Yanbo CHE，Wen ZHANG，Wei LI

Key Laboratory of Smart Grid of Ministry of Education, Tianjin University, Tianjin 300072, China

The Design of MPPT Controller in Photovoltaic System

***Abstract**. In photovoltaic power system, the maximum power point changes under different circumstances, so it is meaningful to track the unique point to provide maximum power for the load. In this paper, we designed the main circuit and control circuit of the maximum power point tracking controller. This controller uses the observation and perturbation method to achieve the maximum power point tracking. At last we tested the efficiency of the controller, the experimental result demonstrates that the system tracks the maximum power point rapidly, works safely and reliably.*

***Streszczenie.** W artykule przedstawiono projekt elektronicznego sterownika do śledzenia punktu mocy maksymalnej. Budowę urządzenia oparto na teorii obserwacji i perturbacji. Zawarte wyniki eksperymentalne potwierdzają skuteczność śledzenia i szybkość reakcji na zmiany w systemie PV. (**Projekt sterownika do śledzenia punktu mocy maksymalnej dla systemu paneli fotowoltaicznych**).*

Keywords: MPPT, Photovoltaic System, Observation and Perturbation Method, Boost Circuit
Słowa kluczowe: MPPT, system fotowoltaiczny, teoria perturbacji i obserwacji, układ wzmacniający.

Introduction

With the arrival of energy crisis, people are increasingly concerned about the distributed generation and micro-grid [1]. And new energy has became a research focus in recent years, especially the solar power generation technology. Under the support of the government and the technological breakthrough, solar power generation developed rapidly. With the cost of photovoltaic cell drops, photovoltaic system supplys power not only for the remote area which lacks electrical power, but also for people's daily life. In these systems, MPPT(maximum power point tracking) controller is needed to obtain the maximum available power [2].

The Principle of MPPT Control

There are many ways to achieve the MPPT functionality, such as incremental conductance, fuzzy logic, observation and perturbation method, and so on[2]. Because the observation and perturbation method has many advantages, it is widely used in photovoltaic system. As we all know, the *P-U* characteristic curve of photovoltaic cell is a single peak function[3], so we can track the maximum power point with the observation and perturbation method. The observation and perturbation method uses the thought of step search, that is, at first, give a voltage disturbance ΔU to the output voltage of photovoltaic cells by changing the duty ratio, and then, observe the change of output power P and its direction, adjust ΔU according to the change of P, so as to find the maximum power point[2]. In this system, the boost circuit can not only increase the direct voltage but also can achieve the MPPT functionality. The equivalent circuit of photovoltaic system is a voltage source E in series with a resistance R_i. The voltage source E is the open-circuit voltage U_{oc} of photovoltaic cells, mainly effected by outside temperature. While R_i equals U_{oc}/I_{sc}, where I_{sc} presents the short-circuit current of photovoltaic cells, mainly effected by the sunlight intensity. MPPT can be achieved when the external resistance R_o matches the equivalent resistance R_i.

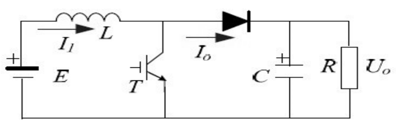

Fig.1. Boost circuit structure

The boost circuit structure is shown in Fig.1[3]. When the circuit runs steadily, $EI_1 = U_oI_o$, and

$$I_i = \frac{U_o I_O}{E} = (\frac{T}{T_{off}})^2 \frac{E}{R} = \frac{E}{R_{eq}}$$

where :

$$R_{eq} = R(\frac{T_{off}}{T})^2 = R(1-\frac{T_{on}}{T})^2 = R(1-D)^2$$

As a result, the steady boost circuit can be equal to the model in which the photovoltaic cells provide energy for the equivalent load R_{eq} directly. Both the MPPT controlling and the voltage boosting function are implemented in the boost circuit. The output current and voltage of photovoltaic are detected to compute the output power, and the MPPT is achieved by regulating the duty ratio D of the PWM drive signal. In boost circuit, the equivalent load R_{eq} changes with the value of D, when R_{eq} equals to R_i, the output power of photovoltaic cells is maximum. Based on the analysis above, we can use the method of perturbation and observation to achieve the MPPT.

