CHEMICAL ENGINEERING TRANSACTIONS

VOL. 67, 2018

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Valerio Cozzani, Bruno Fabiano, Davide Manca

ISBN 978-88-95608-64-8; **ISSN** 2283-9216

DOI: 10.3303/CET1867121

Design and Simulation of Power Generation System Based on Photovoltaic Cells

Miaomiao Wang[a,*], Yanhua Jin[b], Shuo Liang[a]

[a]School of Information Engineering, Handan College, Handan 056001, China
[b]Electronic And Information Engineering Experiment And Training Center, Handan College, Handan 056001, China
w.mm840217@163.com

Based on the volt-ampere characteristics and internal structure of photovoltaic (PV) cells, this paper uses Simulink to construct PV cells simulation model, maximum power point control simulation model, control circuit dq algorithm simulation model, SVPWM modulation algorithm simulation model, grid-connected PV power generation system simulation model, and it performs simulation studies on the maximum power tracking control of the PV power generation system. The simulation results show that the method of grid-connected inverter control can maximize the maximum power point tracking of the PV power generation system, which is of high practical values.

1. Introduction

The development of the electric power industry, the advancement of material science, and the deepening of society's understanding of clean energy have made it possible for the solar energy which has abundant reserves to have a good application prospect. PV power generation is one of the main forms of solar energy utilization. Due to the flexible installation and configuration of photovoltaic equipment, as a supplement to the power supply of large power grids, it occupies an increasingly important position in the energy system (Yuan et al., 2015). PV power generation system is a new type of power generation system that utilizes the photovoltaic effect of PV cells to convert solar energy into electrical energy, then store the energy or supply it directly to the load. Considering various factors, this paper mainly introduces the grid-connected PV power generation system which connected to the State Grid (Luo et al., 2014).

2. Photovoltaic power generation system

In order to effectively increase the PV power generation efficiency, it is now quite common to add a maximum power point tracking (MPPT) control device to the PV power generation system (Hu et al., 2014). The basic composition of a MPPT-based PV power generation system includes: PV arrays, controllers, DC/DC converters, and DC/AC inverters. Its system structure is shown as Figure 1:

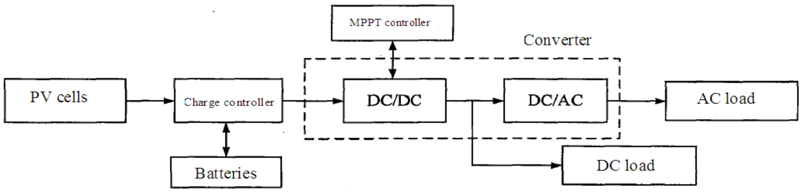


Figure 1: The composition of PV power generation system

PV cells and batteries are energy sources and energy storage devices of the MPPT PV power generation system; the controller includes a charge controller and an MPPT controller; the charge controller acts on the battery pack to realize charge and discharge control of the battery pack, the maximum power point tracking controller is the core controller of the MPPT PV power generation system; the converter determines the safety,

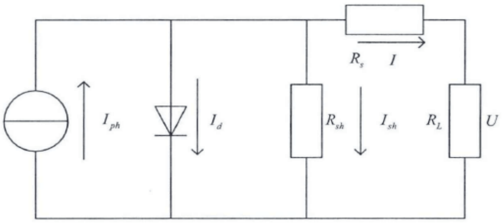
Please cite this article as: Wang M., Jin Y., Liang S., 2018, Design and simulation of power generation system based on photovoltaic cells, Chemical Engineering Transactions, 67, 721-726 DOI: 10.3303/CET1867121

stability and efficient operation of the entire system, and the most important components are the DC converter and the inverter.

2.1 PV cells

PV cells are devices that convert light energy into electrical energy based on photochemical effects or photovoltaic effects. The conversion efficiency is related to its own semiconductor materials, and it is influenced by the light intensity, ambient temperature, etc. as well.

