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Design and Performance of Multistage Axial Flux Permanent Magnet Generators

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Abstract: Population growth and housing needs are growing rapidly, causing electricity providers to have to increase electric power capacity. Under these circumstances, innovation of generators or micro scale power plants is needed. This research aims to design Axial Flux Permanent Magnet Generators which have 4 Rotors and 4 Stators. This generator is planned to have a low rotation of 500 RPM with an planned output voltage of 49.7 V with a disc-shaped construction, using a bar magnet and a neodymium-iron-boron NdFeB magnet attached to the material in the form of a disc. This disc is made of acrylic and aluminum as a lightweight base that rotates on its axis to cause a magnetic field to produce electrical energy. In measuring voltage with a speed of 500 RPM and using 4 generators, the highest voltage on generator 1 is 21.10 V with a frequency of 51.70 Hz. In the measurement of no-load multi-stator and multi-rotor generators, an output voltage of 48.1 V is generated with a frequency of 51.70 Hz. In measurements on a multi-stator and multi-rotor generator with a load of 40 W, a voltage of 45.2 V is generated with a current of 0.06 Amperes. At a load of 80 W a voltage of 43.3 V is generated with a current of 0.14 Amperes, while a load of 120 W produces a voltage of 41.5 V with a current of 0.21 Amperes.

INTRODUCTION

Currently, population growth in Indonesia grows rapidly and accompanied by housing growth, making electricity providers have to increase the power capacity of the existing one. This situation led to the innovation of generators or micro scale generators which are considered helpful[1]. Generator as the first mover is still very little in use. Various regions in Indonesia which have many renewable energy sources in the form of water energy also do not utilize this potential optimally. In fact, a micro-hydro power plant is a type of renewable power plant that is environmentally friendly, easy to operate and low operating costs. Initial survey results in river in Manokwari, Indonesia shows that the river has a hydraulic potential of around 29.5kW. Micro-hydro power plants have been planned at this location. The power plant will use a hydraulic potential of 25.2 kW based on a flow rate of 0.3 m^3 s and a head height of 8.6 m[2].

The use of small-scale generators is considered very helpful if it is well developed as the generators are easy to maintain and control and the materials are easily found[3-5]. Generators that are on the market today are generators that have high RPM and require initial electrical energy to create a magnetic field. The harmonic step-time generator model is applied to electric induction and mechanical rotor generators for error measurement, and proposes analytic expressions of simple closed shapes to illustrate. The prediction was then validated by testing on a 30 kW induction generator test rig[6].

Generators that are made must be inexpensive and easy to maintain. The generator that will be developed is Axial Flux type. Axial flux Permanent Magnet Synchronous Generators (PMSG) are designed as double and triple rotor stators, while their electromagnetic and structural characteristics are analyzed. The design aims at axial flux generators placed to the single end of the inner rotor of the engine and permanent magnets placed to the double ends of the middle rotor. One rotor is more than the number of stators used here[7, 8], those are generators with Axial Flux Permanent Magnets 4 Stator 4 Phase 1 Rotors. This design can help in the generation of energy as it is driven by one axis and issued one phase on each side of the stator[9, 10].

This designed generator can be implemented in low flow water turbines and act as a renewable energy which currently has many variations in the development and manufacture of various applications[11]. The shape of the disc makes it easier to manufacture with permanent magnet variations and the number of turns. The more magnets and the number of coils the better the voltage[12, 13].

The number of stators and rotors will affect the results of the generator output created. The more stators and rotors you have the more output you will get. One generator has many outputs that can be used in implementation[14]. This study explains the performance of generators that have one phase output on both sides which makes each output can be used to load directly because it is one phase.

MATERIALS AND METHODS

Methods and engine design

Planning of generator speed: The stator coil (the stator is an alternator component that has the function to produce Alternating Current (AC)) is fixed or fixed to the stator core and is bound to the house so that it does not rotate (static).

