DESIGN AND DEVELOPMENT OF PERMANENT MAGNET BRUSHLESS DC (PMBLDC) MOTOR FOR SOLAR WATER PUMPING APPLICATION

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***Abstract*— Industrial development and population growth have led to a surge in the global demand for energy in recent years. The issues like depleting of fossil fuel resources and green environment lead to utilization of renewable energy sources like solar, wind etc. On the other hand, the electrical energy demand severely affects the agricultural economy of developing countries like India. In Agriculture, water pumping process is the major sector consumer of electricity, and hence energy efficient methods and techniques are to be implemented, particularly in water pumping for irrigation purpose. The solar energy is the ideal form of energy with the feature of being environment friendly and it is utilized for water pumping. Squirrel cage induction motors have been the most popular electric motors for long time. Meanwhile, for solar pumping application, induction motors are used with Power Electronic converters. The disadvantages like low operating power factor, low operating efficiency and cost of induction motor pump have been addressed in this project. The Permanent Magnet Brushless DC (PMBLDC) Motor is found to be one of the best alternate to address the above issues. This project focuses on design, simulation and development of highly durable, low cost, reduced weight, 2.2kW PMBLDC motor suitable for solar water pumping application. The MOTORSOLVE software tool was used to simulate the design.*

***Keywords*— Agriculture, Energy Efficient Motor, MotorSolve, PMBLDC Motor, Solar Water Pump**

1. INTRODUCTION

The gap between demand and supply of electricity in India is not only the issue to be addressed, but increasing the fossil fuel usage and price tag also needs to be addressed. Against this backdrop, renewable energy, more specifically solar energy comes as the solution. On the other hand, the electricity usage by the agricultural sector needs alternate. As a whole, the solar pump is a perfect solution for the current issues. Various types of motors designed for water pumping application needs to be optimized. Induction motors have been the most popular for water pumping application for long time. Meanwhile, for solar pumping application, induction motors are used with converters. Induction motors have many disadvantages like low operating power factor and low operating efficiency. Permanent Magnet Brushless DC Motors can perform better than Induction motors in solar pumping applications. The design of PMBLDC motor for submersible pump application needs careful attention in terms of main dimensions, cost and durability.

2. COMPARISON OF INDUCTION MOTOR AND PMBLDC MOTOR

A. *Selecting a Template (Heading 2)*

Brushless DC and induction drives use motors having similar stators. One of the main differences is that much less rotor heat is generated with the DC brushless drive. Rotor cooling is easier and peak point efficiency is generally higher for this drive. The DC brushless drive can also operate at unity power factor, whereas the best power factor for the induction drive is about 85 percent. Induction machines have no magnets and B fields are "adjustable," since B is proportionate to V/f voltage to frequency. This means that at light loads the inverter can reduce voltage such that magnetic losses are reduced and efficiency is maximized.

TABLE I. COMPARISON OF INDUCTION MOTOR AND PMBLDC MOTOR

Feature	Induction Motor	PMBLDC Motor	Actual Advantage
Speed/Torque Characteristics	Flat	Nonlinear lower torque at lower speeds	Permanent magnet design with rotor position feedback gives BLDC higher starting and low-speed torque
Dynamic Response	Fast	Low	Lower rotor inertia because of permanent magnet
Output Power/ Frame Size (Ratio)	High	Moderate	Both stator and rotor have windings for induction motor

Thus, the induction machine when operated with a smart inverter has an advantage over a DC Brushless Motor magnetic and conduction losses can be traded such that efficiency is optimized. This advantage becomes increasingly important as performance is increased. With DC brushless, as machine size grows, the magnetic losses increase proportionately and part load efficiency drops. With induction, as machine size grows, losses do not necessarily grow. Thus, induction drives may be the favored approach where high-performance is desired; peak efficiency will be a little less than with DC brushless, but average efficiency may actually be better. The Table I shows the comparison between BLDC Motor and AC induction motor.

