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V-I characteristics of a coreless ironless electric generator in a closed-circuit mode for low wind density power generation

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Abstract. This research deals with removal of ironcore lamination in electric generator to eliminate cog torque. A confinement technique is proposed to confine and focus magnetic flux by introducing opposing permanent magnets arrangement. The generator was fabricated and experimentally validated to qualify its loaded characteristics. The rotational torque and power output are measured and efficiency is then analyzed. At 100Ω load, the generator power output increased with the increased of rotational speed. Nearly 78% of efficiency was achieved when the generator was rotated at 250rpm. At this speed, the generator produced RMS voltage of 81VAC. Torque required to rotate the generator was found to be 3.2Nm. The slight increment of mechanical torque to spin the generator was due to the counter electromotive force (CEMF) existed in the copper windings. However, the torque required is still lower by nearly 30% than conventional AFPM generator. It is there concluded that this generator is suitable to be used for low wind density power generation application.

1. Introduction

Ironcore lamination in a generator is used to confine and guide magnetic flux as to boost its efficiency to the maximum. Ironcore as what the name implies, consists of lamination of highly permeability core material which can increase the density of the magnetic flux in over several thousand. The advantage of confining and guiding the flux however giving a major drawback to the generator. When the ironcore lamination is exposed to the magnetic field, magnetic particle in the core tends to line up with the magnetic field of the permanent magnets. When the magnets rotated, its magnetic field changed in direction. This induces continuous movement of the ironcore's magnetic particle for them to align with the change of magnetic field direction and coincidently produces molecular friction. This in turn produces heat and is then transmitted/distributed to the ironcore lamination and windings. Heat causes increases in winding resistance and at the same time retains electromagnetism in the windings and ironcore laminations.

Electromagnetism in the ironcore lamination acted as a magnet and react (attract and repel) with the permanent magnets' field. The more power is generated from the generator, the more power is required to maintain its rotation as the input torque increased proportional to the power output. Therefore, the more heat is generated, the stronger the electromagnetism exists in the core causes unwanted attraction force with the permanent magnets field. Attraction force between permanent magnets and ironcore lamination in a generator or also known as 'cog' is seen as one of the major inefficiency in the generator [1-2].

Cog as the name implies, increases spinning torque where this indirectly increases the amount of work/energy used to spin the generator. Energy to overcome cog is basically proportional to the output power produced. The larger the output power is produced, the larger the amount of torque is required to spin (or maintaining the rotation speed). The presence of cog in the system however has made this conventional generator is far from being usable in low torque application [3-4]. Continuous and consistent power is required to overcome cog and the power varies when rotational speed varies.

There were many attempts made elsewhere to reduce cog to increase the application boundary of a generator [5]. Most of the efforts were focused on the ironcore optimization in design to minimize the effect of cog [6]. However, the presence of cog is still inevitable [7]. Effort made by removing iron core material from an electric motor had demonstrated great success more than a decade ago. The success story of this ironless motor has been widely shared by both among the researchers and industries. The idea behind this achievement is by removing the iron core lamination and replace it with non-ferrous material. The ironless motor works flawlessly and one of the major advantage came from it is outstanding positional accuracy and repeatability due to no cogging affecting the positioning.

Similar idea may be applied to demonstrate coreless generator design. Effort made on this subject however, is still lacking [8-10]. The idea of removing ironcore lamination material may cause non-concentrated flux and leads to deterioration in output power efficiency [3]. However, there is a method which may be used to concentrate and focus magnetic flux to create denser magnetic field. An additional permanent magnets arrangement added to the generator may be a solution to address this issue. The absence of ironcore lamination in the system also represent cog free rotation. This provides advantage in terms of very low starting torque and less counter electromotive force is produced.

2. Material and equipment

In the closed-circuit test for the ironless coreless electricity generator, a 2hp three-phase induction motor was used to function as the prime mover to rotate the rotor of the generator. This induction motor had a rating no-load rotational speed of 1400RPM, input voltage of 220V to 240V for delta connection, input voltage of 380V to 415V for star connection, rating current of 5.64A to 6.15A for delta connection and rating current of 3.26A to 3.56A for star connection with efficiency of 75.5% if the load usage was below half of the motor but 78.5% if the load usage was above three quarters of the motor. Table 1 shows the specification of the induction motor.

Table 1. Specification of the three-phase induction motor used in the experiment.

	Type of connections	
	Star connection	Delta connection
Horsepower	2hp	
No-load rotational speed	1400RPM	
Efficiency (<1/2)	75.5%	
Efficiency (>3/4)	78.5%	
Input voltage	380V-415V	220V-240V
Rating current	3.26A-3.56A	5.64A-6.15A

Since the motor was using alternating current supply to power up, the inverter was used to convert the direct current supply into alternating current supply so that the motor could operate. Based on the data obtained from the manufacturer datasheet of the inverter, the inverter had an efficiency of 96% when working within the rated load. Wires were used to connect the power source to the inverter. They were also used to connect the inverter to the motor. To measure the wave frequency and the voltage output of the three-phase circuit of the ironless coreless electricity generator, the oscilloscope was used. The oscilloscope was connected to the end of the three-phase circuit by using wires. The tachometer was used to measure the rotational speed of the rotors of the generator. DC electronic load was used to analyse the currents and power output when the generator was subjected to load. Figure 1 shows the block diagram for the connection of the ironless coreless electricity generator in closed circuit test.

