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Research Article

Research on Battery Charging-Discharging in New Energy Systems

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Abstract: As an energy storage component, the battery plays increasingly important role in new energy industry. Charging and discharging system is the vital part of the application of the battery, but the charge and discharge are always designed separately and carried by different part in the traditional application. Additionally, most battery discharge mode and method are always simplified which cannot ensure to meet the demand of power utilization. In the actual energy storage system, the design of the energy converter, which make the power storage and supply as a whole and the design of the charge and discharge method, will play an important role in efficient utilization of the battery system. As a part of the new energy system, the study makes battery and the charging and discharging system as a whole to store energy, which can store and release electric energy high efficiently according to the system state and control the bidirectional flow of energy precisely. Using TMS320F2812 as the control core, the system which integrates charging and discharging with battery monitoring can achieve the bidirectional Buck/Boost power control. It can achieve three-stage charging and selective discharging of the battery. Due to the influence of the diode reverse recovery time, current oscillation will appear. In order to eliminate the oscillation, we can set the circuit to work in critical conduction mode. The experimental result shows that the system can achieve the charging and discharging control of lead-acid battery and increase the battery life time further.

Keywords: Buck/Boost, critical conduction mode control strategy, DSP, lead-acid battery, three-stage charge

INTRODUCTION

As the structure of the global energy is developing in the direction of green, the appliance of lead-acid batteries in new energy has fast development. In wind energy, solar energy, tidal energy and other new energy systems, the power fluctuates greatly due to the impact of changes of natural conditions. So the energy storage battery is essential to stabilize the power output, especially in some large systems (Bimal, 2000). Besides, as a kind of distributed power, it can balance the new energy to ensure the system stable and reliable. The battery is not only an important energy storage device, but also a stable power supply device, such as ones in electric vehicles and other mobile devices (Xu and Sankaram, 1993; Hua and Lin, 2000) In conclusion, a battery can affect the life time of the system due to the important role it playing in new energy system. To solve the problem, the property of a battery needs to be improved, as well as the design of the charging and discharging strategy. At present the battery charging and discharging system is designed mostly for some UPS systems (Noworolski *et al*., 1991) and the application in large new energy system is less. Literature (Sauer and Garche, 2001) only gives the design and model of battery in photovoltaic systems. In addition most articles only study the charging method (Cope and Podrazhansky, 1999; Bo-Yuan and Yen-Shin, 2012) and present few clear design scheme of the charging circuit. The battery discharge mode and method are also not detailed and charge and discharge of battery have been usually separated into two parts (Koutroulis and Kalaitzakis, 2004). Even through Analog control chips are still used, the control precision can not satisfy the requirement of accuracy. Digital control is the trend of control method in the field of the industry. As the battery charging is electrochemical reaction, charging methods will have influence on the speed of the charge. A lot of references have presented the improvement in the traditional three-level charging method (Reid and Glasa, 1984; Guo and Huang, 2010), such as intermittent charge, pulse charge and negative pulse charge. But the realization methods are more complex and cannot ensure to make the battery charging speed improved significantly

This study will study the Valve-Regulated Lead-Acid Battery (VRLA) and optimize the design of the charging and discharging strategy to improve the property of the battery. The system uses relatively simple and practical Buck/Boost converter topology. Through the improvement of this topology and the optimization of the hardware circuit and the control method, we can make the system achieve stable charging and discharging with high efficiency, which

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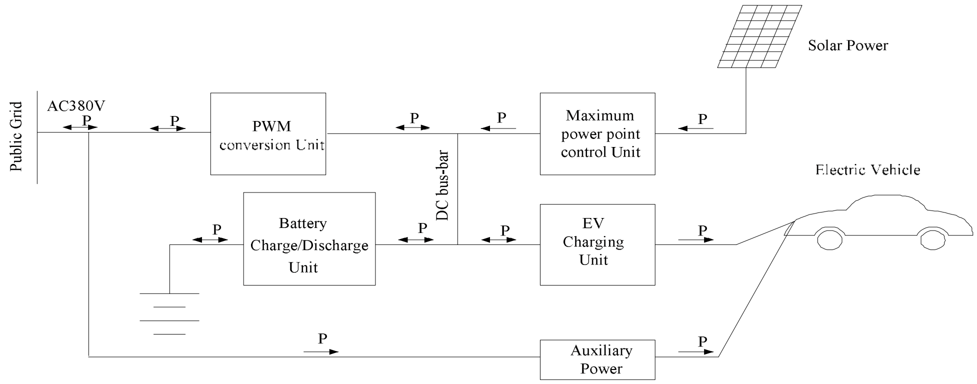


