Volume 10, Issue 7, pp. 15-19, July 2026.
International Journal of Scientific Engineering and Science
ISSN (Online): 2456-7361

Analysis of Magnetic Material Characteristics in the Modeling of a 12-Slot 8-Pole Permanent Magnet Synchronous Generator (PMSG 12S8P) Using the Finite Element Method (FEM)

Mil'al Mizan Al Hamid[1], Agus Adhi Nugroho[2]
[1, 2]Master of Electrical Engineering Program, Faculty of Industrial Technology, Universitas Islam Sultan Agung, Semarang, Indonesia-50112

***Abstract*— *The increasing demand for electrical energy in Indonesia is driving the development of renewable energy sources, one of which is Wind Power Plants (WPP). For micro-scale WPPs, the application of a three-phase Permanent Magnet Synchronous Generator (PMSG) with a 12-slot 8-pole (12S8P) configuration is considered highly suitable as it can operate at low rotational speeds and offers flexibility in its electromagnetic design. This study aims to analyze the effect of utilizing two types of permanent magnet materials, namely PM:12 (Br: 1.2; μr: 1.0) and Neodymium Iron Boron (NdFeB), on the performance characteristics of the 12S8P PMSG. The research methodology involved modeling and simulation based on the Finite Element Method (FEM) using MagNet Infolytica software, with rotational speed variations ranging from 500 to 3000 RPM and resistive loads between 10 and 60 Ω. The analyzed parameters include current, voltage, torque, input power, output power, and generator efficiency. The simulation results indicate that the PM:12 material produces significantly higher current, voltage, torque, and output power compared to NdFeB. The maximum output power generated by PM:12 reached 3346.1 W with an efficiency of 79% at a speed of 2500 RPM and a load of 10 Ω. Meanwhile, NdFeB demonstrated more stable and efficient operational characteristics at low rotational speeds, making it more suitable for applications that prioritize energy efficiency and performance stability.*

***Keywords*— *Wind Power Plant (WPP), Permanent Magnet Synchronous Generator (PMSG), Finite Element Method (FEM), Permanent Magnet, PM:12, Neodymium Iron Boron (NdFeB), Generator Efficiency.*

I. Introduction

The development of Wind Power Plants (WPP) and the optimization of Permanent Magnet Synchronous Generator (PMSG) performance have attracted considerable attention due to the increasing demand for renewable energy systems. Previous studies have demonstrated the feasibility of employing PMSG technology in low-speed wind energy conversion applications. Prasetijo et al. investigated the application of permanent magnet generators for low-speed electricity generation and reported their suitability for renewable energy conversion systems operating at low rotational speeds [1]. In addition, Anam et al. utilized the Finite Element Method (FEM)-based MagNet Infolytica software to design a 100-Watt 12-slot 8-pole (12S8P) PMSG and obtained a no-load output voltage of 21.65 V at a rotational speed of 100 RPM [2]. Furthermore, studies on permanent magnet generators have shown that the selection of magnetic materials significantly influences magnetic flux distribution, induced voltage, output power, and overall generator efficiency [3],[4].

Recent developments in PMSG technology have also focused on improving generator performance through optimization of machine geometry, slot-pole combinations, and magnetic material characteristics. Research on axial-flux permanent magnet generators demonstrated stable electrical output and promising efficiency characteristics under various operating conditions [4]. Meanwhile, simulation-based studies using MagNet Infolytica have confirmed that FEM analysis is an effective approach for evaluating electromagnetic behavior and predicting generator performance before physical prototyping [2], [5].

Although the 12S8P PMSG configuration has been widely investigated, studies focusing on its performance under low wind speed conditions commonly found in Indonesia, ranging from 2.5 m/s to 6 m/s, remain limited. Furthermore, comparative analyses of PM:12 (Br: 1.2 T; μr: 1.0) and NdFeB magnetic materials in terms of magnetic flux distribution, electrical output characteristics, torque, output power, and electro-mechanical efficiency are still scarce. Therefore, this study presents a comprehensive comparison of the magnetic flux characteristics and electro-mechanical performance of PM:12 and NdFeB magnets applied in a 12S8P PMSG model. The simulation is conducted using the Finite Element Method (FEM) at rotational speeds ranging from 500 RPM to 1500 RPM under purely resistive loads of 10 Ω, 20 Ω, and 30 Ω to evaluate the influence of magnetic material properties on generator performance.

