

Simulation of BLDC Motor Drive Systems for Electric Vehicles Using Matlab Simulink

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Abstract. The defining scientific developments of our time would not have been possible without the use of simulations. The aim of the research is to create a simulation of a BLDC motor. When creating a simulation, great emphasis must be placed on defining the purpose of the simulation. This basically determines the structure and complexity of the model. The model discussed here was created so that an optimization task could be defined more precisely by inserting it as a sub-model into a vehicle dynamics model. Scalability was another aspect, that is, to be able to increase the accuracy of the model with measured data in the future, as well as to be able to validate it. During the research, a BLDC motor efficiency map generation program was created, as well as an environment for testing the generated data. The created system gives researchers the opportunity to use a shape-correct efficiency model when simulating a BLDC motor even without measured data. This makes it possible to discover real relationships between model parameters when performing optimization.

Keywords: vehicle, Matlab, BLDC, dynamic simulation, submodel, electric motor

Introduction

The purpose of this article is to introduce a simulation model suitable for analysing BLDC motor drives used in electric vehicles. If the simulated motor is physically available, there is an opportunity to measure the efficiency map. R. Wang and his colleagues measured the driving and braking efficiency map of a pure electric ground vehicle (Wang *et al.*, 2011). This method is unavailable to us, so another solution must be used. H. Patel and H. Chandwani simulated a BLDC motor in Matlab Simulink and verified it (Patel and Chandwani, 2021). The detailed simulation of the electric motor provides an opportunity to achieve higher accuracy, but for this it is necessary to verify the simulated model. The combined FEM simulations also have too much simulation time. A good example of this can be seen in the research of R. Caramia and his colleagues (Caramia, Piotuch and Pałka, 2014). Our goal is to create a flexible submodel that can be easily modified and can be run quickly. In the book of L. James and L. John can be found a simple method to parameterise the electric motor losses based on the physical base (Larminie and Lowry, 2012). In our research this method was used to model a series of BLDC motors.

1. The BLDC motor simulation block

Due to our later research goals, the simulation of BLDC motor drives with several performance levels is necessary. For this purpose, a series of BLDC motors were created with different power ranges. Later these motors will be used in vehicle dynamics simulations. Table 1 contains the main parameters of created motor series.

Table 1 Main parameters of created motor series

Maximum torque	Maximum power
60 Nm	20 kW
100 Nm	40 kW
150 Nm	60 kW
200 Nm	80 kW
250 Nm	100 kW

This wide power range makes it possible to analyze the behaviour of the vehicle dynamics model in extreme load cases. In order to analyze the dynamic behavior of BLDC motor drive system a simulation diagram is defined by using Matlab/Simulink, see in Figure 1. This simulation diagram represents a measuring testbench. This simulation model - in addition to the BLDC motor - also contains the battery, DC/DC converter, speed controller, inertial moment load, and sensors.

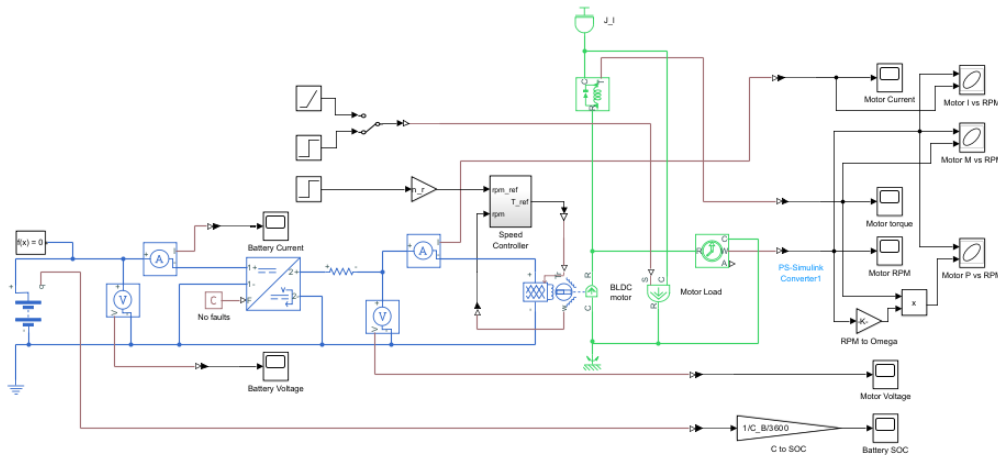


Figure 1 The simulation diagram of drive system

As can be seen in the diagram above, the different physical domains are represented by different colours. The blue color represents the parts of the electrical system, the green color represents the rotating mechanical signals, the light brown color represents the general physical signals, and the black color represents the Simulink signals. The inputs include the reference speed of the motor which is the input signal of the motor controller. This controller creates the required torque signal for the motor. In the simulation diagram the brake torque input can also be found which can be a step function or a ramp function. During the simulation first the BLDC motor speed increases to the reference 3000 RPM and then at 12 seconds the brake torque is applied. Between the active blocks, the voltage and current of the battery and the DC-DC converter as well as the torque and speed of the motor were measured.

