IPTEK The Journal of Technology and Science, 33(2), 2022 (e/pISSN:2088-2033, 0853-4098)

DOI: 10.12962/j20882033.v33i2.13532 | Received 5 July, 2022; Revised 19 August, 2022; Accepted 8 Sept, 2022

ORIGINAL RESEARCH

VARIETY OF CHARACTERISTIC MAGNETIC MATERIAL ON PERMANENT MAGNET SYNCHRONOUS GENERATOR (PMSG)

Syamsyarief Baqaruzi*[1,4] | Amrina Mustaqim[2,4] | Putty Yunesti[3,4] | Gde KM Atmajaya[1,4] | Ali Muhtar[2,4] | Sabhan Kanata[1,4]

[1]Dept. of Electrical Engineering, Institut Teknologi Sumatera, South Lampung, Indonesia

[2]Dept. of Physics Engineering, Institut Teknologi Sumatera, South Lampung, Indonesia

[3]Dept. of Energy System Engineering, Institut Teknologi Sumatera, South Lampung, Indonesia

[4]Research and Innovation Center for Conservation and Renewable Energy, Institut Teknologi Sumatera, South Lampung, Indonesia

Correspondence

*Syamsyarief Baqaruzi, Dept of Electrical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia. Email: syamsyarief.baqaruzi@el.itera.ac.id

Present Address

Kampus ITERA, Jl. Terusan Ryacudu,
Lampung Selatan 35365, Indonesia

Abstract

Wind energy conversion system, one of the main components is a Permanent Magnet Synchronous Generator (PMSG). During the past two decades, many types of permanent magnet generators for wind power applications have been the research topic. This study focuses primarily on designing a PMSG to create, simulate, and analyze an internal permanent magnet topology with twelve plots and eight poles. We limit with the simulation was carried out at a rotational speed of 1000rpm, and a type of permanent magnet material, Ceramic 11, SmCo 26/26, and NdFeB 48/11. The result of the analysis is that permanent magnets applied in the design of a generator impact its output power and efficiency. At 15 Ω and 60 Ω loads, SmCo 26/26 and NdFeB 48/11 are the only ones that fulfill the specified requirements in this investigation. The permanent magnet type with the most optimal characteristics is Neodymium Iron Boron 48/11 because it has a high flux density, thus causing the electrical energy generated to be greater than other types of permanent magnets. The 48/11 NdFeB permanent magnet generates the most output power, 2110.86 W when loaded with 15 Ω. The best efficiency of 89.38 percent for the PMSG 12 slot eight poles occurs when the load is 15 on the 48/11 NdFeB permanent magnet.

KEYWORDS:

Magnetic Material, Neodymium Iron Boron 48/11, PMSG, Permanent Magnet, Wind Energy

1 | INTRODUCTION

High energy demands force us to explore new energy sources to meet them. RES (Renewable Energy Sources) may be viable for meeting energy demands. As a result, RES research must continue to be developed so that there will be no energy shortages in the future as fossil energy stocks decline. Wind energy is one type of renewable energy that we may use. Wind energy is a sustainable energy source that can convert kinetic energy to mechanical and electrical energy[1, 2].

The wind turbine is coupled to a permanent magnet generator with a generator input, which is mechanical torque supplied by the wind turbine. A permanent magnet generator is a power plant that utilizes permanent magnets to produce a magnetic field without needing external excitation. Because of its simple design, we can quickly identify the appropriate number of poles, allowing us to utilize this generator for high or low-frequency applications[3]. As a result, replacing traditional induction machines with permanent magnet synchronous generators (PMSG) has recently attracted much attention. PMSG machines, on the other hand, do not have a rotor winding, resulting in smaller copper losses and hence a greater efficiency than induction machines[4]. The number of wind turbines installed has risen dramatically in recent years. Most wind turbines on the market feature a gearbox that allows a generator to run rotating at high speeds. In the case of wind turbines, the main benefit of a direct drive is the reduction of failures and maintenance spinning at a high rate. The significant advantage of a direct purpose in wind turbines is the decrease in failures and maintenance[5, 6].

An appropriate generator for low wind speeds in Indonesia, where wind speeds range from 3 to 9 meters per second. Generators with low rotational operating characteristics, such as permanent magnet generators. Decreased motor volume owing to the lack of windings utilized for the rotor excitation field, increased efficiency due to reduced copper rotor losses, and improved dependability due to the absence of brushes and slips are among the benefits of rings[7], design and analysis considering magnet usage of permanent magnet synchronous generator using analytical method. This permanent magnet generator makes it simple to create 12 generators with the required power capacity, voltage, and speed[8]. This can be accomplished by modifying or tweaking its characteristics, such as the number of coil turns, the number and size of magnets, and the magnetic material employed. One of the criteria affecting the properties of a generator is the type of magnetic material employed. This is related to the reasons that every kind of magnetic material transmits magnetic flux differently, affecting its use in a low-speed, multipole, and permanent magnet synchronous generator demagnetization is also adequately considered[9, 10].

This paper describes the permanent magnet material NdFeB 48/11 with variants of R. SmCo. NdFeB is a form of the permanent rare-earth magnet with a higher flux density than other types of ferromagnetic magnets. With a small volume, rare-earth permanent magnets can have a high flux density, allowing them to construct high-efficiency machines with minimal power losses and compact materials[11]. NdFeB is a permanent magnet with the maximum flux density. Hence it is the best type of magnet currently available. Consequently, NdFeB permanent magnets are being utilized extensively in producing equipment requiring excellent efficiency[12, 13].

