A Research on Photovoltaic Energy Controlling System with Maximum Power Point Tracking

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Abstract

This paper introduces a photovoltaic energy system, controlled by a dc-dc converter and a single-phase bi-directional PWM converter to realize the inversion. A current controlling (MPPT) method of tracking the maximum power point and forcing the system to operate close to this point is used. An artificial neural network is used in the MPPT system and its robustness and insensitivity to the intermittent weather conditions is enhanced. Uc3854 is used as an inversion current controller, which has a high performance in harmonics and power factor.

Keywords: maximum power point tracking, photovoltaic system, power conditioning, neural network

1 Introduction

The photovoltaic system (PV) has attracted much attention due to the oil crisis and environment pollution in recent years [1]-[4]. Its main merits are: 1) inexhaustible; 2) pollution-free; 3) abundant; 4) silent and with no rotating parts, and size-independent electricity conversion efficiency. The main drawback is that: 1) from an operational point of view, a photovoltaic array experiences large variations of its output power under intermittent weather conditions. Those phenomena may cause operational problems at a central control center in a power utility, such as excessive frequency deviations, spinning reserve increase, etc.; 2) its initial installation cost is considerably high. Integrating the PV power plant with other power sources such as diesel backup [2], fuel cell backup [3], battery backup[1],[3] super conductive magnetic energy storage backup are ways to overcome variations of its output power problem. An important consideration in the operation of a photovoltaic system is to achieve the maximum output power by means of continuously adjusting the PV array operating point for the given conditions. Various maximum power point tracking algorithms to fulfill this task are being considered or are currently used in PV applications to obtain as much generation power as possible.

In this paper, battery backup method are proposed and the photovoltaic power is controlled by a boost dc-dc converter and transferred into a single phase converter, providing power sources to the local load systems, or connecting to the existing grid supply. To achieve a unit power factor and optimized the output current, average current control method are used and implemented by a integrated chip uc3854. The main controlling unit is a digital signal processor (DSP). With the DSP-based controller, maximum power point tracking and output current modulation can be achieved rapidly, and artificial neural network is used in the MPPT system and the system robustness and insensitivity to the intermittent weather conditions is enhanced.

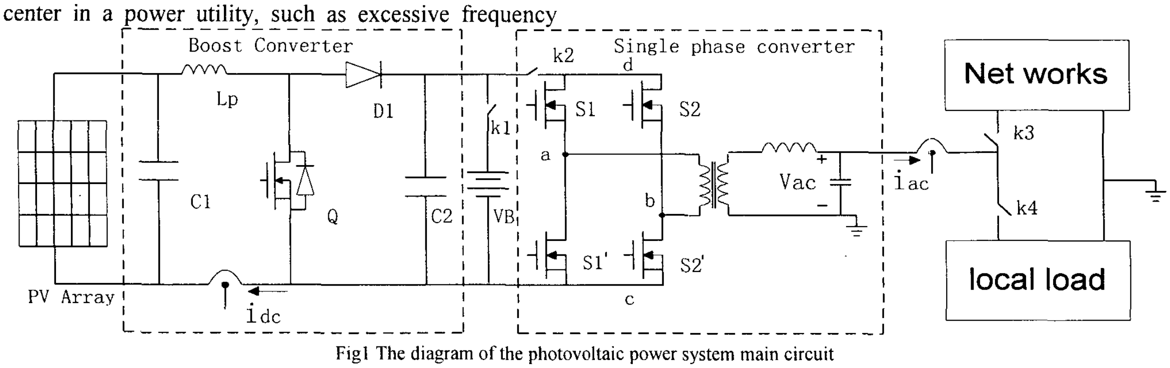


Fig1 The diagram of the photovoltaic power system main circuit

2 Power Topology and MPPT Control

The principle power circuit, shown in up figure, is composed of photovoltaic array, a dc/dc converter, battery and a single-phase bi-directional converter connected with the battery, in which the power can flow from battery to the load and also from utility to the battery. So in a cloudy day or in the night the network can charge the battery. The boost dc/dc converter is used to step up the photovoltaic voltage to the dc link level of inversion. In terms of the states of the four switches the actual operation methods are shown in table 1.

