February17, 2014

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC, V5A 1S6

Re: ENSC 440 Functional Specification for an Advanced Function Maximum Power Point Tracking Battery Charger for 12 Volt Lead-Acid and 16 Volt Ni-Cad Batteries

Dear Professor Rawicz:

The attached document illustrates the Functional Specification for an Advanced Function Solar Power Batter Charger for 12 Volt Lead-Acid and 16 Volt Ni-Cad Batteries proposed by Solar Solutions. Our product, Helios MK-I, allows the user to efficiently charge a battery using a solar panel as a power source by implementing an MPPT algorithm.

The purpose of the Functional Specification is to outline the functionality of Helios MK-I's. This includes the Engineering standards, the process details, technical correctness, and the sustainability and safety of our product.

Solar Solutions consists of five members and is receiving funding from Analytic Systems, which is North America's fastest growing power conversion company [1]. You may contact me by phone at 604-761-4568 or by email at rhargrov@sfu.ca if you have any concerns or questions about our proposal.

Sincerely,

Richard Hargrove

Richard Hargrove
President and CEO
Solar Solutions

Enclosure: *Functional Specification for an Advanced Function Maximum Power Point Tracking Battery Charger for 12 Volt Lead-Acid and 16 Volt Ni-Cad Batteries*

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Functional Specification for an Advanced Function Maximum Power Point Tracking Battery Charger for 12 Volt Lead-Acid and 16 Volt Ni-Cad Batteries

ENSC 440: Capstone Project, ENSC 305: Project Documentation

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Executive Summary

Energy is increasingly becoming a scarce commodity; many governments and institutions are now investing in harvesting energy in a more viable, sustainable and affordable fashion. Solar panels, although a work in progress, are steadily advancing to become the standard method of harvesting solar energy [2]. Helios MK-I benefits from these advances by using proven methods such as MPPT and digital control to efficiently and optimally charge lead acid batteries.

The design of Helios MK-I will consist of different development phases. Please note that these phases are in parallel and will require multiple revisions before completion. The prototype will support the following functionalities given below.

- Fully functioning MPPT
- Serial-communication to microprocessor using Visual Basic
- Finished RS-232 communication link with Flash memory

Furthermore, the prototype shall be able to adhere to the following requirements.

- Input Voltage Range : 8 Volts to 32 Volts
- Maximum In/Out Current: 20 Amps
- Maximum Output Voltage: 20 Volts

We expect Helios MK-I to be fully functional by the end of the semester with at least one specific solar panel. If time permits, Helios MK-I shall function with any solar panel. We expect the complete cycle of the project to be completed by the end of the semester.

Lastly, Helios MK-I will adhere to the following standards and guidelines set by Canadian Standards Association (CSA) and Underwriters Laboratories Inc. (UL): UL 1012 and C22.2 No 107.2-01 [3].

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1. Introduction

This functional specification outlines requirements of the Helios MK-I battery charger as proposed by Solar Solutions. Helios MK-I is an advanced MPPT battery charger which draws optimal power from solar panels for the purpose of charging Lead-acid batteries. The product aims to replace existing battery chargers that are currently used in various remote sites within British Columbia and elsewhere.

1.1 Scope

This document outlines the functional requirements of the Helios MK-I. These requirements are used to describe the proof-of-concept product as well as the fully functioning product. Furthermore, this document will be used by the team members of Solar Solutions as a guideline for research and development and will be traceable in future design documents.

1.2 Intended Audience

This functional specification is intended for use by all team members of Solar Solutions and Analytic Systems. Moreover it is expected that each team member refer to the functional specification throughout different phases of development to ensure overall design goals can be met. Furthermore, this document will serve to assess the prototype after production by comparing the achieved functionality versus targeted functionality. Lastly, this document will aid in further testing.

1.3 Classification

Design requirements that are defined by the Functional Specification will be designated throughout the document by the following:

[R#] where the # will be replaced by a numeral designating each separate requirement.

