

Electric Vehicle Mathematical Modelling and Simulation Using MATLAB-Simulink

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Abstract: As Electric Vehicle is becoming a promising alternative for sustainable and cleaner energy emission in transportation, modelling and simulation of Electric Vehicle has attracts increasing attentions to the researchers. This paper presents a simulation model of Full Electric Vehicle in Matlab-Simulink platform to examine power flow during motoring and regeneration. Every components of the key system drive train consist of motor, battery, motor controller and battery controller were acknowledged and modelled from their mathematical equations. All simulation results were plotted and discussed. The torque and speed conditions during motoring and regeneration were used to determine the energy flow, performance and efficiency of the drive.

Key words: Electric Vehicle, Dc motor battery, controller

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I. Introduction

The first electric vehicle (EV) was built between 1832 and 1839, was not until 189[3], after A.L. Ryker built an electric tricycle and William Morrison built a six-passenger wagon, In 1902 Wood created the Electric Phaeton, which was more than an electrified horseless carriage and surrey. “The Phaeton had a range of 18 miles, a top speed of 14 mph and cost \$2,000 [1]. In the 1960s and 1970s electric vehicles reemerged because internal combustion vehicles were creating an unhealthy environment for the people at that time.

II. Description of an Electric Vehicle

The electric vehicle (EV) is propelled by an electric motor, powered by rechargeable battery packs, rather than a gasoline engine. From the outside, the vehicle does not appear to be electric. In most cases, electric cars are created by converting a gasoline-powered car. Often, the only thing that clues the vehicle is electric is the fact that it is nearly silent [3].

Under the hood, the electric car has: 1) An electric motor 2) A controller 3) A rechargeable battery. The electric motor gets its power from a controller and the controller gets its power from a rechargeable battery. The electric vehicle operates on an electric/current principle. It uses a battery pack (batteries) to provide power for the electric motor. The motor then uses the power (voltage) received from the batteries to rotate a transmission and the transmission turns the wheels [2]. Four main parts make up the electric vehicle: the potentiometer, batteries, direct current (DC) controller, and motor.

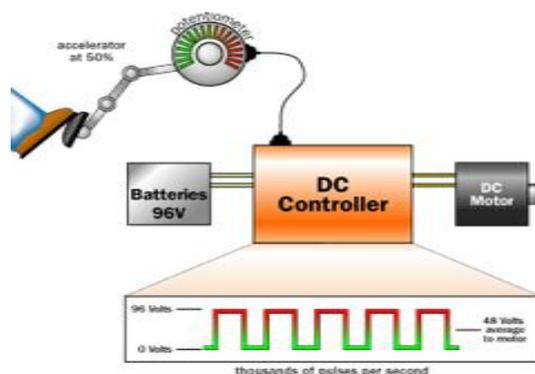


Figure 1: Parts of an electric vehicle

III. Parts and their Functions

Potentiometer: It is circular in shape and it is hooked to the accelerator pedal. The potentiometer, also called the variable resistor, provides the signal that tells the controller how much power is it supposed to deliver.

Batteries: The batteries provide power for the controller. Three types of batteries: leadacid, lithium ion, and nickel-metal hydride batteries.

DC Controller: The controller takes power from the batteries and delivers it to the motor. The controller can deliver zero power (when the car is stopped), full power (when the driver floors the accelerator pedal), or any power level in between. If the battery pack contains twelve 12-volt batteries, wired in series to create 144 volts, the controller takes in 144 volts direct current, and delivers it to the motor in a controlled way [2].

The controller reads the setting of the accelerator pedal from the two potentiometers and regulates the power accordingly. If the accelerator pedal is 2 percent of the way down, the controller pulses the power so it is on 2 percent of the time and off 7percent of the time. If the signals of both potentiometers are not equal, the controller will not operate [2].

Motor. The motor receives power from the controller and turns a transmission. The transmission then turns the wheels, causing the vehicle to run.

IV. Theory of Operation of EV

When the driver steps on the pedal, the potentiometer activates and provides the signal that tells the controller how much power it is supposed to deliver. There are two potentiometers for safety. The controller reads the setting of the accelerator pedal from the potentiometers, regulates the power accordingly, takes the power from the batteries and delivers it to the motor. The motor receives the power (voltage) from the controller and uses this power to rotate the transmission. The transmission then turns the wheels and causes the car to move forward or backward.

