MICROCONTROLLER BASED BATTERY CHARGER

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ABSTRACT

This thesis is about how power electronics can be implementing on embedded system program. Major in power electronics and controlling using embedded system is what the purpose of this project. This battery charger is supposed to be the fastest charging time among chargers that have nowadays. By using power electronics component that can handle big current and voltage this battery charger should be charging battery faster. Methodology that was use is SMPS topology that is Switch Mode Power Supply and using MOSFET as switching frequency. A switched-mode power supply, switching-mode power supply or SMPS, is an electronic power supply unit (PSU) that incorporates a switching regulator. The SMPS rapidly switches a power transistor between saturation and cutoff with a variable duty cycle whose average is the desired output voltage. The main advantage of this method is greater efficiency because the switching transistor dissipates little power in the saturated state and none in the off state. Other advantages include smaller size and lighter weight from the elimination of low frequency transformers and lower heat generation from the higher efficiency. Disadvantages include greater complexity, the generation of high amplitude, high frequency energy that the low-pass filter must block to avoid EMI, and a ripple voltage at the switching frequency.

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CHAPTER 1

INTRODUCTION

1.1 Overview project

This project is to make a prototype of microcontroller battery charger. This project is about making a fast battery charger than nowadays battery charger.

This battery charger will use an SMPS full-bridge dc-dc converters due to the high efficiency of the full-wave converter. It is also because that full-bridge converter has high frequency transformer that can isolate voltage on first and second stage. This is due to the safety of the circuit itself.

This battery charger will give output current that is between 10 to 20Amp. This battery charger has six stages where these stages will be implementing into the PIC microcontroller. By implementing all the stages into the PIC microcontroller, the PIC itself will control all the feedback circuit that need to be control that is current, temperature and voltage.

1.2 Objective

The objective of this project is to;

i. To fast charge an 80Ah battery using PIC microcontroller.
   - By supplying high current in the circuit, we will make time to charge the battery faster.

ii. To implement battery charging states into PIC
   - The six stages of battery charger will be implementing into the PIC microcontroller.
   - The six stages are;
     - ✓ Charge Qualification state
     - ✓ Current Regulation state
     - ✓ Voltage Regulation state
     - ✓ Float Charge state (temperature)
     - ✓ Charge Suspend state
     - ✓ Charge Cycle complete state

1.3 Scope of project

Scopes of this project are;

i. To build a full-bride high frequency battery charger.
   - By using the full-bridge converter that have high frequency transformer.

ii. To test the circuit using a function generator.
   - Before all the six stages were implementing into the PIC microcontroller, function generator will be use to make sure we will get output current and voltage and output waveform that we need.

iii. To replace the function generator using PIC and control the full-bridge.
   - After we get the output that we need, all the stages of battery charger and PWM controller will be implementing into the PIC microcontroller so that the PIC will control the Pulse Width Modulator of the circuit that needed.

iv. To implement feedback control and charging control to the PIC.
   - The six stages of battery charger that are Charge Qualification state, Current Regulation state, Voltage Regulation state, Float Charge state (temperature), Charge Suspend state and Charge Cycle complete state will be implementing into PIC microcontroller.

1.5 Problem statement and solution

1. Battery charger nowadays cannot hold high current and temperature.
   - Use full-bridge circuit as it can handle high current.
   - Use **MOSFET** as switches because it can handle high current and rated power. Turning on and off is very simple. Only need to provide *VGS* =+15V to turn on and 0V to turn off. Also Mosfet can handle gate voltage up to 400V. Gate drive circuit is simple.

