

# Simulation of Measurement of Synchronous Motor parameters using SPWM

Shivaprasad I Badami<sup>1</sup>, Suresha C<sup>2</sup>, Kushal Basutkar<sup>3</sup>

<sup>1</sup>PG student, Department of Electrical & Electronics Engineering, RV College of Engineering, Bangaluru, Karnataka, India.

<sup>2</sup>Assistant Professor, Department of Electrical & Electronics Engineering, RV College of Engineering, Bangaluru, Karnataka, India.

<sup>3</sup>Senior Architect, Drive Electronics, Robert Bosch Engineering and Business Solutions Ltd, Bangaluru, Karnataka, India.

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**Abstract** - In this paper, a method is proposed in order to measure various Synchronous Motor parameters like Stator Resistance, phase and line voltages, phase and line currents and Stator inductance in direct and quadrature axis. Permanent Magnet Synchronous Motor (PMSM) is a type of Synchronous Motor on which the method is applied and results are analyzed. The method is applicable for all types Synchronous Motors. A SIMULINK/MATLAB model of PMSM is generated on which the method is applied and results are analyzed.

**Key Words:** Permanent Magnet Synchronous Motor, Electrical parameters, Motor parameters and Sinusoidal Pulse width Modulation technique.

## 1. INTRODUCTION

Nowadays new motors are invented. So, a common system is necessary in order to measure various Motor parameters. Control techniques like Field Oriented Control (FOC) requires measurement of Motor parameters precisely. The method discussed is used to measure various Motor parameters like phase and line voltages, stator resistance and stator Inductance in direct and quadrature axis. A SIMULINK/MATLAB model of PMSM generated, on which discussed method is employed and results are analyzed.

In [1], paper discusses on high degree of automation, direct display and very high accuracy measurement. The system overcomes the traditional PMSM measurement. LabVIEW is used to measure various motor parameters of PMSM. Voltages are injected in q and d axis of test board. The results are sent to LabVIEW for analyses and various motor parameters of PMSM are measured.

In [2], A sensor-less field oriented control scheme is used to measure various motor parameters of PMSM. Linear Active Disturbance Rejection Controller-Based

Sensor-less control scheme is employed for the purpose. The conventional method has two problems mainly phase delay and speed fluctuation. The proposed method is used to overcome the problem. The method utilizes liner state observer, to estimated back emf of PMSM without switching function and propositional current controller The proposed linear active disturbance rejection controller based sensor-less field Oriented Controller scheme is validated by both simulation and experimental results for a 275-W salient-pole PMSM drive in which the permanent-magnet synchronous is similar to the traction motor used in Toyota Prius hybrid electric vehicles at a reduced scale

In [3], various PMSM motor parameters are calculated using a 16 bit Microcontroller. Conventional method of calculation of PMSM motor parameters using RLC meter is avoided as it gives less accurate results. The method can be used for both surface-type as well as interior-type of PMSM. The method integrates into open-loop startup procedure of sensor-less control drives.

In [4], the results of this paper show the effectiveness of the paper. This paper presents a new procedure for electrical parameter measurement of PMSM based on its voltage equation taking account of all losses such as copper loss, stator loss, mechanical loss, and stray loss. This method is simple and does not need complex theory and special equipments.

In [5], a novel calculation method for the incremental inductance of motor winding is adopted, and a data processing technique is presented. Nonlinear incremental inductance of the motor winding was tested with the dynamic hysteresis loop method. The validity of the parameters FEM simulation results was confirmed by the measuring method. Accordingly, a mathematical model of nonlinear incremental inductance of SPMSM was built which provides a

practical gist to determine uncertainty range of inductance parameter.

In [6]. Electrical parameters investigation of a surface Permanent Magnets Synchronous Motor (PMSM). Several methods have been using for the resistance and inductance measurement. Unfortunately, the standard techniques do not always allow the estimation of the inductances saturation curves and therefore the new approaches are shown in the paper.

## 2. METHODOLOGY

Sinusoidal Pulse width Modulation technique is used to generate gate pulse for MOSFETS of B6 Bridge Inverter. An input of 12V is given as to Inverter and output voltage of 12V (24V peak to peak) is obtained. A PMSM model is generated in order to measure Stator Inductance in direct and quadrature axis.

