# MODELLING OF PMSM REPORT

*Name: Mostafa Mohamed Mostafa Saleh*

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## 1. Abstract

This report focuses on modeling a Permanent Magnet Synchronous Motor (PMSM) using MATLAB. Our goal is to understand the motor's behavior through mathematical modeling and simulation. We employ MATLAB's capabilities to create a PMSM model, covering both its electrical and mechanical aspects.

The methodology involves developing the motor's equations and using transformation techniques like Clarke and Park transformations. MATLAB's power enables us to convert these equations into a functional model.

Simulation results provide insights into how the PMSM starts up and performs under steady conditions and help us to control the motor and try different control techniques.

## 2. PMSM Overview

The Permanent Magnet Synchronous Motor (PMSM) stands as a pivotal technology in the realm of electric motors. Characterized by its efficiency, precise control, and high-power density, the PMSM finds applications in various industries, including electric vehicles, robotics, and industrial automation.

At its core, the PMSM operates based on the interaction between the stator's rotating magnetic field and the permanent magnets embedded in the rotor. This arrangement eliminates the need for field windings in the rotor, enhancing the motor's efficiency and reducing its maintenance requirements.

The PMSM's operation is characterized by synchronous rotation between the stator and rotor magnetic fields, ensuring optimal alignment and minimal energy losses. This synchronous behavior enables precise control of speed, torque, and position, making the PMSM a prime choice for applications demanding high accuracy and dynamic performance.

In contrast to other motor types, the PMSM's simple mechanical structure and direct linkage between the rotor and load contribute to its reliability and reduced mechanical losses. Furthermore, advancements in motor drive technology and control algorithms have propelled the PMSM's performance, enabling efficient utilization of power and enhanced controllability.

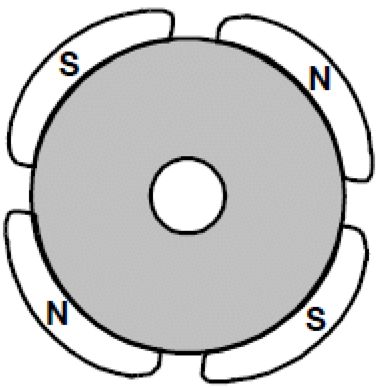
There are two main types of Permanent Magnet Synchronous Motors (PMSMs): Interior Permanent Magnet (IPM) and Surface Mounted Permanent Magnet (SMPM). These two types differ in the arrangement and location of the permanent magnets in the motor's rotor.

1. Interior Permanent Magnet (IPM) PMSM:

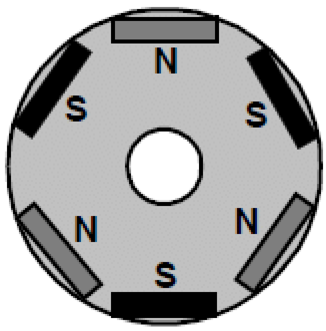
In an IPM, the permanent magnets are embedded within the rotor core, closer to the center of the rotor. The rotor's magnetic field interacts with the stator's winding, producing torque. This design provides several advantages, including increased efficiency, improved power density, and enhanced control over torque and flux. IPM PMSMs are particularly suitable for high-performance applications that require precise control over a wide range of operating conditions, such as electric vehicles and industrial automation.

2. Surface Mounted Permanent Magnet (SMPM) PMSM:

In an SMPM, the permanent magnets are mounted on the surface of the rotor, facing outward. The magnets' magnetic field interacts with the stator's winding, generating torque. SMPM PMSMs are simpler in construction compared to IPM PMSMs, and they often have lower manufacturing costs. However, SMPM PMSMs may exhibit slightly lower efficiency and control capabilities compared to IPM designs. These motors are commonly used in applications where cost-effectiveness is a priority, such as household appliances and certain industrial applications.




*Surface Mounted PMSM*




*Interior PMSM*

## 3. Modeling Methodology

In the modeling of Permanent Magnet Synchronous Motors, the Clarke and Park transformations are essential mathematical tools that simplify the equations governing the motor's behavior. These transformations are particularly useful in converting the three-phase stator currents and voltages into a two-coordinate reference frame, simplifying the analysis and control of the motor.

