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Experimental Study of Boost Converter Based PV Energy System

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***Abstract*—**This paper proposes an implementation of boost converter for a resistive load using photovoltaic energy as a source. The model of photovoltaic cell and operating principle of boost converter are presented. A PIC microcontroller is used in the close loop control to generate pulses for controlling the converter circuit. To performance evaluation of boost converter, a variation of output voltage of PV panel is done by shading one and two cells.

***Keywords*—**Boost converter, Microcontroller, Photovoltaic power generation, Shading cells.

I. Introduction

RENEWABLE energy sources play an important role in electricity generation. People are finding the benefits of having their own renewable energy system more attractive than they ever had before. Specially, energy from the sun is the best option for electricity generation as it is available everywhere and is free to harness. The merits of solar PV system are cleanness, relative lack of noise or movement, as well as their ease of installation and integration when compared to others. Since the cost of the electric energy from PV panels is still high, the scientific community is working for maximizing the PV conversion efficiency.

The solar energy conversion systems can be connecting to a large electrical transmission grid, or to the storage or auxiliary energy supply. Auxiliary energy may be supplied either as heat before the power conversion system, or as electricity after it. If the photovoltaic route is chosen, extra electricity may be stored, usually in storage batteries, thereby extending the operating time of the system, the storage batteries are ordinary used in the home solar conversion system to satisfy its operation and maximize power tracking purposes. The objective is to collect the maximum possible power from solar panels at all times, regardless of the load [1].

The solar energy conversion system provides the complete utilization of the solar energy impinging on solar collectors by having cylindrical lens type collection panels. The PV combiner box is necessary to combine many wires into a few wires. The DC-DC converter converts a DC input voltage, to a DC output voltage, with a magnitude lower or higher than the input voltage.

DC-DC converters are considered to be of great economical importance in today's society, and are perhaps one of the few electronic circuits that are commonly used in switching power supplies, generally are widely used at home solar systems to produce the desired output power.

This paper presents an experimental study of boost converter based PV energy system. We present in the first a model of one diode of PV module. The operating principle of boost converter is shown in the second part. In third part, the different experimental results obtained are presented.

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II. Modeling of PV Module

PV system directly converts sunlight into electricity. The basic device of a PV system is the PV cell. Cells may be gathered to form modules or arrays. The practical equivalent circuit of a PV module is shown in Fig. 1 [2], [3].

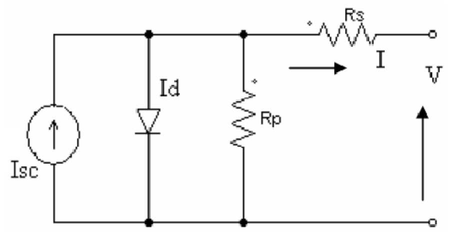

Fig. 1 Equivalent circuit of a PV module

In the equivalent circuit, the current source represents the current generated by light photons and its output is constant under constant temperature and constant irradiance. The diode shunted with the current source determines the I-V characteristics of PV module. There is a series of resistance in a current path through the semiconductor material, the metal grid, contacts, and a current collecting bus. These resistive losses are lumped together as a series resistor (Rs). Its effect becomes very noteworthy in a PV module. The loss associated with a small leakage of current through a resistive path in parallel with the intrinsic device is represented by a parallel resistor (Rp). Its effect is much less noteworthy in a PV module compared to the series resistance, and it will only become noticeable when a number of PV modules are connected in parallel for a larger system. The characteristic equation which represents the I-V characteristic of a practical photovoltaic module is given below.

$$I = I_{pv} - I_0 \left[\exp\left(\frac{V + IR_S}{V_t n} \right) - 1 \right] - \frac{V + IR_S}{R_P} \tag{1}$$

where I and V are the PV cell current and voltage respectively, I_{PV} is the photovoltaic current, Io is the reverse saturation current of diode, Vt = NskT/q is the thermal voltage of the array with Ns cells connected in series, k is the Boltzmann constant (1.3806*10-23J/K), T is the temperature of the p-n junction, q is the electron charge and n is the diode ideality constant. I_{PV} and I_0 are given as follows.

$$I_{pv} = \left\{\left[1 + a\left(T - T_{ref}\right)\right] I_{SC}\right\} \left[\frac{G}{1000}\right] \tag{2}$$

$$I_0 = I_{0T_{(ref)}} \left[\frac{T}{T_{ref}}\right]^{\frac{3}{n_e}\frac{qE_g}{nK}\left[\frac{1}{T_{ref}} - \frac{1}{T}\right]} \tag{3}$$

where "a" is temperature coefficient of Isc, G is the given irradiance in W/m2 and Eg is the band gap energy (1.16eV for Si). The single PV module specification is given in Table I.