TABLE1
OPERATION METHODS

·	K1	K2	K3	K4
Method1	ON	OFF	OFF	OFF
Method2	ON	ON	ON	OFF
Method3	ON	ON	ON	ON
Method4	ON	ON	OFF	ON
Method5	OFF	ON	ON	OFF
Method6	OFF	ON	ON	ON
Method7	OFF	ON	OFF	ON
Method2b	ON	ON	ON	OFF
Method3b	ON	ON	ON	ON

Method 1: the energy created by the photovoltaic array is transferred to the battery;

Method 2: the energy created by the photovoltaic array and battery are inverted to utility networks;

Method 3: the energy created by the photovoltaic array and battery are inverted to utility networks and local loads;

Method 4: the energy created by the photovoltaic array and batteries are inverted to local loads;

Method 5: the energy created by the photovoltaic array is inverted to utility networks directly;

Method 6: the energy created by the photovoltaic array is inverted to utility networks and local loads;

Method 7: the energy created by the photovoltaic array is inverted to utility local loads.

Method 2b 2: the batteries are charged by the photovoltaic array and the networks;

Method 3b: the batteries are charged by the photovoltaic array and the net works and the local loads are connected to the net grids;

The electric power generated by a solar array fluctuates depending on the solar radiation value and temperature. The PV array that converts the solar insolation into electrical energy consists of several solar cells connected in series and parallel fashion in order to form a PV source capable of delivering desired voltages, currents and its equivalent circuit is shown in Fig. 2. The circuit consists of a light-dependent current source and a group of resistances, including internal shunt resistance, R_{sh}, and series resistance, R_s. The series resistance should be as low as possible and its shunt resistance should be very high, so that most of the available current can be delivered to the load. Considering this assumption, the characteristics of a solar cell are detail concerned the literature[1]. Fig 3 shows the influence of solar insolation in temperature 28°C.To track the maxim power point of the photovoltaic array, MPPT controller is used to form the current reference i^*_{ref} of the dc/dc converter.

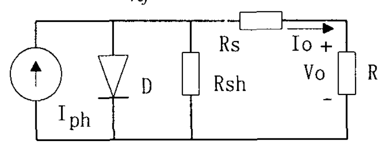


Fig 2. Solar array equivalent circuit

Under a stable insolation, the P-V and I-V characteristics of a roof mounted-PV array are monotonous, and from the character of the system the current reference is given in terms of follows

$$i^*_{ref}(n+1) = i^*_{ref}(n) - Sign[e(n)] * K_{cst} \quad (1)$$

$$e(n) = \frac{P_{PV}(n) - P_{PV}(n-1)}{V_P - V_P(n-1)} \quad (2)$$

where K_{cst} is a negative constant.

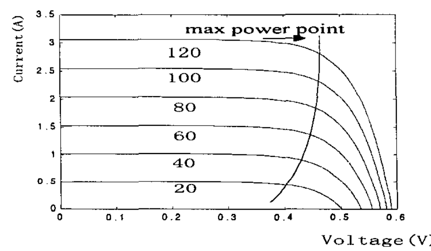


Fig 3. Influence of solar insolation [mW/cm] (28C).

A photovoltaic array experiences large variations of its output power under intermittent weather conditions. It is difficult for the conventional PI modulation system to keep track of the rapid PV power output changes. A artificial neural network modulator[10], shown as Fig. 4, is used to control the dc/dc boost converter own to its robustness. The parameter is given as follows:

$$\begin{cases} v_1(k) = i_{ref}(k) \\ v_2(k) = i_{dc}(k) \end{cases} \quad (3)$$

$$x_i = v_i(k), i = 1,2$$

for the hidden layer, the neuron inputs are given as:

$$v'_j(k) = \sum_{i=1}^{2} \omega_{ij} x_i(k) \qquad j=1,2,3 \quad (4)$$

And outputs of the hidden layer are:
Proportion parameter:

$$x'_1 = v'_1(k) \quad (5)$$

Integral parameter:

$$x_2'(k) = x_2'(k-1) + v_2'(k) \qquad (6)$$

Differential parameter:

$$x_3'(k) = v_3'(k) - v_3'(k-1) \qquad (7)$$

NN output is :

$$v_n'' = \sum \omega_{jh}' x_j'(k) \qquad h = 1 \qquad (8)$$

$$x_h'' = v_h''(k) \qquad (9)$$

The feedback algorithms is:

$$J = \frac{1}{p} \sum_{k=1}^{p} [r(k+1) - y(k+1)]^2 \qquad (10)$$

$$\omega_{jh}'(n_0 + 1) = \omega_{jh}'(n_0) - \eta \frac{\partial J}{\partial \omega_{jh}'} \qquad (11)$$

$$\omega_{ij}(n_0 + 1) = \omega_{ij}(n_0) - \eta \frac{\partial J}{\partial \omega_{ij}}, \qquad (12)$$