Table 1.1: Power Device Table

Device Type	Year made	Rated Voltage	Rated Current	Switching Frequency	Rated Power	Drive Circuit	Comments
SCR	1957	6kV	3.5kA	500Hz	100s MW	Simple	Cannot turn-off using gate signal
GTO	1962	4.5kV	3kA	2kHz	10s MW	Very Difficult	King in very high power
BJT	1960s	1.2kV	400A	5kHz	1 MW	Difficult	Phasing out in new product
MOSFET	1976	500V	200A	1MHz	100 kW	Very Simple	Good performance in high frequency
IGBT	1983	3.3kV	1.2kA	100kHz	100s kW	Very Simple	Best overall performance

2. Battery charger nowadays do not fast charge.
   - Made a battery charger that gives high current output.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of charging stage

There are six stages to implement battery charger into PIC microcontroller. That are (MICROCHIP, 2008);

i. Charge Qualification state
   - During Charge Qualification, the battery's temperature and voltage are measured to determine the next charging state.

ii. Current Regulation State
   - The Current Regulation state is entered from Charge Qualification state. Battery charging is initiated. For lead batteries, this charge voltage can vary with temperature. Colder temperatures can allow the battery to use higher charging voltages.

iii. Voltage Regulation State

- Voltages while the charge current decreases (or tapers) to the user-specified minimum current threshold.

iv. Float Charge State (Temperature)

- In the Float Charge state, a lower charge target voltage is applied. As in Current Regulation state, the target voltage can be a constant or can vary with temperature. The resulting taper current is measured and compared against threshold current. This helps to maintain a full charge. There is only one possible next state and that is Charge Cycle Complete. Charge Cycle Complete is entered when the voltage reaches the float voltage target and the current tapers to less than threshold current or the float timer expires.

v. Charge Suspend State

- In the Charge Suspend state, no current is applied to the battery pack. Charge Suspend state always progresses to Charge Pending state.

vi. Charge Cycle Complete State

- When the current is less than the taper current threshold and the voltage is greater than the target voltage, End-of-Charge is triggered.

2.2 Selecting circuit topology

State that DC-DC converter has their characteristic. There are full-bridge converter have high frequency transformer. This high frequency transformer can isolate voltage from primary and secondary circuit. This is due to the safety precaution. Also full-bridge converter has high efficiency. The input for Full-Bridge converter must be dc fixed voltage because these full-bridge converters are dc to dc converter. It can operate in 4 quadrant of the $i_o - v_o$ plane. The two switches never off simultaneously. Thus, power can flow in either direction. There 2 type of PWM switching that is PWM with bipolar voltage switching and PWM with unipolar voltage switching. PWM bipolar switching where switches A+ and B- and A- and B+ are treated as pairs. Switches in each pair turn on and off simultaneously. PWM unipolar switching is also referred as the double-PWM switching. The switches in each inverter leg are controlled independently of the other leg. (Mohan, Underland, Robbins, 2003);

2.3 Types of battery

This article state that the fastest time that a battery can be charge is cannot be less than 30 minutes. There are four rechargeable battery chemistries are in practical use today: Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH), Gelled Lead-Acid (PbSO4), and Lithium-Ion (Li+). (MAXIM, 2007);

2.4 DC link

This article states the use of DC link. Voltage DC link inverters are frequently fed via uncontrolled rectifier bridges from the single-phase or the three phase mains. There, in the DC link usually aluminum electrolytic capacitors (connected in series and/or in parallel) are used to; (Johann W. Kola, Thomas M. Wolbank and Manfred Schrodl, 2005);

i. Compensate the difference between the power requirement of the inverter (whose mean value is constant in steady state operation) and the output power of the input rectifier bridge varying with two or six times the mains frequency
ii. Supply the input current of the inverter with pulse frequency,
iii. Reduce the spreading of current harmonics with pulse frequency into the mains,
iv. Supply transient power peaks and
v. Protect the inverter from transient peaks of the mains voltage

2.5 Full-bridge DC/DC converter

Advantages of using Full-Bridge DC/DC Converter are power handling capabilities, stability, and symmetry and DC/DC using a high frequency transformer which is one of the most efficient ways to step-up the voltage. The high frequency transformer is also much smaller and lighter than a standard 8.5kVA 60Hz transformer. (Dan Burger, Eric Dougan, Joe Oberle, Sean Periyathamby, 2006)

2.6 PIC Architecture

There are 2 types of PIC Architecture which are Von-Neumann Architecture and Harvard Architecture. The one that will use in this project were Harvard Architecture.

