

DESIGN OF MAXIMUM POWER POINT TRACKING (MPPT) BASED PV CHARGER

Mr. S. K. Patil¹, Mr.D.K.Mahadik²

¹(Associate Professor, Department of Electrical Engineering, Government College of Engineering Karad, India)

²(PG Student, Department of Electrical Engineering, Government College of Engineering Karad, India)

ABSTRACT : Maximum Power Point Tracking (MPPT) is used in photovoltaic systems to maximize the photovoltaic array output power, irrespective of the temperature, irradiation conditions and electrical characteristics of the load. A new MPPT system is developed, consisting of DC to DC converter, which is controlled by a microcontroller based unit.

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 a 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. Overcharging of the battery can be avoided using the pulse-charging scheme with adaptive rest period.

The main difference between the method used in the MPPT system and other techniques used in the past is that the PV array output power is used to directly control the DC to DC converter, thus reducing the complexity of the system.

Keywords - Charge Controller, Converter, microcontroller, MOSFET, MPPT, PV array

I. INTRODUCTION

Solar power is a renewable source of energy, which has become increasingly popular in modern times. It has obvious advantages over non-renewable energy sources, such as coal, oil and nuclear energy. It is non-polluting, reliable and can produce energy anywhere that there is sun shining, so its resources are not going to run out anytime. It even has advantages over other renewable energy sources, including wind and water power. Solar power is generated using solar panels, which do not require any major mechanical parts, such as wind turbines. These mechanical parts can break down and cause maintenance issues and can also be quite noisy. Both of these issues are virtually non-existent with solar panels. Also, the solar cells, that connected together make up the solar panel, can last up to several decades without replacement.

However, there is a drawback to solar power energy can only be produce when the sun is shining. To overcome this, usually solar panels are coupled with back up rechargeable batteries, which can store excess power generated during the day and use it to provide energy to systems when there is no sun shining. In this way solar power can be used to power houses and other large scale systems. In these systems dc to ac conversion is needed. This is because the solar panel produces an output that is dc (direct current) and the power supply in homes usually runs on ac (alternating current), so conversion is required. For this project, the load to be connected only requires dc input, so dc to ac conversion is not needed. Instead, dc to dc conversion would be used to provide the correct power to the system from the power generated by the solar panel. Using this information, a number of design solutions were determined and considered.

1.1 EQUIVALENT CIRCUIT OF SOLAR CELL

The equivalent circuit of a PV cell is demonstrated below in Fig.1.

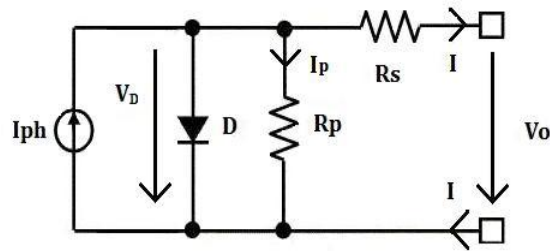


Fig. 1: Equivalent Circuit of a PV Cell

A PV array consists of several photovoltaic cells in series and parallel connections. Series connections are responsible for increasing the voltage of the module whereas the parallel connection is responsible for increasing the current in the array. Typically a solar cell can be modeled by a current source and an inverted diode connected in parallel to it. It has its own series and parallel resistance. Series resistance is due to hindrance in the path of flow of electrons from n to p junction and parallel resistance is due to the leakage current.

In this model we consider a current source (I) along with a diode and series resistance (R_s). The shunt resistance (R_{SH}) in parallel is very high, has a negligible effect and can be neglected. The output current from the photovoltaic array is

$$I = I_{sc} - I_d \quad (1)$$

$$I_d = I_o (e^{qV_d/kT} - 1) \quad (2)$$

where I_o is the reverse saturation current of the diode, q is the electron charge, V_d is the voltage across the diode, k is Boltzmann constant (1.38×10^{-19} J/K) and T is the junction temperature in Kelvin (K).

