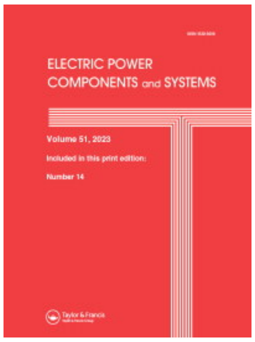
ELECTRIC POWER COMPONENTS and SYSTEMS
Volume 51, 2023
Included in this print edition:
Number 14

Taylor & Francis
Taylor & Francis Group

Electric Power Components and Systems

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/uemp20

An Analysis of the Design of a Low Rotational Speed Permanent Magnet Generator That Uses Radial Flux

Karthikeyan Sathasivam, Ilhan Garip, Ahmed Majed Althahabi, Sami Mohammed, Ali Ihsan Alanssari, Yaqeen S. Mezaal, Jameel Mohammed Ameen Sulaiman & Taif Alawsi

To cite this article: Karthikeyan Sathasivam, Ilhan Garip, Ahmed Majed Althahabi, Sami Mohammed, Ali Ihsan Alanssari, Yaqeen S. Mezaal, Jameel Mohammed Ameen Sulaiman & Taif Alawsi (2023): An Analysis of the Design of a Low Rotational Speed Permanent Magnet Generator That Uses Radial Flux, Electric Power Components and Systems, DOI: 10.1080/15325008.2023.2215772

To link to this article: https://doi.org/10.1080/15325008.2023.2215772

Published online: 05 Jun 2023.

Submit your article to this journal

Article views: 10

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=uemp20

Electric Power Components and Systems, 0(0): 1–10, 2023
© 2023 Taylor & Francis Group, LLC
ISSN: 1532-5008 print / 1532-5016 online
DOI: 10.1080/15325008.2023.2215772

An Analysis of the Design of a Low Rotational Speed Permanent Magnet Generator That Uses Radial Flux

Karthikeyan Sathasivam,[1] Ilhan Garip,[2] Ahmed Majed Althahabi,[3]
Sami Mohammed,[4] Ali Ihsan Alanssari,[5] Yaqeen S. Mezaal,[6]
Jameel Mohammed Ameen Sulaiman,[7] and Taif Alawsi[8]
[1]Department of Mechanical Engineering, Syed Ammal Engineering College, Ramanathapuram, Tamil Nadu, India
[2]Department of Electrical and Electronics Engineering, Nisantasi University, Istanbul, Turkey
[3]Al-Manara College For Medical Sciences, Maysan, Iraq
[4]College of Medical Technology, Al-Farahidi University, Baghdad, Iraq
[5]Al-Nisour University College, Baghdad, Iraq
[6]Al-Esraa University College, Baghdad, Iraq
[7]Department of Dental Industry Techniques, Al-Noor University College, Nineveh, Iraq
[8]Scientific Research Center, Al-Ayen University, Thi-Qar, Iraq

CONTENTS

Keywords: output power, radial flux permanent magnet generator, stator teeth width mounting, double stator, output voltage

Received 2 March 2023; accepted 14 May 2023

Address correspondence to Karthikeyan Sathasivam, Department of Mechanical Engineering, Syed Ammal Engineering College, Ramanathapuram, Tamil Nadu, India. E-mail: karthikeyan@syedengg.ac.in

Abstract—A radial flux permanent magnet generator can be effectively used in generating wind power at low speeds. This generator uses a combination of permanent magnets and a stator to produce electricity from the wind's kinetic energy. The permanent magnets are arranged in a radial pattern, which reduces the amount of heat lost and therefore increases the generator's efficiency. This design allows for a low rotational speed, which makes it suitable for applications such as wind turbines. The air gap between the rotor and the stator affects the output voltage and power due to the decrease in magnetic flux. This study aims to increase the generator's output voltage and output power by fitting stator teeth widths to the stator teeth. The stator teeth width fitting design method adjusts the air gap between the stator and the rotor to a uniform size. This helps to reduce the pulsating torque and ensure that the output voltage and power are maximized. The three variables are the stator slot width, the rotor slot width, and the air gap width. By adjusting these variables, the stator teeth width fitting design method can adjust the air gap between the stator and rotor.

1. INTRODUCTION

Specialty technologies, such as solar, wind, and geothermal power, have become increasingly popular as countries strive to reduce their reliance on nonrenewable sources of energy [1]. In addition, they are transitioning to using more sustainable sources of energy. This has the potential to be a highly efficient and reliable source of energy. Wind turbines convert wind energy into electricity by capturing its kinetic energy. In the case of rotating wind turbines, a wind speed of 5 m/s is considered a low wind speed. Even at these low speeds, wind turbines can generate electricity with an efficiency of up to 40%. As the wind speed increases, so does the efficiency, reaching up to 50% or even higher in some cases. This makes wind turbines a very attractive option for renewable energy production [2]. Permanent magnets are able to effectively transform the kinetic energy of the wind into electrical energy. Without permanent magnets, energy conversion can be less efficient at lower wind speeds, making them less attractive for generating power. Permanent magnets provide a constant magnetic field and therefore require less energy to generate the same output power, compared to electromagnets. Additionally, permanent magnets are able to generate high torque at lower speeds, which helps to reduce the size and cost of the generator [3]. Permanent magnet generators are efficient as they generate magnetic fields with minimal power consumption. This makes them ideal for low-speed power generation systems, as they can generate power without dissipating too much energy. Additionally, the presence of an air gap between the magnetic field and the generator helps reduce magnetic losses [4]. The reluctance of the air gap creates a force that opposes the magnetic flux, which reduces the strength of the magnetic field. This reduces the ability of the generator to convert mechanical energy into electrical energy, resulting in a decrease in output voltage and power. This design uses a radial flux permanent magnet generator which utilizes a concentric air gap to reduce the reluctance of the air gap, thereby reducing the opposing force and increasing the strength of the magnetic field [5]. This leads to an increase in the efficiency of the generator, resulting in higher output voltage and power. The stator tooth width installation design method takes into account the number of teeth on the stator and the frequency of the pulsating torque. By adjusting the stator tooth width, the effective value and frequency diversity of the pulsating torque can be significantly reduced, thus minimizing the overall impact on the motor [6]. The stator tooth width can be adjusted to reduce the air gap flux density, which in turn reduces the effective value and frequency of the pulsating torque. This helps to minimize the overall impact on the motor and its energy efficiency. The pulsation torque is directly proportional to the motor vibration and inversely proportional to the output power [7]. Thus, when the pulsation torque is reduced, the motor vibration is reduced and the output power is increased. By reducing the pulsation torque, the uneven frequency distribution can be reduced which in turn reduces the motor vibration and increases the output power. This helps improve the motor performance and overall efficiency [8].

