Z - H CONVERTER WITH A NEW SIMPLE MPPT FOR PHOTOVOLTAIC POWER GENERATION SYSTEM

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Abstract: *Power electronic converters play the role of power conditioning unit in solar energy to electrical energy conversion for voltage conversion and acquiring the maximum power from the photovoltaic array. Z-H converters are the recently introduced power converters with buck and boost capability. They extend a greater range of output voltage, provide high reliability and reduce ripple and in-rush currents in the circuits. So, they can perform as power conditioning units and render better results compared to conventional power converters. Moreover, Z-H converter does not need the front end diode as compared to the basic Z-source converter without compromising the performance under buck and boost operations. The operating principle with equivalent circuits and the steady state analysis are provided. A 37W solar panel with 36 series connected cells is taken in this work for simulation and implementation. A 300W photovoltaic array is developed from these panels and integrated with Z-H converter. A simple maximum power point tracking technique using perturb and observe algorithm is proposed to extract maximum power from the photovoltaic array at any operating conditions. The complete system is modeled and simulated using MATLAB. Also the proposed concepts are verified experimentally using a laboratory prototype.*

Key words: *maximum power point tracking, photovoltaic, power conditioning, Z-H converter.*

1. Introduction

The increasing energy demand and environmental awareness led to a need for an alternative sustainable source of energy. The use of solar energy is being increased in many applications because of its cleanness environmental concerns, and little maintenance. The power generation from other renewable sources like wind, hydro and wave power also depend on the sun as the primary source. And the power obtained from the solar energy always help to reduce emission of green house gases in the environment and thus reduce global warming. Many applications such as solar power generation, solar vehicle, battery charging, solar water pumping, and satellite power systems have been developed using this technology [1]. Now a days, the direct conversion of solar energy into electrical energy using photovoltaics is growing as an important power generation technology. However, there are two major problems in PV power generation systems: low conversion efficiency, generally around 15%, and solar PV power fluctuates continuously with weather conditions. Furthermore, the I-V characteristic of the solar panel is nonlinear and is varied with solar irradiance and temperature. So, if the solar panel is directly connected to the electrical loads, it is not guaranteed to get the optimal power delivery. Generally, an unique point can be seen on the P-V characteristic curve, called the Maximum Power Point (MPP), at which the whole PV system operates to produce its maximum output power. Thus, the maximum efficiency can be achieved at MPP only.

A DC-DC power converter, called a maximum power point tracker (MPPT), is mostly used as the interface between the solar panel and the load to maintain the operation at the MPP. This is achieved by controlling the voltage or current of the solar panel independently. The MPPT can track and locate the MPP of the PV array for the available solar irradiance and temperature if controlled by an MPPT algorithm in a right manner. Hence, a complete PV power generation system should be equipped with a PV array, a suitable DC-DC converter and an MPPT algorithm.

Many dc-dc converter circuits are proposed in literature for photovoltaic energy conversion application, some of them are deduced from basic non-isolated dc-dc converters, such as buck, boost, buck-boost, cuk converter, and others derived from isolated dc-dc converters, such as fly-back, forward converter [2-4]. Also, there are some half bridge and full bridge converter topologies available for photovoltaic applications. These converters have many significant advantages and can meet the needs of many applications [5,6]. But they suffer two major limitations of short circuit effect and limited voltage gain.

Z-source dc-dc converters are recently introduced to give better results and eliminate the above disadvantages of the conventional converters [7,8]. A bridge type Z-source converter topology named as Z-H converter with additional features has been newly developed [9]. In this paper the operating principle of the Z-H DC-DC converter and its integration with PV array is explained for standalone photovoltaic applications. The popular, perturb and observe MPPT is simplified to crop maximum power from the PV array under varying solar irradiance level and temperature.

2. Z-H DC-to-DC Converter

Fig.1 shows the circuit topology of Z-H converter. The gating signals of *SW2* and *SW3* are complemented to that of *SW1* and *SW4*. But the gating signals for *SW2* and *SW3* can be in phase, or have a phase shift of 180^{o} to reduce the voltage ripples.

