COMPARATIVE ANALYSIS OF THE VARIATION OF THE IRON GAP DISTANCE AND THE NUMBER OF POLES IN A DOUBLE ROTOR GENERATOR OF PERMANENT MAGNETS USING FINITE ELEMENTS

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ABSTRACT

Axial flux generators are machines coupled to wind generation turbines, which is why the need arises to analyze new configurations that allow us to face the increase in energy needs worldwide. This document proposes, in analysis, design and simulation of three topologies of a permanent magnet double rotor generator for low speed and low power applications, through the finite element method in 2D in COMSOL software, taking as reference the air gap distance (3mm, 6mm and 9mm) and the effect this has on the flux density, in addition, a variation to the number of poles (8 poles, 12 poles and 16 poles), observing the impact on the output voltage of each of the generators. The results obtained show that the slotted stator topology has a lower decrease in flux density as the air gap increases, while the purely coreless topology presents a better behavior in the output voltage waveform when varying the output voltage. number of poles. The use of the finite element method within the design of new generators allows optimizing the dimensioning of the topologies, in addition, facilitating the possibility of proposing new scenarios that allow observing the behavior of the machine, through changes in the density of flux across the teeth and core of the stator, the voltage generated, and the number of poles.

KEYWORDS: Double Rotor, Halbach Matrix, Air Gap, Generated Power, Finite Elements, Number of Poles

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1. INTRODUCTION

Currently, the importance of renewable energies has increased, due to the growth in energy needs presented in recent years, which raises the search for new power generation solutions coupled to small-scale low-power wind turbines without running risks of loss of excitement. An effective alternative for this are axial flux permanent magnet double rotor generators [1,2].

The term axial flux, arises due to the location of the magnetization of the permanent magnets, since it is oriented axially, producing a magnetic field parallel to the axis of rotation, on which the rotor and stator discs present are supported [3-6]. Furthermore, this generator has several advantages such as a shorter axial length, less but, a more compact structure and an acceptable efficiency at low rotational speed [7,8].

Research on the design and construction of permanent magnet double rotor generators has brought increasing scientific interest in recent years, thanks to its advantages over other machines, and its adaptability for low power or low speed applications, however, There are very few studies about the topologies in applications of low speed and low power for power generation, for this reason, this study proposes the use of the finite element method for the design, analysis and simulation of the various configurations of double rotor , avoiding additional costs or rebuilding a physical prototype.

2. TOPOLOGIES OF AXIAL FLUX PERMANENT MAGNET GENERATOR

An axial flux permanent magnet generator is characterized by the number and arrangement of rotor and stator discs present, in addition, it is one of its main advantages by allowing several possibilities of structure in its stator and rotor, resulting in various topologies, shown in figure 1 [1-4,9]:

Figure 1: Topologies a) One side; b) Double rotor; c) Double stator; d) Multi-disc [4].

A single-sided generator is composed of a rotor disk and a stator disk, however, this topology presents the lowest efficiency and large attractive forces between the disks [3,5,8]. The two-sided generator is composed of a double rotor or a double stator [1], as an advantage it allows to cancel the mechanical forces between the stator and rotor discs during operation, in addition, it is more appropriate for low power applications [1 , 3,8], as a disadvantage it presents attraction between the magnets of the rotors [10]. The multiple disc generator, is composed of several rotor and stator discs [3] [8], presents high power density and good efficiency [11], however, it presents magnetic attraction forces between the stator and rotors, due to the multiple air gaps [7,11].

Figure 2 shows a comparison of the two configurations of the topology of the sides, that is, double rotor and double stator.

Advantages	
Greater space available for the winding and lower iron losses in the rotor [1]. Most used in low speed applications [2]. Better performance, that is, higher efficiency [7,10]. Higher torque density [12,13]. The magnets located in the rotor function as fans [14]	It has a simpler and easier manufacturing process [1,5]. Provides smoother operation during transient operations [1]
Double rotor	Double stator
It has higher copper losses [1]. The rotor surface mounted ferrite topology is heavier than the spoke type, its axial length and outer diameter is larger [2].	Longer axial length [7] Lower performance due to high flux links [7].
Disadvantages	

Figure 2: Comparison between double rotor and double stator.