II. Theoretical Framework and Modeling

A. Wind Power and PMSG Characteristics

The proposed system is designed for a micro-scale WPP using a TSD-500 horizontal-axis wind turbine with an assumed aerodynamic efficiency (Cp) of 40%. The theoretical mechanical power extracted from the wind is expressed as:

$$Pwind = \frac{1}{2} \cdot \rho \cdot A \cdot V^3$$

Where ρ is the air density (kg/m³), A is the turbine's swept area (m²), and V is the wind speed (m/s). To eliminate cogging torque at low wind speeds, a 3-phase cogging-less salient pole PMSG configuration is utilized. The induced electromotive

International Journal of Scientific Engineering and Science
Volume 10, Issue 7, pp. 15-19, July 2026. ISSN (Online): 2456-7361

force (EMF) in the generator relies on Faraday's law of induction, determined by the rate of change of flux linkage:

$$E = -N\frac{\Delta\lambda}{\Delta t}$$

The overall electro-mechanical performance of the PMSG is evaluated based on its power conversion efficiency:

$$\eta = \frac{Pout}{Pin} x100\%$$

B. Finite Element Method (FEM) and Magnetic Materials

This research utilizes MagNet software to computationally solve the electromagnetic field distribution using the 2D Finite Element Method (FEM) approach. The fundamental magnetic relationship governing the simulation is:

$$B = \mu o.\mu r.H$$

Where B is the magnetic flux density, H is the magnetic field intensity, and μ0 = 4π × 10^{-7} H/m

The computational modeling focuses on the second quadrant of the B-H curve (demagnetization characteristics) of two permanent magnets: Neodymium Iron Boron (NdFeB) and PM:12. The core parameters analyzed are the Remanence (Br), representing the residual flux density, and the Coercivity (Hc), representing the reverse intensity required for demagnetization. Evaluating these parameters within the 12S8P topology ensures the identification of optimal field saturation and recoil permeability under the specified operational rotational speeds.

III. Research Methodology

This research employs a quantitative approach utilizing 2D Finite Element Method (FEM) simulations via MagNet Infolytica software. The methodology is structured to evaluate the electromagnetic and electro-mechanical performance of the PMSG. The technical procedure consists of the following core stages, as illustrated in the research flowchart (Figure 1).

The research data in this study were obtained and analyzed in the form of tables and graphs. These tables and graphs illustrate the relationship between the rotational speed (RPM) and the resistive load (Ω).

TABLE 1. Simulation Test Results at 500 RPM

Material	Load	Current	Voltage	Torque	P In	P Out	Efisiency
PM:12 Br:1.2 mur 1.0	10	4.08	40.82	5.6	293.39	167.19	0.57
	20	2.11	42.21	3.93	205.97	89.42	0.43
	30	1.42	42.62	3.33	174.44	60.99	0.35
	40	1.06	42.28	3.01	157.75	45.42	0.29
	50	0.85	42.69	2.82	147.6	36.65	0.25
	60	0.71	42.83	2.69	140.73	30.74	0.22
NdFeB: Neodymium Iron Boron	10	3.666	36.664	3.633	190.55	139.071	0.729
	20	1.8922	37.845	2.278	118.52	73.686	0.621
	30	1.28	38.418	1.791	92.783	50.813	0.547
	40	0.959	38.367	1.53	78.939	38.011	0.481
	50	0.7688	38.44	1.371	70.535	30.524	0.432
	60	0.6418	38.512	1.264	64.857	25.528	0.393

TABLE 2. Simulation Test Results at 1000 RPM

Material	Load	Current	Voltage	Torque	P In	P Out	Efisiency
PM:12 Br:1.2 mur 1.0	10	7.91	79.15	8.73	913.98	629.38	0.69
	20	4.18	83.67	5.81	608.16	351.12	0.58
	30	2.83	84.83	4.66	487.65	240.45	0.49
	40	2.15	85.94	4.06	424.91	185.26	0.44
	50	1.73	86.74	3.69	386.32	151.33	0.39
	60	1.45	86.92	3.43	359.32	126.8	0.35
NdFeB: Neodymium Iron Boron	10	3.631	36.31	3.599	365.8	138.5	0.3786
	20	1.881	37.63	2.26	221.8	73.41	0.3309
	30	1.2674	38.024	1.771	169.4	49.80	0.293
	40	0.9591	38.36	1.517	142.4	38.01	0.266
	50	0.766	38.3	1.35	125.6	30.29	0.2411
	60	0.639	38.361	1.46	137.9	25.42	0.184