These are pros and cons of Harvard Architecture. This architecture overcomes the memory bottle neck by splitting the memory into instruction (code) and data areas. (PIC programming – Architecture, 2006)

Table 2.1: Pros and cons of Harvard Architecture

PROS	CONS
• Data and address busses can be different widths. This means the programme memory word can be wide enough to incorporate an instruction and a literal (fixed data) in a single instruction.	• Slightly more confusing at first.
• A build-in two-stage pipeline overlaps fetch and execution of instruction, meaning most instructions execute in a single clock cycle.	• Hardware is more complicated.

2.7 Power Transformer

This article is about Magnetic Design for Switching Power Supplies. There are six sections on how to design it. Section that was read is section 4. This section explains about on how Power Transformer was design. There are several things that must be considered when designing Power Transformer. We must consider the losses, temperature, energy storage, thermal resistance, topology, frequency and others. This article also has an example on calculation on making this Transformer. ()

2.8 Enhanced CCP port

When programming for Enhance Capture/Compare/PWM (ECCP) Module, the pin configuration must be do first. These pins were use when 2 or 4 PWM want to be generating from the PIC. To configure ECCP pin, first of all bit 7-6 must be set according to topology that were used for the project switching circuit. Bit 5-4 will be set to low LBs if decide to use it as PWM mode. Bit 3-0 set as Enhanced CCP mode select bit. (MICROP, pic18f2455_2550_4455_4550 datasheet, 2006)

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, explanations about all the circuit that were done for this project will be told. This chapter will be divided to Hardware configuration and software configuration since this project will be used both hardware and software. All the calculation also will be state into this chapter. The entire figure related to this project will be added in this chapter along with the explanations.

