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Simulation and Analysis of the Magnetic Flux of an Electric Generator for Microgeneration

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ABSTRACT

In this work, the digital modeling of an electric generator for microgeneration of energy is done, as well as the behavior of the magnetic flux in the generator is shown. This is done with the aim of analyzing the viability of using an energy generating system, driven by the continuous flow of passersby on a surface, from the study approach and the elements that make up the machine. The development of the analysis is based on simulation with the help of software that operates with the finite element method. This is done with the purpose of knowing the behavior of the magnetic flux in the generator, to determine the main parameters involved in the electric power generation process in this type of generators.

KEYWORDS: *Simulation, Digital modeling, Electric generator, Microgeneration, magnetic flux.*

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I. INTRODUCTION

Throughout history the use of electricity has become the main point of operation and development of human societies. It was not until the 19th and 20th centuries when man discovered how to take advantage of the energy contained in fossil fuels, such as natural gas, oil, coal, etc. This fact allowed to accelerate the production processes of millions of companies, giving rise to the industrial revolution.

Today, there is a considerable increase in energy demand to meet the needs of large populations in different cities. In addition, a great dependence on fossil fuels has been created, however, it is known that the reserves of these fuels are finite, and in the long term they will finally be depleted. In turn, the use of these energetic elements generates high amounts of carbon dioxide, the most important anthropogenic (generated by people) with a notable alteration of the greenhouse effect. With the above, a new panorama is envisioned where the implementation of renewable systems that are not limited in terms of resources to obtain electricity, can represent a large part of the energy supply following the principles of sustainability and efficiency.

Currently, renewable energy technologies have presented a great development in different global regions, with the presence of bioenergy, hydroelectricity, wind, among others, one of the most important being solar energy. Renewable energy sources are generally considered sustainable for the simple fact of being inexhaustible, and it is unlikely that the rate of exploitation carried out by man will approach the rate of replacement of nature. However, the use of this type of energy is subject to various technical limitations [1].

It is notable that renewable energies are favorable in the sense that their social and environmental impact is friendlier than that of fossil fuels, however, renewable sources are less concentrated than those of fossil fuels, so that large areas are required. for your production. This entails a greater visual impact as is the case with wind turbines. Likewise, the monetary cost of some renewable sources is higher than traditional fuels, so it is necessary to reduce this economic gap directly affected by the increase in the price of fossil fuels, a situation that has been occurring in recent years. In this way, renewable sources begin to attract an important part of the world market.

Considering the aforementioned and in the current context, where the increase in the price of energy is constant, microgeneration has a promising future in both industrial and non-industrial sectors [2].

Microgeneration is the development of small generation centers located as close as possible to the consumption center. It is the generation of electrical energy on a small scale that can be obtained mainly from the wind or the sun, however, there are other ways to obtain it, such as piezoelectricity.

II. GENERATOR CONSTITUTION

Next, the proposed type of generator is shown that will be modeled considering an application of power generation by the flow of people in a certain area. This type of generators adapts to a type of tiles that are placed on the floor. Mainly consists of a rotor and a stator. The outer diameter of the rotor is smaller than the inner diameter of the stator, thus allowing the rotor to rotate freely, thus presenting a continuous and uniform air gap. Both the stator and the rotor are constructed of highly permeable materials, so the reluctance of each is negligible compared to the reluctance of the air gap.

For the generator to be analyzed, the magnetic field is produced by a series of permanent magnets where the main advantage is that an external excitation system is not required, allowing the machine to be smaller and not show any type of energy consumption. Figure 1 shows the distribution of the coils, where the induced electromotive force is found. The coils are positioned on the generator stator.

