Design and Analysis of Permanent Magnet Synchronous Generator for Wind Energy Conversion System using Ansoft-Maxwell

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ABSTRACT

Now-a-days Permanent magnet synchronous generator plays a major role in the Wind energy conversion system. This project deals with the design of 1.5 kW, 500 rpm, 230V,50Hz multi pole permanent magnet synchronous generator for direct drive wind energy conversion system using the software Ansoft Maxwell. This design is based on considering the parameters such as diameter of core, core length, machine type, material type, number of poles, number of armature conductors and slot etc., The RMxprt construction obtained from the above parameters are exported to Maxwell 3D design to perform the Magnetostatic analysis which involves validation of design, analysis setup, boundaries and excitation.

Keywords : *Magnetostatic Analysis, Cogging torque, Pole, Armature conductors, Air gap flux density.*

1. INTRODUCTION

Permanent magnet generators can be divided into two groups: geared machines and direct-driven machines. Currently, the tendency to eliminate the gearbox from the permanent magnet generator structure is increasing because the gearbox brings additional weight and costs, demands regular maintenance, generates noise and incurs losses. However, many problems may occur while constructing a new direct-driven permanent magnet generator design [2][3].

The energy converters using permanent magnets include a variety of configurations, and such terms as motor, generator, alternator, stepper motor, linear motor, actuator, transducer, control motor, tachometer, brushless dc motor and many others are used to describe them[5]. The stator of the machine (motor) is identical to the stator of a multiphase AC machine. However, the new component is the rotor, which in contrast to conventional rotors relies on permanent magnets as the source of excitation rather than an electric current in windings[5][6]. The optimum rotor configuration, rotor electromagnetic and mechanical design, as well as the stator electromagnetic design must be matched to achieve a higher efficient machine of the desired load characteristics, high power factor, and high efficiency and performance [7].

The advantages of PM machines over electrically excited machines are Higher efficiency and energy yield, No additional power supply for the magnet field excitation, Improvement in the thermal characteristics of the machine due to absence of the field losses, Higher reliability due to the absence of mechanical components as slip rings, Lighter and therefore higher power to weight ratio.

The attractiveness of PM generators is further enhanced by the availability of high-energy PM materials such as neodymium-iron boron. The advantages of permanent magnets in PMSG are they do not require an additional DC supply for the excitation circuit and they avoid the use of slip rings, hence it is simpler and maintenance free.

2. WIND ENERGY CONVERSION SYSTEM MODEL

The basic diagram of the wind energy conversion system to be analyzed on this paper is illustrated in **Fig. 1.** The system is composed by a wind rotor which transforms the kinetic energy from the wind with wind speed in mechanical torque in the shaft. The shaft drives directly the PMSG, which generates power with variable-frequency and alternate current. A rectifier bridge with a bulky capacitor Clink is responsible for AC-DC conversion to form the DC link.

The Static compensators connected on main bus between generator and bridge rectifier. It consists of a six-switch, three-phase voltage source inverter (VSI), a CDC capacitor on the DC side of the inverter, and a LF to suppress high-frequency currents originated by the switching of the VSI. A bank of capacitors C is used for filter high-frequency voltage occasioned by the inverter.

2. PMSG CONSTRUCTION BY ANSOFT MAXWELL

2.1 Ansoft Maxwell and RMxprt

Ansoft Maxwell is the premier electromagnetic field simulation software for engineers tasked with designing and analyzing 3-D and 2-D electromagnetic and electromechanical devices such as motors, actuators, transformers, sensors and coils. Maxwell includes 3-D/2-D Magnetic Transient, AC electromagnetic, Magnetostatic, Electrostatic analysis.

Ansoft corporation RMxprt is used for preliminary motor design.It gives easy and fast response in convenient form. Different rotor configuration, permanent magnet and core materials are optimized using RMxprt parametric analysis mode. It is able construct any type of machines whether it is AC or DC machine, ex: PMSM, IM, SRM.

