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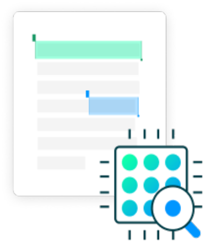

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RESEARCH ARTICLE | MAY 08 2023

Rotor magnetic performance of 3 phase low speed knockdown generator

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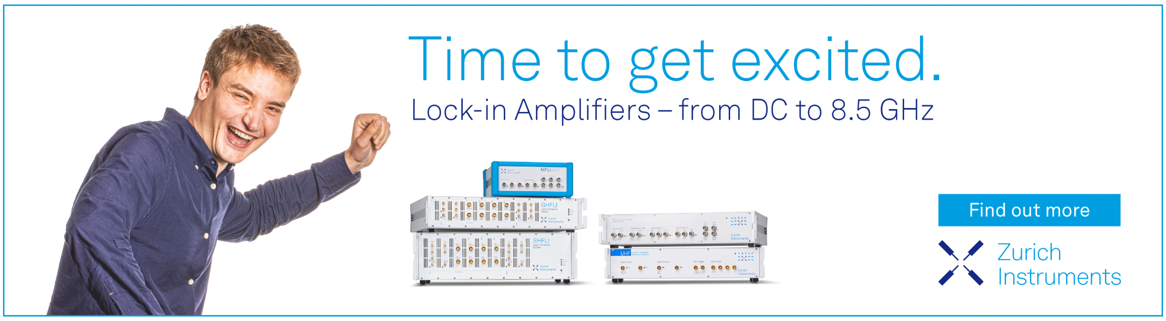

Rotor Magnetic Performance of 3 Phase Low Speed Knockdown Generator

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Abstract. Magnetic performance is important in low-speed generator. Variation of permanent magnet amount was proposed to investigate length of permanent magnet effect on a low-speed permanent magnet knockdown generator. A rotor of 18 cm in diameter, 5 cm thickness was applied for 18 poles stator with average resistance of 0.84 ohm of each coil. The rotor poles had 0.97 - 2.91 cm ND 52 permanent magnet as the magnetic field source. Speed of 25 - 350 rpm was applied to record its power and voltage performance. Load was varied using 35 watts bulbs arranged in parallel. The results show that permanent magnet length has effect on its performance in term of voltage and power. The thicker the magnet is the higher are the voltage and power and its loss. However, a split trend of power indicates that the magnetic performance was not optimal.

INTRODUCTION

Magnetic performance is important in permanent magnet electrical machinery. It affects output and efficiency of the system. It was reported that the air gap of axial machine with trapezoidal coils of 2 mm provided the best for the performance among the other gaps [1]. The authors also mentioned that evenly magnetic field distribution took place on the different shape of the stator core and rotor magnet. The magnets were rectangular and the stator shape was trapezoid. Other author studied the performance of applying permanent magnet replacing the rotor conductors of induction motor resulting voltage drop due to load. The voltage of no-load is proportional to the speed started from 70 V for 2000 rpm [2]. A similar result of dropped voltage also reported in some articles [2,3]. All of these generators were designed to apply single permanent magnet bars for their rotor poles.

In addition to the performance, construction of permanent magnet generator was another topic of the studies. Some construction issues investigated are brush existence, multi axes, and flux direction. Number of axes with the concept of multiple axes as the way to increase the output were discussed [4,5]. Double axes increase the rotation speed which increases the output voltage of generator. Double axes which ware applied to axial generator increase the speed of flux rotation. Different direction of upper and lower magnet create the flux crossing the coils in double speed [4]. Triple rotor was also reported as the method to increase the power density [5]. Another topic of the construction, is about the flux direction. Axial and radial flux directions became discussion of some authors [1,2,6,7]. The common radial construction as the common induction machine has drawback of the needs of brushes providing electricity current from the coils. The axial construction is easier to make it as a brushless machine and preferable for small scale system [6]. The absence of brush increases the reliability of the machine. There were no friction loss and sparking problem. Rotation speed were also field of study due to need of the driver [2,8]. Economic consideration was studied

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to find the optimum design [9]. Direct and indirect driver were considered during designing a machine [10,11]. Method of FEM was popularly applied for analysis [6,7,12,13]. However, the construction regarding practical issues of the user such as the knowledge and serviceability generator are still out of the discussion.

The article discusses the magnetic performance of a knockdown type generator. The machine is designed with coils which can be easily replaced and reassembled as knockdown parts in order to meet the simplicity requirement. Number of coils and their connections are adaptable to change according to necessity. However, the article only focuses on 18 stator coils combined with 24 poles rotor expected to work under 300 rpm which is applicable for direct driven generator of renewable energy [14]. Three phase generation was provided to supply the multiphase rectifying.

