Evolution in Electrical and Electronic Engineering Vol. 4 No. 2 (2023) 133-139

EEEE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Charge Controller for Solar-Wind Hybrid Energy Harvesting System

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DOI: https://doi.org/10.30880/eeee.2023.04.02.018
Received 28 June 2023; Accepted 31 July 2023; Available online 30 October 2023

Abstract: The usage of renewable energy in society is growing broader and diversified day by day as environmental awareness is gradually being raised by the new generations. Moreover, the hybrid way of green energy harvesting has become a new trend with the intent to increase the reliability and quality of energy harvesting which is also expected to decrease the cost in terms of electrical tariff. The main objective of this article is to design and construct a prototype of the portable solar-wind hybrid energy harvesting system which is proposed with an innovative concept of a hybrid charge controller. The charge controller is designed to regulate both sources with different corresponding voltage levels which result in a common desired output voltage level. The maximum regulated output for the current of 6.21A is 13.8 V where the maximum output power is 85.7 W. The most significant limitation of this converter is the acceptance range of input voltage level for regulation is quite narrow after tunned with certain desired output voltage levels. The portability of this system makes it possible to be applied on vehicles and automatic machines as it is capable of supporting small power application devices.

Keywords: Hybrid Energy Harvesting, Charge Controller, Energy Management System

1. Introduction

Environmental awareness has been gradually recognized by society which started to reflect and advocate for the protection and preservation through a series of actions such as campaigns, education and legislation [1]. However, some of the cleaning sites like lakes and seas might have difficulty conducting cleaning operations as hazards might posed due to unpredictable conditions. Hence, a cleaning machine was introduced to replace humans in a high-risk and complicated operation.

Generally, a typical mobile machine is powered by a battery system that is designed with an assigned operating duration [2]. Battery recharging or battery replacement is needed when the stored energy in the battery is not sufficient to supply the machine load. It could be a burden when a battery low happens during operation as the machine needs to be retrieved manually.

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Moreover, renewable energy sources such as solar, wind and hydro have sprung up as an alternative path or backup of the power grid supply since they can reduce energy costs and pollution towards the environment [3]. However, the power supply of a single-source harvesting system is not that stable as compared to a power grid supply in which the harvesting power might fluctuate due to environmental factors.

Hence, the solar-wind hybrid energy harvesting system is designed and developed as the main power supply for the lake surface cleaning machine. The hybrid sources could strengthen and provide a more stable power supply for the machine with the aid of an energy management system.

2. Materials and Methods

2.1 Materials

Specifications and properties of materials, equipment, and other resources used in the current study described in this section:

- 80 W monocrystalline solar panel
- 15 W DC generator
- MOSFET IRF4905
- BJT 2N2222A
- 10A4 diodes
- 3mH inductors
- 2uF capacitors

2.2 Methods

The diagram illustrates the wiring construction of the hybrid energy charge controller. The input voltage of both sources is detected by 25 V DC voltage sensors respectively and sends the measurement signals back to the processor [4]. The processor receives the signals and compares the voltage value with the ideal voltage value that is set in the command. Then, the processor selects the level of the pulse width modulation (PWM) according to the input voltage range and send the signals to the base pin of the BJT 2n2222 to control the MOSFET for switching purpose indirectly [5]. Figure 1 shows the circuit design of the Arduino-based charge controller.

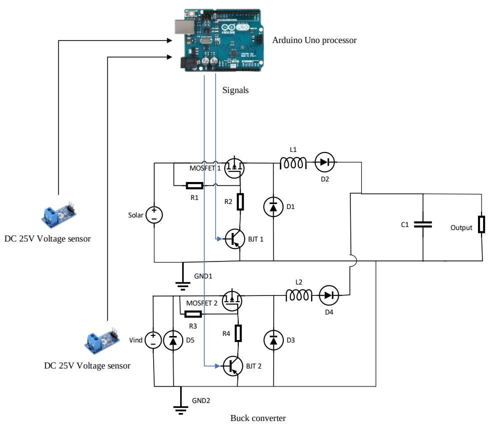


Figure 1: Circuit design of the Arduino-based charge controller.

