International Journal of Mathematical, Engineering and Management Sciences
Vol. 7, No. 4, 491-502, 2022
https://doi.org/10.33889/IJMEMS.2022.7.4.032

Design of Solar Photovoltaic Based Portable Water Filter

Mashhood Hasan
Department of Electrical Engineering Technology,
College of Applied Industrial Technology (CAIT),
Jazan University, Jazan, Kingdom of Saudi Arabia.
Corresponding author: mhasen@jazanu.edu.sa

Waleed Hassan Alhazmi
Department of Mechanical Engineering,
Jazan University, Jazan, Kingdom of Saudi Arabia.
E-mail: waalhazmi@jazanu.edu.sa

Waleed Zakri
Department of Mechanical Engineering,
Jazan University, Jazan, Kingdom of Saudi Arabia.
E-mail: Wzakri@jazanu.edu.sa

Anwar Ulla Khan
Department of Electrical Engineering Technology,
College of Applied Industrial Technology (CAIT),
Jazan University, Jazan, Kingdom of Saudi Arabia.
E-mail: anwarkhan@jazanu.edu.sa

(Received on February 02, 2022; Accepted on May 05, 2022)

Abstract
In this work, a hardware model of solar photovoltaic system-based water filter is designed to support the Qatrah program of Kingdom of Saudi Arabia. A solar photovoltaic system provides active energy to charge the battery of 24 Volt via dc to dc boost converter (step-up converter) and battery energy is used to run the dc pump of water filter in remote areas. A boost converter increases the input voltage level of solar panel upto 25 Volt fix to run the dc motor of solar pump and at same time it charges the batteries in sun light. The boost converter switch is pulsed at maximum output power of solar. It is extracted using maximum power point tracking (MPPT) system. An Arduino Nano microcontroller is used to extract the pulse of dc to dc boost converter at MPPT of solar photovoltaic system.

Keywords- Arduino Nano, dc to dc converter, dc motor pump, potable water, Solar PV system.

1. Introduction

Nature and water for people: United Nations Educational, Scientific and Cultural Organization (UNESCO) ecohydrology approach for a new water culture at the United Nations General Assembly. The United Nations Educational, Scientific and Cultural Organization (UNESCO) was born on 16 November 1945, headquarter at Paris. Nature balanced the eco system and ensure the world population have sufficient portable (drinking) water while population face cries of portable water. As stated in (Nature and water for people, 2020), according to UNESCO data, one person out of three persons are living without portable water.

Kingdom of Saudi Arabia (KSA) is one of the countries where 100 percent water is distilled. Numbers of companies are available to sell water while KSA government supplies filter water to domestic purpose. In

spite of that public prefer to purchase filter water in bulk which causes plastic bottle demand. Moreover, Saudi government launched Qatra program to save water where Qatrah is an Arabic name of droplet (Minister of Environment, 2019). An announcement of KSA government related Water and Agriculture objectives to minimize daily per capita consumption from 263 ltrs to 200 ltrs by 2020 and to 150 ltrs by 2030. It is hard to minimize daily consumptions of water if agriculture demand and population are raising rapidly. Thus, in this work authors have decided to support the government program by aware the people about the solar energy (renewable energy) based potable water filter which is easily mounted at agriculture field site and at remote area (Hasan et al., 2022; Jurasz et al., 2020; Talayiya et al., 2020). Many research scholars worked out on solar irrigation system using brushless dc (BLDC) motor via dc to dc converter (Kumar & Sing, 2019; Kumar & Sing, 2017).

Some researchers work on special motor with renewable energy resources (Singh et al., 2018) where the BLDC motor is more efficient than any other motor. A very few good articles are available to review on portable water filter based on solar energy system. A. Kamboj et al. developed portable water quality testing device using Arduino (Kamboj et al., 2021).

