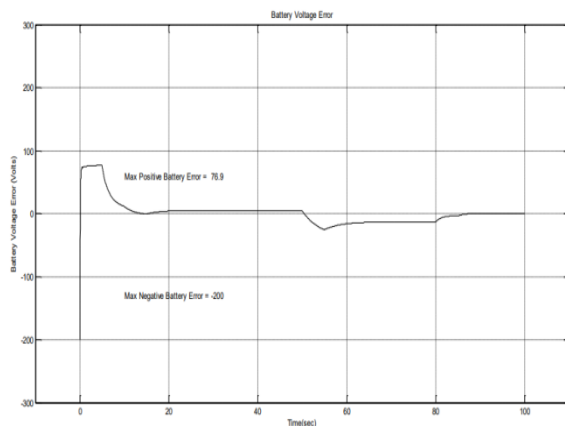


Figure 9: Battery voltage error vs time

The plot Gain vs time is shown below in figure 10

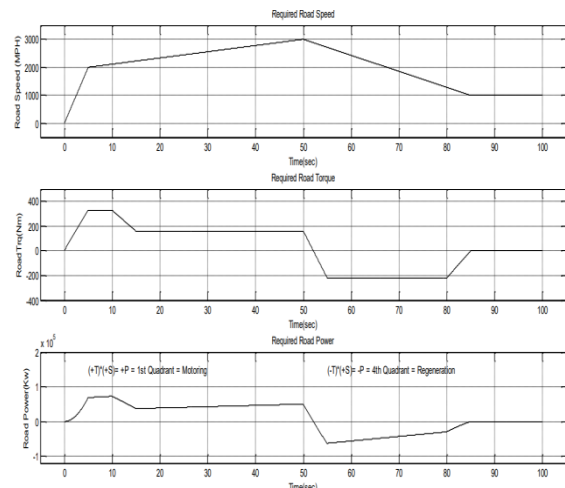
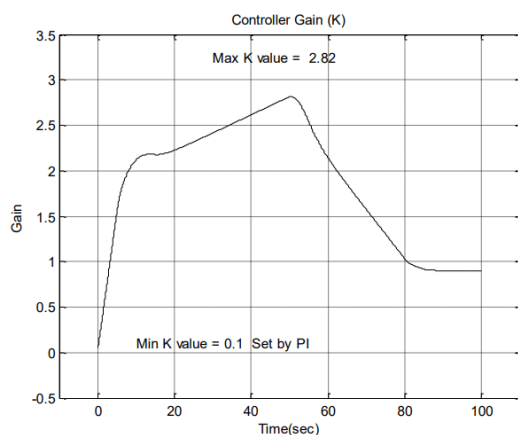


Figure 10: Motor Voltage, current and power curves .

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