Fig.1:Integrated design flow of Ansoft- Maxwell and Simplorer

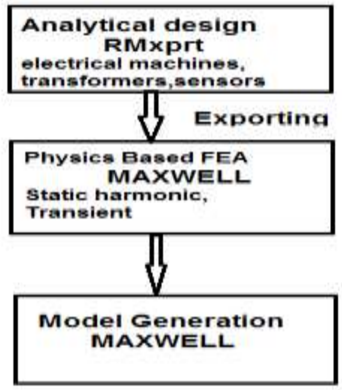

Fig.2:Design flow of Ansoft – Maxwell

2.2 Steps for design

The steps involved in designing PMSG by Ansoft-Maxwell are

(i)The machine type is chosen in the Rmxprt construction .

(ii)The obtained parameters of PMSG such as inner and outer diameter of stator and rotor, no of poles, no of slots , pole arc and pole pitch, width and height of the pole body and pole shoe, no of parallel branches etc are applied .

(iii)Then the number of coils, length of the coil, resistance of the field coil , and magnet parameters such as remenence, magnetic coercivity, relative permeability of the magnet, magnetic reluctance, are also applied in the rotor configurations.

(iv)Then the constructed design, parameters are validated and are analysed for the machine construction, parameters set up to give Rmxprt construction of PMSG.

(v)Then this Rmxprt construction is exported to Maxwell 3D design to obtain a 3D model of PMSG which is undergone a Magnetostatic analysis which is a finite element technique.

(vi)This validate the various excitation, boundary condition and optimetrics to produce the results.

3. DESIGN OF PMSG

To design a 1.5kW Permanent magnet synchronous generator with a speed N=500rpm, efficiency =0.95, Frequency =50Hz, voltage= 230V...

3.1 Design of Stator

The output equation of synchronous machines is Output KVA is

$Q=C_oD^2Ln_s$ (1)

where C_o is the output coefficient given by

$C_o=11B_{av}\,ac\,K_w10^{-3}$ (2)

D- diameter of Stator (m), L- length of core(m)

Product $D^2L = Q/C_o.n_s$ m³

Synchronous speed n_s=2f/p (rps) (3)

Peripheral speed o armature

V_a=π D N “m/s” (4)

For a round pole face L =ΨT

=ΨπD/p. (5)

The poles are attached to the pole body. The ratio of pole arc to pole pitch Ψ is assumed as 0.67 for the round poles in which length of the pole is equal to width of the pole shoe [2].

When all the turns are connected in series then Turns/phase is given by, Turns/phase

$T_{ph}=E_{ph}/4.44fØK_w$ (6)

The number of coils is more than the required minimum number of coils. Hence best choice for number of coils is 462.

Number of turns per coil =Z/2c.

The slot opening should be as small as possible in order to reduce flux pulsation losses. With increase in depth of the slot the eddy current loss in conductors increases, specific permeance of slot increases, reactance voltage increases and its becomes difficult to fabricate the laminations with narrow width at the roots of teeth.

Factors considered before finalizing the slot dimensions are Flux density in tooth, Flux pulsations, Eddy current loss in conductors and the reactance voltage.

Total number of armature conductors =slots x conductor per slot.

Total armature conductors= $6T_{ph}$

Number of slots S_s= 3pq (7)

where p-no of poles

q- slots/pole/phase. (2 to 4)

The slot width (Ws) =πD /2Ns.(m) (8)

Slot pitch y_s= πD/S_s (9)

(< 25mm for small machines)

3.2 Design of Pole body and Pole shoe

A larger value of air gap results in lesser noise, better cooling, reduced pole face losses, reduced circulating currents and less distortion of field form. Also larger air-gap results in higher mmf which reduces armature reaction. The mmf required for the flux across the air gap is approximately 80% of the no load field mmf [2], then

Mmf required for air gap,

Atg =800,00$B_gK_gL_g$ (10)

Where K_g =1.15 =gap contraction factor

L_g is length of the air gap

B_g is the flux density in the air gap.

Armature mmf per pole ATa =ac.τ /2

Magnet Reluctance (Rm);

Rm =H_c x N_m /B_r πDL (I/Hm) (11)

where H_c is the Magnet co-ercevity

N_m is the Number of poles

B_r is the Magnet remanence

Magnet thickness T_m is

T_m = (Gap flux factor (P_c) + air gap reluctance(R_g)) / magnet reluctance (R_m) (12)

Slot fill factor =Total slot copper area (A_c) / total slot area(A_w). (13)

The reluctance of the magnetic material can be estimated using the following equation, Reluctance, S =length/area x1/permeability =l /Aμ.