The structure of the article is composed of 6 main parts. The 1st part is the introduction mentioning about the area of the study. It is followed with the construction of the knockdown generator and its theory. The method to evaluate performance of the generator will appear on the 4th part. Discussion of the voltage and power performance of the generator becomes the 5th part and concluded in the last part.

THE KNOCKDOWN GENERATOR

Generator generally consists of 2 main parts; they are stator and rotor. The stator is usually functioned to provide magnetic field and the rotor excites the electricity distributed to the grid. However, the evaluated generator has different approach. The electricity is generated on the stator and the field is excited using permanent magnet in rotor. Unlike the axial generator that were commonly developed for low speed as in [11,15], the generator has radial flux. It was also a single rotor type. General appearance of the generator is provided in figure 1. Therefore, principally, this radial generator has similarity with common induction machine with rotor spinning inside of the stator.

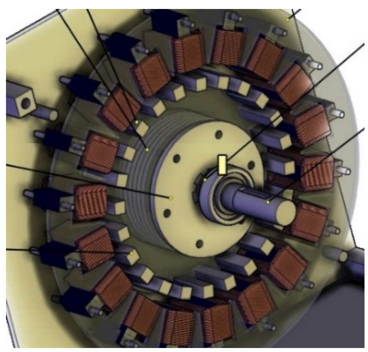


FIGURE 1. The construction of evaluated knockdown generator. The flux direction is radial and the coils are placed on stator.

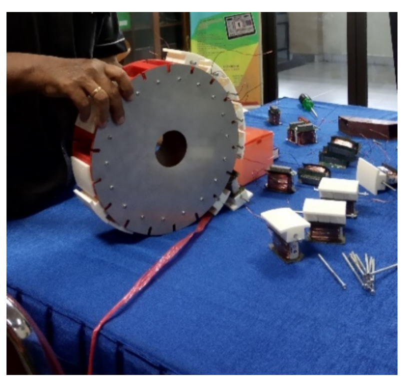


FIGURE 2. Coils on the shell and the stator frame where the coils are placed.

The stator was composed of 18 coils. A coil was placed in a shell that can be put on the frame to create stator coils. The frame was built using 3D printing. The method was also used to make shells where coils with the core was placed. The shell, coils and the stator frame are shown in figure 2. The white are shells of the coils and the red is the stator frame. The coils were made of 200 turns 0.8 mm copper wire with average weight of 97.6 g. Its resistance was 0.84

ohm averagely. The inductance of the coil in 1 kHz sinusoid signal was 669.9 μH. The star connection was applied to the coils. Every phase had 6 coils which were connected in series.

The rotor was designed to have 24 poles. The rotor was composed of acrylic body and core of soft-iron to connect the magnets. These magnets were ND 52 type with dimension of 40 x 9.7 x 9.7 mm^3. This rotor was completed with bearings to stand the rotor inside of the stator. The air gap between the rotor and the coils poles was 3 mm. The rotor shape is shown in figure 3.

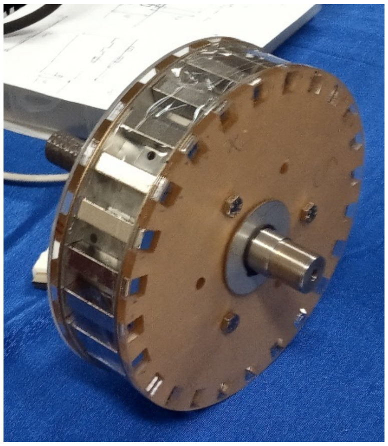


FIGURE 3. The rotor is composed of permanent magnets as the poles.

THEORY

Theoretically, generated voltage (ε_{gen}) of coils is proportional to the rate of the magnetic flux (φ) as mentioned in the equation (1). The equation shows that the voltage is also function of poles number (N_p), coils number (N), and frequency (f). It also inverses function of phase number (N_{ph}). Assuming that frequency is proportional to the rotation speed by 60, the voltage on ports (ε_{port}) can be expressed as equation (2). C_0 is the coefficient of magnetic and C_1 is the voltage proportional to flux depleted on the circuit.

$$\varepsilon_{gen} = -CN\frac{N_k N_p}{N_{ph}}\varphi f \quad (1)$$

$$\varepsilon_{port} = C_0 s + C_1 \quad (2)$$

Power is function of current and voltage. In connection with load, the relation of power and speed depends also on the inner resistance. The optimal condition take place as the inner resistance of the generator is equal to load. The relation of the power and current can be shown in equation (3). The equation assumes that the current is equal along the circuit. The measured power at the output indicates loads affected the power loss of the circuit.