Basically, the Arduino will produce the corresponding PWM signals for voltage regulation before supplying to loads [6]. While the energy management system emphasizes on relay control based on the conditions encountered. Figure 2 and Figure 3 show the flowchart operation of the solar-wind hybrid energy harvesting system and energy management system respectively. Meanwhile, Figure 4 shows the circuit design of the energy management system in the form of a flowchart and diagram respectively [7].

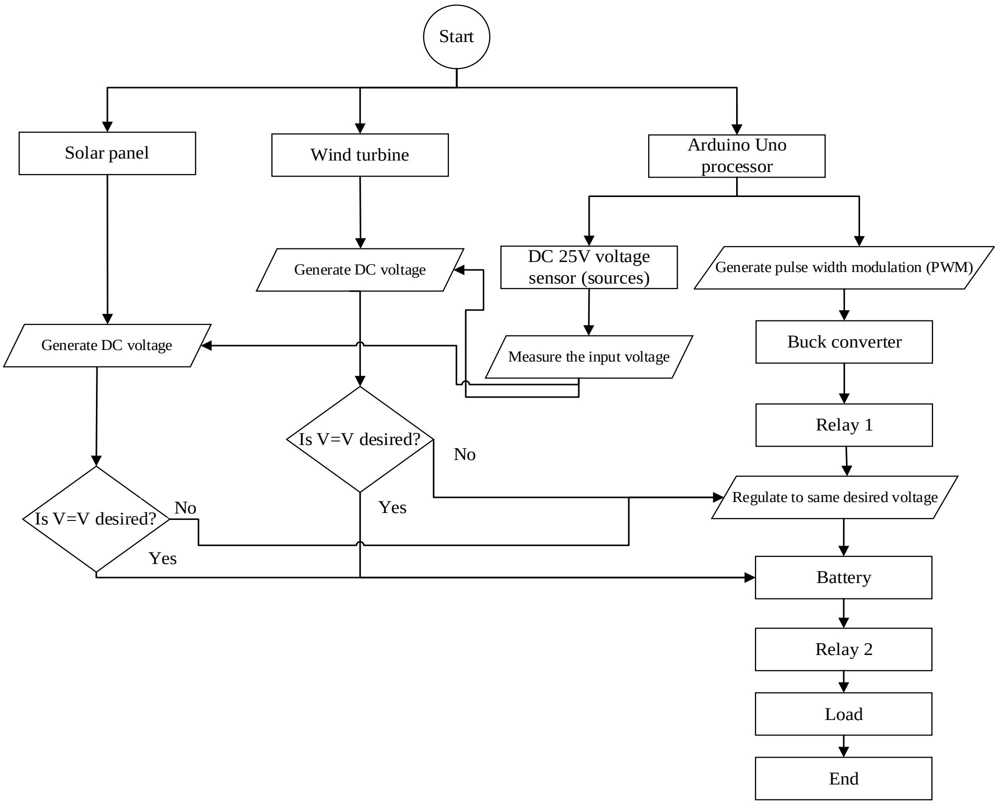


Figure 2: Flowchart of the operation of Solar-Wind Hybrid Harvesting System

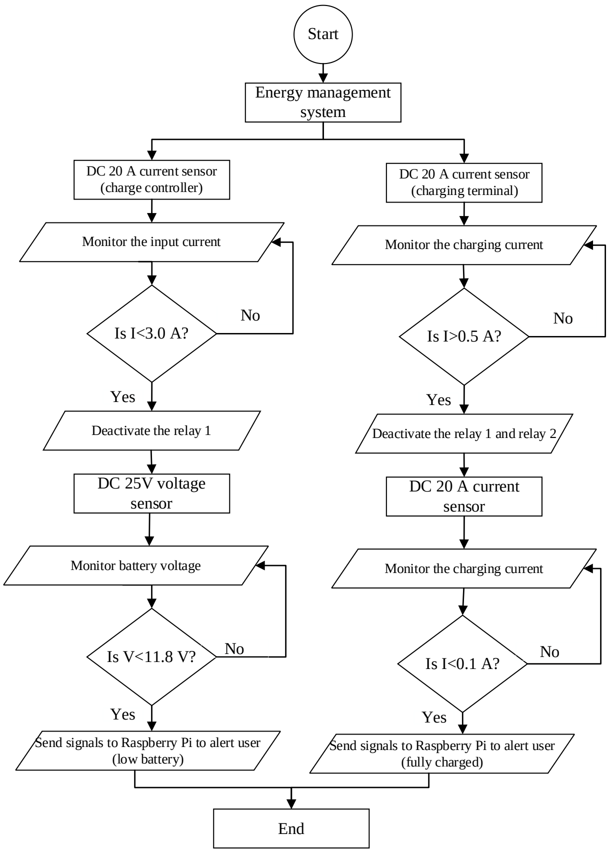


Figure 3: Flowchart of the operation of energy management system

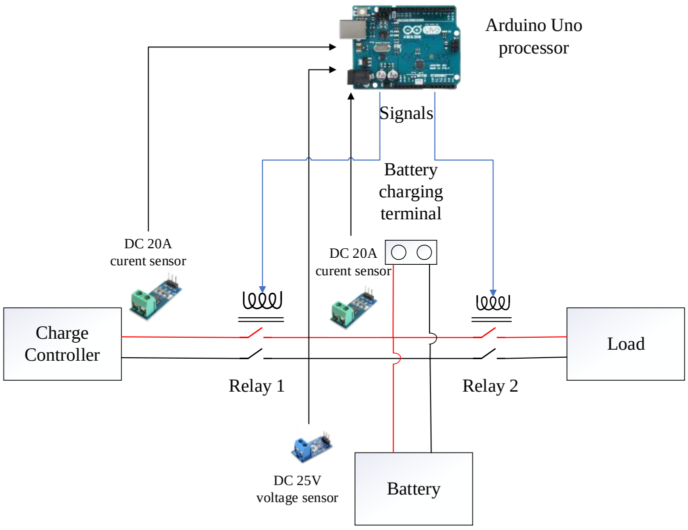
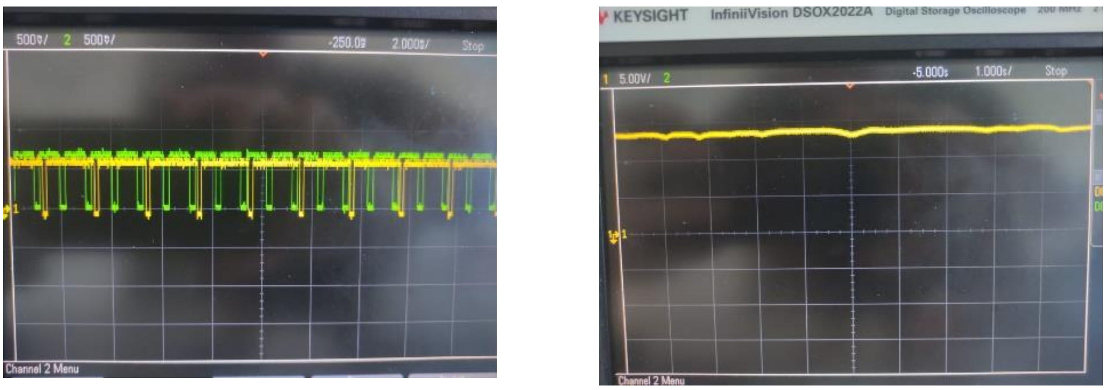


Figure 4: Circuit Design of the Energy Management System

3. Results and Discussion

3.1 Performances of portable solar-wind hybrid energy harvesting system

The maximum integrated output voltage is 13.8 V while the maximum integrated output current of 6.21 A with an efficiency of 95.1% while the output voltage ripple is around 5% which is based on calculations [8]. The result data is not much different from the solar system which indicate that the solar system dominates the largest part as compared to a wind turbine in term of power supply yet the wind system still has contributions to the energy harvesting. Figure 5 depicts the output result of the solar-wind energy integrated system.



(a) (b)

Figure 5: Generation of two identical PWM signals towards (a) controller and (b) Output waveform of integrated regulated voltage

3.2 Analysis of Energy Consumption and Distribution of The Prototype

The actual total maximum demand of the whole lake surface cleaning machine is 68 W which assures the power supply designed is adequate to supply the normal operation of the machine. Aside from the power supply from the green sources, the backup battery power withstand duration has also been calculated which is capable of providing 2.04 hours of backup power that could be supplied by the battery toward the machine when encountering an input source outage [9]. Table 1 shows the total consumption of each component in the machine.

