Design of an FPGA-Based Lithium-Ion Battery charger system

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of technology

In

Electronics and Communication Engineering

By

CHANDER PAL SINGH

10407015

And

NAVEEN KAUSHAL

10407013

Department of Electronics and Communication Engineering

National Institute of Technology

Rourkela

2008

National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled, **"Design of FPGA Based Lithium ion Battery charger system"** submitted by Sri Chander pal singh and Sri Naveen Kaushal in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Mechanical Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

Prof. Dr. K.K.Mahapatra

Dept. of Electronics and Communication Engineering

National Institute of Technology

Rourkela – 769008

ACKNOWLEDGEMENT

I would like to articulate our deep gratitude to our project guide **Prof. Dr.K.K. Mahapatra** who has always been our motivation and source of inspiration and constant guidance for carrying out the project.

It is my pleasure to refer Microsoft word 2007 of which the compilation of this report would have been impossible.

An assemblage of this nature could never have been attempted without reference to and inspiration from the works of others whose details are mentioned in reference section. I acknowledge my indebtedness to all of them.

Last but not the least to all of my friends who were patiently extended all sorts of help for accomplishing this undertaking.

Date

Chander pal singh

Naveen Kaushal

CONTENTS

ABSTRACT

Nowadays, the number of portable electronics products such as mobile telephones and laptop computers has grown explosively. These developments have resulted in massive demand for secondary batteries. The advantages of lithium-ion batteries include no memory effect, high operation voltage, and high energy density. Therefore, it is the most popular secondary battery for consumer electronics.

In this paper, a FPGA (Field Programmable Gate Array)-based lithium-ion battery charger system is developed. The concerned charger system consists of an FPGA-based controller, a data acquisition system and a programmable power source. The proposed system can achieve the goals such as digital programmability, user-friendly interface, data monitoring ability and stable voltage/current source. According to the experimental results, the proposed charger system is capable of charging the lithium-ion batteries with less than 1.5 % current ripple.

CHAPTER 1

INTRODUCTION

INTRODUCTION

A **battery charger** is a device used to put energy into a cell or (rechargeable) battery by forcing an electric current through it. Nowadays, the number of portable personal telecommunication systems such as mobile phones and laptop computers has grown explosively. These developments have resulted in massive demand for batteries. Secondary batteries are often used in these equipments because they are cost-effective over the lifetime of the product. Recently, widely used secondary batteries such as NiCd and NiMH are not satisfying people’s requirements due to lack of high-energy capacity and bulky size. Furthermore, another consideration is possibly the environmental pollution, such as the cadmium in a NiCd battery. In contract, many advantages, such as no memory effect, high operation voltage, and high energy density forward the lithium–ion (Li–ion) battery in becoming the acceptable battery for portable electronic systems The performance and longevity of lithium ion batteries depend, to a large extent, on the quality of their chargers. The conventional lithium ion batteries' charging occurs in two steps, the battery is charged at a constant current until the battery voltage reaches the predefined upper voltage limit (4.1 or 4.2 V) followed by a constant voltage charging until the current reaches a predetermined small value. This method is often called constant current-constant voltage (CC-CV) charging method and is often adopted in commercialized battery charging ICs. However,CC-CV is not suitable for rapid charging since the constant voltage charging seriously extends the charging time and also reduces the cycle life of the battery. Other advanced charging method such as multi-stage constant current charging algorithm or pulse charging algorithms have been proposed.

These methods require a digital controller to implement the complex charging strategy. Conventionally, microprocessor-based digital control scheme has been applied to the charger system design. Microprocessor-based control schemes have the advantages of flexibility, higher reliability and lower cost. However, the demanding requirements of advanced charging algorithms imposed tremendous

computation load on the microprocessors. Therefore, FPGAs are utilized because the high-speed hard-wired logic can enhance the computation

capability of the digital controllers. The FPGA-based digital controller has the advantages of elegant hardware, higher computation speed, and short period of timing for prototyping. In addition,the whole system may be implemented in only a single FPGA chip consequently the circuit is very compact.