The stator coil consists of 12 coils of insulated wire wrapped around a slot around the stator core. Each roll has the same number of turns. The relationship between the speed of the stator rotational field (rpm) and the frequency of the generator which is inversely proportional to the number of poles based on the rotation per minute can be determined in the following way:

$$n_g = \frac{120 \times f}{p} (\text{rpm}) \quad (1)$$

Where:
n_g = The generator speed (rpm)
f = Frequency (Hz)
p = Represents the number of magnetic poles in the stator

Permanent magnet rotors: This design uses rotor from aluminum coated acrylic material with a diameter of 30 cm^2; the rotor is designed to produce 12 poles with neodymium magnets. The design of this axial flux generator rotor uses neodymium magnets by determining the quantities using the following equation:

Maximum flux density: The maximum magnetic flux density values are:

$$B_{max} = B_r \times \frac{L_m}{L_m + \delta} (T) \quad (2)$$

Where:
B_{max} = Represents the flux density (T)
B_r = The residual induction (T)
L_m = The magnetic height (m)
δ = The air gap (m)

Extensive magnetic field: Designing the location of permanent magnets on the generator rotor as follows:

$$A_{magn} = \frac{\pi\left(ro^2 - ri^2\right) - \tau f\left(ro - ri\right) N_m}{N_m} (m^2) \quad (3)$$

Where:
A_{magn} = Magnet area (m^2)
π = phi (3.14 or 22/7)
r_i = Represents the inner radius of the magnet (m)
ro = The outer radius of the magnet (m)
τf = The distance between magnets (m)
N_m = The number magnetism

Maximum flux: To find the maximum flux of the permanent magnet produced, the following equation is used:

$$\varnothing_{max} = A_{magn} \times B_{max} (\text{Wb}) \quad (4)$$

Where:
$\varnothing_{max}$ = The maximum flux (Wb)
A_{magn} = The area of the magnet (m^2)
B_{max} = The flux density (T)

Number of stator coils: While the number of stator coils (Ns) needed for the stator is used the following equation:

$$N_s = p \times \frac{N_{ph}}{2} \qquad (5)$$

Where:
N_s = The number of stator coils
N_{ph} = The number of phases'
p = The number of magnetic poles

Number of stator coils: Copper wire is one of the many types of electrical conductors based on the material. This type of wire is the first metal used as wire and cable material. The function of copper wire is often used for winding materials in electric generators. Determining the number of turns (N) is one of the most important things in the design of radial flux generators. The number of turns is influenced by several parameters such as the area of the soft iron core to be used. If the area of the iron core is fixed and the number of turns increases the smaller the copper wire used and vice versa, the less the coil the greater the size of the copper wire.

Induction voltage: The voltage from the generator induction of the generator being generated can be calculated using the following equation:

$$E_{rms} = 4.44 \times N \times f \times \varnothing_{max} \times \frac{N_s}{N_{ph}} (V) \qquad (6)$$

Where:
E_{rms} = The voltage from the generator induction (V)
N = Represents the number of turns
F = The frequency (Hertz)
$\varnothing_{max}$ = The maximum flux (Wb)
N_s = The number of stator coils
N_{ph} = The number of phases

Single phase generator power: The power of the generator being generated can be calculated through the following equation:

$$S_{1\varnothing} = V_{L\text{-}N} \times I (VA) \qquad (7)$$

Where:
$S_{1\varnothing}$ = The generator power (VA)
$V_{L\text{-}N}$ = The generator voltage (V)
I = Represents the current (Ampere)

Design results: From Eq. 7, we get the result that this generator is designed to work at a frequency of 50 Hz and rotates at a speed of 500 Ratio per minute. The output voltage is designed 49.1 V in no-load conditions. By using aluminum-coated acrylic rotor with a diameter of 30 cm^2, the rotor is designed to produce 12 poles with Neodymium magnets and then the rotor is formed, so that, permanent magnet can be inserted. The number of coils is 10 pieces. This value is obtained from the large number of

