Journal of KIIT. Vol. 15, No. 12, pp. 181-188, Dec. 31, 2017. pISSN 1598-8619, eISSN 2093-7571 181
http://dx.doi.org/10.14801/jkiit.2017.15.12.181

Development of a 300W Generator for Lightweight Wind Turbine

Hee-Kune Lee*, Hee-Joon Lee**, and Sun-Hyung Kim***

This work was supported by the Soonchunhyang University Research Fund.

Abstract

As a population of leisure activities grows and diversifies, there is a great demand for portable and environment-friendly power generation systems. A small wind power generation system is emerging as a suitable power generation equipment to meet these needs. The most important thing when developing a small portable wind turbine is to reduce the weight of the generator and increase the efficiency. The existing 300W wind turbine generator weighs about 10kg, which is heavy to carry. Therefore, a new generator weighing less than 4kg to make it easy to carry with high efficiency has been developed. In addition, considering complicated characteristics of wind volume and topography of Korea, a small wind turbine that can be used in urban and rural areas individually was constructed. Through basic designing and optimization, the lightweight and efficient generator was manufactured. It is a 300W wind turbine designed and fabricated with reduced weight as a prototype. The average output voltage of the generator was 24.7V at 900rpm no-load test. On a load test with the average line voltage 36.8V and the average phase current 2.62A, when the mechanical input was 339.84W, an average voltage output of the generator was measured as 289.5W with efficiency of 85.18%. The generator weight was 3.84kg.

요 약

레저 활동 인구의 증가와 다양화로 이동용 전력 시스템에 대한 수요가 많고 친환경적인 전력 발전 시스템에 대한 요구가 늘어나고 있으며 이를 충족 시킬만한 발전 장비로 소형 풍력 발전시스템이 대안으로 떠오르고 있다. 이동용 소형 풍력발전기를 개발할 때 가장 중요한 사항으로는 발전기의 무게를 줄이고 효율을 증가시키는 것이다. 기존의 300W급 풍력 발전기의 무게는 10kg정도로 이를 4kg이하로 줄여서 휴대가 용이하게 하면서 고 효율의 풍력 발전기용 발전기를 설계 제작하였다. 또한, 돌풍이 발생하는 한국의 풍량과 지형의 특성상 미풍에서도 발전이 가능하고 도심 및 농어촌 등에서도 독립적으로 사용할 수 있는 소형 풍력발전기를 설계 제작하였다. 기초설계 및 최적화설계를 통해 가볍고 효율이 높은 발전기를 제작하였다. 본 논문에서는 중량을 줄인 300W급 풍력발전기를 설계하고 시제품으로 제작 하였다. 제작한 300W 풍력발전기는 무부하 시험 시 정격속도 900rpm에서 평균출력전압이 24.7V이었으며, 제작된 발전기의 부하시험시 평균 선간전압 : 36.8V, 평균 상전류 : 2.62A로 기계적 입력이 339.84W일 때 출력전력은 289.5W로 측정되었고 이때의 효율은 85.18%이었다. 제작된 발전기 무게는 3.84kg이었다.

Keywords
characteristic test, high efficiency, lightweight, optimization design, small wind turbine

* Kongju National University Adjunct Professor
- ORCID: http://orcid.org/0000-0001-7116-3059
** Mirtech RnD Co. CEO
- ORCID: http://orcid.org/0000-0001-8555-1191
*** Dep. of Information and Communication Engineering, Soonchunhyang University
- ORCID: http://orcid.org/0000-0002-7623-0617

· Received: Oct. 10, 2017, Revised: Nov. 20, 2017, Accepted: Nov. 23, 2017

· Corresponding Author : Sun-Hyung Kim
Dep. of Information and Communication Engineering, Soonchunhyang University
Tel.: +82-41-530-1344, Email: shkim@sch.ac.kr

Ⅰ. Introduction

Population growth in leisure activities has brought about a good deal of demand for portable and eco-friendly power generation systems. Small wind power systems have emerged as one of the alternatives to fill the demands[1].

Research on the existing permanent magnet type generators has been conducted mainly to increase the efficiency and reduce the cogging torque. In this paper, a method of reducing the weight of a generator at the same efficiency was studied.

