PERFORMANCE OF PERMANENT MAGNET SYNCHRONOUS GENERATOR (PMSG) 3 PHASE RADIAL FLUX RESULTS MODIFICATION OF INDUCTION MOTOR

Ahmad Raafi Fauzi[1], Rama Arya Sobhita[1], Anggara Trisna Nugraha[1], Anisa Fitri Santosa[2,*]

[1]Department of Ship Electrical Engineering, Surabaya State Shipping Polytechnic, Indonesia
[2]Bio-Industrial Mechatronics Engineering, National Chung Hsing University, Taiwan

*Correspondence Author: g112040521@mail.nchu.edu.tw

Abstract

Abstract: The demand for electrical energy in Indonesia has experienced a significant surge, becoming indispensable for nearly all modern activities. However, despite this surge, the primary energy source for power plants continues to heavily rely on fossil fuels. Consequently, it is imperative to transition towards renewable energy sources to mitigate environmental impact and tackle the prevailing energy crisis. In response to this need, permanent magnet synchronous generators have emerged as a promising alternative within the electricity industry. These generators operate by utilizing permanent magnets to generate a magnetic field within the coil, thereby eliminating the necessity for excitation current. By leveraging renewable energy sources such as wind or hydro power, these generators strive to optimize electricity production and alleviate the ongoing energy crisis. This research project aims to repurpose materials sourced from used water pump motors, including rotors and stators, to construct permanent magnet synchronous generators. The process involves incorporating permanent magnets into the rotor and modifying the original motor winding. Through rigorous testing involving the application of a 40 Ohm load and varying rotational speeds between 2000 and 1600 rpm, the research reveals that the generator can generate a minimum power output of 0.7 Watts at 200 rpm and a maximum power output of 41.8 Watts at 1600 rpm. The optimal efficiency of 75.78% is attained at 400 rpm. Overall, this research underscores the potential of repurposing existing materials to develop renewable energy solutions, offering a sustainable approach to addressing not only the energy needs of Indonesia but also those of other regions globally.

Keyword: Synchronous generator, Rotating speed variation, Power

1. Introduction

The rapid population growth in Indonesia has led to a corresponding surge in the demand for electrical energy, which has become an essential commodity in modern society (Andika & A. Hamzah, 2018a, b; Nugraha et al., 2022). Historically, fossil fuels have been the primary source for electricity generation, but the dwindling supply of these conventional energy sources poses a significant challenge. In light of this, the adoption of new renewable energy sources presents a viable solution to address the increasing energy needs of the community (Piggott, Kirby, & Piggott, 1999; Sunarlik, 2017; Suhada & Yasri, 2018).

However, the high cost of materials required for constructing generators remains a barrier for many individuals, prompting them to rely on conventional electricity supplied by PLN (Stephen, 1999; Goeritno & Hidayat, 2015). To circumvent this issue and make generator construction more affordable, it is possible to repurpose used items such as water pump motors (Soepranto et al., 2018; Sofyan et al., 2023). These motors share similar construction principles with conventional generators and can be modified to create robust and cost-effective generator alternatives (Nugraha et al., 2023a, b, c, d, e, f, g). By leveraging existing materials and technology, communities can access reliable electricity generation solutions without incurring prohibitively high costs.

2. Material and methods

In conducting a research, there are several stages that must be carried out to achieve goals and get a good and accountable research result According to the research (Supiyadi et al., 2023; Intyanto et al., 2023) the equation used for adjusting sensor readings is as follows:

2.1. Flowchart Diagram

The research stages are outlined in a flow chart presented as Figure 1, while Figure 2 depicts the flow chart to be utilized in this study. If the current value aligns with the calculated value, data collection will proceed.

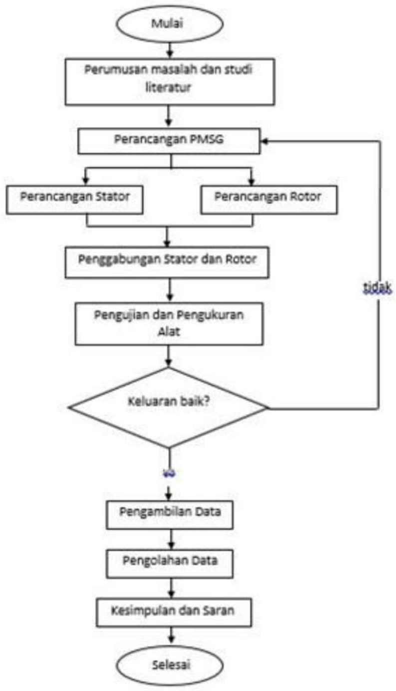
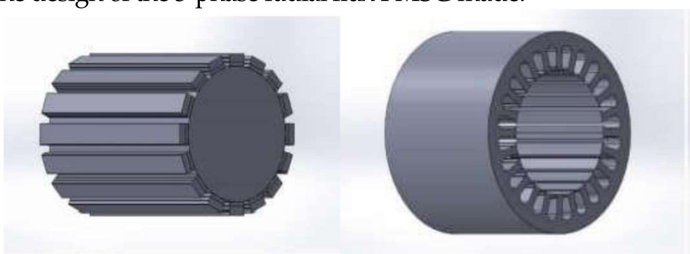


