

Space Vector Modulation Technique for Electric Drive Vehicle

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Abstract

In concern about the healthy environment and sustainable development, the replacement of combustion engine with electric motor is becoming essential in automobile industry. Various nations have taken serious steps towards their Electric Vehicle Mission in order to reduce the pollution thus by eliminating the green gases emission into the atmosphere. This paper uses a space vector modulation technique to improve the controllability and efficiency of an inverter used in Field oriented control of Induction Motor of Electric Vehicle. The system is modeled and simulated in Matlab simulink and results are satisfied with the electric vehicle index.

Keywords: *Combustion engine, Electric vehicle mission, Vehicle index, Atmosphere, Induction motor*

INTRODUCTION

The development and adoption of green vehicles are considered as major solutions to reduce green house gas levels in the atmosphere to an acceptable level. The electric vehicles are the best alternative for combustion engine to reduce the air pollution [1]. The Electric vehicles run on alternative sources of energy such as only electricity, hybrid energy or bio-fuels [3]. In an attempt to control global warming countries around the world are coming up with the stringent emission norms to curb the levels of green house gas emissions from vehicles. The main units present in EV are an electrical energy source, power converter, electric motor, and sensing and control unit[2]. An accelerator pedal is connected to the controller to determine, how much power from battery pack must be delivered to the motor to overcome the vehicle load in different conditions.

This paper investigates the designed key features of EV propelled by three phase Induction Motor. The purpose is to create a simple EV model with low cost, achievable requirement, performance and safety. The paper also describes the field

oriented control (FOC) combined with space vector modulation (SVM) technique to improve the transient and steady state of the EV drive. This paper is frames as, SVM technique, model development; finally simulation results are discussed with conclusion.

PRINCIPLE OF SPACE VECTOR MODULATION TECHNIQUE

It is a type of modulation technique being used in modern inverter control. Space vector modulation technique is used to reduce the switching losses and increases the inverter efficiency considerably [4]. The SVM decreases the distortion of the output alternative current of the inverter. The armature plane is divided into six sectors, each of 60° . It has six active vectors (v_1-v_7) and two null vectors(V_0 and V_7). The switching sequences are generated in each sector. The eight possible switching vectors are six active vectors, $v_1(100)$, $V_2(110)$, $V_3(010)$, $V_4(011)$, $V_5(001)$, $V_6(101)$ and two null vectors $V_0(000)$ and $V_7(111)$. The vector division is shown in the figure 1.

To generate the switching sequence the

Vref and angle θ must be determined for every sector. The reference voltage vector vref is generated by using voltage vectors (V1, V2) and one null vector in that sector. Also, the associated time duration T1, T2, T0 of the voltages V1, V2, Vref should be defined as well as the switching time of each transistor of the inverter as depicted in Fig.2. For example, in sector 1, V1 with an interval time T1 and vector V2 has interval time T2 then vector V0 or V7 for interval time T0. While Vref varies from zero to the maximum amplitude, Vref_max, before nonlinear over modulation is reached. To make sure, the

summation of time for these states equals to the reference vector period [3].

These interval times can be calculated as follows:

$$V_{ref} = V_n \cdot T_1 + V_{n+1} \cdot T_2 + V_{null} \cdot T_0 \quad (1)$$

$$T_1 = T \cdot m \cdot \sin(60 - \Delta\theta),$$

$$T_2 = T \cdot m \cdot \sin(\Delta\theta)$$

$$T_0 = T - T_1 - T_2 \quad (2)$$

Where T is a switching period, m is the modulation factor (0-1), and $\Delta\theta$ is the angle between Vref and Vn.

