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On the Design of an Intelligent Battery Charge Controller for PV Panels

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Abstract

The electricity generations of photo voltaic (PV) panels are strongly related with insolation and temperature. The insolation and temperature are not stable, since the electricity generations of the PV panels are not stable. In PV systems, insolation and temperature continuous vary. Therefore, the maximum power point tracking (MPPT) techniques are used to give the highest power to the loads/batteries. The MPPT process is performed with a power electronic circuit and it overcomes the problem of voltage mismatch between the PV panels and the batteries/loads. In this study, a microcontroller is employed to develop battery charge control system for PV panels. The system is composed of a microcontroller (Microchip PIC18F2550), a buck-boost type DC-DC converter, a resistive load, and lead acid battery. In the system, MPPT, charge control, and discharge algorithms are executed by a program embedded within the microcontroller. The program also has ability to perform some data acquisition process and acquired data are sent to the personal computer (PC) through the USB communication port. In addition the system has able to be followed and controlled by the graphical user interface (GUI).

Keywords: PV panels, Charge controller, Buck-boost converter, Lead acid battery, LabVIEW

1. Introduction

Renewable energy sources are an attractive issue due to environmental protection. Solar power is one of the important topics in renewable energy sources. So, many researches have addressed the improvement of solar power system. Many types of PV power conversion systems have been developed including the grid-connected system for reducing the power from the utility and the stand-alone system for providing the load power without the utility [1]. In case of stand-alone system is usage, batteries are required for energy storage. Electricity generations of solar panels are strongly related with solar radiation intensity. However the intensity is not stable. Therefore, charge efficiency is a very important topic in solar systems. Charge controllers are designed to improve charge efficiency and safety. The primary function of a charge controller is to protect the battery from overcharge and over discharge in a stand-alone PV system [2]. There are a lot of studies about the charge controller in the literature. Harrington and Dunlop (1992) analyzed the typical strategies for battery charge regulation in stand-alone PV systems and conclude that the battery information is very important in designing PV systems [2]. Ullah et al. (1996) focused on the design of a super-fast battery charger based on National's proprietary neural network based neural fuzzy technology. They compared their method with conventional fast chargers and indicate that their method reduce the charging time [3]. Masheleni and Carelse (1997) designed an intelligent charge controller, incorporating an SGS–Thompson microcontroller, ST62E20 and discussed the advantages of such charge controllers [4]. Hsieh et al. (2001) proposed a fuzzy-controlled active state-of-charge controller (FC-ASCC) for improving the charging behavior of a lithium–ion (Li–ion) battery. In this method, a fuzzy-controlled algorithm is built with the predicted charger performance to program the charging trajectory faster and to remain the charge operation in a proposed safe-charge area (SCA). They increased the charging speed about 23% [5]. Yi et al. (2007) presented a novel switch-mode charger controller IC for improve the charging efficiency of valve regulated lead-acid (VRLA) battery and save its life. They achieved fast transient response and the precisions of both constant current and constant voltage charge modes met the specifications well [6]. Chiang et al. (2009) presented the modeling and controller design of the PV charger system implemented with the single-ended primary inductance converter (SEPIC) and gave a detailed modeling of the SEPIC with the PV module input and peak-current-mode control. The system has been proved to be effective in the MPPT and power balance control. The MPPT controller was implemented with the Matlab real-time control in their study [1]. Tesfahunegn et al. (2011) proposed a new solar/battery charge controller that combines both MPPT and over-voltage controls as single control function. They conducted two case studies in Simulink/Simpower, first to evaluate the performance of the designed controller in terms of transient response and voltage overshoot. Secondly, realistic

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irradiance data is used to evaluate the performance of the developed charge controller in terms of parameters such as PV energy utilization factor and overvoltage compared to the conventional hysteretic on/off controller. They achieved good transient response with only small voltage overshoot, better in terms PV energy utilization and same level of over-voltage control [7]. There are some applications which are use MPPT controller [11-13]. Dakkak and Hasan (2012) analyzed a charge controller based on microcontroller in stand-alone PV systems and they conclude that such systems reduce the power consumption for charging battery and give flexibility to the designer [8]. Karami et al. (2012) focused on the load type and suggest new methods to reach the MPP depending on the load state and the development of the PV array mathematical model. They analyzed the effect of temperature and irradiance on the battery charger and showed the difference between the direct-coupled and the indirect-coupled applications of a PV panel [9]. In this study, a microcontroller based charge control system is designed. The system can be used as an infrastructure for engineering students educated on PV panels. The charge control system is composed of two main parts: 1- Hardware, 2-Software. First part is presented in Section 2 whereas, the second part is detailed in Section 3. Finally, the results are presented in Section 4.

