# Implementation of a Stand-alone Photovoltaic Pumping System with Maximum Power Point Tracking

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***Abstract*- Photovoltaic (PV) pumping systems with maximum power point tracking (MPPT) technique aims at obtaining the highest possible power to the pump under various isolation and temperature, thus overcomes the mismatch between the photovoltaic panel and the pumping load. A simple method of tracking the maximum power points and forcing the system to operate close to these points is presented in this paper. The MC68HC908GP32 micro control unit (MCU) is employed to implement the proposed MPPT controller. Experimental results will also show the performances of the photovoltaic pumping system with the MPPT technique.**

***Keywords*- solar energy, maximum power point tracking, photovoltaic pumping.**

## I INTRODUCTION

The electric power generated by the PV panel varies with the solar radiation and temperature. By neglecting the internal shunt resistance, the I-V characteristics can be expressed as equation [1]:

$$I = I_L - I_0\left[e^{\frac{q(V+IR_s)}{AKT}} - 1\right] - \frac{V + R_s I}{R_{SH}} \qquad (1)$$

where I and V are the output current and output voltage of the PV panel, respectively. And $I_L$ is the generated current under a given insolation, $I_0$ the reverse saturation current, q the charge of an electron, K the Boltzmann's constant, A the ideality factor for a p-n junction, T the temperature rise (K), and $R_s$ the intrinsic series resistance of the PV panel. Also $R_{SH}$ is the additional parameter to meet the required precision.

The saturation current $I_0$ varies with temperature according to equation [2]:

$$I_0 = C_D T^3 e^{\left(-\frac{eE_G}{AKT}\right)} \qquad (2)$$

$$I_L = 5.46\times10^{-3} E_{Tp}[1 + 0.001(T - 298)] \qquad (3)$$

where $C_D$ is the diffusion capacitance, $E_G$ is the band-gap energy of the semiconductor used in the panel, and $E_{TP}$ is the insolation in $mW/cm^2$.

Equation [1] to equation [3] are combined together in the computer simulations. Fig.1(a) and Fig.1(b) show the simulated I-V and P-V characteristics of the ideal PV panel.

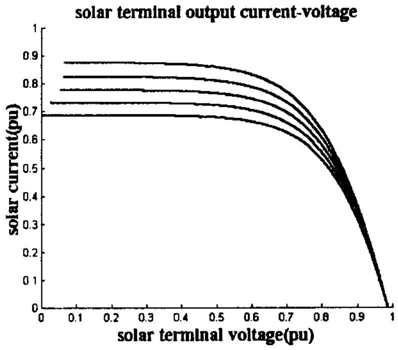

Fig1(a) PV terminal I-V characteristics

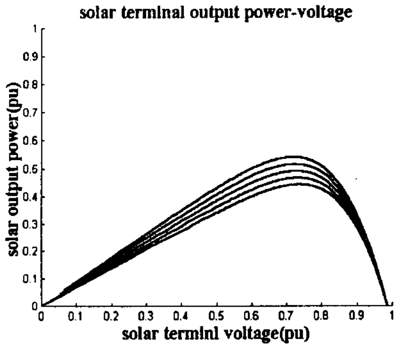

Fig1(b) PV terminal P-V characteristics

In Fig1(a) and Fig1(b), the series of curves are the output characteristics under different insolation. Obviously, a stronger insolation may result in a higher output power provided no temperature rise exists. As a matter of fact, there are a lot of factors such as the solar radiation, temperature, and load condition will significantly affect the nonlinear output characteristics. Each curve in Fig.1(a) and Fig.1(b) has a maximum power point (MPP), which is the optimal operating point for the efficient use of the PV panel. These characteristics will determine the design of the inverter and the control system.

## II SYSTEM DESCRIPTION AND MPPT ALGORITHM

Fig.2 illustrates the simplified diagram of the stand-alone PV pumping system. The whole system has only PV panels, a MPPT controller and a motor-pump. The proposed MPPT controller consists with the current sensor, voltage sensor, Micro Control Unit, the PWM control, and the main circuit. With the power feedback control, the PV panel is controlled to operate at the maximum power point, and thus pumping up water as much as possible.

