Analysis of the Effect of Magnetic Thickness and Rotating Speed on PMSG 24 Slot 16 Pole Characteristics

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Abstract – Wind energy is one of the alternative energies that can overcome global warming caused by fossil energy. Permanent Magnet Synchronous Generator (PMSG) has a higher efficiency compared to other types of generators. The previous permanent magnet synchronous generator model was only able to produce efficiency at a rotational speed of 500 rpm of 67.30% and at a rotational speed of 1500 rpm of 80.9%, so further research is needed to get a higher efficiency value. This study aims to analyze the effect of magnetic thickness and rotational speed on PMSG characteristics and obtain a higher efficiency value. Using variations in magnetic thickness of 7.5mm, 9 mm, and 10 mm and variations in rotational speed of 500 rpm, 1000 rpm, and 1500 rpm using software based on Finite Element Methode, this study obtained the results of the largest current, voltage, input power, and output power at a magnetic thickness of 10mm with a rotational speed of 1500 rpm of 20.40 A, 204.06 V, 4979.60 W, and 4266.21 W, with the greatest efficiency being in the magnetic thickness of 9mm and 10 rpm of 89.20%.

Keywords: Magnetic thickness, rotating speed, efficiency, PMSG.

I. INTRODUCTION

Fossil fuels are a major factor causing global warming. Based on the decision of the Minister of Energy and Mineral Resources concerning the Ratification of the Business Plan for the Supply of Listirk Power PT. PLN in 2018-2017, the generation energy mix is targeted for 2025 with a classification of coal at 54.4%, EBT at 23%, gas at 22.2%, and fuel at 0.4%. [1]. Renewable energy sources such as water, solar, and wind are alternative energies that can be used as a solution to reduce fossil energy consumption [2]. [3] [4] Wind energy is one of the potential energies. There is potential in Indonesia, but it is not as big as in subtropical countries, and Indonesia has not fully maximized it. One of the functions of wind energy is as a wind power plant (PLTB) on a small and large scale [5].

Generators are an important component in PLTB systems; the type of generator commonly used is a permanent magnet generator [6]. Synchronous Permanent Magnet Generator (PMSG) is an important component that has a role as a converter of mechanical energy into electrical energy [7]. PMSG has two main components, namely the rotor and stator. The rotor as a drive will produce a magnetic field [8] and [9]. The rotor and stator consist of an iron core arrangement made of laminated electrical steel. This provision is selected based on the good permeability value of the material during the generator's rotation, which will increase the magnetic flux density. The induced voltage value on the coil will be affected by the magnetic flux density [10].

A permanent magnet synchronous generator (PMSG) is a generator that uses magnets as a magnetic flux generator; therefore, this type of generator is capable of producing electrical energy at wind speeds of around 3–12 m/s. This type of generator has a higher efficiency than the type of induction generator because it has a simpler shape, making it lighter, neater, and more densely arranged [11] [12]. The thickness of the permanent magnet and the rotational speed greatly affect the value of the magnetic flux that will be produced. This is because the thicker the permanent magnet used, the more magnetic flux will be produced. In this case, it will also affect the efficiency value produced by the Permanent Magnet Synchronous Generator (PMSG). The movement of the magnetic flux greatly affects the number of magnetic flux lines entering the iron core. The parameter of the speed of movement of the magnetic flux is directly proportional to the magnitude of the electromotive force voltage (GGL) generated. The faster the rotation of the rotor, the more magnetic flux lines enter the core of the stator coil. This will cause voltage stress generated by the stator coil, but the rotational speed of the rotor can also cause the temperature of the generator to increase, which will also cause the efficiency value of the generator to decrease [1] [13] [14].

Previously, the design of a permanent magnet synchronous generator that discusses the effect of rotational speed on efficiency was carried out, and in the study it was only able to produce efficiency at a rotational speed of 500 rpm of 67% and at a rotational speed of 1500 rpm of 80.9% [15]. In this case, the research still needs a faster spin to produce higher efficiency. While the study that discusses the influence of magnetic thickness on PMSG only discusses the value of back EMF and Ke, the highest result of back EMF is at a 9mm magnetic thickness of 22.08 V [2]. In this study, the author suggests that future studies can compare output power and efficiency and other magnetic thickness variations in order to get an even distribution of flux.

