A HYBRID PV-WIND GENERATOR SYSTEM USING A MAXIMUM POWER POINT TRACKING TECHNIQUE

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ABSTRACT: A hybrid renewable energy system is described which consists of twelve photovoltaic (PV) panels and a wind generator and can supply continuous electric power of 1.5 kW. An Energy Management System (EMS) was developed for this purpose in order to maximize the electric power produced using a maximum power point tracking (MPPT) method and consists of Buck-type DC/DC converters controlled by a microcontroller. The main difference between the method used in this system and other techniques used in the past is that the generated power controls directly the DC/DC converters, thus reducing the complexity of the system. The resulting system has high efficiency, lower cost and can be easily modified to handle more energy sources. Experimental results show that the use of the MPPT control method may increase the output power of the PV panels by as much as 15%. The energy produced by the renewable energy sources can be stored in lead-acid batteries for a stable supply of electric power. The system can be also connected to a diesel generator, in which case, it becomes 100% autonomous and can be used to supply power to a TV repeater or other applications in islands and remote places.

1. SYSTEM DESCRIPTION

Renewable energy sources and among them photovoltaic (PV) panels and wind generators are widely used today in many applications. They are especially useful in islands and remote areas. They are maintenance and pollution free, but their initial cost is high and, in most applications, they require power DC/DC and/or DC/AC converters for load interface. Using high efficiency power converters which, in addition are designed to extract the maximum possible produced power, can reduce the overall system cost.

This paper describes a renewable energy system that can supply 1.5 kW of power to a TV repeater and which was financed by the Region of Crete under the PEP programs for Crete (1994-1999). The system was developed and constructed at the Technical University of Crete (Electronics Laboratory) with the cooperation of the Technological Educational Institute of Crete, Chania branch (Dept. of Electronics).

The system, whose block diagram is shown in Fig.1, consists of 12 photovoltaic (PV) panels, which can provide a total power of 900 W, and a wind generator that can produce a maximum power of 2200 W.

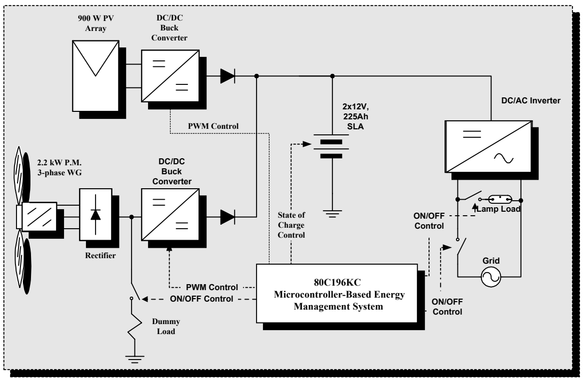


Figure 1 Block Diagram of the System

The hybrid PV-wind generator system has been designed to supply continuous power of 1.5 kW and has the following capabilities:

- Maximizes the electric power produced by the PV panels or by the wind generator by detecting and tracking the point of maximum power.
- Stores the electric energy in lead-acid batteries for a stable repeater operation.
- Controls the charge and discharge processes of the batteries.
- Protects the wind generator from overspeeding by connecting a dummy load to its output.
- Initiates the operation of a diesel generator or connects the system to the electric grid (if available), when the renewable energy sources fail to produce sufficient electric energy.
- Provides continuous and uninterruptible electric power (220 V, 50 Hz) to a 1.5-kW TV repeater.

The above operations were implemented by a system whose block diagram is shown in Fig.1. Buck-type DC/DC converters are controlled by an Energy Management System (EMS) based on a microcontroller, which executes a specifically designed program. Part of the program implements a maximum power point tracking (MPPT) method [1] for detecting and tracking the point at which maximum power is produced by the PV panels or by the wind generator. According to this method, the microcontroller measures the output power of either source and changes the duty cycle of the DC/DC converter control signal. By measuring the voltage and current, the actual output power is calculated and compared to the previous output power value. Depending on the result of the comparison, the duty cycle is changed accordingly and the process is repeated until the maximum power point has been reached (see Fig. 2). This method could be also implemented with analog circuits, instead of using a microcontroller, but the present design has the advantage that it permits easy modification, if additional renewable energy sources (e.g. more PV arrays or wind generators) are used. The incorporation of the MPPT method in the hybrid system results in a more efficient and lower cost system implementation.