Figure 1. Flowchart research

2.2. Design

The following is the design of the 3-phase radial flux PMSG made:



A B

Figure 2. (A) Motor Construction ,(B) Stator Constraction

Figure (A) shows the design and shape of the rotor to be used. The protruding part is the magnet with two layers. while part (B) displays the stator design that will be used (Nugraha et al., 2023h, i, j, k, l, m). The number of slots used is 24 slots where in the slot will be installed coils or windings using email wire with a predetermined size and number (Nugraha et al., 2023n; Apriani et al., 2023). Table 1 is the specification of the generator made.

Tabel 1. Generator specifications

No.	Characteristics	Size
1.	Rotor Diameter	51 mm
2.	Stator thickness	32 mm
3.	Stator Inside Diameter	53 mm
4.	Rotor Length	30 mm
5.	Number of coils	50 lilit
6.	Winding diameter	0.4 mm
7.	Magnet dimensions	40x10x3 mm
8.	Magnetic Materials	Neodymium N50
9.	Air Gap	2 mm

2.3. Winding

Several winding methods are employed in generators to achieve the desired voltage output. The generated voltage should ideally be at its peak and closely resemble a sinusoidal waveform. Each slot within the stator needs to be equipped with coils to maintain its qualification as an electrical apparatus. These slots can be occupied by either a single coil, dual coils, or even multiple coils.

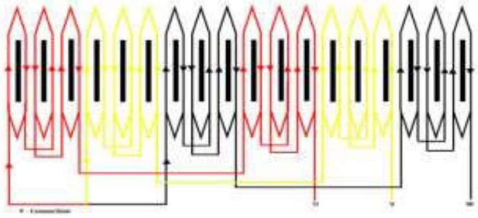


Figure 3. Generator Winding

3. Results and discussion

3.1. Generator Calculations

The power of the generator can be determined using equation 1 (6), and the resulting value is as follows:

$$p = 0{,}053^2 \times 0{,}032 \times 0{,}5\pi^2 \times 0{,}945 \times 6{,}25 \times 1{,}4 \times 12000 \times 0{,}85$$
$$p = 38\ w$$

By using the power value generated according to the calculation of 38 watts, and with a predetermined voltage of 36 volts, the current obtained can be calculated by the formula 2:

$$\mathrm{I} = \frac{38}{\sqrt{3} \times 3 \times 36} = 0{,}21\ A$$

After calculating based on the existing equation, the maximum magnetic flux value is determined to be 0.0004032 Wb. Based on the current value that has been obtained, the safest wire size to use is 0.4 mm. With this information, the number of turns can be determined using equation 3 :

$$Nc = \frac{30}{4{,}44 \times 50 \times 0{,}0004032 \times \frac{24}{3}} = 50{,}27$$

Based on the calculation results above, the number of turns required for the generator is 50 turns. This number of turns will be adjusted to the number of slots available, which is 24. Therefore, a total of 24 coils are required with each coil having 50 turns.

3.2. Generator Testing

Generator testing is carried out when open circuit and when loaded with 40 Ohm. The following are the generator test results

a. Open circuit generator

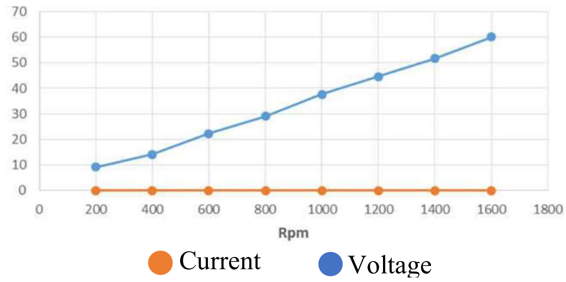
Experiments were conducted following the previously outlined procedures, with rotational speeds ranging from 200 to 1600 rpm. Table 2 displays the test outcomes of the generator under open circuit conditions or without load. The voltage readings indicate that the lowest value recorded is 9.2 V at a rotational speed of 200 rpm, while the highest voltage is attained at 1600 rpm, yielding a voltage of 60.01 V.

