# Experimental investigation of pump as turbine and induction generator for pico hydro power

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## Abstract

The purpose of this research was to do experimental investigation on using water pump-as -turbine (PAT) instead of a conventional turbine for pico-hydro systems and modify standard induction motor to work as induction generator (IG) in order to produce cheaper electricity for rural areas. This Pico hydropower system was under 1.0 kW in range, constructed for experimental bench-scale tests and was installed on small table. The working experimental system was a close loop water flow system designed similarly to a pump-storage hydroelectricity system; consisting of intake system part, PAT and the (IG) parts., A centrifugal pump of 1.5 kW, 220 V was selected as intake system to generate power that could pump water up to 7.7 m with flow rate of 500 lit/min (8.3 $m^3$/s). This r centrifugal pump (1.5 kW, 2.0 pole, working speed 2,900 rpm) was selected as pump-as-turbine (PAT) to r drive a three-phase induction motor (or IM) [1.5 kW (2 HP), 380/220 V, 2.0 pole, 50 Hz] to run in a reverse mode. This IM was set up with a correct capacitor size of C-2C configuration to r change operation into a generator mode. The results of the tests showed that the intake system has the potential to generate hydropower adequate to drive the PAT and IG and to rotate over a synchronous speed of up to a maximum speed of 1,550 rpm. Induction motors can be modified with correct capacitor size C=20 µF and 2C=40 µF and they can then produce single phase electrical power to supply incandescent light bulbs (load of only 300 W, 48 Hz, 218 V), without damaging any of the components used in the testing.

## Key words:

*Pump as turbine, Three-phase induction generator, motor as generator, C-2C for single Phase induction generator.*

## Introduction

Hydropower plants, a renewable energy source contribute to around 16% of the world energy supply. It is the main source of electrical power for countries such as Norway 99%, Brazil 86%, Switzerland 76% and Sweden 50%. Hydropower plants are d classified in terms of power capacity generation; Large, Small, Micro and Pico hydropower plants [1]. The smallest are the Pico hydro power plants that has capacity of electrical power generation of not more than 5.0kW. Pico hydropower systems are very appropriate for providing electricity for developing countries where there are many isolated rural communities and villages that are near streams and small rivers. Most of these villages and communities are far from their countries' power grid line of the country. Many of the houses in these villages and communities require only small electrical power. The electricity is mainly used for small loads such as lighting (5-20 watt lamps) and for small (1-10 watt) appliances such as radio and TV. Hence, Pico hydropower plants, which is "green energy" (that is, a renewable energy sourcw) is a good alternative energy source for these isolated rural areas. is It can be an economical power source because of very low construction costs, short pay-back time, and very appropriate for government investment. As mentioned are earlier, there are no greenhouse gas (GHG) emission, and therefore environmental friendly. Finally, the s and simple construction process is t suitable in rural areas. Pico hydro power can contribute to energy supply in the developing countries, as pico hydro power is most economical in terms of construction and installation costs since Pico hydro power systems require only small weirs for low-head and low-water flow rate r hydropower intake systems. The systems need only a small powerhouse, as the hydro turbine and generator are small. The penstock can use standard water pipes easily found in in developing countries and can be bought from local markets.

Electricity production from pico hydro systems is very simple. Water flowing on streams or small rivers are diverted and channeled to a penstock, which then channel the water through the Pico hydro turbine, where the flowing water rotate the turbine, which then drive generator that produces the electricity. The water is then channeled back into the stream [2]. But Pico hydropower system can be high cost for small loads, if conventional turbine and generator are used. They cannot be locally produced, and even if possible, they cannot be mass-produced, which should drive the production costs. The local demand is generally not very big to make mass production profitable. Usually there will be only one or two orders for these small equipment. Williams [3] reported that conventional turbines have limitations if to be used for the micro hydropower range. A cross-flow turbine requires a large turbine running at slow speed and belt to drive standard generator. A Pelton turbine for example, require three or four jet and nozzles feeds. A small Francis turbine is very expensive for Pico hydropower system. These conventional turbines are hard to manufacture. To produce to supply orders for Pico hydropower systems to be installed for a several households in rural areas will be o very expensive.

Previous researchers have studied about turbines and generators for Pico hydro systems such as Himanshu Nauti, Varun, Anoop Kumar and Sanjay Yadav [4]. They found that a centrifugal pump can certainly be used as hydro turbine without any technical complication, by running them in reverse. Using centrifugal pumps as turbines can be easy as can be used for various flow rates and head to produce electricity within the range of small to micro hydro power systems. Sanjay V.Jain, Rajesh N.Patel [5] reported that reverse running water centrifugal pumps were efficient alternatives for generating and recovering power for small and micro hydro power systems and were available for a wide range of head and flow rates. Centrifugal pumps as turbines have many advantages for use as hydro turbines when compared with other conventional hydro turbines. They are easy to install, low cost thus appropriate for rural areas, less complex to operate, can be mass produced, available for a wide range of head and flows, require short delivery times, and are available in a large number of standard sizes and including spare parts. Mostly, the maximum efficiency in the turbine mode is the same or less than pump mode 5%.