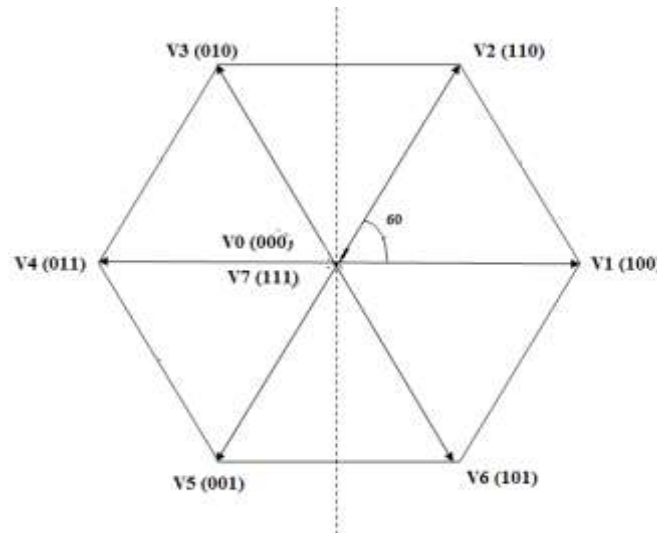


Fig:1.Space Vector Division in SVM

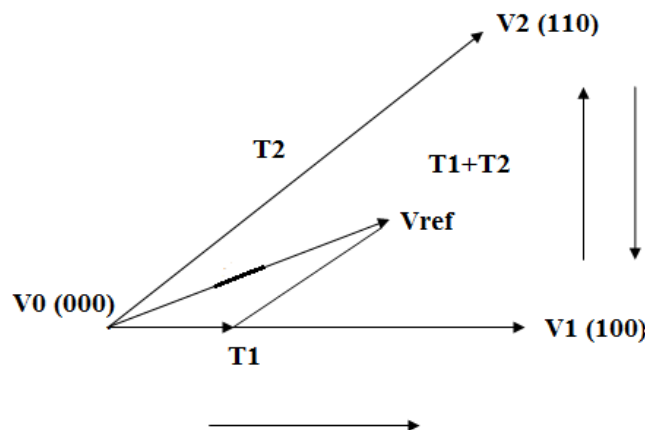


Fig: 2. Time interval calculation in SVM

Field Oriented Control of Motor

Field oriented control converts the

measured motor signal (i.e., currents/voltages) into two components the

field current, and the torque. It is also called as vector control of motor. It may use two types of vector control methods, the direct and indirect methods [6]. The block diagram of Field Oriented control is shown in figure 3.

The direct vector control works with measured flux in stator-rotor gap, while indirect method estimates the magnetic flux from the applied voltages and resultant currents through the model of the motor [7],[8]. The direct torque control produces ripple in flux and torque besides it has a slow transient response to the step change in the torque during start mode [9]. Therefore, FOC with SVM can provide the optimal way to control the traction motor where torque control is required.

In EV application, FOC controls not only the torque but also decreases the electric drive losses. It uses only two sensors to measure instantaneous currents, i_a and i_b . i_c can be calculated from i_a and i_b . i.e., $i_a+i_b+i_c=0$.

Using a Clarke transformation, these three phase currents or voltages are converted into a variant two phase system, $(a,b,c) \rightarrow (\alpha, \beta)$.

$$i_{s\alpha} = i_a, i_{s\beta} = \left(\frac{1}{\sqrt{3}}\right)(i_a + 2i_b)$$

Then a two coordinate time invariant system is outputted by using the Park transformation $(\alpha, \beta) \rightarrow (d, q)$.

The two-axis currents i_d and i_q is rotated to align with the rotor flux using rotor flux position θ .

$$i_{sq} = i_{s\alpha} \cdot \sin \theta + i_{s\beta} \cdot \cos \theta$$

$$i_{sd} = i_{s\alpha} \cdot \cos \theta + i_{s\beta} \cdot \sin \theta$$

The commended currents i_d , i_q and their

measured values generate error signals. The i_d reference controls rotor magnetizing flux while the i_q reference manages induction motor torque output. These error signals are amplified by the proportional-integral (PI) controllers to create correction voltages V_d and V_q . Using the inverse park transformation with a rotor flux position θ , the V_d and V_q are replaced back into the stationary frame to get quadrature voltage values, V_α and V_β . These quantities V_α and V_β are then mathematically translated back into three voltages value V_a , V_b , and V_c using inverse Clarke transformation. This transformation process determines the new PWM duty-cycle. The new estimated angle guides the FOC algorithm in placing the next voltage vector.