The most important factor in developing a small wind generator is to increase the efficiency by reducing the weight while augmenting ease of movement. The existing 300W wind power generators are quite heavy to carry, weighing at about 10kg. The weight of these wind power generators can be reduced to less than 4kg for portability. It can also be developed in a smaller form that can be used in any place regardless of wind strengths. Considering the various types of air volume and geographical features of Korea, a smaller and lighter wind power generator that can be used independently has been developed.

Ⅱ. Design of 300W Wind Turbine Generator System

Since a surface permanent magnet synchronous motor (hereinafter SPMSM) does not require field strengths and field currents, it is possible to make the structure of a wind turbine generator simpler and smaller which leads to decrement of energy losses while increasing operational efficiency. It has the advantage of decreasing cogging torque and torque ripple effect; both of which affect starting torque due to the low effect from harmonics. In light of the benefits of SPMSM, a design of it was developed in this research[2]-[4].

The final, lighter 300W wind turbine generator system was planned by determining a fundamental structure of the generator through basic designing process and decided the detailed size of the permanent magnet[5].

2.1 Basic Design of Wind Turbine Generator System

The electrical loading method was conducted for the 300W wind turbine generator as the basic designing[4]. In this process, combinations of poles and slots, stator wiring, and shapes of stators and rotators were planned.

SPMSM designing requires a relevant selection of polar and slots in accordance with the capacity and purpose of the device. Normally, the number of slots is determined by proportional numbers to the poles and the number of poles is determined by the proportional even number.

Among the combinations of poles and slots, there are ones that are frequently used depending on the amount of cogging torque and outputs. In the case of a ratio of three to three, a smaller generator typically uses eight to twelve poles. In this work, a combination of eight poles and eighteen slots is decided in consideration of the least cogging torque that can generate electricity in the light wind. The ratio of the slots and poles is 2.25[6][7].

With the combination of poles and slots, a total of eighteen coils are designed and six coils are assigned to each phase. These six coils are separated in two of three coils and each phase consists of two coil bundles that are one in a finely spaced coil arrangement. The bundles of coils are winded in different directions as shown in Fig. 1 the Coil 1 and 3 are winded in the same direction whereas the Coil 2 is winded in the opposite.

The initial shape of the generator is shown in Fig. 2. Table 1 shows output power and efficiency in accordance with sizes of frame, stack thickness, and weights of the generator. The sizes of frames vary from 80m to 160m and thickness of stacks differs from 24m and 48m.

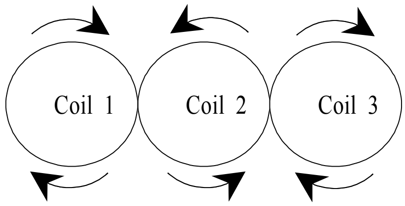


Fig. 1. Coil of one phase coil

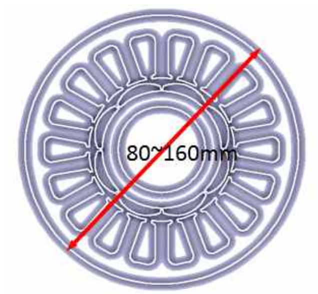


Fig. 2. Initial shape of the generator

Table 1. Output power and efficiency

Frame Size	Stack length	Output Power	Efficiency	Weight
80mm	48mm	324W	73.7%	2.37Kg
90mm	45mm	326.7W	80.4%	2.69Kg
100mm	43mm	316W	85.1%	3.18Kg
110mm	37mm	312.1W	85.9%	3.46Kg
130mm	35mm	316.1W	87.1%	3.78Kg
140mm	28mm	313.9W	88.9%	3.91Kg
150mm	26mm	312.3W	88.9%	4.12Kg
160mm	24mm	311.5W	88.6%	4.22Kg

The approximate sizes of stators, rotors, slots, and magnets are decided based on researchers experiences and resources. The figures of output power and efficiency came out via a calculation program. After checking the output power and efficiency of each trial, the basic shape of the generator was determined.

In planning the basic form of the generator, an approximate setting of a stator and a rotor was done at first. While the external diameter and the thickness were being fixed, detailed designing for the stator and the rotor was done.