Fig. 1: New energy system

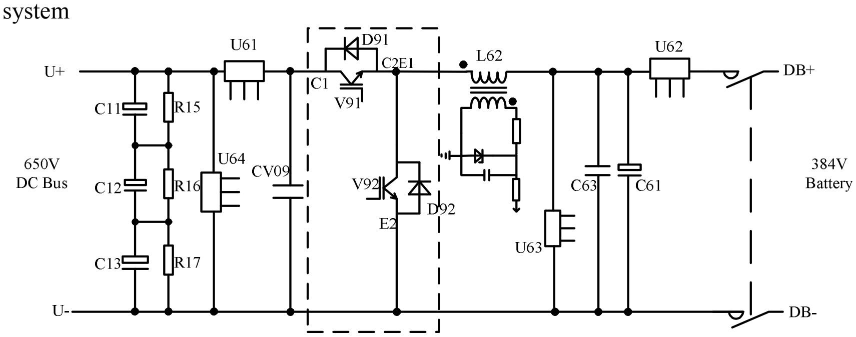


Fig. 2: Buck/boost schematic diagram of a battery bi-directional charging-discharging

extends the life time and improves the state of charge of the battery.

BATTERY ENERGY STORAGE IN NEW ENERGY SYSTEM AND THE CIRCUIT OF CHARGING-DISCHARGING

- **Battery energy storage in new energy system:** Figure 1 shows the structure of the new energy system, which is composed of solar power, electric vehicles charging, batteries energy storage and grid-connected bidirectional inverter. These four parts are linked via the DC bus-bar and they can work as a whole or individually.
  This study shows the design, calculation and test result of batteries energy storage (BES). The main functions of BES unit are to store energy from photovoltaic or the feedback power of electric vehicles and to discharge to supply energy to the electric vehicles when needed by linked to the system via the DC bus. Therefore, the electrical converting circuit of batteries can charge and discharge fastly, convert the working state rapidly and have high precision of stabilizing voltage/current and advanced charging and discharging control mode.

- **The Bi-directional circuit for battery charging-discharging:** The components parameters in the circuit as shown in Fig. 2 are as follows:
  - V91, V92: IGBT (2MBI200N-120), working in the switching frequency of 20 kHz.
  - L62: reactor of 300 uH
  - CV09: capacitance of 0.47uF/1200V
  - C61: capacitance of 150uF/900V
  - U61, U62: current sensor HS-50A-P
  - U63, U64: voltage sensor LV25-P
  - 32 sealed valve-regulated lead-acid cells of 65AH/12V

In this system, the voltage of 32 cells in series is DC384V. (The measured initial voltage range of cell: 12.87-13.1V) The charging voltage of the cell is 14.4-15 V and the maximum charging current whose value is 16.25A is not larger than 25% of the rated value.

Over-discharge means that battery terminal voltage is lower than the required cut-off voltage. It causes batteries serious damage and reduces the life time of the battery. The discharging current is not larger than 3C and a cell cut-off voltage is not less than 1.3V.

- **The principle of buck and boost circuit:** In Fig. 2, Buck circuit is composed of IGBT-V91, freewheeling diode D92 and inductance L62.Power supply in the DC bus-bar side is transported to the battery side through L62 on V91 conduction. DC output voltage is different according to the different duty cycle of V91; therefore the battery is charged by the output voltage which is controlled by V91. Meanwhile V92 and D91 are always state-off.

