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Novel Peak-Power Tracking Algorithm for Photovoltaic Conversion System

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Abstract

In this paper, a novel MPPT (Maximum Power Point Tracking) algorithm for power of PV (Photovoltaic) systems is presented using a boost converter for a connected single phase inverter. On the basic principle of power generation for the PV (photovoltaic) module, the model of a PV system is presented. On the basis of this model, simulation of this PV system and algorithms for maximum power point tracking are described by utilizing a boost converter to adjust the output voltage of the PV module.

Based on output power of a boost converter, single phase inverter uses predicted current control to control four IGBT's switch in full bridge. Furthermore, a low cost control system for solar energy conversion using the DSP is developed, based on the boost converter to adjust the output voltage of the PV module. The effectiveness of the proposed inverter system is confirmed experimentally and by means of simulation. Finally, experimental results confirm the superior performance of the proposed method.

Key Words : MPPT algorithm, PV modules.

1. Introduction

PV energy is the most important energy resource since it is clean, pollution free, and inexhaustible. Due to rapid growth in the semiconductor and power electronics techniques, PV energy is of increasing interest in electrical power applications. The main drawbacks of the PV generation system are high initial installation cost and low energy conversion efficiency. In an effort to overcome these problems, a great deal of research, such as controlling MPPT and high conversion inverter topology, has been conducted over the past ten years [1-2].

In order to obtain sufficient dc voltage, the PV modules are usually connected only in series and have no parallel strings, and therefore a significant reduction in total output power of PV system is often observed under unbalanced generation. It is crucial to operate PV energy conversion systems near maximum power point to increase the output efficiency of PV. However, the nonlinear nature of PV systems is apparent the current and power when PV array depend on the array terminal operating voltage. In addition, the maximum power operating point changes with insulation level and

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temperature. Many tracking control strategies have been proposed such as perturb and observe, incremental conductance, parasitic capacitance and constant voltage [3-4].

The general requirements for maximum power point tracking are simple and low in cost, quick tracking under changeable conditions, and small output power fluctuation. A more efficient method to solve this problem becomes crucially important. Full bridge inverters are widely employed in many applications, especially UPS and photovoltaic converter systems, since they are able to supply alternate voltages with adequacy and frequency to such applications.

There are several PWM techniques used with inverter circuits [5]. But the PWM techniques to reduce noise and size of output filter elements need high switching frequency, the commutation losses are high, and they can be greater than conduction losses, resulting in low efficiency. To improve efficiency in high frequency operation, the technique of pulse width modulation for a single phase inverter is shown [6-7].

Objectives of this study are to improve the energy conversion efficiency of a PV system and high conversion inverter topology. In order to solve the problem tracking of maximum power, this paper describes a solar energy conversion strategy which is applied to a grid-connected single phase inverter by the maximum power point of conversion strategy. The maximum power point of tracking is the controlled output power of PV modules, based on a generated circuit control MOSFET switch of two boost converter for a connected single phase inverter with four IGBT's switch in full bridge.

In modulation technique for the inverter, two switches are modulated in high frequency by the PWM signal, while another two switches are maintained on during positive or negative semi-cycle of modulating waveform and operated in low frequency. The circuit configuration and operation characteristics of the proposed inverter system are described, and the effectiveness of the system is verified experimentally and by means of simulation.

2. The Control Algorithm for MPPT

When employing PV generation systems in urban areas, we should take into account the influence of partial shading of the system. As a result, total output power of the series-connected non-shaded and shaded PV modules decreases significantly, because the generation current of the shaded PV module is less than the optimum current for the other, non-shaded PV modules. Fig. 1 shows a series connection of the two PV modules with connecting the bypass diode in parallel. Fig. 2 shows the output voltage versus power characteristic of the photovoltaic module. In case of unbalanced generation, if we assume that the generation current-voltage characteristic curves of each PV module are the difference, the output power-voltage characteristic curves becomes non generation power control (NGPC), conventional power control (CPC) and MPPT as shown in Fig. 2.

In the case of the non-controlled MPPT, the output power-voltage characteristic curve has two peaks. It is crucial to operate PV energy conversion near maximum power point to increase the output efficiency of PV. In the case of the controlled MPPT, the generation point of each PV module which corresponds to the duty ratio of the boost converter and maximum power can be controlled. For a given off-duty ratio, only one peak point is observed in the output power-voltage characteristic, enabling assured MPPT control on the corresponding off-duty condition.