Holding the outer diameter and maintaining the thickness with the initially determined figures, a detailed designing of the stator and the rotor was carried out.

Table 2. Generator design specification

Parameter	Value	Unit
Rotor Outer Radius	34	mm
Permanent Magnet Height	5	mm
Air Gap	1	mm
Stator Outer Radius	66.8	mm
Rotor & Stator Depth	28	mm
Slot of Coil	18	EA
Coil Turn per Slot	57	Turn
Pole of Magnet	8	Pole

Table 3. Calculation result

Parameter	Value	Unit
Output Power	312.93	W
Generated Voltage	24.751	V_{rms}
Rotation Speed	900	rpm
Efficiency	88.139	%
Phase Resistance	0.484	Ω
Phase Inductance	0.96	mH
Cogging Torque	4.915	mNm
Torque Ripple	34.11	mNm

Table 2 shows the specification of the generator design and Table 3 shows the results calculated with the design specification of Table 2.

The figure of output power and efficiency in the case of the outer diameter at 140mm and stack thickness of 28mm appeared as the best way of meeting the goals of lighter weight and efficiency. Assuming this particular set of design would work with the detailed model later, it was determined as the foundation.

2.2 Optimum Design of Wind Turbine Generator System

In this process, a specific model for the ultimate wind generator was produced by conducting optimized designing based on the previous basic set. The purpose of this process was to reduce the negative influences of cogging and ripples of torque that affected the starting torque. There are various ways to prevent it. A stator or a rotor can be skewed, the structure of slots can be changed, the slot form can be changed, and auxiliary slots can be added. A study on a designing technique that reduces the influences of cogging torque and ripple effects by changing the shape of a permanent magnet was performed. A new technique based on the study, which uses the finite element analysis program and evolutionary optimization algorithm was developed. Using this technique, a shape of permanent magnet with the least influence of cogging and ripples of torque under 300W output power was produced[8]-[10].

Fig. 3 shows the optimized shape of the permanent magnet. The distribution of the optimization model computed by the finite element analysis (FEA) program is shown in Fig. 4. In the magnetic field distribution, there is about 1.2T in the gap between the stator and the rotor, about 1.7T in the middle of the tooth, and approximately 2T at the saturation point of the teeth are distributed.

In the optimized model, the no-load maximum voltage of 35.5V indicates cogging torque over time. While the initial model of cogging torque is 68.4mNm, the optimization model's is 1.9mNm with which the latter shows significant amount of decrease of cogging torque in comparison to the initial model. The total amount of torque ripples produced over time under the normal condition is 9.15% and 3.19% respectively.

III. Manufacturing a 300W of wind turbines

Based on the design previously planned, a 300W scale wind turbine was produced. The manufacturing process of the generator was conducted in the order of laminating layers of iron core and welding, fixing the rotor magnets, winding the wires of the stator, and binding the rotor and the stator.

The material of the iron core used for the stator and the rotor is 35PN440. The iron core was made of several layers of iron plates laminated thicker than the original plan. Surface treatment and welding were done. After welding, the iron cores of side ends were removed and the thickness of the iron core was adjusted to match the thickness in accordance with the plan. Fig. 5 shows the iron cores of the stator one on the left, and the rotor one on the right.

The magnets for the wind turbine are neodymium magnets N39SH with about 1.26T. The wind turbine was designed to have eight poles, four poles alternately being fixed on N pole and S pole. A thermal adhesive with epoxy resin was used to attach the magnets on the rotor and a heat treatment followed. Fig. 6 shows the procedure of the rotor magnet attachment from the left to the right.

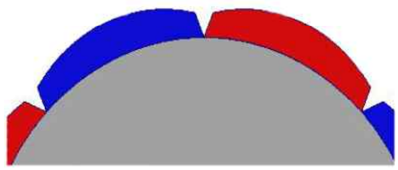


Fig. 3. Optimized shape of permanent magnet

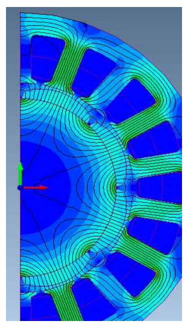


Fig. 4. Magnetic field distribution of the wind turbine optimization model

Fig. 5. Wind power generator stator iron core and rotor iron core

Fig. 6. Rotor magnet attachment process

The stator winding has 18 slots with 18 coils winding up each of the six coils as previously mentioned in the design section. Fig. 7 shows a picture of the wound stator. One side of the wound bundles of wires are connected to the other bundle in the shape of Y connection with one strand of wire per phase pulled out.