In the equivalent circuit, the PV cell is treated as a constant current source. The equivalent circuit of the PV cell is shown in Figure 2.



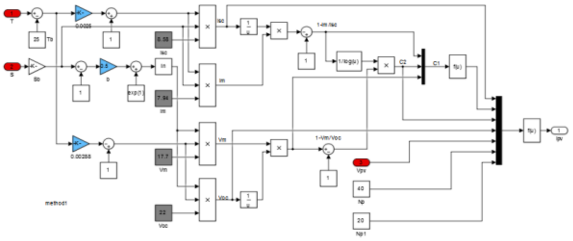


Figure 2: The equivalent circuit of a PV cell

Figure 3: PV battery simulation model

I_{ph} is the photo-generated current, which is in constant state when lighting is constant. For a PV cell, it can be regarded as a constant current source;

I_d is the current generated by the forward bias of the PN junction which is caused by the terminal voltage generated by the flowing the photo-generated current through the load;

Series resistance R_s is the resistance of the base material of the semiconductor material, and the resistance generated by the connection of the metal and the semiconductor.

Bleeder resistance R_{sh} is generated by the defects of unclean wafer edge or micro cracks caused by the manufacturing process, these defects will cause battery edges and metal bridges to leak, resulting in a portion of the current to not pass through the load, and R_{sh} is the equivalent representation of it.

The characteristic equation of PV cell output voltage and output current is:

$$I = I_{ph} - I_o \left\{ \exp[\frac{q(IR_s + U)}{AKT}] - 1 \right\} - \frac{IR_s + U}{R_{sh}} \tag{1}$$

Where, I and U are the output current and voltage of the PV cell, I_o is the reverse saturation current of the diode, q is the amount of electronic charge, A is the characteristic factor of the diode, K is the Bolman constant, T is the temperature of the PV cell.

In the formula, the five parameters I_{ph}, I_o, A, R_{sh}, R_s are not only related to light intensity and battery temperature, but also have many uncertainties. By comprehensive consideration of accuracy and practicality, PV cell suppliers generally provide four parameters: open circuit voltage U_{oc}, short-circuit current I_{sc}, maximum power point current I_m, and maximum power point voltage U_m. The relationship between PV battery voltage and current is simplified as:

$$I = I_{sc} \left\{ 1 - C_1[\exp(U / C_2 U_{oc}) - 1] \right\} \tag{2}$$

At the maximum power point, there is

$$I_m = I_{sc} \left\{ 1 - C_1[\exp(U_m / C_2 U_{oc}) - 1] \right\} \tag{3}$$

Where, C_1 and C_2 can be calculated equivalently at normal temperature.

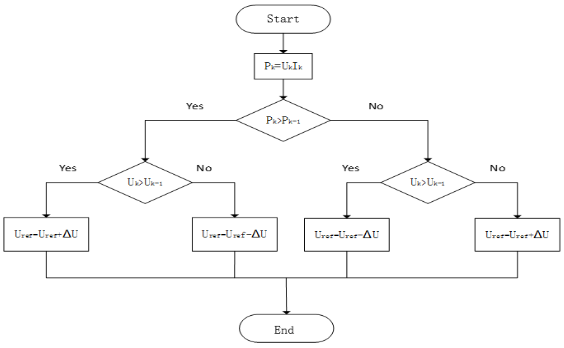
In practical applications, the power of a single PV cell is very small, so single PV cells are often connected in series to form PV arrays, which has the same electrical characteristics as a single PV cell (Hou et al., 2017). The PV cell simulation model built by Simulink is shown in Figure 3.

From the output volt-ampere relationship (2) (3) of the PV cell, it can be seen that the output of the PV cell is non-linear, and its output characteristic curve will change with the change of the lighting conditions and the ambient temperature (When the light intensity remains and the temperature changes, the relationship between PV cell output power and temperature change is negative; when the temperature remains and the light intensity changes, the relationship between PV cell output and light intensity is positively correlated). In real life, in order to achieve the expected conversion efficiency of PV cells, it is necessary to keep the output power of PV cells at the maximum power point as possible. Under certain light intensity and temperature, the output of PV cells has one and only one maximum power (Sivakumar et al., 2015).

