MAXIMUM OUTPUT POWER CONTROL SYSTEM OF VARIABLE SPEED WIND FOR A SMALL WIND TURBINE GENERATOR

Yoko AMANO[1]

Abstract: This paper proposes maximum output power control of variable-speed small wind turbine generator system. Paying attention to an optimum rotor speed of a single phase AC generator which can obtain maximum output power according to natural wind speed, the proposed method adjusts the rotor speed of the single phase AC generator to the optimum rotor speed. Since this adjustment is realized on line, so that, it can be adapted for variable-speed natural wind, a generated power brake links directly with the single phase AC generator, and the rotor speed of the single phase AC generator is adjusted by controlling a generated current that flows FET (Field-Effect Transistor) device as the generated power brake. In order to reduce heat loss of FET device, PWM (Pulse Width Modulation) control is introduced. Moreover, the experimental system for the proposed method is constituted, and the experiment is performed. Finally, the validity and the practicality of the proposed method are confirmed by experimental results.

Keywords: maximum output power control, variable-speed wind turbine generator, small wind turbine generator system, PWM control, generated power brake

1. INTRODUCTION

Recent years, motion that the thermal power generation which uses a limited fossil fuel, and nuclear power generation with fear of a radiation leak will be improved is activated all over the world. There are not fossil fuel drains and worries about environmental pollution, research and development of reproducible alternative energy are furthered briskly. Since wind energy is reproducible and clean energy source of un-drained nature, the wind energy attracts attention greatly.

On the other hand, the electric power industry which is the core of an energy industry rose in the second half of the 19th century, and they were in the flow of enlargement and centralization intently. However, there is a motion which shifts to a miniaturization and distributed type from enlargement and concentration type by the diversification of consumer needs and the change of social structure toward the 21st century.

The wind energy is positioned as distributed power generation; it is one subject that a small generator can carry out the maximum output is important for especially the minimum unit minimal cluster supposing ordinary homes of electric power networks [1]. Inside of small generators, the single phase AC generator is capturing the spotlight as a minimal cluster, since installation has the features, such as easy, a low price, utilization, and miniaturization [2]. However, the wind energy is from that energy density does not spread at least 1/800 compared with water energy, and the irregular nature of wind speed, so that, various efficient controlling methods are proposed to the permanent magnet synchronous generator[3] ~[10].

Generally, the characteristic of a wind turbine generator system changes a lot according to the wind speed, and has nonlinear nature, it is difficult for deciding the optimum operating point in the wind turbine generator system. While using effectively the wind energy of variable-speed small wind turbine with the single phase AC generator, and getting the maximum and stable wind energy, the maximum output power control for variable-speed small wind turbine generator system must be argued.

In this paper, paying attention to the optimal rotor speed of the wind turbine which can obtain the maximum output according to the natural wind speed [2]. A secondary polynomial approximate technique of the relation between the wind speed and the optimal rotor speed is carried out, the technique of performing adjustment for the rotor speed of the single phase AC generator according to the optimal rotor speed is proposed.

In order to on-line realize the adjustment according to the variable-speed wind, a generated power brake is directly linked with the generator, and the rotor speed of the generator is adjusted by controlling the generated current flowed on the generated power brake. Moreover, in order that the generated power brake is constituted by FET (Field-Effect Transistor) device, for reducing heat loss of FET device, it introduces PWM controller (Pulse Width Modulation) to controlling FET device.

Furthermore, an experimental system of variable-speed small wind turbine generator system is constituted, and experiments are performed. Finally, the validity and practicality of the proposed method are confirmed by the experimental results.

2. MAXIMUM OUTPUT POWER CONTROL SYSTEM

The output power P obtained in the wind turbine generator system which consists of the wind turbine rotor linked directly and the single phase AC generator is expressed like the following formula [11].

$$P = \eta \times C_P \left(\frac{1}{2} \rho A V_w^3 \right) \tag{1}$$

here, η is an efficiency of the direct drive turbine, C_P is a power coefficient, ρ is air density (kg/m^3), A is a swept area (m^2), and V_w is wind speed (m/s).