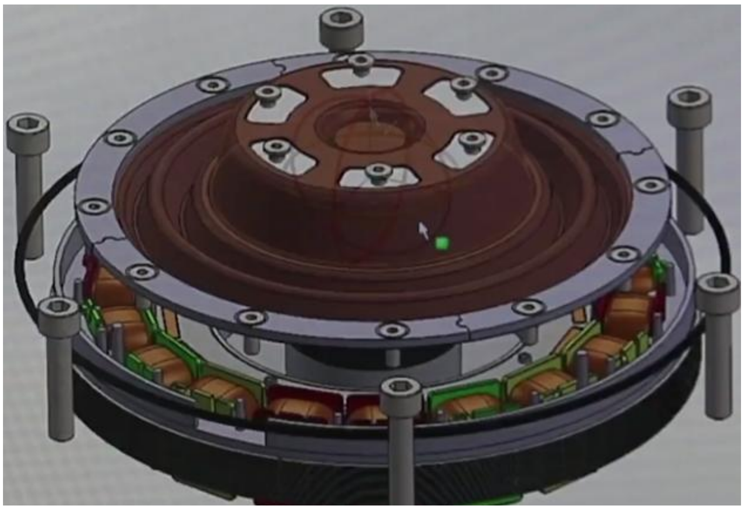
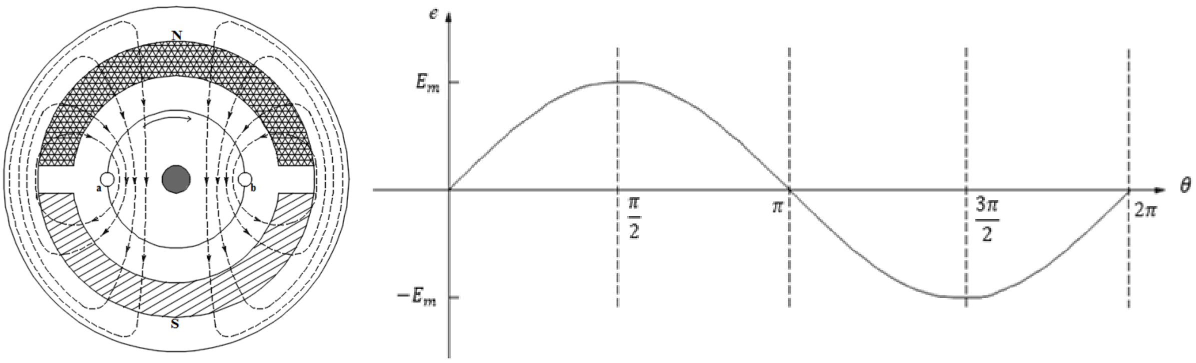


Figure 1. Scheme of the proposed electric generator [4].

It is considered a coil of one turn placed in a constant magnetic field established by two permanent magnets. Figure 2a) shows the two sides of the coil placed diametrically opposite in such a way that the flow through the area of the turn is maximum. When starting from a maximum flow as a reference, the rate of change of this is zero, therefore, the induced electromotive force *(emf)* is zero.

As the coil rotates, the flux that is linked in it decreases causing this change to generate an electromotive force, whose current will flow in a direction such that it establishes a magnetic field in order to oppose the reduction in the flux that passes through the coil.



a) b)

Figure 2. a) A coil of one turn placed in a constant magnetic field. b) Induced voltage in the coil.

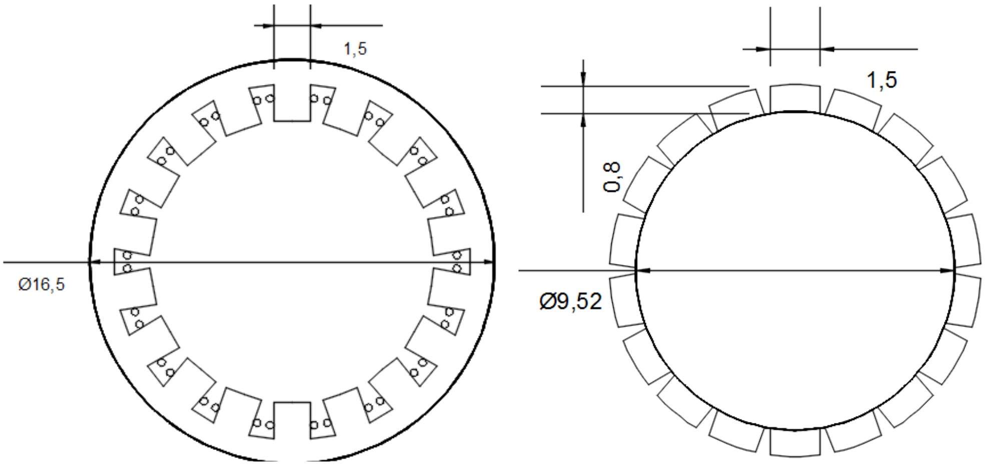
Assuming that the coil has rotated *90* mechanical degrees from its initial position, the flux that links is minimal, however, the rate of change is maximum so the voltage at this point would be maximum. If the rotation continues, the flow will present an increase, so the rate of change will decrease until it reaches zero and it will repeat the same process with the difference that the polarity of the induced *emf* will be the opposite of the first phase. Thus, it is possible to generate alternating electrical voltage from the relative movement of a coil and a magnetic field [5, 6, 7]. Figure 2b) shows the voltage signal induced in the coil by the movement of the magnetic field.

