Design and Development of Axial Flux Generator Using ANSYS RMxprt

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Abstract- This paper describes the design aspects and analysis of dual rotor and single stator Axial Flux Permanent Magnet (AFPM) machine. The inner stator consists of concentrated windings and the outer rotor consists of permanent magnet. Since there is no core in the stator, cogging does not occur. The modelling and analysis of the iron cored machine was done using ANSYS RMxprt. The measured performance of the prototype matches the predicted results. Finally, a prototype machine is fabricated, and experiments are carried out to test its performances by comparing with design topology. The proposed machine has advantages such as a simpler structure, operates at low speed, yield higher energy and light weight.

Indexed Terms- Axial Flux Permanent Magnet (AFPM) Machine, low speed, Neodymium permanent magnets.

I. INTRODUCTION

An electrical machine translates its input electrical power into an output mechanical power i.e. it is an electromagnetic energy conversion device. The history of electrical machines shows that the earliest machines were of the axial-field type. Based on the principle of electromagnetic induction, Faraday invented the Faraday disk, which is also called the homo polar machine. Because of the strong magnetic force existing between the stator and the rotor, these machines were soon replaced by radial-field machines. AFPM machines have number of advantages over Radial Flux Permanent Magnet (RFPM) machines such as they have high power to weight ratio, high aspect ratio, reduced noise and vibration levels, adjustable air gaps and occupies less space etc., AFPM machines are most suitable than RFPM machines for small wind power applications. Depending on the design characteristics and according to the material used in the stator core, AFPMs are classified into two type's namely iron-cored and coreless machines.

II. LITERATURE REVIEW

AFPM machines were first introduced in late 70s and early 80s (Campbell, 1975; Leung and Chan, 1980; Weh et al., 1984). Growing interest in AFPM machines in several applications due to their high torque-to-weight ratio and efficiency as an alternative to conventional radial-flux machines was significant in the last decade (1). Many variations in the design of axial flux permanent machines are possible, including single-sided, double-sided, torus, and multi-disc designs. In single-sided AFPM machines there is one stator and one rotor configuration. Single sided iron core permanent magnet machine is used as the bench mark of the construction of double-sided iron core permanent magnet machine. The drawback of the single stator-single rotor structure is the unbalanced axial force between the rotor and the stator. In double sided single rotor and dual stator configuration leads to the increase in the amplitude of the airgap flux density due to shorter airgap. This reduces the required number of permanent magnets, which yields savings in the machine price. On the other hand, slotting may evoke undesired torque pulsations, but the adopted structure allows the rotation of one stator over one half of the slot pitch with respect to the other, which results in reduced slot ripple and space harmonic component. All extra harmonics create additional flux in the machine which results in high eddy current losses in a conducting rotor and in the permanent magnets (2). AFPM machines having a single stator and dual rotor with the disc structure and the magnets are placed in such a way that the manufacturing flux is in line with the common axis of rotor and stator. These machines generally have relatively high power and torque density (3). The electromagnetic concept of a coreless AFPM is similar to that of a radial-flux machine, but the lack of an iron core removes the attractive forces between the rotor and stator. The absence of these forces reduces the structural loads on the machine, so that considerable weight savings can be realized, even at higher power ratings. As a result of this lower structural load and lack of iron core, the coreless configuration eliminates all ferromagnetic material including the steel laminations that would otherwise be needed in the stator, and so does not incur any associated eddy current or hysteresis core losses (4).

III. AXIAL FLUX PERMANENT MAGNET MACHINES

The machine consists of two external rotors and one internal stator. Air cored stator can be used to reduce the machine weight and gives the machine a lower cut-in speed. Concentrated windings are assembled to form the stator which is assembled using the epoxy resin. The double-rotor, single stator axial flux machine also has relatively high moment of inertia, allowing energy to be stored in the rotating machine to help smooth power output during transients. The rotor consists of permanent magnets made of neodymium. The highest grade of neodymium magnet is N52 is used. These magnets resist demagnetisation and have a high saturation magnetisation.

