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FIELD ORIENTATION CONTROL OF PERMANENT MAGNET SYNCHRONOUS MOTOR FOR ELECTRIC VEHICLE

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Abstract: The work investigates field-oriented control (FOC) speed control in an electric vehicle (EV) powered by an PMSM, which is a permanent magnet synchronous motor, during a full reference drive cycle. Due to its high power density, outstanding efficiency, and better power factor, PMSM motors are utilized in applications that require high performance such servo and robotics drives, electric automobiles, rolling and spinning factories, and packaging machinery. PMSM has created high-performance applications that use the vector control method. The PMSM's vector-based control operation changes the flux and torque-producing elements of the stator currents to mimic an independently stimulated machine. The field-oriented control algorithm is developed using the dynamic PMSM model. The controller is made to work with the rated and distorted characteristics of an electric vehicles.

Indexterms- Permanent magnet synchronous motor, Electrical vehicle, Field oriented control.

I. INTRODUCTION

In today's modern society and industry, motor control systems are crucial. It has several uses, including general-purpose variable speed drives used in wind turbines, high-performance robotics, CNC equipment, and electric vehicles. In recent years, due to development in power electronics and modern theory, the development of AC motor drives became convenient. A sizeable portion of the market for EV motor drives is being taken over by PMSMs. Due to its widespread use; researchers are concentrating more and more on better control techniques for PMSM drives, which vastly increase dynamic efficiency, increase device resilience, and simplify PMSM drive control systems.

Electric equipment has utilized permanent magnets for more than a century. After the industrial use of these sorts of machines increased in the 1990s, attention turned to control strategies for electric machines with permanent magnets. Publications were created and numerous, effective control methods for applications were developed. The use of permanent magnets in electric machines increased significantly as a result of these investigations relating fundamental concepts to emerging technology. PMSMs are a form of permanent magnet that is utilized in much electric equipment. A common control method for AC (alternative current) machinery is vector control. The core concept of vector control is the independent control of the torque-producing currents and fluxes, which are kept apart. Because of a constant excitation flux in PMSMs, which remains consistent even as the rotations per minute fluctuate, vector control in these machines is easier than in various kinds of AC machines. One of the methods for vector control is FOC. Torque control at a slower pace is necessary with this approach. Like a direct current, or DC, motor, the precise flux and torque modification, is the main characteristic of this approach. Sensors are required to track the rotor location in order to get field orientation. For high-power density design methodologies, PMSM drivers are perfect. Due to their traction characteristics, these motors are the most frequently used in electric vehicle applications. The limitations must be changed and computed using a standard PID; thus, this method lacks functional control features. This idea suggested employing FUZZY logic control to alter torque and motor speed when the load diverges in order to prevent such problems. The controllability of speed in PMSM with no overshoot and good transient responsiveness is the main criterion in creating and tweaking the suggested FUZZY logic control. Additionally, it offers precise and ongoing parameter tweaking that is associated with a productive PMSM drive model.

Because of uncertainties, changing characteristics and harmonics in both the motor and the inverter, the performance of the motor degrades. As a result, there are issues with torque, which in turn cause speed oscillations as a secondary issue. Due to the PMSM's design and slots, the cogging torque develops. Torque ripple is reduced via machine design and control methods. The alternative option is preferred because the first method is complex and expensive. The most popular type of controller utilized in a variety of industrial applications is the proportional integrator controller (PI). The ease of use of PI control is a factor in its popularity. Due to its fixed proportional increase and integral time constant, PI controllers are sensitive to changes in parameters, load disturbances, and speed. These problems can be resolved by the fuzzy logic a ruler, one which doesn't use a mathematical model but rather verbal norms that the system operator has acquired via experience.

II. PROPOSED METHODOLOGY

2.1 PERMANENT MAGNET SYNCHRONOUS MOTOR

PMSMs (Permanent Magnet Synchronous Motors) with no brushes are incredibly dependable and effective. They have a lower frame size than AC Induction Motors (AICMs), higher torque, and no rotor current because of their permanent magnet rotor. Due to its high power-to-size ratio, PMSMs may enable you to minimize the size of your device without compromising torque. Similar BLDC motors, PMSMs require commutation, but for best performance, the shape of the waves must be sinusoidal due to the construction of the windings.

