Modeling & Simulation of AC Electric Drive System to Cruise the Vehicle to the Prescribed Speed

Shreasth, Bhupal Singh

Abstract*: Now a days about 90% of the loads are dynamic in nature, where loads are to be operate at different speed for different uses. In this paper, we are analyzing the design and structures of the control system for electric drive equipped with the permanent magnet synchronous motor (PMSM) in the automotive application. In this study, a simulation model of full electric vehicle on the MATLAB-SIMULINK platform is simulated, and components of electric vehicles were discussed. The drive train system components consist of a motor, battery, motor controller, inverter and vehicle interface are modeled according to their mathematical equations.

Index Terms*: Electric Vehicle, vector control Mathematical modeling, MATLAB-Simulink, Simulation.

I. INTRODUCTION

Motion control is required all over the place, either in the household machine or modern purposes. The frameworks that betrothed for this reason are called drives. Such a framework, if utilizes electric motor for control is known as an electrical drive system. The block diagram of the AC electric drive is appeared in Fig. 1. Here the load to the electric drive is an electric vehicle burden to voyage the vehicle to a recommended speed.

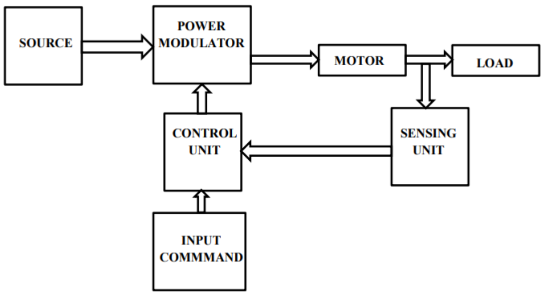

Fig. 1 Block diagram of an AC electric drive.

AC drives are widely used in many application starting from domestic usage to the industrial usage, as well as in the robotics and traction applications. Modern hybrid electric vehicle or battery electric vehicle drives require low weight small volume, high power density and high performance. For this purpose we need a drive system which meets the above requirement of BEVs. There are two types of machines one is induction machine and second is permanent magnet machine, as PMSM have high torque to inertia, strong overloading capacity, high starting torque, simple and reliable in construction. which means that PMSM is suitable for driving system of electric vehicle [1].

As many techniques are imposed for the motion control but whenever its comes to efficient and proper controlling nobody can dominates vector [2].

This study discusses about the simulation of the BEVs, its applicable electrical systems component and its relating equation for confirmation. Additionally, it inspects all the simulation results. In principle, BEV segments incorporates simple transmissions mechanism, battery charging controller, motor and dynamic driver modeling.. Everything has done on MATLAB/SIMULINK.

II. VEHICLE DYNAMICS

Vehicle dynamics means to study the vehicle in motion. Vehicle dynamics is a method to study of causes and effects of vehicle motion. In vehicle dynamics we read out the response of the vehicle when subjected to the external and internal causes where external causes are aero-dynamics, road surface and all the mass component and internal causes are loads and burden level to accelerate the vehicle during driving. It can be reviewed by mathematical modeling of a vehicle represented by the set of equations. Fig. 2 describes the different force acting on the moving vehicle.

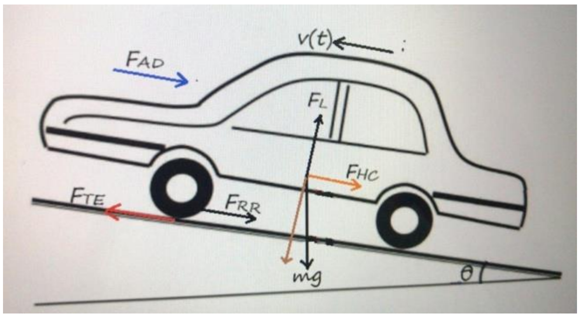

Figure 2. Different force acting on the moving vehicle.

Revised Manuscript Received on October 30, 2019.
* Correspondence Author

Shreasth*, Research Scholar, Dept. of EN, Ajay Kumar Garg Engineering College, Ghaziabad, India.

Dr. Bhupal Singh, H.O.D , Dept of EN, Ajay Kumar Garg Engineering College, Ghaziabad, India.

