# Dynamic Switching Method with Energy Storage Devices in Wind Power Generation


Yuto Iwasaki
*Dept. of Electrical and Electronic*
*Aichi Institute of Technology*
Aichi, Japan
v21705vv@aitech.ac.jp

Tadashi Hosoe
*Dept. of Electrical and Electronic*
*Aichi Institute of Technology*
Aichi, Japan
t-hosoe@aitech.ac.jp

Kazuki Ikeda
*Dept. of Electrical and Electronic*
*Aichi Institute of Technology*
Aichi, Japan
v21703vv@aitech.ac.jp

Tsuyoshi Nishitani
*Dept. of Electrical and Electronic*
*Aichi Institute of Technology*
Aichi, Japan
v22716vv@aitech.ac.jp

Aoi Tanaka
*Dept. of Electrical and Electronic*
*Aichi Institute of Technology*
Aichi, Japan
v22713vv@aitech.ac.jp

Akihiro Tsusaka
*Dept. of Electrical and Electronic*
*Aichi Institute of Technology*
Aichi, Japan
Tsusaka_A@aitech.ac.jp

Kazuto Yukita
*Dept. of Electrical and Electronic*
*Aichi Institute of Technology*
Aichi, Japan
yukita@aitech.ac.jp

Toshiya Nanahara
*Dept. of Electrical and Electronic*
*Aichi Institute of Technology*
Aichi, Japan
tnanahara@aitech.ac.jp

Yasuyuki Goto
*Dept. of Electrical and Electronic*
*Aichi Institute of Technology*
Aichi, Japan
ygoto@aitech.ac.jp


***Abstract*—Recently, the United Nations Sustainable Development Goals (SDGs) have attracted much attention globally. To help achieve SDG7, "AFFORDABLE AND CLEANENERGY" the authors are conducting research on renewable energy, particularly wind power, which is useful even in un-electrified areas. In this study, we conduct simulations and experiments of a "dynamic switching system of storage batteries" that is suitable for fluctuating wind turbine output conditions by changing the connection method of the storage batteries connected to the wind turbine. The experiment results confirmed that the storage batteries could be charged in accordance with the generator rotational speed by switching the batteries.**

***Keywords—Wind Power Generation, Storage Batteries, Renewable Energy***

## I. INTRODUCTION

The seventh goal of the United Nations Sustainable Development Goals (SDGs)[1], "AFFORDABLE AND CLEAN ENERGY" is closely linked to renewable energy, and the provision of clean energy to un-electrified areas is expected to bring us closer to achieving the SDGs. Around the world, research is being conducted on the local production and local consumption of energy using solar, wind, and other renewable energy sources[2]-[5].

To this end, the authors' laboratory is conducting research on wind power generation, particularly among renewable energies that are applicable even in un-electrified areas [6]. Because small wind turbines can rotate at a wide range of speeds, from low to high number of rotations per minute (rpm), a system with a wide power band is required. The power generation system used in this study uses a pole number conversion-type generator developed by the authors [7] to achieve a wide power band that ranges from low to high rpm. In addition, the ability to switch the connection method of the storage batteries enables efficient power generation according to the rpm situation. In this study, the "dynamic switching method" was used to switch the connection of storage batteries according to the power generation status, and the results of simulations and actual experiments using this method in a pole number conversion type generator are reported.

## II. OUTLINE OF THE PROPOSED METHOD

In this research, we develop a power generation system method that is smarter than conventional systems by switching the connection method of storage batteries (hereinafter referred to as "dynamic switching method") in addition to a pole number conversion-type generator.

Fig. 1 shows the proposed system. Fig. 2 shows the switching patterns of the storage batteries in the proposed system. In this study, four 12 V storage batteries were used, as presented in Table 1, and they could be switched between 4 parallel (12 V), 2 series 2 parallel (24 V), and 4 series (48 V) patterns.

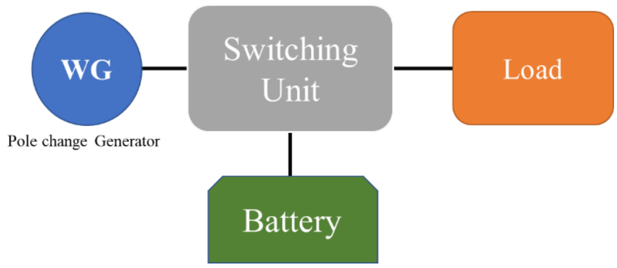



Fig. 1. Block diagram of proposed system.