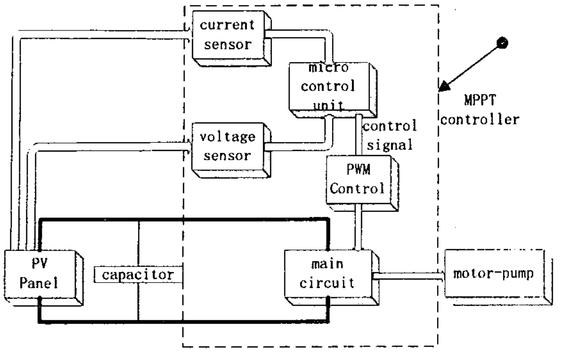

Fig.2 Diagram of the simplified system

Fig.3 illustrates the electrical characteristics of the PV panel under a given atmospheric condition. It can be observed from the curve that the internal impedance is very low on the right side like a voltage source while it turns to be very high at the left side like a current source, and the maximum power point locates at the knee. The MPP can be achieved only when the source internal impedance matches the load impedance. The fact that the current of the converter increases while voltage decreases, results in a negative impedance characteristic inherently. If the system operates on the high impedance side of the characteristic curve in Fig.3, the PV terminal voltage will collapse. Therefore, the PV panel is required to operate within the voltage source region to perform the tracking process.

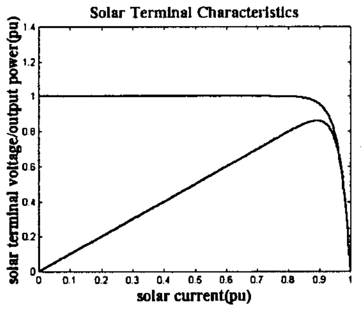

Fig.3 PV characteristics under a given insolation

The proposed MPPT method utilizes the power feedback control. That is to say, the actual PV power is used as the control variable. The maximum power point can be reached by forcing its derivative (dP/dV) equal to zero under the power feedback control. Generally, such approaches are to measure and maximize the power at the load terminal. They maximize the power to the load, not power from the PV panel. In this simplified application, all the measurement is made at the PV terminal, and the output power of the PV panel can be maximized. Yet the full output power may not be delivered to the load completely, due to the power loss of the converter. Therefore, it is necessary for a converter with MPPT to offer a high efficiency over a wide range of operating points. The following set of equations show how the proposed algorithm can be easily formed.

$$\frac{dP}{dt}=\frac{d(VI)}{dt}=V\frac{dI}{dt}+I\frac{dV}{dt}=0 \qquad (4)$$

$$VdI=-IdV \qquad (5)$$

$$\Delta I=VdI \qquad (6)$$

$$\Delta V=-IdV \qquad (7)$$

When the PV panel operates at the MPPs, the equation [4] to equation [7] must be satisfied. From Fig.3, if $\Delta$V is less than $\Delta$I, the PV panel operates at the voltage source region, and the load can be increased to reach the MPP; if the $\Delta$V is greater than $\Delta$I, the PV panel operates at the current source region, the load should be decreased at once to avoid the voltage collapse and at the same time to reach the MPP, and if $\Delta$V equals to $\Delta$I, the load should be kept on since the PV panel has already operated at the optimal point. In this method, the PV system will continuously seek the maximum power points.

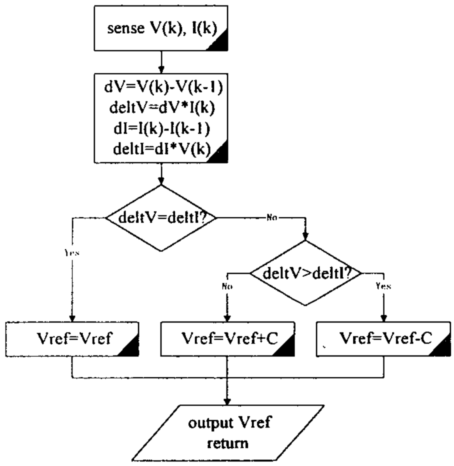

Fig.4 MPPT control flowchart

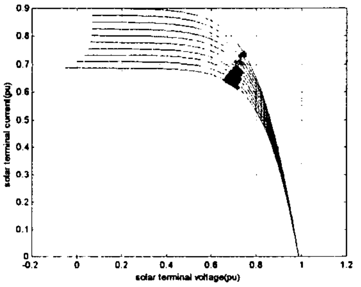

Fig.5 I-V operating point with MPPT (simulated)

