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THE PERFORMANCE OF A LOW-SPEED DIRECT-DRIVE GENERATOR FOR CURRENT ENERGY

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ABSTRACT

The simulation and experiment of two 400 W low-speed direct-drive permanent magnet synchronous generators (PMSGs) installed in a Floating Kuroshio Turbine (FKT) was implemented. We used ANSYS Maxwell design tool to design the 400 W low-speed direct-drive PMSG and simulate the interior magnetic field at different conditions. The test of FKT was carried out in the towing tank in National Taiwan University. The result shows generated power is more than 800 W in direct current (DC) at 1.5 m/s flow rate. The energy conversion efficiency of the PMSG measured from the testing platform is about 0.85. The power coefficient of FKT is about 0.4. It means FKT has high efficiency and stable power output.

Keywords: direct-drive, Kuroshio current, permanent magnet synchronous generator, floating Kuroshio turbine

1. INTRODUCTION

Because ocean has enormous potential for energy [1], many researchers have paid close attention to the marine energy source. Therefore, many background analysis and assessments for ocean current power generation are developed in order to obtain electricity from ocean currents. However, many studies are currently in the research stage and there are few actual power output data generated by the PMSG which was tested under water, making this research at this moment even more precious. This paper is particularly relevant to not only the numerical simulation, but also the successful power generation of the actual current turbine tested under water.

On the other hand, mainly ocean-current areas such as Taiwan [2], Japan [3, 4], and Florida (USA) [5, 6] which face the Kuroshio current or Gulf stream, have been investigated for developing a proper environment with a view to extracting energy from a current flow.

Many Japanese research teams have made many studies on harvesting energy from Kuroshio current. One group proposed a new ocean-current turbine with unconventional shape in order to operate the turbines in the middle layer of a marine current [7]. In addition, NEDO also dedicates in developing Kuroshio turbines. They have completed a 100 kW floating type ocean current power generation system "Kairyu, " which was tested in actual Kuroshio current in the coast of Kuchinoshima, Toshima, Kagoshima Prefecture [8, 9]. Furthermore, the research team from the University of Tokyo and some companies in Japan developed a floating-type system with the twin-turbine. The system has a weathervane function and the depth is controlled by adjusting the buoyancy and the blade pitch [10, 11]. Moreover, they analyzed the motion of the twin-type ocean current turbine with respect to the startup situation [12]. Simulation was also purposed for the situation with real sea to analyze adjusting a blade pitch angle to a proper motion [13].

The goal of this work is to design an 800 W floating Kuroshio turbine (FKT) which is composed of two 400 W permanent magnet synchronous generators (PMSGs). The 400 W low-speed direct-drive generator was designed by finite element software. The parameters, such as materials, winding types, dimensions of the stator and rotor and mesh density, etc. were simulated [14, 15]. After the fabricating of the generator, the 400 W low-speed direct-drive PMSG was tested by the testing platform which is composed of a generator, an encoder, a torque meter, a reducer, and an AC motor. Finally, we also conducted the towing experiment for FKT under water in Department of Engineering Science and Ocean Engineering, National Taiwan University. The generation efficiency of the FKT at various flow rates was measured and analyzed.

2. FINITE ELEMENT SIMULATION

2.1 Simulation results

ANSYS Maxwell design tool was used to design the 400 W low-speed direct-drive PMSG and simulate its performance. The alterative current (AC) power output from the PMSG was rectified by the full wave bridge rectifier circuit so that the simulated output voltage and current were 270 V and 1.48 A, respectively. The simulated power output is the product of DC voltage and DC current so that the power output curve is shown in Fig 1. The simulated power is about 398 W at 150 rpm with a load of 182 Ohm, which is pretty close to the target of 400 W. The average torque is 27.66 N-m at steady state shown in Fig 2.

