February 17, 2014

Dr. Andrew Rawicz
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Re: Functional Specifications - Solar Powered Charger for Offshore Applications

Dear Dr. Rawicz,

The following document contains the functional specifications of our solar powered battery charger for offshore applications. We plan on supplying power to a hydrophone and ISM-band transmitter via a bank of lithium polymer batteries. This battery bank will be charged with a single 250W solar module on an offshore buoy.

With safety and reliability being our company's top priorities, we will be implementing remote performance monitoring and emergency shutdown procedures of our offshore system. This document outlines the normal functionality of our solar charger, the monitoring of system performance, and the failsafe mechanisms in case of an emergency. This document also discusses the various engineering standards that we must follow in order to ensure safe and reliable operation of our product.

The scope of the enclosed specifications is the high-level functionality of our product, rather than a detailed analysis of our design. Our engineers at AquaSol Solutions will use these functional specifications to remain focused on what our product is to accomplish, and on how to implement the desired functionality in a safe and reliable manner.

Sincerely,

AquaSol Solutions

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Solar Powered Charger for Offshore Applications

Functional Specifications

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EXECUTIVE SUMMARY

With the endangerment of resident killer whales along the British Columbia coastline, it is increasingly important to effectively track their migration patterns. The DFO currently employs land-based hydrophones to listen in on killer whale calls. AquaSol Solutions' proposed solar powered battery charging system would allow for hydrophones to be placed in remote offshore locations. The killer whale calls and battery status will be transmitted back to a land-based station via an ISM-band transmitter.

The development of the battery charging and monitoring system will be based on the requirement of supplying continuous power for a duration of twelve days. It will also measure and transmit—to a desktop application—the state of charge and temperature of the batteries, and the humidity within the hardware circuitry enclosure. The system will be designed to allow for dynamic detection of up to two connected battery modules. Additionally, the system will provide alerts and safety shutdown mechanisms in case of unsafe operating conditions.

This document outlines the functionality of the final product and its corresponding subsystems. It will also serve to outline additional project details, including the proposed test plan and overall sustainability of the end product.

GLOSSARY

BMS	Battery Management System
CSA	Canadian Standards Association
DC	Direct Current; DC loads require a constant voltage to power them
DFO	Department of Fisheries and Oceans
GSM	Global System for Mobile Communications
ISM	Industrial, Scientific, and Medical – usually refers to the 2.4-2.5 GHz frequency band for transmitting information
MCU	Microcontroller Unit
MPP	Maximum Power Point
PCB	Printed Circuit Board
STC	Standard Test Conditions

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1. INTRODUCTION

The AquaSol Solutions battery charging and monitoring system will charge batteries using solar modules, and provide continuous monitoring and power to devices for up to twelve days of low sunlight conditions. The functional specifications for this charging and monitoring system, as proposed by AquaSol Solutions, will be outlined in this document.

1.1 Scope

This document describes the high-level functionality that must be met by the proposed battery charging and monitoring system. This document will serve as the basis for future design proposals and the system test plan, as well as to help prioritize the features that will be included in the final product.

1.2 Intended Audience

The functional specification is intended for all of the AquaSol Solutions team members, the DFO, and any additional stakeholders. It will be used as a guide throughout the development of the product to ensure that the end product conforms to the functional specifications set here within.

1.3 Classification

Throughout this document, the following classification system will be used:

[Rn-p] Functional Requirement

Where **n** denotes the functional requirement number and **p** denotes the priority of the functional specification as denoted by one of the following codes:

A This requirement must be met for the proof-of-concept and is critical to the system functionality.

B This requirement should be met for the proof-of-concept and must be met for the final product.

C This requirement applies only to the final product, but is not required for base functionality.

2. General System Requirements

This section presents some general requirements and standards to which the system must conform.

2.1 System Overview

The solar powered charger is required to power offshore DC loads. The proposed system consists of four subsystems: the charging module, the battery bank, the BMS, and the desktop application. The charging module charges the battery bank, which in turn powers the DC loads. The BMS monitors and controls the battery bank, while sending battery data back to the base station via the ISM-band transmitter. The desktop application at the base station receives data wirelessly from the ISM-band transmitter; it then displays the battery data and streams the underwater acoustic data from the hydrophone. The relations between the various subsystems are illustrated in Figure 1.

