The performance of the modified pump motor as a generator on the Pump as Turbine (PAT) power plant

by Dwi Rahmalina

PAPER • **OPEN ACCESS**

The performance of the modified pump motor as a generator on the Pump as Turbine (PAT) power plant

To cite this article: D L Zariatin *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **277** 012016

The performance of the modified pump motor as a generator on the Pump as Turbine (PAT) power plant

D L Zariatin*, S N Fitria, Y Dewanto, Ismail and D Rahmalina

Mechanical Engineering Department, Universitas Pancasila, Jakarta, Indonesia

* E-mail: dedeliazariatin@univpancasila.ac.id

Abstract. There are many types of the hydropower plant. Pump as Turbine (PAT) is one of the simple, practical and low-cost hydropower plants. In PAT technology, a commercial pump available in the market can be modified to become a PAT power plant. This paper is a technical note that describes the guideline to modify the induction pump motor into a generator and analyze the performance of the generator. There are two aspects that must be considered in modifying the motor, namely the motor construction and the output power. In modifying the motor pump, the magnet must be inserted in the rotor. Meanwhile, the wire diameter and the number of winding in the stator are modified to increase the voltage working range. The experimental tests were performed with a laboratory scale PAT power plant to identify the generator performance. The analysis showed that a modified pump motor generated 32.5 VAC and 0.33 Ampere of electrical power (10.725 Watt), only with 2.5 m of water head. The electrical power generated could be improved with a higher water head.

1. Introduction

One of the green energy resources is water, which generates electric power in a hydropower plant. Not only in a large-scale, but a hydropower power plant also can be developed in micro-, even in pico-size, which is suitable for a rural and remote area that cannot be reached by the electric company. However, one of the difficulties to build a micro- or a pico-hydropower plant is to find a turbine in a small capacity. Most of the turbine manufacturer provide only large size turbines [1]. Designing and manufacturing a specific turbine that is suitable for a low capacity turbine is costly. However, there is a low-cost alternative to build a hydropower plant [2], known as Pump as Turbine (PAT) [3]. In PAT, the pump works in reverse and generate electricity.

Many researchers have studied the characteristic of PAT [4] and developed a test facility in laboratories scale [1,5-7]. Most of the test facility used a standalone generator and coupled with the centrifugal pump to produce electricity [8-10]. The motor of the pump is most likely un-used in the PAT power plant because there was no explanation about it.

Williams *et al* [11] explained that the induction motor could operate as a generator in a PAT power plant with the following advantages such as low friction loss in the drive, lower cost (no pulleys, fewer bearings, smaller) longer bearing life (no sideways forces on) and could be provided as one unit. Commonly, the three-phase induction motor is used as a motor pump, which can be modified to become an induction generator. The three-phase induction generator is very suitable for small hydropower plant [12]. However, the three-phase connection must be converted into a single-phase generator.

Even though the modification of induction motor to become a generator is reported successfully [11], there is no comprehensive explanation of how to modify the pump motor to become a generator when using an available pump in the market as a PAT. This paper provides a detailed description of how to alter a motor pump as a generator and test it in a PAT experiment installation.

2. Method

To convert a three-phase motor into a single generator, two capacitors must be connected to the winding, as shown in Figure 1 [12]. Wrong connection of capacitor and winding would result in an unbalanced system and could cause overheating on the winding. The capacitor excitation also would affect the single-phase generator performance [13]. Meanwhile, the ballast load is used to maintain the output voltage.

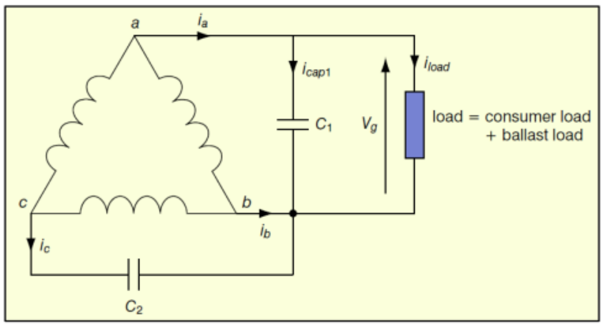


Figure 1. Single-phase output from three-phase connection [12].

In this research, a commercial pump Grundfos NF 30-18 with a 1-phase cage induction motor was converted into a generator. Because a 3-phase motor and generator are more practical than a 1-phase machine [14], therefore the motor winding must be re-arranged. The pump specification is listed in Table 1.

Table 1. Pump specification.

