A Novel 4WD Permanent Magnet Synchronous Motor for an Electrical Vehicle Control Strategy Based on Direct Torque Control Space Vector Modulation Techniques

Mr. Rajeev Singh [1], Mis. Pooja Mishra[2] ,Mr. Ravi Kumar[3],Mr. Ompraksh Bhariya[4]

[1234]*Post Graduate Student, Department of EX, TIT Bhopal, RGPV. Bhopal, Madhya Pradesh, India*

Abstract:- In this work we propose a Direct Torque Control (DTC) Four-Wheels-Drive (4WD) Electric Vehicle (EV) controlled with Direct Torque Control based on Space Vector Modulation (DTC-SVM) is presented, Where the electrical traction chain was well analyzed and studied from the lithium battery, the buck boost to the mechanical load behavior. The speed of four wheels is calculated independently during the turning with the electronic differential system computations which distributes torque and power to each in-wheel motor according to the requirements, adapts the speed of each motor to the driving conditions. The basic idea of this work is to maintain the initial battery state of charge (SOC) equal to 70% and the state of charge energy decreases where the acceleration process and the state of charge energy increase where the deceleration process prototype was tested in several topology conditions and under speed. The simulations carried Mat lab / Simulink verified the efficiency of the proposed DTC-SVM controller and show that the system has a more favorable dynamic performance. The results also indicate that this strategy can be successfully implemented into the traction drive of modern 4WD electric vehicles.

Keywords: 4WD, DTC, DTC-SVM, Electric Vehicle, SOC, Flux ripple.

1.1 INTRODUCTION –The principal constraints in vehicle for transportation are the development of a non-polluting high safety and comfortable vehicle. Taking into account these constraints, our interest has been focus on the 4WD electric vehicle, with independent driving wheel-motor at the front and with classical motors on the rear drive shaft. This configuration is a conceivable solution, the pollution of this vehicle is strongly decreased and electric traction gives the possibility of achieve accurate and quick control of the distribution torque. Torque control can be ensured by the inverter, so this vehicle does not require a mechanical differential gear or gearbox. One of the main issues in the design of this vehicle (without mechanical differential) is to assume the car stability. During the normal driving condition, all drive wheel system requires a symmetrical distribution of torque in the both sides. In recent years, due to problems like the energy crisis and environmental pollution, the Electric Vehicle (EV) has been researched and developed more and more extensively. Currently, most EVs are driven by two front wheels or two rear wheels. Considering some efficiency and space restrictions on the vehicle, people have paid more and more attention attention in recent years to four wheel drive vehicles employing the IM in wheel motor.

The Direct Torque Control (DTC) strategy is a kind of high performance driving technology for AC motors, due to its simple structure and ability to achieve fast response of flux and torque has attracted growing interest in recent years. DTC-SVM with PI controller Direct torque control without hysteresis band can effectively reduce torque and flux ripple, DTC-SVM method can improve the system robustness and effectively improve the system dynamical performance. The DC-DC converter is used with wide range in electric vehicles to ensure the energy required for the propulsion system.

The objective of this paper is to understand the lithium-ion battery compartment controlled by DC-DC converter, each of the wheels is controlled independently by using direct torque control based space vector modulation under several topology and Speed variations.

Modeling and simulation are approved out using the Mat Lab / Simulink tool to study the performance of 4WD proposed system.

ELECTRICAL VEHICLE DESCRIPTION

According to Figure 1, the opposing forces acting to the vehicle motion are: the rolling resistance force F tire due to the friction of vehicle tires on the road; The aerodynamic drag force F aero caused by the friction on the body moving through the air; And the climbing force F slope that depends on the road slope.

The total resistive force is equal to Fr and is the sum of the resistance forces, as in (1).