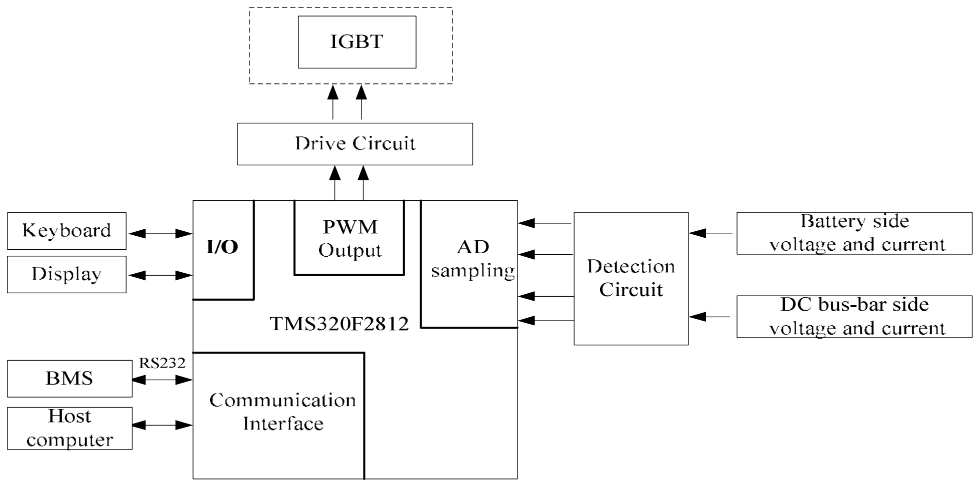


Fig. 3: Overall system design diagram of control circuit

In Fig. 2, Boost circuit is composed of IGBT-V92, freewheeling diode D91 and inductance L62. L62 stores electric energy on V92 conduction. The positive voltage of L62 is in the left after the closing of V92.Energy is transported to the side of DC bus-bar after the voltage of L62 integrates with the battery voltage, so energy in the battery is released through BOOST circuit. Meanwhile V91 and V92 are always state-off (Jun *et al*., 2010; Ned *et al*., 1995).

In the circuit, V91 and V92 mustn't be on conduction at the same time in order to avoid a short circuit.

- **Characteristics of the bi-directional power conversion circuit:** The circuit in Fig. 2 combines Buck circuit with Boost circuit, so that it can achieve bi-directional power conversion through the controlling of V91 and V92.
  The system contains the following advantages:

  - DC/DC converter has advanced control technology.
  - Two IGBTs-V91, V92 and freewheeling diodes D91, D92 in Buck and Boost circuits are integrated in a single module and they make the power circuit simple and easy to be installed and cool.
  - Controlling circuit is simple.
  - The switching frequency of IGBT is up to 20 kHz and the filter reactor is small and light.
  - Batteries work with converters as a whole, so we don't need to replace a battery like traditional charging devices. The overall efficiency of the system is high because the power supply doesn't need to be isolated by the transformer.
  - The energy achieves seamless bi-directional exchange under accurate calculation of the DSP.

When cells are discharged in Boost mode, a relatively high reverse current spike is discovered due to long reverse recovery time (350 ns) of IGBT. In order to avoid the damage, V92 is conducted when the inductor current drops to 0. This method can achieve the effective conduction of the IGBT so that large reverse current can be eliminated and the damage of IGBT and freewheeling diodes is avoided.

By using the critical conduction mode control strategy, V92 is conducted when the inductor current come to be 0, which makes the converter work in the critical conduction mode. Therefore, the inductor should be coupled with the coil when the main circuit is designed. The coupled circuit can output the falling edge to control the opening of IGBT when the inductor current is 0 (Huang, 2006).

- **Control circuit:** Figure 3 shows the overall system design diagram of the control circuit. The main control chip is the TI DSP TMS320LF2812, besides the system includes drive circuit, voltage and current detection circuit, protection circuit, keyboard display circuit and auxiliary power supply.

CONTROL ALGORITHM AND REALIZATION OF DSP

- **Control algorithm:** In conventional cases, as shown in Fig. 4, the charging mode is three-stage: constant current, constant voltage and floating. However, the constant charging current will increase if the DC bus voltage rises fast due to the large amount of electric energy generated by solar power. (experimental subject are ten 12V65AH valve regulated lead acid batteries).

During the transition to the second stage, the charging current should be limited in order to avoid a sudden increase of the current. So the charging mode maintains the first stage namely the charging mode of

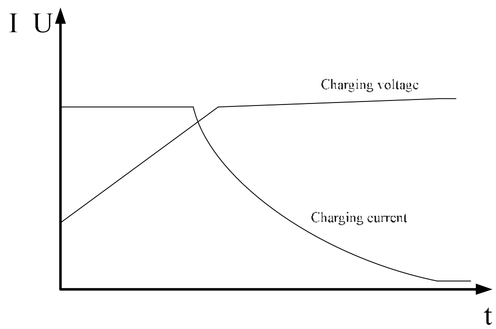
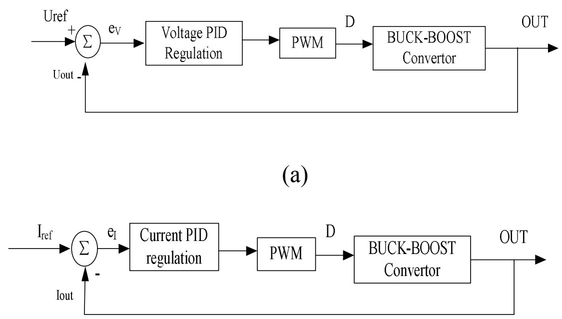


Fig. 4: Conventional battery charging curves



(a)

(b)

Fig. 5: Control diagram of the constant voltage and the constant current control

the constant current when the current doesn't match with the setting value of the second stage.