The double stator design topology allowed for a higher power output and a more reliable operation at a lower wind speed. This was beneficial for wind power applications, as the lower wind speed was able to be converted into more usable energy. The double stator design provides a more efficient and reliable structure than the traditional single stator design [9]. The two stators are connected in such a way that they capture the wind energy more effectively at lower wind speeds and convert it into electrical energy more efficiently. This increased efficiency and reliability help to reduce the cost of wind power generation and make it more economically viable. It is expected that this combination of stator topologies will increase the generator torque, efficiency, and power output [10]. The FEMM 4.2 application will be used to analyze the magnetic field distribution in the generator, and the Lua programming language will be used to simulate the performance of the generator under varying operating conditions [11]. The double stator design topology allows for a larger air gap between the stator and rotor, which increases the efficiency of the generator and reduces the amount of materials needed to build it. Additionally, it also reduces the amount of heat generated. In a double stator radial flux permanent magnet generator, the inner rotor and outer-rotor are combined to provide benefits. This allows more of the rotor's magnetic field to get to the stator, resulting in more torque being generated and higher efficiency. Additionally, because of the larger air gap, the rotor is able to run cooler, reducing the amount of heat generated and increasing the lifespan of the generator. The inner-rotor topology has a smaller rotor diameter, allowing for a higher degree of structural rigidity. The outer-rotor topology has a larger rotor diameter, which permits greater torque production, enabling higher output power to be achieved [12]. The inner-rotor topology offers greater structural stability, which allows for higher-speed operation and improved efficiency. The outer rotor topology provides greater torque, which allows for higher output power and improved performance. The type of magnet used also affects the performance, as different magnet materials can have different properties that impact the overall efficiency. There are a number of excellent magnetic properties associated with NdFeB magnets, including high saturation magnetization and high coercivity [13]. These properties make them ideal for use in radial generators, as they can produce a strong magnetic field and a high efficiency of energy production. The neodymium atom has an exceedingly large magnetic moment, while the iron atoms provide high thermal stability. The boron atom helps to create a strong coupling between the neodymium and iron atoms, resulting in a magnet with high coercivity and a high saturation magnetization [14]. These strong magnetic properties make them ideal for use in radial generators. The combination of the high coercivity and saturation magnetization of NdFeB magnets allows them to hold their magnetic properties even when exposed to high temperatures and high alternating magnetic fields, which makes them ideal for use in radial generators. Additionally, their high torque density allows them to generate a larger amount of torque at a lower operating current, which makes them more efficient than other types of magnets. Radial generators also benefit from NdFeB magnets [15]. This is due to they have a high-energy product, meaning they can generate a higher amount of magnetic force than other types of magnets. This makes them well-suited for use in radial generators, which require the generation of high levels of torque in a small space [16]. NdFeB magnets are made from rare earth elements that have a higher magnetic energy product than other types of magnets. This means that they can generate a higher amount of magnetic force, which is commonly used in radial generators. They are able to generate high levels of torque in a small space, making them more efficient than other types of magnets.

The study concluded that wind turbine generators could generate power reliably and economically. It also found that the turbines could be used to supplement existing sources of electricity. The turbines could also provide a clean, renewable source of energy. The study found that the turbines could be used to reduce greenhouse gas emissions and help to meet local energy demands [17]. The turbines also have a low maintenance cost and are relatively easy to install and operate. Additionally, the turbines are capable of producing energy at a much lower cost than traditional energy sources. This makes them an attractive option for many communities, as they can provide a reliable source of clean energy at a lower cost than other sources. Wind turbines are becoming more efficient and cost-effective as technology progresses, making them more viable as an energy source [18]. The stator is designed to minimize air resistance, allowing the turbine to spin faster and more efficiently, resulting in more energy output for the same amount of input. By reducing air resistance, the stator allows the rotor blades to spin faster, generating more power for the same amount of input. The design also allows for a smaller generator diameter, which helps to maintain a steady frequency of 50 Hz. Furthermore, the generator with the permanent-magnet rotor can be designed with a smaller diameter and lighter weight, allowing it to be more easily transported [19]. Additionally, its higher efficiency at rated load leads to lower energy losses and can reduce the cost of operation. This generator was designed to be used in a wind turbine system, as it was smaller, lighter and more efficient than traditional generators. The modular stator design allowed for easy maintenance and installation, which made it a popular choice for wind turbine applications [17]. First of all, subharmonic flux waves may cause additional losses in fractional-slot windings. Subharmonic flux waves occur when slots are not integral multiples of the pole pairs, which can cause additional losses in the windings [20]. Parallel paths in the winding can cause an imbalance in the magnetic flux, which also leads to additional losses. These circulating currents cause the flux to be distorted and create subharmonic frequency components as a result. This causes additional losses in the windings due to the increase in eddy current losses. The imbalance in the magnetic flux also amplifies the subharmonic flux waves, further increasing the losses. When the two prototypes were tested, the increased eddy current losses were verified [21]. The increase in subharmonic flux waves was also observed, confirming that the imbalance in the magnetic flux was indeed amplifying the losses. The fractional-slot winding and flux-concentration method allow for the generation of a sinusoidal voltage waveform from a low-energy magnet, which can reduce the overall size and cost of the motor. This makes it an attractive option for applications where size and cost are important factors. [22]. The damper windings are made of a large number of turns of insulated copper wire. The windings create a magnetic field which interacts with the stator field to provide damping. This damping helps to reduce the oscillations in the rotor, which helps to improve the efficiency of the generator. The damping provided by the damper windings helps to reduce the electrical losses associated with the generator's operation since the damping reduces the rotor's oscillations [23]. This helps to reduce power output fluctuations and improves the overall efficiency of the generator. The use of a small pole pitch also helps to reduce the electrical losses associated with the generator's operation. The spring and damper will absorb the vibrations and dampen the movement of the stator, ensuring that the pole pitch remains small and the windings remain sufficient [24]. This will also help to reduce the noise generated by the motor. In order to maximize the efficiency of the motor, it is important to keep the pole pitch and winding size as small as possible. By using the spring and damper system, the motor is able to absorb the vibrations and dampen the movement of the stator, allowing for a smaller pole pitch and winding size [25]. This also helps to reduce the noise generated by the motor, making it more efficient and cost-effective. An induction generator with direct drive is compared to a permanent-magnet generator. There are several differences between induction and permanent magnet generators, including their size, weight, and efficiency [26]. A study is conducted on the effect of the rectifier on the generator's rated power and efficiency. In the presence of sinusoidal voltages, the output power and efficiency of a generator are lower than when connected to a diode rectifier. Based on the literature, the existing work has a complicated design and high price, which is a strong negative argument in the case of small turbines with a vertical axis of rotation. The main advantage of these machines is the ability to generate a voltage at very low or highly variable speeds.