Tractive effort: The energy required to move/run the vehicle forward is known as tractive effort. The tractive effort force should overcome the following:

1. Aerodynamic drag force
2. Rolling resistance force
3. Hill climbing/ drag force
4. Acceleration force

A. Aerodynamic Drag Force (F_{AD})

The force exerts by the wind on the vehicle body when the vehicle is in motion is known as aerodynamic force. The resistive force on the vehicle body encounters when the vehicle is moving at the certain speed through the air.
The aerodynamic forces are proportional to the square of the velocity of the vehicle. It is given by:

$$F_{AD} = \frac{1}{2}\rho A_V C_D (v + v_{air})^2 \qquad (1)$$

Where ρ is the density of air in kg/m^3, A_v is the frontal cross sectional area of the vehicle in m^2, C_d is the drag coefficient, V_{air} is the opposing wind velocity flowing towards the vehicle and V is forward velocity of vehicle in m/s respectively.

B. Rolling Resistance Force (F_{RR})

Rolling resistance is brought about by various phenomena occurring in and around the vehicle tires during rolling. The rolling resistance force is caused due to the visco-elasticity of the tyre material. One of the significant impacts is that the repeatedly diversion of the tire causes a hysteresis inside the tire material, which offers increase in an interior force opposing the movement [3].

$$F_{RR} = \mu_{rr}(mg\cos\theta - F_L) \qquad (2)$$

Where,

$$F_L = \frac{1}{2}\rho A_H C_L v^2$$

where the mass of the vehicle (m) in kg and g is the gravity constant in m/s^2. Θ is the angle due to the slope of the road. Regularly the cos(θ) term is disregarded since even its have high grade, for example, 10 % (Θ ≈ 0.1 rad), implies that cos(θ) ≈ 0.995 that is a blunder of under 0.5 % of the moving opposition force. In this study , even the effect of low grade is considered.

C. Hill Climbing/ Drag Force (F_{HC})

The force due to the component of vehicle weight that acts along the slope is known as hill climbing force/grading force. The force required to move a vehicle on the slope has an angle ‘Θ’is known as grading force

$$F_{HC} = mg\sin\theta \qquad (3)$$

When the slope angle is zero, then $F_{HC} = 0$.

D. Acceleration Force (F_{AA})

The effort required to change the speed of the vehicle is known as acceleration force. Both the linear acceleration and angular acceleration should be taken. Therefore,

Linear acceleration (F_{LA}):- according to Newton’s second law :

$$F_{LA} = ma = m\frac{dv}{dt} \qquad (4)$$

Angular acceleration(F_{AA}):- according to Newton’s second law :

$$F_{AA} = J\frac{dw}{dt} \qquad (5)$$

The dynamical motion of a vehicle in one co-ordinate axis is altogether determined by the total of the all of forces acts up on it in that same axis of heading, as portrayed in the translational form is given by

$$ma = m\frac{dv}{dt} = F_{tractive} - F_{resistive} \qquad (6)$$

where m inertial mass in kg to be accelerated incorporating all possible inertias in the powertrain, a is the acceleration of the vehicle in m/s^2 i.e., rate of change of velocity (dv(t)/dt). $F_{tractive}$ is the force required to accelerate the vehicle and $F_{resistive}$ is the summation of all the force encounters on the vehicle body to diminishing the velocity.
Thus the expression for vehicle dynamic can be written as (7) below

$$\frac{dv}{dt} = \left(\frac{1}{m+\frac{G^2 Jm}{r^2\eta_g}}\right)\left(\eta_g T_m \frac{G}{r} - \mu_{rr}(mg\cos\theta - F_L) - mg\sin\theta - \frac{1}{2}\rho A_H C_D v^2\right) \qquad (7)$$

III. BATTERIES

For BEVs application, batteries are the essential source of energy storage. rechargeable batteries are broadly utilized as the significant energy source in BEVs because of their advance technology. In BEVs or HEVs application, the batteries are utilized to convey the energy to the machine system to propel the vehicle and accept the energy (recharge) from the system during regenerative braking. As clearly observed from the above Table I there are number of battery advances pertinent to BEVs, among all innovations the lithium-ion battery is most appropriate and are additionally right, now considered as the most reasonable decision for improvement of the new age EVs.