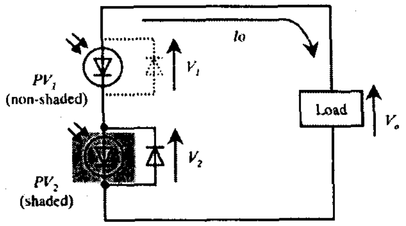


Fig. 1. Series connection of PV modules

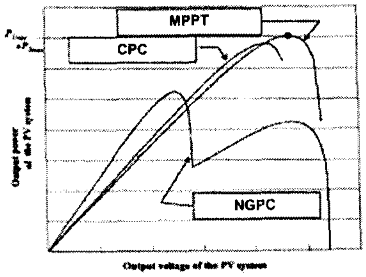


Fig. 2. Output voltage vs power characteristic of PV module

The maximum output power of the system is less than the sum of the maximum generation power of the PV modules, because the PV modules do not operate at peak power simultaneously if the PV modules connected in series differ in optimum current. The nonlinear V-I and P-I characteristics of solar cells are well known [1], [3]. Using the equivalent circuit of Fig. 3, the nonlinear V-I characteristics of PV array can be given as

$$I_{pv} = I_{sc} - I_0\left\{\exp\left[\frac{q(V_{pv}+I_{pv}R_s)}{nkT}\right]-1\right\} - \frac{V_{pv}+R_sI_{pv}}{R_p} \tag{1}$$

where V_{pv} is output voltage of PV, I_{pv} is output current of PV, I_{sc} is the cell short-circuit current (representing isolation level), I_0 is the reverse saturation current, R_s is the series cell resistance, R_p is the shunt cell resistance, k is Boltzmann constant T is PV array temperature (K), q is charge of electron and n is an ideality factor of the p-n junction and depends upon the cell material.

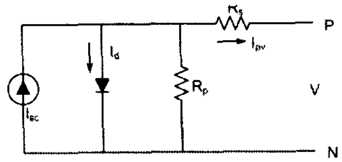


Fig. 3. Equivalent circuits of PV array

Since the series resistance R_s can be ignored, (1) can be simplified as

$$I_{pv} = I_{sc} - I_0\left\{\exp\left(\frac{qV_{pv}}{nkT}\right)-1\right\} \tag{2}$$

$$V_{pv} = \frac{nkT}{q}\ln\left[\frac{I_{sc}+I_0-I_{pv}}{I_0}\right] \tag{3}$$

The output power of the PV array is expressed as

$$P = V_{pv}\times I_{pv} \tag{4}$$

Table 1. Specification of the silicon solar panel

PV power	50 [W]
Open voltage	21 [V]
Current temp. coefficient	$\alpha = 0.002086$ [$A/^\circ C$]
Voltage temp. coefficient	$\beta = 0.0779$ [$V/^\circ C$]
Reverse saturation current	$I_0 = 1.2987\times10^{-4}$ [A]
Short circuit cell current	$I_{sc} = I_{pv} = 2.926$ [A]
Cell resistance	$R_s = 0.0277$ [Ω]
Cell material coefficient	$\lambda(\frac{q}{nkT}) = 0.049$ [$1/V$]
Ideality factor(n)	1.8409

Table 1 is specification of a solar cell module using this paper. Computed (3) and measured V-I as well as P-I characteristics for the Table 1 panel are shown in Fig. 4 for short circuit cell of two levels. This figure illustrates the variations of the cell maximum power point (the maximum of the P-I curves) with respect to short circuit cell of two levels.

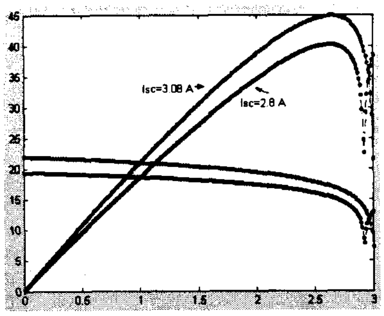


Fig. 4. The V-I and power characteristics of PV module

From (2) and (3), the differential of P to V_{pv} can be expressed as

$$\frac{dP}{dV_{pv}} = I_{pv} + \frac{\Delta I}{\Delta V} \times V_{pv}$$
$$= I_{sc} - I_0\left\{\exp\left(\frac{qV_{pv}}{AkT}\right) - 1\right\} - \frac{qI_0}{nkT}\exp\left(\frac{qV}{nkT}\right) \times V_{pv} \quad (5)$$

From (5), difference error, $e(k)$, can be calculated from maximum power point as

$$e(k) = \frac{\Delta I}{\Delta V} + \frac{I_{pv}}{V_{pv}} = \frac{\Delta P}{\Delta V_{pv}} = \frac{\Delta P}{\Delta I} \quad (6)$$

Where ΔI and ΔV are the incremental of output voltage and current, respectively. Where $\Delta I = I(k) - I(k-1)$, $\Delta V = V(k) - V(k-1)$ and $e(k)$ is input of PI controller. Fig. 5 shows the control algorithm for MPPT which is composed by equation, (6) and block diagrams for inverter control.