If the driver floors the accelerator pedal, the controller delivers the full battery voltage to the motor. If the driver takes his/her foot off the accelerator, the controller delivers zero volts to the motor. For any setting in between, the controller chops the battery voltage, thousands of times per second to create an average voltage somewhere between 0 and full battery pack voltage. The drive shown in Fig 1 shows consumes energy from the battery during motoring. The drive train can also add charge to the battery if the motor is operated as a generator during regeneration. This can occur during braking

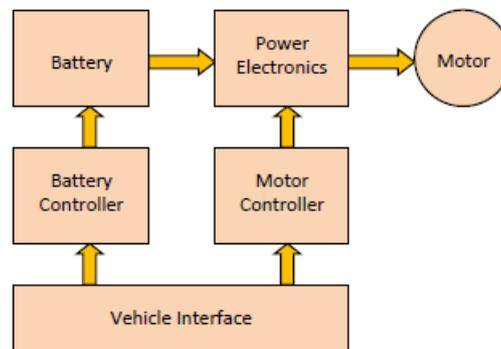


Figure 2: Electric Vehicle Drive Train.

or if the vehicle is being powered by an Internal Combustion Engine (ICE). In the diagram, the battery is frequently constructed of Lithium Ion cells, and supplies 300+ volts and high current to the power electronics. A battery controller monitors key battery parameters and controls the battery pack.

The power electronics unit inverts the DC battery voltage into three-phase AC voltage at the proper frequency and voltage for the motor to meet the requested speed and torque. The AC motor is typically a high efficiency AC Induction Motor (IM) or Permanent Magnet Synchronous Motor (PMSM). These motors can supply either acceleration torque or braking torque for both directions of rotation. When the vehicle's brakes are applied, the motor operates in regeneration mode thus reversing both the current direction and torque direction. The reversed torque direction provides vehicle braking torque while helping to recharge the battery.

The Vehicle Interface communicates with the Battery Controller and Motor Controller, and provides an interface with the vehicle-level controls and sensors. Communication between the separate units involves the use of a Controller Area Network (CAN) communications system.

V. Speed and Torque Values

The simulation that is presented assumes known speed and torque values. If speed values are assumed, then the torque values can be calculated if the wheel dimensions are available and the road load values encountered by the vehicle values are known. The total road load is the sum of the rolling resistance, air resistance, and gradient resistances are known or can be calculated.

VI. Key Equations

Determining the key equations and their corresponding variables and parameters is a necessary first step in model development. Each block in this simplified model represents one or more major equations as listed below.

DC Motor:

As noted earlier, Battery Electric Vehicles (BEV) and Hybrid Electric Vehicles (HEV) frequently use special, high efficiency Permanent Magnet Synchronous Motors (PMSM). This type of motor may be referred to as a brushless DC motor because it runs from DC voltage but does not have brushes. PMSM motors use AC voltage that is supplied by the Motor Controller. The motor controller inverts the DC voltage to produce an AC voltage at the proper voltage and frequency. The voltage and frequency are adjusted to provide the proper motor speed and magnetic field values.

A DC permanent magnet motor was used in the simulation model presented below. This type of motor is not appropriate for BEV or HEV applications due to weight and efficiency considerations.

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

The model does not include power loss due to friction and other rotational losses of hysteresis, eddy current, and windage. The model also does not include the time lag due to energy storage in the rotor inertia. The motor model is based on the following equations.

Developed Torque is proportional to armature current:

Developed motor torque:

$$T_d(\text{Nm}) = K_m * I_A(\text{Amp}) \quad \text{--- Eq(1)}$$

Developed motor voltage:

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

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

$$V_H(\text{Volt}) = I_H(\text{Amp}) * R_A(\text{Ohm}) + L_H(\text{Henry}) * di(t)/dt(\text{A/s}) + V_D(\text{V}) \quad \text{--- Eq(3)}$$

Shaft output torque is equal to developed torque minus friction loss (Bw) and inertial loss (J*dw(t)/dt). Friction and inertial were not specified in the model and are assumed equal to zero. Therefore, developed torque and output torque are equal in this model. However, the model could be easily modified to include these parameters in the future.