From equations 1 and 2,

$$I = I_{sc} - I_o (e^{qV_d/kT} - 1) \quad (3)$$

1.2 CHARACTERISTICS OF PV ARRAY

For the analysis of Photovoltaic array, two characteristics are most important i.e. Current Voltage (I-V) characteristics and Power Voltage (P-V) characteristics.

From Fig. 2, the current generated in the solar cell by the current source (I_{ph}) is proportional to the amount of light falling on it. When there is no load connected to the output V_o , almost all of the generated current flows through diode D. The resistors R_s and R_{SH} represent small losses due to the connections and leakage respectively. There is very little change in V_{oc} for most instances of load current. However, if a load is connected to the output then the load current draws current away from the diode D. As the load current increases more and more current is diverted away from the diode D. So, as the output load varies so too does the output current, while the output voltage V_{oc} remains largely constant. That is until so much current is being drawn by the load that diode D becomes insufficiently biased and the voltage across it diminishes with increase in load. This results in I-V characteristics as shown in Fig. 2.

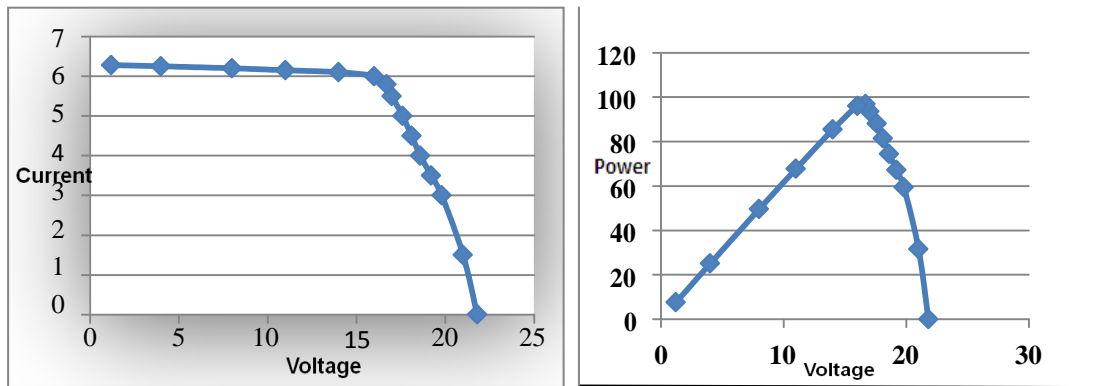


Fig. 3: I-V and P-V characteristics of 100 W Solar Panel

II. BLOCK DIAGRAM

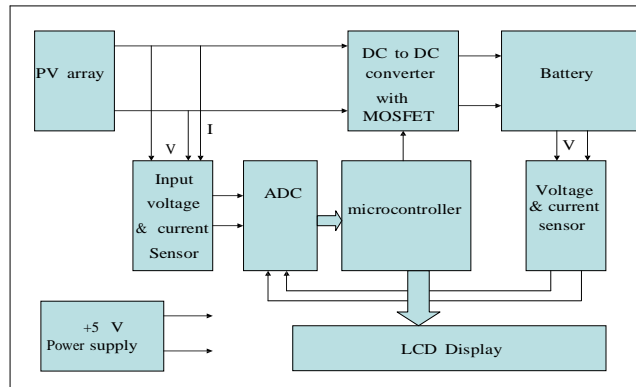


Fig. 4: Block Diagram of MPPT Charge Controller Circuit

The system is devised around microcontroller which is surrounded by Analog to Digital Converter (ADC), LCD display, resistor based voltage divider circuit for measurement of voltage. One more resistor is to be connected in series with battery for measurement of current supplied by PV array. DC to DC converter circuit consists of MOSFETs which are made on and off to control the power. It is switched on and off by the driving square wave signals at the gate. If the semiconductor device is in the off state, its current is zero and hence its power dissipation is zero. If the device is in the on state (i.e. saturated), the voltage drop across it will be close to zero and hence the dissipated power will be very small.

