Australian Journal of Basic and Applied Sciences, 8(4) Special 2014, Pages: 746-751

AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

Photovoltaic - Battery System to Power Fan-Controlled Rice Husk Gasifier Cooking Stove

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ARTICLE INFO

Article history:
Received 20 November 2013
Received in revised form 24 January 2014
Accepted 29 January 2014
Available online 2 April 2014

Keywords:
Stand-alone photovoltaic system, Belonio rice husk gasifier, economics

ABSTRACT

More than three billion people use wood, dung, coal and other traditional fuels for cooking inside their homes. Inefficient wood stoves are responsible for indoor air pollution, respiratory related diseases and deaths but also accelerated deforestation due to excessive fuel consumption. A promising stove is the open-source, fan-controlled, top-lit updraft, autothermal Belonio gasifier. The need of electricity to power the fan proves to be an obstacle for low-income families without access to electricity. The aim of this study therefore was to develop an economical, environmentally friendly, emission-free solution to power the Belonio stove fan. Consequently, a PV-battery system was designed inclusive of charge controller and inverter. The overall efficiency of the PV-battery, battery-inverter, and inverter-fan in the system was found to be 43.8 %. Fan speed had a great effect on inverter efficiency requiring either additional electricity consumers such as lighting or mobile phone charger or the use of a DC fan in which case the inverter can be omitted. However, economically viable fan speed controllers for DC fans must be developed. The daily cost of cooking for an average 5 family household was estimated to be RM 0.40 which can be further reduced with mass production of the stand-alone PV powered Belonio gasifier system.

To Cite This Article: Qurni, U. and Bachmann, R.T., Photovoltaic - Battery System to Power Fan-Controlled Rice Husk Gasifier Cooking Stove. ***Aust. J. Basic & Appl. Sci.,*** *8(4): 746-751, 2014*

INTRODUCTION

Energy is essential to meet our most basic needs: cooking, boiling water, lighting and heating. It is also a prerequisite for good health – a reality that has been largely ignored by the world community. More than three billion people still burn wood, dung, coal and other traditional fuels inside their homes resulting in indoor air pollution responsible for more than 1.5 million deaths a year – mostly of young children and their mothers. Millions more suffer every day with difficulty in breathing, stinging eyes and chronic respiratory disease (WHO, 2006; Naeher *et al*., 2007; Martin II *et al*., 2014). Inefficient wood stoves, for example, also require families to spend significant amount of their daily activities on collecting firewood as well as are responsible for accelerated deforestation due to excessive fuel consumption.

In order to improve the medical, socio-economic and environmental impact of inefficient stoves it is vital to design stoves that have low CO and PM10 emissions, are fuel-efficient, easy to use and affordable. Numerous designs have been proposed over the past few decades that may be classified broadly into natural vs. forced draft, top-lit vs. bottom-lit, autothermal vs. allothermal, gasifier vs. combustion stoves (Hale *et al*., 2012; MacCarty *et al*., 2008; Johnson *et al*., 2010). A promising stove is the open-source, fan-controlled, top-lit updraft, autothermal Belonio gasifier comprising of a small cylinder equipped with a fan in its base, which provides air during the conversion of rice husk into char and flammable gas that can be used for cooking and/or heating (Kumar, 2011). While fan-assisted stoves allow users to control the cooking process they need electricity to power the fan. This proves to be an obstacle for low-income families without access to electricity.

Solar electricity is one of the most accessible forms of renewable energy available, and it can be adapted to fit anyone's specific needs. area commonly used solution for stand-alone power applications is the PV-battery system, which is independent of the national power grid system and uses batteries to store the PV electricity generated for later usage. In order to supply the electricity to the fan unit, inverters are used to convert the direct current (DC) input from the battery into the alternating current (AC) output for the fan. One of the major advantages of the PV-battery system provides silent and clean power with far less maintenance than an engine generator, and the mobility of the system (Mayfield, 2010).

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The main objective of this project was therefore to develop an environmentally friendly, emission-free solution to power the Belonio stove fan.

2. Experimental:

A. Components:

The stand-alone PV system comprised of a sealed 12V, 7.5 Ah lead acid battery (model SPM007SB); a 10 W_P monocrystalline PV module (model SPM010-M); a 12 V, 10 A solar charge controller (GAMMA 2.0) and a 150 W inverter (THETA SPM150MS) connected to a 21 W, 240 V axial fan (Fig. 1 and 2) attached to the Belonio rice husk gasifier. The tilt angle of the PV module was 5° with an azimuth of 180°.

