STUDY ON THE PERFORMANCE OF MICRO HYDRO TURBINE GENERATOR CONVERTED FROM ELECTRIC POWERED PUMP

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Abstract
Hydropower is a renewable source of energy. It has little fluctuation which is different from solar and wind power. The cost of large scale hydroelectricity is generally very low. Adding to large scale, development of small and micro scale hydropower is very efficient in developing countries. However currently small and micro hydro turbine are not mass-produced and are generally expensive. For the purpose of realizing the low cost micro hydropower, the authors modified a low cost electric powered pumping with 750W of rated electric power and converted it to a micro hydro turbine generator. In order to convert the pump to the hydro turbine, the inlet and outlet of water were reversed. In order to convert the induction motor to grid independent type induction generator, capacitors with appropriate capacitance for the excitation were connected to the electric circuit. In this study, the authors carried out the performance tests of the hydro turbine by using pressure gauges, a flow meter, a torque meter and a revolution sensor as measuring devices. Also, we measured the output of the hydro turbine generator by using a power analyzer. As a result, 733.9 W of maximum output power could be obtained by the hydro turbine by 1138.2 W of input water power. (i.e., 16.6 m of head and 7.0 liter/s of flow rate) At this time, 540.8 W of maximum electric power could be obtained by the hydro turbine generator. The authors think the application of this type of micro hydro turbine generator would be very useful in developing countries, like Kenya.

Key words*:* hydro turbine generators, induction generator, reverse running pump turbine

1.0 Introduction

Hydropower is a renewable source of energy. It has little fluctuation which is different from solar and wind power. The cost of large scale hydroelectricity is generally very low. Adding to large scale, development of small and micro scale hydropower is very efficient in developing countries. However currently small and micro hydro turbine are not mass-produced and are generally expensive.
For the purpose of realizing the low cost micro hydropower, the authors modified a low cost electric powered pump with 750W of rated electric power and converted it to a micro turbine generator. In order to convert the pump to the hydro turbine, the inlet and outlet of water were reversed. In order to convert the induction motor to grid independent type induction generator, capacitors with appropriate capacitance for the excitation were connected to the electric circuit.

In this study, the authors carried out the performance tests of the hydro turbine by using pressure gauges, a flow meter, a torque meter and a revolution sensor as measuring devices. Also, we measured the output of the hydro turbine generator by using a power analyzer.

2.0 Theory

2.1 Reverse Running Pump Turbine

The centrifugal pump is one of the most common types of water lifting and transporting device. Mechanical shaft power is converted to water power by the rotating impeller. By reversing the inlet and outlet of water, it is possible to use pump as hydro turbines if the decrease of the efficiency is allowable.
Water power P_W from the pump or to the turbine can be calculated from flow rate Q and water pressure Δp as follows;

$$P_W = \rho g Q \Delta H = Q \Delta p$$

Here, ρ , g , ΔH are water density, gravitational acceleration, and the head, respectively.

Mechanical power P_M to the pump or from the turbine can be calculated from rotational speed $n([s^{-1}]$ = $N[rpm])$ and shaft torque T as follows;

$$P_M = nT = \frac{2\pi N}{60} T$$

The pump efficiency η_P is calculated from input mechanical power P_M and output water power P_F as follows;

$$\eta_P = \frac{P_W}{P_M}$$

On the other hand, the turbine efficiency η_T is calculated from input water power P_W and output mechanical power P_M as follows;

$$\eta_T = \frac{P_M}{P_W}$$

2.2. Grid Independent Type Induction Generator

Induction motors are widely used for industries and home appliances. They are mass produced and their cost is generally cheap. However, in order to work an induction motor, power supply from the electrical grid for providing rotating magnetic field is necessary in general.

The authors converted an induction motor to a grid independent type induction generator, by connecting capacitors with appropriate capacitance for the excitation to the electric circuit. The capacitance needed for the excitation was calculated by the following manner;

No load apparent power of AC generator $S_{line,\,no\,load}$ is

$$S_{line,\,no\,load} = \sqrt{3} V_{line} I_{line}$$

Here, V_{line} and I_{line} are the line voltage and current, respectively.