The discharging mode of the battery is the selective constant voltage or the selective constant current. The charging mode is selected by users or the system and the system can select the discharging mode when the condition is OK.

The control diagrams of the charging system and the discharging system are the same because they use the same modes, shown in Fig. 5.

Control flowchart: The main program achieves some initialization, preparatory work before running the system and displaying when running the system. The initialization includes the system in the DSP, IO conFiguration, all the variables, AD sampling module, EV, etc. After the preparation, open the AD sampling interrupt and interrupt every 50us to sample two groups of voltage and current signals. We can get the actual value after filtering and converting the result of the sampling. Then enter into the charging and discharging subprogram respectively through the judgment of the system operating mode.

The flow chart of the main program is shown in Fig. 6.

The function of the charging subprogram is to achieve stable operation of the charging circuit in three

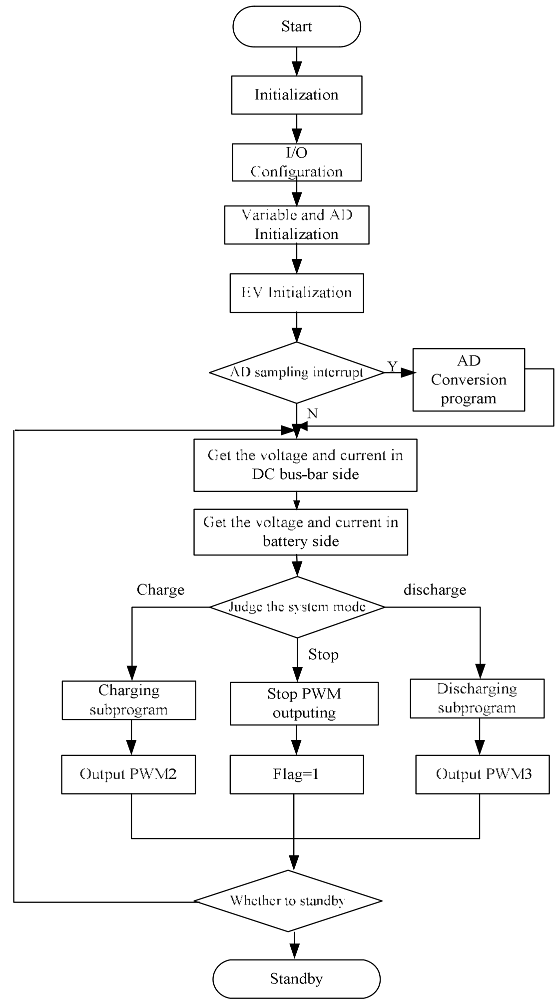


Fig. 6: Flowchart of the main program

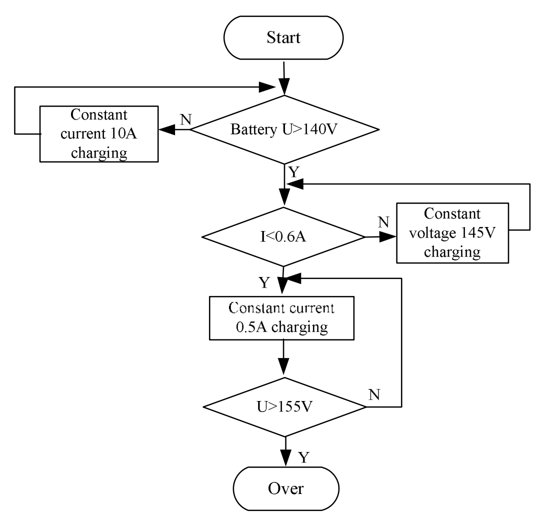


Fig. 7: Subprogram of charging

stages and a smooth transition in the switching processes of various stages. The first stage achieves the constant output current by controlling the duty cycle of