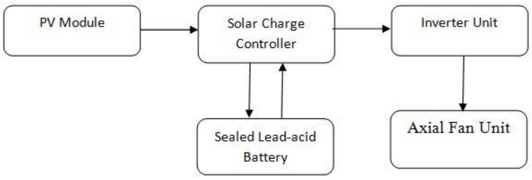


Fig. 1: The block flow diagram of the PV-battery-inverter system. The arrow represents the flow of energy.

Fig. 2: PV-battery-inverter unit connected to the Belonio rice husk gasifier. PV module tilt angle shown for illustrative purposes only.

Effect of weather on battery re-charge time:

The time required to fully re-charge the battery after discharge was monitored at different weather conditions (sunny, cloudy and rainy).

Effect of fan speed on battery operation time:

The time the battery lasts as a function of fan speed (low, medium, and high) was determined, and the electricity consumption of the fan was monitored using a commercially available electricity meter.

Energetic performance:

Battery charge efficiency

$$\eta_{charging} = \frac{Charge\ controller\ to\ battery\ [Wh_{el}]}{PV\ to\ charge\ controller\ [Wh_{el}]} \times 100\,\%$$

Battery discharge efficiency

$$\eta_{discharge} = \frac{Charge\ controller\ to\ inverter[Wh_{el}]}{Battery\ to\ charge\ controller\ [Wh_{el}]} \times 100\,\%$$

Inverter efficiency

$$\eta_{inverter} = \frac{Inverter\ to\ fan\ [Wh_{el}]}{Charge\ controller\ to\ inverter\ [Wh_{el}]} \times 100\,\%$$

Overall efficiency,

$$\eta_{overall} = \frac{\eta_{charging} \times \eta_{discharge} \times \eta_{inverter}}{10000}$$

RESULT AND DISCUSSION

A. Weather effects:

The weather conditions were found to play a less important role on the charge efficiency of the battery. During sunny weather, the average battery charge efficiency was 75.4 % ± 0.4 %, followed by overcast (74.8 % ± 0.1 %) and rainy (74.4 % ± 0.8 %) weather (Fig. 3). The battery charge efficiency is in agreement with the range (67 – 73 %) as reported by Shiroudi *et al*. (2012). The module temperature reached a maximum of 61°C during sunny and 43°C during rainy weather. Higher temperatures reduce the performance of the PV module although the amount of solar radiation received resulted in a greater net electricity production.

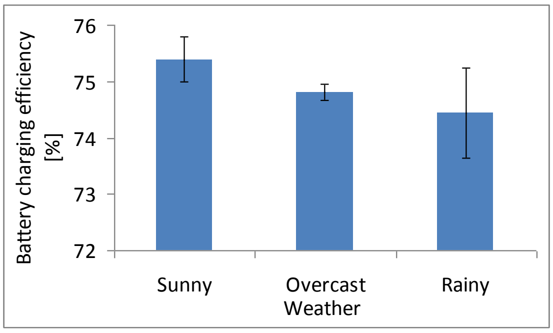


Fig. 3: Average battery charge efficiency as a function of weather.

One factor that may have caused the slightly lower inefficiencies of the system was the electrical power consumption of the charge controller which was greater during overcast and rainy weather due to the longer charging time. From Fig. 3, the average charge efficiency of the PV-battery system was 74.9 %, which was used for the calculation of the overall efficiency of the system.

B. Fan speed effects on battery discharge efficiency:

The average energy consumption of the fan at lowest fan speed was 15.5 ± 0.1 Wh. The average electricity consumption of the fan increased to 16.7 ± 0.2 Wh at medium and 18.16 ± 0.04 Wh at maximum fan speed (Fig. 4).

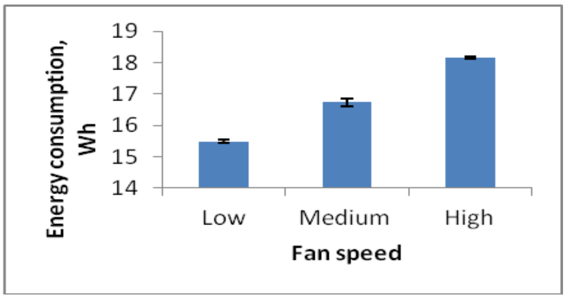


Fig. 4: Average energy consumption of axial fan versus fan speed.

Results of the effect of fan speed on battery discharge efficiency are shown in Fig. 5**.** At fan speed setting 'low', the average inverter efficiency was 92.60 ± 0.04 %, followed by medium (93.0 ± 0.1%) and high (93.4 % ± 0.3 %).

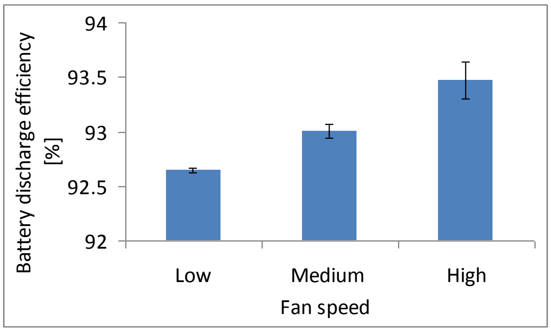


Fig. 5: Battery discharge efficiency as a function of fan speed.