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When a pitch angle is fixed, the power coefficient C_P becomes the function of only tip speed ratio λ defined by the following formula.

$$\lambda = \frac{r\omega}{V_w} \tag{2}$$

there, r and ω express a windmill radius (m) and a rotation angular speed (rad/s) of the wind turbine rotor, respectively.

In order to obtain the maximum output power P_{max}, if the efficiency $\eta = 1$ is assumed, and the speed ratio is set with λ_{opt}, the optimum rotation angular velocity which obtains the maximum output power to given the wind speed V_w will become settled at the following formula.

$$\omega_{opt} = \frac{\lambda_{opt}}{r} V_w \tag{3}$$

Therefore, the control purpose of the maximum output power is expressed as rotor speed control that rotation angular speed ω is made to follow target value ω_{opt}.

However, the large deviation of the efficiency η arises with the actual wind turbine and the actual generator. Since the efficiency η is the nonlinear function related with the wind speed V_w, and has a large gap between the practical measured value and the theoretical calculation value. So that, the identification of the efficiency η about the wind turbine generator system is difficult for the variable-speed natural wind.

3. THE VARIABLE-SPEED SMALL WIND TURBINE GENERATOR SYSTEM

3.1 The usual small wind turbine generator

The composition of the Aerogen 2 wind turbine generator made in LVM Corp. UK is shown in Figure 1. The exchange of electric power from the wind turbine connects with the AC generator is transformed into direct-current electric power through a rectifier, and DC load or a battery.

Conventionally, since the usual Aerogen 2 wind turbine generator is left to the natural wind speed, the maximum output is not obtained, the waveform of generated voltage receives noise easily shown in Figure 2.

Figure 2 shows the waveform which stored up the generated voltage for 5 seconds by the usual Aerogen 2 wind turbine generator, the channel 1 is all sine wave of the generated voltage, and the channel 2 is the plus portion sine wave of the generated voltage. In Figure 2, wave-like maximum and a wave-like minimum value portion

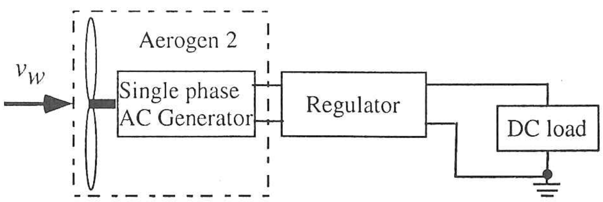

Fig. 1 Configuration of the usual small wind turbine generator Aerogen 2 wind turbine generator

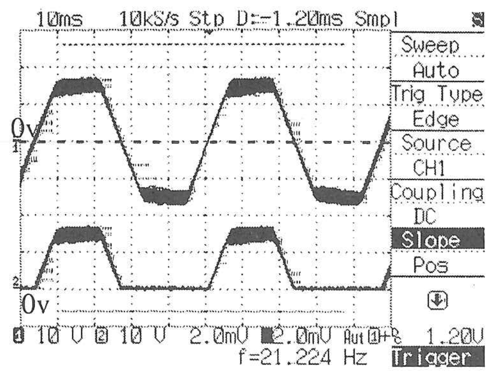

Fig. 2 The generated voltage wave of the Aerogen 2 wind turbine generator by the usual method

found that there was big shakes. It is thought that various noise mixes in the generated voltage by open loop composition of the usual Aerogen 2 wind turbine generator system shown in Figure 1.

3.2 Configuration of the proposed small wind turbine generator system

The composition of the variable-speed small wind turbine generator system proposed in this paper is shown in Figure 3. Its attention is directed to the optimum rotor speed of the wind turbine and the single phase AC generator, it can obtain the maximum output power from the direct drive tribune according to the variable-speed natural wind.

It becomes the experiment variable-speed small wind turbine generator system that added the converter with the optimum rotor speed N_r^* for the wind speed vs rotor speed, a wind speed meter, a laser speed meter that measures the rotor speed N_r of the single phase AC generator, a controller, PWM controller and FET device as the generated power brake.

When comparing the rotor speed N_r of the single phase AC generator and the optimum rotor speed N_r^*, the controller outputs a control signal to lost the rotor speed deviation e_N. By the control signal, PWM controller controls the generated current that is flowing FET device, the generated power brake is applied, then the adjustment for rotor speed of the single phase AC generator is realized.

