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SOLAR PHOTOVOLTAIC-BASED PORTABLE WATER FILTER: DESIGN AND DEVELOPMENT FOR SUSTAINABLE WATER PURIFICATION

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ABSTRACT: A hardware prototype of a solar photovoltaic-powered water filtration system is presented in this study. This prototype is intended to provide assistance to the Qatrah program in the Kingdom of Saudi Arabia. By employing a dc to dc boost converter, more precisely a step-up converter, we are capable of converting the energy produced by a solar photovoltaic system to supply power to a 24V battery. In remote locations, the DC pump of the water filter is powered by battery energy. In order to supply power to the DC motor of the solar pump, the input voltage of the solar panel is increased to 25 volts via a boost converter. Furthermore, solar energy is utilized to recharge the batteries. Solar energy is at its peak output on days when the boost converter switch pulses. To extract it, we utilize the maximum power point tracking (MPPT) system. The pulse of the DC to DC boost converter during maximum power point tracking (MPPT) of the solar photovoltaic system is measured using an Arduino Nano microcontroller.

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

1. INTRODUCTION

Nature and water for people: Ecohydrology is the subject of UNESCO's current efforts to establish a new water culture at the United Nations General Assembly. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) was established on November 16, 1945, with its principal office situated in Paris. Notwithstanding the substantial demand for potable water, the natural ecosystem maintained equilibrium and ensured universal access. Statistics cited in the report "Nature and water for people (2020)" by UNESCO indicate that one-third of the global population lacks access to potable water.

The method employed to purify all water within the Kingdom of Saudi Arabia (KSA) is distillation. In addition to the abundance of water-selling establishments, the KSA government also supplies filtered water for domestic consumption. Despite this, bulk purchases of filtered water continue to occur, thereby increasing the demand for plastic bottles. The Saudi government initiated the Qatra initiative in an effort to conserve water. The Arabic word "Qatrah" translates to "droplet" (Minister of Environment, 2019). The government of the Kingdom of Saudi Arabia (KSA) has established objectives pertaining to water and agriculture, specifically reducing daily per capita utilization from 263 liters to 200 liters by 2020, and subsequently to 150 liters by 2030. Mitigating daily water consumption becomes a formidable task in the face of significant population growth and agricultural expansion. The authors of this study aim to promote a government initiative by disseminating information regarding an easily installable solar-powered portable water filter suitable for remote and rural regions (Hasan et al., 2022; Jurasz et al., 2020; Talayiya et al., 2020). Considerable scholarly investigation has been devoted to solar irrigation systems that employ a DC-DC converter and a brushless DC (BLDC)

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motor (Kumar & Sing, 2019; Kumar & Sing, 2017).

The focus of Singh et al.'s (2018) research is an innovative motor that utilizes renewable energy sources. Among all types of motors, the BLDC motor exhibits the highest efficiency. The online literature regarding solar-powered portable water filters is limited in quality. A compact apparatus for quantifying water quality was devised by Kamboj et al. utilizing Arduino technology (Kamboj et al., 2021).

In order to provide assistance to the Qatrah program in the Kingdom of Saudi Arabia, the investigators of this research endeavor constructed a tangible prototype of a solar photovoltaic-powered water filtration system. By means of a DC to DC boost converter, the 24-volt battery of the water filter is recharged with solar-generated DC power. The DC compressor of the water filter is powered by batteries in remote areas far from urban centers. In an effort to recharge the 24V DC battery, which is located in a remote location, the input voltage is increased by means of a boost converter. We precisely coordinate the activation of the boost converter switch to coincide with the solar panel's peak power output. In order to optimize power extraction from available resources, the maximum power point tracking (MPPT) system is implemented. The rapid tracking system demonstrated by Hussain et al. (2019) operates effectively across a spectrum of irradiance conditions. The authors utilized an Arduino Nano microcontroller to detect the pulse of the dc to dc boost converter during maximum power point tracking (MPPT) of the solar photovoltaic (PV) system.