2.2 PMSM MATHEMATICAL MODEL

The voltage-based equations of PMSM for the rotating reference dq-axis are provided in the following equations using Park transformation.

$$V_d = R_s I_d + L_d \frac{dI_d}{dt} - \omega L_q I_q \tag{1}$$

$$V_q = R_s I_q + L_d \frac{dI_q}{dt} - \omega (L_d I_d + \varphi_f) \tag{2}$$

Where Ld, Lq, and Rs stand for direct, quadrature inductance, and phase resistance, respectively. The flux linkage is presented by φf. These are the flow equations are:

$$\varphi_d = L_d I_d + \varphi_f \tag{3}$$

$$\varphi_q = L_q I_q \tag{4}$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ \varphi_f \end{bmatrix} + \begin{bmatrix} L_d & 0 & 0 \\ 0 & L_q & 0 \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ \varphi_f \end{bmatrix} \tag{5}$$

$$\omega \begin{bmatrix} 0 & -L_q & 0 \\ L_d & 0 & 0 \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ \varphi_f \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} \varphi_d \\ \varphi_q \end{bmatrix} = \begin{bmatrix} L_d & 0 & 0 \\ 0 & L_q & 0 \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ \varphi_f \end{bmatrix} \tag{7}$$

$$[V] = \begin{bmatrix} V_d \\ V_q \end{bmatrix}; \; [R] = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \end{bmatrix}; \; [I] = \begin{bmatrix} I_d \\ I_q \end{bmatrix} \tag{8}$$

$$T_e = \frac{3}{2} p(\varphi_d I_q - \varphi_q I_d) \tag{9}$$

$$T_e - T_r - f\omega_m = J \frac{d\omega_m}{dt} \tag{10}$$

$$\omega = \omega_m p \qquad (11)$$

ωm is the mechanical speed of rotor

Tr, Te are external load torque and electromagnetic torque.

J, f is friction constant and moment of inertia p is the pole pair

To understand easily the model has been simplified and written below:

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} R_s & 0 \\ 0 & R_s \end{bmatrix} \begin{bmatrix} I_d \\ I_q \end{bmatrix} + \begin{bmatrix} L_d & 0 \\ 0 & L_q \end{bmatrix} \frac{d}{dt} \begin{bmatrix} I_d \\ I_q \end{bmatrix} \qquad (12)$$

$$\omega \left(\begin{bmatrix} L_d & 0 \\ 0 & L_q \end{bmatrix} \begin{bmatrix} I_d \\ I_q \end{bmatrix} + \begin{bmatrix} 0 \\ \varphi_f \end{bmatrix} \right) \qquad (13)$$

$$[V] = [R][I] + [L]\frac{d}{dt}[I] + \omega([A][I] + [\phi]) \qquad (14)$$

$$[V] = \begin{bmatrix} V_d \\ V_q \end{bmatrix} : [R] = \begin{bmatrix} R_s & 0 \\ 0 & R_s \end{bmatrix} : [I] = \begin{bmatrix} I_d \\ I_q \end{bmatrix} ; \qquad (15)$$

$$[L] = \begin{bmatrix} L_d & 0 \\ 0 & L_q \end{bmatrix} ; [A] = \begin{bmatrix} 0 & L_q \\ L_d & 0 \end{bmatrix} : [\varphi] = \begin{bmatrix} 0 \\ \varphi_f \end{bmatrix} \qquad (16)$$

There are mainly three types of motor commutation techniques: trapezoidal, sinusoidal, and field orientation control. Let's see which type of motor can be considered and why. Firstly, we will see that trapezoidal commutation logic is relatively easy. The main advantage of this technique is its simple control scheme, high speed and high torque, and low switching losses. We also have some disadvantages, which are high torque ripple and audible electrical noise. Secondly, we will see that sinusoidal control is similar to trap control in that the load is modified compared to trap, and here low audible noise, low torque ripple for stable loads, and high motor efficiency are the advantages, whereas high switching losses, more complex control compared to trap, and high ripple torque for dynamic loads are the disadvantages of sinusoidal control. Lastly, we will discuss FOC. This method aims to produce the most torque possible, even under dynamic loads. This is done by always applying torque 90° perpendicular to the rotor position. With FOC, we can achieve the lowest audible noise and higher efficiency. We also retain high motor speed, which can be further increased by the field weakening method technique. The real challenge with FOC is complex control, which usually requires a microcontroller and user-defined programming code.

2.3 FIELD ORIENTED CONTROL

Blaschke proposed the FOC concept in 1970. In the unique dq0 coordinate system, the stator current was separated into the torque component and magnetized under the constant rotor fux, and the control of (AC) motors can be identical to that of an unexcited DC motor. Performance is constrained by basic controls like the V/Hz technique. The induction motor needs to be controlled using a more complicated control strategy in order to obtain higher dynamic performance.