2. System Requirements

The complete general requirements of the Helios MK-I Battery Charger system are presented in this section.

2.1 System Overview

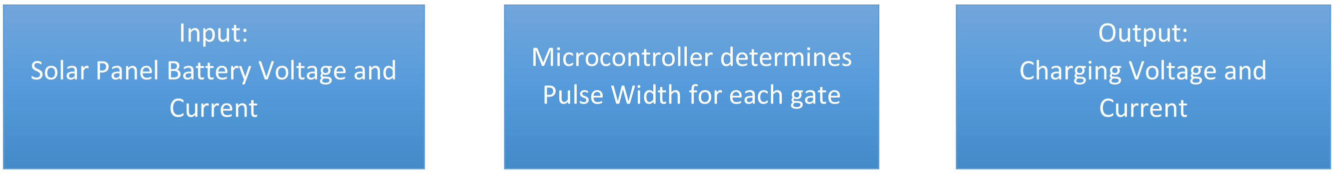

Figure 1: *System Overview of general input and output handling.*

The project will incorporate a 64-pin microcontroller, operational amplifiers, comparators, temperature sensors and other circuit components soldered onto a PCB, all housed within an aluminum enclosure. Measured currents, voltages and temperatures are fed into a microprocessor, analyzed and used to adjust duty cycles to implement MPPT, stepping up/down solar panel output and battery charging. There exist multiple charging states which depending on converter output voltage, input voltage, load current, battery type and the state of charge of said battery.

HM1 will only charge if sunlight is incident upon the solar panels, operation will be optimal in high sunlight. Evidently, a shaded area is not a good place for solar panels.

2.2 General Requirements

[R1] The retail price of the battery charger shall be under $1000.
[R2] The MPPT algorithm shall provide optimal performance.

2.3 Physical and Mechanical Requirements

[R3] The PCB shall fit into a 2U rack mount chassis.
[R4] The PCB may fit into a 1U rack mount chassis
[R5] The PCB may fit into a typical Analytic Systems Enclosure
[R6] The PCB shall weigh less than 8lbs.

2.4 Electrical Requirements

[R7] The PCB shall be powered by the Battery or by the Solar Panels.
[R8] The maximum usable Solar Panel Voltage shall be 36V.
[R9] The maximum floating Solar Panel Voltage shall be 48V.
[R10] The minimum Solar Panel Voltage shall be 8V.
[R11] The maximum current (in/out) shall be 20A.
[R12] The maximum converter output voltage shall be 20V.
[R13] The battery charger shall output 300W maximum.
[R14] The battery charger shall output 50W minimum.
[R15] The battery charger shall produce minimal EMI.

2.5 Environmental Requirements

[R16] The battery charger shall function at -20°C ambient temperature.
[R17] The battery charger shall function at 80°C ambient temperature.
[R18] The battery charger chassis shall not heat to over 60°C at 25°C ambient temperature.
[R19] The battery charger shall operate normally between sea level and 2000M above sea level.
[R20] The battery charger shall operate normally between 0 and 90% humidity.
[R21] The battery charger may meet RoHS.
[R22] The battery charger shall be between 0 and 40dB at 3ft. under any condition.

2.6 Reliability and Durability

[R23] The battery charger shall be resilient to harsh weather conditions.
[R24] The battery charger shall not be user serviceable.
[R25] The battery charger shall be able to run continuously.
[R26] The battery charger shall have an MTBF longer than 5 years.
[R27] The battery charger shall survive a fall from 1m on any face or corner.

2.7 Safety Requirements

[R28] The battery charger input shall be isolated from the chassis by at least 500VDC.
[R29] The battery charger output shall be isolated from the chassis by at least 500VDC.
[R30] The battery charger will have a fuse with a 30A rating.
[R31] The battery charger will have a crowbar implemented into the design.
[R32] The battery charger shall be contained in an enclosure.
[R33] The battery charger shall not be combustible.
[R34] The battery charger shall not cause damage to a compatible solar panel.
[R35] The battery charger shall not cause damage to a compatible battery.
[R36] The battery charger shall not damage a battery hooked up in reverse.
[R37] The battery charger shall not damage a solar panel hooked up in reverse.