III. GENERATOR GEOMETRY

It is convenient to estimate the generator measurements considering a tile application in such a way that the number of grooves in the stator is the maximum allowable for the generation of higher magnitude voltage levels. The proposed generator has a circular geometry like conventional generators, with the difference that its dimensions are considerably smaller than those of a common machine. It consists of a stator and a rotor mechanically coupled to each other, allowing the free rotation of the rotor within the area comprised by the stator.

It is important to mention that the linear to rotational motion transfer mechanism is not shown in the generator diagrams as the analysis approach is purely electrical and magnetic. Its existence is taken for granted and the simulation focuses on the behavior of the elements that directly intervene with the generation of electrical energy.

Figure 3 shows the main geometry and dimensions of the generator stator and rotor. The stator has a diameter of *16.5 cm* and *18 slots*, each *1.5 cm* wide, on which the coils are placed, figure 3a). The generator has *18 magnets* on the rotor that alternate their polarity based on their location, and will directly affect *18 coils* wound in *18 slots* in the stator.



a) b)

Figure 3. Generator main geometry: a) Stator. b) Rotor.

The rotor has a diameter of *9.52 cm* and *18 poles* each *1.5 cm* wide corresponding to the dimensions of the slots in the stator, figure 3b). The dimensions of the rotor were based on the distribution of the *18 magnets* placed uniformly in the circumference comprised by the internal area of the stator. Each magnet has a width of *1.5 cm* and the diameter of the surface where they are mounted is *9.52 cm.*

IV. CONSIDERATIONS OF DIGITAL MODELING

For the execution of the simulation, certain considerations were taken into account, in order to facilitate information processing and simplify the study:

- It is suggested that there is a wound coil per slot, so there are 18 coils in the stator. For simulation purposes, each coil has a single turn, which are connected in series to obtain a considerable voltage level.
- In order to be able to observe the behavior of the machine and the generated voltage curve, the speed at which the machine rotates is 60 rpm. This speed is a requirement for the model to function properly.
- It is considered that the generation occurs on the coil sides.
- The material selected for the stator and rotor cores will not present magnetic saturation and therefore there will be no losses.

Permanent Magnets: It was assumed that the permanent magnets that are the source of the magnetic flux that will allow the induction of an electromotive force in the coils, are made of neodymium, due to its high magnitude of remanence B_r and its high coercivity H_c.

According to the required dimensions and seeking to obtain the highest possible remanence, it is assumed that the rotor magnets are neodymium magnets, with dimensions of *15 mm* wide by *15 mm* long by *8 mm* high, block type, with nickel plating, B_r remanence between *1.29 to 1.32 Teslas[T]* and *N42* magnetization.

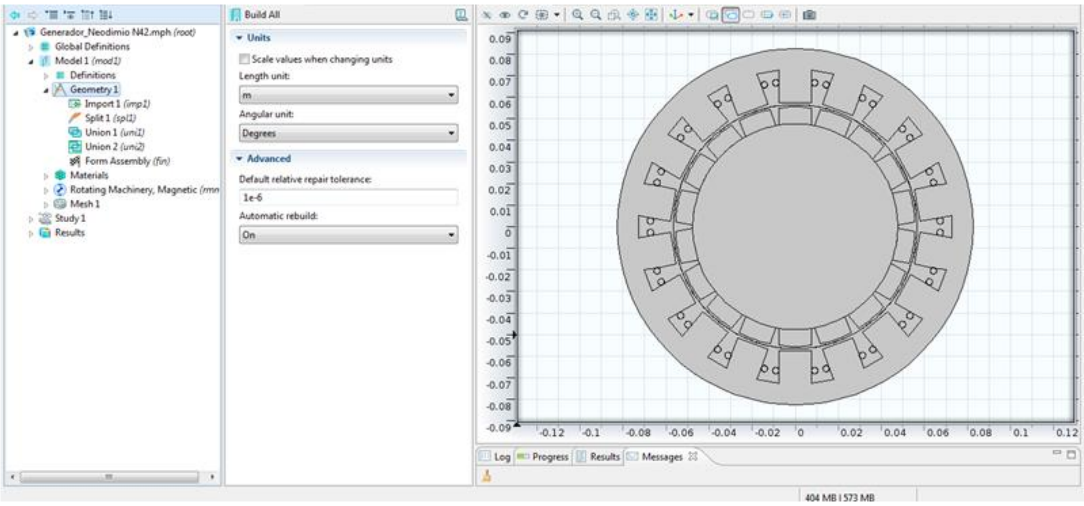
The designation *N42* is a relative measure of the quality of the material used in the manufacture of the magnet. The 42 corresponds to the maximum energy product of the magnet being approximately *334 kJ / m*^{2} while the letter *N* refers to the maximum temperature of use, which in this case the magnet can be exposed to temperatures of up to *80° C.*

