Research for Electric Brake Using NTC Thermistors on Micro Wind Turbine

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***Abstract*—As a brake system for small wind turbine, mechanical brake and electric brake by the short circuit of 3-phase permanent magnet generator are used. However, an electric braking method may damage the rotor and/or blades by rapid stop of the generator revolution. Moreover, generator winding may also be damaged by large short-circuit current. In this paper, the electric braking method using NTC thermistors (negative temperature coefficient resistors) is proposed as a braking system for a cheaper and safe micro wind turbine.**

I. INTRODUCTION

Recent year in Japan, we can see wind turbine generators of 300-500W and photovoltaic of tens W as a rise of environmental consciousness at some elementary schools as education, parks, city area for monument, and company roof for public relations of environment. Small wind turbines [1,2] are defined that the area swept by the rotor blades is less than 200 m^2 (the rotor diameter of 16 m) by IEC (International Electrotechnical Commission). However, they are classified micro, mini, and small. Especially, small wind turbines of which the rotor diameter is less than 3 m are called micro wind turbines.

The micro wind turbines are required as follows: power generation with a breeze, quiet, having brake system, and batteries, etc. Moreover, when the micro wind turbines are installed, we ought to consider for a high housing density area, wind conditions, and a friendly and/or formative artistic design for natural environment, and so on.

The method of controlling or stopping the rotor revolution of a micro wind turbine is divided roughly into an aero brake, a mechanical brake, and an electric brake. The aero brake consists of a pitch control to which the angle of blades is changed in the direction passed through a wind, a stall control which makes a stalling state for the flow of the wind behind blades, or a yaw control which diverts the surface of revolution of blades. The mechanical brake is a disk brake which forces the brake pads and is stopped by friction. The electric brake decreases the speed of rotor revolution because of the magnetic force between the permanent magnet and the generator winding with a 3-phase short circuit. Furthermore, there is also a compound braking system of these methods. It is selected from the whole wind power generating system for considering of safety, elements and the assembly, maintenance, life time, cost and so on.

In this paper, the electric brake using NTC thermistors (negative temperature coefficient resistors) [3] is examined, when the wind is strong over the furling speed [4], or the battery is charged over voltage. Usually, a discharge equipment, which consists of 3-phase resistor, is chosen as a protection device. When the micro wind turbine needs to stop for some protections, a couple of relay terminals changes the side to the discharge equipment. However, the rotor blades are rotating slowly, because electric current produced by the generator flows in the resistor of 2.5 ohms of each phase. If the value of the resistor is in the vicinity of zero, like a short circuit, large short-circuit current flows in the winding and it will be damaged. Moreover, by the sudden stop of the revolution of the blades, the large braking torque may also damage them.

NTC thermistors show initial resistance of several ohms and then show about zero ohms by Joule heating. Some NTC thermistors are chosen as the discharge equipment. The rotor blades stop after sufficient time progress, safely.

II. CONTROL SYSTEM OF MICRO WIND TURBINE

A. Specification of the micro wind turbine

In this research, the micro wind turbine currently sold in Kitac Corp. is used as an example of a micro wind turbine system. The specification is shown in Table I.

The revolution speed of the blades decreases after working of the discharge equipment, when wind velocity exceeds the furling and/or the battery voltage exceeds 30V.

B. Control system

The control system of the micro wind turbine is shown in Fig.1. The generator G generates electric power with 3-phase alternating current by revolution of the rotor blades. The current is rectified and charged a couple of batteries [5]. The electric power stored with the battery temporarily is transformed into the power supply of 100V with single phase (for the commercial power supply apparatus in Japan) by the inverter.

