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Design of a Solar Charge Controller For DC Load Output

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Abstract- **One of several ways to provide power to off grid locations is through stored electrical energy devices such as batteries. This paper presents the design of an economical solar charge controller to be used in a stand-alone solar home system for providing power and increase lifespan of the battery. The designed system uses a direct current DC/DC converter and a microcontroller which implements the Perturb and Observe, algorithm of the maximum power point tracker (MPPT). The prototype is tested with 100 W photovoltaic panel and a 12 Volt lead acid battery.**

Keywords; Charge controller, Perturb and Observe, Microcontroller, Photovoltaic System, DC/DC converter.

I. INTRODUCTION

Sustainable development goals must be reliable, affordable, economically viable and socially acceptable and environmentally sound. To foster sustainable energy development sector, Botswana must innovate technology that reduces reliance on the finite resources to generate electricity. Unreliable electricity access is a detriment to economic growth. Researchers and policy makers have since made efforts to use the renewables or natural sources of energy such as solar which can be harnessed to generate electricity that can be supplied to remote areas. To take advantage of solar energy, there must be a way to store the generated solar energy for later use when the sun sets. One system that can supply solar generated stored energy is a solar home system. A Solar Home System (SHS) is a small-scale electricity supply system for households that are off the main power grid or have unreliable access to electricity supply. It harvests the sunshine and generates electricity which is then stored in a battery to provide power at night and during cloudy days when photovoltaic panels do not produce enough energy [1]. Solar Home Systems generate direct current that can be used for a range of applications including powering electrical appliances, lighting and powering electronic devices. Solar energy provides sustainable environmental and health benefits. By replacing fossil energy sources with renewable ones such as solar, wind, biomass, the move addresses emission issues caused by burning coal and reduces reliance on finite energy resources.

A solar home system typically includes one or more photovoltaic modules consisting of solar cells, a charge controller which distributes power and protects the batteries and appliances from damage and at least one battery to store energy for use during the hours when the sun is down. For many people, living in locations away from the main power grid, a custom-made solar home system is a way of connecting dc voltage to their homes to be used in dc machines. A standard 12-volt solar panel which can be used to recharge a battery, could be putting out, much more voltage than the battery needs. This difference in voltage between the required 12 volts need for the battery and actual volts being generated by the solar panel translates into a greater current flow into the battery. The result is that too much unregulated solar current will overcharge the battery causing the electrolyte solution within the batteries to overheat, resulting in a shortened battery life and ultimately, complete failure of the battery. The quality of the charge will directly affect the lifespan of any connected battery, so it is extremely important to protect batteries of a solar charging system from being overcharged, or even undercharged, and we can do just that using a battery charge regulation device called a charge controller [2]. A charge controller or alternatively a charge regulator is basically a voltage and/or current regulator, to keep batteries from overcharging. It regulates the voltage and current coming from the solar panels and going to the battery. Most 12-volt panels produce about 16 to 20 volts, so if there is no regulation, the batteries will be damaged from overcharging There are two known types of charge controllers; pulse width modulation (PWM) and maximum power point tracking (MPPT) which operate by adjusting charging rates of batteries depending on the maximum capacity and also monitor the battery temperature to prevent overheating [3] .This work proposes the design an affordable, reliable solar home system charge controller that uses locally sourced components for monitoring the charging status of a battery. The prototype will be used in homes that are located remotely from the main power grid for supply of electrical energy. This system will provide users will the ability to monitor their energy consumption, making it cost effective.

Fig 1: Direct connection of a battery to a solar panel.

A. Related Work

Most works in the literature have studied and designed charge controllers as discussed in [5, 6, 7]. These works Jim Drew on his article about designing a solar cell battery charger deduced that all solar powered devices feature researchable batteries and the objective is to extract much power as could be reasonably be expected to charge the batteries rapidly and maintain the charge. He also stated that solar based cells are intrinsically inefficient devices but they do have a point of most extreme power yield (Maximum power output) and operating at that point is a great desire. Figure 2 above shows, sun powered cell produces current in extent to the measure of daylight falling on it, while the cell's open-circuit voltage remains generally steady. Greatest power yield happens at the knee of each bend, where the cell transitions from a consistent voltage.

