Journal of Power and Energy Engineering, 2014, 2, 47-52
Published Online April 2014 in SciRes. http://www.scirp.org/journal/jpee
http://dx.doi.org/10.4236/jpee.2014.24007

Power Stabilization System with Counter-Rotating Type Pump-Turbine Unit for Renewable Energy

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Received December 2013

Abstract

Traditional type pumped storage system contributes to adjust the electric power unbalance between day and night, in general. The pump-turbine unit is prepared for the power stabilization system, in this serial research, to provide the constant power with good quality for the grid system, even at the suddenly fluctuating/turbulent output from renewable energies. In the unit, the angular momentum changes through the front impeller/runner must be the same as that through the rear impeller/runner, that is, the axial flow at the outlet should be the same to the axial flow at the inlet. Such flow conditions are advantageous to work at not only the pumping mode but also the turbine mode. This work discusses experimentally the performance of the unit, and verifies that this type unit is very effective to both operating modes.

Keywords

Power Stabilization; Pump-Turbine; Counter-Rotation; Impeller; Generator Motor

1. Introduction

To contribute preventing the global warming, the efficient use of clean energy resources, such as a solar power, a wind power and so on, is indispensable, while the electric power is provided steadily for the grid system.

In this serial research, a power stabilization system with a counter-rotating type pump-turbine unit is developed for providing instantaneously the constant output to the grid system. In the pump-turbine unit, front and rear impellers/runners rotate conversely, inner and outer armatures also counter-rotate at the same torque. In the pumping mode, the rotating speeds of both the impellers are adjusted automatically by the smart control. Hence, the unstable characteristic and cavitation can be suppressed effectively [1]. Moreover, the unit in the turbine mode has fruitful advantages that not only the induced voltage is sufficiently high without supplementary

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How to cite this paper: Miyaji, T., Kasahara, R., Kanemoto, T., Kim, J.-H., Choi, Y.-S. and Umekage, T. (2014) Power Stabilization System with Counter-Rotating Type Pump-Turbine Unit for Renewable Energy. *Journal of Power and Energy Engineering*, **2**, 47-52. http://dx.doi.org/10.4236/jpee.2014.24007

equipment such as a gearbox, but also the rotational moment hardly acts on the mounting bed because the rotational torque is counter-balanced in the armatures/runners [2]. In this paper, the hydrodynamic performance of the pump-turbine unit with the counter-rotating type impellers designed exclusively for pump mode is investigated experimentally in the power stabilization system.

2. Power Stabilization System with Pumped Storage

Figure 1 shows the diagram of the power stabilization system with the counter-rotating type pump-turbine unit. The system is mainly composed of the electric accumulator with the minimal capacity, the power control device, and counter-rotating type pump-turbine unit.

As the wind power station is the most distinctive for the unstable and fluctuating output among the renewable energy resources, it was applied as an example for the power stabilization system of this work. **Figure 2** shows the output from field tests of the intelligent wind power unit in house works [3], and its output was averaged every one minute as shown in **Figure 3**, where the average output is arbitrarily 16,000 times as high as one in **Figure 2**. It is assumed conveniently, here, that the wind power station should provide the constant power P_G of 1 MW for the grid system. The output from the wind power unit connects directly to the electric accumulator, and the power control device detects that the output is higher or lower than P_G. The power control device demands the electric accumulator not only to provide the constant power P_G for grid system but also to operate the pump-turbine unit at the pumping mode by the surplus power, while the wind velocity is faster than that giving P_G, as shown in **Figures 1** and **3**. That is, the surplus output is stored, at once, as the potential energy by the pumping mode. On the contrary, as shown in the same figures, the power control device demands the pump-turbine unit to operate at the turbine mode converting from the stored potential energy to the hydroelectric output, so as to take P_G with accompanying the shortage output from the wind power unit. Then, the pumping

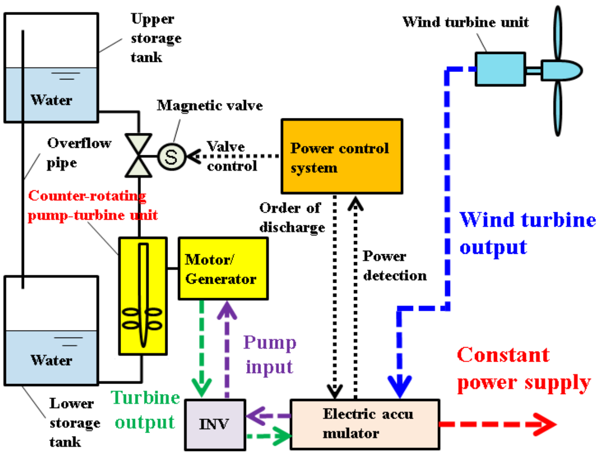

Figure 1. Power stabilization system.

