DESIGN ANALYSIS OF ELECTRICAL MACHINES THROUGH INTEGRATED NUMERICAL APPROACH

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Abstract

An integrated design platform for the newer type of machines is presented in this work. The machine parameters are evaluated out using developed modelling tool. With the machine parameters, the machine is modelled using computer aided tool. The designed machine is brought to simulation tool to perform electromagnetic and electromechanical analysis. In the simulation, conditions setting are performed to setup the materials, meshes, rotational speed and the excitation circuit. Electromagnetic analysis is carried out to predict the behavior of the machine based on the movement of flux in the machines. Besides, electromechanical analysis is carried out to analyse the speed-torque characteristic, the current-torque characteristic and the phase angle-torque characteristic. After all the results are analysed, the designed machine is used to generate S block function that is compatible with MATLAB/SIMULINK tool for the dynamic operational characteristics. This allows the integration of existing drive system into the new machines designed in the modelling tool. An example of the machine design is presented to validate the usage of such a tool.

Keywords: Machine design, Electromagnetic analysis, FEA, CAD

1.Introduction

Modern electrical machines are slowly taking over conventional electrical machines as they exhibit better performance in term of torque, speed, efficiency and THD [1-2]. Most of the new electrical machines are designed to cater for

Nomenclatures	
CAD	Computer Aided Design
DRORPMM	Double Rotor Outer Rotor Permanent Magnet Machine
DRSRM	Double Rotor Switched Reluctance Machine
DRSynRM	Double Rotor Synchronous Reluctance Machine
DSSRM	Double Stator Switched Reluctance Machine
FEA	Finite Element Analysis
GUI	Graphical User Interface
ORPMM	Outer Rotor Permanent Magnet Machine
PM	Permanent Magnet
SRM	Switched Reluctance Machine

specific application. For the case of the double-rotor type motor as applied to some application that required two motors for bidirectional application. By using a dual-rotor motor [3-4], the space allocated for the motor is minimal. New electrical machines mostly adapt high density magnets to enhance the power density [5-6]. Despite that, designing a new electrical machine is very tedious without the aid of numerical tools. Besides, it is very hard to test a new machine under different operating condition and the only way to achieve that is to test the machine experimentally. With advancement of computational tools, the tedious process involved in electrical machine design is replaced by adaptation of integrated numerical tool that surface across different computing tools [7-9].

2. Design Methods

For the required specifications, the size of the machine, the number of slots in the machine, the number of poles in the machine and the number of conductor in the machine are identified. The machine design equations is used in GUI deployment that allows the user to determine the machine sizing based on some of the inputs like power, rotation and voltage input. The results of the GUI are validated before entering the development stage. FEA tool is used to model out the chosen machine in electromagnetic tool. The electrical machine is designed using JMAG designer. 2-D numerical modelling is generated based on the sizing. Magnetic transient study is setup to allow conditions setting in JMAG. The condition setting includes include rotational force, speed of rotation, mesh sizing, FEM coil, circuit configuration, simulation step sizing, torque nodal force, materials, and the winding configuration of the machines. Electromagnetic analysis to determine the flux flow and flux density in the machines and electromechanical analysis to determine the speed, torque and efficiency of the machines is done. Figure 1 shows the methodology involved in this design and Fig. 2 shows the GUI of the MATLAB that gives the desired dimensions.

The recommended dimensions from the MATLAB are used to develop the machine using numerical tool. After performing machines design and analysis, the new machine is imported to SIMULINK for drive integration. The machine in modern day comes together with drive and controller that are catered to control the machine within the allowable operating condition. The drive and controller allows the machine to operate within a wide range of speed/torque in different conditions. Therefore, it is essential to integrate a drive system into a new machine to perform analysis on the performance of machine under various operating condition, for