An article [4] proofed an idea for optimized and safe battery charging system for home, using solar charge controller by connecting the solar panel and the battery. This helps utilise solar in proficient way and expand the lifetime of battery too. Because of this, it very well may be comprehended that the condition of charge of battery is improved. They also compared the modelling of a charge controller and can be classified as single stage and multi stage regulators which are constant current and constant voltage regulators, series charge controller, shunt charge controller and combined series shunt charge controller.

From [5] article PWM and MPPT are the two distinct sorts of charging strategies sun oriented charge controllers can use to charge batteries from a sunlight based panel. The two advances are broadly utilized in the off-grid solar industry and are both extraordinary alternatives for effectively charging the battery. Pulse with modulation become an integral factor when the battery bank if full, it plays a big role on switching between connecting the battery which regulates the battery voltage keeping it constant.

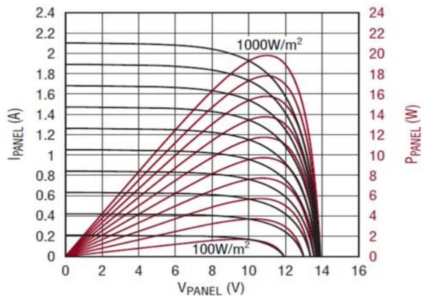

Fig 2: V-I graph for the solar panel

II. SOLAR HOME SYSTEM COMPONENTS

A. Solar Panel

A solar panel is a package connected assembly of photovoltaic cells. It can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications. Every solar panel has an I-V curve or I-V characteristics associated with it.in our case we are trying to extract as much as possible from the I-V curve.

B. Lead Acid Battery

Lead acid battery is an electrical storage device that uses a reversible chemical reaction to store energy. It uses a combination lead plates or grids and an electrolyte consisting of a diluted sulphuric acid to convert electrical energy into potential chemical energy and back again**Invalid source specified.**.All batteries tend to experience several phenomena, which affect their performance. Some of these conditions are named below, with proper charge design the following can be avoided increasing the lifespan of the battery.

- Self-discharge.
- Gassing
- Sulfation
- Freezing
- Dehydration

C. Charge Unit

There are basically different charging methods that all have different effects ad complications when designing. The main aim of the charging unit is to cut the supply when the battery is full and to start charging when low.

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III. MAXIMUM POWER POINT TRACKING ALGORITHM

Maximum power point tracking (MPPT) algorithms are very important when it comes to maximising the power output at any moment.in many applications, the load can demand more power than the PV system can deliver. Therefore, there are many different approaches to maximising the power from a PV system, this range from using simple voltage relationship to move complexes multiple sample based analysis. The following are some of the conventional Maximum power point tracking methods;

- Constant voltage method
- Open circuit voltage method
- Short circuit current method
- Perturb and observe method
- Incremental conductance method

The algorithm is implemented in the microcontroller which will be controlling the DC-DC converter.

IV. SYSTEM DESIGN

In all, our project is to design solar charge controller with LCD display for voltages and use the MPPT method with "Perturb and Observe" algorithm to obtain the maximum power with the help of the pic controller. To save power loss the solar charge controller uses less switch.

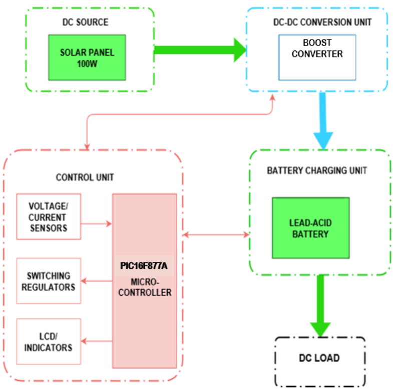

Fig 3: System flow chart

A. *Sizing*

The size of the solar panel depend on the overall output power of the load. Suppose we were to design three LED lights that operate at 15 W for 5hours per day has been selected and 4 smartphone chargers each operating at 5W for a period of 4 hours per day. Using a 5 Sun Peak hours which is common in Botswana;

$$Total\ power = \frac{305Wh}{5hrs} = 61\ W \qquad (1)$$

TABLE 1: TOTAL POWER OF LOAD

Description Iterm	Rating	Quantity	Number of Hours	Total Power
Smartphone charger	5 W	4	4	80 Wh
LED lights	15 W	3	5	225 Wh
Total Power				305 Wh