As the reactive power to be provided by the excitation capacitors Q_{line} equals the no load apparent power, so

$$Q_{line} = S_{line,\,no\,load} = \sqrt{3} V_{line} I_{line}$$

Hence, the reactive power per phase Q_{phase} of 3 phase generator is

$$Q_{phase} = \frac{Q_{line}}{3} = \frac{V_{line} I_{line}}{\sqrt{3}}$$

For delta connected capacitors, the voltage per phase V_{phase} is

$$V_{phase} = V_{line}$$

Current per phase I_{phase} is

$$I_{phase} = \frac{Q_{phaee}}{V_{phase}} = \frac{l_{line}}{\sqrt{3}}$$

Here, capacitive reactance X_C can be written as follows;

$$X_C = \frac{V_{phaee}}{I_{phase}} = \frac{1}{2\pi f C}$$

Here, f and C is the frequency and capacitance of the circuit, respectively.

Accordingly, the capacitance needed for the excitation was calculated by

$$C = \frac{I_{phase}}{2\pi f V_{phaee}}$$

The motor efficiency η_M is calculated from input electric power P_E and output mechanical power P_M as follows;

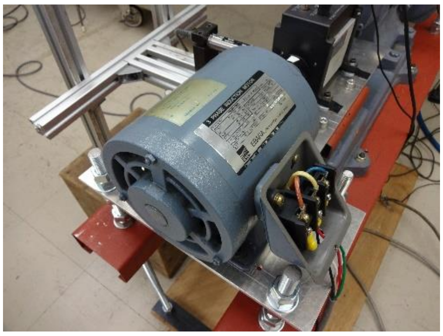
$$\eta_M = \frac{P_M}{P_E}$$

On the other hand, the generator efficiency η_G is calculated from input mechanical power P_M and output electrical power P_E as follows;

$$\eta_G = \frac{P_E}{P_M}$$

3.0 Tested Hydro Turbine Generator

The authors converted a motor pump Ebara SFM50 to a hydro turbine generator. Fig. 1 (a) and (b) show the pump and the motor parts, respectively. Table 1 shows the specification. The rated power and the rotational speed of the motor is 750W.and 1410rpm at frequency of 50Hz. This class of the motor pump can be procured for less than 600$ in Japan.
As the capacitor for excitation, the film capacitor CMKS-J (for AC250V) was used. The cost of this type of a 10 mF capacitor is less than 10$. The authors connected one or more capacitors to each phase and tested.



(a) Pump part *(b) Motor part*
Fig. 1 Based motor pump

Table 1: Specification of the based motor pump

Model	Ebara 50SFM		
Flow rate [m^3/min]	0.16		0.32
Head [m]	10.5		7.2
Rated power [W]		750	
Pole		4	
Phase		3	
Voltage [V]	200	200	220
Frequency [Hz]	50	60	60
Current [A]	3.8	3.4	3.4
Rotational speed [rpm]	1410	1700	1720

4.0 Experimental Apparatus and Method

4.1 Performance Tests of the Hydro Turbine

First, the authors looked over the characteristics of the tested hydro turbine. The experimental apparatus for hydro turbine tests is shown in Fig.2. The rotating shaft of the tested hydro turbine was connected to a generator. A torque meter (Kyowa TPS-A-50NM) was put between the tested hydro turbine and the generator. Flow rate Q and pressure p of water were measured by a vortex flow meter (Universal Flow Monitors UV2M1) and two pressure meters (Keyence AP-30), respectively. The flow rate from the motor pump was changed by an inverter. Also, the electric load connected to the generator was changed by another inverter. Then the rotating speed N and torque T were measured by a revolution meter (Ono Sokki LG-916) and the torque meter at each flow rate, respectively.

