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Study of Single Sensor Based Maximum Power Point Tracking Techniques for Solar Water Pumping System

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***Abstract*: This paper describes new techniques of maximum power point (MPP) tracking for solar water pumping system. The latter system consists of a PV array, a DC/DC buck converter and a universal motor coupled to a centrifugal pump. A conventional hill climbing method is employed to seek the MPP using the motor-pump rotation speed or the pump outlet pressure information. Experimental results are presented and a comparison with conventional algorithm which requires both voltage and current sensors is provided.**

Key words:
MPP,
Buck converter,
Microcontroller,
Motor-Pump,
Tachometer,
pressure sensor

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1. INTRODUCTION

Solar PV water pumping is done all over the world and greatly enhances the quality of life of people's living in rural and remote communities. Solar PV water pumping systems are almost maintenance free, reliable, produce no emissions and have long operation period. The simplest configuration of solar PV pumping systems consists of PV array, a direct current (DC) motor that drives a water pump and a water storage tank. Unfortunately, when PV array and pump are directly coupled, this leads to a certain mismatch between the actual and optimum operating voltage of the PV generator and therefore causes energy losses. The mismatch can be overcome by introducing a matching DC/DC converter that continuously seeks MPP of solar generator.

Numerous strategies and algorithms have been developed to find and track the MPP of a PV generator. Among all MPP tracking techniques, perturbation and observation and hill climbing methods are widely applied in the MPP tacking controllers due to their simplicity, easy implementation and requiring only voltage and current sensors [1]. A generalized sensor reduction technique, on the other hand, requires complex computation and, therefore, its primary advantage is only in improving reliability of the overall system by eliminating the current sensor [2].

A comparison of single sensor based MPP tracking methods for a solar PV water pumping system is investigated in this work. These methods offer advantages of the simplified hardware configuration and low cost by using only one sensor to measure the motor-pump rotation speed or pump outlet pressure. These latter are used by an MPPT to maximize the power drawn from the PV array. The proposed techniques are implemented on a low cost 8-bit RISC microcontroller (PIC16f877) to control the duty cycle of DC/DC buck converter with pulse width modulation (PWM) in a solar PV water pumping system including a PV array, a motor-pump and a water storage tank.

2. PV ARRAY AND DC MOTOR-PUMP CHARACTERISTICS

The PV solar array generates electrical power as a direct current. The produced power varies with amount of sun shining on the array and temperature. If the latter is held constant, this power variation results in a variable current at a fixed voltage. Increasing (decreasing) temperature reduces (increases) PV array generated power.

The test bench includes a PV array which consists of 10 modules. An accurate solar cell electrical model is used based on a photo–current source, a single diode junction and a series resistance (Figure 1) with temperature dependence [3]. The model evaluation in matlab is shown in Figure 2 by the I-V curves for different insolation levels.

The motor-pump comprises a surface centrifugal water pump coupled to universal motor. The Figure 2 shows motor-pump behavior superimposed on I-V curves characteristic. At any time, the operating point is the intersection of the two characteristics. At different irradiance levels and constant temperature, the intersection points are far from the MPP. To overcome this problem, a MPP tracker can be added to maintain the PV array operating point at MPP.