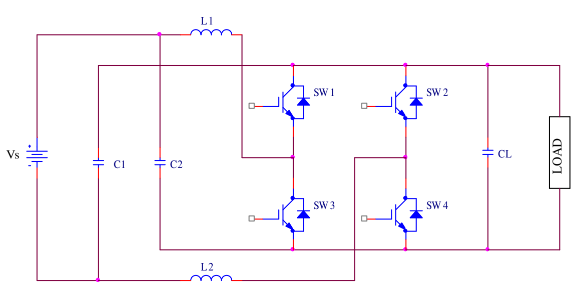

Fig.1. Z-H DC to DC converter topology

The Z-H converter has two operating modes: current charging mode and current discharging mode. During current charging mode, the capacitor *C2* charges the inductor *L1* and the capacitor *C1* charges the inductor *L2* for a duration of T_o. The equivalent circuit of this operating mode is shown in Fig.2. During the current discharging mode with an interval of T_1, *L2* discharges to *C2* and *L2* discharges to *C2*. The corresponding equivalent circuit is shown in Fig.3.If same values of inductors and capacitors are used, then we can write equations (1) and (2).

$$V_{L1} = V_{L2} = V_L \quad (1)$$

$$V_{C1} = V_{C2} = V_C \quad (2)$$

Now, during current charging mode

$$V_L = V_C \quad (3)$$

And from Fig.3, during current discharging mode

$$V_L = V_S - V_C \quad (4)$$

But the output voltage is same during both operating modes and is given as

$$V_o = 2V_C - V_S \quad (5)$$

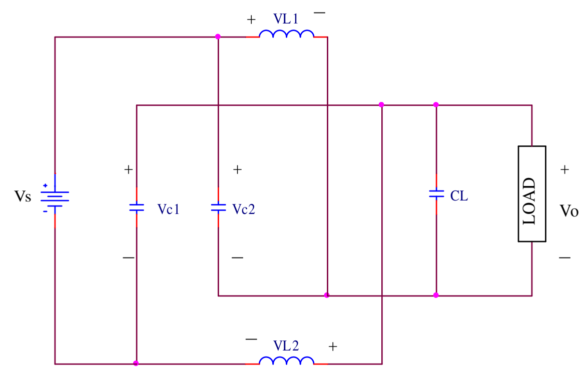

Fig.2. Equivalent circuit of current charging mode

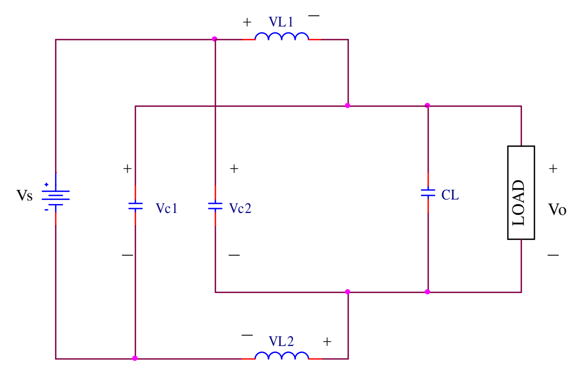

Fig.3. Equivalent circuit of current discharging mode

In steady state condition, the average voltage of the inductor is zero during one switching interval. So from equations (3) and (4), we can write

$$V_C T_0 + (V_S - V_C) T_1 = 0 \quad (6)$$

From equation (5), the capacitor voltage is expressed as

$$V_C = \left(\frac{1-D}{1-2D} \right) V_S \quad (7)$$

where D is the duty cycle for *SW2* and *SW3* and is defined as

$$D = \frac{T_0}{T_0 + T_1} \tag{8}$$

The expression for output voltage can be derived from equations (5) and (7) and is given as

$$V_o = \left(\frac{1}{1-2D} \right) V_S \tag{9}$$

Hence the voltage gain of the Z-H converter is

$$G = \frac{V_o}{V_S} = \frac{1}{1-2D} \tag{10}$$

The output voltage is positive for the duty cycle values from 0 to 0.5, but negative for 0.5 to 1. The graph relating the voltage gain and duty cycle is shown if Fig.4.