V. DIGITAL MODEL

For the realization of the digital model it is required to follow a series of steps and program configurations in order to guarantee that the system converges correctly to the desired study. The steps used in setting up the digital model are shown below:

CAD File

To begin the digital modeling begins with the import of the *CAD* file (*Computer-Aided Design*) that contains the geometry of the system. It is established that the unit of length with which the software interprets the scheme is in meters and the rotor and stator are indicated as two separate geometric objects in order to create an assembly and define the identity pairs, figure 4. The dimensions of the device are set from the *CAD* software in which the geometry is made.



Units

☐ Scale values when changing units

Length unit: m

Angular unit: Degrees

Advanced

Default relative repair tolerance: 1e-6

Automatic rebuild: On

Figure 4. CAD file import and execution of Boolean operations.

Parameters definition

Once the geometry is configured, the parameters that the model operates on are entered. The length of the turn in third dimension is *0.015 m*, the same as the length of the magnets, while the rotation speed of the machine is set to *60 rpm*, since in this way one revolution per second is presented, which allows the program to obtain sequential data on the behavior of the flux density, as well as the voltage generated in the coils.

Model couplings

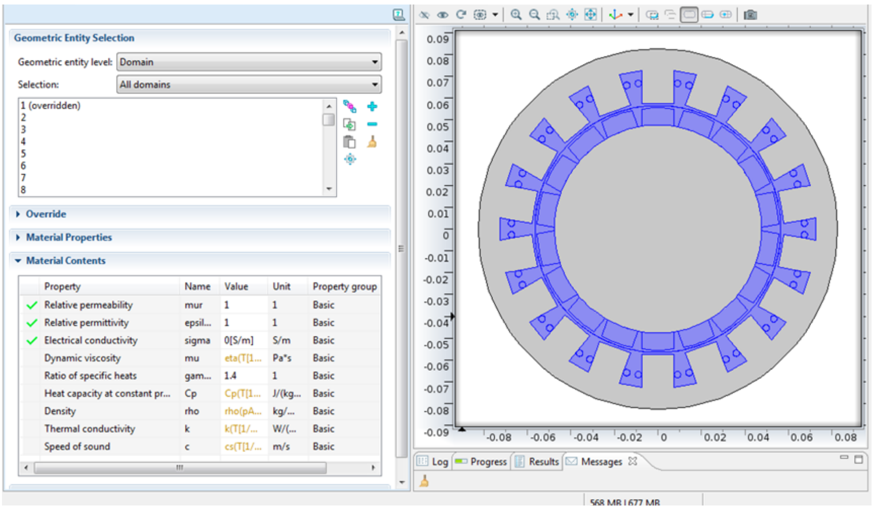
A model coupling establishes the relationship between different parts of the model. The relationship is established by means of operators that take an expression as their argument. For the consideration of the coils in the stator of the machine, an integral type coupling is generated which represents the connection of the arguments of each domain belonging to a conductor section of each coil per slot. Since each turn has two connection terminals, two integration couplings are created, representing the connections with the adjacent turns. That is, a coupling is also generated for the left hand turn section, which finally represents the series connection between all the windings. A third coupling represents the surface variable in which the electric field manifests.

Rotation settings

Because the machine exhibits rotational motion, a speed setting is applied to the rotor. It is determined that the rotation speed of the machine will be that established in the *rpm* parameter. The domains selected to present movement are those corresponding to the rotor core, the permanent magnets and the air between the poles.

Materials configuration

In the *software*, the materials node displays the library of options with which the model can be configured. It is arranged that the space in which the magnets and the coils are immersed, as well as the air gap and the space between grooves is air. Figure 5 shows the selection of domains to determine the air immersed space of the machine.



