# Design & Analysis of Axial Flux Permanent Magnet Synchronous Generator

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***Abstract-* An axial flux permanent magnet (AFPM) machine with dual rotors and single air-cored stator is studied in this project. An improved design of an ironless axial flux permanent magnet synchronous generator (AFPMSG) is presented for direct-coupled wind turbine application. The design for a low-speed, direct-drive, axial flux permanent magnet (AFPM) generator with a coreless stator and rotor that is intended for application to small wind turbine power generation systems. The main focus of this study is to improve the power output and efficiency of wind power generation by investigating the electromagnetic and structural features of a coreless AFPM generator. The design is validated by comparing the performance achieved with a prototype. The results of our comparison demonstrate that the proposed generator has a number of advantages such as a simpler structure, higher efficiency over a wide range of operating speeds, higher energy yield, lighter weight and better power utilization than conventional machines. The design and manufacturing processes for coreless axial flux permanent magnet generators are described for low cost rural electrification applications, where local production of small wind turbines is considered. Finally, a prototype machine is fabricated, and experiments are carried out to test its performances by comparing with design topology.**

***Keywords*-AFPM, AFPMSG, PM, AFM, RFM.**

## INTRODUCTION

Since generation of electricity is becoming very important and sensitive issue day by day. As we know wind energy is one of the cleanest, free and cheapest forms of energy. Wind energy is playing a vital role in generation of electricity, mostly in small scale residential or rural areas where electricity is not easily reachable. So the selection of economical and efficient wind generator is become very important topic for research now a days. Therefore many literatures were published on design and analysis of Axial Flux Machines (AFMs). The diverse studies shows that AFMs are become very attractive and cost effective alternatives for Radial Flux machines (RFMs) especially for applications such as small wind power system, aircrafts, compact engine generator sets, hybrid electric vehicles and direct battery charging.

Axial Flux Permanent Magnet (AFPM) machine size and shape are important features in applications where space is limited, so compatibility is crucial. Since PM machines are increasingly become very dominant machines with cost competitiveness of high energy PMs such as Neodymium Iron boron (Nd2Fe14). They are more efficient because field excitation losses are eliminated rotor loss reduction. Hence the generator efficiency is improved and high power density is achieved. 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 generators are most suitable than radial flux PM generators for small wind power applications.

The axial flux permanent magnet synchronous generator (AFPMSG) with high ratio of generator diameter to generator length is one of the appropriate choices in direct coupled wind turbine. Depending on design characteristics and according to the material used in the stator core, AFPMSGs are classified into two types: 1) iron-cored and 2) ironless generators. Compared with iron-cored generators, ironless generators have the advantages of lightweight, high efficiency, no cogging torque, and simple construction. Moreover, in ironless generators, considering the negligible attraction force between the stator and the rotor, the structural mass of the generator is of lightweight and provides reliable design for large generator diameters. However, because of the large effective length of the air gap, which requires a larger amount of PM material, in these generators, the active material cost is higher than iron-cored machines. In other words, the advantages of lower structural mass and higher generator diameter are obtained at the cost of higher active material price.

## LITERATURE REVIEW

Wind power, considered as one of the cleanest renewable energies, is now receiving more and more attention. In some developing countries like China, with the supportive policies of the government, the utility of wind power is growing fast. Many wind power stations with large scale wind turbines have been built to provide electricity to the grid in places with good wind resources. However, in some remote but windy areas where grid is not available, small low-speed stand-alone high-efficiency wind generators can be very attractive for household electrical appliance as well as outdoor monitor equipments. So the selection of economical and efficient wind generator is become very important topic for research now a days. Therefore many literatures were published on design and analysis of Axial Flux Machines (AFMs).The diverse studies shows that AFMs are become very attractive and cost effective alternatives for Radial Flux machines (RFMs) especially for applications such as small wind power system, aircrafts, compact engine generator sets, hybrid electric vehicles and direct battery charging.