Parameter	Specification
Voltage	220 – 240 V
Current (AC)	9.5 A
Power	2.1 kW
Electric Frequency	50 Hz
Flow-rate	12 – 37 m^3/h
Rotational speed	2850 rpm

In general, the construction of cage induction machine consists of seven main components such as a shaft, cage rotor, stator iron core, 3-phase of the stator winding, terminal box, cooling fan, and motor frame, as shown in Figure 2. There are three components of the motor that were modified to change a motor to become a generator, namely the shaft, cage rotor, and the cooling fan. Detail modification is discussed in the further explanation.

3. Modification process

The modification process is relatively easy. An ordinary workshop with adequate tools could perform the modification. The process is classified into 6 (six) general steps started by disassembly of the motor pump and end up by testing its performance. Figure 3 illustrates the modification procedures.

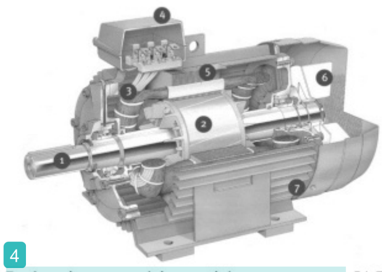


Figure 2. Induction machine with cage rotor [15]: 1, shaft; 2, cage rotor; 3, stator three-phase winding; 4, terminal box; 5, stator iron core; 6, cooling fan; 7, motor frame.

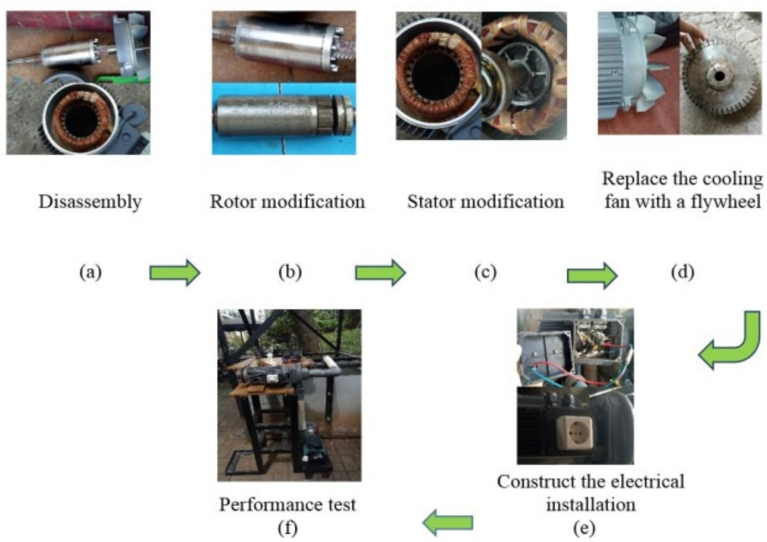


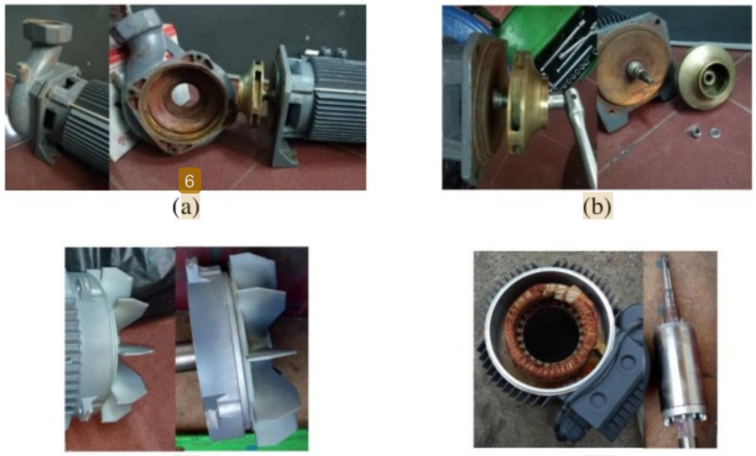
Figure 3. Modification process.

Step-1 Disassembly

Disassembly the pump by opening four bolts and take off from the pump housing as shown in Figure 4 (a). After that, disassembly the impeller by using a monkey wrench as shown in Figure 4(b). Figure 4(c) shows the cooling fan which is dis-attached from the motor. The last disassembled components are the rotor shaft and the stator, as shown in Figure 4(d).