Geometric Entity Selection

Geometric entity level: Domain

Selection: All domains

1 (overridden)
2
3
4
5
6
7
8

Override

Material Properties

Material Contents

	Property	Name	Value	Unit	Property group
✓	Relative permeability	mur	1	1	Basic
✓	Relative permittivity	epsil...	1	1	Basic
✓	Electrical conductivity	sigma	0[S/m]	S/m	Basic
	Dynamic viscosity	mu	eta(T[1...	Pa*s	Basic
	Ratio of specific heats	gam...	1.4	1	Basic
	Heat capacity at constant pr...	Cp	Cp(T[1...	J/(kg...	Basic
	Density	rho	rho(pA...	kg/...	Basic
	Thermal conductivity	k	k(T[1/...	W/(...	Basic
	Speed of sound	c	cs(T[1/...	m/s	Basic

Figure 5. Specification of regions in air.

In the same way, the domains corresponding to the regions of the generator constituted by a flux-conducting magnetic material are selected.

Permanent magnet and core properties

A mean remanence value B_r is taken for the assumed magnets. Since it is desired to represent the remanence quantity as a radial field, a new cylindrical coordinate system is generated. The *Ampere Law node* is used to define the magnetic characteristics of the magnets. It is considered that *9* of the *18 magnets* in the rotor present the section with the north polarity to the outside of the machine and the remaining *9* the section with south polarity. For both cases, the temperature of the medium is set at *20°C* and a pressure of *1 atmosphere*. For the configuration of the remaining flux density per magnet, the created cylindrical coordinate system is selected, and a value of *1.3 [T]* is entered.

In the same way, the *Ampere Law node* is used to configure the *9 remaining magnets* that will be the south poles of the rotor. For the configuration of the core characteristics, only the domains belonging to it are selected, the same temperature and pressure conditions are applied that were configured for the poles and the magnetic field relationship will depend on the *HB curve* option in the material.

Since the geometry of the model is an assembly, in order to relate the two border sections between the magnets and the cores, the identity pair option is selected. This indicates that both regions overlap and are related on the same interface.

Mesh structure

For the selection of the meshing, the adaptability of the network to the geometry of the system is considered, for this reason the type of *mesh* defined to parameterize the geometry and behavior of the generator is of the *Free Triangular* type. The type of mesh suitable for conducting the dynamic study must meet the requirement of being susceptible to stretching, allowing the program to compile while exhibiting flexibility with the movement of the rotor. A predefined mesh of *coarser* type is selected.

Time dependent study

A stationary study is established, which allows observing the behavior of the magnetic flux through the grooves and cores. However, the main phenomenon starts from a rotational movement that travels a certain distance in a certain time, which gives rise to an induced *emf* as a function of time. This is why it is necessary to add a type of *Time Dependent* study, analyzing a time lapse that shows the generation of energy present in the coils.

To define the time to be analyzed, it is necessary to know the period of the tension generated in the machine. The following equation as a function of the period of the electrical signal indicates that:

$$T = \frac{120}{nP} = \frac{120}{(60)(18)} = 0.1111\ [s]$$

With a rotation speed of *60 rpm* and *18 pole* generator. In this way, the analysis period will be from *0 to 0.11 [s]*, in intervals of *0.01 [s]* allowing to observe in *11 iterations*, the flow in the generator and the voltage signal produced.

Setting variables

The *Global Definitions* node, in addition to configuring the parameters to which the simulation operates, allows you to enter in the variables tab the expressions that describe the *induced emf* based on the generated couplings and the established parameters. Parameters such as the induced voltage in the coil and the area of the conductor.

Running simulation

With the defined parameters and the configurations adapted to the dynamic study of electrical energy production by means of a generator with the described characteristics, the simulation is executed. To show the results, it is established that the software represents the behavior of the magnetic flux density by means of a surface layer. In the same way, a contour layer is configured to visualize the lines of flux through the elements that make up the magnetic circuit.

VI. RESULTS

One of the first tests carried out was to check the mesh coupling in stator grooves, permanent magnets and coils. The mesh structure, once configured in the model, adapts to the geometry, becoming more dense in the smaller sections of interest for calculation, figure 6.