The reference frame dq-axis is rotating at speed ω_e while the rotor which has a_r , b_r and c_r windings, rotates at speed ω_r . The hypothesis windings q_r^* and d_r^* are rotating at a speed of the rotor flux vector because the reference frame is attached with rotor flux vector. Therefore, FOC for an induction machine can be performed based totally on a motor model in dq-axis fixed to the stator stationary reference frame. Rotor current i_{qr} must be replaced with stator current and the slip can expressed as:

$$\omega_{sl} = \omega_e - \omega_r = \frac{r_r}{L_r} L_m \frac{i_{qs}^e}{\psi_{dr}^e} = \frac{L_m}{Z_r} \frac{i_{qs}^e}{\psi_{dr}^e}$$

The motor torque is given as

$$T_e = \frac{3 P L_m}{2 L_r} (i_{qs}^e \psi_{dr}^e - i_{ds}^e \psi_{qr}^e)$$

Response of vector controlled induction motor drive is

$$T_e = \frac{3 P L_m^2}{2 L_r} i_{qs}^e i_{ds}^e$$

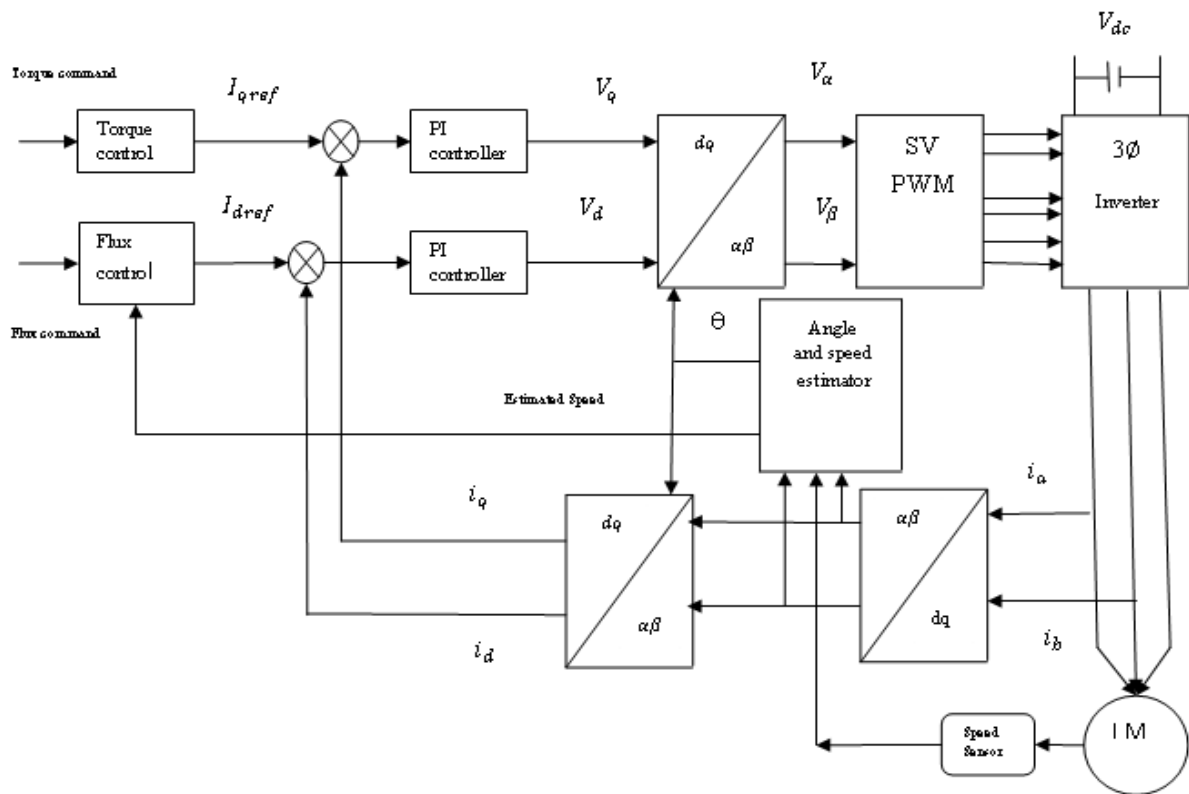


Fig. 3. Field Oriented control of Induction motor

Where P is number of poles of IM, L_m is mutual inductance between the stator and the rotor, L_r is the rotor inductance, i_{qs} , i_{qr} , i_{ds} and i_{dr} are q-axis stator and rotor currents and d-axis stator and rotor currents respectively. i_{ds}^e is torque component and i_{ds}^e is flux component. If the IM requires high speed, the direct current component through the IM has to be controlled. To have a good torque response, the flux component must be constant and the torque component must be varied.