Battery and Charger

Types of chargers:-

1. Simple
2. timer-based
3. fast
4. intelligent
5. USB based

The most commonly used batteries in the market are the Ni-Cd, Ni-NH and Li-ion types, all of which have their capacity measured in mAh. This value indicates the amount of current the battery can supply for a certain amount of time. For example a 500 mAh battery should be able to supply 500mA continuously for 1 hour or 50mA for 10 hours. Simply speaking, the larger the battery capacity, measured in mAh, the longer the battery can supply current. However in order to achieve maximum efficiency and cost-effectiveness from the battery it is essential to ensure that the battery is fully charged. To do this it is not only necessary to choose battery chargers that can recharge batteries in a short time but also to detect when the battery is in the fully charged state. For the purpose of a quick-charge in one hour, the current of the charger must stay at 500mAh/1h=500mA. For a so-called 500mAh capacity battery, a charging current of 500mA is called 1C. If Ni-Cd or Ni-NH batteries are recharged without first fully discharging, then they will suffer from a reduction in their overall capacity, a phenomenon known as the memory effect. Li-ion batteries however do not suffer from memory effect and will not experience the same capacity reduction if recharged without first fully discharging. During the recharge process it is important to know when the battery has reached the fully charged condition. Without the ability to detect this condition, the charger will continue to source current into the battery even after it has reached the fully charged state, a situation which can cause damage to batteries. The following shows the method to detect the fully charged state of Ni-Cd, Ni-NH and Li-ion batteries.

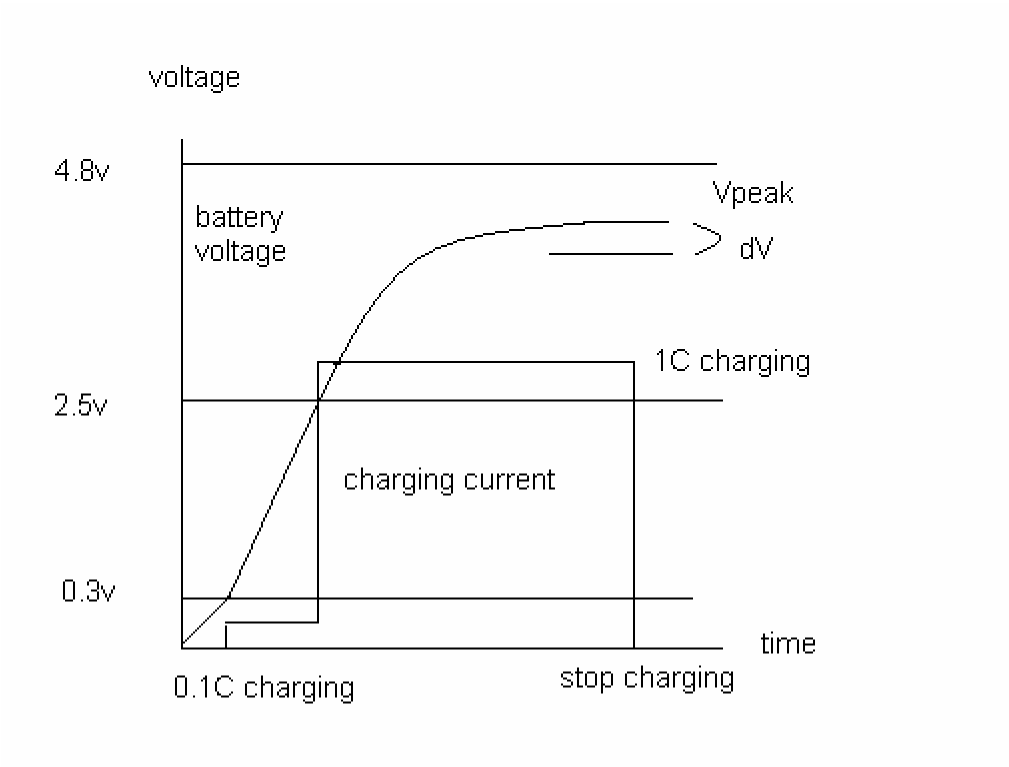
CHAPTER 2

CHARGING PROCESS OF BATTERIES

CHARGING PROCESS OF BATTERIES

The charging methods for both Ni-Cd and Ni-NH batteries are the same. The following describes several methods of detecting when the full charge condition has been reached.

Charging curve for Ni-Cd and Ni-NH batteries



- If the measured voltage on the rechargeable battery is lower than 0.3V, the charging process will not be executed. When the voltage exceeds 0.3V, the charger will charge the battery with a constant current of 0.1C until the voltage reaches 2.5V at which point the charging current will be increased to 1C.

Depending upon the charger, whenever the VPEAK status or dV occurs, the charging process will end.