An improved design of an ironless axial flux permanent magnet synchronous generator (AFPMSG) is presented for direct-coupled wind turbine application considering wind speed characteristics. For accurate analytical design of the generator, distribution of the flux in all parts of the machine is obtained through a modified magnetic equivalent circuit model of AFPMSG [1].The design for a low-speed, direct-drive, axial-flux permanent-magnet (AFPM) generator with a coreless stator and rotor that is intended for application to small wind turbine power generation systems. The main focus of this study is to improve the power output and efficiency of wind power generation by investigating the electromagnetic and structural features of a coreless AFPM generator. The design is validated by comparing the performance achieved with a prototype. The results of our comparison demonstrate that the proposed generator has a number of advantages such as a simpler structure, higher efficiency over a wide range of operating speeds, higher energy yield, lighter weight and better power utilization than conventional machines. It would be possible to manufacture low-cost, axial-flux permanent-magnet generators by further developing the proposed design [2].

The performance of a coreless stator axial flux permanent magnet generator is calculated by using hybrid method which uses combination of finite element analysis (FEA) and theoretical analysis. The method is then incorporated into a multidimensional optimization procedure to optimally design a large power coreless stator AFPM generator [3]. Small-scale wind power applications require a cost effective and mechanically simple generator for a reliable energy source. The use of direct driven generators, instead of geared machines, reduces the number of drive components, which offers the opportunity to reduce costs and increases system reliability and efficiency. [4]. An axial flux permanent magnet (AFPM) generator with two rotors and single air cored stator is designed and applied for vertical shaft small power off grid wind generating system. In this paper a 1KW, 300 rpm, air cored outer rotor surface mounted AFPM is designed and analyzed [5]. Design and manufacturing process for coreless axial flux permanent magnet synchronous generators are described for low cost rural electrification applications, where local production of small wind turbines is considered [6].

## EXISTING SYSTEM

- **Existing System with Limitations**

Since there are no's of conventional PM generators are available for converting wind energy into electrical energy such as radial flux PM generators (synchronous or asynchronous, induction generators etc.But these conventional Radial Flux PM(RFPM) generators have no's of disadvantages as compared to AFPM generator such as they have low power density ,low torque, high cost, high cogging torque, less efficiency, fixed air gaps, high noise and vibration levels ,low torque to weight ratio and large in size etc.The slotted or non-slotted RFPM generators are also available .But the non-slotted RFPM generator has small aspect ratio (Diameter to length ) results in high core losses. One advantage of this RFPM generator over AFPM generator is that they have better heat transfer.

- **Various Topologies of AFPM Machines**

AFPM generator 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. Many variations in this basic design are possible, including single-sided, double-sided, torus, and multi-disc designs.

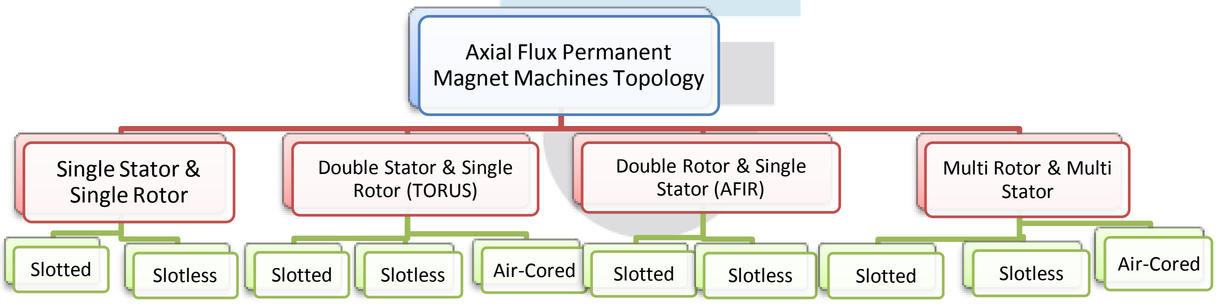


Fig. 1 Various Topologies Of AFPM Machines

## PROPOSED TECHNIQUE

The AFPM generator reduces all the disadvantages discussed above of the existing conventional RFPM generator. Since there are no's of configurations of AFPM generators are available for direct drive small and medium wind power generators such as single rotor single stator, slotted or slotless double rotor single stator(TORUS) and slotted or slotless double stator single rotor also called as Axial Flux Internal Rotor(AFIR) etc. In this dissertation a dual rotor and single air-cored-stator AFPM generator for low speed small wind power application is designed and analyzed. Then performance characteristics are analyzed by testing the model. Finally results are compared.