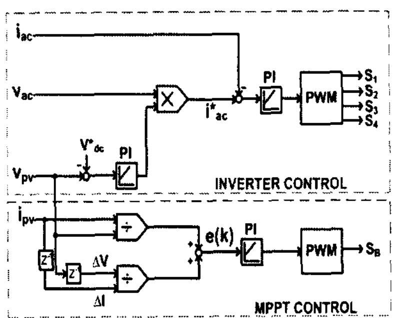


Fig. 5. Proposed a control algorithm for PV module and block diagram for inverter

3. Pv Inverter System

Fig. 6 shows the system configuration of the proposed PV inverter system. This system consists of a two solar array (60W), boost converter, a single phase inverter and DSP (controller).

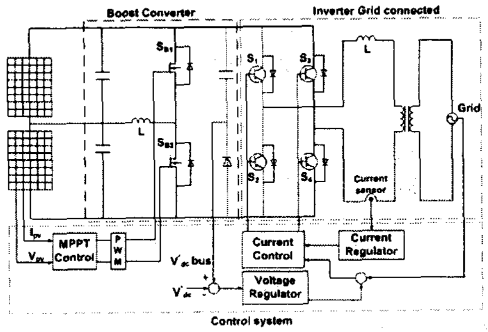


Fig. 6. Grid connected PV inverter system

3.1 Boost converter and MPPT

The power flower of the PV system is controlled by varying the on/off duty cycle of the switch with the boost converter. The average voltages are determined by the (7).

$$\frac{V_{out}}{V_{input}} = \frac{1}{(1-D)} \quad (7)$$

Where V_{out} and V_{input} are the output and input voltage of the converter and D is the duty cycle of the switch S. The input power of the converter is equal to the output power of the converter if the converter is ideal, yielding the following equation.

$$I_{out} = I_{input} \times (1-D) \quad (8)$$

$$R_{input} = \frac{V_{input}}{I_{input}} = \frac{V_{out}}{I_{out}}(1-D)^2 = R_{out}(1-D)^2 \quad (9)$$

From (9), when the load (R_{out}) is fixed, the input resistance R_{input} can be controlled by varying the duty cycle. Therefore, the operating point of the solar cell can be controlled by the duty cycle.

3.2 Single phase inverter [6]

A single-phase inverter is shown in fig. 6, where the inverter circuit is composed of DC source from boost converter, four switch IGBT's, inductance and controller (DSP). The duty cycle of the inverter varies between ± 100[%] and the amplitude of the inverter voltage, V_{invt} is proportional with the dc-link voltage V_{dc} and the duty cycle.

This inverter is used with a three level modulation [2]. The switches S_1 and S_2 are modulated in high frequency by PWM signal, while switches S_3 and S_4 are modulated low frequency by PWM signal.

Inverter circuits converts direct current to alternative current by predicted current control to control current to be sine wave. Fig. 7 illustrates that drive pulse is obtained by comparison between a modulating current waveform and a carrier triangular waveform.

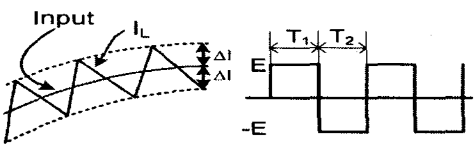


Fig. 7. Modulating and carrier wave forms

From predictive current control, line current, ΔI can defined as

$$\Delta I = I(t_n + T_s) - I(t_n) = \frac{V_s(t_n) - V_{inv}(t_n)}{L} T_s \quad (10)$$

Where, I = inverter line current, V_s= source voltage, V_{inv}= output voltage of inverter. Then V_{inv} can calculated as

$$V_{inv}(t_n) = V_s(t_n) - \frac{L}{T_s}[I(t_n + T_s) - I(t_n)] \quad (11)$$

Current of single phase inverter can be controlled by switch. $S_1 \sim S_4$ The switch S_1 and S_2 are used to shape the waveform which follows the reference current, while the switch S_3 and S_4 are used to correct the polarity of the waveform. Hence, the V_{inv} can be described as

$$V_{inv} = d_k \cdot V_{dc} \quad (12)$$

Where d_k is the duty ratio for switch S_1 and S_2 over one switch period and V_{dc} is the DC bus voltage from the boost converter. The change in line current over one period can be defined as

$$\Delta I = I(t_n + T_s) - I(t_n) = I(t_n) - I(t_n - T_s) \quad (13)$$

From equation (12), (13) can define the duty ratio for the single phase inverter as a function of source voltage (V_s) and the change in line current (ΔI) as

$$d_k = f(V_s, \Delta I) = \frac{1}{V_{dc}}[V_s - \frac{L}{T_s}\Delta I] \quad (14)$$

