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" PMS MOTOR CHARACTERISTICS PERFORMANCE SIMULATION VALIDATION THROUGH EXPERIMENTAL RESULTS"

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Abstract

This research presents the T-I (Torque-Current) performance characteristics of PMSM (Permanent Magnet Synchronous Motor), simulated validation by experimental results. PMSM is being studied because it has a sinusoidal back e.m.f., more complicated control, and low noise. To determine the performance of the PMSM, simulation using MATLAB Simulink and laboratory experimentation are crucial. Using hardware configuration for experimentation and a Digital Signal Processor (DSP-2812) advanced controller, PMSM drives are used to assess performance in a lab setting. Applications for automation, electric vehicles, and traction employ PMSM. The characteristics study of PMSM is crucial and required for all applications. In the MATLAB/Simulink environment, a simulation model for the PMSM is created using the proportional integral (PI) controller technique. Applications in industry frequently use PI controllers. PMSM experiments are carried out in a lab setting using load tests and a digital storage oscilloscope (DSO). Waveforms and test data are captured for use in simulation modelling and experimentation. Performance metrics for torque-current characteristics are plotted. Eventually, all findings from simulations and experiments are verified and presented. Both simulation and experimentation comparisons of the T-I characteristics of PMSM are very close to comparable.

Key Words PMSM, Simulation, PI, DSP, Experimentation

Introduction

Author introduced direct torque control (DTC) method incorporating Space Vector Pulse Width Modulated (SVPWM) inverter for speed control of PMSM drive [1]. Author proposed simplified speed control scheme using genetic algorithms, without current sensing with direct voltage control [2]. Author described for PMSM drive mathematical modeling, simulation and analysis of sinusoidal pulse width modulation (SPWM) using MATLAB/Simulink platform [3]. Author presented analysis and performance evaluation of an efficient power fed PMSM adjustable speed drive with steady state characteristics. The torque, phase current and fed power obtained by using finite element method are verified by experimental measurement [4]. Author suggested experimental method for determination of efficiency of PMSM. The utilization rate of PMSM is increased in industry applications [5]. Author presented improved model predictive torque control to reduce torque ripple for PMSM [6]. Author proposed hybrid dual mode control (HDMC) for PMSM drives. The effectiveness of HDMC is verified by experimental results [7]. Author introduced direct torque model predictive control approach in polyphase PMSM drive applications [8]. Author suggested performance analysis of PMSM drive using vector control technique and verified by simulation method in MATLAB/Simulink environment [9]. Author discussed dead beat direct torque and flux control method to determine the performance of PMSM. The performance aspects of electromagnetic torque and stator current ripple reduction are improved using the said method [10]. Author elaborated on neural network vector controller for PMSM drives to overcome drawbacks of conventional vector control methods [11]. Author adopted space vector pulse width modulation speed control strategy for PMSM [12]. Author explained direct torque control of PMSM using MATLAB/Simulink. The result obtained shows characteristics for torque and efficiency [13]. Author introduced digital signal processor based direct torque control method using space vector modulation for PMSM drives. The simulated and experimental result shows effectiveness of said method [14]. Author presented field oriented control for PMSM drive. A sinusoidal pulse width modulated PMSM drive system is modeled and simulated in MATLAB/Simulink environment [15].

PMSM has continuous stator flux position variation and sinusoidal back emf. Possible to have three phases ON at the same time, content no torque ripple at the commutation. Less harmonics due to sinusoidal stimulation, low core losses and high switching losses at same switching frequency. Control algorithms are mathematically intensive, more complex control (continuous 3 phase sine wave), higher maximum achievable speed and low noisy. The PMSM is same as synchronous machine, only change is permanent magnet is mounted on the rotor. The magnetic material Neodymium Iron Boron (NdFeB), which replaces electromagnet, is used in PMSM. The stator is star linked and its operation is based on the magnetic locking between stator and rotor. Rotor pole position must be known for magnetic locking. The issues (sparking at brushes, frequent maintenance and mechanical commutation) in DC machines are overcome in permanent magnet machines. Mechanical commutation is replaced by electronic commutation [16-20].