Using a factor of 1.4 to cater for diturbances

$$Total\ power = \frac{305Wh}{5hrs} * 1.4 = 85.4\ W \qquad (2)$$

Going for a panel that produces a minimum of 85.4 W is used but for standard rate,a solar panel of 100 W was selected.

B. *DC-DC converter*

In a boost converter, the output voltage is greater than the input voltage –hence the name "boost". A boost converter using a power MOSFET.

Why boost converter

- The inductor current is continuous.
- The circuit is operating in the steady state.
- The capacitor is large enough to assume a constant output voltage.

a. *Design Assumptions*

The output voltage is achieved by fast switching the device. The output voltage depends on the switching frequency applied to the device and it depends on the duty cycle of the frequency

The voltage and current ripple must be less than 0.5%. The switching Frequency is assumed 25 KHz. The Inductor current is assumed continuous100% efficient.

$$output\ current = Io = \frac{Po}{Vo} = \frac{100}{30} = 3.33A$$

$$The\ Duty\ ratio,\ \frac{Vo}{Vin} = \frac{1}{(1-\propto)}$$

$$\propto = \frac{(Vo - Vin)}{Vo} = \frac{30-12}{30} = 0.6$$

$$Load\ resistace = \frac{Vo}{Io} = \frac{30}{3.333} = 9.0\ \Omega \approx$$

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$$Lmin = \frac{R \propto (1-\propto)^2}{2f} = \frac{9 \times 0.6(1-0.6)^2}{2 \times 25000} = 69\ uH$$

L must be greater than Lmin so

$$L = 81\%\ of\ lmin = 0.81 \times 69\ uH = 55.99\mu H$$

Capacitor value

$$C \geq \frac{\propto}{R * \left(\frac{dv}{v}\right) * f} = \frac{0.6}{9 \times 0.005 \times 25000} = 0.000533\ F \approx 540\mu F$$

Taking a capacity or of 560F at most which is commonly available.

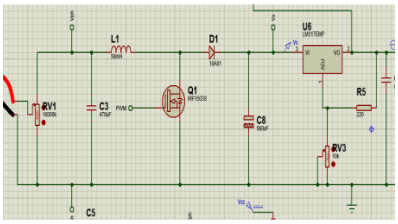


Fig 4: Boost converter

C. Power supply unit

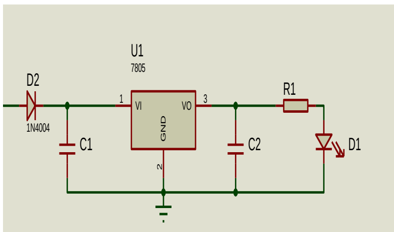


Fig 5: Power supply

For the microcontroller and sensors (voltage and current) they operate at lower voltage, a stable power supply was designed using LM7805 voltage regulator. Another reason for embedding the circuit in the system is because it produces a fixed output voltage.

In the data sheet it shows that the input voltage should be in range of 7 to 25 volts and our panel minimum voltage is around 11 volts and 18 Volts' maximum making it suitable for application. Input voltage will be applied across the first and second pin of 7805, Second pin is common to both input and output. It is connected to ground. Output voltage is taken across the third and second pin. Output voltage is fixed and will be 5V.

The Diode D2 is responsible for allowing current in one direction.

The capacitor C1 is present in the circuit in case there is an AC signal since it is a DC device like most amplifiers, it can become unstable if variations in supply voltage cause a change in output voltage. Capacitor C2 near the output, it helps in the transient response.