Battery type	Lead –acid	Ni-Cd	Ni-MH	Lithium-ion
Energy density(w/kg)	30-40	45-80	60-120	110-160
Power density	180	150	250-1000	1800
Nominal voltage	2V	1.25V	1.25V	3.6V
Overcharge tolerance	High	Moderate	Low	Very low
Self-discharge	Low	Moderate	High	Very low
Operating temperat-ure	-20-60℃	-40-60℃	-20-60℃	-20-60 ℃
Cycle life	200-300	1500	300-500	500-1000

Table I. General technical performance of different types of batteries used in BEVs [4].

A simple equivalent circuit diagram of the elctro-chemical battery is appeared in the figure 3. Where Vt is the terminal voltage and Voc is the ideal voltage at no load. R_{ch} and R_{dis} is the internal resistance. R_{ch} denotes the internal resistance during charging and R_{dis} denotes the internal resistance during discharging of battery [5].

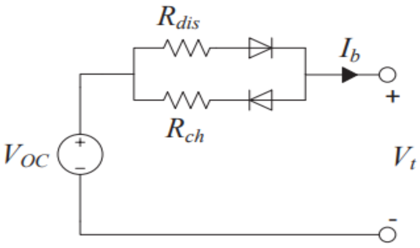

Fig 3 Simple equivalent circuit of battery.[5]

The terminal equation during discharge is given by

$$V_t = V_{oc} - R_{dis} I_b \tag{8}$$

The charging state i.e., amount of the energy in the battery is usually explained by the term state of charge (SOC). The SOC is relying on the battery current over time is given by

$$SOC(t) = SOC_{init} - \frac{\int_{to}^{t} I_b(\tau) d\tau}{Q_{tot}} \tag{9}$$

where SOC_{init} represents the initial state of charge value, Q_{tot} (Ah) represents the total charging capacity of a battery.

IV. POWERTRAIN OF BEVs

Powertrain of electric vehicle comprise of the component which converts the electrical energy received from the battery bank and delivered as the mechanical energy to propel the vehicle [6]. The Fig. 4 represents the component in the powertrain of BEVs.

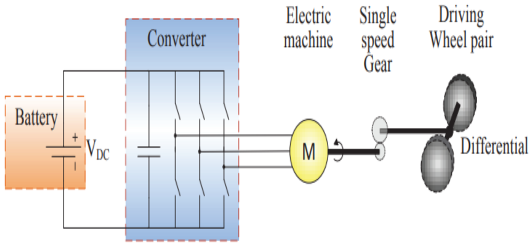

Figure 4. Simple schematic sketch of a BEV powertrain.

A. Permanent Magnet Synchronous Motor.

Be For high speed PMSMs, the rotor doesn't contains the damper winding. In this way the model of PMSM in the dq-coordinate system is represented in Fig. 2.6, where d-q refers to the rotor frame of reference, which is also called as synchronous coordinates. The direct or d-axis practically refers to the axis in the direction of magnetic flux from a magnet crossing the centre of the magnets, whereas the quadrature or q-axis refers to the axis crossing in the middle of the two magnets for two pole machine. These axis are separated 90 electrical degree from one another.

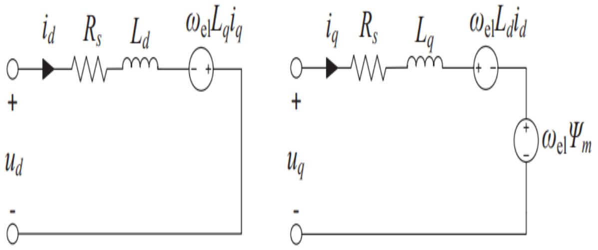

Figure 5. Equivalent circuit model of PMSM

The dynamic d-axis and q-axis stator voltage equation as a function of d-axis and q-axis stator current, i.e., i_q and i_d are

$$u_d = L_d \frac{di_d}{dt} + R_s i_d - \omega_{el} L_q i_q \tag{10}$$

$$u_q = L_q \frac{di_q}{dt} + R_s i_q + \omega_{el} L_d i_q + \omega_{el} \Psi_m \tag{11}$$

Where R_s is stator winding resistance, w_{el}, w_r are the electrical angular speed and rotor angular speed respectively. L_d , L_q are the q-axis and d-axis windings inductances and Ψ_m is the flux linkage associated to the permanent magnet. When thinking about the electrically steady state conditions, the di/dt-terms might be omitted.

