Tidal Power Generation with Counter-rotating Generator

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Abstract

This paper describes a tidal power generation system with counter-rotating generator. The method of charging is charging current control. The demonstration experiment was conducted by the method using counter-rotating generator and the usual method at Kanmon Straits. They showed both equivalent charging power. However the mechanical loss of the generator's stator had more than twice in this generator. Therefore the power generation capacity increases by selecting generator that the stator loss is smaller.

Keywords: Tidal Current, Counter-rotating generator.

1. Introduction

In modern society, fossil fuel electric power generation of the current main generation has limitations of fuel. Therefore, the development of new energy alternative to fossil fuel is hurried, and methods of power generation by natural energy have been proposed ⁽¹⁾. Although there are solar, wind and wave power generation. Methods of power generation utilizing tidal current have not been put to practical use due to the low energy density.

The tidal current is ocean stream by tidal phenomenon. Moreover, a tidal power generation system converts the energy of tidal flows into electricity with water turbine. Then, the energy is stable source, since tidal current is not affected by weather unlike wind power, and it is disposed to flow at a constant frequency ⁽²⁾. Furthermore, as a density of seawater is more than 800 times greater than that of air, the current velocity of 1 m/s corresponds to the wind speed of 9 m/s in air because the energy of a fluid is proportional to the density and the cube of the stream velocity. Thus, the tidal power generation is expected as a promising way of utilizing the natural energy ⁽³⁾.

Fig. 1. System of tidal power generation.

In this study, the system outline of tidal power generation is shown in Fig.1. The battery potential is 24 V. The water turbine is Darrieus type and the generator is three-phase counter-rotating one. The charging method used charging current control which is able to follow maximum efficiency of the water turbine ⁽⁴⁾.

2. Tidal Power Generation

2.1 Energy Theory

The fluid kinetic energy per unit time P is given by:

$$P = \frac{1}{2} \rho A V^3 \quad (1)$$

(ρ : fluid density, A : projected area, V : fluid velocity)
The Maximum shaft power of ideal water turbine P_{tmax} is described by:

$$P_{tmax} = \frac{8}{27} \rho A V^3 \quad (2)$$

From Eq. (1) and Eq. (2), the peak efficiency of the water turbine η_{tmax} is as follows:

$$\eta_{tmax} = \frac{P_{tmax}}{P} = 0.593 \quad (3)$$

Actually, η_{tmax} is described as power coefficient C_p . Therefore, the shaft power P_t is expressed in the following equation:

$$P_t = \frac{1}{2} \rho A V^3 C_p \quad (4)$$

2.2 Darrieus Water Turbine

In the present study, a Darrieus water turbine was selected in a vertical axis water turbine. It has the three straight blades in the rotor as shown in Fig. 2a. Regardless of tidal current direction, this turbine is unidirectional rotation. Demonstration unit size is shown in Fig. 2b. Each axis turns opposite direction and drives rotor and stator of the generator.

2.3 Counter-rotating Generator

Fig.3a shows usual generator configuration. In a counter-rotating generator, each turbine is connected to the rotor and the stator as shown in Fig. 3b. The stator of the generator normally fixed a base is driven counter direction behind rotor spin. It doubles the relative speed of stator and rotor. This feature has an advantage in slow rotation water turbine. The specifications of the generator are listed in Table 1 and the generator that was actually used is shown in Fig. 4. The following points are expected.

(a) Generating power will be available at low revolution since relative speed is doubled. Therefore, it leads to high efficiency of the generator.

(b) The number of generator is only one because one turbine rotates the rotor, and another rotates the stator. Thus, power generation systems will become compact.

In the demonstration equipment, the ratio of generator's rotating speed to water turbine's one is 1 to 2.

2.4 Charging Current Control

As a method of charging the battery to follow maximum efficiency of water turbine, we used charging current control. When a power coefficient of water turbine peaks the speed ratio is approximately 2. Also the speed ratio means the ratio of water turbine's rotation speed to water velocity. In general, they are needed in order to obtain the maximum electric power. This method is able to estimate maximum power and charge a battery without information of a water velocity. In this method the relationship between rotation speed and output power is approximated by a function. In fact, the function is used a cubic curve because output power is proportional to the cube of water velocity (or rotation speed) from Eq. (4). Moreover it decides the utilizable output power from rotation speed. This relationship between rotation speed and output power was obtained by floating charge⁽⁴⁾.

(a) Darrieus water turbine in Kanmon Straits

(b) Size of demonstration unit

Fig. 2. Water turbine.

(a) Usual generator

(b) Counter-rotating generator

Fig. 3. Type of generator.

Fig. 4. Actual generator.

Table 1. Specifications of the generator.

Rated voltage [V]	200
Rated current [A]	13.4
Rated speed [rpm]	150
Pairs of poles	16

(a) Experiment arrangement for measuring rotor loss

(b) Experiment arrangement for measuring stator loss

Fig. 5. Experiment arrangement.

Fig. 6. Output power vs. rotation speed.

2.5 Loss Characteristic

The rotation speed of stator is doubled than usual in the case of counter-rotating connection. Therefore the loss characteristic of the generator has a huge effect on power generation efficiency. The performance test was conducted

with torque testing machine. Fig. 5 shows the experimental arrangement. Fig. 5a measures the loss characteristic of the rotor part and Fig. 5b measures the stator's one. Also, each loss value P_{loss} is defined by the following formula:

$$P_{loss} = 2\pi nT \text{ [W]} \quad (5)$$

(n : rotation speed [rps], T : torque value [Nm])

3. Experiment

3.1 Charging Battery Test

Figure 6 is shown the experimentally-obtained relationship between rotation speed and output power P_{out} in counter-rotating⁽⁴⁾. Moreover the approximation formula is described by:

$$P_{out} = 0.0293\omega_m^3 - 34 \quad (6)$$

(ω_m : angular velocity of the water turbine [rad/s])

Similarly, the formula for usual method is as below:

Fig. 7. Estimated water velocity and ratio speed on counter-rotating.

Fig. 8. Estimated water velocity and ratio speed on usual.

Table 2. Charging power.

	Usual	Counter-rotating
Charging power [kWh]	0.217	0.204

method. Both of these method followed the maximum efficiency of water turbine because the speed ratio was located near 2 m/s. Table2 shows the charging power when both charged the battery the same amount of time. The charging power was comparable.

3.2 Loss Characteristic Test

The generator loss of stator and rotor were shown in Fig. 9. The mechanical loss of the stator is greater than the rotor's loss. Moreover the loss was about 2.5 times the usual in counter-rotating.

4. Conclusions

In this paper we described the tidal power generation with counter-rotating generator. Also, we compared method of rotating rotor (usual method) and rotating rotor and stator (counter-rotating). It is assumed that the reason the charging power in counter-rotating was equal to usual method is the stator's loss was too large. Therefor selecting a generator that a loss characteristic of stator is smaller is important.

Fig. 9. Loss characteristic.

$$P_{out} = 0.011\omega_m^3 - 2.74 \quad (7)$$

Fig. 7 and 8 showed the relationship estimated water velocity and speed ratio on counter-rotating and usual

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