- Clarke Transformation

The Clarke transformation, also known as the α-β transformation, is applied to the three-phase stator currents. It transforms these currents from the phase domain (a, b, c) to a two-dimensional orthogonal reference frame (α, β)

$$\underbrace{\begin{bmatrix} X_\alpha \\ X_\beta \end{bmatrix}}_{X_{\alpha\beta}} = \underbrace{\frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}}_{T_{ABC\to\alpha\beta}} \underbrace{\begin{bmatrix} X_A \\ X_B \\ X_C \end{bmatrix}}_{X_{ABC}}$$

*Clarke Transformation*

- Park Transformation

The Park transformation, also referred to as the dq transformation. It rotates the α-β coordinates by an angle that corresponds to the rotor position. As a result, the transformed dq frame aligns with the rotor's magnetic axis, simplifying the analysis of the motor's magnetic field. This transformation is especially beneficial for analyzing the interactions between the rotor and stator and for control purposes.

$$\begin{bmatrix} X_\alpha \\ X_\beta \end{bmatrix} = \underbrace{\begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix}}_{T_{dq\to\alpha\beta}} \begin{bmatrix} X_d \\ X_q \end{bmatrix}$$

*Park Transformation*

By applying the Clarke and Park transformations, the complex three-phase motor equations are simplified into two orthogonal coordinates that align with the motor's magnetic field.

**Mathematical Model for IPMSM**

$$V_d = R_s i_d + L_d \frac{di_d}{dt} - \omega L_q i_q$$

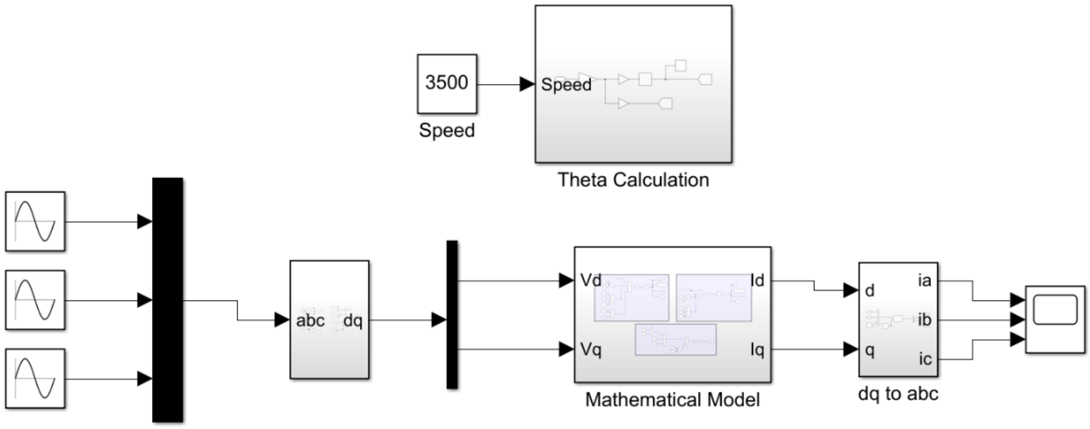
$$V_q = R_s i_q + L_q \frac{di_q}{dt} + \omega L_d i_d + \omega \psi_{PM}$$

$$T_{dev} = \frac{3}{2} P((L_d - L_q) i_d i_q + \psi_{PM} i_q)$$

$$\theta = \int \omega \, dt$$

The provided equation allows us to calculate the id and $i_q$ values for the model, given that the model's inputs are the speed and voltage in the dq reference frame. This equation helps establish how $i_d$ and $i_q$ relate to these inputs, aiding in understanding the motor's behavior.