Mechanical Output: For synchronous salient machine the electro-mechanical torque produced by the machine is given by the equation as

$$T_e = \frac{3n_p}{2K^2}\left(\Psi_d \mathrm{i}_q - \Psi_q \mathrm{i}_d\right) = \frac{3n_p}{2K^2}\left(\Psi_m i_q + \left(L_d - L_q\right) i_d i_q\right) \tag{12}$$

Where flux linkage in the q-axis and d-axis are denoted by Ψ_q and Ψ_d respectively. Scaling constant for transformation between 3-phases to 2-phase space vectors is denoted by K. For magnitude constant scaling, K ought to be set to 1.

B. Vector Control Strategy.

The Vector control technique is also known as field orientation control (FOC) technique. In this technology of motion control, we control the flux producing and torque producing component independently. This technique also identifies both the torque and flux component separately that why we can produce high torque at very low stator current, thus makes it control similar to that of the separately energized DC machine. In this type of control the speed up to the base speed or rated speed is accompanied in constant torque region and above the rated speed is accompanied in field weakening region or constant power region. Block diagram of this control system is shown in Fig 6.

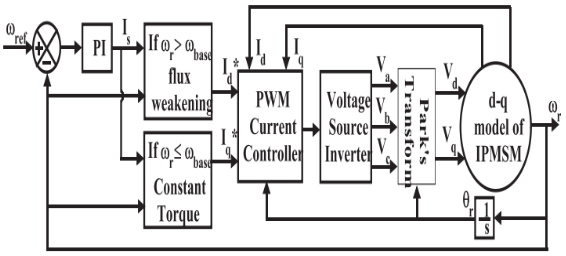

Figure 6. Close loop implementation of PMSM drive system.

C. Three Phase Inverter.

The converter which converts the DC source to AC source is known as inverter. Its function is to convert the DC voltage from the battery bank to the symmetrical AC voltage magnitude and frequency as required.

For wide range of speed control operation, the 3-phase voltage source inverter is used in controlling the frequency and voltage amplitude. There are many topologies for example neutral point clamped inverter (NPC) inverter and varieties of multi level inverters. The two level inverter topology is utilized in modern application, represented in the figure7. Both the NPC inverter and varieties of multi level inverters recently been of expanding interest focusing on automobiles use [7].

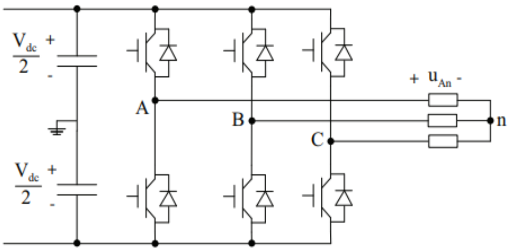

Figure 7. Representation of a 3-phase VSI.

D. Pulse Width Modulation.

Pulse width modulation (PWM) is required for operating the voltage source inverter. As the VSI consists of switches, to turn off and turn on these switches appropriately we are using PWM. In VSI the three poles of the inverter is continuously connected to either +Vdc or –Vdc to get a specific voltage level. The difference between the PWM and other modulation technique is the way in which a voltage vector is combined and utilization of the zero vector to produce a specific voltage level in contest with the given reference voltage. The selection of the vector to be combined will effects both the efficiency and performance of the drive and even produces current harmonics [8].

In triangular comparison based PWM the common triangular carrier waveform is compared with three phase modulated signal which is out of phase 120◦ electrical degrees, as it is appeared in Fig. 8 [8]. When the modulated signal is greater than the carrier wave, top device on the leg/pole of the VSI is ON. While lower device is ON when the modulated signal is less than the carrier waveform.