The control flowchart of the proposed maximum power point tracking method which is shown in Fig.4 illustrates the details of the decision process. The simulation result in Fig.5 shows the estimated operating points of the algorithm.

## III EXPERIMENTAL RESULTS

The proposed converter with MPPT was evaluated with the system shown in Fig.2, which has no back-up battery to support the load during insufficient sun power. As a result, the motor may operate at a very low frequency, and no water could reach the ground level under the condition. Actually, in order to avoid the low frequency operation, the system may force the output frequency to zero while the insolation gets too weak to pump up water, and restart the frequency while the irradiation gets enough for pumping again.

Fifty-four modules of solar arrays are used in the testing system with a maximum power output of 46 watts and open circuit voltage of 21 volts for each one. Every twenty-seven modules are connected serially, and two branches are in parallel connection. The angle between the panel and waterlevel is 49o, and the waterlevel is underground of 14m.

Two experiments were carried out seperately on March 9th, 2001, a sunny day and March 30th, 2001, a cloudy day in Beijing. Fig6(a) Fig6(b) and Fig7 show the data aquired on the sunny day, while Fig8(a) Fig8(b) and Fig9 show the data aquired on the other day.

In Fig6(a) and Fig6(b), the points represents the measured voltage-current in per unit and the output power in per unit, while the curves are the simulated I-V characteristics of the PV panels. Fig7 shows the corresponding output power in per unit from 11:30 a.m. to 4:05 p.m. on March 9th., 2001.

In the simulation process, the insolation is defined as a set of discrete constants and the temperature rise of the PV panel is neglected. As a result, in Fig6(a) and Fig6(b), the simulated I-V and P-V characters are a set of seperated curves and the open circuit voltage of each curve converges at the same point. Whereas, in the actual operation, the irradiation is a continuous variable and the open circuit voltage is variational which could hardly be predicted due to the uncertainties of the atmosphere. For example, the temperature rise of the PV panel may affect both the open circuit voltage and the output power. Therefore, the maximum power points under different insolation will not concentrate on a single curve, but within a narrow area near to that curve as shown in Fig6(b).

Fig7 shows the output power from 11:30 a.m. to 4:05 p.m. It changed steadily with the insolation until it stopped when the frequency fell below 25Hz. It can be concluded from these figures that the proposed tracking method successfully forces the system to operate at the points very near to the simulated maximum power points under a favorable atomasphoric condition.

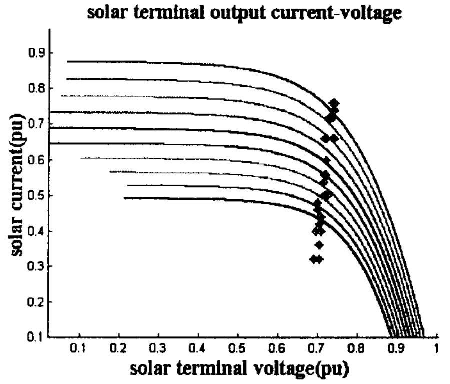

Fig.6(a) I-V operating point with MPPT (1)

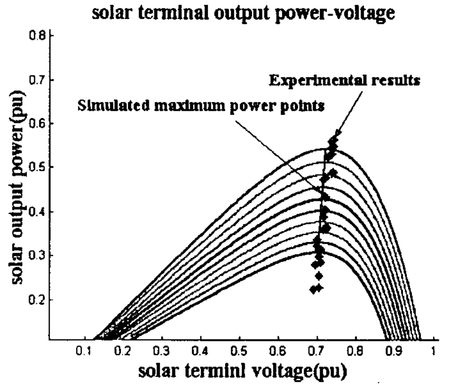

Fig.6(b) P-V operating point with MPPT (1)

