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FOC CONTROLLED PMSM BY USING SVPWM

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ABSTRACT: Electric motors (EVs) are gaining good sized traction as a sustainable transportation strategy to mitigate greenhouse fuel emissions and reduce reliance on fossil fuels. This paper presents a complete evaluation of electrical vehicle machine simulation, focusing on various components which include vehicle dynamics, Speed, torque and pace, etc., The paper investigates the role of advanced manipulate strategies like discipline oriented manage(FOC) by the use of space vector pulse width modulation (SVPWM). Electric powered vehicle system simulation serves as a precious device for comparing the performance, scalability, and sustainability of EV deployments. Everlasting magnet synchronous motor is used to supply the constant torque for long time frame. Wireless Charging of Electric Vehicles.

KEYWORDS: Electric Vehicles, Vehicle Dynamics, Torque, Speed, Field Oriented control (FOC), Space Vector Pulse Width Modulation (SVPWM), and Permanent Magnet Synchronous Motor (PMSM).

I.INTRODUCTION

The increasing concern over environmental sustainability and the imperative to reduce reliance on fossil fuels, electric vehicles (EVs) have emerged as a promising solution for the transportation sector. EVs offer the potential to significantly mitigate greenhouse gas emissions and decrease dependency on finite energy resources. The paper explores the role of power train efficiency in determining overall vehicle performance, with a particular emphasis on torque and speed. Widely used DC drives in industrial applications are less reliable and less efficient as compared to AC drives. Here involves modelling and simulating an Electric Vehicle power train set, which includes a battery pack, permanent magnet synchronous motor, motor controller, and an inverter. FOC (Field Oriented Control) i.e., vector control is an innovative method of variable frequency control. RPM which is Constant is given as input to existing system, which is fed into a Proportional Integral (PI) controller, whose output is again fed into two PI controllers, one to get quadrature current, another is used to get the dc. Inverter inputs a dc voltage of 48V from the battery and converts into 3ph voltage. The 3-phase AC motor output is controlled using FOC utilizing two controllable variable frequency drive with inverter output variables.

Two controllable variable frequency drive inverter variables at the output (voltage and frequency) are used to control three-phase AC motor output is known as FOC or vector control. This can also be known as variable frequency drive control. In machines capable of good performances like a wide speed range, better torque-speed characteristics along with a very fast acceleration-deceleration property FOC control scheme is used. If we consider the volume and cost this technique is also the most reliable and efficient. [1-2]

In addition to traditional control strategies, such as proportional-integral-derivative (PID) control, the paper investigates the potential of advanced control techniques like Field Oriented Control (FOC) utilizing Space Vector Pulse Width Modulation (SVPWM). FOC offers precise control over motor torque and speed, enhancing overall system efficiency and performance. By utilizing SVPWM, which enables smoother motor operation, FOC can further optimize EV operation and contribute to increased energy efficiency.

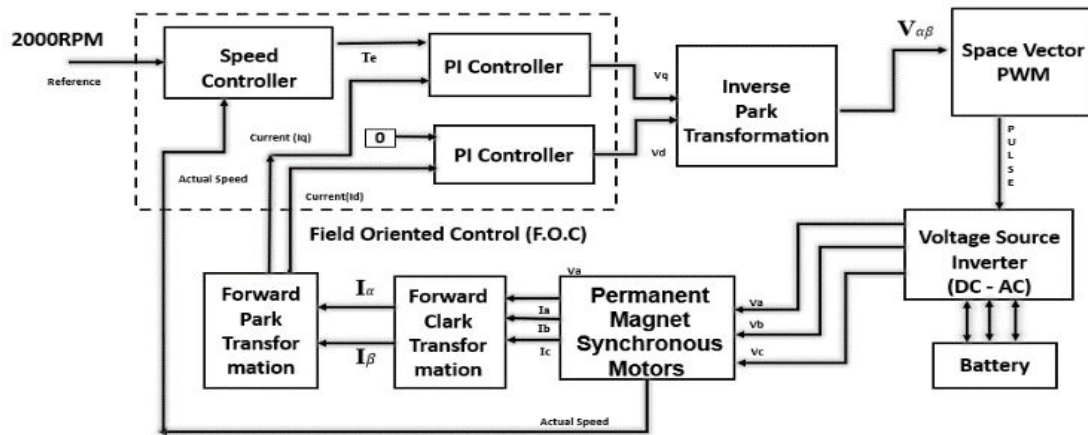


Fig1. Block diagram of FOC Controlled PMSM by using SVPWM.