Previous research that has examined permanent magnet synchronous generators has been done quite a lot. In the study Analysis of the Effect of Permanent Magnet Material on the Characteristics of Radial Synchronous Generators (18 Slot, 16 Pole), this research uses software based on the Finite Element Method. From the results of this study, we obtained the highest efficiency of 91% using magnetic material Br 1.2 nuts 1.0, but in this study we were only able to produce an output power of 131.22 W [16]. Research entitled Analysis of the Effect of Thickness and Type of Stator Rotor Iron Core on the Characteristics of Permanent Magnet Synchronous Generators (18 Slots, 16 Radial Flux Poles): The purpose of this study is to vary the thickness and type of iron core to analyze the effect of iron core thickness on characteristics using Finite Element Method-based software. From the results of this study, the average current was 17.44 A, the voltage was 52 V, the torque was -24.84 Nm, the input power was 1,300 W, and the output power was 1,011 W, but this study was only able to produce an efficiency of 73% [10]. In the research on Stator Material Permeability Analysis on Permanent Synchronous Generator Modeling 12 Slot 8 Pole using Finite Element Method, this study aims to analyze the permeability value of materials from iron cores using the Finite Element Method. In this study, the highest permeability results were obtained in soft pure iron remko material with a permeability value of 0.00004 Wb/Am [17]. In the Efect of Thickness and Type of Magnet against EMF Back PMSG 12S8P with FEM Study, this study aims to analyze the effect of magnetic thickness and magnetic material on back EMF by varying the thickness of 3mm and 6mm using the FEM method. From this study, the highest results were obtained at 6mm magnetic thickness using PM 12 Br 1.2 Mur 1 magnet material on an average of 21.13 V [13].

Based on previous research in this study varying the thickness of 7.5mm, 9mm, and 10mm magnets with speed variations of 500rpm, 1000rpm, and 1500rpm, with the aim of analyzing the influence of variations in magnetic thickness and rotational speed on the value of current, voltage, output power, and input power and getting the highest efficiency, using Infolytica Magnet Software based on Finite Element Methode, the data obtained from the software will be processed so that it can become comparison results from variations in magnetic thickness and rotational speed.

II. Methods

1. Research Flow Chart

This study will analyze the characteristics of the permanent magnet synchronous generator using Infolytica magnet software based on the finite element method. The PMSG simulation has the following steps: (1) Categorize the display in the magnet software. (2) Make a permanent generator by modeling synchronous magnets. 24 slots, 16 poles; (3) set load parameters; (4) test variations in magnetic thickness and rotational speed; (5) process and retrieve simulated data. This research method will be presented through the following flow chart:

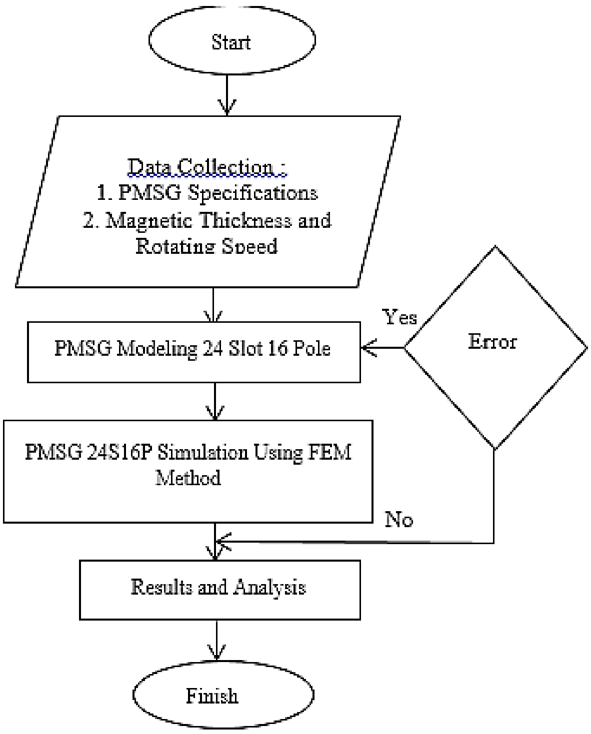

Figure 1. Research Flow Chart

2. PMSG Specifications

Table 1. PMSG Specifications

Specifications	Descriptions
Slot	24
Pole	16
Dimension	90x90x40 mm
Number of Windings	35
Magnetic Material	PM12: Br 1.2 mur 1.0
Rotor Material	Remko
Stator Material	Remko
Coil Material	Copper : 5.77e7
Airgap Material	*Air*
Airbox Material	*Air*