### 2.1 SPWM

SPWM stands for Sinusoidal Pulse Width Modulation. It is a technique generally used to generate gate pulses to MOSFETS of B6 Bridge Inverter. Unipolar SPWM is used to generate the triggering pulses. Sinusoidal wave of 50Hz is chosen as reference wave. Triangular wave of 16 KHz is chosen as carrier signal.

### 2.2 B6 Inverter

Inverter is a device that converts input dc into ac signal. B6 Bridge Inverter has 6 MOSFETS, triggered by gate pulses. Input voltage level to B6 inverter varies as per the application [2]. In this system input to B6 Inverter is 12V.

B6 Inverter can operate in two modes:

- 120 degree conduction mode
- 180 degree conduction mode

In 180 degree conduction mode three switches operate at a time. Conduction time of each switch is 60 degree [2]. In 120 degree conduction mode only two switches operate at a time. Conduction angle of each switch is 120 degree. In this system B6 Bridge Inverter with 120 degree conduction is considered [5]. Output line voltages of B6 Bridge Inverter are given to PMSM motor, in order to measure the various Motor Parameters of PMSM.

### 2.3 PMSM

PMSM stands for Permanent Magnet Synchronous Motor. PMSM is one of type of Synchronous Motor generally used as drive for various applications [2]. The method developed to measure various Motor Parameters and control using ECU is suitable for all

types of Synchronous Machines [3]. PMSM is considered to illustrate the method employed. PMSM model is generated in MATLAB for analysis of method employed. The construction of PMSM is such that the stator is made up of three phase windings and rotor is made up of Permanent Magnets [3].

Various types of PMSM are:

- Radial field
- Axial field

In radial field, the flux direction is along the radius of machine. In axial field the flux direction is parallel to Motor Shaft [2]. Radial field PMSM is generally preferred compared to axial type of PMSM. Here, Radial type of PMSM is used for illustration of method employed to measure various Motor Parameters of Synchronous Motor and to control using ECU.

Three phase input is given from B6 Bridge Inverter and the motor is made to rotate. The stator resistance is measured using single phasing and blocked rotor condition [2]. An algorithm is generated in order to achieve this effectively. Other motor parameters like Inductance in D and Q axis is measured by solving the set of equations, from inputs that are taken when the motor is made to run under normal condition [1].

Various advantages of PMSM over conventional Synchronous Machine are:

- PMSM are more efficient
- PMSM can be controlled precisely
- PMSM can be used as Variable Frequency Drives (VFD) etc.

Various applications of PMSM are:

- Used in Electric Vehicles
- Robotics
- Automation
- Industrial Drives etc

### 2.4 Measurement of Motor Parameters

Resistance of Stator winding should be measured in order to calculate various other Motor parameters. Motor is made to run under single phasing and blocked rotor condition in order to find the stator resistance, constant dc voltage of 0.6V is supplied and half of the ratio of output voltage across winding and current through them gives stator resistance.

$$\text{Stator Resistance} = \frac{V_o}{I_o} = 0.1\text{ohm} \quad (2.1)$$

The measured voltages and currents in abc plane is converted into D and Q plane by set of equations listed below:

$$I_d = \frac{2}{3} \times (\sin(\theta) I_a + \sin(\theta - \frac{2\pi}{3}) I_b + \sin(\theta + \frac{2\pi}{3}) I_c) \quad (2.2)$$

$$I_q = \frac{2}{3} \times (\cos(\theta) I_a + \cos(\theta - \frac{2\pi}{3}) I_b + \cos(\theta + \frac{2\pi}{3}) I_c) \quad (2.3)$$

$$I_o = \frac{1}{3} \times (I_a + I_b + I_c) \quad (2.4)$$

$$V_d = \frac{2}{3} \times (\sin(\theta) V_a + \sin(\theta - \frac{2\pi}{3}) V_b + \sin(\theta + \frac{2\pi}{3}) V_c) \quad (2.5)$$

$$V_q = \frac{2}{3} \times (\cos(\theta) V_a + \cos(\theta - \frac{2\pi}{3}) V_b + \cos(\theta + \frac{2\pi}{3}) V_c) \quad (2.6)$$