From the previous literature reviews, this research has decided to emphasize the using centrifugal water pumps instead conventional turbines for Pico hydro systems. This is because of the following factors; can be mass produced at low cost, available in a large number of standard sizes, available for a wide range of head and flows, and lower cost when compared with manufacturing specifically-designed hydro turbines for Pico hydro systems. Usually, a water pump consists of centrifugal turbine and induction motor and it can be an integral water pump set. Induction motor is the electrical machine use, as prime mover to drive the turbine. It can have both single and three phase input power, that means a three phase induction motor can be selected and modified to work as induction generator in the same time. Moreover, integrated water pump sets have short delivery time, spare part easy available and easily purchased from local markets, as well as, they can use standard water pipes and fittings for supplying and draining water from the systems.

R.C. Bansal, Senior Member [7] reported that the advantages of using an induction generator instead of a synchronous generator include their reduced unit cost and small size, ruggedness, having brushes without DC parts, and self- protection against severe overload and short circuit. Using induction machines as generators were becoming more popular for renewable energy source but they require reactive power and the poor voltage regulation under varying speed were a major drawback of induction generator. Mubarak Shah and Sakda Somkun [8] studied squirrel-cage induction motor (SCIM) suitable for working as generator due to its advantage over synchronous generator such as their robustness, brushless construction, low cost, reliability, rare maintenance, and availability in a wide power range. But SCIM requires correct size of excitation capacitor to build up terminal voltage from residual magnetism. When SCIM was excited by the capacitor in delta configuration, it becomes C-2C configuration for single phase distribution. Krishna Grrung and Peter Freere [9] studied and reported that the influence of excitation capacitor in delta configuration C-2 C on a 4 pole, 3 phase self- excited squirrel cage three phase induction generator for Pico hydro by fixed speed of generator at 1,500 rpm, was the best configuration; giving an output power above 300 W and efficiency of up to 67%.

Many researchers had been emphasized that a water centrifugal pump could certainly be installed as a hydro turbine to replace a conventional hydro turbine without any technical complication. Running reverse as turbine instead of that of a e conventional turbine and three phase induction motor, it could be modified to be a single phase generator by using the correct size of a capacitor installed in delta circuit at terminal in C-2C configuration. This will be a good alternative and has high potential application for Pico hydro systems. Water centrifugal pumps, h can be installed easily, have low cost even in rural areas, less complex, can be mass produced, available for a wide range of head and flows, available in a large number of standard sizes, has short delivery time and has available spare parts.

Therefore, using pump as a turbine and the motor as generator can be good alternative to make Pico hydropower systems more suitable for electricity production in rural areas. In this research, a t water centrifugal pump was installed instead of a conventional hydro turbine. The three-phase induction motor was modified to be single phase induction generator. These were used to construct the Pico hydropower system in test bench that has small size, movable and low cost. The system will be tested before it is installed in real site. Usually, the water centrifugal pumps consist of an impeller turbine coupled with three-phase induction motor integrated as one set that can be modified to a generator. But when the turbine and the generator are integrated into one set, there will be limitations at this experimental scale. The speed of the generator will be fixed only by the flow rate from source and will limit the selection of other generator types needed to increase electrical power system or to match the PAT performance in order to follow the site conditions. Since the water flow rate for Pico hydropower system is very low, there is a need to change the speed of generator, which makes maintenance hard when the generator has a problem. Accordingly, the experimental generator t will be separated from the pump-as turbine (PAT) and will be connected instead using a pulley and belt.

## 2. Experimental design and system operation

A schematic diagram of Pico hydropower system is shown on Fig. 1. The concept design and the working process of the pico hydropower system test bench is shown as a close loop system, similar to a pump storage hydroelectric power plant system.