3. PMBLDC MOTOR DESIGN

A Permanent Magnet Brushless DC motor is essentially a DC motor without the mechanical commutation of the brushed DC motor. PMBLDC motors are powered by direct current, having electronic commutation system instead of mechanical brushes and commutators. Permanent Magnet Brushless DC motor design model having 24 slots 4 pole 3 phase 2.2Kw Slotted Motor and Inner rotor type. Permanent Magnet rotor is designed with Ceramic-10. Torque produced by the Motor is given by (1). Where k_T is the Torque constant and I will be the current in the Motor. k_T the value of 1.35 K_E and K_E is the EMF constant.

$$\text{Torque } T = k_T I \qquad (1)$$

EMF Generated by the Motor is given by (2), where N is the speed of the Motor.

$$EMF = \frac{2\pi N}{60} K_E \qquad (2)$$

Permanent Magnet Rotor Force calculated by (3), Here B_r is Residual flux has 2200 Wb/m^2 L_m is Magnet length A_m is Magnet Area.

$$\text{Force } F = 0.58\, B_r^2 L_m \sqrt{A_m} \qquad (3)$$

Flux produced in PMBLDC Motor is by (4), B_{av} is average flux density b is Pole arc and L be the length of the Stator core.

$$\text{Flux } \Phi = B_{av}\, b\, L \qquad (4)$$

Number of stator conductors calculated by (5) here E is EMF a is number of parallel paths and P is the number of poles in the Motor.

$$\text{Number of conductors } Z = \frac{60 \times E \times a}{\emptyset \times N \times P} \qquad (5)$$

Electric loading is calculated by (5), Electric loading is the combinations of Number of conductors Z, current I and stator outer diameter D.

$$\text{Electric Loading ac} = \frac{Z \times I}{2\pi \times D} \qquad (6)$$

Slot area given by (7),

$$\text{Slot area } A_{slot} = \frac{\frac{No.of Conductors}{slot} \times Conductor Diameter^2}{0.7} \qquad (7)$$

Motor copper loss given by (8), here k_θ is Temperature constant $R_{20^\cdot}$ is Resistance of motor at the temperature of 20^0.

$$\text{Copper loss } P_{CU} = 3 k_\theta R_{20^\cdot} I^2 \text{ (w)} \qquad (8)$$

Iron loss of the PMBLDC Motor given by (9), where ⅄ is the ratio of I_{RMS} and I and X varies from 2.8 to 3.6.

$$\text{Iron loss } p_s = 2\left(⅄ - \sqrt{\frac{2}{3}}\right) R_{20^\circ} I^X (w) \qquad (9)$$

4. MOTOR SOLVE SIMULATION TOOL

A. *Design and Performance Parameters*

MOTORSOLVE PMBLDC is a design software tool used for brushless DC Motor simulation. MOTORSOLVE eliminates the need to create two separate machine models for thermal and electromagnetic analysis. One machine model can perform both of these two analyses. Designing of PMBLDC Motor in Motor Solve Software started with the general settings, which includes initializing units for all parameters and selecting the material for each and every component for permanent magnet brushless DC motor. PMBLDC Motor having 24 slots 4 pole 3 phase 2.2Kw. Design parameters of PMBLDC Motor shown in the Table II.

TABLE II. PMBLDC MOTOR DESIGN PARAMETERS

Design Parameters	Four Poles
Supply voltage	220v
Rated speed	1500 rpm
Air gap thickness	0.5
Maximum outer Diameter	100 mm
Maximum Length	300 mm
Number of slots	24
Coil span	3
Number of phases	3
Coil fill factor	50
Number of turns	24
Rotor Stator ratio	0.55

The speed of 1500 rpm can be obtained by increasing the poles with limited size. By varying the poles the coil span can be changed for preferred performance. The design parameters of 4 pole machines have different slots and varying number of turns. Performance parameter of the

PMBLDC Motor is given in the Table III. PMBLDC Motor of 4 pole rotor, 24 stator slots, 2.2 KW shown in Figure 1.

TABLE III. PMBLDC MOTOR PERFORMANCE PARAMETERS

Design Parameters	Four Poles
Current	10 A
Power	2.2 KW
Outer Diameter	94 mm
Stack Height	300 mm
Stator Diameter ratio	0.55
Back EMF ratio	0.9
Power factor	0.89
Torque per unit volume	$0.92*10^{-5}$ Nm/mm^3

