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SOLAR ENERGY BASED DC GRID AUTO IRRIGATION

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Abstract: The main objective of this project is to provide the water to the farming field automatically by finding the water requirement of the field with the help of sensors and to provide the supply to the pump with a help of PV powered energy from solar panel through SEPIC converter. The primary objective is to overcome the water scarcity prevailing at present and to use the water available in efficient manner. In order to maintain a constant voltage across the pump, SEPIC converter (Single Ended Primary Inductor Converter) is used which is able to achieve high efficiency with a wide input and output voltage ranges with a small size. But in conventional power converter, it cannot maintain a wide operation range with high efficiency especially if up and down voltage conversions has to be achieved. Some of the limitations of conventional buck-boost converter like inverted output, pulsating input current, high voltage stress make it unreliable for wide range of operation. In order to overcome these limitations, SEPIC converter is used. The SEPIC converter which is a DC-DC converter provides positive regulated output voltage for the provided input voltage. This design is suitable for applications whose input voltage has got wide variations around the nominal voltage, for battery based applications, Maximum power Point Tracking in PV applications, regulating the voltage in renewable applications such as wind, solar, Hydel power generation, power electronic based applications and Industrial application.
Keywords: Arduino, Controlling, PV Panel, SEPIC converter, Sensor.

1. INTRODUCTION

Renewable energy technologies are playing an increasingly important role in supplying the world's electricity demands. In particular, the photovoltaic (PV) generation system, a promising source of energy for the future, is evolving rapidly and showing an industrial growth of approximately 40% per year worldwide. Solar energy which is free and abundant in most parts of the world has proven to be an economical source of energy in many applications. The energy received from the sun is so enormous and so lasting that the total energy consumed annually by the entire worlds is supplied in as short a time as a half hour. On a clear day the suns radiation on the earth can be 3000 watts per square meter depending on the location. The sun is a clean and renewable energy source, which produces neither green-house effect gas nor noxious waste through its utilization. The photovoltaic process is completely solid state and self-contained. There are no moving parts and no materials are consumed or emitted. Consider the advantages that photovoltaic systems have over competing power options: They are non-polluting no detectable emissions. They can be stand-alone systems that reliably operate unattended for long periods. They may be combined with other power sources to increase system Reliability. They can withstand severe weather conditions including snow and ice. They consume no fossil - their fuel is abundant and free.

2. BLOCK DIAGRAM

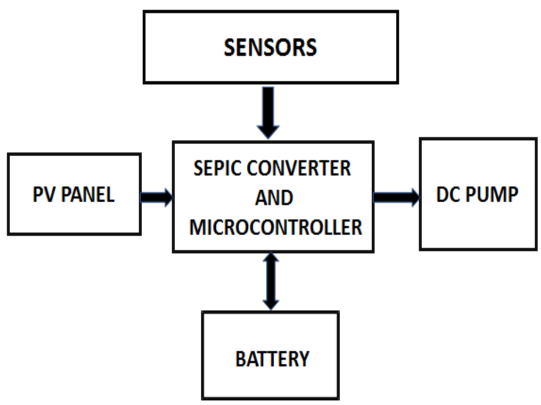

Fig 1: Overall Block diagram

Fig 1, shows the overall block diagram and tells about the connection of various components of the block.

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3. SEPIC CONVERTER

SEPIC converter is a dc-dc converter with property of both step-up and step-down with positive output. SEPIC stands for SINGLE ENDED PRIMARY-INDUCTOR CONVERTER. The prominence of this converter is working like buck-boost converter with a positive output voltage.

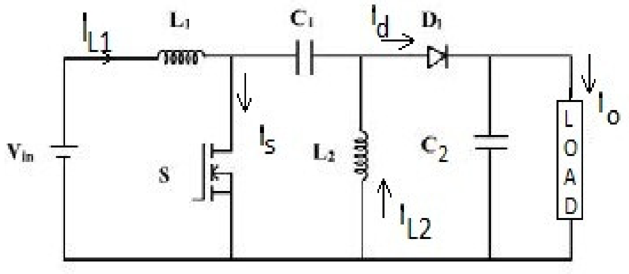

Fig 2: Circuit diagram of SEPIC converter

SEPIC converter is a type of DC-DC converter allowing the electrical potential (voltage) at its output to be greater than or less than at its input. The output of the SEPIC converter is controlled by the duty cycle of the control transistor. It is a Buck-Boost derived topology, but has a non-inverted output i.e., the output voltage polarity is same as the input voltage. Here it consists of a series(coupling) capacitor C1 is mainly used to couple energy from the input to the output(and thus can respond more gracefully to a short circuit output)and being capable of true shutdown, when the switch is turned off i.e., its output drops to zero volt. SEPICs are useful in applications in which battery voltage can be above and below that of the regulators intended output. For example, a single lithium battery typically discharges from 4.2volts to 3 volts, if other components require 3.3volts, then the SEPIC would be effective.

