Battery Charging System for Tidal Power Generation

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Abstract: This paper describes a charging system to follow maximum efficiency of the water turbine. It charges a battery with electric power by tidal power generation at Kanmon Straits. The generator is counter-rotating three-phase one and is driven by Darrieus turbine in parallel. The generator output is converted to direct current and the battery is charged. The methods of charging are floating charge and charging current control. We confirmed that floating charge of simple equipment charged 2.7[kWh] at a large tidal range period. The charging current control was able to follow the maximum efficiency under more than 0.8[m/s] current speed.

Keywords: Tidal Current, Darrieus, Battery Charging System, Counter-rotating

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 sea-water 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].

Darrieus type was selected in the water turbine. In addition, the twin-turbine configuration was preferred in the tidal current power generation than the single turbine [3]. In this study, counter-rotating generator was used. Each turbine is connected to the rotor and the stator as shown in Fig. 1, and these rotate in the opposite direction. Therefore this system is possible to charge the battery more under low rotation speed unlike previous tidal power generation system.

This paper describes a charging system to convert tidal power into electric energy.

2. Tidal Power Generation

2.1 Energy Theory

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

$$P = \frac{1}{2} \rho AV^3$$  (1)

($\rho$: fluid density, $A$: projected area, $V$: fluid velocity). The Maximum shaft power of ideal water turbine $P_t$ is described by:

$$P_{t max} = \frac{8}{27} \rho AV^3$$  (2)

From Eq. (1) and Eq. (2), the peak efficiency of the water turbine $\eta_{max}$ is as follows:

$$\eta_{max} = \frac{P_{t max}}{P} = 0.593$$  (3)

Actually, $\eta_{max}$ is described as power coefficient $C_p$. Therefore, the shaft power $P_t$ is expressed in the following equation:

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

Figure 1: Principle of Counter-Rotating generator.
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. 2(a). Regardless of tidal current direction, this turbine is unidirectional rotation. Demonstration unit size is shown in Fig. 2(b). Each axis turns opposite direction and drives rotor and stator of the generator.

2.3 Counter-Rotating Generator The counter-rotating generator is shown in Fig. 3. 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. The following points are expected.

2.4 System of Tidal Power Generation The system outline of tidal power generation is shown in Fig. 4. The battery potential is 24[V]. Methods of charging are floating charge and charging current control in the charging system.

2.5 Outline of Floating Charge Figure 5 shows the circuit configuration of floating charge. First, outputs of generator are transformed to fix appropriate voltage. Second, the rectifier converts alternate current into direct cur-
rent. It has some advantages. In the first place, this system is simple. Next, when the turbine rotates low speed, the output voltage is lower than battery voltage. The rectifiers are off all. Therefore, the charging current is zero. As tidal current speed increases enough to be charged the battery, the voltage exceeds 24[V] and rectifiers are on. The charging current is decided by impedance of generator and rectifier. Since the impedance is generally small, the current increases rapidly to change of voltage.

2.6 Outline of Charging Current Control

Circuit configuration of charging current control is shown in Fig. 6. The direct current power is used for charging by the step-down chopper circuit. The chopper circuit is driven by SuperHitachi 7125 (SH7125) microcomputer as shown in Fig. 7. SH7125 received frequency of the generator \(f_g\) from the frequency/voltage converter (F/V converter). Moreover, the charging current is controlled from \(f_g\). Also, charging current is measured by current sensor.

The charging flow is as below:

(a) Obtain angular velocity of the generator \(\omega_m\):

\[
\omega_m = 2\pi f_g/p = 2\pi n_0 \tag{5}
\]

\((p: \text{pairs of poles}, n_0: \text{rotation speed [rps]})\)

(b) Calculate output power \(P_{out}\)

Fig. 8. is shown the relationship between rotation speed and \(P_{out}\). \(P_{out}\) is proportional to the cube of fluid velocity from Eq. (4), and rotation speed is proportional to fluid velocity. Thus, \(P_{out}\) is also proportional to the cube of \(\omega_m\). This graph was approximated by cubic curve. The obtained equations are described by:

\[
P_{out} = 0.0212\omega_m^3 - W_f \tag{6}
\]

\[
W_f = 42 \tag{7}
\]

\((W_f: \text{mechanical and electric loss [W]})\)

3. Experiment

3.1 Floating Charge

The transformer ratio was set so that the water turbine does not stall. Moreover, the transformer ratio was 100 to 30. Therefore, we tried charging tests in the ratio. This experiment was performed to verify the performance of demonstration unit.

The results of floating charge were shown in Fig. 9. The battery voltage was increased in Fig. 9(a). As shown in Fig. 9(b), the charging power was 2.7[kWh] at a large tidal range period.
3.2 Charging Current Control First, we confirmed that the current is controlled constant value as shown in Fig. 10. The single-phase transformer was used instead of the generator. The transformer voltage was varied against arbitrary charging current.

Second, the charging system was built as shown in Fig. 11. Moreover, it was tested to confirm the charging operation. Also, we used two types of equations of $P_{\text{out}}$. Type1 is Eq. (6) and Type2 is following equation. In Type2, the generator load is heavier than Type1.

$$P_{\text{out}} = 0.0293\omega_m^3 - 34 \tag{9}$$

The test results were shown in Fig. 12. The battery was charged because the voltage increased in Fig. 12. Figure 13 and Fig. 14 showed the relationship estimated water velocity and speed ratio on type1 and type2. The water turbines are maximum efficiency in speed ratio 2[m/s]. More than 0.8[m/s] water velocity, the speed ratio was located near 2[m/s]. Therefore, the turbines were peak efficiency.

However, following the efficiency was inadequacy below 0.8[m/s] water velocity.

4. Conclusion

In this paper, we described the charging system for tidal power. It was shown that the floating charge system can charge in simple configuration. Moreover, in demonstration
experiment, the battery was charged 2.7[kWh] at a large tidal range period. In charging current control, following maximum efficiency was realized under more than 0.8[m/s] water velocity.

References


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