2.4 Why Field Oriented Control

A V/Hz control technique has some inherent restrictions, which are well known for the asynchronous machine. You can get past these restrictions using FOC control by separating the effects of the torque and the magnetizing flux. The torque-producing portion of the stator flux can now be thought of as independent torque control thanks to decoupled control of the magnetization. With decoupled control, the magnetization can be kept at the right level and the speed can be adjusted by adjusting the torque.

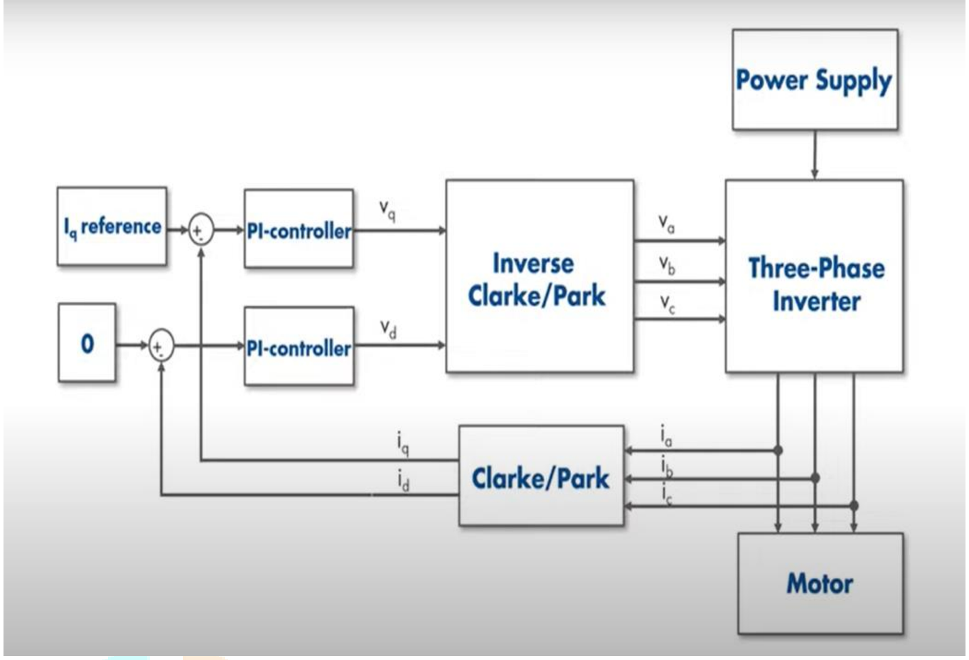

Figure1 Block Diagram of Proposed methodology

The actual speed of the machine is compared with a reference value, and the error is given as input to the PI controller so that the error can be manipulated to be given as input to the next stage. So, the reference speed is compared with the actual speed, and error is manipulated with the help of the PI controller, and that is given as input to the next stage, which is quadrature axis current, which becomes the reference quadrature current. The actual quadrature current is derived from the park transformation block, where the line currents Ia, b, and c are measured and converted to dq axis currents.

III. SIMULATION AND MODEL

According to the theory outlined above, the models have been simulated using a variety of speed control (vector control) approaches. Every simulation is carried out in a distinct setting. The driving operation of PMSM in the zone of operation with constant flux is the main topic of the simulation. To compare various control techniques, certain simulations were run and the results obtained. The simulation carries out three different parts; two of them are crucial, and the third will be generating the output signals. Part 1 is about how we have a battery and have taken a bridge converter (also known as an inverter). We are giving the gate pulses to the switches inside the bridge converter, and the output of the bridge converter is connected to PMSM. The reference speed given is 500 rpm. In Part 2, the k block converts rpm to rad/sec. Inside that, we will have the FOC part. The diagram has been shown below. This part mainly deals with FOC and the workings of it, as earlier we saw the technical explanation of FOC with Clarke and Park. Here, too, we have different subparts, and the explanation is as follows: Some actual and reference value operations will be done.

The reference speed is given to the comparator, and it is compared with the actual speed. The error is derived, and it is given as input to the PI controller. The output of the first PI controller becomes the input to the inner loop. The outer loop deals with speed control, whereas the inner loop deals with current control. Here, the reference ID is 0, and the value is compared with the direct axis current, and again, the error is manipulated with the PI controller. Here we gave the reference d axis and q axis currents; this park inverse transform converts them into frames. Again, this is given to Clarke's inverse transformation, where it converts into corresponding 3-phase voltages. This uref block converts voltages into 6 PWM signals for all switches in the inverter.