1. Hardware architecture of the charge controller

Hardware of the system is composed of a microcontroller (Microchip PIC18F2550), PV panel, a buck-boost type DC-DC converter, a resistive load, lead acid battery, USB communication circuit, load switching circuit, some measurement circuits (temperature, current, and voltages etc.), LCD display to observe some data, and buttons to control the system, manually. These parts of system are presented in below, separately.

1.1. Microcontroller

The PIC18F2550 microcontroller has 8 bit microprocessor, 32KB flash memory, 16 bit instruction length, 256B eeprom, 24 input/output (I/O) ports, 10 analog to digital (A/D) converter inputs which have 10 bit resolution, one 8 bit timer, two 16 bit timers, two pulse with modulation (PWM) pins which have aproximitly 10 bit resolution, and USB communication ports. This microcontroller is ran 48MHz clock frequency. PV panelA mono- crystalline PV panel is used in this study. The PV panel has 20W power, 21V open circuit voltage (V_{OC}), 1.32A short circuit current (I_{SC}), 1.12A maximum power current (I_{mp}), and 18V maximum power voltage (V_{mp}). This PV panel has 36 cells and these cells are tested at standard conditions ($1000W/m^2$ irradiation and 25^oC temperature). The sizes of PV panel are $275x620x22mm$ and the panel is mounted on a platform (Figure 1).

Buck–Boost converter. The buck–boost converter is a type of DC/DC converter. In this study buck-boost converter is realized by two switching element (Figure 2). This circuit works as a positive buck-boost converter and it is able to be used as buck or boost converter, separately. The circuit has $68\mu H$ coil and $10\mu F$ output capacitor. IRF540 n-channel power mosfets are selected as the switching elements. These mosfets have 100V drain source voltage (V_{DSS}) and 30A drain current (I_D). Gates of the mosfets are driven with 25MHz PWM signal. Diode of buck and boost are chosen 1N5822 schottky rectifier which has 40V peak repetitive reverse voltage (PRRV) and 3A average rectifier forward current (ARFC). In this scheme, C_VOUT capacitor is used to overcome the output voltage repeal and R_VOUT is used to protect to mosfets from no load condition.

Fig. 1. PV panel and position of PT100 sensor

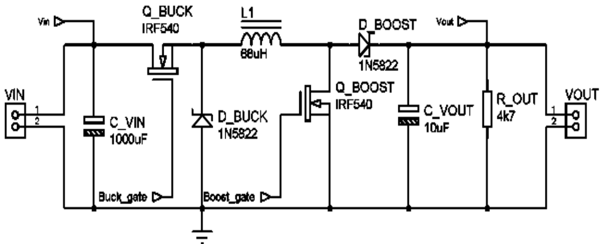

Fig. 2. The schema of buck-boost controller

The battery and resistive load In this system, a lead acid battery is employed to store electricity generation of PV panel (Figure 3). The battery has 12 V output and 7Ah capacity. Charge voltage of the battery is 13.8V. Resistive load is used to discharge the battery for the next charging cycle. The resistive load has 12V voltage and 5W power (Figure 3). By means of the resistive load discharge characteristic of battery can be obtained.

Fig. 3. The battery and load

Resistive load is connected to battery via a contact of relay. The wiring shema of resistive load, battery, and relay is presented in Figure 4. The relay is programmatically controlled with microcontroller.

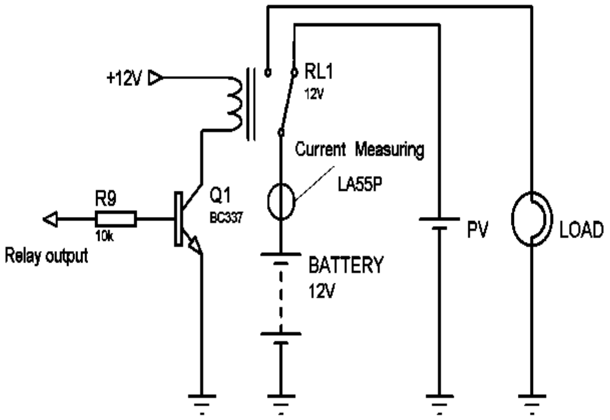

Fig. 4. Load and battery switching circuit

1.2. Measurement circuits

In the system, front layer temperature of PV panel, PV panel current, PV panel voltage, and battery voltage parameters are measured by some special circuits. Since measuring of junction temperature is not possible, layer temperature of the PV is measured in this system. Therfore, the temperature sensor is placed in the layer of PV panel. However, shade effect of the sensor is prevented. A PT100 sensor is used to sense the layer temperature (Figure 1).