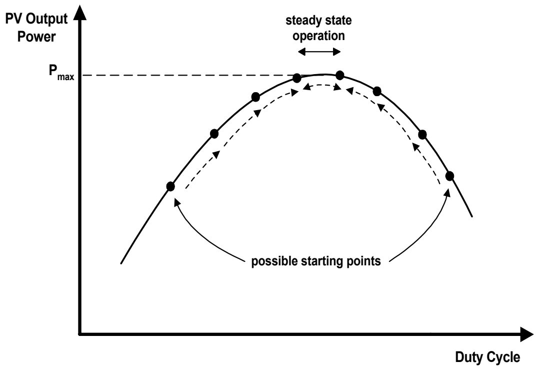


Figure 2 The MPP tracking process

In Fig. 1, a battery stack is used as a load to the PV array or to the wind generator. For given atmospheric conditions, the battery charging current depends on the PV (or the wind generator) output power and the battery voltage. The battery voltage increases according to the charging level and it is monitored to prevent overcharging.

The system control unit consists of (a) an Intel 80C196KC low-power consumption, CMOS micro-controller with external EPROM and SRAM, (b) the interface circuits which comprise sensors and signal conditioners connected to the microcontroller A/D converter and (c) an IC driver for the power MOSFETs. The power consumed by the control unit is about 1 Watt and is supplied by the battery, which is being charged by the DC/DC converter.

The microcontroller unit, 80C196KC, features a 10-bit, 8-channel, successive approximation A/D converter, which is used by the control program to measure the signals required for the power flow control. The 10-bit resolution is adequate for the present application. Also, it features three PWM outputs with program-controlled duty cycle and 39.2-kHz maximum frequency, when driven by the 20-MHz clock of the unit. Each of the PWM outputs can be used to control a separate MPPT system. This type of microcontroller was chosen because it has the necessary features for the proposed system, such as an on-chip A/D converter, PWM outputs, 16-bit architecture, high clock rate, low-power consumption and low cost.

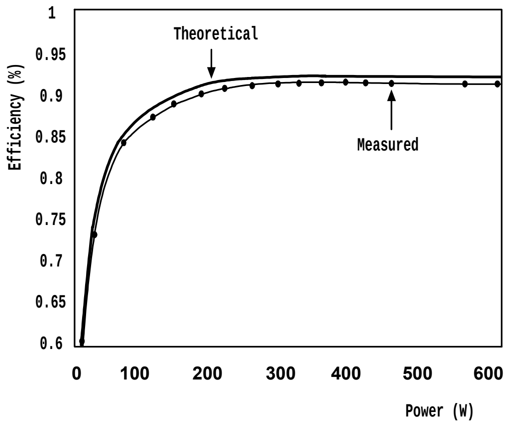
A commercially available DC/AC inverter is used for the supply of ac power to the TV repeater. All the other of electronic devices for energy conversion and control were developed in the Electronics laboratory.

2. THEORETICAL AND EXPERIMENTAL RESULTS

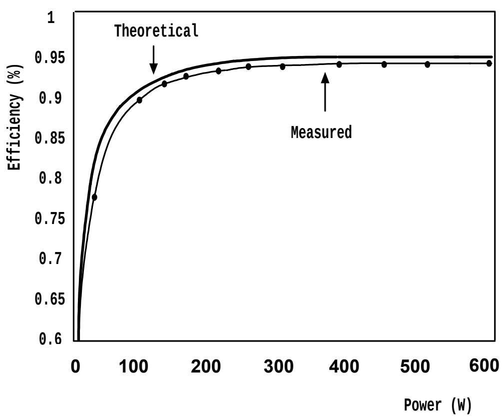
A prototype system has been developed using the above-described method and tested in the laboratory. The PV array used with this system consists of 12 Siemens, SP75 type modules, giving a 900-W maximum power at an irradiation of 1 kW/m^2 and a temperature of 25^{o}C. The wind generator is a 3-phase, 16-pole, permanent magnet type with a wingspan of 3.6 m. At a wind speed of 17 m/sec, it produces 100 V rms per phase which is then applied to a 3-phase diode rectifier resulting in a fairly smooth DC voltage.