TABLE I.
SPECIFICATION OF THE MICRO WIND TURBINE

Model	FD2.5-500
Rotor diameter [m]	2.5
Rated power [W]	500
Rated wind speed [m/s]	8
Cutin wind speed [m/s]	3
Furling wind speed [m/s]	25
Height of tower [m]	5.5

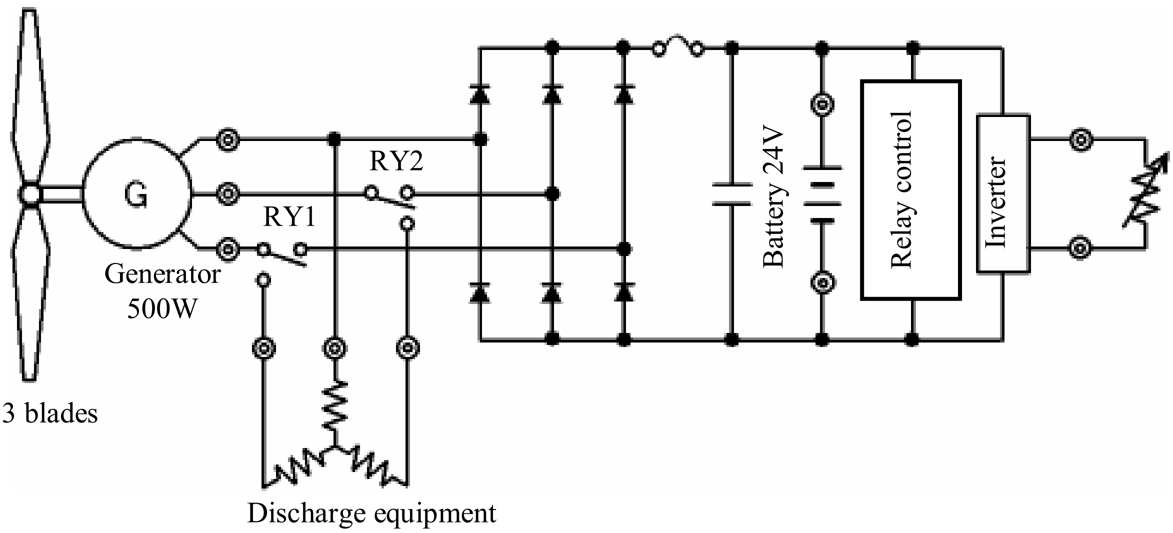

Fig.1. Control system of the micro wind turbine.

Fig. 2 is a model of a control device operation. Calm, the battery voltage of 20V, and the electric supply stop state to the load are assumed as an initial state. When wind exists with over cutin speed, the generator G generates, and the battery charge starts, when the battery terminal voltage exceeds charge start voltage of 24V. When the battery voltage exceeds electric supply voltage of 28V, the inverter works and the electric supply to the load will begin. If the battery is charged up to 30V, the discharge equipment works to protect the full charged battery by the relays (RY1 and RY2). After the battery is consumed until the voltage of 28V, the discharge equipment turns off and the battery is recharged, and the flow chart is repeated. On the other hand, if wind is less than the cutin speed, the electric power of the battery is consumed by the load and the battery voltage falls. If the battery voltage is less than the battery protection voltage of 20V, the battery is isolated from the load, and the electric power supply to the load stops.

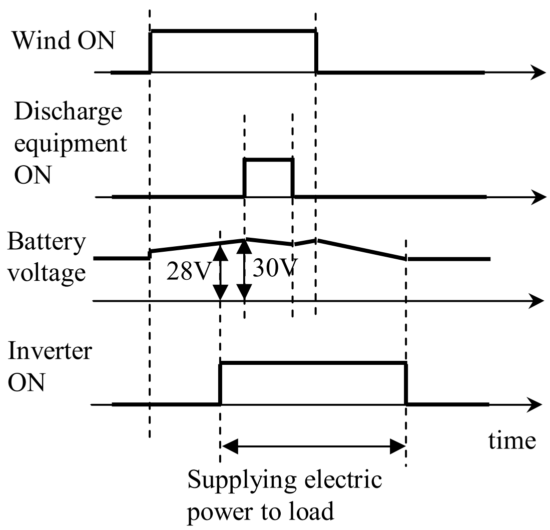

Fig.2. Control device operation.

TABLE II.
SPECIFICATION OF NTCS

Model	10R8A	120R3A
Max current [A]	8	3
Resistance [Ω] at 25℃	10	120
Resistance [Ω] at Max current	0.01	0.90
Diameter [mm]	22	22

For the generator limiting, when wind speed exceeds the furling wind velocity of 25 m/s, it is necessary to suspend the revolution of the blades safely. In this control system, an electric brake works using a method of 3-phase short circuit with inserting the discharge equipment.