2. MODEL DESCRIPTION

Figure 1 illustrates the linkage between a 100W solar photovoltaic (PV) system and a boost converter, which reduces the output to 25V to facilitate the charging of a 24V battery. By utilizing a pulsed dc to dc boost converter, the power output of the Nano Arduino microcontroller is increased. The algorithm for maximum power point tracking (MPPT) is executed by a microcontroller. Monitoring the voltage and current of the solar PV system, a microprocessor generates a pulse when it reaches its maximum output. To ensure the correct passage of charging current, a boost converter increases the voltage output of the battery. A 48-watt DC motor is powered by a 24-volt battery. In order for the six-stage water filter to function, the pressure differential between the water pump and the DC motor must be 110 psi (pounds per square inch). By utilizing solar energy, a solar-powered water filter purifies water in six distinct stages, transforming contaminated water into potable water. Two apertures are located on the membrane. One proceeds to the subsequent stage of the procedure, while the other is dedicated to the recycling of water.

3. PARAMETERS TO DESIGN A PROPOSED MODEL

Solar photovoltaic (PV) six stage water filter components include a solar panel, solar battery converter, 24 volt battery, 48 watt DC motor, and six stage filter. The following is an exhaustive description of these components and the process by which they were constructed:

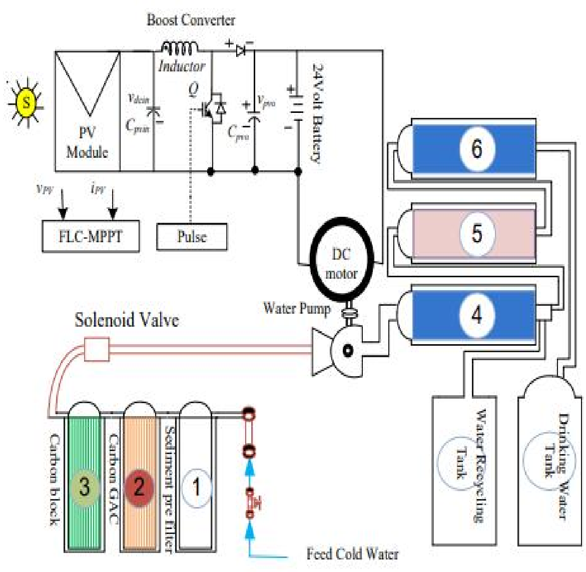

Figure 1. An overview of hardware model with its major components.

Maximum Power Point Tracking System

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The power measurement derived from the UNO Arduino Board, a Nano microcontroller, is 100 Watts. This value is determined by measuring the short circuit current of 4.2 Amperes and the open circuit voltage of 19.6 volts. To ascertain the current in milliamperes and the voltage in volts, it is necessary to employ both a current sensor and a voltage sensor. In accordance with sensor voltage and current measurements, the UNO Arduino board executes its code. A program for developing MPPT systems is created. In this investigation, we employed the widely recognized incremental conductance maximum power point tracking (INC-MPPT) technique, one of several methodologies available for constructing an MPPT system. The approach is predicated on analyzing the characteristics of photovoltaic (PV) modules in order to maximize their power output. Figure 2 illustrates a flowchart that can be employed to develop a program responsible for producing the duty cycle.

Boost Converter

The schematic representation of a step-up converter from direct current (dc) to direct current (dc) is illustrated in Figure 3(a). Conversely, Figure 3b illustrates the current waveform of an inductor. In order to construct a boost converter, one would require a parallel capacitor, an input DC source, an inductor, an electrical switch, and a diode (Wang et al., 2004). To store electromagnetic energy, the output terminal of the inductor is connected in parallel with the electronic switch (Q). When switch (Q) is connected in parallel with the inductor at time T1, the inductor will accumulate electromagnetic energy in the form of an electric current. Current is supplied to the diode (D) so that it may charge the 24 A battery. At time T2, the inductor experiences a negative voltage across its path due to the inactivity of Q and a decrease in its energy. To determine the resulting voltage, the subsequent mathematical formula can be utilized:

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

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

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

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

In this instance, Vin represents the input voltage, VL represents the voltage across the inductor, and Vo represents the output voltage of the boost converter. The following methods are possible for estimating the mean output voltage using Equations (1) through (4):

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

When duty cycle D is equal to zero, the step-up converter operates in buffer mode, as shown in Equation 5. A distinction cannot be made between the voltages at the input and output. In contrast, the output voltage varies as the duty cycle D approaches unity. Theoretically, the output will be an infinite value if D equals 1. The output voltage can be altered by adjusting the value of D. The administration of the D value is possible through the implementation of an MPPT (Maximum Power Point Tracking) system.

