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PMSM Motor and Control for Electrical Vehicle Application

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Abstract:

In this study, we will discuss how the performance of SVPWM (space vector pulse width modulation) inverter supplied permanent magnet synchronous motors is improving (PMSM). The technique for electrical drives discussed in this paper is called space vector pulse width modulation (SVPWM). The method of design for space vector pulse width modulation has been investigated in great detail, and the findings suggest that it may have potential for application in the actual world. As an illustration, the SVPWM is implemented in drives for permanent-magnet synchronous motors so that both the speed and the current may be controlled. In this paper, we utilized three different closed loop control strategies. In addition to the two inner loops that make up the current control feedback loop, there is also an outer feedback loop that is utilized to make the speed of the PMSM drive as fast as it possibly can be. The torque and flux are kept distinct in the field-oriented control (FOC) system that has been developed for the PMSM drive. This results in a quicker response and simplifies the process of controlling it.

Keywords: FOC, Simulink/MATLAB, DTC, PMSM, Motor, SVPWM Inverter

1. Introduction:

The use of alternating current (AC) machine drives has grown steadily during the last three decades. Automated robotics, metal-cutting machines, precision machining, and other applications have all made use of the Permanent Magnet Synchronous Machine (PMSM). PMSM drive systems are well-suited for high-performance applications that require a quick dynamic response, high power factor, a wide speed range, and other desirable characteristics. Consequently, the utilization of PMSM drives in low and medium power applications will increase in the future. PMSM drives are able to handle high-performance criteria,characteristics such as a quick dynamic response, a high power factor, and a broad working speed range. The traction drive of electric vehicles and locomotives has only lately been implemented using PMSM[1-2].

Controlling the current in an inverter-fed PMSM drive can be done in one of four ways such as hysteresis, ramp comparison, synchronous frame PI, or predictive control. Controlling a system with hysteresis is a common practice[3-7]. The hysteresis current controller provides a number of benefits, including a quick response to transients and an easy implementation, but it demonstrates a high switching frequency in the inverter that is not constant. An inverter's maximum switching frequency can be limited by employing the ramp comparison current control approach, as well as the generation of harmonics that are clearly defined[3]. A low pass filter-like property of the controller's control technique causes magnitude and phase delay faults in a steady state, even after the gains have been modified. PI current control of the rotor synchronous frame has been offered as a remedy to these kinds of errors[14]. The present control is executed within a rotor-synchronous reference frame when using this kind of control.Calculating the necessary voltages and then compelling. The SVPWM control system's method for defining the switching duties that are the responsibility of the inverter switches consists of two steps: the first step is for the motor phase currents to follow the applicable references, and the second step is for the motor phase currents to follow the applicable references. Assuming that the specifications for both the motor and the inverter are valid, the SVPWM inverter has the ability to respond swiftly to transients while also maintaining an exact steady state[19-21].

2. PMSM Modeling:

The mathematical model for the wound rotor synchronous motor is very similar. Because there is no external source on the rotor side and time-dependent flux variations are insignificant, the rotor voltage equation is unneeded. PMSM models can be determined using the rotor reference frame [9]. Phase can be expressed as a variable in the electrical dynamic equation.

2.1.PMSM Motor And Control For Electric Vehicle Application:

On the basis of the following assumptions, a model of a PMSM that does not have a rotor reference frame now has a damper winding in it:

1. Saturation can be ignored.
2. The wave nature of emf is sinusoidal.
3. It is not necessary to worry about eddy currents or hysteresis losses.

1. There are no field current dynamics.

Voltage equations are given by:

$$V_q = R_s I_q + W_r \lambda_d + \rho \lambda_q \tag{1}$$

$$V_q = R_s I_d - W_r \lambda_q + \rho \lambda_d \tag{2}$$

linkages flux as given such as

$$\lambda_q = L_q I_q \tag{3}$$

$$\lambda_d = L_d I_d + \lambda_f \tag{4}$$

Substituting equations (3) and (4) into (1) and (2)

