Design of Power Switching and Distribution Circuits for Solar Power Generation

Yun-Parn Lee and En-Chi Liu

Abstract—With the development of clean energy, switching and distribution issues in a photovoltaic system are getting much attention in recent years. This paper designs a DC to AC inverter and power switching and distribution system between a solar power system and the municipal system by using the Darlington amplifier structure with the photosensitive resistor and accompanying relays, and details the system circuits. The proposed system can achieve a stable output of 110 V AC, as well as self-generating driving voltage and switching between the municipal electrical system and the solar power system. The mathematic analysis and actually test results demonstrate that the proposed method is an easy, inexpensive, and low cost way to build a solar power switching and distribution system.

Index Terms—Darlington amplifier, energy efficiency, photosensitive resistor, photovoltaic power.

1. Introduction

When solar panels receive sunlight, a device can be used to track the maximum power so as to ensure efficiency and maximum power generation. An automatic switching circuit can be utilized to switch power between the solar panel system and the general municipal power system as needed. When the amount of generated solar power and stored battery power is insufficient for the demand, the power will be automatically switched to the municipal city grid. The load can be utilized for 24 hours. The output of the battery storage system is channeled through a quasi-resonant pulse-width-modulated (PWM) DC to AC inverter[1], an AC conversion transformer, and a power filter to obtain 110 V AC output which can be utilized for general household use. Fig. 1 shows the architecture of the solar power system. Fig. 2 shows a block diagram of the power switching system.

There are many research papers on photosensitive cells and its applications have been published before. Miranda[2] proposed a photo-sensitive resistor in an overload preventing design. Layer[3] suggested using a photosensitive resistor to design an automatic ellipsometer. In addition, the photosensitive resistor has been used extensively in camera’s shutter circuit for photography[4],[5] and Pacholok[6] proposed a high power factor switching type battery charger. Lee[7] put forward a wall switch and lamp assembly unit to use the photosensitive resistor. However, Lee did not show any detail circuit diagram. Sham[8] suggested a photosensitive switching apparatus for an electric appliance. Delwiche[9] suggested using a cadmium-sulfide (CdS) photosensitive resistor in their electronic circuit design on a broadcast call unit for bird control. Although Lee[10] and Ranjit[11] put forward an excellent power distribution system for future homes, and the detailed circuit design are yet to be done. In this paper, we proposed to use the photosensitive resistor with relays to construct a solar power switching circuit and a power distribution circuit. In Section 2, we show the parallel connection between the municipal grid and solar power system, the detailed circuit design principles and small signal equivalent circuit are presented. In Section 3, we give the experimental data and test results. Finally, conclusions are drawn.

Fig. 1. Diagram of the solar power generation system.

Fig. 2. Block diagram of the solar power automatic switching system.
2. Parallel Connection between the Municipal Grid and Solar Power System

The power from the solar energy conversion system needs to be converted from the general AC 110 V current to a total of five DC voltages\cite{12}, which are used in the quasi-resonant PWM DC to AC converter. This is done with a power switching circuit and a power filtering circuit. One of these voltages is +15V used to supply the sinusoidal generating circuit\cite{13}. A solar power distribution circuit is illustrated in Fig. 3. Fig. 4 is the circuit for AC to DC converters.

2.1 Booster Circuit and Reverse Voltage Circuit

This section describes the solar energy booster circuit and the reverse voltage circuit\cite{14}. The solar energy from the panels flows through the charge and discharge controller to the storage batteries. By connecting a boosting circuit, the inputs are further divided into +20 V and –20 V. The purpose of this circuit is to facilitate the exchange of power between the municipal power grid and the solar power supply. To achieve this purpose, we utilize an integrated circuit (IC) MC34063 which is in line with our needs. It can not only boost the voltage but also convert it to a negative voltage of –20 V.

Fig. 5 shows the comparator invert input of the pin 5 connected to the external resistors \( R_1 \) and \( R_2 \) and the feedback circuit for the generation of the output voltage, which can be written as

\[
V_{out} = 1.25 \left( 1 + \frac{R_2}{R_1} \right) .
\]  

(1)

It is also can be seen that the RS flip-flop is driven by an internal oscillator. From a comparison of the voltage at the pin 5 and MC34063’s internal reference voltage of 1.25 V, we note that when the voltage at pin 5 is less than the reference voltage, the comparator output of the jump at the Q-ended is in the high-voltage state, therefore \( T_1 \) and \( T_2 \) are conducted. When the input voltage increases the charge on the output filter capacitor, the voltage at the pin 5 is higher than the reference voltage of 1.25 V, therefore, the RS flip-flop is blocked. This means that the Q-ended is in the low-voltage state, and \( T_1 \) and \( T_2 \) are not conducted. The oscillator input is used to monitor the peak current of the oscillator pulse. The capacitance \( C_0 \) which connects to the pin 2 and pin 5 can monitor the oscillator frequency. In addition, \( C_0 \) can decide the switching time of the switch \( T_1 \).