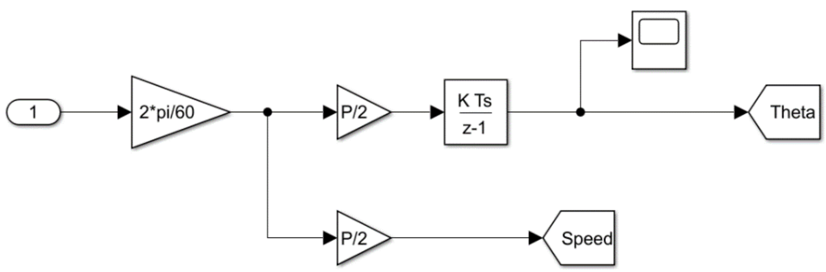
## 4. MATLAB Implementation



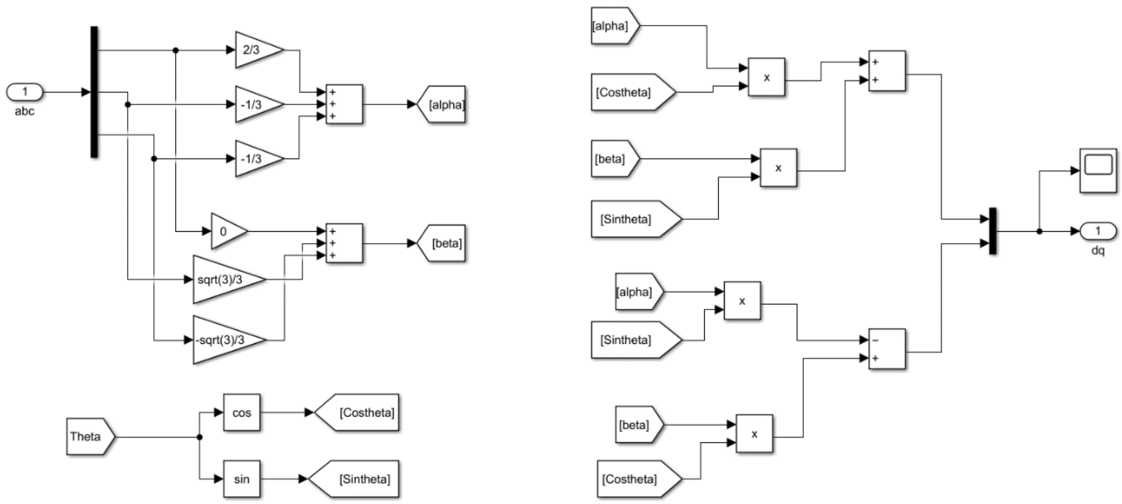

Initially, a three-phase voltage is introduced with an amplitude of (220*sqrt (2)/sqrt (3)), and the phases are shifted by 120 degrees between each other. Subsequently, the calculation of the electrical angle (θ) is performed to determine the specific theta value corresponding to the motor's speed. This calculated angle is then utilized to execute a coordinate transformation from the abc reference frame to the dq reference frame using the Clarke and Park transformations.

The mathematical model, which includes the equation describing the PMSM motor, is used after obtaining the dq reference frame. This model makes it possible to derive the generated motor torque as well as the $i_d$ and $i_q$ current components. Then the $i_d$ and $i_q$ components are converted back to the abc reference frame to obtain the corresponding iabc current components for the motor, alongside the motor's torque value.

