Modeling and Analysis of Grid-Connected Inverter for PV Generation

Neng Cao
School of Automation
Wuhan University of Technology
Wuhan, 430070, China
E-mail: whutcn@163.com

Yajun Cao
Electronics and Information School
Yangtze University
Jingzhou, 434023, China
E-mail: caoyajun17101@163.com

Jiaoyu Liu
School of Automation
Wuhan University of Technology
Wuhan, 430070, China
E-mail: liujiaoyu_2006@163.com

***Abstract*—In order to improve the efficiency of photovoltaic generation as well as the power quality, grid-connected inverters for PV generation research was carried out for photovoltaic maximum power point tracking. Based on some current studies on the incremental conductance method, an advanced incremental conductance control algorithm was proposed, which can track maximum power point rapidly and accurately. The oscillation phenomenon, which exists near the maximum power point, was improved at a great extent, so to the efficiency of photovoltaic cells generation electricity. The inverter control system has an advantage in its high speed and flexibility by applying advanced control algorithm. And the source harmonic current is remarkably reduced. In addition, the power factor is enhanced and the power quality is improved. Finally, according to the principle of inverter control system and based on the analysis on the mathematical model of photovoltaic inverter, a simulation model of that is established based on MATLAB/SIMULINK.**

Keywords-PV; grid-connected; inverter; MPPT; incremental conductance method; MATLAB

I. INTRODUCTION

Along with the development of global industrialization, human's energy demand is increasing day by day. In accordance with the above case, since the mid-twentieth century, countries all over the world are taking measures, which aimed at improving energy efficiency and advancing the structure of the energy to solve the energy crisis and protect the environment[1]. The development of new energy and renewable energy, for purpose of achieving sustainable development, is an urgently problem to be solved. Among them, the solar energy is the focus of the new energy development and utilization.

Photovoltaic generation is recognized as one of the most technical contents and the prospects of technology, due to its predominance over environmental protection and sustainability. Inverter technology is the key technology of photovoltaic power grid. As the interface device between solar cells and the power grid , the grid inverter play a vital role in the new energy development and utilization, affecting the economics and reliability of the photovoltaic (PV) grid generation system directly. Therefore, improve the photovoltaic (PV) grid inverter work performance and transmission quality becomes the focus of research in recent years [2]. According to the photovoltaic array mathematical model, a PV grid inverter simulation model based on MATLAB is established. Having improved the traditional control algorithm, we put forward a new design scheme of the model, upon which the experiment of the maximum power point tracking and photovoltaic (PV) grid inverter simulation is realized.

II. PV ARRY SIMULATION MODEL

Photovoltaic array output is nonlinear, and there's a strong correlation between the output power and light intensity, environmental temperature. The PV cells terminal voltage changes according to light intensity and environment temperature, so the output power is changed; solar cell equivalent mathematical model [3-4] are as follows:

$$I = I_{ph} - I_p - I_{D1} - I_{D2} \tag{1}$$

where I is the PV cells terminal current when light is shone on them, I_{ph} is photocurrent, I_{D1} and I_{D2} are the current through the diodes, respectively, I_p is the leakage current.

$$I_p = \frac{V + IR_s}{R_p} \tag{2}$$

$$I_{D1} = I_{O1}(\exp[\frac{q(V + IR_s)}{kT}] - 1) \tag{3}$$

$$I_{D2} = I_{O2}(\exp[\frac{q(V + IR_s)}{AkT}] - 1) \tag{4}$$

where V is the PV cells terminal voltage when light is shone on them, R_s is the equivalent series resistance, R_p is the equivalent parallel resistance, I_{O1} and I_{O2} are the diode reverse saturation current, A is diode ideality factor, q is the electronic charge, k is the disposal of Boltzmann's constant, T is the temperature, E is the solar radiation intensity, N_s is The number of series cells, N_p is the number of shunt cells.