Where

$$\frac{\partial J}{\partial \omega_{jh}'} = \frac{\partial J}{\partial y_h} \bullet \frac{\partial y_h}{\partial x_h} \bullet \frac{\partial x_h''}{\partial v_h''} \bullet \frac{\partial v_h''}{\partial \omega_{jh}''} \qquad (13)$$

$$\frac{\partial J}{\partial \omega_{ij}} = \frac{\partial J}{\partial y} \bullet \frac{\partial y}{\partial x_h''} \bullet \frac{\partial x_h''}{\partial x_j'} \bullet \frac{\partial x_j'}{\partial v_j'} \bullet \frac{\partial v_j'}{\partial \omega_{ij}''} \qquad (14)$$

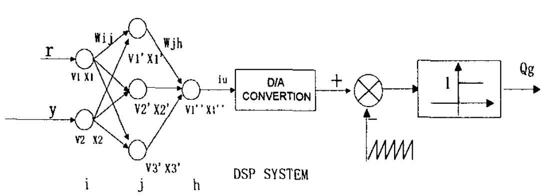


Fig4 the control diagram of the dc/dc boost converter

And Qg is the gate signal to the MOSFET Q shown in Fig 1.

3 Control of the Single Phase Converter

To decrease the harmonics and improve the power factor, a current inner loop is used in inversion stage, named average current mode control method. The current error is amplified and compared to a large amplitude saw tooth (oscillator ramp) at the PWM comparator inputs. Average current tracks the current program with a high degree of accuracy, enabling less than 3% harmonic distortion to be achieved with a relatively small inductor. In fact, average current mode control functions well even when the mode boundary is crossed into the discontinuous mode at low current levels. The outer voltage control loop is oblivious to this mode change.

When the inverter transform the energy to the net grid, the current loop is programmed by the rectified sinusoidal signal which is synchronized with the grid voltage so that the output to the grid will appear to be resistive. By changing the average amplitude of the current programming signal, the output power is controlled. An integrated circuit chip uc3854 [8], [9] is used here shown as Fig 6. An analog multiplier in the chip creates the current programming signal by multiplying the rectified line voltage with the outer loop error amplifier so that the current programming signal has the sinusoidal shape. and a monopole modulation methods is used that the gate signal wave form is shown as Fig.5

The current programming signal must match the rectified sinusoidal as closely as possible to maximize the power factor. If the outer loop bandwidth were large it would modulate the input current to keep the output voltage constant and this would distort the input current horribly. Therefore the outer loop bandwidth must be less than the input line frequency. But the output voltage transient response must be fast so the voltage loop bandwidth must be made as large as possible.

The output power varies with the i_{ref} given by the DSP controller. The current feedback modulator change the feedback current gain to change the output current, shown in Fig 6. And in fact the modulator is also a pulse width modulator.

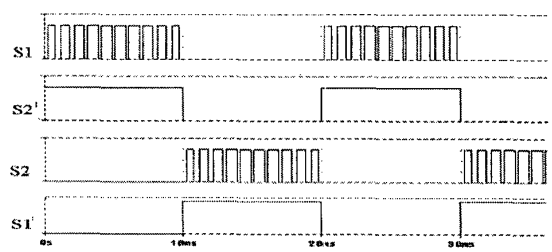


Fig 5 the unipolar SPWM gate signal waveform of MOSFETS

Because the out put of the voltage error amplifier is divided by the square of the dc power line voltage, the output of the voltage error amplifier, then, controls the input power level of the inverter. This can be used to limit the maximum power that the circuit can draw from the power line. If the power line voltage is clamped at some value that corresponds to some maximum power level, output of the error amplifier will not draw more than that amount of power from the line as long as the input voltage is within its range.

When the inverter is connected with the local load, the current loop is programmed by the rectified output voltage that created by the DSP to get a stable output.