Fig. 3. Block diagram of PWM DC to AC Converter

Fig. 4. Diagram of AC to DC converter circuit.
Fig. 5. MC34063 and booster circuit.

Fig. 6. Reverse-voltage circuit.

Fig. 7. Solar power switching circuit in parallel connection with the city grid.

Fig. 8 shows the relation between resistance of the photosensitive resistor and the photon flux density. In addition, the relationship can be expressed by
\[ R_{\text{DS}} = e^{-\eta \Phi A} \]  
(2)

where \( \eta \) stands for the quantum efficiency, \( \Phi \) is the electronic charge, and \( A \) is the area of the photosensitive resistor. Because of the different material quality, receiving light area, and other factors, we have different ranges of resistance changes.

We want to use a Darlington amplifier with relays and photosensitive resistors for switching purposes. Two cascaded transistors are used to build the Darlington amplifier for a large current gain. Combining the relay with a Darlington amplifier is an easy and inexpensive method to build a power switching circuit. Fig. 9 shows a small signal equivalent circuit of the power switching circuit. In this diagram, \( R_{\text{CDS}} \) stands for the photo-sensitive resistor, \( I_R \) is the current flow through the relay coil, \( \beta_1 \) and \( \beta_2 \) are the \( h_{\text{FE}} \), where \( h_{\text{FE}} \) is the small-signal current gain of the two transistors, and \( g_{m1} \) and \( g_{m2} \) are the conductance of the two transistors in the Darlington pair configuration. Therefore, we have

\[ V_{s1} = I_S r_{s1} \]  
(3)

where \( I_S \) is the short circuit current between base and emitter, \( r_{s1} \) is internal resistance between base and emitter, and \( V_{s1} \) is the voltage across base and emitter. Also, \( g_{m1} V_{s1} = g_{m2} V_{s2} = \beta_1 I_S \), and

\[ V_{s2} = (I_S + \beta_1 I_S) r_{s2} = (1 + \beta_1) I_S r_{s2} \]  
(4)

The current driving the relay is equivalent to

\[ I_R = g_{m1} V_{s1} + g_{m2} V_{s2} \]
\[ = \beta_1 I_S + g_{m2} (I_S + \beta_1 I_S) r_{s2} \]
\[ = \beta_1 I_S + \beta_2 I_S + \beta_1 \beta_2 I_S = (\beta_1 + \beta_2 + \beta_1 \beta_2) I_S \]
\[ = (\beta_1 + \beta_2)^2 - \beta_1 \beta_2 I_S \]  
(5)

So, the current gain of this configuration is equivalent to

\[ (\beta_1 + \beta_2)^2 - \beta_1 \beta_2 \]  
(6)

The finished implementations of the power switching circuits are shown in Fig. 8 and Fig. 10.

3. Experimental Results and Discussion

Energy conversion efficiency is between 0 and 100%, which is a quantitative measurement of the output power versus the input power. If we express that the power delivered by the solar panel is \( P_{\text{Solar}} \), the power delivered by the AC source is \( P_{\text{AC}} \), and the power output used by the device is \( P_{\text{out}} \), the energy conversion efficiency can be expressed as (7), when the power circuit is connected to the AC source:

\[ \eta_{\text{AC}} = \frac{P_{\text{out}}}{P_{\text{AC}}} \]  
(7)

Or, the energy conversion efficiency can be expressed as (8), when the power circuit is connected through the solar panel:

\[ \eta_{\text{Solar}} = \frac{P_{\text{out}}}{P_{\text{Solar}}} \]  
(8)

In our experiments, we tested and actually measured two different devices and plotted the energy efficiency diagram in Fig. 11.
4. Conclusions

Most of the power switching circuits are currently using mechanical devices which are bulky and easily damaged. In this study, we design and analyze a photovoltaic switching circuit using the photosensitive resistor, Darlington amplifier, and relays, which can quickly switch power input between the city grid and solar energy system. Under an independent mode of operation, this system can directly convert solar power into 60 Hz, 110 V AC in order to provide a power source for small household loads. Our experimental data confirm the feasibility of the system.

References


Yun-Parn Lee received his M.S.E.E. and M.S. degrees in mathematics from the University of Cincinnati in 1979 and 1980, respectively, and the Ph.D. in electrical and computer engineering from the University of California, San Diego, in 1995. His major research interests include optical computing, vision and pattern recognition, VLSI and optoelectronic system design, and artificial neural networks. Dr. Lee’s name is listed in the Who’s Who in Science and Engineering, the 4th edition, 1998–1999. During his career, Dr. Lee has worked for Sony, Philips, NEC, and SST (Silicon Storage Technology, Inc). Dr. Lee is currently an assistant professor with the Department of Electronic Engineering, Ming Chuan University, Taoyuan.

En-Chi Liu received his B.S.E.E. degree from Ming Chuan University in 2010 and M.S.E.E degree from Chung Cheng Institute of Technology in 2013. He is an assistant engineer with Wistron Company, Taipei. His research interests include the electronic circuit design, semiconductor manufacturing process, and optoelectronics device design and simulation.