- If the voltage of a rechargeable battery exceeds VMAX, (VMAX=4.8V), this will be detected as an over voltage error condition and the charger will cease operation. Possible reasons for this may be a wrongly inserted battery.
- If the charging time exceeds 80 minutes, this indicates a battery of larger capacity which will require a longer charging time. Other reasons for longer charging times may be a battery in poor condition, in which case the charger may be unable to detect a VPEAK status or dV condition and therefore continue charging. A default charging time of 80 minutes will also provide a safety precaution against overcharging and possible damage to the battery or other dangerous conditions.

Fast charging of Ni-Cd, Ni-NH and Li-ion batteries can only be done after the battery voltage has exceeded 2.5V. Until this point is reached the battery has to be charged at a current of 0.1C, after the battery voltage has exceeded 2.5V then a fast charge current of 1C can be applied. In battery charger design it is also necessary to include a function to automatically detect if a battery has been placed in the charger. To achieve this, the charger should from time to time check the voltage on the battery holder, if this voltage exceeds 0.3V then it could be assumed that a battery has been placed in the charger, if the voltage is less than 0.3V then it could be assumed no battery has been placed in the charger. When detected, the placed battery should be placed in a standby condition ready for charging. Because of the limitation of only being able to charge one set of batteries at a time, the standby batteries need to be charged individually. If, after charging, the battery is not removed from the charger it will remain in the standby condition. To fully prevent it being charged again it must be removed from the charger. As for discharging before charging,

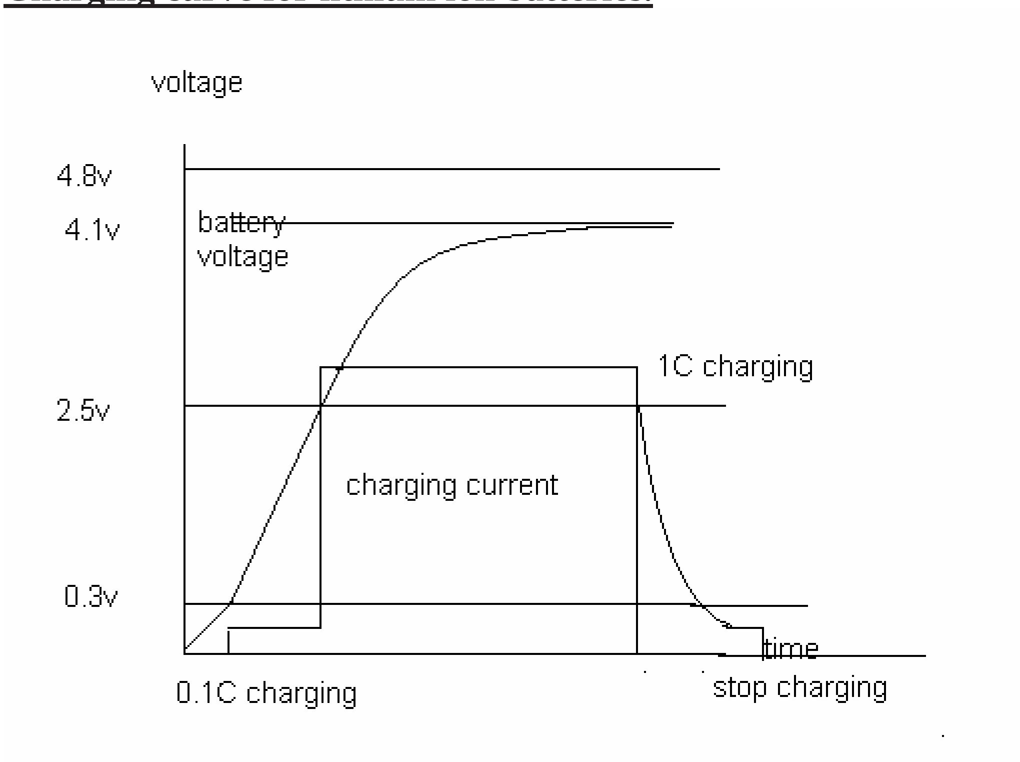
Ni-Cd and Ni-NH batteries need to be discharged with a current of 0.1C. When the voltage falls to below 2.2V, the charger will stop discharging the battery and begin the charging cycle automatically. As Li-ion batteries do not suffer from memory effect, they do not require discharging.

Methods of detecting when the full charge condition has been reached.