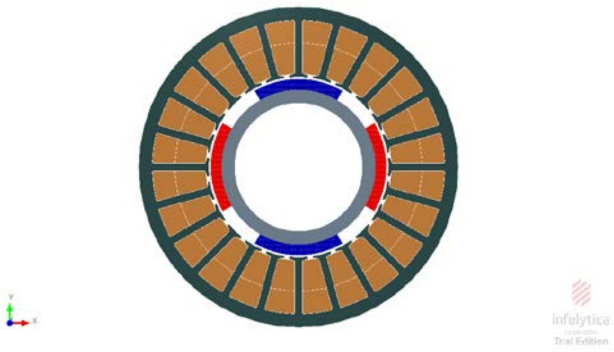

Fig. 1 *24 Slot, 4 Pole PMBLDC Motor*

B. Airgap Flux, EMF and Torque

Air gap is one of main concern for designing of any type of electrical motor Figure 2 shows the PMBLDC Motor Air gap flux. Efficient operation of electromagnetic devices requires that the magnetic circuit contain materials offering low resistance to the passage of magnetic flux. That minimizes the amount of electrical energy needed to create the magnetic field.

Fig. 2 *Airgap Flux*

In a brushless DC motor as a result of motor torque, the EMF produced is known as “back EMF.” It is so called because this EMF that is induced in the motor opposes the EMF of the generator. The Figure 3 shows the relation between the voltage and source phase angle. The back EMF that is induced in the Permanent Magnet Brushless DC motor is directly proportional to the speed of the armature and field strength of the motor, which means that if the speed of the motor or field strength is increased, the back EMF will be increased and if the speed of the motor or field strength is decreased, the back EMF is decreased.

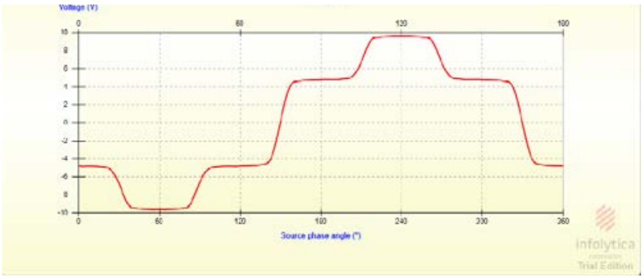

Fig. 3 *Back EMF*

Cogging torque of PMBLDC Motor is the torque due to the interaction between the permanent magnets of the rotor and the stator slots shown in the Figure 4. It is also known as detent or 'no-current' torque.

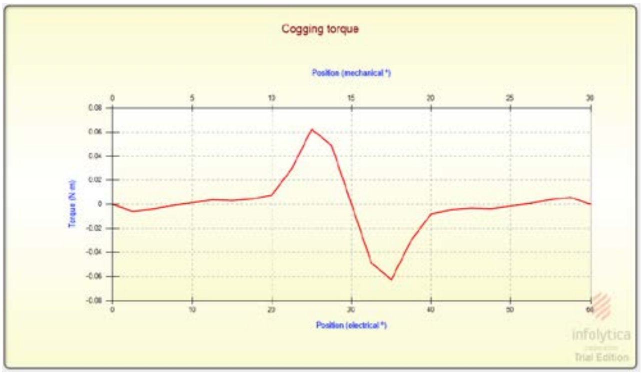

Fig. 4 *Cogging Torque*

Permanent Magnet Brushless dc motors are widely used in applications which require wide range of speed and torque control because of its low inertia, fast response, high reliability and less maintenance. The Figure 5 shows the speed torque characteristics of PMBLDC motor. The torque constant up to certain speed and it decreases due to decrease in speed variation. Losses that occur in a motor are divided roughly into copper loss and iron loss since the copper loss is given by I^2R, By decreasing the coil current or the winding resistance copper loss reduce. To reduce the winding resistance, coil length reduced and improved coil fill factor to achieve high efficiency shown in the Figure 6. The block given in the right side shows the complete description of the every change between torque and speed. The efficiency of the different pole machines also be calculated.