Permanent Magnet motors are classified into two types, on the basis of back emf waveforms: (i) Permanent Magnet Synchronous Motor (PMSM) -sinusoidal and (ii) Permanent Magnet Brushless DC (PMBLDC) Motor-trapezoidal. For proper operation of these motors require rotor position sensing, to maintain the synchronism between rotor position and to start & provide suitable commutation sequence to stator windings. Usually, to sense the rotor position three hall effect sensors are assembled on stator. The MATLAB simulation platform is used for closed loop speed control of permanent magnet synchronous motors. Consequently, motivation for various applications using the characteristics of PMS motor needs study. The signal from the Hall Effect sensor is supplied to the controller to produce gate pulses for the switches of the bridge converter, which is how the PMSM is driven. Any power electronic switch can be used in a bridge converter, but due to the high power application, MOSFET or IGBT switches are typically preferred. Controlling the PMSM is equivalent to controlling the converter's switching. The speed of PMSM is used as feedback, and the controller is provided with the difference between the actual value and the reference value in order to control the speed of PMSM [21-24].

The T-I (Torque-Current) characteristics of the PMS motor are the focus of this research because they are crucial for a variety of applications. For closed loop speed regulation of the PMS motor, MATLAB simulation performance is used. It uses the PI (Proportional Integral) control approach, which is frequently employed in industrial settings. Using an advanced DSP (2812) control approach, experimental performance measurements with a fully loaded PMS motor are explored. In this study, we employed a 4 pole PMSM to analyze the performance of the drive, employing a sophisticated DSP (2812) speed controller and an inverter fed SPWM approach to manage speed in closed loop operation under various loading situations.
The PMS motor is simulated using MATLAB simulink. The PI controller is used to reduce steady-state error, improve damping, increase rise time, and achieve stable operation. Research is carried out in the laboratory on the hardware configuration of a PMS motor drive, employing an advanced DSP control approach under various loading circumstances. For simulation and experimentation, test data and waveforms are recorded. The performances of torque-current characteristics are plotted. Ultimately, all experimental and simulation results are validated and presented. The work's originality has been demonstrated as follows, with more innovative and fresh work described. The PMS motor simulation is obtained using MATLAB/SIMULINK. PMSM is tested at full load, and torque and efficiency are determined based on experimental measurements. PMSM torque-current characteristics are compared in both simulation modelling and experimental are very close to comparable.

II Mathematical Modeling

The equivalent circuit for one phase of d-axis and q-axis of PMS motor is as shown in figure 1(a) & (b) respectively. Rs & Lls are resistance and inductance respectively connected in series along with ωrλq for d-axis & ωrλd for q-axis .The mathematical modeling of PMS motor for all equations are detailed below.