Permeability of magnetic material(μ) =$\mu_r.\mu_o$

μ_r =Relative permeability

μ_o =4π x10^{-7} H/m =Absolute permeability of free space.

NdFeB SH materials has temperature 150°c (or) 302 °F, B_r =11.2 and H_c =10.7

Relative permeability of magnet μ_r =B_r / (H_c) x μ_o.

Air gap reluctance R_g =N_m.g /πDLμ_o.(I/H) (14)

Where N_m=Number of poles

g=Air-gap thickness

D=Diameter

L=Length:

μ_o=Permeability of air =1.256 x10^{-3} x10^{-3}.H/m.

Flux per pole=(Bav*πDL)/p (Wb/m) (15)

Flux in the pole body, φ_p=Cl x φ. (16)

Leakage co-efficient Cl =1.12 to 1.25.

Area of the body, $A_p = \varphi_p / B_p$ (m^2) (17)

B_p - Flux density in the pole body.

Length of pole, $L_p = L - (0.001 \text{ to } 0.015)$ m.

Net iron length of pole $L_{pi} = 0.9L_p$ (m)

Width of the pole, $b_p = A_p / L_{pi}$ (18)

Height of pole body, $h_p = h_f$+ Thickness of insulation and clearance.

Height of pole shoe $H_s = 2d_d$, (19)

d_d - diameter of damper winding

$d_d = A_d/N_d$

=area of damper bar per pole/ number of bar per pole.

Short circuit ratio is defined as the ratio of field current for OC to the field current for the SC current.

Short Circuit Ratio = Field current for OC volt / Field current for SC current

SCR $= OF_o / OF_s$,

where OF_o =per unit field current required to develop

rated voltage on open circuit.

OF_s =per unit field current required to develop

rated current on short circuit.

3.3 Design rules upon slots and combinations

The number of poles has to full fill three absolute requirements [2]

1. First of all the pole number must be an even number.

2. Further the number of pole pairs, Pp, in sections, of the machine cannot be a multiple of the phase number, since this would lead to unbalanced windings.

3. The final requirement is that the number of poles cannot be equal to the number of slots. Since this would lead to an undesired cogging torque.

3.4 Design Specification

Chosen specific magnetic loading= 0.5Wb/m^2, specific magnetic loading = 35000A/m and Winding factor=0.955. By using the above calculations mentioned above and taking the assumptions above, the dimensions obtained are,

3.5 Stator Design

Outer Diameter of stator= 240mm

Inner diameter of stator=170mm

Core length= 0.90m.

Pole pitch =0.189m

Pole arc b=0.1273 m.

Peripheral speed of armature Va =25.30 m/s.

Number of slots =30

Slot width=1.9mm

Number of conductors= 720.

Conductor per slot =2

3.6 Rotor Design

Outer Diameter of rotor=170mm

Inner diameter of rotor=140mm

Armature winding terminal voltage= 230V

Number of parallel path = 2.

Current per parallel path Iz =1.71Amp.

Conductor per pole= 120.

Flux per pole Φ =0.05 WB/m^2

Slots per pole arc =4.5578Sa.

Minimum number of coils, Cmin =460.

Net iron length Li=137mm

Air gap length=1mm

Armature current Ia =3.41A.

Remanence Br =11.2 and

Coercivity =10.7

Relative permeability of magnet μr =833.38 x 10^3.

Armature mmf per pole ATa =257.25 A

Magnet reluctance Rm = 4.92 x10^2

Air gap reluctance (Rg)=1.289.g x10^6

Length of coil =2.818m.

Resistance of field coil Rc =164.38Ω

Coil current Ic =1.472 A

Slot fill factor = 4.0597 x10^{-6}

Conductor current density Ja = 2.9A/mm².

Line current I_L = Power/(V*efficiency)=3.588A.