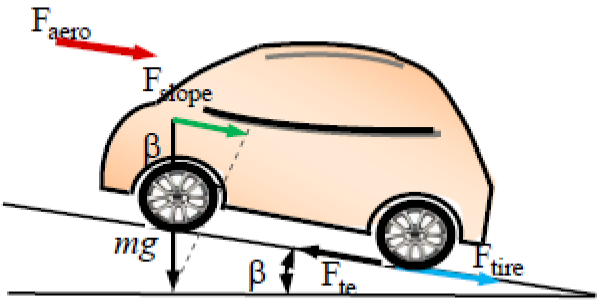

Figure 1. The Forces acting on a vehicle moving along a slope

$$F_r = F_{tire} + F_{aero} + F_{slope} \quad (1)$$

The rolling resistance force is defined by:

$$F_{tire} = mgf_r \quad (2)$$

The aerodynamic resistance torque is defined as follows:

$$F_{aero} = \frac{1}{2} \rho_{air} A_f C_d v^2 \quad (3)$$

The rolling resistance force is usually modeled as:

$$F_{slope} = mg \sin(\beta) \quad (4)$$

Where r is the tire radius, m is the vehicle total mass, Fr is the rolling resistance force constant, g is the gravity acceleration, ρ air is air density, Cd is aerodynamic drag coefficient, Af Is the frontal surface area of the vehicle, β is the road slope of angle. Values of these parameters are shown in Table 1.

Table 1. Parameters of the electric vehicle model.

r	0.32m	A_f	2.60m^2
m	1300 Kg	C_d	0.32
f_r	0.01	ρ_{air}	1.2kg/m^3

$$\theta_s = \tan^{-1}\left(\frac{\phi_{qs}}{\phi_{ds}}\right) \quad (8)$$

The Electromagnetic torque T_{em} can be given as follows:

$$T_{em} = \frac{3}{2} p \left(\phi_{ds} i_{qs} - \phi_{qs} i_{ds}\right) \quad (9)$$

The SVM principle based on the switching between the adjacent active vector and two zero vectors during a one switching period. It uses the space vector concept to compute the duty cycle of the switches.

2.1 DTC and DTC-SVM STRUCTURES

Figures 2.1 and 2.2 represent two configurations of DTC controlled PMSM drive respectively; Both of them use the same flux vector and torque estimators. However, the torque and flux hysteresis controllers and the switching table are replaced by a PI torque controller and a predictive calculator vector voltage reference calculator to be applied to stator coils of the inductor motor.

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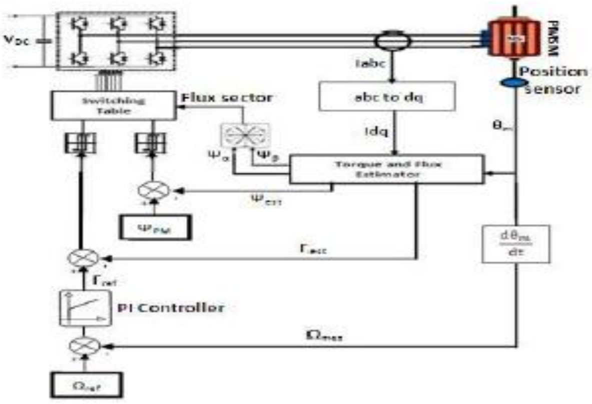


Fig.2.1 Basic DTC scheme for Space Vector Modulation drive with speed loop

In the proposed DTC-SVM scheme with speed loop control, shown in Figure 2, after correction of the mechanical speed through the PI controller, the torque PI controller delivers Vsq voltage to the predictive controller and also receives, more the reference amplitude of the Stator flux Ɵsr, information from the torque and flux estimator namely, the amplitude and position of the current stator flux measured current vector.

