Solar UPS for Home Router

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Abstract—Renewable energy sector relies heavily on solar energy. Most solar users are aware that solar panels currently are not efficient but there is not much awareness regarding the charge controller’s efficiency which plays a major role in the output of the solar panel. For this project Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT) charge controllers were researched in depth. The conclusion drawn from the research was that MPPT charge controllers are much more efficient. The MPPT charge controller designed for this project incorporates a micro-controller typically used in Arduino. The micro-controller also enables the addition of a User Interface (UI). After designing and implementation stages, the MPPT charge controller was tested against a PWM charge controller. The analysis revealed that MPPT charge control yields much more power, especially during low light condition. This project was successful on many levels in terms of making an efficient charge controller using readily available inexpensive components, simple design, providing a user interface and keeping the cost low.

I. INTRODUCTION

The trend of solar panels contributing more and more towards the power consumption is bound to stick around, but the missing important piece of solar power harvesting is often not talked about. Most solar users are aware that solar panels currently are not efficient but there is not much awareness regarding the charge controller’s efficiency which plays a major role in the output of the solar panel. For solar energy to become the biggest contributor, charge controllers must become more efficient as well resulting in the least amount of solar energy being wasted. This project focuses on inexpensively creating a MPPT charge controller using easily available parts and writing code to accomplish the task at hand. A dummy load in the form of a home internet router is used. In addition to that we would also need a charge control mechanism for the end device to prevent the battery’s high-power output from destroying the end device which in our case is a home internet router. This project designs and implements a step-down converter (Buck-Converter) which is highly efficient and reduces the amount of power loss from the battery to the load. The home internet router is a dummy load, anything else could have been used.

After thoroughly testing and investigating the MPPT charge controller, the conclusion was that a 100-Watt solar panel and a 25 Ah battery could keep a home internet router powered for close to 12 hours during low light conditions and up to 16 hours on a bright day. The similar configuration of solar panel, home internet router and battery were tested with a standard PWM charge controller as well. The PWM charge controller could keep the home internet router powered for up to 12 hours on bright days but in low light conditions only up to 5 hours. It was very clear that MPPT charge controllers are the future of the industry. The major reason that PWM charge controllers are still being sold is because MPPT charge controllers are slightly more expensive. Because of careful component selection and design elements for this project, the MPPT charge controller designed for this project cost close to 43 USD which is very close to the price of a PWM charge controller with similar specifications for voltage and amperage.

II. MAXIMUM POWER POINT TRACKING (MPPT)

MPPT is a technique used commonly with wind turbines and solar systems to maximize power extraction under all conditions. The central problem addressed by MPPT is that the efficiency of power transfer from the solar cell depends on both the amount of sunlight falling on the solar panels and the electrical characteristics of the load. As the amount of sunlight varies, the load characteristic that gives the highest power transfer efficiency changes. This load characteristic is called the maximum power point and MPPT is the process of finding this point and keeping the load characteristic there. Electrical circuits can be designed to present arbitrary loads to the photo-voltaic cells and then convert the voltage, current, or frequency to suit other devices or systems, and MPPT solves the problem of choosing the best load to be presented to the cells in order to get the most usable power out. Solar cells have

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a complex relationship between temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve [1].

Given below is an I-V curve that I was able to build after experimenting with output of a solar panel in various light conditions. The solar panel used for this experiment was a 10-Watt panel:

![IV Curve (Voc = 21.3V)](image)

As illustrated by the chart above, there is a certain point on the graph where the power (voltage * current) is maximum. As the lighting condition, temperature or load characteristics changes, this sweet spot will change too. The job of the micro-controller used in the MPPT design is to keep track of this sweet spot and keep the output in this sweet spot so maximum power can be extracted out of the solar panel to charge the battery. It is the purpose of the MPPT system to sample the output of the PV cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. When a load is directly connected to the solar panel, the operating point of the panel will rarely be at peak power. The impedance seen by the panel derives the operating point of the solar panel. Thus, by varying the impedance seen by the panel, the operating point can be moved towards peak power point. Since panels are DC devices, DC-DC converters must be utilized to transform the impedance of one circuit (source) to the other circuit (load). Changing the duty ratio of the DC-DC converter results in an impedance change as seen by the panel. At a particular impedance (or duty ratio) the operating point will be at the peak power transfer point. Based on what we know now, it is not feasible to fix the duty ratio with such dynamically changing operating conditions. MPPT implementations utilize algorithms that frequently samples panel voltages and currents, then adjust the duty ratio as needed. Micro-controllers are employed to implement the algorithms [4]. There are various ways MPPT algorithms be implemented, this project implements the method known as perturb and observe because its rather simple and does yield the desired results effectively. In this algorithm a slight perturbation is introduce to the system. This perturbation causes the output power of the solar module to vary. If the power increases due to the perturbation, then the perturbation is continued in the same direction. After the peak power is reached the power at the MPP is zero and next instant decreases and hence after that the perturbation reverses as shown below [3]:

![Perturb and Observe](image)