- By measuring dV: in a fully charged condition the battery voltage will fall. If successive reductions of 10mV is detected 8 times (dV > 10mV for 8 times), the battery will be taken as being in a fully charged state.
- By measuring VPEAK: if VBAT is found to be less than VPEAK after a time period of one minute then the battery can be considered fully charged, however if VBAT is greater than or equal to VPEAK after one minute the timer should be reset and the value measured again after a similar period of time.
- By measuring VMAX: when VBAT reaches VMAX, the battery can be considered fully charged.
- By using a safe timing method: if the charging time is greater than the setup time, the battery can be considered fully charged.

- By measuring battery temperature: when the battery is in the fully charged condition the temperature will rise if charging continues, providing a fully charged measurement parameter.

Charging curve for lithium ion batteries.



- If the measured voltage on the Li-ion battery is lower than 0.3V, the charging process will not be executed. Once the voltage exceeds 0.3V, the battery will be charged with a 0.1C constant current until the voltage reaches 2.5V, at which point the charging current will increase to 1C. When the voltage reaches 4.1V, the battery will be charged with a constant voltage source at a fixed voltage of 4.1V. When this occurs the charging current will start to fall slowly. When the charging current falls below 0.1C the charging process will stop.

- If the charging voltage of a rechargeable battery is larger than 4.8V, this may indicate an incorrect placement of the battery in the charger, in such a case the charger should cease charging to avoid any possible danger.
- If the charging time exceeds 80 minutes, the battery may still need a longer charging time if it has a larger capacity. Another reason for longer charging times may be that the battery is in poor condition resulting in the battery being unable to reach its fully charged voltage level. By keeping the charging time limited to 80 minutes potential situations of overcharging and other possible

dangerous situations can be avoided.

CHAPTER 3

DESIGN PRINCIPLE

DESIGN PRINCIPLE:-

Before designing a suitable charger, it is necessary to understand the different characteristics of each kind of rechargeable battery. There are several methods to determine if a Ni-Cd or Ni-MH battery is fully charged: one method is to detect a sudden reduction in the battery voltage, another is to detect a rise in battery temperature. Using the method of temperature rise to detect a fully charged battery may however be erroneous due to the effects of the surrounding

temperature. It is therefore recommended that the method of checking for a sudden reduction in battery voltage is used as this has proven to be a reliable method. Additional protection is also provided in the way of measuring charging times and stopping the charging process if the time exceeds 80 minutes to prevent overcharging and battery damage. In the case of Li-ion batteries, when fully charged, the voltage will be maintained at 4.1V, so when this condition is reached, the charge current will be reduced to less than 50mA. Also if after 80 minutes the battery has not reached a full charge condition then the charging process will be terminated.

In the case of Ni-MH or Ni-Cd batteries, it is also required to provide an indicator to show if discharging is required. Note that discharging before recharging can reduce any memory effects that may have been built up in the battery prior to this charging process. Li-ion batteries do not suffer from memory effect and therefore do not require discharging. For multi-cell charging, note that Ni-MH and Ni-Cd batteries need to be charged in series.

Charging current: Charging the battery with a fast charge current of 500mA or slow charge current of 50mA depends on the battery voltage. If the voltage exceeds 2.5V, then a fast charge value of 500mA can be used. If the voltage is lower than 2.5V, a slow charge value of 50mA should be used which can switch to 500mA after the battery volt age reaches a value higher than 2.5V.

In this presentation FPGA-based battery charger system is presented and implemented. The concerned charger system consists of an FPGA-based controller, a data acquisition system and a programmable power source. The data acquisition system is used to record battery parameters during the charging or discharging process, these data can then be used to determine the effectiveness of the charging strategy. The programmable power source uses a multiphase buck converter topology; the benefits of this kind of topology include lower output current ripple, higher di/di ramp rate and lower inductance values. According to the experimental results, the proposed charger is capable of charging the lithium-ion batteries with less than 1.5 % current ripple.

This paper is organized as follows: section II describes the hardware configuration of the proposed charger system. Section III describes the

software part of the proposed system.