4. CONSTRUCTION OF PMSG IN ANSOFT- MAXWELL

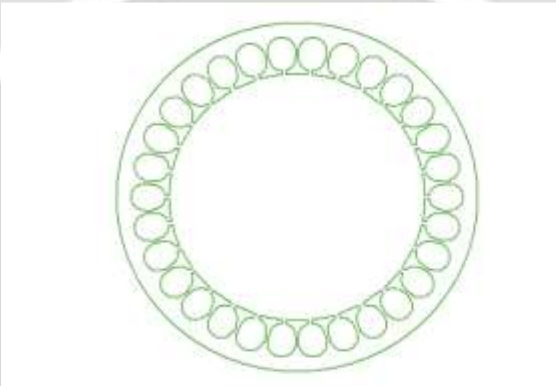

Fig.3: Stator design

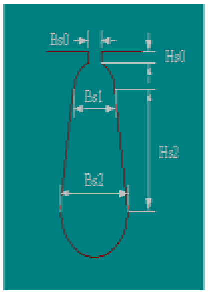

Fig.4:Stator slot design

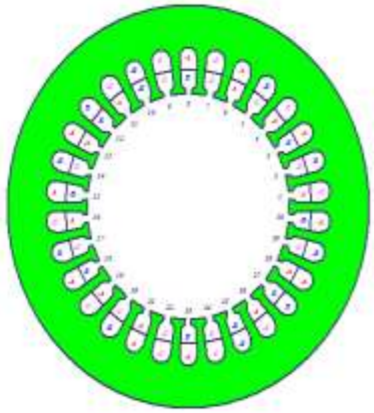

Fig.5: Windings of Stator

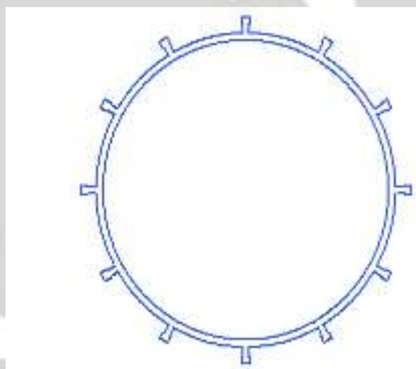

Fig.6: Rotor design

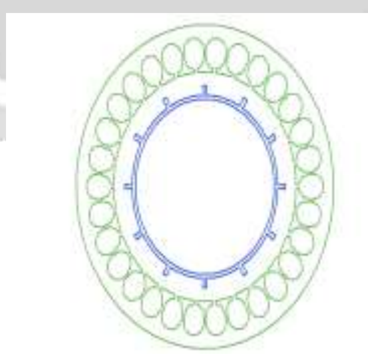

Fig.7: Entire Ansoft-RMxprt Construction

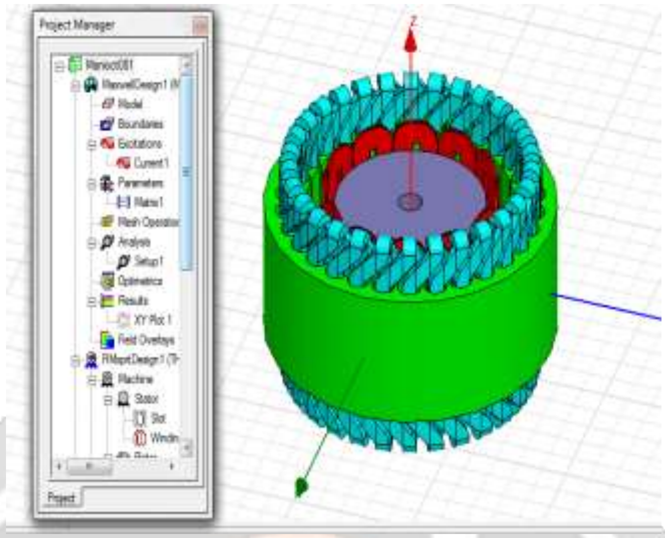

Fig.8: Ansoft RMxprt Construction of PMSG Export to Ansoft- Maxwell 3D Design

4.1 Magnetostatic Analysis

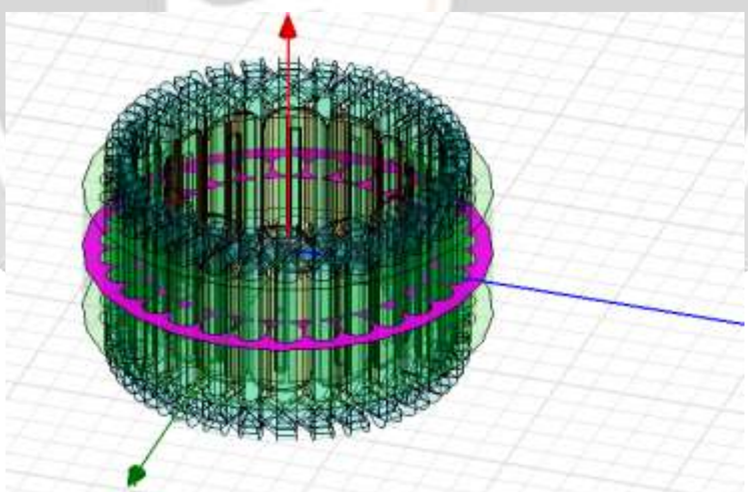

Fig.9: Sectioning of Stator and Rotor for Magnetostatic Analysis

The steps for Magnetostatic analysis involves, (i)The RMxprt construction of permanent magnet synchronous generator is exported to Maxwell 3D design.

(ii)Then this 3D model of PMSG is validated and analysed for the throughout Maxwell construction obtained from RMxprt , boundary condition,and various excitation operations.

(iii)For the magnetostatic analysis we have to section the stator and rotor core in 3D model into number of sections.

(iv)This produces the sections of the 3D model and this section is taken for the magnetostatic analysis.

(v)Select one of the sections and delete other sections. For that section an excitation current is applied.

5. SIMULATION AND RESULTS

Mathematical analysis of Low speed permanent magnet generator simulated by Ansoft Maxwell and RMxprt software. And simulation result are no-load induced winding voltage at line and phase , cogging torque is the torque due to the interaction between the permanent magnets of the rotor and the stator slots , air gap flux density distribution , Power factor, their armature currents are shown.