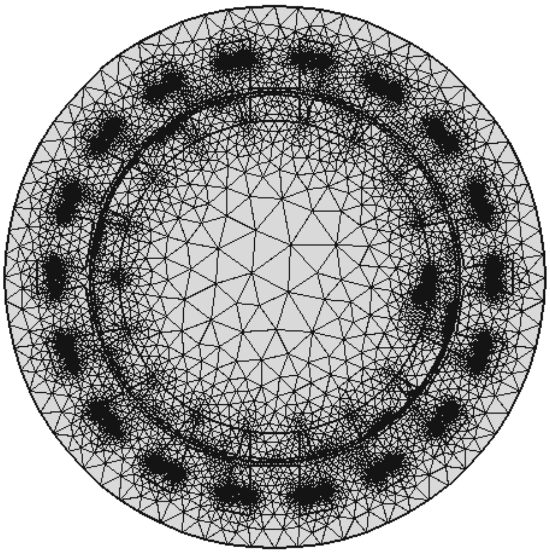


Figure 6. Mesh distribution in the generator geometry.

The distribution of the computational network is particularly coupled to the indicated study regions. Figure 7 shows a close-up of the coupling in the main sections to be analyzed of the generator. Mesh coupling is considered adequate.

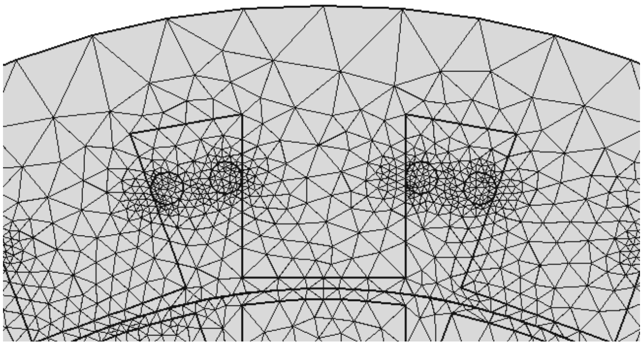
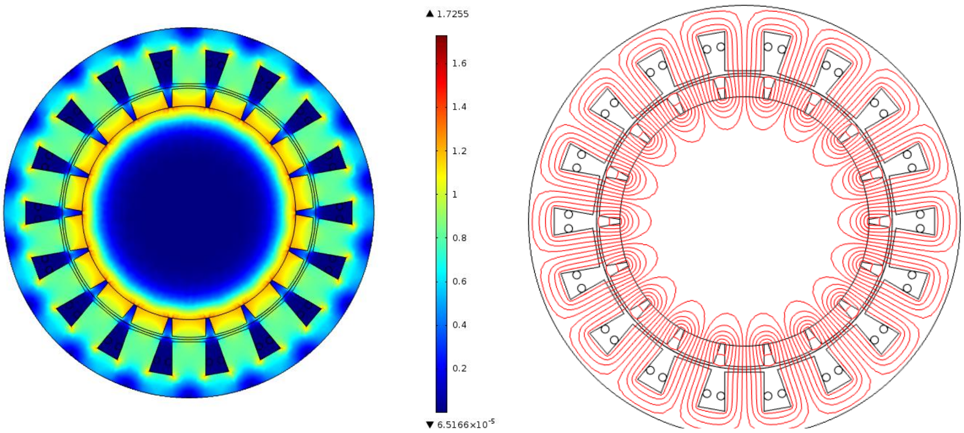


Figure 7. Mesh coupling in stator slots, permanent magnets, and coils.

Another of the tests carried out was the distribution of the generator's magnetic flux over time. Figure 8a) shows the magnetic flux density in the rotor and stator, indicating as a function of color code the intensity with which it is distributed in the different regions of the iron slots, without losses.



a) b)

Figure 8. Flux density in the generator: a) Rotor and stator. b) Propagation of magnetic flux lines.

The color bar on the right hand side indicates the flux density in *Teslas [T]* in the different regions of the machine according to the established geometry. Figure 8b) shows the linear distribution of the magnetic flux provided by the magnets, allowing to know the interaction between the source and the medium in which the magnetic effect is propagated.

It can be seen that the flux density in the rotor occurs with greater intensity in the spatial regions between the magnets, while in the stator a large amount of flux is in the slots (desired effect) and at the edges of the same, figure 9.