IV. THEORETICAL CALCULATIONS

i) Selecting the number of pole-coil number

This parameter that defines the machine design aspect is the magnet width (pole arc) to pole pitch ratio values between 0.4 and 0.7 (9),

$p=120f_{nom}/n_{nom}$

ii) Maximum magnetic flux density

The magnetic flux density near the magnet's surface Bmg is usually set at about $B_r/2$, where B_r is the remanent magnetic flux density. The maximum flux per pole Φ_{mg} is calculated using

$\varphi_{mg}=Bmg*2*pi*r(r+h)$

iii) Coil leg width

Given the number of turns per coil N_c and the stator's axial thickness t_w, the coil leg width W_c is calculated for a value of the heat coefficient C_q that is equal to 0.3 W/cm^2 and where I_{acmax} is the maximum machine current and ρ is the electrical resistivity of copper (9).

$W_c=(I_{acmax}*N_c)/\sqrt{((2*C_q*K_f*t_w)/\rho)}$

iv) Conductor size

The copper cross-sectional area S_c and the copper diameter d_c can be calculated using (9)

$d_c=\sqrt{(4*S_c)}/pi$

where $Sc=k_f*w_c*t_w/N_c$

v) Inner and outer diameter of machine

The inner diameter is calculated in a geometrical manner and then the outer diameter is calculated simply by adding the active length of the machine. The inner and outer diameters of the machine are calculated using (9)

$R_{in}=((2*Q*W_c)+(p*W_m))/(2*pi)$

$R_{out}=R_{in}+2W_m$

where W_m is the diameter of the magnet

TABLE I Machine specifications

S.No	Parameter	Range
1	Rated output power	14 W
2	Rated Voltage	16V
3	Rated speed	1000 rpm
4	Number of Stator Poles	6
5	Number of Rotor Poles	12

TABLE II Axial Flux Machine dimensions

S.No	Parameter	Value (mm)
1	Outer Diameter	95
2	Inner Diameter	55
3	Air Gap	0.5
4	Magnet Radian Length	15
5	Magnet Axial Thickness	8

V. DESIGN OF AFPM USING RMXPRT

RMxprt is an interactive software package used for designing and analyzing electrical machines. It is a template based electrical machine design tool that provides fast, analytical calculations of machine performance and we can export the same to 2-D and 3-D geometry creation in ANSYS Maxwell. Using RMxprt, we can simulate and analyse various machines. RMxprt creates a truly customized machine

S.NO	SPECIFICATION/DIMENSION	ASPECT/VALUE
1	Output Power (W)	14.0007
2	Input Power (W)	19.9958
3	Total Loss (W)	5.99512
4	Efficiency (%)	70.0181

design flow to meet market demand for higher efficiency, lower cost machines (10). A key benefit of RMxprt is its ability to automatically set up a complete Maxwell project. The set up includes the appropriate symmetries and excitations with coupling circuit topology for rigorous electromagnetic transient analysis. RMxprt automatically generates a reduced order model, considering the nonlinearities and eddy effects where further electric drive analysis can be achieved.

VI. RESULTS

A. Stator geometry using RMxprt

Fig.1 shows the geometry of the axial flux machine with 6 stator poles and 24 stator slots.

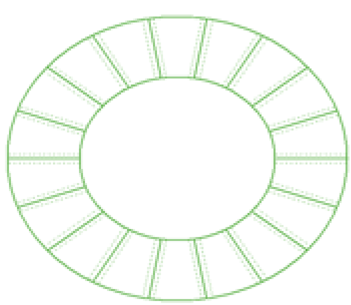
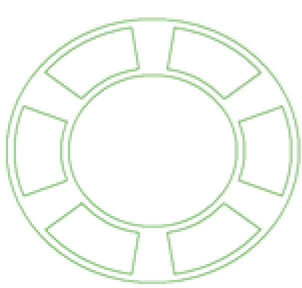


Fig.1 Twenty-Four Slot Stator Geometry



B. Rotor geometry using RMxprt

The rotor consists of 6 poles as shown in fig.2 based on which the neodymium permanent magnets are placed.