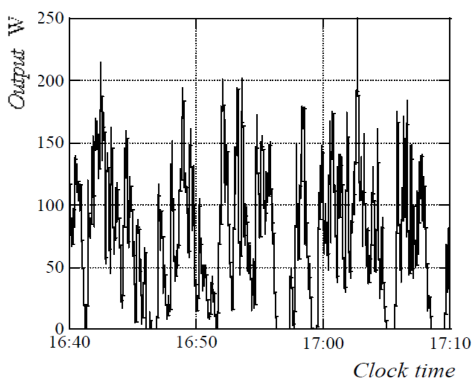

Figure 2. Output from the wind power unit in house.

mode or the turbine mode is instantaneously operated in the alternative every one minute in **Figure 3**, judging the output from the wind power unit. The final target of this serial work is to make average time short as possible.

Figure 4 shows the water volume of the upper and the lower storage tanks in the power stabilization system while operated just above. Moreover, **Figure 5** shows the integrated wattmeter in the accumulator, where the pumping/turbine head is 15 m, the input is 625 kW at the pumping mode, and the hydroelectric output is adjusted to guarantee P_G in response to the output from the wind power unit. The electrical accumulator re- quires the capacity up to 24 kWh as shown in **Figure 5(a)**, while the power stabilization system operates in **Figure 4**. The capacity 24 kWh is 1 - 8th of the capacity of the electrical accumulator installed traditionally in the wind power station without the proposed stabilization system, as confirmed in **Figure 5**. To put the above stabilization system into the practical use, the suitable pump-turbine unit suitable for above operations should be prepared.

3. Counter-Rotating Type Pump-Turbine Unit

3.1. Model Unit

The unit designed exclusive for the pumping mode, which is very important for the pumped storage, was

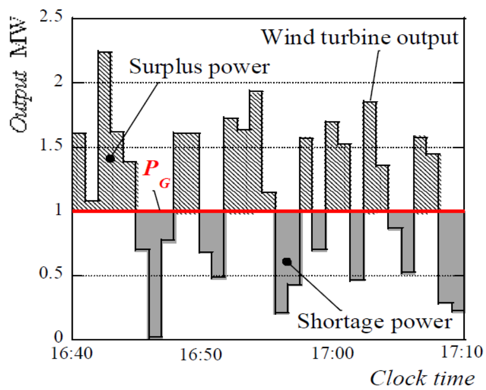

Figure 3. Resultant output averaged every 1 minute.

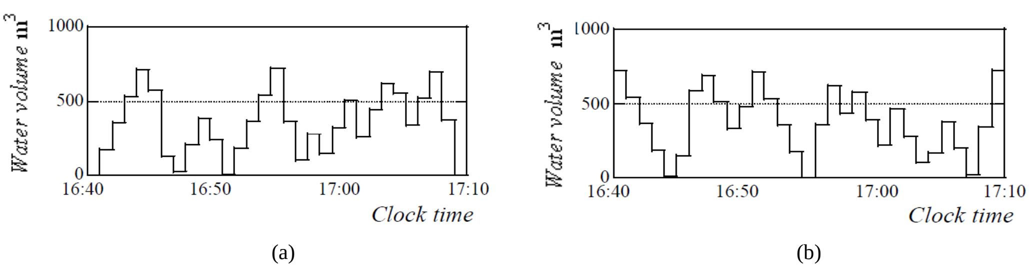

Figure 4. Water volume in the storage tanks. (a) Upper storage tank; (b) Lower storage tank.