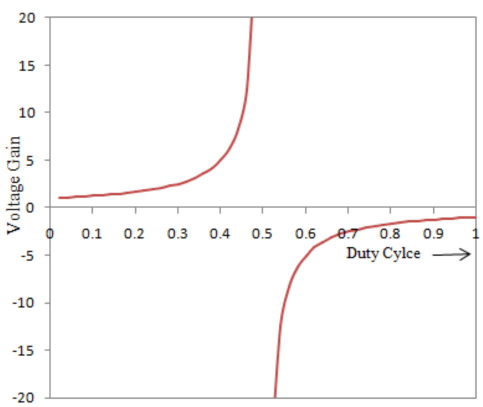

Fig.4. Voltage gain vs duty cycle plot

The output voltage is positive for the duty cycle values from 0 to 0.5, but negative for 0.5 to 1. The graph relating the voltage gain and duty cycle is shown if Fig.4.

The capacitors are designed to reduce the ripple from output voltage. If the allowable voltage ripple is $\%V_r$, the capacitor values are computed from equation (11).

$$C_1 = C_2 = \frac{D(1-D)}{f\, R_L\,(1-2D)\,\%V_r} \tag{11}$$

Similarly based current ripple the impedance source inductors are designed. If $\%I_r$ is the allowable current ripple, the equation (12) is used to calculate the inductor values.

$$L_1 = L_2 = \frac{2D(1-2D)\,R_L}{f\ \%I_r} \tag{12}$$

The efficiency of the Z-H converter is given in equation (13).

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_o\,I_o}{V_s\,I_s} = \frac{1}{1+\dfrac{P_{loss}}{P_{out}}} \tag{13}$$

where P_{loss} is the total losses in the converter and its expression is given in equation (14).

$$P_{loss} = P_{switch} + P_{rL} + P_{rC} + P_{rCf} \tag{14}$$

where P_{switch} is the losses in power switches, P_{rL} and P_{rC} are the losses in impedance network inductors and capacitors and P_{rCf} is the loss associated with filter.

3. Photovoltaic Module and MPPT

A PV cell is a basically PN junction semiconductor junction (diode). The incident solar radiation on a PV cell makes the current flow by photovoltaic effect. This current, known as photo current is proportional to the solar irradiation. The P-V and I-V characteristics of the PV cell is non-linear in nature and they usually vary with solar radiation intensity and temperature and. A one diode electrical model equivalent circuit is used in this work to model the PV cell [10]. This model has a dependent current source, a diode in parallel with this source, a parallel resistor and a series resistor. Many number of these cells are connected in series to form a PV module in order to reach a high voltage at the terminals. A PV array is the complete power-generating unit composed of any number of PV modules.

However, the characteristic of the PV array is non-linear shown in Fig.5, the maximum output power of the PV array exists only at its maximum power point. When direct connection of the PV array a load is made, the operating point is rarely fixed at the maximum power point (MPP). Hence, it is necessary to operate the PV array at its maximum power point to increase the efficiency of the energy conversion system. But, this maximum power point varies with solar irradiance level and temperature. Therefore, the tracking of the maximum power point is a continuous and complicated process.