3. CHARACTERISTICS OF THE TOPOLOGIES

Taking the above information as a reference, when highlighting the characteristics of the double rotor topology in low speed and low power applications, it is proposed to carry out an analysis on the variation of the air gap distance and the number of poles in the 3 topologies proposed in [fifteen].

It is important to highlight that for the 3 topologies a HALBACH type axial magnetization matrix is used, which allows eliminating the distance between the two irons in the rotor discs, where the permanent neomidium magnets are located, since they have a higher efficiency characteristic. , due to which it eliminates field excitation losses, resulting in a significant reduction in rotor loss. Therefore, the efficiency of the generator [1] is improved.

The first topology is a purely coreless configuration (figure 3a), the second topology is a TORUS type configuration without slot (figure 3b) and the third topology consists of a slotted stator (figure 3c) [15].

Figure 3: Topologies: a) Purely coreless; b) TORUS without slot; c) Slotted stator [15].

4. DESIGN OF TOPOLOGIES

The main parameters for sizing a topology are the outer and inner diameter of the rotor, number of poles, number of coils, number of turns per phase, number of turns per coil, number of revolutions, power output, magnetic flux density and output voltage [2,16]. Within the design, it is important to take into account the relationship between poles and coils for a suitable choice depending on the application [3], and the value of the air gap, especially in the case of a slotless stator, since this can determine the effectiveness of the generator especially in topologies with stator without slots [16]. In addition, to consider the symmetric distribution of the magnets and coils along the circumference of the rotor and stator discs [1, 16].

The criteria for sizing the topologies, by varying the number of poles, are a maximum output power of 10 watts, a wind speed of 1.8 m / s, a maximum outer rotor diameter of 300mm and an area transverse conductor of 0.326mm² (22 AWG.), with which the design is made taking as a reference what is stated in [15] and Figure 4, which shows the relationship between the design parameters.

Figure 4: Relationship of design parameters.

For the purely coreless topology, taking into account the final accommodation of the concentrated trapezoidal winding, an outer rotor diameter of 250mm is chosen, and the induced voltage expected for this topology is 10 volts. 8,12 and 16 poles are chosen, the dimensions obtained are shown in table 1.

Table 1: Pure coreless topology dimensions for 8,12,16 poles.

Parameter		Dimenssions		
External diameter	D_{outer}	250 mm	250 mm	250 mm
Inside diameter	D_{inner}	140 mm	140 mm	140 mm
Number of poles	$\# poles$	12	8	16
Number of coils	N_C	9	6	12
Coils per phase	N_{BP}	3	2	4
Air gap	g	3 mm	3 mm	3 mm
Outer pole passage	Pp_{outer}	65,45 mm	98,17 mm	49,09 mm
Inner pole passage	Pp_{inner}	36,65 mm	54,98 mm	27,49 mm
Synchronous speed	N_s	137,51 rpm	137,51	137,51
Frequency	f	13,75 Hz	9,17 Hz	18,33 Hz
Number of turns	N_{CP}	270	270	270
Long IP	IP_{large}	55 mm	55 mm	55 mm
Outdoor wide IP	$IP_{outwide}$	16,36 mm	24,54 mm	12,27 mm
High IP	IP_{high}	7 mm	7 mm	7 mm
Indoor wide IP	IP_{inwide}	9,16 mm	13,74 mm	6,87 mm
High stator	$Stator_{high}$	7 mm	7 mm	7 mm

For the TORUS topology without slot, a rotor outer diameter of 250mm is maintained, and a stator outer diameter of 240mm, taking into account the type of winding to be used. The induced voltage for this topology is 18 volts, 8,12 and 16 poles are chosen for the design. Table 2 shows the dimensions obtained for this configuration:

Table 2: Dimensions TORUS topology without slot for 8,12,16 poles.

