Design of Direct Driven Alternators for Renewable Energy Applications

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Abstract

Permanent magnet generators for renewable energy application have been subject of research during last two decades. Several kinds of rotating electrical generators exist for several applications, including synchronous, induction and DC machines. Doubly Fed Induction Generator is proposed as an alternative solution with respect to the cost of such a system. However, a bigger emphasis in the report has been put on the design of direct driven Permanent Magnet Synchronous Generator (PMSG) to get obtain higher energy conversion efficiency at lower speeds by avoiding gear boxes and this type of PMSGs are compatible for Wind and water Turbines. Further different topologies of direct driven PMSGs with a focus on configurations, different windings and thermal behavior is presented and prototype of a direct driven PMSG is designed and the designs verified by means of Finite Element Analysis (FEA) and thermal modeling size of Direct driven PMSG to obtain optimisation methodology for an. Further describes an analytical optimization of a longitudinal, inner rotor, radial flux, surface mounted PMSG with distributed winding and natural air cooling system. An FEA model of the optimized machine is developed and the results are illustrated.

1. Introductio

Renewable energy turbines like Wind and hydrokinetic turbines are low speed in nature because of the lower fluid velocity. To match the Speed (N) -Torque (T) characteristics of these turbines with alternators, Gear boxes were used and coupled with High speed electric generators result in high starting torque in addition to losses. So designing of direct driven generators will able to match the turbine N-T characteristics without any mechanical power transmission systems like gear boxes, belts, etc. Further, when operating in water, it is critical to not add any new pollutants in the form of oil leaking from gear boxes.

2. Objective

The main objective is to design and optimise low speed permanent magnet synchronous generator working for renewable energy applications. Wind and water turbines work on a variable speed principle. The required topology of PMSG is a surface mounted machine with distributed winding. This type of winding suits for low speed applications since implementing a high number of poles is easy. The major benefit of high pole numbers is the eradication of gearboxes. Gearboxes result in lower availability of the entire system and they cause high amounts of non-user friendly audible noise. Reduction of magnetic noise of the machine is targeted at the design stage. Additionally, the chosen topology can be easily scaled by increasing the length of the machine. Of paramount, at the design stage, the objective function is to reduce manufacturing expenses and cost of active material.

3. Need of direct driven alternators in Renewable Energy Systems (RES)

Water and wind turbines usually low speed in nature. To increase the power conversion efficiency, gear box is required to be avoided or gear ratio can be reduced. It can be done by designing and optimising the direct driven electric generators. Fixed speed electric generators are recommended where the fluid is steady. Variable speed electric generators are required where the fluid flow has kept changing based on environmental conditions. Below are the design challenges of low speed electric generator design. A direct driven RES cannot employ a conventional high speed (and low torque) electrical machines. The weight and size of electrical machines increases when the torque rating increases for the same active power. Therefore, it is an essential task to consider an electrical machine with high torque density, in order to minimize the weight and the size. The PM synchronous machines have a higher torque density compared with induction machines. Thus a However, since the cost effectiveness of PMSG is an important issue, low manufacturing cost has to be considered as a design criterion in further steps. There are a number of different PMSG topologies; some of them are very attractive from the technical point of view. However, some of the state of the art topologies suffesr from complication in a manufacturing process which results in high production costs. PM excitation offers many different solutions. The shape, the size, the position, and the orientation of the magnetisation direction can be arranged in many different ways.

4. Design optimisation methodology

The design of the low speed PMSG is influenced by its rotational speed and power. Typical low speed PMSGs (Fig1) use a rotating field which is excited with more number of rare earth magnets and a stationary winding that produces alternating current. The achievable power of an electrical machine with a radial air-gap between stator to the rotor is roughly proportional to the square of the air-gap diameter and the axial length of the machine at the air-gap, keeping other parameters fixed. On the other hand, the amount of the electromagnetic active material in a high pole-number machine is proportional to the air-gap diameter and its length. This means that, for equal power and rotational speed, a doubling of the diameter approximately halves the need for active material. Furthermore, the power losses within the machine are generally related to the quantity of active material, so that increasing the diameter also would greatly improve the efficiency. Thus,underwater low speed PMSG for low rotational speeds, especially direct drive hydro and wind generators have a large diameter (D) and a short length (La).