Ⅳ. Characteristic Test of the Generator

Based on the basic designing and optimization process of the 300W scale wind turbine, the generator was produced. We carried out a characteristic test of the 300W wind turbine to check its cogging torque, output power of the motor, and the product specifications[11][12].

The basic specifications of wind power generators, resistance, inductance, and weight were measured. Fig. 8 shows the picture of the test. Picture (a) displays inductance measurement, (b) shows resistance measurement, and (c) shows the weight of measurement test. Measurements resulted in inductions at 4.7mH, line resistance 1.084Ω, and weight at 3.84kg.

Cogging torque of the generator was measured. After the 300W scale wind generator test sample was tightened to the torque meter, it was measured from 0˚ to 360° clockwise while rotating it at 1rpm.

Fig. 9 shows the wind generator and cogging torque meter connected to the test measurement and Fig. 10 shows a graph of the torque output. Measured value of cogging torque was a minimum of -33mNm and a maximum of 69.2mNm with the average value of 51.3mNm. The waveforms of periodic torque generated by the windings and magnets were verified.

Fig. 7. Coil-wound stator

(a) (b)

(c)

Fig. 8. 300W class wind turbine generator specification measurement, (a) Inductance measurement test, (b) Resistance measurement test, (c) Weighting test

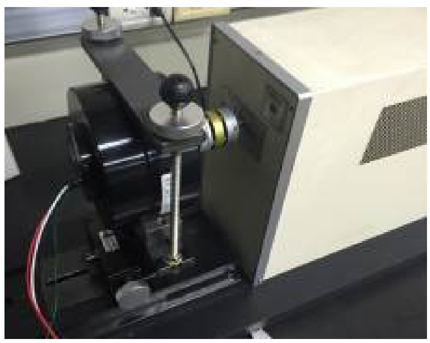


Fig. 9. Cogging torque test

A no-load test and a load test were done. The load test was carried out at the rated load. The no-load test was to measure the counter electro-motive force when the generator is at no-load. After the sample was locked in the environmental chamber dynamo, the counter electromotive force was measured by a power analyzer while increasing the rotations per minute by 50 from 0 to 3,000.

Fig. 11 shows the sample for the no-load test after locking and Fig. 12 shows the measured data of the counter electromotive force in the no-load test. The rated operational standard of the designed wind turbine was set to 900rpm when the ambient wind direction was 12m/s. A 300W level wind turbine generator at a rated speed of 900rpm, the counter electromotive force of U was measured as 24.7V_{rms}, 24.9V_{rms} for V, and 24.9V_{rms} for W, and the average voltage was 24.9V_{rms}. The output voltage was 4.15V_{rms} at the minimum wind speed of the generator 150rpm and was 54.8V_{rms}, at the maximum wind speed 1998rpm.