Parameter		Dimensions		
Rotor outer diameter	D_{outer}	250 mm	250 mm	250 mm
Rotor inner diameter	D_{inner}	140 mm	140 mm	140 mm
Number of poles	# poles	12	8	16
Number of coils	N_C	9	6	12
Coils per phase	N_{BP}	3	2	4
Air gap	g	3 mm	3 mm	3 mm
Outer pole passage	Pp_{outer}	65,45 mm	98,17 mm	49,09 mm
Inner pole passage	Pp_{inner}	36,65 mm	54,98 mm	27,49 mm
Synchronous speed	N_s	137,51 rpm	137,51 rpm	137,51 rpm
Frequency	f	13,75 Hz	9,17 Hz	18,3 Hz
Number of turns per phase	N_{CP}	525	525	525
Long IP	IP_{large}	55 mm	55 mm	55 mm
Outdoor wide IP	$IP_{outwide}$	16,36 mm	24,54 mm	12,27 mm
High IP	IP_{high}	13 mm	13 mm	13 mm
Indoor wide IP	IP_{inwide}	9,16 mm	13,74 mm	6,87 mm
High stator	$Stator_{high}$	12 mm	12 mm	12 mm
Stator outer diameter	$D_{outerstator}$	240 mm	240 mm	240 mm
Stator inner diameter	$D_{innerestator}$	150 mm	150 mm	150 mm
Coil height	$Coil_{high}$	4 mm	4 mm	4 mm

For the slotted stator topology, a rotor outer diameter of 250mm is maintained, and a stator outer diameter of 240mm, the induced voltage for this topology is 63 volts and 8, 12 and 16 poles are chosen for the design. Table 3 shows the dimensions obtained for this configuration:

Table 3: Slotted stator topology dimensions for 8,12,16 poles.

Parameter		Dimensions		
Rotor outer diameter	D_{outer}	250 mm	250 mm	250 mm
Rotor inner diameter	D_{inner}	140 mm	140 mm	140 mm
Number of poles	# poles	12	8	16
Number of coils	N_C	9	6	12
Coils per phase	N_{BP}	3	2	4
Air gap	g	3 mm	3 mm	3 mm
Outer pole passage	Pp_{outer}	65,45 mm	98,17 mm	40,09 mm
Inner pole passage	Pp_{inner}	36,65 mm	54,98 mm	27,49 mm
Synchronous speed	N_s	137,51 rpm	137,51 rpm	137,51 rpm
Frequency	f	13,75 Hz	9,16 Hz	18,33 Hz
Number of turns per phase	N_{CP}	420	420	420
Long IP	IP_{large}	55 mm	55 mm	55 mm
Outdoor wide IP	$IP_{outwide}$	16,36 mm	24,54 mm	212,27 mm
High IP	IP_{high}	13 mm	13 mm	13 mm
Indoor wide IP	IP_{inwide}	9,16 mm	13,74 mm	6,87 mm
High stator	$Stator_{high}$	12 mm	12 mm	12 mm
Stator outer diameter	$D_{outerstator}$	240 mm	240 mm	240 mm
Stator inner diameter	$D_{innerestator}$	150 mm	150 mm	150 mm
Coil height	$Coil_{high}$	6 mm	6 mm	6 mm
Slotted width	s_{wide}	20 mm	20 mm	20 mm
High slotted	s_{high}	6 mm	6 mm	6 mm

5. RESULTS

The flux density for the three topologies is shown in Figures 5 to 13, taking into account a variation for the air gap distance of 6mm and 9mm, in each of the double rotor topologies.

The simulations for the flux density of topology 1 are presented in Figure 7, in which it is observed that having an air gap of 3 mm, an approximate value of 0.8 tesla is obtained in the stator. From Figures 8 and 9, by increasing this distance every 3 mm, it is observed how the flux density decreases in the stator and from 9 mm, a minimum value of 0.2T is already obtained. The flux density at the magnetic poles also decreases to a lesser extent and remains at a value greater than 1.4T in all cases.

Figure 5: Topology 1 with 3mm air gap [15].

