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An Advanced Solar MPPT Algorithm with Intelligent Battery Charger

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Abstract- *In this paper an advanced maximum power point tracking algorithm for photovoltaic arrays with an intelligent battery charger is proposed. The algorithm detects the maximum power point of the PV. The computed maximum power is used as a reference value (set point) of the control system. ON/OFF power controller with PWM switching control the operation of a Buck chopper such that the PV module always operates at its maximum power computed from the MPPT algorithm. And an intelligent battery charging algorithm is added for long life of both deep cycle and lead Acid battery. The major difference between the proposed algorithm and other techniques is that the proposed algorithm is used to control directly the power drawn from the PV. The proposed MPPT has several advantages: simplicity, high convergence speed, and independent on PV array characteristics. The experimental Results show that the use of the proposed MPPT control increases the PV output power by as much as 35% compared to the case where the dc/dc converter duty cycle is set such that the PV array produces the maximum power at 1 kW/m2 and 25^0 C.*

Index Terms: Battery charging, DC/DC converters, Maximum Power Point Tracking (MPPT), Microcontrollers, and Photovoltaic systems.

1. INTRODUCTION

Renewable sources of energy acquire growing importance due to massive consumption and exhaustion of fossil fuel. Among several renewable energy sources, Photovoltaic arrays are used in many applications such as Water pumping, battery charging, hybrid vehicles, and grid connected PV systems.

As known from a (Power-Voltage) curve of a solar panel,
there is an optimum operating point such that the PV delivers the maximum possible power to the load. The optimum operating point changes with the solar irradiation, and cell temperature. Therefore, on line tracking of the maximum power point of a PV array is an essential part of any successful PV system. A variety of maximum power point tracking (MPPT) methods is developed. The methods vary in implementation complexity, sensed parameters, required number of sensors, convergence speed, and cost [1].

This paper presents a simple MPPT scheme that does not
require special measurements of open circuit voltage or short circuit current.

The proposed algorithm is divided into two major parts:

Maximum power computation and Battery charging computation with four special stages which increases the system efficiency by preventing overcharging of battery and system.

The maximum power is computed online using direct power of PV array. The computed maximum power is compared with instantaneous actual PV power, the error between reference (maximum) power and actual power activates ON/OFF controller with PWM drive DC/DC buck chopper.

2. PV SYSTEM CHARACTERISTICS

A solar cell basically is a p-n semiconductor junction.

When exposed to light, a dc current is generated. The
Generated current varies linearly with the solar irradiance. The standard equivalent circuit of the PV cell is shown in Fig. 1.

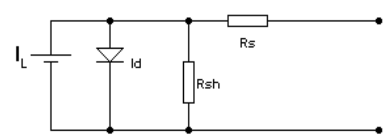

Fig. 1 Equivalent circuit of PV solar cell

The basic equation that describes the (I-V) characteristics of the PV model is given by the following equation:

$$I = I_L - I_O\left(e^{\frac{q(V+IRs)}{kT}} - 1\right) - \frac{V+IRs}{IRsh} \qquad (1)$$

Where:
I is the cell current (A).
I_L is the light generated current (A).
I_O is the diode saturation current.
q is the charge of electron = 1.6x10-19 (coul).
K is the Boltzmann constant (J/K).
T is the cell temperature (K).

Rs , Rsh are cell series and shunt resistance (ohms).
V is the cell output voltage (V).

Solar panels convert photons from the sun striking their surfaces into electricity of a characteristic voltage and current. The solar panel's electrical output can be plotted on a graph of voltage vs. current: an IV curve. We represent the current in amps and V represents the voltage in volts. The resulting line on the graph shows the current output of the panel for each voltage at a specific light level and temperature (Fig. 2). The current is constant until reaching the higher voltages, when it falls off rapidly. This IV curve is applicable to the electrical output of all solar panels.

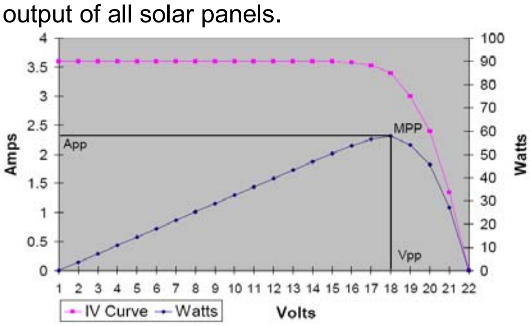

Fig. 2 Solar Panel IV Curve with MPPT[7].