Substituting the three equations (2) (3) (4) into (1) establishes the equation as

$$I = I_{ph} - I_{O1}(\exp[\frac{q(V + IR_s)}{kT}] - 1) - I_{O2}(\exp[\frac{q(V + IR_s)}{AkT}] - 1) - \frac{V + IR_s}{R_p} \tag{5}$$

The solar cells terminal current of the PV array can be expressed as

$$I = N_p\{I_{ph} - I_{O1}(\exp(\frac{q[(V / N_s) + (I / N_p)R_s]}{kT}) - 1)$$

$$-I_{O2}(\exp(\frac{q[(V/N_s)+(I/N_p)R_s]}{AkT})-1) - \frac{(V/N_s)+(I/N_p)R_s}{R_p}\} \quad (6)$$

Some parameters in the above formula are shown as

$$\begin{cases} I_{ph}=K_0E(1+K_1T) \\ I_{O1}=K_2T^3\exp(\frac{K_3}{T}) \\ I_{O2}=K_4T^{3/2}\exp(\frac{K_5}{T}) \\ A=K_6+K_7T \\ R_s=K_8+\frac{K_9}{E}+K_{10}T \\ R_p=K_{11}\exp(K_{12}T) \end{cases} \quad (7)$$

Where $K_0=-5.729\times10^{-7}$, $K_1=0.1098$, $K_2=44.535$, $K_3=-1.264\times10^4$, $K_4=11.800$, $K_5=-7.317\times10^3$, $K_6=2.000$, $K_7=0, K_8=1.070$, $K_9=1.613\times10^3$, $K_{10}=-4.470\times10^{-3}$, $K_{11}=2.303\times10^6$, $K_{12}=-2.812\times10^{-2}$.

According to the mathematic model above, a simulation model of PV array is established as shown in Figure 1.

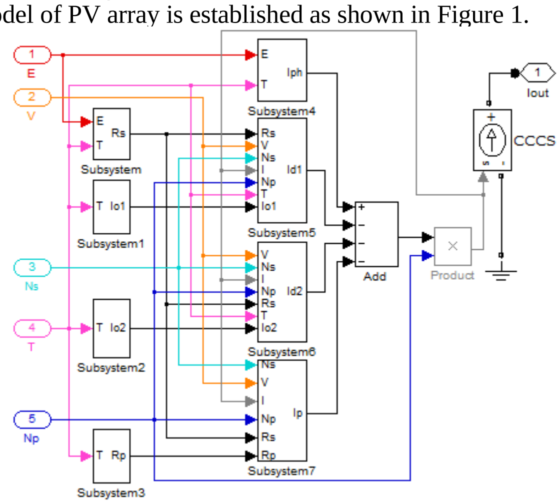

Figure 1. PV array model

III. MPPT ALGORITHM

A. *MPPT*

Photovoltaic cell array output is nonlinear, and its output voltage and power is associated with light intensity, environmental temperature and load condition. Under certain environment, the output voltage of photovoltaic cell will be different in a certain range. The output power of photovoltaic cells arrives at maximum only in a certain output voltage value, called the maximum power point. Therefore, making the PV system work at around the maximum power point is called the maximum power point tracking (MPPT).

Different MPPT algorithms were proposed, say hill-climbing control method, conductance increment method, three-point comparison method, constant voltage method and so on. These principles of the algorithm differ from each other, so to the control effect. Among them, the incremental conductance method is widely used for the superiority of its accuracy and efficiency. Specifically, it has the highest tracking accuracy, and it will still maintain good performance even if in the circumstances of environment changing rapidly.

B. *Improved Conductance Increment Method*

Incremental conductance method completes the maximum power point tracking function by comparing the solar cell array of instantaneous immittance with the immittance variation method [6].

Assume that the output power of the photovoltaic cells is

$$P=UI \quad (8)$$

Calculating the derivative of the above equation to the variable U, so as to get equation

$$\frac{dP}{dU}=\frac{d(IU)}{dU}=I+U\frac{dI}{dU} \quad (9)$$

Suppose the output voltage of the photovoltaic cells is U_{max} when working at the maximum power point. Thus, according to the P-V character curve of the photovoltaic cells, we can conclude that when $\frac{dP}{dU}>0, U<U_{max}$; when $\frac{dP}{dU}<0, U>U_{max}$; when $\frac{dP}{dU}=0, U=U_{max}$.