$$V_o = \frac{1}{3} \times (V_a + V_b + V_c) \quad (2.7)$$

Where,

V<sub>a</sub> = Voltage measured across a phase

V<sub>b</sub> = Voltage measured across b phase

V<sub>c</sub> = Voltage measured across c phase

V<sub>d</sub> = Voltage in D axis

V<sub>q</sub> = Voltage in Q axis

V<sub>o</sub> = Voltage in 0 axis

I<sub>a</sub> = Current measured through a phase

I<sub>b</sub> = Current measured through b phase

I<sub>c</sub> = Current measured through c phase

I<sub>d</sub> = Current in D axis

I<sub>q</sub> = Current in Q axis

I<sub>o</sub> = Current in 0 axis

Inductance of PMSM calculated by solving a system of equations listed below:

$$V_d = I_d \times R_{ph} + L_d \times \frac{dI_d}{dt} - L_q \times I_q \times 2\pi \times f \quad (2.8)$$

Since, during steady state the rate of change of current in D axis is zero

$$V_d = I_d \times R_{ph} - L_q \times I_q \times 2\pi \times f \quad \text{and} \quad (2.9)$$

$$V_q = I_d \times R_{ph} + L_q \times \frac{dI_q}{dt} + L_d \times I_d \times 2\pi \times f \quad (2.10)$$

Since, during steady state the rate of change of current in Q axis is zero

$$V_q = I_d \times R_{ph} + L_d \times I_d \times 2\pi \times f \quad (2.11)$$

Where,

V<sub>d</sub> = Stator voltage in D axis

V<sub>q</sub> = Stator voltage in Q axis

R<sub>ph</sub> = Resistance of stator winding per phase quantity

L<sub>d</sub> = Stator Inductance in D axis

L<sub>q</sub> = Stator Inductance in Q axis

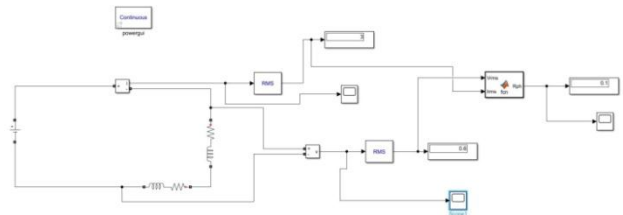
f = Operating frequency = 50Hz

The above equations are solved to get stator Inductance in D and Q axis.

### 3. SIMULATION AND RESULTS

#### 3.1 Simulation of Measurement of Stator resistance of PMSM

The simulation circuit of Measurement of Stator Rotor Resistance of is simulated as shown in Fig 1.



**Fig-1:** Simulation Circuit of Measurement of Stator Resistance

An input of 0.6V is supplied to PMSM under single phasing and Blocked rotor condition. During this condition the half of ratio of rms value of voltage and current gives per phase resistance. Measurement of Stator Resistance is essential in order to calculate the other motor parameters.

The voltage measured using MATLAB are shown in Fig 2.



**Fig-2:** Voltage measurement of Measurement of Stator Resistance

The current measured using MATLAB are shown in Fig 3, which is used for calculation of resistance of stator winding.



**Fig-3:** Current measurement of Measurement of Stator Resistance

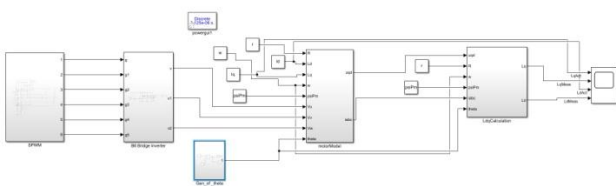
The resistance measured using MATLAB are shown in Fig 4, which is used to control PMSM.