[R38] The battery charger shall not explode.
[R39] The battery charger shall not be susceptible to mold.

2.8 Performance Requirements

[R40] The battery charger shall have an on and off switch.
[R41] The battery charger shall have an initiation mode where it checks all of its inputs for faults and starts up the converter.
[R42] The battery charger shall have a soft start to ensure reliability and safety.
[R43] The battery charger shall be capable of trickle charge, bulk charge, and float charge.
[R44] The charge modes and the conditions that need to be met to transition between them shall be user definable.
[R45] The battery charger shall enter sleep mode when the solar panels are not usable, this must draw less than 1mA RMS from the battery.
[R46] The battery charger shall be capable of entering sleep mode in case of any fault.

2.9 Usability Requirements

[R47] A program shall accompany the battery charger to allow solar panel and battery selection by a user.

3. Microcontroller Requirements

The microcontroller is in charge of controlling the input voltage across the solar cells (MPPT) and the output voltage/current for the battery. The duty cycle is chosen by monitoring the current, voltage and other variables on the system. Firmware will be embedded into the microcontroller to oversee correct system operation.

The microcontroller will be powered by the battery or solar panel and will enter sleep mode to converse energy when the charger is not operating. The MPPT algorithm will be implemented in the code to provide maximum power transfer at any time.

3.1 General Requirements

[R48] The minimum amount of pins on the microcontroller will be 40.
[R49] We shall select a microcontroller that can be programmed with embedded C.
[R50] The microcontroller shall function between -25°C and 85°C.
[R51] The microcontroller shall be capable of being monitored by third party device.
[R52] The microcontroller shall be reprogrammable.

4. PCB Requirements

Almost all components will be placed on the PCB. Traces on the PCB shall carry both weak communication signals and the power signal path.

- Maximum Voltage 300V
- Maximum Current 50A
- Low Power Loss
- Noise Reduction
- EMI
- Ringing

4.1 General Requirements

[R53] The PCB shall function between temperatures of -40°C to 135°C.

[R54] The PCB shall have 4 copper layers.

4.2 Physical Requirements

[R55] The PCB shall fit in the enclosure.

[R56] The PCB shall have strategically placed structural mounting holes.

5. Enclosure

The enclosure will contain all parts of the battery charger. The purpose of the enclosure is to protect the charger from the exterior environment that may cause harm to the parts and prevent it from functioning normally. The enclosure also acts as a heat sink; power components shall be mounted close to the enclosure to dissipate heat. Some causes from the exterior environment that would affect the functionality of the battery charger include:

- Hunters mistaking the battery charger for an animal.
- Animals seeking shelter from the weather or trying to find a home.
- Harsh weather conditions; rain, snow, dust, and heat/cold.
- Twigs, leaves etc.

Because of the purpose of the enclosure, it must be resilient, durable, and reliable.

Measurements will be made for the dimension of the enclosure to ensure the PCB fits.

5.1 General Requirements

[R57] The enclosure shall not be toxic.
[R58] The enclosure shall not disturb the environment.

5.2 Physical Requirements

[R59] The enclosure shall be distinguishable so hunters do not mistake it for an animal, and animals do not mistake it for food, accommodation or a piece of territory.
[R60] The enclosure shall be durable to withstand weather and environment conditions.

6. Standards Referenced

Standards are an integral part of any engineering project. The following relevant standards will be referenced to ensure our product is marketable:

- CSA-C22.2 NO. 107.2-01 – Battery Chargers [4].
- UL1012.
- RoHS [5].