II.RECENT WORKS

Field Oriented Control (FOC) is a popular method for controlling Permanent Magnet Synchronous Motors (PMSM) due to its efficiency and precision. Space Vector Pulse Width Modulation (SVPWM) is a technique commonly used in FOC to generate the required voltage vectors to control the motor.

Recent works in the field of FOC controlled PMSM using SVPWM have focused on several key areas:

Improved Control Algorithms: Researchers are continuously developing more efficient and robust control algorithms for FOC. These algorithms aim to enhance the motor's performance in terms of speed control, torque response, and energy efficiency.

Sensorless Control: There is a growing interest in sensorless control techniques for PMSM, eliminating the need for position sensors such as encoders or resolvers. Advanced observer-based techniques and machine learning approaches are being explored to estimate rotor position and speed accurately.

Software Implementation: Alongside advancements in control algorithms, researchers are also focusing on the software implementation aspects of FOC-controlled PMSM systems. This includes developing power electronics converters, optimizing switching patterns, and reducing losses to improve overall system efficiency.

These recent advancements demonstrate the ongoing research efforts to enhance the performance, efficiency, and reliability of FOC-controlled PMSM systems using SVPWM. As technology continues to evolve, we can expect further innovations in this field, contributing to the broader adoption of electric propulsion systems.

III.PROPOSED WORK

A.PMSM Motor:

In a coetaneous motor, the rotor rotates with the coetaneous speed of the motor. The rotor is handed with a DC excitation. The stator is given a three-phase force. A rotating glamorous field as in case of an asynchronous motor is make which causes a glamorous locking between itself and the dc excitation by creating north and south poles. In the other half- cycle of operation, stator poles will change their oppositeness, and now the reverse will do i.e. rotor south pole will be attracted to stators north pole. (1-2)

Therefore, the rotor will witness palpitating necklace, and due to rotor indolence, it'll not rotate in either direction. thus, the coetaneous motor isn't a tone- starting machine. Now, if the rotor is rotated by external means similar that rotor poles are continuously under the influence of stator poles of contrary opposition indeed with continuously changing opposition, the rotor will start rotating in one direction. Indeed, after removing the external means the, rotor and stator poles are interlocked and the rotor will rotate with the coetaneous speed. The rotor should be rotated with similar speed that it moves through a distance of pole pitch within a partial period of force. The Coetaneous motor and induction motor are the two most extensively used motors in the electric vehicle operations. The only working difference among the two being that induction motor runs at a speed lower than the coetaneous speed while coetaneous motor runs at coetaneous speed. Due to its high effectiveness and high necklace viscosity, coetaneous motor finds its operation in servo, wind turbines, and electric vehicles.