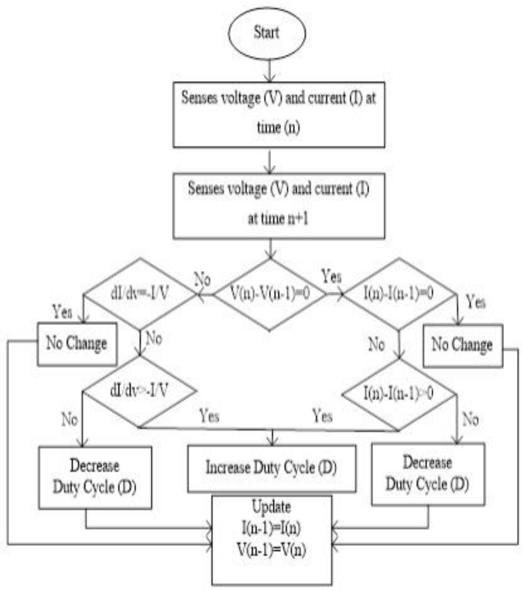

Figure 2. An algorithm for generation pulse at maximum power of solar system.

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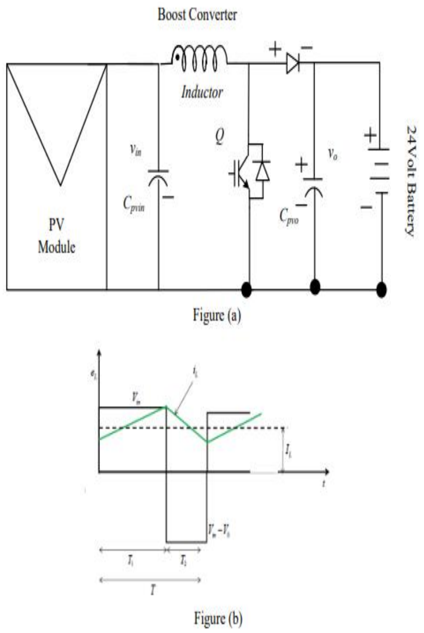

Figure 3. (a) a schematic diagram of dc to dc steps up converter and (b) shows the inductor current waveform.

Battery

A wide range of battery varieties store energy exclusively as direct current (DC). A pair of 12-volt lead acid batteries are utilized to supply power to the device's 48-watt, 24-volt DC motor. By connecting the batteries in series, a total of 24 volts is produced. A lead acid cell that operates as a voltaic cell and an electrolytic cell is illustrated in Figure 4 (Singh et al., 2022; Zhou et al., 2021). Although a voltaic cell produces electricity, its power is ultimately depleted. The charged cell operates in the manner of an electrolytic cell. The quantity of charge necessary for the cell to produce electricity in the opposite direction is determined by Equation (6). PbO2 is applied to the cathode, whereas lead (Pb) is deposited on the anode. The combination of H2SO4 with water results in an increase in its density. The charge response is as follows:

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

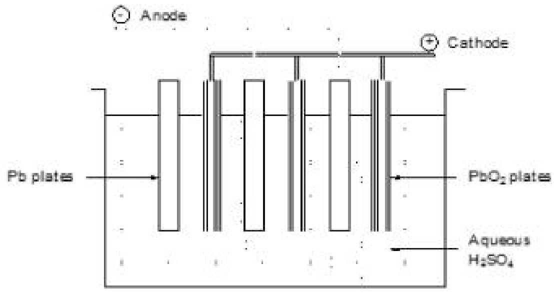

Figure 4. Lead storage cell.

Water Filter

The water filter illustrated in Figure 5 is a six-stage reverse osmosis (RO) system that employs a transparent membrane to efficiently segregate contaminants, sizable particles, and ions. The filtration procedure comprises six consecutive stages, which are as follows:

At stage 1:- At present, polypropylene silt is being utilized for the purpose of dust segregation from minute particulates. In order to maintain peak performance, this stage must be replaced every month or every two months. Polypropylene waste is sold for a cost of less than twenty-five cents.