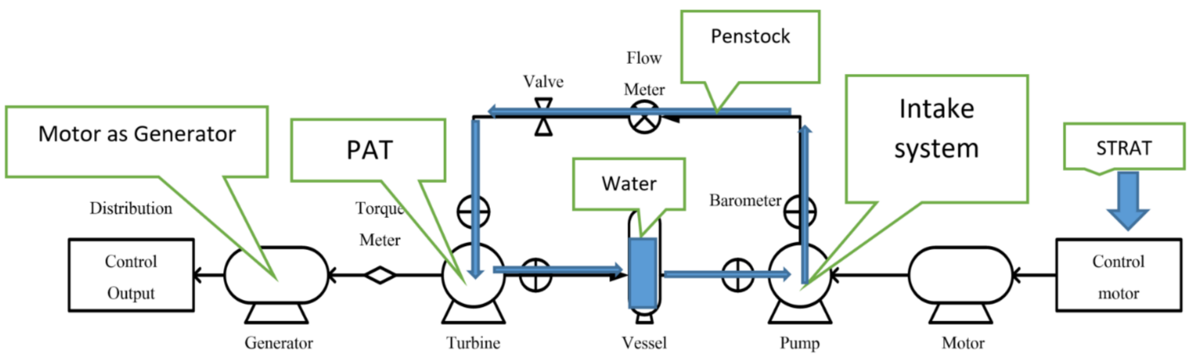



Fig. 1. Design of Pico hydropower system test bench diagram.

The system starts at the intake. The system to r generate hydro power consists of [1] a single-phase water centrifugal pump (1.5 kW (2 HP), 2.0 pole), that can pump water to an elevation of 7.7 m, with flow rate of 500 lit/min, and [2] the control panel (Circuit Breaker) for pumping water from the vessel to feed into the penstock, which has a barometer, flow meter and a release valve. Water is pumped into the turbine that drive the motor of the generator. The water is then released back to vessel for pumping back to the system through the intake.

When water is channeled to the PAT, the impeller of PAT will rotate and drive the induction generator to rotate at the same time to produce electrical power in range 1.0kW supply. This for load testing. There are 10 important components and equipment for the experimental test bench as shown in Table 1.

Table 1 Components and equipment of pico hydropower system test bench**.**

| No. | Component | Specification |
|---|---|---|
| 1 | Cement Mixing tank (Vessel) | 220 lit or 77 cm x107 cm x29 cm |
| 2 | Centrifugal water pump (PAT) | 1.5 kW, 4pole, 2,900 rpm |
| 3 | Flow rate Meter (Barometer) | 300 lit/min,1.75 Mpa below, DC 24 V |
| 4 | Auxiliary water Pump | Head 7.7 m, 500 lit/min 220 V, single phase |
| 5 | Flow regulation | Gate Valve |
| 6 | Three Phase Induction motor (IG) | 1.5 kW,380 V/220 V,4 pole, 1430 rpm, 50 Hz |
| 7 | Run Capacitor | 15,20,25 µF |
| 8 | Incandescent Lamp | 5x100 W, 50 Hz |
| 9 | Circuit breaker | 15 A |
| 10 | Cable THW 1x2.5 sq.mm | 450/750 V PVC 70 C |
| 11 | Penstock | PVC water pipe diameter 3.0inch, length 1.0 m |

Design and experimental investigation of pump as turbine and induction generator test bench for pico hydropower has been conducted. It consisted of testing the following of main components.

*Intake system par*t - this consisted of a single phase centrifugal pump [Mitsubishi WCL-2205FT) power motor [1.5 kW (2 HP), voltage 220 V, frequency 50 Hz] shown on Fig. 2. This can pump water up to 7.7 meter with a flow of 500 lit/min (from Performance pump curves). Both the inlet and outlets have a diameter of 3.0 inch. The intake system feed into the close loop system, through the penstock [diameter of 3.0 inch for feed], to the PAT. The intake system pump water from the vessel (water reservoir) up to the penstock to drive PAT. Estimate hydropower from intake system past was based on potential input and output power following equation (1) and (2).

$$P_{in} = H * Q * g \tag{1}$$

$$P_{out} = H * Q * g * \eta \tag{2}$$

**Where**

$P_{in}$ = Hydropower from Intake system

$P_{out}$ = Electrical power output of Generator

$H$ = Head (Meter)

$Q$ = Water flow rate in penstock (liter/second)
$g$ = Gravity force (9.81 $m/s^2$)
$\eta$ = Efficiency of system

The estimation of the electrical power from the pico hydropower system is based on equations (1) and (2), where the water flow rate ($Q$) is the amount of water flows per second. Normally, the available water flow is more than what is needed since the water flow requirement for Pico hydro power systems are small. The head ($H$) is the vertical distance from the top of penstock to the bottom of water turbine. The Pressure ($P$) is expressed as a head and is measured in Newton per square meter ($N/m^2$) or Pascal ($Pa$) by using the following equation:

$$P = \rho g H \tag{3}$$

Which then results to the following equation:

$$H = P/\rho g \tag{4}$$

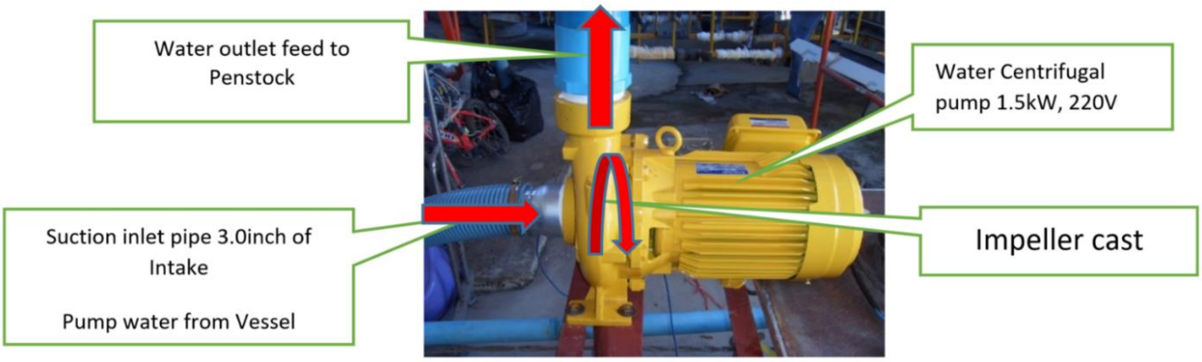



Fig. 2. Intake system (Mitsubishi WCL-2205FT).

The estimated hydro power generation based on the as calculated using equations (1) and (2) are shown on Table 2.

Table 2 Estimate of hydro power and electrical power output from intake system.

| No | Power Estimate | Parameters | | | | Result (Watt) |
|---|---|---|---|---|---|---|
| | | Flow rate ($m^3/s$) | Head (m) | Gravity ($m/s^2$) | Efficiency | |
| 1 | Hydropower | 8.3 | 7.7 | 9.8 | - | 628 |
| 2 | Generator out put | 8.3 | 7.7 | 9.8 | 0.9 | 565 |

ump as turbine (PAT), standard three phase induction water centrifugal pump [(Mitsubishi WCM-1505 FT) 1.5 kW (2 HP), 380 V/220 V, 2.0 pole, turbine speed 2,900 rpm] was use as hydro turbine instead of conventional hydro turbine. This was done by setting up the impeller to rotate in reverse, as in a turbine-mode or pump-as-turbine (PAT). The water centrifugal pump consists of three phase induction motor and an impeller of 185 mm in diameter, which is made from stainless steel (SUS304) laser welding in one set. The diameter of both inlet and outlet of pump have same size are 2.0 inch that shown in Fig. 3(a) and (b).

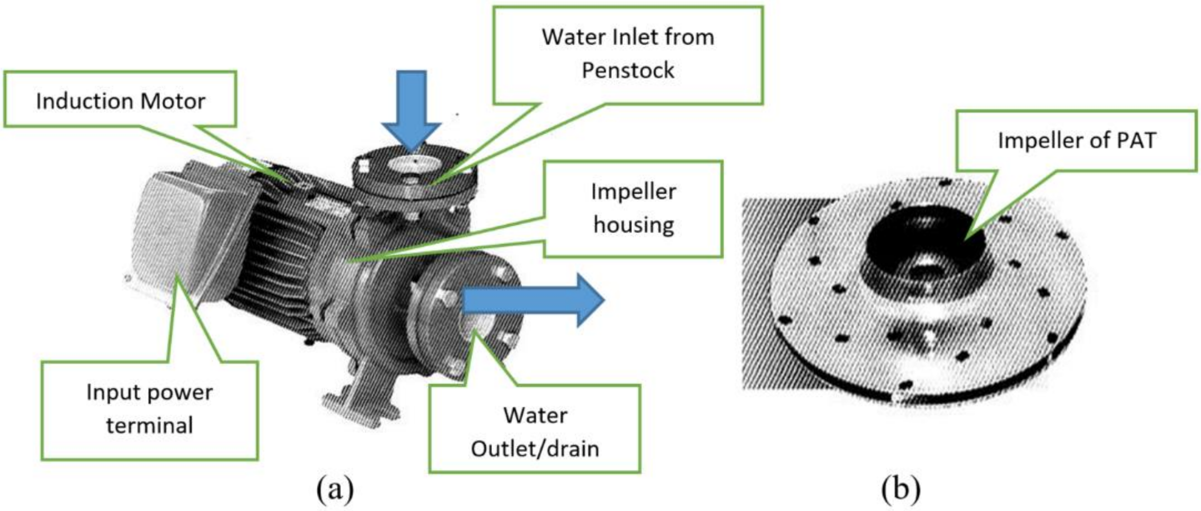



Fig. 3. Water centrifugal and Impeller.