2 | PREVIOUS RESEARCHES

In previous research, a number of connections were drawn between the employment of PMSG and wind energy conversion systems, including the control side, the component stress side, and the temperature in the work area. Fig. 1 shows a mind map of the research plan to reach the research output, which is how to design the determined PMSG, then analyze and simulate the employed material. The simulation was conducted at a rotating speed of 1000rpm, using an inside permanent magnet with a generator of type 12 slots, eight poles, and a particular type of permanent magnet material. The SmCo 26/26 and NdFeB 48/11.

This research aims to compare several synchronous machines based on their maximum power output. This study examines different elements of PMSG, including topologies with controlled and uncontrolled rectifiers, grid-connected and standalone modes of operation, various control techniques of PMSG-based WECS, and contemporary optimization strategies[14]. Next, this research provides a sensor failure resilient control strategy for direct drive permanent magnet synchronous generator (PMSG) wind energy conversion systems (WECSs). The measurement accuracy of WECS quantities such as generator and grid-side currents, generator speed, and dc link voltage is of the utmost importance for ensuring the reliable and efficient operation of PMSG-based WECSs. These measurements are required to derive control actions for the power electronic interfaces in the WECSs[15]. Next up, this paper provides a comprehensive overview of the grid-integrated WECSs that utilize permanent magnet synchronous generators (PMSGs). It examines trends in converter topologies, control approaches, and energy extraction methods in PMSG-based WECSs[16].

The following explanation verifies. It was established that the high-speed generator is electromagnetically affected by the leaking magnetic flux created by the two shaft materials. To minimize damage and vibration of the rotating body caused by scattering

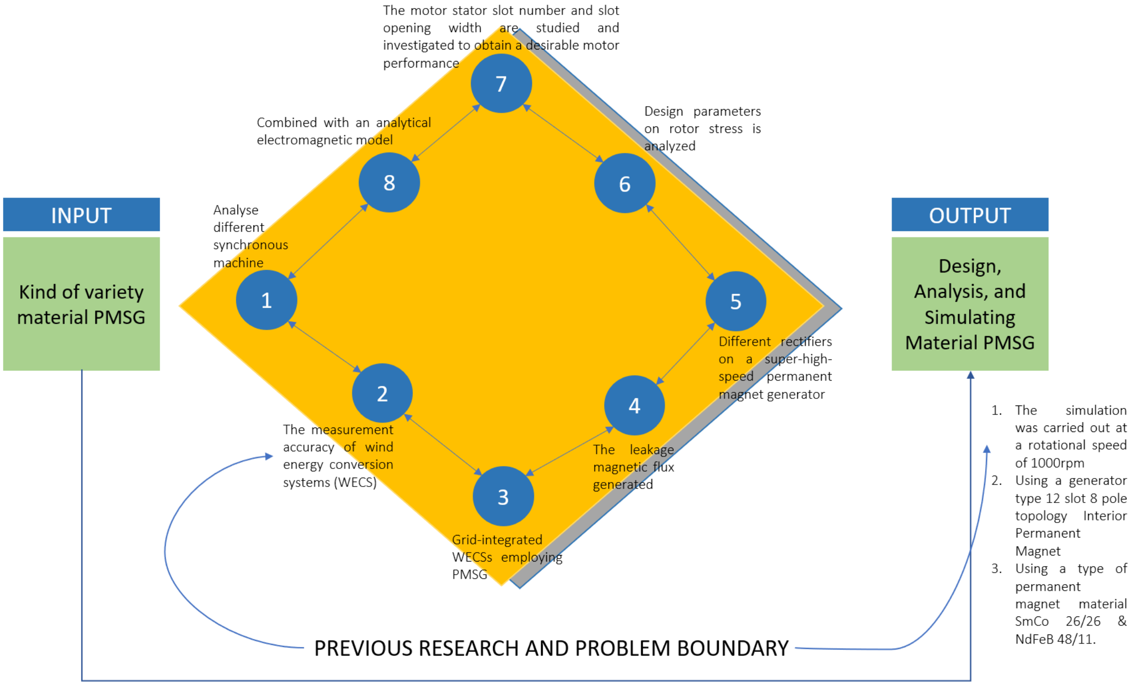


FIGURE 1 The previous research and problem boundary.

during high-speed rotation, it is crucial to estimate the natural frequency mode and critical speed precisely. Consequently, the mechanical properties of the planned model were examined. In this paper, we present a design technique that considers electromagnetic effects and mechanical properties[17], an impact of various rectifiers on a super-high-speed permanent magnet generator (SHSPMG) utilized in a micro gas turbine distributed generating system. Using a 117 kW, 60,000 rpm SHSPMG as an example, the effects of PWM and unregulated rectifiers on generator performance were compared[18]. The most negligible impact of design factors on rotor stress, including PM material, rotor temperature, sleeve thickness, PM thickness, and rotor diameter, is investigated in depth. In addition, the rotor dynamics, including the impacts of bearing stiffness, impeller mass, rotor diameter, the core length, and gyroscopic effect, have been examined in depth[19]. The motor is studied with its design considerations concluded for high-speed application. Then, the HSPMM air gap flux density is analytically calculated and verified by the finite element method (FEM). The motor stator slot number and slot opening width are studied and investigated to achieve a desirable motor performance. Finally, the optimization rotor pole arc pole pitch can increase the fundamental component proportion in the motor back electromotive force[20]. Also, considering how incorporating the axial stress component and the temperature, the model may be utilized for rapid multiphysics design. FEM has verified it at several temperatures, geometries, and speeds with low an error at multiple geometries and geometries. Finally, the model is integrated with an electromagnetic analytical model to demonstrate motor interactions[21].