$$V_q = R_s I_q + W_r (L_d I_d + \lambda_f) + \rho L_q I_q \tag{5}$$

$$V_d = R_s I_d - W_r L_q I_q + \rho (L_d I_d + \lambda_f) \tag{6}$$

The motor's produced developed torque is provided by

$$T_e = 3/2\left(\frac{P}{2}\right)(\lambda_d I_q - \lambda_q I_d) \tag{7}$$

The equation of mechanical torque is given by

$$T_e = T_l + B\ W_m + j\left(\frac{dWm}{dt}\right) \qquad (8)$$

Finding the answer to the equation for the rotor's mechanical speed Eq. (8)

$$W_m = \int\left(Te - TL - B\frac{Wm}{j}\right) dt \qquad (9)$$

And $$W_m = Wr\ (P2) \qquad (10)$$

In the equations above, Wr is the electrical rotor’s speed, and Wm is itsmechanical speed. Using the dynamic dq model, the motor's transient and steady-state behavior can be modeled. Park's transformation is used to turn the voltages and currents of three phases into the dqovariable.The following equations are obtained when the rotor reference frame's phase voltage variable Vabc is changed to Vdq0:

$$\begin{bmatrix} Id \\ Iq \\ Io \end{bmatrix} = 2/3 \begin{bmatrix} cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \qquad (11)$$

The inverse transformation is given by:

$$\begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} = \begin{bmatrix} cos\theta & -\sin\theta & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} Id \\ Iq \\ Io \end{bmatrix} \qquad (12)$$

Where λf = rotor magnetic flux,L_d = d-axis stator inductanceL_q= q-axis statorinductance,

R_s = stator resistance, Te = electromagnetic torque, T_l = load torque, W_m = mechanicalspeed

W_r =angular speed, J = moment of inertia, B = coefficient of friction, P = no. of pol

The torque motor that was constructed can be described as As can be seen from the as mentioned equations, the torque is produced by a combination of two distinct mechanisms. The first concept to be introduced is that of "the mutual response torque," which refers to the interaction between iq and the permanent magnet.The second term is "the reluctance torque," which is caused by the difference in reluctance between the direct and quadrature axes [9].Keeping in mind that the motor's Ld equals its Lq and its Ls, the formula for the torque produced by a PMSM is as follows:

$$T_e = \frac{3}{2} p \psi_n i_{rq} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

When there is a direct axis stator current, the direct-axis and quadrature-axis currents do not become separated, and the model becomes nonlinear as a result. The torque equation makes this abundantly evident Eq. (12).If we assume id = 0, the system becomes linear, then vector control of PMSM becomes more dynamic.

In general, this is how the PMSM's mechanical equation can be written:

$$T_e=J_M\omega_M+T_d+B_M\omega_M \quad \text{..........} (14)$$

Where,

ω_M= rotor angular speed,
J_M = motor moment inertia constant,
B_M = damping coefficient,
T_d = torque of the motor external load disturbance,
T_e= electromagnetic torque.

3. SpaceVector Pulse Width Modulation (SVPWM)

The SVPWM is comprised of the following four significant processes:

A. Sector Identification,
B. Vector action time,
C. Computation of switching time
D. Generation of PWM,

Figure 3. depicts the steps involved in creating SVPWM. These six fundamental vectors (x=1, 2,3,...,6) are used to divide the three-phase voltage source inverter (VSI) into six sectors, as shown in Fig.4. Only the two fundamental vectors, Vx and Vx+1, are required in order to create any voltage vector in this space; yet, it is still possible to do so. V1 and V2 can be concatenated to express this voltage, for example, in Segment I voltage vectors Inside each switching cycle, Components of Vx are connected to the occupied and unoccupied times represented by Tn, as well as the null vector. The hexagon that is created by the fundamental space vectors surrounds the region that has the highest value of Vs and contains it entirely. As a direct consequence of this, the greatest magnitude of Vs needs to be confined to the envelope's minimum radius when it is circling Vsis.