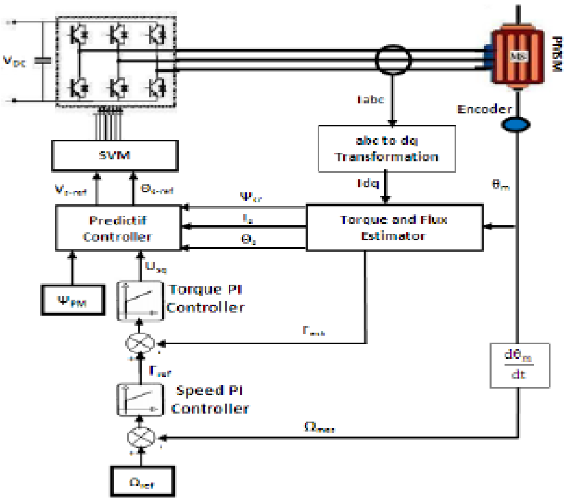


Fig.2.2 Block diagram DTC strategy based Space Vector Modulation

After the calculation, the predictive controller determines the polar coordinates of the stator voltage command vector for space vector modulator, which finally generates the pulses S1, S3 and S5 to control the inverter.

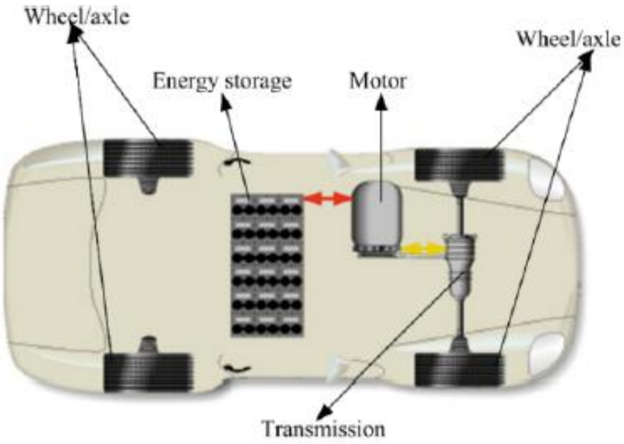


Fig.3.1 The Driving Wheels Control System

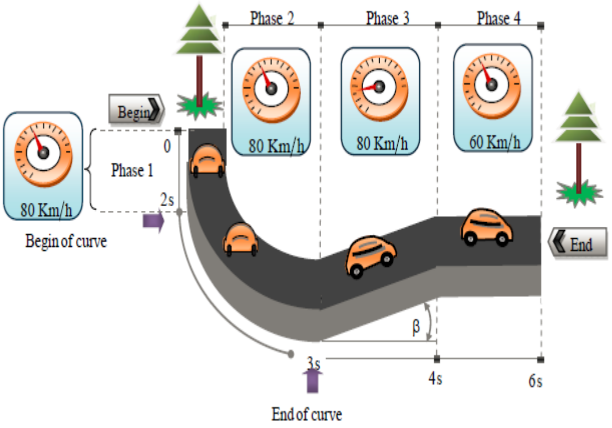


Fig.3.2 The Chosen road Topology Test

4.1. POWER ELECTRONICS

The Lithium-ion battery must be able to supply sufficient power to the EV in accelerating and decelerating phase, which means that the peak power of the batteries supply

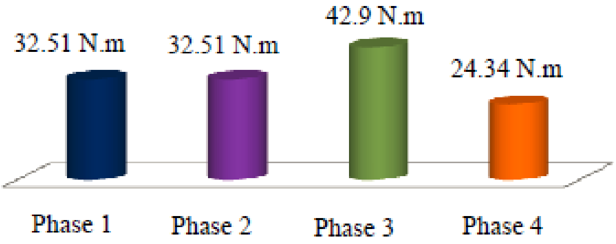


Fig. 4.1 Evaluation of the globally vehicle resistive Torque Compared to nominal motor Torque in different phases.

5.1 MATLAB/SIMULINK MODEL

The MATLAB Simulink model of Park's transformation which is used for 3-phase to two axis conversion is shown in Figure7.1.By using this we can analyze the PMSM in D.C. analysis.