3 | MATERIAL AND METHOD

In this chapter, we will model PMSG 12 slot eight pole topology Interior Permanent Magnet (IPM) with modifications in the kind of permanent magnet material, with variations in load (R) of 15, 60, and 100. In this research, the author has determined that a generator with a rotational speed of 1,000 rpm is required to satisfy the anticipated WECS requirements, as shown in Table 1.

As seen in Fig. 2 , we employ three steps in the simulation procedure. The initial step involves simulating PMSG 12 slot eight pole IPM architecture using Ceramic 11 permanent magnet material and R variation. Ceramic 11 is a permanent ferrite magnet with a low flux density but is commonly utilized due to its inexpensive manufacturing cost. The second phase models a PMSG 12-slot, 8-pole IPM architecture with magnetic material SmCo 26/26 and variation R. The third phase, which involves modeling PMSG 12 slot eight poles utilizing permanent magnet NdFeB 48/11 material with varying R, follows.

TABLE 1 The expected generator specifications.

Parameter	Value	Unit
Power Output	500	Watt
Efficiency	88 to 90	%

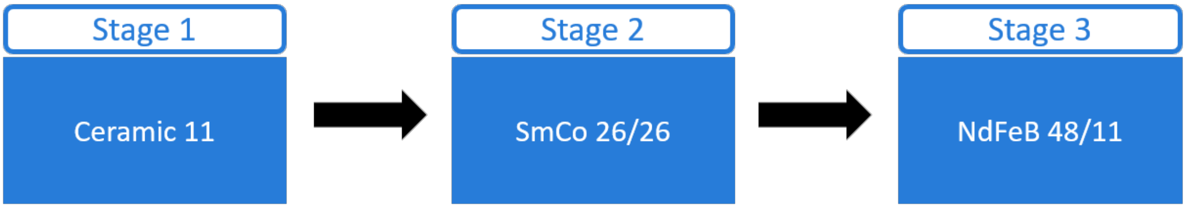


FIGURE 2 The phases of the simulation process.

The functioning mechanism of the WECS is initiated by the wind caused by the temperature differential between two locations, which results in varying air pressure. Wind energy is the mass, density, and velocity of moving air. Wind energy will cause the wind turbine blades to revolve, and the spinning of the propellers will cause the generator to rotate and generate a three-phase alternating current voltage. After that, the created electrical energy is sent to the controller, whose output is a DC voltage. Eq. 1 may determine the magnitude of the electromotive force (EMF) generated in the radial flux generator.

$$E_{ph} = 4.44 f N_{ph} k_w k_s \phi_{max} \tag{1}$$

where E_{ph} has generated induced voltage (Volt), f is frequency, N_{ph}s the number of coil twists, The k_w is twists factor (l), k_s is slope factor (0.984), φand max is magnetic flux (Wb).

Torque is the amount of force used to drive the generator. To calculate the generator torque, we can use the Eq. 2.

$$\omega = \frac{2\pi n}{60} \tag{2}$$

Where ωis angular speed (rad/s), and n is revolutions (rpm).

$$V = IR \tag{3}$$

Where V is voltage (Volt), I is current (Ampere), and R is resistance (Ohm/Ω)

$$K_e = \frac{V}{\omega} \tag{4}$$

Where k_e is EMF constant.

$$T = K_e I \tag{5}$$

Where T is torque (Nm).

The input power is the power introduced into the generator, whereas the output power is the power created by the generator. Calculating input and output power enables us to determine the generator's efficiency. We can use Eq. 6 and Eq. 7 to select the generator's input and output power.

