Braking Circuit of Small Wind Turbine Using NTC Thermistors under Natural Wind Condition

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***Abstract*—An electric brake by a three-phase short-circuit system used as the brake equipment of a small wind turbine damages the rotor blades by a rapid revolution stopping of the generator. Moreover, the generators windings may also be damaged by a large short-circuit current. In this paper, the electric braking circuit using the NTC thermistors (negative temperature coefficient resistors) is proposed as a braking system for a cheaper and safe stop of the small wind turbine. The effect under the natural wind condition is examined by the field test using a 500W small wind turbine.**

Keywords: wind power, small wind turbine, NTC thermistors

I. INTRODUCTION

Recently, constructions of wind power generation and photovoltaic energy system against environmental problems such as global warming are advanced to the use of natural energy in Japan [1]. We can see small wind turbines of about 300-500 W for environmental consciousness and independent power supply at some parks, schools, and on streets. Small wind turbines are defined as the swept area by the rotor blades with less than 200 m^2 (the rotor diameter of 16 m) by IEC (International Electrotechnical Commission) [2,3]. A basic configuration of the small wind turbine as the block chart is shown in Fig.1. The components are rotor blades, a generator, a control unit with a battery, and so on. The small wind turbine should have a brake system to prevent the overspeed so that an extremely large centrifugal force may work by the strong wind. In addition, the brake system is also necessary for the overcharge prevention of the battery or the maintenance.

The method of controlling or stopping the rotor revolution is divided into a mechanical brake, an aero brake, or an electric brake [4]. Disk brakes are generally used for the mechanical brake. The brake pad stops the revolution of the rotor blades by friction. The aero brake is divided into a pitch control to which the angle of blades is changed in the direction passed through a wind by sensing the wind velocity or the generation output, a stall control which makes a stalling state for the flow of the wind behind the blades, or a yaw control which diverts the direction of the blade revolution. The electric brake decreases the speed of the rotor revolution because of the magnetic force between the permanent magnet and the generator windings with the 3-phase short circuit. Furthermore, the control and/or braking methods combine them. However, the electric braking method causes some damages that are for the rotor blades by a rapid revolution stopping of the generator and the burnt wire of the generator winding by the large short circuit current. The conventional braking methods also make a rapid stopping of the rotor blades. In addition, the cost of establishment and maintenance is expensive. To solve these problems, it is necessary that a cheap and safe brake system stops the revolution of the generator gradually and reduces the burst current.

In this report, the electric braking circuit using the NTC thermistors (negative temperature coefficient resistors) [5] is proposed as a new stop technology for the small wind turbine [6]. The effect in natural wind condition is examined by the field test. A discharge equipment that consists of three-phase resistors decreases the speed of rotor revolution more gradually than the three-phase short-circuit system. However, the rotor blades are rotating slowly, and cannot be stopped completely because the current keeps flowing. A control system to make the values of resistance low by changing resistors is complex. In that respect, NTC thermistor shows the initial large resistance of several ohms and then shows about zero ohms by the self Joule heating. At first, a little current flows into the generator windings, the braking torque is small, and then the braking torque grows large when the resistance value of the NTC thermistors become low. They return to the original state when the current flowing into the NTC thermistor is lost and the temperature fallen. The NTC thermistors can be used repeatedly about 700 times [5]. Therefore, the number of revolution of the rotor blades decreases gradually by using NTC thermisitors, and they stop safely after a sufficient time progress.

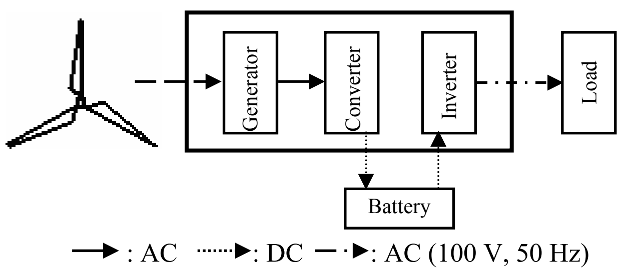

Fig.1. Basic structure of small wind turbine.

II. ELECTRIC BRAKING CIRCUIT USING NTC THERMISTORS

A. NTC thermistor

NTC thermisitor is a semiconductor device that has the initial resistance of several ohms, and the value of resistance decreases according to the temperature rise exponentially. In this study, NTC thermistor "1R30A" is used from the advantages that the maximum current is large and the initial resistance of the braking circuit is able to be changed easily by their series connection. The specification of 1R30A is shown in Table I.

