THE APPLICATION OF MAXIMUM POWER POINT TRACKING TECHNIQUE IN A PV-W/G HYBRID SYSTEM

E. Koutroulis [1], J. Kaliakatsos [2] and K. Kalaitzakis [1]

[1] Technical University of Crete, Dept. of Electronic & Computer Engineering
GR-73100, Chania, Crete, GREECE
[2] Technological Education Institute of Crete, Branch of Chania
GR-73132, Chania, Crete, GREECE

ABSTRACT

In this paper, the most common maximum power point tracking (MPPT) techniques, which have been applied in both photovoltaic (PV) and wind generating (W/G) systems, are reviewed. Results of the application of a novel MPPT technique to a hybrid renewable energy system are also presented. The proposed MPPT unit is part of an Energy Management System (EMS) composed of DC/DC power converters controlled by a microcontroller unit. The advantage of the proposed method, compared to other techniques used in the past, is that the generated power controls directly the DC/DC converters, while it does not require the exact knowledge of the optimal PV and W/G power vs. voltage and speed of rotation characteristics, thus reducing the complexity of the system. The experimental results show that by the use of the proposed MPPT control method the power produced by the PV and W/G sources is near optimal.

INTRODUCTION

The installation cost of Photovoltaic (PV) and Wind Generator (W/G) systems is relatively high and in most cases it is further increased by the cost of a power conditioner (DC/DC or DC/AC converter), which is required for load interface. The overall system cost can be reduced using high-efficiency power converters, which are conditioned such that the maximum possible power is extracted from the PV or the W/G power source. The power characteristic of either a PV or a W/G source, as shown in Figure 1, has a hill-shaped form and a single maximum power point, which shifts according to the atmospheric conditions (curves C_1, C_2 and C_3). Under source-load matching conditions, maximum power is extracted from the renewable energy source (Maximum Power Point Tracking, MPPT).

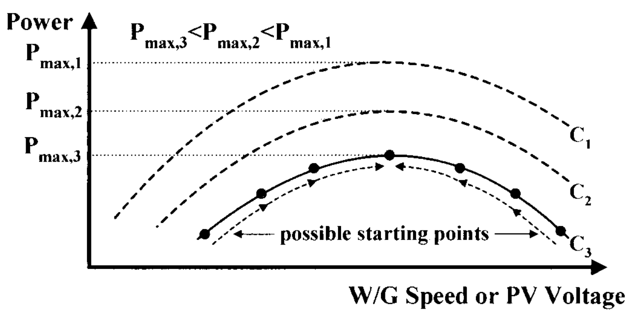

Figure 1: The PV and W/G power characteristics under varying atmospheric conditions.

A simple technique, which has been applied in PV systems, is to compare the PV voltage or current with a reference voltage (or current) corresponding to the maximum power point, under specific atmospheric conditions, while the resulting error is used to control a power converter [1]. However this method is not accurate since both the temperature and irradiation variations result in power loss. Alternative methods are based on the principle that at the maximum power point holds that $dP/dV = 0$. This principle has been implemented in [2] by directly calculating the power slope as:

$$\frac{dP}{dV}(n) = \frac{P(n) - P(n-1)}{V(n) - V(n-1)} = \frac{V(n)I(n) - V(n-1)I(n-1)}{V(n) - V(n-1)} \quad (1)$$

where P(n), V(n) and I(n) are samples of the PV power, voltage and current respectively.

According to the Incremental Conductance method [3], depicted in Figure 2(a), replacing $P = VI$ results in:

$$\frac{dI}{dV} = -\frac{I}{V} \quad (2)$$

where V, I are the PV voltage and current respectively.

The disadvantage of these methods is that the control system complexity increases the overall system cost.

The most commonly used W/G MPPT control technique, shown in Figure 2(b), requires knowledge of the W/G optimal power vs. rotating speed characteristic [4], which is not always known accurately and also changes because of rotor aging. The W/G speed of rotation is measured and the corresponding optimal power is compared to the actual output power, while the resulting error is used to control the power converter. In an alternative version [5], the power converter control is based on the error between the optimal and actual W/G speed of rotation.

In this paper, the application of an alternative MPPT control method in a hybrid PV-W/G system is presented. The proposed technique is based on measurements of the PV (or W/G) output power and appropriate control of a DC/DC converter duty cycle until the maximum power point is reached. The advantage of this method is that it does not require knowledge of the RES source optimal power characteristic, while it minimizes the control circuit complexity, thus reducing the system cost. The proposed method has been applied to a hybrid PV-W/G system in order to optimize the energy production of both input sources.