However, in this paper authors developed a hardware model of solar photovoltaic system-based water filter to support the Qatrah program of Kingdom of Saudi Arabia. In a water filter, solar energy provides dc power source to charge the 24 Volt battery via dc to dc boost converter and battery power is used to run the dc pump of water filter in remote areas. A boost converter increases the input voltage level and charge the 24 Volt dc battery in remote area. The boost converter switch is pulsed at maximum power point of solar panel. It is extracted using maximum power point tracking (MPPT) system. In the research article, fast tracking system under variation of irradiance are available (Hussain et al., 2019). While authors used an Arduino Nano microcontroller to extract the pulse for dc to dc boost converter at MPPT of solar photovoltaic system. The contribution of the authors is given as follows,

- A solar energy based portable water filter is designed for a remote area
- A dc to dc boost converter with feedback is designed to charge the 24 Volt battery
- An MPPT is programmed to pulse dc to dc converter at maximum power of solar photovoltaic

This paper is organized as, model description is given in the section 2, in section 3, parameters to design a portable water filter while in section 4 results are discussed and at last paper is concluded.

2. Model Description

As it is shown in Figure 1, a 100Watt solar photovoltaic (PV) system is connected boost converter to generate 25 volt and charge the 24Volt battery. A dc to dc boost converter is pulsed through microcontroller Nano Arduino at maximum power point. An algorithm of maximum power point tracking (MPPT) system is programmed in a microcontroller. A microcontroller senses voltage and current of solar PV system to generate pulse at maximum power point. A boost converter generates higher voltage than battery for proper flow of charging current. A 24 battery supply the dc current to run the dc motor rating 48Watt. The dc motor is associated with water pump to run six stage water filter which needs a 110 psi (pound per square. inch) pressure to properly work. Thus, solar based water filter takes impure water and after six stage processing it supplies portable water (drinking water). The membrane has two output, one goes for further stage to processing while other goes to water recycling.

3. Parameters to Design a Proposed Model

The solar photovoltaic (PV) based six stage water filter consists many components like solar panel, solar battery charger, 24 Volt battery, 48 Watt DC motor and a six stage filter. The description and design of

these component are given as follows.

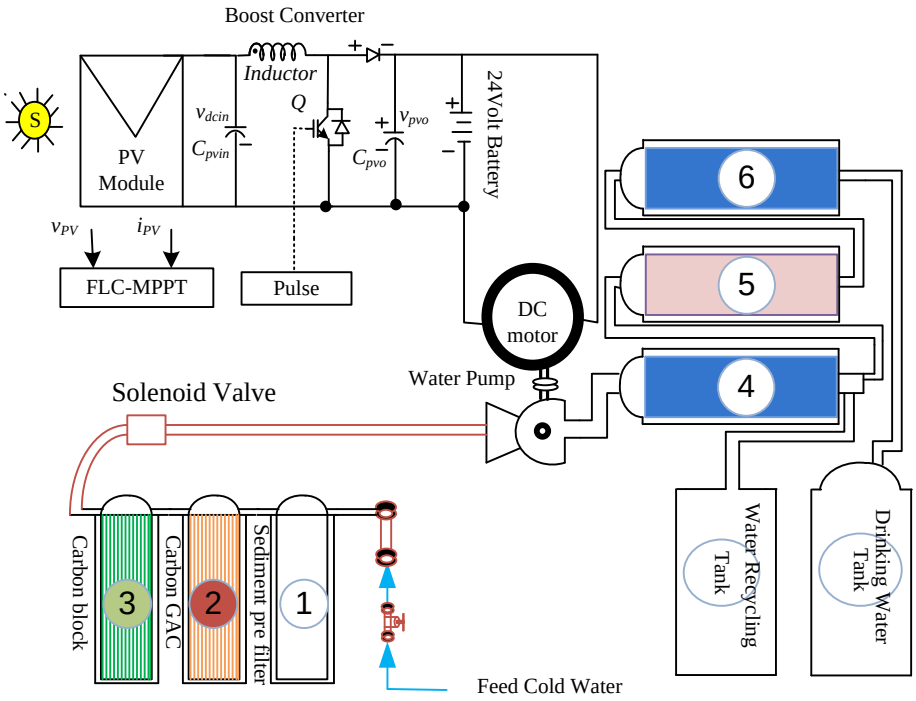

Figure 1. An overview of hardware model with its major components.