III. SEPIC MPPT PV CHARGE CONTROLLER

A SEPIC circuit is used to realize a PV charger that can both step up and step down the PV panel voltage for battery charging. Continuous input inductor current is helpful in achieving a high MPPT accuracy. According to the maximum power transferring theorem, the following relationship equation can be derived,

$$R_{th} = V_{mp} / I_{mp} = R_{in} = R_b (1-D)^2 / D^2$$

Where, V_{mp} and I_{mp} represent the PV panel voltage and PV

panel current at maximum power point, respectively. The input resistance R_{in} of the SEPIC circuit can be regulated by directly controlling the converter duty cycle D . As long as the circuit is operated under maximum power transfer condition, MPPT can be achieved.

As shown in Fig. 6, there are two charging stages for the proposed PV charger. At the beginning of the charging process, a continuous MPPT-charging scheme is adopted to extract maximum power from the PV panel. Under a constant solar power condition, the battery current will decrease in accordance with the increase in battery voltage. When the SOC of battery reaches a 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.

Overcharging of the battery can be avoided using the pulse-charging scheme with adaptive rest period.

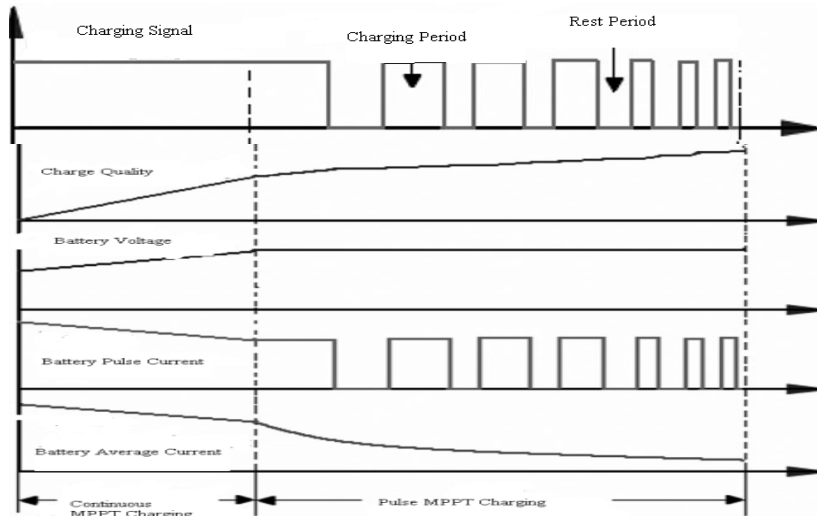


Fig. 6: Theoretical waveforms of the proposed PV charge controller

IV. DESIGN CONSIDERATION

For the system proposed in this paper, MPPT is used to increase the efficiency of battery charging. A perturb and observe (P&O) method characterized by important advantages such as simplicity and good performance is hereby adopted. The maximum power of the PV panel can be extracted both in the continuous MPPT charging stage and in the charging period of the pulse MPPT charging stage. Fig.7(a) shows the detailed charging current waveform.

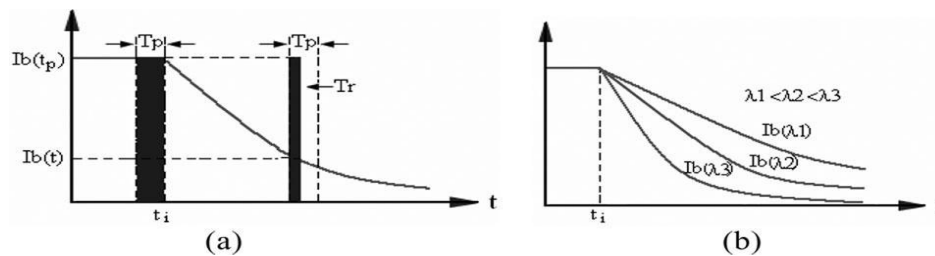


Fig. 7(a) Average charging current waveform and (b) exponential profiles with different λ during the pulse charging stage.