TABLE I
PV MODULE ISOFOTON-50 SPECIFICATIONS

Electrical Characteristics	Value
Maximum Power(Pmax)	50W
Voltage at Pmax(Vmp)	17.4V
Current at Pmax (Imp)	2.87A
Open-circuit voltage(Voc)	21.6V
Short-circuit current (Isc)	3.2A

III. Boost Converter

The dc-dc boost converters are used to convert the unregulated dc input to a controlled dc output at a desired voltage level (Fig. 2). They generally perform the conversion by applying a dc voltage across an inductor or transformer for a period of time (usually in the 20 kHz to 5 MHz range) which causes current to flow through it and store energy magnetically, then switching this voltage off and causing the stored energy to be transferred to the voltage output in a controlled manner. The output voltage is regulated by adjusting the ratio of on/off time. This is achieved using switched-mode, or chopper, circuits whose elements dissipate negligible power. Pulse-width modulation (PWM) allows control and regulation of the total output voltage. It is considered as the heart of the power supply, thus it will affect the overall performance of the power supply system [4], [5].

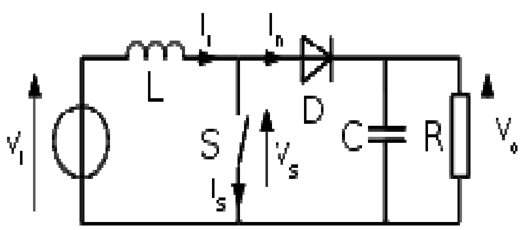

Fig. 2 Boost converter

The dc-dc boost converter shown in Fig. 2 is operated in two modes.

A. Mode 1

When the MOSFET switch is in ON state (closed), the whole circuit will be divided into two loops one at the output side and another at the input side. The closed loop at input consisting of inductor gets charged by the current flowing through the loop during this period. This current will increase linearly till the time the switch is in closed condition. In the same time interval, inductor voltage is also high as it is not delivered to any load but to itself. Diode is off during this mode. The equivalent circuit representation of mode 1 is shown in Fig. 3.

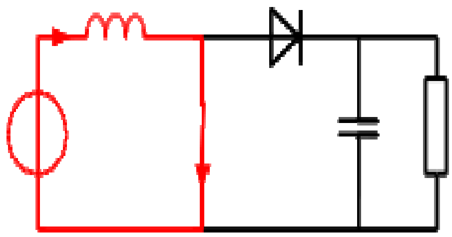

Fig. 3 Equivalent circuit of mode 1

B. Mode 2

When the switch is in OFF state (Open), there will be a closed loop consisting of power source, inductor and RC load. The energy stored in the inductor during ON state is discharged to the RC load circuit through the diode. Thus inductor current is reducing linearly, charging the capacitor at the load side. The equivalent circuit for mode 2 is shown in Fig. 4.

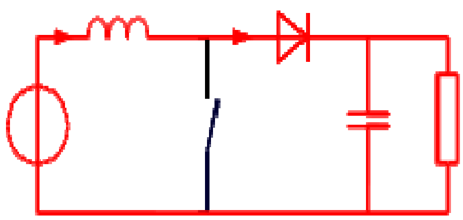

Fig. 4 Equivalent circuit of mode 2

Thus for closed switch time inductor gets charged and capacitor is delivering the required power to the load, and for the opened switch time inductor will discharge supplying the full power to load and charging capacitor simultaneously.

IV. Experimental Results

Fig. 5 presents control and power cards of the boost converter. The components of these cards are presented respectively in Tables II and III.

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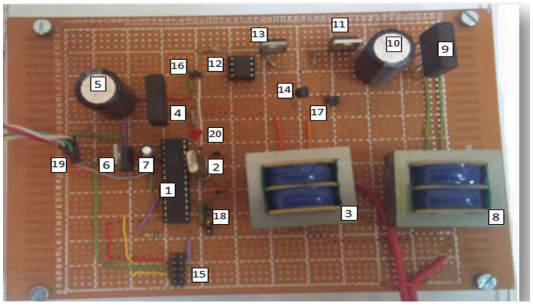
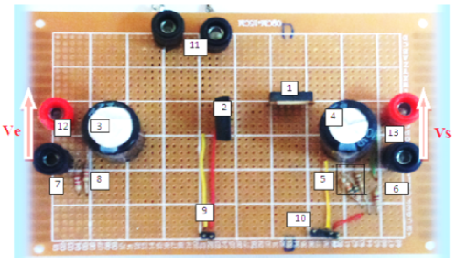


(a)



(b)

Fig. 5 Control and power cards of the boost converter

TABLE II
DIFFERENT CIRCUITS COMPONENT OF CONTROL CARD

Component	Designation	
1	PIC	
2	Quartz	
3	Transformer	
4	Diode bridge	
5	Capacitor 4700 µF	Power supply 0+5 V
6	Regulator 7805	
7	Capacitor 10 µF	
8	Transformer	
9	Diode bridge	Power supply (0 +12V)
10	Capacitor 4700 µF	
11	Regulator 7812	
12	Optocoupleur VO2630	
13	Regulator 7805	
14	Bipolar transistor 2N2222	
15	Connector (PIC programmer)	
16	Connector (output PWM 5V not isolated)	
17	Connector (output PWM 12V isolated)	
18	Connector (arrived Ve and Vs)	
19	Connector (to PC)	
20	Output (Led)	