TABLE I. SPECIFICATION OF 1R30A.

Resistance [Ω] at 25 ˚C	1
Maximum current [A]	30
Resistance [Ω] at Max current	0.03

Figure 2 shows the temperature characteristic. In Fig.2, the value of resistance of 1R30A decreases from 1 ohm in initial to about 0.02 ohms with rising the temperature. And it shows that 1R30A returns to the original state when its temperature falls to the previous temperature. In addition, the unit price of 1R30A is cheap with 2.1 US$.

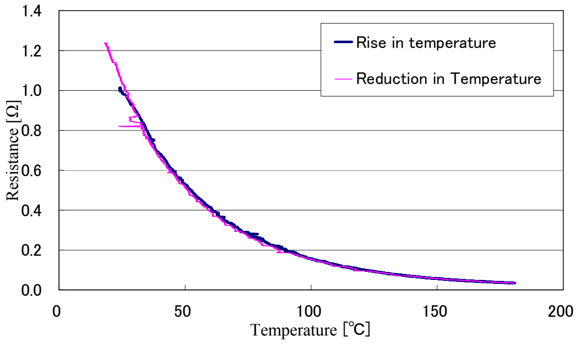

Fig.2. Temperature characteristics of 1R30A

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B. The structure of Electric braking circuit using NTC thermistors.

The short circuit current at the rated speed of the 500 W small wind turbine is 24 A. Among the available NTC thermistors, only 1R30A (Resistance at 25 ˚C: 1Ω, Rated current: 30 A) stands a maximum current more than 24 A. The braking circuit is comprised by a series-connected some 1R30A to each phase of a three-phase with Y-connection. The rotor blades can be decelerated more gradually for an advantage to connect the larger number of NTCs in series because the initial resistance value of each phase increases and then the electric current flowing into the circuit is reduced. Moreover, it is also the advantage that we can produce the braking circuit with a different initial resistance value as it has the large maximum current of 30 A. The name of the braking circuit is written "1R30A×X" in this report. The X is the quantity of 1R30A which is connected to each phase in series.

III. EXPERIMENTAL SETUP

In this reserch, the electric braking circuit using NTC thermistors as a cheap and safe stop technology for a small wind turbine is proposed, and the effects using the 500 W small wind turbines are examined by the field test in Niigata city, Japan.

A. Specification of the small wind turbine

The small wind turbine is shown in Fig.3. Table II shows the specification. The inertia moment of the rotor blades is 2.88 kg・m^2.

Fig.3. Small wind turbine.

TABLEII.
SPECIFICATION OF THE SMALL WIND TURBINE

Model	FD2.5-500
Type of generator	Permanent-magnetic Synchronous generator
Rotor diameter [m]	2.5
Rated power [W]	500
Rated wind velocity [m/s]	8
Cutin wind velocity [m/s]	3
Cutout wind velocity [m/s]	25
Height of tower [m]	5.5

B. Control system of the small wind turbine

Figure 4 shows the controller of the small wind turbine used by this research. The 500W generator G generates electric power by the revolution of the rotor blades as a 3-phase alternating output power. The output power is rectified and charged a battery [7]. The electric power stored with the battery temporarily is transformed into the commercial power supply of 100 V/50 Hz with a single phase in Japan by the inverter. Figure 5 shows the operation model of the controller. Calm, the battery voltage of 20 V, and the electric supply stop state to the load are assumed as an initial state. If a wind blows over the cutin speed, the generator G generates. The battery charge starts, when the voltage exceeds the battery charge start voltage of 24 V. When the battery voltage exceeds the electric supply voltage of 28 V, the inverter works and the system will begins to supply to the load.