At second Stage:- Granular activated carbon (GAC) eliminates chemical contaminants to effectively purify contaminated water. Updates must be applied to its services every two years in order to guarantee optimal functionality. The acquisition fee for GAC exceeds $5.

At third Stage:- One frequently utilized approach to eliminate chlorine (CTO) is by employing a carbon block. Changes must be made to its services every two years in order to guarantee optimal functionality. The acquisition fee for GAC exceeds $5.

At fourth Stage:- RO is employed to facilitate the classification of ions and molecules, both of which are extremely minute particles. Periodic maintenance is necessary for the service every two to three years in order to guarantee its optimal functionality. RO is priced at an estimated ten dollars.

At fifth Stage:- The application of internal carbon in this particular case functions to augment the taste of potable water. Annual maintenance must

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be performed on the device to guarantee its correct operation. An integrated carbon slurry costs around $5.

At sixth Stage:- Alkaline technology is subsequently utilized to improve the purity of potable water through the introduction of minerals. It is recommended that the service be modified at six-monthly intervals in order to maintain optimal functionality. A quantity of alkaline costs roughly $5.

Figure 5. Six stage water filter process.

4. RESULTS ANALYSIS

A hardware prototype of a six-stage solar photovoltaic (PV) system built upon a water fitting is illustrated in Figure 6. A 100-watt power source is connected to a boost converter, which operates at an open circuit voltage of 19.6 volts and a peak voltage of 18 volts. At full power output, the boost converter measures the voltage and current of the solar PV panel. The construction of a portable water system powered by solar photovoltaics can be achieved through the utilization of a direct current (DC) to direct current (DC) step-up converter and a six-stage water filtration system. It increases the voltage of the energy it absorbs to 25.6 volts. Following this, the process continues by recharging a 24-volt battery to provide power to the DC motor pump. The adjustment of the output voltage is achieved through the manipulation of the duty cycle, denoted as D. Instructions for D are transmitted via the feedback voltage, whereas the microcontroller computes the duty ratio.

The operational efficiency of the solar panel is depicted in Figure 7 across a range of sunlight intensities. In the presence of vivid sunlight, the open circuit voltage is 19.6 volts; however, in the absence of sunlight, it falls to 17 volts. 2.6 volts is the voltage differential between the greatest and lowest positions. When information is transmitted to the solar battery charger from the feedback voltage sensor, the output voltage remains relatively constant. In all load conditions, the feedback processor maintains a constant output voltage. A modification must be made to the input DC voltage so that a stable output voltage can be achieved. Through mathematical manipulation of the duty cycle (D), it becomes possible to elevate the output voltage to the designated level. In contrast to the 23 volts of the battery, the boost conversion voltage is 25.6 volts. The corresponding data is illustrated in Figure 8. The charge current of the battery is 32.8 mA at a voltage of 23 volts, while the DC motor pump in the water filter necessitates 71.6 mA for typical functioning. The data is illustrated in Figure 9.

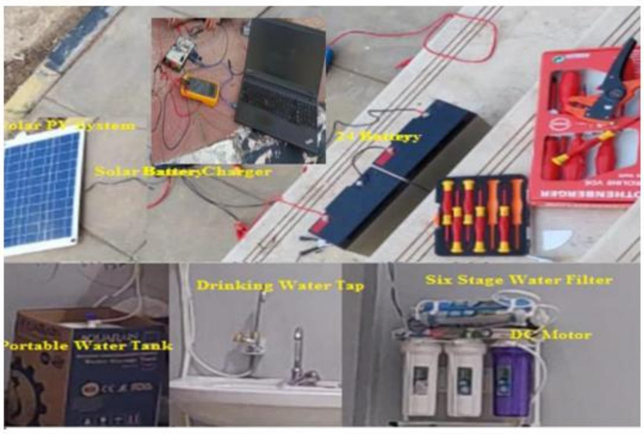

Figure 6. A hardware model of solar photovoltaic based portable water filter.