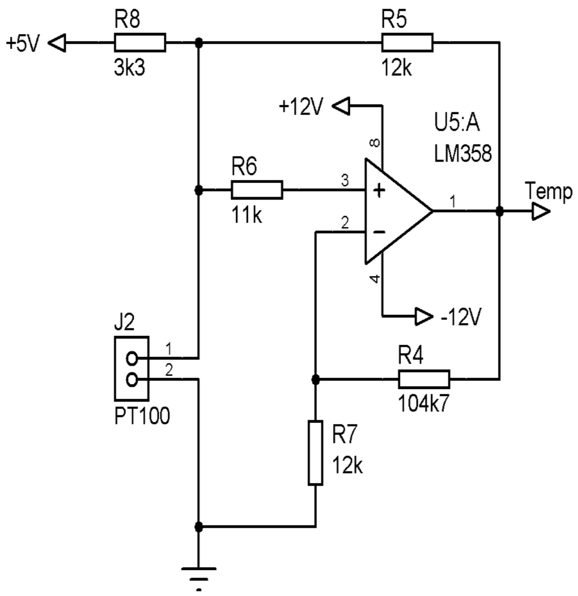

Fig. 5. The schema of PT100 amplification circuit

The PT100 amplification circuit including LM358 Op-Amp is seen in Figure 5. In this circuit a very few current (approx. 1.4mA) is crossed through the PT100 sensor. Since the current cross through the sensor cause heat, some measuring errors should be occurred. To prevent such errors the current must be limited around 2 mA. It is possible to adjust the gain of op-amp via R4 and R7 resistances. By means of R5 feed-back resistor, linearity of amplifier is guaranteed. In Figure 6, temperature versus output voltage characteristic is illustrated. It is obvious from this figure that output voltage alters by temperature, linearly.

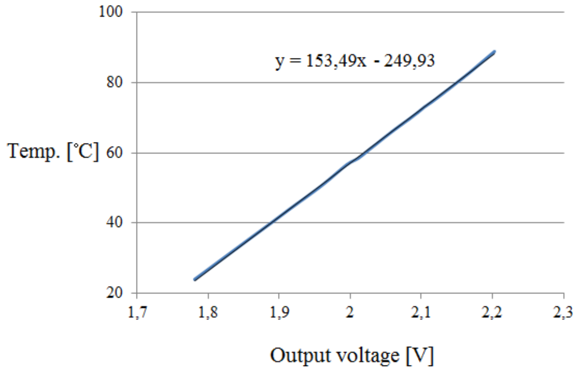

Fig. 6. Relationship between temperature and output voltage

The output voltage of op-amp is connected to the analog input of microcontroller and it is digitized by ADC. Digitization levels are converted to real temperature values using equation shown in Figure 6. Second measurement circuit is designed to measure battery and load currents. The circuit consists of a LA55P current transducer, and amplification circuit. The LA55P current transducer is very sensitive and it is quite suitable to measure battery current. The LA55P has 50A nominal primary current rms (I_{PN}), and 25mA nominal secondary current (I_{SN}). Since microcontroller is not appropriate to measure current, a current to voltage converter circuit is designed (Figure 7).

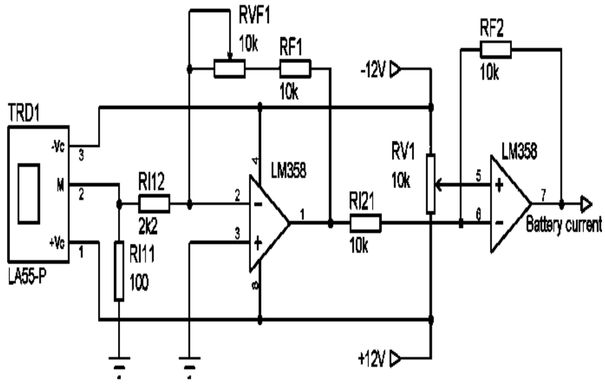

Fig. 7. Current to voltage converter circuit

In this circuit, current flowed through the measurement pin of LA55P (M) is caused a voltage drop on 100Ω resistance. The voltage is amplified and inverted by first and second op-amp respectively. In second op-amp, voltage is applied by a variable resistance to positive input pin of the op-amp. By means of this voltage, offset value is obtained. Furthermore, by this way it is possible to measure negative current. Since it is not possible to perform negative voltage by microcontroller, such as alternative way is used. Relationship between battery current passing through the primary of LA55P and op-amp output voltage are seen in Figure 8.