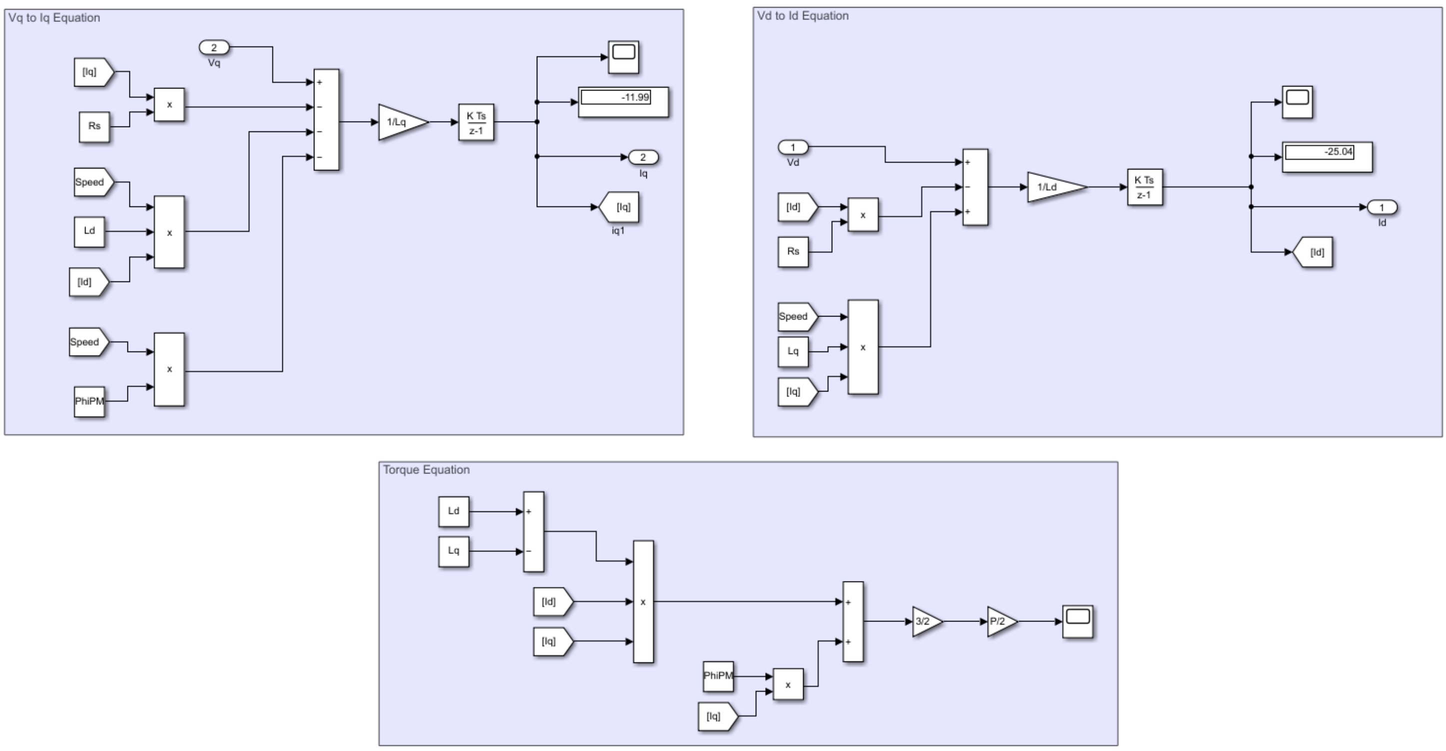
- Theta calculation



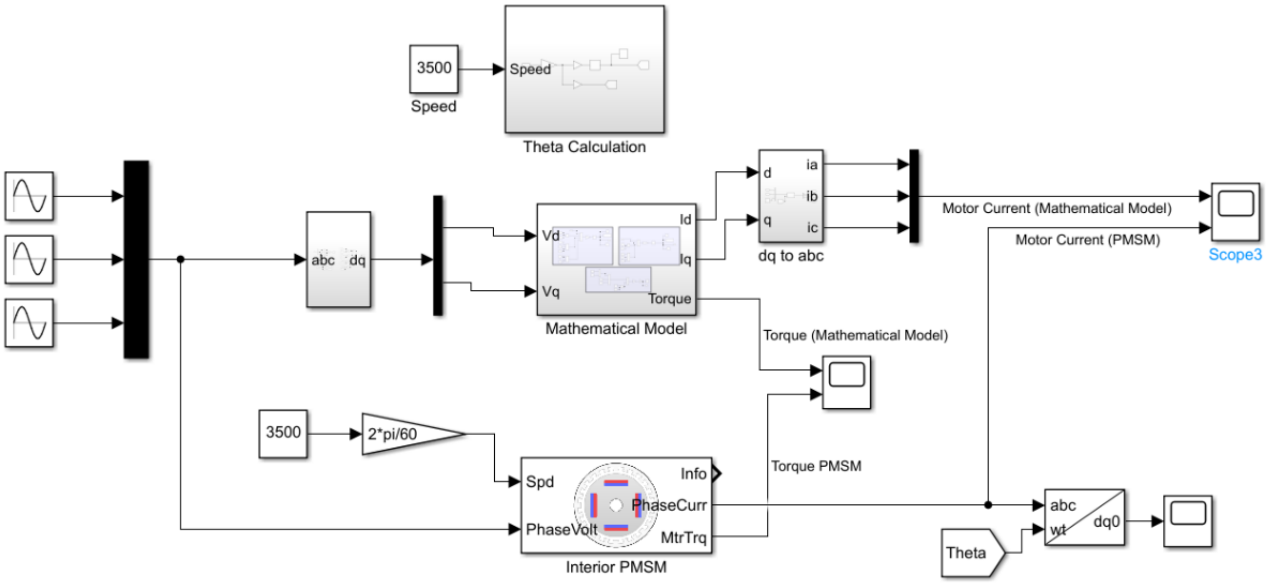