3. Experimental setup and procedures

Before connecting the circuit to the induction motor, it was first aligned with the ironless coreless electricity generator. The center of motor shaft should be around 189mm from the surface of test bed to align them with the shaft of the ironless coreless electricity generator. The plate which supported the motor was then tightened using M8 bolts and nuts after the height of motor was set. The distance between the ironless coreless electricity generator and the motor was aligned horizontally by adjusting the generator. The bottom surface of the ironless coreless electricity generator was then locked on the test bed using M8 bolts and nuts. After the induction motor was well aligned with the generator, the connection between the induction motor and the generator was tightened with specifically made socket using socket cup point grub screws.

After the test bed was completely set up (Figure 2), the three-phase induction motor was connected using star connection as it could support higher voltage. The inverter was connected to power supply and the motor after the ironless coreless electricity generator and the motor were in place. The three-phase circuit of the ironless coreless electricity generator was then connected to the oscilloscope. When all the mechanical assembly and electrical assembly were done, the experiment began. After the power supply was switched on, a specified amount of power transferred to the motor was set by the inverter. The input power of the motor was controlled by the inverter using frequency input in the inverter. Once the setting was done and the rotational speed of the rotor was stabilized, the rotational speed of the rotor was observed using tachometer and recorded. To clearly obtain the graphical output wavelength from the oscilloscope, the x-axis was set to 10 milliseconds per column and y-axis was set to 50V per division, depending on the output voltage of the experiment. When the rotors were rotating, wave frequency and the output voltage were produced. When everything was observed to have been completed, screenshots of the oscilloscope were taken and the data were transferred into the computer for data extraction process. DC electronic load was used to give the generator load and measure the output current and power generated.

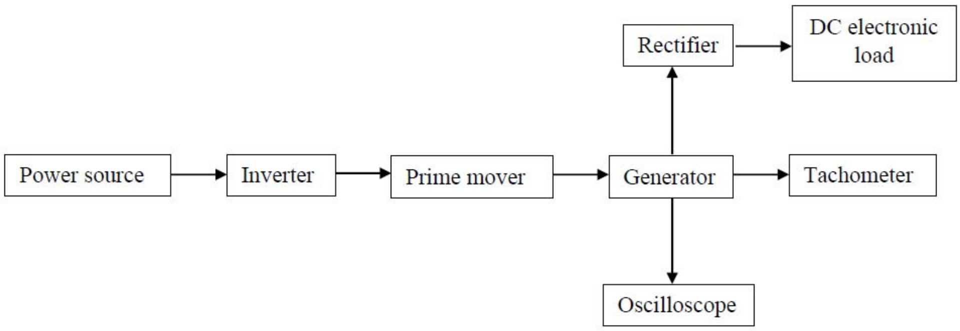

Figure 1. Block diagram for the connection of closed circuit test.

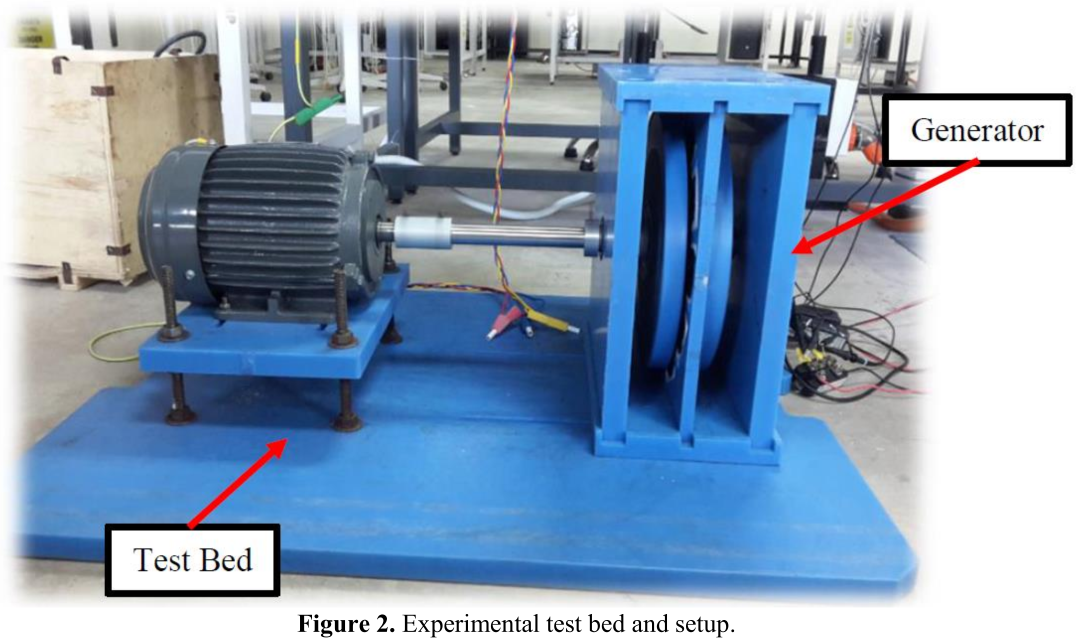

Figure 2. Experimental test bed and setup.