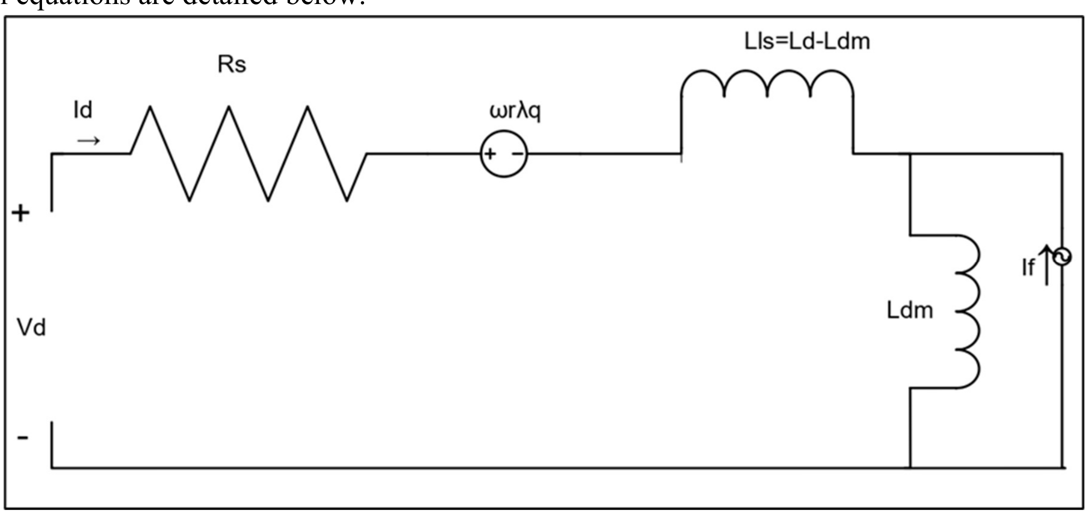

Figure 1(a). Equivalent circuit of PMSM d-axis

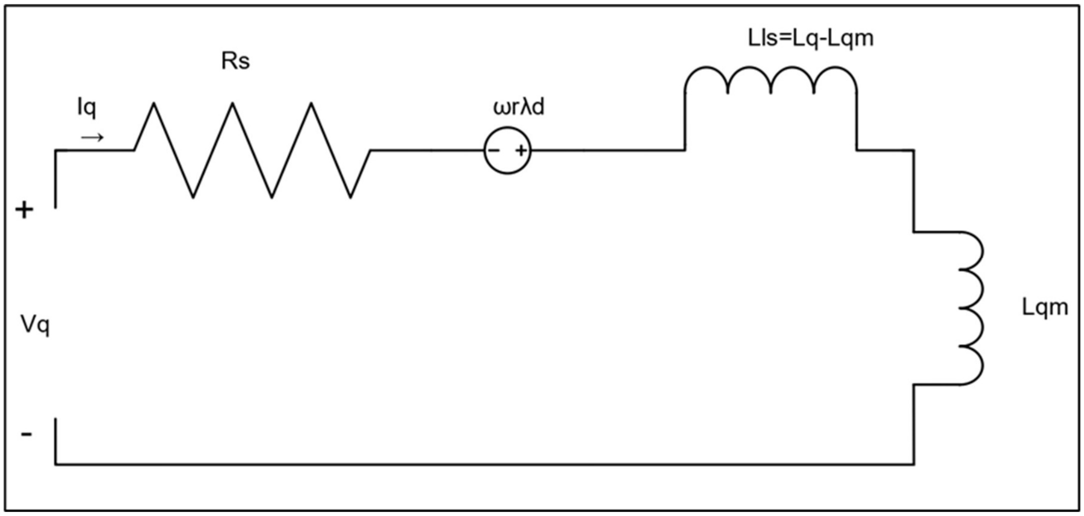

Figure 1(b). Equivalent circuit of PMSM q-axis

The voltage equations for d-axis and q-axis are,

$$Vd = Rsid - \omega r\lambda q + \rho\lambda d \quad (1)$$

$$Vq = Rsiq + \omega r\lambda d + \rho\lambda q \quad (2)$$

Where,

ρ is the differential operator i.e. d/dt.

Flux linkages are given by equations,

$$\lambda d = Ldid + \lambda f \quad (3)$$

$$\lambda q = Lqiq \quad (4)$$

Substituting (3) & (4) into equations (1) & (2), we get,

$$Vd = Rsid - \omega rLqiq + \rho(Ldid + \lambda f) \quad (5)$$

$$Vq = Rsiq + \omega r(Ldid + \lambda f) + \rho Lqiq \quad (6)$$

The electromagnetic torque of motor is,

$$Te = \frac{3}{2}\left(\frac{p}{2}\right)(\lambda diq - \lambda qid) \quad (7)$$

The mechanical torque equation is,

$$Tem = B\omega + Jm\frac{d\omega}{dt} + TL \quad (8)$$

Where,

Tem = Torque in Nm

ω = Rotor angular velocity in rad/sec.

B = Viscous friction in Nm/sec.

Jm = Moment of inertia in Kg- m^2.

TL = Load torque in Nm.

This is all about modeling of PMS motor [25-26].

III Simulation Modeling

Figure 2 depicts the MATLAB simulation model of the PMS motor that is used in the MATLAB Simulink environment. Inverter output to stator and switching methods are used to operate the PMSM in order to obtain sinusoidal back emf. Different torques are applied to the PMSM. To get rid of steady state error and boost performance up to a certain speed, utilize a PI controller. A predetermined speed of 2700 rpm is used to operate the PMSM drive. The load fluctuations (increased or lowered) cause a brief change in speed before returning to the original value of the specified speed. Once feedback is provided through the controller, speed error is decreased, and as a result of even better feedback, the PMSM is able to resume running at the 2700 rpm programmed speed. As a result, PI controller is crucial for managing PMSM speed and hence widely used in industry applications.