For the heat loss of FET device decreases greatly by controlling the generated current followed on FET de-

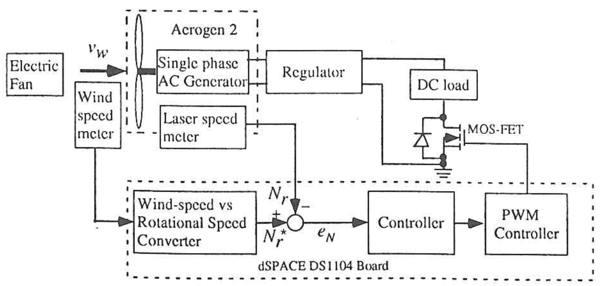

Fig. 3 Configuration of the proposed variable-speed small wind turbine generator system

Table 1 Specifications of the Aerogen 2 wind turbine generator

Item	Specification
rated output / rated wind-speed	20 (W) / 10.5 (m/s)
generator	single phase AC generator
blade diameter	580 mm
blade number	5
weight	5 kg
output voltage	12 (V)
survival wind-speed	40 (m/s)

vice, PWM controller is used. This structure of the small wind turbine generator system is simple and low cost, the response speed that follows the maximum output power according to wind speed can become quick [3].

4. THE EXPERIMENTAL SYSTEM

4.1 The small wind turbine generator

Since the approach of this research is shown concretely, the Aerogen 2 wind turbine generator with the specification of table 1 is taken up as a control object. On the other hand, the characteristic measurement result of output power vs. rotor speed is shown in Figure 4. This expresses the experiment result corresponding to the formula (1) including the efficiency η.

By Figure 4, the maximum output power obtained for every wind speed is made Figure 5. The optimum rotor speed of the windmill for obtaining the maximum output power to every wind speed is shown in Figure 6.

The relation between the optimum rotor speed and the wind speed of interesting one is alignment by the theoretical formula (3). Direct is carried out and it is becoming nonlinear like Figure 6 in fact.

Therefore, by this research, in order to obtain optimum rotor speed from the given wind speed, the characteristic curve of Figure 6 is approximated by the following secondary polynomial.

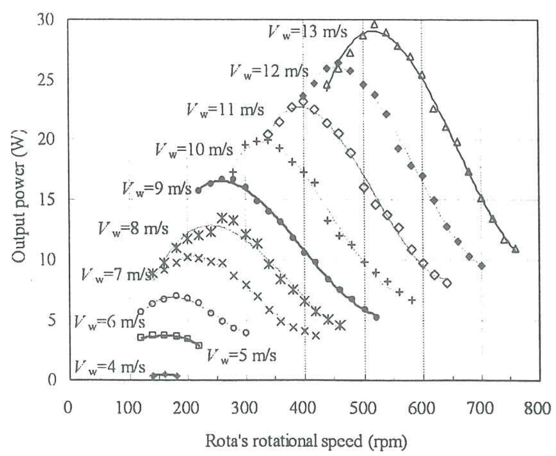

Fig. 4 Characteristic of output power vs. rotor speed of the Aerogen 2 wind turbine generator

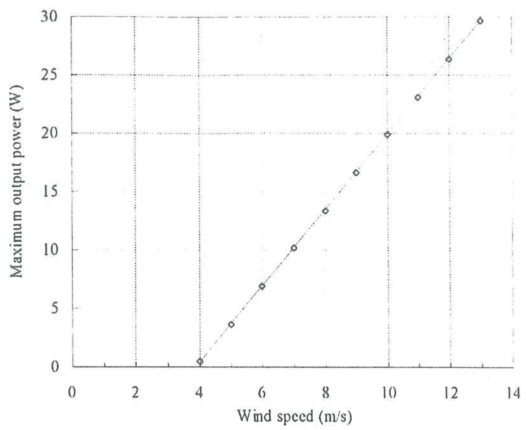

Fig. 5 Characteristic of maximal output power P vs. wind speed V_w of the Aerogen 2 wind turbine generator