$$\varepsilon_{gen} I_m = \varepsilon_{port} I_m + \varepsilon_l I_m \quad (3)$$

In condition of without load, the measured power indicated loss power at the circuit at specific current. Loss includes core loss, copper loss, and mechanical loss. It can be expressed as equation (4). The copper loss is function of current, while the core loss is assumed to be constant. The mechanical loss is function of the magnetic flux.

$$\Delta P = P_c + P_{cp} + P_{mech} \quad (4)$$

METHOD

Measuring the magnetic performance of a generator, simply can be done by applying equation (2) to find the magnetic relation to the speed. Then, equation (4) is applied to the differences between power function of rotation speed with and without load. It can be used for tracing the electricity circuit loss. Removing electricity loss leads to the magnetic performance of the machine.

To collect the data, some experiment steps were performed. They were conducted to measure speed, voltage, and current. These steps included variation of speeds and load variations to the evaluated generator. To understand the effect of the magnet thickness, additional magnet was conducted with variation of the magnet thickness from 9.7 mm – 2.91 mm.

Variation of speed was conducted with inverter setup. The inverter provided range of rotation speed from 25 rpm to 350 rpm without load condition. Applying load, the speed dropped in addition to voltage drop. The voltage drop due to load was uncontrolled. The power was also uncontrolled and calculated naturally from the measured voltage and current. The voltage and the current are probed at the output.

Load was applied using incandescent bulb of 12 volts. The bulbs were connected in parallel with the help of switch. The switches were used to control load. Each bulb had output rate of 35 W. Assuming it was totally resistance, the resistance of the bulb was 2.92 ohm.

RESULTS AND DISCUSSION

The relation of the rotation speed and the output voltage of the generator is shown in figure 4. The graph shows that the voltage increases linearly as the rotation speed increases in the same trend. The figure also reveals that the thicker is the magnet, the higher the output voltage is. Regarding equation (2), with s as the rotational speed, the coefficients of the first term are 0.17,0.21, and 0.22 for 1,2, and 3 magnets thickness, respectively. The thicknesses of the magnets were 0.097, 0.184, and 0.291 m for 1,2, and 3 magnets, respectively. The first part of the equation trends shows that the increase of the magnet thickness does not correlate the flux amount linearly. There are conditions when addition of the permanent magnet length does not increase flux number significantly. The negative number of the second term coefficient shows voltage loss. Positive number of single magnet result indicates the output was not totally linear and tends to be power. It happens as the output load was rectified using bridges and connected to capacitive filter.