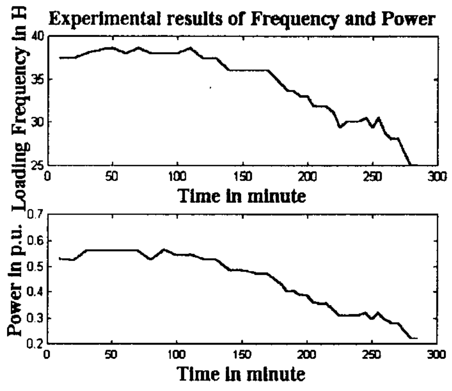

Fig.7 Output power within a day (1)

In Fig8(a) and Fig8(b), the points represents the measured voltage-current in per unit and the output power in per unit, and the curves are the simulated P-V characteristics of the PV panels. Fig9 shows the corresponding output power in per unit from 10:30 a.m. to 3:40 p.m. on March 30th., 2001.

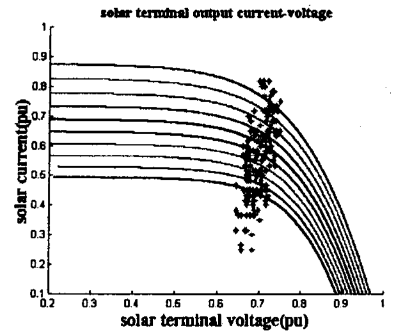

Fig.8(a) I-V operating point with MPPT (2)

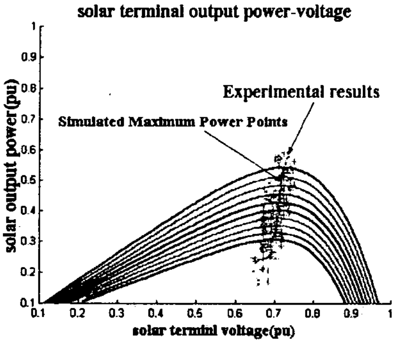

Fig.8(b) P-V operating point with MPPT (2)

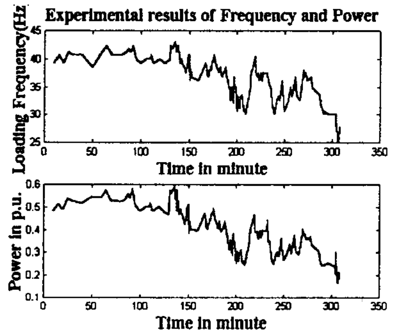

Fig.9 Output power within a day (2)

Similarly, from Fig8(a) and Fig8(b), the proposed tracking method operated favorablly even under the volatile insolation. And due to the diversification of the clouds, there might be a larger deviation than in Fig6(a) and Fig6(b).

From Fig9, the clouds varied randomly and strongly, and the output power during the whole day changed with it. It is safe to say that the system can be forced to operate very near to the maximum output power in a cloudy day without any unstable factor. The changes in the solar power and solar voltage can be well tracked. Even under the passing-by cloud, the system can be back to normal operation state quickly after the cloud passed.

In the actual system, in order to obtain the data acurately, the voltage and current are sampled at 10khz, and the power is calculated at the same time. From the experimental experiences, it is verified that the speed of sampling can effectively avoid the voltage collapse.

## Ⅳ CONCLUSIONS

The purpose of MPPT technique in the stand-alone system is to utilize the highest possible power to pump up water. The proposed power feedback control algorithm requires only two sensors and no battery bank. The MC68HC908GP32 MCU, which operates at 8Mhz, was employed to implement the proposed MPPT controller. A higher efficiency compared with the conventional solar pumping system with constant voltage and a better response for the system under rapid atmospheric condition variations since the fast execution speed can be obtained. Simulation results show the feasibility of the proposed control algorithm. And experimental results also verify the performances.

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