instance, the temperature of the machine or the magnet. Figure 3 shows the methods of the transition of the machine design in various platforms.
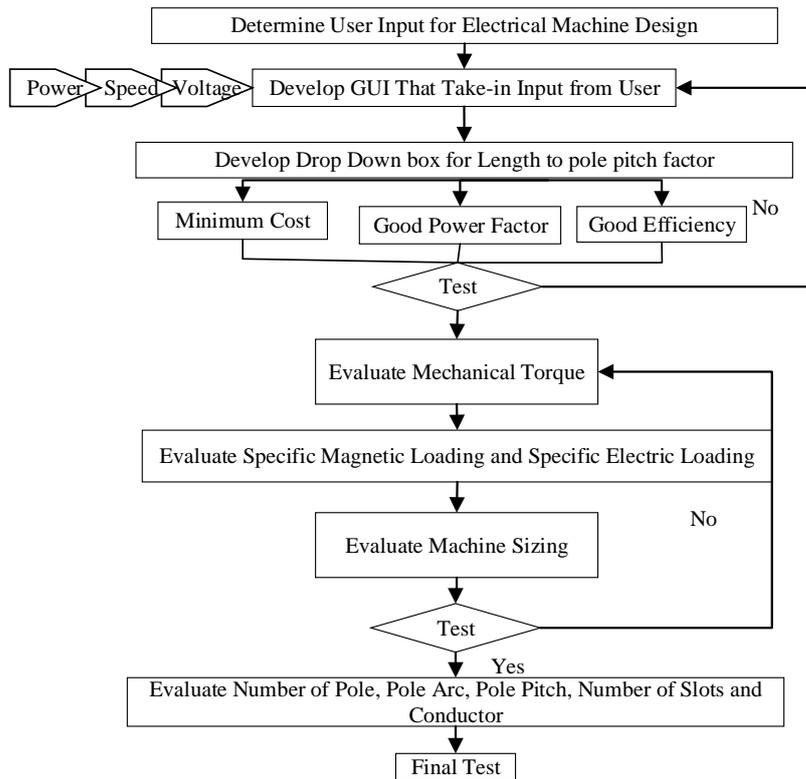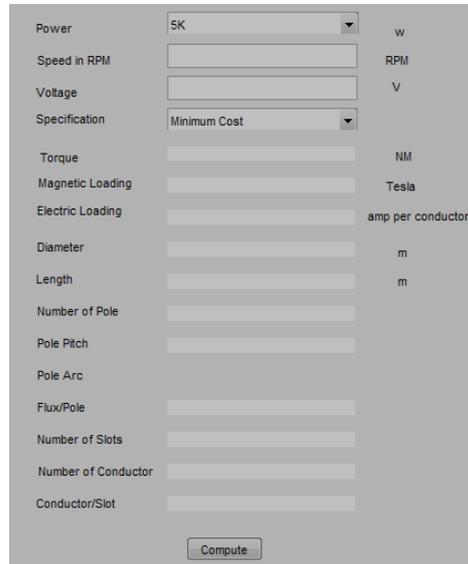

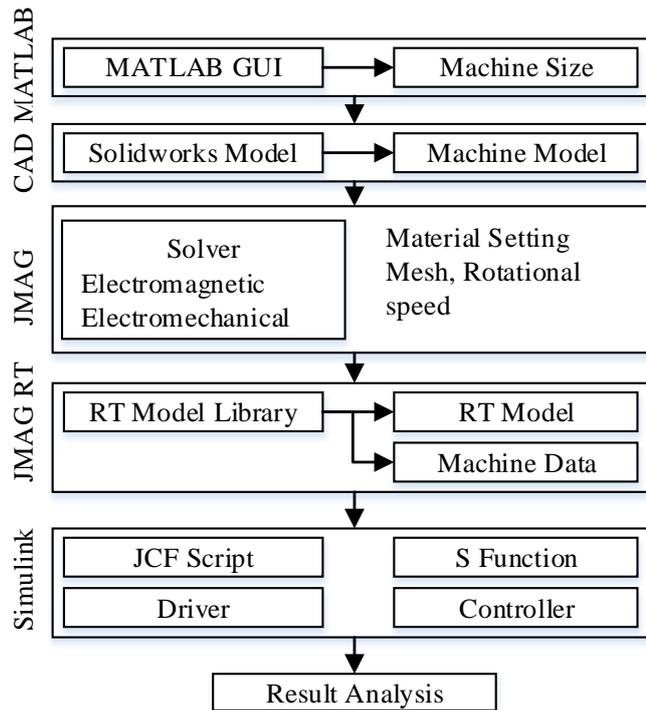**Fig. 1. GUI methodology.**

Fig. 2. GUI interface.