VEHICLE LOAD MODEL

First step in analyzing the performance of a vehicle is to create a vehicle model and testing it with different possible load conditions. So to design a model, the form of forces that may act on the vehicle should be analysed for the correct

selection of motor and battery requirement. Consider a vehicle with mass m is moving at speed v in a hill upward with an inclination θ , it will observe an opposite force downwards, which will resist its movement in upward direction. These resistive forces are: rolling resistance, aerodynamic drag resistance, and grading resistance. The equation of motion along electric vehicle's longitudinal axis is expressed by the following equation [10]:

$$F_t = F_{rr} + F_{ad} + F_{hc} + F_{ac} \quad (3)$$

Where F_t , F_{rr} , F_{ae} , F_{hc} , F_{ac} and F_{wa} represent the total traction force, the road rolling resistance, aerodynamic resistance, grading resistance, and acceleration resistance, respectively. The various operating conditions for Electric vehicle is discussed in [11].

Table: 1. Dynamic Parameters

Parameters	Value
Mass of the vehicle (M_v)	1200 kg
Coefficient of aerodynamic drag (C_{ad})	0.26
Tire rolling resistance coefficient (C_{rr})	0.010
Wheel radius (r_d)	0.250 m
Front area (A_f)	2.200 m ²
Density of air (ρ_a)	1.205 kg/m ³
Effective rolling radius	0.25 m
Gear ratio (N_g)	7.2 -
Gear efficiency (η_g)	100 %
Horizontal distance from CG to front axle (h_{df})	1.4 m
Horizontal distance from CG to rear axle (h_{dr})	1.4 m
CG height from ground (h)	0.5 m

ELECTRIC MOTOR AND BATTERY FOR EV

Electric Motor Drive

The selection of right electric motor is very necessary for the matched performance of the vehicle. The type and usage of vehicle should be considered while selecting an electric drive. The electric motor with high starting torque is preferred for EV. When the vehicle starts off, the motor speed is low and works in the constant torque state, as long as speed is higher than the rated speed it works in the constant power state. Now a day's Induction motor drives are gaining popularity among the EV because of their high performance, reliability, low maintenance and good variable speed control. For its reliable operation, ruggedness, low maintenance requirements, and high efficiency, IM motor drives will continue to be employed in EVs. Various PWM techniques are used for the variable speed control, employing the advanced technique with perform well and reduce the switching losses very much. So controlling an induction motor becomes tedious task and a critical issue, especially for the EV applications where both fast transient responses and excellent steady state speed performance are required.

Battery Choice

The first step to design and size a battery is

to understand the battery parameters [12], [13]. For EV propulsion, the battery must produce voltage and current according to the motor requirements and peak power requirement of the vehicle in the typical driving cycle [14],[15]. These parameters such as energy density and specific energy, maximum sustainable discharge rate, life cycle, operating temperature, and capacity and state of charge (SOC) can be monitored to achieve a long life of battery operating conditions.

SIMULATION RESULTS

The simulations are carried out using Matlab-Simulink. The matlab/simulink block for Electric drive system is shown in figure 4. The EV Control consists of a battery, inverter, induction motor, vehicle load and a sensing and control unit. Apart from these important units it may include temperature cooling units etc. the lithium battery is used as the source of electric power. The inverter converts the DC to AC, the Inverter incorporates the SVM for varying the frequency of its output signal. The output of inverter is connected to the three phase Induction Motor. The induction motor drives the load, the sensor with sense the load parameters and control block with contains the FOC algorithm, controls the SVM and varies the inverter output to effectively control the speed of the induction motor.