- Abc frame to dq frame



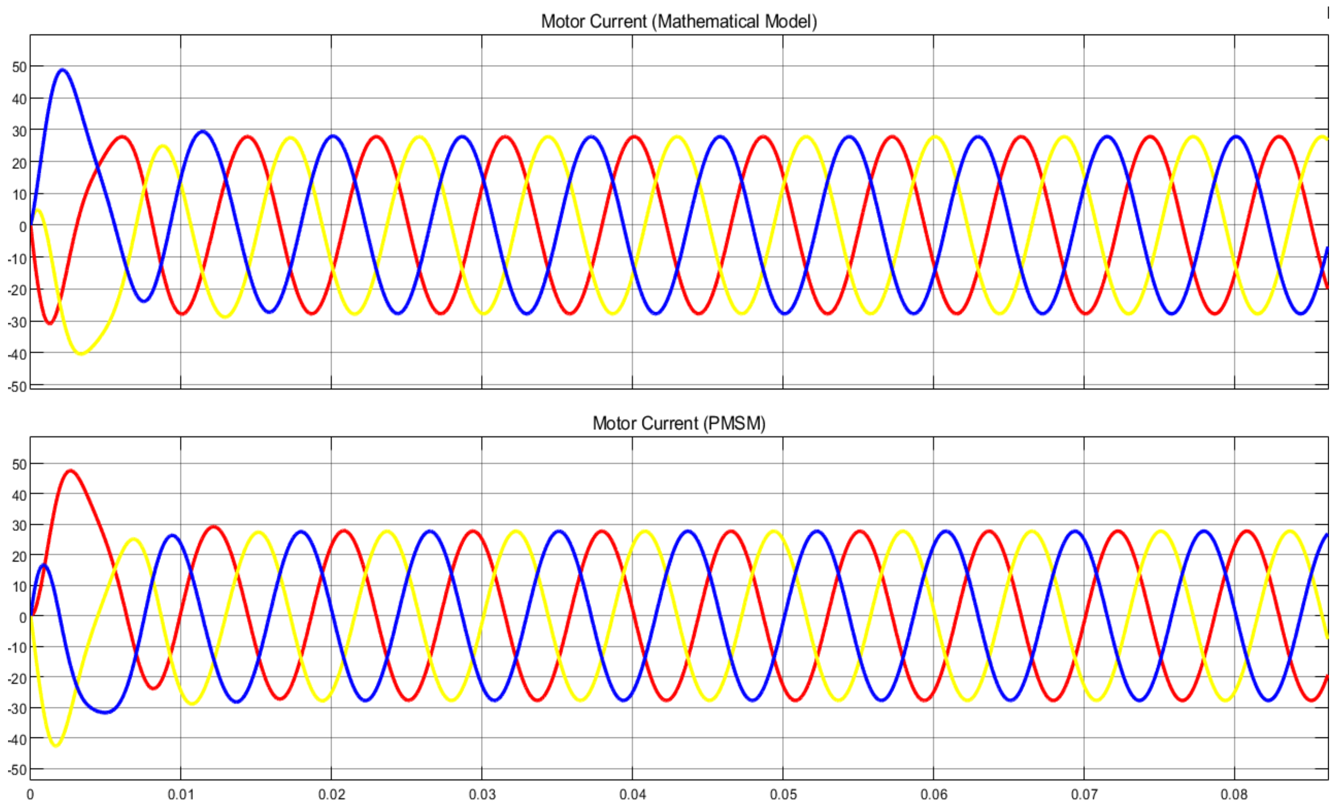

- Mathematical Model