Fig. 3. SIMULINK integration.

SIMULINK Model file is generated along with JMAG-RT model. SIMULINK enable the simulation of machine drive system but only limited to handful amount of machines that are already available in their database. With such approach, any new machine is simulated via JMAG-SIMULINK interface. This allows the user to perform multiple simulations which include the loss in the machine, controller operation and the performance of machine under different temperature. The block function is used to perform a typical drive system as shown in Fig. 4. Figure 5 shows the interface developed for the S-block model of the developed machine (using Fig.4). Figure 6 shows the modelled machine with the drive systems with the controller systems. Now this machine model can be used for any type of algorithm developed through the MATLAB to study further the behaviour of the system under various operating conditions.

3. Design Case: Synchronous Reluctance Machine (SynRM)

A 12 slots 4 poles Synchronous Reluctance Machine (SynRM) as shown in Fig. 7 consists of 2 structures, which are the rotor and the stator. The SynRM is designed using CAD tool based on the geometries of the machine evaluated by developed MATLAB GUI. The dimension of SynRM is shown in Table 1.

After SynRM is modeled out using the numerical tool, conditions setting are performed on the structure based on the configurations shown in Table 2. The winding configuration of the machine is shown in Fig. 8.
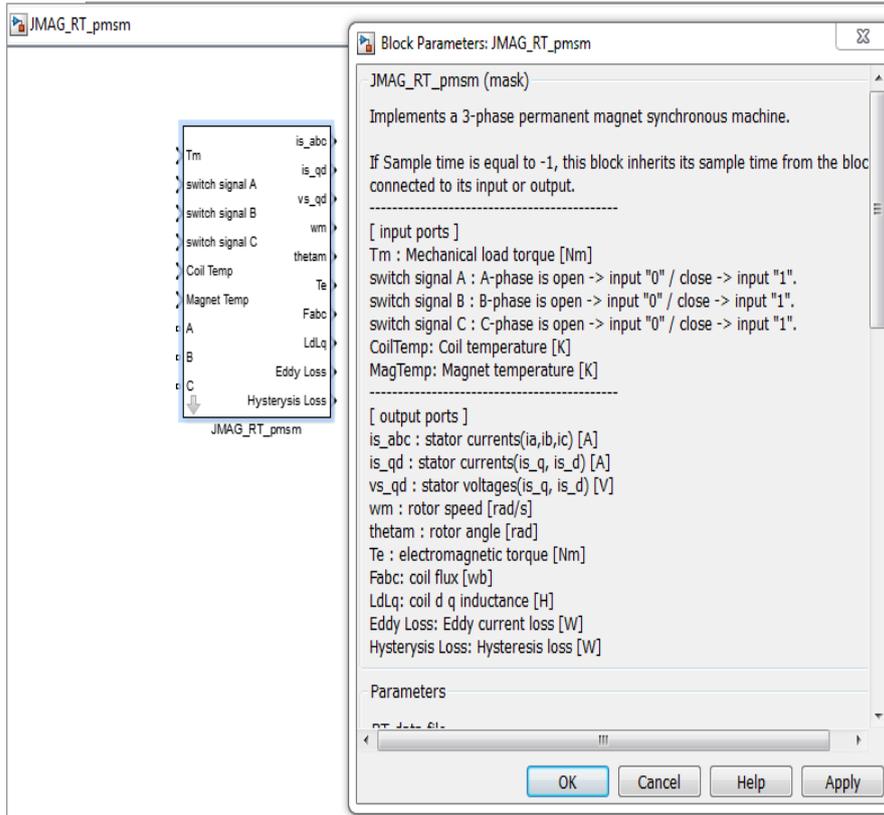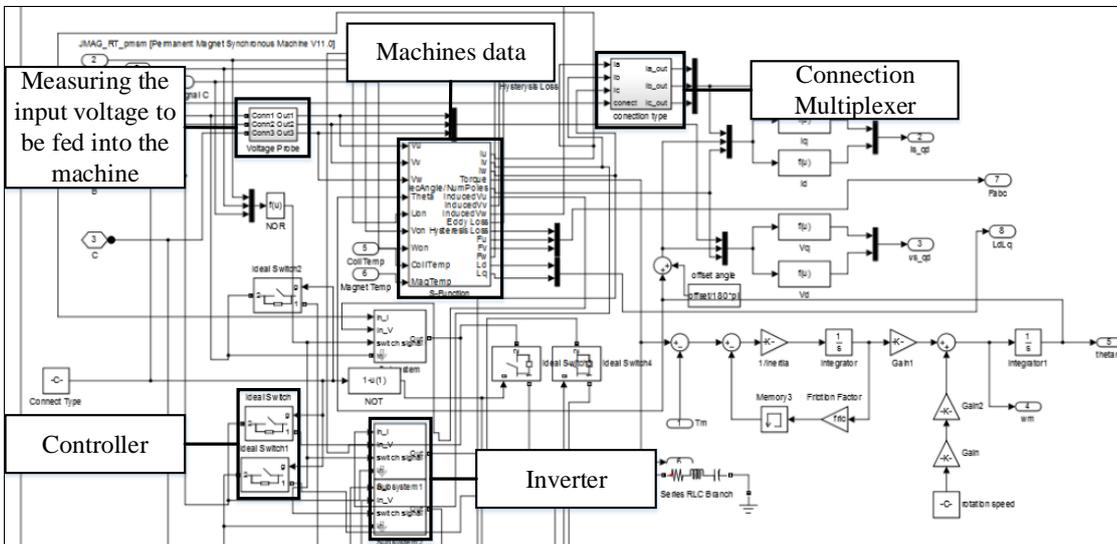
Fig. 4. JMAG-RT in SIMULINK.
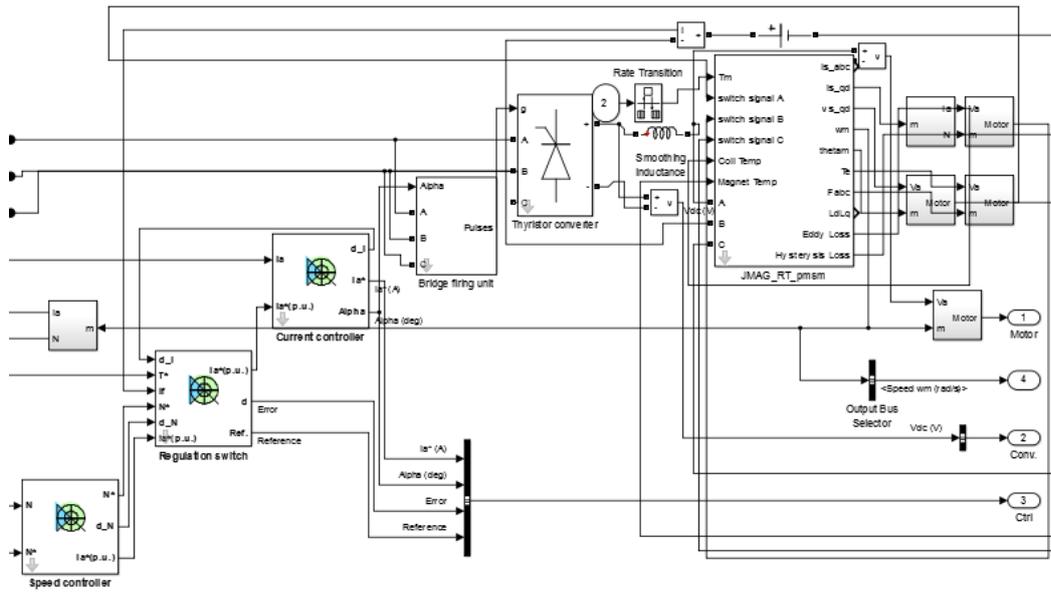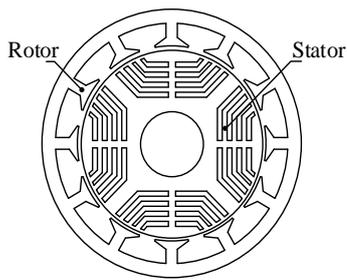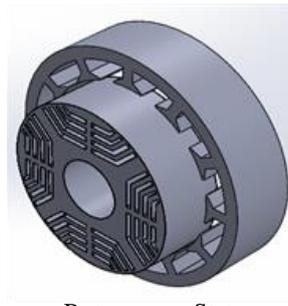