The DC/DC converters are of Buck type and are used for the detection and tracking of the point of maximum power produced by the PV panels and the wind generator. They perform also the conversion of the high DC voltage to a lower level (24 V) for charging the lead-acid batteries.

The theoretical values were calculated using data provided by the manufacturers of the circuit elements. The theoretical and measured efficiency for various output power levels is shown in Fig. 3(a) and (b) for the PV panels and the wind generator, respectively. It is seen that in both cases the efficiency is quite high and relatively constant for a wide output power range.



(a)

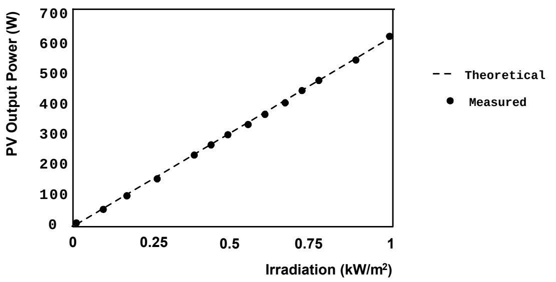


(b)

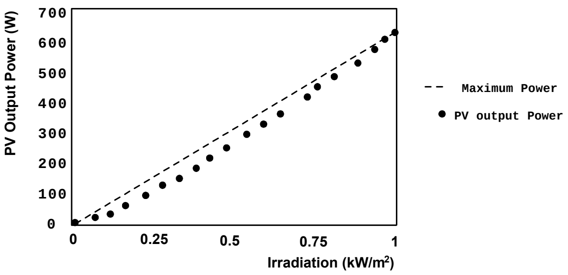
Figure 3 Theoretical and experimental efficiency of the DC/DC converters designed for (a) the PV panels and (b) the wind generator

The actual PV output power and the corresponding theoretical maximum output power for various irradiation levels is shown in Fig. 4(a). It is verified that the proposed system always tracks the PV maximum power point. Figure 4(b) shows the PV output power for various irradiation levels, with the MPPT control disconnected and with the DC/DC converter duty cycle set such that the PV array produces the maximum power at 1 kW/m^2 at 25^{o}C. The theoretical maximum PV power at each irradiation level is also indicated in the same figure. A comparison between

Figs. 4(a) and 4(b) shows that the use of the proposed MPPT control method increases the PV output power by as much as 15% for irradiation levels in the range of 0.2-0.75 kW/m^2 at 25^oC.



(a)



(b)

Figure 4 Results of the MPPT method on PV output power (a) with the proposed MPPT system in operation (b) without the proposed MPPT system, but with the duty cycle adjusted such that the maximum power is produced with solar radiation of 1 kW/m^2 at 25^oC.

Figure 5 shows the wind speed and the wind generator output voltage and current. The wind generator is connected to the dummy load (11Ω), since the actual TV repeater was not connected and the PV power was sufficient for battery charging.

The PV array output voltage and current are shown in Fig. 6, when the PV array is connected to a commercially available battery charger. The global irradiation, when these measurements were performed, is also shown on the top of the figure. It is seen that the PV array output power is lower than the expected maximum PV power under the irradiation conditions shown, since the battery charger does not perform an MPPT operation.

The PV array output voltage and current and the corresponding global irradiation are shown in Fig. 7, when the PV array is connected to a power grid through an inverter which performs an MPPT operation. It is seen that the power produced is higher in this case. However, the inverter often loses its synchronization with the grid, resulting in power loss because the inverter suspends its operation until it synchronizes again with the grid.