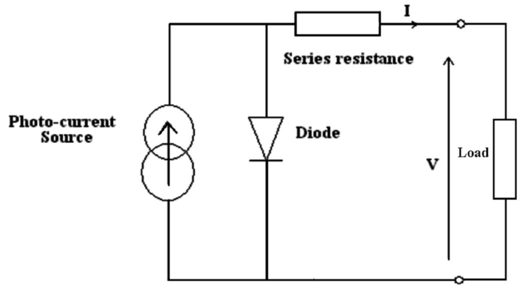

Fig. 1. Equivalent circuit of PV solar cell

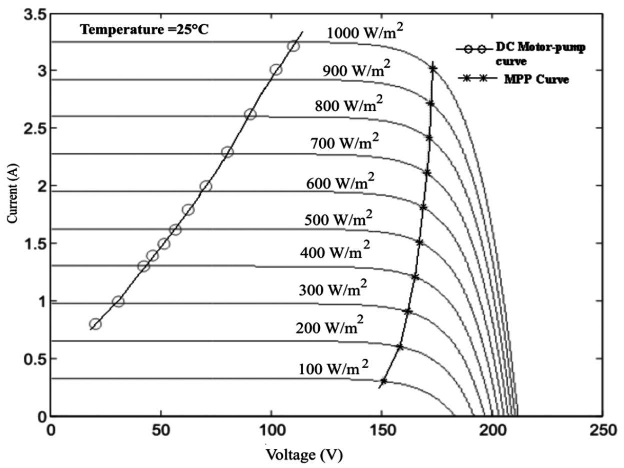

Fig. 2. DC motor-pump I-V curve on PV I-V curves for varying insolation

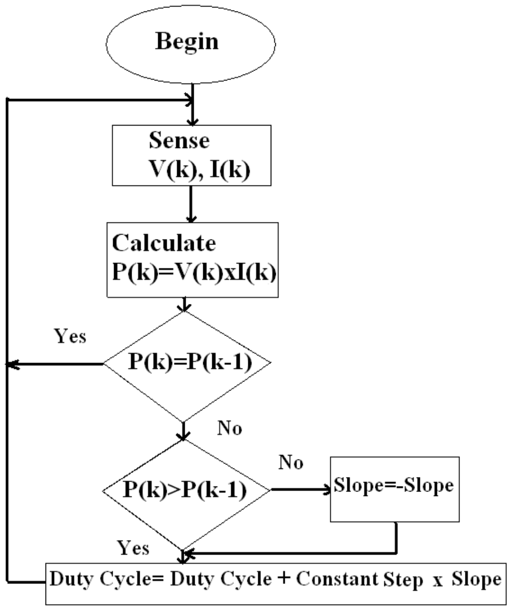

Fig. 3. Flow chart of the hill climbing MPP tracking method

3. MAXIMUM POWER POINT TRACKING METHODS

3.1. Hill climbing mpp tracking method

In this method, the DC/DC converter input voltage (V (k)) and current (I (k)) are measured and the input power (P (k)) is calculated for each iteration. The input power is compared to its value calculated in the previous iteration and according to the result of comparison; the sign of "slope" is either complemented or remains unchanged. Then, the PWM output duty cycle is changed accordingly. The MPP tracking algorithm is shown in Figure 3.

3.2. Speed control based MPP tracking method

This method has simple feedback structure by using only one sensor to extract the maximum power from a PV array. It operates by periodically incrementing or decrementing the duty cycle of a DC/DC converter and comparing the present motor-pump rotation speed (SP (k)) value with the previous measurement (Figure 4). If the duty cycle changing leads to an increase (decrease) in motor-pump rotation speed, which means an increase (decrease) in array's power, the subsequent changing is made in the same (opposite) direction. In this manner, maximizing rotation speed leads to maximizing PV array output power under different insolation conditions [4].

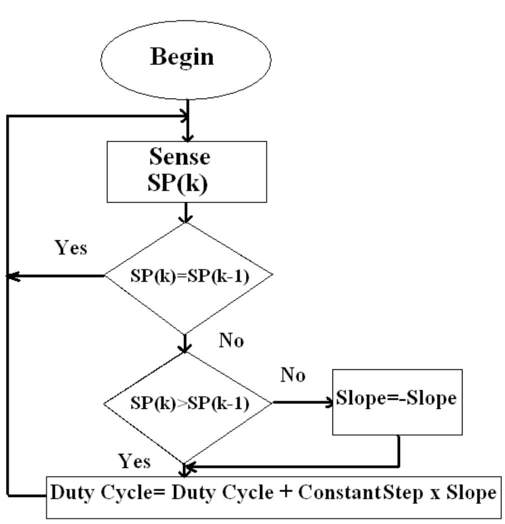

Fig.4 Flow chart of the speed control based MPP tracking method

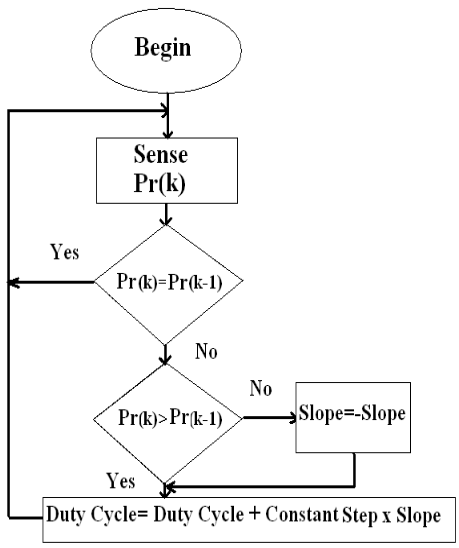

Fig. 5. Flow chart of the pressure control MPP tracking method

3.3. Pressure control based MPP tracking method

This method operates by periodically incrementing or decrementing the duty cycle of a DC/DC converter and comparing the present pump outlet pressure (Pr (k)) value with the previous measurement (Figure 5). If the duty cycle changing leads to an increase (decrease) in the pump outlet pressure, which means an increase (decrease) in