Fig. 5. JMAG RT circuitry in SIMULINK.

Fig. 6. Machine drive electronics

a. Cross-sectional view.

b. Exploded view.

c. Fabricated 2-D.

Fig. 7. SynRM.
Table 1. SynRM main dimension.

Parameter	Unit(mm)
Outer rotor diameter	80
Outer rotor inner diameter	65
Air gap length	0.5
Stack Length	50
Turns per pole	58
Rated current (*I*)	5*A*

Table 2. SynRM Settings.

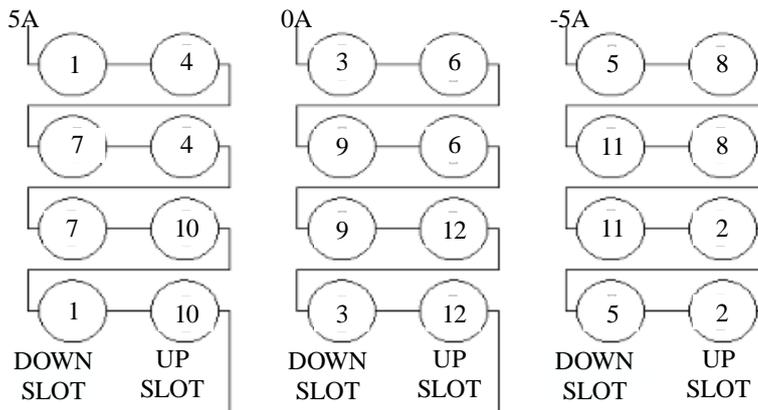| Properties Property		Value
Full Model Conversion	Stack Length	50mm
Step Control	Type	Regular Interval
	Steps	33
	Division	11520
Stator Core, Rotor Core	Material	JFE Steel: 50JN400
	Lamination	98 %
Magnet	Material	NEOMAX-42
	Number of Poles	4
Coil	Material	JSOL: Copper
Rotation Motion	Target	Rotor Core
	Displacement Type	0-1600(400 increment)
Rotation Motion	Rotation Axis	Upward
Torque: Nodal Force	Target	Rotor Core
Mesh Properties	Mesh Type	Slide Mesh
	Rotational Mesh	On

Fig. 8. Winding Configuration.

After the electromagnetic analysis is performed on the model, the model is converted to JMAG-RT model in which a data file is generated during the process of conversion to JMAG-RT. The data file is a SIMULINK block file that consists the mathematical modeling of the novel electrical machine which is not available in SIMULINK database. This allows further machine controller analysis in block diagram simulation environment.

4. Results and Discussions

The result on the electromagnetic analysis is performed on the model by using FEA tool is presented in this section. In order to analyse the machine a common factor term is introduced as motor constant square density that includes volume, power and torque of the machines.