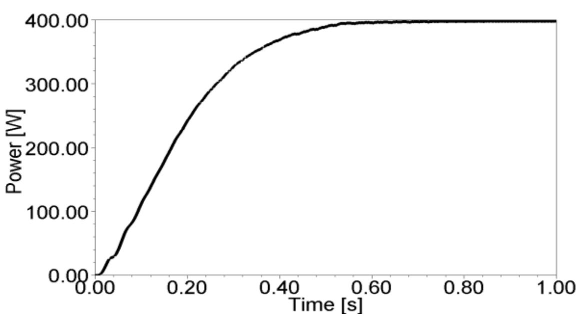

Fig 1 Simulated DC power after rectifier

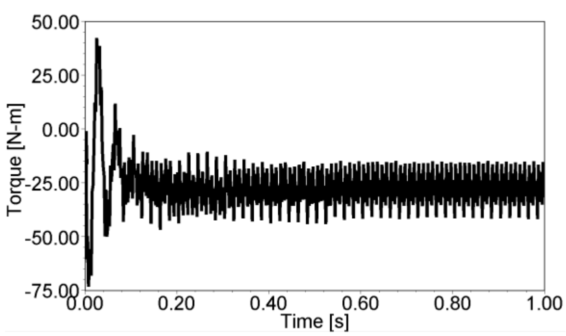

Fig 2 Simulated torque of the PMSG at 150 rpm with a load of 182 Ohm

Fig 3 shows the simulated and actually tested DC power output of the PMSG from 30 to 150 rpm. Also, the load of the full wave bridge rectifier circuit connected to AC power output in simulation and testing platform is 182 Ohm. It is obvious that the simulation results are very close to the measured results at different rotation speeds particularly at the rated rotation speed of 150 rpm. The errors between the simulated power output and tested power output are about 24.4 % to 0.5 %. The biggest error is 24.4 % at 60 rpm and decreases to 13.3 % at 90 rpm, 6.8 % at 120 rpm and 0.5 % at 150 rpm.

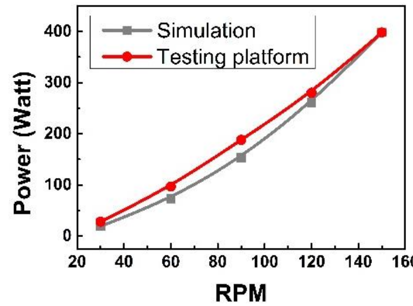

Fig 3 Simulated and tested DC power output of the PMSG at different rpm

3. TESTING OF TWO GENERATORS

3.1 Testing platform

The generator was tested on the testing platform which is composed by a motor, a reducer, a torque meter and an encoder shown in Fig 4.

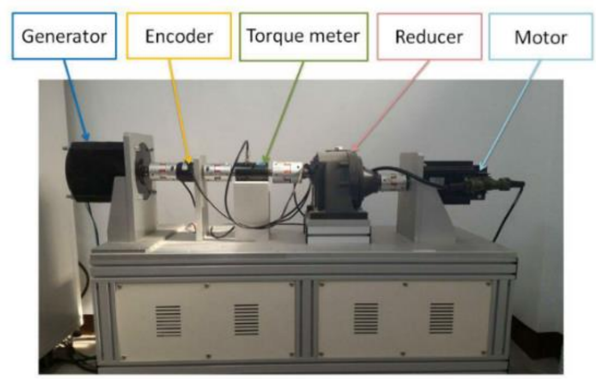

Fig 4 Illustration of the testing platform [16]

The motor is controlled by the computer to rotate at the certain speed. The reducer then reduces the rotation speed and increases the torque which can make the tested PMSG rotate and then produce AC power output. The AC power output is transferred to DC power output. The values of torque and rotation speed of the PMSG are measured by the torque meter and encoder. The power loss in AC-DC is about 5 W to 25 W as the increasing rotation speed from 30 rpm to 150 rpm.

3.2 Testing results

Fig 5 shows the DC power output is a function of the rotation speed. The experiments were started at 30 rpm and increased 10 rpm for each step. The experiments were stopped once the power output reached 450 W in order to avoid overheating and other damage. From Fig 5, the power is about 400 W at 150 rpm with the load of 182 Ohm. The generator even can reach 445 W at 160 rpm and the other generator is about 436 W.

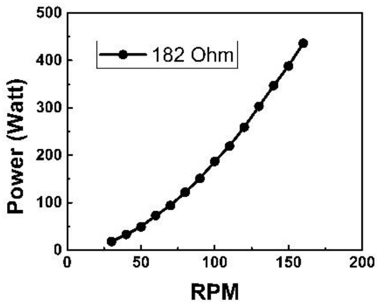

Fig 5 Generator power tested by platform

Fig 6 shows the energy conversion efficiency of the tested PMSG in the testing platform calculated by the ratio of mechanical energy from the motor to power output from the PMSG. The difference at the low rotation speed was caused by the unstable power output. This situation was improved when the generator was operated at a higher rotation speed, especially around the rated speed of 150 rpm. The highest energy conversion efficiency is about 0.85 at the rated rotation speed of 150 rpm with the load of 182 Ohm.