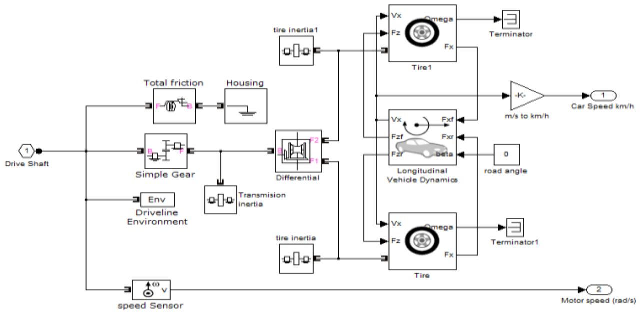


Fig. 5.1 Simulink model of Measuring Subsystem

The Simulink model for proposed SVM topology and also flux estimator for PMSM are shown in Figure 7.2.and Figure7.3 respectively

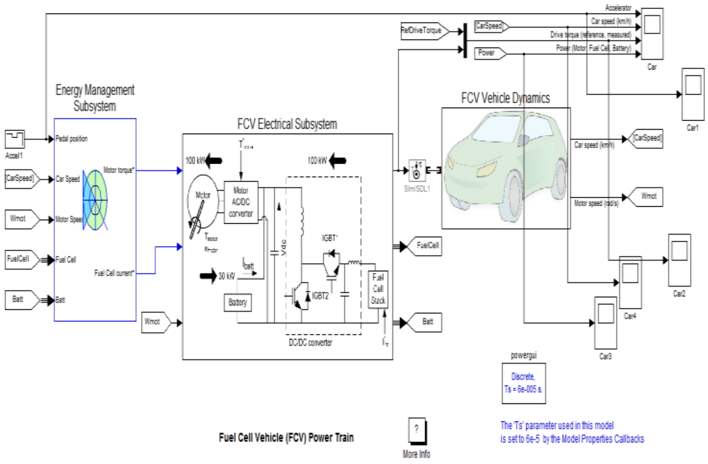


Fig5.2. Matlab/Simulink model of PMSM for DTC-SVM method

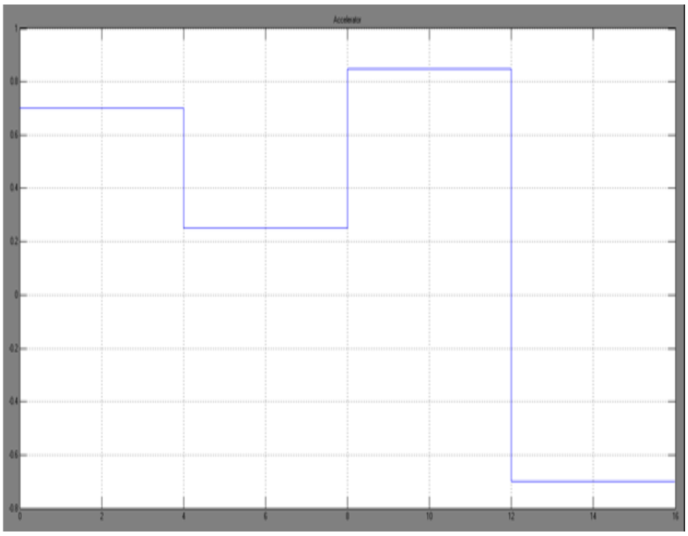
The complete Matlab/Simulink model of proposed DTC-SVM topology for PMSM is shown in Figure.

8. RESULTS OF THE SIMULATION

The DTC-SVM simulation results are presented in Figures 13 to 17, respectively. At first, the machine starts under a speed set point of 1000 rpm without load. In fact, it is seen in the simulation results that the flux and torque waves are reduced considerably under the modified DTC. Figure 15 shows the steady state currents under PMSM of modified DTC, respectively.