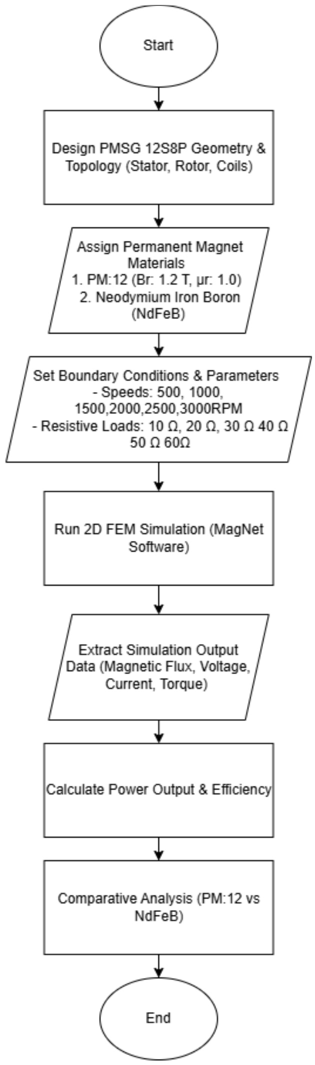

Fig. 1. Research flowchart

IV. Result and Discussion

TABLE 3. Simulation Test Results at 1500 RPM

Material	Load	Current	Voltage	Torque	P In	P Out	Efisiency
PM:12 Br:1.2 mur 1.0	10	11.77	117.67	11.65	1829.60	1389.31	0.76
	20	6.17	123.45	7.49	1176.46	763.93	0.65
	30	4.22	126.54	5.93	931.59	535.29	0.57
	40	3.18	127.37	5.06	794.11	406.72	0.51
	50	2.57	128.64	4.51	708.33	331.79	0.47
	60	2.16	129.61	4.14	650.00	280.85	0.43
NdFeB: Neodymium Iron Boron	10	3.584	35.84	3.76	581.8	137.1	0.235
	20	1.866	37.32	2.45	367.7	73.12	0.198
	30	1.261	37.849	1.973	289.5	49.8	0.172
	40	0.952	38.111	1.721	248.9	37.76	0.151
	50	0.765	38.254	1.56	223.9	30.37	0.135
	60	0.639	38.36	1.249	169.4	25.43	0.15

TABLE 4. Simulation Test Results at 2000 RPM

Material	Load	Current	Voltage	Torque	P In	P Out	Efisiency
PM:12 Br:1.2 mur 1.0	10	14.82	148.19	13.71	2872	2202.8	0.77
	20	8.01	160.29	9.04	1892	1291	0.68
	30	5.57	166.95	7.10	1487	931.18	0.63
	40	4.24	169.40	6.03	1261	719.51	0.57
	50	3.40	169.87	5.32	1114	578.91	0.52
	60	2.82	171.25	4.83	1011	489.99	0.48
NdFeB: Neodymium Iron Boron	10	3.59	35.9	3.692	765.7	138	0.18
	20	1.869	37.39	2.36	474.5	73.7	0.155
	30	1.263	37.912	1.87	369.0	50.2	0.136
	40	0.953	38.15	1.87	369.0	38.0	0.102
	50	0.766	38.3	1.46	280.6	30.5	0.108
	60	0.64	38.4	1.362	257.8	25.5	0.0992

Volume 10, Issue 7, pp. 15-19, July 2026.