Thus, we can obtain

$$\begin{cases} U<U_{max}, \frac{dI}{dU}>-\frac{I}{U} \\ U>U_{max}, \frac{dI}{dU}<-\frac{I}{U} \\ U=U_{max}, \frac{dI}{dU}=-\frac{I}{U} \end{cases} \quad (10)$$

If $dU=0$ and $dI=0$, then the PV system has been at the maximum power point. If $dU=0$ while $dI\neq0$, then it will adjust voltage reference based on the sign of dI (positive and negative). If $dU\neq0$, it will adjust the output voltage of the photovoltaic cells according to the relation between dI/dU and $-I/U$ so as to track the maximum power point.

When applying the relationship between dI/dU and $-I/U$ to adjust the working voltage, there will be greater demand in terms of the hardware operation processing speed and data storage capacity, and it is difficult for the system to track maximum power point rapidly and accurately. When adjusting reference output voltage based on the sign of dP/dU (positive and negative), tracking of real-time and accuracy is greatly improved comparing with traditional methods, in addition, hardware requirements standard will also reduce. The improved conductivity incremental method of control flow chart is shown in figure 2.

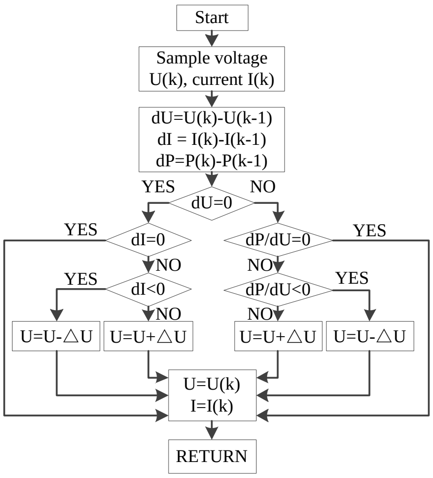

Figure 2. Flow chart of improved incremental conductance method

When the environment changes, the output voltage of the PV cells system track the maximum power point in a smoothly way in response, so that the oscillation phenomenon, which exists near the point of maximum power point, was improved at a great extent and the efficiency of photovoltaic cells generation electricity as well.

IV. DESIGN OF PV GRID-CONNECTED INVERTER

A. The topology and principle of the PV grid-connected inverter

The structure of PV grid-connected inverter is as shown in figure 3 [7]. The system is mainly composed of the former stage of DC - DC converter, intermediate DC bus and the level of DC - AC inverter. The DC - DC converter boosts the DC voltage. Firstly, sample the photovoltaic cells output voltage and current, and compute the collected signals based on improved conductivity incremental control algorithm. And then control the switch state of the DC booster circuit to realize maximum power. The only function of the former stage is to realize MPPT.

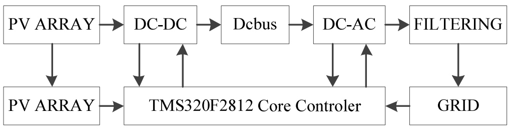

Figure 3. PV grid-connected inverter controller diagram

The DC - AC converter adopts double PI control. The outer loop keep DC bus voltage stable, inner loop is used to control the stability of the output current. The control flow chart is as shown in Figure 4.

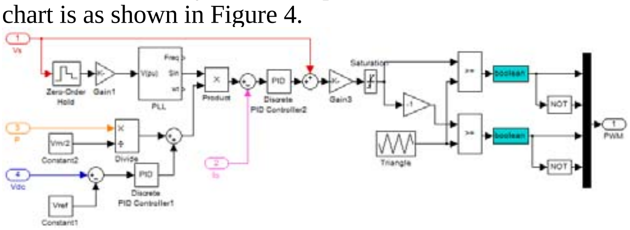

Figure 4. Flow chart of DC-AC control

Voltage outer loop is used to control the intermediate dc bus voltage V_{dc} . When the photovoltaic cells output power is greater than the inverter output power, the V_{dc} voltage will increases because of the residual energy accumulation. Thus, it is necessary to increase the inverter output power to consume the surplus energy and make V_{dc} voltage drop, in other words, to increase the output current. On the other hand, it will reduce output current to make V_{dc} voltage rise, keeping the voltage V_{dc} steady near the enactment value.