3.2 HARDWARE CONFIGURATION

3.2.1 Battery charger circuit diagram

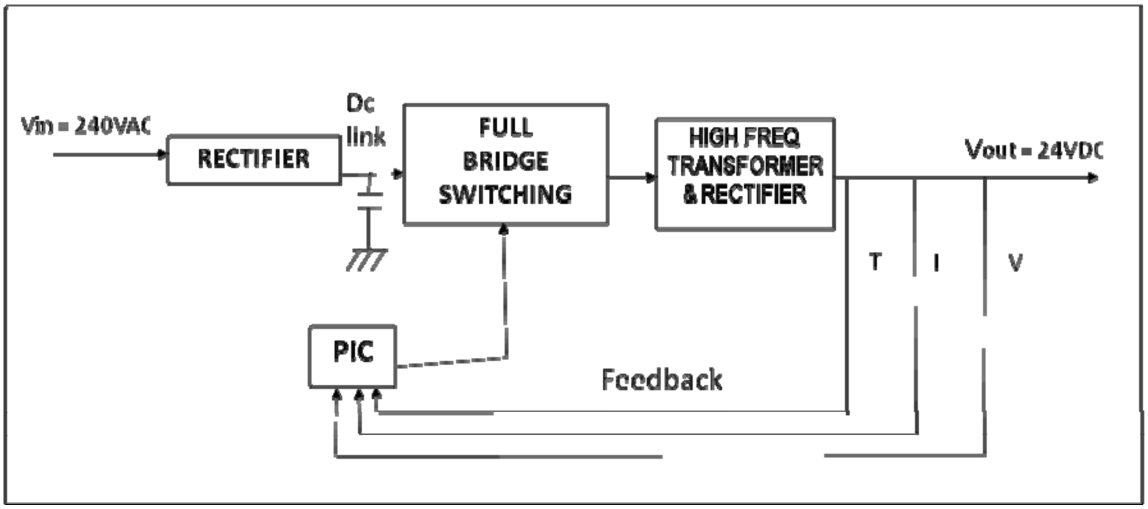

Figure 3.1 Block Diagram of Battery Charger

Above is the block diagram of a microcontroller based battery charger. The entire component in above circuit we called SMPS (switched mode power supply). DC power supply has 3 outputs. One is for 5V, 15V, and 350V. 5V will be supplied for PIC, temperature sensor, current sensor and voltage sensor.15V will be supplied at driver MOSFET. For drain voltage MOSFET we will use maximum 150V supplied to it. PWM will be programming in the PIC to gives pulse to MOSFET to control the output voltage. The output voltage from the transformer will be connected to current sensor and voltage sensor to check whether the voltage and current flow to the battery will not exceed the maximum voltage and current of the battery. Temperature sensor will check the temperature of the battery and if the temperature battery high, the system will automatically disconnect. PIC will be programmed all the stage of charging the battery and the PWM switching. The output voltage that will be out from the circuit above is 24V while the output current is 10A.

3.2.2 Overall Calculation

i. Rectifier 1 ;

Input voltage = 240V_{AC}

$$V_{OUT1} = \sqrt{2}(V_{IN}) \tag{3.1}$$

$$= \sqrt{2}\ (240)$$

$$= 339.41V_{DC}$$

ii. Rectifier 2;

State that $V_{OUT} = 24V$

$$V_{IN(rec2)} = \frac{V_{OUT}}{\sqrt{2}} \tag{3.2}$$

$$= \frac{24}{\sqrt{2}}$$

$$= 16.97V$$

iii. Frequency;

$D_{min} = 10\%\ , D_{max} = \ 90\%$

From datasheet POWER MOSFET (IRF740),

$t_{ON} = 17ns, t_{OFF} = 10ns$

$t_r = 10ns, t_f = 10ns$

From datasheet HALF-BRIDGE DRIVER (IR2109)

$t_{ON} = 750ns, t_{OFF} = 200ns$

$t_r = 150ns, t_f = 50ns$

$$f_{max} = \frac{4\ [1 - D(max)]}{3\ [t_{r(slowest)} - t_{f(slowest)} + 4t_{off(min)}]} \tag{3.3}$$

$$f_{max} = \frac{4\ [1 - 0.9]}{3[150ns - 50ns + 4(200ns)]}$$

$= 148.14kHz$

iv. Full Bridge ;

$V_{OUT\,(full\,bridge)} = V_{IN(rec2)} = 16.9V$

V_{OUT}

Where: T is the switching time or the inverse of the frequency $\left(\frac{1}{f}\right)$, $\left(\frac{N_P}{N_S}\right)$ is the transformer turns ratio and (t) is the pulse width time.

$$T = \frac{1}{f} \quad (3.5)$$

$$= \frac{1}{148.14kHz}$$

$$= 6.725\mu s$$

Solving for t:

$$t = \frac{V_{OUT} N_P T}{2V_{IN} N_S} \quad (3.6)$$

$$Duty\ cycle\ (D) = \frac{t}{T} \quad (3.7)$$

v. $Find\ P_{OUT}$;

State that $I_{OUT} = 20A\ and\ V_{OUT} = 34V$

$$P_{OUT} = (I_{OUT})(V_{OUT}) \quad (3.8)$$

$$= (20)(34)$$

$$= 680W$$

vi. Find input current, I_i ;