The Main Circuit Design Of MPPT Controller

1. Structure of the controller

The MPPT controller structure is shown in Fig.2, the system consists of photovoltaic modules, main circuit, voltage current sampling circuit, drive circuit and DSP. The DC output of photovoltaic cells is boosted by the boost circuit and the MPPT function is also achieved at the same time. DSP is the core of the control circuit, the output voltage and current of the photovoltaic are sampled and then sent to the DSP's A/D sampling terminal. After the MPPT algorithm processed in DSP, the PWM signals can be adjusted to control the conduction of IGBT in boost circuit. Switch power sources provide 3.3V, 5V and ± 15V for the core chips of the sampling and driving circuit.

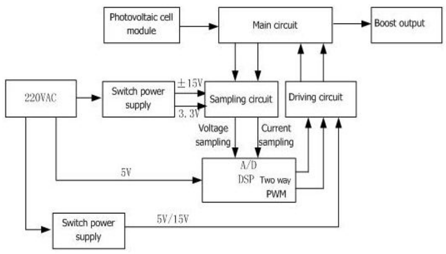

Fig.2. MPPT controller structure

In the main circuit, there are two solar battery inputs, through the RLC filter circuit, the MPPT function can be achieved in the boost circuit[4,5]. In boost circuit, the load voltage rises when the inductance current discharges to the load. The anti-reverse charging device is used to prevent reverse charge to photovoltaic cells when the load voltage is higher than photovoltaic battery voltage such as in the night or rainy days, or it might cause the damage of the photovoltaic cells. The sampled voltage and current of photovoltaic cells act as the reference in the DSP2407 program to complete the MPPT function. The storage inductor is used to store energy when IGBT is in on-state. The reverse recovery time of diode is long when the output voltage is relatively high, so the fast recovery diode is used to isolate the reverse voltage within hundreds of nanoseconds to prevent IGBT from short circuit led by the capacitance when the IGBT is in on- state.

2. Sampling circuit design

In the voltage sampling circuit, the voltage of photovoltaic cells is sampled by voltage transducer, then it is supplied to the ADCIN0 and ADCIN3 pin of DSP. The maximum input voltage of DSP A/D terminal is 3.3V, therefore, it is needed to provide protection device to limit the voltage in the voltage sampling circuit. If the sampling output voltage is higher than 3.3V, the output voltage will be clamped in 3.3V. The Current sampling circuit principle is the same as the voltage sampling circuit.

3. Energy storage inductance design

The inductance is energy storage device. When IGBT is in on-state, the energy supplied by the power will be stored in the inductance, when IGBT is in off-state, both the power and the inductance which has stored energy supply electric power for the load through the diode, the capacitance is charged to maintain the output voltage when IGBT is in the on-state next time. In this system, inductance in boost circuit are designed when the frequency is 20kHz. If the frequency is too high, it would cause negative influence on the circuit. Firstly, increasing the switching frequency of IGBT will increase switching loss, thus increase the size of the radiator. Secondly, it will also reduce the cycle of IGBT action, then the cycle of the program running in DSP will also be reduced so that the program is more difficult to write. Input conditions of the design is shown in Table 1.

Table 1. Input conditions of boost circuit

Input power	Input voltage	Switch frequency
5000W	400V	20KHz

Under these input conditions we can get the value of inductance L=1520μH after calculation[5]. Experimental results show that the inductance can satisfy the requirements of normal work. The charge and discharge current wave of the inductance is shown in Fig.3.