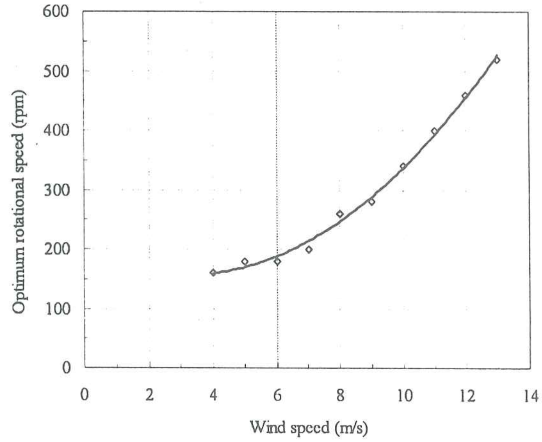

Fig. 6 Characteristic of optimum rotor speed ω_{opt} vs. wind speed V_w of the Aerogen 2 wind turbine generator

$$N_r^* = 3.7879V_w^2 - 23.545V_w + 193.21 \quad (4)$$

4.2 The composition of experimental equipment

The photograph of the experimental system used for the proposed method is shown in Figure 7. The natural wind is generated using an electric fan, the wind speed can be arbitrarily adjusted by changing the input voltage of the electric fan by the control programme.

The Aerogen 2 wind turbine generator outputs the direct-current generated current that is poured over FET device and DC load. On the other hand, the wind speed meter transmits the wind speed signal to the converter of the wind speed vs rotor speed, and changes the wind speed signal into the optimum rotor speed N_r^* based on the formula (4) which approximated the characteristic of the optimum rotor speed vs the wind speed shown in Figure 6.

The rotor speed deviation signal e_N with the rotor speed N_r of the direct drive turbine and the optimum rotor speed N_r^* is inputted into the controller. Then, the controller outputs the control voltage to PWM controller,

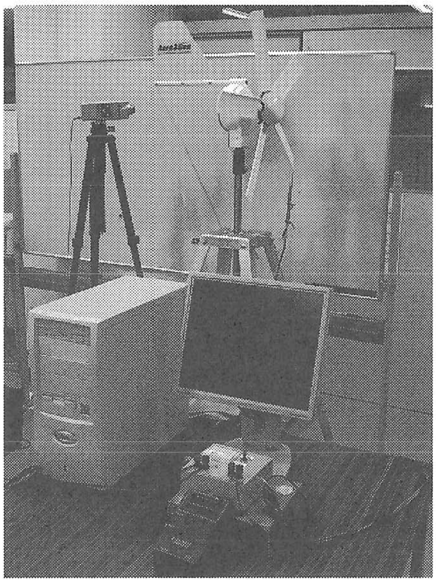

Fig. 7 The picture of the experimental small wind power system

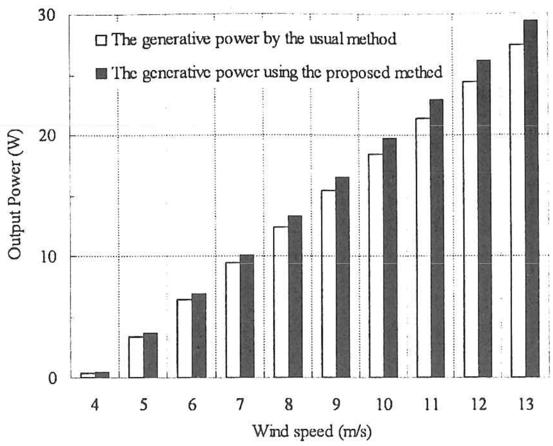

Fig. 9 The generative power comparison of the Aerogen 2 wind turbine generator using the proposed method and the usual method

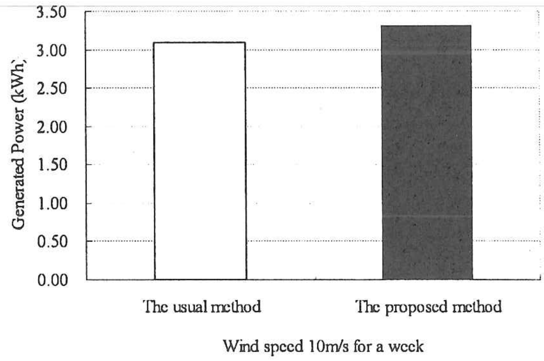

Fig. 10 The measurement of generate characteristic for wind speed 10 (m/s)

and it is controlling the generated current which flows FET device, then it adjusts the rotor speed of the Aerogen 2 wind turbine generator for the rotor speed deviation can become zero.