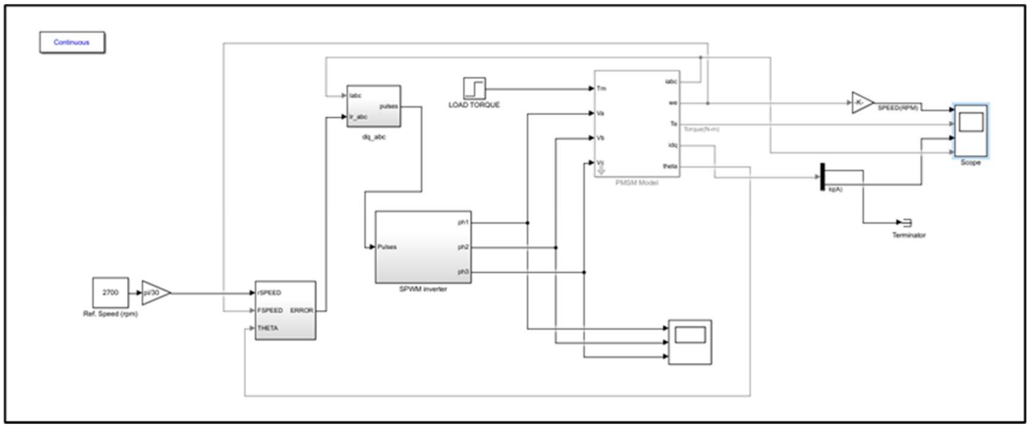

Figure 2. Simulation model of PMSM

Figure 3 depicts the simulation model results for speed control of a PMS motor drive using a PI controller. It plots the speed (N), stator current (Iabc & Iq), and electromagnetic torque (Te) of a PMS motor against time. Load torque is applied to the simulation model in steps of 0.5 Nm from 0 to 3.0 Nm. Kp = 10 and Ki = 2 are the PI controller parameters. The simulation's steady state response time is 0.038 second.