3. GENERAL MPPT TECHNIQUES

The problem considered by MPPT methods is to automatically find the voltage VMPP or current IMPP at which a PV array delivers maximum power under a given temperature and irradiance. In this section, commonly used MPPT methods are introduced in an arbitrary order.

A. Fractional Open-Circuit Voltage

The method is based on the observation that, the ratio between array voltage at maximum power VMPP to its open circuit voltage VOC is nearly constant.

$$VMPP \approx k1\ VOC \qquad (2)$$

This factor *k1* has been reported to be between 0.71 and 0.78. Once the constant *k1* is known, VMPP is computed by measuring VOC periodically. Although the implementation of this method is simple and cheap, its tracking efficiency is relatively low due to the utilization of inaccurate values of the constant *k1* in the computation of VMMP.

B. Fractional Short-Circuit Current

The method results from the fact that, the current at maximum power point IMPP is approximately linearly related to the short circuit current ISC of the PV array.

$$IMPP \approx k2\ ISC \qquad (3)$$

Like in the fractional voltage method, *k2* is not constant. It is found to be between 0.78 and 0.92. The accuracy of the method and tracking efficiency depends on the accuracy of K2 and periodic measurement of short circuit current.

C. Perturb and Observe

In P&O method, the MPPT algorithm is based on the calculation of the PV output power and the power change by sampling both the PV current and voltage. The tracker operates by periodically incrementing or decrementing the solar array voltage. If a given perturbation leads to an increase(decrease) in the output power of the PV, then the subsequent perturbation is generated in the same (opposite) direction. So, the duty cycle of the dc chopper is changed and the process is repeated until the maximum power point has been reached. Actually, the system oscillates about the MPP. Reducing the perturbation step size can minimize the oscillation. However, small step size slows down the MPPT. To solve this problem, a variable perturbation size that gets smaller towards the MPPT.

However, the P&O method can fail under rapidly changing atmospheric conditions. Several research activities have been carried out to improve the traditional Hill-climbing and P&O methods. Reference [4] proposes a three-point weight comparison P&O method that compares the actual power point to the two preceding points before a decision is made about the perturbation sign. Reference [5] proposes a two stage algorithm that offers faster tracking in the first stage and finer tracking in the second stage. To prevent divergence from MPP, modified adaptive algorithm is proposed in [6].

D. Incremental Conductance

The method is based on the principle that the slope of the PV array power curve is zero at the maximum power point.

$(dP/dV) = 0$. Since $(P = VI)$, it yields:

$$\Delta I/\Delta V = -I/V, \text{ at MPP} \qquad (4.a)$$
$$\Delta I/\Delta V > -I/V, \text{ left of MPP} \qquad (4.b)$$
$$\Delta I/\Delta V < -I/V, \text{ right of MPP} \qquad (4.c)$$

The MPP can be tracked by comparing the instantaneous Conductance (I/V) to the incremental conductance (ΔI/ΔV).The algorithm increments or decrement the array reference voltage until the condition of equation (4.a) is satisfied. Once the Maximum power is reached, the operation of the PV array is maintained at this point. This method requires high sampling rates and fast calculations of the power slope.

4. PROPOSED MPPT METHOD

Most MPPT techniques attempt to find (search) the PV
voltage that results in the maximum power point V_{MPP} , or to find the PV current I_{MPP} corresponding to the maximum power point. The proposed algorithm tracks neither the V_{MPP} nor the I_{MPP}. However, it tracks directly the maximum possible power P_{MAX} that can be extracted from the PV. The flowchart of the proposed MPPT method is shown in Fig. 3.

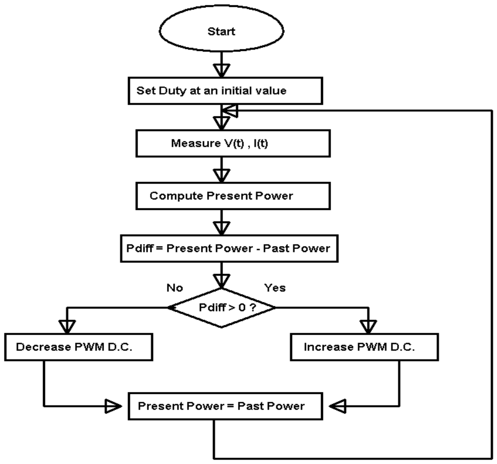

Fig. 3 Flowchart of the proposed MPPT algorithm

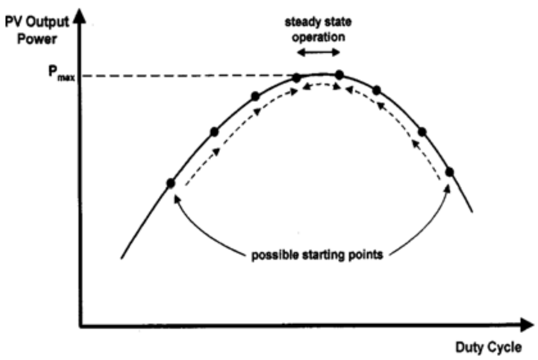

Fig. 4 MPP tracking process.