MPPT charge controller uses PWM to keep the batteries regulated but can also increase the output of the solar array by finding the maximum power point of the array (which is a higher voltage than the battery bank) and reducing the voltage to charge the batteries. This can result in up to a 30 percent increase in output of the solar array. It also allows for a higher voltage transmission from the solar array to the controller keeping wire losses to a minimum. MPPT charge controllers also ensure that the battery bank is never overcharged by using stages which include bulk, absorption, float and equalization charges to make your batteries last as long as possible without over charging [2]. Manufacturing firms that manufacture MPPT charge controllers locally do achieve their goal of efficiently extracting maximum power out of a solar panel, but they come at a cost which most consumers cannot afford. I was successful in extracting maximum power out of solar panel using a micro-controller and my design did incorporate a user interface in the form of a 16 x 2 display with a fraction of the cost.
The heart of this project is the MPPT charge controller which extracts maximum power out of a solar panel. A micro-controller constantly tracks the maximum power point of the solar panel and varies the load characteristics seen by the solar panel to extract maximum power and charge a battery. A typical lead acid battery charges between 13.8V and 14.4V. The MPPT charge controller keeps the panel voltage output in this range and draws whatever current it possibly can. On a bright sunny day using a 100-Watt solar panel, the MPPT charge controller can extract close to 6A while keeping the voltage in that range, but on a cloudy day, it might only be able to produce 1A or 2A while keeping the voltage in that range. Based on the use case for this project, MPPT charge controller is not the only design element that is needed to complete this project. The home network router used in this project has requirements for which a buck converter would also have to be designed. The router used in this project requires 5.1 VDC and 2.2 A. A Buck Converter needs to be designed that has an output voltage of 5.1v and there will be a drain of 2.2A on it. The block diagram is given below:

![System Block Diagram](image)

The MPPT charge controller is comprised of a few different sectors. The advantage of that being that these sectors could be individually simulated. There is a synchronous converter used in the MPPT charge controller design which needs to turn one MOSFET on while turning the other off and vice versa. This can later be controlled with PWM. Given below is the schematic for this part of the MPPT charge controller:

![Synchronous Buck Converter Schematic](image)

![Synchronous Buck Converter Simulation](image)

In the figure above, we can see IR2015 Half-Bridge driver switching. We can see that when one MOSFET is off, the other turns on and vice versa. We see some ripple because this half-bridge driver has a 540 ns off time. During experimentation, switching was controller using a function generator while waveform was obtained using an oscilloscope, but later we will use the micro-controller to control switching which varies with PWM.
We started with a simple synchronous buck converter as given below:

![Simple Synchronous Buck Converter](image)

Typically, a buck converter consists of one MOSFET but the addition of this second MOSFET enables the circuit to be controller using Pulse Width Modulation (PWM). A buck converter (step-down converter) is a DC-to-DC power converter which steps down voltage (while stepping up current) from its input (supply) to its output (load). This PWM enabled synchronous converter provides more control when implemented together with a micro-controller. Next step was to control the synchronous buck converter using a programmed micro-controller. To accomplish this, a half-bridge driver IR2104 was used together with ATmega328. Next, input and output current/voltage monitors were introduced to the design. It is important to remember that the information collected by the input and output voltage/current monitor will not only be used in the user interface to show the user the output voltage of the panel but also for code in the micro-controller to adjust switching. With all these in place, the micro-controlled was programmed to use the perturb and observe algorithm discussed above which, after trial and error yielded the desired results. The final schematic is given below:

![MPPT Charge Controller Schematic](image)

A 4-layer PCB was made with 4 terminals on it. First one being a 5V terminal to power just the micro-controller and the LCD to see if the system is functioning without switching. Second terminal being a 12 V terminal to power the entire system and see switching. Third terminal was for the input coming from the solar panel and lastly the fourth terminal was output going to the battery. The micro-controller and LCD were not soldered on the PCB but rather used female headers for, to keep the system as modular as possible. Another advantage of this setup was that the micro-controller code could be updated if need be.

V. MICROCONTROLLER

The microcontroller is responsible for not only performing perturb and observe but also for the user interface, reading data from input and output current sensors, controlling the battery charging circuit and transmitting data. The goal to extract maximum power is achieved becomes of the algorithm for which some pseudo code is given below:

```cpp
void buck_update()
{
    if(buck_duty_cycle) //DC-DC converter is currently running
    {
        if((InputVoltage<Stop_Voltage) || (InputCurrent<NoCurrent))
            buck_disable();
        else
        {
            if((InputVoltage<perfectVoltage) || (OutputVoltage>High_Voltage)
                || (InputCurrent>UpperCurrentLimit) || (OutputCurrent>UpperCurrentLimit))
                buck_duty(buck_duty_cycle-1);
            if((InputVoltage<perfectVoltage) && (OutputVoltage<Low_Voltage))
                buck_duty(buck_duty_cycle+1);
        }
    }
    else
    {
        if(InputVoltage>Start_Voltage)
            buck_duty((uint8_t) (255*OutputVoltage/InputVoltage));
        buck_turnoff();
    }
}
```

![MPPT Charge Controller Schematic](image)

VI. CONCLUSION

MPPT charge controller can be created and implemented using inexpensive parts which will keep the cost low and at the same time yield more power than any PWM charge controller. Perturb and observe algorithm works perfect and can be implemented in nearly all scenarios.
REFERENCES