ISSN (Online): 2456-7361

TABLE 5. Simulation Test Results at 2500 RPM

Material	Load	Current	Voltage	Torque	P In	P Out	Efisiency
PM:12 Br:1.2 mur 1.0	10	18.26	182.62	16.24	4252.4	3346.1	0.79
	20	9.91	198.16	10.47	2739.8	1971.6	0.72
	30	6.83	204.79	8.19	2144.0	1402.5	0.65
	40	5.26	210.22	6.93	1815.1	1107.2	0.61
	50	4.25	212.27	6.11	1598.3	903.73	0.57
	60	3.54	212.34	5.51	1443.3	754.01	0.52
NdFeB: Neodymium Iron Boron	10	3.56	35.625	3.91	1032.2	137.7	0.133
	20	1.85	37.09	2.613	672.50	73.05	0.108
	30	1.256	37.69	2.13	542.29	49.90	0.092
	40	0.9497	37.98	1.72	432.47	37.88	0.087
	50	0.763	38.17	1.72	432.47	30.53	0.07
	60	0.638	38.29	1.62	404.01	25.56	0.063

TABLE 6. Simulation Test Results at 3000 RPM

Material	Load	Current	Voltage	Torque	P In	P Out	Efisiency
PM:12 Br:1.2 mur 1.0	10	21.48	214.77	18.26	5736.8	4622	0.81
	20	11.65	233.05	11.74	3687.8	2721	0.74
	30	8.04	241.30	9.24	2903.0	1950	0.67
	40	6.21	248.56	7.78	2443.5	1548	0.63
	50	5.07	253.37	6.85	2152.2	1286	0.6
	60	4.25	255.14	6.18	1940.0	1087	0.56
NdFeB: Neodymium Iron Boron	10	3.546	35.46	3.58	1134	137.8	0.121
	20	1.86	37.211	2.27	697.2	74	0.106
	30	1.259	37.79	1.788	537.7	50.38	0.0937
	40	0.952	38.106	1.535	455.1	38.22	0.083
	50	0.765	38.288	1.379	404.2	30.77	0.076
	60	0.64	38.406	1.272	369.7	25.75	0.069

A. Current Characteristics Analysis

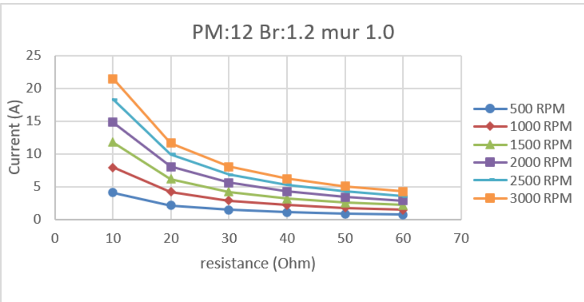

Fig. 2. Current graph of PM:12 (Br: 1.2, μr: 1.0)

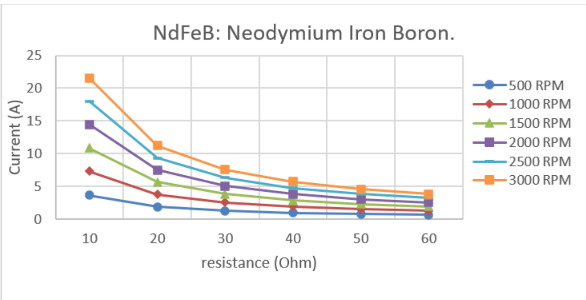

Fig. 3. Current graph of NdFeB (Neodymium Iron Boron)

Based on Figures 2 and 3, the generator utilizing PM:12 (ferrite) magnets produces a significantly higher current compared to NdFeB (>20 A compared to 3.5 A at 3000 RPM). Although PM:12 is highly responsive to rotational increases, this massive current has the potential to generate excessive heat. Conversely, the NdFeB current output is much lower but demonstrates a stable increase. In conclusion, PM:12 is suitable for high-current applications, whereas NdFeB is far more ideal for systems that prioritize stability and power efficiency.

B. Voltage Characteristics Analysis

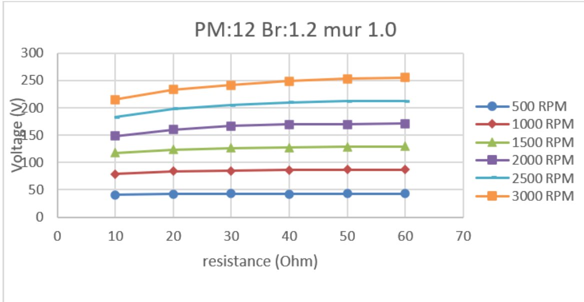

Fig. 4. Voltage graph of PM:12 (Br: 1.2, μr: 1.0)