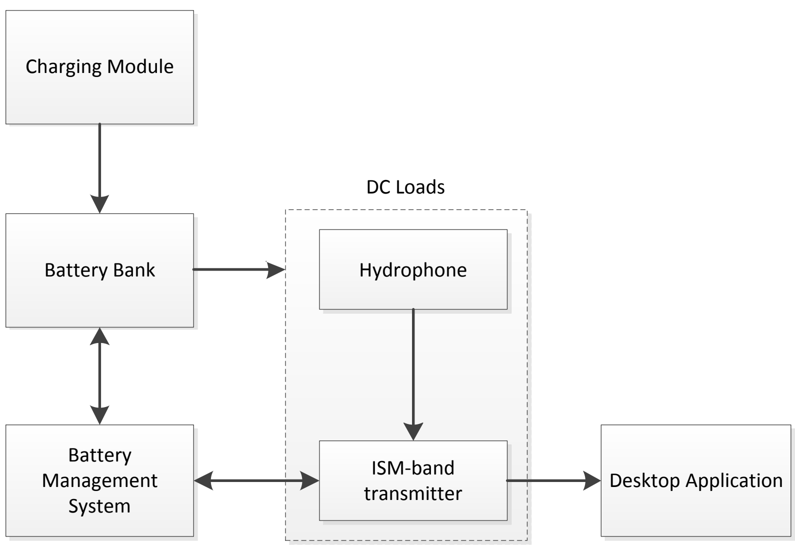

Figure 1: Solar powered charger subsystems

The entire system will be attached to an offshore navigational buoy. The charging subsystem, which includes a solar module, will be placed on the buoy above the surface of water. The rest of the system will be secured in waterproof housing units and placed underwater. Placing the battery bank—the heaviest part of the system—underwater serves to both anchor the buoy and prevent too much weight from being placed on it. To ensure that the weight under the buoy is uniformly distributed, the underwater subsystems will be placed into three separate waterproof units. The central unit will contain the BMS, while the battery bank will be separated into two equally-weighted battery packs.

The BMS will monitor the battery conditions and regularly send this data to the base station via the transmitter. In the event of battery failure or overheating, the BMS will disconnect the battery and send an emergency signal. A backup battery exists (not explicitly shown in Figure 1) in case the entire battery bank fails. The ISM-band transmitter and hydrophone are provided; our system will interface with them.

2.1 General Requirements

[R1-A] The system must provide continuous power to the hydrophone and ISM-band transmission unit for up to twelve days of low sunlight.

[R2-A] The system must be able to provide both continuous power, and power at a lower periodic rate.

2.2 Physical Requirements

[R3-B] The system shall be attached to a navigational buoy.

[R4-B] The charging module shall be placed on the buoy, above water level.

[R5-A] The system, except for the charging module, must be placed underwater in waterproof housing units.

[R6-B] The underwater subsystems shall be divided into one central control unit, and two opposite-facing and equally-weighted units to ensure equal weight distribution off the buoy.

[R7-B] The system shall weigh no more than 90 kg.

2.3 Environmental Requirements

[R8-A] The charging module must operate at temperatures between -20 and 40 °C.

[R9-A] The charging module must operate at a relative humidity between 0 and 100%.

[R10-B] The charging module shall have mechanisms in place to mitigate animal-based soiling of the solar module.

[R11-A] The rest of the system, except for the charging module, must operate at a relative humidity between 40 and 60%.

[R12-A] The system, except for the charging module, must operate at temperatures between 0 and 30 °C.

[R13-B] The system, except for the charging module, shall be mechanically robust enough to withstand strong underwater currents.

2.4 Usability Requirements

[R14-A] The system must have an associated desktop application at the remote station to display battery data.

[R15-C] The associated desktop application shall be easy to use.

[R16-B] The battery bank shall be easily detachable from the system.

[R17-C] The BMS shall be easily configurable.

2.5 Maintenance Requirements

[R18-B] The system shall provide, on average, autonomous power for two weeks.

[R19-C] The charging module shall not need any cleaning during each two week period that the system is deployed.

2.6 Safety and Reliability

[R20-A] The system must have manual shutdown switches to isolate the battery for maintenance.

[R21-A] The system must electronically disconnect batteries that overheat.

[R22-A] The system must have a backup power source in case all batteries fail.

[R23-A] The system must notify the base station of any emergencies, failures, or abnormal conditions with regard to the batteries.

[R24-A] The system must electronically disconnect the charging module from the battery bank in the event of unsafe charging conditions for the battery.

[R25-B] The waterproof housing units shall be connected to one another using waterproof SubConn connectors [1].

2.7 Engineering Standards

[R26-B] The system shall conform to the CSA Canadian Electrical Code Sections 2 through 18, Section 26, and Section 50 [2].

[R27-B] The system shall be RoHS compliant [3].

3. DC Loads

The solar powered charging system needs to power two external DC loads: a hydrophone to record the killer whale calls, and an ISM-band transmitter to stream the data. The hydrophone draws a maximum of 2W, while the ISM-band transmitter draws a maximum of 8W. Both loads need to run 24 hours a day. The solar charging system is therefore being designed to continuously supply 10W of power to the loads.

3.1 Electrical Requirements

[R28-A] Both loads must handle the voltage swing of the battery (20V-29.2V).

[R29-A] Both loads must handle sudden shutdown of the battery.

3.2 Physical Requirements

[R30-A] The hydrophone must have watertight power and data connectors.

3.3 Safety Requirements

[R31-A] Both loads must have built-in reverse polarity protection.