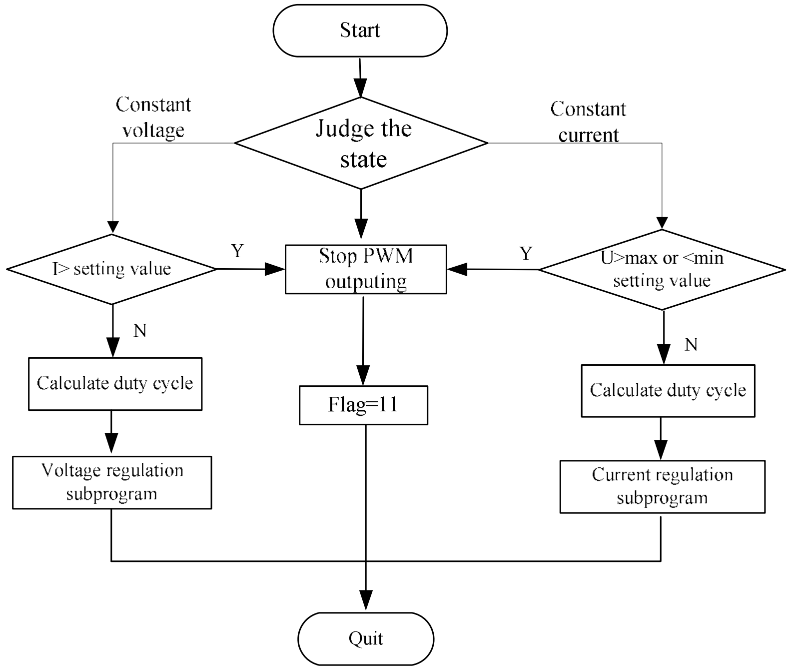


Fig. 8: Subprogram of discharging

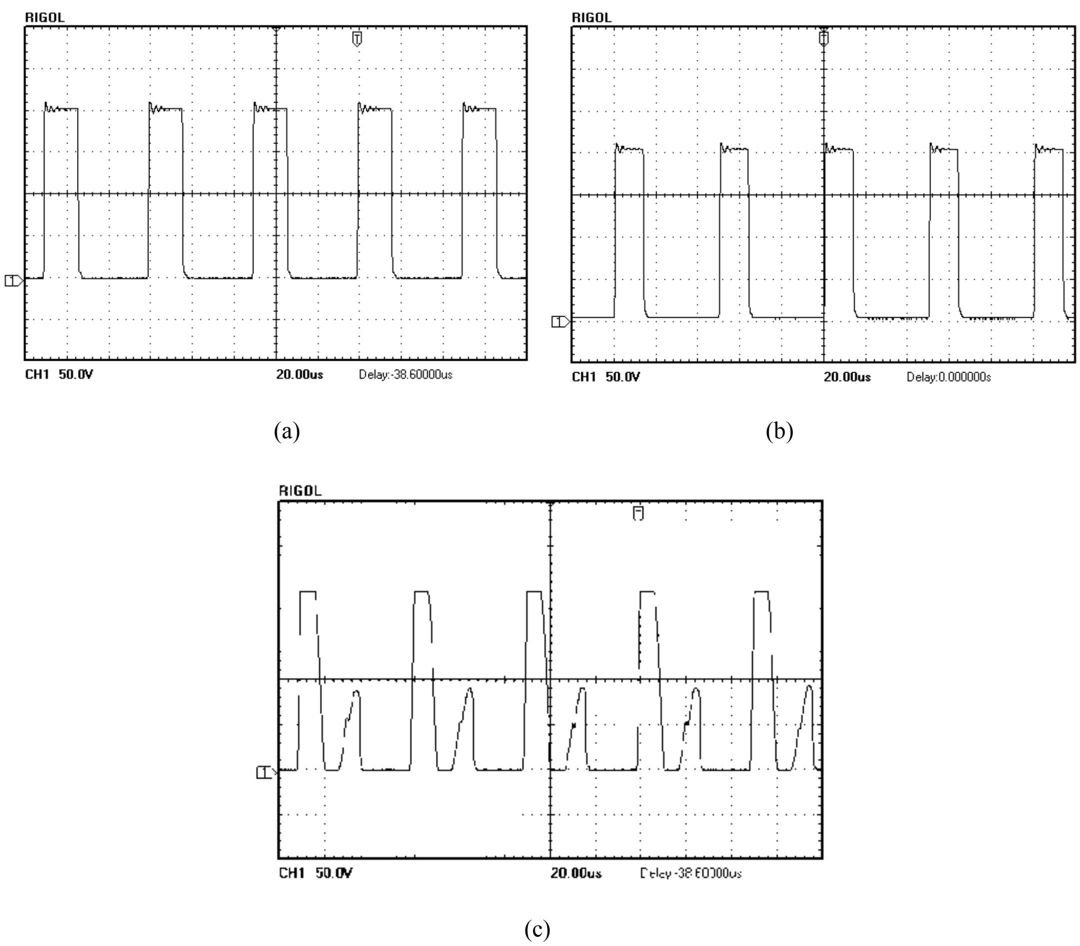


Fig. 9: C-E voltage waveforms in different stages

PWM to keep the charging current constant (such as 10A). Before entering the second stage, in order to ensure that the charging current has no mutation, a transition stage needs to be set in the program. Similarly, in the third stage, the charging current is maintained at a floating state and when the charging voltage rises to the upper limit of the battery, the charging stage ends. The flow chart of the charging subprogram is shown in Fig. 7.