According to the Manufactures specification the values are not restricted, for 0.33µF and 0.1µF were chosen for C1 and C2 respectively. The fixed voltage regulator has a regulated output voltage of 5V is a current limiting resistor connected in series with an LED (power indicator) that indicates that the circuit is on.

$$R1 = \frac{Vs - V_D}{I_D} = \frac{5-2}{0.01} = 300\Omega \qquad (3)$$

Vs = 12V

Vd =2V

Id = (10mA-20mA)

D. Voltage regulator

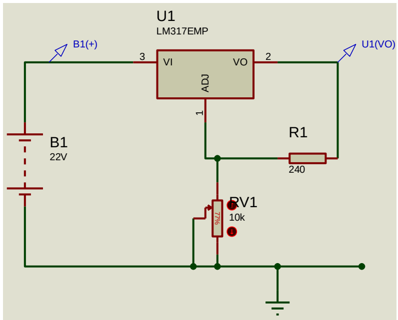


Fig 6: Voltage regulator

LM317 is an adjustable voltage regulator which takes an input voltage of 3- 40V DC and provides a fixed output voltage of 1.25V to 37V DC. It requires two external resistors to adjust the output voltage.in our case the DC-DC converter will boost the voltage and not provide a fixed voltage.The boost output is varying between 0- 29 volts ,the regulator will provide a fixed Voltage for charging the battery.

The required voltage for charging = 13.6V

Output Voltage= 13.6V+0.6=14.3V (0.6 voltage drop of the diode that is blocking the current from the battery). The Output Voltage of the regulator is dependent on external resistor values R1 and RV1 the variable resistor which can be fixed to get the fixed voltage but for our case it will be left to vary in case of charging different batteries.

$$Vout = 1.25 \times \left(1 + \frac{RV1}{RV1}\right) \qquad (4)$$

The above equation is used to calculate resistors. The recommended value for R1 is 240Ω but it can also be some other value between 100Ω to 1000Ω.

For example if the target output voltage is 16V then the R2 value is calculated as following:

16 = 1.25x (1 + R2/240) => R2 = 2832Ω.

E. Voltage Sensor

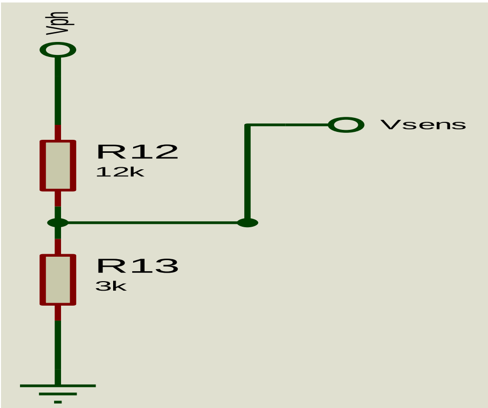


Fig 7: Voltage Sensor

Voltage divider network is used as voltage sensor for the microcontroller. The resistance values chosen are 12kΩ and 3kΩ. This gives the resistance ratio of 8.2KΩ/ (32KΩ+8.2KΩ) = 0.20 and therefore gives the maximum input voltage to the A/D conversion channel is 0.20×25=5

F. Current sensor

In the circuit diagram, maximum output of 17-volt DC source is applied to a 33 Ohm load. Current passing through this is measured with help of shunt resistor and a PIC16F877A microcontroller. The microcontroller cannot read current directly since they can only sense voltage. Therefore, this is why the current need to be converted into voltage form to be able to be read by the microcontroller. A 0.5 Ohm shunt resistor is used by connecting two 1 Ohm resistors in parallel. When current passes through shunt resistor, voltage appears across shunt resistor. This voltage can be easily measured with the help of analogue to digital converter channel of PIC16F877A microcontroller. This measured voltage value can be converted back into current in programming using ohm's law formula:

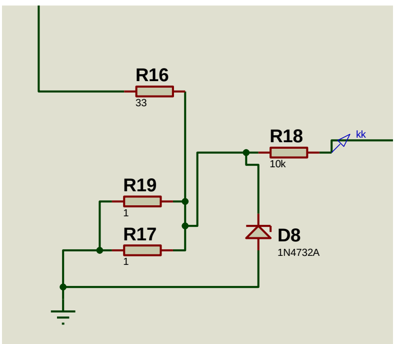


Fig 8: Current sensor

G. Protection

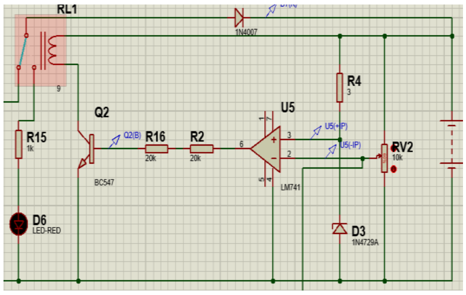


Fig 9: Protection Unit

Operational amplifier it's used to compare the reference value set from the battery with the varying voltage to the load. The output of the Operational amplifier is used to switch the MOSFET, based on the output voltage, so that the relay can be energized and de-energized, changing state to protect the battery.

H. Microcontroller

The microcontroller works with 5V from the supply, we have proposed a scheme as based on the use of conventional DC-DC converter, where combination of voltage and power feedback control system is implemented with the use of artificial intelligence Algorithm, which results in tracking strategy that makes output response faster, maximizes the power extracted from the solar module, and maintains the power delivered to the load. Maximum power point tracking is assured by varying duty cycle of the PWM signal to control MOSFET switch applied to a boost converter. The control logic is implemented to a microcontroller.

The chosen microcontroller to be the heart of our project is PIC16F877A, its duty will be based on displaying the measured voltage on LCD and producing the pulse for the MOSFET switch together with MPPT algorithm. The PIC16F877A micro controller is commonly used because it's to use and it has many internal peripherals. ADC interface and parallel slave port interface and its large programming memory. The external clock has been used which results in faster operation since you can select a 20MHz instead of 8MHz oscillator. External clock has been used which results in faster operation since you can select a 20MHz instead of 8MHz oscillator.

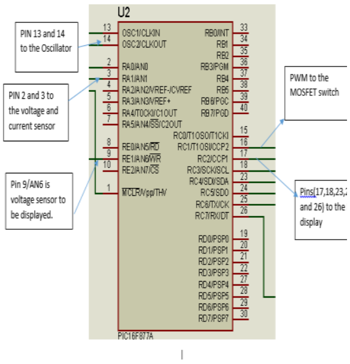


Fig 10: Microcontroller Pin layout

a. writing a code in MIKRO-c

Writing a code or programming on pic can be done in several languages such as assembler, C, BASIC &FLOW CODE etc. These are the most common ones and widely used languages, assembler is a mid-level language but are usually programmed very slowly and take up very least amount of space in the memory and giving the best result with execution. On the other hand, Programme on C language are very easy to learn and the instructions are really easy to understand. The disadvantage with it is that it is slower than Assembler. In this project C programming language is used using the software MIKRO C Pro for PIC. After writing the code it is compiled to hex file using ANSI C compiler

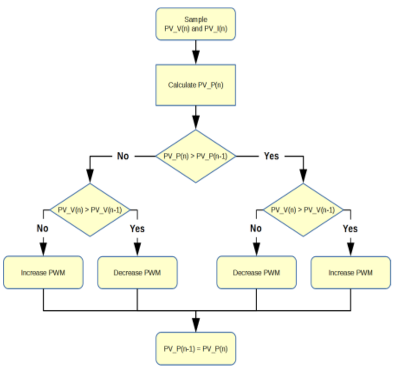


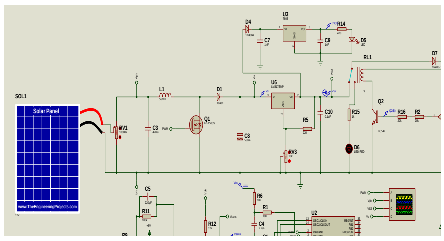
Figure 11: MPPT-P&O algorithm

```
void MPPT(void)
{
ADCON0= 0;
measuredvoltage = ADC_Read(0);                /*
Read the voltage input from ADC channel 0 */
ADCON1= 1;                    /* select RA1 */
measuredcurrent = ADC_Read(1);   /* Read the
current input from ADC channel 1 */
power =(measuredvoltage*measuredcurrent);

    if (power>powerold)
    {   if (measuredvoltage >voltageold)
        {
          pwm++;
        }
        else
         {
           Pwm--;
         }
    }
      else
     {   if (measuredvoltage >voltageold)
         {
           pwm--;
         }
         else
         {
           pwm++;
         }
      }
         measuredvoltage=voltageold;
        power=powerold;
         PWM2_Set_Duty(pwm);

      }
```