Generator part, a three phase induction motor (Mitsubishi-Super Line) power motor [1.5 kW(2 HP), 4.0 pole, 380/220 V, 50 Hz ,work speed 1,430 rpm and synchronous speed 1,500 rpm] was selected as induction generator(IG) with a correct capacitor size and was connected in C-2C configuration as input terminal of the motor as shown on Fig. 4(a). Induction generator was installing separate from PAT that was connected by belt that shown as Fig. 4(b). Generator will be driven PAT in reverse mode at 1,500rpm to generate electrical power under 1.0 kW supply light bulb 5x100 W by with correct size of capacitor for self- excitation current and drive it to spin at synchronous speed for working as generator mode.

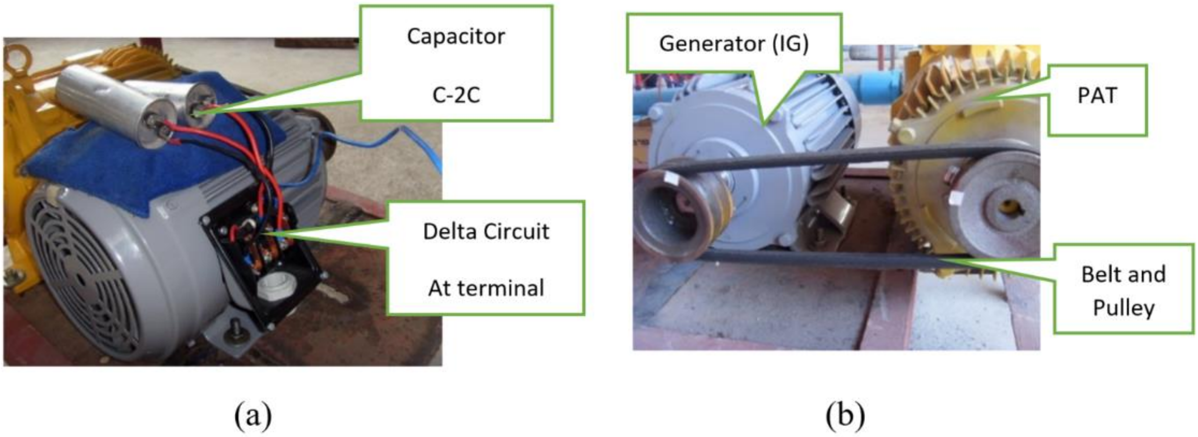



Fig. 4. Motor as generator (a) and PAT and IG connection (b).

Capacitor and C-2C connection, a Standard capacitor run type from an air conditioner system from the local market was selected as excitation device of the motor. As generator, that capacitor was connected in C-2C circuit at delta circuit of terminal of a motor that was r a modified three phase induction motor to change its operation to a single phase generator. The correct size of the capacitor for excitation can be solved using the following equation (5):

$$C = \frac{I_C * 10^6}{2\pi f_m * V_m} \quad (5)$$

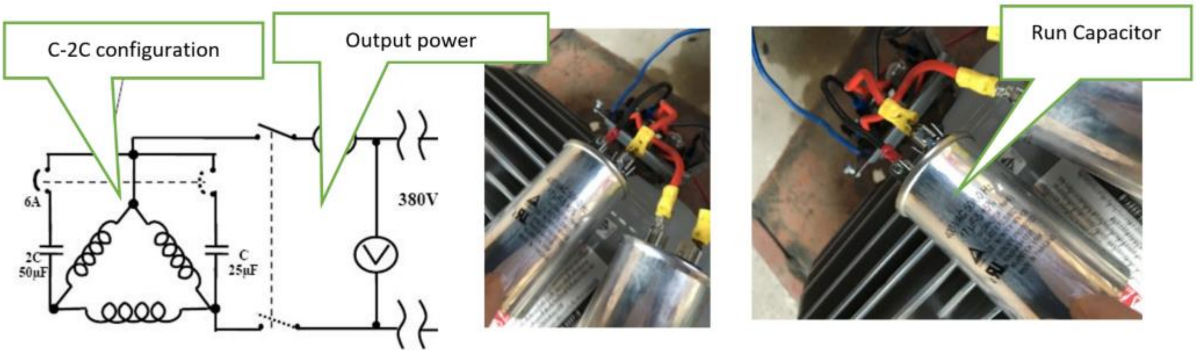
When (Use for delta configuration only)

$I_C$ = Capacitor Current (A)

$f_m$ = Frequency of motor ($H_z$)

$V_m$ = Voltage of motor (V)

Equation (5) can be calculated using the following parameters; P = 1,500 W, Frequency = 50 Hz, rate current = 5.9 A, voltage 220 V at 1,500 rpm and power factor 0.9. Results show that the following correct capacitor (C) size; C =20 μF and 2C= 40 μF to connect to a delta circuit of output of three phase motor in C-2C configuration. The installation is shown on Fig. 5(a), 5(b) and (c) below:




(a) Delta Circuit C-2C (b) C-2C connection (c) Capacitor Connection

Fig. 5. (a)Delta circuit at terminal of motor and (b), (c) C-2C connection.

