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Research paper

Development and Experimental Study of a Small-Scale Energy Harvester for Domestic Usage

Ahmad Muzaffar Abdul Kadir, Wan Norhisyam Abd Rashid, Shahrizal Saat, Ab Wafi Ab Aziz

Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka
**Corresponding author E-mail: muzaffar@utem.edu.my*

Abstract

Energy harvester is the system which gather energy from the external environment sources such as radio waves, air flow, water flow, solar energy, wind energy and kinetic energy and specially used to power or recharge small electronic devices. One of the biggest potential which can be utilized to generate energy is the water flow in the home water pipes. Instead of letting the water flow through the pipe, a small water turbine is fixed on the pipe to let the water flow through the pipe and at the same time it will generate electricity to charge a battery. This complete system is installed at the water tank on the roof. A battery monitoring system is developed to monitor the performance of the small energy harvester system. The complete system consists of converter, generator and a monitoring system. To determine the state of charge of the 12V lead-acid battery, a monitoring system that manipulate signal from the signal conditioning system which acquire signal from the DC-DC booster will be converted by using Analog-to-Digital Converter (ADC) and then transferred to smartphone through Bluetooth Module to monitor the status of battery.

Keywords: *Battery Monitoring Systems; DC-DC boost converter; State-of-charge (SOC), State-of-health, battery.*

1. Introduction

In the early days, energy has been produced by the watermills, windmills and conventional solar power systems. In the era of technology, energy harvester is widely used for domestic usage since it utilizes renewable energy sources. Energy Harvester also known as power harvester or energy scavenger is a process to capture energy from environment and then it is converted into usable electric power (Wahab, Islam, Bhuyan, Jahariah, & Ali, 2017). Energy harvester supplies power to electronic devices where there is no conventional power source. This is the new way to produce power supply on its own or in another word self-powered devices (Priya et al., 2017; Reddy, Umapathy, Ezhilarasi, & Uma, 2015; Skow, Cunefare, & Erturk, 2014). With energy harvester system, there are two significant advantages over battery powered devices namely: literally never ending sources and zero negative effect to the environment.

There are two categories of energy harvesting techniques which include macro- scale energy harvesting and micro-scale energy harvesting technologies. Macro –scale technology is normally developed to feed the power to the power distribution system whereas, micro-scale energy harvesting technology has the capabilities to extract tiny power in the term of milliwats from the environment such as solar, vibration, thermal and biological sources (Raju, 2008).

Apart from taking advantage of this new technology, a significant increase of awareness among people to consider the usage of renewable energy has contributed to the importance of developing energy harvester technology which can help to reduce the negative impact of fossil fuel to the global climate (Firdaus et al., 2016; Hadi, Rashid, Hashim, Mohamad, & Kadmin, 2017; Ohunakin, 2010). Moreover, the increasing energy demand has boosted the effort of looking the new way to fulfill the demand. The potential of energy harvester technology has become the eye opener to the authorities to support and enhance the research and development of this new technology (Zainal, Hussein, Siwar, & Ahmad L, 2015).

Energy harvester has also become part of the smart homes in which it is utilized to make sure that the power consumption and energy usage are optimized significantly. Sensor nodes, smart electronic devices and intelligent electricity networks have become batteryless with the help of energy harvester technology (Alam, Reaz, & Ali, 2012). There are several advantages of using energy harvesting technology in the building. The maintenance cost can be reduced by eliminating the needs to replace batteries or any devices which depend on the life-span of batteries. The size of electronic devices can be reduced and the energy which is wasted within the building can be also captured for a better purpose (Matiko, Grabham, Beeby, & Tudor, 2014).

(Carli, Brunelli, Benini, & Ruggeri, 2011) have presented that measured design gathers the energy from each of the associated energy harvester subsystems in a simultaneous and free-way. A lithium-ion or nickel-metal hydride rechargeable battery connected to ensure the framework against long stretches of ambient energy shortage and enhances its general reliability. An energy harvester defined as interface between the renewable ambient energy sources and one or a few vitality customers or loads. The genuine test in the configuration of energy harvester system is to give consistent and stable power supply to the load compare to the accessibility attributes of the vitality sources. To perform the end-to-end power exchange with the most extreme conceivable effectiveness and it should act as a buffer between the variable power utilization of the last framework and the wide element range of the encompassing sources.

(Casini, 2015) has done a comprehensive study about in-pipe hydro systems for urban and building scale. He mentioned that, in –pipe hydro system has a few advantages over other types of energy harvesting sources such as wind and solar. Wind and solar are exposed to intermittency however, in-pipe hydro system can provide constant amount of flow and energy can be generated continuously. There are two types of in-pipe hydro systems namely internal and external systems. Each of these systems has benefits over each other's. In this project, we tried to develop and perform experimental study on the small scale energy harvester for domestic usage. We used a small water turbine which replicate the external in-pipe system. Figure 1 shows the overall framework of the system.

