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Design of High Energy Lithium-Ion Battery Charger

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Abstract: The lithium ion battery emerged in the commercial market in 1991 and introduced new technology advantages over its energy storage predecessors. Lightweight, high energy density and low maintenance are among the key advantages that it offers. Ten years after its debut, lithium ion secondary battery makes its first orbit around the Earth. Since then, lithium ion is considered the next milestone in rechargeable batteries.

***Index Term-* Lithium ion Charger, Li-Ion Battery, Charger, Li-Ion.**

I. INTRODUCTION

Lithium-ion battery is a rechargeable battery that has the highest energy density, lightweight, small in size and long shelf life. However, Li-ion battery charging is slightly more complicated as several factors must be considered especially when the battery pack consists of series connected Li-ion battery cells. Moreover, the battery cannot be over-charged due to its chemistry limitations. Therefore, exceptional control unit is required in controlling both charging and discharging process in order to ensure that Li-ion battery is extended life. In this paper, the Li-ion battery charger is designed for high energy applications such for storage system in linear generator system, backup power system, and electric and electric hybrid vehicle. The battery charger is designed to charge 29.4V, 90Ah Li-ion battery pack in which the battery pack comprises 7 cells of 4.2V, 90Ah Li-ion battery connected in both series and parallel.

II. CHARGING BASICS

Batteries are exhaustively characterized to determine safe yet time-efficient charging profiles. The optimum charging method for a battery is dependent on the battery’s chemistry (Li-Ion, NiMH, NiCd, SLA, etc.). However, most charging strategies implement a 3-phase scheme:

1. Low-current conditioning phase
2. Constant-current phase
3. Constant-voltage phase/charge termination

All batteries are charged by transferring electrical energy into them. The maximum charge current for a battery is dependent on the battery’s rated capacity (C). For example, a battery with a cell capacity of 1000mAh is referred to as being charged at 1C (1 times the battery capacity) if the charge current is 1000mA. A battery can be charged at 1/50C (20 mA) or lower if desired. However, this is a common trickle-charge rate and is not practical in fast charge schemes where short charge-time is desired.

Most modern chargers utilize both trickle-charge and rated charge (also referred to as bulk charge) while charging a battery. The trickle-charge current is usually used in the initial phases of charging to minimize early self-heating which can lead to premature charge termination. The bulk charge is usually used in the middle phase where the most of the battery’s energy is restored.

During the final phase of battery charge, which generally takes the majority of the charge time, either the current or voltage or a combination of both are monitored to determine when charging is complete. Again, the termination scheme depends on the battery’s chemistry.

For instance, most Lithium Ion battery chargers hold the battery voltage constant, and monitor for minimum current. NiCd batteries use a rate of change in voltage or temperature to determine when to terminate. While charging a battery, most of the electrical energy is stored in a chemical process, but not all as no system is 100 percent efficient. Some of the electrical energy is converter to thermal energy, heating up the battery. This is fine until the battery reaches full charge at which time all the electrical energy is converted to thermal energy. In this case, if charging isn’t terminated, the battery can be damaged or destroyed. Fast chargers (chargers that charge batteries fully in less than a couple hours) compound this issue, as these chargers use a high charge current to minimize charge time. As one can see, monitoring a battery’s temperature is critical (especially for Li-Ion as they explode if overcharged). Therefore, the temperature is monitored during all phases. Charge is terminated immediately if the temperature rises out of range.