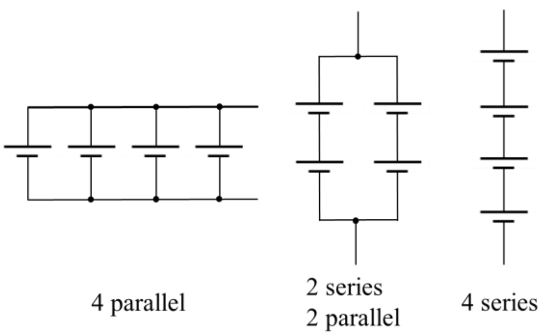



Fig. 2. Storage Battery Switching.

The characteristic equation of the generator used in this system is then shown below.

$$Vop = Vc \times N \tag{1}$$

$$I = ( Vop - Vbatt ) / R \tag{2}$$

$$P = Vbatt \times I \tag{3}$$

Vop: open-circuit voltage [V], Vc: electromotive force [V/rpm], Vbatt: storage battery voltage [V], N: speed [rpm], I: output current [A], R: coil winding resistance [Ω], and P: generator output [W].

The characteristics of the storage battery used in this study are shown in Table 1: standard voltage 12.0 V, current capacity 12.0 Ah, charge voltage range 10.5 V–14.9 V, and maximum charge current 4.8 A.

## III. Simulation

For the proposed method, we conducted a simulation to determine the number of revolutions at which charging could be performed based on the equation presented in Chapter 2. The purpose of this simulation was to obtain the open-circuit voltage [V], output current [A], and output power [W] calculated from the equation, plot a graph, and read the rpm range where charging can take place on the graph. In this system, because a dynamic switching method is used for the pole-number conversion-type generator, multiple combinations are generated for each pole number and storage battery voltage value. Specifically, the pole number conversion-type generator used in this study can be converted into four patterns (8-pole, 4-pole, 2-pole, and 1-pole), and the dynamic switching method can be switched into three patterns (12 V, 24 V, and 48 V), as shown in Chapter 2. This means that 12 combinations of patterns are possible for the two elements of the pole number conversion and dynamic switching methods (Fig. 3). Simulations were performed to confirm the power bands for each combination. The following simulations show the results obtained when the number of generator poles is fixed and the battery voltage is switched in each case.

TABLE I. Battery Characteristics

| | |
|---|---|
| Nominal voltage | 12.0 V |
| Rated capacity | 12.0 Ah (20hr) |
| Cut-off voltage | 10.5 V |
| Charging voltage | 14.9 V (Max) |
| Charging current | 4.8 A (Max) |

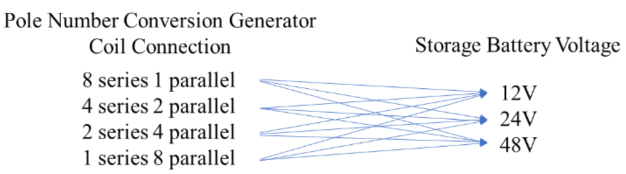
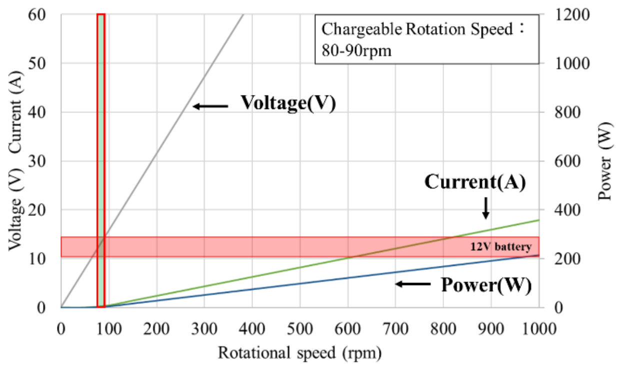



Fig. 3. Combination of number of generator poles and storage battery voltage.