3.1 Maximum Power Point Tracking System

A 100-Watt, 19.6-volt open circuit voltage and 4.2 Ampere short circuit current are sensed from a Nano microcontroller (UNO Arduino Board). A current sensor and voltage sensor are used to extract current in milli ampere and 5 volts. The senses current and voltage are used to run the program inside the UNO Arduino board. A program is developed to design MPPT system. There are many concepts to develop MPPT system while in this work a commonly used incremental conductance maximum power point tracking (INC-MPPT) method is taken. It is based on observation of photovoltaic (PV) characteristics to optimize the power available from PV solar panel. In Figure 2, a flow chart is presented to develop a program through which it generates the duty cycle.

3.2 Boost Converter

In Figure 3(a), a schematic diagram of dc to dc steps up converter is presented whereas in Figure 3(b), inductor current waveform is depicted. The various parameters are required to design a boost converter such as an input dc source, inductor, electronic switch, diode and parallel capacitor are needed (Wang et al., 2004). The output terminal of inductor is connected to electronics switch (Q) in parallel which makes inductor to store electromagnetic energy. If switch (Q) is short circuited to the inductor for time T1, the inductor stores electromagnetic energy in current form and passes through diode (D) to charge the 24 Volt battery. As Q is off for time T2 and inductor energy falls the voltage across inductor becomes negative sign. Following mathematical equation can find the output voltage which are given as,

$$V_{in} = V_L + V_o \quad (1)$$

$$V_L = L\frac{di}{dt} = V_{in} - V_o \quad (2)$$

$$L\frac{di}{dt} = L\frac{\Delta i}{\Delta t} = V_{in} - V_o \quad (3)$$

$$\Delta I = \frac{V_{in}}{L} T1 \quad (4)$$

Where V_{in} is the input voltage, V_L is the inductor voltage and V_o is the output voltage of the boost converter. Using equation (1)-(4) the average output voltage can be estimated as follows

$$V_o = V_{in} + L\frac{\Delta I}{T2} = V_{in}\left(1 + \frac{T1}{T2}\right) = V_{in}\frac{1}{1-D} \quad (5)$$

From equation 5, if duty cycle D is zero**,** the step up converter works under buffer condition. It means input and output voltage is same. Whereas, output voltage become sensitive when duty cycle D approaches one. It means if D is equal to one output becomes infinity value as a theoretically. Thus, output voltage is controlled by controlling of value of D. The D value is being controlled by designing a MPPT.

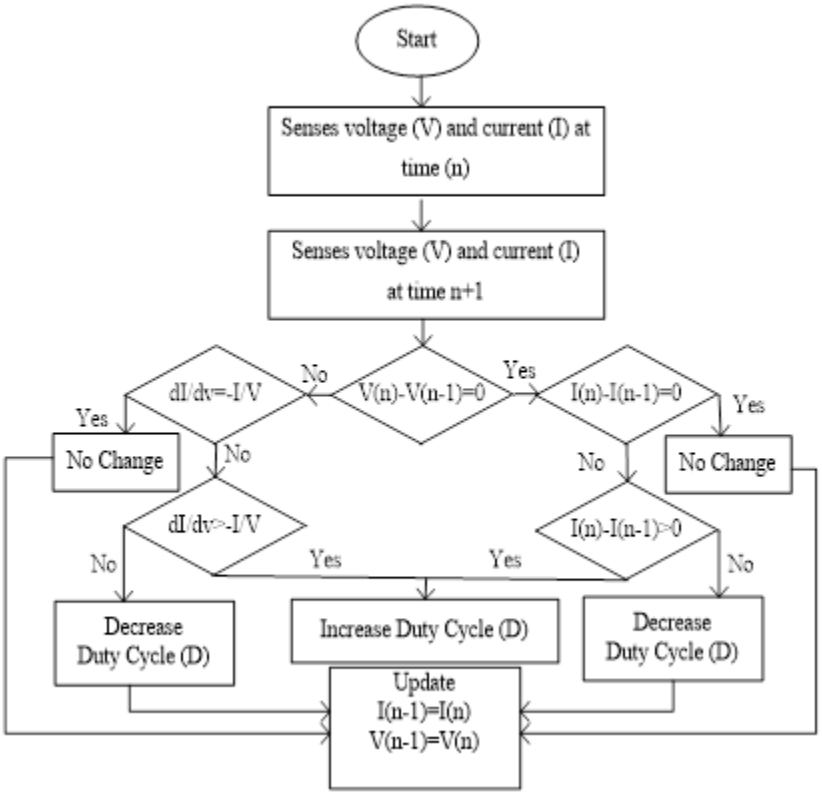

Figure 2. An algorithm for generation pulse at maximum power of solar system.