The motor physical constant, K_m , is a physical parameter that depends upon the construction of the motor. In the SI system K_m has units of (Amp/Nm) or (Volt/(rad/sec)). At the electrical– mechanical interface inside the motor the developed electrical power ($P = I_A * V_D * K_m$) is equal to the developed mechanical power ($P = K_m * T_d * W_D$).

In the motor model the mechanical friction and inertia as well as the magnetic power losses have been set to zero. Therefore, the power loss will only occur in the armature resistance, and the time lag will only occur in the armature inductance.

Motor Controller:

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

High side voltage is equal to K times the low side voltage:

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

Controller High Side Current:

High side current is equal to 1/K times the low side voltage:

$$I_H = (1/K) * V_L \quad \text{--- Eq(5)}$$

Battery:

The battery is modelled as a voltage source with an internal resistance. The model accounts for internal power loss in the resistance of the battery. There is no time lag component in the model. The battery is assumed to have a constant internal voltage, E_B . The battery terminal voltage V_B , is equal to the sum of the internal voltage and resistance voltage drop. The battery voltage and battery current are equal to the controller low side voltage and current.

$$V_B(\text{Volt}) = I_A(\text{Amp}) * R_A(\text{Ohm}) + E_B(\text{Volt}) \quad \text{--- Eq(6) Battery model calculation:}$$

$$V_L(\text{Volt}) = I_L(\text{Amp}) * R_A(\text{Ohm}) + E_B(\text{Volt}) \quad \text{--- Eq(7)}$$

Assuming: $V_B = V_L$ and $I_A = I_L$

The battery model uses the current and voltage information from the Motor Controller to calculate the required battery's internal voltage. This voltage is compared with the actual E_B value to create a battery voltage error, $BERR$, and that error is used by the PI controller model to adjust the loop gain.

$$BERR = E_B(\text{actual}) - E_B(\text{calculated}) \quad \text{--- Eq(8)}$$

Proportional Integral (PI) Controller:

The PI controller accepts the $BERR$ signal from the Battery Model and uses proportional (K_p) and integral (K_i) to calculate the gain K value that is used by the Motor Controller.

$$K = (K_p + s * K_i) * BERR \quad \text{---- Eq(9)}$$

VII. Simulink Model and Results

The electrical vehicle simulated model is shown in Figure 3.

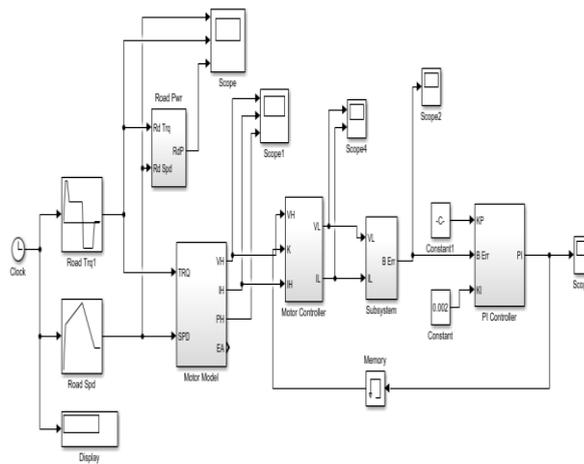


Figure 3: Simulink model of Electric Vehicle

Road speed values can be assumed depending on road characteristics. If speed values are assumed then the torque values can be calculated if the wheel dimensions are available. The road load values encountered by the vehicle values are known. The total road load is the sum of the rolling resistance, air resistance, and gradient resistances which are known or can be calculated.

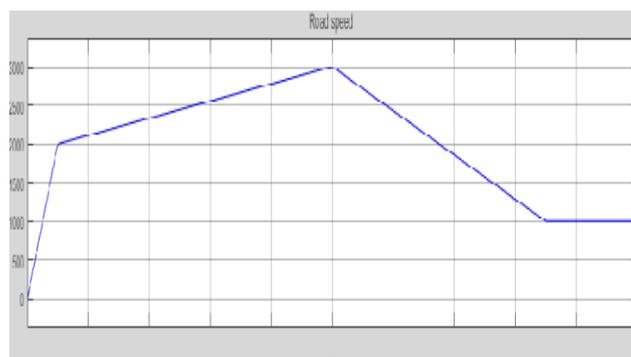


Figure 4: Road Speed characteristics

Speed values=[0 2000 3000 1000 1000]
 Speed time= [0 5 50 85 100]
 Torque values = [0 330 330 160 160 -220 -220 0 0]
 Torque time = [0 5 10 15 50 55 80 85 100]