Tabel 2. Result open circuit

Revolution per minute (RPM)	Voltage (V)	Current (A)
200	9.2	0
375	13.9	0
400	14.25	0
600	22.3	0
800	29.12	0
1000	37.68	0

Revolution per minute (RPM)	Voltage (V)	Current (A)
1200	44.57	0
1400	51.72	0
1600	60.01	0

Figure 3. Graphic result



The graph depicting voltage and current values under open circuit conditions illustrates their variation with changes in rotor rotational speed. It is observed that as the rotational speed of the generator increases, the voltage value also shows a corresponding increase.

b. Loaded generator

Tests were conducted using a 40 ohm lime resistor at the same range of rotation speeds, i.e. 200 to 1600 rpm. From the data listed in Table 3, it can be observed that the lowest voltage and current values occurred at a speed of 200 rpm, with a voltage of 6.4 V and a current of 0.11 A. In contrast, the highest voltage and current values were recorded at a rotation speed of 1600 rpm, with a voltage of 41.8 V and a current of 1 A.

Tabel 3. Result Load circuit

Revolution per minute (RPM)	Voltage (V)	Current (A)
200	6.4	0.11
375	9.6	0.23
400	10.8	0.25
600	16.4	0.39
800	21.2	0.5
1000	27.3	0.6
1200	32.6	0.79
1400	36.6	0.89
1600	41.8	1

3.3. Analyze

From the data obtained during testing, the input power can be calculated using the voltage generated under no load and the current drawn under load. This calculation can be performed using the following equation 4:

$$P_{in} = \sqrt{3} \times E_a \times I_L$$

Tabel 4. Input power value

Revolution per minute (RPM)	Voltage (V)	Current (A)	Power
200	9.2	0.11	1.75
375	13.9	0.23	5.54
400	14.25	0.25	6.17
600	22.3	0.39	15.06
800	29.12	0.5	25.22
1000	37.68	0.6	39.16
1200	44.57	0.79	60.99
1400	51.72	0.89	79.73
1600	60.01	1	103.94

The minimum power value is observed at a speed of 200 RPM, measuring 1.75 watts, while the maximum power value is recorded at 1600 RPM, amounting to 103.94 watts. Additionally, the analysis of output power values can be conducted by utilizing the voltage and current measurements obtained under load conditions as follows :

$$P_{out} = \sqrt{3} \times V_T \times I_L$$

Tabel 5. Output power value

Revolution per minute (RPM)	Voltage (V)	Current (A)	Power
200	6.4	0.11	1.22
375	9.6	0.23	3.82
400	10.8	0.25	4.68
600	16.4	0.39	11.08
800	21.2	0.5	18.36
1000	27.3	0.6	28.37
1200	32.6	0.79	44.61
1400	36.6	0.89	56.42
1600	41.8	1	72.40

The lowest power value occurs at 200 RPM, which is 1.22 watts, while the maximum power occurs at 1600 RPM, reaching 72.40 watts [7].Efficiency is calculated by comparing the input power with the output power, using the following equation 3 [8]:

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

It can be seen that the best efficiency value during testing was at a speed of 400 rpm with an efficiency value of 75.79%.

Tabel 6. Result efficiency

P IN	P OUT	Efisiensi
1.75	1.22	69.57
5.54	3.82	69.06
6.17	4.68	75.79
15.06	11.08	73.54
25.22	18.36	72.80
39.16	28.37	72.45
60.99	44.61	73.14
79.73	56.42	70.77
103.94	72.40	69.66

4. Conclusion

The test results demonstrate a clear correlation between the generator's rotational speed and the power generated, with higher speeds resulting in greater power output. At a rotational speed of 1600 rpm, the generator achieves its highest power output, generating 72.40 watts. Conversely, the lowest power output of 1.22 watts is observed at a speed of 200 rpm. Efficiency, measured as the ratio of output power to input power, peaks at 75.79% when the generator operates at 400 rpm under a load of 40 ohms.

These findings underscore the importance of optimizing rotational speed to maximize power generation efficiency. By understanding the relationship between rotational speed and power output, further improvements can be made to enhance the performance and effectiveness of the generator in meeting energy needs efficiently.