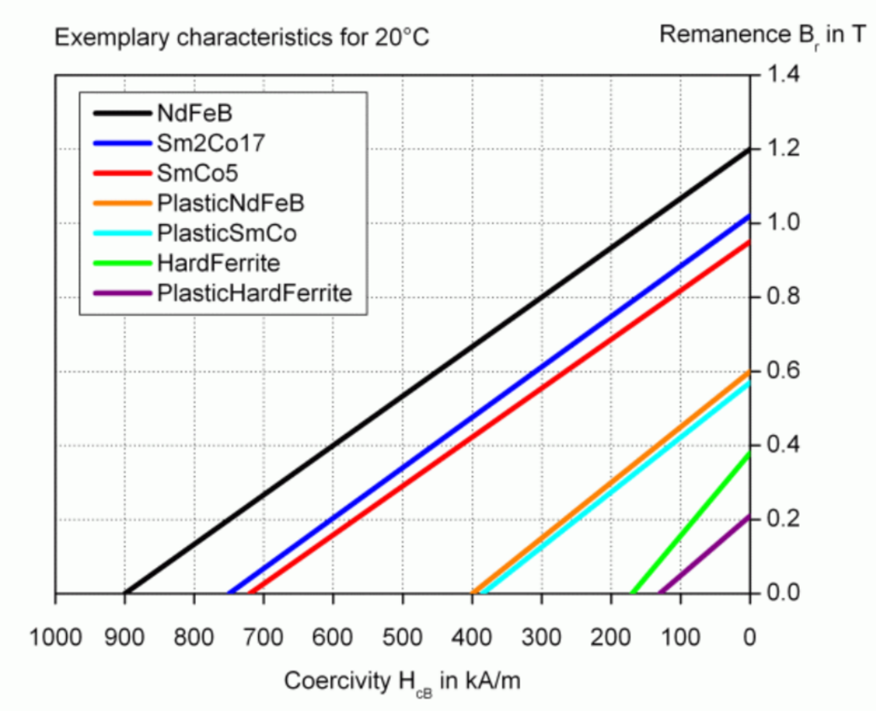


FIGURE 3 The linear demagnetization curves are modeled [22].

$$P_{in} = \frac{2\pi n}{60} T \tag{6}$$

where P_{in} is power input (Watt).

$$P_{out} = IV \tag{7}$$

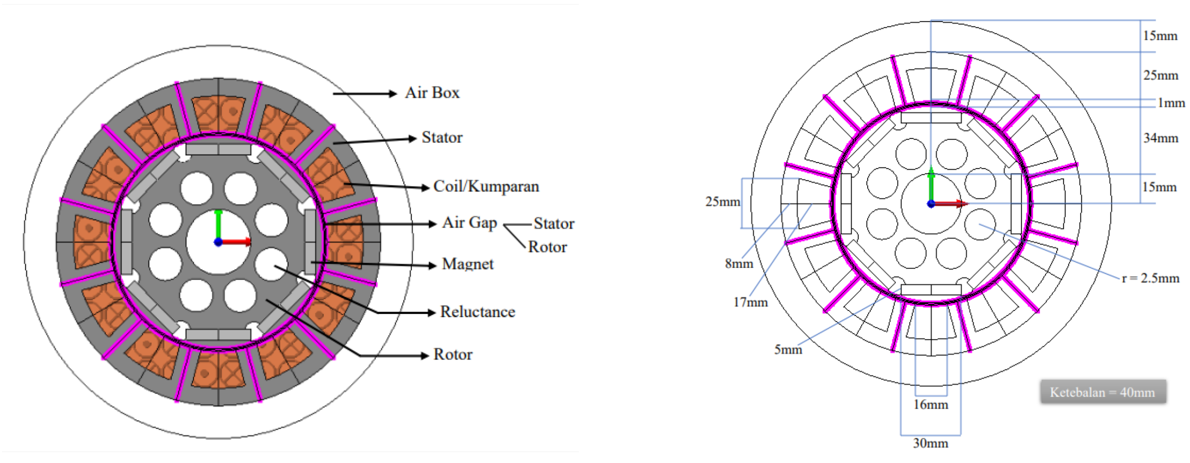
where P_{out} is power output (Watt).

Next, we examine the generator's efficiency, which is the input power ratio to output power. If the output power supplied by the generator is not significantly different from its input power, the generator will be more efficient. To calculate the generator's efficiency, we follow Eq. 8.

$$\eta = \frac{P_{in}}{P_{out}} \times 100\% \tag{8}$$

where η is efficiency (%).

NdFeB is the finest permanent magnet material among the alternatives. The flux density of NdFeB is greater than that of other ferromagnetic materials. Additionally, the cost of NdFeB is now more reasonable. Therefore, NdFeB permanent magnets are utilized more frequently than different permanent magnet types. Due to the absence of excitation losses, generators with permanent magnets have a higher degree of efficiency than generators with DC source excitation systems. They are thus commonly utilized, notably in wind turbines. Due to their simplified design, permanent magnet generators are neater, lighter, and more compact. However, the amount of excitation delivered to the permanent magnet generator cannot be modified since the magnetic flux produced is constant, preventing the generation of a variable excitation current. Fig. 3 provides typical values for remanence, coercivity, and the temperature coefficient of remanence for popular permanent magnetic materials[22].



(a) (b)

FIGURE 4 PMSG 12 slot 8 pole IPM topology, (a) generator configuration (b) physical parameters

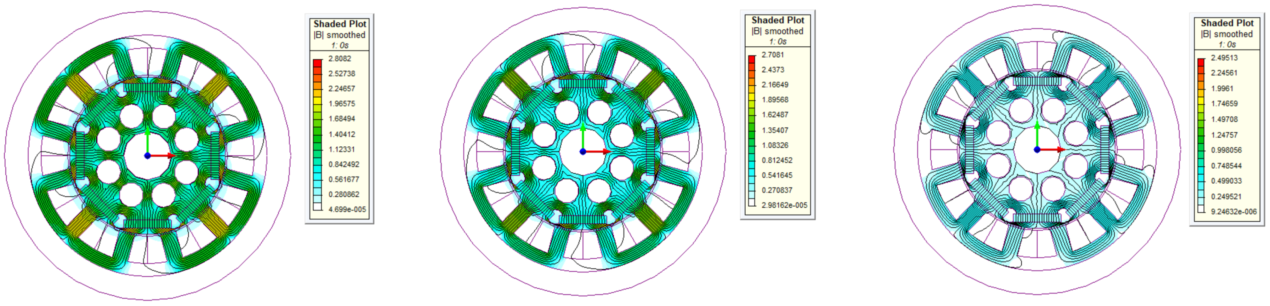


FIGURE 5 Flux flow, (a) Neodymium Iron-Boron 48/11, (b) Samarium Cobalt 26/26, (c) PM Ceramic 11.