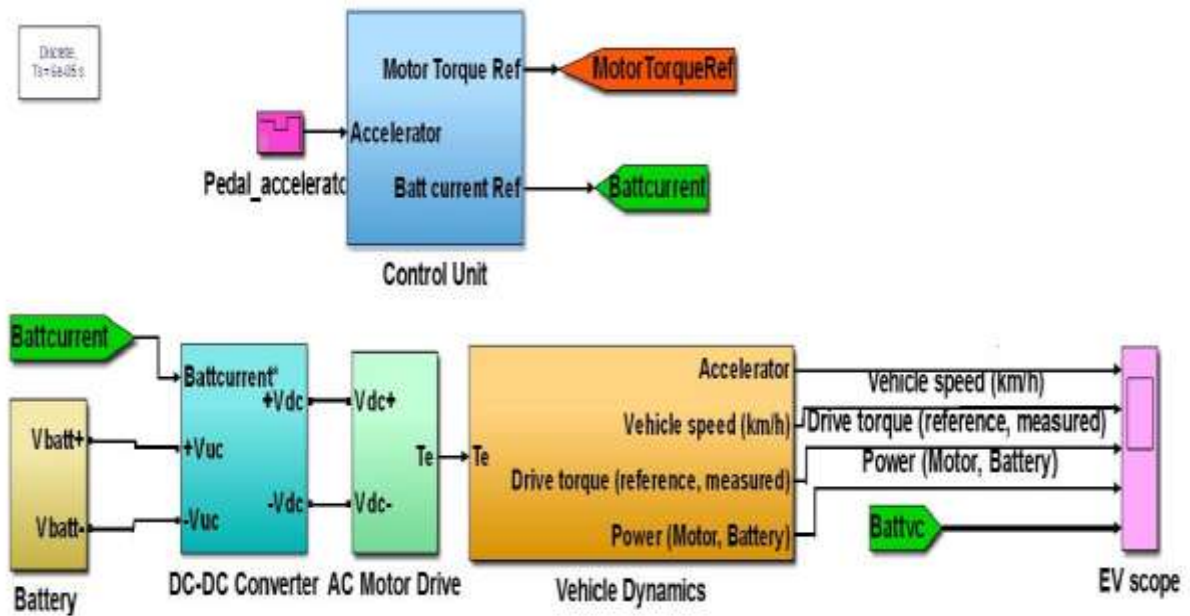


Fig: 4. Matlab/simulink for Electric vehicle drive system

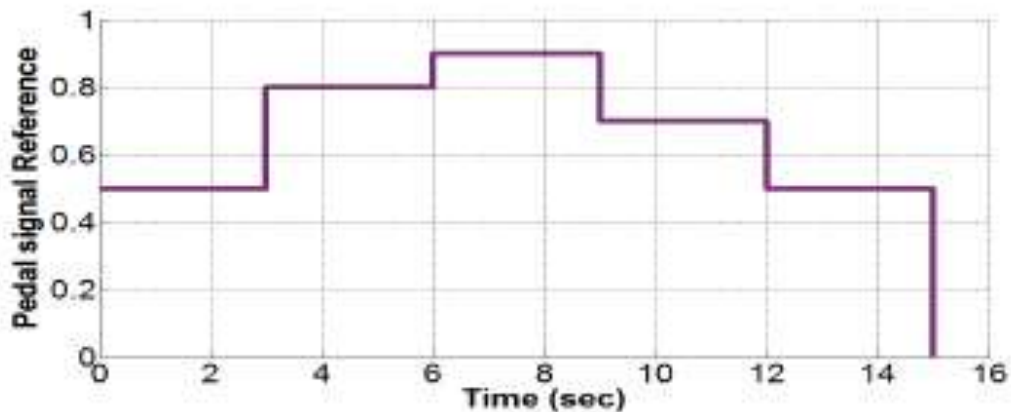


Fig: 5. Reference step signal to the control unit.

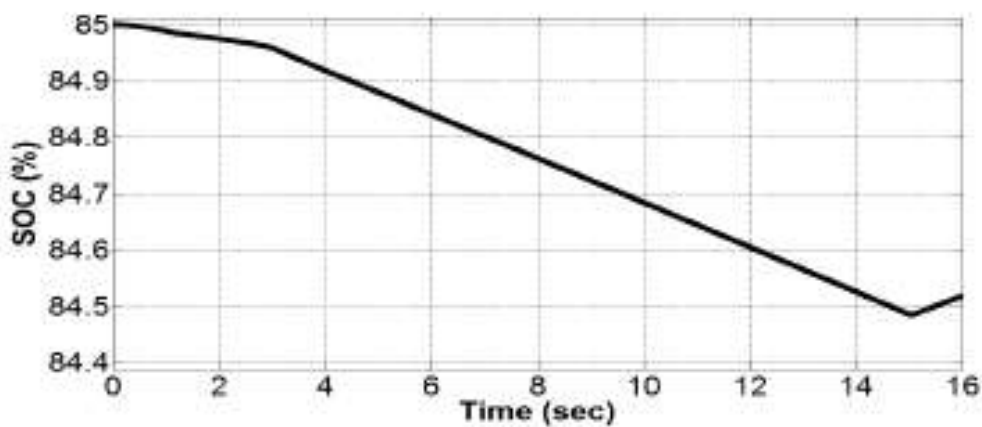


Fig: 6. Discharge of battery over time

A torque actuator from Simulink is used to couple the torque developed by the motor

shaft with the vehicle gearbox splitting to the wheels through the differential. The

motor torque for the EV can be determined if the vehicle load and acceleration are known. The vehicle parameters can be modified for electric motor to produce the required torque. The reference signal through the acceleration pedal is shown in figure 5.