TABLE III
COMPONENT OF POWER CARD

Component	Designation	
1	Diode(BYT 30P-1000)	
2	Transistor MOSFET IRFP054	
3	Capacitor (4700µF)	
4	Capacitor (4700 µF)	
5	R1=0.88kΩ	Divider 1
6	R2=4.7 kΩ	
7	R3=2.2kΩ	Divider 2
8	R4= 8.2kΩ	
9	Ve, Vs	Connector (to control card)
10	Connector (arrived PWM)	
11	Inductor connection	
12	PV panel connection	
13	Load connection	

Fig. 6 presents cascade composed by PV panel - boost converter - resistor load. The microcontroller PIC16F876A of control card compare the receive output voltage of the boost converter with the reference of Vsref=24V, and send the PWM signal to the transistor MOSFET of power card of boost converter. PC receives through its serial port, the values of the input and output voltages of the boost converter.

Three tests are done to this cascade. The first is to use a PV panel without shading; the second and the third tests are to use a PV panel with shading one and two cells respectively (Fig. 7).

Fig. 8 presents input Ve and output Vs voltages and duty ratio D of boost converter. For time t < 15S (PV panel without shading (Fig. 7 (a)), the input voltage is Ve= 18V, we note that the output voltage Vs=Vsref=24V.

At t = 15S we shading one cell of PV panel (Fig. 7 (b)), we observe that input voltage decrease from Ve= 18V to Ve=15V. Output voltage of boost converter is maintained constant Vs=Vsref=24V.

At t = 25S we shading two cells of PV panel (Fig. 7 (c)), we remark that input voltage decrease from Ve= 15V to Ve= 5V. Output voltage of boost converter is maintained constant Vs=Vsref=24V.

From Fig. 8 (b), we note that the duty ratio D increases in the two cases of shading cells to correct the amplitude of output voltage.

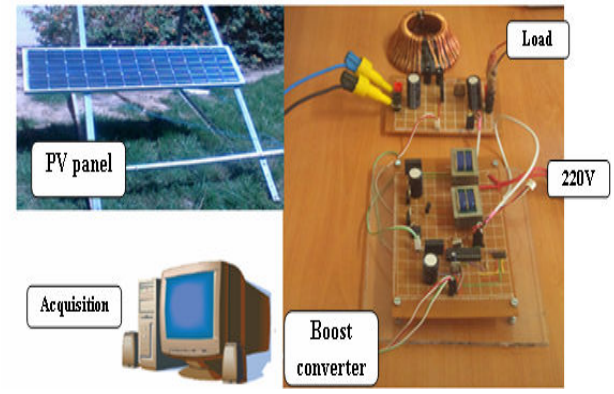


Fig. 6 Cascade of PV panel – Boost converter - Resistor load

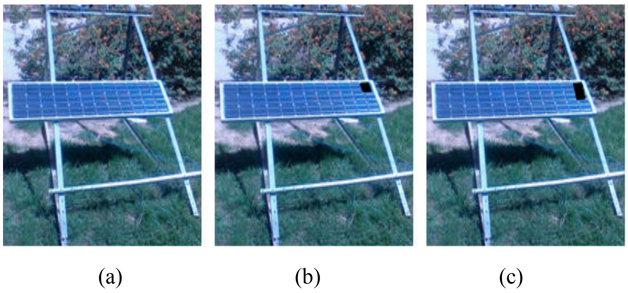


Fig. 7 PV panel without shading, shading one cell, shading two cells

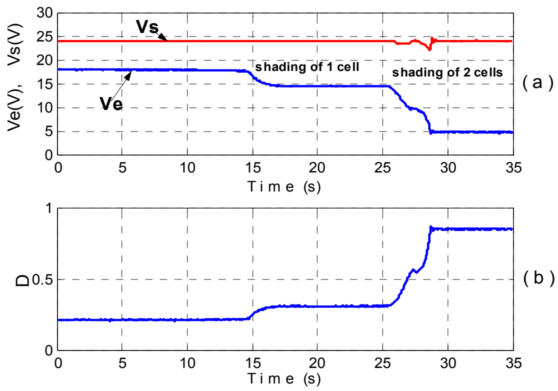


Fig. 8 Input and output voltages and duty ratio D of converter

V. CONCLUSION

This paper presented the experimental work of a Photovoltaic panel feeding a resistive load. A boost converter is used as interface between PV module and the load. A microcontroller PIC16F876A was used to generate the pulses for driving the switch of the boost converter. The input and output DC voltage waveform were shown in the results. These results showed the excellent performance of the boost converter in response to severe changes in output voltage of PV module.

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