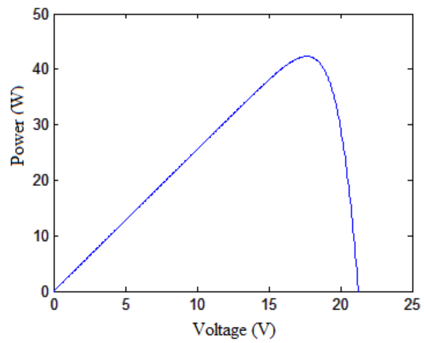

Fig.5. Characteristic of a PV array

Generally, the maximum power point tracking process requires a power converter to be placed between the PV array and the load. The converter will regulate the output current or voltage of the PV array so that maximum energy flows from PV to load. This voltage or current control is achieved by changing the duty cycle of the converter based on the PV output power. A suitable maximum power point tracking system should be employed to adjust the duty ratio of the converter. There are at least nineteen methods of MPPT control algorithms have been developed [11-16]. A simple MPPT method derived from the perturb and observe (P&O) principle is proposed in this work to obtain the maximum power. The new method does not track the PV voltage or current. But it tracks the maximum potential power of PV array that can be taken out through the Z-H converter. For varying climatic conditions, the available power tracking through the converter is achieved by controlling its duty cycle. An initial value of duty cycle is set initially (around 20%) in this algorithm. The instantaneous value of PV power is estimated from the measurements of PV voltage and current. The error in PV power between two consecutive samples determines duty cycle of the Z-H converter and the sign of perturbation. The flow chart explaining the principle of the simple P&O MPPT is shown in Fig.6.

4. Results and Discussions

A commercial PV panel from SOLKAR manufacturer is taken in this work whose model parameters are estimated based on the Shockley diode equations. One SOLKAR panel has 36 series connected polycrystalline PV cells and provides 37W of nominal maximum power. The other parameters are listed in Table 1.

The single diode model of the PV panel is implemented using MATLAB. The solar irradiation and cell temperature are the inputs given to the developed model and outputs are the P-V and I-V characteristics.

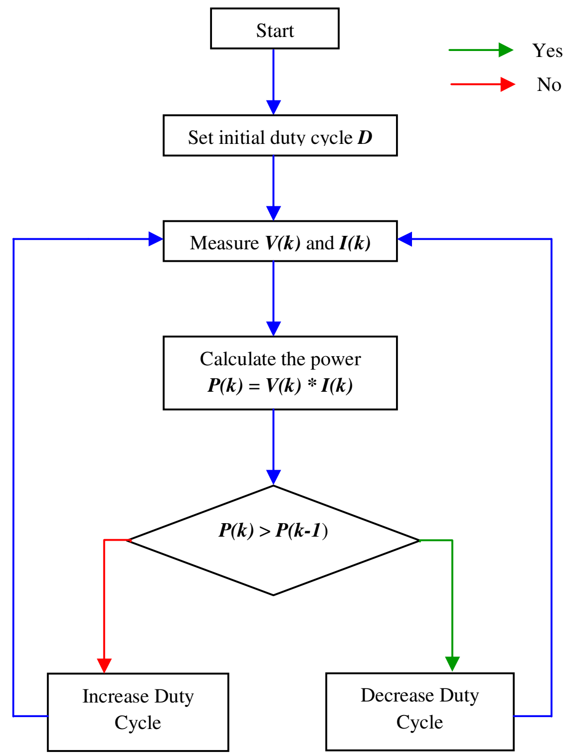

Fig.6. Flowchart of proposed simple P&O MPPT Algorithm

Fig.7 and Fig.8 show P-V and I-V characteristics of the PV panel for various solar irradiation levels. Similar characteristics for various temperatures can also be obtained.

Table 1
Parameters of PV panel

Parameters	Value
Maximum power (Pm)	37.08 W
Open circuit voltage (Voc)	21.24 V
Short circuit current (Isc)	2.55 A
Voltage at maximum power (Vmp)	16.56 V
Current at maximum power (Imp)	2.25 A
Series resistance (Rs)	0.47 Ω
Shunt resistance (Rsh)	145.62 Ω
Diode ideality factor (A)	1.5

A PV array is formed with four series connected PV modules each consists of two parallel SOLKAR PV panels. Therefore, at standard conditions (1000

W/m^2 and 25^o C) the PV array gives the following maximum power and associated voltage and current.