4.1. Electromagnetic analysis

The flux flow in the machine is shown in Fig. 9 (a) and the flux density is shown in Fig. 9 (b). Flux density contour plot is shown in Fig. 9 (c). Figure 9 (a), the winding machine is excited to form 4 flux path confirming that the winding configuration of the machine is correct. The flux flow is directed by the barrier design to minimize the flux leakage. From Fig. 9 (b) and Fig. 9 (c), the flux density is highest at the stator side and this is because the windings are winded over the stator and when the windings are excited, the stator becomes electro magnetized and therefore lead to high flux density at stator side compared to the rotor side. However, excessive flux contributes to heating issue. The flux density is minimum when closer to the shaft as there is no magnetic source at the rotor side.
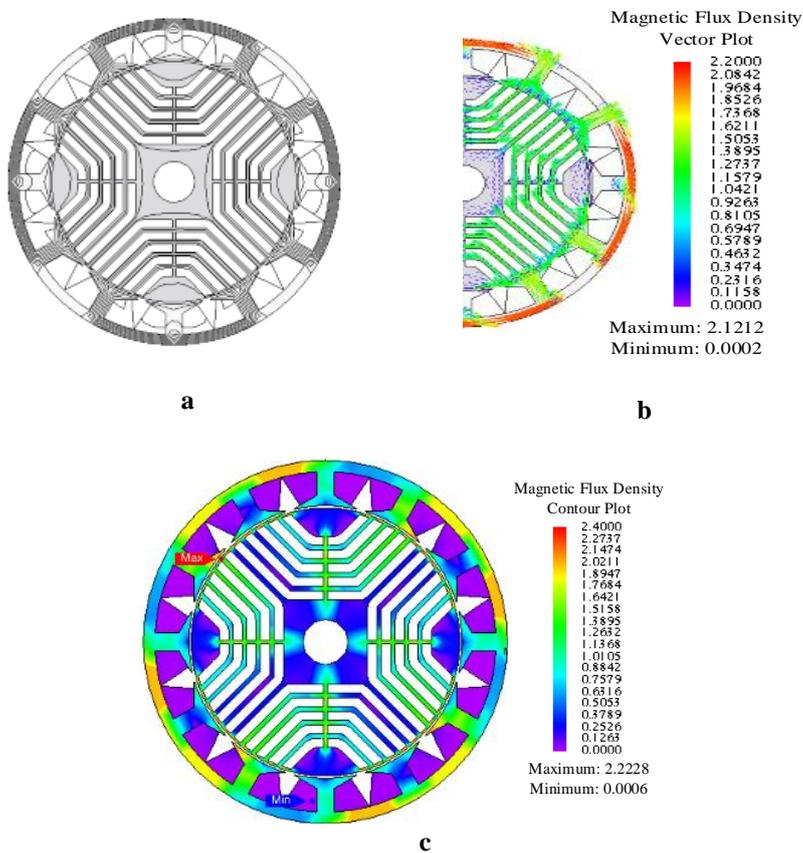

a

Magnetic Flux Density
Vector Plot

Maximum: 2.1212
Minimum: 0.0002

b

Magnetic Flux Density
Contour Plot

Maximum: 2.2228
Minimum: 0.0006

c

Fig. 9. Electromagnetic analysis.

4.2. Evaluation of the developed machine

For comparison on the level of performance for conventional and proposed structure, the methods of calculation Motor Constant Square Density G is used. The Motor Constant Square Density (G) is given as in Eq. (1).

$$G = \frac{(K_m)^2}{V} \tag{1}$$

where K_m is the machine constant in [Nm/A/W$^{-(1/2)}$], V is the volume of the machine [m^3]. The machine constant can be further expressed as in Eq. (2).

$$K_m = \frac{K_T}{\sqrt{P}} \tag{2}$$

where K_T is the torque constant [Nm/A] and P is the input power to the coil winding [W]. The torque constant is given as in Eq. (3).

$$K_T = \frac{T_{avg}}{I} \tag{3}$$

where T_{avg} is the fundamental torque [Nm] and I is the maximum current input to the machine [A].

Table 3. SynRM motor constant square density.

