DESIGN AND OPTIMIZATION OF HIGH EFFICIENT CHARGE CONTROLLER FOR A SOLAR PHOTOVOLTAIC SYSTEM POWER GENERATION

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Abstract—A high efficient charge controller used in solar PV power generation is proposed. The system comprises mainly of charge controller connected to a PV and an inverter. The Maximum Power Point Tracking (MPPT) algorithm in the charge controller uses Estimate perturb and perturb (EPP) method which gives an estimate for every two perturb process in search of maximum output from the PV panel. This paper details the analysis of the EPP method. A 10W prototyping PV system was implemented with a boost dc-dc converter using a Micro controller to execute the proposed MPPT algorithm. Different MPPT algorithms were tested for fast changing environmental conditions, and the test results are analyzed and compared. It is demonstrated that the EPP method is a promising MPPT control scheme for PV systems. This method significantly improves the tracking accuracy and speed of MPPT control mechanism.

Key words—charge controller, Estimate-Perturb-Perturb (EPP) method, Maximum Power Point Tracking(MPPT), microcontroller, PV systems.

I. 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[1-5]. The optimum operating point changes with the solar irradiation, and cell temperature. Therefore, control system for tracking the maximum power point of a PV array is an essential part of any successful PV system. A High efficiency charge controller with maximum power point tracking (MPPT) algorithm is developed. The maximum power point tracking (MPPT) control of the PV system is therefore critical for the success of a PV system. The MPPT control is[6-11], in general, challenging, because the sunshine condition that determines the amount of sun energy into the PV array may change all the time, and the current voltage characteristic of PV arrays is highly nonlinear.

A PV system for the grid-connected applications is typically composed of five main components: 1) a PV array that converts solar energy to electric energy, 2) a dc-dc converter that converts low dc voltages produced by the PV arrays to a high dc voltage, 3) an inverter that converts the high dc voltage to a single- or three-phase ac voltage[12-18], 4) a digital controller that controls the converter operation with MPPT capability, and 5) a ac filter that absorbs voltage/current harmonics generated by the inverter.

The main technical requirements in developing a practical PV system include a) an optimal control that can extract the maximum output power from the PV arrays under all operating and weather conditions, and b) a high performance-to-cost ratio to facilitate commercialization of developed PV technologies. Since the PV array has a highly nonlinear characteristic, and its performance changes with operating conditions such as insolation or ambient temperature, it is technically challenging to develop a PV system that can meet these technical requirements.

This paper proposes a new method for the charge control of PV systems. This control algorithm uses one estimate process for every two perturbs processes in search of the maximum PV power output. In this estimate perturb-perturb (EPP) method, the perturb process conducts the search over a highly nonlinear PV characteristic, and the estimate process compensates the perturb process for irradiance-changing conditions. This paper illustrates that EPP method can significantly improve the tracking accuracy and speed of the MPPT control.

II. EXISTING MPPT METHODS

A. Perturb-and-observe (P&O) Method

The perturb-and-observe method, also known as perturbation method, is the most commonly used MPPT algorithm in commercial PV products. This is essentially a "trial and error" method. The PV controller increases the reference for the inverter output power by a small amount, and then detects the actual output power. If the output power is indeed increased, it will increase again until the output power starts to decrease, at which the controller decreases the reference to avoid collapse of the PV output due to the highly non-linear PV characteristic[19-24].

Although the P&O algorithm is easy to implement, it has a number of problems, including 1) the PV system cannot always operate at the maximum power point due to the slow trial and error process, and thus the solar energy from the PV arrays are not fully utilized; 2) the PV system may always operate in an oscillating mode even with a steady-state sunshine condition, leading to fluctuating inverter output; and 3) the operation of the PV system may fail to track the maximum power point due to the sudden changes in sunshine.

B. Open-and Short-circuit Method Stage

The open- and short-circuit current method for MPPT control is based on measured terminal voltage and current of PV arrays. By measuring the open-circuit voltage or short-circuit current in real-time, the maximum power point of the PV array can be estimated with the predefined PV current-voltage curve[25-30]. This method features a relatively fast
response, and do not cause oscillations in steady state. However, this method cannot always produce the maximum power available from PV arrays due to the use of the predefined PV curves that often cannot effectively reflect the real-time situation due to PV nonlinear characteristics and weather conditions. Also, the online measurement of open-circuit voltage or short-circuit current causes a reduction in output[31-35].