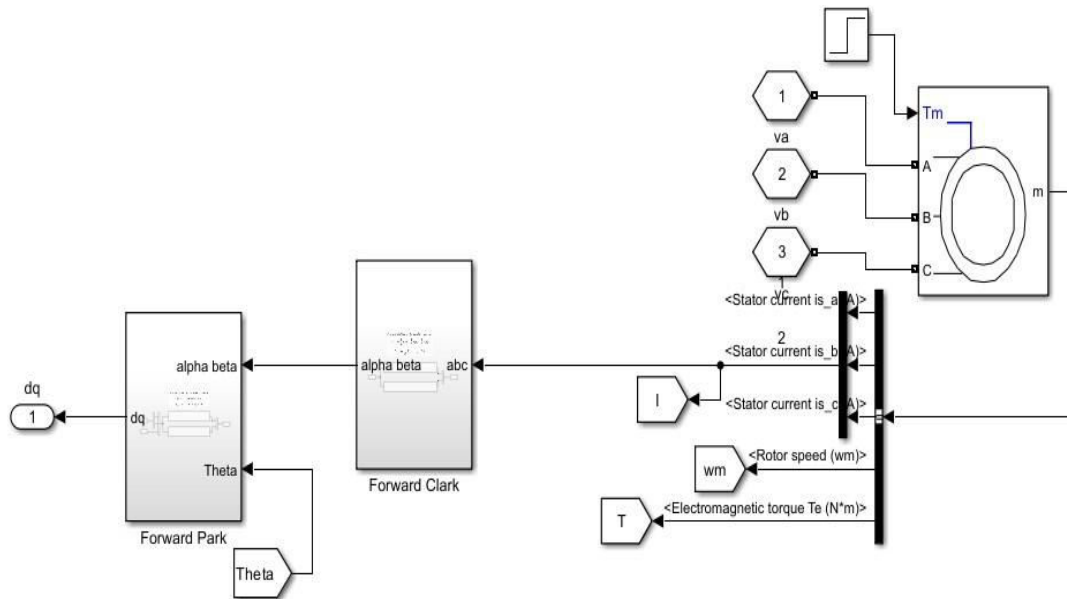


Fig 2 : PMSM simulink model

In the PMSM motor model, the input is the three- phase voltage, which is attained from the inverter, the three- phase voltage is converted the direct and quadrature axis voltages through Clarke and Park transforms, the affair of the block gives the two axes currents and electromagnetic necklace. With the id and command, Iabc, which is the three- phase current, is reckoned using inverse Clarke and Park's transforms. Theta and the motor's speed are rad/ sec is calculated with the help of a mechanical block shown in the figure.

B. Field Oriented Control:

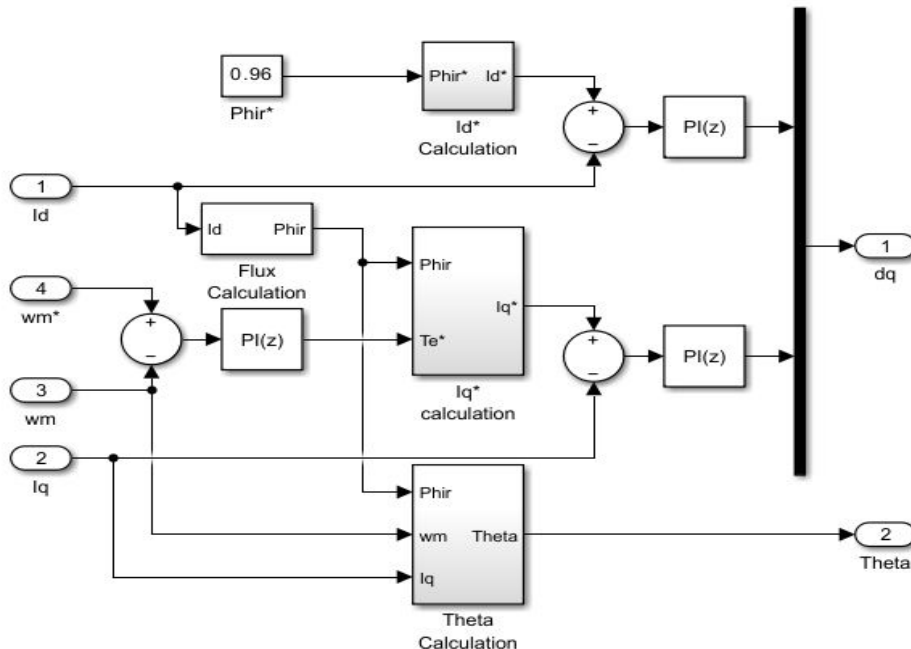


Fig 3: Field Oriented Control model

A solar PV (photovoltaic) array comparatively simpler and more effective motor control method is field-oriented control (FOC), also known as vector control, which splits the three-phase stator component into two orthogonal components. The direct axis component is accountable for the flux, while the quadrature axis component is in charge of producing the torque. The reference components, which are used to create reference id and Iq, are compared to the actual components using the PI controller in this control method. Because of this, electric motors may run smoothly

over their whole speed range and produce their maximum torque at low or no speed.

