Control for Photovoltaic Grid-Connected Generation System

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Abstract: Firstly, this paper introduces the operational principle and performance characteristic of photovoltaic cells, and describes the equivalent circuit and mathematical model. Secondly, this paper introduces several traditional MPPT control algorithms. Based on the maximum power of the fast track process and stability, an improved intermittent scan method is designed to implement the maximum power output in the photovoltaic grid-connection generation system and improve system performance and maximum power point tracking speed. Finally, this dissertation analyses the targets of grid-connected inverter control and studies the control strategies.

Keywords: grid-connected inverter; photovoltaic; maximum power point tracking (MPPT)

太阳能光伏发电系统并网控制

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摘　要：首先对太阳能电池的工作原理及工作特性进行介绍，详细分析太阳能电池工作的等效电路和数学模型；其次，介绍了几种最大功率点跟踪的控制方法；最后，分析光伏并网逆变器的控制目标，研究其控制策略，并设计了基于 SPWM 的电压/电流型并网逆变器控制的控制系统数学模型。

关键词：并网逆变器；光伏；最大功率点跟踪

1 Introduction

With the situation of energy resource crisis and the problem of circumstance pollution become more and more severity,exploitation and utilization the clean and regeneration energy resource is imperative.Solar energy is one of the most clean,practical and large scale regeneration energy resources.The whole world focuses on the use of Photovoltaic (PV).The PV grid-connected system will be the main utilization of solar energy，so it will be developed rapidly. Furthermore,with the development of high-performance Digital Signal Processor (DSP)chip，it is possible that some most advanced control strategies can be used to the PV grid-connected system.Under this background，the dissertation deeply researches the PV grid-connected inverter.It has significance to research on the PV grid-connected system.

2 The operational principle and performance characteristic of photovoltaic cells

The operational principle of photovoltaic cells bases on the photovoltaic effect of semiconductor PN junction. The so-called photovoltaic effect, that is, when the object is irradiated by light, electromotive force and electric current will generated with the changes of charge distribution in the object.When sunlight or other light irradiates semiconductor PN junction, the voltage which was commonly known as photovoltaic voltage will be generated between the two sides of the PN junction, so that the short-circuit current will be generated when the PN junction in short circuit. The phenomenon is well-known photovoltaic effect.

2.1.Equivalent Circuit and Mathematical Model of photovoltaic cells

In order to describe the working status of the cells, an equivalent circuit offen is used to simulate the cells and load systems. The equivalent circuit of solar cells is shown in Fig.1, where I_{ph} represents photocurrent, I_d denotes the current through diode, R_{sh} is parallel resistance, R_s represents series resistance,I represents load current,and V denotes load voltage.

From the equivalent circuit of solar cells, the voltammetric (I-V) equation can be obtained, which is:

$$I=I_{ph}-I_0\left\{\exp\left[\frac{q\left(V+IR_s\right)}{\alpha KT}\right]-1\right\}-\frac{V+IR_s}{R_{sh}} \tag{1}$$

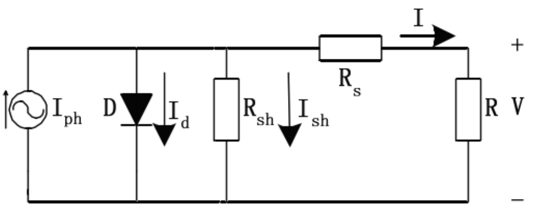

Figure 1. equivalent circuit of solar cells

Where I_{ph} represents photocurrent, I_0 denotes diode reversal saturation current (typically for photovoltaic cells, its order of magnitude as 10^{-4} A),q is electronic charge which is 1.6×10^{-19} ,V represents output voltage, α denotes ideality factor of P-N junction which values 2.8 when the temperature T = 300K,K is the Boltzmann constant which as 1.38×10^{-23} J/K , T is absolute temperature, R_s represents series resistance which is lower resistance, less than 1,and R_{sh} is parallel resistance which is high resistance, on the magnitude of $K\Omega$.

2.2.The I-V output characteristics of solar cells

The I-V characteristics of solar array is one of the most important technical data in system analysis. Fig.2 shows that it has a strong non-linear nature.The relation of the maximum power and voltage, current can be shown from the graph.