CHAPTER 4

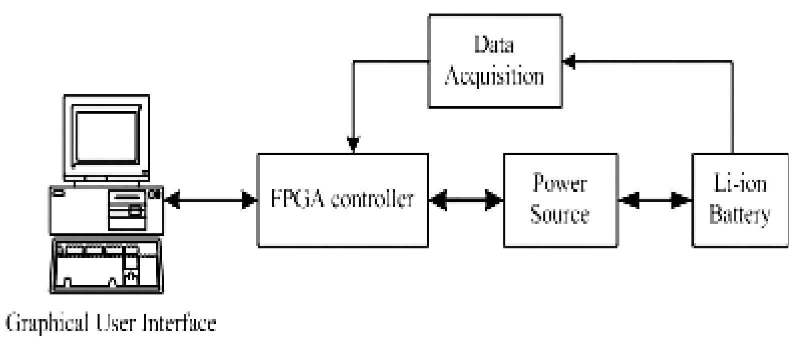
HARDWARE CONFIGURATION

The Hardware Configuration

Fig. 1 shows the block diagram of the proposed charger system. In Fig. 1, the FPGA chip is used to control the timing and executes the gating of the needed switches in the power source and then gathers and analyzes data from the data acquisition circuit. Multiphase PWM modulation strategies and interfacing IC driving signals are also realized using the FPGA chip to achieve better performance. In this paper, VHDL (Very high speed integrated circuit

Hardware Description Language) is utilized to design the control strategy of the proposed system. The proposed FPGA controller attempts to meet the

flexibility, ease of use and low cost requirements for most consumers and industrial applications.



Block diagram of the proposed charger

The whole system can be divided into three major parts: FPGA controller, data acquisition subsystem and programmable power source

subsystem. Detailed descriptions about each subsystem will be given in the following sections

FPGA controller

FPGA controller provides the gating signals of multiphase buck converter, outputs the voltage/current command, control the interfacing ICs and communicate with the graphical user interface (GUI). In the proposed system, the main control strategy is implemented using the FLEX10K70 FPGA device from Altera Corp. The block diagram of the FPGA-based control unit is shown in Fig. 2. In Fig. 2, the FPGA gathers and analyzes battery status data (voltage and current) from the A/D module. In order to simplify the circuit and reduce cost, only one A/D conversion IC (ADC0804) is used. Therefore, an additional analog switch is required to select the input signals into A/D conversion IC. After obtaining the required charging status data, necessary gating signals are then determined through the built-in signal interleaving circuits and are outputted through PWM module. In order to continuously monitor the charging process, a universal synchronous asynchronous receiver transmitter (USART) module is implemented in the main controller. In addition, the operating status of the charger can also be displayed real-time on a 16x2 LCD display. Remote on/off control and charging/discharging control is realized through general purpose I/O ports.

Data acquisition subsystem

From Fig. , the data acquisition system consists of the following circuits: -

- Sensors to measure the following variables:

Voltage in the battery terminal, Current sinked/sourced by the battery during the charge/discharge process (this current is measured through a hall effect sensor) and battery temperature.

- Amplification, level adaption and filtering circuits for the analog signals from the different sensors.
- 8 bits Analog to Digital Converters (ADC).
- Analog to Digital Converters Interface. It controls the sampling of data.
- Acquisition control system. It is the main controller of the whole data acquisition system.
- Communication interface. It controls the data transmitting to/from the graphical display interface.