Actually, the algorithm shown in Fig.3 starts by setting PWM to an initial value (half or any other Duty value).Actual PV voltage and current are measured. Then, the instantaneous value of PV power $P_{Present}$ is computed. The error between $P_{Present}$ and P_{past} is input to main MPPT algorithm. The output of the controller is used to drive the power mosfet of the Buck Chopper such that the $P_{Present}$ tracks P_{MAX}. Till now, the real maximum power is not tracked. To track the maximum power, the error between $P_{Present}$ and P_{past} is checked. If the error is lower than a certain upper limit (0.5 Watt), this means that the power drawn from the PV is within allowable value, so we can increment PWM by a certain step size. This new value of $P_{Present}$ is stored and used to control the actual power of the PV to track this new value. Then the algorithm is repeated again. When the error between $P_{Present}$ and P_{past} exceed the upper limit it means that the PV is no longer able to deliver this value of P_{MAX} . Therefore, we have to decrement of PWM by a certain step size . The MPP tracking process is shown in Fig. 4.

4. CHARGING METHOD

Most Battery Chargers in present market are using simple constant current or constant voltage method for charging, where battery cost is more than 40% of whole system. Our project is focused on increasing battery life with intelligent four stage battery charging with combining Solar MPPT. Because DC load is directly connected with MOSFET switching circuit, we can easily disconnect battery from load when it is overload and short-circuit! And because PV is connected with DC/DC buck to Battery; we can control current when battery is full charge. So four necessary steps are Sun rise, Bulk , Float, Sun Set. The flowchart of the charging method is shown in Fig.5.

Before MPPT algorithm runs it is always checked battery voltage and PV panel watt. If present PV watt is less than 5watt then it is considered that PV cannot operate at MPPT. It is now sunrise or sun set. So deliver whatever power is present to the battery. If battery is reached its maximum voltage, it is full charge. So deliver certain amount of power to keep battery voltage constant (Float charging). And if PV power is more than 5watt and battery isn't full yet then MPPT algorithm runs and we say it bulk charging.

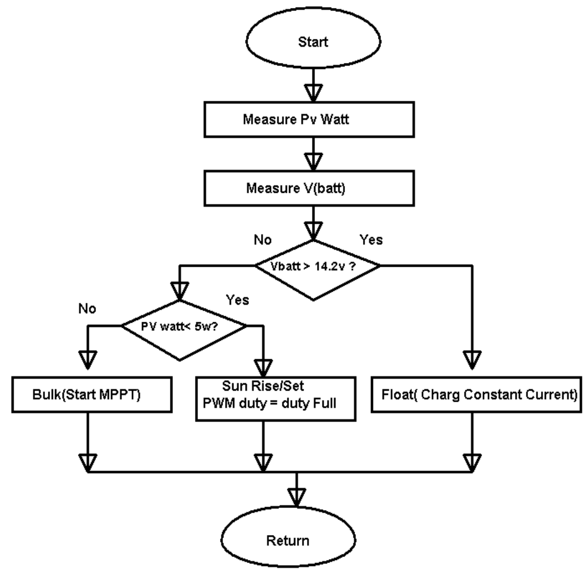

Fig. 5 Flowchart of the battery charging algorithm

5. SYSTEM MODELING

The block diagram of the PV system under investigation is shown in Fig. 6. The Block of PV power system is Designed and Simulated in Proteus ISIS. The simulation parameters are summarized in Table I.