Step-2 Modification the rotor

Cut the rotor with hand grinding into two pieces as shown in Figure 5(a) and 5(b), and take off the shaft from the rotor as shown in Figure 5(c). Place six steel rings with an outer diameter of 60 mm, the inner diameter of 29 mm and 20 mm in length. Then put five iron laminated rings intermittently with each steel rings as shown in Figure 6. Carefully attach the 24 permanent magnets for each iron laminated rings. In this research, 120 pieces of neodymium magnetic with the length of 30 mm, the width of 5 mm, and thickness 3 mm. Then cover the rotor with 2 mm thickness of the rounded metal sheet.

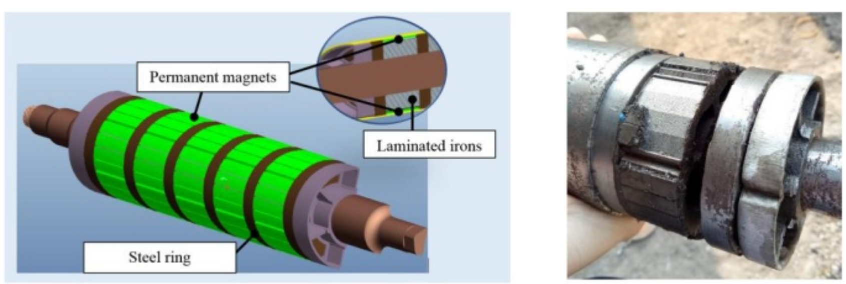


(a) (b) (c) (d)

Figure 4. Disassembly the pump and the motor.

(a) (b) (c)

Figure 5. Modification of rotor (a) cage cutting, (b) cut cage, (c) shaft.



(a) (b)

Figure 6. Rotor modification (a) rotor schematic, (b) modified rotor.

Step-3 Modification of stator

To change the motor phase, the motor winding must be modified. Table 2(a) provides the originating data stator winding. The stator has 24 slots and 0.8 mm-diameter cable is used in the original motor. Meanwhile, wire with a diameter of 0.6 mm is used for the winding modification. Table 2(b) provides the adjustment of the stator winding.

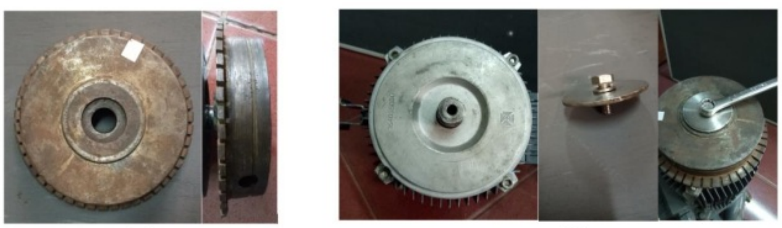
IOP Conf. Series: Earth and Environmental Science **277** (2019) 012016 doi:10.1088/1755-1315/277/1/012016

Table 2. Winding data of the motor.

(a) Original Winding		
	Number of pole steps	Number of windings
Main winding	6	25
	8	25
	10	25
	12	25
Starting winding	10	53
	12	53
(b) Modified Winding		
	Number of pole steps	Number of windings
Winding	6	65
	8	65

Step-4 Replacement of the cooling fan with a flywheel

The flywheel is installed on the generator to smooth the shaft rotation because a constant velocity is difficult to maintain. The wheel made of iron with an outer diameter, thickness and weight of 40 mm, 10 mm, and 4 kg, respectively. Figure 7(a) shows the flywheel, meanwhile Figure 7(b) shows the installation process. The flywheel installation is performed after the rotor, stator and motor cover is re-assembled.



(a) (b)

Figure 7. (a) The flywheel, (b) Flywheel installation.

Step-5 Construction of electrical installation

In the electrical installation, a step-up transformer is used to increase the output voltage. Cables, IN4007 diode, screws, plug, are used for the electrical installation

Step-6 Performance test

There were two tests performed to analyze the generator performance. Figure 8 shows the installation used for the first performance test, where the water directly flows into PAT. A feeding pump was used to flows the water into the housing and rotates the impeller to generate electricity. The distance between the feeding pump and PAT was approximately 1 meter. Two digital multi testers (Fluke II with accuracy ±0.4%+1) were used to measure the voltage and current.

Figure 9 shows the second installation where the water drops 2.5 m above the PAT. This installation represents the actual condition of PAT if placed in the rural or remote area. To characterize the generator performance for different flow-rates, a valve was used to control the flow-rate flow into the PAT. In both of the installation tests, two digital multi testers (Fluke II with accuracy ±0.4%+1) were used to measure the voltage and current. A digital tachometer with accuracy 0.05%+1 and sampling ratio of 0.8 over 60 rpm was used to measure the rotational speed of the flywheel. A Sea DN50 flow-rate sensor was used to measure the flow-rate before entering the PAT.