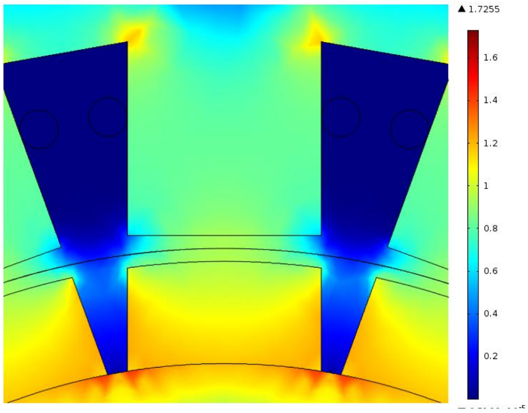


Figure 9. Density of the magnetic flux in a slot.

Figure 10 shows the direction of the flux as a function of the position of the faces of the magnets with north and south polarity distributed in the rotor.

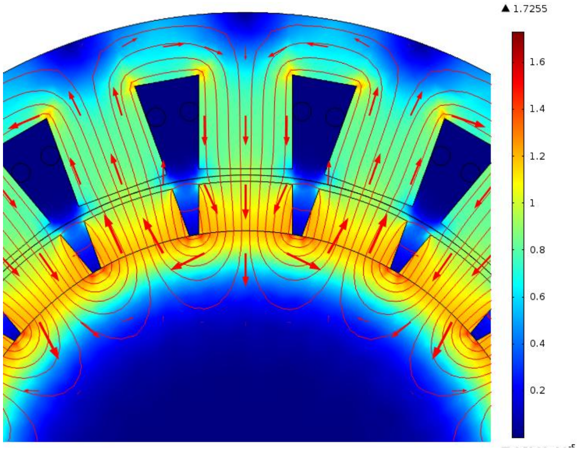


Figure 10. Behavior of the direction of the magnetic flux.

Figure 11 shows the results obtained from the simulation in an initial time from which it is possible to start for the dynamic study. The magnetic flux density in the rotor and stator is shown, indicating in function of color code the intensity with which it is distributed in the different regions of the grooves, this without considering losses.

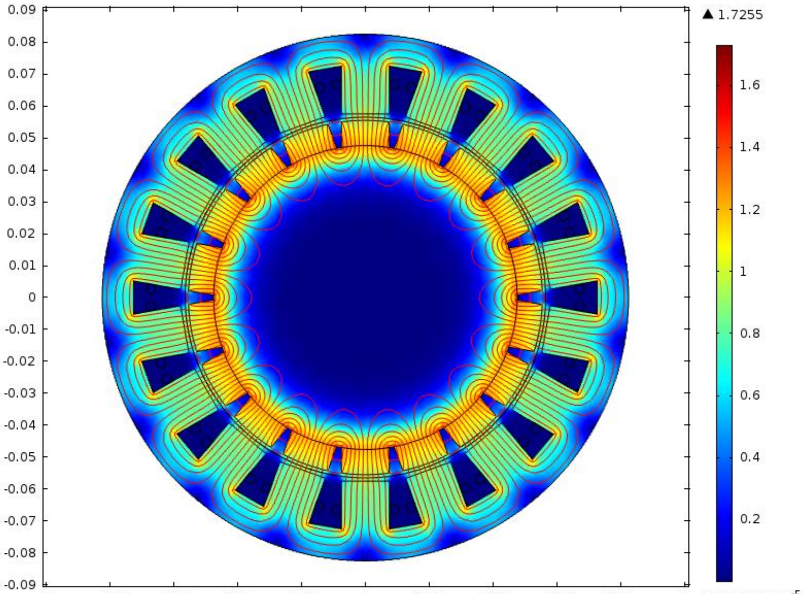


Figure 11. Magnetic flux distribution of the generator in an initial time.

VII. CONCLUSIONS

The computational simulation allowed to graphically observe the behavior of the magnetic flux of the machine, corroborating the voltage generation. Based on the results obtained, it can also be concluded that, according to the construction of the machine, the materials used, the geometric arrangement of the coils and the established flow levels, the microgeneration of electrical energy is viable. In this way it is possible to create arrangements between generators on a given surface to increase the voltage and current level as required by the load to be supplied.

It is possible to optimize voltage levels by varying the levels of magnetic flux, as well as by configuring a larger generator that allows for windings of greater conductor gauge and greater area. The use of the energy produced by the flow of people in a given space is viable according to what has been analyzed. The generator designed to use the resource of people's footsteps has favorable characteristics for the transformation of mechanical energy into useful electrical energy for general use of low voltage and power devices.

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