2. Definition of the efficiency map for the BLDC motor drive system

The efficiency map for the BLDC motor drive system – due to the lack of measuring possibilities – was created by using the following equation (Larminie and Lowry, 2012).

$$\eta_m = \frac{\text{output power}}{\text{output power} + \text{losses}} = \frac{T \cdot \omega}{T \cdot \omega + k_c \cdot T^2 + k_i \cdot \omega + k_w \cdot \omega^3 + C} \quad (1)$$

Where:

$k_c \left[\frac{W}{Nm^2} \right]$ – copper losses coefficient

$k_i \left[\frac{W}{\frac{rad}{s}} \right]$ – iron losses coefficient

$k_w \left[\frac{W}{\left(\frac{rad}{s}\right)^3} \right]$ – windage losses coefficient

$C [W]$ – constant power losses

$T [Nm]$ – motor torque

$\omega \left[\frac{rad}{s} \right]$ – motor speed

By using Equation 1 a lookup table of efficiency map was created for simulation purposes.

3. Results

One of the aims of this research is to tune the k_c , k_i , k_w , C parameters to generate efficiency maps similar like a catalogue efficiency map. Two of generated maps were shown in Figure 2.

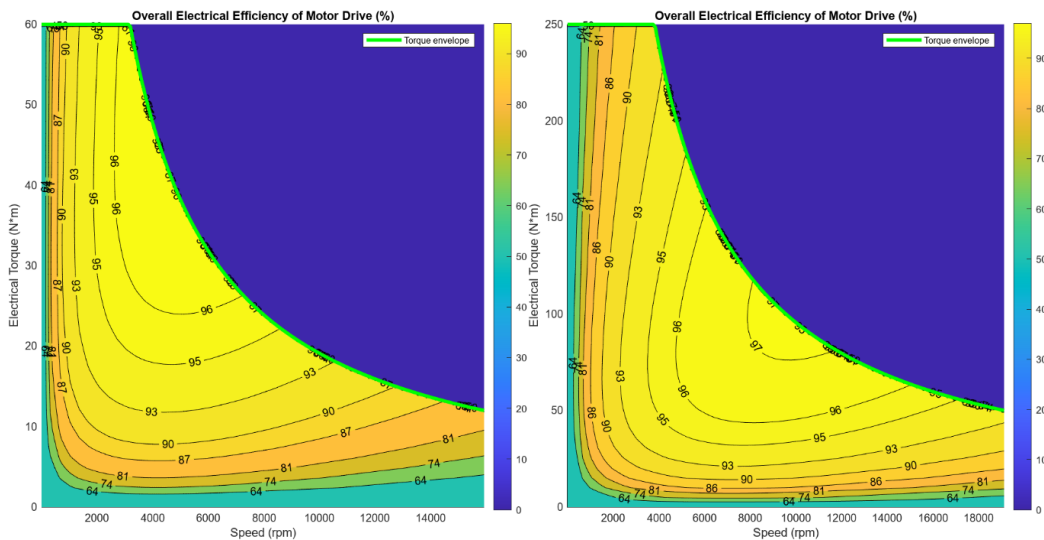


Figure 2 Generated efficiency maps

(Maximum torque 60 Nm and maximum power 20 kW on left,

Maximum torque 250 Nm and maximum power 100 kW on right)

In order to make it easier to follow the simulation, the input and the output data were plotted. These can be seen in Figure 3.