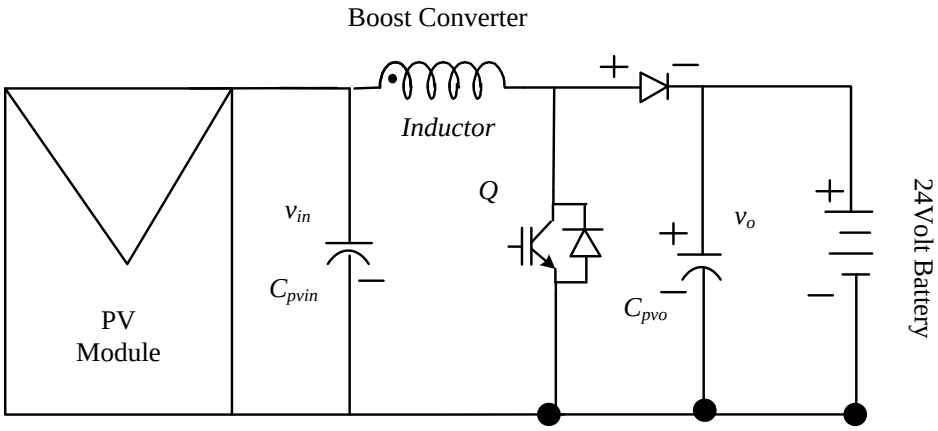

Figure (a)

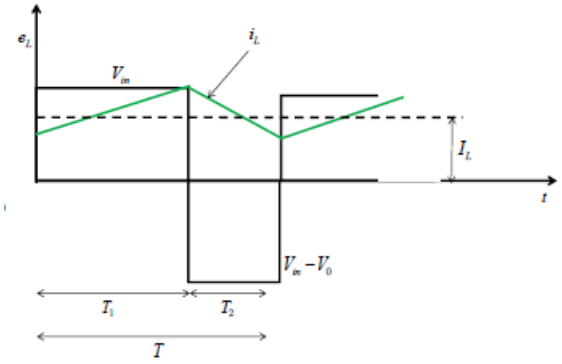

Figure (b)

Figure 3. (a) a schematic diagram of dc to dc steps up converter and (b) shows the inductor current waveform.

3.3 Battery

There are various types of batteries which stores dc energy only. In this model a two 12 volt lead acid battery has been taken to run the 48Watt, 24 volt DC motor. The batteries are connected in series to develop 24 Volt. In Figure 4, a lead acid cell able to function as a voltaic cell and as an electrolytic cell (Singh et al., 2022; Zhou et al., 2021). When it acts as a voltaic cell, it supplies electrical energy and becomes "run down". When it is recharged, the cell operates as an electrolytic cell. The cell is charged to pass electric current in reverse direction which is given in equation (6). Lead Pb is deposited on anode while PbO2 on cathode. The aqueous solution H_2SO_4 density increases. The reaction for charging is given as follows:

$$2PbSO_{4(s)}+2H_2O+Energy \underset{\text{discharging}}{\overset{\text{charging}}{\rightleftharpoons}} Pb(s)+PbO2(s)+2H_2SO_4 \quad (6)$$

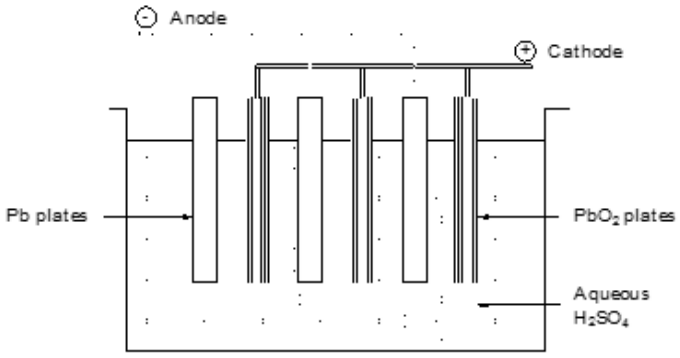

Figure 4. Lead storage cell.