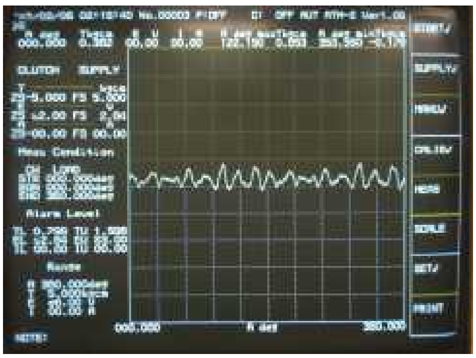


Fig. 10. Graph of cogging torque measured

Fig. 11. Generator no-load test

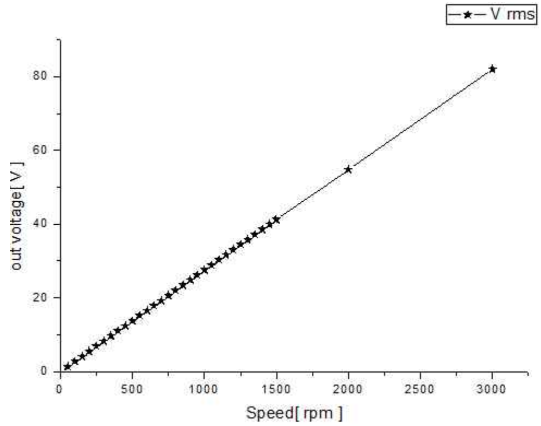
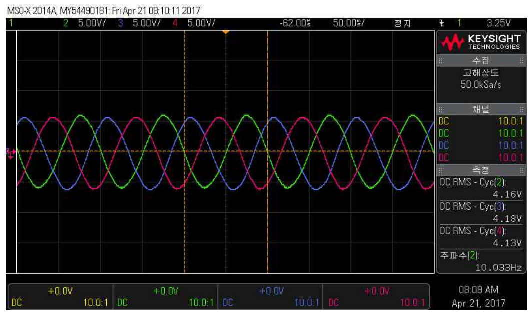
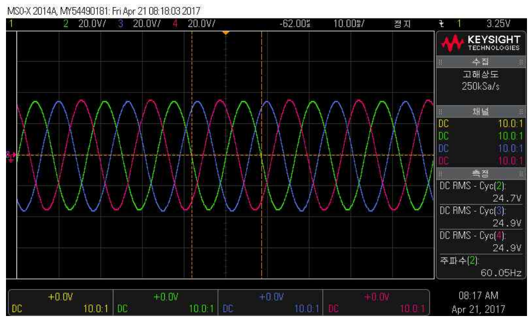


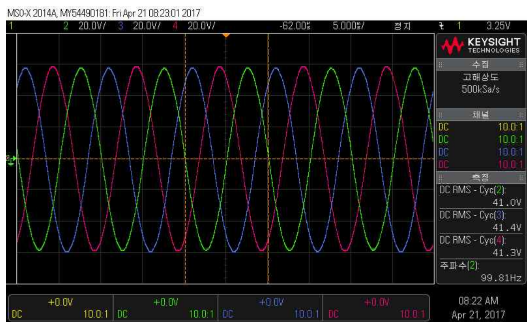
Fig. 12. Data of the No-Load counter EMF measurement



(a) 150rpm



(b) 900rpm



(C) 1998rpm

Fig. 13. No-Load output voltage of each phase of 300W class wind turbine generator

Fig. 13 shows the no-load output voltage of each phase measured by an oscilloscope, (a) with 150rpm, (b) with 900rpm, and (c) with 1998rpm. The no-load average output voltage of a 300W class wind turbine was about $4.15V_{rms}$, which indicates that the output voltage of sine wave was inducted at the start wind speed. The average output voltage at the rated speed of 900rpm was about $24.7V_{rms}$ and $54.8V_{rms}$ was measured at the maximum wind speed of 1998rpm.

The load test is to measure output voltage, current, and efficiency of the generator by measuring the electric power generated when the output terminals of U, V, and W of the sample are connected to the resistant delta wire and are locked to the environmental chamber dynamo rotating at 900rpm. Fig. 14 shows the load test of the generator. The test result shows that the average line voltage is $36.8V_{rms}$ and the average phase current is 2.62A. The power output was 289.5W when mechanical input was 339.84W and the efficiency of the generator is 85.18%.

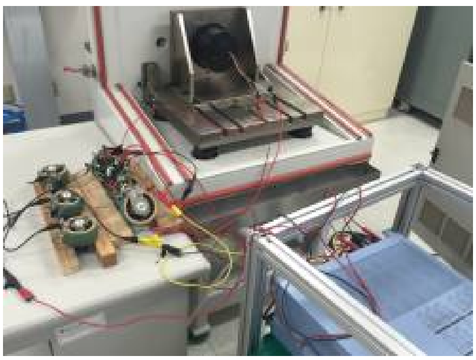


Fig. 14. Generator load test

V. Conclusion

A characteristic test was conducted after manufacturing a lightweight wind turbine generator based on the design of wind turbines. The electric loading planning was used to construct the basic design of the generators such as the shape and size at the beginning stage of designing the wind generator and the optimum designing for the permanent magnet and torque was done at the optimization designing stage. In the latter stage, there was no change made on the basic shape of the generator, but the cogging torque was reduced from 68.4mNm to 1.9mNm and torque ripple was decreased from 9.15% to 3.19%.