III. BRAKING THE REVOLUTION OF THE BLADES USING NTC THERMISTORS

The 3-phase short circuit of the generator may cause serious damage, that is a large short-circuit current flows in the winding and the blades receive large torque as the revolution decreases rapidly. NTC thermistors have the initial large resistance of several ohms. Joule heating of the NTC makes the lower resistance of about 0.1 ohms. Therefore, at first the short-circuit current is small enough without winding damage, and then the blades stop gently by using NTCs instead of the discharge equipment. Moreover, if the temperature of NTC falls, it returns to the initial resistance, and the generator reboots. About 700-repetition use is possible for NTCs [3].

A. NTC thermistors

The specification of NTCs is shown in Table II. Two kinds of NTCs, which have each different initial resistance at 25℃, are examined.

B. Experiment on braking characteristics for the micro wind turbine

An experimental device and the schematic diagram are shown in Figs. 3 and 4, respectively. In Fig.3, the experimental simulation device consists of an induction motor with a small tire and a 3-phase synchronous generator connected with a large tire, and is imitating

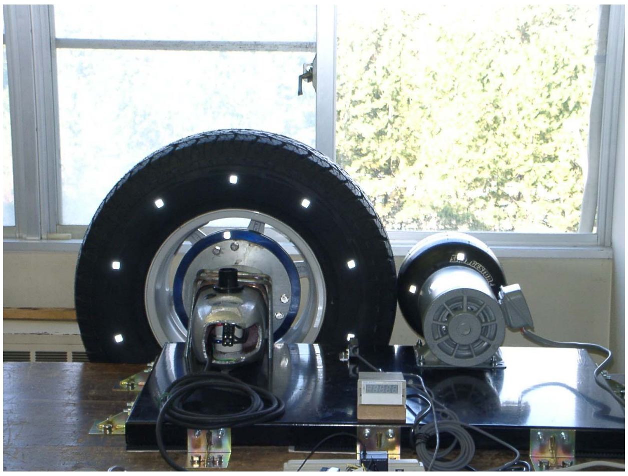

Fig.3. Experimental device.

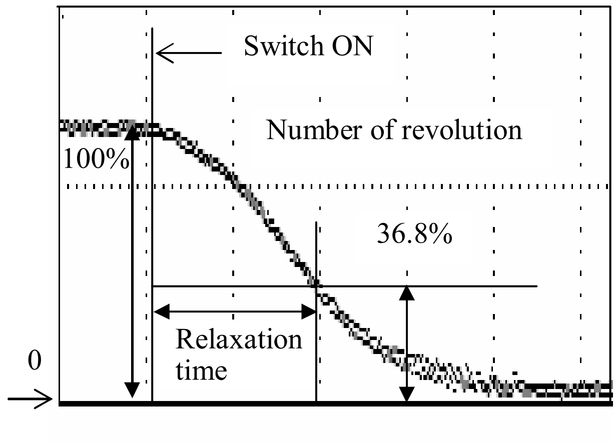

Fig.5. A model of relaxation time.

wind power. The tire attached to the generator is the same moment of inertia of 2.88 kg·m^2 for the blades. In Fig. 4, a discharge equipment with Y connection of NTCs is connected with the generator at arbitrary number of revolution. Line voltage, line current, output electric power, and number of revolution are observed, and the braking characteristic is measured.

The definition of relaxation time is shown in Fig. 5. In this paper, relaxation time for braking of generator is defined as follows, and it is measured. After a switch S turns ON, the number of revolution decreases exponentially. The relaxation time is defined as a time until it slows down to 1/e = 36.8 % for initial number of revolution of 100 %.

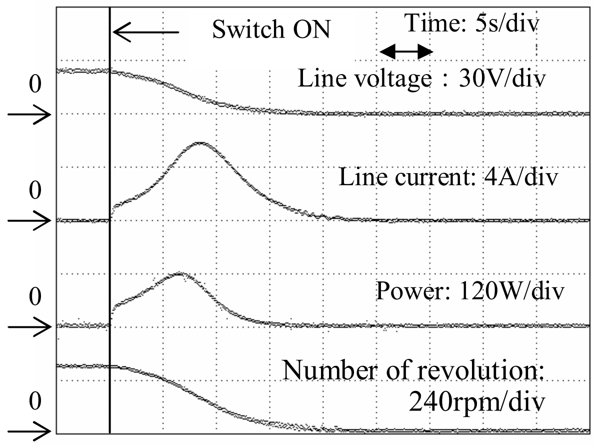

Fig.6. An example of waveforms (10R8A at 300 rpm).