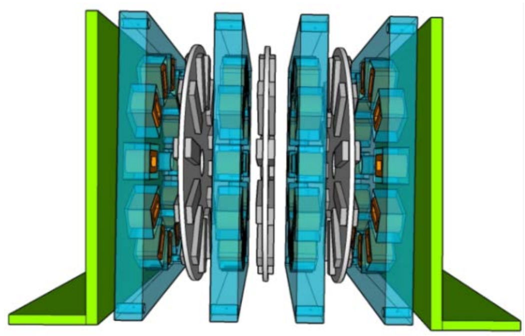

Fig. 1: Front view of 4 stator neodymium permanent magnet generators which are blue, 4 gray rotors and brown for spills

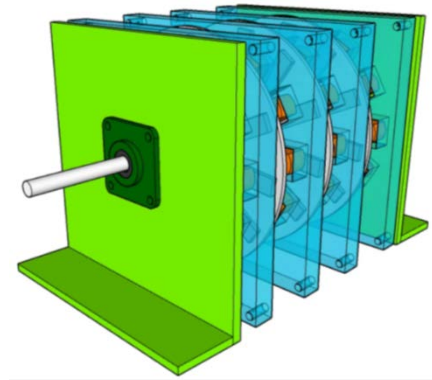

Fig. 2: Side view of neodymium 4 stator 4 rotor permanent magnet generator using white shaft and green generator housing

magnets in the rotor, so that, the stator circumference adjusts the rotor circumference. Another consideration is that the coil can be completely surpassed by magnetic flux. While the number of stator coils (N_s)) needed for the stator uses with the number 2 (Phase and Neutral) and p uses 12 poles, as shown in Fig. 1-3. The number of stator coils is N_s used 12 coils using Eq. 8:

$$N_s = p \times \frac{N_{ph}}{2} \qquad (8)$$

To determine the distance between the magnet and the circumference of the rotor the design aims to determine the number of magnets in accordance with its poles, the distance between the magnet and the radius of the rotor and its location on the rotor plate 80 cm^2 is presented in Fig. 4, that is the geometry of the permanent magnetic rotor. With a total of 12 coils with 336 turns presented in Fig. 1 and 3. This value is obtained from the large number of magnets in the rotor, so that, the

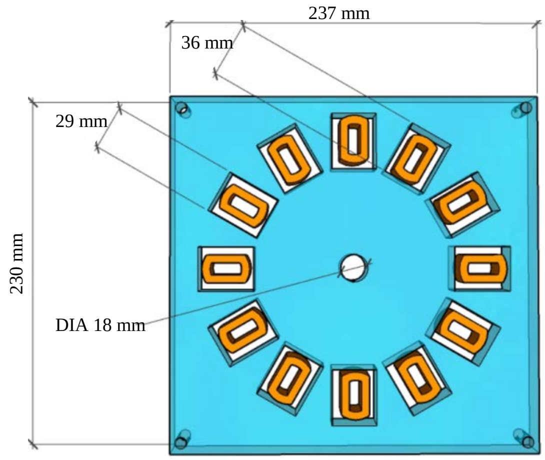

Fig. 3: Geometry of the stator coil

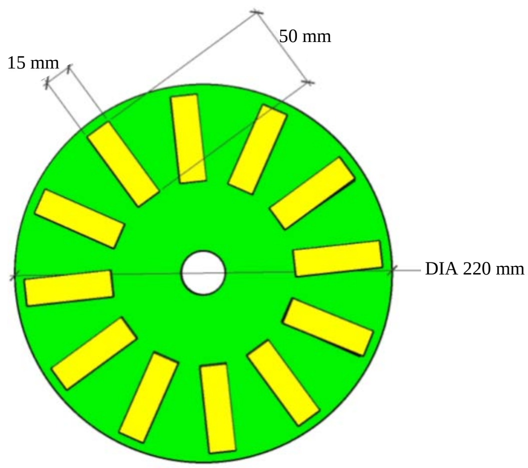

Fig. 4: Geometry of permanent magnetic rotors

circumference of the stator adjusts around the rotor. Another consideration is that the coil can be completely surpassed by magnetic flux.