2. MATERIALS AND METHODS

2.1. Modeling

The purpose of the research is to develop a better understanding of the electrical and mechanical behavior of the generator and its components. This will allow for improved design, optimization and control of the generator [27]. This allows researchers to observe the performance of the system under various conditions and to identify any problems or weaknesses that may exist. It also allows them to make predictions about the system's behavior under different conditions, which can be used to improve its performance. By making changes to the system and running simulations, researchers can identify areas of potential improvement and test different scenarios to find the most efficient solution. This helps them to optimize the system for the highest possible performance and minimize the risk of damage. Simulations are often multiple times, each time with different variables and conditions, to identify the most optimal implementation of the system. This helps to identify any potential problems that may arise in real-world implementation, allowing researchers to make changes to the system before implementation to ensure the best possible results. Generator modeling makes it possible to investigate the dynamic behavior of a wind turbine more accurately [28]. It allows researchers to simulate and analyze the performance of the turbine under a variety of conditions, such as different wind speeds and varying air temperatures, to identify any potential issues that may arise in real-world implementation. The generator rotates at a speed of 300 revolutions per minute. This study uses a displacement factor value of 0.86 and an angular displacement of 12° for the stator. A permanent magnet of type NdFeB N52 has been used for this application. This study specifies a full load current of 1.5 amperes and a phase resistance of 43.9963 ohms. Table 1 shows the stator parameters for the generator, as well as Table 2, shows the rotor parameters for the generator.

$$N_{TD} = \frac{N_P N_S}{FPB\ [N_P, N_S]} \tag{1}$$

$$\alpha_M = \frac{360^{\circ}}{N_{TD}} \tag{2}$$

The pulsating torque value is observed based on the number of pulsation events (N_{TD}) and the machine's mechanical angle of rotation (α_M). According to Eq. (1), N_{TD} is directly related to the number of rotor poles and stator slots, but inversely related to the greatest common factor of these parameters. A machine's full rotation angle also known as N_{TD} is shown in Eq. (2).

2.2. Mounting Design for Stator Tooth Width

This design method aims to reduce the amount of magnetic flux produced by the rotor, which helps reduce the intensity of the magnetic field in the air gap. Additionally, increasing the length of the air gap further reduces the field intensity as the flux has to travel a further distance. This decrease in magnetostatic energy is due to the fact that the magnetic field lines in the gap become more concentrated [29]. This reduces the number of field lines that can be stored and thus the amount of magnetic flux generated as shown in Eq. (3).

$$W_A = \frac{2\pi L_S\left(R_2^2 - R_1^2\right)}{4\mu_\theta}\sum_{n=0}^{\infty} G_{nN_k} X B_{nN_k} X\, Cos nN_k \propto \tag{3}$$

$$G_{nN_k} = \frac{1}{n\pi} X \frac{N_s}{N_k}\left(sin\ nN_k \frac{x}{2}\right) + \left(sin\ nN_k \frac{y}{2}\right) \tag{4}$$

These parameters are used to calculate the electromagnetic forces between the stator and the rotor, which determine the torque and output of the W_A. For example, the stator stack length (L_S) affects the magnetic flux density (B) which in turn affects the electromagnetic forces. The electromagnetic forces are proportional to the square of the flux density (B), which is the reason the stator stack length is important in the calculation. The greater the flux density, the greater the magnitude of the electromagnetic forces will be, resulting in increased torque and output from the

	Stator	
Parameters	*Outer-stator*	*Inner-stator*
Diameter outside (mm)	290	210
Diameter inside (mm)	245	160
Length of stack (mm)	40	40
Number of slots	40	40
Air gap width	1	1
Diameter of wire	0.9	0.9
Factor of coil fill	0.9	0.9

TABLE 1. Radial flux permanent magnet generator stator parameters.

	Rotor	
	Outer-rotor	*Inner-rotor*
Diameter outside (mm)	240	230
Diameter inside (mm)	220	208
Magnet thickness	7	7
Number of poles	20	20
Magnet material	NdFeB N52	

TABLE 2. Radial flux permanent magnet generator rotor parameters.