P_m = 4 x 2 x 37 = 296W
V_{mp} = 4 x 16.43 = 65.72V
I_{mp} = 2 x 2.25 = 4.5A

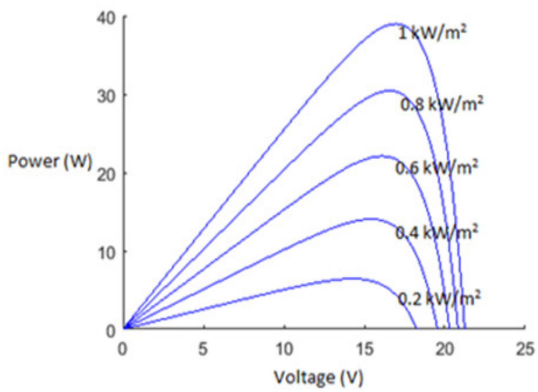

Fig.7. P-V curves of the PV module

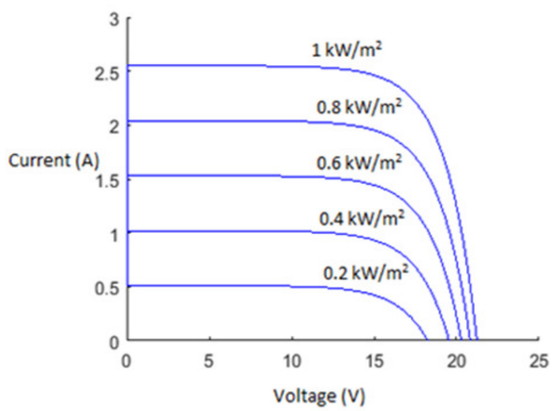

Fig.8. I-V curves of the PV module

The Z-H converter is integrated with the above PV array using MATLAB/Simulink for simulation studies. A laboratory model is also developed with same specifications. Both simulation and experimental readings are obtained at the solar irradiation of 900 W/m^2 and at the temperature of 38^o C. The inductors and capacitors in the Z-H converter are designed and the values are: L_1 = L_2 = 3mH and C_1 = C_2 = 1000µF. The switching frequency is 10 kHz. All the four switches in the converter are IGBTs and are selected based on the current and voltage ratings in the system. The complete system is simulated and the capacitor voltage, the output voltage, and the load current waveforms of converter are given in Fig.9. The PV voltage and the output voltage obtained from the experiment are shown in Fig.10. The simulated and experimental graphs of PV power obtained with the MPPT are shown in Fig. 11 and Fig.12.