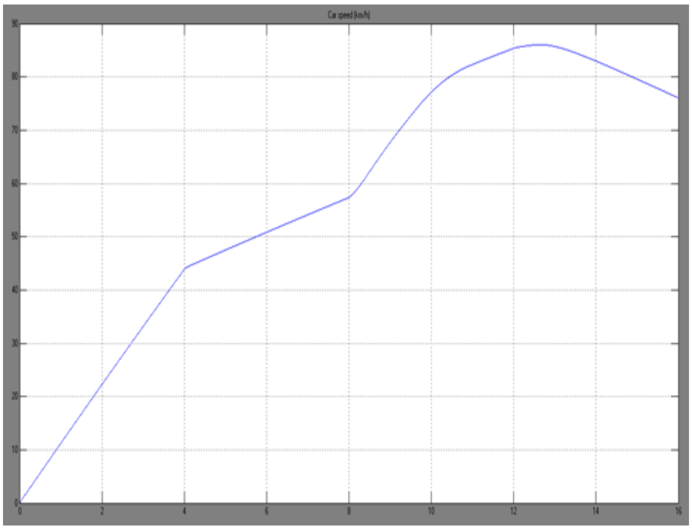
This is mainly because in the SVM algorithm, contrary to the hysteresis controller and the PI controller, the switching frequency is constant and also in SVM many vectors (IGBT states) are selected to adjust the torque and the ripple of the flux in each Sampling time, DTC only selects a vector to adjust the ripple within the hysteresis bands of the torque and flow regulators. Note that the sampling frequency of the modified DTC is only half that of the DTC. The reason for the high distortion in the DTC is mainly due to the fact that the switching function of the inverter is only updated at the sampling time and also the number of vectors applied to adjust the torque and the ripple of the flow.

Although the switching frequency of the basic DTC (ranging from 3.5 to 5 kHz) is lower than that of the DTCSVM (10 kHz), which means a lower switching loss, however, the basic DTC distortion is too high . From the results of the simulation, it is observed that the steady-state performance of DTC-SVM is much better than the basic DTC.