5.1 Ansoft-RMxprt curves

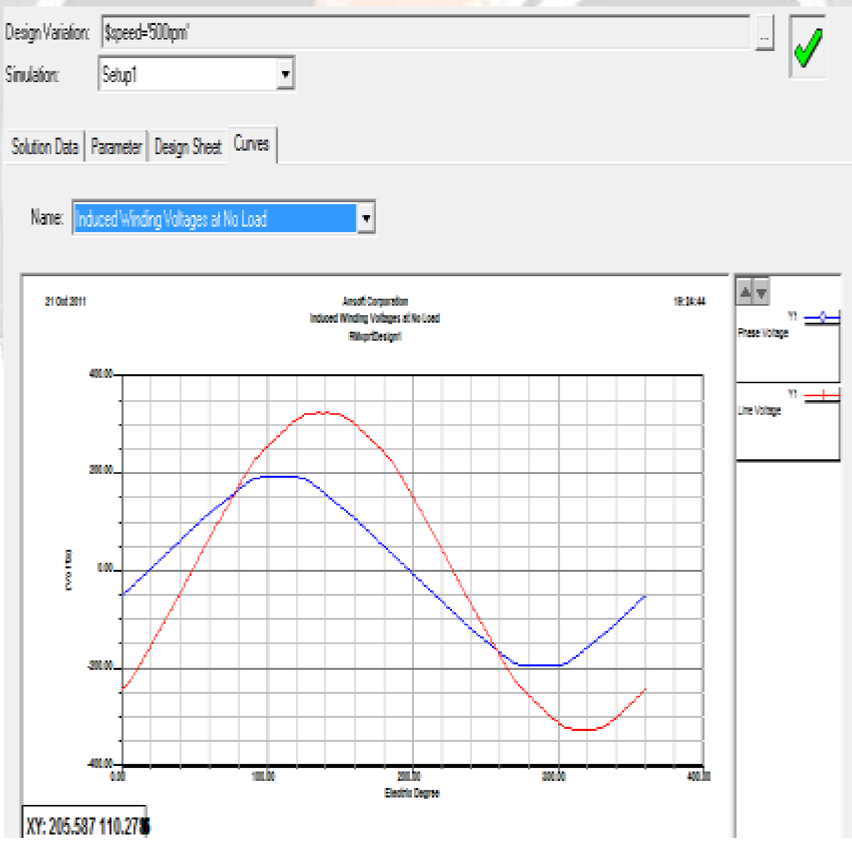

Fig.10: Induced winding voltage at line and phase

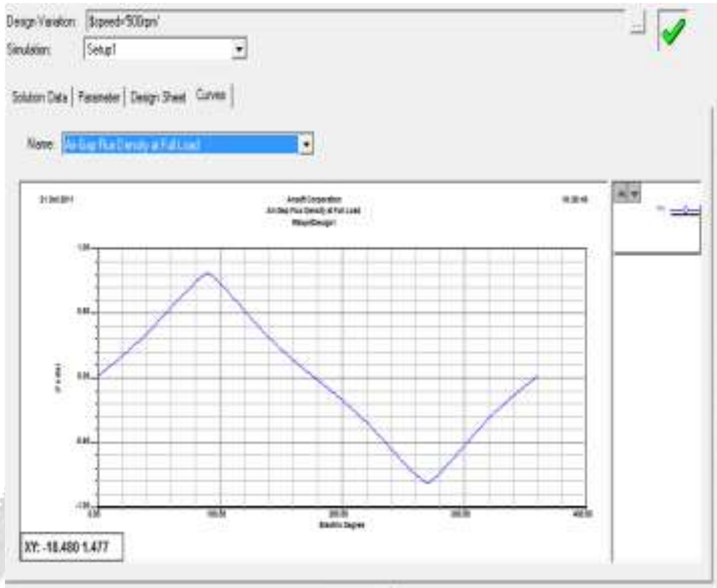

Fig.11: Air-gap flux density distribution

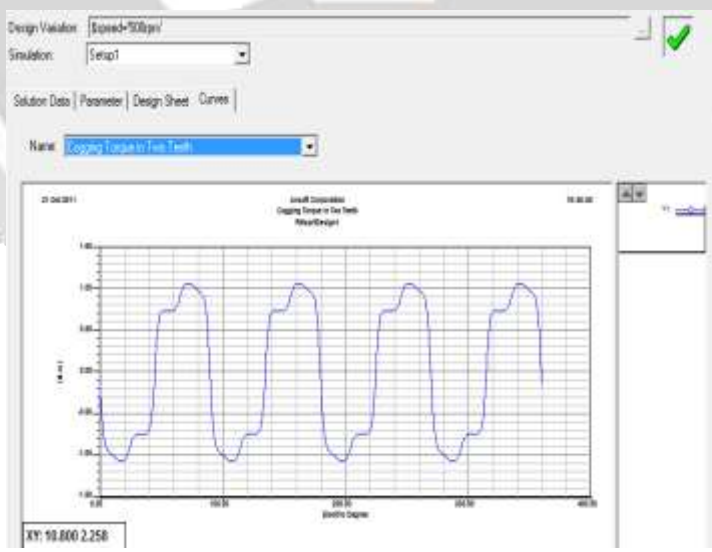

Fig.12: Cogging torque in two teeth

5.2 Ansoft-Maxwell curves

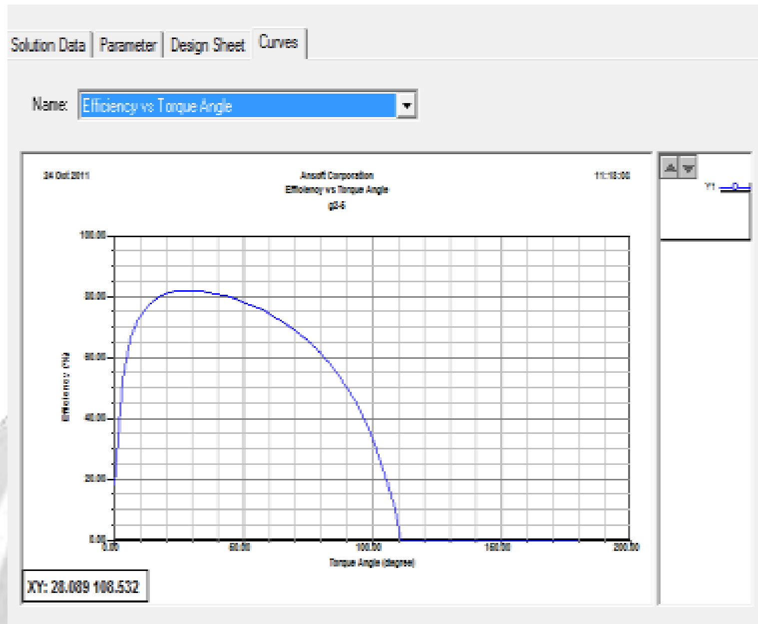

Fig.13: Efficiency Vs Torque angle

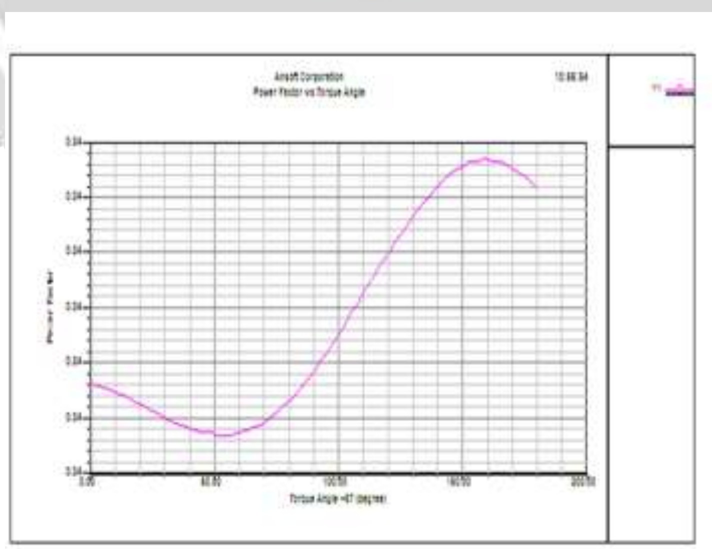

Fig.14: Power factor Vs torque angle

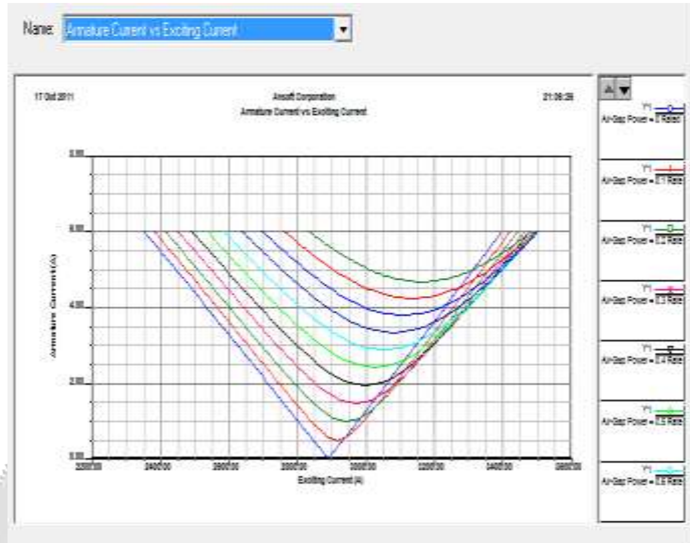

Fig.15: Armature current Vs exciting current

The above **Fig.11**: shows that cogging torque which is the unwanted phenomenon leads to oscillation and torque pulsations in the teeth get reduced to 1N-M , the higher values of this cogging torque produced due to the multi poles cause more noise and also the **Fig.12:** shows the efficiency of this permanent magnet synchronous motor which is obtained as 80%. The **Fig.10:** shows the flux density distribution in air gap, **Fig.9:** shows the sinusoidal phase and line voltage induced in the winding.

6 CONCLUSION

A 1.5 kW , 50Hz, 500 rpm Permanent Magnet Synchronous Generator with multi poles was designed and simulated. The resulted design has produced an efficiency of 80% and with reduced Cogging Torque up to 1N-m which is the undesirable phenomenon at low speeds. And this design approach is useful for low speed wind turbine and in direct drive wind energy systems. This simulation was carried out by Ansoft-RMxprt and Maxwell software which produced an ideal characteristics that is suitable for low speed wind turbines.

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