First, determine the state and select the discharging mode namely the constant voltage or the constant current. In the discharging mode of the constant voltage, ensure the current to be maintained in the setting range and then calculate the duty cycle via the setting voltage value and control the opening and closing of IGBT by the voltage regulating subprogram. The discharging mode of the constant current is similar to the constant voltage.

The flow chart of the discharging subprogram is shown in Fig. 8.

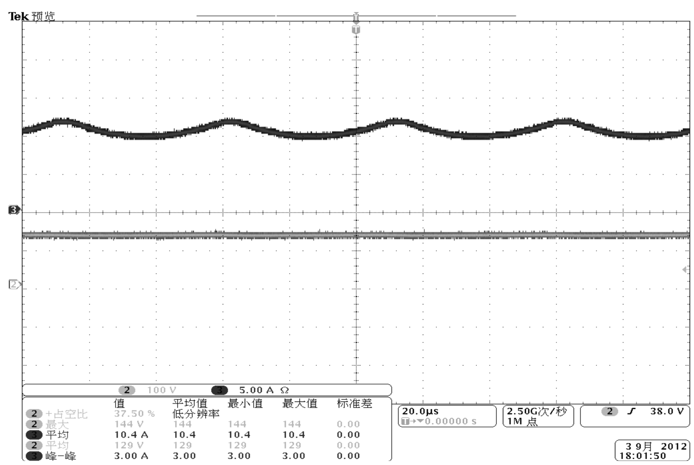
EXPERIMENTAL RESULTS AND ANALYSIS

- **Waveform for charging:** In the first stage, charge the battery with relatively large current at the beginning of the charging. We use 10 A to charge the battery and the terminal voltage of the battery gradually increases linearly and enters the second stage when the voltage increases to 140 V.

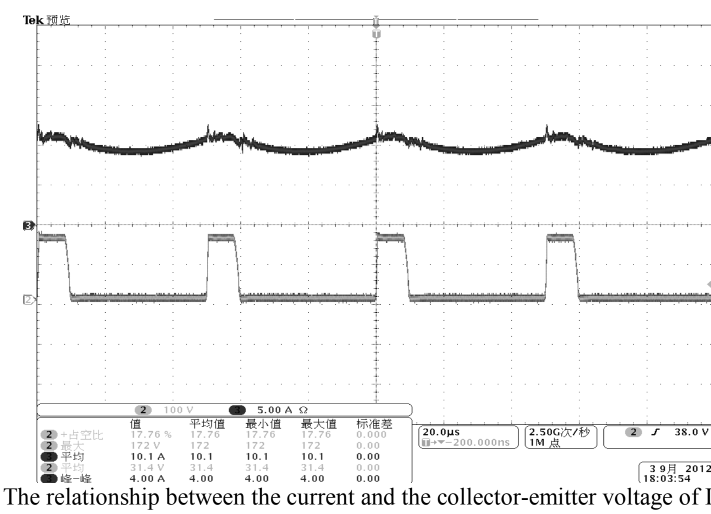
In the second stage, use 145 V to charge when entering the constant voltage mode and the charging current rapidly decreases exponentially. The third stage begins when the current reduces to 0.6 A.

In the third stage, use the smaller current 0.5 A to charge the battery, namely floating. The charging ends and the system stops running when the battery voltage rises to 155 V.