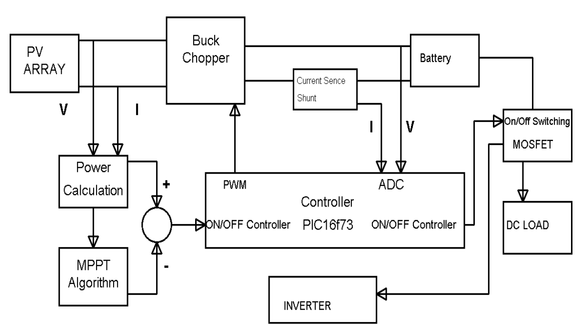

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Fig. 6 Block diagram of PV system under investigation

TABLE I
SIMULATION PARAMETERS

Chopper Frequency	20kHz
R load C load	1~100Ω 2200uf
Buck Chopper	MOSFET

TABLE II
KEY SPECIFICATION OF SOLAR PANEL

Maximum Power P_{MAX}	100W
Voltage At Max Power V_{MAX}	22V
Current At Max Power I_{MAX}	5.2A
Short Circuit Current I_{SC}	4.5A
Open Circuit Voltage V_{SC}	39v

6. SYSTEM PERFORMANCE

A prototype MPPT system has been developed using the above-described method and tested in the laboratory. The PV array, which is to be used with this system giving a 100 W maximum power and an 39V open-circuit voltage at an irradiation of 1 kW/m and a temperature of 25 ^{o}C.

The system efficiency is defined as

$$\eta = \frac{Po}{Pin} = \frac{Po}{Po + Pd} \tag{5}$$

Where and are the dc/dc converter input and output power, respectively, while is the power loss. The power loss consists of the MOSFET and diode conduction and switching losses, the inductor core and copper losses and the control system power consumption.
The theoretical values were calculated using data given by the manufacturers of the circuit elements. The theoretical and measured efficiency for various output power levels is shown in Fig. 7. It is seen that the efficiency is quite high and relatively constant for a wide output power range.

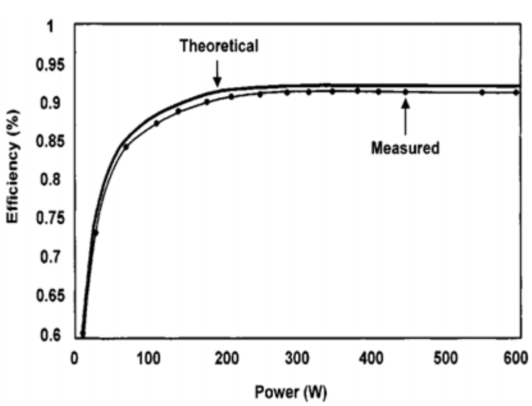

Fig. 7 System efficiency under PV MPPT conditions at 25 ^{o}C.

Figure 8 illustrates data collected from the prototype PPT connected to two 100 watt solar panels on roof. In this example, the MPPT was charging a 12v battery with intelligent battery charging system. The data from the MPPT was output by 16×2 Alpha numeric LCD display collected, stored and graphed on PC.
On the graph (Fig. 8), the line labeled "MPPT On" shows the watts generated by the solar panels when the MPPT was running. Every 10 seconds the PPT set the DC/DC converter to a 1/1 ratio simulating a direct connection between the solar panel and the battery. The watts are measured and plotted on the graph as "MPPT Off" showing the power that would be generated by the solar panel if it was directly connected to battery. The difference in watts between "MPPT On" and "MPPT Off" is the power gained by using the PPT. In this case the battery is being charged with about 30% more power when the MPPT is on.

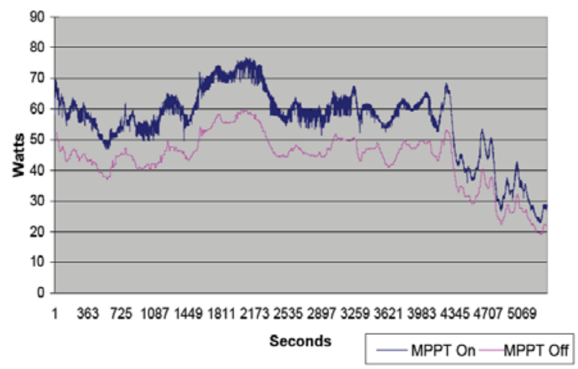

Fig.8 MPPT Watts Recorded with Proposed Solar System.

7. CONCLUSION

The paper proposes an advanced MPPT method that requires only measurements of PV voltage and current with the need to any environmental measurements (temperature, irradiance). The method is considered as an advanced perturb and observe method where cost effective hardware & software implementation is preferred. However, the principle difference between the proposed method and any other tracking method is that the proposed method attempts to track and compute the maximum power and controls directly the extracted power from the PV to that computed value. While, any other method attempts to reach the maximum point by the knowledge of the voltage or the current corresponding to that optimum point.
The proposed method offers different advantages which
are: good tracking efficiency, relatively high convergence speed and well control for the extracted power thanks to the direct power control unit based on the ON/OFF PWM controller with intelligent charging system.

8. REFERENCES

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