Single stator and Dual rotor AFPM machine has a PM disc rotor mounted on the rotor surface and coreless stator winding immersed in epoxy resin. The magnetic force may twist the structure very easily. It is subject to unbalanced axial force between rotor and stator, so, unlike structures with balanced axial forces, it requires more-complex bearing arrangements and thicker rotor disk.

## GENERATOR STRUCTURE AND DESIGN CHOICE

**Proposed generator structure**

- Fig 1 shows the constructional view of AFPM generator selected for proposed application with coreless stator winding. The machine configuration consists of the following components: two rotor disks, permanent magnets, stator support, stator housing, windings and bearing.
- The two rotor disks are on both sides of the stator disk. The axially magnetized PMs are glued to the surface of each steel rotor back iron in an N-S-N-S arrangement such that the magnets on one rotor disk are directly aligned with an opposite pole on the other disk. In this way, the completed rotor disks attract each other.

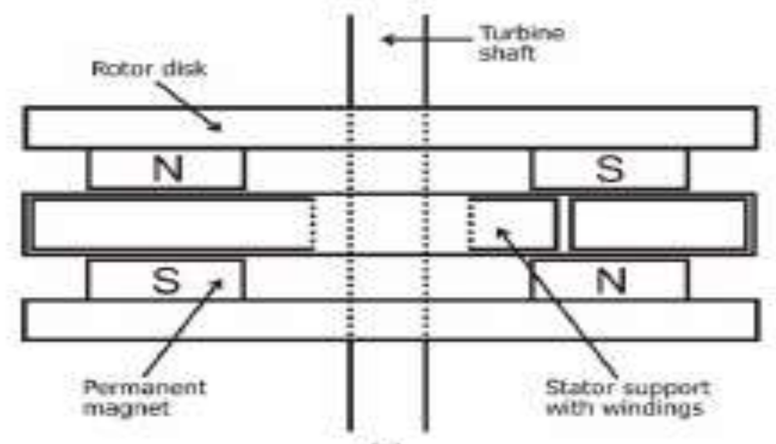


Fig. 2 Constructional View Of AFPM Synchronous Generator

**(a)** **(b)**

Fig. 3 (a) and (b) shows the front view of stator and rotor.

### BASIC OPERATING PRINCIPLE

- According to faraday's law of electromagnetic induction, "Any change in the magnetic flux passing through coil, will induce a voltage in that coil".
- More rapid movement or stronger flux induces a higher voltage in each turn of each coil. The no. of coil turns, flux & rpm are factors on which the voltage produced by the coil is depends. At low speed the coil will produce low voltage.

- When turbine reaches a certain cut-in speed, the voltage is become a nearly enough to charge a battery. Only when the speed is above the cut-in speed the stator feeds current into the battery.
- Generally the electrical output of the turbine will depend upon the strength of the wind and the size of the blades. The blades produce mechanical energy that is converted to electricity by alternator.

### MEASURES FOR COST REDUCTION

- The manufacture of the generator that will meet the requirements requires careful selection of generator configuration, material and manufacturing methods.
- The materials were selected based on two major criteria: availability and cost.
- To fulfill these criteria often means that the generator efficiency has to be sacrificed.
- The Following are the measures implemented to achieve cost Generator Configuration Coreless stator.
- Preformed coils were used which were formed using a simple winding device. This eliminates the need for a winding machine (needle winding machine).
- Surface mounted PM rotor disks

### PERMANENT MAGNET SELECTION

The rare earth magnets, SmCo and NdFeB are become popular because of their greater power density, high conductivity, high flux density and the linearity of their demagnetization curves. NdFeB is preferred because it is cheaper and more readily available. Therefore, NdFeB magnets are selected for use in PMG with some conservatively assumed values.

### MATERIAL AND TOOL SELECTION

- All materials and tools used in the construction of generator need to be easily sourced and at low costs.
- These materials can be easily found anywhere in Maharashtra for exp. In Bhumi Enterprises in pune and wood workshops.
- Back iron disks need to be cut with plasma pantograph router are available in Shalimar Engineers, Faridabad, Haryana.
- Bearing hub required for rotation of generator is a car or trailer hub which can be found in Proton Metal crafts Private Limited, Pune.
- Finally the neodymium magnets (NdFeB) which are the stronger magnets for less volume when compared to ferromagnet are available JR Strong Magnet Pvt. Ltd, Pune
- Polyster resin is a material that can provide support for the stator coils which lay in the air and protection from corrosion for the magnets. It is available in Gayatree Polymers Private Limited, Pune.