Figure 9a shows the C-E (collector-emitter)voltage of V 91 in the first stage of the charging. The Buck circuit



(a) The charging current and voltage of the battery



(b) The relationship between the current and the collector-emitter voltage of IGBT

Fig. 10: Current and voltage waveforms in the constant current stage

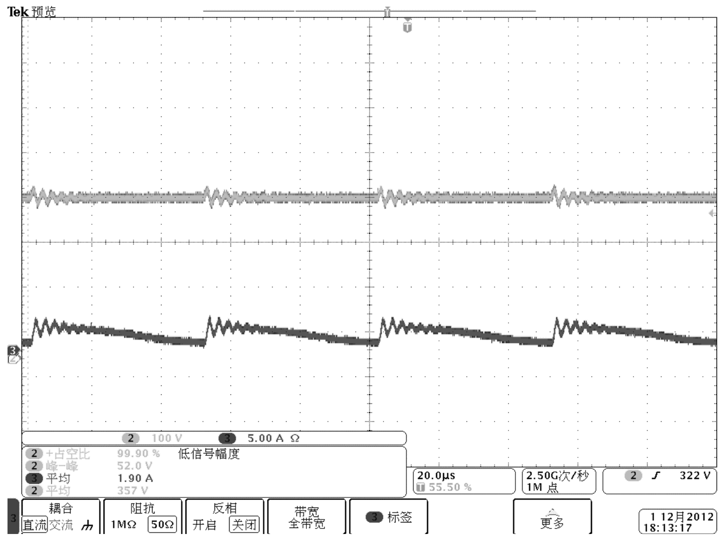


Fig. 11: Output current and voltage in constant voltage discharging mode

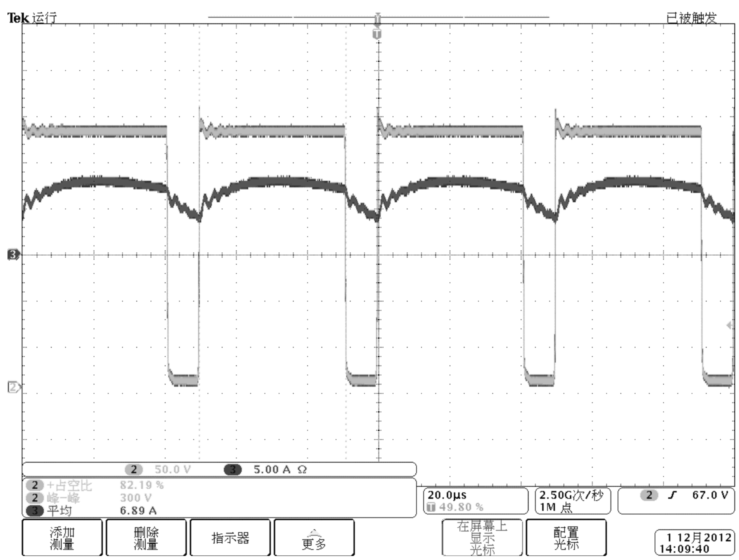


Fig. 12: Current and C-E voltage of IGBT in constant current discharging mode

outputs the constant current whose value is 10 A and duty cycle D gradually stabilizes at 67.2%. Figure 9b shows the C-E voltage of V 91 in the second stage of the charging. The output voltage is 145V which is the set value and the duty cycle is 72.8%. Figure 9c shows the C-E voltage of V91 in the third stage of the floating. The output current is 0.5A and the duty cycle is 81.3%. There will be current interruption causing the spikes because the floating current is too small. The phenomenon appears when the current in the second stage gradually decreases.

We set 10A to charge the battery in the constant current mode and the waveform of the inductive current is high-frequency saw-tooth and the effective value is 10A, shown in Fig. 10. Figure 10 shows the relationship between the current and the collector-emitter voltage of IGBT. When IGBT is on conduction, the inductor is charged and the current rises. On the contrary, the inductor is discharged and the current decreases. The rising rate is lower than the descending rate because the turn-on time is long.

- **Waveform for discharging:** Through the experiment we can get the waveform when the battery is discharged in the two kinds of mode. Figure 11 is the waveform of discharging voltage and current in constant voltage discharging mode. As the Fig. 12 shows, the discharging voltage is set to be 350V and the current will decrease gradually with the discharging time increasing, as well as the voltage of battery. For maintaining a constant output voltage, duty cycle will increase gradually. Figure 12 shows the waveform of output current and the CE-voltage of IGBT in constant current