V. RESULTS AND ANALYSIS



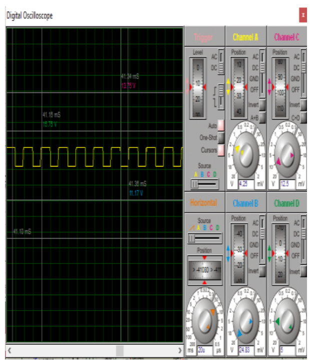


Fig 13: 50 % Pulse

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The duty cycle is 50 % from Fig 13, the regulated voltage from channel C is 14.38 V. the boosted voltage is 29.50 V and the input is 11.17V

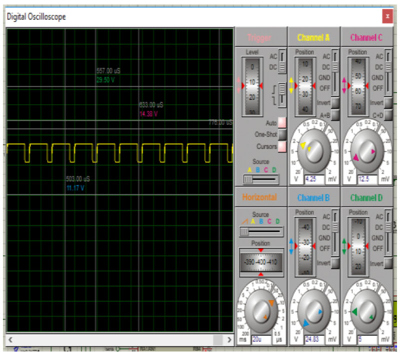

Fig 14: 60 % Pulse

The duty cycle is 60 % from Fig 14 the regulated voltage from channel C is 14.38 V. the boosted voltage is 29.50 V and the input is 11.17V.

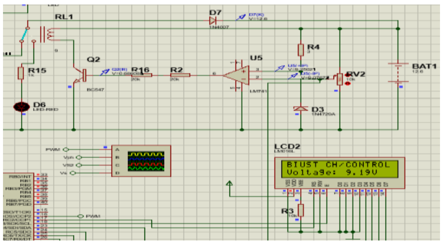

Fig 15: charging circuit

When the voltage of the battery to be charges is less than 9.20V the relay change state and connect the battery to be charging system as indicated in Fig 15

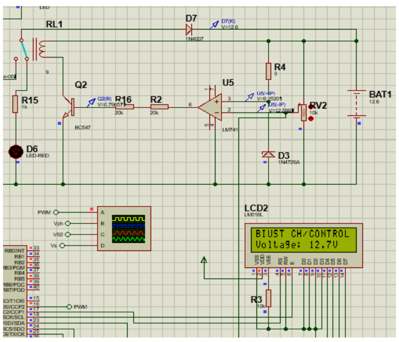

Fig 16: disconnect from solar panel

When the voltage of the battery to be charges is more than 12.6 V the relay change state and disconnect the battery from the charging system as indicated in Fig16

DISCUSSION

From the results we obtained, it showed that the voltage from the panel will always vary depending on the sun intensity hence this affects the voltage to the charger. This agrees with what we have found out in the literature review, a boost converter can be used to boost the voltage from the panel to make it suitable for charging with the help of MPPT algorithm to extract maximum power from the solar panel by varying the duty cycle to switch the MOSFET on or off. The microcontroller played a big role as it generates the PWM and displayed the output voltage on the LCD. The LED indicators are used for monitoring the state of the charger as it protects the battery from overcharging and discharging. Our results answer the objectives we set in the beginning.

CONCLUSION

In this project analysis of a solar charge controller with DC output has been carried out. To extract out maximum power boost converter is used, the energy then goes through the charge controller that monitors overcharging by the help of the relay and storing the energy in the battery. The battery is monitored by another circuit to protect it from over-discharging when is used by the load. Therefore, our motto has been achieved to make a solar charge controller as batteries will be monitored and kept safe increasing their lifespan and productivity.

RECOMMENDATIONS

Even though a boost can do, we will recommend a further study on a buck-boost charge controller as it maintains the constant voltage. Also we will recommend a further study on interfacing the microcontroller with the charge controller so that the microcontroller can control the flow of current into the battery until it gets full.

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