W_A. The air permeability (μ_0) and air gap relative permeance (G) also affect the electromagnetic forces [30]. The air permeability (μ_0) and air gap relative permeance (G) are the parameters that control the flux density, and therefore the magnitude of the electromagnetic forces. The larger the rotor and stator radius (R_2), the larger the W_A and the more torque can be generated. This, in turn, increases the output of the machine. The air gap relative (GnNK) permeance is a measure of the motor's efficiency and is used to calculate the motor's torque and power output. It is important for designers to understand how the air gap relative permeance affects the motor's performance in order to design an efficient motor as shown in Eq. (4). The relative permeance is a measure of the degree to which a material allows a magnetic field to pass through it. As the permeance increases, the strength of the magnetic field increases, which increases the electromagnetic force [27]. The size of the W_A affects the amount of torque and output because the larger the W_A, the more space is available to store and release energy, which increases the torque and output. Using Eq. (5) and the values in Table 3, "x" and "y" are calculated. A positive n will produce a relative permeance value (GnNK) near zero, and an even n will produce a relative permeance value equal to zero. The result of this is that the air gap energy is minimized.

Variables	x (mechanical degree)	y (mechanical degree)
A	7.5	10.5
B	12	12
C	6.6	11.6

TABLE 3. Variable "x" and "y" values.

$$\sin\ nN_L\frac{a}{2}+\sin\ nN_L\frac{b}{2}=0 \tag{5}$$

$$\tau = \frac{2\pi L_S\left(R_2^2-R_1^2\right)}{2\mu_\theta}\ X\sum_{n=0}^{\infty}G_{nN_L}XB_{nN_L}X\sin\ \ nN_L \propto \tag{6}$$

Based on Eq. (6), the pulsating torque can be reduced to zero. A radial flux permanent magnet generator's double stator design is shown in Figure 1. There is no difference in the width of stator teeth "x" and "y", which is 9 mechanical degrees. The design method of installing the stator teeth width is based on the number of rotor slot openings. The stator tooth width "x" is calculated based on the number of rotor slot openings, while the stator tooth width "y" is calculated based on the stator tooth width "x" plus the amount of clearance necessary for the rotor slots to be installed.

2.3. Radial Generator

Voltage and Power Equations Based on Faraday's law, this means that if the number of turns (N) and the rate of change of the flux (d∅/dt) are both increased, the induced voltage (Ei) will also increase. In addition, the power generated by the generator (P) is proportional to the square of the induced voltage (Eï2) and the number of turns (N) in the coil. On the other hand, the change in the coupled flux is directly proportional to the number of turns in the coil and the change in the magnetic flux. As the number of turns of the coil increases, the relative change in the flux also increases this is shown in Eq. (7).

$$E_i = N\frac{d\emptyset}{dt} = \frac{d\Psi}{dt} \tag{7}$$

The increase in the number of turns of the coil creates a stronger magnetic field, which in turn increases the coupled flux. This increased flux causes a larger induced emf, as the magnetic field is stronger, and the change in the flux is more pronounced with respect to time change ($d\psi$) and position change (dt). As the rotor speed increases, the magnetic field generated by the windings also increases, thus increasing the flux of the coupled flux. This increased flux causes an increase in the induced emf, as the magnetic

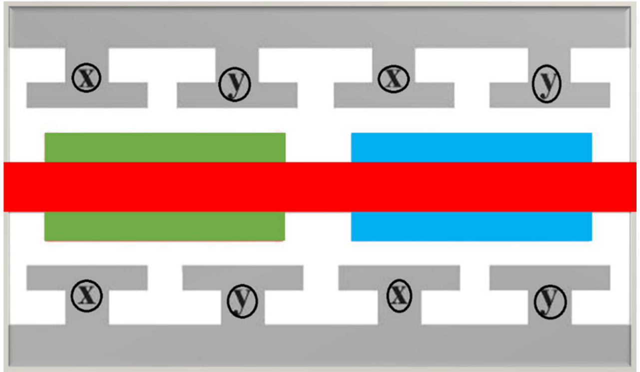

FIGURE 1. A permanent magnet generator with radial flux stator gear.

field is stronger and the change in flux is more pronounced with respect to the rotor speed per second (V_{rotor}), hence the increase in the induced emf [21]. The speed of the rotor in this study is 5 m/s, which is the speed at which it rotates. Equation (8) illustrates this in more detail. The magnitude of the flux through the coil is proportional to the strength of the magnetic field (B), the number of turns (N) of the coil and the area of plane surface ($\dddot{n}\ dS$) through which the flux is passing. Thus, the magnitude of the flux is proportional to the strength of the magnetic field and the number of turns of the coil, and inversely proportional to the area of the plane surface. It can be seen from Eq. (9).

$$E_i = \frac{d\Psi}{dz} X \frac{d\Psi}{dt} = v_{rotor} X \frac{d\Psi}{dz} \tag{8}$$

$$\Psi = N \oint \dddot{B}\ X\ \dddot{n}\ dS \tag{9}$$

The power per phase (P) increases with increasing load current and load resistance, as shown in Eq. (10). This is because the power generated is the product of the voltage and current, and both of these increase when the load current (I_{FL}) and resistance decrease (R_{FL}). A simple formula for determining R_{FL} can be found in Eq. (11). When the load current (IFL) decreases, the voltage and current increase, thus increasing the power generated [18]. Conversely, when the resistance (R_{FL}) decreases, the voltage and current also increase, thus increasing the power generated. The formula in Eq. (11) is used to calculate the load impedance, which is assumed to be resistance only when the system is under full load conditions. Equation (12) shows the effects of induced electromagnetic fields (EA), currents (I), resistances (R), and inductive reactances (XL) on generator terminal voltage (VT).

