Design and Construction of A 30 amps Charge Controller Using Perturb and Observe Method

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Abstract: The main aim of this research is to design and construct a 30amp solar charge controller using Maximum Power Point Tracking (MPPT) to maximize the photovoltaic array output power, irrespective of the temperature, irradiation conditions and electrical characteristics of the load.

There are two charging stages for the proposed PV charger. At the beginning of the charging process, a continuous MPPT-charging scheme is adopted. When the State of Charge (SOC) of battery reaches its set given condition, a pulse-current-charging scheme with an adaptive rest period is applied to obtain an average charging current with an exponential profile. During the charging period, the MPPT function is retained to achieve high charging efficiency.

The result gotten from this research adopted using the MPPT system and other techniques used in the past, are that the PV array output power is used to directly control the synchronous buck converter, thus reducing the complexity of the system and also protect the battery from repetitive overcharges.

Keywords: Photovoltaic panel, Maximum Power Point Tracker [MPPT], DC-to-DC converter, Microcontroller.

I. INTRODUCTION

Crisis of electricity is a major problem in the present era. This problem is even more critical for a densely populated poverty corrupted developing third world country like ours. However, it is difficult in come up with innovatory ideas to reduce and conserve wastage of energy which could be utilized by areas where there is inadequate power supply. The word Photovoltaic is simply the combination of Greek words that is Light and the name of a renowned physicist Allesandro Volta. He was the first to research and discover the direct conversion of sunlight into energy by means of solar cells [1]. As at today in our world the utilization of solar energy is been under harnessed hence developing country should look inward and encourage the use of renewable energy so as to compensate for the short fall in power generation, thereby improving technological and social economy wellbeing of its citizenry.

Design Overview. Charge controllers are electrical and electronic devices deployed in power system circuit to prevent overcharging of battery and other associated components in the system and also protect against overvoltage, when a charge controller of a system is out this could led to poor performance of the system, reduce battery durability, performance and lifespan of the battery, and may pose serious safety risk for the operator. Charge controller may also prevent batteries from completely draining ("deep discharging"). A simple charge controllers stop charging the battery connected to it when the charging gets to its maximum set value and start charging when the battery drains to the minimum set level [2]. Harrington and Dunlop in 1992 analyzed the typical strategies for battery charge regulation in stand-alone PV systems and conclude that the battery information is very important in designing PV systems [3].

Solar Cell Equivalent Circuit. Solar panel consists of several photovoltaic cells which could be connected in series or parallel depending on the goal the system is to achieve. When photovoltaic cells connected in Series this increases the voltage of the module and when it’s been connected in parallel the current in the array is been increased. A typically a solar cell could be modeled using a simple current source and an inverted diode which are connected in parallel. An equivalent circuit for solar cell is shown in Fig.I.[4].

II. DESIGN ANALYSIS

Although various algorithms such as perturb and observe method, Incremental conductance method, parasitic capacitance and constant voltage method may perform MPPT, it is important to know that other method could also perform MPPT functions, thus there is need to also consider some grail areas the ability of an algorithm to detect multiple maxima, costs, and convergence speed formed our discussion in using the perturb and observe method.

However, the designed Solar Charge Controller system was critically analyzed with the related theories and calculations, the system is composed of ATmega 328P microcontroller, ACS712 current sensor which senses current from the solar panel, the buck converter is made up of the synchronous MOSFET switches and the energy storage devices inductor and capacitors to steps the higher solar panel voltage down to the charging voltage of the lead-acid battery, voltage divider circuits to
decrease the voltage being measured to within the range of the Arduino analog inputs in order to measure both solar panel and battery. IR2104 MOSFET driver drives the high and the low side MOSFETs using the Pulse Width Modulation signal from the microcontroller.

From the research a dc voltage supply was obtained from the solar panel with fluctuations and was regulated using DC-DC converter to 12volt battery terminals, it’s output was not a pure dc, however it had some ripples. To reduce these ripples we used filters (high frequency ripple filter). To reduce high frequency ripples electrolytic capacitors was used.

The capacitor C2 act as filter circuit to reduce the effect of ripples from the power supply i.e 220uF/25V between the positive battery terminal of 12V dc and the LM7805 voltage regulator smooth the output voltage.

From the National Semiconductor products datasheet a voltage regulator KA 7805 IC with the specification as follows: regulated output voltage 5V, output current 1A. The 7805 was deployed in the design to effectively regulate the output voltage going into the microcontroller to 5V by further adding another capacitor C3.
Design Analysis of the Control Unit

The ATmega328 microcontroller comes preprogrammed with a boot loader that allows you to upload new code to it without the use of an external hardware programmer.

Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. Which operate at 5 volts, each pin on the micro controller can provide or receive 20 mA as recommended operating condition which also have an internal pull-up resistor (disconnected by default) of 20-50k ohm. A maximum of 40mA is the maximum value that must not be exceeded on any I/O pin to prevent permanent damage to the microcontroller [5].

The ATmega 328P Arduino Uno also has 6 analog inputs, labeled A0 through A5, each of which provide 10 bits of resolution (i.e. 1024 different values). The microcontroller is used in processing the input data which is been displayed at the output photovoltaic system. This process includes reading signals and data from sensor values, controlling of battery-charging circuitry, monitoring system performance and anomalies in the system, along with transmitting such data [7]. The system is programmed in such a way that it operates at maximum power point. The pseudo code used in perturb and observe method is given below.

```c
void set_charger(void) {
    switch (charger_state) {
    case no_battery:
        disable_charger();
        break;
    case sleep:
        pulseWidth = 512;
        disable_charger();
        break;
    case bulk:
        PerturbAndObserve();
        enable_charger();
        break;
    case Float:
        pulseWidth = 1022;
        battery is charged)
        if (bat_volts < BAT_FLOAT) enable_charger();
        else disable_charger();
        break;
    case error:
        disable_charger();
        break;
    default:
        disable_charger();
        break;
    }
}
void PerturbAndObserve()
if ((pulseWidth == 300) || (pulseWidth == 1022) || (sol_watts < old_sol_watts)) trackDirection = -trackDirection; // if pulseWidth has hit one of the ends reverse the track direction
pulseWidth = pulseWidth + trackDirection;
}
```
Design Analysis of the Sensor Unit

The ACS712 sensor has the ability to read the current value and also convert it into a realistic voltage value that links the measurement of sensitivity.

As per data sheet for a ACS 712 (5A) model:
1. The sensitivity is put at 185mV/A.
2. The sensor can measure both positive and negative currents ranging from (-5A to 5A),
3. The Power supply is 5V
4. The middle sensing voltage is at 2.5V when there is no current.

Calibration:
Value = (5/1024)*analog read value
Where the analog read value is 1020
Value = (5/1024)*1020 = 4.998
But as per data sheets offset is 2.5V (When current zero you will get 2.5V from the sensor’s output)
Current in amp = (value-2.5)/0.185

Design Analysis of the Switching Unit

The key ingredient of MPPT hardware is a switch-mode DC-DC converter. MPPT uses the converter for regulating the input voltage at the PV MPP and providing load matching for the maximum power transfer

Working Principle:

When the MOSFET is ON
When the MOSFET is ON, current flows through the inductor (L), load (R) and the output capacitor (C). In this condition the diode is reverse biased. So no current flows through it. During the ON state magnetic energy is stored in the inductor and electrical energy is stored in the output capacitor.

When the MOSFET is OFF
When the MOSFET is off, stored energy in the Inductor is collapsed and current complete its path through the diode (forward biased). When stored energy in the inductor vanishes, stored energy in the capacitor is supplied to load to maintain the current.

Selecting the Inductor size: Calculating the inductor value is very critical in the design of buck converter, assuming the converter is on continuous current mode (CCM). This implies that the inductor does not fully discharge within the switch-off time. The following equations assume an ideal switch (zero on-resistance, infinite off-resistance and zero switching time) and an ideal diode.

We are designing for a 50W solar panel and 12V battery
Input voltage (Vin) =15V
Output Voltage (Vout)=12V
Output current (Iout) =50W/12V =4.16A = 4.2A (approx)
Switching Frequency (Fsw)=50 KHz

Calculation

\[ L = \left( V_{in} - V_{out} \right) \times D \times \frac{1}{F_{SW}} \times \frac{1}{dI} \]

………………………………………………………….. (1)

Where dI is Ripple current
For a good design typical value of ripple current is in between 30 to 40 % of load current.