Fig.3. The charge/discharge current of inductance

4. RC absorption circuit design

RC absorption circuit is designed to reduce the IGBT switching loss. In the high-frequency circuit, it will produce high di/dt and dv/dt which would produce inductive voltage in the power loop of parasitic inductance, and it will exert a big impact on IGBT, it might even damage the device. When the PWM control signal current shares a current loop with main current there will generate a ground loop, it will turn on the off-state IGBT. So, a buffer absorbing circuit should be designed to limit the transient overvoltage and overcurrent during switch process, this will guarantee the safety operation of the power components. As is shown in Fig.4, IGBT drive voltage waveform without RC absorption circuit have a big voltage fluctuation in the moment of IGBT conduction. After adding the RC absorption circuit, the drive voltage waveform has less voltage fluctuation, and the power loss also decreases, as depicted in Fig.5.

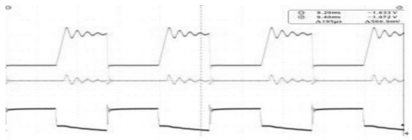

Fig.4. The drive waveform without absorption circuit

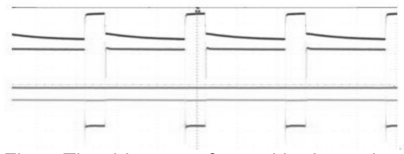

Fig.5. The drive waveform with absorption circuit

5 Driving circuit design

The IGBT driving circuit includes two parts: trigger signal processing and IGBT boost driving. The trigger signal can protect IGBT. The two PWM signals produced by DSP and the trigger signal decide the input signal of the light-coupled device. The light-coupled device, which is the core of the driving circuit has excellent electrical insolation properties. The Drive waveform of IGBT is shown in Fig.6.

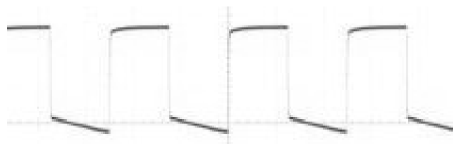

Fig.6.The drive waveform of IGBT

System Software Design

1 Software design overview

The software system of MPPT is realized by the DSP TMS320LF2407A. In this system, all programs should be executed in the underflow interrupt period of cycle register. Because the IGBT frequency is high, the requirement for real-time performance is very strict, assembly language is selected. It can directly operate the register, optimize the structure of software, meet the quickness requirement of software by using different types of jump statement. At the aspects of precision, we sampled the voltage and current involved in the program repeatedly and got the average, in this way the precision can be increased as high as possible.

2 System program flow. The flow chart of the program is shown in Fig.7. In the initialization process of the system, all the setting of DSP is completed. Such as take two A/D conversion module work at cascade model, let A/D conversion work in start and stop mode, set the cycle of timer to 0.05ms, enable underflow interrupt of timer1, let the counter work in the continuous increase or decrease mode, and so on. After the initialization, the program comes into dead circulation, waits for interruption and then executes the relevant program[6,7]. Accomplish the signal sampling, adjacent moment power comparison, compare register updating and the PWM duty ratio adjusting in order. After all the control instruction executed, clear the interrupt flag, then return to main program for the next interrupt events. A/D conversion use the ADC module installed in DSP2407, in this system the 16 analog input channels work in cascade mode to sample the voltage and current signals of these two photovoltaic cells, four channels (ADCIN0 ~ ADCIN3) is used, and the convert results are stored in the result register. The interrupt flow chart is shown in Fig.8.

