Conversion characteristics of permanent magnet synchronous generator on wave energy converter

Yasutaka Imai, Shuichi Nagata, and Tengen Murakami

Institute of ocean energy, Saga University
Honjo 1, Saga, 8408502, Japan

imaiy@cc.saga-u.ac.jp
nagata@ioes.saga-u.ac.jp
murakami@ioes.saga-u.ac.jp

I. KEYWORDS

Wave energy converter, Electric conversion, Permanent magnet synchronous generator

II. ABSTRACT

Wave energy converters transform ocean energy which varies irregularly into electricity with a constant voltage and constant frequency. The converted electricity must satisfy the grid-connection requirements [1] in the frequency fluctuations and voltage fluctuations, and must be maximized as much as possible.

To maximize the power that satisfies the requirements, it is necessary to optimize the rating of the electrical components, which include generators, inverters and converters. However, a method of selecting electric parts have not been established. This is because the input energy is irregular and it covers several disciplines such as machinery, electricity, hydrodynamics and control. Therefore, it is necessary to fabricate a power conversion system in the laboratory and select elements and control that maximize power conversion under input conditions simulating ocean waves.

III. TEST BENCH

A concept of the oscillating-water-column type wave energy converter was shown in Fig.1. Wave energy entering and leaving the air chamber creates a two-way flow of air. Wells turbine and impulse turbine make unidirectional rotational motion from the flow. Then, the generator was driven by the turbine.

Since the energy of the wave is irregular, the rotational speed of the generator is not constant, so the generated should be rectified to connect a grid. The irregular power is rectified by a power conversion device which include inverters and converters. A test bench simulating the conversion was shown in Fig.2, and its concept was shown in Fig.3. Specifications of the major elements were shown in Table 1.

The rated output of the servomotor was 5 kW. The motor reproduces the fluctuation of rotation of the turbine shaft based on numerical simulation and actual sea area experiment. A flywheel that simulates the inertia of the turbine was set between the servo motor and the generator. The generator was a permanent magnet synchronous type and had a rated output of 5.5 kW. A converter and an inverter were connected for rectification. Torque and angular speed motor gives the experiment was measured power in W1, W3, W4 shown in Fig.1.

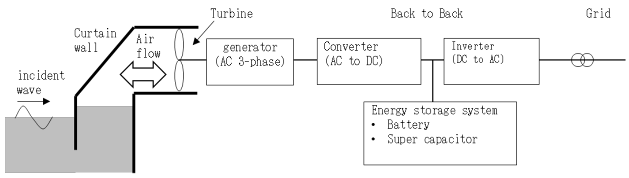

Fig.1 Concept of an oscillating water column (OWC) type wave energy converter

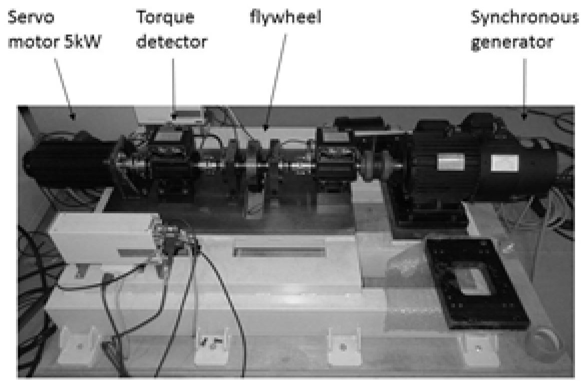

Fig.2 Test bench arrangement

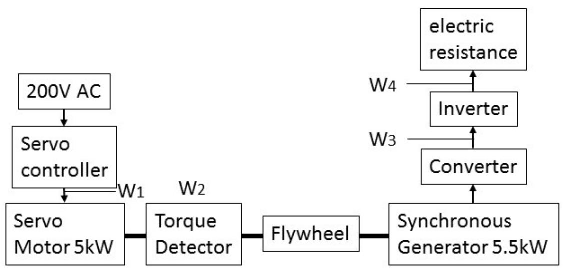

Fig.3 Concept of a test bench

Table 1 Specification of electric parts

Parts	Type	Note
Servo motor	GYS50205, Fuji electric	rated power 5kW at 3000min-1
Torque Detector	SS-200, Ono sokki	20Nm max
Synchronous generator	GNF2114A, Fuji electric	Permanent magnet synchronous generator, 6 poles, rated power 5.5kW at 1500min-1
Converter	FRN1.5VG1S-2J, Fuji electric	
Inverter	CIMR-DA2A 0005BAA Yasukawa electric	