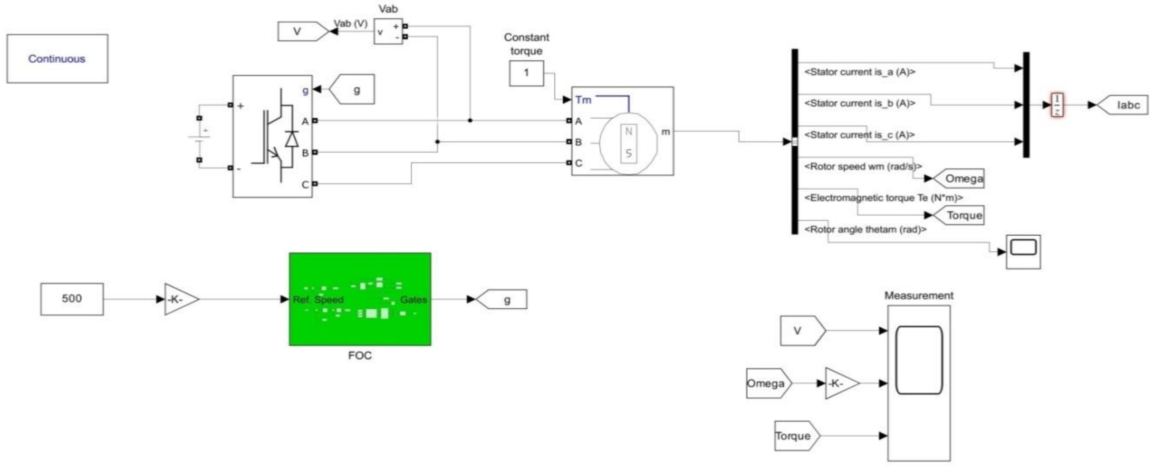

Figure 2 MATLAB circuit diagram of Field oriented control for PMSM motor

Similarly, like FOC here also we have done the simulation of fuzzy control based FOC of PMSM. Here we are going to implement FOC for PMSM. So, the motor is an 8 per motor; basically, the number of poles per series is 4, so the number of poles would be eight. So the maximum speed produced by the motor for a frequency of 50 Hz would be 750 rpm. So the inverter model is available, and for the inverter we are going to give gate pulses, and here we are also having a battery. The rated voltage of the battery is kept at 100, and the rated capacity is 100 amps. Here we have the reference speed that has been given for 1 second, which would be 500 rpm, and for the remaining time, it would be 750 rpm. This becomes the reference speed. For that reference speed, we are comparing it to the actual speed in terms of rad/sec. Here are the inputs for the fuzzy logic controller: The FLC gets two inputs: one is an error, and the other is a change in error. So, this will compute the change in error. Using a multiplexer, we are giving an error and a change in error as inputs to the FOC and outputs. The output of FOC is given to the next stage, where the actual quadrature axis current will be compared with the output of FOC. So, the FOC becomes the reference Iq; this reference is compared with the actual Iq current, and then an error is calculated, and this error will be given to the Pi controller as input. Here we will have actual quadrature axis and current quadrature axis currents, which will be measured by measuring phase currents. By measuring, this will be fed to Clarke's transformation. Basically, it will convert 3-phase to 2-phase currents, and again we need to go for Dq transformation, which is Clarke-Park transformation. After all the internal processes, again calculating the error has been calculated and the error will be given to the PID controller. The output of the PID controller becomes direct axis voltage and quadrature axis voltage. Initially, Clarke to park transformation has been done. But now the park to Clarke transformation is done. Here inverse Clarke transformation is done and the output of this will be the voltages Va, Vb, and Vc.