3. Variation of Magnetic Thickness and Rotating Speed

The rotating speed and magnetic field can be determined using the following equation :

1. Rotating speed (rpm)

$$n = \frac{120f}{p} \quad (1)$$

n represents the rotating speed (rpm), f frequency (Hz) and p represents the number of poles

2. Maximum flux density

$$Bmax = Br.\frac{lm}{lm+\delta} \quad (2)$$

Br is the magnetic flux density (Tesla), lm is the magnetic thickness (cm) and δ is the distance between the rotor and the stator (cm)

3. Magnetic flux density

$$\emptyset max = Bmax\ Amagn \quad (3)$$

$\emptyset max$ is the Maximum Flux (Wb), $Bmax$ is the maximum flux density and $Amagn$ is the magnetic area (m2)

Table 2. Variations in Magnetic Thickness and Rotating Speed

Num	Magnet Thickness	Rotating Speed
1	7.5 mm	500 rpm
2	9 mm	500 rpm
3	10 mm	500 rpm
4	7.5 mm	1000 rpm
5	9 mm	1000 rpm
6	10 mm	1000 rpm
7	7.5. mm	1500 rpm
8	9 mm	1500 rpm
9	10 mm	1500 rpm

4. Modeling of Permanent Magnet Syncrhonous Generator (PMSG)

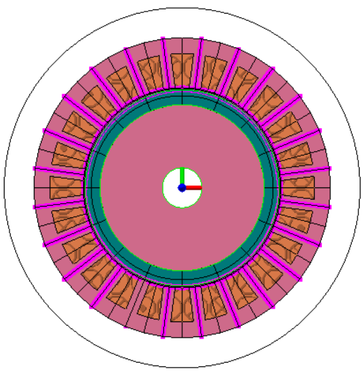

Figure 2. PMSG 24S16P modeling

Figure 2 is a modeling of the Permanent Magnet Synchronous Generator 24 Slote 16 Pole, this type of generator consists of 24 coil chambers or windings and 16 magnetic poles, 8 magnets facing south and 8 magnets facing north.Simulasi PMSG 24S16P dengan Menggunakan Metode FEM.

Before carrying out the solving process, PMSG will be rotated according to predetermined speed variations and then given a load of 10 Ohms to get output results from the generator.

The characteristic output value consists of:

1. Current

The current output results are obtained from the comparison of voltage and resistance, the current value is very dependent on the rotational speed of the generator (rpm) [16].

$$I = \frac{V}{R} \quad (4)$$

I represents current (Amperes), V represents voltage (volt) and R is load (Ohm)

2. Voltage

Voltage is the electromagnetic induction produced by the generator.

$$\varepsilon = -N\frac{\Delta\emptyset}{\Delta t} \quad (5)$$

Ɛ represents the induction GGL (V), N represents the number of windings, ΔØ the change in magnetic flux (Wb) and the Δt time lapse (s)

3. Input Power

In the calculations to obtain the value of the input power is as follows:

$$Pin = \frac{\tau\ x\ RPM\ x\ 2\ Phi}{60} \quad (6)$$

The pin represents the inlet power (W), τ represents torque (Nm) and n is the rotating speed (rpm)

4. Output Power

To obtain the output power using the following equation::

$$Pout = V\ x\ I \quad (7)$$

5. Efficiency

The efficiency value is obtained by the result of comparing input power with output power using the following equation:

$$n = \frac{Pout}{Pin} x\ 100\% \quad (8)$$

III. Results and Discussion

This test uses variations of 7.5mm, 9 mm, and 10mm magnetic thicknesses with speed variations of 500 rpm, 1000 rpm, and 1500 rpm. This test uses a load of 10 ohms. From the simulation results of magnetic software, current and voltage results are obtained, and input power and output power are produced by calculations from existing equations.