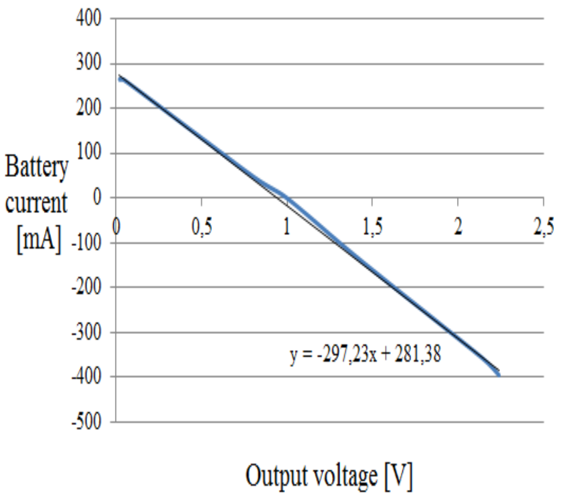

Fig. 8. Relationship between battery current and output voltage

It is obvious from Figure 8 that for 400 mA case, circuit output voltage is at approx. 2V level and there is almost a linear relationship between output voltage and battery current. The negative current is denoted that the current flows from battery to load and positive current is denoted that the current flows from PV panel to battery. The battery current output is wired to analog input of microcontroller. Equation seen at Figure 8 is employed to convert digital values produced by microcontroller to real current values.
To measure battery and PV panel voltages, different circuits are designed and used. These circuits are composed of very simple voltage dividing, filter, and protect circuits (Figure 9). The voltage dividing circuit is employed to adjust the ADC input level. High frequency components (noises) are destroyed with filter circuit. The protection circuit is formed of 5V zener diode and it guaranties that ADC input voltage level is not over than 5V level. Since battery and PV panel voltage measuring circuits are same, the measuring circuit of PV panel voltage is not given in Figure 9.

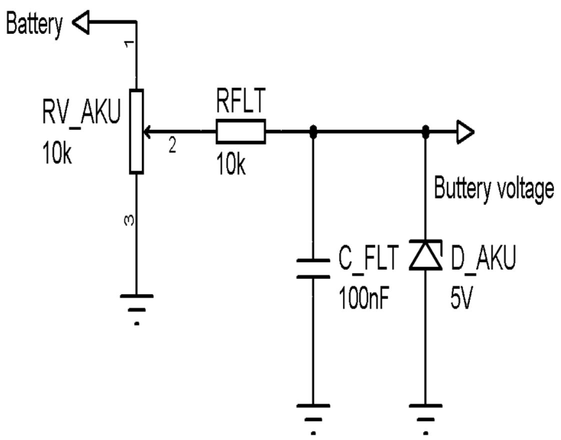

Fig. 9. Battery voltage measuring circuit

Our charge controller design for PV system is illustrated in Figure 10. It has a LCD panel to observe data. It also has buttons that are placed near LCD panel to implement buck and boost operations, manually.

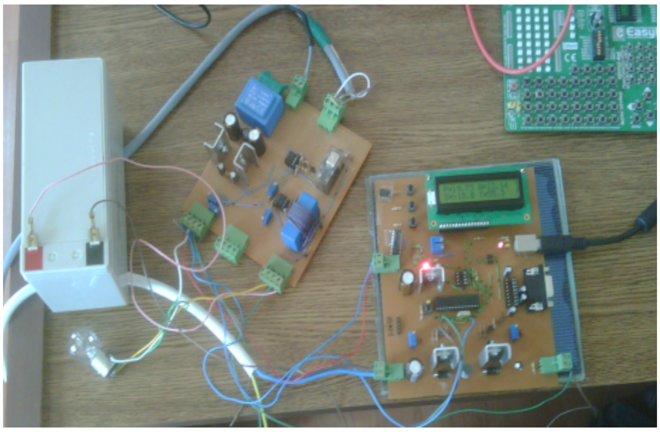

Fig. 10. The circuit of charge controller for PV panel

2. Software architecture of the charge controller

In this system, software architecture is originated two main parts. First one is a control program embedded within the microcontroller. Second one is a GUI program operated in PC. These are detailed below.