2.2 MPPT control principle

PV array output has strong nonlinear characteristics. Different ambient temperature and solar irradiance will affect the output power of PV cells. Therefore, the maximum power point tracking measures must be adopted to ensure that the PV array can maintain maximum power output under different working environments, thereby improving the PV cell's power generation efficiency. After comprehensive analysis, disturbance observation is used to achieve the tracking of the maximum power point of the PV array. The principle is shown in Figure 4.

Essentially, the disturbance observation introduces an error fluctuation, compares with the previous state, and searches for the maximum value every time. Under a certain working environment, the maximum power point is unique, so after a finite number of iteration cycles, the maximum power point can be found. If the iteration period is relatively small, the fluctuation amplitude near the maximum power point Pm is smaller, but the algorithm period becomes longer and the dynamic response is poorer; if the iteration period is larger, the situation is the opposite (Yan and Han, 2012). The simulation model built by Simulink is shown in Figure 5.



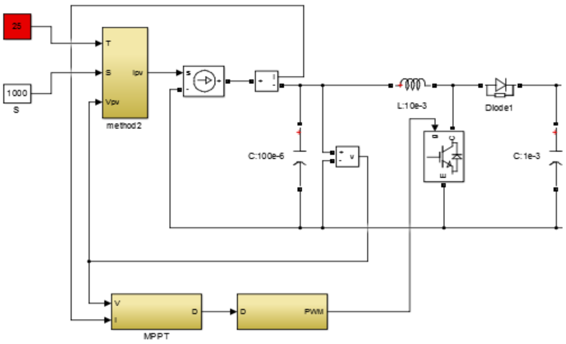


Figure 4: Workflow of disturbance observation

Figure 5: Simulation model of disturbance observation

The simulation parameters are set as follows: Tref=25°C, Sref=1000kW/m^2, Isc=8.58A, Im=7.94A, Um=17.7V, Uoc=22V, the number of PV cells in series Np=20, and the number of parallel branches Np1 =20.

According to the algorithm principle of disturbance observation, the judgment amount ΔP, ΔU can be designed as the positive direction of the voltage increment. If the judgment is positive, it auto-increments; if the judgment is negative, it auto-decrements, it stops until the PV cells reach the maximum output power point.

2.3 Control circuit

The control circuit adopts the Boost circuit-based three-phase power supply inverter control and the dq decoupling control. This kind of algorithm has higher inverter efficiency, better dynamic response characteristics, and smaller harmonic waves of the inverter output voltage. This kind of inverter performs feedback control in the dq space, PI controller enables the system to have certain stable precision. At the same time, the dq decomposition also makes the system have a double closed-loop control effect of voltage and current (Wang et al., 2014). The Simulink-built dq algorithm model is shown in Figure 6:

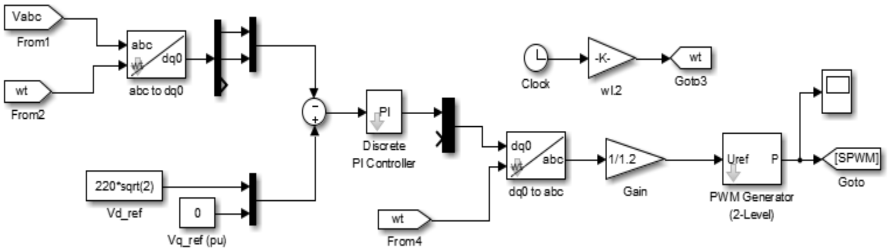


Figure 6: Simulink-built dq algorithm model

2.4 Inverter circuit

At present, in order to make use of the electric energy efficiently, normally, many industries do not use the AC power provided by the AC grid as electric energy directly, but convert it using electronic technology according to the electricity demand, so as to obtain the required electric energy. These electrical energies are obtained by rectifying and converting the original electrical energy via inverter combination circuit. Inversion is the process of converting DC power into AC power. The circuit that completes the inverter function is called the inverter circuit. The device that implements the inverter process is called the inverter power or the inverter. The inverter structure diagram is shown in Figure 7.