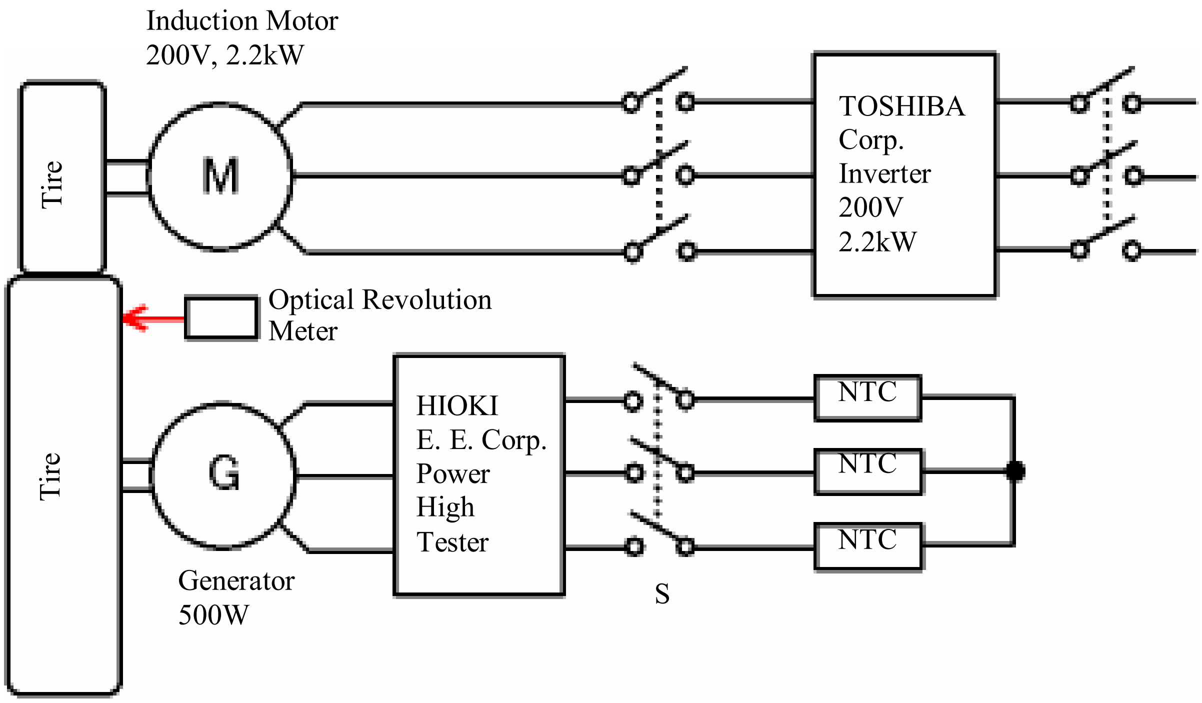

Fig.4. Schematic diagram.