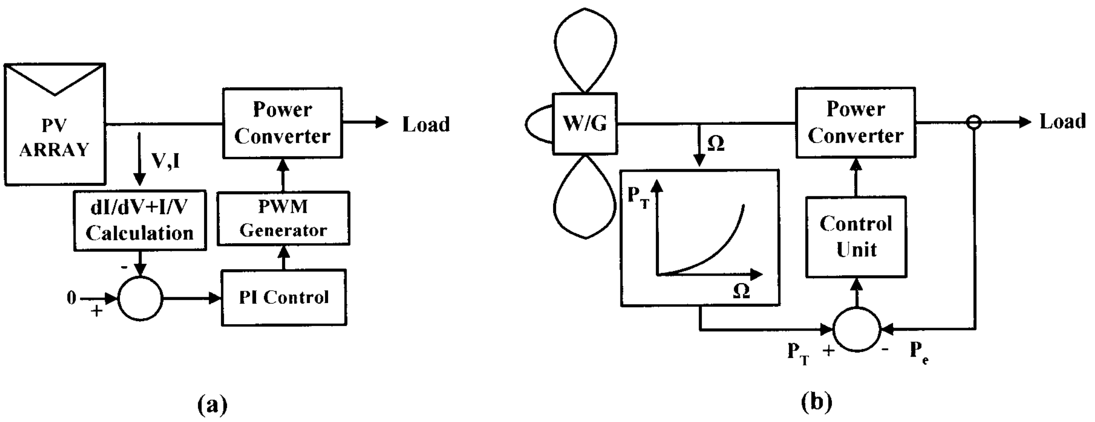

Figure 2: MPPT techniques: (a) application of the incremental conductance method in a PV system and (b) W/G control system.

SYSTEM DESCRIPTION

An experimental hybrid PV-W/G system has been developed, as shown in Figure 3. The RES power source consists of a 450W PV array and a 2kW, 3-phase W/G, which are interfaced to a 24V, 225Ah nominal capacity battery stack through Buck-type DC/DC converters, in order to store the energy surplus.

A commercially available DC/AC inverter is used to supply the system load (220V, 50Hz), specifically the lamp array of a parking lot, while in case of low RES energy production the electric grid is used as an alternative power source. A microcontroller-based Energy Management System (EMS) has been developed in order to control the DC/DC converters, monitor the battery state of charge, and perform the dummy-load and output-load ON/OFF control functions.

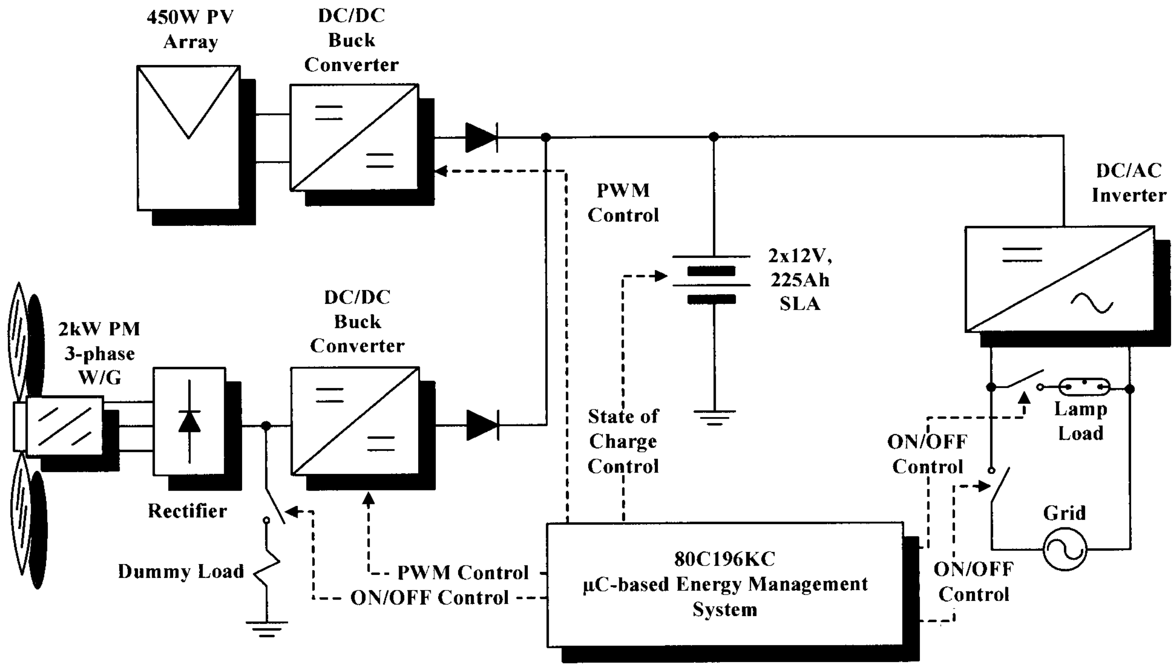

Figure 3: Block diagram of the hybrid system.