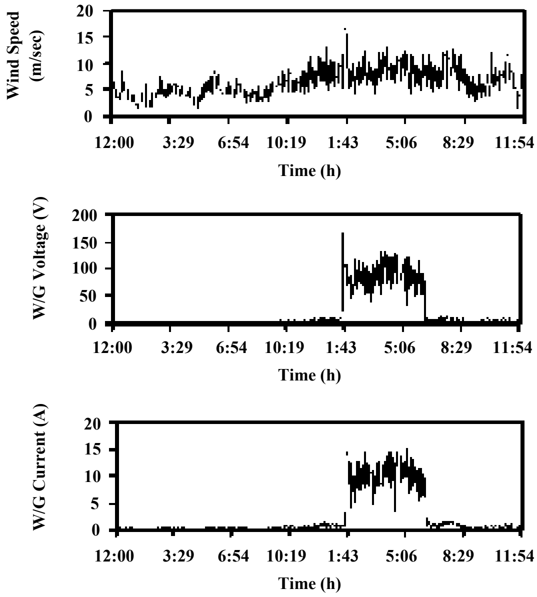


Figure 5 Wind Generator speed, voltage and current

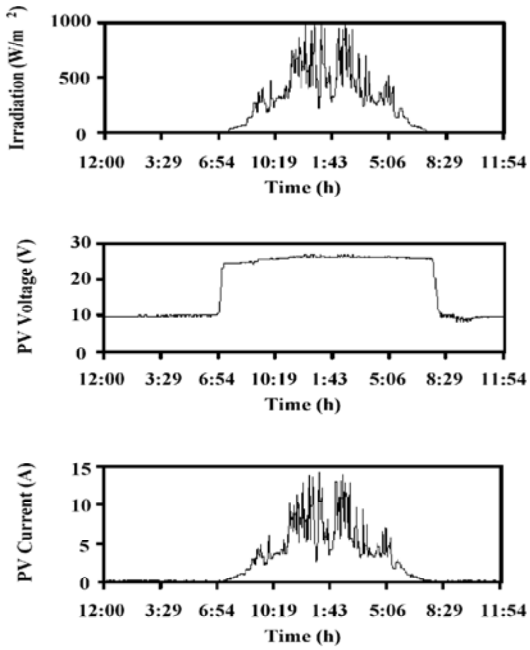


Figure 6 PV array irradiation, voltage and current without MPPT

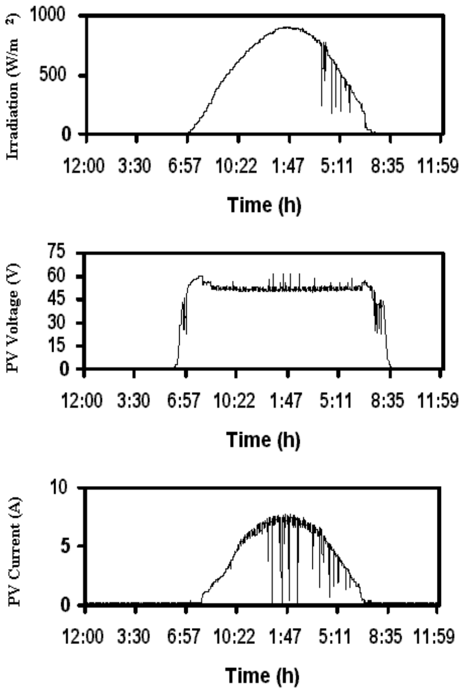


Figure 7 PV array irradiation, voltage and current, when connected to a power grid through an inverter with MPPT

3. CONCLUSIONS

A hybrid renewable energy system was described which could supply 1.5 kW of power to a TV repeater. It consists of a photovoltaic (PV) array and a wind generator for the production of electric power and an Energy Management System (EMS) for the maximization of the electric power produced utilizing a maximum power point tracking (MPPT) control technique. The resulting system has high-efficiency, low-cost and can be easily modified to handle more energy sources. Experimental results show that the use of MPPT control increases the output power by as much as 15%. The excess of energy produced is stored in lead-acid batteries for a stable supply of electric power to a TV repeater or any other load of 1.5 kW. The system can also be connected to a diesel generator, in which case, it becomes a 100% autonomous energy system and can be used in islands and other remote places to supply power to various applications.

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