CIRCUIT OPERATION:

The SEPIC exchanges energy between the capacitors and the inductors in order to convert from one voltage to another. The amount of energy exchanged is controlled by switch S1,which is typically a transistor such as a MOSFET, MOSFETs offer much higher input impedance and lower voltage drop than bipolar junction transistor(BJTs), and do not require biasing resistors as MOSFET switching is controlled by differences in voltage rather than a current, as with BJTs.

CONTINUOUS CONDUCTION MODE:

A SEPIC is said to be in continuous-conduction mode (“continuous mode”)if the current through the inductor L_1 never falls to zero. During a SEPIC’s steady-state operation, the average voltage across capacitor C_1 (V_{c1})is equal to the input voltage (V_{in}).Because capacitor C1blocks direct current(DC), the average current through it(I_{C1}) is zero, making inductor L_2 the only source of load current. Therefore, the average current through the inductor L_2 (I_{L2}) is same as the average load current and hence independent of the input voltage.

Looking at average voltages, the following can be written

$$V_{in} = V_{L1} + V_{C1} + V_{L2} \quad (1)$$

Because the average voltage of V_{C1} is equal to $V_{IN,}$

$$V_{L1} = -V_{L2} \quad (2)$$

For this reason, the two inductors can be wound on the same core since the voltages are the same magnitude, their effects of the mutual inductance will be zero, assuming the polarity of the windings is correct. Also, since the voltages are the same in magnitude, the ripple currents from the inductors will be equal in magnitude.

The average currents can be summed as follows:

$$I_{D1} = I_{L1} - I_{L2} \quad (3)$$

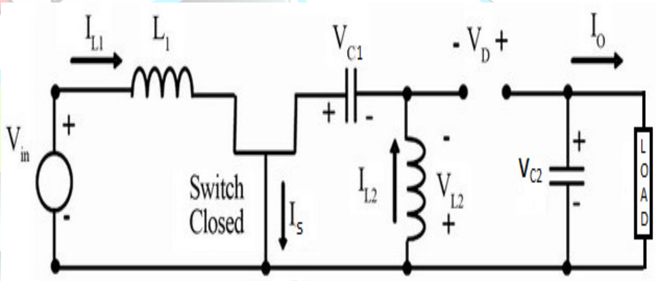

Fig: 3 circuit operation when switch S1 is closed.

When switch S1 is turned on, current I_{L1} increases and the current I_{L2} increases in the negative direction. (Mathematically, it decreases due to arrow direction). The energy to increase the current I_{L1} comes from the input source. Since S1 is a short while closed, and the instantaneous voltage V_{C1} is approximately $V_{in,}$ the voltage V_{L2} is approximately $-V_{in.}$ Therefore, the capacitor C1 supplies the energy to increase the magnitude of the current in I_{L2} and thus increase the energy stored in L2.The easiest

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way to visualize this is to consider the bias voltages of the circuit in a D.C. state, then close S1.

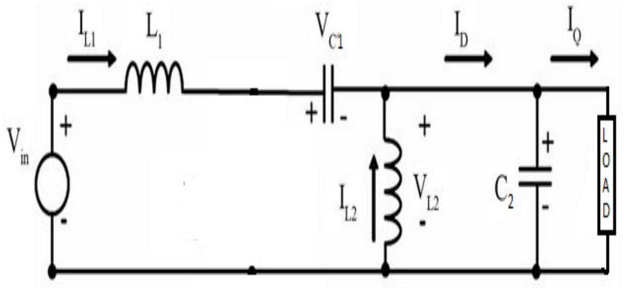

Fig: 4 Circuit operation when switch S1 is open

When switch S1 is turned off, the current I_{C1} becomes the same as the current I_{L1}, since inductors do not allow instantaneous changes in current. The current I_{L2} will continue in the negative direction, in fact it never reverses direction. It can be seen from the diagram that a negative I_{L2} will add to the current I_{L1} to increase the current delivered to the load.