Based on the results of the designing process, a wind turbine generator was manufactured and characteristic tests for the generator were carried out. The result of the no-load test for the 300W wind turbine generator weighing 3.84kg shows that its average output voltage is $24.7V_{rms}$ at the rated speed of 900rpm and its generating efficiency is more than 85%. This study enabled the design of wind turbines to be manufactured to produce more efficient power generation than conventional generators.

References

[1] Jan olof Helldin, Jens Jung, Wiebke Neumann, Mattias Olsson, Annas Karin, and Fredrik Widemo, "The Impacts of wind power on terrestrial mammals", Naturvårdsverket report no 6499, Aug. 2012.

[2] C. C. Chan and K. T. Chau, "Novel Permanent Magnet Motor Drives for Electric Vehicles", IEEE Trans. on Industrial Electronics, Vol. 43, No. 2, pp. 331-339, Apr. 1996.

[3] J. H. Kim, S. G. Kang, and S. Y. Jung, "Design of SPMSM for Eelectric Power Steering in vehicle Considering Cogging Torque reduction", 2015 KIEE 46th Conference, pp. 123-124, May 2015.

[4] T. Takeuchi, "DAIGAKUKATEI DENKI SEKKEIGAKU", Korean language edition, pp. 27-64, Dong-Il publishing Co. 1994.

[5] J. G. Park, G. S. Cha, H. J. Lee, and Y. S. Kim, "Design of a wind turbine generator with low cogging torque by using evolution strategy", Journal of the Korean Academia-Industrial cooperation Society, Vol. 17, No. 11, pp. 755-760, Nov. 2016.

[6] J. R. Hendershot. Jr and T. J. E. Miller, "Design of Brushless Permanent- Magnet Motors", pp. 3-1-3-74, MagnaPhysics, Mar. 1994.

[7] H. J. Lee, Y. M. Kim, J. S. Oh, M. H. Ku, K. H. Baek, and G. S. Cha, "1kW Class of Small Wind Generators Cogging Torque Reduction Method of Research", 2012 KIEE Conference, pp. 288-290, Nov. 2012.

[8] J. Kwak, S. Min, and J. P. Hong, 2010, "Optimal Stator Design of Interior permanent Magnet Motor to Reduce Torque Tipple Using Level Set Method", IEEE Trans. Magn., Vol. 46, No. 6, pp. 2108-2111, Jun. 2010.

[9] K. Yoo-Gyu and K. Won, "Ubiquitous Sensor Network Design Using Genetic Algorithm Based on Ranking Selection Technique", The proceedings of the 2010 KIIT Summer Conference, PP. 187-190, May 2010.

[10] M. Kasper, "Shape Optimization by Evolution Strategy", IEEE Trans. on Magnetics, Vol. 28, No. 2, pp. 1556-1559, Feb. 1992.

[11] S. H. Thomas, T. M. Jahns, and W. I. Soong, "Torque Ripple Reduction in Interior Permanent Magnet Synchronous Machines Using the Principle of Mutual Harmonics Exclusion", Industry Applications Conference, 558-565, Sep. 2007

[12] H. G. Kim and J. S. Kong, "Characteristics Analysis of Permanent-Magnet Generator for Small Wind Turbine", 2009 KIEE 39th Conference, pp. 708-709, Sep. 2009.

Authors

Hee-Kune Lee

2008 : PhD science
2015 ~ Now : Sejong Academy of Science and Arts. Director
2016 ~ Now : Kongju National University. Adjunct Professor
Research interests : Chemistry Education, Maker Education

Hee-Joon Lee

2001 : PhD degrees in Department of Electrical Engineering, SCH
2001 : Soonchunhyang University Contract professor
2011 : Mirtech RnD Co. CEO
Research interests : Renewable Energy, Electrical machine, Superconducting

Sun-Hyung Kim

He received his B.S., M.S. and Ph.D. degrees in Electronic Engineering from Sungkyunkwan University, Korea, in 1979, 1981 and 1988, respectively. Since 1989, He has been a professor in Department of Information and Communication Engineering, Soonchunhyang University. His research interests include Data Communication, Embedded system, IoT, etc.