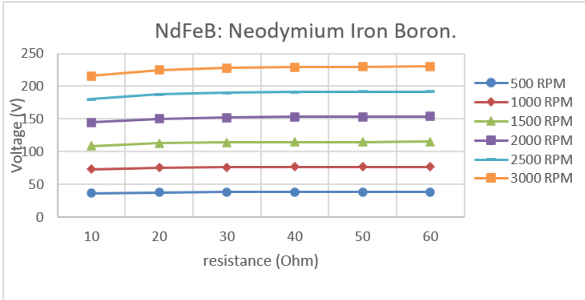

Fig. 5. Voltage graph of NdFeB (Neodymium Iron Boron

Based on Figures 4 and 5, the PM:12-based generator generates a substantially higher voltage (>250 V at 3000 RPM) and increases significantly alongside the RPM, whereas NdFeB tends to remain constant in the range of 35–39 V. Although both show stable voltage profiles against load resistance variations, their intended applications differ. Consequently, PM:12 is ideal for high-voltage and high-power demands, while NdFeB is recommended for low-voltage applications that require strict stability and efficiency.

C. Torque Characteristics Analysis

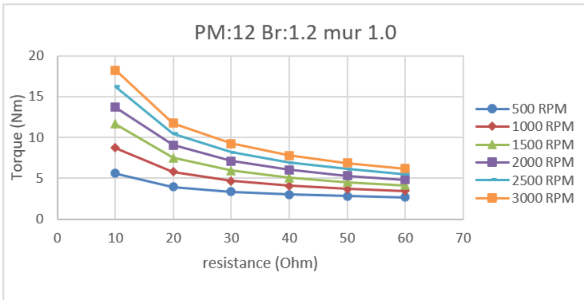

Fig. 6. Torque graph of PM:12 (Br: 1.2, μr: 1.0)

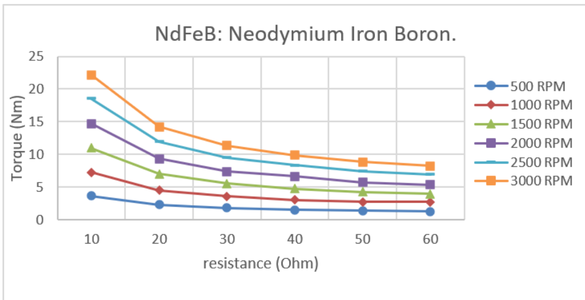

Fig. 7 Torque graph of NdFeB (Neodymium Iron Boron)

Based on Figures 6 and 7, the PM:12 generator yields a much higher peak torque (>18 Nm at 3000 RPM at low resistance), which subsequently drops drastically at higher resistances. This high torque consequently increases the mechanical load on the generator shaft. On the contrary, the NdFeB generator torque is much lower (maximum 3.9 Nm) but exhibits a flatter and more stable decline profile. In conclusion, PM:12 excels in massive output despite placing heavier loads on the prime mover, while NdFeB is recommended for light mechanical applications prioritizing rotational stability and prime mover efficiency.

D. Input Power Characteristics Analysis

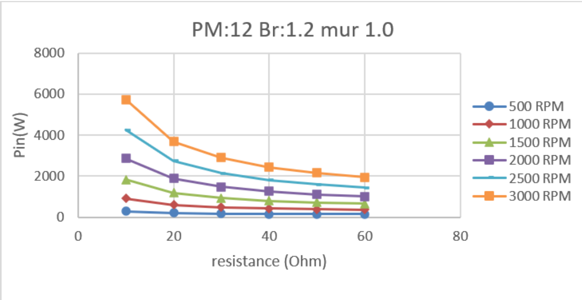

Fig. 8. Input power graph of PM:12 (Br: 1.2, μr: 1.0)

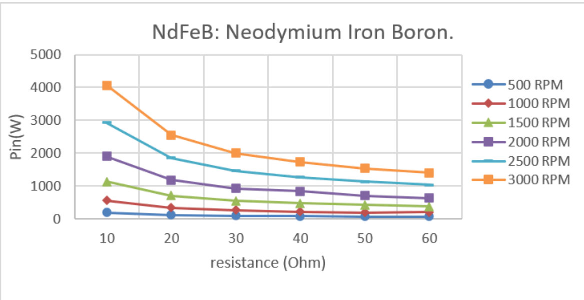

Fig. 9. Input power graph of NdFeB (Neodymium Iron Boron)