1. Current

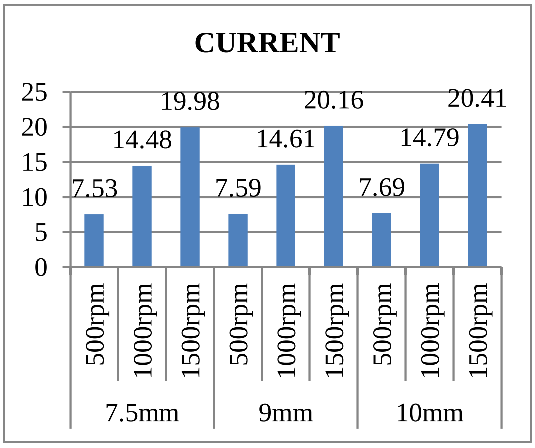

Figure 3.Effect of Magnetic Thickness and Rotating Speed on Current

It can be seen in figure 3 that the current results depend on the thickness of the magnet and the rotational speed of the rotor; the thicker the magnet and the rotational speed used, the higher the current results obtained. At a thickness of 7.5 mm and a rotational speed of 500 rpm, the initial value obtained is 7.53 A; this result continues to increase by 19.98 A at a rotational speed of 1500 rpm. The magnetic thickness of 9mm at a rotating speed of 500 rpm gives a current result of 7.59 A. This value will continue to increase at a rotational speed of 1500 rpm with a current of 20.16 A. The magnetic thickness variation of 10 mm at a rotational speed of 500 rpm produces a current of 7.69 A; this variation also experiences an increase in current at a rotational speed of 1500 rpm with a current result of 20.41 A. Based on the analysis, this result corresponds to the sound of Faraday's law, where the induced electromotive force arises proportional to the rate of change of magnetic flux and where the GGL of induction is directly proportional to the current produced.

2. Voltage

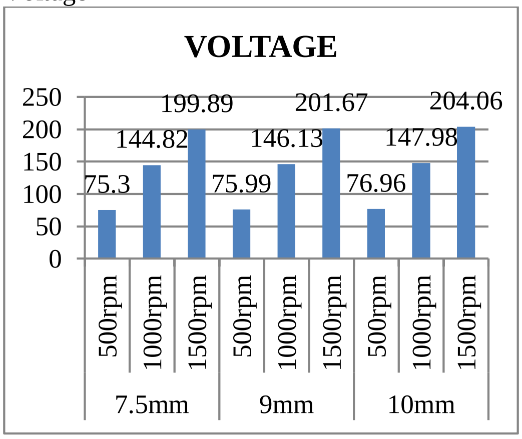

Figure 4. The Effect of Magnetic Thickness and Rotating Speed on Voltage

It can be seen in figure 4, the rotating speed of 500 rpm with a magnetic thickness of 7.5mm to 9mm and 10mm has increased voltage, the final result of the voltage will always be high if the rotating speed is also added Based on these results, it can be concluded that the faster the rotational movement in the magnetic excitation system of the rotor, the more magnetic flux lines will enter the core of the stator coil, This causes the induced voltage stress generated in the stator coil to be greater which results in the voltage value will increase.