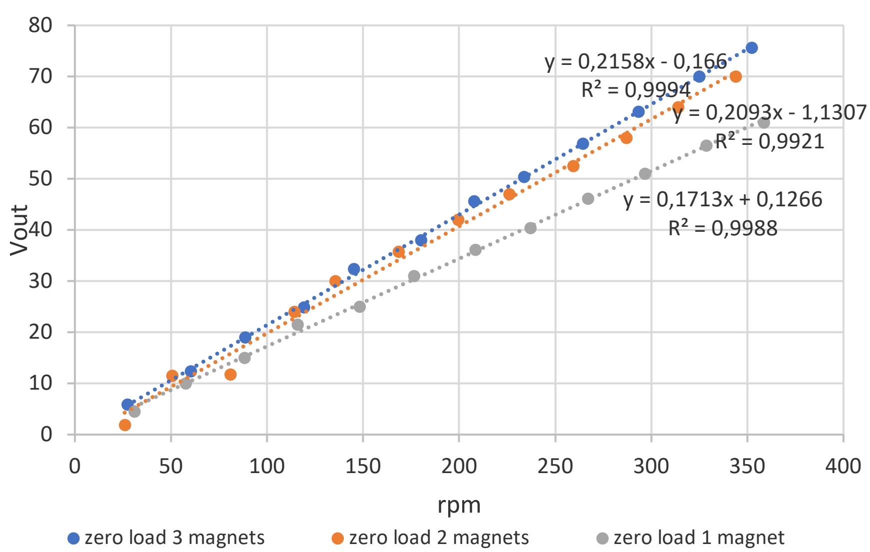
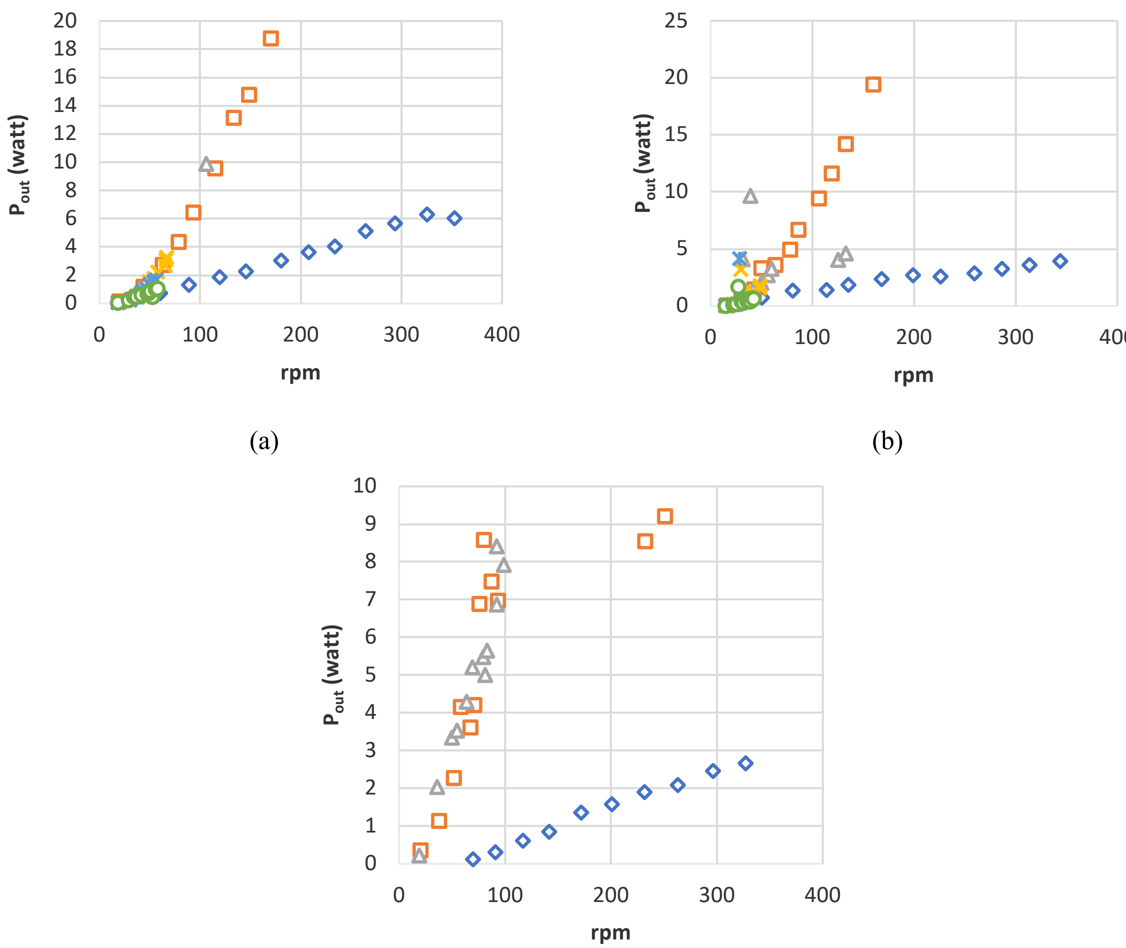


FIGURE 4. The output voltage as the function of the rotation speed in condition without load.

The relation of the power and rotation speed indicates that power loss of the core was proportional to the speed. It is shown in figure 5 when the speeds theoretically were applied without any load. Without any load, the output powers were also function of the permanent magnet thickness. Maximum powers of 2.91 cm, 1.82 cm, and 0.97 cm magnet thickness are 6.4 W, 3.9 W, and 3,2 W, respectively. It also means that thicker magnet rotor has more power loss.

The figure also reveals that the difference of power between loaded and unloaded circuit increased as the speed increasing in quadratic trend. However, the voltage increased linearly. It indicates that output was also determined by the current in loaded condition. It means that load circuit and rotor coils were important because of different flux amount [7]. Regarding the speed was very low, the effect of the speed to the coils reactive impedance was small as well. Therefore, resistance of the coils was dominant factor. Assuming that every phase had 5ohm, resistance as summation of 6 serial coils, the reactive impedance of a phase coil was also addition of its own coils.



(c)

FIGURE 5. The output power as the function of the rotation speed (a) 2.91 cm magnet thick (b) 1.82 cm magnet thick (c) 0.97 cm magnet thick. The rhombic, the square and the triangle points are no load, one load, and two parallel loads, respectively.

CONCLUSION

The evaluated generator shows that output voltage and the power are function of magnetic field rate. The voltage was linear function of the field, while the power was in quadratic relation of the magnetic field rate. Thicker permanent magnet on rotor makes more power loss. The generator was not in ideal condition as the relation of the rotation speed and power was split.

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