Current inner loop is used to control the stability of the output current. Multiplying I_o by the sine table value, we obtain alternating output current baseline value. Compare this baseline value current with the actual output current, we can obtain the error ΔI . After PID adjustment, ΔI will become $\Delta I'$. Then, we can obtain the wave, comparing which with the triangular carrier to produce four PWM signals, by adding $\Delta I'$ to the sampling ac voltage V_s . Using the four PWM signals to control the full bridge inverter switch for inverter. Considering the fact that the sinusoidal signal is based on grid voltage signal, which is the synchronous signal for power, the output current is the same frequency and phase as the grid voltage. Finally the sinusoidal current of line side and unity power factor is realized.

Because the control of the front and the back is relatively independent, this kind of control method has good control performance. The input stage of the system is designed mainly for tracking the maximum power point. The output stage regulates the output power according to the input power, simplifying the control system. The control algorithm has the good rapidity and the stability.

B. Simulation results of PV grid-connected inverter

Methods 500 PV cells in series and 1000 in parallel, under the environment temperature of 300K, light intensity $1000W/m^2$, the grid voltage $220V$, $50Hz$, intermediate dc bus voltage $450V$, the simulation time is $0.4s$, use the PV array model for simulation results. The PV grid-connected inverter model is as shown in Figure 5. The waveforms of the output voltage, output current and output power of the former DC/DC converter is as showns in Figure 6. The DC-link voltage, AC current and active power of the latter inverter waveforms are as shown in Figure 7. The output voltage and current of the line side are as shown in Figure 8.

It can be seen from the Figure 6 that the PV array output power is always around the maximum power point, demonstrating the validity of the maximum power point tracking control algorithm. In Figure 7, after the system stabilization, the DC-link voltage is around about 450V. In Figure 8, the grid current remains the same frequency and phase as the grid voltage, the power factor is equal to 1, and in the line side, and the active power is nearly equal to the photovoltaic array output power.