3.4 Water Filter

In Figure 5, a six-stage reverse osmosis (RO) water filter is presented where RO consists permeable membrane to isolate unwanted molecules, large particles and ions. The six-stage filter process are as given as,

At stage 1:- Dust and send particles are separated at this stage using polypropylene sediment. Every month or two month this stage needs to change for proper working. The cost of polypropylene sediments is less than 1/4 USD.

At second Stage:- Chemical dissolve can be separated from impure water using granular active carbon (GAC). Every six month it requires service to change for proper working. Cost GAC is nearly 5 USD.

At third Stage:- It is widely used to separate chlorine using carbon block (CTO). Every six month it requires service to change for proper working. Cost GAC is nearly 5 USD.

At fourth Stage:- Here, RO is used to separate the very tiny particles like molecules and ions. Every two to three years, it requires service to change for proper working. Cost RO is nearly 10 USD.

At fifth Stage:- Here, Inline Carbon is used to improve the taste of drinking water. Every year, it requires service to change for proper working. Cost Inline Carbon is nearly 5 USD.

At sixth Stage:- Here, at the last stage minerals is mixed in pure water to enhance the quality of water using Alkaline Every six month, it requires service to change for proper working. Cost Alkaline is nearly 5 USD.

Figure 5. Six stage water filter process.

4. Results Analysis

In Figure 6, a hardware model of six stage water fitter based solar photovoltaic (PV) system is presented. A 100 watt 19.6 volt (open circuit voltage and at maximum power point 18 volt) is connected with a solar battery charger (boost converter). The boost converter senses the voltage and current of solar PV panel at maximum power point. A dc to dc steps up charger boosts the input voltage upto 25.6 Volt and charges a 24 Volt battery to run the dc motor pump which is combined with six stage water filter to make a single solar PV based portable water system. The output voltage can be controlled by duty cycle D. The control of D depends on feedback voltage which is sensed through microcontroller and provides accurate duty ratio.

The performance of solar panel under various condition of solar irradiance is shown in Figure 7. The open circuit voltage under maximum solar irradiance is 19.6 Volt while under shadow is 17 Volt. The maximum and minimum voltage difference is 2.6 Volt. The output voltage is almost remained constant when feedback voltage sensor sends the signals to solar battery charger. Under various load condition the output voltage is remain constant because of feedback controller. For this, it has to vary input DC voltage to reach sufficient voltage or constant output voltage. The mathematically, the output voltage is controlled at higher level by changing duty cycle (D) to generate desire level output voltage. The output voltage of boost converter is 25.6 while battery voltage is 23 Volt. It is seen in Figure 8. However, the charging current of battery is 32.8mA under 23 Volt of battery while DC motor pump of water filter is taking 71.6mA under normal condition. It is seen in Figure 9.