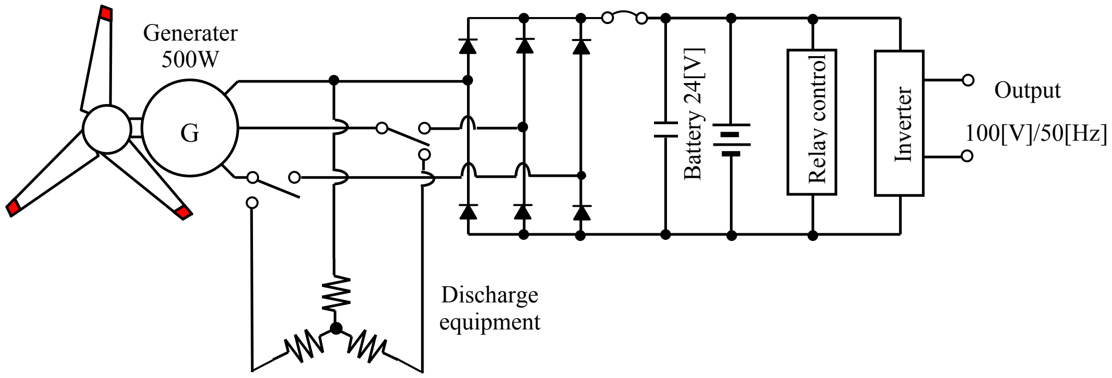

Fig.4. Control system of the small wind turbine.

If the battery charge continues and the battery voltage reaches 30 V, the discharge equipment is connected to protect the battery by the relay. After the battery is consumed until the voltage of 28 V, the discharge equipment turns off and the battery is recharged. And the flow chart is repeated. On the other hand, if the wind stops, 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 20 V, the electric power stops to supply to the load.

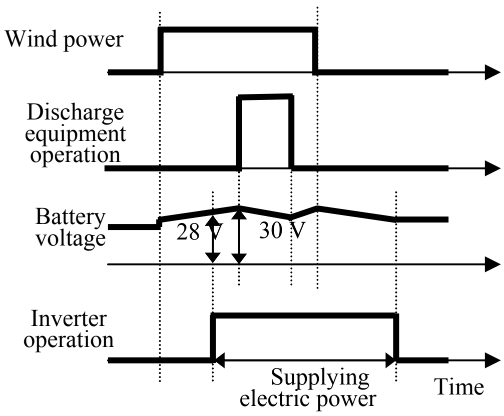

Fig.5. Operation model of control system.

For the control of small wind turbines, when the battery voltage exceeds the battery protection voltage and/or a wind velocity exceeds the cutout wind velocity, it is necessary to stop the revolution of the rotor blades safely.

In this research, the number of revolution of the rotor blades is decreased by connecting the braking circuit using NTC thermistors to the generator output terminal when the wind velocity exceeds the cutout wind velocity of 25 m/s or the battery voltage exceeds 30 V.

C. *Experiment on braking characteristic for small wind turbine*

A schematic diagram of the experimental device is shown in Fig.6. In Fig.6, the generator output of the small wind turbine is opened and the rotor blades are rotated. When the number of revolution of the rotor blades has reached to arbitrary number, the switch SW is connected to the A-circuit formed with the NTC thermistors or the B-circuit. The line current, the number of revolution, and the variation of the wind velocity are measured. In this experiment, the quantity of 1R30A which is connected to each phase in series is changed up to 5, and the braking circuit with the different resistance is examined. In addition, the SW is connected with B-circuit as a comparison to the conventional 3-phase short-circuit brake.

The definition of the relaxation time is shown in Fig.7. In this paper, the relaxation time for braking of the generator is defined as follows, and it is measured. After the switch SW turns ON, the number of revolution decreases exponentially. The relaxation time is defined as time until it decreases to 1/e =36.8 % for the initial number of revolution of the generator defined as 100 %.

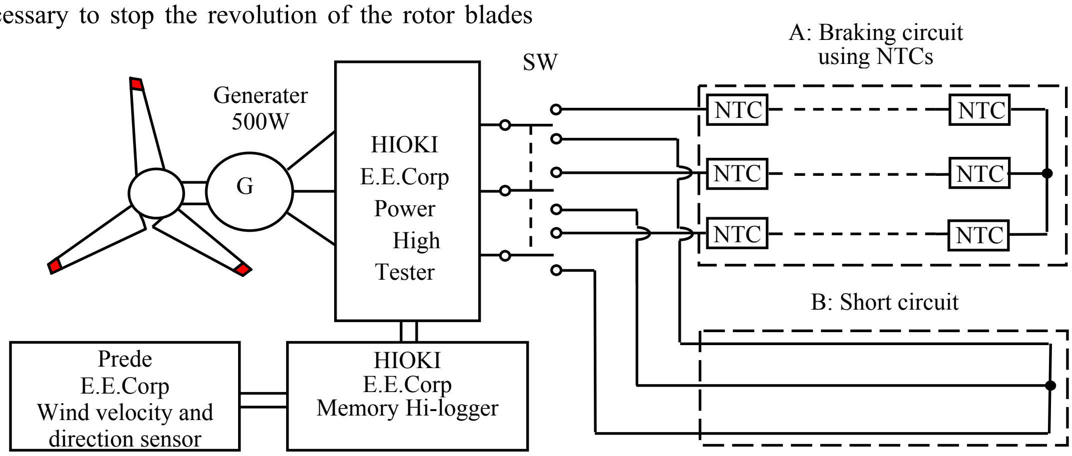

Fig.6. Schematic diagram of experimental device.