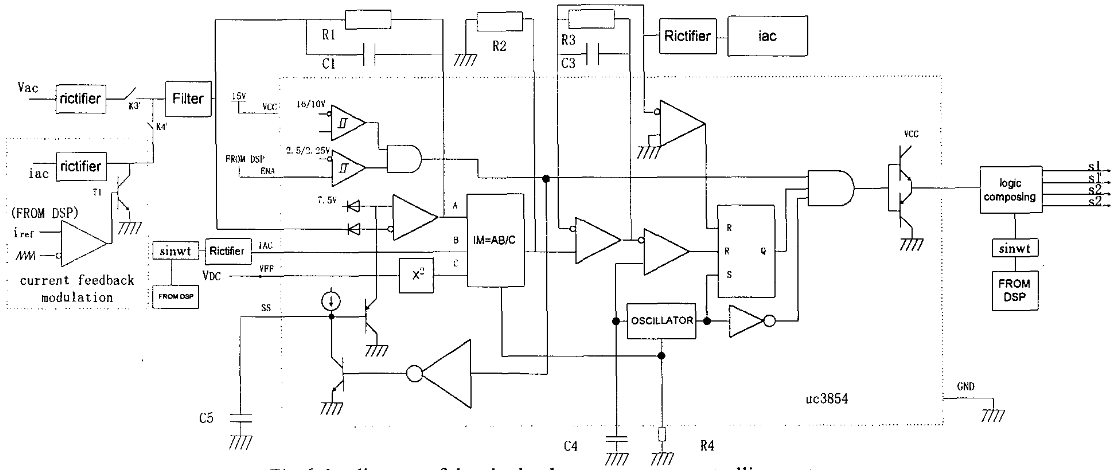


Fig 6 the diagram of the single phase converter controlling system

4 Simulation and Experimental Results

A 4kw-prototype converter has been built. And the algorithm is realized by a DSP. The experimental photovoltaic array is 300-W. Some experiments have been done and shown as follows for operation methods 1 to methods 7.

Photovoltaic array output power and voltage locus is showed in Fig7.and the maximum power point is about 300 W. the result show that the MPPT is achieved.

Fig 8(a), (b) illustrate that in the system, under different insolation conditions the NN control modulator works more robustly and there is any DC output oscillation in a PID controlled modulator converter. The simulation parameters are specified power, 0.5 specified power and 0.1 specified power respectively.

The stable state current waveforms and the voltage curve show that the harmonics is optical and unit power factor is achieved. Fig 9 illustrates the unit power factor in the operation method 2.

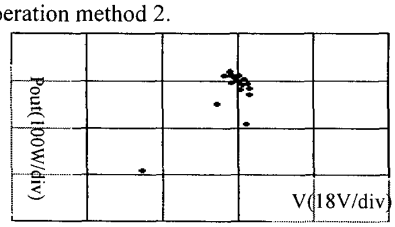
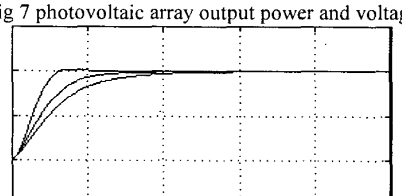


Fig 7 photovoltaic array output power and voltage


(a)output of NN control boost converter

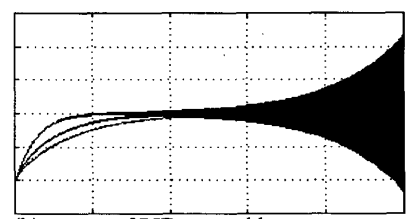
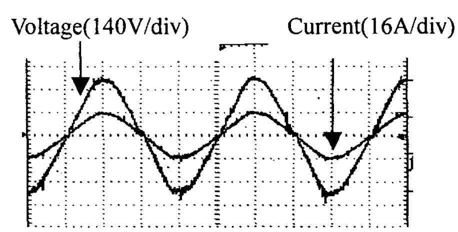

(b) output of PID control boost converter

Fig8 Comparison of NN and PID modulator



(time:5ms/div)

Fig 9 Experimental phase voltage waveform and current waveform

5 Conclusion

The paper has proposed a PV control system in which a dc/dc converter and a single-phase converter are used. The maximum power point tracking algorithms is used to increase the efficiency of the PV system by a current control method. Artificial neural network fits for the MPPT system and it shows robustness and insensitivity to the intermittent weather conditions. Average current mode control method can be realized in the full bridge converter by uc3854, and unity power factor is achieved in operation of connecting to net grid.

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