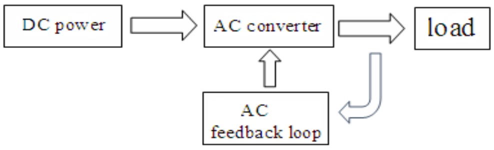
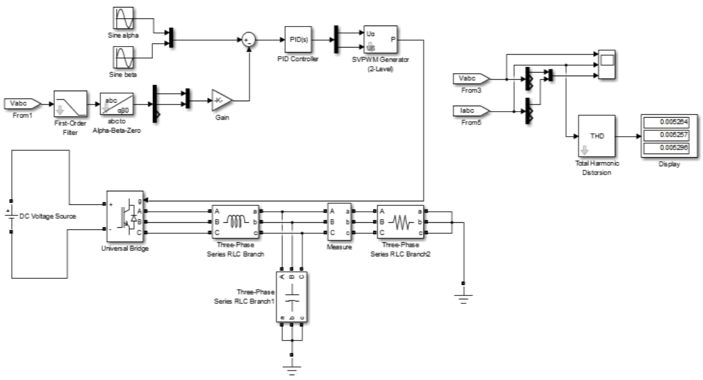


Figure 7: Power inverter structure

The inverter is actually a control system. The output of the inverter system is changed by adjusting one or several reference values, thereby improving the steady state and dynamic performance of the output voltage of the inverter power supply. The most important component of inverter technology is the realization of control technology and control measurement. The control technology is mainly combined with modulation technology to achieve the required waveform output. The modulation technology uses SVPWM, which is a pulse modulation wave generated by a specific switching pattern composed of three power switching components of three power inverters, which can make the output current waveform get close to the ideal sine waveform as much as possible (Fan, 2009). The Simulink simulation model of the SVPWM algorithm is shown in Figure 8.

After the three-phase inverter output voltage went through Clark transform, it transformed the voltage vector in the abc coordinate system into the voltage vector in the dq coordinate system. The transformed orthogonal voltage vector and the standard orthogonal reference voltage vector are taken as errors, and the PI algorithm is used as the feedback control. The output orthogonal voltage signal undergoes Park transform and converts the orthogonal voltage vector in the dq coordinate system into the voltage vector in the abc coordinate system to generate a three-phase voltage waveform that is lagging by 120 degrees in turn. The simulation output waveform is shown as Figure 9.

The result of the simulation is that the THD content is about 0.5%, this result is very satisfactory. (THD module is to detect the voltage harmonic factor, which is one of the standards to measure the quality of the output waveform of the inverter power. The smaller the harmonic factor, the lower the waveform distortion rate, the closer the output voltage waveform is to the standard sine reference signal.) Phase A output is current waveform and harmonic wave content (harmonic wave display within 1000Hz, with 50Hz as the fundamental wave), the load is a symmetrical three-phase load of 30 ohms, the even harmonic content is extremely low, while odd harmonic content is higher, among which, the switching frequency is 5000Hz, so the harmonic wave content near the switching frequency is the most, but due to the LC filter’s suppression of high-frequency harmonic waves, the high-frequency harmonic waves decay very quickly.