RESULTS AND DISCUSSION

One phase axial flux permanent magnet generator testing is carried out to determine the planning results. If done with a good measuring instrument or with a high degree of accuracy the test results will be more accurate. No-load testing is carried out for 3 h for capturing data on current, current and rpm. The test was conducted on campus 2 of the ITN Malang electro lab building, 1st floor, Electric Energy Conversion Laboratory. The experimental results are presented in Table 1.

The measurement results of Generators 1, 2, 3 and 4 without load can be seen from 0-700 Rpm with the voltage obtained an average of 16.60 V on the stator 1, 15.03 V on Generators 2, 12.72 V on the stator 3 and 13 V on the stator 4 with a frequency of 41.16 Hz per RPM. At a speed of 500 RPM the voltage generated at Generator 1 is 21.10 V with a frequency of 51.70 Hz. The speed of 500 RPM voltage generated on Generator 2 is 18.88 V with a frequency of 51.70 Hz. Speed of 500 RPM voltage generated on the generator stator 3 12.72 V with a frequency of 51.70 Hz. The speed of 500 RPM voltage generated by generator 4 is 16.20 V with frequency of 51.70 Hz, in the no-load experiment above the average voltage generated by the four Generators is 14.34 V per RPM with an average frequency produced by 41.16 Hz per RPM.

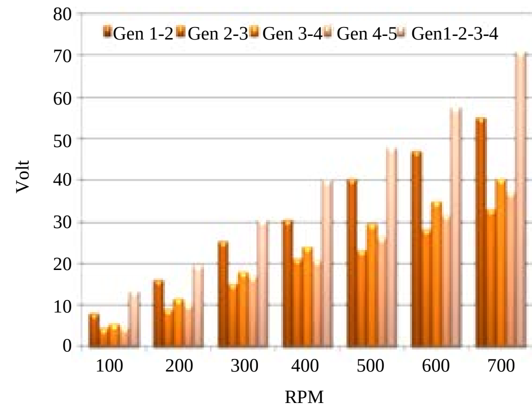

Fig. 5: Graph of no-load experiments with a series connection between. Generators 1, 2, 3 and 4 towards RPM

Table 1: No-load trial

RPM	Stator Voltage (V) Generator 1	Generator 2	Generator 3	Generator 4	Frequency
100	3.80	3.50	3.00	3.40	10.30
200	8.00	7.30	5.27	6.60	20.70
300	12.60	11.20	10.20	9.80	31.40
400	16.70	15.03	13.18	13.00	42.10
500	21.10	18.88	16.40	16.20	51.70
600	24.70	22.73	19.12	19.40	61.00
700	29.30	26.58	21.90	22.60	70.90
Average	16.60	15.03	12.72	13.00	41.16

The measurement results of Generators 1, 2, 3 and 4 are presented in Table 2 and Fig. 5. Where the no-load experiment with a series relationship can be seen from 0-700 Rpm with the voltage obtained an average of 31.96 V on the Generator 1 and 2, 19,34 V on Generators 2 and 3, 21,30 V on Generators 4 and 1, 40,13 V on generators 1,2,3 and 4. While at speeds of 500 RPM the voltage generated on multi rotor generators and multi stator is 48.1 V with a frequency of 51.70 Hz.

Load testing: In the load test, 3 incandescent lamps with 40 W of each incandescent power capacity are used. At the time of testing, the data is taken from the multi rotor and stator generator voltage output and is presented in Table 3.