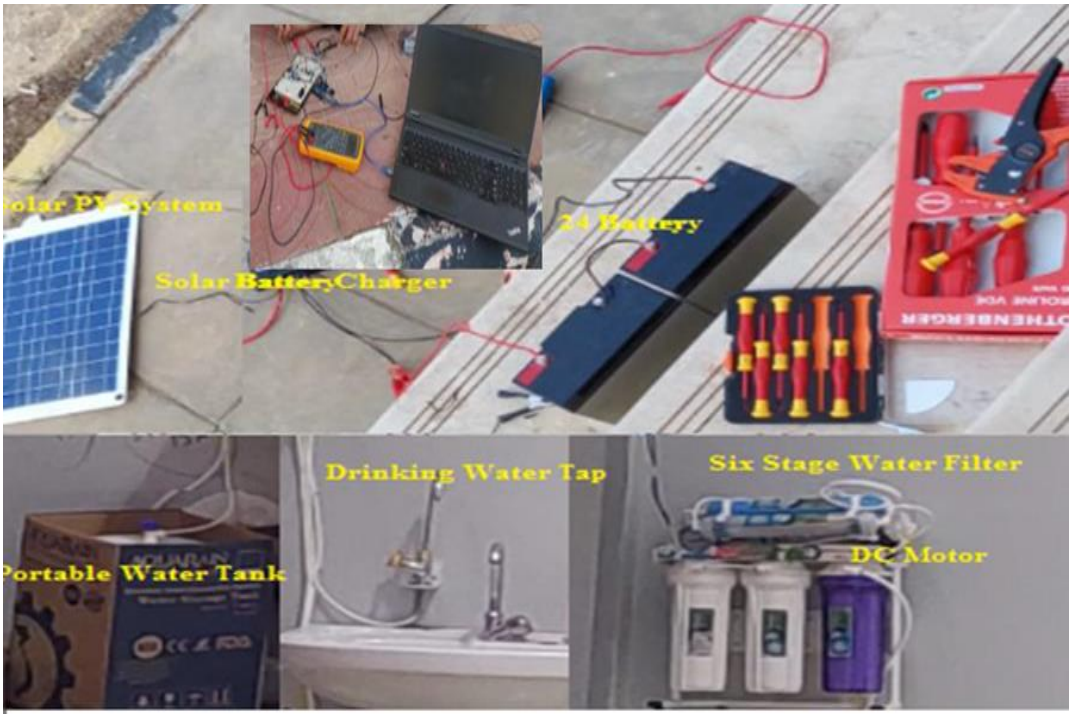

Figure 6. A hardware model of solar photovoltaic based portable water filter.

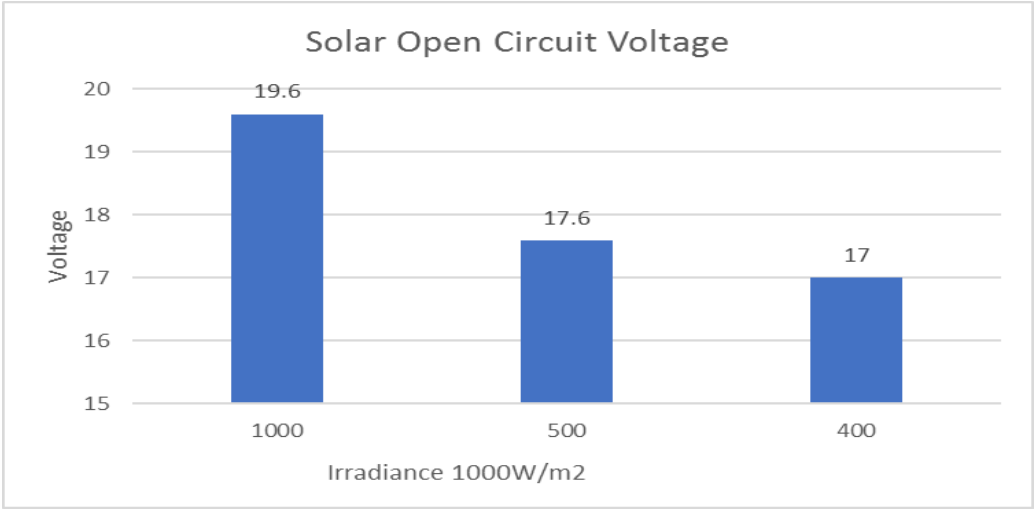

Figure 7. Open circuit voltage of solar panel under various condition of solar irradiance.

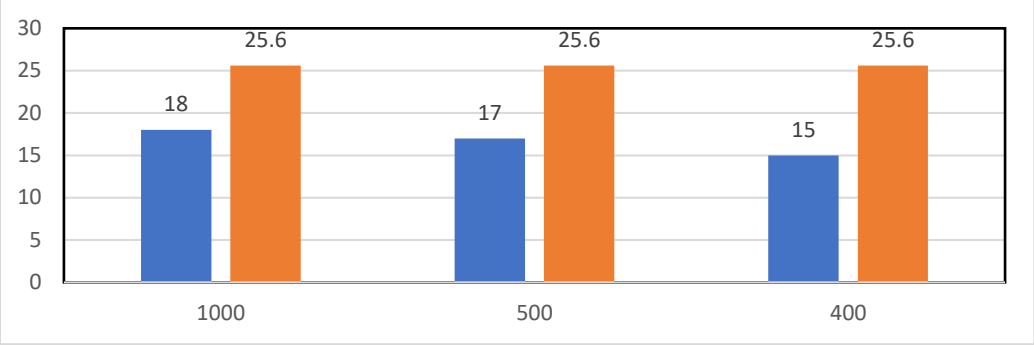

Figure 8. Voltage at MPP of solar panel vs output voltage of solar battery charger under various condition of solar irradiance.