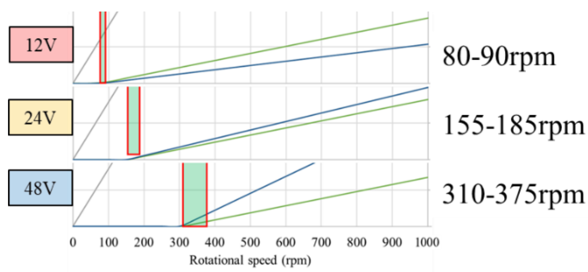
### A. *Simulation of a pole-converting generator fixed to 8-pole*

Fig. 4(a) shows the results obtained when the pole-converting generator is fixed to 8-pole and the voltage of the connected storage battery is 12 V. The graph in this study has the number of revolutions [rpm] on the horizontal axis, voltage and current on the first axis of the vertical axis, and power on the second axis. For a storage battery voltage of 12 V, it can be confirmed that the open-circuit voltage exceeds 12 V and the current begins to flow when the generator speed approaches 80 rpm. The red band indicates the possible values of the storage battery voltage, which in the case of 12 V ranges from 10.5 V to 14.8 V according to the storage battery characteristics in Table 1. For the case of 12 V, the maximum charge current was 19.2 A based on the storage battery characteristics. The points where both the voltage and current are within the specified range are indicated by red boxes. In other words, in the case of the 8-pole, 12 V combination, it was confirmed that the rechargeable rpm was 80–90 rpm. Similarly, simulations were conducted for the 8-pole case with storage battery voltages of 24 V and 48 V, and the results are shown in Fig. 4(b) together with the case with a storage battery voltage of 12 V. For a storage battery voltage of 24 V, charging was found to occur at rotational speeds of 155–185 rpm. For a storage battery voltage of 48 V, charging was found to occur at rotational speeds of 310–375 rpm.

In this way, it was confirmed that when the generator is set to 8-pole, the dynamic switching system can significantly change the range of rotational speeds at which power can be generated.




(a) Voltage, current, and power characteristics of 8-pole 12 V.




(b) Power generation characteristics at each battery voltage.

Fig. 4. Charging characteristics at 8-pole.

*B. Simulation of a pole-converting generator fixed to 4-pole*

Fig. 5 shows the results of the simulation of the charging characteristics of a 4-pole generator. 4-pole simulations were performed in the same way as the 8-pole simulations, but for three different battery voltages (12 V, 24 V, and 48 V). In this case, it was confirmed that the number of revolutions at which power can be generated varies greatly for each storage battery voltage, with charging occurring within the range– 155–185 rpm when the storage battery voltage is 12 V, 310–375 rpm when the storage battery voltage is 24 V, and 615–755 rpm when the storage battery voltage is 48 V.

Compared to the 8-pole fixed case, the 4-pole case has a higher rpm range than the 8-pole fixed case, and charging does not start until the rpm exceeds 600 rpm at a storage battery voltage of 48 V in the case of the 4-pole case.

*C. Chargeable RPMs fort each battery voltage when the number of poles is fixedv*

As Sections 3.1 and 3.2 show the rechargeable RPM at each battery voltage for the 8-pole and 4-pole fixed cases, the remaining 2-pole and 1-pole fixed cases were simulated, and all results are summarized in Fig. 6. In Fig. 6, the bottom row of the horizontal axis shows the four patterns of the number of poles in the pole-converting generator, and the top row shows the three voltage patterns of 12 V, 24 V, and 48 V handled by the dynamic switching system. The vertical axis represents the number of revolutions, and the number of chargeable revolutions for each combination is indicated by the orange rectangles. Note that the graphs do not show the rotation speed at which charging starts for the 2-pole 48 V case and the 1-pole 24 V and 48 V cases because the rotation speed exceeds 1,000 rpm. It can be seen that for each pole number of the pole-number conversion-type generator, the higher the storage battery voltage, the higher is the rechargeable rpm. In addition, depending on the combination, there are places at which the rechargeable rpm overlaps. For example, in the case of the 8-pole 24 V and 4-pole 12 V generators, the rechargeable speeds both range from 155–185 rpm. When the generator is at the above speeds, the torque of the wind turbine must be considered to determine the combination that will provide better charging. From the above simulations, we determined the rechargeable rotational speeds and issues at each battery voltage for a fixed number of poles.