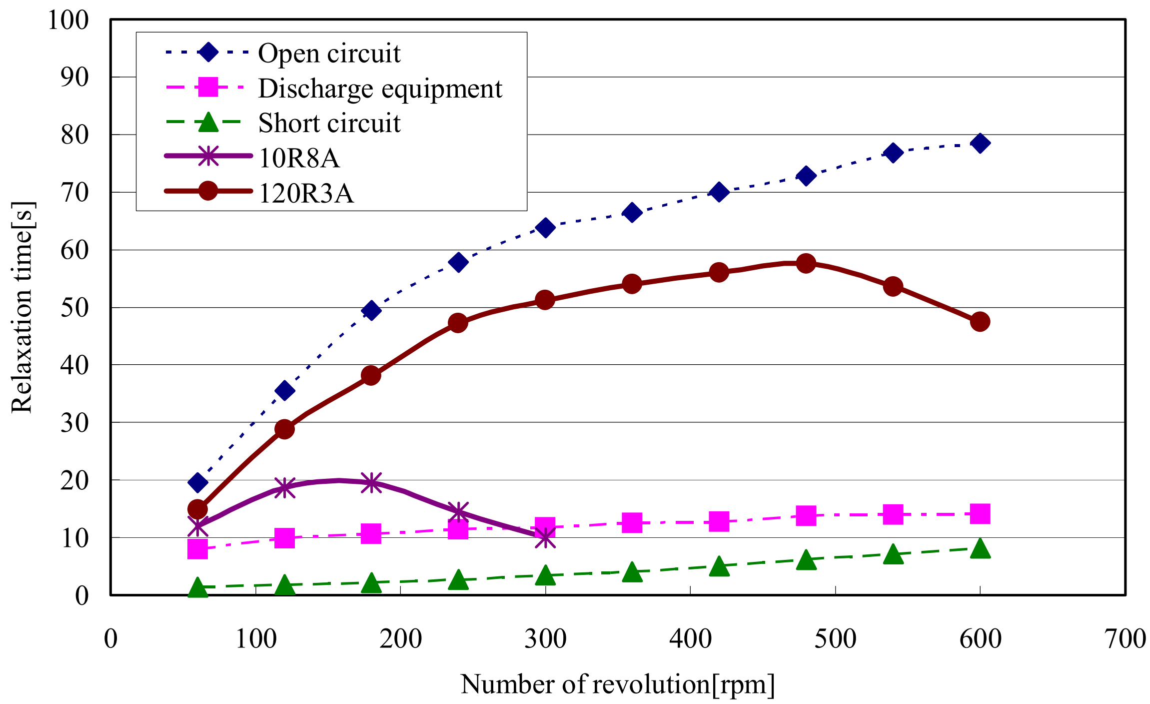

Fig.7. Relaxation time dependences on number of revolution

IV. Experiment Results and Discussions

A. Relaxation time

The waveforms of the line voltage, the line current, the output electric power, and the number of revolution are shown in Fig. 6. The relaxation time in the range of 0-600 rpm is shown in Fig. 7. Data for the short circuit, the open circuit, and the resistor of 2.5 ohms each phase with Y connection is also shown to compare with the NTCs. On the NTC element of 10R8A, since the rated current is 8 A, the discharge equipment is measured up to 300 rpm. On the 120R3A, it can be used more than 550 rpm of the rated number of revolution, and the relaxation time becomes long, that is the generator stops gently.

B. Maximum current flowing into the winding

The maximum current flowing into the generator winding at arbitrary number of revolution is shown in Fig. 8. Although the value near rated current is observed on 120R3A, it can be used within the limits.

C. Maximum torque and maximum torsional stress around the axsis of the generator

When objects are stopped revolving, a braking torque occurs to the axis of the revolution. The braking torque T_R is obtained by the moment of inertia I_R multiplied by the angular acceleration a_R [rad/s^2] as following equation.

$$T_R = I_R \cdot a_R \text{ [N·m]} \qquad (1)$$

The maximum value of the braking torque is defined as the maximum braking torque T_{max}. Relations between T_{max} and the number of the generator revolution are shown in Fig. 9. Although when the electric brake does

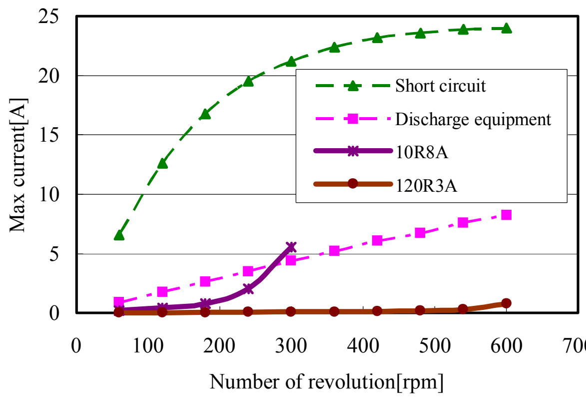

Fig.8. Maximum current.

not work in a case of open circuit, the braking torque exists, this is considered to be the influence of friction at the roller bearing of the rotor and tires.