Electrical Load for test, this experiment selected incandescent lamps [5x100 W (500 W) 220 V, 50 Hz single phase] as power load for testing the generator part of the Pico hydropower system/ This is shown on Fig. 6 below:


(a) (b)

Fig. 6. Electrical load for testing.

**The Complete construction of Pico hydropower system test bench**

The experimental pump as turbine and induction generator for Pico hydro power test bench was installed at the Electrical Industrial Technology Department, Phetchabun Rajabhat University. The various components of overall system are shown (both front and back side) on Fig. 7 (a) and (b) below:

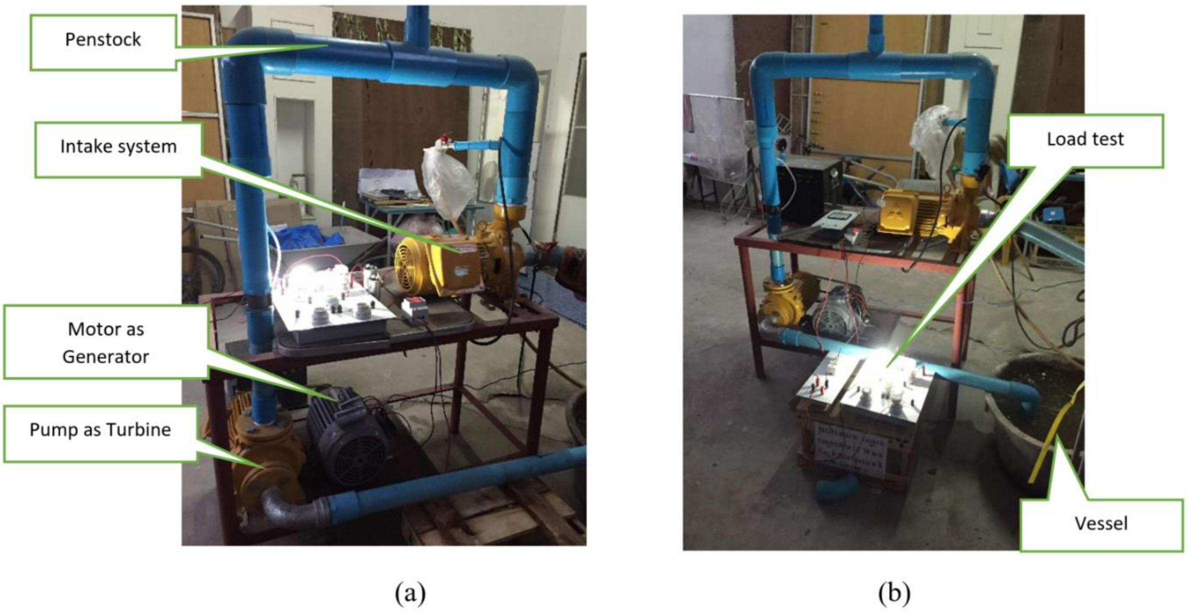



Fig. 7. Experimental of pico hydropower system test bench.

**Procedure of Test**

The series of experimental test bench involved estimating the hydropower potential to drive the turbine. The first experimental test bench involved using a suction pipe as intake system to pump water from the Vessel [capacity of 140 lit (37 cm x 99 cm) to the penstock [diameter of 3.0 inches]. The water was then channeled through a reducer [pipe diameter of 2 inches, length 0.5m] and flowed back to the vessel again. Measurement data were collected from the barometer and the flow meter 4 times. The second test involved using the water centrifugal pump as turbine (PAT) as intake system to generate hydro power. As before, water was channeled through the penstock. Measurement was done at the outlet of the PAT, but which was connected to a generator. Measurement data were collected from the barometer, flow meter and tachometer. The third test involved connecting the PAT with the three phase induction motor (IM) by belt and pulley. Again, as before, water was fed into the intake system and channeled to the penstock to generate hydro power. Measurement was done at the outlet of the PAT that was connected with the three-phase induction motor. Measurement data were collected from the barometer, flow meter and tachometer for 180 mins. The fourth l test involved determining the effect when the PAT was connected to an induction generator, using a correct capacitor size determined from equation (5). Smaller and over-sized capacitors were obtained from the local market and were modified in C-2C configuration. The three-phase induction motor and PAT were connected with belt and pulley. As previously, water is fed into the penstock to generate hydro power. Measurements are done at the outlet of the PAT, that was connected with induction generator which setup was modified with a capacitor, but without load connected. Measurements l data were collected from the barometer, flow meter and tachometer for 180 min. The final test involved the full experimental test of the pump as turbine (PAT) and induction generator was. The experimental test involved connecting the generator to loads. The generator supplied electricity to 5 x 100 W incandescent lamps. Capacitor test involved correct capacitor size as determined by equation (5), and lower and over-sized ones. Measurement data were collected from the barometer, flow meter, tachometer and power meter for 180 mins.