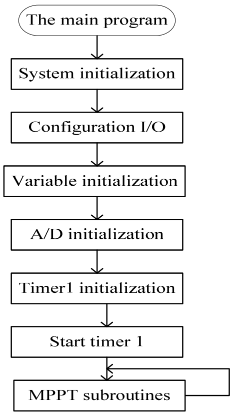

Fig.7 System program flow chart

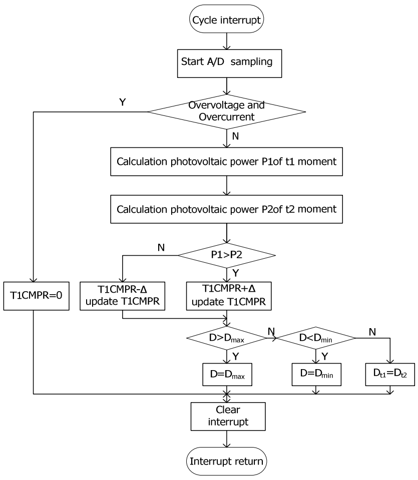

Fig.8 Interrupt flow chart

The passive detection method is used to protect the system. In actual protection process, measure the current value of circuit, then judge whether the circuit is working in T1PWM interrupt service program normally. Once the current value is beyond normal range, the program stop immediately, and turn the output of the EV module which generates PWM waveform to low level, this can turn off the IGBT rapidly, and cut off the control circuit. In boost circuit, the duty ratio is not allowed to be 1, so the duty ratio is limited in a certain range from 0.1 to 0.9. If the control value is beyond the range during actual execution process, it will use the maximum or minimum value instead.

The Experimental Phenomenon Analysis

Experimental conditions: 12:00 of 20st Nov, 2011, the weather is fine, and the temperature outside is 12ºC. The power of single piece of photovoltaic cell is 270W, the open circuit voltage is 40V, 15 pieces of photovoltaic cells are in series. The experiment results are shown in Fig.9. From the waveform we can see that the operating voltage of the resistive load is relatively low without MPPT controller. After the voltage tends to stable, the output voltage will have a slight fluctuation because the duty ratio of the boost circuit is adjusted by the controller in a small extent. It will take about 20ms to track the maximum power point. And after that, the system will work stablely.

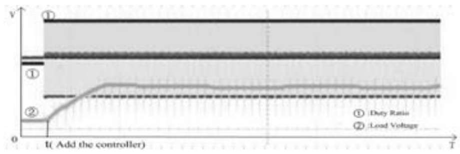

Fig.9. MPPT experiment waveforms

Conclusion

In this paper, the MPPT of photovoltaic system is deliberated. Based on the theoretical foundation, we designed a photovoltaic MPPT controller and carried out relevant tests. The experiment result verifies the reliability and stability of the main circuit and control circuit. And it also shows that the controller can track the maximum power point quickly and work stably around it.

Acknowledgments

This work was supported by the National Key Foundational Research Project (973) 'Distributed Generation Supply System Pertinent Foundational Research' (No.2009CB219700).

REFERENCES

[1] Yanbo CHE, Jian CHEN，Research on Design and Control of Microgrid System，Electrical Review, ISSN 0033-2097,R.88 NR 5b/2012,83-86
[2] Xing ZHANG, RenXian CAO, Solar Photovoltaic Grid-Connected Inverter And its Control[M],Beijing: China Machine Press,2010:195-272
[3] LV Bin, Yanbo CHE and Chengshan WANG, Design Of Grid-Connected Photovoltaic System Using Softing Cut-in Control, Sustainable Power Generation and Supply, 2009
[4] Shan LIN, The Maximum Power Control Of Solar Power Generation System [J]. New Energy, 1999, 21 (2) : 25 -27
[5] Yan WANG, The Research On MPPT Control Method Of Photovoltaic Power Generation System[master's degree thesis], Baoding, North China Electric Power University , 2007:28-31
[6] Biying REN, Yanru ZHONG, Xiangdong SUN, The Research On MPPT Method Based On Fuzzy Control [J], Power Electronic Technology, 2008, 42（11）：47-48
[7] Xiaoguang YANG, Ning DING, Controlling Method With Integrating MPPT And Soft-Switching Technique In A Solar Charger[J], Acta Energiae Solaris Sinica,Vol.31,No.8,Aug 2010

***Authors**:*
Yanbo CHE： Associate professor in School of Electrical Engineering & Automation, Tianjin University, Tianjin China. E-mail: ybche@163.com;
Wen Zhang： Master student in School of Electrical Engineering & Automation, Tianjin University. Tianjin China, E-mail ： tjuzhangwen@126.com
Wei LI：Master student in School of Electrical Engineering & Automation, Tianjin University. Tianjin China, E-mail ： liwei_19900301@163.com.