IV. RESULTS AND DISCUSSION

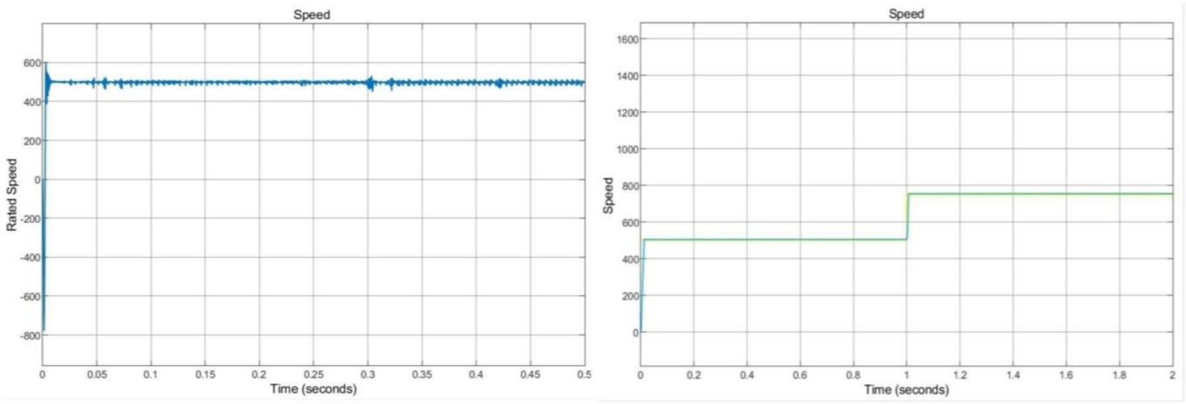

Figure 3 Output waveform of rated speed using field oriented control and Fuzzy logic control.

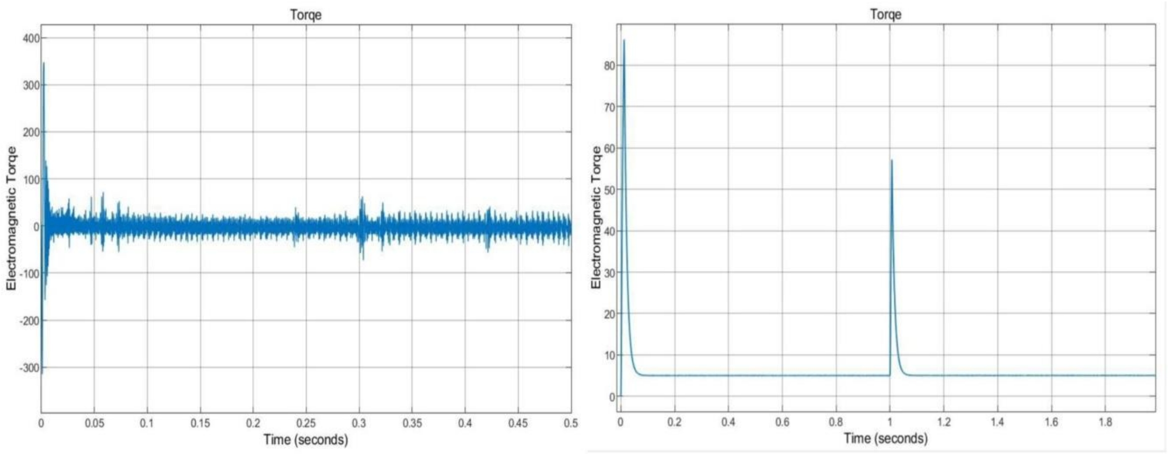

Figure 4 Output waveform of rated Torque using field oriented control and Fuzzy logic control.

PARAMETERS	VALUES
Weighting factor	1
Viscous friction	0.0004924 kgm/s^2
Stator Resistance	0.0485 ohm
Rated current	11.36A
Rated speed	500 rpm
Rated torque	1.432 Nm
q-axis inductance	0.02H
PM motor Flux	0.088Wb
Number of Pole Pairs	4
d-axis inductance	0.012H

Table 1 Specifications of motor.

Parameters	FOC	FOC using FUZZY logic
Steady State Comparison	2.7 sec	2.1 sec

Table 2 Comparison for steady state performance of PMSM motor.

Constraints	FOC	FOC using FUZZY logic
Settling Time (sec)	0.21	0.16
Rising time (sec)	0.040	0.016

Table 3 Comparison for transient response of PMSM motor.

Parameters	FOC	FOC using FUZZY logic
Torque Ripple (Nm)	0.58	0.49

Table 4 Comparison for torque ripple.

V. CONCLUSION

The project concludes the field oriented control of permanent magnet synchronous motor by using fuzzy logic control. The learning factors of fuzzy logic are speed and torque have been improved with better and high performance and greater efficiency compared with using only PI controller. Fuzzy speed controller is used to achieve closed loop operation by exchanging the speed regulator with a conventional PID and fuzzy controller this helps in reduction of torque ripple which will reduce the noise of motor while running. This type of motors are not only used in electrical vehicle which also can be used in various industrial applications and some house hold appliances and efficiency also is in higher terms.

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