IOP Conf. Series: Earth and Environmental Science **277** (2019) 012016 doi:10.1088/1755-1315/277/1/012016

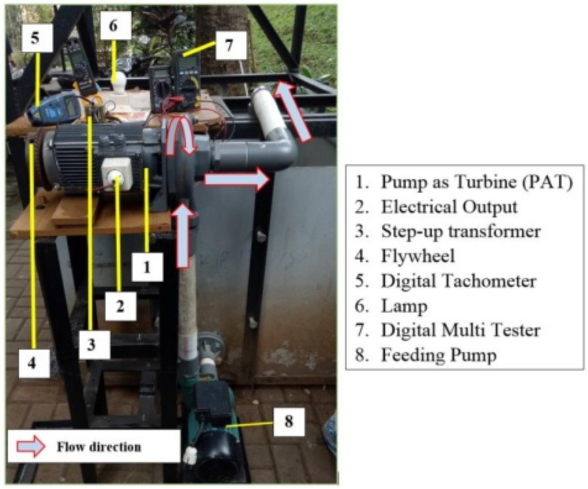
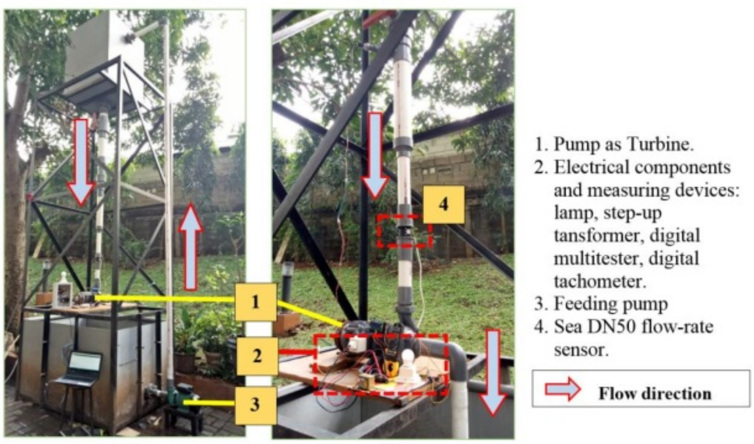


Figure 8. Installation for the performance test.



(a) (b)

Figure 9. Second installation for the actual performance test.

4. Result and discussion

The result of the first test is shown in Table 3; meanwhile, Table 4 shows the result of the test on the second installation.

Table 3 shows that 18.164 Watt of electric power was generated when the water pumped directly to the PAT by a feeding pump as shown in Figure 8. Direct flow eliminated the flow losses such as pressure, friction and velocity losses in the installation. It generated a maximum of electric power.

Table 3. The generator performance in the first installation test.

Rotational speed (n, rpm)	Voltage (V, Volt)	Step-up Voltage (V, Volt)	Current (I, Ampere)	Power (P, Watt)
1510	2.53	47.9	0.38	18.164

Table 4. The generator performance in second installation test.

Flow-rate (L/min)	Rotational speed (RPM)	Output Voltage (Volt)	Current (Ampere)	Power (Watt)
15	0	0.02	0	0
25	0	0.03	0	0
45	648.1	20.2	0.23	4.646
60	648.7	20.9	0.24	5.016
75	717.7	28.1	0.27	7.587
80	729.7	29.1	0.29	8.439
85	772.6	30.2	0.30	9.06
90	792.8	31.9	0.31	9.887
105	805.3	32.2	0.32	10.304
115	828.1	32.5	0.33	10.725

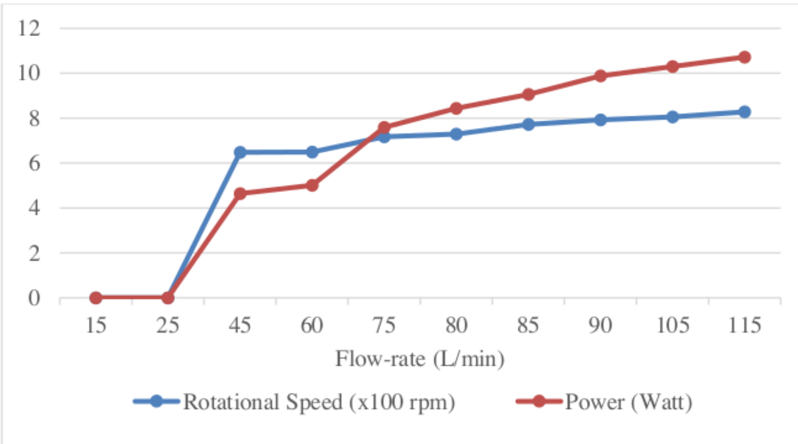


Figure 10. Rotational speed and power generated at different flow-rates in second installation test.