Based on Figures 8 and 9, the input power requirement for the PM:12 generator is substantially higher, reaching >5700 W at 3000 RPM (low resistance), compared to NdFeB which only absorbs approximately 1134 W. As the resistance value increases, the input power decline curve for PM:12 reduces drastically, whereas NdFeB shows a much more gradual decline. This confirms that the high electrical output (current, voltage, and torque) of PM:12 is directly proportional to its massive mechanical power consumption. Therefore, PM:12 fits systems aiming for large power outputs, while NdFeB is highly efficient and ideal for applications with limited mechanical input power that demand operational stability.

E. Output Power Characteristics Analysis

Based on Figures 10 and 11, the output power of the PM:12 generator demonstrates a significant advantage, reaching >4600 W at 3000 RPM (low resistance) before degrading sharply to ~1000 W at high resistance. Conversely, the NdFeB output power capacity is much smaller (maximum ~138 W) with a flatter and more stable decline profile around 20–30 W at higher resistances. This aligns with the high mechanical power requirement of PM:12 to achieve such outputs. In conclusion, PM:12 material is recommended for large-scale applications requiring high power, whereas NdFeB is more ideal for light-scale systems that specifically prioritize energy conversion efficiency and power stability.

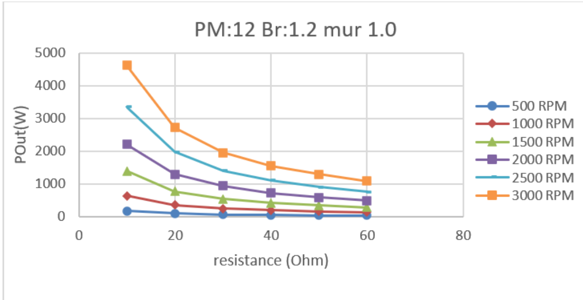

Fig. 10. Output power graph of PM:12 (Br: 1.2, μr: 1.0)

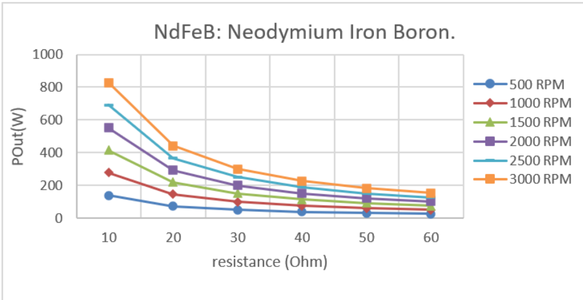

Fig. 11. Output power graph of NdFeB (Neodymium Iron Boron)

F. Efficiency Characteristics Analysis

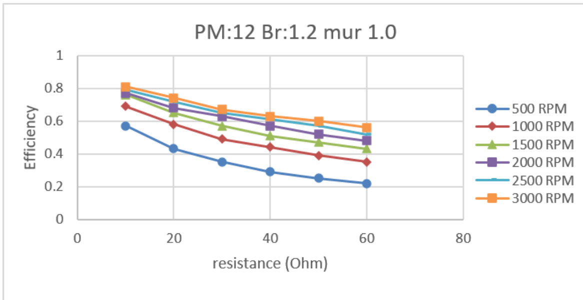

Fig. 12. Efficiency graph of PM:12 (Br: 1.2, μr: 1.0)

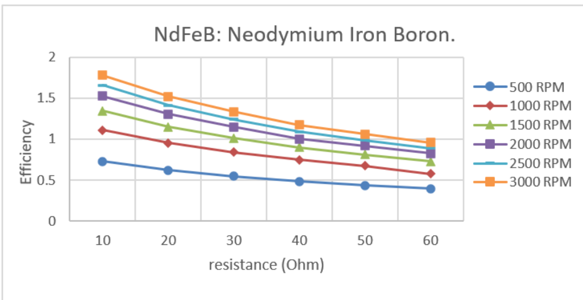

Fig. 13. Efficiency graph of NdFeB (Neodymium Iron Boron)

Based on Figures 12 and 13, the efficiency (η) of the PM:12 generator reaches a maximum point of around 70% at low resistance but degrades sharply to the 20% range as the load resistance increases. Conversely, the NdFeB generator exhibits an overall higher and more stable efficiency profile in the 30%–70% range across various resistance variations, regardless of

Volume 10, Issue 7, pp. 15-19, July 2026. ISSN (Online): 2456-7361

the small absolute output power generated. This highlights a clear performance trade-off: PM:12 is prioritized for applications seeking massive output power despite efficiency drops at high loads, whereas NdFeB is highly recommended for applications emphasizing high energy conversion efficiency and performance stability.