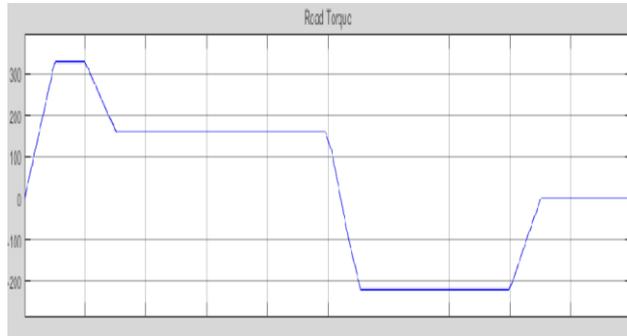


Figure 5: Road Torque characteristics

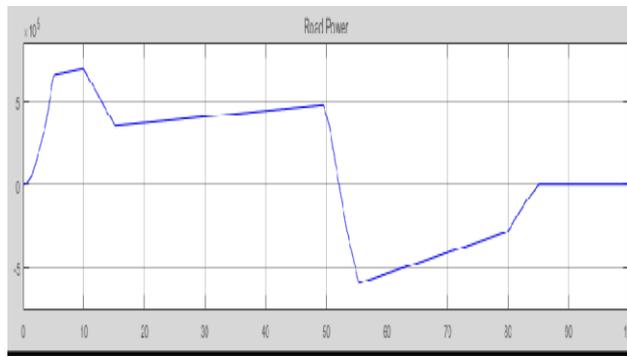


Figure 6: Road Power Characteristics

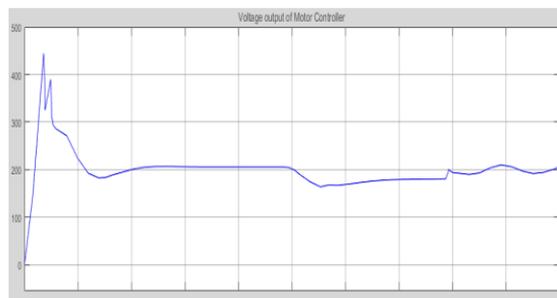


Figure 7: Voltage output of motor controller

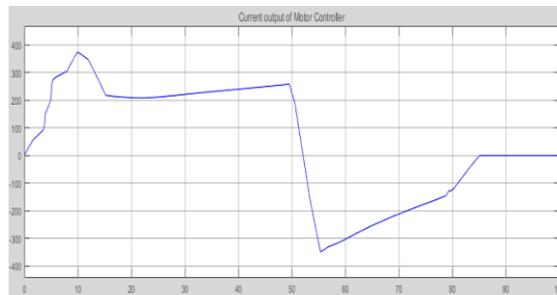


Figure 8: Current output of motor controller

When both torque and speed are positive values the DC Motor is providing torque in the direction of rotation. This is normal motoring operation. However, when the motor torque is in the opposite direction to the speed, then the motor is being pushed and acting as a generator.

A conventional Speed-Torque 4-Quadrant map shows +/-Speed on the x-axis and +/-Torque on the y-axis. When the speed and torque have the same polarity then power is being transferred from the motor to the load,

and the motor is in the motoring mode or 1st Quadrant operation. However, when the speed is positive and the torque is negative, then the motor is being pushed by the external mechanical source. This results in energy being transferred back to the battery. In this case the motor is operating in the 4th Quadrant of the Speed-Torque map.

When both current and voltage are positive values then the DC Motor is providing torque in the direction of rotation and power is being transferred to the load. This is normal motoring operation. However, when the motor current is in the opposite polarity of the voltage at T=50 ms then the motor is being pushed and acting as a generator with current flow back into the battery.