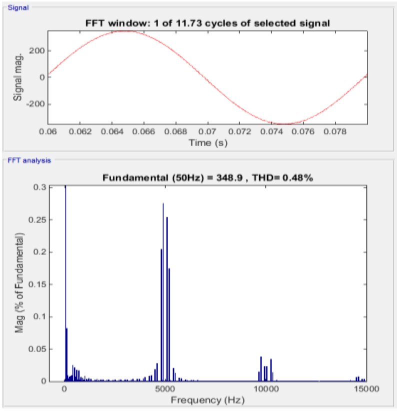


Figure 8: Simulink simulation model of SVPWM algorithm

Figure 9: Simulation output waveform

3. System design

The entire PV power generation system adopts a grid-connected inverter structure (Sun, 2012), its structure is shown in Figure 10:

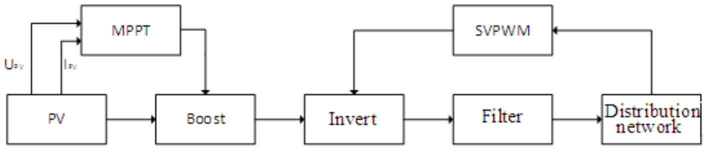
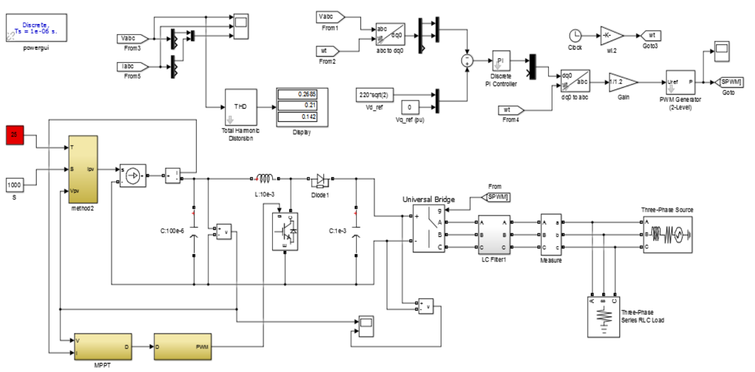


Figure 10: Photovoltaic grid-connected inverter system structure

Considering that the PV array is affected by the working environment and the output voltage is not stable, the MPPT algorithm (achieved by disturbance observation) is used to ensure that the PV array operates at the maximum power point. In the grid-connected PV power generation system, in order to match the grid-connected voltage and stabilize the output voltage, at the same time of tracking the maximum power of the PV, we also need to increase the output voltage to the voltage value required by the grid connection (Chen, 2014) via Boost circuit. The inverter topology adopts a three-phase inverter bridge structure and is controlled by SVPWM method. The simulation model of the entire system is shown in Figure 11.



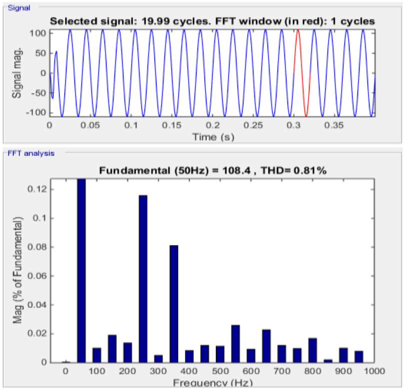


Figure 11: System simulation model

Figure 12: Simulation output three-phase current waveform

It is assumed that the load of the power distribution network is a resistive load, the short-circuit power of the distribution network is 100 MVA, the frequency of the power grid is 50 Hz, the power grid voltage is 380 V, and the load power is 50 KW.

When the solar irradiance is sufficient, the solar PV array starts working, converts the solar energy into electrical energy, and outputs a direct current of a certain voltage range. The MPPT algorithm calculates the voltage corresponding to the maximum power point of the solar panel, calculates the duty cycle required for outputting the direct current, drives the switching tube of the Boost chopper circuit, and finally obtains a more stable DC power supply as the DC side of the inverter. The topological structure of the inverter adopts a three-phase inverter bridge structure, which is controlled by the SVPWM method. The three-phase voltage output is filtered by LC filter, connected to a load of 50 kW, and connected to a power supply with a short-circuit capacity of 100 MVA as a distribution network.