**Fig-4:** Resistance measurement of Measurement of Stator Resistance

### 3.2 Measurement of various PMSM parameters

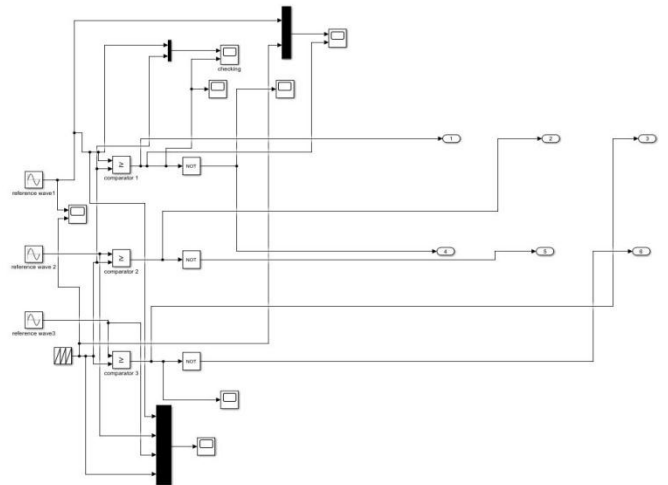
In order to control PMSM, we need to measure the inductance in direct and quadrature axis. The Fig 5 shown below is a block diagram of measurement of various parameters of PMSM.



**Fig-5:** Model showing Measurement of various PMSM parameters

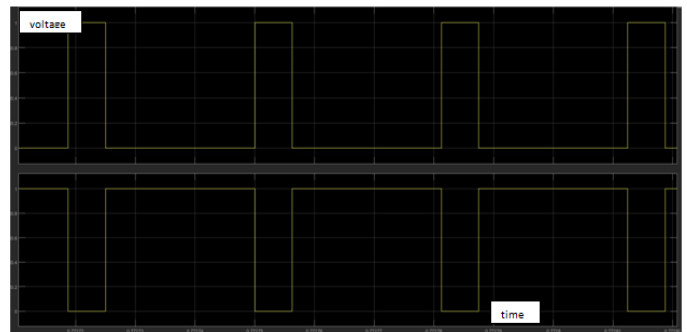
### 3.3 SPWM

SPWM block is used to generate pulses to trigger the MOSFETs of B6 Inverter Bridge. SPWM technique is well known technique where reference wave is compared with triangular wave in order to generate pulses to trigger MOSFETs. Reference wave is a sinusoidal wave of 50Hz, and carrier wave is a triangular wave of 16 KHz. The Fig 6, shows the MATLAB model for generation of gate signals for B6 bridge Inverter.



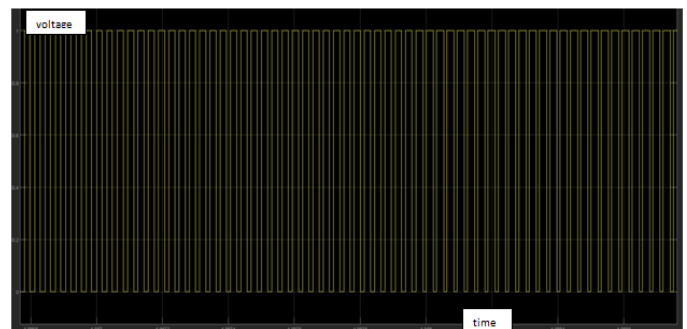
**Fig-6:** Model showing SIMULINK block of SPWM

Fig 7, shows the voltage supplied to MOSFETs Q1 and Q4 in order to trigger them. It can be observed that the voltages are in anti phase to each other.



**Fig-7:** Voltage waveforms to trigger MOSFETs Q1 and Q4 respectively

Fig 8, shows the output voltage of SPWM used to trigger MOSFETs of B6 bridge Inverter.



**Fig-8:** Output waveforms of SPWM used to trigger MOSFETs

### 3.4 B6 Bridge Inverter

B6 Bridge Inverter is a device used to convert input dc signal to ac signal. 12V is given to Inverter as an input and an output of +12V and -12V is obtained [3]. Various output wave forms of B6 Bridge Inverter as shown

below. Fig 9, depicts the MATLAB model used to implement B6 Bridge Inverter

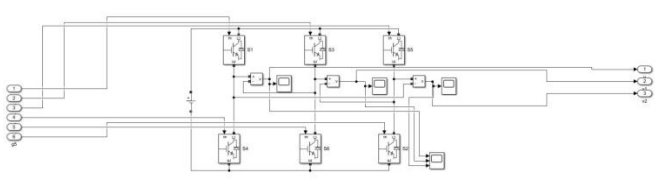


Fig-9: Model showing B6 Bridge Inverter

Fig 10, shows the output voltage of B6 Bridge Inverter given to phase a of PMSM.