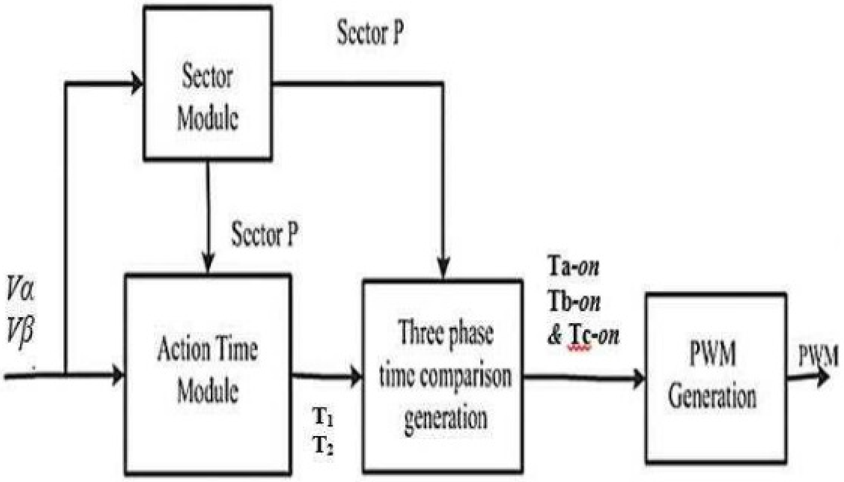


Fig.1. Block Diagram of SVPWM

The Clarke Transformations are used to translate the three-phase a-b-c voltage to the - reference frame for the computation of sector and vectors. The d- q- voltages are used to derive the -voltages in PMSM Field oriented control.

3.1 Sector Identification

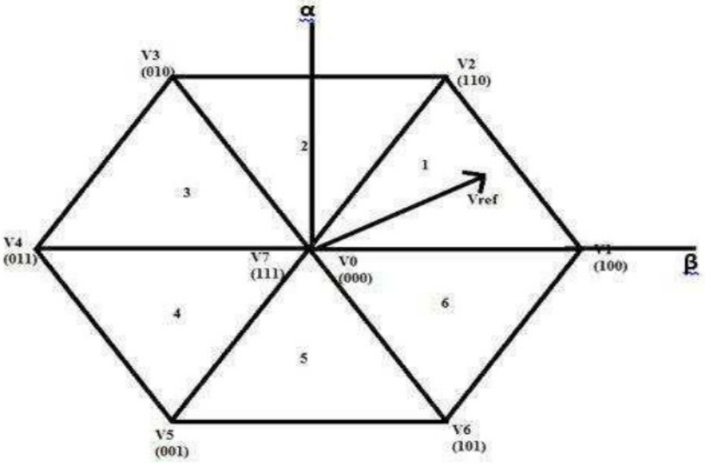


Fig.2. Sectors of SVPWM

There must be a specified location for the reference vector so that time intervals and switching sequence may be established. Using the following approach, one can determine what sector of the reference output voltage vector they are looking for. There are three intermediate variables that are called Vrefs 1 through 3.

$$V_{ref1} = V_{\beta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

$$V_{ref2} = \frac{\sqrt{3}}{2}V_{\alpha} - \frac{1}{2}V_{\beta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

$$V_{ref3} = -\frac{\sqrt{3}}{2}V_{\alpha} - \frac{1}{2}V_{\beta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

There are two possible values for logical variables: 0 and 1, respectively, for A, B, and C when certain requirements are met:

If Vref 1 is greater than 0, then A is equal to 1, otherwise A is equal to 0 (17)

IfVref 2 is greater than 0, B is equal to 1, else B is equal to 0 (18)

Otherwise, if Vref 3 >0, C=1 (19)

With the help of the logical variables A, B, and C, the value of the variable N may be determined to be:

$$N=A+2B+4C \quad (20)$$

The sector is mapped using N values (P) Calculation of the basic voltage vector's action times T1 and T2.

t1 and t2 are the two most common vectors in a given sector. The employment of space angles and trigonometric functions in the calculation of t1 and t2 values in standard SVPWM algorithms makes the procedure more difficult. Using these two values, one may calculate these values. To map the orthogonal decomposition rates of the fundamental vectors, one method that can be utilized is called the volt-second balancing approach.