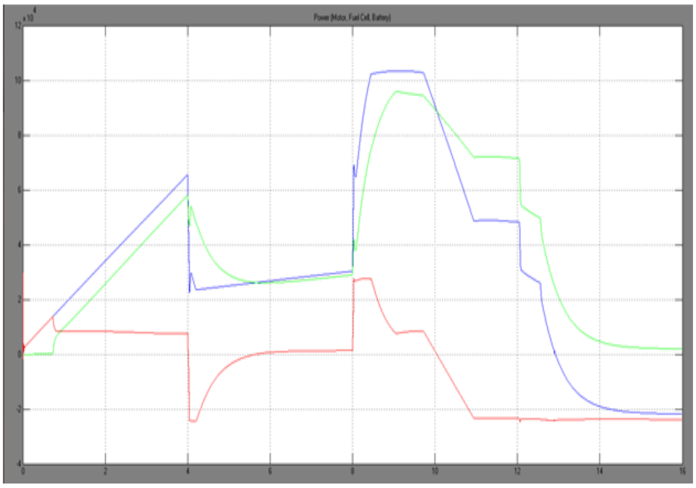
Phase 1 Phase 2 Phase 3 Phase 4

Fig6.Variation of vehicle Accelerator at Different Phases



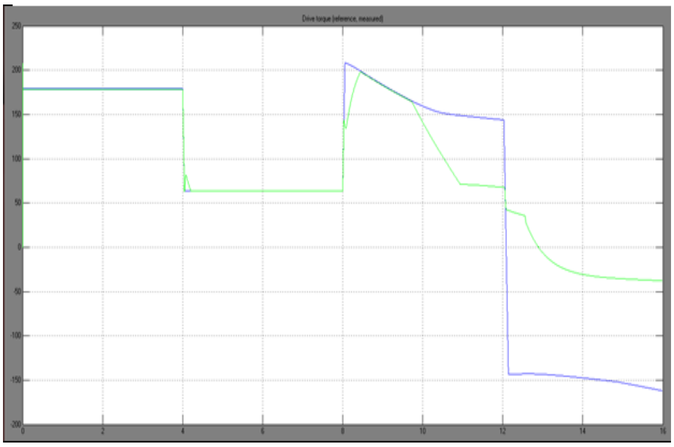
PHASE 1 PHASE 2 PHASE 3 PHASE 4

Fig.7. Variation of Car speed at different Phases



Phase1 **Phase 2** **Phase 3** **Phase 4**

Fig.8. Variation of Drive torque at different Phases



Phase 1 **Phase 2** **Phase 3** **Phase 4**

Fig.9. Variation of Power at different Phases

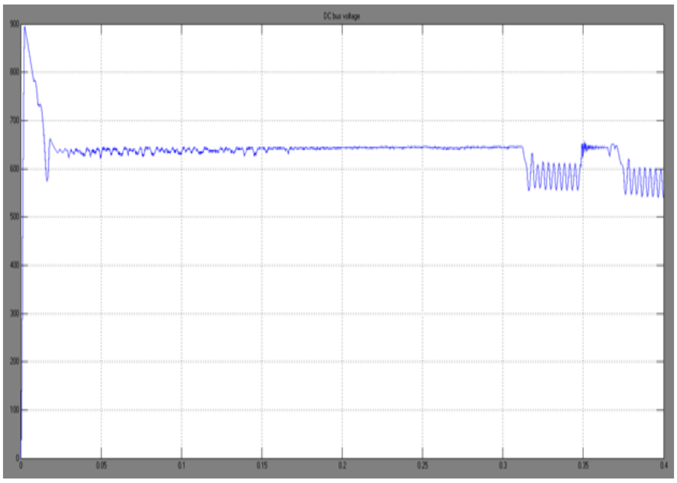
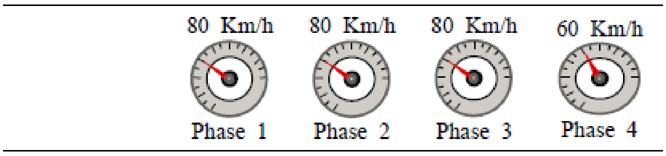


Fig10. Buck Boost DC- DC Converter behavior under several speed Variations

Table 8 The relationship between the traction chain power electronic characteristics and the distance travelled at different phases



$D_{travelled\ [m]}$	**125.40**	**79.40**	**81.10**	**120.60**
SOC $_{diff\ [\%]}$	**0.43**	**0.21**	**0.28**	**0.241**
$P_{consumed[Kw]}$	**9.86**	**9.86**	**12.98**	**18.41**

5. Conclusions

In this work, a new method of design and optimization for PM brushless machines is proposed to satisfy the requirements of the multiple driving conditions in electric vehicles. It has been shown that the proposed design method taking into account the maximum speed of operation and performance specifications over the entire speed range is effective to give a first brushless PM machine with well yields. Furthermore, based on the increase of the d-axis inductance and while maintaining a constant PM flux link, the proposed optimization method can reach a wider constant power rate range as well as reduce losses and improve efficiency On envelope torque velocity, speed. As a result, the SOC of energy storage is increased, thus improving the utilization ratio of the energy. Both the analysis and the results of the simulation reveal the viability of the optimal PM brushless machine to be applied in the EV, thus verifying the validity of the proposed design and the optimization method for EV traction machines.

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Rajeev Singh: - He is a Post Graduate Student in Power Electronics Engineering at the T.I.T College Bhopal. His fields of interest for an electric Vehicle, Control system, Total harmonics distortion, direct torque control from space vector motor, he has currently one paper published in International journal. He has one year experience in teaching field.

Pooja Mishra:- She is a Post Graduate Student in Power System Engineering at the T.I.T College Bhopal. His fields of interest for an Advance Power System, Control system, Auto reclosing, she has currently one paper published in International journal.

Om Prakash Bhariya: - Mr. Om Prakash is Assistance Professor with Electrical and Electronics Engineering Department of Oriental College of Engineering Bhopal, India since 2017. He has earned his Master Degree in Engineering & Technology from T.I.T, R.G.P.V Bhopal, and India. He has completed his Bachelor of Technology on 2013. Mr. Om prakash has 1 years of academic and research experience in 2016. His research areas are Advanced Power System Control, Electrical Drives, and Electrical Machine.

Ravi Kumar:- He is a Post Graduate Student in Power Electronics Engineering at the T.I.T College Bhopal. His fields of interest for an Advance Power System, Control system, Renewable energy sources, he has currently one paper published International journal.