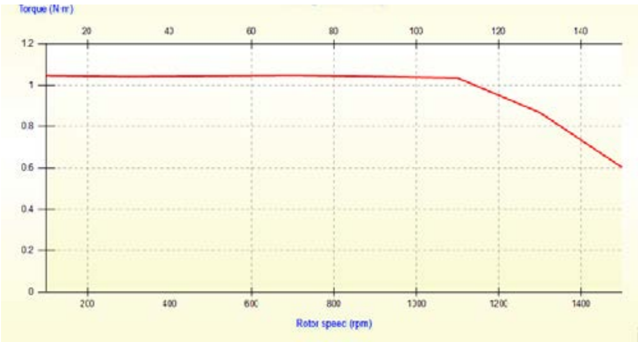

Fig. 5 *Speed Vs Torque*

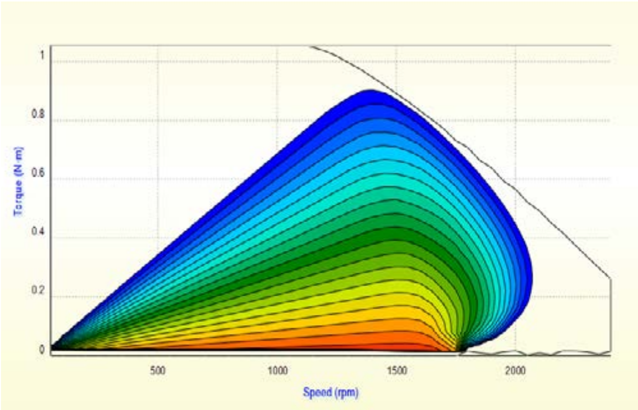

Fig. 6 *Efficiency*

When expressing the same phenomenon as an intensive property, the heat capacity is divided by the amount of substance, mass, or volume, so that the quantity is independent of the size or extent of the sample. The molar heat capacity is the heat capacity per unit amount of a pure substance and the specific heat capacity, often simply called specific heat, is the heat capacity per unit mass of a material. Heat capacity of PMBLDC Motor shown in Figure 8.

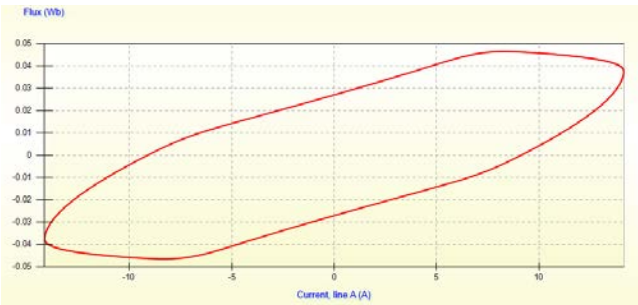

Fig. 7 *Current Vs Flux*

Heat flux or thermal flux is the rate of heat energy transfer through a given surface, per unit time. The SI derived unit of heat rate is joule per second. Heat flux density is the heat rate per unit area. Heat rate is a scalar quantity, while heat flux is a vector quantity.

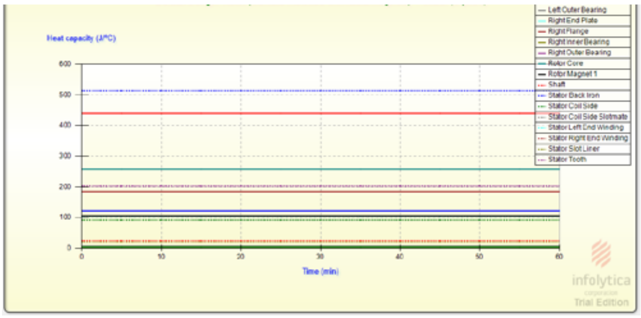

Fig. 8 *Heat Capacity*

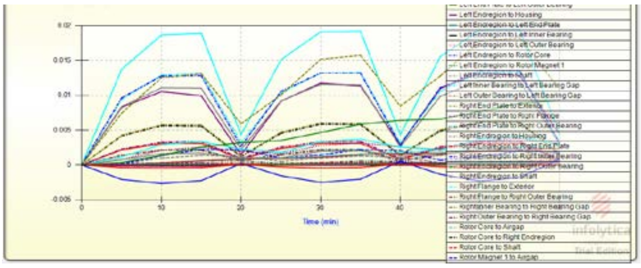

Fig. 9 *Heat Flux*

5. Conclusion

The cost effective and performance effective design of water pumps used in agricultural sector contribute to energy efficient measures taken against the global energy crisis. The utilization of solar energy for water pumping application is also one of the effective measures. The contribution was strengthened by careful design of PMBLDC Motor which is best alternate to Induction Motor. A PMBLDC Motor for solar water pumping application was designed and simulated using by MOTORSOLVE simulation tool is used.

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