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Short communication

A novel power converter for photovoltaic applications

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Abstract

A simple and economical power conditioner to convert the power available from solar panels into 60 Hz ac voltage is described. The raw dc voltage from the solar panels is converted to a regulated dc voltage using a boost converter and a large capacitor and the dc output is then converted to 60 Hz ac using a bridge inverter. The ratio between the load current and the short-circuit current of a PV panel at maximum power point is nearly constant for different insolation (light) levels and this property is utilized in designing a simple maximum power point tracking (MPPT) controller. The controller includes a novel arrangement for sensing the short-circuit current without disturbing the operation of the PV panel and implementing MPPT. The switching losses in the inverter are reduced by using snubbers. The results obtained on an experimental converter are presented.

Keywords: Solar panels; Bridge inverter; Maximum power point tracking controller

1. Introduction

Photovoltaic (PV) energy is gaining greater visibility during the last several years as a convenient and promising renewable energy source. It has several advantages compared to other forms of renewable energy like wind energy. The main drawbacks of PV energy are the high cost of manufacturing silicon solar panels and the low conversion efficiency [1,2]. With the newer techniques of manufacturing crystalline panels and efficient power converter design, it is possible to make the PV project cost-effective. The development of economical power conversion equipment for PV energy will have much impact in the future. The conversion of the output voltage from a solar panel into useable dc or ac voltage has to be done at its maximum power point (MPP) and this makes the conversion scheme complicated. There are several methods of PV conversion with maximum power point tracking (MPPT) [3–7]. Some of the methods use complicated control circuit involving microcomputers. Economical power converters with simpler MPPT will help to make the power conversion viable.

The paper presents a power converter system that includes a novel MPPT scheme that is integrated into the converter itself. The MPPT method is simple and is based on the relationship that exists between the short-circuit current of the PV panel and the load current the panel supplies at MPP. A boost converter is used to provide a higher, regulated voltage to the bridge inverter. The short-circuit current needed for MPPT is obtained by using the switch in the boost converter. Suitable snubber is added to the switches of the inverter to reduce the losses thereby increasing the efficiency of the converter. Experimental waveforms of the power converter are presented.

2. Characteristics of solar panel

Solar panels providing PV outputs as high as 120 W per panel are commercially available. The output dc voltage and current vary with light intensity (L) and temperature (T). The current–voltage characteristic of a solar panel is given by [1]:

$$I = I_L - I_D[e^{QV_{oc}/AKT} - 1] \quad (1)$$

where I is the output current, I_L the light-generated current, V_{oc} the open-circuit voltage, and T the absolute temperature. The short-circuit current I_{sc} will be approximately equal to I_L. The output current I_L will be proportional to light intensity (L) as shown in Fig. 1(a). The power supplied by the solar panel will vary with temperature as shown in Fig. 1(b)

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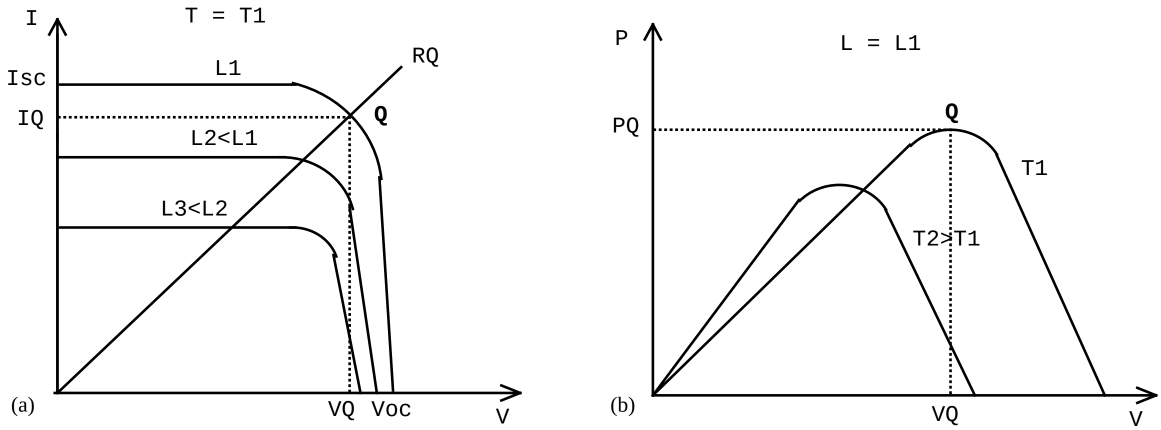

Fig. 1. *I–V* and *P–V* characteristics of PV panel at different light levels (*L*) and temperatures (*T*).