### BLOCK DIAGRAM OF AFPM GENERATOR

Fig. 4 shows block diagram representation of AFPM generator, as we can see we can rectify the output voltage of generator to charge the battery. Further we can use bridge inverter to achieve AC voltage, and then we can increase the voltage magnitude by using step up transformer.

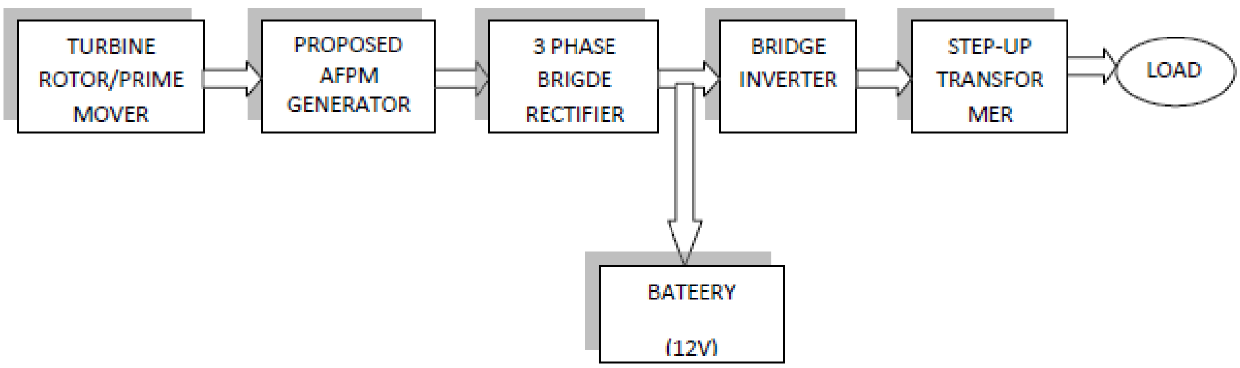


Fig.4. Block diagram representation of AFPM Synchronous Generator Design Parameters

**STATOR AND ROTOR**

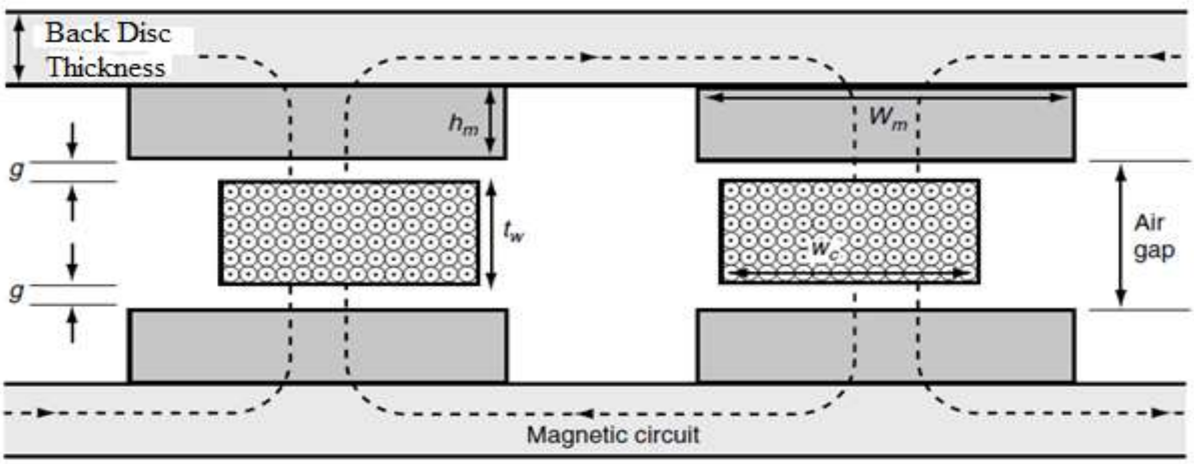


Fig. 5 Axial dimension of the Generator (Rotor Disks & magnets Stator Coils & Clearance)