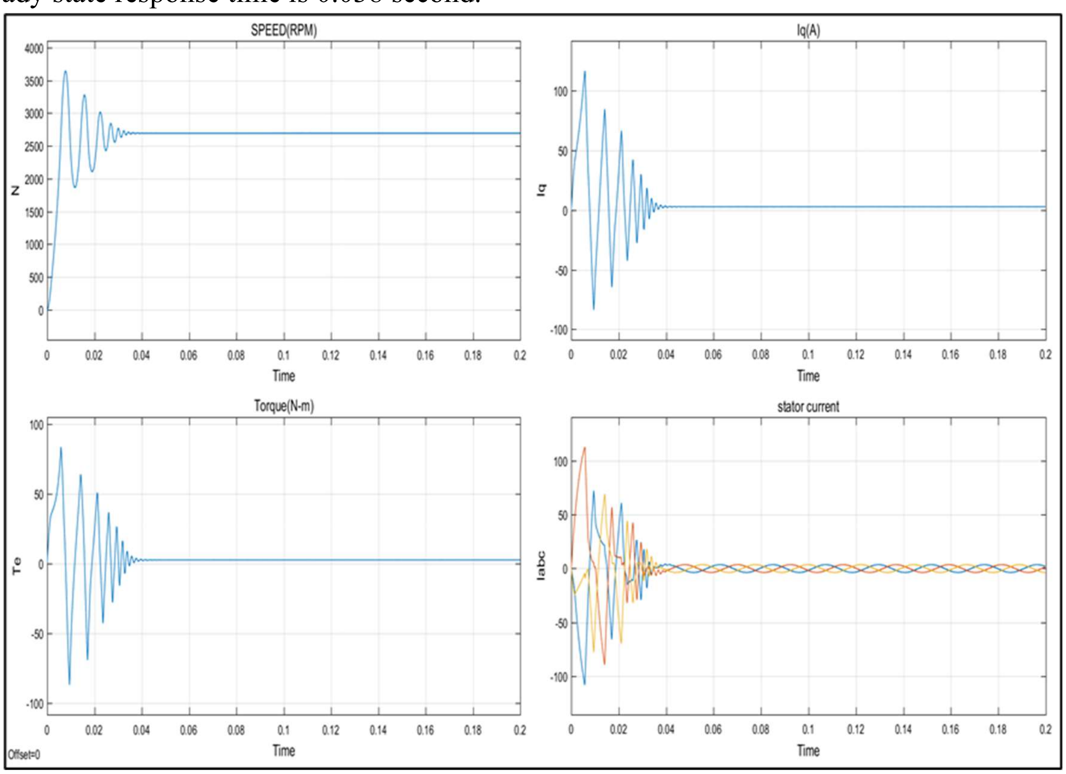

Figure 3. PMSM Simulation Results-Waveforms of N, Te, Iq & Iabc.

Table 1 shows the simulation results.

Table 1 : Simulation results

Sr. No.	Input Voltage Volt	Input Current Amp	Speed rpm	Torque Nm
1	300	0.94	2700	0
2	300	1.25	2700	0.5
3	300	1.58	2700	1.0
4	300	2.50	2700	1.5
5	300	3.01	2700	2.0
6	300	3.82	2700	2.5
7	300	4.02	2700	3.0

IV Experimental Setup

The purpose of this experimental investigation is to completely load the PMSM up to the motor's rated current and measure performance, such as efficiency and torque. Because PMSM is in a closed loop regulated drive, it is tested at a single speed. After loading, the speed will decrease, but the controller will automatically adjust it to the single speed. Hence, we are able to set any speed value up to the motor's rated speed. The feedback sensor QEP (Quadrature Encoder Pulse) and converter power module are used to operate motors. Eddy current dynamo braking is the form of braking used for PMSM.

The PMS motor's specifications and ratings are listed below: - eddy current dynamo as the loading type, power of 1 hp, voltage of 310 dc volts, current of 3.8 amps, speed of 3000 rpm, and torque of 2.5 Nm.

The experimental PMSM setup is shown in figure 4. It consists of a converter power module (cpm), which uses QEP sensor feedback and is managed by a DSP-2812 controller. It uses eddy current dynamo loading. PMSM is set to run at 2700 rpm. Inverter switches receive pulses from the processor that are applied to match the set and actual speed. DSP is used to program the PI controller.

When the load is at its lowest, or when the battery's voltage and current are both zero, ac voltage is first provided using a three-phase auto transformer to the converter power module (cpm), which is then connected to an eddy current dynamo. To provide power electronics switches (MOSFET) with pulses in cpm, the DSP (2812) controller is turned on. By choosing the closed loop operation mode in Code Composer Studio, the program is run in the controller. After then, the load is gradually increased while experimental measurements are made.

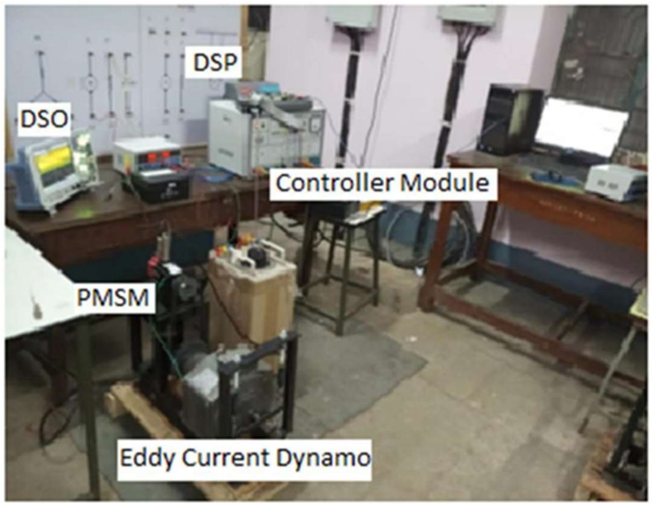

Figure 4. Experimental setup of PMSM

Table 2 includes the experimental findings. The motor speed is held constant at 2700 rpm, the motor torque ranges up to 2.5427 Nm, and the motor current reaches 3.8Amp. The motor's efficiency is estimated to be 85.95%.