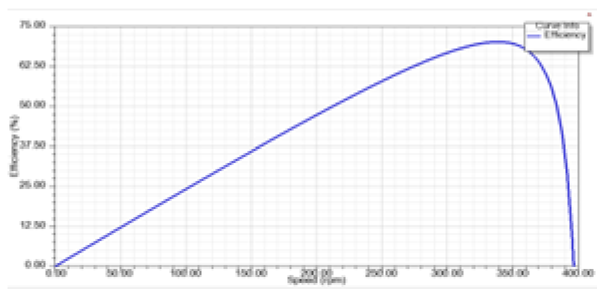
C. Performance analysis

After designing and simulating the machine using RMxprt, the results have been obtained. TABLE III. interprets about the power, total losses and efficiency parameters.

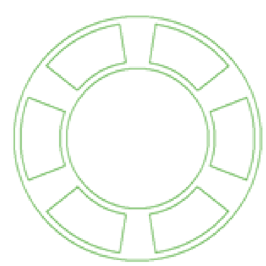
TABLE III Results of RMxprt

D. Waveforms

1) Efficiency Vs Speed -The efficiency of the designed AFPM Machine is shown in Fig.4 which shows maximum efficiency at the rated speed



2) Current Vs Speed - The Fig.4 shows the speed curve with reference to the input RMS current



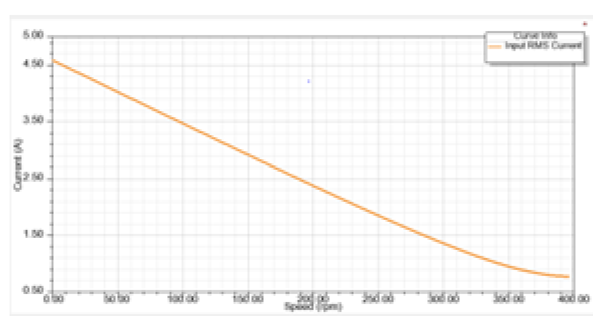
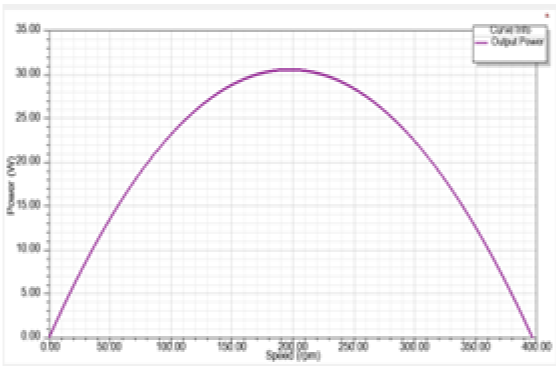


Fig. 4 Current Vs Speed

3) Output power Vs Speed - Fig.5 shows the speed curve with refernce to the rated output power. At the rated output power maximum speed is obtained.



CONCLUSION

A Finite Element Analysis time transient simulation is performed using the available design and simulation tools, ANSYS RMxprt. The EMF and terminal voltages for each phase at rated speed of 300 rpm are approximately 22.5V the peak. The simulated results are used to fabricate the hardware. To increase the output power, a great number of pole-pairs are needed. At these low speeds, the output power increases, so there is no need to use more magnets to increase the number of pole pairs. The elimination of steel laminations and core made of ferromagnetic material thus lowers structural loads and its associated eddy current and hysteresis losses. They lower the cogging torque and noise while operating. Thus, a coreless-stator AFPMG machine is highly efficient than that of a conventional machine. In addition, the machine is made smaller and is cheaper to manufacture.

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