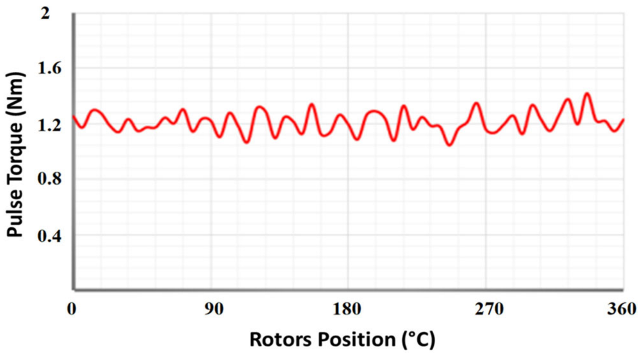

FIGURE 2. The initial generator design's pulse torque.

$$P = I_{FL}\ X\ R_{FL} \tag{10}$$

$$R_{FL} = \sqrt{\left(\frac{\theta}{I_{FL}}\right)^2 - X_L{}^2 - R} \tag{11}$$

$$v_T = e - 1(R + X_L) \tag{12}$$

3. RESULTS AND DISCUSSION

The results showed that the output power of the generator increases significantly with the increase in pulsation torque. Moreover, it was observed that the output power of the generator increases linearly, up to a certain point, after which it plateaus. There are 4 variables discussed, variable A is related to the width of the stator teeth, while variable B is related to the distance between the stator teeth [8]. Variable C is related to the angle of the stator teeth. Finally, the initial design of the generator is the overall design before it is modified.

3.1. Generator Initial Design

The maximum output power achieved by the generator initially was 1070 W. This was due to the generator's limited capacity to convert mechanical energy into electrical energy, as well as the fact that the generator was designed to operate at a relatively low speed. A full rotation of the pulse device results in the graph in Figure 2. The pulse torque frequency distribution in Table 4 shows a pulse torque effective value of 1.214 Nm. Table 4 provides the exact values for the pulse torque and its frequency distribution which can be used to analyze the performance of the device. According to the initial design, each phase output voltage is 169 V, the phase resistance at full load is 121.4 Ω, the full load current is 2.25 A, and the three-phase power is 759 W. Three-phase power is equal to the phase voltage multiplied by the phase current, so the phase

Design configuration	Effective value (Nm)	Frequency distribution
Initial design	1.215	0.082
Variable design A	0.522	0.133
Design variable B	0.458	0.206
Design variable C	0.514	0.209

TABLE 4. Comparison results of pulsating torque values on all generator designs.

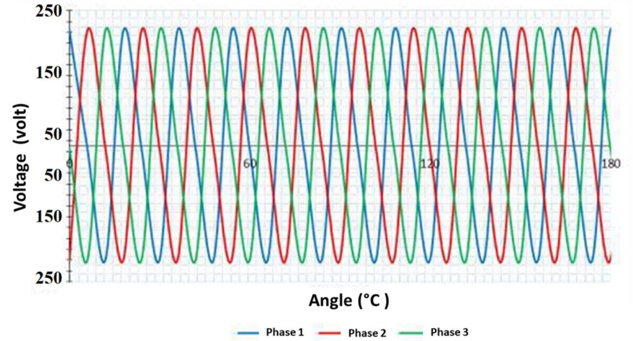

FIGURE 3. Initially designed generator voltage in 3 phase.

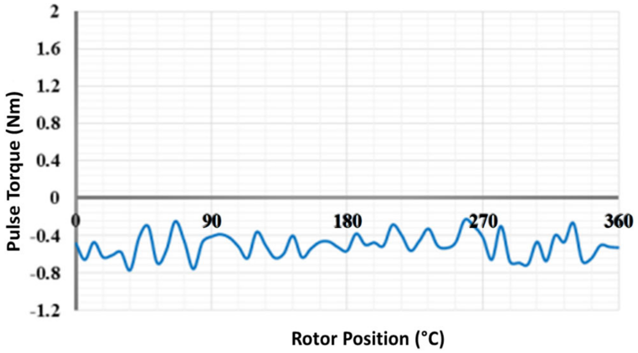

FIGURE 4. Pulse torque graph with variable A.

voltage multiplied by the phase current becomes the phase voltage. According to Eq. (13), the motor can generate a maximum power of 1070 watts. This suggests that the generator is capable of producing as shown in Figure 3, the initial design of the generator leads to the following voltage results. the required power output of 1070 W, as long as the voltage is at or above the graph's peak point [12]. This gives the motor the potential to maximize its power output if the voltage is maintained at a constant level.

$$P = \sqrt{2\ XP_{total}} \tag{12}$$

In Table 3, the variable A design's pulsation torque results are provided. A comparison of the initial design of the pulsation torque and its actual value reveals that the latter has decreased by 57%. Figure 4. shows the torque values associated with the design with variable A present. There was an increase of 66% in the frequency distribution of pulsating torque as a result of the experiment [19]. It can be concluded that the increased frequency distribution means that the torque value generated during one full rotation is not more stable than it was before. This design is shown in Figure 5 in terms of output voltage. In the full-load condition, the voltage of each phase is 170.4 V or an increase of 1.44%, the resistance of each phase is 113.54 Ω, the full load current is 2.25 A, and the three phase power is 763.9 W. Compared to variable C, which is equal to 1080.4, there is an increase of 0.88% in the maximum output power at variable C.

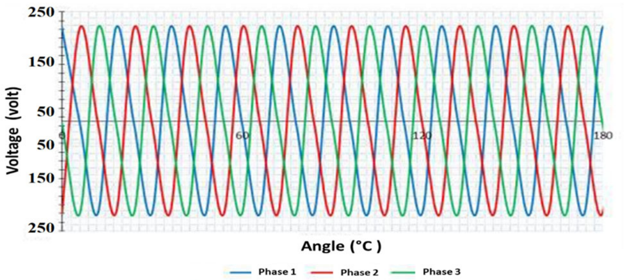

FIGURE 5. Voltage on a 3-phase design with variable A.

3.2. Variable B Design Output

The results of the pulsation torque values are shown in Figure 6 for the case where the variable B is used to create a design. In comparison with the initial design, the frequency distribution increased by 158% compared with the final design. A decrease of 63% was achieved when compared to the initial design of the pulsation torque value, which was 0.4559 Nm. In Figure 7, you could see the graph illustrating the results of the design output voltage on variable B in the design. The output voltage of each phase in this design is 171.9 V or an increase of 2.32%, the resistance of each phase at full load condition is 114.2 Ω, the full load current of each phase is 2.25 A. According to the initial design, the maximum output power is 1089.6 W, which represents an increase of 1.74%.