Table 2 : Experimental results

Sr. No.	Input Voltage Volt	Input Current Amp	Speed rpm	Torque Nm
1	300	1	2700	0
2	300	1.45	2700	0.5651
3	300	2	2700	1.1301
4	300	2.5	2700	1.5539
5	300	3	2700	2.0483
6	300	3.5	2700	2.2602
7	300	3.8	2700	2.5427

DSO records the waveforms of motor characteristics. Figure 5 depicts the input current, pwm pulses, torque, and dc voltage (Vdc)/current (Idc) waveforms recorded in DSO for PMSM, respectively.

Two DSO probes with attenuation of 1:10 are employed. Several output terminals are provided in the converter power module for pulses, current, feedback sensor signals, and so on. Several waveforms are collected and stored in DSO by attaching probes to the appropriate terminals. The x-axis represents time, and the y-axis represents voltage. As time is shared by all waveforms, voltage equates to current in the current waveform or torque in the torque waveform.

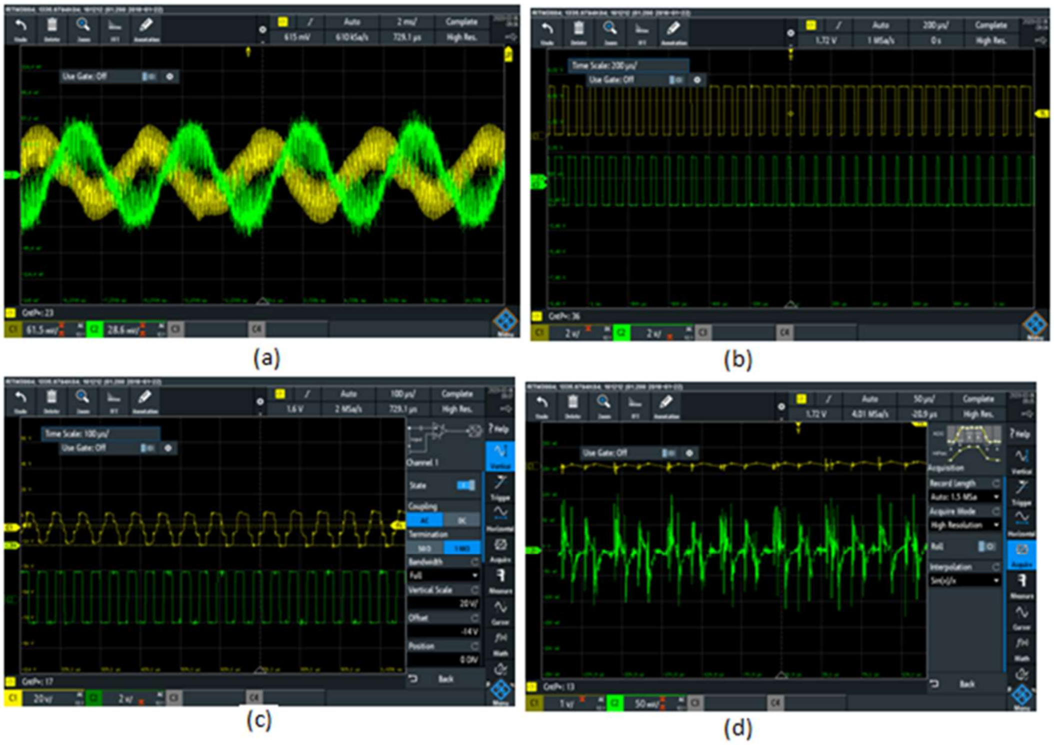

Figure 5. PMSM Experimental Parameters (a) Input Current (b) PWM Pulses (c) Torque (d) V_{dc} & I_{dc}

V Result and Discussion

This paper's goal is to examine the T-I characteristics and performance of PMSM utilizing MATLAB/SIMULINK and laboratory testing. The goal of the experiment is to fully load the PMSM up to the motor's rated current in order to measure performance, such as efficiency and torque. Because PMSM is in a closed loop regulated drive, it is tested at a single speed. After loading, the speed will decrease, but the controller will automatically adjust it to the single speed. Hence, we are able to set any speed value up to the motor's rated speed. The feedback sensor QEP (Quadrature encoder pulse) and converter power module are used to operate motors. Eddy current dynamo braking is the form of braking used for PMSM.