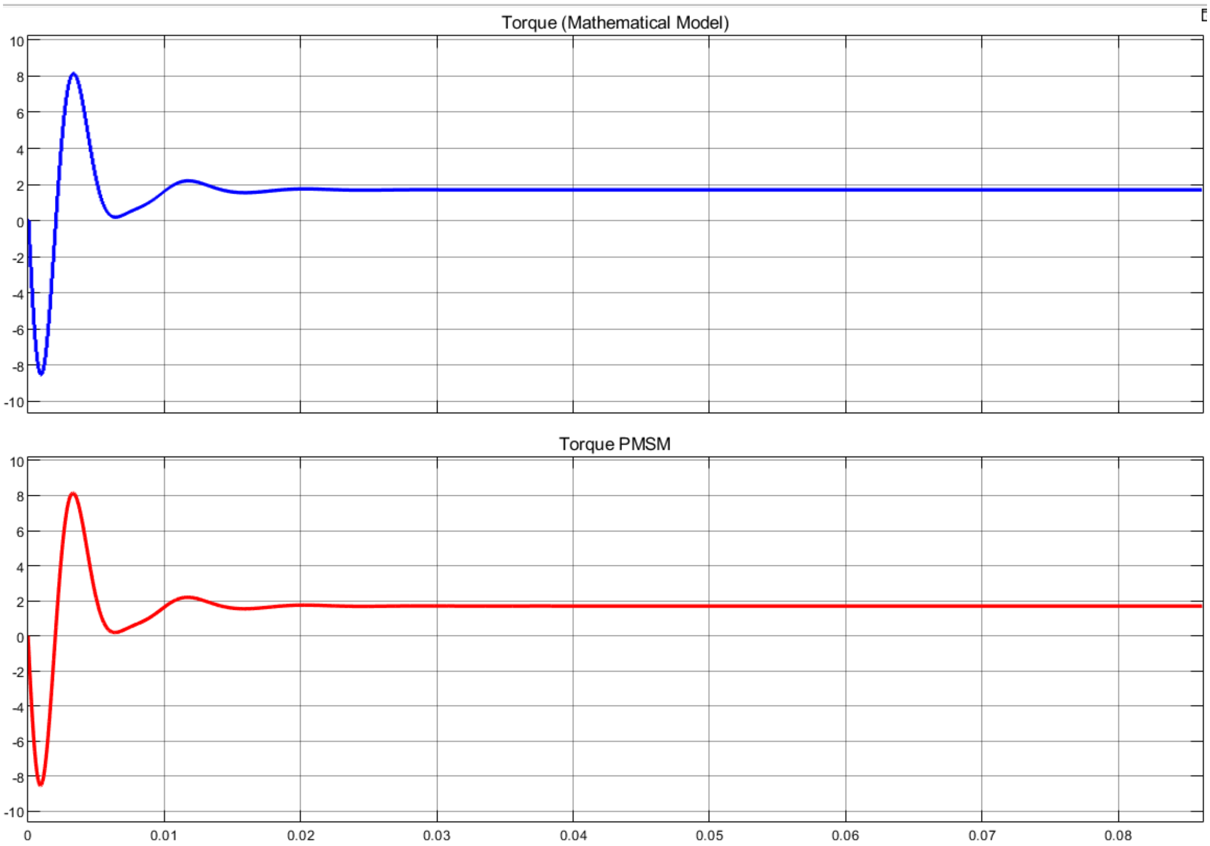
- IPMSM from MATLAB to compare the results.