A design with variable C led to a 162% increase in the frequency distribution of the design, which is the most significant increase. The design of this motor has, therefore, the highest chance of causing large eddy currents and reducing motor performance due to the motor vibration caused by this design [17]. The torque value of the pulse had decreased by 58%. Figure 8 shows the pulsating torque results for this particular design of motor. This design has a maximum output power of 1106.4 W,

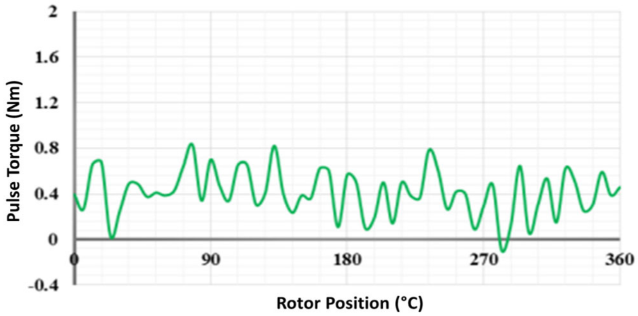

FIGURE 6. Pulse torque graph with variable B.

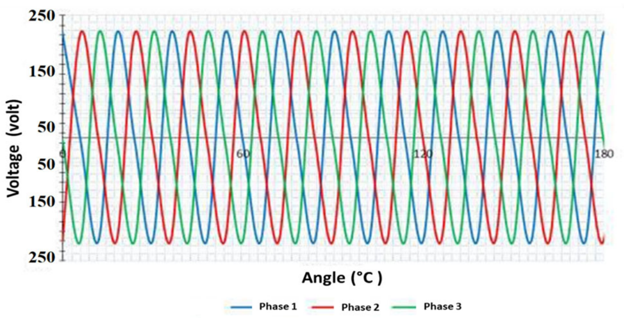

FIGURE 7. Voltage on a 3-phase design with variable B.

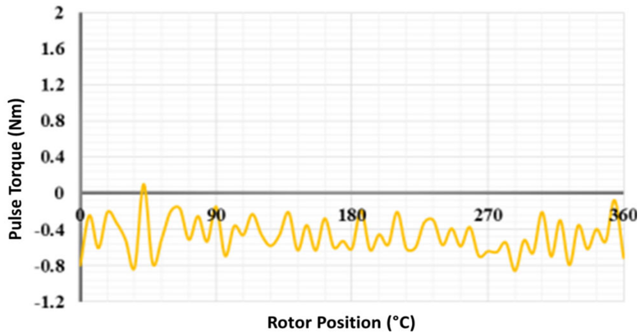

FIGURE 8. Pulse torque graph with variable C.

which is a significant improvement of 3.4% compared to the previous design. In this case, the voltage output is 174.6 V, which is a decrease of 3.95%, the resistance of 116 S and the current drawn at full load is 2.25 A, resulting in a decrease of 3.95%. Figure 9 shows a graph illustrating the output voltage as a function of time.

4. CONCLUSION

According to the study, both generator voltage and power were successfully increased over the initial design by 3.95% and 3.4%, respectively. This was achieved by optimizing the

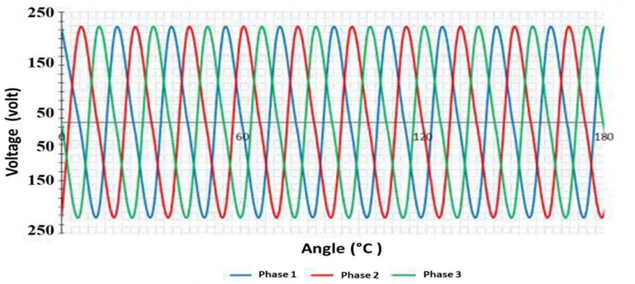

FIGURE 9. Voltage on a 3-phase design with variable C.

windings and connections of the rotor and stator, while keeping the size of the generator the same. This allowed for a higher output of power with a smaller generator size. This is because the generator's design parameters were changed, such as the number of stator poles, the number of rotor poles, and the air gap flux density, which all had a positive effect on the output voltage and power. Changes in the number of stator and rotor poles allowed for increased magnetic flux density within the air gap, which in turn allowed for a higher generator output voltage. Additionally, changes in the air gap flux density meant that the output power of the generator could be more effectively controlled. A decrease in the effective value of the pulsating torque means that the generator can output higher levels of power without having to produce a higher frequency, which is where the output voltage and power increased. By decreasing the pulsating torque, the generator is able to maintain the same frequency while increasing its power output. This is because the decrease in pulsating torque reduces the amount of energy lost between the generator and the load, allowing the generator to output a greater amount of power without having to increase its frequency. However, because the frequency distribution was not stabilized, the generator can still be susceptible to fluctuations in output. This is because when the frequency is not stabilized, the frequency of the generator can still fluctuate, resulting in a change in the torque produced by the generator. This can lead to an increase in energy lost between the generator and the load, reducing the amount of power the generator can output. In this case, there is a vibration in the motor that can cause eddy currents, which means the generator output power cannot be increased significantly. This is because eddy currents cause a loss of power in the generator due to the opposing magnetic fields created by the vibration. This means the generator cannot generate more power because the opposing fields reduce the efficiency of the generator. This is due to the eddy currents generated by the vibration interfere with the flow of the magnetic field, causing the voltage and current to drop. The decrease in power is caused by the opposing magnetic fields created by the vibration. These opposing fields reduce the efficiency of the generator, preventing it from generating more power. The eddy currents reduce the flow of the magnetic field, resulting in a decrease in voltage and current which further reduces the power output.