## IV. Experiments Using Actual Equipment

For tests using actual equipment, a storage battery switching circuit was designed [8], and charging tests were conducted using a pole number conversion-type generator. This section describes the results in detail. The external appearance and the system of the experiment are shown in Fig. 7. The speed of the pole-changing generator was controlled by an inverter and electric motor. The switching unit consists of several relay circuits, as shown in Fig. 7, to allow manual pole number conversion and dynamic switching. In addition, this study considers only the charging of storage batteries and does not consider the load.

In this study, the rotational speed of the pole number conversion-type generator was limited to 400 rpm. In other words, the graph in Fig. 6 indicates that in this experiment, sufficient power can be generated for a combination of three patterns: 8-pole 12 V, 8-pole 24 V, and 4-pole 24 V.

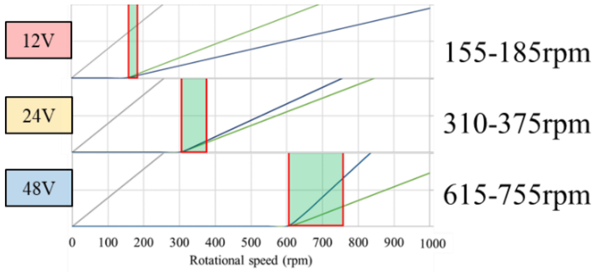



Fig. 5. Charging characteristics at 4-pole.

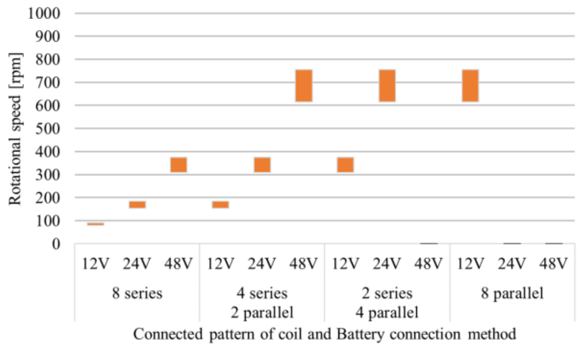



Fig. 6. Number of rechargeable revolutions for each combination.

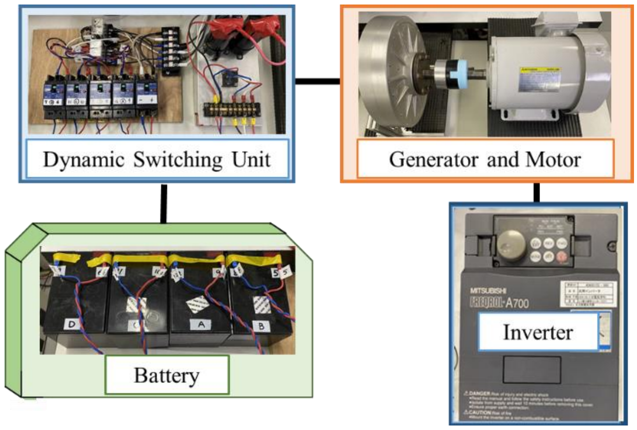



Fig. 7. Appearance and system.

In this experiment, when the pole number conversion generator is fixed at 8-pole, the storage battery was dynamic switching from 12 V to 24 V, when the pole number conversion generator is fixed at 4-pole, the storage battery voltage was dynamic switching from 12 V to 24 V, and finally, the dynamic switching and pole number conversion were combined, from 8-pole 12 V to 4-pole 12 V, and finally switched to 8-pole 24 V.

Fig. 8 shows the results of the experiment obtained using an actual machine. The horizontal axis is time [s], the first axis is power [W] and rotation speed [rpm], and the second axis is voltage [V] and current [A]. In this experiment, the rotational speed was increased at constant acceleration. Because the charging current is limited to 10 A in the prototype circuit of this study, dynamic switching and pole number conversion were performed when the charging current was 8 A. Fig. 8(a) shows the result of fixing the number of poles of the pole number conversion generator to 8-pole and switching the storage battery voltage from 12V to