Let dI =35% of rated current
\[ dI = 35\% \text{ of } 4.2 = 0.35 \times 4.2 = 1.47A. \]

\[ L = \left( 15.0 - 12.0 \right) \times 0.8 \times \left( \frac{1}{50} \right) \times \left( \frac{1}{1.47} \right) = 32.65\text{uH} = 33\text{uH} \]

(approx). …………………….. (2)

Implementation

The order of construction started with the processing unit with its associated components, next is the MOSFETs and the JP connectors along with the fuse holders, also the MOSFET driver, the LM7805 voltage regulator, which is part of the power supply unit was constructed, then the LCD and LEDs was also implemented.
Implementation of the Sensor Unit

The ACS712 was soldered; the Vero board beside MOSFET Q1 and the Solar panel voltage divider, three female jumper wires was connected to the three pins of the current sensor i.e GND pin, Vout pin, and the Vcc pin. The input/output terminals of the sensor are connected from the solar panel to MOSFET source pin while the former pins are connected to the microcontroller as follows: GND-GND, Vout-A1, and Vcc-5v of the microcontroller to complete the hardware connection.

Implementation of the MOSFET Driver

The 8 pins DIP was solder just above the Arduino header pins, add 10uF capacitor and a 0.1uF capacitor in between the pin-1 and pin-4, solder the diode (D2) in between pin-1 and 8, solder the capacitor (C7) in between pin-8 and pin-6 with two 200ohms resistors (R7 and R8) in series to pin-2 and pin-3 respectively.

Implementation of the Processing Unit

This is the most essential section of the system as it is the component in charge of controlling the functionality of the entire home automation system. Firstly cut the two rows of male and male header pin with 15 pins in each, a diagonal nipper was used to cut the headers. Solder the male header pins, to ensuring that the distance between the two rails fits the Arduino Uno. The male headers are used to mount the Arduino Uno at the surface while the other male headers at the opposite part of the board which are soldered for external connection with the Arduino Uno board.

Implementation of the Display Unit

A 20X4 char LCD was used for monitoring solar panel, load parameters and battery. For simplicity with a I2C LCD display is chosen. It needs only 4 wires to interface with the arduino. Comparing this research with earlier designed the LCD was consuming more of power. With its main cause as LCD back light, a push switch was installed to control the back light by default the back light will be in OFF condition. When the switch is been switch ON it will only be active for 15 seconds and again goes OFF. The hardware set up of the LCD display module interface with the ATmega 328P microcontroller was achieved by connecting the following pins of the LCD;

Vcc--> 5V, GND-->GND, SDA-->A4 and SCL-->A5

Column-1: Solar panel voltage, Current and Power
Column-2: Battery Voltage, Charger state and State Of Charge
Column-3: PWM duty cycle and load status

Pin 1 was soldered to a jumper wire connected to ground, and pin 2 using a jumper wire was connected to the +5 volts supply from the microcontroller.
Figure 10: The flow chart for perturb and observe method

Results
The result shows difference between the method used in this MPPT system and other techniques previously used in the past PV array output power is used to directly control the synchronous buck converter, thus reducing the complexity of the system and also protect the battery from repetitive overcharges by monitoring the State of the battery while charging. The result is as shown in the table below.

Table 1: Charging State of the Battery

<table>
<thead>
<tr>
<th>STATE OF CHARGE</th>
<th>12 VOLT BATTERY</th>
<th>VOLTS PER CELL</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>12.7</td>
<td>2.12</td>
</tr>
<tr>
<td>90%</td>
<td>12.5</td>
<td>2.08</td>
</tr>
<tr>
<td>80%</td>
<td>12.42</td>
<td>2.07</td>
</tr>
<tr>
<td>70%</td>
<td>12.32</td>
<td>2.05</td>
</tr>
<tr>
<td>60%</td>
<td>12.2</td>
<td>2.03</td>
</tr>
<tr>
<td>50%</td>
<td>12.06</td>
<td>2.01</td>
</tr>
<tr>
<td>40%</td>
<td>11.9</td>
<td>1.98</td>
</tr>
<tr>
<td>30%</td>
<td>11.75</td>
<td>1.96</td>
</tr>
<tr>
<td>20%</td>
<td>11.58</td>
<td>1.93</td>
</tr>
<tr>
<td>10%</td>
<td>11.31</td>
<td>1.89</td>
</tr>
<tr>
<td>0</td>
<td>10.5</td>
<td>1.75</td>
</tr>
</tbody>
</table>

SUMMARY
The operation of the PV system may fail to track the maximum power due to sudden change in environmental conditions. The charge controller takes into cognesces the voltage level of the panels and compares it with the battery voltage level. The charge controller automatically decide what is the best power needed from the panel to charge the battery which in turn gives the best voltage to get maximum current into the battery.

Efficiency of charge controller varies widely depending weather, temperature, battery state of charge etc. Furthermore, microcontroller based system provides accurate control of the devices as the program is burned into the permanent memory and performs fast calculations. Battery gets charged rapidly when MPPT algorithm is implemented in the system. If Perturb and

References