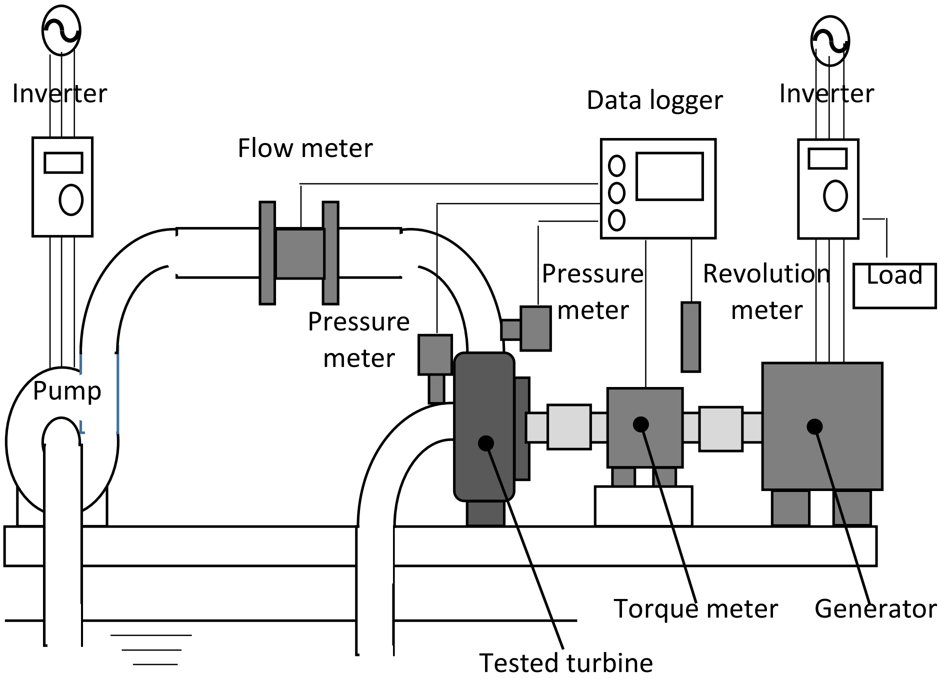


Fig. 2 Experimental apparatus for hydro turbine tests

4.2 Performance Tests of the Generator

Next, the authors looked over the characteristics of the tested generator. The experimental apparatus and the electric circuit for generator performance tests is shown in Fig.3. The rotating shaft of a motor was connected to the tested generator. A torque meter (Kyowa TPS-A-50NM) was put between the motor and the tested generator. In order to measure the electric output power P_G, voltage V, current I and frequency f of each phase, a power analyzer (HIOKI 3390) was used. Also, the rotating speed N and torque T were measured by a revolution meter (Ono Sokki LG-916) and the torque meter at each flow rate, respectively.

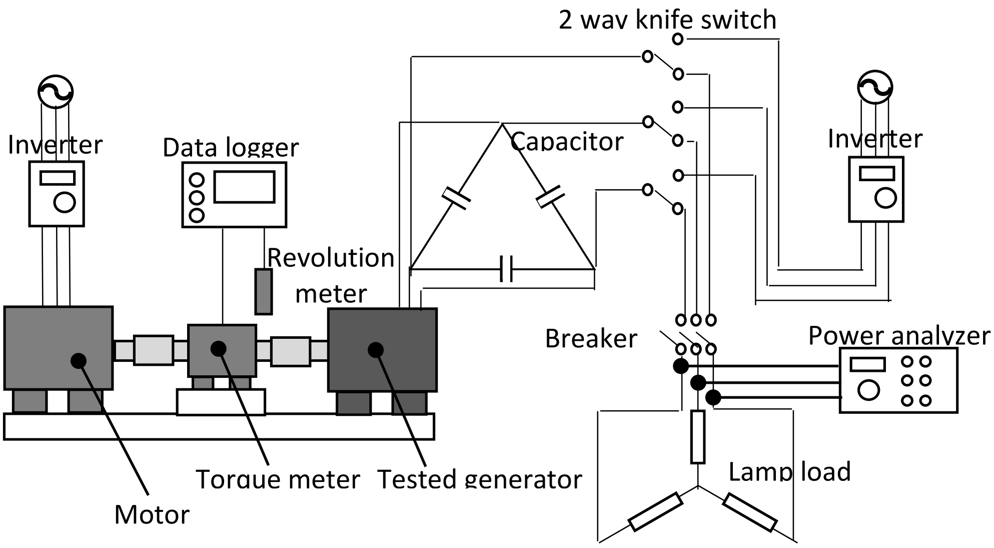


Fig. 3 Experimental apparatus for generator tests

In the experiment, first, the capacitors were charged by connecting to the electricity grid. After charging, the motor was rotated by the power supply from the electricity grid, and controlled by the inverter. Then the breaker was switched on and the tested generator was connected to the lamp load. The authors also changed the capacitance of the capacitors and the capacity of the lamp load, then compared the results.