Credit authorship contribution statement

Ahmad Raafi Fauzi: Conceptualization, Writing – review & editing. **Rama Arya Sobhita**: Supervision, Writing – review & editing. **Anggara Trisna Nugraha**: Conceptualization, Supervision, Writing – review & editing. **Ahmad Fahrendi Shofian**: Supervision, Writing – review & editing. **Anisa Fitri Santosa**: Conceptualization, Supervision, Writing – review & editing.

References

Andika and A. Hamzah, "Perancangan dan Pembuatan Generator Fluks Radial Tiga Fasa Magnet Permanen Kecepatan Rendah," Univ. Riau, vol. 5, no.1, pp. 1-8, 2018.

R. A. Madani, Sutisna, dan A. Andang, "Modifikasi Motor Induksi Menjadi Generator Sinkron Magnet Permanen 24 Slot 8 Pole", Universitas Siliwangi.

H. Piggott, T. Kirby, and H Piggott, Windpower Workshop Windpower Workshop Building Your Own Wind Turbine. 1999.

W. Sunarlik, "Prinsip Kerja Generator," PRINSIP KERJA Gener. Sink., p. 6, 2017.

I. Suhada, M.O & Yasri, "Aspek Rancangan Generator Magnet Permanen Fluks Radial Kecepatan Rendah," vol. 5, pp. 1-7, 2018.

C. Stephen J, Electric Machinery Fundamentals, 5th ed. Australia, 1999.

A. Goeritno and A. Hidayat, "KONSTRUKSIROTOR MAGNET PERMANEN FLUKS RADIAL UNTUK ALTERNATOR FASE TUNGGAL," pp. 1-7, 2015.

Soepranto, M. Shiddiq, U. Wibawa, and T. Utomo, "Jurnal Teknologi Elektro, Universitas Mercu Buana ISSN: 2086-9479 Pengereman Regeneratif Motor DC Tanpa Sikat (BLDC) UntukPengisian Baterai Pada Sepeda Elektrik Soeprapto Fakultas Teknik Program Studi Teknik Elektro UnggulWibawaFakultas Teknik Pr," vol. 9, no. 1, pp. 1-9, 2018. system," *IOP Conf Ser Earth*

Environ Sci, vol. 512, no. 1, p. 012163, Jun. 2020, doi: 10.1088/1755-1315/512/1/012163.

Mochammad Sofyan, Syaifudin Syaifudin, Andjar Pudji, Anggara Trisna Nugraha, and Bedjo Utomo, "Comparative Analysis of Water and Oil Media on Temperature Stability in PID Control-Based Digital Thermometer Calibrator," Indonesian Journal of Electronics, Electromedical Engineering, and Medical Informatics, vol. 5, no. 2, pp. 73–78, May 2023, doi: https://doi.org/10.35882/ijeeemi.v5i2.274.

Anggara Trisna Nugraha, Moch Fadhil Ramadhan, and Muhammad Jafar Shiddiq, "Quadcopter Movement Analysis Using Output Feedback Control Based on Line of Sight," JEEMECS (Journal of Electrical Engineering, Mechatronic and Computer Science), vol. 6, no. 1, pp. 1–10, Feb. 2023, doi: https://doi.org/10.26905/jeemecs.v6i1.6033.

Anggara Trisna Nugraha, Leonardi Agus Wahyudi, D. Ilham, and Novsyafantri Novsyafantri, "Simulasi Pengaturan Kecepatan Motor DC Seri dengan Menggunakan Penyearah Terkendali," vol. 13, no. 01, pp. 9–20, May 2023, doi: https://doi.org/10.47709/elektriese.v13i01.2348.

Anggara Trisna Nugraha, Rachmat Marjuki, D. Ilham, and Fahmi Ivannuri, "Sistem Kontrol Tegangan pada Generator Induksi 3 Phasa dengan PLC Voltage," Elektriese Jurnal Sains dan Teknologi Elektro, vol. 13, no. 01, pp. 21–33, May 2023, doi: https://doi.org/10.47709/elektriese.v13i01.2347.

Anggara Trisna Nugraha, Mochamad Dhani Inwanul Farikh, D. Ilham, and Reza Fardiyan As'ad, "Penyearah Terkontrol Satu Phasa Gelombang Penuh terhadap Motor DC 3 HP," vol. 13, no. 01, pp. 42–49, May 2023, doi: https://doi.org/10.47709/elektriese.v13i01.2352.

Ramadhan Aditiya Supiyadi, Purwidi Asri, and Anggara Trisna Nugraha, "Rancang Bangun Prototipe Sistem Kontrol UV Conveyor dan Monitoring Kadar Air Cacahan Plastik Berbasis Mikrokontroler," Elektriese Jurnal Sains dan Teknologi Elektro, vol. 13, no. 01, pp. 34–41, May 2023, doi: https://doi.org/10.47709/elektriese.v13i01.2349.