Laboratory testing and simulation are used to study PMSM performance. The PMSM is loaded from no load to full load during the experiment. The efficiency at full load is estimated to be 85.95%. Within 0.038 seconds, the simulation's response in steady state is attained. At a fixed speed of 2700 rpm, their torque current characteristics are contrasted. It is depicted in figure 6. The entire torque zone, simulation modelling findings, and experimental results are discovered to be nearly equivalent. Torque also rises as current does. As a result, the experimental findings serve to validate the PMSM simulation model. Comparisons of the T-I (Torque-current) characteristics of PMSM in simulation and experiment are extremely near to being comparable.

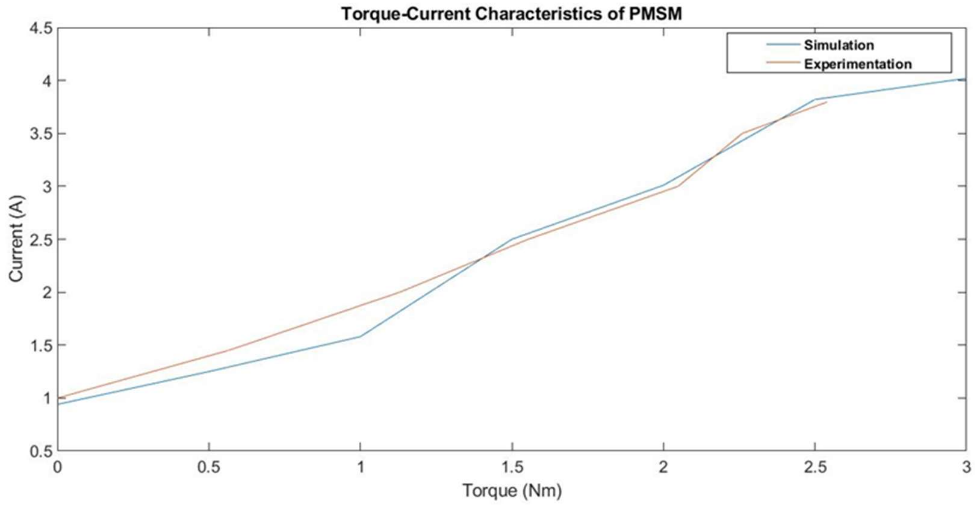

Figure 6. Comparison of Torque-Current Characteristics of PMSM

VI Conclusion

This research presents the torque-current characteristics performance of PMSM utilizing MATLAB/SIMULINK and laboratory experimentation for PMSM. The PMSM simulation model is developed in MATLAB using a PI controller, and the simulation is run at various load torques. The simulation's steady state response time is 0.038 second. For testing the performance in the laboratory, a PMSM drive with DSP (2812) advance controller and hardware setup for experimentation is used. The obtained efficiency of PMSM is 85.95%. As a result of the availability of solid state drive technology, PMSM and PI controller are gaining appeal in industry applications as compared to other motors. For simulation and experimentation, test data and waveforms are recorded. Ultimately, all experimental and simulation results are validated and presented. PMSM torque-current characteristics are compared in both simulation & experimentation, are very close to comparable.

The article focuses on the performance of T-I characteristics in PMSM simulation and experimental validation. The PMSM simulation is obtained using MATLAB/SIMULINK. PMSM is tested at full load, and efficiency and torque are computed using experimental data. Both simulated and experimental results are found to be extremely close to each other. Torque increases as current increases. The analysis of T-I (Torque-current) characteristics is critical in all applications. Hence, the work's novelty has been demonstrated, and additional innovative and fresh work has been articulated.

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Author contributions: contribution of work with respect to the state of the art: i) MATLAB simulation and Experimentation on PMSM drive are done. ii) Methodology planned for T-I characteristics validation in simulation & experimentation. iii) All efficiency & torque calculations are done. iv) Result comparison graphs are plotted from all experimental measurements and simulation results. v) Original draft preparation of paper is written. vi) Detailed survey of the literature and state of art which were essential for the completion of this review paper.

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