Using Kirchhoff's Current Law, it can be shown that

$$I_{D1} = Ic1 - I_{L2} \quad (4)$$

It can then be concluded, that while S1 is off, power is delivered to the load from both L_2 and $_{L1}$. C_1, however is being charged by L_1 during this off cycle, and will turn recharge L_2 during on cycle. Because the potential (voltage) across capacitor C_1 may reverse direction every cycle, a non-polarized capacitor may be used in some cases, because the potential (voltage) across capacitor C_1 will not change unless the switch is closed long enough for a half cycle of resonance with inductor L_2, and by this time the current in the inductor L_1 could be quite large.

The capacitor C_1 is required to reduce the effects of the parasitic inductance and internal resistance of the power supply. The buck/boost capabilities of the SEPIC are possible because of capacitor C_1 and inductor L_2.Inductor L_1 and switch S_1 create a standard boost converter, which generates a voltage (V_{s1}) that is higher than $V_{in,}$ whose magnitude is determined by the duty cycle of the switch $S_{1.}$ Since the average voltage across C_1 is V_{in}, the output voltage (V_0) is $V_{s1} - V_{in}$. If V_{s1} is less than double $V_{in,}$ then the output voltage will be less than the input voltage. If V_{s1} is greater than double $V_{in,}$ then the output voltage will be greater than the input voltage.

4. DESIGN OF SEPIC CONVERTER DESIGN SPECIFICATION:

Input supply Voltage (Vin) =12 volts
Power (P)=24 Watts
Output Voltage (Vout) =12 Volts
Max Input Voltage (Vin-max) =13.5 Volts
Switching Frequency (Fsw) =8 KHz
Voltage Ripple (Vripple) =0.05%

DESIGN CALCULATION:

Duty Cycle consideration:

For a SEPIC converter operating in continuous conduction mode (CCM), the duty cycle is given by

$$D=\frac{V_{out}+V_D}{V_{in}+V_{out}+V_D}$$

V_D is the forward voltage drop of the diode D1.Therefore the maximum duty cycle is given by

$$D_{max} = \frac{V_{out}+V_D}{V_{in(min)}+V_{out}+V_D}$$

Assume that VD is 0.7V,

$$Dmax = \frac{12+0.7}{10.5+12+0.7}$$

$Dmax$ =0.5474

The minimum duty cycle is given as

$$D_{min} = \frac{V_{out}+V_D}{V_{in(max)}+V_{out}+V_D}$$

$$Dmin = \frac{12+0.7}{17+12+0.7} = 0.4276$$

The load resistance is given as,

$$R = \frac{V^2 out}{P}$$

$$R = \frac{(12)^2}{24} = 6\Omega$$

The output current is given as,

$$Iout = \frac{Vout}{R}$$

$$Iout = \frac{12}{6} = 2\ amps$$

INDUCTOR SELECTION:

For determining the inductance, is to allow the peak-peak ripple current be approximately 20% of the maximum input current at minimum input voltage.The ripple current flowing in equal value of both the inductors L1 and L2 is given by,

$$\Delta I_L = I_{in} \times 20\%$$

$$\Delta I_L = I_{out} \times \frac{Vout}{Vin(min)} \times 20\%$$

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$$\Delta I_L = 2 \times \frac{12}{10.5} \times 20\% = 0.4571 \; amps$$

The inductor value is calculated by,

$$L_1 = L_2 = L = \frac{Vin(min)}{\Delta I_L \times f_{sw}} \times Dmax$$

Where f_{sw} is the switching frequency and D_{max} is the duty cycle at minimum input voltage.

$$L_1 = L_2 = L = \frac{10.5 \times 0.5474}{0.4571 \times 8 \times 1000} = 1.57\text{mH}$$

The peak current in the inductor, to ensure the inductor does not saturate, is given as,

$$I_{L1(peak)} = I_{out} \times \frac{V_{out} + V_D}{V_{in(min)}} \times \left(1 + \frac{20\%}{2}\right)$$

$$I_{L1(peak)} = 2 \times \frac{12 + 0.7}{10.5} \times \left(1 + \frac{20\%}{2}\right) = 2.660 \; amps$$

$$I_{L2(peak)} = I_{out} \times \left(1 + \frac{20\%}{2}\right)$$

$$I_{L2(peak)} = 2 \times \left(1 + \frac{20\%}{2}\right) = 2.2 \; amps$$

COUPLING CAPACITOR SELECTION:

As per the thumb rule, the ceramic capacitor is taken as C_1=10µF.The RMS current of the coupling capacitor is given as,

$$I_{C1(rms)} = I_{out} \times \sqrt{\frac{V_{out} + V_D}{V_{in\,(min)}}}$$

$$I_{C1(rms)} = 2 \times \sqrt{\frac{12 + 0.7}{10.5}} = 2.199 \; amps$$

The ripple voltage is calculated as,

$$\Delta V_{C1} = \frac{I_{out} \times D_{max}}{C_1 \times f_{sw}}$$

$$\Delta V_{C1} = \frac{2 \times 0.5474}{10 \times 10^{-6} \times 8 \times 10^3} = 13.685V$$

OUTPUT CAPACITOR SELECTION:

In a SEPIC converter, when the power switch Q1 is turned on,the inductor is charging and the output current is supplied by the output capacitor. As a result the output capacitor sees large ripple currents.Thus the selected output capcitor must be capable of handling maximum.RMS current in output capacitor is

$$I_{cout(rms)} = I_{out} \times \sqrt{\frac{V_{out} + V_D}{V_{in(min)}}}$$

The ESR,ESL and the buck capacitance of output capacitor directly control the output ripple.As shown in figure,we assume half of the ripple is cause by the ESR andwhere other half is caused by amount of capacitance.So

$$ESR \leq \frac{V_{ripple} \times 0.5}{I_{L1(peak)} + I_{L2(peak)}}$$

$$ESR \leq \frac{0.05 \times 12 \times 0.5}{2.66 + 2.2} = 0.06172\text{m}\Omega$$

$$C_2 \geq \frac{I_{out} \times D}{V_{ripple} \times 0.5 \times f_{sw}}$$

$$C_2 \geq \frac{2 \times 0.7}{0.05 \times 12 \times 0.5 \times 8 \times 10^3} = 3.5mF$$

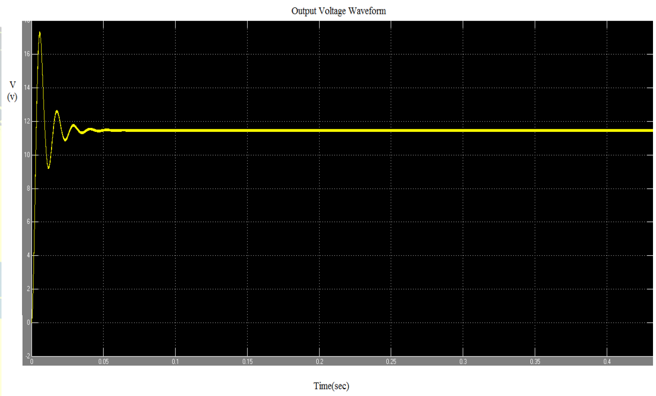

Fig: 5 Output Voltage waveform of SEPIC Converter

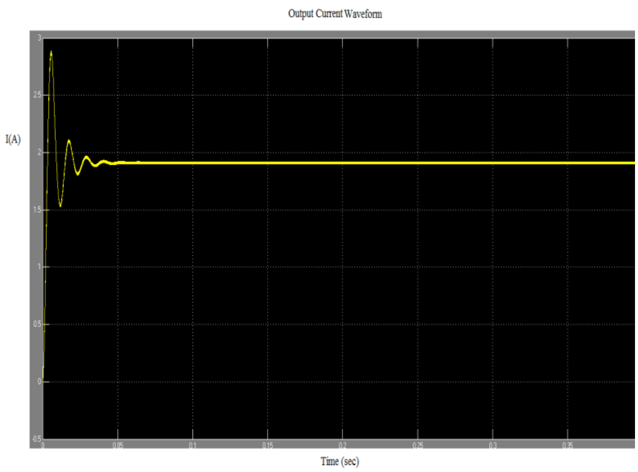

Fig: 6 Output Current Waveform of SEPIC Converter

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5. ARDUINO

Arduino is a toll for making computers that can sense and control more of the physical world than your desktop computer. It is an open source physical computing platform based on a simple microcontroller board and a development environment for writing software for the board. Arduino can be used to develop interactive objects, taking input from variety of switches or sensors and controlling a variety of lights, motors and other physical outputs. Arduino projects can be standalone or they communicate with software running on computer (eg. Flash, processing). The arduino programing language is an implementation of wiring, a similar computing platform, which is based on the processing multimedia programming environment. There are many other microcontroller and microcontroller platforms available for physical computing.