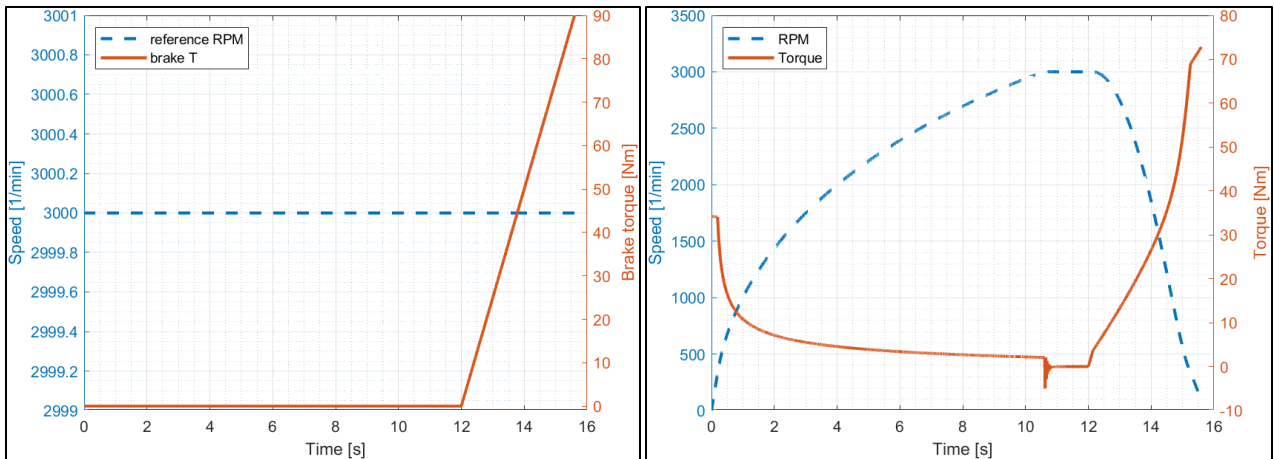


Figure 3. Inputs and outputs of simulation
 (The reference speed of motor and the brake torque on left,
 The measured motor speed and torque on right)

It can be seen here that the motor speed increases to the reference RPM and then decreases. During this, the brake torque continuously increases from 12 seconds. Figure 4 shows the efficiency map, the motor curve and the simulated RPM-torque diagram.

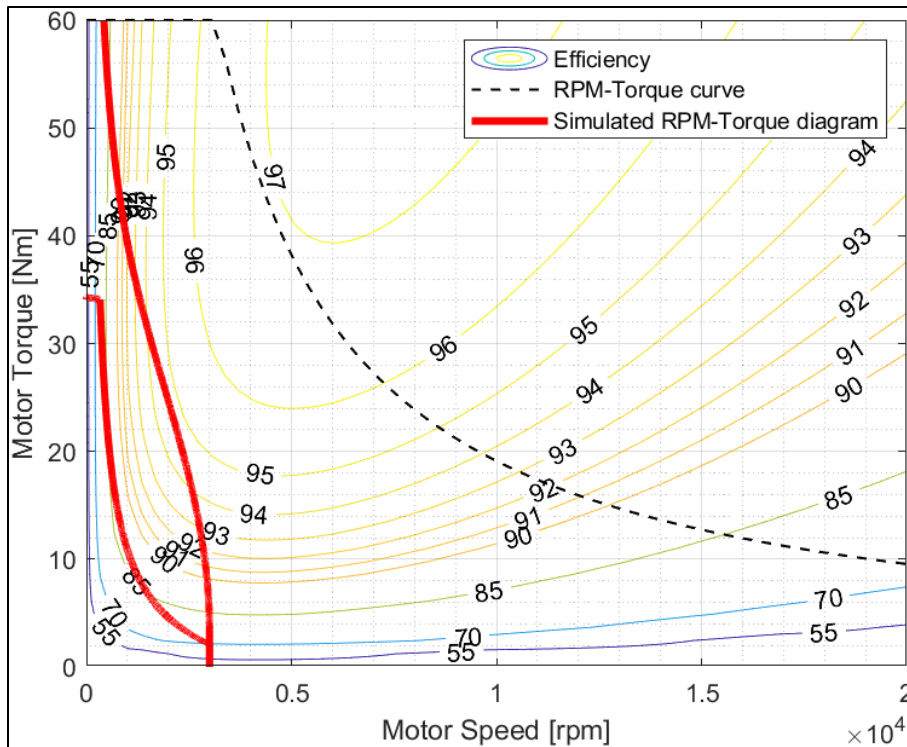


Figure 4. The Efficiency map and the simulated RPM-Torque diagram

4. Summary

In this article the dynamic simulation possibilities of a BLDC motor drive system was presented. A simulation model was created by using the Matlab/Simulink simulation environment. The parameters of the simulation model were set so that the simulation provided realistic results. The demonstrated model later will be used for dynamic simulations and optimizations of electric vehicle drivetrains.

5. Acknowledgments

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