C. Incremental Conductance Algorithm

All The main task of the incremental conductance algorithm is to find the derivative of PV output power with respect to its output voltage that is dP/dV. The maximum PV output power can be achieved when its dP/dV approaches zero. The controller calculates dP/dV based on measured PV incremental output power and voltage. If dP/dV is not close zero, the controller will adjust the PV voltage step by step until dP/dV approaches zero, at which the PV array reaches its maximum output[36-40]. However, it has the disadvantage of possible output instability due to the use of derivative algorithm. Also the differentiation process under low levels of insolation becomes difficult and results are unsatisfactory.

D. Fuzzy Logic and Other Algorithms

Since the PV array exhibits a non-linear current voltage or power-voltage characteristic, its maximum power point varies with the insolation and temperature. Some algorithms such as fuzzy logic or artificial neural network control and voltage with non-linear and adaptive in nature fit the PV control. By knowledge based fuzzy rules, fuzzy control can track maximum power point[41-45]. A neural network control operates like a black box model, requiring no detailed information about the PV system. After learning relation between maximum power point voltage and open circuit voltage or insolation and temperature, the neural network control can track the maximum power point online. The disadvantage of these controls is the high cost of implementation owing to complex algorithms that usually need a DSP as their computing platform.

III. PRINCIPLE OF PROPOSED EPP METHOD

A new method to improve the tracking speed of the P&O is proposed. This method is named the EPP that uses one estimate mode between every two perturb modes. The EPP method proposed in this paper, with an addition of the estimate mode, considers the changing irradiance in the control that significantly improves the MPPT performance and uses one estimate mode for every two perturb modes increases significantly the tracking speed of the MPPT control, without reduction of the tracking accuracy. Fig. 2 shows the time sequences for the P&O method and the EPP method. Comparing with the P&O method, the EPP method has a tracking speed of 1.5 times faster. Therefore the EPP method has obvious advantages over the P&O method.

IV. DESIGN OF CHARGE CONTROLLER

The charge control consists of three sections – Voltage Control, MPPT control Unit, and Solar Array Protection. The Voltage Control block consisted of two DC to DC converters that boost the solar array voltage. Secondly, the Charging Unit consisted of the PIC microcontroller, PWM, MOSFET, and protection diodes. It is computed with the maximum power point algorithm. Lastly, the Solar Array Protection block consisted of the protection diodes used to prevent solar panel damage. Fig 3 shows the overall system circuit of PV system and Table 1 shows the components used for the circuit.

A. Voltage Control

The DC/DC Buck Converter stepped down the solar array output voltage to 5v in order to power the PIC, DAC and ADC. The DC/DC Boost Converter stepped up the 5v output from the Buck Converter to 12v in order to power the PWM.

B. MPPT Control Unit

This unit contains the ADCs, DACs, PIC microcontroller, PWM, MOSFET, MOSFET driver, inductor, and protection diodes. The ADC changes the analog output of the solar array into a digital signal to be manipulated by the PIC microcontroller. The DAC works in the opposite direction of
the ADC. It changes the digital output from the PIC to an analog signal, which regulates the PWM.

The PIC microcontroller which is programmed with EPP algorithm performs all of the calculations necessary to obtain the maximum power point. The PIC receives the input voltage directly from the solar array and converts the voltage to a digital signal via the ADCs. In order to determine the input current, the output voltage of the voltage divider was sent to the PIC as a digital signal via the ADCs. Having both the input voltage (V) and current (I) from the solar array, the power could be determined (P=V*I). The output current was calculated using the input power and the output voltage. This value was then converted to an analog signal via the DACs and sent to the PWM. The PWM received the adjusted voltage and current from the PIC, and changed its duty cycle accordingly. This duty cycle controlled the MOSFET.

The MOSFET acted like a switch. When it was on, it closed the circuit and sent the power to ground, preventing the overcharging of the battery array. When it was off, the circuit opened, and the power was sent through the protection diodes to the battery array. The protection diodes prevented current from flowing back to the batteries and potentially damaging the solar array. By placing the diodes in parallel, the overall resistance decreased, and allowed a greater amount of current to pass through which increases the output power.

C. Solar Array Protection Block

The voltage divider took the voltage from the solar array and stepped it down to a maximum voltage of 4.08V. This prevented the ADC from “blowing out.” Without the voltage divider, the solar array would send too large of a voltage for the ADC to handle. Protection diodes were utilized to prevent the current from flowing back to the solar array and causing damage to it.