6. FIRING CIRCUIT FOR MOSFET

Firing voltage for MOSFET is around 12V.But the firing pulse obtained from the arduino is 5V only. This 5V obtained from the arduino is not enough to fire the MOSFET. So it is necessary to shift the firing pulse from 5V to 12V.For this purpose TLP250 is used.It act as a level shifter and shift the firing pulse from 5V to 12V.

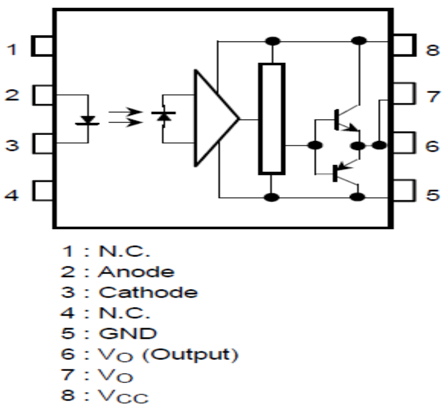
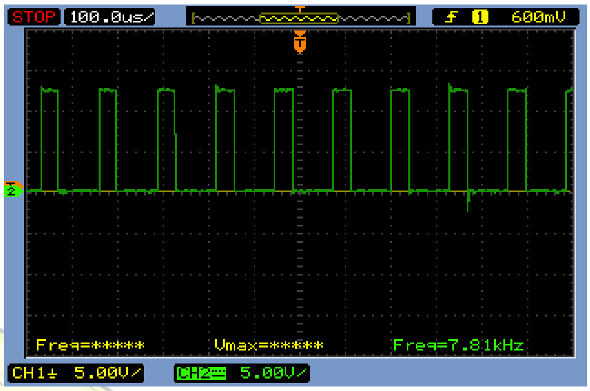
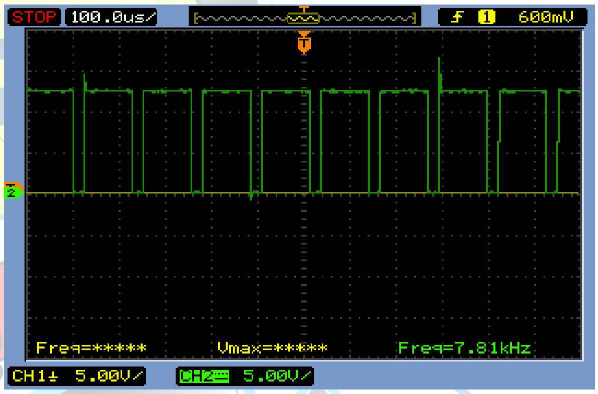


Fig: 7 Pin configuration of TLP250

7. FIRING PULSE WAVEFORM OF MOSFET



30% Duty Cycle Variation



80% Duty Cycle Variation

8. SIZING OF BATTERY

Output power = 24W
Motor to run per day = 1 hour.

STEP 0:
Energy required to run the motor= o/p×workinghour
= 24×1
= 24Wh.

Actual energy required (Considering DC-DC load converter with losses } =Energy req to operate converter efficiency = 24Wh/0.9

Actual energy required = 26.67Wh

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Step1:
Req. Charge Capacity= Actual Energy Required / Battery Voltage
=26.66/12
= 2.22Ah
Step2:
Depth of Discharge (DOD) for battery = 70%
Battery Capacity = Required Charge Capacity / DOD
= 2.22/0.7
= 3.17Ah
Market Availability of Battery= 3.5Ah

SPECIFICATIONS OF BATTERY:

Rated Voltage	12 V
Rated Current	3.5 Ah

Table: 1 Specifications of battery

9. SIZING OF PV PANEL

Step0:
Energy Required = Battery Capacity × Voltage
= 3.5Wh ×12V
= 42 Wh
Step1:
Total Wattage of PV Panel = Energy req./Time of charging
= 42Wh/6hr
= 7 W

Total Wattage of PV Panel (Including DC-DC Losses) = Total Wattage of PV panel / Converter efficiency of converter × Pumping Efficiency × Operating Factor

= 7 / 0.9*0.3*0.75

= 34.56

Step2:
No. of PV Panel Required = 34.56/40
For 40Wp each = 0.86 ≈ 1

Maximum Power	30Wp
Open Circuit Voltage (V_{OC})	17 V
Short Circuit Current (I_{SC})	1.8 A
Maximum Peak Voltage (V_{mpp})	21 V
Maximum Peak Current((I_{mpp})	2 A