$$P_{OUT} = P_{IN} \quad (3.9)$$

$$[(I_o)(V_o)] = [(I_i)(V_i)]$$

$$[(20)(34)] = [(I_i)(240)]$$

So, $I_i = 2.83A$

3.2.3 Power Supply circuit diagram

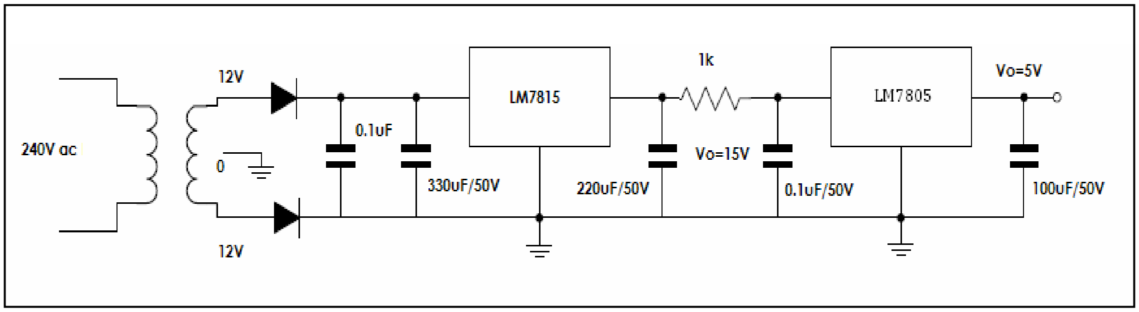

Figure 3.2 Power Supply 5V, 15V

There are three different DC voltages rating for the circuit. Each is used in different part in the circuit. Voltage rating in the circuit is 350 Vdc, 15 Vdc and 5Vdc. Voltage 15Vdc is used to turn on the MOSFET gate, 5 Vdc is used in Vcc and as enable for IC's. For 15V and 5V, power supply which supplied 24V is used and two voltage regulators is used to get the voltage rating needed. Circuit connection of the voltage regulator can be referred in figure 5. Figure 4 show circuit connection for 350V of unregulated voltage source. The connection will be supplied directly to the MOSFET drain voltage, V_{dd}.

3.2.4 MOSFET driver circuit diagram

This project will be used both high and low side of MOSFET driver. This is because the circuit topology for this project used were full – bridge converter. As we can see in above figure, figure 5 shows circuit diagram for using 2 MOSFET. MOSFET that we will use is IRF740. This is due to the high current rating and high drain voltage that it can take. For this MOSFET, it can take up to 400V drain voltage. As for MOSFET driver we will use IR2109. One driver can driven two Mosfet at one time by giving high and low pulsed output.