C. SVPWM:

A three-phase electric motor can be driven by a given voltage vector using the Space Vector Pulse Width Modulation (SV-PWM) modulation technique (permanent magnet or induction machine)

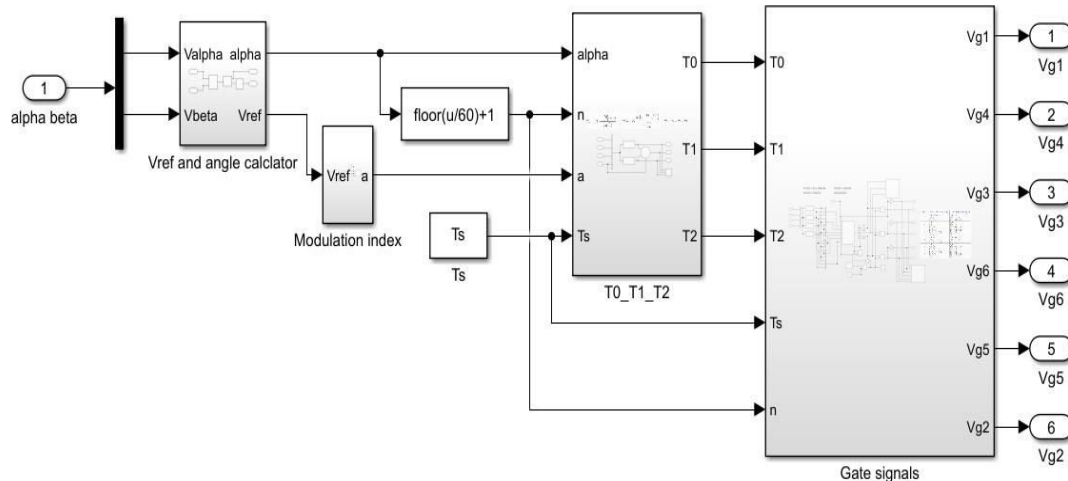


Fig 4: Space Vector Pulse Width Modulation

Fig shows a block diagram of a three-phase inverter system that uses space vector pulse width modulation (SVPWM) to generate control pulses for the inverter switches. SVPWM is a technique that is used to reduce harmonic distortion in the output voltage of a three-phase inverter. It works by transforming the three-phase reference voltages into a two-dimensional dq reference frame, and then calculating the switching times for the inverter switches based on the location of the reference vector in the dq plane.

The block diagram consists of the following main blocks:

- V_{ref} and angle calculator: This block calculates the three-phase reference voltages and the angle of the reference vector.
- Alpha, beta transformation: This block transforms the three-phase reference voltages into the dq reference frame.
- Sector determination: This block determines the sector in which the reference vector is located.
- Time calculation: This block calculates the switching times for the inverter switches based on the sector in which the reference vector is located and the modulation index.
- Triangle carrier generator: This block generates a triangular carrier signal.
- Comparator: This block compares the switching times with the triangular carrier signal to generate the gate signals for the inverter switches.

The switching times are calculated such that the average voltage applied to each phase of the load is equal to the corresponding reference voltage. This helps to reduce harmonic distortion in the output voltage of the inverter.

Here are some of the advantages of using SVPWM:

- Reduced harmonic distortion in the output voltage
- Improved efficiency
- Lower switching losses
- Higher output voltage quality

All things considered, SVPWM is an effective method for raising three-phase inverter performance.

The aim is to simulate a three-phased sinusoidal waveform with changeable frequency and amplitude using a steady state DC voltage and six switches (such as transistors).

There are two issues with this.

- The DC-link voltage is the only voltage level that is accessible, and it may be considered to be constant—at least for the sake of simplicity.
- There are just six voltage angle combinations possible. without any intermediary position. A motor needs a voltage vector that rotates smoothly, not one that steps back and forth by 60 degrees.

Three-phase voltage provided by the grid:

An animation of a three-phase voltage provided by a grid may be seen below. When an induction machine is directly linked to the grid, it goes via this.



Two separate, yet equivalent formulations are used to demonstrate the three-phase system:

- A vector diagram that displays the vector sum (space vector) for each of the three stages.
- A standard instantaneous sine wave depiction that further displays the space vector that results.