## 3. Results and Discussion

### *3.1 Intake system test*

The experimental test bench of the intake system to estimate the hydropower potential involved using a suction pipe as intake system to pump water from the Vessel [capacity of 140 lit (37 cm x 99 cm) to the penstock [diameter of 3.0 inches]. The water was then channeled through a reducer [pipe diameter of 2 inches, length 0.5 m] and flowed back to the vessel again. Measurement data were collected from the barometer and the flow meter 4 times.

The experimental data was collected by flow meter and use equation (1) and (2) and performance curve of pump for calculate. The results of the intake system tests are shown on Table 3.

Table 3 Hydro power and generator output from intake system.

| No | Power Estimate | Parameters | | | | Result (Watt) |
|---|---|---|---|---|---|---|
| | | Flow rate ($m^3$/ s) | Head (m) | Gravity ($m/s^2$) | Efficiency | |
| 1 | Hydropower | 4.3 | 7.7 | 9.8 | - | 324.4 |
| 2 | Generator output | 4.3 | 7.7 | 9.8 | 0.9 | 292.0 |

The results of the intake system tests show that the e intake system, at a water flow rate 4.3 $m^3/s$ in the penstock found that can generate hydropower 324.4 W with head 7.7 m that could produce electrical power 292 W, based on calculations using equations (1) and (2). However, the t actual hydro power generated was reduced to just 273 W lower than the estimates shown on Table 2.

### *3.2 Effect of using integral water pump to work as turbine (PAT).*

The results of the is experimental tests based on the data collected from the barometer, flow meter and laser tachometer; when the integrated water pump ran in the reverse mode as turbine without motor showed that the PAT can spin in the reverse mode with over than a synchronous speed 1,500 rpm to maximum speed 2,200 rpm, at constant speeds for 180 min. The results are shown on Table 4.

Table 4 Effect of testing water pump that work in reverse mode power as hydro turbine (PAT) for the pico hydro power systems.

| No. | Time (Min) | Speed of PAT (RPM) | Flow rate (Lit/min) | Pressure (Psi) | Suggestion status |
|---|---|---|---|---|---|
| 1 | 60 min | 2,200 | 260 | 0.9 | No damage all |
| 2 | 120 min | 2,200 | 260 | 0.9 | No damage all |
| 3 | 180 min | 2,200 | 260 | 0.9 | No damage all |

According to Table 4, the PAT can spin well in the reverse mode and can work as hydro turbine [without induction Motor (IM) and any complication] using a centrifugal pump [1.5 kW,220 V, 2.0 pole, 50 Hz] as intake system with constant speed for 180 min. The speed of the turbine, measured using a laser tachometer installed at the shaft of the PAT, indicated a constant 2,200 rpm over the synchronous speed of the induction generator [4.0 pole] There were no damage in any component of the PAT (such as impeller, cast and bearing) even with a flow rate of 260 lit/min (4.3 lit/s) and at a pipe pressure of 0.9 psi.

*3.3 Effect of PAT and IM when were connected by pulley and belt.*

This experimental test l aimed to show the effects when the PAT and IG are connected together by a pulley (diameter of 2.0 inches) and belt (length of 12 inches). The test used the intake system to channel water through the penstock into the PAT and IM for 180 minutes in which the speed of the turbine and the generator, the water pressure and flow rate of systems were measured. There was no damage to both the PAT and IM when both are rotated by hydropower at 1,850 rpm. Their speed of both the turbine and induction motor was decreased from 2,200 rpm to 1,850 rpm (The speed of PAT rotation was measured using a digital laser tachometer). The measurement indicated a pressure and water flow rate 0.7 psi and 220 lit/min, respectively. This is shown on Table 5.

Table 5 Result effect of PAT and IM when were connected by pulley and belt test.

| No. | Time (Min) | Speed of PAT (RPM) | Speed of Motor (RPM) | Flow rate (Lit/min) | Pressure (Psi) | PAT status (perceive) |
|---|---|---|---|---|---|---|
| 1 | 60min | 1,850 | 1,850 | 220 | 0.7 | No damage |
| 2 | 120min | 1,850 | 1,850 | 220 | 0.7 | No damage |
| 3 | 180min | 1,850 | 1,850 | 220 | 0.7 | No damage |

According to Table 5, the speed of the turbine and generator are equal, but flow rate and water pressure of the pico hydro system decreased when the PAT was connected to an IG. The PAT and IG could be connected by belt and pulley without any effect on pico hydropower system.