Where X, Y, and Z are determined by the following:

$$X = \frac{\sqrt{3} V_\beta T_s}{V_{dc}} \text{...} (21)$$

$$Y = \left(\frac{3}{2} V_\alpha + \frac{\sqrt{3}}{2} V_\beta \right) \frac{T_s}{2V_{dc}} \text{............................} (22)$$

$$Z = \left(-\frac{3}{2} V_\alpha + \frac{\sqrt{3}}{2} V_\beta \right) \frac{T_s}{2V_{dc}} \text{..........................} (23)$$

4.Block Diagram of Simulation Model for SPWM control

Advancing the technology of permanent magnet synchronous motors driven by SVPWM inverter (PMSM). SVPWM for electrical drives is the subject of the study. The space vector pulse width modulation design method should be implemented after a thorough investigation. The SVPWM is a method to regulate and control permanent magnet synchronous motors. Three closed-loop control techniques are employed in this project. The PMSM drive speed is optimized by an outer loop in conjunction with two inner loops that regulate current. With the FOC technique for PMSM drives, torque and flux are separated, allowing for faster response and simpler control.

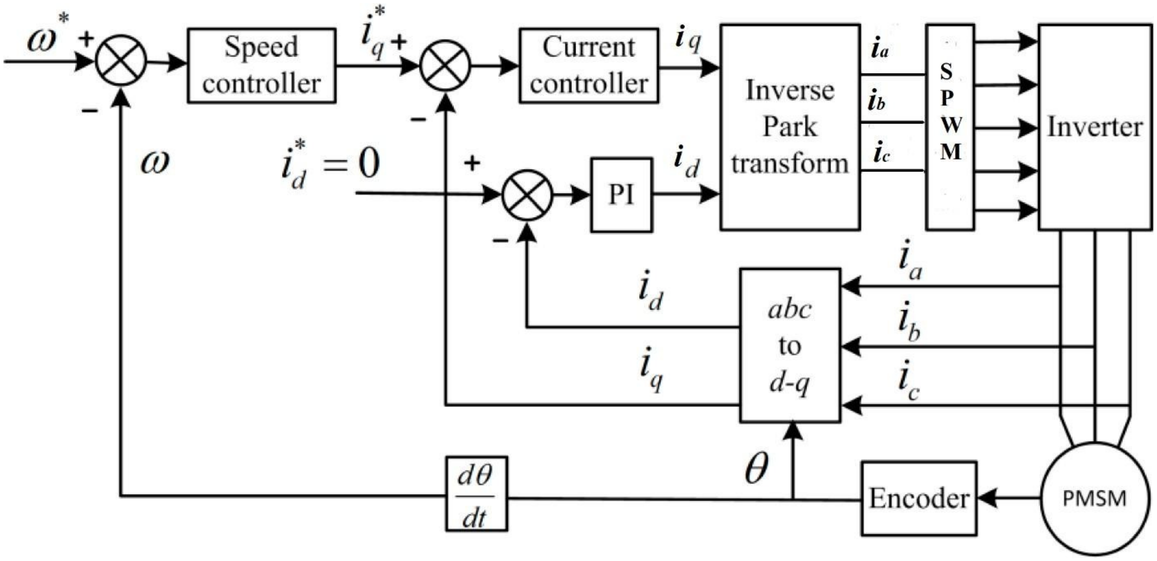


Fig. 3. FOC of SPWM control

5. Field Oriented Control (FOC) of PMSM

Fig. 4 shows the overall block diagram of the FOC of the PMSM. With the use of electric current sensors, this control system determines the stator currents ia and ib, from which it derives the current coefficient ic. The Clarke and Park transformations take the electric currents ia, ib, and ic and turn them into the revolving coordinate system's direct components iq, id. Electric current loop's negative feedback amount Thenie, id. Speed PI is responsible for regulating the gap in speed that exists between the speed that is supplied and the speed that is received as feedback..Iq* and id* deviations are responsible for controlling the output of the

PI regulators for the iq*-torque component and the q-axis reference component, as well as the output phase voltage Vq*/Vd* on the D-Q rotating coordinate system. To obtain the voltage vector components V and V in a stator phase, the inverse Park transformation applies the -coordinate system to Vq* and Vd*If the stator phase voltage vector V, V and its sector number are known, voltage space vector PWM can be used for closed-loop PMSM control. A PMSM rotor segment receives no stimulation, hence id* is 0. When simulating Surface Mounted PMSMs, this paper employs the singular SVPWM to approximate Field Oriented Control (FOC).