Table: 2 Specification of PV Panel

10. CONFIGURATION OF SEPIC CONVERTER

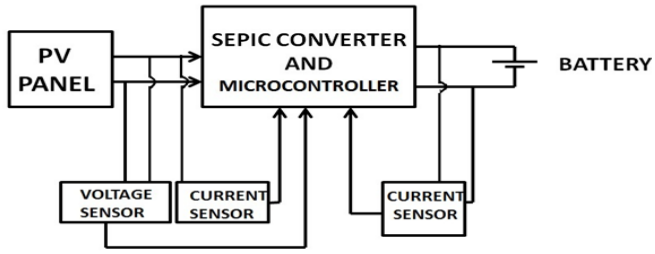

Figure: 8 Block diagram of configuration 1

In this mode PV acts as source and Battery acts as a load. Firstly, the battery is charged using constant current charging method through SEPIC converter. The voltage sensor and current sensor are used to monitor the voltage and current to the SEPIC converter at the input side. A current sensor is used at the output side to monitor the current through the battery.

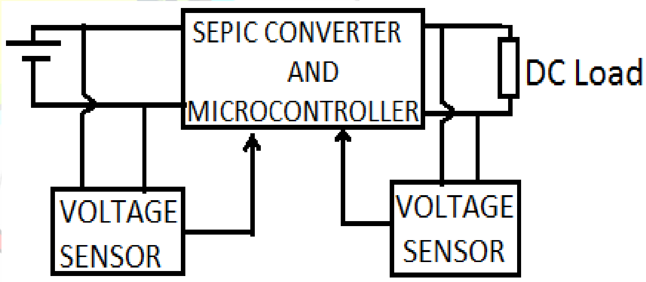

Figure: 9 Block diagram of configuration 2

In this mode Battery acts as a source and Pump acts as a load. The input to load is provided through the SEPIC converter. A voltage sensor is provided at both the input and output side. As the input is provided through the SEPIC converter a constant voltage is provided across the load. The voltage sensor at the output side is used to cut off the battery when depth of discharge goes beyond 70%.

11. DC MOTOR

A DC pump is used as load. 12V Small DC Water Pump. A DC water pump is a device which has a hermetically sealed motor close-coupled to the pump body. The main advantage of this type of pump is that it prevents pump cavitations, a problem associated with a high elevation difference between pump and the fluid surface.

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Power	24 W
Voltage	12 V
Current	2 A
Discharging Capacity	300 litres / hour

Table: 3 Specification of DC Pump

Small DC water pumps push fluid to the surface as opposed to jet pumps having to pull fluids.

12. SENSORS

Soil Moisture Sensor:

Soil moisture sensors measure the volumetric water content in soil. Since the direct gravimetric measurement of free soil moisture requires removing, drying, and weighting of a sample, soil moisture sensors measure the volumetric water content indirectly by using some other property of the soil, such as electrical resistance, dielectric constant, or interaction with neutrons, as a proxy for the moisture content. The relation between the measured property and soil moisture must be calibrated and may vary depending on environmental factors such as soil type, temperature, or electric conductivity. Reflected microwave radiation is affected by the soil moisture and is used for remote sensing in hydrology and agriculture. Portable probe instruments can be used by farmers or gardeners. Soil moisture sensors typically refer to sensors that estimate volumetric water content. Another class of sensors measure another property of moisture in soils called water potential; these sensors are usually referred to as soil water potential sensors and include tensiometers and gypsum blocks.

13. CONCLUSION

SEPIC converter was designed and developed as per the specification. SEPIC converter was simulated in open loop in MATLAB SIMULINK environment. Sizing of PV panel and battery was calculated as per load requirement.Firing circuit to trigger the MOSFET was developed.Program to generate PWM for desired frequency was developed using Arduino IDE. The SEPIC converter with DC pump as load was tested. Interfaced voltage sensor with SEPIC converter in the input and output side and developed program to cut out battery and maintain output voltage of SEPIC converter at constant value respectively. Tested the configuration 1 hardware (battery as input, SEPIC converter as interface and DC pump as load) . Interfaced voltage sensor and current sensor with SEPIC converter in the input side and developing program to implement MPPT algorithm for battery charging. Tested the configuration 2 hardware (PV as input , SEPIC converter and battery as load). Integration of configuration 1 and configuration2 was done.Tested the overall hardware model to evaluate its performance.

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