Since the high-speed response is required for the wind power control, the operation of the controller adopted PID control with sufficient effect. Moreover, in order to reduce exothermic loss of FET device, the experimental system is conducted by the "PID+PWM" control type which added PWM controller with a carrier frequency of 20 kHz.

Using a DS1104 board made from dSPACE, it realizes all of the converter, PID controller, and PWM controller of the wind speed vs the optimum rotor speed, and performs the wind power experiment on-line through the operation panel of Figure 8 on the computer.

5. THE EXPERIMENTAL RESULTS

The output power for the wind speed from 4 (m/s) to 13 (m/s) of the Aerogen 2 wind turbine generator is shown in Figure 9. In Figure 9, a white left bar graph is the output power of the usual Aerogen 2 wind turbine generator, and a black right bar graph is the output power of the Aerogen 2 wind turbine generator using this proposal. Even if wind speed changed from 4 (m/s) to 13 (m/s), it is clarified that the right bar graph 1.07 times than the left bar graph.

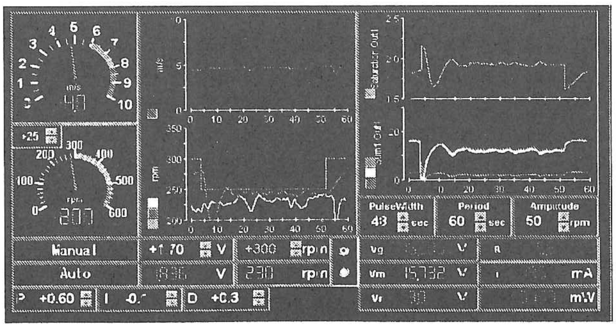

Fig. 8 Operation panel for experiment

The generated electric power of the Aerogen 2 wind turbine generator for one week to the wind speed of 10 (m/s) is shown in Figure 10, the white left bar graph expresses the generated electric power 3.09 (kWh) of the usual Aerogen 2 wind turbine generator, and the black right bar graph expresses the generated electric power 3.31 (kWh) of the Aerogen 2 wind turbine generator by this proposal.

Moreover, the generated electric power of the Aerogen 2 wind turbine generator for one week to the natural wind which wind speed is random from 4 (m/s) to 13 (m/s) is shown in Figure 11. In Figure 11, the white left bar graph shows the generated electric power 2.34 (kWh) of the usual Aerogen 2 wind turbine generator, and the black right bar graph shows the generated electric power 2.50 (kWh) of the Aerogen 2 wind turbine generator by this proposal.

According to Figure 10 and Figure 11 that is the results

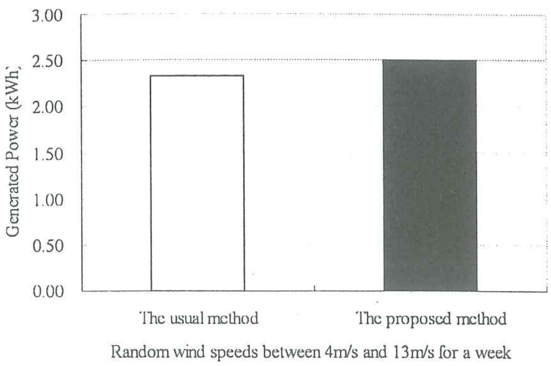

Fig. 11 The measurement of generate characteristic for random natural wind

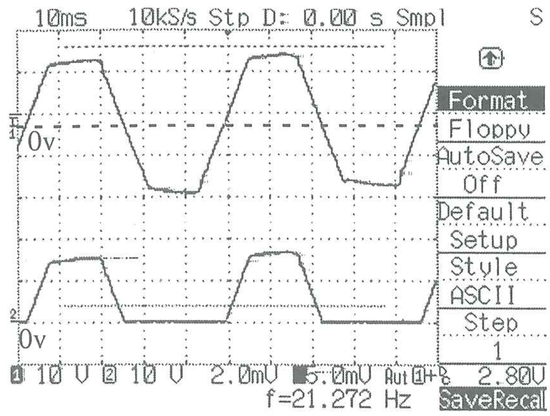

Fig. 12 The generative voltage wave of the Aerogen 2 wind turbine generator with the proposed method