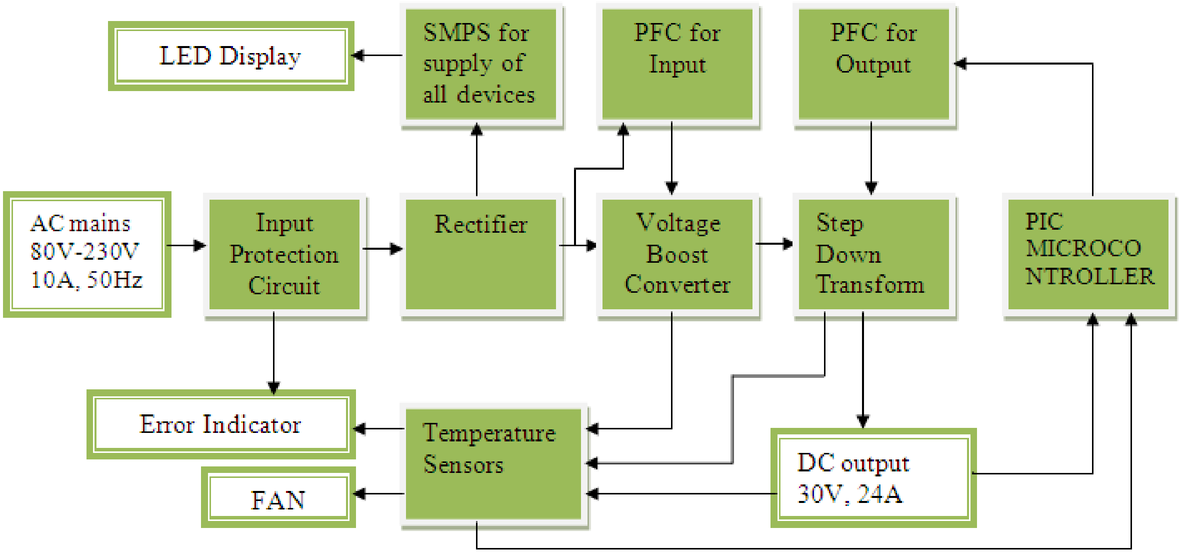

Fig.1. Block Diagram

III. FLOWCHART

Flow chart is shown in Appendix.

IV. LI-ION BATTERY CHARGER - HARDWARE

Currently, Li-Ion batteries are the battery chemistry of choice for most applications due to their high energy/space and energy/weight characteristics when compared to other chemistries. Most modern Li-Ion chargers use the tapered charge termination, minimum current, method to ensure the battery is fully charged.

A. BOOST CONVERTER

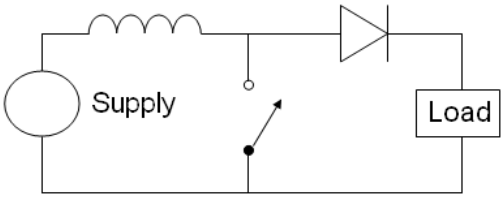

Fig.2. Boost Converter

The input to the charger is a 120Vac wall outlet, and the input to the buck converter (for the scaled up version) is up to 350Vdc, thus an AC-DC converter is necessary to supply the batteries with power. The major options are various switching mode power supplies (boost, fly back, and full-bridge) and a linear step-up transformer. Switching mode power supplies (SMPS) transfer relatively small amounts of Charge at a time through inductors at high frequency (100 kHz), whereas step up transformers transfer larger amounts of charge at 60 Hz. This leads to a significant cost difference between the two options, since a SMPS requires much smaller magnetic cores; it was decided to use a SMPS. Of the options for SMPS, we decided to go with a power factor correction boost converter topology. The advantages of this design include widespread use (and Thus lower cost and large knowledge base) and efficiency. Since the converter actively corrects the average current drawn to reflect the AC voltage, the power factor supplied is close to unity effectively lowering current drawn and greatly increasing efficiency. Another advantage to using the PFC boost converter is that it can accept inputs between 115Vrms-240Vrms and provide 350V at all inputs. The UC3854 from Unitrode is a PFC boost converter control integrated circuit. It takes output voltage and current feedback and alters the gate voltage of a power transistor to control a boost converter. The boost converter will not be made in simulating the scaled down system. This would involve developing a low voltage sinusoidal high power input source, and the scaled down system would just add to the total project cost.

For the scaled down system we will be able to use series dc power supplies instead, and the boost converter will only be considered for the scaled up 350V system.

B. BUCK CONVERTER

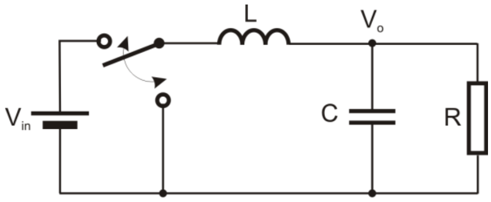

Fig.3. Buck Converter

The most economical way to create a tapered termination charger is to use a buck converter. A buck converter is a switching regulator that uses an inductor and/or a transformer (if isolation is desired), as an energy storage element to transfer energy from the input to the output in discrete packets (for our example we use an inductor; the capacitor is used for ripple reduction). Feedback circuitry regulates the energy transfer via the transistor, also referred to as the pass switch, to maintain a constant voltage or constant current within the load limits of the circuit. The buck circuit in our system is able to generate 243-324 Volts, and contains an inductor, a transistor, and a diode that control charge through the inductor. It alternates between connecting the inductor to the source voltage to store energy in the inductor and discharging the inductor into a load. The MOSFET driver uses a 3.3V pulse width modulation (PWM) voltage signal from the PIC16F819 to a 12V signal to switch the power MOSFET. The MOSFET driver is albe to isolate both low and high voltage system easily and minimize losses with MOSFET switching.