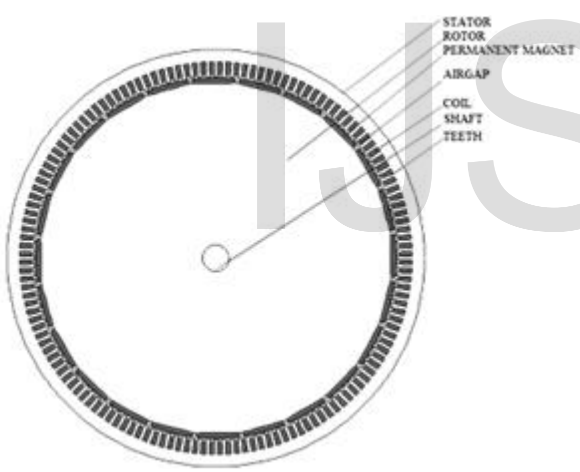

Fig 1 - Cross sectional view of the Direct driven PMSG

Even for a large generator, with a diameter of several meters, the air-gap should not exceed a few millimeters, to avoid excessive magnetisation requirements. This means that the mechanical construction needs to be designed in order to maintain the air-gap against the powerful force of attraction between the rotor and the stator. As can be seen from the figures, the permanent magnet under water alternator is of multi-pole multi-phase type and comprises an internal stator with a plurality of teeth. The teeth are separated by a like number of slots intended to house the windings in which the electromotive force is induced. The alternator also comprises an external rotor, facing the teeth of the stator at its inner surface, a plurality of permanent magnets are applied which are advantageously made of rare earths. The magnets are

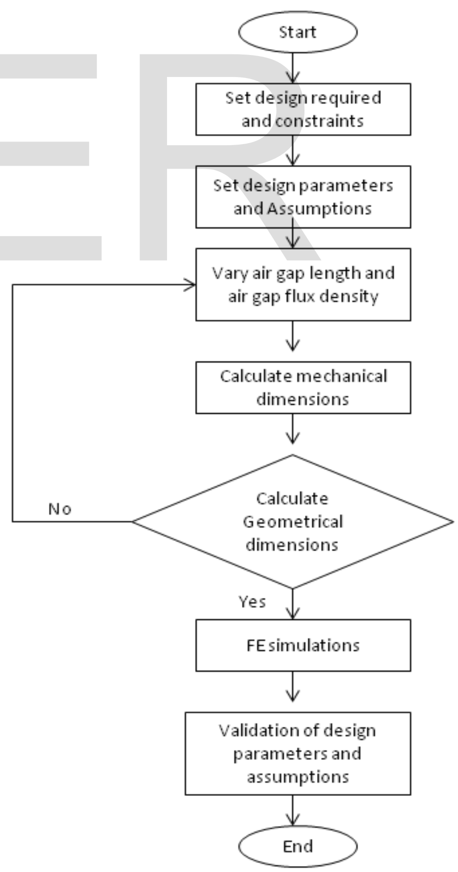

Fig 2 Flow chart for design and optimisation of PMSG

magnetised and trapezoidal shape in cross-section of approximately rounded-corner perpendicular to the alternator axis, with the major base of their two bases being curved concentrically to the axis of the alternator and the minor base being either curved concentrically to the alternator axis and hence be concave, or convex, or flat and perpendicular to the radius of the alternator.

5. Designing of the prototype

A 1kVA PMSG prototype is designed and optimised using the design and optimisation process (Fig 2). Table 1 shows the requirement considered suitable for domestic wind turbine and 1kW hydrokinetic turbine.

Table 1 Design requirements

Capacity (Q)	1000 VA
Terminal Voltage (V)	415V
Rated speed (N)	100 rpm
Number of Phases (q)	3 phase
Number of poles (p)	24
Type of PMSA	Rotating field, Radial flux

6. Material selection

The Active material of the machine includes permanent magnet, steel sheet for the rotor and stator laminations and copper for windings (Table 1). Suitable materials are chosen to provide sufficient electromagnetic performance and average cost.