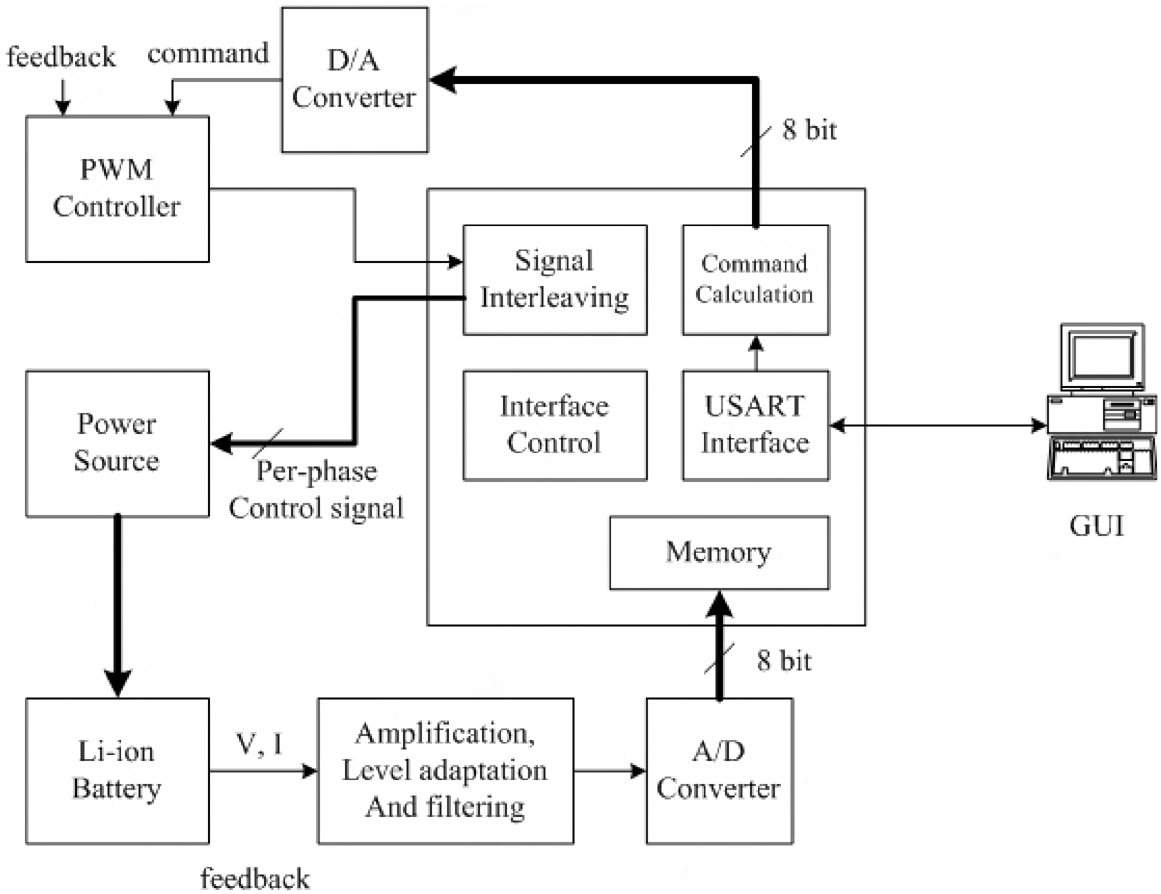


Fig. 2 Block diagram of the FPGA controller

Programmable power source

The programmable power source uses an interleaved multiphase buck converter topology. Interleaving greatly reduces the current ripples to the output capacitors, which in turn greatly reduces the steady-state output voltage ripples, making it possible to use very small inductances to improve transient responses. Interleaving converters with small inductances reduces both the steady-state voltage ripples and the transient voltage spikes, so that a much smaller output capacitance can be used to meet the steady-state and transient voltage requirements. The power density can also be significantly improved. Fig. 3 shows a typical diagram of a four phase buck converter used in this proposed system. Generally speaking, an N-phase converter consists of N identical converters with interconnected inputs and outputs. The duty cycles of adjacent channels have a phase shift of N/360o, where N is the total channel number. Fig. 4 shows the gating signals required for a four phase converter.

The benefits of the multiphase approach can be summarized as follows. This approach allows a small output inductance to be used in order to increase the energy transfer speed. This small inductance makes the output transient response much faster. The interleaving approach can reduce the ripple current and increase the ripple frequency, which makes it possible in order to reduce the output capacitance to improve the transient response, as well as to increase the converter efficiency. The interleaving techniques also make it possible to parallel the output inductors of the individual modules during the transient.