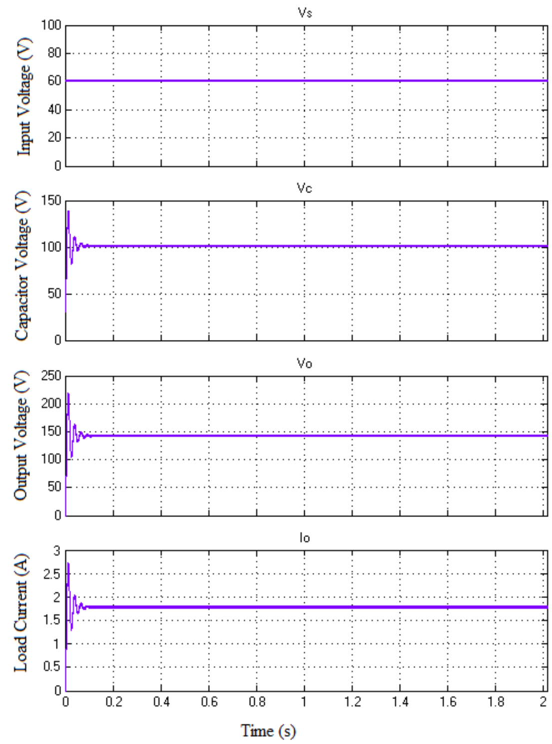

Fig.9. Simulation waveforms of Z-H DC to DC converter

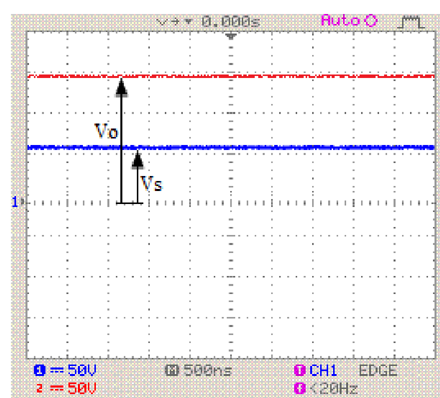

Fig.10. PV voltage and converter output voltage

To calculate the efficiency practically, the following resistances are measured. The dc resistance of impedance source inductors are measured as 0.73Ω. The impedance source capacitors are electrolytic capacitors with measured dc resistances of 0.2 Ω and the resistance of filter capacitor is 0.052Ω. The input power obtained from the PV array at the considered operating condition is 254.4 W. The output power is $V_o.I_o$ = 142.4 x 1.68 = 239.23 W. So the efficiency under this condition is calculated as 94.04%. Fig.13 shows the variation in DC output voltage if the load resistance varies manually under constant solar irradiation.

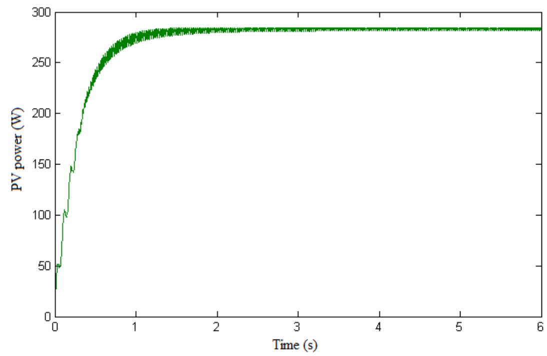

Fig.11. Simulation result of PV power tracking

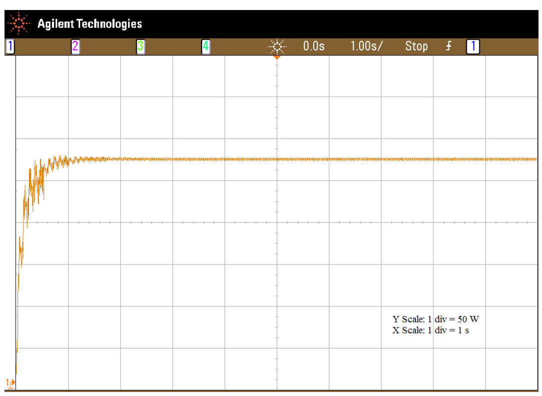

Fig.12. Experimental result of PV power tracking

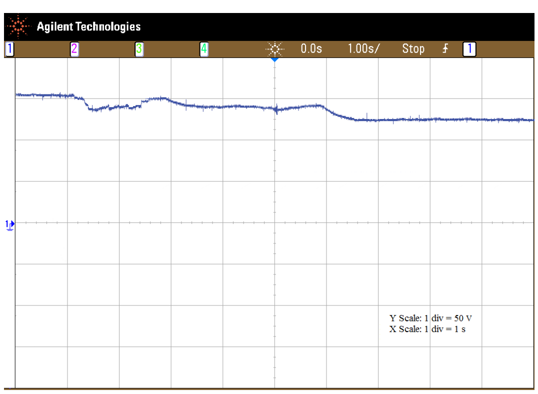

Fig.13. Experimental result of DC output voltage variation

5. Conclusions

A new photovoltaic power conditioning system using Z-H dc-dc converter is developed. The operating principle of Z-H converter and the steady state analysis are explained. The shoot-through states need not be maintained in this converter like Z-source inverter. The maximum power point tracking is achieved with a new simple MPPT technique with high tracking efficiency. The complete system is modeled and simulated using MATLAB/Simulink software. Also the proposed concepts are verified experimentally using a laboratory prototype. From this examination it is found that the usage of Z-H dc-dc converter and the proposed MPPT algorithm for tracking maximum power point is very effective.

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