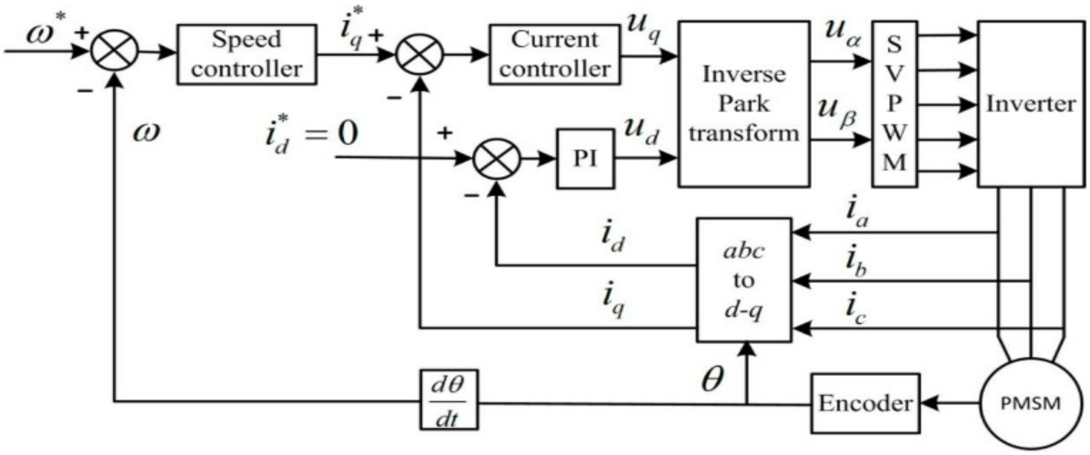


Fig.4. FOC of SVPWM control

6. Simulation and results and discussions

Figure 5 shows the speed response of a PMSM motor driven by an inverter at 300 rpm.There has been no overshoot. It's easy to see that the proposed controller is good at tracking in steady state. The PMSM drive can go from 0 to 300 rpm in 0.011 seconds, and then it stays at 300 rpm.