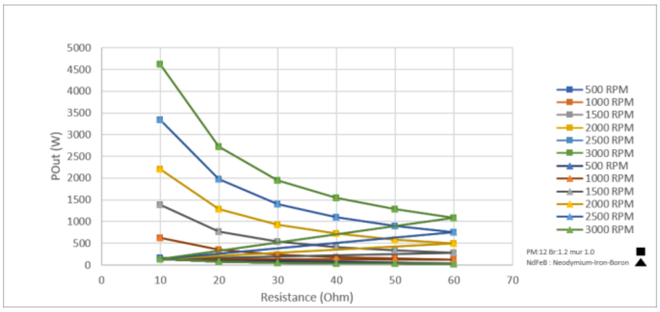

Fig 14. Output power comparison between the two magnetic materials

Based on Figure 14, comparing the output power reveals a significant performance disparity. The output power of PM:12 is highly sensitive to speed and load, surging drastically to 4622 W (at 3000 RPM, 10 Ω) before dropping sharply as resistance increases. Conversely, the NdFeB output profile is far more stable and less affected by rotational speed variations, with an output range of 137 W (low resistance) to 25 W (high resistance).

V. Conclussion

1. Effect of Loading: The increase in load resistance is inversely proportional to the generator's overall performance. As the load resistance increases, the current, mechanical torque, output power, and generator efficiency experience a significant decrease, whereas the generated voltage tends to remain constant and stable.
2. Correlation between Rotational Speed and Magnetic Material: The efficiency characteristics of the magnetic materials are highly dependent on the rotational speed (RPM). The Neodymium Iron Boron (NdFeB) magnetic material operates at its highest efficiency level at low rotational speeds (500 RPM). Conversely, the PM:12 (Br: 1.2; µr: 1.0) material demonstrates a significantly superior performance dominance across the medium to high-speed range (1000–2500 RPM).
3. The Most Optimal Material: Comprehensively, PM:12 (Br: 1.2; µr: 1.0) emerges as the most optimal magnetic material for application in this 12S8P PMSG model. This material has proven capable of generating a massive maximum output power of 3346.1 W, achieving a maximum efficiency level of up to 79% at an operational rotational speed of 2500 RPM.

References

[1] H. Prasetijo, Ropiudin, and B. Dharmawan, “Generator Magnet Permanen Sebagai Pembangkit Listrik Putaran Rendah,” *J. Din. Rekayasa*, vol. 8, no. 2, pp. 70–77, 2012.

[2] M. C. Anam and M. Irfan, “Perancangan Generator 100 Watt Menggunakan Software Elektromagnetik Infolityca,” vol. 2, no. 1, pp. 27–36, 2017.

[3] I. M. W. KASTAWAN and R. HIDAYAT, “Simulasi Distribusi Fluks dan Tegangan Generator Magnet Permanen Satu-Fasa Hasil Modifikasi Motor Induksi Rotor Sangkar Satu-Fasa,” *ELKOMIKA J. Tek. Energi Elektr. Tek. Telekomun. Tek. Elektron.*, vol. 12, no. 3, p. 784, 2024, doi: 10.26760/elkomika.v12i3.784.

[4] M. Yuhendri, D. Doni, and A. F. Ikhfa, “Rancang Bangun Generator Magnet Permanen Fluksi Aksial Single Stator Single Rotor,” *Simetris J. Tek. Mesin, Elektro dan Ilmu Komput.*, vol. 14, no. 2, pp. 339–350, 2023, doi: 10.24176/simet.v14i2.9750.

[5] M. N. U. R. Kholis, P. Studi, T. Elektro, F. Teknik, and U. M. Surakarta, “Skripsi mohammad nur kholis software magnet,” 2020.