Table 2 Material list of PMSG

Armature lamination grade	M19 CRNO 0.5 mm stamping
Field lamination grade	M19 CRNO 0.5 mm stamping
Stator windings	Copper
Permanent magnets	MQ2-15-18
Gap between stator and rotor/ Vents	Air
Shaft	SS 316L
Enclosure	Aluminum

7. Results of FEA simulations

The mechanical dimensions of the PMSG were taken as the input of the Alternator designing tool–GenAC (M/s. Magne forces) and motor solve (M/s. Infolytica) software with selected materials (Table 2). The current density of

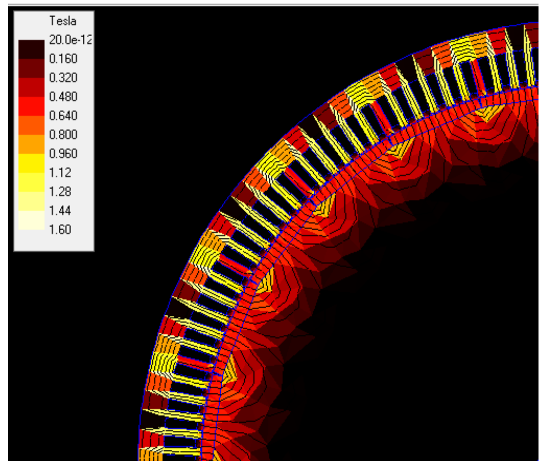

Fig 3 Magnetic flux density of GenAC

the field coils and the magnetic flux density between stator and rotor alternator efficiency test torque sensor were simulated and are shown in Fig 2, Fig3 from the Infolytica results it is found that the B_{av} value lying

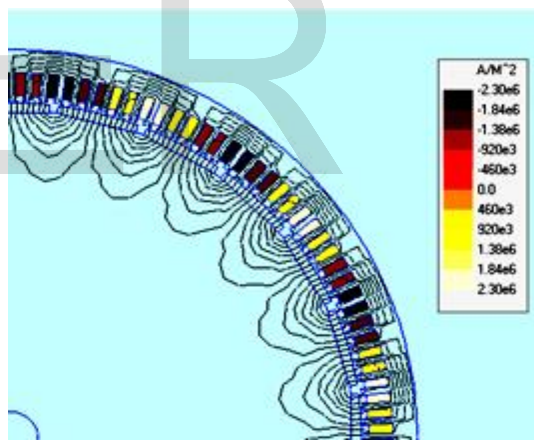

Fig 4 Current density by Gen AC

around 0.85T (Fig 2). Whereas the Gen-AC tool has given the Bav is 0.9 Fig (3).These values are in line with the hand calculation done using analytical relations and empirical equation. Below table shows the design table.

Table 3 design table

Parameter	**Value**
Capacity	1kVA
Efficiency	93.3%
Vline	173.2
Eph	122.4894

Frequency	20 Hz
Speed	1.667 r.p.s
Pole	24
Current	3.33
Slots	144
Number of windings per phase	566 turns
Conductor area	2mm2
Slot width	0.005m
Slot height	0.014m
Stamping	M-19 Steel
Shfat dia	32mm

8. Conclusion

In this work, a surface mounted, radial flux, inner rotor, longitudinal 1kVA direct driven PMSG with distributed winding and natural air cooling is optimised. Active material includes iron, copper and PM material. Selection of topology is based on the design and optimisation process. For instance, to scale up the machine for higher torque rating, the length of the machine can be increased by three times and a new design can be avoided. The optimisation objective function is set to minimize the cost of active material. A FEM model is developed in Gen-AC, Motor solves and the performance are verified. Results from FEM analysis show low harmonic contents in the induced voltage and the air gap flux density. Also by employing a distributed winding a high winding factor of 0.966 is achieved. The efficiency is 93.3 % at nominal load which cannot be obtained with the gear coupled generating system.

9. Acknowledgements

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