During the pulse charging stage, an average charging current with an exponential profile is recommended by the battery manufacturer's manual to maintain a constant battery voltage level $V_{b, set}$. The equation of the average charging current $I_b(t)$ can be expressed as follows:

$$I_b(t) = I_b(t_i) \times e^{-\lambda t} \quad (4)$$

where the attenuating factor λ determines the charging speed. The relationship between the rest period T_r and the attenuating factor λ can be derived by

$$T_r = (I_b(t_i) - I_b(t) / I_b(t_i)) \times T_p = (1 - e^{-\lambda t}) T_p \quad (5)$$

where T_p is the charging cycle of the pulse current charging.

A constant battery voltage $V_{b, set}$ is retained using an exponential average charging current during the pulse-charging stage. However, the battery voltage may be over $V_{b, set}$ due to the decline in the battery capacity if a fixed attenuating factor λ is adopted. To prevent the battery from overcharging, an adaptive rest period T_r could be realized by sensing the battery voltage. As the battery voltage goes over a given value $V_{b, m}$, the rest period T_r can be extended to change the attenuating factor λ and slow down the charging speed according to (5).

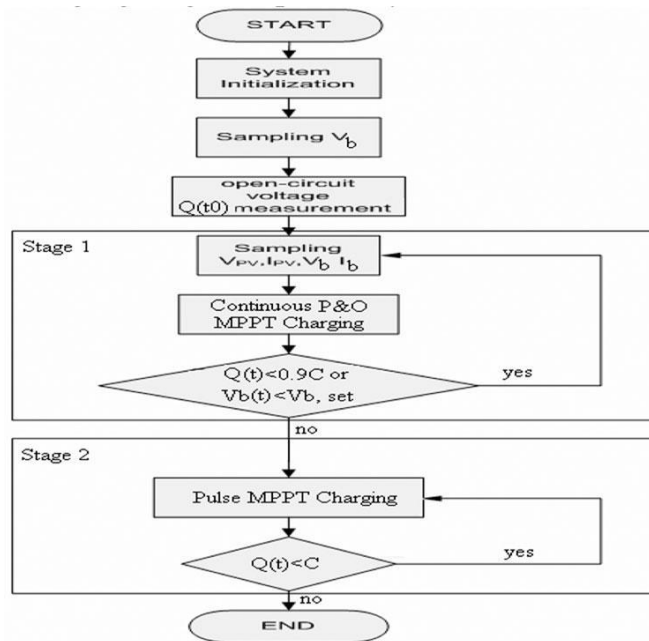
Fig. 8 shows a flowchart of the studied charging scheme.

The initial open-circuit battery voltage $V_{b, oc}(t_0)$ is measured at the beginning of the charging process. The initial charge quantity $Q(t_0)$ can then be estimated as follows:

$$Q(t_0) = (V_{b, oc}(t_0) - V_{b, ec}) / (V_{b, fc} - V_{b, ec}) \times C \quad (6)$$

where $V_{b, ec}$ and $V_{b, fc}$ are the open-circuit battery voltages under fully discharged and fully charged conditions, respectively, and C denotes the rated battery charge quantity.

During the continuous MPPT charging stage, the P&O MPPT algorithm was used to extract the maximum power of the PV panel. The charging process was switched to the pulse MPPT charging stage from the continuous MPPT stage when the estimated battery charge quantity $Q(t)$ reached up to $0.9 C$.



That is recommended in the battery manufacturer's manual. Taking battery deterioration into consideration, pulse MPPT charging was also enabled as long as the battery voltage rose to a given voltage $V_{b, set}$ for overcharge

prevention. During the charging period of the pulse MPPT charging stage, MPPT was retained to achieve high charging efficiency. A pulse charging current with an exponential average profile is used to relax the electrolyte reaction and prolong battery lifetime.