6.1. Parameters of PMSM

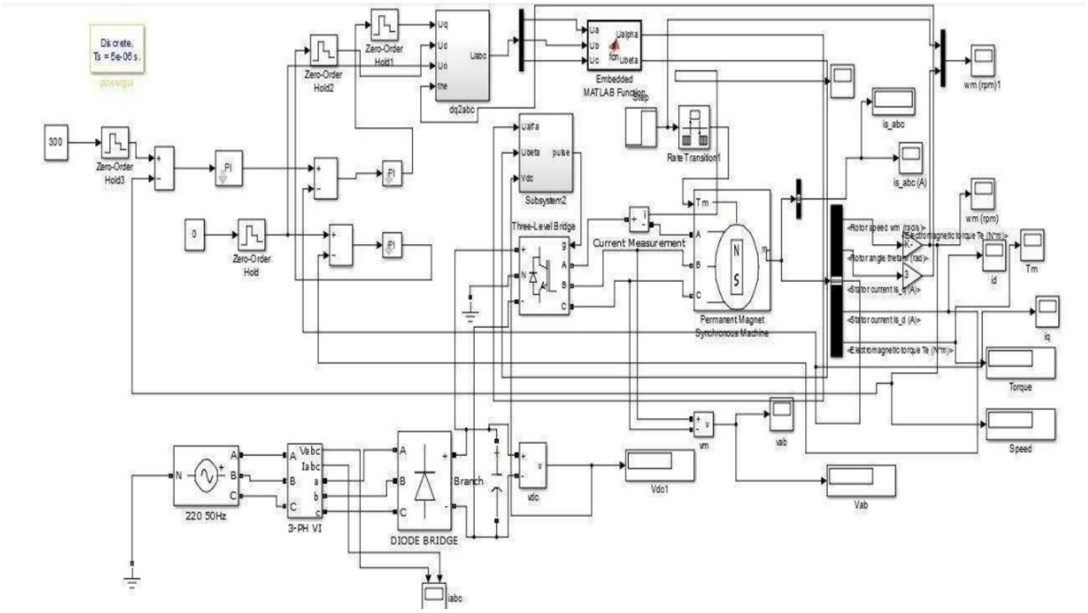


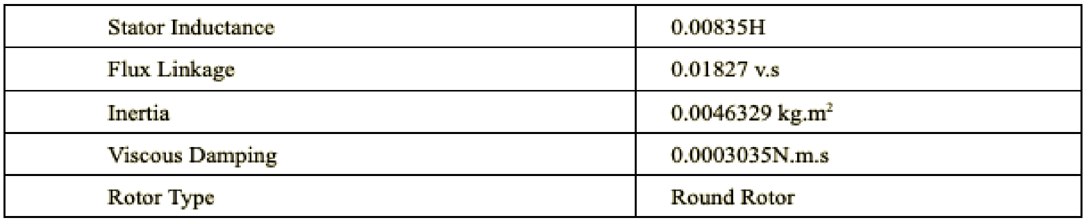
Fig.5. Schematic Representation of the Simulation of an SVPWM Inverter Fed PMSM Drive

The parameters of a permanent magnet synchronous motor are listed in the table below.

Table 1: Parameters of PMSM

Name of Parameters	Value
Number of Pole Pair ρ	4
Stator resistance	0.9585Ω

Fig.5 shows the Permanent Magnet Synchronous Drive's electromagnetic torque can be seen here. After 0.011 seconds, the torque value has steadied.



Stator Inductance	0.00835H
Flux Linkage	0.01827 v.s
Inertia	0.0046329 kg.m^2
Viscous Damping	0.0003035N.m.s
Rotor Type	Round Rotor

According to the SVPWM approach, an inverter-fed PMSM motor operating at a reference speed of 300 RPM is shown in Fig.5. There hasn't been any evidence of overshoot. It's easy to see that the suggested controller's steady state tracking accuracy is quite excellent. To start with, the PMSM drive can go from 0 to 300 revolutions per minute in just 0-0.011 seconds before stabilizing at that speed.

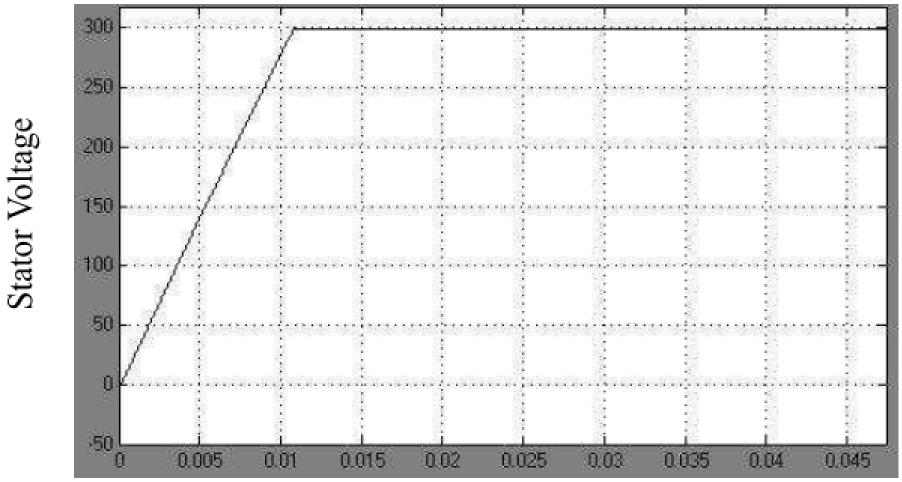


Fig.6 Speed R*esponse*

Fig.6 The stator direct axis and quadrature axis voltage is shown. D-Q voltage is represented on the axis in milliseconds