Figure 3 shows the equal space vector of a phase sinusoidal system. Typical three-phase system, seen here in both vector and sinusoidal forms. The space vector that results from combining the three vectors is the black vector. It is evident that the magnitude of the space vector is constant.

The topology of a two-level inverter:

Due to its affordability and ease of use, the two-level inverter architecture is now the most used. Higher level converters are not covered in this article since they are primarily employed in high voltage applications. The schematics of a two-level inverter that are connected to a motor equivalent, a DC-link capacitor, and a passive diode front end.

Anti-parallel diodes and snubbers are not displayed.

The popular inverter topology is shown in the diagram above. Presented from left to right are the following:

- A three-phase diode rectifier and three-phase supply;
- A DC-link capacitor for voltage stability and energy storage
- Three output terminals and an analogous star-connected (ungrounded) induction machine; an inverter bridge with six transistors;
- Not shown are the motor's back-EMF, anti-parallel diodes covering the transistors, and snubber circuit.

The preceding diagram may be significantly reduced to help illustrate the usage of space vector PWM: Initially, it is possible to simplify the DC-link voltage and make it constant. Usually, it changes with load, although not significantly within the time ranges specified in this article. Therefore, for the remainder of the article, the supply and diode rectifier won't be displayed. Second, by using a single SPDT switch that indicates whether the top or bottom transistor is closed for each of the two bridge leg transistors, each leg of the inverter bridge may be made simpler. It is not essential and nor interesting to consider the circumstance where both transistors in one leg are open. Furthermore, it is expected that one or both of the transistors on each inverter leg are closed at any one moment. Legs V and U in this example have closed lower transistors, whereas Leg W has closed top transistors. The direction is indicated by the arrows. The transistor combination in the example above has the bottom transistor open and the higher transistor closed on the leftmost leg (W). The bottom transistor is closed while the higher transistor is open in the other two legs (V and U). This means that W-phase will receive a positive voltage while the other two phases receive a negative voltage. The current path from the positive DC link to the negative DC link is depicted by the current arrows.

The magnitude and direction of the eight fundamental vectors. At origin, the zero vectors v_0v_0 and v_7v_7 are shown. Normally, the basis for every angle is the U-phase. The windings' actual placement inside the stator, spaced 120 degrees apart around its circumference, is the source of the angles. Each winding fills two angles with a 180° separation since it can contain both positive and negative voltage. It is now clear from the reduced schematic that there are three switches, each of which has the ability to be in two distinct positions.

From here on, these six configurations—which correspond to various voltages given to the attached motor—will be referred to as fundamental vectors. Since the final two show 0 volts on the terminals, they are known as zero vectors.

000 - v_0v_0 (zero vector), 001 - v_1v_1 (Phase +U), 010 - v_2v_2 (Phase +V), 011 - v_3v_3 (Phase -W), 100 - v_4v_4 (Phase +W), 101 - v_5v_5 (Phase -V), 110 - v_6v_6 (Phase -U), 111 - v_7v_7 (zero vector)

Each of the three binary digits refers to one bridge leg where the value 1 indicates that the top transistor is closed whereas the value 0 indicates that the bottom transistor is closed.

The motor voltage and current directions that occur from each of the eight combinations are displayed below.

Press any image to enlarge.

$v_0 - 000$, $v_1 - 001$, $v_2 - 010$, $v_3 - 011$, $v_4 - 100$, $v_5 - 101$, $v_6 - 110$, $v_7 - 111$

Synthesizing output voltage:

Thus far, only the converter's ability to output DC-link voltage to the terminals and the ways in which each of the six use able vectors influences the motor's current and voltage directions have been demonstrated. A voltage correlation between fundamental vectors 1 and 3. The reference voltage may be replicated by quickly switching between these two vectors and the zero vectors. By rapidly switching between neighboring voltage vectors and timing the on and off timings, this section will demonstrate how to synthesize any voltage vector.

An example of a reference vector that the inverter must create using the fundamental vectors at its disposal is shown to the right.