4.3 Performance Tests of the Hydro Turbine Generator

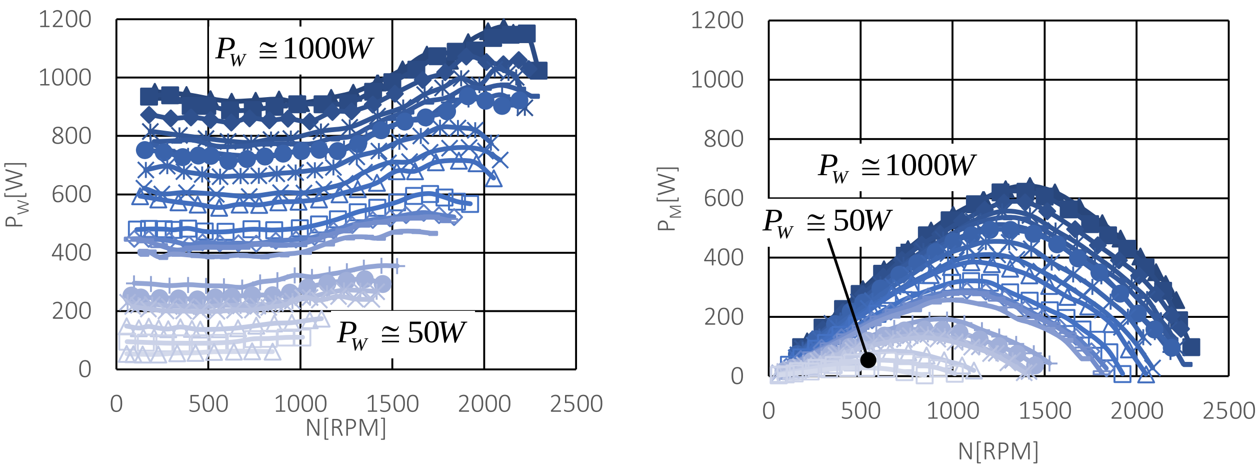
Thirdly, the authors looked over the characteristics of the tested hydro turbine generator. Devices explained in 4.1 and 4.2 were used for these experiments. The picture of the experimental apparatus for the hydro turbine generator tests is shown in Fig.4.

Fig. 4 Experimental apparatus for hydro turbine generator tests

5.0 Experimental Results and Considerations

5.1 Performance Test of the Hydro Turbine

Fig.5 (a) and (b) show the input power (water power) to and the output power (mechanical power) from the hydro turbine, which were obtained as results of the performance tests of the hydro turbine, respectively. From Fig. 5 (b), it is found that the output power P_M increases with the increase in the input power P_W . Also, it is found that the optimum rotational speed N to maximize the output power exists at each input power. The maximum output power P_M was 642W at rotational speed N =1420 rpm and input power P_W $\cong$1000 W. At this time, the turbine efficiency η_T was 65.2 %.

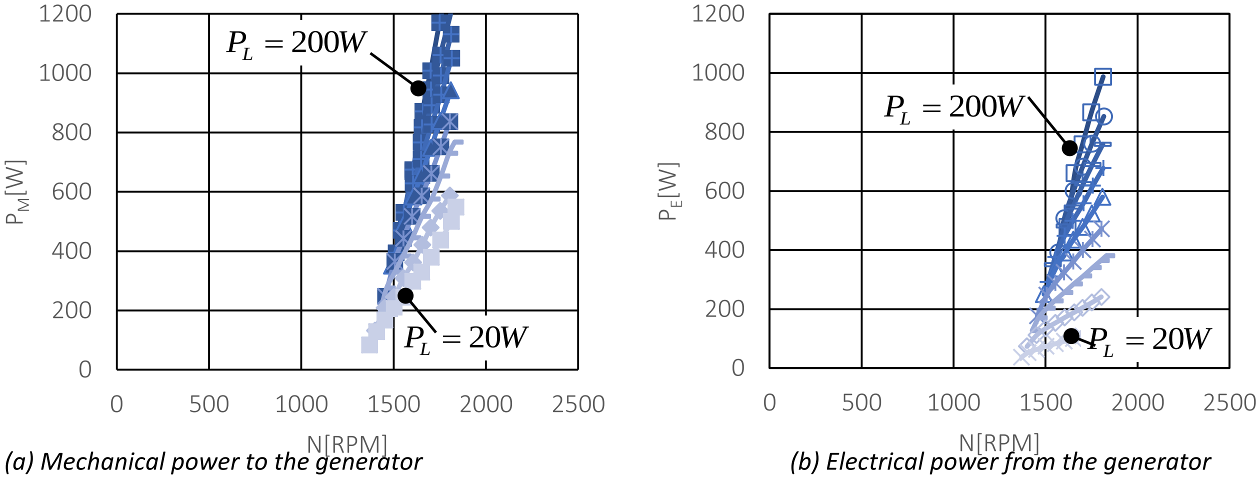


(a) Water power to the turbine *(b) Mechanical power from the turbine*

Fig. 5 Experimental results (Hydro turbine tests)