The MPPT program flowchart [6] used to control each of the DC/DC converters is shown in Figure 4. The microcontroller accepts the voltage and current measurements, calculates the output power of the respective source and compares it with the output power at the previous step.

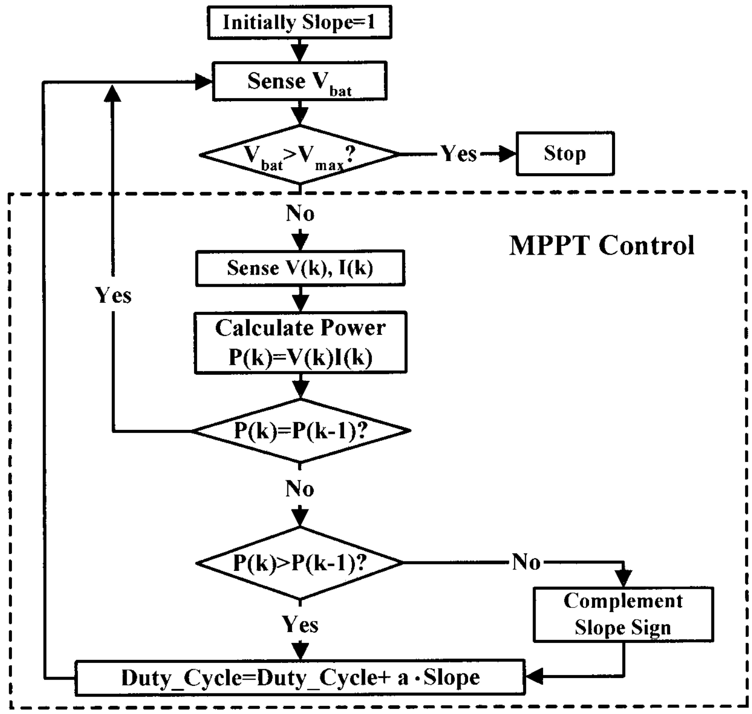

Figure 4: The control algorithm flowchart

According to the comparison result, the duty cycle is modified properly. The process is repeated until the maximum power point has been reached. A program variable named "Slope" takes the values ±1, indicating whether the duty cycle must be increased or decreased. The battery voltage is also monitored to prevent overcharging. Since the MPPT operation depends on the comparison of successive power samples rather than their exact values, the control system operation is less sensitive to the sensors accuracy. The duty cycle is controlled with an 8-bit word, resulting in a $1/2^8 = 0.4\%$ resolution, which is adequate for the proposed system.

The microcontroller unit, based on the Intel's 80C196KC, features all necessary characteristics for the proposed application, such as 16-bit architecture, low power consumption and high clock rate, while it features an on-chip 10-bit, 8-channel A/D converter and three PWM outputs with 8-bit, program-controlled duty cycle.

THEORETICAL AND EXPERIMENTAL RESULTS

The MPPT control method described above has been tested on the hybrid system, with a PV array consisting of Siemens SP75 type solar modules, having a 450W maximum output power capability, installed with a 35° inclination. The global irradiation on horizontal plane and the ambient temperature variations over the test time period are shown in Figures 5(a) and (b), respectively. The corresponding theoretical maximum output power, P_e, over the same time period, shown in Figure 5(c), is estimated as follows:

$$P_e = [V_{oc} - K_V(T_C - 25)][I_{sc} + K_I(T_C - 25)]\frac{G_\beta}{1000}FF_{T_C} - P_L \quad (3)$$

$$\text{where: } T_C = T_A + \frac{T_{NC} - 20}{800}G_\beta \quad (4)$$

and V_{oc} is the open-circuit voltage at 25°C (V), I_{sc} is the short-circuit current at 1kW/m^2, K_V is the open-circuit voltage temperature coefficient, K_I is the short-circuit current temperature coefficient, T_C is the cell temperature (°C), T_A is the ambient temperature (°C), T_{NC} is the normal operating cell temperature (°C), G_β is the irradiation at 35° inclination (W/m^2), estimated from the measured global irradiation at 0°, FF_{T_C} is the fill factor at T_C and finally P_L is the cables power loss (W).