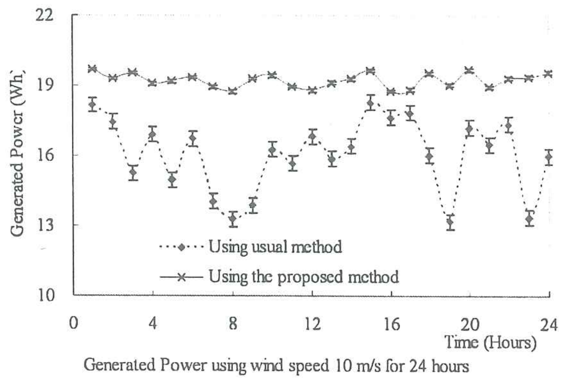

Fig. 13 The comparison of the generated power for the Aerogen 2 wind turbine generator

measured the wind speed of 10 (m/s) and the random natural wind for one week, we can see that the generated electric power of the Aerogen 2 wind turbine generator by this proposal could rise about 1.07 times than the usual Aerogen 2 wind turbine generator.

In Japan, the annual average wind speed in the installation area of the wind energy of the northern northeast area in Hokkaido, Kanto Hokuriku and the central part Kinki area, and the inside Shikoku and the Kyushu Okinawa area is 8 (m/s)-10 (m/s), and 10 (m/s) order occupies about 70- 80% [12]. Therefore, it is thought that the maximum output control system of the variable-speed small wind turbine generator system proposed in this paper has practicality and validity.

Further, the waveform which stored up the generated voltage of the Aerogen 2 wind turbine generator by this proposing method for 20 seconds is shown in Figure 12. Comparing with the waveform of Figure 2, it turns out that the noise is removed that the waveform is shown in Figure 12.

Moreover, the generated power data and standard deviation of the generated electric power that the wind speed of 10 (m/s) in 24 hours is shown in Figure 13. In Figure 13, the dotted line and the solid line express the generated electric power and the range of its standard deviation value for every hour of the usual Aerogen 2 wind turbine generator and the Aerogen 2 wind turbine generator by the proposal, respectively.

From the measurement result of the generated electric power, the average value of the generated electric power with the usual Aerogen 2 wind turbine generator is 16.04 (Wh), the average value of the generated electric power using the Aerogen 2 wind turbine generator by the proposal is 19.22 (Wh), and becomes 1.20 times than the usual Aerogen 2 wind turbine generator.

On the other hand, the standard deviation by the usual Aerogen 2 wind turbine generator is 1.56, the standard deviation of the Aerogen 2 wind turbine generator using the proposal is 0.30, and becomes 0.19 times than the usual estrogen 2 wind turbine generator.

By the comparison result of Figure 13, the Aerogen 2 wind turbine generator using the proposal can get that the generated electric power is up 1.20 times, and the standard deviation of the generated electric power is small 1/5 than the usual Aerogen 2 wind turbine generator. So that, we can expect to obtain the generated electric power with little change.

6. CONCLUSION

In order to utilize the thin energy density of wind energy, the maximum output control for the variable speed small wind turbine generator system with the single phase AC generator is proposed in this paper. For realizing the optimal rotor speed on obtaining the maximum output power from the direct drive turbine, the relation with the optimal wind speed and the rotor speed of the generator combined with the direct windmill rotor is controlled. Moreover, PWM control was introduced in order to reduce exothermic loss of FET device applied as the generated power brake to control the single phase AC generator as much as possible.

Furthermore, the experimental system of the proposed method was build, and the results of the experiment were examined, it was confirmed that the proposed method has the validity and practicality. In the future, in order to improve the response speed of this proposed method, we have plan to use a one chip devices, such as DSP and

FPGA, and realize low heat of the generated power brake and so on.

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