Table 1
Test data on solar panels

I_{sc} (A)	I_Q (A)	V_{oc} (V)	V_Q (V)	P_Q (W)	I_O/I_{sc}
1.91	1.71	74.62	59.82	102.6	0.895
2.40	2.16	74.31	58.17	125.3	0.897
3.51	3.12	71.65	54.39	169.7	0.887
2.24	2.02	183.60	143.5	289.0	0.900
2.80	2.53	181.30	138.9	350.0	0.904
3.19	2.87	179.04	138.5	397.0	0.899

and it is seen that it reaches a maximum at one particular operating point Q. It is also seen that the power output will be more at lower temperatures. The characteristics of solar panels with active load can be obtained through simulation [3,4]. In order to maximize the output from a solar panel, it has to be operated at the point Q with specified values of V_Q and I_Q or in other words at a specified load resistance R_Q. This makes the power converter complex by requiring a separate circuit for MPPT [1].

The control scheme proposed in this paper will adopt a novel approach in which the relationship existing between the short-circuit current (I_{sc}) and the MPP current (I_Q) is used for designing the power converter. Table 1 contains experimental data showing the relationship between I_{sc} and I_Q and the maximum power at different light levels. It is seen that the ratio of I_Q to I_{sc} is almost constant at 0.9.

Several solar panels will be interconnected in series to obtain a dc voltage large enough for supplying power to the grid under average sunlight [5]. Too high a voltage will result in under-utilization of the solar panels and an increase in the voltage rating of switching devices in the power converter.

3. Power conversion scheme

The generalized power circuit of the PV converter is shown in Fig. 2. The scheme will be used to supply 60 Hz ac power into the ac mains and also supply local loads. The dc voltage from the PV panel is stepped up by the boost converter made up of the inductor L_{in}, MOSFET M_b, and diode D_1. The output from the boost converter will charge the capacitor C_{dc}. Switches M_1 through M_4 form the bridge inverter for converting the output voltage of the boost converter into a 60 Hz ac voltage. The inductor L_o is used to remove the high-frequency ripple from the output voltage/current. The controller generates the gate pulses for all the MOSFET switches. The controller will use a simple electronic circuit including commercial ICs for signal splitting and driving.

The PWM inverter will use an R–C–D snubber for each of its switches in order to reduce the switching losses [8]. The lower-order harmonics in the output voltage will be eliminated using a suitable modulation technique like sine pulse width modulation (SPWM). The modulation index of the PWM inverter will be used to control the output power so as to operate at MPP.

Identifying the MPP for a given light condition and operating the converter for that condition are the critical parts in the design of a PV conversion system. The MPPT methods reported in literature use complex control circuits with a digital signal processor (DSP) or a microprocessor [6]. They also use sensors and adopt perturbation technique for maximizing the power output. The block diagram of the control scheme used in this project is shown in Fig. 3. The MPP tracking is done by measuring the short-circuit current I_{sc} and adjusting the actual load current to be equal to a desired fraction (0.9) of I_{sc}. The current I_{sc} is measured by shorting the panel by turning on M_b for an extended interval and the voltage across the sensing resistor R_s represents the short-circuit current. In the proposed method, the short-circuit current I_{sc} will be sensed by applying an extended pulse to the MOSFET M_b once in several switching cycles. This is in addition to the periodic gate pulse of a chosen duty cycle that provides the necessary boost action. The illustrative waveforms are shown in Fig. 4. The current pulses sensed during the extended intervals have transient peaks in addition to steady state portion. They are further processed using a