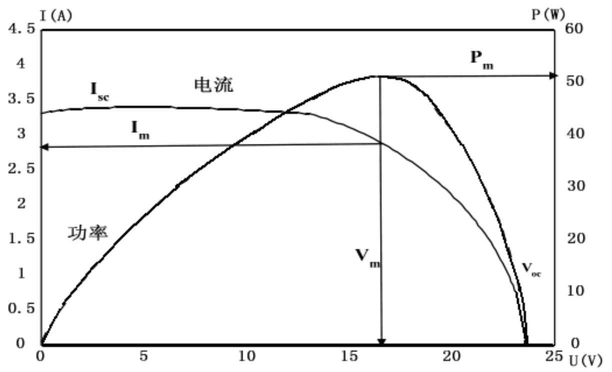

Figure 2. the I-Vcharacteristic of the solar arrays

Where short-circuit current I_{sc} represents the maximum output current at a given temperature and sunshine, open circuit voltage V_{oc} represents the maximum output voltage at a given temperature and sunshine, I_m represents the current of the maximum power point at a given temperature and sunshine, V_m represents the voltage of the maximum power point at a given temperature and sunshine, P_m represents the possible maxmum output power from the solar array at a given temperature and sunshine. The maxmum power in the maxmum power point is :

$$P_m=I_mV_m \tag{2}$$

3 The principle of maximum power point tracking

In the solar photovoltaic system, solar cell is the most basic segment, it need to improve the conversion efficiency of solar cells to improve the efficiency of the whole system, so that output power will be the maximum power. However, the I-V characteristics of solar cells has non-linear character, and it changes with the change of external environment (temperature, sunlight intensity), so that it's not easy to control. But, there must be a maximum power point at a particular temperature or sunlight intensity.It is shown from Fig.2 which is the I-Vcharacteristic of the solar arrays. Therefore, maximum power point tracking(MPPT) research is essential. The the process of Maximum power point tracking(MPPT) is essentially a self-optimizing process, that is, it controls the maximum output power by controlling the solar battery terminal voltage. Fig.3 shows the characteristics of the output power of the solar array. From the chart, we can see that, when solar cells works on the left side of the maximum power point voltage, its output power will increase with the increase of battery terminal voltage, when the solar cells works on the right side of the maximum power point voltage, its output power will decrease with the rise of battery terminal voltage. In addition, the maximum power point tracking (MPPT) control also can determine which work area it is running according to the solar voltage , current values and power values which are collected first, then control of tracking will be implemented according to different work orders within the different work area. But it must pay attention to the affect of sunlight intensity and environment on solar array open circuit voltage and short circuit current.

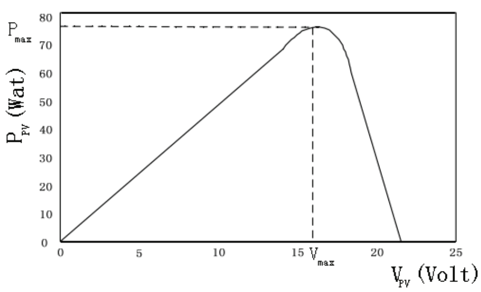

Fig.3. the characteristics of the output power of solar array

3.1. Constant Voltage Tracking(CVT)

By analysis of the characteristics of the output power of solar array with the different sunlight intensity,it can be seen that, the maximum power points almost distribute on both sides of a vertical line when the sunlight intensity is high. Therefore, the maximum output power of photovoltaic cells could be considered to be put out when the voltage is a point for a constant voltage, which greatly simplifies the MPPT control system design. Thus, it comprise a type of MPPT control by constant voltage tracking(CVT) method. In this way, we just need to get the maxmum output voltage value from the manufacturers and then put the output voltage at the maximum output voltage . This method is simple to control the tracking, easy to be implemented, higher reliability, but poor control accuracy especially for the areas where temperature changes

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greatly between the day and night and in seasons. In addition, this approach ignores the affect of the temperature on the open circuit voltage of photovoltaic cells, lacks accuracy.

3.2 Increamental Conductance Algorithm (ICA)

Incremental conductance algorithm is also one commonly method used to MPPT control. Through the output power of solar array, it can conclue out that the slope at the the maxmum power point P_m is zero,so there is that:

$$P_{max}=VI \tag{3}$$

$$\frac{dP}{dV}=I+V\frac{dI}{dV}=0 \tag{4}$$

$$\frac{dI}{dV}=-\frac{I}{V} \tag{5}$$

Equation(5) is the constraint for the maximum power point, that is, when the variable quantity of the output conductance is equal to the negative of the output conductance, the solar array works on the maximum power point. If they are not equal, it need to determine dP/dV is more than zero or less than zero.

The greatest advantage of this tracking method is that, its output voltage can follow the changes in a smooth manner when the solar intensity has changed, and its voltage fluctuation is less than perturb and observe method, but its algorithm is more complicated and it takes considerable time to perform A/D conversion in tracking process, which the will cause considerable difficulties on the control with microprocessor.

3.3. Intermittent Scan Method

This approach is based on the constant voltage tracking (CTV) method, just replace the V_m value from the company office with a value obtained by regular scan. The concept ot this method is that,we scan the solar array voltage in regular,and record the current value according to the different voltage at the same time,and then easily find out the maximum power point by comparison of output power on different points of the solar array, without the searching all the time.