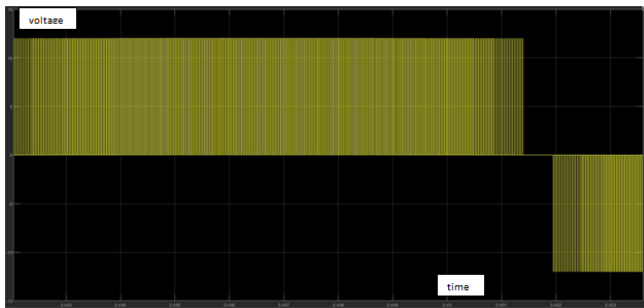


Fig-10: Output voltage waveform at phase a

Fig 11, shows the output voltage of B6 Bridge Inverter given to phase b of PMSM.

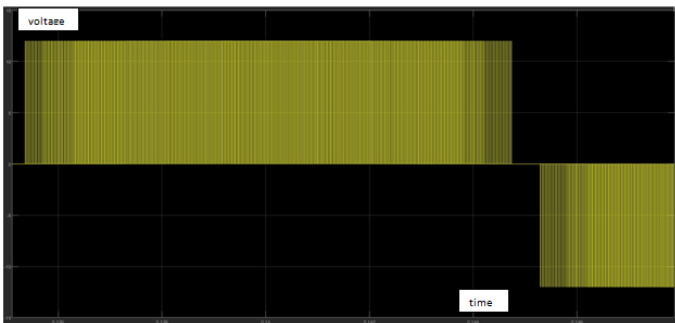


Fig-11: Output voltage waveform at phase b

Fig 12, shows the output voltage of B6 Bridge Inverter given to phase c of PMSM.

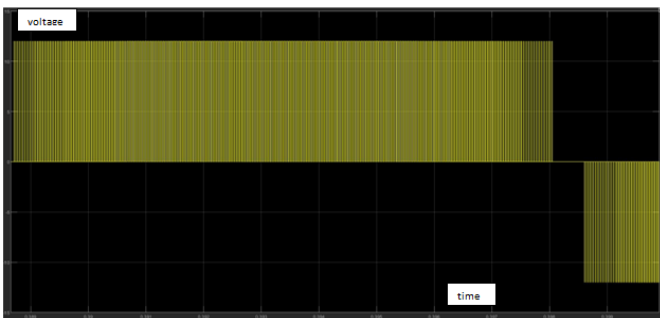


Fig-12: Output voltage waveform at phase c

Fig 13, shows the output voltage of B6 Bridge Inverter given windings of PMSM, with phase shift of 120 degree.

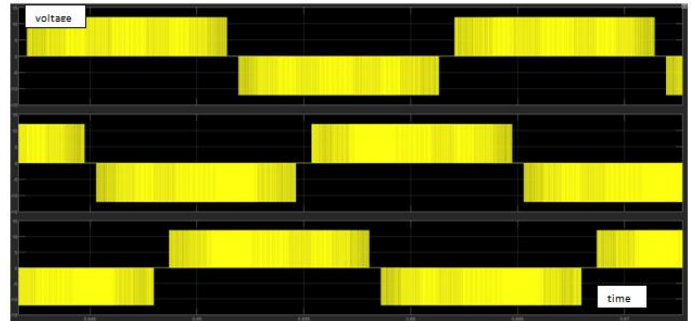


Fig-13: Output Voltage of B6 Bridge Inverter

### 3.5 PMSM

PMSM stands for Permanent Magnet Synchronous Machine. Generated algorithm which is common for all type of Synchronous Machine is tested on PMSM. A MATLAB model is generated as shown in Fig 14.

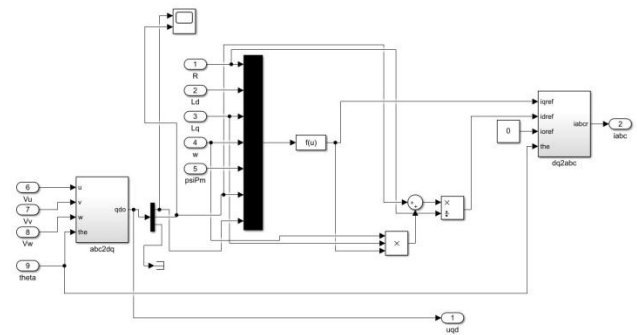


Fig-14: MATLAB Model of PMSM

Fig 15, shows the conversion of measured parameters from abc to dq0 domain, used in measurement of various motor parameters.