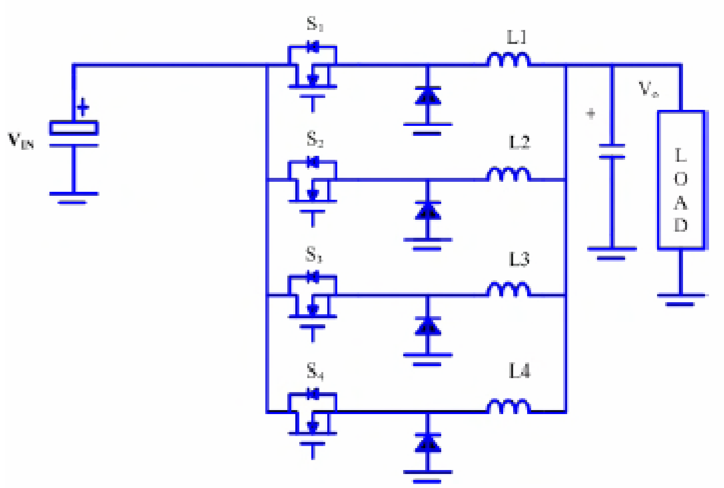


Fig. 3 A four phase buck converter

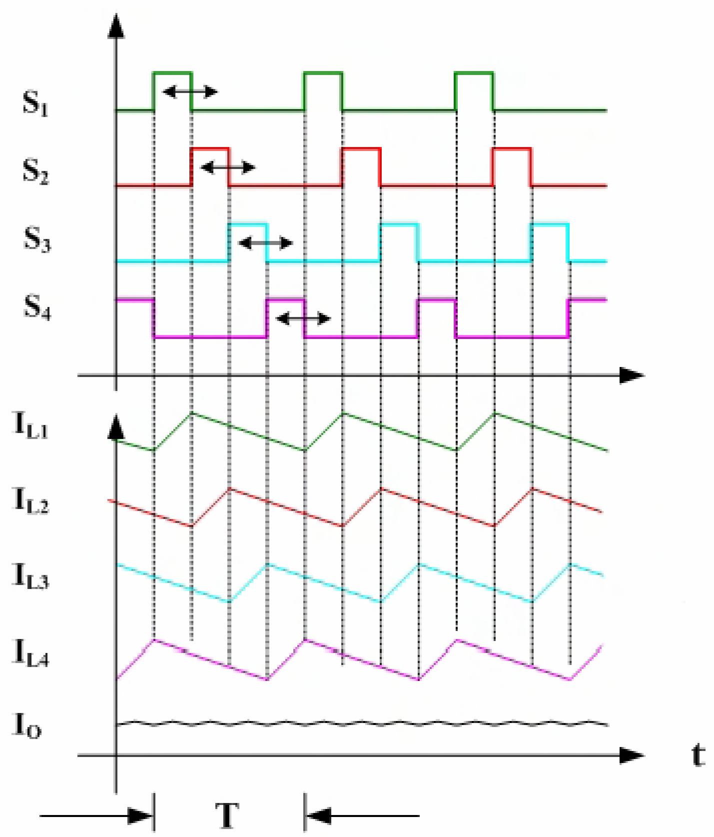


Fig. 4 Gating signal of a four phase buck converter

CHAPTER 5

PWM SIMULATION

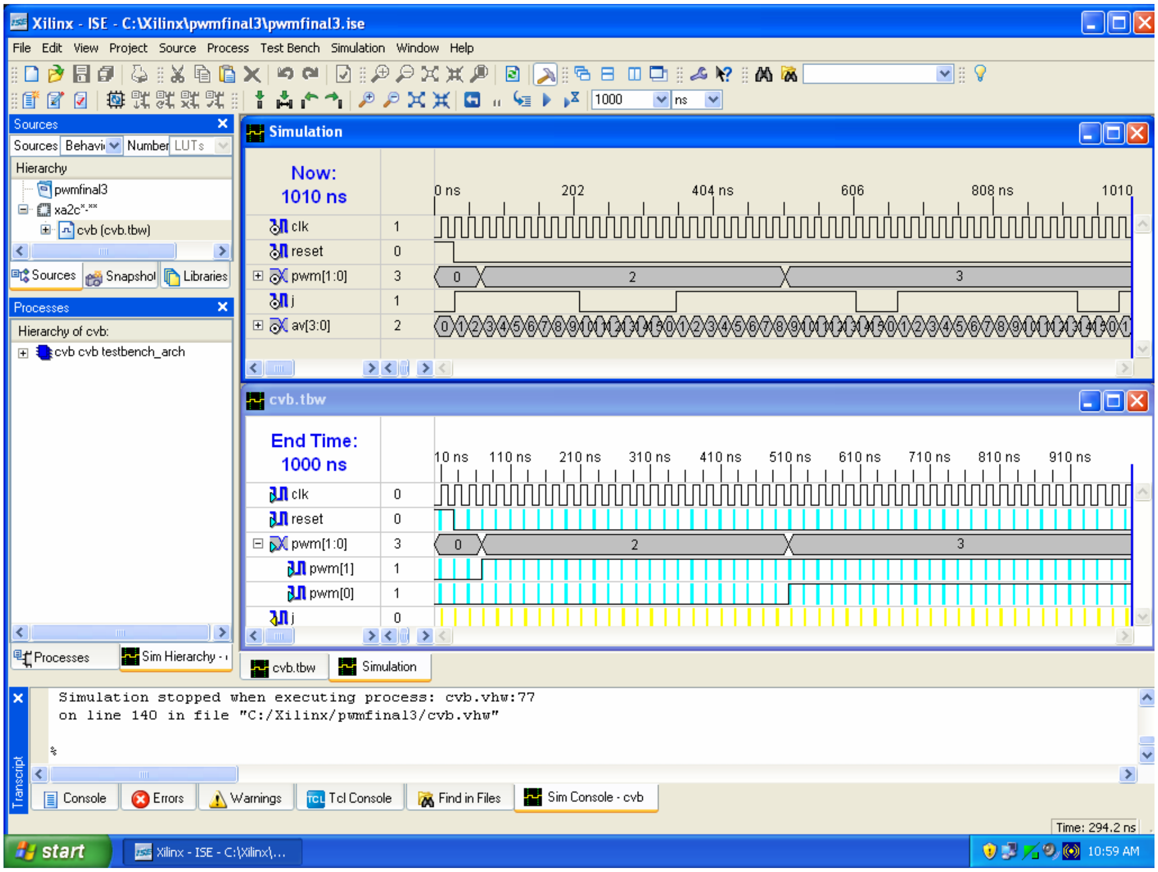
PWM GENERATION PROGRAM FOR DIFFERENT DUTY CYCLES