4 | RESULTS AND DISCUSSION

4.1 | Design

This PMSG design employs twelve coils, with each coil containing 100 turns. The PMSG has eight magnetic poles. Fig. 4 illustrates the layout of the used PMSG 12-slot 8-pole. The PMSG design uses eight magnetic poles or eight poles. The greater the number of poles in a generator, the more power it will generate. This is because, as the number of magnets increases, so does the magnetic field, causing the magnetic flux to rise and the electrical energy to rise. Then, expanding the size of a generator can change the quantity of magnetic flux that is produced. The wider the diameter, the greater the magnetic flux and flux density, which increases the electrical energy generated, and conversely.

The depiction below depicts the flux flow that is observed in this investigation. If the color of the flux flow is near red, as seen in the diagram, the flux density increases, leading to an increase in electrical energy production. The type of permanent magnet with the densest flux flow is NdFeB 48/11. Hence the theory is that NdFeB permanent magnets will have the ideal properties compared to other types of permanent magnets.

4.2 | Analysis and Simulation

The effect of changes in the type of permanent magnet material on the characteristics of the generator can be viewed from several parameters, namely voltage, current, torque, input power, output power, and efficiency. The results of the PMSG voltage characteristics of the 8-pole plot of the IPM topology can be seen in Fig. 6 .

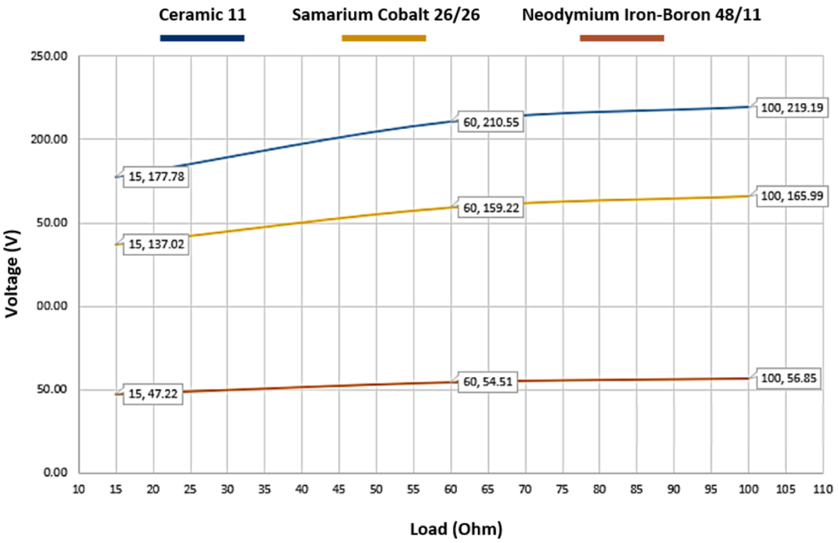


FIGURE 6 The variations in permanent magnet material affect the generator's voltage.

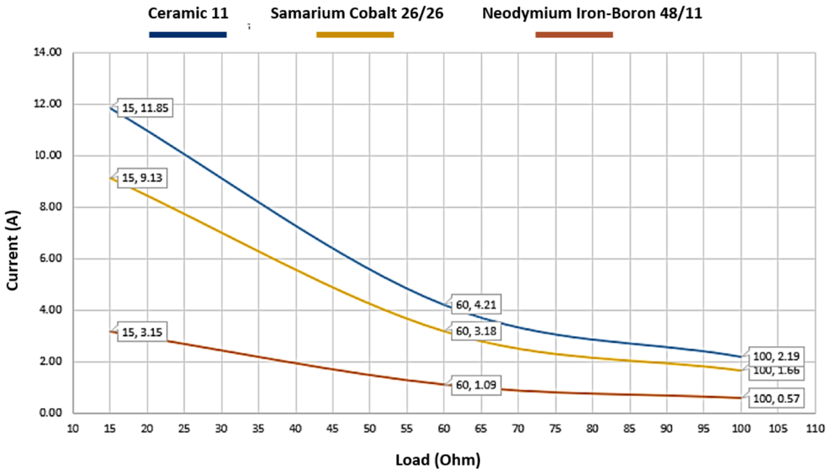


FIGURE 7 The variations in permanent magnet material affect the generator's current.

Based on Fig. 7 , it is clear that the type of permanent magnet NdFeB 48/11 has the most stress when R 100 has a voltage value of 219.19 V. This is consistent with the initial idea, given that the kind of permanent magnet NdFeB 48/11 has the maximum flux density and hence generates more electrical energy. Consequently, this generator has a voltage characteristic; the more significant the R (load) value, the greater the voltage. In line with the Eq. 3, V and R are directly proportional.

Fig. 8 demonstrates that the NdFeB 48/11 material is again the most optimum, providing 11.85A of current at R 15. Inversely proportional to the voltage characteristics, such that the bigger R, the higher the voltage, and the stronger the current characteristic of R, the lower the current. This is consistent with the Eq. 3, i.e. $I = \frac{V}{R}$, where I and R are inversely proportional.