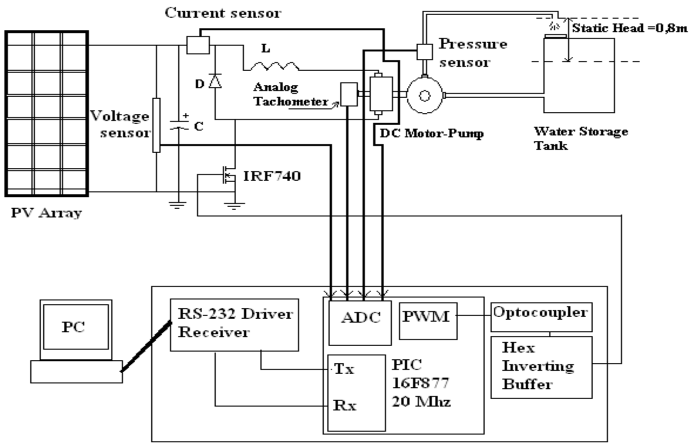

Fig. 6. Block diagram of the experimental bench

array's power, the subsequent changing is made in the same (opposite) direction. In this manner, maximizing pump outlet pressure leads to maximizing PV array output power under different insolation conditions.

4. SYSTEM DESCRIPTION

A detailed block diagram of the proposed system is shown in figure 6. A DC/DC buck converter is used to interface the PV array output to universal motor driven centrifugal pump. By measuring the following parameters: PV array voltage and current, voltage produced by an analog tachometer and voltage produced by a digital pressure sensor, we can easily determine PV array output power, rotation speed of the motor-pump and pump outlet pressure respectively. After that the controller on chip 10-bit PWM generator output drives the DC/DC buck converter according to each algorithm [5]. The buck converter comprises: MOSFET switch IRF740, diode BYT71, coil (L=100μH) and PV array voltage filtering capacity (C=1000μF) [6]. The switching frequency (6 KHz) is designed to obtain low output ripple. To implement the serial communication with the PC which has data recording software of the PV array voltage and current, rotation speed and pressure, the only component needed is a line driver and receiver chip (MAX232).

5. EXPERIMENTAL RESULTS

The test of MPPT algorithms was conducted on clear sky (Average insolation 524 W/m^2, average temperature: 32.7°C. According to the PV array generated power or rotation speed or pressure information, the microcontroller computes the output and generates a command representing the duty cycle given by the microcontroller PWM pin which is isolated by an optocoupler (6N135), amplified by a hex buffer-inverter converter (HEF4049) and applied between gate terminal and source terminal of the N-channel MOSFET. The converter duty cycle is adjusted such that maximum PV array output power is extracted under all operating conditions and transferred to motor-pump which in turn draws water from a water storage tank in a closed hydraulic system.

Figure 7 shows PV array voltage obtained by application of the hill climbing, speed and pressure control methods. It can be seen from latter figure that the voltage decreases to reach the optimal voltage, whereas the PV array current increases (Figure 8). The PV array generated power is given by Figure 9 where speed control algorithm seeks the MPP with small deviation. The power curves obtained by application of conventional hill climbing and pressure control methods are nearly identical with large deviation around the MPP which decreases in the steady state. The pressure curves have almost the same form of the PV array generated power curves (Figure 10). The last figure confirms that the algorithm based on speed control has small deviation with fast convergence to reach the MPP, and therefore more rotation speed will increase flow rate.