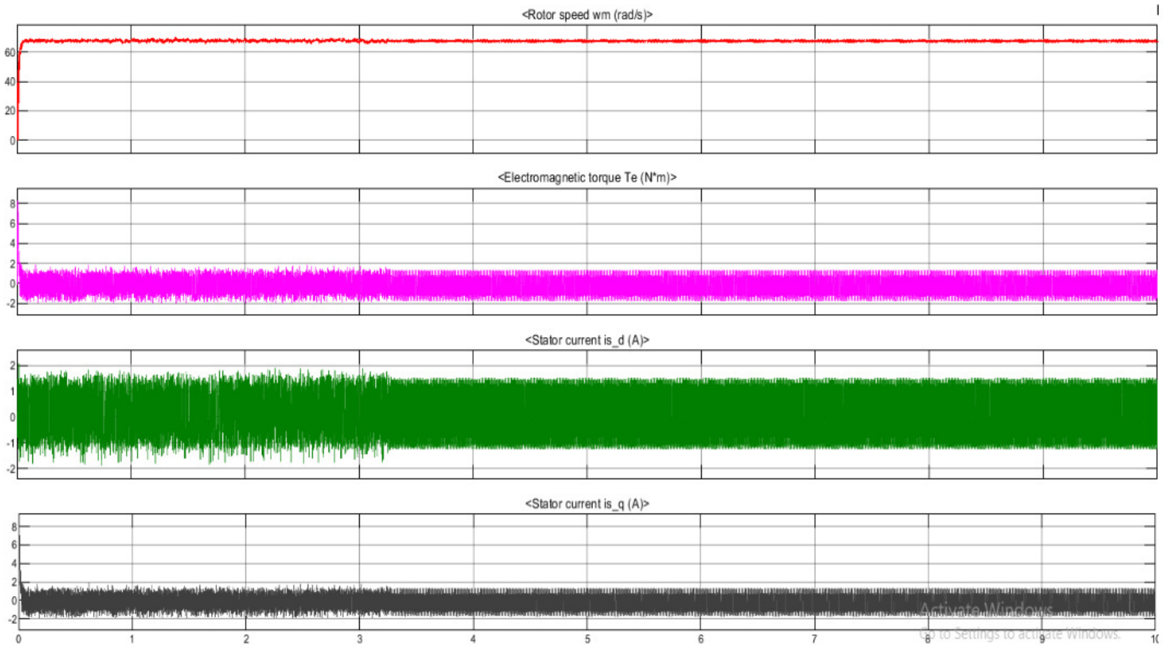


Fig.7 Simulation Results for SPWM control

Stator Inductance	0.00835H
Flux Linkage	0.01827 v.s
Inertia	0.0046329 kg.m^2
Viscous Damping	0.0003035N.m.s
Rotor Type	Round Rotor

Figure 8 shows the voltage at which a permanent magnet synchronous motor can be started. The SVPWM inverter outputs a voltage. For the SVPWM inverter, a cleaned-up 3-phase DC voltage is used as the voltage source.