Fig. 9 shows the simulation results. At a rotational speed of 1000rpm, the PMSG 12 slot eight pole topology IPM has the maximum torque of 22.55 Nm for the permanent magnet material NdFeB 48/11. According to Eq. 3 and Eq. 5, the torque is inversely proportional to R. Hence its value will decrease as R increases.

Input power is the power introduced into the generator, whose formula value is affected by the generator's torque and rotational speed. In this discussion, we use the same rotational speed, 1000 rpm. We will see the characteristics of the input power. The

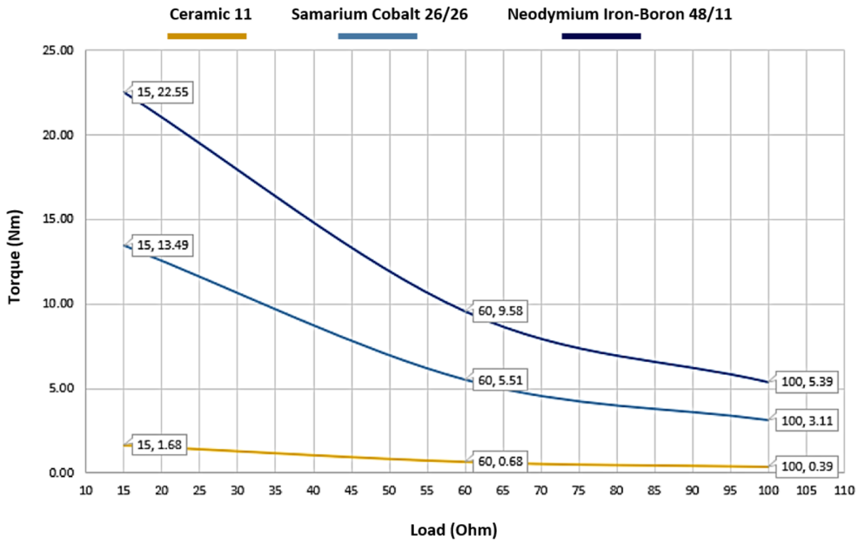


FIGURE 8 The variations in permanent magnet material affect the generator's torque.

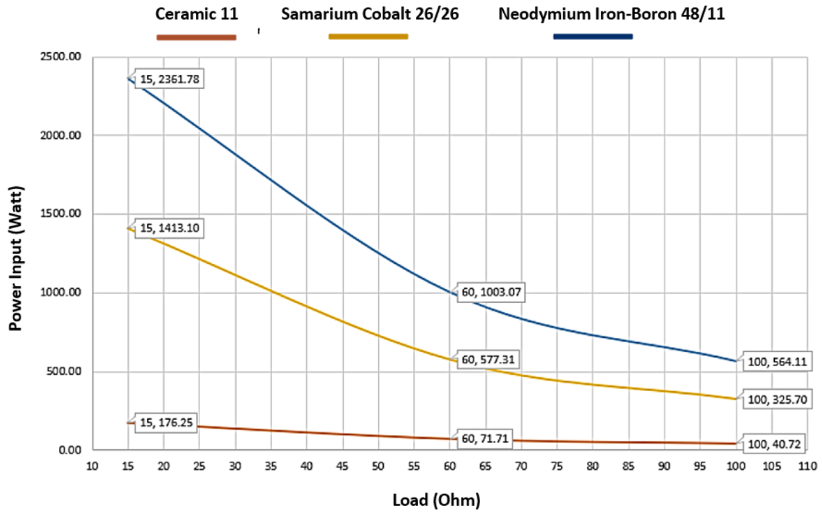


FIGURE 9 The variations in permanent magnet material affect the generator's input power.

gathered data yields the most significant input power of 2,361.78 W at R 15 for the permanent magnet NdFeB 48/11 type. It can be observed that the input power characteristic of PMSG 12 slot eight pole IPM architecture is that when R increases, the input power value decreases. According to Eq. 6, the input power value is directly proportional to the torque value. Still, the torque value is inversely proportional to the R-value, according to Eq. 3 Eq. 4, and Eq. 5. Calculating the output power using Eq. 7. SmCo 26/26 and NdFeB 48/11 are the types of permanent magnets that can fulfill the output power parameters based on the simulation and calculation findings, as shown in Fig. 10 . These two permanent magnets are capable of providing output power of more than 500 W at R 15 and R 60, with the NdFeB permanent magnet material delivering the most output power at R 15, which is 2110.86 W. This is because NdFeB has a high flux density, resulting in increased output power, but the Ceramic 11 permanent magnet has a low flux density, resulting in low output power. The achieved output power surpasses the prior design and simulation output power value of 1879.94 W.