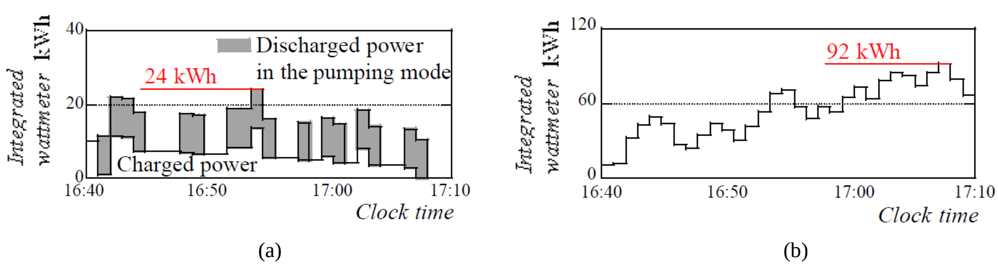

Figure 5. Capacity in the electric accumulator. (a) With power stabilization system; (b) Without power stabilization system.

prepared for the preliminary experiments. **Figure 6** shows the counter-rotating type axial-flow pump unit. The major specifications at the normal operation are the theoretical head H_{ET} = 4.4 m, the discharge Q = 1.78 m^3/min, the individual impeller speed $n_F = n_R$ = 1500 min^{-1} (subscripts F and R denote the front and the rear impellers). The specific speed of the individual impeller is N_S = 1100 m, m^3/min, min^{-1}, and the specific speed as the pumping unit with the counter-rotating type impellers is N_{ST} = 1320 m, m^3/min, min^{-1}. The impeller diameters D are 150 mm, and the boss ratio is 0.4.

3.2. Counter-Rotating Type Impellers

The blade profiles of this unit are shown in **Figure 7** and its dimensions are given in **Table 1**, where RQ and Z are the distances in the circumferential/tangential and the axial directions divided by D, and b_d is the inlet and the outlet angles of the blades measured from the axial direction (subscript 1 to 4 denote the inlet and the outlet of the front and rear impellers, respectively). The numbers of the front and rear blades are 5 and 4 in the pumping mode (the numbers of the front and the rear blades are 4 and 5 in the turbine mode). Impeller/Runner B used in the experiments was designed by the three-dimensional inverse method to improve the exclusively pump performance [4].

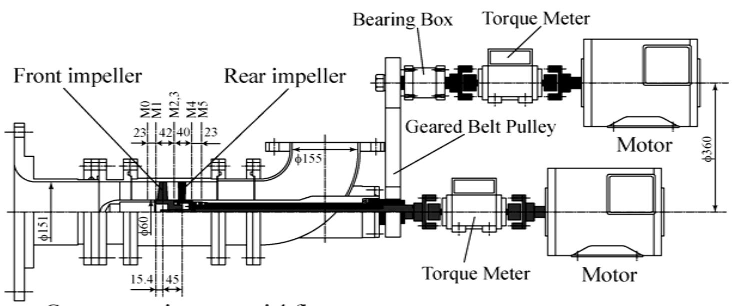

Figure 6. Trail model of the counter-rotating type pump turbine unit.

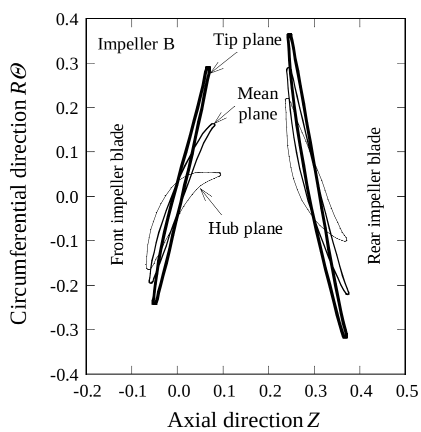

Figure 7. Blade profiles of the counter-rotating type impeller.

Table 1. Blade angles and solidities.

Impeller		Blade angle (deg.)				Solidity	
		β_{d1}	β_{d2}	β_{d3}	β_{d4}	Front	Rear
	Hub	−76.9	−14.9	71.9	42.9	0.99	0.89
B	Mean	−79.2	−58.0	77.2	70.1	0.82	0.82
	Tip	−80.4	−79.0	79.9	75.9	0.81	0.78