V. LI-ION BATTERY CHARGER - SOFTWARE

The software example that follows demonstrates a Li-Ion battery charger using the PIC16F819. The microcontroller is designed for high-level languages like “C” and includes an 8-bit PIC based micro-controller, an 10-bit ADC, 2k FLASH, an 10-bit PWM, and a 2% accurate oscillator all on chip. The algorithms discussed are written entirely in “C” making them easily portable. Refer to the PIC16F819’s datasheet for a full description of the device.

A. CALIBRATION

To ensure accurate voltage and current measurements, the algorithms use a two-point system calibration scheme. In this scheme, the user is expected to apply two known voltages and two known currents, preferable, one point near ground and the other point near full-scale. The algorithm then takes these two points, calculates a slope and an offset for both the current and voltage channels, and stores the results in FLASH. All future conversions are scaled relative to these slopes and offset calculations. Note that if an external amplifier is used for the current channel, it will need to be calibrated with a similar two-point calibration scheme to ensure maximum accuracy.

B. Temperature

To monitor the temperature, the algorithms use the NTC as well as PTC thermistor.

C. Current

The charge-current to the battery cells is monitored by taking a differential voltage reading across a small but accurate sense resistor. The current is digitized by the on-chip 8-bit ADC and scaled accordingly via the slope and offset calibration coefficients. An external gain stage may be necessary if more resolution is desired for the current measurement.

D. Voltage

The battery’s voltages are divided down and monitored via external resistors. Note that this example uses the supply voltage as the ADC voltage reference. Any monitored voltage above the reference voltage must be divided down for accurate monitoring. If a more accurate reference is required, an external voltage reference can be used. Adjustment to the divide resistors must be made accordingly.

Charging - Phase1

In phase 1, (for description purposes, we assume the battery is initially discharged), the ‘PIC regulates the battery’s current to $I_{LOWCURRENT}$ (typically 1/50 C) until the battery’s voltage reaches $V_{MINVOLTBULK}$. Note that the battery’s charge current is current limited to $I_{LOWCURRENT}$ to ensure safe initial charge and to minimize battery self-heating. If at any time the temperature increases out of limit, charging is halted.

Charging - Phase 2

Once the battery reaches $V_{MINVOLTBULK}$ the charger enters phase 2, where the battery's algorithm controls the PWM pass switch to ensure the output voltage provides a constant charge-current I_{BULK} to the battery (rate or bulk current is usually 1C and is definable in the header file as is $I_{LOWCURRENT}$ and $V_{MINVOLTBULK}$.

Charging - Phase 3

After the battery reaches V_{Top} (typically 4.2 V in single cell), the charger algorithm enters phase 3, where the PWM feeds back and regulates the battery's voltage. In phase 3, the battery continues to charge until the battery's charge current reaches $I_{MINIBULKI}$, after which, the battery is charged for an additional 30 minutes and then charge terminates. Phase 3 typically takes the majority of the charging time.