3. Input Power

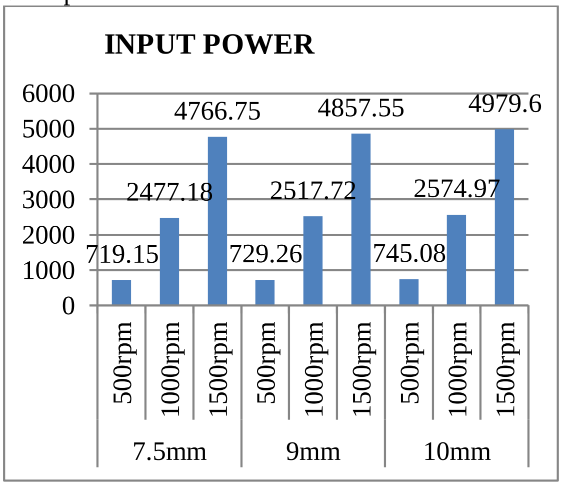

Figure 5. The Effect of Magnetic Thickness and Rotating Speed on Input Power

Figure 5 is the result of input power. It can be seen in the picture that there is a change in input power that continues to increase in line with the increase in magnetic thickness and rotation speed. This is based on the influence of variations in magnetic thickness and rotational speed on the torque produced by the generator. From figure 7, the highest input power value is at a magnetic thickness of 10mm with a rotational speed variation of 1500 rpm.

4. Output Power

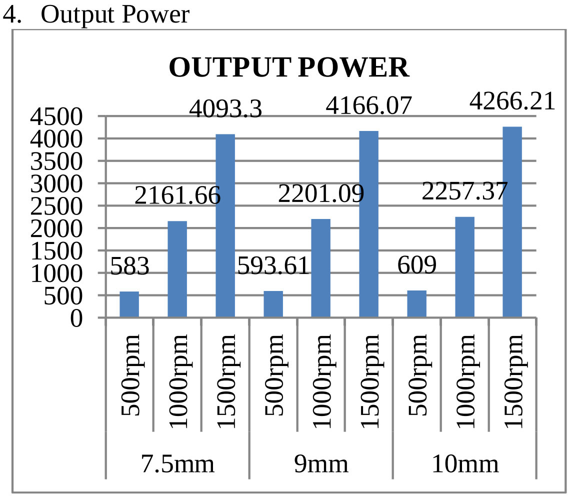

Figure 6. The Effect of Magnetic Thickness and Rotating Speed on Output Power

Figure 6 shows the results of various output powers. Due to the influence of current and voltage caused by the increase in electromagnetic induction value produced by the generator along with the increase in magnetic thickness and rotation speed, the largest output power is produced by a magnetic thickness of 10mm with a rotational speed variation of 1500 rpm.

5. Efficiency

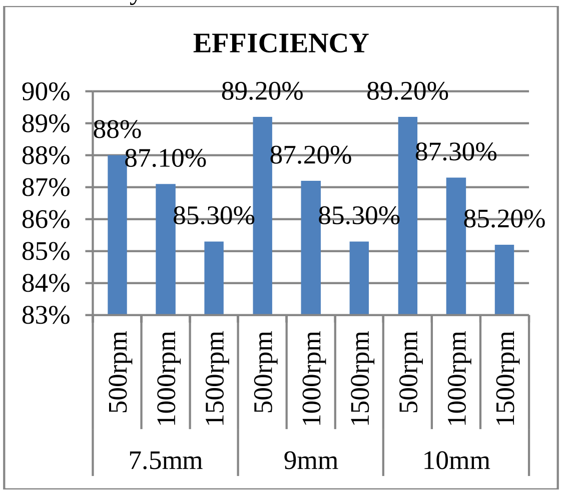

Figure 7. The Effect of Magnetic Thickness and Rotating Speed on Efficiency

The highest efficiency value is at 9mm and 10mm magnetic thicknesses with the same rotation speed of 500 rpm, with an efficiency of 89.2%. Based on the results of Figure 7, variations in magnetic thickness of 7.5mm, 9 mm, and 10mm decreased efficiency values when varied at rotational speeds of 1000 rpm and 1500 rpm. This is because the rotational speed produced by the rotor can affect the temperature in the generator, so efficiency will decrease if the rotor rotation continues to increase.

IV. CONCLUSION

After conducting research by varying the magnetic thickness and rotational speed on the Permanent Magnet Synchronous Generator 24 Slot 16 Pole, the highest results were obtained with a magnetic thickness of 10mm. Variations in rotational speed of 1500 rpm were 20.40 A, 204.06 V, an input power of 4979.60 W, and an output power of 4266.21 W. While the greatest efficiency was in the thickness of 9mm and 10mm with a speed variation of 500 rpm of 89.20%. Based on these results, variations in magnetic thickness and rotational speed greatly affect the characteristic values produced by the Permanent Magnet Synchronous Generator (PMSG).

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