From the figure, it is seen that the reference is located between v_1v_1 and v_3v_3 . This sector is called sector 1. It is now possible to quickly alternate between these two basic vectors to emulate a voltage vector at $38.3 \times 38.3^\circ$. The two zero vectors v_0v_0 and v_7v_7 are also used to add dead time to the switching pattern. This dead time reduces the magnitude of the voltage and is necessary when the reference voltage is below 100%. Real synthesis can be achieved using triangle waves as a trigger. First, assume that the desired voltage reference is already available, e.g. calculated with the inverse Clarke/Park transformation described in Vector Control for Dummies. The figures below illustrate how the desired voltage is converted to binary on/off signals for each of the three inverter legs using a triangular wave. Six different examples are presented, each with a different angle in different sectors. Sector 1 - 18° , Sector 2 - 95° , Sector 3 - 150° , Sector 4 - 189° , Sector 5 - 285°

D. Inverter:

The inverter is used to convert DC voltage from the battery into three-phase AC voltage, which powers the inverter PMSM motor. Six switches make up the inverter; two are operated at a time, each for a specific period of time. The switches are often constructed of MOSFETs or IGBTs. The inverter, which receives a Dc voltage as input and generates PWM gate pulses to produce a three-phase pulsing signal, is the universal block.

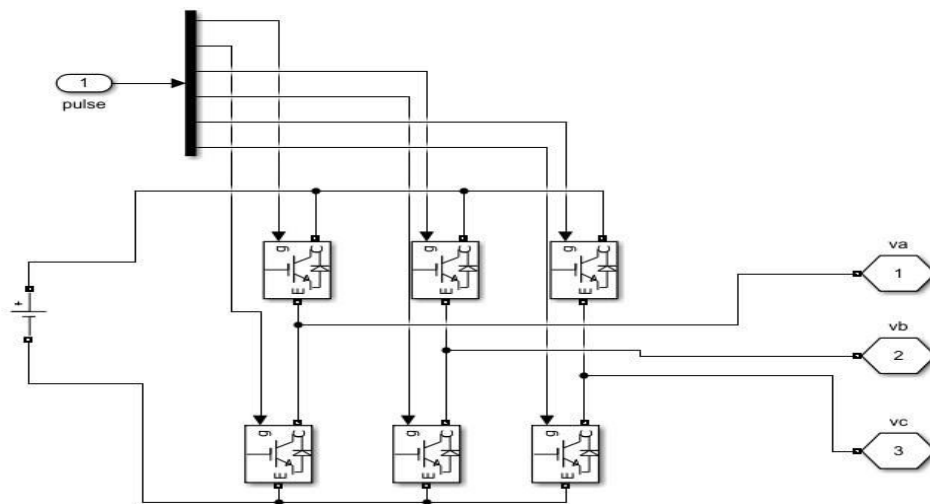


Fig 5: Inverter model

1.1 Mathematical Expressions and Symbols

E. Clark Transform:

The Forward Clark Transform is a mathematical operation used in electrical engineering and power systems, particularly in the analysis of three-phase alternating current (AC) systems.

Three phase quantities are converted into the two coordinate systems i.e. alpha and beta. Above formula is used for conversion. This transformation simplifies the analysis and control of AC systems.

$$\alpha(t) = \frac{2}{3}a(t) - \frac{1}{3}b(t) - \frac{1}{3}c(t) \tag{1}$$

$$\beta(t) = \frac{1}{\sqrt{3}}b(t) - \frac{1}{\sqrt{3}}c(t) \tag{2}$$

Above formulas are used for conversion.

F. Inverse Park Transform:

It is the inverse operation of the Park Transform is commonly employed in the control of three-phase alternating current (AC) systems, particularly in applications such as motor control and power electronics. The Inverse Park Transform converts the coordinates back from the dq reference frame to the ABC reference frame. The equations for the Inverse Park Transform are as follows: Let θ represent the electrical angle.

Given the dq components V_d and V_q , the inverse Park Transform yields the corresponding α, β components V_α, V_β as follows:

$$V_\alpha = V_d \cos\theta - V_q \sin\theta \tag{3}$$

$$V\beta = Vd\sin\theta + Vq\cos\theta \tag{4}$$

IV.RESULTS AND DISCUSSION

A Step signal input with amplitude of initial value 120 and final value of 160. Reference Speed of 2000 RPM is given as input. After running the model for 2 seconds, the following results will be obtained: -

Speed: The speed of the Permanent magnet synchronous motor is compared with the time period. Here the time period is taken as 1 second. Here the step signal is compared with the motor speed.