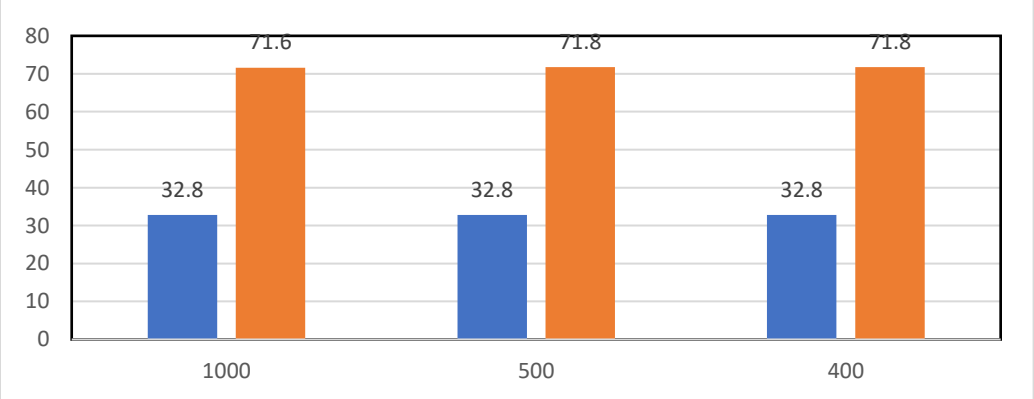

Figure 9. Charging current of solar panel vs dc pump current under various condition of solar irradiance.

Performance of water filter:- A six stage water filter is connected with solar panel to run the DC motor pump and perform the filtering process. In this case two important test is conducted of water. In Figure 10, total hardness dissolve (THD) or total dissolve solid (TDS) in parts per million (ppm, 1ppm=1 mg/L $CaCO_3$) water is conducted and found the impure water having 743 TDS while portable water is 104 TDS. The test shows that the filter is working satisfactory under this test. Moreover, in the second test pH value of water is conducted. The impure water before filter is having pH value 7.13 while after filter the water the pH value is 8.17 which is shown in Figure 11.

Figure 10. THD after filter and before filter.

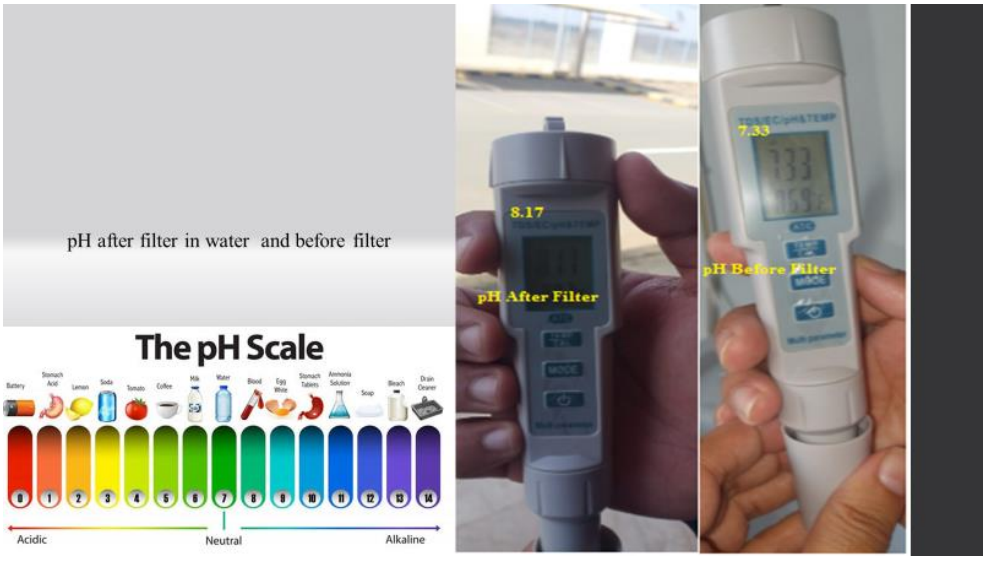

Figure 11. pH after filter and before filter.