4. Performance

Figure 8 shows the unit discharge $Q_{11}[= Q/(D^2H^{1/2})]$, unit torque $M_{11}[= M/(D^3H)]$, unit input or the output $P_{11}[= P/(D^2H^{3/2})]$, the hydraulic efficiencies in the pumping mode $h_h[=rgQH/P]$, and the turbine mode $h_h[= P/(rgQH)]$, the unit rotational speeds of the front and the rear impellers/runners $N_{11\,F,R}(= n_{F,R}D/H^{1/2})$, and the unit relative rotational speed $N_{11}(= nD/H^{1/2})$, while the head is kept constant H = 2 m. The water is pumped up while the discharge Q_{11} is positive at the positive N_{11} and Q_{11}, which is called the pumping area (I). It is necessary to make the rotational speed N_{11} faster than 150 m, min^{-1}, for pumping up. The slower rotational speed cannot pump up, because the pump head is in proportion to the square rotational speed. Therefore, the braking area (II) exists where Q_{11} is negative even at the positive N_{11}. The negative rotational speed is in the turbine mode (III). That is, the rotational speed must be increased rapidly when the operation changes from the turbine to the pumping

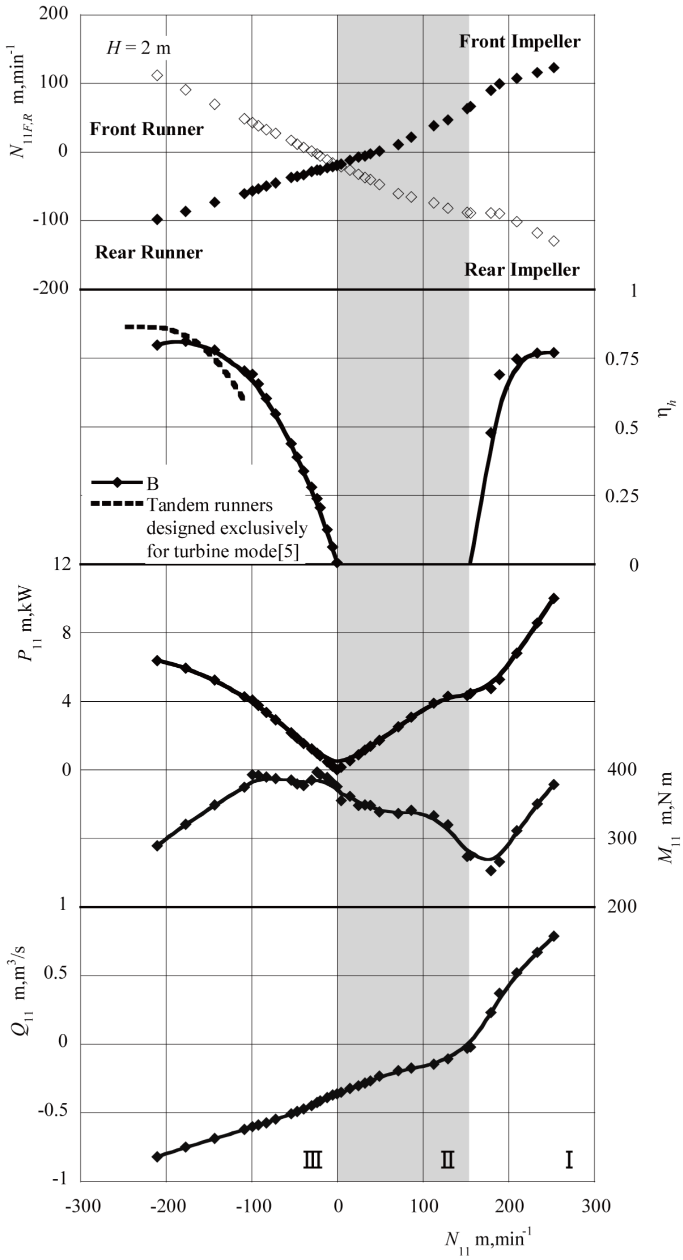

Figure 8. Overall performances of the counter-rotating type pump-turbine unit.

modes. In $Q_{11} = -0.45 \sim -0.35$ m, min^{-1} at the turbine mode, the front runner N_{11F} rotates in the same direction as the rear runner N_{11R} but faster than N_{11R} to take the output. The hydraulic efficiency is maximum at the moderate rotational speed, and the value nearly corresponds to the efficiency (the dot line) of the counter-rotating type hydroelectric unit designed exclusively for turbine mode [5].

These results suggest that this type unit has greatly effective performance for both pumping and the turbine modes.

5. Conclusion

The power stabilization system with the counter-rotating type pump-turbine unit was proposed to provide the constant power with high quality for the grid system. The hydrodynamic performance of the counter-rotating type pump-turbine unit with the impellers designed exclusively for pumping mode was also investigated experimentally, and proved beneficial operation at not only the pumping but also the turbine modes.

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