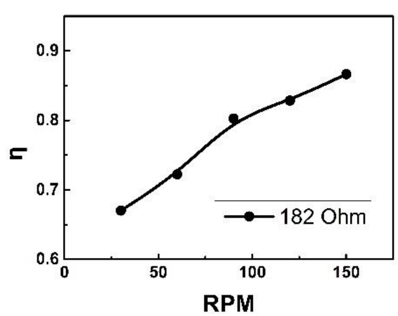

Fig 6 Energy conversion efficiency of the tested PMSG in the testing platform

4. FLOATING KUROSHIO TURBINE

4.1 Introduction of Floating Kuroshio Turbine

The 800 W FKT was constructed with 5 main components, a foil float, vertical supports, a cross beam, rotor blades and a nacelle. The foil float uses wing-shaped design to create the lift when the current flows through FKT; the vertical supports are used to connect the foil float and the nacelle; the rotor blades are the fluid power elements for driving the generators; the nacelle is used to accommodate the direct-drive PMSGs, an encoder and other components. The goal of the FKT is to generate 800 W power output from two PMSGs at the flow rate of 1.5 m/s [17].

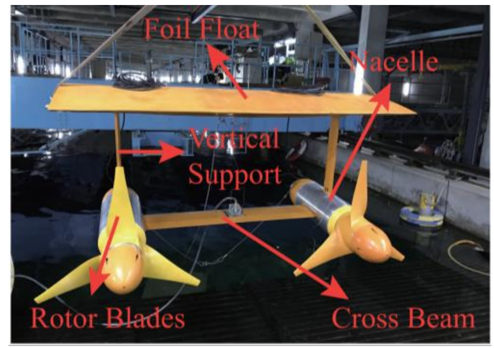

Fig 7 800 W Floating Kuroshio Turbine (FKT)

4.2 Experiment result

Fig 8 shows the generated power from a PMSG in the towing tank experiment at different rotation speeds with the load of 182 Ohm. The different rotation speeds are corresponding to the carriage speed between 0.7 m/s and 1.5 m/s which are the flow rates of Kuroshio current on the east side of Taiwan. The DC power output of the PMSG is more than 400 W at the rated rotation speed of 150 rpm. The highest power output measured in the experiment in the towing tank is 466 W.

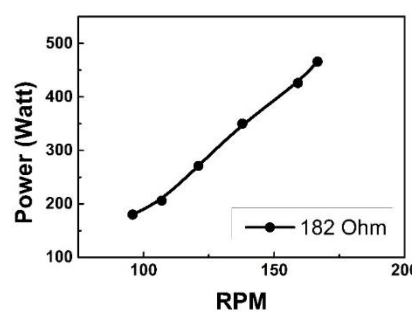

Fig 8 The power output of a PMSG installed in the FKT in the towing tank

Fig 9 shows the power coefficient (Cp) of the generator installed in FKT from the towing tank experiments, calculated from input energy and output energy. Input energy means the current energy flows through the FKT which is very similar to a wing turbine and output energy means electrical power output generated from the generator. The experiments were performed at different rotation speeds corresponding to the carriage speeds with the load of 182 Ohm. The power coefficient is about 0.4 between 90 rpm and 170 rpm. It means that the efficiency of FKT is high and stable, very suitable for the marine energy.

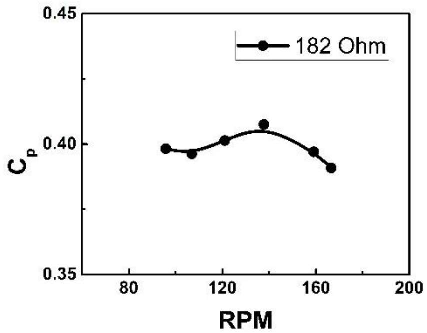

Fig 9 The power coefficient (Cp) of FKT system from towing tank

5. CONCLUSION

In this paper, a new type of marine-current turbine FKT is designed to harvest the kinetic energy of currents. In order to develop a Floating Kuroshio Turbine, ANSYS Maxwell software is used to design and simulate the 400 W low-speed direct-drive PMSG. The simulated PMSG generates 398 W with 27.66 N-m which is close to the real generator data tested from the testing platform. In addition, the real experiments and tests of the 400 W low-speed direct-drive PMSG are carried out by the testing platform. Consequently, the generated power of a generator can reach 400 W and the energy conversion efficiency is about 0.85. Finally, the Floating Kuroshio Turbine were conducted in the towing tank with the speeds from 0.7 m/s to 1.5 m/s flow rates in accordance with the flow rates of Kuroshio current. The measured power output of a generator is more than 400 W at the speed of 1.5 m/s. The power coefficient of FKT is about 0.4.

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