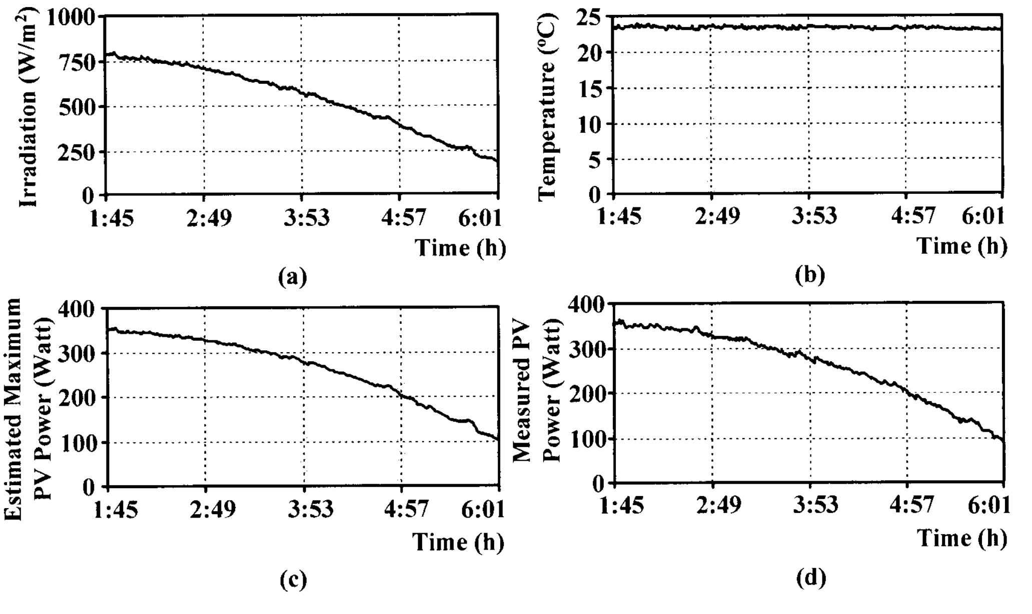

Figure 5: The measurements during the test time period of the proposed system: (a) the global irradiation, (b) the ambient temperature, (c) the estimated maximum PV power and (d) the measured PV output power

The measured PV array output power, using the proposed system, is shown in Figure 5(d). It can be observed that it matches the estimated maximum power shown in Figure 5(c), with an average deviation of 1.8%. Experimental results show that using the proposed MPPT method, the power is increased by as much as 15%, compared to the case where the converter duty cycle is adjusted such that the maximum power is produced at $1kW/m^2$ and 25°C.

In order to further validate the proposed method, experimental results using a commercial solar battery charger with no MPPT capability, have been produced. During the bulk-charging phase of the charger, the PV array is directly connected to the battery stack. The maximum power, estimated using Eqn. 3, and the measured PV output power are shown in Figure 6. The measured PV array output power has a 36% average deviation from the estimated maximum power, while the maximum deviation in the low power region (50-100W) is approximately 70%.

The same MPPT control method has also been used to maximize the W/G power production and preliminary results have shown that the generated power follows the optimal power line at various wind speeds, with a maximum deviation of 7%, mainly due to the rectifier power loss.

The DC/DC converter efficiency in both RES input source cases is relatively constant and higher than 90% in a wide output power range. This is advantageous in RES applications since the power production changes continuously due to the varying atmospheric conditions.

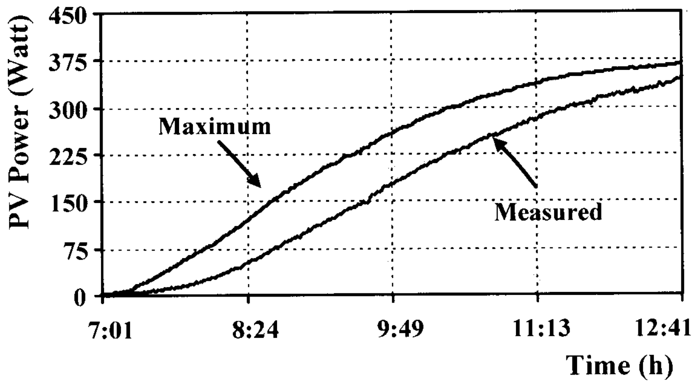

Figure 6: The estimated maximum and the measured PV output power using a commercial solar converter.

CONCLUSIONS

The application of a novel MPPT control method to a hybrid PV-W/G system has been presented. The advantage of the proposed method is that the generated power controls directly the DC/DC converters, while it does not require the exact knowledge of the optimal PV and W/G power vs. voltage and speed of rotation characteristics, thus reducing the complexity of the system. The experimental results verify that using the proposed method the power produced by both the PV and W/G sources is near optimal. The resulting system has high efficiency and low cost, while it can be easily modified to handle more types of renewable energy sources.

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