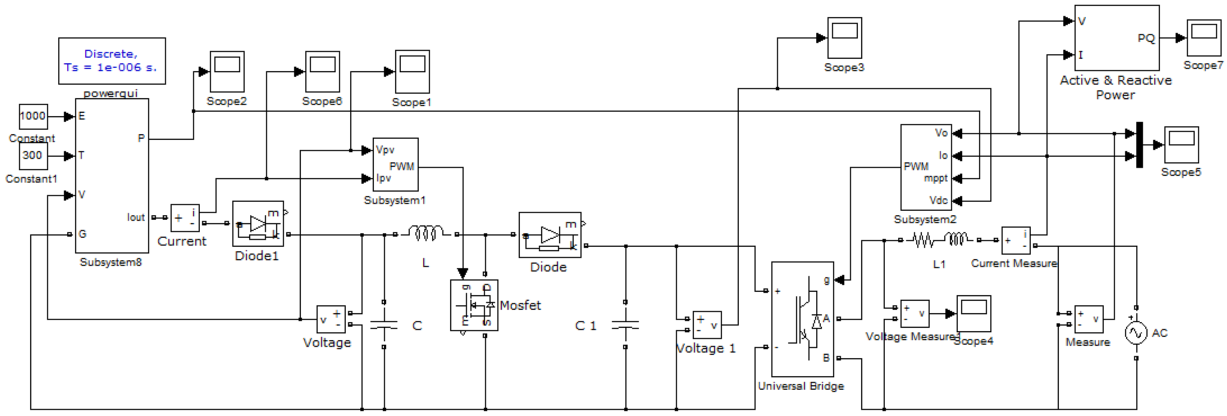

Figure 5. Photovoltaic inverter simulation model

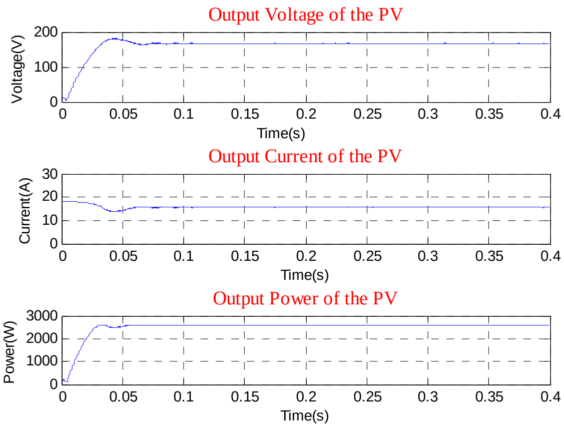

Figure 6. The former DC/DC converter

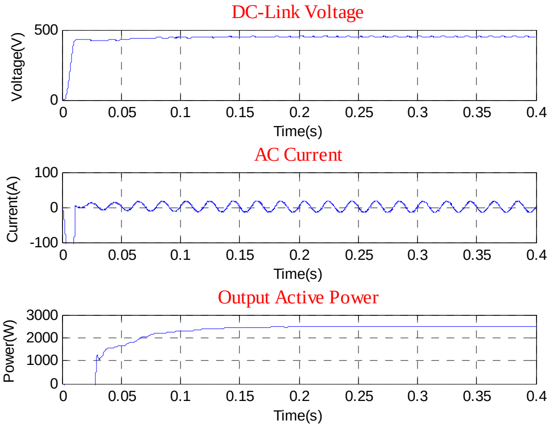

Figure 7. The latter inverter

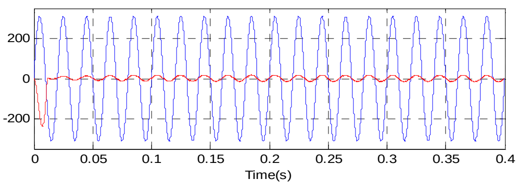

Figure 8. Output Voltage and Current

V. CONCLUSION

According to the mathematical model of the PV array, a simulation model is set up. After some analysis and research on the traditional incremental conductance method, this paper proposed an improved incremental conductance method, and the proposed can rapidly and accurately track the maximum power point, in addition, the algorithm guarantees to stabilize the system fast near the maximum power point, so as to improve the efficiency of PV power generation. PV grid-connected inverter control structure is made of two level control modes. the former DC/DC converter achieve maximum power tracking control, the latter inverter keeps the DC bus voltage stable and realizes the connect grid function. Both couple each other through the intermediate DC bus, making the system match simply. The control algorithm has the good rapidity and the stability. The simulation results indicate that the system is stable and has good performance. DC bus voltage is around 450V , the PV array output power remains in the maximum power point and achieves a good sinusoidal output wave. The results indicate that the simulation achieved expected results.

REFERENCES

[1] C. H. Wu, *The Research of Inverter for PV Generation*, Shanghai: Shanghai University, 2008

[2] X. Zou, and L. Z. YI, "Constant-frequency Hysteresis Current Control of PV grid-connected Inverter," *Electric Power Automation Equipment*, 2008, 4(28), pp. 58-62.

[3] L. Pan, "Photovoltaic inverter design and control," *Energy and Energy Efficiency*, 2011, pp. 83–85.

[4] W. D. Wang, Z.K. Wen, "Matlab Simulation of Photovoltaic Arrays," *Electroinc Components & Device Applications*, 2010, 12(9), pp. 89-90.

[5] Z. J. Tang, C. L. Wang, X. F. Fang, "MPPT Implementation Strtegy Based on the Conductance Increment Method," *Power Electronics*, 2011, 45(4), pp. 73-75.

[6] X. Y. Li, X. Wang, F. Zheng, "The MPPT Improved Algorithm and Simulation under Changing Irradiance of Grid-Connected PV Systems," *Energy Technology*, 2009, 30(5), pp.272-279.

[7] H. Z. Yang and X. M. Jin, "Research on Grid-Connected Photovoltaic Inverter of Maximum Power Point Tracking," *The University of Traffic*, 2004, 28(2), pp.65-68.