2.1. Microcontroller program

The program embedded in microcontroller performs measure, control, display, and communication tasks. In below flowchart of this program is presented (Figure 11).

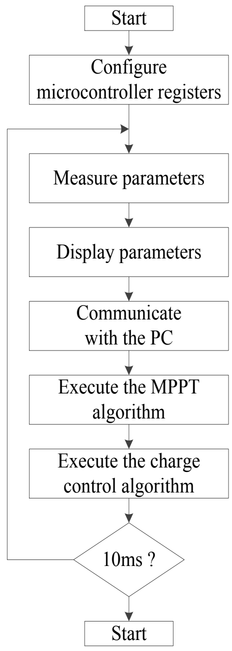

Fig. 11. Flowchart of microcontroller program

Special register of microcontroller are adjusted as a first step. Then the parameters are measured by ADC converter unit. After this procedure, measured parameters are display in LCD module (Figure 10). Following the displaying procedure, the PC communication subroutine is operated by USB interface unit. Finally, the MPPT and charge control algorithm are executed. All of these processes are operated in 10ms interval.

2.2. GUI program

In control section, to fulfill all the measurement and control functions, a GUI in LabVIEW is designed (Figure 12). Various components are built to observe the data and control the parameters in the interface program. It is possible to select the communication part and to observe the panel and battery voltage values using GUI, instantly. Buck and boost operations can be implemented manually, besides. An illustration of the GUI is presented in Figure 12.

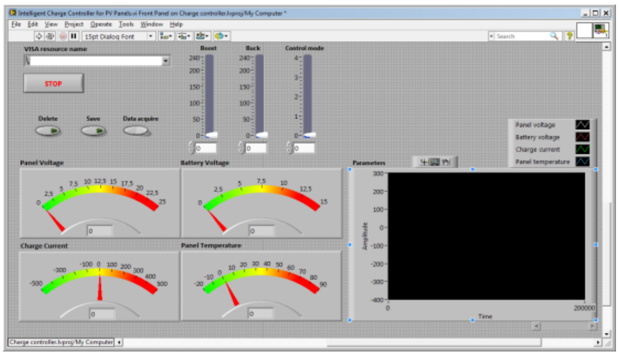

Fig. 12. Picture of computer interface (Front panel of VI)

LabVIEW is an object oriented software. Therefore it is possible to design or define objects and it is possible to connect these objects to each other without writing codes. Each function or procedure is stored in a program that is defined as VI (Virtual Instrument) and consists of two main components; front panel and block diagram [14, 15]. The front panel given in Figure 12 corresponds to a VI program that is designed to control the experimental set and acquire the experimental data used in this study. Front panels are the user interfaces containing data input and control components. Block diagrams are the panes where the functions are defined graphically. A block diagram may contain one or more sub VI that may be made similar to sub-procedure in text base programs (Figure 13).

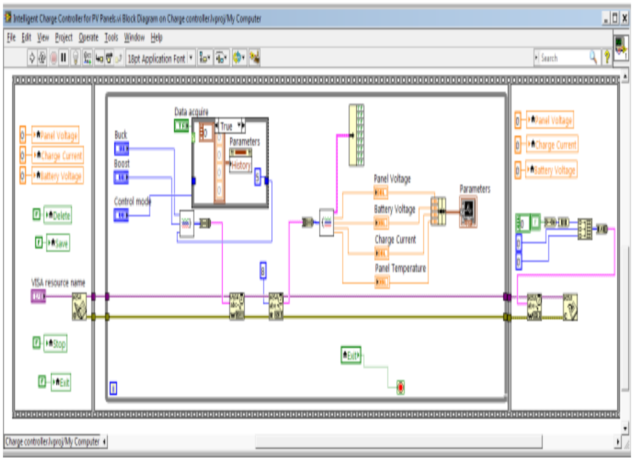

Fig. 13. Block diagam of VI

4. Conclusions

In this study, an intelligent charge controller system is designed. Designing and testing different MPPT algorithms on the system can be regarded as future studies. The buck-boost DC-DC converter including two switching element is preferred for the system. To improve charge efficiency MPPT control is needed. It is of vital importance to measure PV panel voltage, PV panel current and junction temperature parameters to develop an accurate MPPT algorithm. By the system developed in this study, it is possible to measure and analyze all of these parameters. Furthermore, it is possible to test MPPT algorithms such as Pertub and Observe (P&O), incremental conductance, and constant voltage etc. The system is user friendly since a GUI is built under LabVIEW environment. It is possible to test some MPPT and charge control algorithms via designed system

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