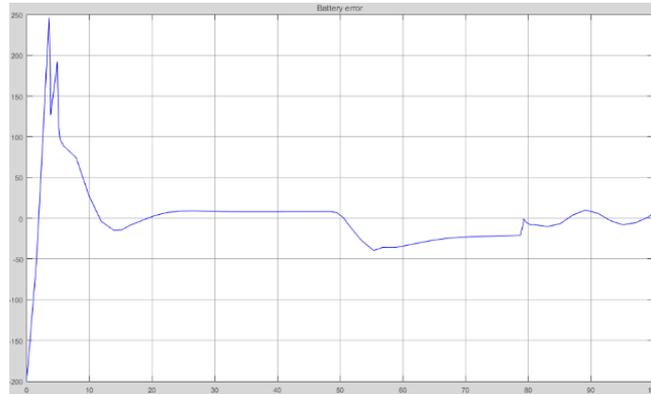


Figure 9: Battery Voltage Error

The simulation model adjusts the controller gain (K) to meet drive torque and regeneration requirements. The simulation compared the nominal battery internal voltage, $V_B = 200$ volts or $V_{Batt(actual)}$, with a calculated battery voltage based on the motor voltage and current values to get $V_{Batt(calculated)}$. The difference, V_{Berr} , was used as an error signal input to the Proportional Integral (PI) Controller. This V_{Berr} signal was plotted over the range of the simulation operation. This plot is shown below in Figure 9: Battery Voltage Error (BErr).

The maximum error of -200 occurs at the very beginning of the simulation. This large error is a natural response to starting the simulation. The simulation quickly recovers and holds an error of about +76 during the initial starting of the motor. It is normal to have a higher error here because the motor developed voltage, $V_D(Volt) = WD (rad/sec)/Km$, is low during startup, especially when the current is increasing.

The negative error occurs during regeneration. By reviewing the motor voltage drop equation, $V_L (Volt) = I_L(Amp) * R_A(Ohm) + E_B(Volt)$, the change in current polarity will cause the reverse polarity of the $I_L(Amp) * R_A(Ohm)$ term. This voltage change will impact the magnitude of the input and output of the PI controller because of the reduced difference between the calculated and actual voltage in the error equation, $BERR = EB (actual) - EB (calculated)$.

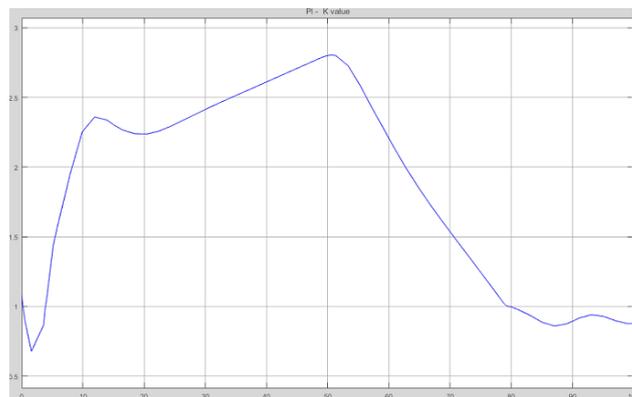


Figure 10: PI controller -K value

The minimum value of Gain K is 0.4 and maximum value of gain K is 2.8.

The battery in electric vehicle is producing sufficient electric power required to overcome the road speed and torque in the simulated results.

VIII. Future of the EV

Future electric cars will most likely carry lithium-ion phosphate(LiMn₂PO₄) batteries that are now becoming popular in other countries. The LiFe₂PO₄ batteries are rechargeable and powerful and are being used in electric bikes and scooters. Electric cars will most likely adopt this technology in the future.

Another technology that is likely for future electric cars is the increased use of supercapacitors and ultracapacitors for storing and delivering electrical charge. Many of these batteries are currently being used in conjunction with hybrid car prototypes, so these are expected in the electric car future markets as well.

If the developers of future electric cars can create vehicles with a range of 300 miles per charge, a charging time of five to ten minutes, and safety in operating the vehicles, the market is wide open for them. Researchers are working on improved battery technologies to increase driving range and decrease recharging time, weight, and cost. These factors will ultimately determine the future of EVs [8].

IX. Conclusion

In this paper road speed and torque values are taken and simulated using MATLAB/Simulink. The battery voltage required is calculated and the torque and speed conditions during motoring and regeneration were simulated to determine the energy flow and performance of the drive. This simulation results can be used for electric vehicle applications.

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