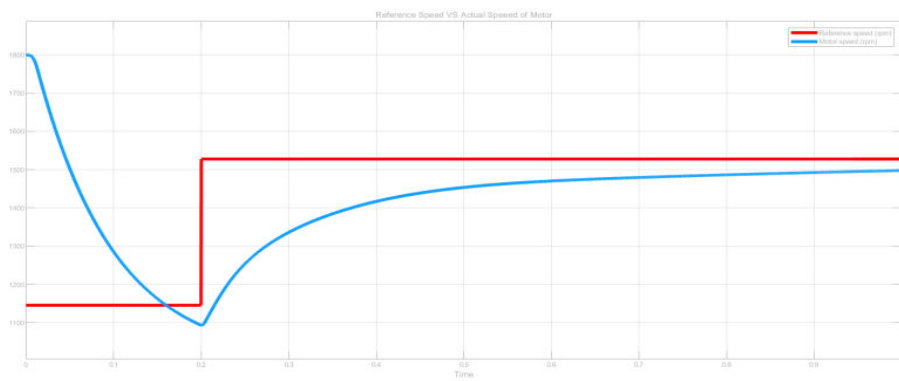


Fig 6: speed of PMSM

Error Currents: If we start the PMSM motor ,it produces some error direct and quadrature currents. The Error currents are shown in the figure.

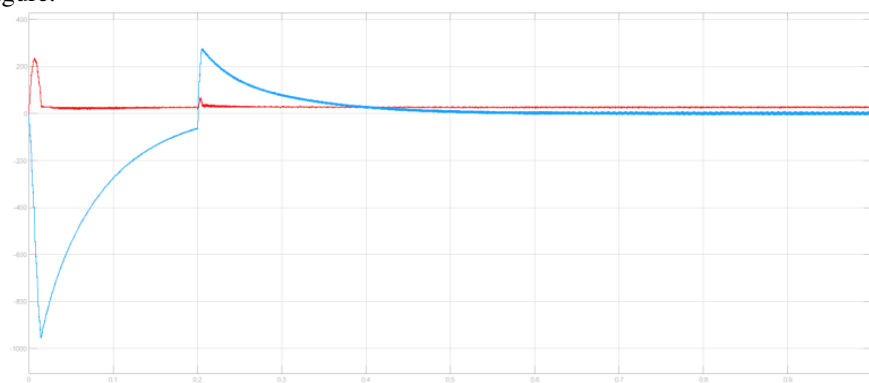


Fig7: dq error currents before control

Stator currents:

The Stator currents are shown in the figure. The Error currents at transient state are converted into the Stable condition.

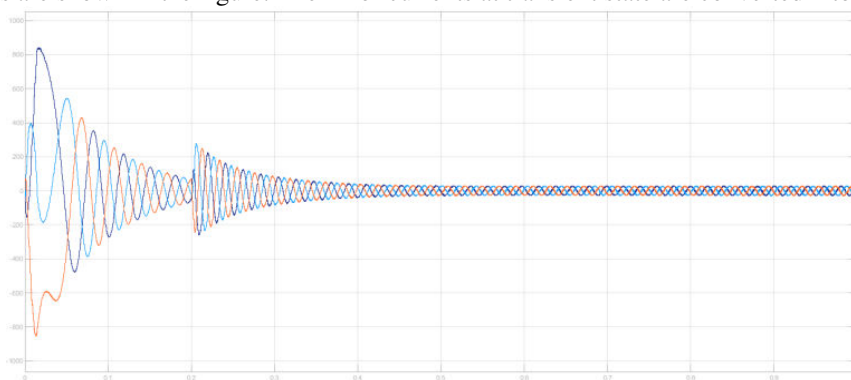


Fig8: Stator currents of PMSM

Phase and Line Voltages :

The Inverter converts DC to AC voltages.AC phase and line voltages are shown in the below figures