REFERENCES

[1] S. Huang, J. Chen, M. Su, and C. Chen, "Predicting the class of salt contamination for wind turbine blade under a lightning strike using fuzzy inference system and probabilistic neural network," *Elect. Power Compon. Syst.*, vol. 51, no. 4, pp. 351–365, 2023. DOI: 10.1080/15325008.2023.2168315.

[2] I. M. O. Mohammed, M. N. Gitau, and R. C. Bansal, "Elimination of the voltage output fluctuations of a Vienna active rectifier-I integrated under unsymmetrical faults based wind power plant," *Elect. Power Compon. Syst.*, vol. 49, no. 20, pp. 1567–1579, 2021. DOI: 10.1080/15325008.2022.2135049.

[3] A. Selim, S. Kamel, F. Jurado, and M. Abdel-Akher, "A comprehensive modeling for wind turbine generator and DSTATCOM into backward/forward load flow algorithm," *Elect. Power Compon. Syst.*, vol. 50, no. 14–15, pp. 788–799, 2022. DOI: 10.1080/15325008.2022.2141923.

[4] D. Guha, P. Kumar Roy, and S. Banerjee, "Frequency control of a wind-diesel-generator hybrid system with squirrel search algorithm tuned robust cascade fractional order controller having disturbance observer integrated," *Elect. Power Compon. Syst.*, vol. 50, no. 14–15, pp. 814–839, 2022. DOI: 10.1080/15325008.2022.2141925.

[5] M. Ebrahimi, M. Verij Kazemi, and S. Asghar Gholamian, "Detection of partial demagnetization fault in wind turbine permanent magnet generator using a data-driven method," *Elect. Power Compon. Syst.*, vol. 50, no. 9–10, pp. 530–537, 2022. DOI: 10.1080/15325008.2022.2136789.

[6] W. Liu, Y. Liu, L. Fu, M. Yang, R. Hu, and Y. Kang, "Wind power forecasting method based on bidirectional long short-term memory neural network and error correction," *Elect. Power Compon. Syst.*, vol. 49, no. 13–14, pp. 1169–1180, 2021. DOI: 10.1080/15325008.2022.2050445.

[7] I. M. O. Mohammed, M. N. Gitau, and R. C. Bansal, "Ride-through capability of mmc based wind power plant integrated under a dc-link fault," *Elect. Power Compon. Syst.*, vol. 50, no. 3, pp. 133–148, 2022. DOI: 10.1080/15325008.2022.2135643.

[8] C. Amarendra and K. H. Reddy, "PSO supported dual matrix converter for doubly fed induction generated driven by variable speed wind turbine system," *Int. J. Renew. Energy Res.*, vol. 10, no. 1, pp. 131–142, 2020.

[9] N. Mishra, A. Jain, A. Nair, B. Khanna, and S. Mitra, "Numerical and experimental investigations on a dimpled Savonius vertical axis wind turbine," *Int. J. Renew. Energy Res.*, vol. 10, no. 2, pp. 646–653, 2020.

[10] R. Ika Putri, M. Rifa'i, Ika Noer Syamsiana, and F. Ronilaya, "Control of PMSG stand-alone wind turbine system based on multi-objective PSO," *Int. J. Renew. Energy Res.*, vol. 10, no. 2, pp. 998–1004, 2020.

[11] A.-M. I. Aldaoudeyeh and K. Alzaareer, "Evaluating the accuracy of wind turbine power-speed characteristics fits for the generator control region," *Renew. Energy Res.*, vol. 10, no. 2, pp. 1031–1041, 2020.

[12] K. Naresh, P. Umapathi Reddy, P. Sujatha, and C. R. Reddy, "Control of DFIG based wind turbine with hybrid controllers," *Renew. Energy Res.*, vol. 10, no. 2, pp. 1488–1500, 2020.

[13] Y. Yulianto, A. Pracoyo, and B. Priyadi, "The rotating speed set of wind turbine using the pendulum as an angle blades control," *Renew. Energy Res.*, vol. 10, no. 42, pp. 1919–1926, 2020.

[14] M. Chakib, T. Nasser, and A. Essadki, "Contribution of Variable speed wind turbine generator based on DFIG using ADRC and RST controllers to frequency regulation," *Renew. Energy Res.*, vol. 11, no. 1, pp. 320–331, 2021.

[15] A. E. Sayed and E. Erturk, "Minimizing cogging torque in permanent magnet synchronous generators for small wind turbine applications," *Renew. Energy Res.*, vol. 11, no. 2, pp. 691–700, 2021.

[16] B. Fatma, M. Abdelkarim, A. Achraf, and K. Lotfi, "Coordinated control of SMES and DVR for improving fault ride-through capability of DFIG-based wind turbine," *Renew. Energy Res.*, vol. 12, no. 1, pp. 361–371, 2022.

[17] G. Rodrigues Bruzinga, A. J. S. Filho, and A. Pelizari, "Analysis and design of 3 kW axial flux permanent magnet synchronous motor for electric car," *IEEE Latin Am. Trans.*, vol. 20, no. 5, pp. 855–863, 2022. DOI: 10.1109/TLA.2022.9693571.

[18] Y. G. Guo *et al.*, "Comparative study of 3D flux electrical machines with soft magnetic composite cores," presented at Conf. Rec. 2002 IEEE Indus. Appl. Conf. 37th IAS Annual Meet., vol. 2, pp. 1147–1154, 2022.

[19] F. Profumo *et al.*, "Plastic electric motors: A viable solution for axial flux machines," presented at Indus. Elect. Proc. 2002 IEEE Int. Sympo., vol. 1, pp. 1–10, 2022.

[20] Y. Bi, F. Chai, and L. Chen, "The study of cooling enhancement in axial flux permanent magnet motors for electric vehicles," *IEEE Trans. Ind. Applicat.*, vol. 57, no. 5, pp. 4831–4839, 2021. DOI: 10.1109/TIA.2021.3098251.