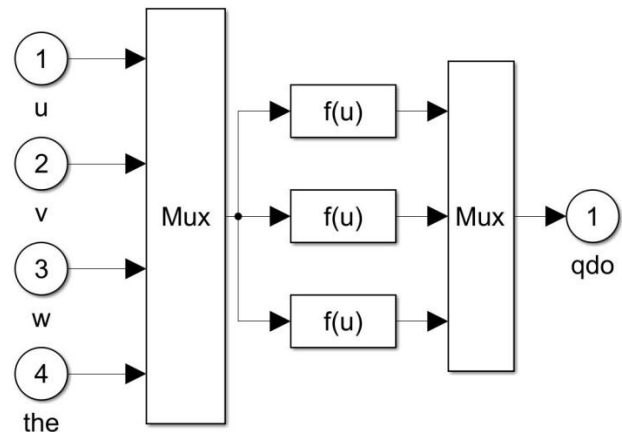


Fig-15: MATLAB Model of conversion of abc in dq0 domain



Fig 5.16 shows the conversion of measured parameters from dq0 to abc domain, used in measurement of various motor parameters.

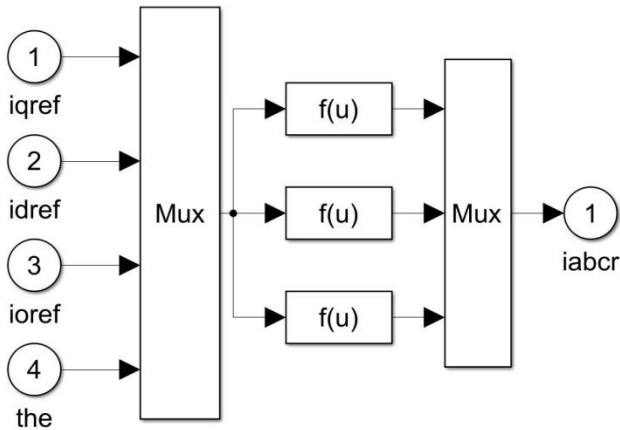


Fig-16: MATLAB Model of conversion of abc to dq0 domain

Fig 17, shows MATLAB model used to generate theta, which varies from 0 to two pi.

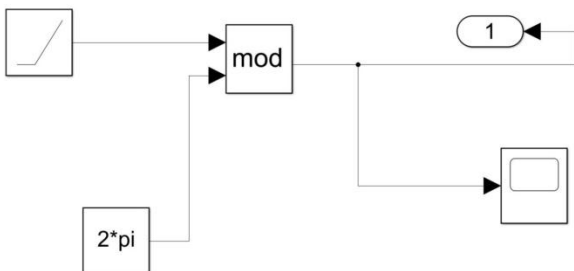


Fig-17: MATLAB Model of generation of angle theta

Fig 18, shows the output waveform of generated angle theta that varies from 0 to two pi. It is measured in radians.

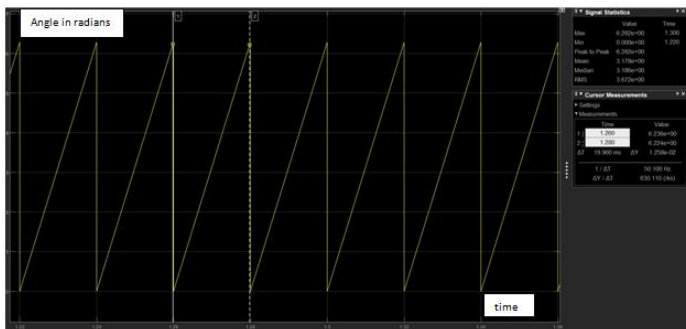


Fig-18: Waveform of angle theta with time

### 3.6 Measurement of Ld and Lq

A model is generated to measure stator Inductance in D and Q axis. A set of linear equations are solved in order to get Inductance of stator. Fig 19, shows the MATLAB

model used to solve a pair of linear equations in order to get Stator Inductance in D and Q axis.