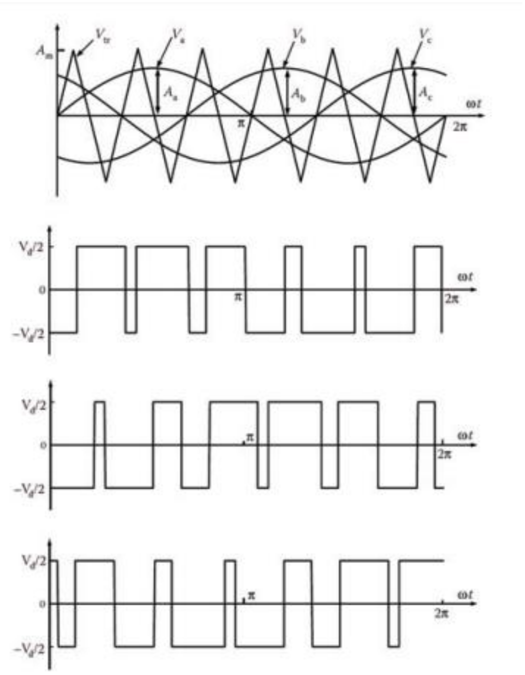

Figure 8. Pulse width modulation for a two-level inverter. a) modulating three phase voltage signal and triangular carrier waveform. b),c),d) Firing voltages of the switches.

V. SIMULATION

Based on the output and input relation between each module, a velocity and current closed loop simulated model of PMSM drive control system is built in matlab/simulik as appeared in figure 9. The motor parameters are ; max torque and max power of the motor is 60 Nm and 37 kw respectively. The whole battery electric vehicle is simulated in matlab which includes vehicle dynamics, battery and control system of PMSM machine as shown in Fig. 10.

Table II. Parameters of vehicle dynamics.

Sr. No.	PAPRMETER	VALUE
1	Mass (m)	1200 kg
2	Density(ρ)	1.25 kg/m^3

3	Gravity(g)	9.81 m/s^2
4	Drag coefficient(C_d)	0.024
5	Rolling coefficient(μ_{rr})	0.02
6	Frontal area(A_H)	1.5 m^2
7	Lift coefficient(C_L)	0.044
8	Inclination angle(Θ)	0-30 degree
9	Gear ratio(G)	10.83
10	Efficiency of gear (η)	0.97
11	Radius of tire(r_m)	0.3 m

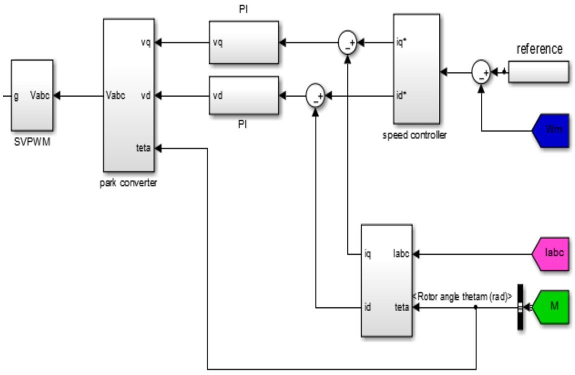

Figure 9. Simulation of PMSM drive control system.

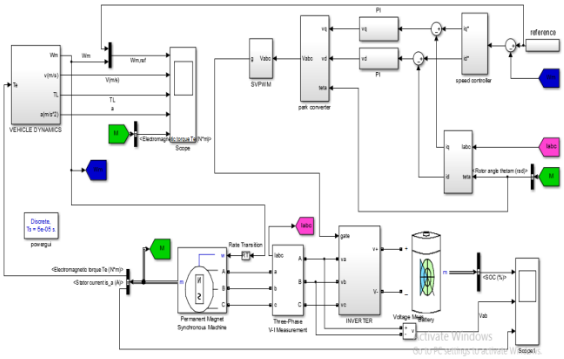

Figure 10. Simulation of BEV.

VI. RESULTS AND DISCUSSION

As shown in figure 10, the BEV simulation model has been made by the mathematical equations that are applied by all subsystem blocks. Figure 11 represents motor speed and motor torque respectively. Fig.12 represents the battery current state of charge and battery voltage respectively.