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;
use IEEE.STD_LOGIC_ARITH.ALL;
use IEEE.STD_LOGIC_UNSIGNED.ALL;

---- Uncomment the following library declaration if instantiating
---- any Xilinx primitives in this code.
--library UNISIM;
--use UNISIM.VComponents.all;

entity first is
   Port ( clk : in  STD_LOGIC;
          reset : in  STD_LOGIC;
                              pwm:in std_logic_vector(1 downto 0);
          j : out STD_LOGIC;
          av : out  STD_LOGIC_VECTOR (3 downto 0));
end first;

architecture Behavioral of first is
signal y: std_logic_vector(3 downto 0):="0000";
signal m:std_logic:='0';


 begin
 process(clk,pwm)
 variable high:std_logic_vector(3 downto 0);
 variable width:std_logic_vector(3 downto 0);
            begin
            if(pwm="00") then
            high:="0010";
            width:="1111";
            elsif(pwm="01")then
            high:="0100";
            width:="1111";
            elsif(pwm="10")then
            high:="1000";
            width:="1111";
            elsif(pwm="11")then
            high:="1100";
            width:="1111";
            end if;
```

```
   if(clk'event and clk='1') then

             if (reset = '1') then
        m<='0';
                 y<= "0000";
      elsif (y<high) then
                          m<='1';
                                          y<=y+"0001";
                     elsif (y>high and y<width) then

                          m<='0';
                                          y<=y+"0001";

              elsif(y=width)then
                          m<='0';
                                          y<="0000";
                     else

                          y<=y+"0001";
                     end if;
             end if;
end process;
av<=y;
j<=m;

end Behavioral;
```

CHAPTER 6

RESULT AND CONCLUSION



Xilinx - ISE - C:\Xilinx\pwmfinal3\pwmfinal3.ise
File Edit View Project Source Process Test Bench Simulation Window Help
Simulation
Now: 1010 ns
clk 1
reset 0
pwm[1:0] 3
j 1
av[3:0] 2
cvb.tbw
End Time: 1000 ns
clk 0
reset 0
pwm[1:0] 3
pwm[1] 1
pwm[0] 1
j 0
Simulation stopped when executing process: cvb.vhw:77
on line 140 in file "C:/Xilinx/pwmfinal3/cvb.vhw"
Console Errors Warnings Tcl Console Find in Files Sim Console - cvb
Time: 294.2 ns

Conclusion

An FPGA-based charger system for lithium ion batteries was presented. In order to monitor the operating parameters during charging/discharging processes, a VHDL program was also developed. The proposed charger system can operate in constant voltage or constant current charging mode; the voltage/current command can be set by the user using the designed program. The proposed charger system features the following advantages such as low output voltage/current ripple, high efficiency and digital programmability. Moreover, FPGA solutions are especially suitable for situations where time to market, cost and size are important constraints. Through recording the battery voltage, current and temperature, the influence of the previous battery charge and discharges in the battery capacity; the influence of the charging strategy and the actual battery charge state in the efficiency and speed of the charge process can be further investigated.

REFERENCES

- FPGA based Li-ion battery charger system.

  ieeexplore.ieee.org/iel5/9709/30649/01414963.pdf?arnumber=1414963.

- Wikipedia.org

- Lithium ion battery charger system by Yi- hwa Liu, Jen-Chung Li *Department of Electrical Engineering, Chang Gung University, Taoyuan, Taiwan*.