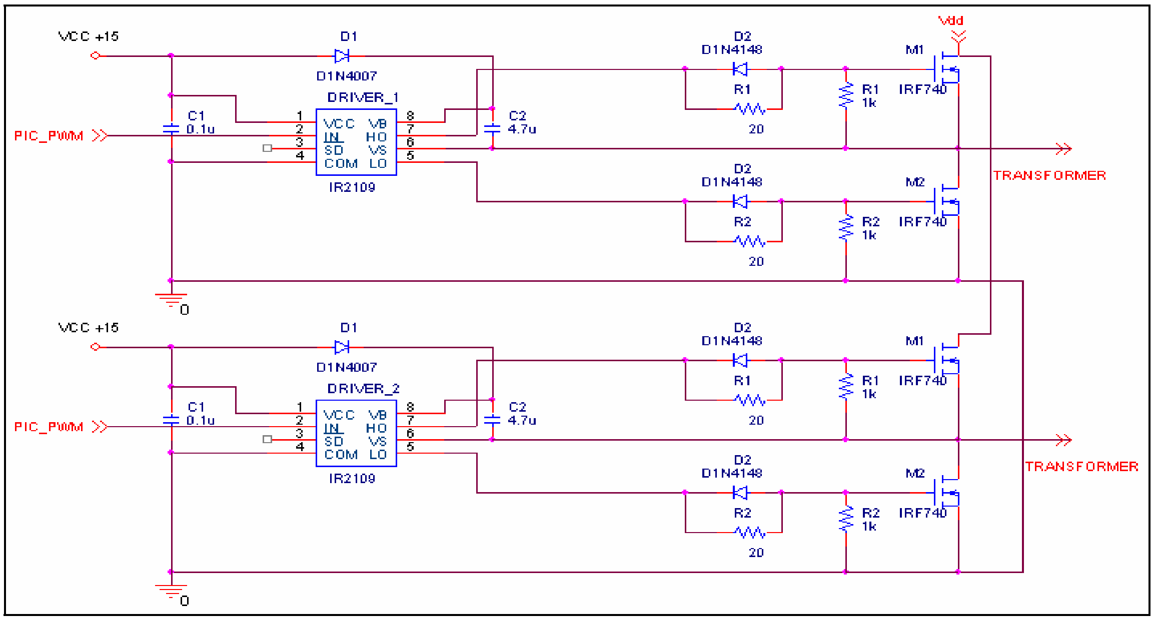

Figure 3.3 Circuit diagram for MOSFET driver

3.2.5 TIMING CHARACTERISTIC

To a battery charger with available components, the specified system input voltage should be able to be incremented from 10% to 90% or its maximum value. From the system block diagram, the components at hand are power MOSFET FA57SA50LC for the power switch IR2101 for the driver, PIC18F4550 for the PWM controller and form the table from the components elements for the fall-time (tf), rise-time (tr), minimum on-time (ton (min)) and minimum off-time (toff (min)).

Table 3.1: Rise and Fall Time

Bil	Component	tr(ns)	tf(ns)
1	FA57SA50LC	152	118
2	IR2101	170	90

Table 3.2: Minimum On and Off Time

Bil	Component	ton(min) (ns)	toff(min) (ns)
1	FA57SA50LC	32	108
2	IR2101	220	220

3.2.6 Determine the frequency range available for the system

(a) D(min)=10%

(b) D(max)=90%

(c) tr(slowest)=170ns

(d) tf(slowest)=118ns

(e) ton(min)=220ns

(f) toff(min)=220ns

Insert the frequency range data in the equation:-

$$fswitch \le \frac{4D(\min)}{tr(slowest) + tf(slowest) + 4ton(\min)}$$ (3.10

$$fswitch \le \frac{4(0.1)}{170ns + 118ns + 4(220ns)}$$

$$fswitch \le \frac{0.4}{1168ns}$$

$$fswitch \le 342kHz$$

3.2.7 Power Transformer

As for this project, a power transformer with high frequency setup will be design. There are few steps in designing high frequency transformer. The purpose of a power transformer in Switch-Mode Power Supplies is to transfer power efficiently and instantaneously from an external electrical source to an external load. In doing so, the transformer also provides important additional capabilities such as the primary to secondary turns ratio can be established to efficiently accommodate widely different input/output voltage levels, multiple secondaries with different numbers of turns can be used to achieve multiple outputs at different voltage levels and separate primary and secondary windings facilitate high voltage input/output isolation, especially important for safety in off-line applications

Step 1. Define the power supply parameters pertaining to the transformer design :

$$V_{IN}\ range : 240V \tag{3.11}$$

$o/p\ 1 : 34V\ , 10A$

$o/p\ 2 : none$

$cct\ topology : full - bridge\ converter$

$switching\ frequency : 200kHz$

$Transformer\ frequency : 200kHz$

$Maximum\ loss\ (absolute) : 2.5W$

$Max\ °C\ rise : 40°C$

$Cooling\ method : Natural\ Convection$

Step 2. Define absolute duty cycle limit D_{lim} tentative normal D_{max} at low V_{IN} (to provide headroom for dynamic response), and normal $V_{IN}\,D$:

$Absolute\ Limit, D_{lim} : 0.9$

$Normal\ D_{max} : 0.45$ (this is due to D/2 because in Power Transformer article it state that it is better to think this transformer operating at D/2, retaining a consistent definition of D throughout the power supply design)

$$Normal\ V_{IN} \times D : 108V \tag{3.12}$$

$$V_{IN} \times D_{lim} : 216V$$

Step 3. Calculate output voltages plus diode and secondary IR drops at full load :

$$V_{o1'} : 34 + 0.4 = 34.4V \tag{3.13}$$

$V_{o2'} : n/a$