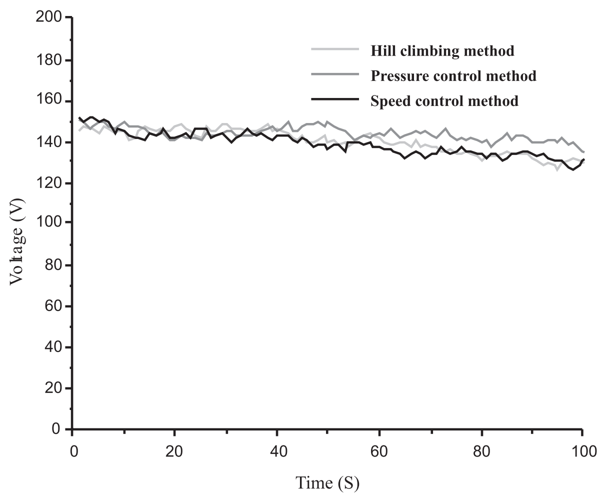

Fig. 7. PV array voltage

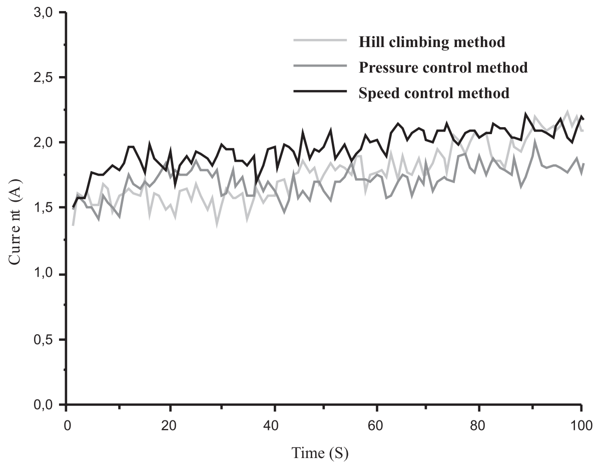

Fig. 8. PV array current

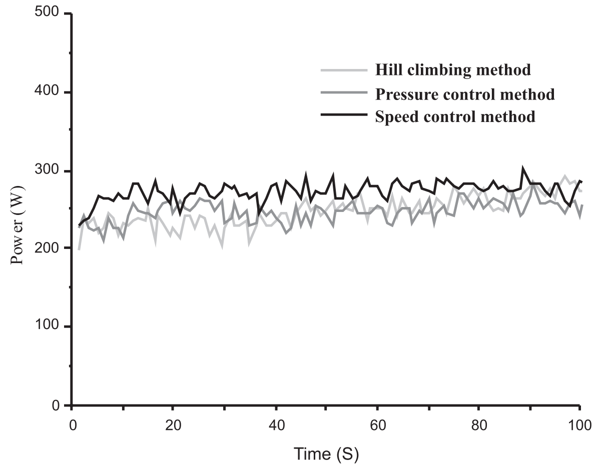

Fig. 9. PV array generated power

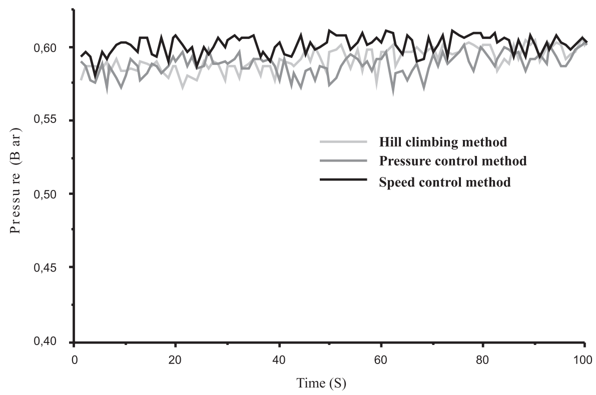

Fig. 10. Motor-pump outlet pressure

6. CONCLUSION

In this paper, a MPP Traker for solar PV water pumping system using single sensor techniques have been developed. Solar energy is captured by a PV array and delivered into a motor-pump through a DC/DC buck converter which performs the function of tracking the MPP. The system is controlled by a RISC microcontroller based on an analog

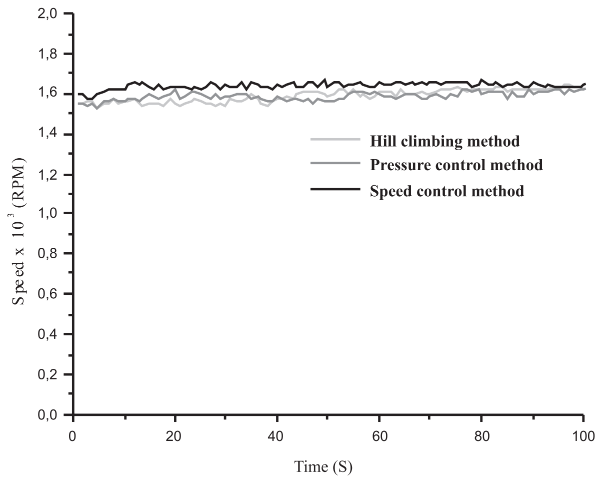

Fig. 11. Motor-pump rotation speed

tachometer or a pressure sensor to draw the maximum available power that the PV array can generate under all operating conditions. It has shown that the speed control based MPP tracking method offers better performance than the conventional or the pressure control method.

6. APPENDIX

PV module type LA361K51, SI-polycrystalline, Kyocera, $V_{open\ circuit}$ = 21.5V, $I_{short\ circuit}$ = 3.25A, Maximum Power = 51W_p at 1000 W/m^2 and 25°C.

Universal motor, LEBOYLD, Nominal Voltage = 220V, Nominal Current = 4.9A, Rated Power = 1HP, Nominal Speed = 3100 rpm.

Centrifugal water pump, Electropompe CM100 (The pump shaft is coupled to the driver which is the universal motor)

LEBOYLD Analog Tachometer.

SIEMENS SITRANS P Pressure Sensor, 0-4 Bar.

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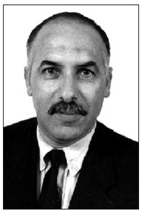

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