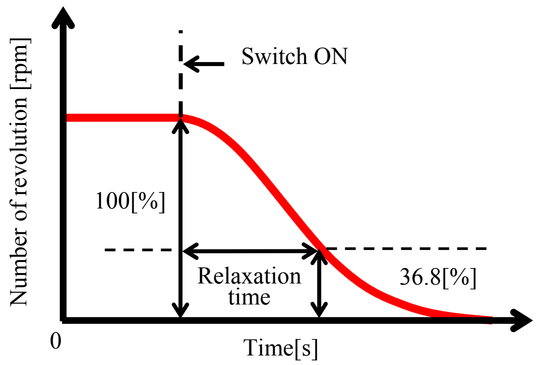

Fig.7. Relaxation time.

IV. EXPERIMENT RESULTS AND DISCUSSIONS

The waveforms of the number of revolution and the line current for the short circuit and the braking circuit using NTCs (1R30A×3) are shown in Figs.8 and 9, respectively. The initial number of revolution of the generator is 360 rpm. Figure 8 shows that the number of revolution decreases rapidly and the large line current flows suddenly soon after the short circuit brake is used. It is the reason that the large short circuit current flows to the generator windings and the load to the generator has entered an overloaded state. On the other hand, figure 9 shows that the number of revolution decreases gradually for the braking circuit using NTCs as compared with the short circuit brake and the maximum value of the line current can be reduced. It is reason that the larger line current doesn't flows to the generator windings rapidly and the load to the generator does not affect the revolution of the generator suddenly because the initial resistance of NTC thermistors works as a load.

The waveforms of the number of revolution and the line current using the discharge equipment connected with the generator output are shown in Fig.10. The Number of revolution and the line current rise and fall with the variation of the wind velocity. The rotor blades cannot be decelerated enough under the natural wind condition with the discharge equipment. Therefore, it is effective that the braking circuit using NTC thermistors is used for the controller to prevent the overcharge of the battery.

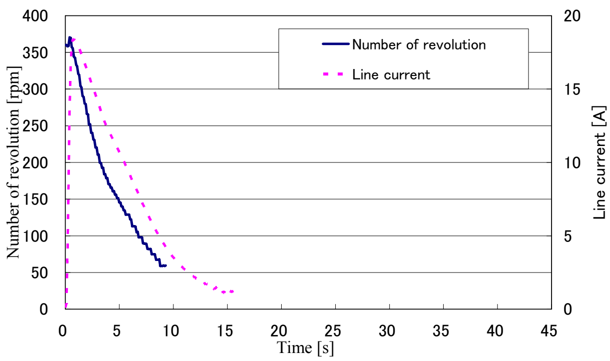

Fig.8. Number of revolution and line current
(short circuit, average wind velocity: 5[m/s]).

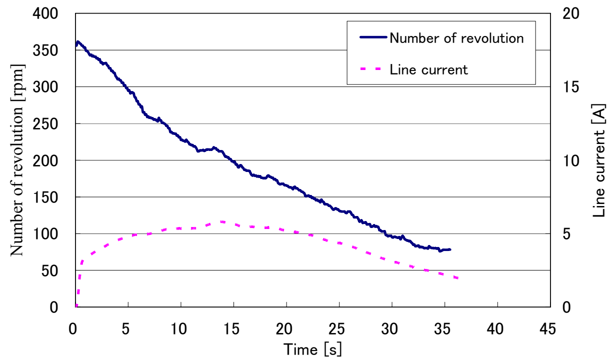

Fig.9. Number of revolution and line current
(1R30A×3, average wind velocity: 5[m/s]).

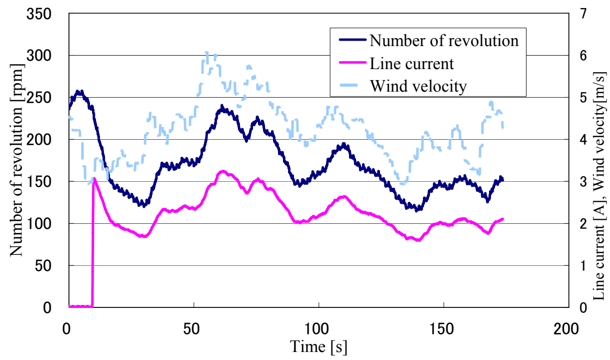

Fig.10. Number of revolution and line current
(Discharge equipment, average wind velocity: 4.2[m/s]).