7. Environment and Safety

Helios MK-I is an electronics product and by its nature will be harmful to the environment. Nevertheless, steps have been taken to minimize detrimental effects. First, components have been selected such that RoHS and WEEE standards are met or exceeded; individual components within Helios MK-1 will not contain lead, mercury, cadmium and several other banned substances. These chemicals and elements have shown to be extremely insidious to humans and the general environment. Due to the strong push to modernize and reduce impact of electronics production, one can now easily find a wide range of components that meet or exceed ROHS, WEEE and other environmental standards.

Nevertheless, meeting standards such as WEE or ROHS does not translate into a benign design and a harmless product. For example, one might wonder what environmental damages are incurred while mining the copper ore for the wires or what toxins are released during the purification of the silicon ore for the semiconductor dies [7].

Steps have been taken to insure the production of Helios MK-I is as harmless as possible. Nevertheless two elements present in the device seriously damage the claim to a safe and benign product. First and foremost, as of today, the wave soldering process used for the PCB is Lead based. This means even though our components themselves contain no lead, our PCB will. In the future plans are to switch to a lead-free process, but for now, lead is present in large quantities. The other harmful element present is tantalum. Tantalum is used in low ESR bulk and decoupling capacitors. As of today no cheap alternatives exist, other capacitors are prone to causing oscillations if used, and datasheets have requested tantalum. Even though tantalum itself is completely inert and safe to humans and the environment it is one of the root causes of a bloody civil war in Africa, which has involved such tragedies as child warfare and genocide.

7.1 OPERATION

During operation, the device shall release no harmful emissions or in any way be harmful to the environment. On the contrary, the device shall prove an environmentally friendly way of powering remote sites. Other alternatives to solar panels include large oil reserves, small scale nuclear reactors, wind and hydro power. Out of these solar is the only solution which both offers no moving parts, meaning less maintenance. Furthermore, hydro creates ecological hazards for salmon. Therefore, in some cases, solar power is the best environmental and most economical option.

7.2 End of Life And Safety

Once end of life is reached, there will be no way to reuse the PCB or the circuit components in other electronics products. This is due to the soldering methods used, specifically surface mount soldering. However, several components can be salvaged and recycled. These include the inductor, heat sinks, wires and the PCB ground plane. All of these can be salvaged for their copper content in a safe and economically viable fashion.

The chassis is designed with extruded aluminum. This element is in high demand and can easily be either reused as a chassis or more likely recycled for its purified aluminum content.

The MOSFETS, diodes and other components we have chosen contain mostly benign elements such as silicone, epoxy and copper [8]. If they are sent to the landfill they shall not leach any harmful elements into the surroundings. But they cannot be easily reused in other devices in any economically viable fashion.

Our product could fail catastrophically in several ways. First, it could short circuit the battery. This would be bad, put simply. Currents approaching 1kA would flow through the battery and wires heating them up to the point of combustion. Once lead acid batteries catch fire, tremendous amounts of energy can be released. The potential of harm is great. To prevent this nightmare scenario several current sensors have been placed in the path of the battery that will hopefully open circuit the battery if over current is sensed. Obviously this won't do much if a technician drops a wrench onto the terminals of the battery, but these are risks one must take in order to use this type of energy storage.

Current sensors are also placed in the input path of the solar panel, serving similar purpose. The device is built to handle the case of excessive voltage input, excessive current input and the case where the batteries are installed the wrong way with polarities reversed. None of these conditions will cause damage to the device unless inputs are several times their maximum.

The device is also built to operate safely through a wide operating temperature range and shut down if temperature on any of the major components throughout the circuit is higher than acceptable.

The second fault condition that can occur is overcharging the battery, this too could lead to battery explosions. To prevent this Helios MK-I uses intelligent digital control which estimates SOC of the battery and takes into consideration several other parameters to insure the battery is charged in the safest way possible.

The device is built such that it poses no harm to users of the device. Under normal conditions the enclosure of the case is bolted to the zero reference point of the circuit, which is the ground. This ensures if for whatever reason something inside is shorted to the case, it will short and the current sensors would shut the device down. Due to the fact that the device operates over a low voltage range, there is no chance that the device can electrocute the user. The largest voltage present on the device shall not exceed 60V. This is the maximum safe DC voltage before the risk of electrocution becomes present.