[21] W. Le *et al.*, "Design of a novel stator water-cooling system for yokeless and segmented armature axial flux machine," presented at 2021 IEEE 4th SCEMS., pp. 1–4, 2021. DOI: 10.1109/SCEMS52239.2021.9646096.

[22] Y. Lu *et al.*, "Electromagnetic force and vibration study on axial flux permanent magnet synchronous machines with dual three-phase windings," *IEEE Trans. Ind. Electron.*, vol. 67, no. 1, pp. 115–125, 2020. DOI: 10.1109/TIE.2018.2890494.

[23] C. Sun *et al.*, "Multi-objective comprehensive teaching algorithm for multi-objective optimisation design of permanent magnet synchronous motor," *IET Elect. Power Appl.*, vol. 14, no. 13, pp. 2564–2576, 2020. DOI: 10.1049/iet-epa.2020.0322.

[24] F. Pranji¢ and P. Virti, "Designing rotor disks of a coreless axial flux permanent magnet machines by using simplified fem and an approximation method," *IEEE Trans. Energy Conver.*, vol. 35, no. 3, pp. 1505–1512, 2020.

[25] Y. Qin *et al.*, "Noise and vibration suppression in hybrid electric vehicles: State of the art and challenges," *Renew. Sust. Energy Rev.*, vol. 124, pp. 109782, 2020. DOI: 10.1016/j.rser.2020.109782.

[26] L. Jia *et al.*, "Dual-skew magnet for cogging torque minimization of axial flux PMSM with segmented stator," *IEEE Trans. Magn.*, vol. 56, no. 2, pp. 1–6, 2020. DOI: 10.1109/TMAG.2019.2951704.

[27] R. B. R. Prakash, P. Srinivasa Varma, C. Rami Reddy, M. Dilip Kumar, A. Giri Prasad, and E. Shiva Prasad, "Maximum power point tracking for permanent magnet synchronous generator based wind park application," *Renew. Energy Res.*, vol. 12, no. 1, pp. 361–371, 2022.

[28] R. K. Garmode, V. R. Gaval, S. A. Kale, and S. D. Nikhade, "Comprehensive evaluation of materials for small wind turbine blades using various MCDM techniques," *Renew. Energy Res.*, vol. 12, no. 2, pp. 981–992, 2022.

[29] M. H. Rady, R. K. Garmode, M. Gooroochurn, and S. A. Kale, "Effect of blade root dimensions on physical and mechanical characteristics of a small wind turbine blade," *Renew. Energy Res.*, vol. 12, no. 3, pp. 981–992, 2022.

[30] M. B. Farghaly and E. S. Abdelghany, "Study the effect of trailing edge flap deflection on horizontal axis wind turbine performance using computational investigation," *Renew. Energy Res.*, vol. 12, no. 4, pp. 1942–1953, 2022.

BIOGRAPHIES

Karthikeyan Sathasivam is presently working as Professor in the Mechanical Engineering Department at Syed Ammal Engineering College, Ramanathapuram, Tamilnadu, India. He is having 20 years of teaching experience. He has produced three Ph.D. scholars and presently guiding 5 Ph.D. scholars. He has published 50 (SCI) and 36 (Scopus) research papers in International and National Journals. He received many research funds from AICTE, DRDO, and TNSCST. He finished his doctoral research in Engine Testing at Anna University, Tamilnadu, India, in 2015. He obtained his post-graduation in Anna University, Chennai from 2004 to 2007 and Bachelor of Engineering in Madurai Kamaraj University, Tamilnadu, India, from 1991 – 1995 from the same college. Currently he is act as a guest editor of different Journal like Elsevier, Springer, Hindawi, etc… His specialized area is thermal engineering, biofuel, engine, and solar technology.

Ilhan Garip was born in 1963 in Turkey. He received his diploma in Electrical Education from Gazi University, Turkey in 1985. Then he did his MSc in Electrical Education in the field of 650W AC/DC power supply design and application at Gazi University in 1996. Finally, he did his PhD at Gazi University in Turkey on Developing of an experimental set for parallel connection of alternators for education purposes and evaluation of it's effectiveness in 2008. He became an assistant professor, in 2018 respectively. He has published more than 20 papers, 20 conference papers. More than 8 of his papers have been cited in SCI. He served as the Strategy Development Expert at TRT (STATE). He is currently an assistant professor at Nisantasi University. His research interests include electric power components and systems.

Ahmed Majed Althahabi is working at Al-Manara College for Medical Sciences, Maysan, Iraq. He is doing research and teaching for the last 5 years. He has published nearly 6 papers at the national and international levels. He has attended many conferences at the international level. His research interests include electric power components and systems.

Sami Mohammed is working as an Asst. prof at College of Medical Technology, Al-Farahidi University, Baghdad, Iraq. He is doing research and teaching for the last 3 years. He has published nearly 6 papers at the national and international levels. He has attended many conferences at the international level. His research interests include electric power components and systems.

Ali Ihsan Alanssari is working as an Asst. prof. in the Al-Nisour University College, Baghdad, Iraq. He is doing research and teaching for the last 5 years. He has published nearly 4 papers at the national and international levels. He has attended many conferences at the international level. His research interests include electric power components and systems.

Yaqeen S. Mezaal is working as an Asst. prof at Al-Esraa University College, Baghdad, Iraq. He is doing research and teaching for the last 8 years. He has published nearly 6 papers at the national and international levels. He has attended many conferences at the international level. His research interests include electric power components and systems.

Jameel Mohammed Ameen Sulaiman is working as an Asst. prof, Department of Dental Industry Techniques, Al-Noor University College, Nineveh, Iraq. He is doing research and teaching for the last 4 years. He has published nearly 7 papers at the national and international levels. He has attended many conferences at the international level. His research interests include electric power components and systems.

Taif Alawsi, is working as an Asst. prof, Scientific Research Center, Al-Ayen University, Thi-Qar, Iraq. He has published nearly 4 papers at the national and international levels. He has attended many conferences at the international level. His research interests include electric power components and systems.