4. Closed circuit tests results and discussions

There were 12 sets of experiments carried out in the various rotational speed constant load tests starting from 104RPM al the way up to the 250RPM. It can be observed that the mechanical torque required to rotate the generator was nearly 3Nm throughout the speeds. However, there is slight fluctuation of mechanical torque due to the force required to overcome rotor inertia at low speed is slightly larger than at higher speed. At rotational speed of 250RPM, output power produced was 66.1W and the output RMS voltage was 81V. At this voltage, the output current of 0.814A was produced, at mechanical torque of 3.24Nm. The generator efficiency was found at 77.95%. Table 2 summarizes the results of power input and output, mechanical torque, rotational speed and efficiency of the generator. As shown in the Table 2, it was noted that the power, current and output voltage produced by the three-phase circuit of the ironless coreless electricity generator increased when the rotational speed of the rotors of the ironless coreless electricity generator increased. This is because when the rotors of the generator were spinning faster, the frequency of magnetic flux cutting in the three-phase circuit on the stator of the ironless coreless electricity generator increased proportionally. When there was more magnetic flux cut by the three-phase circuit in the stator, the voltage per phase produced by the ironless coreless electricity generator also increased [12]. The significant amount of torque required to spin the generator is due to the force required to get the generator spun at constant speed and overcoming the counter electromotive force generated by the copper windings. However, the torque is still 30% lesser if compared to the ironcore type AFPM generator [13]. Figure 3 shows efficiency plot for the generator. The efficiency increased with the increasing of the rotational speed and the increment starts to slow down when it hits 200rpm. Beyond 238rpm, the increment of efficiency is no longer significant. At this point, the it can be concluded that with the increasing of rotational speed, the generator operates at nearly 78% of efficiency. The inefficiency is due to the electromagnetic losses and as well as mechanical losses due to friction between rotational bodies and support bearings used in the system.

Table 2. Results for torque and efficiency in various rotational speed constant load tests.

Speed (RPM)	Voltage (V)	Current (A)	Power input (W)	Power output (W)	Torque (Nm)	Efficiency (%)
104	33	0.300	32.83	10.7	3.01	32.59
118	38	0.360	37.47	13.8	3.03	36.83
131	43	0.410	39.28	17.3	2.86	44.04
145	46	0.460	41.53	21.4	2.73	51.53
158	51	0.500	44.72	25.2	2.70	56.35
171	55	0.546	49.64	30.3	2.77	61.03
184	60	0.592	52.47	35.9	2.72	68.41
198	65	0.636	58.63	41.3	2.83	70.43
211	69	0.682	63.42	46.9	2.87	73.95
224	72	0.727	68.20	52.1	2.91	76.39
238	77	0.771	76.32	59.5	3.06	77.96
250	81	0.814	84.80	66.1	3.24	77.95

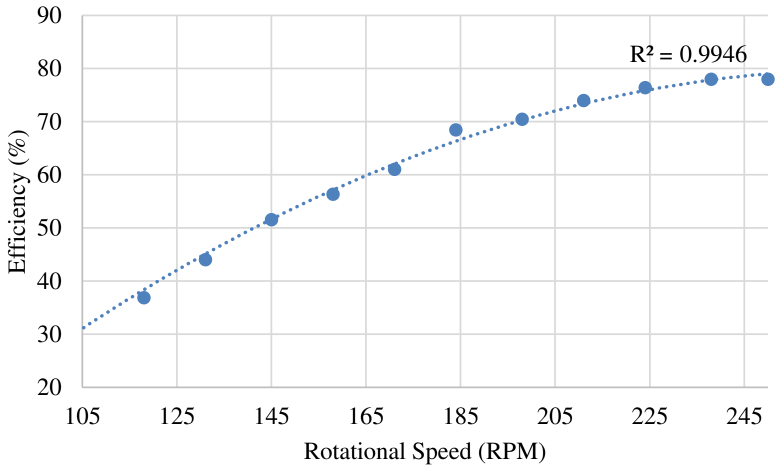

Figure 3. Efficiency of the system at various rotational speed.

5. Conclusions

It can be concluded that the maximum efficiency achieved by the generator is nearly 78%. At this efficiency, the output voltage tested was 81VAC. The rated torque at this rotational speed was found at 3.2Nm which is around 30% lesser than what conventional AFPM generator has to offer.

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