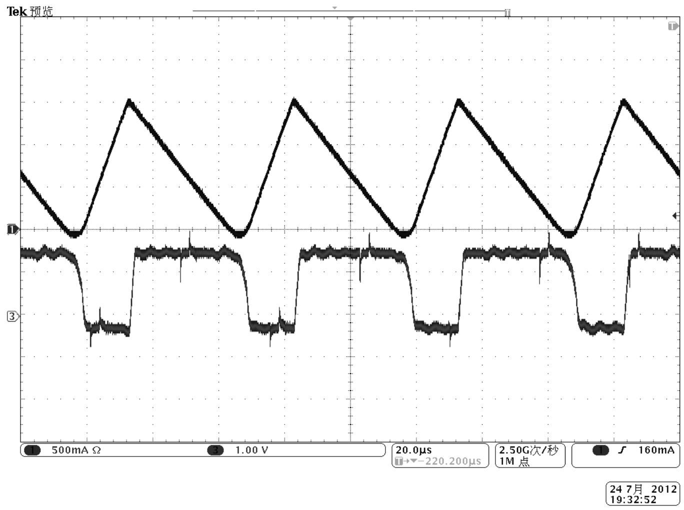


Fig. 13: Zero-current detection wave of the inductor

discharging mode. Discharging current is constant at 7A and the pulse duty cycle is 17.8%.

We can find that there are current oscillations and voltage spikes when the IGBT works. The reason for the phenomenon is that the diode reverse recovery time is too long and makes the parasitic inductance and parasitic capacitance in the circuit resonant. In order to eliminate the current oscillation, we can make the circuit operate in critical conduction mode. Therefore, it is necessary to design a zero-current detection circuit. In this study, this circuit is designed and tested by experiments. The waveform is shown in Fig.13. When the inductive current reaches zero, the detection circuit outputs the falling edge and IGBT is controlled to open by DSP. The function of the critical conduction mode is to eliminate the reverse recovery of the freewheeling diode by turning on the active switch when the inductor current drops to zero.

CONCLUSION

The study researches the charging-discharging system of the lead-acid battery in new energy system and achieves the bidirectional Boost/Buck power circuit which combines charging with discharging. The system achieves three-stage charging and selective discharging of the battery. The experiment shows that the system can achieve the control of charging and discharging of the lead-acid battery and increase the utility ratio and the life time of the battery. To realize the safe use of the battery further, battery management system is conFigured to test a single cell so that the battery can be better maintained. In addition, the system control algorithm can also continue to be improved to make the system more stable.

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REFERENCES

Bimal, K.B., 2000. Energy, environment and advances in power electronics. IEEE T. Power Elec., 15: 688-701.

Bo-Yuan, C. and L. Yen-Shin, 2012. New digital-controlled technique for battery charger with constant current and voltage control without current feedback. IEEE T. Ind. Elec., 59: 1545-1553.

Cope, R.C. and Y. Podrazhansky, 1999. The art of battery charging. Proceeding of the 14th Annual Conference on Applications and Advances, pp: 233-235.

Guo, Y. and L. Huang, 2010. The charging technology for lead-acid battery with a negative pulse [C]. Proceeding of Asia-Pacific Power and Energy Engineering Conference (APPEEC), Beijing Inst. of Technol., Beijing, China, pp: 1-3.

Hua, C.C. and M.Y. Lin, 2000. A study of charging control of lead-acid battery for electric vehicles. Proceeding of International Symposium on Industrial Electronics, Cholula, Puebla.

Huang, S.W., 2006. A novel zero-current-switching pulse-width-modulated buck converter for battery chargers. MA Thesis, Kun Shan University.

Jun, H., Y. Shiyan and Y. Wei, 2010. Research on the Zero-Current BUCK/BOOST Bi-directional DC/DC Convertor. Elec. Power Elec. Technol., 44 (7).

Koutroulis, E. and K. Kalaitzakis, 2004. Novel battery charging regulation system for photovoltaic applications [J]. IEEE Proc. Power Appl., 151(2): 191-197.

Ned, M., M.U. Tore and P.R. William, 1995. Power Electronics Converters, Applications and Design. 2nd Edn., John Wiley and Sonsnc, New Delhi.

Noworolski, Z., J.M. Noworolski and C.A. Bennett, 1991. A microcomputer-based UPS battery management system. Proceeding of 13th International Telecommunications Energy Conference (INTELEC), pp: 177-180.

Reid, D.P. and I. Glasa, 1984. A new concept: intermittent charging of lead-acid batteries in telecommunication systems. Proceeding of International Telecommunications Energy Conference (INTELEC), Bell-Northern Research Ltd., P.O. Box 3511, Station C, Ottawa, Ontario, K1Y 4H7 Canada, pp: 67-71.

Sauer, D.U. and J. Garche, 2001. Optimum battery design for applications in photovoltaic systems theoretical considerations [J]. J. Power Sour., 95(1-2): 130-134.

Xu, X. and V.A. Sankaram, 1993. Power electronics in electric vehicles: Challenges and opportunities. IEEE/IAS Annu. Meet. Conf. Rec., pp: 463-468.