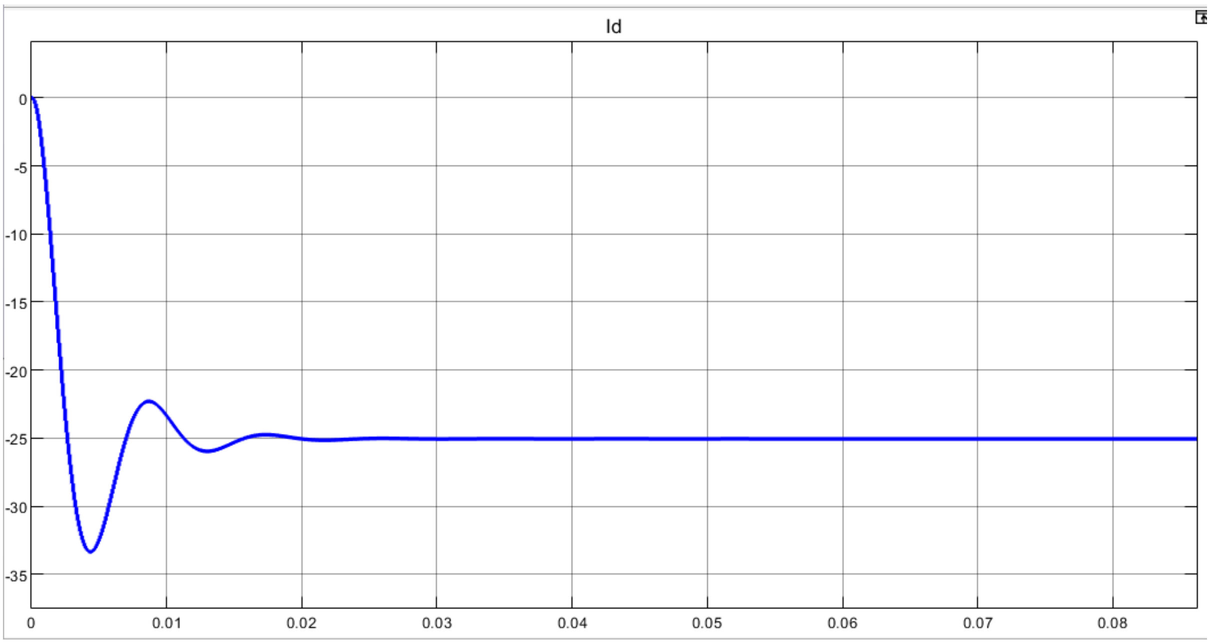

## 5. Simulation Results



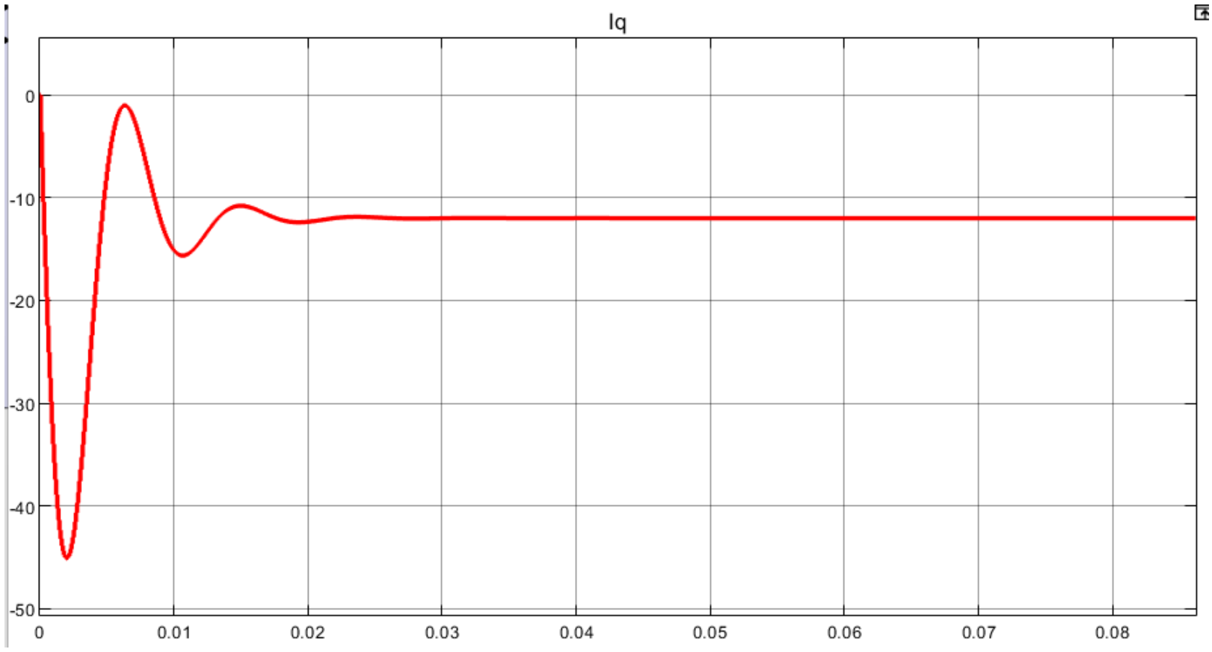

*Motor Current*




*Motor Torque*




*Id Current*




*Iq Currrent*

## 6. Conclusion

This report achieved its goals of comprehending, modeling. Through MATLAB and transformation techniques, we simplified complex equations, enabling insights into motor dynamics.

IPMS has magnets within the rotor core, boosting torque efficiency. SMPMSM has external magnets, potentially leading to slightly lower torque efficiency. The choice depends on required torque performance, efficiency, and application demands.

The established mathematical model can be applied to explore control techniques like Field-Oriented Control (FOC) on the motor. By implementing FOC and observing its impact on performance and dynamics, we can assess its effectiveness in regulating speed, torque, and overall operation.

Due to the absence of inertia and friction values required for implementing the swing equation, the model is incomplete. Therefore, I have developed only the electrical model.