24V. Initially, charging was performed at 8-pole 12V, and at the start of 64 s, the current exceeded 8 A, so dynamic switching was performed and the combination was changed to 8-pole 24 V. The graph shows that dynamic switching resulted in stable power generation as the rotational speed changed. Fig. 8(b) shows the result of fixing the number of poles in the pole number conversion generator to 4 poles and dynamically switching the storage battery voltage from 12 V to 24 V. Initially, charging was performed at 4-pole 12 V, and after 70 s, the charging current reached 8 A, and dynamic switching was performed at 4-pole 24 V. After the switchover, the battery did not reach a sufficient number of revolutions per minute to generate power at 4-pole 24 V, confirming that the battery could not be charged. Finally, Fig. 8(c) shows the results of dynamic switching and pole number conversion, changing from 8-pole 12 V to 4-pole 12 V, and then to 8-pole 24 V. The experiment started with 8-pole 12 V, and 28 s into the measurement, the rotation speed reached approximately 80 rpm, and charging of the storage battery began. Charging at 80 rpm confirmed that the system operated as simulated. At 66 s after the start of the measurement, the charging current exceeded 8 A. At this time, the number of poles was converted, and the generator poles were changed from 8-pole to 4-pole, resulting in a temporary decrease in current, which reduced the generator torque and caused the rotation speed to increase rapidly. At 72 s, the charging current exceeded 8 A. Therefore, the combination of four poles and 12 V was changed to 8-pole and 24 V. Here, because the storage battery was switched from 12 V to 24 V, a large increase in power was observed. Since the set rotation speed of 330 rpm was reached in the first 75 s of the measurement, the current, voltage, and power were all constant.

Thus, by combining the dynamic switching method for switching the storage battery connection and the pole number conversion method, it was confirmed that charging can be performed by changing to a state with charging characteristics suitable for fluctuating rotational speed.

## V. Conclusion

In this paper, a new control method for wind power generation systems is proposed. The characteristics of the dynamic switching method were confirmed using data calculated from theoretical equations, and dynamic switching and pole number conversion were performed on an actual wind-turbine. It was confirmed that the charging of the storage battery could be performed in accordance with the rotational speed of the generator.

In the future, we intend to automate the system and conduct experiments using an actual device under natural wind conditions.


## Acknowledgment

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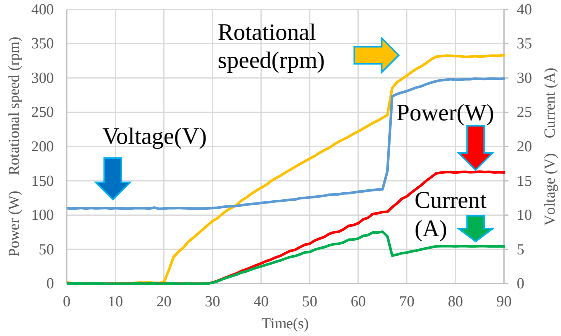
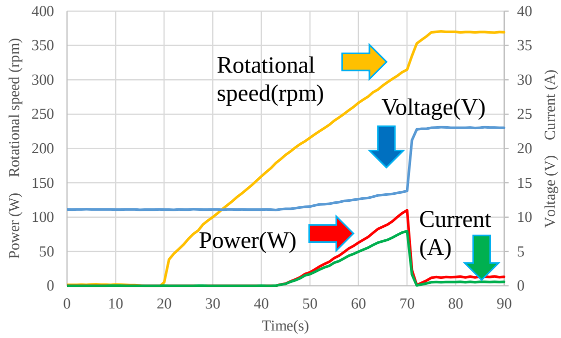
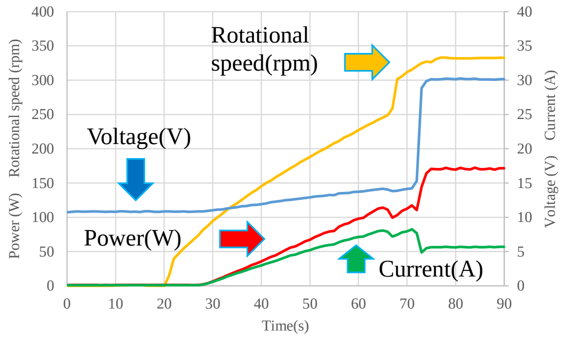



(a) 8-pole 12V to 8-pole 24V.




(b) 4-pole 12V to 4-pole 24V.




(c) 8-pole 12V, 4-pole 12V to 4-pole 24V.

Fig. 8. Experiments with actual equipment: Charging characteristics.

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