The time length T_{pulse} of pulse MPPT charging stage can be calculated as follows:

$$T_{\text{pulse}} = t_f - t_i = \lambda^{-1} \ln(0.1C\lambda I_b(t_i)) \quad (7)$$

Where t_f and t_i are the ending and starting times of the pulse MPPT charging stage, respectively.

V. ADVANTAGES AND DISADVANTAGES

For comparing MPPT based charge controller with the existing types, advantages and disadvantages of both are to be considered.

5.1 Advantages of existing analog charge controllers

1. The circuit is simple to implement.
2. It is cheap and accommodates very less size.

5.2 Disadvantages of existing analog charge controllers

1. Efficiency is very low as the circuits do not consider input power and output power. Thus any mismatch between input and output power may lead to loss of power resulting in lower efficiency.
2. The status of charged battery can be known only from LED. If red LED glows it means battery is discharged and when no LED glows it means battery is charged. Thus the actual battery voltage cannot be known.
3. The system cannot be used for large current applications.
4. No display has been connected so that actual battery voltage cannot be monitored.
5. The analog ICs have been implemented which are not intelligent devices.

To overcome above disadvantages, the MPPT based system is developed. This system uses microcontroller which is an intelligent device, it switches ON and OFF the MOSFET according to status of battery (whether fully charged or discharged). In addition, it also displays the present voltage on battery indicating actual status of battery.

5.3 Advantages of MPPT based Charge Controller over existing Controllers

1. The system uses MPPT algorithm hence the efficiency of the system is higher.
2. 16x2 LCD display have been interfaced hence battery voltage can be displayed on it. The user will be informed regarding battery status without use of LED.
3. The system is designed for large current ratings in Ampere.
4. Microcontrollers are implemented which are intelligent chips. Hence the system can be modified as per the need of application.
5. Use of microcontroller ensures reliability of the system.
6. The system is user friendly hence can be easily operated by users.
7. System is compact and handy.

5.4 Disadvantages of proposed system over existing systems

1. The system is costly as compared to existing analog charge controllers.
2. Programming of microcontrollers is required which increases the software cost and creates complexity at the time of making prototype.
3. Computers are needed to write and burn the software in microcontrollers.

VI. CONCLUSION

Perturb and Observe algorithm is simple method as it uses only voltage sensor to sense PV array voltage. Time complexity of this method is also less as compared to other methods (Incremental Conductance, Fractional open circuit voltage, Fractional short circuit current, Fuzzy Logic Control, Neural Network Control). Such type of algorithm is required as solar energy is uncertain source of power. The voltage and current greatly depends upon insolation and temperature, hence the maximum power point gets varied. MPPT is an electronic system that does not physically vary the module towards sun to obtain maximum power but instead it varies electrical operating point of modules so that modules can deliver maximum available power. The operation of the PV system may fail to track the maximum power due to sudden change in environmental conditions. The charge controller looks at the output of the panels, and compares it to the battery voltage. It then Fig.s out what is the best power that the panel can put out to charge the battery. It takes this and converts it to 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. It performs fast calculations as 16 MHz crystal is used. Battery gets charged rapidly when MPPT algorithm is implemented in the system. If Perturb and Observe method is used frequently, the MPPT tracking method proves to be best over the methods like analog charge controllers , on off charge controllers, PWM charge controllers as in MPPT attempt is always made to charge the battery at maximum possible power of input source.

The MPPT based charge controllers are best suitable for wind and solar systems as they track the maximum power in case of power fluctuations at the input side due to environmental condition variation. Hence it is recommended to use the MPPT based charge controllers. Use of microcontroller based systems provides huge computational capability and reduction in the hardware. Microcontroller is a mini computer and brings much more accuracy in the control of MOSFET and IGBT. The MPPT charge controller operates with high efficiency (90% or even higher) as compared to existing charge controllers.

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