Fig 1: The Block Diagram of the Energy Harvesting system.

2. Methodology

The energy harvesting system as shown in Figure 1 consists of the charge controller, microcontroller, Bluetooth Module and smartphone. When the smartphone is connected with Bluetooth, the signal data which depicts the battery status will be displayed on the smartphone.

In this part, each of the components will be described individually together with its functional concept. The electricity is generated by the small water turbine which will convert the kinetic and potential energy to mechanical work and it will produce electricity. There are several advantages of using hydro power including flexibility, lower maintenance and operating cost, large storage capacity, high reliability and high efficiency (Chen, Yang, Liu, Lau, & Lo, 2013; Hwang, Lee, & Kim, 2009). A water turbine can generate maximum power output when the water deflects on the turbine blade and produce kinetic energy:

$$Kinetic\ Energy = \frac{1}{2}\, m\, v^2$$

Lets consider the efficiency of the turbine η and its installation. Maximum output power Pmax is given by

$$P_{max} = \frac{1}{2}\eta\rho Q v^2$$

Pmax = maximum output power
v = velocity of the water flow
Q = volume of the water flowing through the turbine per second.
Q is given by

$$Q = Av$$

where A is the swept area of the turbine blades.
Thus

$$P_{max} = \frac{1}{2}\eta\rho A v^3$$

From the equation we know that the power output is proportional to the cube of the velocity of the water. Table 1 shows the electrical specification of the small water turbine.

Table 1. Electrical Specification of the small water turbine

Parameter	Value
Output Voltage	12 V
Insulation Resistance	10 MΩ
Max Pressure (Outlet Closed)	0.6 Mpa
Max Pressure (Outlet Opening)	1.2 Mpa
Start Pressure	0.05 Mpa
Mechanical Noise	≤ 55 dB
Generator Life	≥ 3000 Hrs

The charging process is controlled by the charger controller. This will prevent the battery from overcharge and deep discharge which will damage the battery. Charging process will stop when it reaches maximum set point which is around 14V. Any excess discharging process can be stopped at minimum set point at 11V.

3. Results and Discussion

Test has been done on water turbine to test the capability of the small water turbine to generate electric. When the water pressure is increased, the output current and the output voltage is increased. Table shows the output voltage and the output current of water turbine with different water pressure.

Table 2. Output voltage for different water pressure

Water pressure, psi	Output voltage, V
0	0
6.25	3
12.5	7.8
18.75	10.3
25	11.8
31.25	11.8
37.5	11.8
43.75	11.8

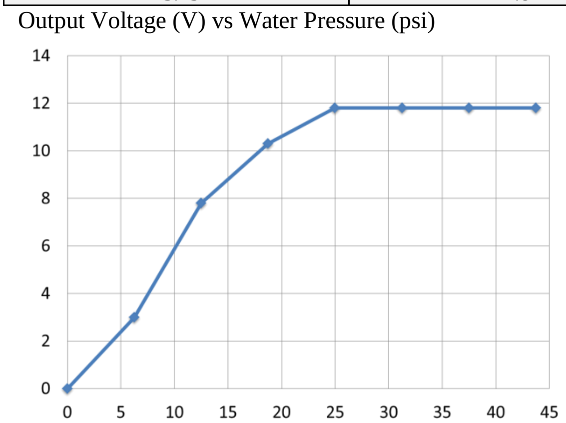

Fig 2: Output voltage (V) for different water pressure (psi)

Figure 2 shows a graph of output voltage against water pressure. It shows increasing values of voltage as water pressure increases.

Table 3. Output current for different water pressure.

Water pressure, psi	Output current, A
0	0
6.25	3
12.5	7.8
18.75	10.3
25	11.8
31.25	11.8
37.5	11.8
43.75	11.8

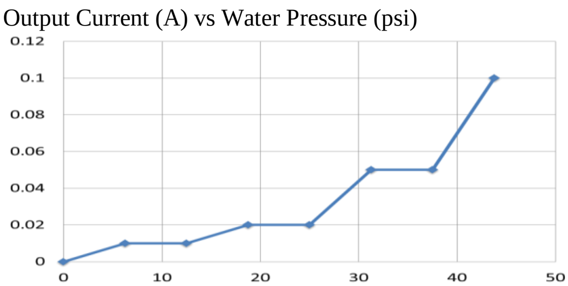

Fig 3: Current values (A) for different water pressure (psi)

Figure 3 shows a graph of output current values (A) against water pressure (psi). It shows increasing values of current as water pressure values increases.