IV. MODEL STUDY

Fig.4 shows the equivalent circuit of a synchronous generator [2]. To simplify the generator model, the armature resistance was neglected and the impedance was treated as the synchronous reactance Xs. Fig.5 shows a vector diagram of this circuit. The terminal voltage of the generator (V_G) was reference of the phase.

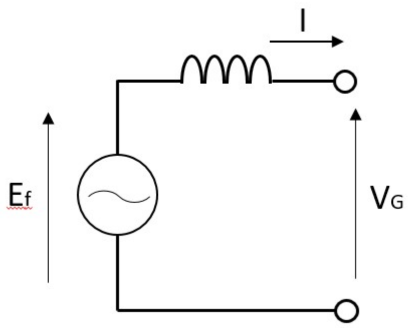

Fig.4 Equivalent circuit of a synchronous generator

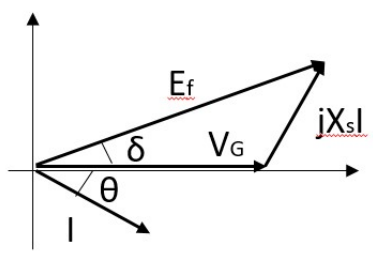

Fig.5 Phaser diagram of the equivalent circuit

δ was a phase between induced voltage E_f and V_G (internal phase angle). θ was the power factor angle, and the power factor is represented by cos θ. Active power P and reactive power Q were given by the following equations,

$$P + jQ = \dot{V}_G + \overline{\dot{I}} \tag{1}$$

The dot on the symbol represents a complex number, and the bar on the symbol represents a conjugate complex. The internal induced voltage is expressed by the following equation.

$$\dot{E}_f = V_G + jX_s \dot{I} \tag{2}$$

From this equation, (1) is expressed by the following equation.

$$P + jQ = \frac{j\overline{\dot{E}}_f V_G - j\left|\dot{V}_G\right|^2}{X_s} \tag{3}$$

The internal induced voltage E_f is expressed by the following equation.

$$E_f = \left|\dot{E}_f\right| \cos\delta + j\left|\dot{E}_f\right| \sin\delta \tag{4}$$

From this equation, (3) is expressed by the following equation.

$$P + jQ = \frac{\left|\dot{E}_s\right|\left|\dot{V}_G\right| \sin\delta}{X_s} + j\frac{\left|\dot{E}_s\right|\left|\dot{V}_G\right| \cos\delta - \left|\dot{V}_G\right|^2}{X_s} \tag{5}$$

Table 2 shows the experimental results at constant speed. The rotation speed of the generator was changed from 400 rpm to 1200 rpm. Cos(δ+θ) is the power factor. In the case of a synchronous generator, when the power factor is close to 1, it approaches the rated output. This generator does not generate electricity at 400 rpm. At 600 rpm, the active power is small. Power factor approaches 1 above 800 rpm and the active power increases. In this system, it is necessary to design not to use the rotation speed below 800 rpm.

Table 2 Experimental results

rpm	δ [deg]	θ [deg]	cos(δ+θ)	P [kW]
400	-181.45	0.14	-1.00	-0.11
600	0.76	78.18	0.19	0.02
800	1.03	-0.39	1.00	0.25
1000	1.85	-1.12	1.00	0.65
1200	2.97	-2.46	1.00	1.27

V. CONCLUSION

A test bench simulating the power conversion of the wave power generator was manufactured and the power conversion characteristics were investigated.

REFERENCES

[1] Japanese agency for natural resources and energy, *Guideline for grid-connection related to electric power quality* (in Japanese), 2017 http://www.enecho.meti.go.jp/category/electricity_and_gas/electric/summary/regulations/pdf/keito_guideline.pdf

[2] The institute of electric engineers of japan, *A technology of constant determination and performance calculation for permanent magnet synchronous machines* (in Japanese), 2010.