Table 2: No-load trial in series connection

RPM	Series stator Voltage (V) Generator 1-2	Generator 2-3	Generator 3-4	Generator 4-1	Multi rotor and sator generator
100	8.30	4.60	5.60	5.1	13.50
200	16.30	9.30	11.80	10.4	19.80
300	25.50	15.20	18.10	17.1	30.50
400	30.70	21.30	24.10	21	40.20
500	40.60	23.30	29.50	26.5	48.10
600	47.10	28.50	35.20	31.8	57.60
700	55.20	33.20	40.40	37.2	71.20
Average	31.96	19.34	23.53	21.30	40.13

Table 3: Voltage ratio with and without load 40 W

	40 W load series connection; Multi-rotor and stator generator voltage			
RPM	No load	Loaded	Drop voltage	Current
100	13.5	9.8	3.7	-
200	19.8	18.7	1.1	0.02
300	30.5	27.6	2.9	0.02
400	40.2	36.5	3.7	0.04
500	48.1	45.4	2.7	0.06
600	57.6	54.3	3.3	0.06
700	71.2	63.2	8	0.07
Average	40.1	36.5	3.6	0.00

Table 4: No load and load voltage comparison (80 W)

	80 W load series connection; Multi-rotor and stator generator voltage			
RPM	No load	No load	No load	No load
100	13.5	9.30	4.20	-
200	19.8	18.10	1.70	0.02
300	30.5	23.10	7.40	0.06
400	40.2	29.50	10.70	0.11
500	48.1	43.30	4.80	0.14
600	57.6	48.10	9.50	0.15
700	71.2	58.90	12.30	0.16
Average	40.1	33.47	6.66	0.11

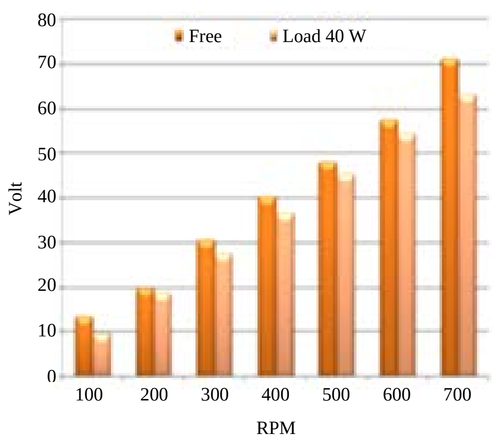

Fig. 6: Graph of comparison of no-load voltage and load with 40 W load

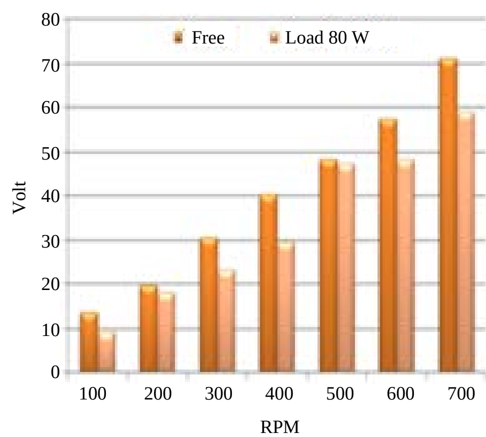

Fig. 7: Graph of comparison of no-load voltage and load with 80 W load

The measurement results of the multi rotor generator and the stator with a load of 40 W can be seen from 0-700 Rpm with a comparison of the load voltage and no-load voltage obtained on average at no load of 40.1 V and at the time of loading of 36.5 V, so that, it can be seen an average voltage drop of 3.6 V per RPM (Fig. 6). Whereas in the speed of 500 RPM the no-load voltage generated is 48.1 V and has a load of 45.2 V because it can be seen that the voltage drop generated is 2.7 V. With Amperes produced at 0.06 Amperes.

The measurement results of the multi rotor generator and stator with a load of 80 W can be seen from 0-700 Rpm in Table 4 and Fig. 7. With a comparison of the load voltage and no load, the voltage obtained is an average of 40.1 V at no load and when burdened by 43.3 V, so that, it can be seen an average drop voltage of 6.66 V Per RPM. Meanwhile, in the speed of 500 RPM the no-load voltage generated is 48.1 V and has a load of 47.3 V because of that, we can see the voltage drop produced by 4.8 V. With the current generated is 0.14 Amperes.