Set the PV array parameters Tref=25°C, Sref=1000kW/m^2, Isc=8.58A, Im=7.94A, Um=17.7V, Uoc=22V, the number of PV cells in series Np=40, and the number of parallel branches Np1=20. The output of the three-phase voltage and current waveforms is shown in Figure 12. It can be seen that the voltage and current are in the same frequency phase, indicating that after the grid connection, the inverter system can better transmit the generated power to the grid. There are glitches in the current waveform, which is due to the opening of the inverter bridge. It is difficult for the LC filter circuit to completely eliminate this part, but the effect of suppression is still quite obvious.

Figure 12 shows the A-phase current waveform of the PV array output when S=1000 kW/m^2. At this point, from the rated capacity of the PV array power generation, it can be seen that the current harmonic wave only takes 0.81%, and the main current harmonic waves come from the 5-order harmonic and the 7-order harmonic.

4. Conclusions

Using the MTTP control method based on PV cell characteristics and Boost circuit, a grid-connected PV power generation system was designed using Simulink to build the PV array, control circuit, inverter circuit and system circuit model. Through analysis of simulation results, the feasibility and practicality of the entire system scheme were verified.

Acknowledgments

This work is supported by Plan Project of Science and Technology of Hebei (Grant No.15210207) and Plan Project of Handan College (15012).

References

Chen X.J., 2014, Research on MPPT Photovaltic Generation System Based on Boost Converter, Hangzhou: Zhejiang University of Technology.

Fan X.M., 2009, Simulation of SVPWM based on SIMULINK, Electric Drive Automation, 31(3), 19-21.

Hou Q.W., Xiao J.M., Chen C., 2017, Practical Model of PV and Maximum Power Point Tracking Control, Control Engineering of China, 24(S0), 92-97.

Hu C.W., Li B.G., Wang L.M., Teng N.N., Simulation Research on MPPT Control System with Photovoltaic(pv) Power Generation Based on Boost Circuit, Electro-optic Technology Application, 29(1), 84-88.

Hu Y.Y., Zhang R.Y., Wang J., 2014, Development status and prospect of solar photovoltaic power generation in China, Journal of Hebei University of Science and Technology, 35(1), 69-72.

Jian D.R., Wang S.Y., Tian J.F., 2015, Electric Parameter Acquisition System Based on ARM, Chemical Engineering Transacions, 46(49), 289-292, DOI: 10.3303/CET1546049

Luo F.Z., Mi Z.F., Wang C.S., Fang C., Li D.W., Liu L., 2014, Comprehensive Low-carbon Benefit Analysis Models of Grid-connected Photovoltaic Power Generation Projects, Automation of Electric Power Systems, 38(17), 163-169, DOI: 10.7500/AEPS20140131002

Sivakumar P., Kader A.A., Kaliavaradhan Y., Arutchelvi M., 2015, Analysis and Enhancement of PV Efficiency with Incremental Conductance MPPT Technique under Non-linear Loading Conditions, Renewable Energy, 81, 543-550, DOI: 10.1016/j.renene.2015.03.062

Sun Z.S., 2012, The Study of Grid-connected Photovoltaic Generation System based on MATLAB Simulation, Nanchang: Nanchang Hangkong University.

Tian Y.F., He J.A., Huang Z.W., 2004, Simulation and Analyzation of Space Vector PWM, Processdings of the EPSA, 16(4), 68-71.

Wang Y., Lin X., Pedram M., 2014, Adaptive control for energy storage systems in households with photovoltaic modules, IEEE Transactions on Smart Grid, 5(2), 992-1001, DOI: 10.1109/TSG.2013.2292518

Yan L., Han N., 2012, Improved Maximum Power Point Tracking Techniques in PV systems, Modern Architeeture Electric, 3(3), 33-37.

Yuan J.H., Xu Z.H., Chen X., Li B., 2015, Research on the synchronization technology adopted in the Boost circuit of photovoltaic generation system, Electrical Measurement & Instrumentation, 52(12), 30-35.

Zhang T.F., Suo X.S., Zhang M., Li S., 2015, Study on Color Classification Method of Solar Based on Fuzzy Clustering Algorithm, Chemical Engineering Transacions, 46, 187-190, DOI:10.3303/CET1546032.