If the load has inductance with a small resistance, modulation depth (h_s) is always satisfied as

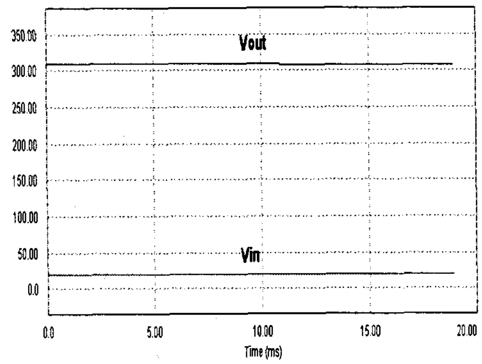
$$|h_s| < \frac{E}{L} \quad (15)$$

4. Simulation and Experiment

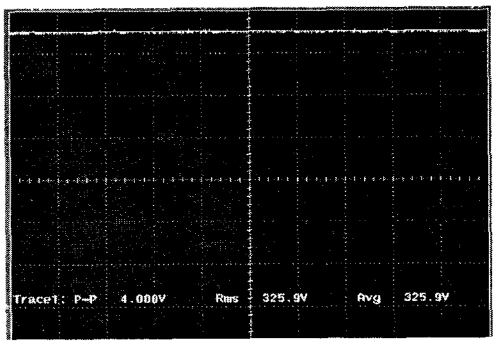
The photovoltaic inverter system of maximum power point tracking using the proposed control algorithm is constructed of a two stage boost converter, a two PV module, full bridge inverter and DSP controller. The switch used was MOSFET and diodes used were the HFA15. Simulation results obtained by using simulation software PSIM6 and using set of parameters, table 2.

Table 2. System parameters

Solar array 60[W]	V_{oc}	24[V]
	I_{sc}	3.54[A]
Boost converter	L_{con}	1[mH]
	C_{con}	4700[μF]
Inverter	AC 전원	220[V], 50[Hz]
	L_{inv}	1[mH]



(a)



(b)

Fig. 8. Experimental output voltage of boost converter

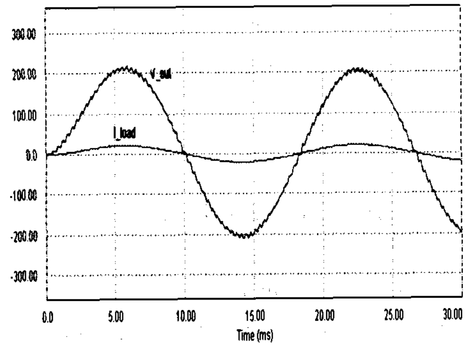


Fig. 9. Simulated output voltage and current of single phase inverter

Fig 8 shows (a) the simulated and (b) the experimental output voltage of the boost converter obtained by using modulation of MPPT control. As can be seen, the experimental results indicate very good operation.

Fig. 9 shows the simulated output voltage and a load current of single phase inverter, using simulation software PSIM6 and using set of parameters, table 1, V_{dc}=320[V] and f_s=20[kHz] The switch and diodes were considered ideal in the simulation.

Fig. 10 shows the experimental results for the inverter drive when the value of L, C and f_s are the same as specified in the simulation. The switch used was IGBT 20F and diodes used were the HFA15.

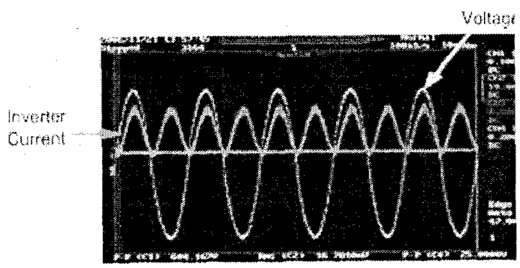


Fig. 10. Experimental output voltage (100V/div) and load current (1A/div) of a liner load

The experimental results show output voltage and load current obtained by using modulation. It can be seen that the experimental results are close to the simulation results.

5. Conclusion

In order to solve the problem tracking of maximum power of a PV system and high conversion inverter, this paper describes a solar energy conversion strategy which is applied to a single phase inverter with four IGBT's switch in full bridge and to a connected MOSFET switch of boost converter. The authors present a novel peak-power tracking algorithm for PV systems. The switches are controlled by a DSP with which a voltage-based and a current-based peak-power control can be easily implemented.

The generation control circuit allows a photovoltaic module to operate at peak capacity, simply by detecting the output power of the PV module. Furthermore, the generation control circuit attenuates low-frequency ripple voltage which is caused by the full-bridge inverter across the photovoltaic modules. The effectiveness of the proposed inverter system is confirmed experimentally and by means of simulation.

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Biography

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