Magnetic Flux density near magnet surface is given as

$$B_{mg} = \frac{B_r}{1 + \mu_{rrec} \frac{(g + 0.5t_w)}{h_m} k_{sat}}$$

$$\mu_{rrec} = \frac{1}{\mu_0} \frac{B_r}{H_c}$$

Since the maximun flux per pole can be calculated as,

$$\Phi_{\max} = B_{mg} \cdot w_m \cdot l_a$$

Now,using basic equations for electromagnetic induction and assuming almost sinusoidal magnetic flux density,the required turns per coil can be calculated as,

$$N_c = \frac{\sqrt{2}E_f}{q \cdot 2\pi \cdot k_w \cdot \Phi_{\max} \cdot n \cdot p / 120}$$

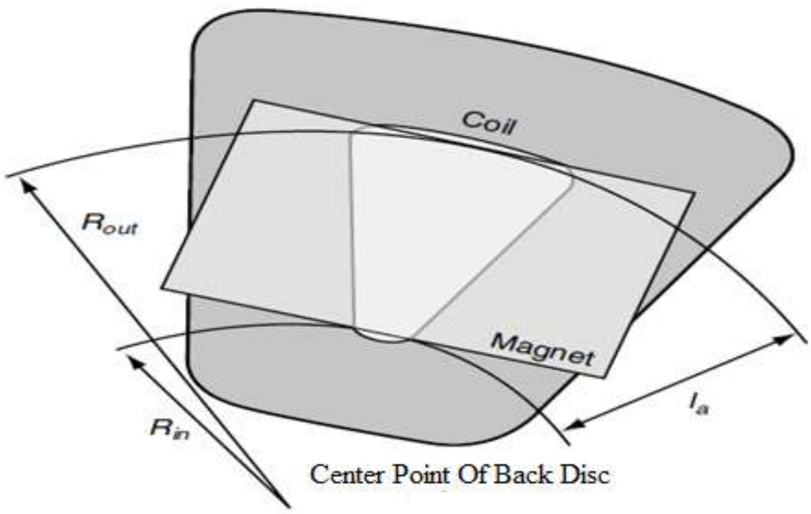


Fig.6 Inner Radius, Outer Radius & Active Length Of Generator

Maximun current density of the winding is considered as,

$$J_{\max} = \frac{I_{ac\max}}{s_c}$$

The cross section area Sc can be calculated as,

$$s_c = \frac{Areacopper}{N_c} = \frac{k_f \cdot w_c \cdot t_w}{N_c}$$

And the copper diameter dc as

$$d_c = \sqrt{\frac{4 \cdot s_c}{\pi}}$$

The inner and outer diameter of the generator can be calculated as,

$$R_{in} = \frac{2Q \cdot w_c + p \cdot w_m}{2\pi}$$

$$D_{out} = D_{in} + 2 \cdot l_a$$

Generator Frequency, Numbers of Pole and Coil Number

The nominal frequency selected in this case is 50HZ.

Number of poles can be calculated as,

$$p = \frac{120 f_{nom}}{n_{nom}}$$

Now the coil numbers can be calculated as,

$$Q=(ai*3P)/2$$

Induced EMF and Power Losses

The RMS value of the electromotive force (EMF) induced by the flux density in the stator phase winding is

$$\text{Erms} = \frac{1}{2}\sqrt{2}\,\text{kwNc}(\text{R0}^2 - \text{Ri}^2)\text{wmBmg}$$

The losses that occur in this type of generator can be grouped into two as,

$$P_{loss} = P_{stator} + P_{rotor}$$

## CONCLUSION

Since the overall performance of a wind power generation system depends largely on the conversion efficiency of the power generator, a coreless AFPM generator is proposed that can be easily integrated into a wind turbine for low-speed applications. The AFPM generators of direct-drive small wind turbines are usually driven at relatively low speeds. Therefore, 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. Coreless configurations feature no ferromagnetic material, as they are subject to much lower structural loads and thus have no need for steel laminations in the stator. This eliminates the associated eddy currents and hysteresis core losses. They all have a lower cogging torque and make less noise while operating. Given the absence of core losses, a coreless-stator AFPMG machine operates at a higher efficiency than a conventional machine, regardless of the rotational speed. In addition, the machine can be made smaller and is cheaper to manufacture.

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