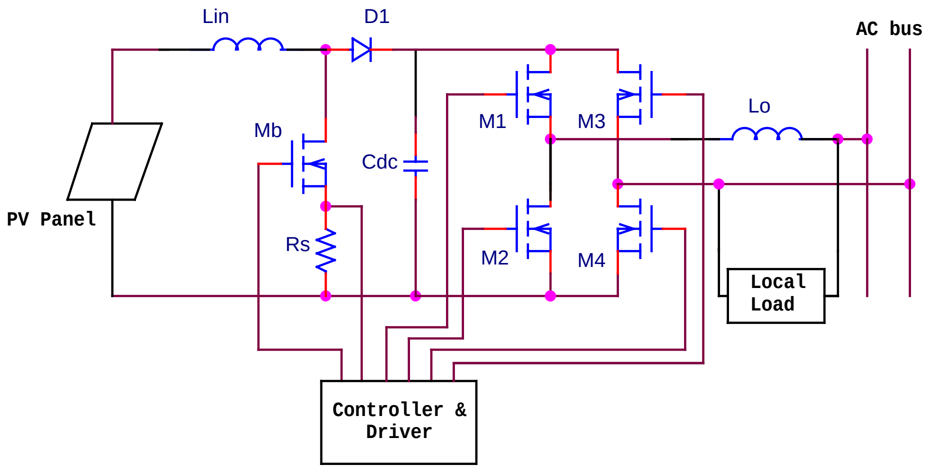

Fig. 2. Power circuit of proposed converter system.

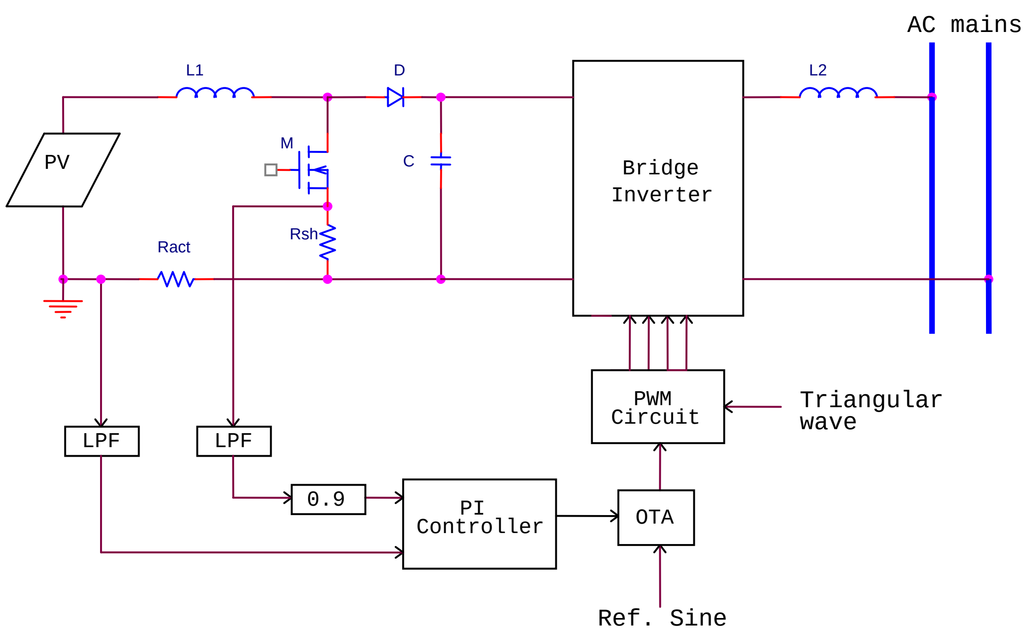

Fig. 3. Block diagram of the control scheme.