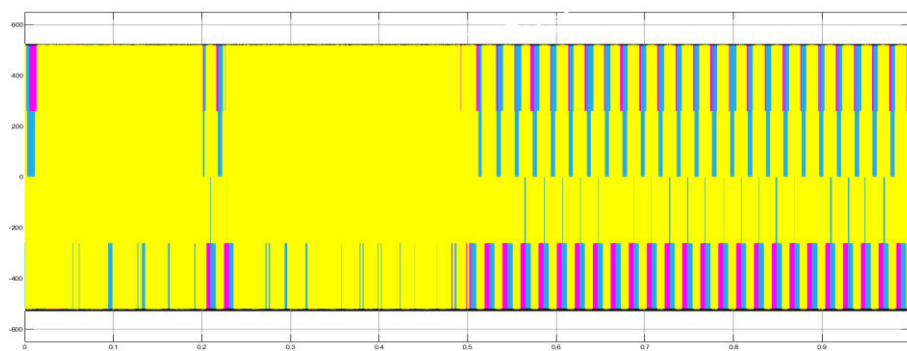


Fig 9: phase voltages

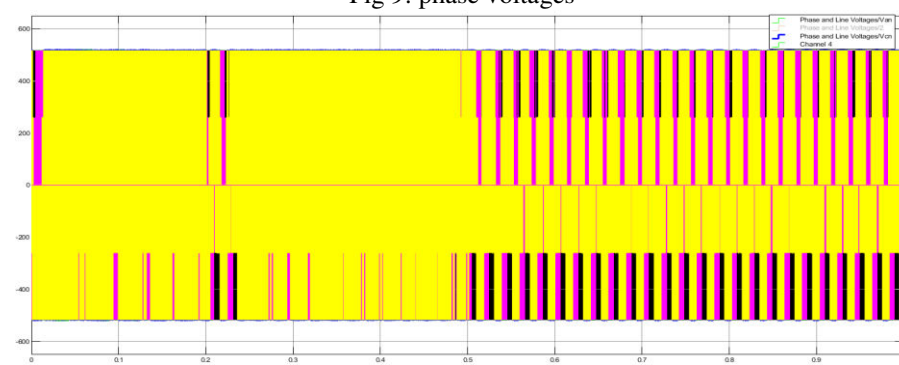


Fig 10: line voltages

4.1 COMPARISON

EXISTING METHOD	PROPOSING METHOD
<ul style="list-style-type: none"> • Universal bridge is used to generates the pulses in this method. • Speed of the Motor can't be varied effectively. • Starting torque is low compared to PMSM. • Cost is high. • The battery pack consists of 33*12 li-ion cells arranged in a combination of series and parallel. • In battery, 33 are cells connected in parallel and 12 are modules connected in series. 	<ul style="list-style-type: none"> • Space Vector pulse width modulation is using to produce the gate pulses. • A DC source with 780V is inter-connected with the Inverter. • Field Oriented control is using to control the speed of Permanent Magnet Synchronous Motor. • PMSM produces maximum Constant torque for a long time. • Speed and position of the rotor can be controlled by FOC. • Starting torque is high due to permanent magnets. • Size of PMSM is Compact.

V.CONCLUSIONS

The electric vehicle is rapidly increasing in the Automation Industry. It helps in reduction of pollution in the environment. This paper is a MATLAB/Simulation model of an FOC controlled PMSM by using SVPWM. The MATLAB/Simulink model shown in this paper is mainly Field Orient Controlled PMSM .The Step signal is taken as the Input to the motor. The Step signal has initial value of 120 and the final value of 160. The results shown in this paper is to improve the speed of the Permanent Magnet Synchronous Motor. The results are observed when the 2000 RPM is given as input. The Clark's and park's transforms are used for Field Oriented Control to comfortable and better control of the speed of the motor. The Space Vector pulse width modulation is used to produce the gate pulses in the circuit. In simulation, normally the time period is taken as one second for observing the results. When the input is changed, the system response will change quickly. The time period of response is very less. The paper act as introduction for the control of the PMSM motor. Hence, its modelling helps and optimize the performances.

After the control of the PMSM we can observe the following outputs:

- The Speed of the Motor
- Direct and Quadrature currents
- The Stator current of the motor
- Torque of the motor
- Phase voltages
- Line voltages

By observing these outputs we can conclude that the proposed method is more efficient than the existing method.

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