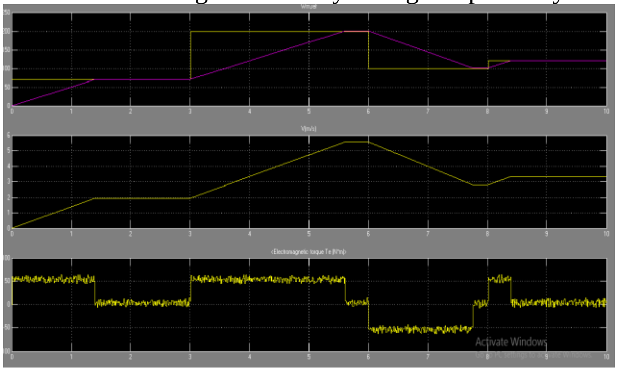

Figure 11. Response of motor.

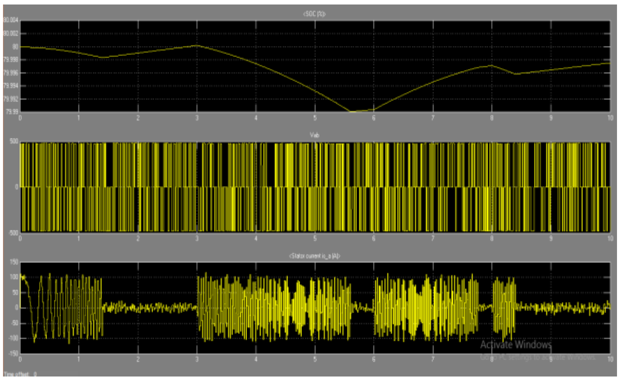

Figure 12. Response of battery.

VII. CONCLUSION

As per the needs of BEVs, the mathematical analysis of PMSM and BEVs components, motion control using SVPWM technology is designed in MATLAB/SIMULINK. The results analysis shows that the system has fast response and good robustness, which could meet the demand of wide speed range BEVs.

REFERENCES

1. S. Song, J. Gong, W. Lin, and G. Wang, “Modeling and simulation of space vector control system for pure electric vehicle driven by permanent magnet synchronous motor” , Journal of wuhan university of technology, vol. 34, no. 4, pp. 118-122, 2012.
2. J. Agrawal and S. Bodkhe, "Functional modeling and simulation of inverter fed permanent magnet synchronous motor drive,"Annual International Conference on Emerging Research Areas: Magnetics, Machines and Drives (AICERA/iCMMD), Kottayam, 2014, pp. 1-6.
3. T. D. Gillespie, Fundamentals Of Vehicle Dynamics, 1st ed. Society of Automotive Engineers, Inc., 1992.
4. K.E. Aifantis, S.A. Hackney, and R.V. Kumar, “High Energy Density Lithium Batteries, Materials, Engineering, Applications,” Wiley-Vch Verlag GmbH & Co. KGaA, Weinheim, 2010.
5. V. Johnson, “Battery performance models in {ADVISOR},” Journal of Power Sources, vol.110,no.2,pp.321-329,2002.[Online].Available:http://www.sciencedirect.com/science/article/pii/S0378775302001945
6. I. Takahashi and N. Noquchi, " A new quick response and high efficiency control strategy of an induction motor », IEEE Trans. on Industry Application. vol. 22, no. 5, pp. 820-827, Sept/Oct. 1986.
7. L. Harnefors, Control of Variable-Speed Drives. Department of electronics, Malardalen University, Vasteras, Sweden: Applied signal processing and control, 2002.
8. Ned Mohan; Tore M. Undeland; William p. Robbins, Power Electronics, (ISBN:978-0-471-22693-2), John Wiley and Sons, Inc.

AUTHORS PROFILE

Shreasth is pursuing M.Tech in Electrical and Electronics Engineering from AKG Engineering College, Ghaziabad. He has earned his degree in Electrical Engineering from Dr. APJ Abdul Kalam Technical University, Lucknow (Formerly UPTU).

Dr. Bhupal Singh received the post graduation degree from MNNIT, Allahabad and Ph.D from IIT Delhi. He owns a vast experience of teaching under graduates and post graduates in his career currently he is working as HOD (Electrical and Electronics Engineering) at AKG Engineering College, Ghaziabad. He is the author various research papers in national and international journals. His research area includes Biomedical Signals and Biomedical Instrumentation & Control.