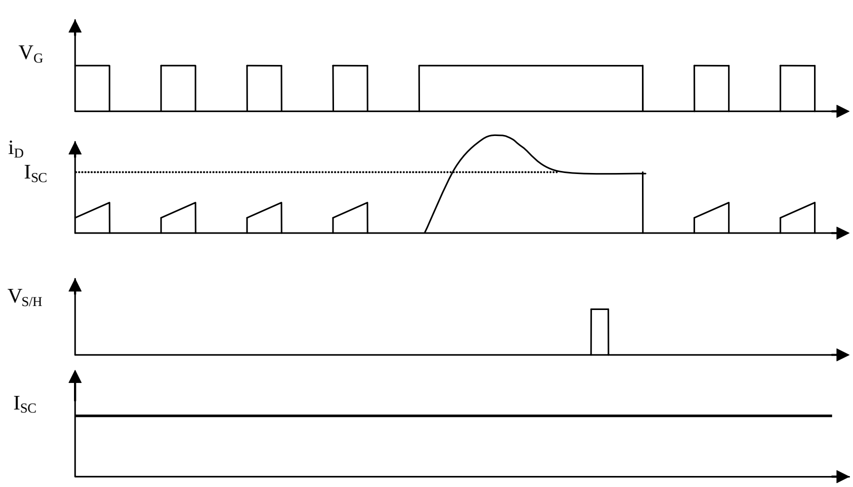

Fig. 4. Illustrative waveforms of MPPT controller.

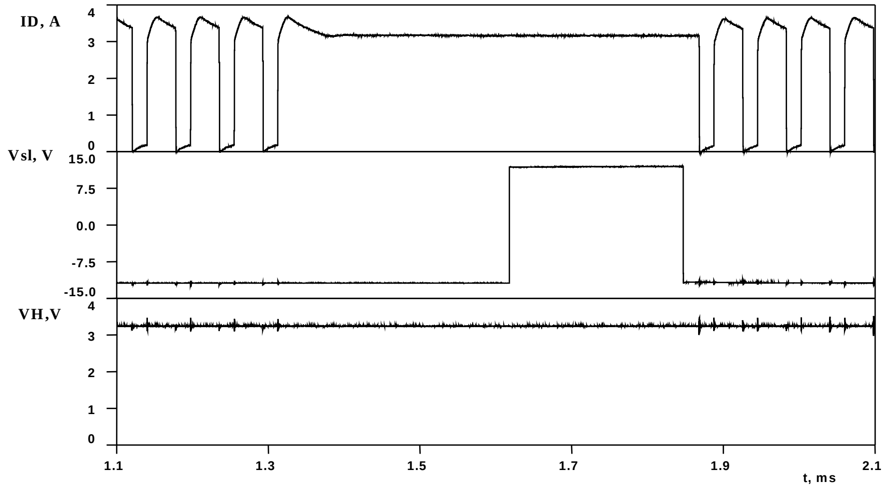

Fig. 5. Waveforms of drain current, sampling pulse, and output of S/H amplifier.

sample-and-hold (S/H) circuit and the sampling pulses are also shown in Fig. 4. The output of the S/H circuit becomes the short-circuit current I_{sc}. The output of the S/H circuit serves as the reference for the loop that controls the inverter output.

The modulation index of the inverter is adjusted until the actual load current is equal to the desired fraction of I_{sc}. This will be implemented using a simple current feedback loop with a PI controller. The output of the PI controller varies the gain of an operational transconductance amplifier (OTA) and hence the amplitude of the reference sine wave applied to the PWM circuit. Since the rate of variation of light intensity is low, it is possible to achieve a satisfactory response by using a PI controller. The width of the extended pulses is to be adjusted in such a way that it is long enough to allow the short-circuit pulse to reach the steady state and at the same time relatively short so that the output from the solar panel is missed only for a small fraction of time.

4. Experimental results

The complete power converter system was built and tested. The power converters were built using Power MOSFET switches. Fig. 5 shows the waveforms of the drain current (i_D), the sampling pulses (V_{Sl}), and the output of the S/H amplifier (V_H). The drain current shows the high-frequency pulses with a specific duty cycle, and the extended pulses for sensing I_{sc}. The PWM output of the inverter and the output current (sinusoidal) are shown in Fig. 6. The carrier frequency for the inverter is set at 40 kHz. It is also to be noted that the switches in the PWM are provided with snubbers that help to minimize the switching losses. The waveforms of the reference sine wave (60 Hz) and the output current are shown in Fig. 7 and it is seen that they are in phase. The frequency spectrum of the output current is shown in Fig. 8. It is seen that the output current contains very little harmonics.