5.2 Performance Test of the Generator

Fig.6 (a) and (b) show the input power (mechanical power) to and the output power (electrical power) from the generator, which were obtained as results of the performance tests of the generator, respectively. From Fig. 6 (b), it is found that the output power P_E increases with the increasing the input power P_W and rotational speed N . The maximum output power P_E was 987 W at rotational speed N =1814 rpm, the capacity of the lamp load P_L =200 W per phase and capacitance C =25 mF. (The voltage, the current per phase and the frequency was 142 V, 2.3 A and 57.8 Hz, respectively.) At the time of P_L =200 W per phase, the generator efficiency η_G was 76.4 % at 1620 rpm and 73.0 % at 1814 rpm.

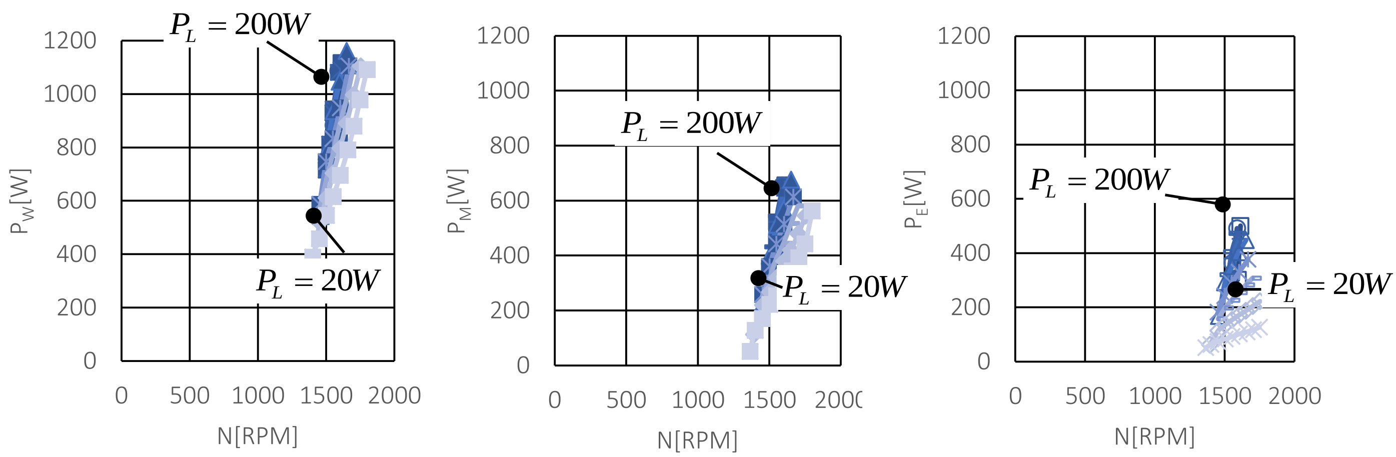


(a) Mechanical power to the generator *(b) Electrical power from the generator*

Fig. 6 Experimental results (Generator tests, $C = 25\mu F$)

5.3 Performance Test of the Hydro Turbine Generator

Fig.7 (a), (b) and (c) show the water, mechanical and electrical power, which were obtained as results of the performance tests of the hydro turbine generator at capacitance C =25 mF, respectively. The maximum electrical power P_E was 500 W at rotational speed N =1613 rpm, the capacity of the lamp load P_L =200 W per phase and capacitance C =25 mF. (The voltage, the current per phase and the frequency was 92.0 V, 1.8 A and 51.2 Hz, respectively.) At the time of P_L =200 W per phase, the turbine efficiency η_T , generator efficiency η_G and total efficiency η was 58.7 %, 76.3 % and 44.8 % at 1613 rpm, respectively.



(a) Water power *(b) Mechanical power* *(c) Electrical power*

Fig. 7 Experimental results (Hydro turbine generator tests, $C = 25\mu F$)

6. Conclusion

In this study, the authors carried out the performance tests of the hydro turbine by using pressure gauges, a flow meter, a torque meter and a revolution sensor as measuring devices. Also, we measured the output of the hydro turbine generator by using a power analyzer

As a result, 733.9 W of maximum output power could be obtained by the hydro turbine by 1138.2 W of input water power. (i.e., 16.6 m of head and 7.0 liter/s of flow rate.) At this time, 540.8 W of maximum electric power could be obtained by the hydro turbine generator.
The authors think the application of this type of micro hydro turbine generator would be very useful in developing countries, like Kenya.

References

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