Gramandha Wega Intyanto, Ahmad Arbi Trihatmojo, Dwi Ariani Finda Yuniarti, and Anggara Trisna Nugraha, "ELDOC - Design of Electric Dolly Camera for Video Recording Using the Omni-Direction Wheel," Walisongo Journal of Information Technology, vol. 5, no. 1, pp. 41–52, Jun. 2023, doi: https://doi.org/10.21580/wjit.2023.5.1.16463.

Anggara Trisna Nugraha, Joessianto Eko Poetro, Perwi Darmajanti, Misbakhul Mu'in, and F. Habib, "ANALISIS ALIRAN DAYA DAN CAPASITOR PLACEMENT PADA SISTEM KELISTRIKAN PT BLAMBANGAN BAHARI SHIPYARD DENGAN SOFTWARE ETAP," Jurnal 7 Samudra, vol. 8, no. 1, Nov. 2023, doi: https://doi.org/10.54992/7samudra.v8i1.133.

Anggara Trisna Nugraha, Yuning Widiarti, Dwi Sasmita Aji Pambudi, N. Moh., and F. Habib, "PERANCANGAN DAN IMPLEMENTASI HYBRID PANEL SURYA DAN TURBIN ANGIN TERINTEGRASI MULTI INPUT CONVERTER DC/DC DENGAN FUZZY LOGIC PADA SISTEM AERATOR TAMBAK UDANG," Jurnal 7 Samudra, vol. 8, no. 1, Jun. 2023, doi: https://doi.org/10.54992/7samudra.v8i1.134.

Anggara Trisna Nugraha, Yuning Widiarti, Rini Indartini, S. Ika, and N. Muhammad, “RANCANG BANGUN SISTEM ALARM JAM NAVIGASI JEMBATAN BERBASIS PENGENALAN DENGAN METODE FACENET,” Jurnal 7 Samudra, vol. 8, no. 1, Jun. 2023, doi: https://doi.org/10.54992/7samudra.v8i1.137.

Anggara Trisna Nugraha, Frosedo Brilian Bintang Syahara, Urip Mudjiono, Rini Indarti, and S. Ika, “PROTOTYPE SISTEM CONTROL SUHU DAN MONITORING KELAYAKAN TINGKAT KEKERUHAN DAN VISKOSITAS MINYAK PADA TRANSFORMATOR DISTRIBUSI BERBASIS INTERNET OF THINGS,” Jurnal 7 Samudra, vol. 8, no. 1, Jun. 2023, doi: https://doi.org/10.54992/7samudra.v8i1.135.

Anggara Trisna Nugraha, A. Arief, Rini Indarti, N. Edy, and S. Ika, “RANCANG BANGUN PENDETEKSI KEBAKARAN DINI PADA KAPAL IKAN BERBASIS IoT DENGAN KOMUNIKASI LoRa,” Jurnal 7 Samudra, vol. 8, no. 1, Jun. 2023, doi: https://doi.org/10.54992/7samudra.v8i1.136.

Anggara Trisna Nugraha, Moch Fadhil Ramadhan, Muhammad Jafar Shiddiq, and Muhammad Fikri Fathurrohman, “Comparison of Insulated Switch Gear with Desiccant Addition to SF6 Gas Quality System at Waru Substation,” JEEMECS (Journal of Electrical Engineering, Mechatronic and Computer Science), vol. 6, no. 2, pp. 77–86, Aug. 2023, doi: https://doi.org/10.26905/jeemecs.v6i2.6044.

A. T. Nugraha, M. I. I.A, S. I. Yuniza, and N. Novsyafantri, “Penyearah Setengah Gelombang Tiga Phasa Tak Terkontrol Menggunakan Motor Induksi Tiga Phasa,” Elektriese: Jurnal Sains dan Teknologi Elektro, vol. 11, no. 02, pp. 78–88, Aug. 2022, doi: https://doi.org/10.47709/elektriese.v11i02.1667.

M. Apriani, Ayu Nindyapuspa, Friska Dyah Ayu Febri Cahyani, and Anggara Trisna Nugraha, “Recovery of sugarcane bagasse as adsorbent for chromium (Cr) (III) removal,” IOP Conference Series: Earth and Environmental Science, vol. 1265, no. 1, pp. 012006–012006, Nov. 2023, doi: https://doi.org/10.1088/1755-1315/1265/1/012006.