Figure 6: Topology 1 with 6mm air gap.

Figure 7: Topology 1 with 9mm air gap.

The flux density of topology 2 with an air gap of 3 mm is shown in figure 10, in which it is observed that an approximate value of 0.9T is obtained in the stator, while when increasing the distance of the air gap the field decreases drastically by 6 mm, and from 9 mm a value of 0.5 T is already reached in the stator (figures 11 and 12). The same happens with the field density at the magnetic poles of the rotors.

Figure 8: Topology 2 with 3 mm air gap [15].

Figure 9: Topology 2 with 6mm air gap.

Figure 10: Topology 2 with 9mm air gap.

The flux density of topology 3 with an air gap of 3 mm is shown in Figure 13, in which it is observed that an approximate value of 1.1T is obtained in the stator. From figures 14 and 15, it is obtained that this topology presents the least variation of the flux density in the stator, since, with an air gap distance of 9 mm, a value of 0.8T is achieved, the same it happens with the density at the magnetic poles.

Figure 11: Topology 3 with 3 mm air gap [15].

Figure 12: Topology 3 with 6mm air gap.

Figure 13: Topology 3 with 9mm air gap.

The results of the simulations for topology 1 by varying the number of poles are shown in Figures 14 to 16, where it is evidenced that a decrease in the number of poles increases the waveform deformation of the output voltage, while an increase in The poles for this topology allow a waveform closer to a sinusoidal one, maintaining the same phase shift for the 3 waves independent of the number of poles.

Figure 14: 1-12-pole topology: a) No-load voltage; b) Voltage under design load [15].

Figure 15: 1-8 pole topology: a) No-load voltage; b) Voltage under design load.

Figure 16: 1-16 pole topology: a) No-load voltage; b) Voltage under design load.

The results of the simulations for topology 2 to the varial number of poles are shown in Figures 17 to 19, where it is evidenced that a decrease in the number of poles causes a slight flattening in the waveform where they intersect, while that an increase in the poles for this topology improves the waveform especially under load, decreasing the distortion a little.

Figure 1: Topología 2-12polos: a) Voltaje en vacío; b) Voltaje bajo carga de diseño [15].

Figure 2: Topología 2-8polos: a) Voltaje en vacío; b) Voltaje bajo carga de diseño.

Figure 3: Topología 2-8polos: a) Voltaje en vacío; b) Voltaje bajo carga de diseño.

The results of the simulations for the topology 3 al varial the number of poles are shown in figures 20 to 22, where it is evidenced that a decrease in the number of poles increases the distortion in the voltage waves, while an increase in the poles for this topology improves the waveform only under load, therefore reducing distortion.

Figure 20: 3-12-pole topology: a) No-load voltage; b) Voltage under design load [15].

Figure 21: 3-8 pole topology: a) No-load voltage; b) Voltage under design load.

Figure 22: 3-16 pole topology: a) No-load voltage; b) Voltage under design load.

6. CONCLUSIONS

A purely coreless design, and with a slotted stator, presents better behavior when varying the distance of the two air gaps and the number of magnetic poles present in the double rotor topology, on the contrary, in a design without a slot, due to exposure of the conductors at the flux densities present in the generator, a greater effect is evidenced for small variations in the air gap distance and the number of poles, which causes eddy currents in the conducting wires, resulting in greater copper loss and the core.

Thanks to the symmetry of the proposed topologies, the variation in the number of poles occurs in a variation, especially in the generator's working frequency, and in the waveform of its output voltages. In the purely coreless topology, an increase and decrease in the poles affects the distortion and the waveform, however, the value of the output voltage, remains very close both in no-load and under load, while for the topology of slotted stator, an increase or decrease in the magnetic poles, causes an increase or decrease in the output voltage.

Increasing the air gap distance has a lesser effect on topology 3, due to the slotted stator and short end teeth, as it minimizes the air gap present between the discs, and causes an increase in power density. While for the topology an increase in the gap has a great impact on the power density in the stator, since doubling it reduces the density drastically.

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