Table 1: Consumptions of each component in the machine

No.	Components	Voltage consumed (V)	Current consumed (A)	Quantity	Power consumed (W)
1	Motor (propeller)	11.35	0.69	2	15.66
2	Stepper motor (conveyor)	3.30	1.28	1	4.23
3	Arduino Uno processor (power system)	6.85	0.48	1	3.29
4	Arduino Uno processor (movement control)	6.74	0.36	1	2.43
5	Raspberry Pi 4 model B	6.13	3.46	1	21.21
6	Battery (float charge)	13.7	1.26	1	17.26
Total load demand					67.09

Whereas for energy distribution, the mainstream output of the charge controller has been divided into 3 streams with different voltage levels (13.8 V, 6.6 V and 3.7 V) to fit with different component voltage required. The value of 13.8 V is the original output from the controller while the other voltage levels are further regulated by the voltage regulators as shown in Figure 6. The distribution of power to several streams is necessary to reduce the demand burden instead of only bearing one mainstream [10]. The power distribution of each regulator is tabulated in Table 2.

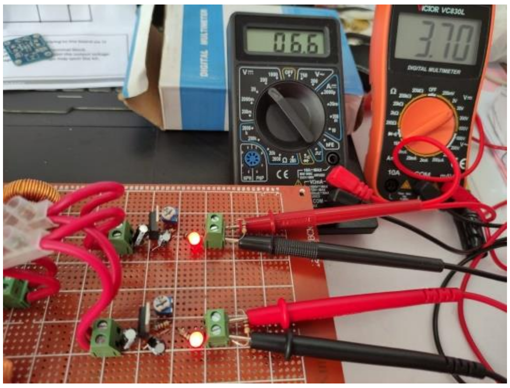


Figure 6: Results of regulated output voltage

Table 2: Power distribution of each regulator

Regulator	Power distributed (W)
13.7 V	32.92
6.6 V	26.93
3.7 V	4.23

3.3 Analysis of Energy Management System

The energy management system will respond based on the conditions encountered. When the source current is lower than the threshold current (3A), relay 1 which is located between the charge controller output and the battery terminal will be switched off to isolate the green source from the system to let the battery fully take control of the power supply. Meanwhile, the Arduino starts to monitor the battery's health by its current voltage level as the Arduino will send an alert signal toward the Raspberry Pi when the state of charge of the battery reaches 30% or below. Figure 7 shows the response of the alert signal upon different battery voltage levels.

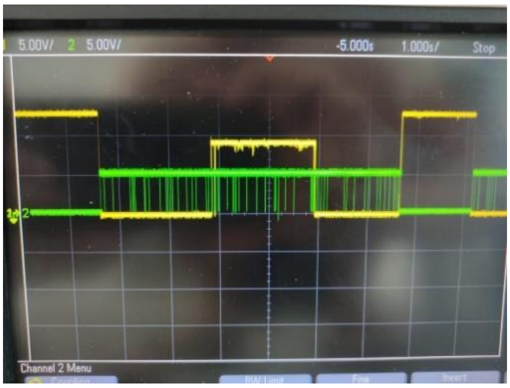


Figure 7: Response of alert signal upon battery voltage level

On the other hand, the relay 2 which is located between battery and load will be switched off when the machine is charging by the on-land charging station. This feature has been achieved via the current sensor installed at the charging terminal where it sends signal back to the Arduino when there's current flow from the particular terminal. The purpose of this feature is to increase the battery charging efficiency by shading the load partially. Figure 8 shows the waveform of load voltage upon the relay 2 response.

Figure 8: Waveform of load voltage upon relay 2 response

4. Conclusion

In conclusion, the system is capable of producing stable DC output when encountered with different voltage levels from both sources via the Arduino-based hybrid charge controller. The use of Arduino Uno allows for a flexible and adaptable system that can be easily upgraded to meet the changing needs of the device requirements. A prototype of this system can be a valuable step in testing and evaluating the proposed system and its features. By implementing the prototype in a real-world setting, feedback can be gathered from users and used to improve the system's usability and user-friendliness.

Acknowledgement

The authors would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

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