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>PART NUMBER</th>
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<tbody>
<tr>
<td>PIC Microcontroller</td>
<td>PIC16F877A</td>
</tr>
<tr>
<td>DC to DC Converter (5V)</td>
<td>PT4122A</td>
</tr>
<tr>
<td>DC to DC Converter (12V)</td>
<td>TPS6374IP</td>
</tr>
<tr>
<td>Pulse Width Modulator</td>
<td>TL598CN</td>
</tr>
<tr>
<td>Diode</td>
<td>16CTU04S</td>
</tr>
<tr>
<td>Digital to Analog Converter</td>
<td>LTC1451CN8</td>
</tr>
<tr>
<td>MOSFET</td>
<td>IXFX90N20Q</td>
</tr>
<tr>
<td>MOSFET driver</td>
<td>MAX4420CPA</td>
</tr>
</tbody>
</table>

V. SIMULATION OF PV CHARACTERISTICS

Simulations are carried out for different irradiance levels programmed in the MATLAB for a 10W panel. It is used to find the PV characteristics and the maximum power point voltage, current and power. TABLE II shows the specification of the solar PV module used. The MATLAB program was coded with Newton-Raphson iterative method to find maximum voltage and current for different irradiation. The results shown in Fig 4 and Fig 5 is the maximum power point voltage, current and power. Maximum point voltage is about 17.5V and current is around 0.59A and power is around 10W.

<table>
<thead>
<tr>
<th>Table 2: Specifications of PV module</th>
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<tr>
<td><strong>Electrical and Mechanical:</strong></td>
</tr>
<tr>
<td>Maximum power (P_max)</td>
</tr>
<tr>
<td>Open Circuit Voltage (Voc)</td>
</tr>
<tr>
<td>Short circuit current (Isc)</td>
</tr>
<tr>
<td>Tolerance of P_max</td>
</tr>
<tr>
<td>Cell Size (mm)</td>
</tr>
<tr>
<td>No. of cells</td>
</tr>
<tr>
<td>Dimensions (mm)</td>
</tr>
<tr>
<td><strong>Thermal Characteristics:</strong></td>
</tr>
<tr>
<td>Open-circuit voltage(Voc)</td>
</tr>
<tr>
<td>Short circuit current (Isc)</td>
</tr>
</tbody>
</table>
Fig 3. Overall system circuit

Fig 4. Adjusted I-V curve

Fig 5. Adjusted Power curve
VI. TESTING AND RESULTS

With all the design consideration overall hardware setup was made for practical testing and results. Fig. 3 Shows the circuit connections from all the components and Fig. 6 shows the setup of the hardware. The testing was made for three conditions

a) PV system with battery and without charge controller.

b) PV system with existing P&O MPPT algorithm based charge controller.

c) PV system with proposed EPP MPPT algorithm based charge controller.

Basic charge controller works with reference to the simulation results mpp voltage 17.5V which is set as the reference voltage for the MPPT algorithm, based on the set voltage and the reference voltage Charge controller i.e., microcontroller receives at the input from pin1 and pin2.

For EPP process controller estimates the voltage from solar panel and checks with the reference voltage 17.5V and perturbs twice to improve the voltage to reference voltage if the panel voltage is less. The PIC was programmed to continuously loop that automatically checks and updates the maximum power point improve the power.

The readings of the testing is calculated for power output and compared. The results are plotted in graph and shown below. Fig. 7 Shows the power output from solar panel with battery and without charge controller. Fig. 8 shows the power output of the P&O MPPT algorithm charge controller. Fig. 9 shows the power output from the proposed EPP MPPT algorithm charge controller.

In pin1 it receives voltage set V proceeding from the PV solar panel. In pin 2 it receives voltage ref V that simulates the maximum point of power for the chosen solar panel, proceeding from the microcontroller. Then a comparison is performed and a logical value: 0 or 1 is generated. This value is again submitted to a comparison with a slope generated with constant frequency and maximum amplitude of 17.5V. Depending on the exiting value from the first comparator, a new logical value is generated, 0 or 1 (or 0 or 17.5V respectively) that, in turn, will affect the final state of the bipolar transistors responsible for controlling the gate switch. This final value is a PWM signal with determined duty cycle that can vary depending on the voltage value of set V. If set V is greater than ref V transistor GATE SWITCH is ON. Otherwise if set V is lower than ref V, transistor GATE SWITCH is OFF.

Fig. 6. System Hardware

Fig. 7. Average Power Output from the PV panel and battery without charge controller

Fig. 8. Average Power Output from the PV panel and battery with P&O charge controller
VI. CONCLUSION

A new charge control method for the MPPT control of PV systems is proposed here. It illustrates the method which provides accurate and reliable maximum power tracking performance even under a rapidly changing irradiance condition. The results have verified the tracking accuracy of proposed MPPT control increase in PV system output power. The EPP algorithm is tested versus the most popular P&O algorithm. The algorithms were tested against fast change in irradiance, fast change in temperature and step change in irradiance. The EPP algorithm achieved more power comparable to the P&O speed.

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