Measurement results of multi rotor and stator generators with a load of 120 W can be seen from 0-700 Rpm presented in Table 5 and Fig. 8 with a comparison of the load voltage and no-load voltage obtained on average at no load of 40.13 V and when the load is 30.03 V, we can see an average voltage drop of 10.1 V per RPM. Meanwhile, in the speed of 500 RPM the no-load voltage generated is 48.1 V and is loaded with

Table 5: Comparison of no-load and no-load voltages load (120 W)

	120 W load series connection; Multi-rotor and stator generator voltage			
RPM	No load	No load	No load	No load
100	13.50	12.50	1	-
200	19.80	14.80	5	0.090
300	30.50	18.90	11.6	0.120
400	40.20	28.60	11.6	0.180
500	48.10	41.50	6.6	0.210
600	57.60	42.10	15.5	0.210
700	71.20	51.80	19.4	0.240
Average	40.13	30.03	10.1	0.175

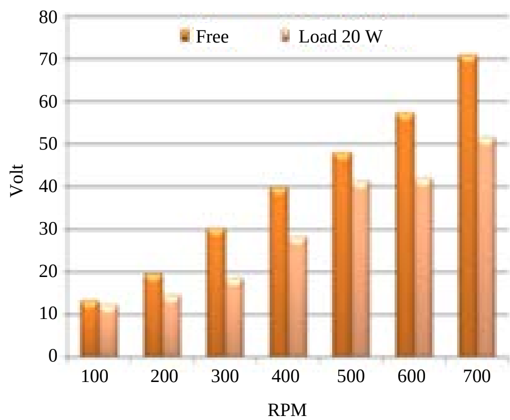

Fig. 8: Graph of comparison of no-load voltage and load with a load of 120 W

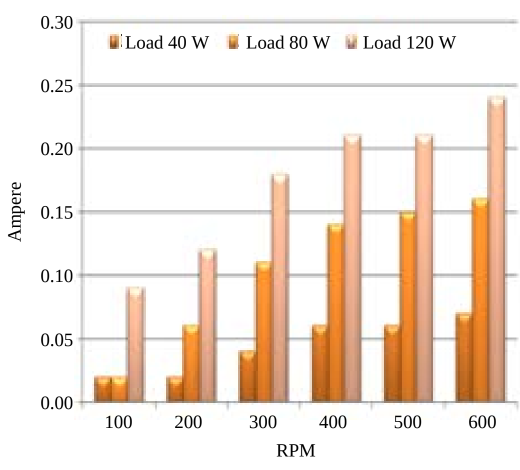

Fig. 9: Comparison graph of multi rotor and stator generator currents

41.5 V because of that, we can see the voltage drop produced by 6.66 V with the current generated by 0.21 Amperes.

The results of measurement of currents from multi rotor and stator generators with a load of 40, 80 and 120 W from 0-700 Rpm presented in Fig. 9. With the ratio of load currents obtained on average at 40 W loads of 0.0 Ampere and at a load of 80 W at 0.1 Ampere and at a load of 120 W at 0.2 Ampere. 14 Amperes and at a load of 120 W of 0.21 Amperes.

CONCLUSION

From the research done, it can be seen that the neodynium 4 stator 4 rotor permanent magnet axial flux generator as a substitute for generators on the market is the latest breakthrough as an initial energy generator. With a generator rotation of 500 Rpm at nominal rotation and a frequency of 50 Hz in the plan that is made to produce 49.7 V of pure AC, at voltage measurements with a speed of 500 RPM get the voltage on generator 1 is 21.10 V, Genertor 2 is 18, 88 V, Generator 3 is 12.72 V and Generator 4 is 16.20 V with a Frequency of 51.70 Hz, while in a no-load measurement the multi-stator and multi-rotor generators produce an output voltage of 48.1 V with a frequency of 51, 70 Hz and the measurement is loaded with a speed of 500 RPM multi-stator and multi-rotor generator with a load of 40 W produced a voltage of 45.2 V with a current of 0.06 Amperes, at a load of 80 watts produces a voltage of 43.3 V with a current of 0, 14 Amperes and at a load of 120 W is produced a voltage of 41.5 V with a current of 0.21 Amperes.

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