Efficiency is the ratio between the output power and the input power. A good generator is a generator that has little losses so that the input power and output power are not much different. Based on simulation findings and calculations shown in Fig. 11 , the permanent magnet materials that fulfill the specified requirements are SmCo 26/26 and NdFeB 48/11, with efficiencies exceeding

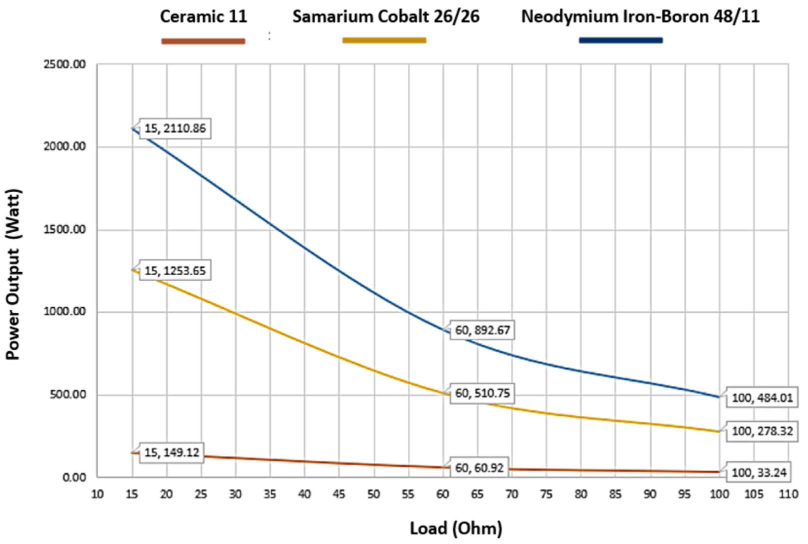


FIGURE 10 The variations in permanent magnet material affect the generator's output power.

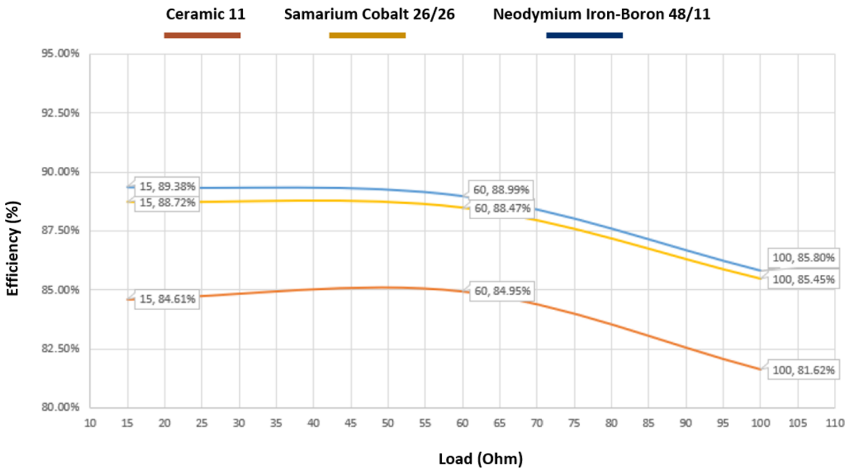


FIGURE 11 The variations in permanent magnet material affect the generator's value efficiency.

88% at R 15 and 60. The permanent magnet with the highest efficiency, 89.38 percent at R 15, is NdFeB 48/11. The efficiency rating surpassed the previous design and simulation's efficiency value of 89.38 percent, i.e., 0.1 percent efficiency improvement. However, while using NdFeB, we must additionally monitor the generator's temperature, as NdFeB has features that make it susceptible to overheating, which can reduce the generator's efficiency. This is because heat can result in power losses.

This generator has the property that the more excellent R, the lesser its efficiency. This is determined by the output power value, which decreases as R increases. This generator fits the criteria for a 1000rpm rotating speed for periods R of 15 Ω and 60 Ω, but not 100 Ω.

5 | CONCLUSION

After designing and simulating PMSG 12-slot 8-pole generators with varied permanent magnet materials, it was discovered that each material has its unique generator performance characteristics. In this discussion, a comparison will be made between the generator's performance based on numerous factors, including voltage, current, torque, input power, output power, and efficiency, as revealed in the analysis and simulation findings before. NdFeB 48/11 offers the highest performance across all criteria compared to permanent magnet material. At 15 loads, the permanent magnet NdFeB 48/11 can provide 2110.86 W of output power with an efficiency of 89.38 percent. This is because this material type has a higher flux density than other materials. In addition, the second-best material is SmCo 26/26, which has an output power of 1253.65 W and an efficiency of 88.72%. Ceramic 11 is hence the sort of material that is suboptimal. In Ceramic 11, the generator has an efficiency of 84.61 percent and generates 149.12 W of output power. The output power and efficiency are less than those of the materials NdFeB 48/11 and SmCo 26/26. This is because this sort of material has a low flux density. The value of the flux density in a magnetic material is also affected by the substance's permeability; the more significant the magnetic permeability of a material, the greater the value of the flux density. Therefore, while developing a generator, the material's flux density and magnetic permeability must be addressed.

This generator can produce 500 W of electricity with an efficiency of 88 percent, given its expected specs. So, based on the simulations conducted, the permanent magnet materials that fulfill these parameters are NdFeB 48/11 and SmCo 26/26, with output power above 500 W and efficiency above 88%. Still, Ceramic 11 does not match the specifications due to its output power. Under 500 W, the efficiency is less than 88%.

CREDIT

Syamsyarief Baqaruzi: Conceptualization, Methodology, and Software. **Amrina Mustaqim:** Data curation, Writing- Original draft preparation. **Putty Yunesti:** Visualization, Investigation. **Gde KM Atmajaya:** Supervision. **Ali Muhtar:** Writing-Reviewing and Editing. **Sabhan Kanata:** Software, Validation.