This intermittent scan method need only milliseconds (5-10ms)to determine, while the time of the regular scan could extend to second grade. We should calculat the maximum power and the mathching voltage V_m with a specific light intensity and temperature by scanning and control the output of the Pulse Width Modulation(PWM), so that we can make the system work on the point according to the V_m . This approach generally does not cause swing.

4 MPPT of the photovoltaic grid-connnected inverter

To find out the best MPPT control method, we should not only compare the advantages and disadvantages of each method, but also select the optimal algorithm of the topology and load characteristics of the photovoltaic system according to the actual applications. We assume that the system uses two grid-connected inverter, MPPT is implemented at the first stage of transformation, and the control of connecting grid and other controls are implemented at the second stage of transformation, so that we reduce the complexity of controls and increase the accuracy of each stage control.

4.1 Targets of Photovoltaic Grid-connected inverter control

Photovoltaic system is a device which transforms direct current (DC) from the solar panels into alternating current(AC) and then supply power to the power system. It is actually an active inverter system. The target of the photovoltaic grid-connected control is that: control the output alternating current from the inverter to be the stable, high-quality sine wave and the AC must be the same frequency, phase with the net voltage. Therefore, we chose grid-connected inverter output current to be the amount charged . The equivalent circuit of the voltage and current under grid-connected is shown in Fig.6 and the vector graph of voltage and current under grid-connected is shown in Fig.7. In the figure, V_a represents AC voltage in the inverter circuit, and V_{net} denotes the net voltage. Because of the output filter inductor L in the grid-connected inverter, there will be phase difference between the AC voltage in the inverting circuit and the grid voltage, that is, in order to meet the relation on the phase between the output current and grid voltage, the inverter output voltage will lag behind the grid voltage.

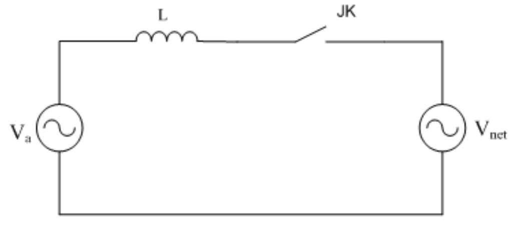

Fig.4. the equivalent circuit of the voltage and current under grid-connected

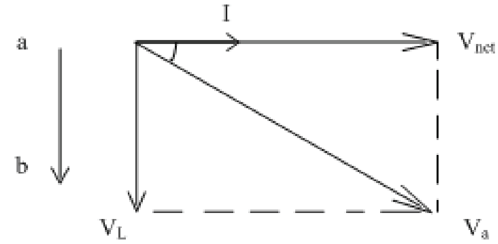

Fig.5. the vector graph of voltage and current under grid-connected

In the photovoltaic grid-connected generation system, grid-connected inverter should work in the active inverting state and its power factor should be 1 in order to avoid polluting the grid. When the grid voltage V_{net} is certained, if regulate the V_L along the ab direction, we can see the inductance voltage vector V_L lag 90°behind the grid voltage vector V_{net}, and the output current I lead 90°before the inductance voltage vector V_L, so that the output current I and grid voltage V_{net} are in the same phase.The grid-connected output without pollution is implemented.

4.2 Control Strategies of Photovoltaic Grid-connected Inverter

Photovoltaic grid-connected inverter control part is the key point of the inverter design, and using the advanced control technology is essential key technique to improving the inverter performance. As the high frequency of power electronic devices and the increase of the computing speed of the microprocessor, especially with the emerge of high-performance digital signal processor (DSP), it is possible to use advanced control strategies into the photovoltaic grid-connected control.

At present,the program widely used in the photovoltaic grid-connected generation system is that:firstly,transform the solar energy into electric energy form;secondly,adjust the electric energy into DC voltage which meets the requirements of full-bridge SPWM inverter;finally,convert solar energy back to the AC power system though the full-bridge SPWM inverter. The leading section in the whole system is the inverter,in which we use the SPWM inverting technology. In order to reduce the grid-connected devices'impacts in the grid-connected operating, the network inverter should meet the following conditions according to qualifications of granted cycle parallelling of the power system:

- Inverter output voltage should be about equal to the grid voltage, and the general error should be within 10%;
- Inverter output frequency should be close to the grid frequency, and the general frequency error should be no more than 0.4Hz;
- Inverter output voltage and grid voltage should be the same phase, and the general phase error should be no more than 10 degrees.

Therefore, the control system need to accomplish the following tasks:

- Collect analogues such as DC,AC voltage and current used to monitor and control;
- Provide the SPWM signals whose pulse width and frequency can be changed from time to time to the power device driver;
- Detect the frequency of the grid voltage and the phase should be digital phase-locked;
- Receive the protection signals such an over-current, over-voltage, and implement automatic protection.

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