*3.4 Effect of experimental test bench when IG was connected by capacitor in C-2C configuration (No-load).*

This l test aim to demonstrate an experimental test bench wherein a l capacitor C-2C configuration in delta circuit was installed to modify to make IM work as am IG. The first test involved installing a lower-size capacitor based on C = 15 µF and 2C 30 µF for (the lower size) testing. The second test installed capacitor of C = 20 µF and 2C = 40 µF (the calculated size) for testing. The final time test installed an oversize capacitor of C = 25 µF and 2C = 50 µF (for the over size) testing. Test results found that water flow rate of system decreased when connected by capacitor of any size, with the pressure remaining constant pressure. These results are shown on Table 6.

Table 6 Effect of experiment test bench when IM was connected with C-2C (No-load).

| No. | Size of Capacitor ( µF) | | Flow rate (lit/min) | Pressure Psi | Speed of PAT (rpm) | Speed of IG (rpm) |
|---|---|---|---|---|---|---|
| | C | 2C | | | | |
| 1 | 15 | 30 | 210 | 0.7 | 1,650 | 1,650 |
| 2 | 20 | 40 | 200 | 0.7 | 1.530 | 1,530 |
| 3 | 25 | 20 | 195 | 0,7 | 1,410 | 1,410 |

Table 6 shows that the capacitor, depending on the size of the capacitor can reduce or increase the speed of the o turbine. The correct size of capacitor = 20 ( µF) should be selected, or an oversize can be calculated to synchronize the speed of generator to make it suitable to generate electrical power.

*3.5. Effect of experimental test bench when IG was connected to supply full load test.*

In this test of the Pico hydro power test bench, five incandescent lamps [100 W, 220 V, 50 Hz] were connected to fully test bench the generator part circuit as shown on Figure 8(a) and the results of experimental test is shown on Fig. 8(b). As before, to generate electrical power, water was fed to the intake system part and then channeled into the penstock to drive the PAT and IG, rotating it verse mode.

The result of the testing showed that the speed of the PAT and IG decreased suddenly when switch on for of the load test. A constant 1,550 rpm was reached with a capacitor C = 15 μF and 2C = 30 μF and a lower of speed of 1,320 rpm when C = 20 μF and 2C = 40 μF; where both capacitors were installed in C-2C configuration. Power output of the system is adequate only for generating n electrical power to for a load of 3 x 100 W (or total of 300 W) incandescent lamp as shown on Table 7.

Table 7 Effect of experimental test bench when IG was connected to supply full load test.

| Size of Capacitor (μF) Single Phase Generator | | Speed of Generator | Voltage | Freq. | Load 5 x 100 W Incandescent Lamp | |
|---|---|---|---|---|---|---|
| C | 2C | (rpm) | | Hz | status | Power out |
| 15 | 30 | 1,550 | 218 | 48 | On -3lamp | 300W |
| 20 | 40 | 1,450 | 212 | 48 | On- 3lamp | 300W |
| 25 | 20 | 1,320 | 209 | 48 | On- 3lamp | 300W |

Accoding data from Table 6 should to sellect size of capacitor C = 20 μF and 2C = 40 μF due to generator of pico hydro power test bench could generate elctrical power with nearby synchronous speed but should sellect three phase induction motor that higher power rate 1.5 kW for incandescent lamp 500 W.

(a)

(b)

Fig. 8. Incandescent lamp for experimental test of test bench (a) and (b).

## 5. Conclusions

The experimental tests in this research aimed to develop a design for pico hydropower system that is low cost, easy to install and generate electrical power that can be used in small rural households, which are off-grid (far away from the grid line and far for extension). The end objective of the research is to promote pico hydropower in developing countries that still have unelectrified areas far from the grid. Pump as turbine (PAT) connected to an induction generator is a good alternative design for pico hydropower generation. This study designed, fabricated and test bench such a system, which is around 0.1 kW range. In addition, the power output of this system, which used a water centrifugal pump as hydro turbine instead conventional turbine and use induction motor as generator instead synchronous generator to supply a load consisting of candescent lamps (capacity = 5x100 W) was measured. dein the result of experimental tests showed the good potential of a water centrifugal pump operated as hydro turbine, connected to an induction motor operated as s generator to generate electrical power, as a possible design for a pico hydro power generation supply, to supply electricity for lighting in small rural households. However, the voltage and frequency, and power output of the system decreased allowing only power supply to a lower incandescent lamp load of equal to 3x100 W (or total of 300 W).

## 6. Acknowledgements

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## 7. References

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