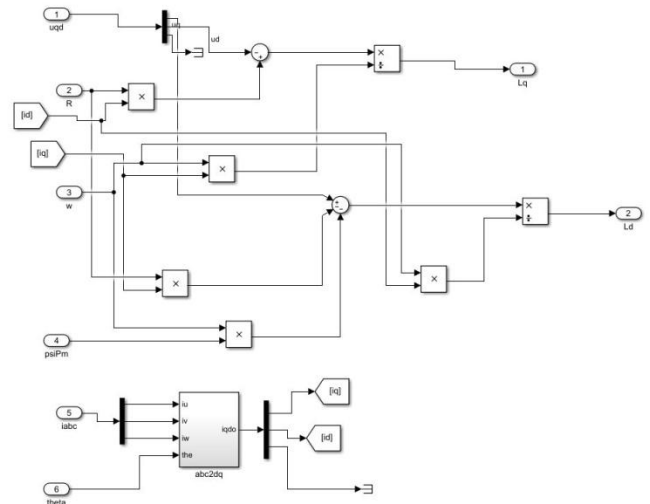


Fig-19: MATLAB Model of measurement of Ld and Lq of PMSM

Fig 20, shows MATLAB model used to convert measured values from abc to dq0 domain.

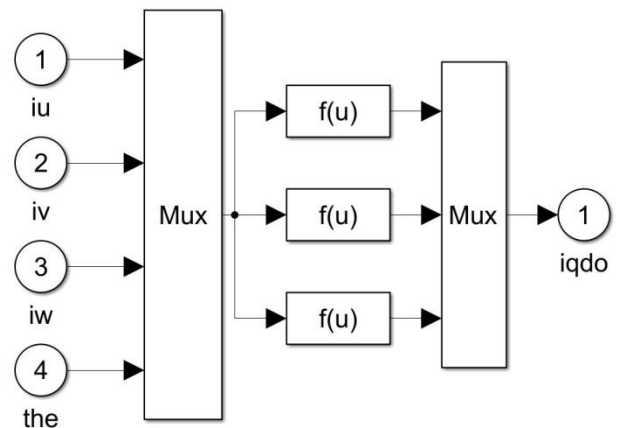


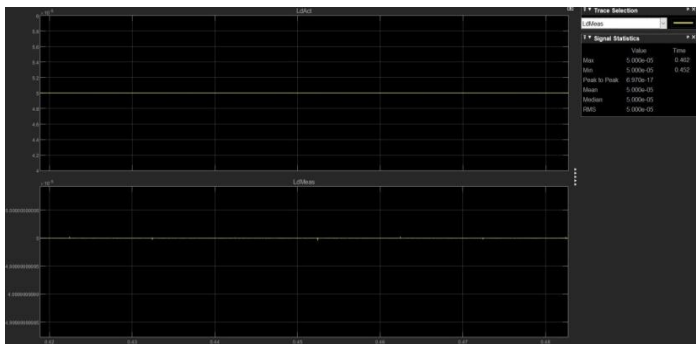
Fig-20: MATLAB Model of conversion of abc to dq0 domain

Fig 21, shows the waveforms of measured and actual Inductance in Q axis of PMSM.



Fig-21: Measurement of actual and measured Inductance in Q axis

Fig 22, shows the waveforms of measured and actual Inductance in D axis of PMSM.



**Fig-22:** Measurement of actual and measured Inductance in D axis

The actual quadrature axis inductance of PMSM was found as 0.7uH and measured actual inductance was found around 0.7uH, with the accuracy greater than 0.1%.

The actual direct axis inductance of PMSM was found as 0.5uH and measured actual inductance was found around 0.5uH, with the accuracy greater than 0.1%.

#### 4. CONCLUSIONS

A MATLAB model is generated in order to test the generated control algorithm. A separate model is implemented for measurement of Stator resistance and Stator Inductance of in D and Q axis effectively. A dc voltage of 0.6V is supplied to model Stator resistance measurement model and output is analyzed in order to get Stator resistance. Sinusoidal Pulse width Modulation technique is employed to calculate Stator Inductance in D and Q axis. Other Motor parameters can be estimated by analyzing the output of model that is generated. Sinusoidal voltage of 50Hz is used as Reference wave and a triangular wave of 16 KHz is used as carrier wave in order to develop the Sinusoidal PWM. B6 Bridge Inverter is used to supply voltage to PMSM and the various outputs are analyzed effectively. The accuracy of measured and actual direct and quadrature axis Inductance is greater than 0.1%.

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