Figure 10 plot the data of the second installation test from Table 4. It is found that at the lower flow-rate up until 25 L/min, the impeller did not rotate. After the valve 3/10 opened, the flow-rate was increased to 45 L/min and rotate the PAT shaft. The rotational speed of the shaft was continued to increase along with the electrical power generated by the modified motor. For the flow-rate above 75 L/min, the generator shows better performance as the electrical power increase above the rotational speed.

5. Conclusion

In this research, a motor of a commercial pump was modified and turn into a generator for the Pump as Turbine (PAT) power plant. There were seven steps to modify the motor, including the performance test. It is found that 18.64 Watt was generated in the first installation test, where the water pumped directly into the PAT by a feeding pump. In the second installation that represented the actual condition of the PAT in the rural or remote area where the water was fell from 2.5 m above the PAT, 10.725 Watt of electrical power generated in the PAT power plant.

Acknowledgment

This research was funded by The Ministry of Research Technology and Higher Education of Indonesia in a grant scheme of "Tim Hibah Pasca Sarjana".

References

[1] Jain S and Patel R 2014 *Renew. Sustain. Energy Rev.* **30** 841-68
[2] Williams A 1997 *Pump as Turbine - a user's guide* (London: Intermediate Technology Publication)
[3] Prasad V, Shukla S and Joshi S 2006 *Indian Pumps* **38** 5-9
[4] Zariatin D, Kumbarasari S and Rahmalina D 2018 *MATEC Web of Conferences* **159** 02024.
[5] Zariatin D, Rhakasywi D, Ade F and Setyo A 2017 *MATEC Web of Conferences* **108** 04014.
[6] Suarda N M, Suarnadwipa and Adnyana W B 2006 *The 2nd Joint Int. Conf. Sustainable Energy and Environment* (Bangkok) B-008
[7] Rossia M, Righettia M and Renzia M 2016 *Energy Procedia* **101** 1207-14
[8] Giosio D, Henderson A, Walker P, Sargison J and Gautam P 2015 *Renew. Energy* **78** 1-6
[9] Nautiyal H, Varun, Kumar A and Yadav S 2011 *Energy Sci. Technol.* **1** 79-86
[10] Du J, Yang H, Shen Z and Chen J 2017 *Energy* **137** 431-40
[11] Williams A A, Smith N P A, Bird C and Howard M 1998 *Water Environ. J.***12** 175-8
[12] Ekanayake J B 2002 *Power Eng. J.* **16** 61-7
[13] Rahim Y H A, Alolah A I and Al-Mudaiheem R I 1993 *IEEE T. Energy Conver.* **8** 389-95
[14] Price G D 2014 *Power Systems and Renewable Energy: Design, Operation, and Systems Analysis* (New York: Momentum Press)
[15] Freris L and Infield D 2008 *Renewable Energy in Power Systems* (West Sussex: John Wiley & Sons, Ltd.)

The performance of the modified pump motor as a generator on the Pump as Turbine (PAT) power plant

ORIGINALITY REPORT

9%	6%	7%	3%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	mafiadoc.com Internet Source	3%
2	www.matec-conferences.org Internet Source	2%
3	A. A. Williams. "Pumps as Turbines and Induction Motors as Generators for Energy Recovery in Water Supply Systems", Water and Environment Journal, 6/1998 Publication	1%
4	www.freeenergyplanet.biz Internet Source	1%
5	"Fluid Mechanics and Fluid Power – Contemporary Research", Springer Science and Business Media LLC, 2017 Publication	1%
6	Gilbert, Scott F.. "Ecological Developmental Biology", Oxford University Press Publication	<1%

7	Submitted to Aston University Student Paper	<1%
8	Lecture Notes in Electrical Engineering, 2016. Publication	<1%
9	Ombeni John Mdee, Cuthbert Z. Kimambo, Torbjorn K. Nielsen, Joseph Kihedu. "Analytical Evaluation of Head and Flow Rate Off-Design Characteristics for Pump as Turbine Application", Journal of Fluids Engineering, 2018 Publication	<1%

Exclude quotes	Off	Exclude matches	Off
Exclude bibliography	On		