As the battery SOC depletes with 0.5%

over the 16-second acceleration as shown in Fig.6, the motor power and torque were responding to overcome the vehicle load at this interval. As the acceleration starting from initial $t = 0.0s$ to $t = 1s$, the vehicle and motor speed reached 10 km/h and 900rpm as depicted in Fig. 7 and Fig.8, respectively.

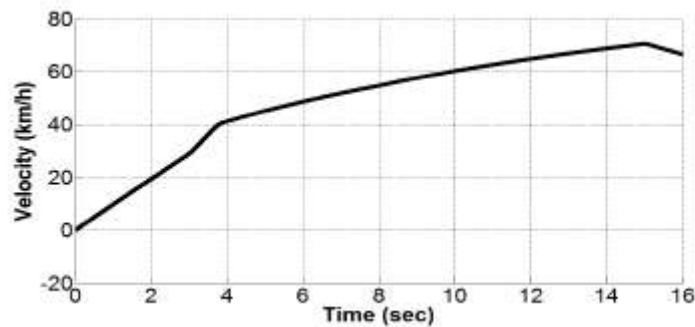


Fig: 7. Electric Vehicle speed vs. time

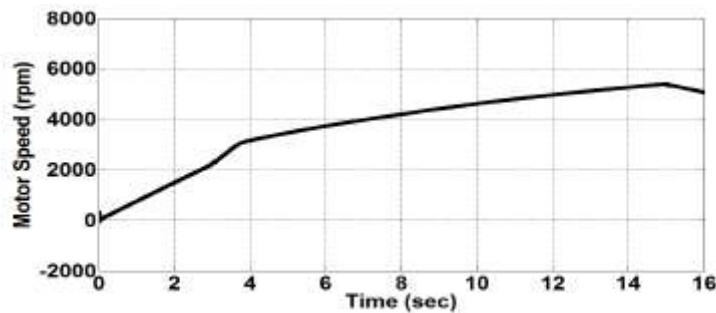


Fig: 8. Motor Speed vs. Time

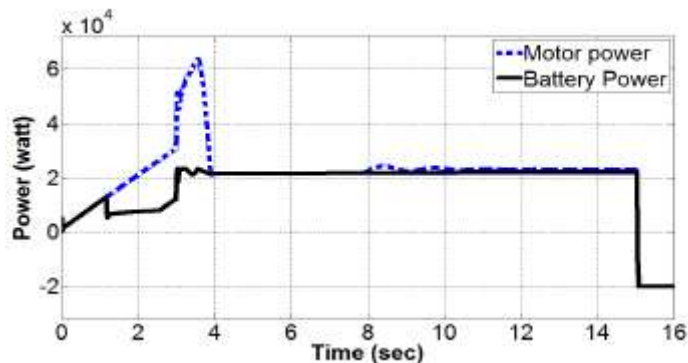


Fig: 9. Battery and Motor's drive power comparison

While the required torque follows the reference torque. Between $t = 1 - 4 s$, the vehicle and motor speed reached 40 km/h and 3000 rpm respectively, while torque continued to nearly 200 Nm during this

motor based speed.

Figure 9 shows the drive power of both battery and Motor. When the vehicle slows down or commanded acceleration

is negative both motor and vehicle speeds decreased respectively. The simulation result of acceleration time when the speed is 0-60 km/h during 10 sec, can extremely meet the acceleration index for EV.

CONCLUSIONS

In this paper an electric vehicle model has developed and controlled using field oriented control and space vector modulation technique in matlab-simulink. It shows the vehicle speed reached 60 km/h and the motor torque reached around 50 Nm in less than 10 seconds. This speed satisfies the acceleration index for the EV. From the simulation results, it's simple to determine the battery discharging capacity and EV's performance.

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