Table 4. Flow rate at different water pressure

Water Pressure (psi)	Flow rate (L/hour)
0	0
6.25	128
12.5	310
18.75	368
25	408
31.25	464
37.5	488
43.75	580

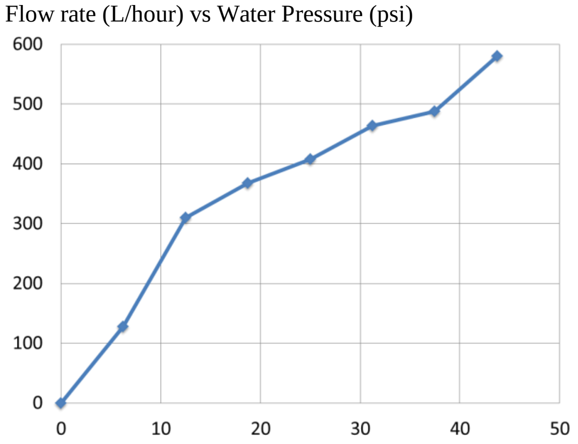

Fig 4: Flow rate (L/hour) for different water pressure (psi)

Meanwhile Figure 4 shows a graph of flow rate (L/hour) for different water pressure (psi). It also shows increasing values of water volumetic flow rate.

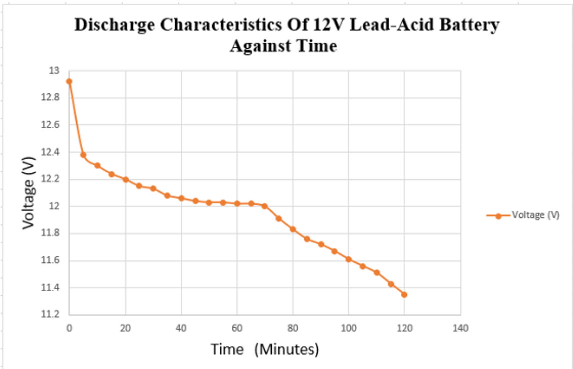

Fig 5: Discharging Process of 12V Lead acid batteries

Figure 5 shows the analysis of discharge characteristics of 12V lead-acid battery against time (minute) during daytime room temperature in order to monitor the performance of battery at room temperature. The initial voltage of the 12V lead-acid battery is 12.92 V without applied load. When the load was applied to the 12V lead-acid battery, the voltage of battery decreases from 12.92 V to 11.35 V with the rate of discharge times about 120 minutes or 2 hours. These is due to the chemical reaction of sulfuric acid within the positive terminal and negative terminal of the 12V lead-acid battery with lead sulfate or the process known as sulfation of battery. When the battery keeps on discharge, the lead sulfate coat increasingly on the plates and cause the 12V lead-acid battery starts to discharge from 12.92 V till the battery completely discharged with the lead sulfate will completely cover on the plates inside battery cell. The rate of discharge time of lead-acid battery affected by surrounding temperature which effects the performance of battery change with the surrounding temperature. During high temperature at daytimes, the electrolyte inside battery cells activate chemical process of sulfation inside battery cell which causes the battery discharge at shorter duration times compare to room temperature at night times which require longer duration times for discharge the battery.

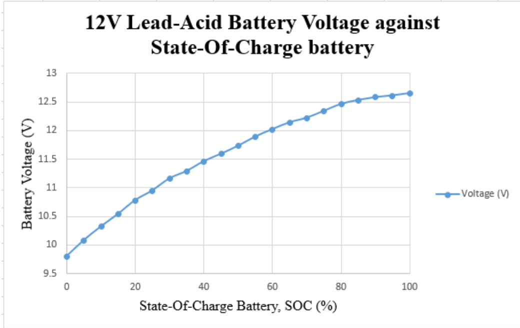

Fig 6: The Charging Process of 12V Lead Acid Battery

Figure 6 shows the analysis of 12V lead-acid battery voltage (V) against state-of-charge battery, or SOC (%) at normal room temperature. The minimum voltage of lead-acid battery is 9.8 V and SOC battery at 0 %. When the lead-acid battery is charging at constant voltage, the maximum voltage is 12.65 V and SOC is 100 % which means that the lead-acid battery fully charging with maximum storage of voltage capacity with 12.65 V inside the battery cells. During the charging lead-acid battery process, the heat losses of I^2 R inside battery cells due to the temperature and current input leads to rate of chemical conversion process inside lead-acid battery cells. The internal resistance of 12 V lead-acid batteries approximately about 90 mΩ which have affects to the effective capacity of battery cells. As the lower the value of internal resistance inside lead-acid battery, the lower the heat losses during charging process under high current input to the lead-acid battery. The resistance of electrolyte increases and the effective battery cells plates decreases inside the 12V lead-acid battery will leads to rapid aging process battery and reduce the state-of-charge battery performance.

4. Conclusion

Based on the experiment results, we can conclude this energy harvesting system can be used to charge a small 12V lead acid battery. Water flow in the pipe has been successfully utilized to charge the battery. These results further support the idea of establishing a small scale energy harvester system for domestic usage. Furthermore, this study has thrown up many questions in need of further investigation. Further work needs to be done to study different types of batteries and other generation schemes which can be used as one of the sources for the energy harvester system.

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