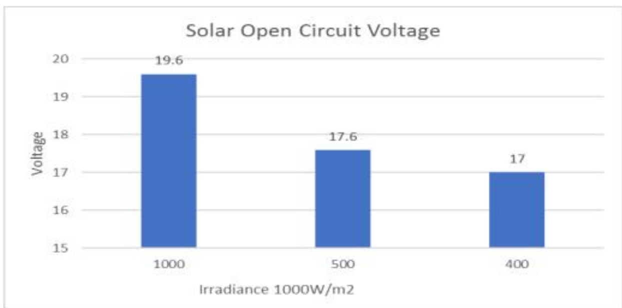

Figure 7. Open circuit voltage of solar panel under various condition of solar irradiance.

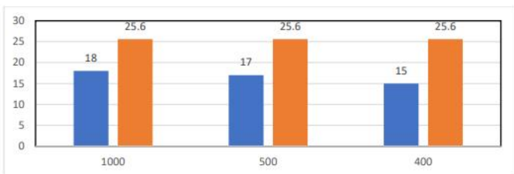

Figure 8. Voltage at MPP of solar panel vs output voltage of solar battery charger under various condition of solar irradiance.

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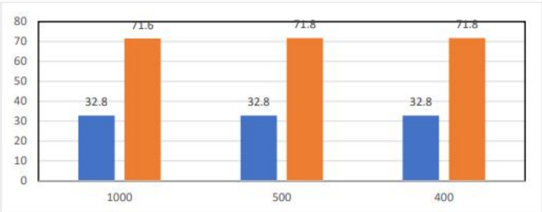

Figure 9. Charging current of solar panel vs dc pump current under various condition of solar irradiance.

Performance of water filter:- A solar screen connected to a DC motor pump and a six-stage water filter provides power for the filtration procedure. Two critical water studies are performed under these conditions. The proportion of parts per million (ppm) used to denote the total hardness dissolve (THD) or total dissolve solid (TDS) of water is illustrated in Figure 10. One ppm is equivalent to one milligram per liter (mg/L) of calcium carbonate ($CaCO_3$). The concentration of contaminants in dirty water is 743 parts per million (ppm), while that of portable water is 104 ppm. The test results indicate that the filter is operating effectively. In the second measurement, the pH level of the water is additionally assessed. As shown in Figure 11, the pH of the contaminated water increased from 7.13 at the outset to 8.17 following filtration.

Figure 10. THD after filter and before filter.

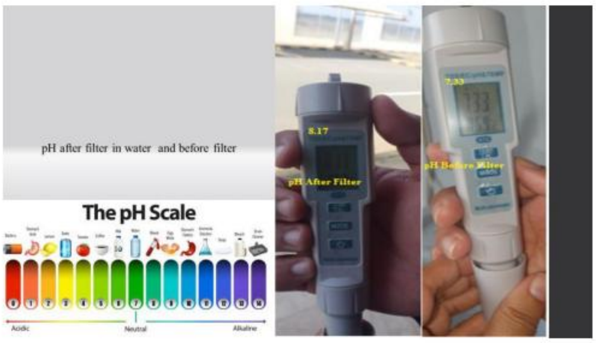

Figure 11. pH after filter and before filter.

5. CONCLUSION

The efficacy of a portable water filter is improved by one that incorporates photovoltaic technology. Interconnections exist between each component of the model to guarantee its correct operation. Utilizing an incremental conductance maximum power point tracker (INC-MPPT), signals are generated at the solar system's maximum power and then transmitted to the boost converter. Energizers are charged through the utilization of a boost converter when they are exposed to sunlight. At night, the DC motor is powered by the energy supplied by the batteries. By means of a six-stage filtration procedure, the DC motor pump converts contaminated water into potable water at a pressure of 110 psi. By utilizing the Arduino UNO processor, the boost converter is configured to pulsate at maximum power point tracking (MPPT). The microcontroller possesses the ability to identify minimal electrical potentials, specifically 5 volts, and milliamperes of current. In order to facilitate a smooth charging process, data is collected and analyzed from the output side of the 24-volt battery. The proposed model is exhibiting favorable performance, which has led to a rise in its market value.

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