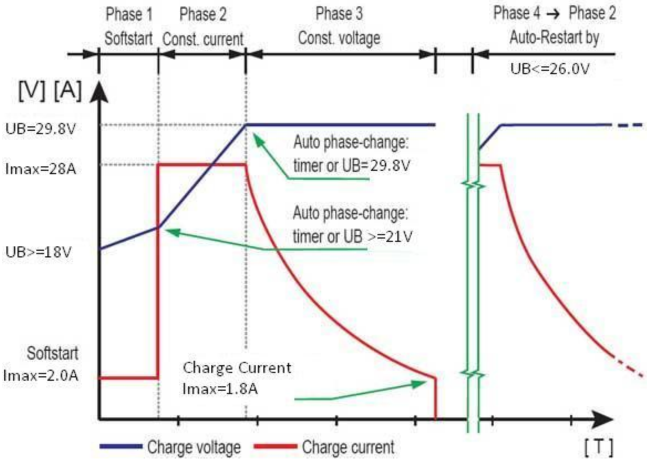

Fig.4. Charging Graph

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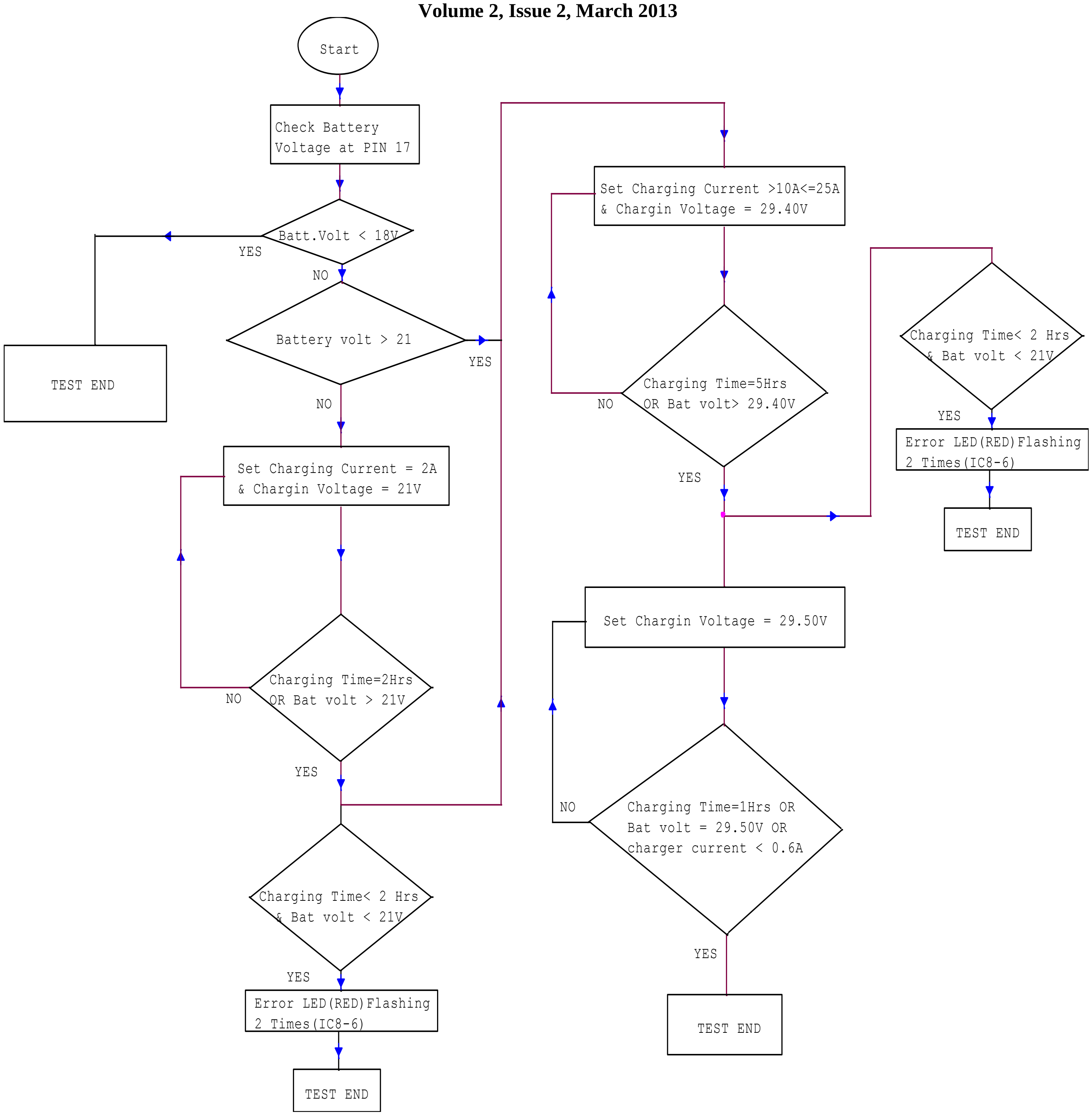
Start
Check Battery Voltage at PIN 17
Batt.Volt < 18V
YES
NO
TEST END
Battery volt > 21
YES
NO
Set Charging Current = 2A & Chargin Voltage = 21V
Charging Time=2Hrs OR Bat volt > 21V
NO
YES
Charging Time< 2 Hrs & Bat volt < 21V
YES
Error LED(RED)Flashing 2 Times(IC8-6)
TEST END
Set Charging Current >10A<=25A & Chargin Voltage = 29.40V
Charging Time=5Hrs OR Bat volt> 29.40V
NO
YES
Charging Time< 2 Hrs & Bat volt < 21V
YES
Error LED(RED)Flashing 2 Times(IC8-6)
TEST END
Set Chargin Voltage = 29.50V
Charging Time=1Hrs OR Bat volt = 29.50V OR charger current < 0.6A
NO
YES
TEST END