References

1. Bahramara S, Moghaddam MP, Haghifam MR. Optimal planning of hybrid renewable energy systems using HOMER: A review. Renewable and Sustainable Energy Reviews 2016;62:609–620.
2. Kanata S, Baqaruzi S, Muhtar A, Prasetyawan P, Winata T. Optimal Planning of Hybrid Renewable Energy System Using HOMER in Sebesi Island, Indonesia. International Journal of Renewable Energy Research 2021;11:1507–1516.
3. Tretiak O, Blümler P, Bougas L. Variable single-axis magnetic-field generator using permanent magnets. AIP Advances 2019;9:1–9.
4. Shapovalov RV, Brent G, Moshier R, Shoup M, Spielman RB, Gourdain PA. Design of 30-T pulsed magnetic field generator for magnetized high-energy-density plasma experiments. Physical Review Accelerators and Beams 2019;22:1–8.
5. Freire NMA, Cardoso AJM. Fault detection and condition monitoring of pmsgs in offshore wind turbines. Machines 2021;9:1–26.
6. Baqaruzi S, Miranto AA, Wahyuda D. The Effect of Halbach Array Configuration on Permanent-Magnet Synchronous Generator (PMSG) Outer-Runner. International Journal of Engineering, Science and Information Technology 2021;1:16–23.
7. Lee JH, Lee HK, Lee YG, Lee JI, Jo ST, Kim KH, et al. Design and Analysis Considering Magnet Usage of Permanent Magnet Synchronous Generator Using Analytical Method. Electronics (Switzerland) 2022;11:205.
8. Trongtorkarn M, Theppaya T, Techato K, Luengchavanon M, Kasagepongsarn C. Relationship between starting torque and thermal behaviour for a permanent magnet synchronous generator (Pmsg) applied with vertical axis wind turbine (vawt). Sustainability (Switzerland) 2021 8;13:9151.
9. Putri TD, Liliana L. Analisis Pengaruh Material Magnet Permanen Terhadap Karakteristik Generator Sinkron Radial 18 Slot 16 Pole. Power Elektronik : Jurnal Orang Elektro 2022 1;11:45–50. https://ejournal.poltektegal.ac.id/index.php/powerelektro/article/view/3279.

10. Eklund P, Eriksson S. The influence of permanent magnet material properties on generator rotor design. Energies 2019;12:1314.

11. Duan L, Lu H, Zhao C, Shen H. Influence of Different Halbach Arrays on Performance of Permanent Magnet Synchronous Motors. In: Proceedings of 2020 IEEE International Conference on Artificial Intelligence and Computer Applications, ICAICA 2020; 2020. p. 994–998.

12. Žežulka V, Straka P. The creation of a strong magnetic field by means of large magnetic blocks from NdFeB magnets in opposing linear Halbach arrays. Journal of Magnetics 2016;21:364–373.

13. Lupu IG, Grosu MC, Cramariuc O, Tudorache F, Nastac DC, Hogas HI. A cost-effective method for obtaining single magnetic cotton yarns. The Journal of The Textile Institute 2021;0:1–8. https://doi.org/10.1080/00405000.2021.1989819.

14. Jain A, Shankar S, Vanitha V. Power generation using permanent magnet synchronous generator (PMSG) based variable speed wind energy conversion system (WECS): An overview. Journal of Green Engineering 2017;7:477–504.

15. Saha S, Haque ME, Mahmud MA, Tan CP. Sensor fault resilient operation of permanent magnet synchronous generator based wind energy conversion system. In: 2017 IEEE Industry Applications Society Annual Meeting, vol. 2017-January; 2017. p. 1–8.

16. Tripathi SM, Tiwari AN, Singh D. Grid-integrated permanent magnet synchronous generator based wind energy conversion systems: A technology review. Renewable and Sustainable Energy Reviews 2015;51.

17. Lee JI, Bang TK, Lee HK, Woo JH, Nah J, Choi JY. Design of the high-speed pmsg with two different shaft material considering overhang effect and mechanical characteristics. Applied Sciences (Switzerland) 2021;11.

18. Qiu H, Zhao X, Wei Y, Tang B, Yi R, Cui G, et al. Comparative analysis of super high-speed permanent magnet generator electromagnetic and temperature fields with the PWM and uncontrolled rectifiers. EPE Journal (European Power Electronics and Drives Journal) 2020;30.

19. Du G, Huang N, He H, Lei G, Zhu J. Parameter Design for a High-Speed Permanent Magnet Machine under Multiphysics Constraints. IEEE Transactions on Energy Conversion 2020;35.

20. Zhang Y, McLoone S, Cao W. High speed permanent magnet motor design and power loss analysis. In: 2017 IEEE Transportation Electrification Conference and Expo, Asia-Pacific, ITEC Asia-Pacific 2017; 2017. p. 1–6.

21. Burnand G, Araujo DM, Perriard Y. Very-high-speed permanent magnet motors: Mechanical rotor stresses analytical model. In: 2017 IEEE International Electric Machines and Drives Conference, IEMDC 2017; 2017. p. 1–7.

22. Helmns D, Blum DH, Dutton SM, Carey VP. Development and validation of a latent thermal energy storage model using modelica. Energies 2021;14:1–22.

How to cite this article: Baqaruzi S., Mustaqim A., Yunesti P., Atmajaya G.K.M., Muhtar A., Kanata S. (2022), Variety of Characteristic Magnetic Material on Permanent Magnet Synchronous Generator (PMSG), *IPTEK The Journal of Technology and Science*, *33(2):129-139*.