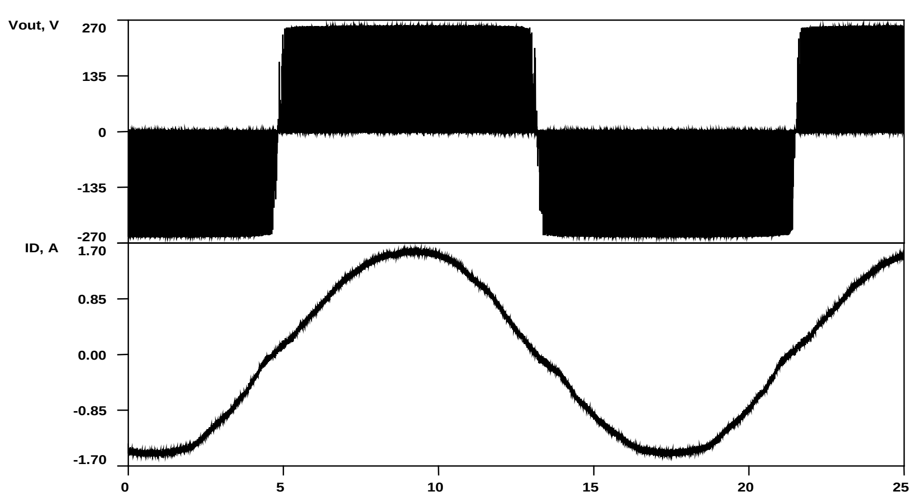

Fig. 6. Waveforms of inverter output voltage (PWM) and output current.

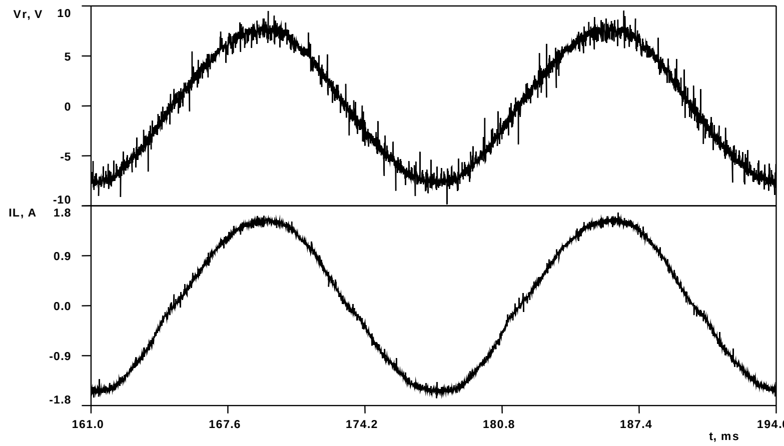

Fig. 7. Waveforms of reference sine voltage and output current.

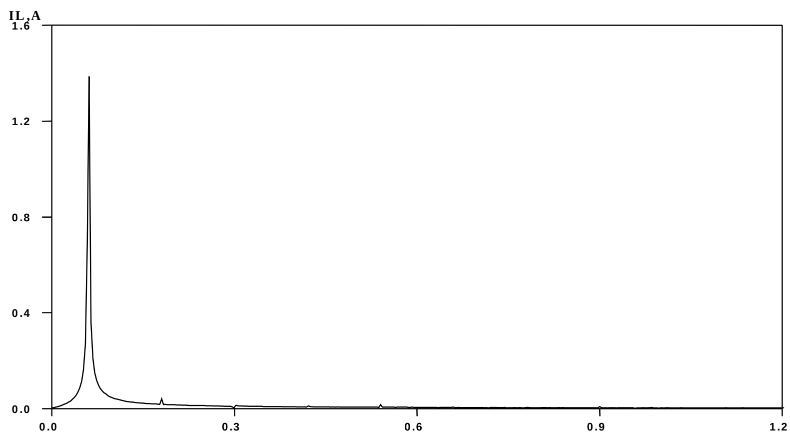

Fig. 8. Frequency spectrum of output current.

5. Conclusions

An economical converter system for converting the output from PV panels into 60 Hz ac voltage is presented. The boost converter helps to provide a regulated dc voltage that is then converted into an ac voltage. The MOSFET switch in the boost converter also provides control signal for maximum power point tracking. The inverter output waveform has very little harmonics and the efficiency is also high.

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