The maximum current flowing into the generator windings after braking at the arbitrary number of revolution is shown in Fig.11. It is possible that the current value flowing into the generator windings is reduced by the braking circuit using NTCs compared with the short circuit brake.

The relaxation time in the range of 0-420 rpm is shown in Fig.12. The relaxation time becomes long by the braking circuit using NTCs compared with the short-circuit brake. In other words the revolution of the generator has decelerated gradually.

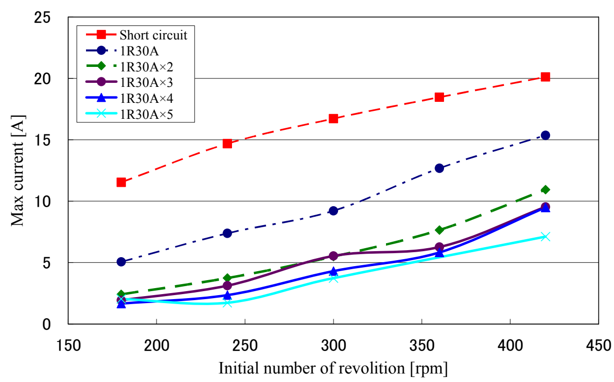

Fig.11. Maximum current.

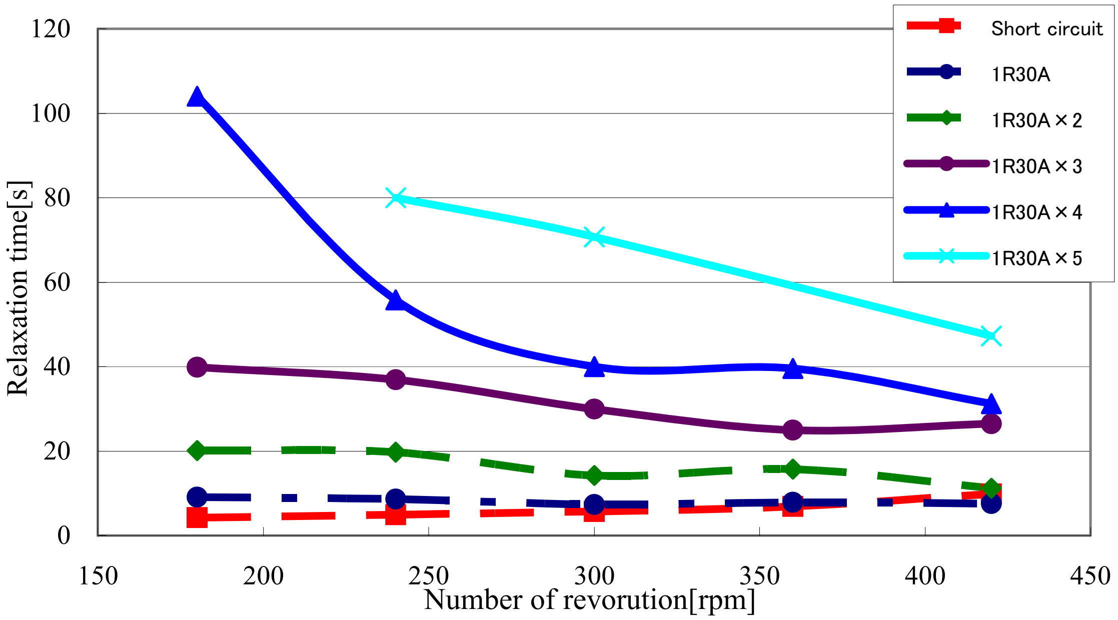

Fig12. Relaxation time.

V. CONCLUSIONS

Characteristics on the electric braking system for the 500W small wind turbine are measured by the field test. By inserting the braking circuit comprised by the Y-connection NTC thermistors into the generator output terminal, the gently braking of the rotor blades is possible. In addition, the braking circuit can reduce the current value flowing into the generator windings. Therefore, the braking circuit using NTCs can brake the rotor blades safely and is cheap compared with the conventional braking method of the small wind turbine.

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