5. Conclusion

The performance of a portable water filter model integrated with solar PV system is working unconditionally acceptable. Each part of the model is connected to perform its task accurately. An incremental conductance maximum power point tracker (INC-MPPT) is designed using an algorithm for generating pulse at maximum power of solar system and fired to the boost converter. A boost converter charges the batteries in sun light and at night, batteries supplies the power to the dc motor. The dc motor pump develops 110psi to filter impure water into portable water using six stage filter process**.** Moreover,

an UNO Arduino microcontroller is programmed to pulse the boost converter at MPPT. Microcontroller senses the voltage and current at low level voltage (5 Volt) and low level current in milliampere. It processes and takes feedback from output side 24 Volt battery voltage for smooth charging. A combined set up of proposed model is working satisfactory and hence its trade value is appreciating.

Conflict of Interest

The authors confirm that there is no conflict of interest to declare for this publication.

Acknowledgments

The authors extend their appreciation to the Deputyship for Research& Innovation, Ministry of Education in Saudi Arabia for funding this research work through project number RUP-4.

References

Hasan, M., Alhazmi, W.H., & Zakri, W. (2022). A fuzzy rule based control algorithm for MPPT to drive the brushless dc motor based water pump. *Journal of Intelligent Fuzzy System*, *42*, 1003-1014.

Hussain, A., Garg, M.M., Korukonda, M.P., Hasan, S., & Behera, L. (2019). A parameter estimation based MPPT method for a PV system using lyapunov control scheme. *IEEE Transactions on Sustainable Energy*, *10*(4), 21232132.

Jurasz, J., Canales, F.A., Kies, A., Guezgouze, M., & Beluco, A. (2020). A review on the complementarity of renewable energy sources: Concept, metrics, application and future research directions. *Journal of International Solar Energy Society*, *195*, 703-724.

Kamboj, A., Garg, P., Bansal, D., Sankar, A., & Bukya, M. (2021). Development of android app-based portable water quality testing device using arduino. *2021 9th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO)*, 1–4.

Kumar, R., & Sing, B. (2017). Solar PV powered BLDC motor drive for water pumping using Cuk converter. *IET Electric Power Applications*, *11*(2), 222–232.

Kumar, R., & Sing, B. (2019). Grid interactive solar PV-based water pumping using BLDC motor drive. *IEEE Transactions on Industry Applications*, *55* (5), 5153-5165.

Minister of Environment. (2019). Qatrah program to rationalize water consumption, Water and Agriculture. *Press Release at the March 17–19 Saudi Water Forum 2019*. https://www.zawya.com/en/press-release/saudi-arabia-launches-program-for-a-drastic-reduction-in-water-use-g9clmdyg.

Nature and water for people. (2020). *UNESCO's ecohydrology approach for a new water culture at the United Nations General Assembly*. https://en.unesco.org/news/nature-and-water-people-unescos-ecohydrology-approach-new-water-culture-united-nations-general.

Singh, B., Sharma, U., & Kumar, S. (2018). Standalone photovoltaic water pumping system using induction motor drive with reduced sensors. *IEEE Transactions on Industry Applications*, *54*(4), 3645–3655.

Singh, B.V., Hasan, M., Malik, H., & Sunori, S. (2022). A data-driven intelligent hybrid method for health prognosis of lithium-ion batteries. *Journal of Intelligent & Fuzzy Systems*, *42*, 897-907.

Talayiya, T., Shah, D., Patel, N., Yagnik, H., & Shah, M. (2020). Implementation of artificial intelligence in agriculture for optimization of irrigation and application of pesticides and herbicides. *Artificial Intelligence in Agriculture*, *4*, 58-73.

Wang, J., Reinhard, M., Peng, F.Z., & Qian, Z. (2004). Design guideline of the isolated DC-DC converter in green power applications. *The 4th International Power Electronics and Motion Control Conference, 2004. IPEMC*, *3*, 1756-1761.

Zhou, C., Zhang, J., Wang, X., Yang, Y., Xu, P., Li, P., Zhang, L., Chen, Z., Feng, H., & Wu, W. (2021). Review—betavoltaic cell: The past, present, and future. *ECS Journal of Solid State Science and Technology*, *10*, 027005.