The increase of average battery discharge efficiency was marginal and arguably caused by a better performance of the charge controller at higher current flow.

From Fig. 5**,** the average discharge efficiency was determined to be 93.0 %, which was used for the calculation of the overall efficiency of the system.

C. Fan speed effects on inverter efficiency:

This experiment was conducted concurrently with the experiment that established the relations between fan speed and battery discharge efficiency.

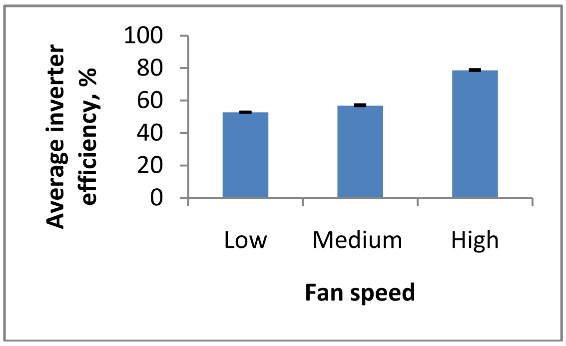


Fig. 6: Average inverter efficiency versus fan speed setting.

The inverter converted the incoming 12V, direct current from the battery into 240V, 50 Hz alternating current as required by the fan of the Belonio rice husk gasifier. While using the low fan speed setting, the average inverter efficiency was 52.7 % ± 0.3%, which increased to 57.0 ± 0.7% at medium and 78.7 ± 0.6 % at maximum fan speed (Fig. 6).

The increase of inverter efficiency with power consumption was expected since inverter efficiency is dependent on the load. In order to improve the inverter efficiency a smaller unit should be selected. However, no smaller units were available in the market at the time of purchase. Alternatively, the load could be increased to improve the inverter efficiency for example through addition of a mobile phone charge station or for lighting purposes.

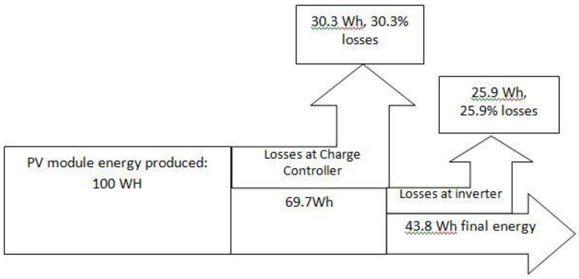
The average inverter efficiency was calculated to be 62.8 %, and used for calculating the overall efficiency of the power system.

D. Overall efficiency of the stand-alone system:

The overall average efficiency of the stand-alone system was found to be 43.8 % (Fig. 7), which is slightly below the range of 50 – 85 % reported in literature (Shiroudi *et al*., 2012).

In order to improve the overall efficiency one could increase the load as discussed. It is also possible to replace the AC fan with a DC fan thus rendering the inverter redundant. However, there is no economically viable speed controller available in the market.

While using the PV-hybrid system, the typical energy produced by the PV module during 10 hours of sun shine (mixed weather), was 47.8 Wh, of which 20.9 Wh reached the fan sufficient to operate the Belonio cooking stove for 1.5 hours per day.



The overall losses in the PV-hybrid system

E. Economics:

Overall capital costs of the stand-alone system and Belonio rice husk gasifier prototype was RM 1500. Assuming a lifetime of 10 years (battery operated in floating charge mode) and no fuel costs for sun and rice husk, the daily cooking costs for a 5 family household were estimated to be RM 0.40 / (d • family). Costs of the prototype can be reduced by an estimated 50 % when mass produced. Other benefits such as improved health, garden soil fertility from the biochar (Kumar, 2012) and extra time for other income-generating activities may also be expressed in financial terms thus further improving the cost-effectiveness of the Belonio gasifier.

Conclusion:

The overall efficiency of the stand-alone system was found to be 43.8 %. Weather and fan speed appeared to have no noticeable effect on battery charge and discharge efficiency, respectively. However, fan speed had a great effect on inverter efficiency requiring either additional electricity consumers such as lighting or mobile phone charger or the use of a DC fan in which case the inverter can be omitted. However, economically viable fan speed controllers for DC fans must be developed. The daily cost of cooking for an average 5 family household was estimated to be RM 0.40 which can be further reduced with mass production of the stand-alone Belonio gasifier system.

ACKNOWLEDGEMENT

We would like to thank Ms Marsita from TATI University College for assisting with the review of the manuscript.

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