Finally a 30A fuse and a crowbar design will be implemented into the design. The fuse will provide a 30A limit if the current were to spike over 30A. This is to provide protection to the circuit and not damage the board or battery. Similarly, the crowbar topology will provide overvoltage protection. Since fuses rely on currents to work, the crowbar will watch for any voltage spikes, protecting the device. The crowbar consist of capacitors, zener diode, thermistor, and resistors.

8. System Test Plan

The components will be tested for their safety, reliability, efficiency, and correctness of numerical values as stated on datasheets. The more important components shall warrant a more intense testing.

Once assembled, point-to-point testing will be conducted on the prototype to insure expected values are achieved throughout the circuit. Further testing on parts include:

- Inductor: Efficiency of energy conversion
- Power Supply (Brick): Brick supplies enough power to the active components
- Current Sensors: Sensed current is accurate with little variance
- Zener diodes: Correct break down voltages
- Fuse: Fuse will open during over currents and will not have false triggers
- Crowbar: Crowbar will activate upon overvoltage and will not have false triggers
- Microcontroller: Sends PWM

Because of the harsh climate in British Columbia, temperature testing is important. The PCB will be tested in a temperature chamber; efficiency of operation throughout the required specified operating region shall be tested. EMI levels will also be tested in an EMI chamber.

By applying different input voltages we will test the MPPT algorithm and observe changes in the Duty Cycle. The algorithm is the key component to the project, as it will dictate the overall efficacy of the device.

Once the device has been thoroughly tested in a lab environment, device will be placed outdoors and monitored to check for MPPT effectiveness, component temperatures and overall ruggedness. Outdoors testing is slightly more difficult to conduct because of time restrictions. without testing the system for extended periods of time in typical environments, it is difficult to gauge the true long-term performance of the device.

9. Fault coping strategies

The table below shows a list of fault conditions and how Helios MK-I is designed to deal with them

Fault condition	Duration of Fault	Coping Mechanism
Lead acid cell voltage exceeds 2.5V	2 Hours	All charging is stopped. Voltage allowed to fall.
Load draws more than 40A	1 Second	Load is disconnected from the battery and charger for 10 seconds.
Load draws more than 40A	2 seconds	The fuse is blow. Must be manually replaced. Load is permanently disconnected
Battery draws more than 40A	1 Second	Battery is disconnected from the charger and Load for 10 seconds
Battery draws more than 40A	2 seconds	The fuse is blow. Must be manually replaced. Battery is permanently disconnected
PCB temperature exceeds 80 Degrees by no more than 5 Degrees	1 Hour	Device is shut down until temperature drops to 75 Degrees.
PCB temperature exceeds 85 Degrees	Instant	Device is shut down until temperature drops to 75 Degrees.
Panel Voltage exceeds 36V by no more 2V	10 Minutes	Device is shut down until voltage is under 36V
Panel Voltage exceeds 36V by more than 2V	Instant	Device is shut down until voltage is under 36V

Table 1: *Specific fault coping strategies to be implemented within the microcontroller algorithm*.

10. Conclusion

Solar Solution is confident that the specifications and requirements for the prototype of Helios MK-I are fully defined in this Function Specification. This functional specification will keep the project focused and allow the members to reference important material. A working prototype for demonstration is scheduled to be complete before the end of the semester.

The system overview provides the general guideline for inputs, intermediate steps, and output results, whereas the microcontroller requirements go into further detail. All general, physical, and safety requirements have been outlined so as to ensure they are incorporated into the design, and that all members of the team have access to the well-established safety requirements. Cradle-to-cradle lifecycle has been analysed and important design decisions have been made based on environmental safety and budget. Fault coping strategies have been established, to further document the safety features and synchronize the group.

11.References

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