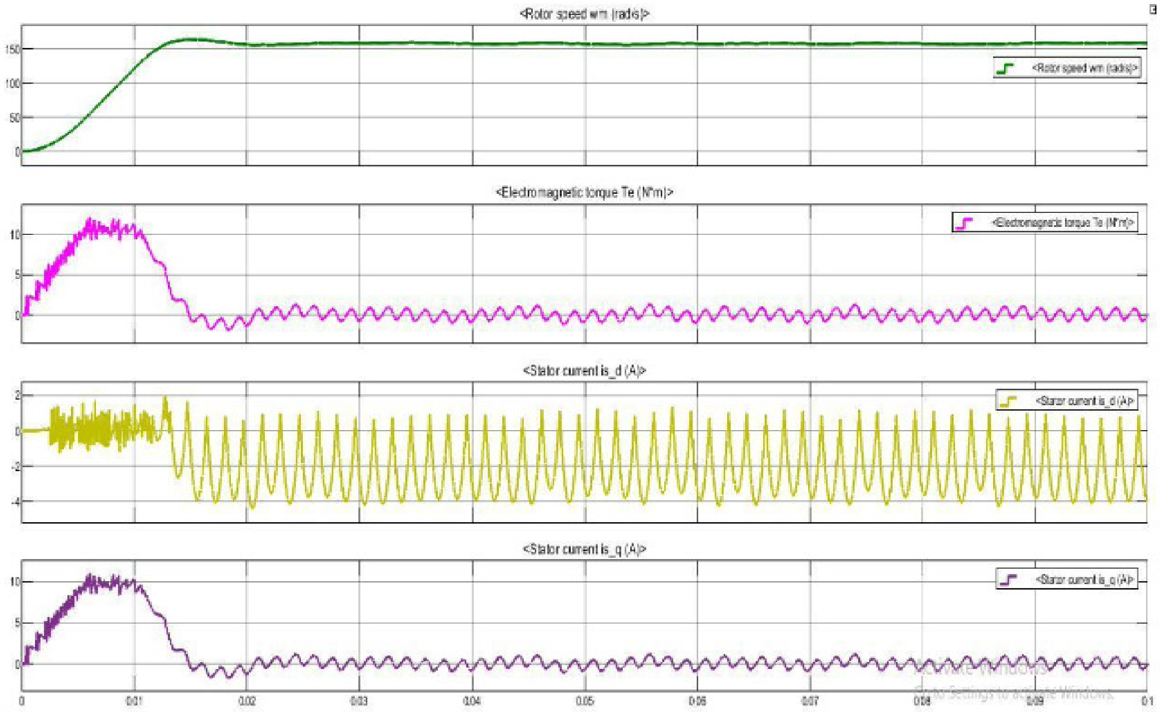


Fig.8 Simulation Results for SVPWM control

The MATLAB/SIMULINK environment was used to create and test Simulink models for two different approaches. SVPWM outperforms SPWM in the simulation, according to the findings. A lot of industrial converters use the SPWM technique. It's the simplest modulation scheme to grasp and put into practice. An inverter's phases can use this technique in one or more ways. Three-phase inverters are required for the SVPWM method due to the higher efficiency they provide. Machine side converters are switched by the SVPWM. Its modulation index is higher, switching loss is lower, and harmonic distortion is reduced compared to SPWM [5]. SVPWM has become popular in three-phase inverters because it gives a greater fundamental voltage output than SPWM at the same DC bus voltage. It is estimated that SVPWM outperforms SPWM by a factor of 15 percent. On the other hand, putting the SVPWM approach into action is a challenge.

Figure 9 shows the results of the SVPWM method's simulations. Time axis-related speed and torque characteristics are displayed. After 0.011 seconds, the PMSM's speed torque characteristic shows on transients and is considered stable.

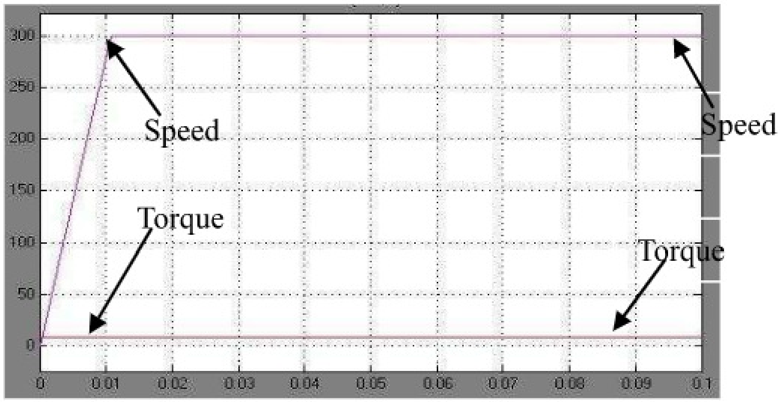


Fig. 9: Speed and motor torque

7. Conclusion

Electric motors and their control methods as well as their efficiency (cost/weight/operation/maintenance demands), dependability (resilience, robustness, fault-tolerance, cooling), and power ratings and vehicle acceleration times were examined in this study.

But because magnets are used in PMSM motors and their controllers, they are more expensive and need to be fixed more often.

Induction and brushed DC motors both need regular maintenance on the slip rings and brushes.On the other hand, brushless DC motors and permanent magnet synchronous motors don't require any special attention.. The least expensive drives are for DC and induction motors. SRM motors are the ones that weigh the least. The most important things are low cost, easy cooling, long life, and fault-tolerant operation. SRM is one of the best electric car motors in terms of how reliable it is. SRM drives are also a good choice because they are affordable and work well.

Im and PM BLDC are the most frequent forms of motor drives, as they are less expensive and more efficient than PMSM andPM BLDC.DC motor drives are a technology that has been around for a long time. There are many benefits to using a PMSM motor instead of an IM or BLDC motor, such as its lightweight, reliability, and ability to control and tolerate faults. These things are especially important for EV. The PMSM motor is the best choice for electric vehicles because of this.

SVPWM outperforms SPWM when it comes to performance. A lot of industrial converters employ the SPWM technique. It's the simplest modulation scheme to grasp and put into practise.This method can be used on one or more of the phases of an inverter. Three-phase inverters are required for the SVPWM approach due to the higher efficiency they provide. Machine side converters are switched by the SVPWM. There is less switching loss and harmonic distortion with this approach than with SPWM.

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