Motor		12s 4p SynRM
I	[A]	5
V	[$\times 10^{-4} m^3$]	2.513
T_{avg}	[Nm]	0.525
P	[W]	25
K_T	[Nm/A]	0.105
K_m	[$Nm/A/W^{-(1/2)}$]	0.021
G	[$Nm^2/A^2/W/m^3$]	1.75

The motor constant square density of SynRM is evaluated as shown in Table 3. After performing the electromagnetic analysis, JMAG-RT model conversion is perform and the SIMULINK block shown in Fig. 10. The S Block function allows the user to perform multiple simulations which include the loss in the machine, controller operation and the performance of machine under different temperature.
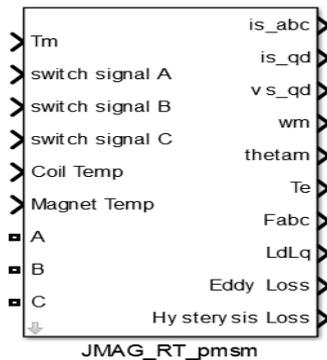

Fig. 10. S Block of SynRM.

4.3. Electromechanical analysis

The torque characteristics of the SynRM are shown in Fig. 11 while the graph of dynamic characteristics is as shown in Fig. 12. From Fig. 11, in a 4 pole machine, the torque waveform is sinusoidal in one pole pitch period which is 90 deg. This indicates that the rotation of the rotor is sync with the supply. Therefore, the motor operate on optimum condition with 50 Hz supply frequency. From Fig. 12, the speed is inversely proportional to the torque production. Figure 13 shows the current torque characteristics under loading conditions.
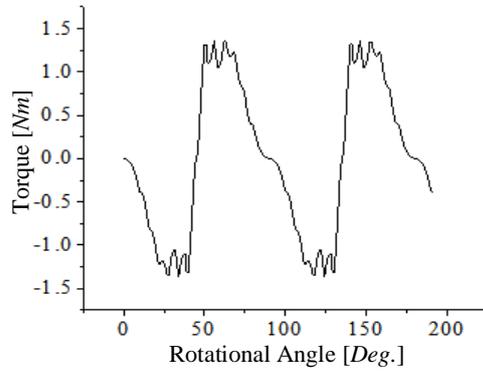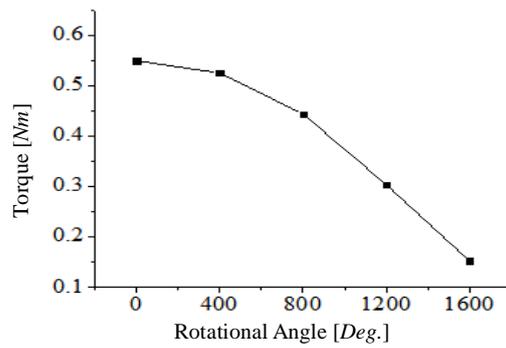
Fig. 11. Static torque characteristics.

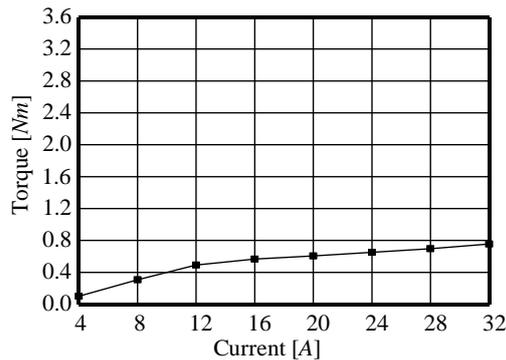**Fig. 12. Dynamic torque characteristics.**

Fig. 13. Current characteristics.

5. Conclusions

The proposed generalized design using integrated numerical tool provides a more thorough process using combination of simulation tool and numerical tool, and test various control algorithm in MATLAB/SIMULINK environment. This generalized design of new electrical machines using integrated numerical tool are very helpful and provide virtual domain to perform analysis of any type of new electrical machine. The powerfulness of such a tool is presented in this paper as for the Synchronous Reluctance Machine.

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