The torsion stress t_R occurred around the generator axis by the braking torque T_R is obtained by following equation,

$$t_R = \frac{2T_R}{\pi r^3} \text{ [N/m}^2\text{]} \qquad (2)$$

where r is the radius of the generator axis. The maximum torsion stress t_{max} is obtained by substituting T_{max} for (2). The value of t_{max} is expressed with the axis on the right of Fig. 9. If Figs. 7 and 8 are compared with Fig. 9, the maximum braking torque is large, since the relaxation time is short and the maximum current is large. That is

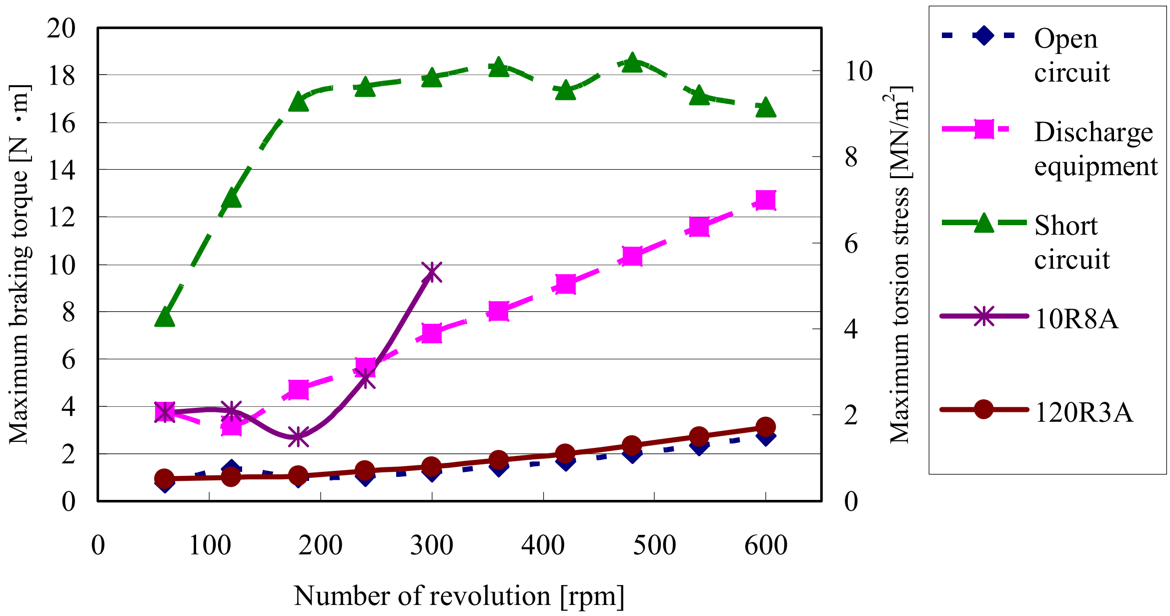

Fig.9. Maximum braking torque and Maximum torsion stress.

reason why the current flowing the winding is large, the rotor receives a large braking torque, and then the generator slows down more quickly. Moreover, the braking torque is limited by using NTC thermistors, that is, some mechanical and electrical loads given to the micro wind turbine become small.

Here, we examine the adequacy of the allowable torsion stress of the axial material which is provided by International Standard or etc. The axial material of the micro wind turbine is the chromium steel SCr440 (Japanese Industrial Standards). The allowable torsion stress is about 60-90 x 10^6 [N/m^2] = 60-90 [MN/m^2]. In Fig. 9, the maximum torsion stress in the case of short circuit is far less than the allowable torsion stress of SCr440. The matter of 3-phase short circuit braking has no problem for about machinery intensity. However, this result is obtained with the imitation experimental device, and does not bring same result under the natural ambience wind yet.

But the allowable current of the generator winding depends on the thickness of the wire. Therefore, the matter of 3-phase short circuit braking using NTC thermistors is effective for micro wind turbines.

V. Conclusions

Characteristics on electric braking system for a micro wind turbine by using an experimental simulation device are measured. By inserting Y connection NTC thermistors into the generator output terminal, the gently electric braking of the rotor blades is possible. Choosing suitable NTCs for the inertia moment of the blades and the generator is able to compose an electric braking system for micro wind turbines. And the cost will be cheap, as compared with other mechanical brake.

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