4. CHARGING MODULE

This subsystem contains a 250W solar module and a charge controller. Its primary function is to harvest solar energy and store it in a battery bank. The solar module converts sunlight into electricity, while the charge controller protects the battery bank from being over-charged. Our requirements are based on providing continuous power in December.

The maximum output of a solar module occurs when rays of sun are normally incident upon its surface [4]. For the optimal recommended solar module tilt angle during the winter months, Seattle, WA (47.45° N, 122.30° W) receives an average of 1.4 peak sun hours in December (the month with the lowest solar resource for this region) [5]. This latitude and longitude are very close to that of Vancouver (49.25° N, 123.10° W). Therefore, the Seattle, WA peak sun hours will serve as the assumed solar resource for design considerations.

The solar module was sized according to the power requirements of the loads. The system powers two 24V DC loads (a 2W hydrophone and an 8W ISM-band transmitter) with a combined power draw of 10W, which need to run 24 hours a day. Lithium battery charging efficiencies are typically 97-99% [6], and charge controllers have typical efficiencies of 93-97% [7]. The assumed solar resource will be, on average, 1.4 peak sun hours in December. The system must allow for an extra 80% loss in performance due to potential shading from bird defecation or crystallized sea salt on the module, degradation of semiconductor over time, and semiconductor temperatures higher than 25°C. Taking all of the above data into account, the module wattage was determined as follows:

$$(10W)x\left(\frac{24h}{day}\right) \div (0.97) \div (0.93) \div \left(\frac{1.4\ sun\ hours}{day}\right) \div (0.80) = 238W$$

The system requires a minimum solar module wattage of 238W.

4.1 Electrical Requirements

[R32-A] Solar module must have a power output of at least 238W at STC.

[R33-A] The solar module must have a MPP voltage capable of charging a 24V (nominal) battery bank.

[R34-A] The charge controller must have programmable voltage set points.

[R35-A] The charge controller must have reverse polarity protection.

[R36-A] The charge controller must have internal short circuit protection.

[R37-A] The charge controller must prevent reverse leakage of power to the solar module at night.

4.2 Physical Requirements

[R38-B] The solar module shall have a surface area less than $2m^2$.

4.3 Safety Requirements

[R39-A] A manual disconnect (circuit breaker) must be installed in between the solar module and the charge controller to disconnect the two for safe maintenance.

4.4 Reliability and Durability Requirements

[R40-C] A deterrent shall be installed on top of the solar module to mitigate the risk of bird defecation, which effectively shades the module and lowers output.

5. BATTERY BANK

The DC loads need to run 24 hours a day so that the migration patterns of resident killer whales can constantly be monitored. A method of supplying the loads with power on overcast days and at night is required.

The battery bank consists of two parallel connected battery packs. Each battery pack will be housed in a watertight container underwater, and a team of scuba divers will pull it up to the surface by means of a winching system on a boat to perform periodic maintenance on it. Therefore, the DFO requested batteries with the highest energy density (lithium polymer) to reduce the weight of the total battery bank.

5.1 Performance Requirements

[R41-A] The batteries must provide at least one week of autonomous power to the loads.

[R42-A] The batteries must provide 10W of power for 24 hours a day to the loads.

[R43-A] The batteries must charge and discharge in an environment of 4°C.

[R44-B] The batteries shall have the capability of being charged via a standard lead-acid battery charge controller with bulk, absorption, and float stages.

[R45-B] The batteries shall operate up to a relative humidity of 95%.

[R46-C] The battery bank charge should not fall below 30% of its capacity.

5.2 Physical Requirements

[R47-B] The battery bank shall weigh no more than 70kg.

[R48-C] An individual battery pack shall have dimensions no larger than 80cm X 30cm X 40cm.

5.3 Safety Requirements

[R49-A] The BMS must protect against potential thermal runaway risks.

[R50-A] The BMS must internally disconnect the battery packs if the voltage drops below 20V. This is needed to protect the loads and to prevent over-discharge of the batteries.

[R51-A] The batteries will be handled in marine environments where they may be splashed with water. The battery enclosure must have an Ingress Protection rating of at least IP 24: the enclosure can be splashed with water from any direction with no harmful effects, and a finger must not have access to hazardous parts [8].

[R52-A] The BMS must detect and isolate the battery module from the charge controller and all other electrical connections when temperature levels of battery exceed the accepted maximum operating threshold of 45º C [9] [10].

[R53- A] The BMS must detect when ambient temperature in the battery enclosure falls below 0ºC, and disconnect the battery from charge controller [9].

5.4 Hardware Requirements

[R54-A] The PCB must have reliable soldered components and wires.

[R55-C] The power supply connection shall be on a separate PCB from the microcontroller for easy replacement.

[R56-A] The monitoring circuit must have a manual shutdown switch.

[R57-B] The monitoring circuit shall be able to select between power sources: the main 24V battery and the backup battery.

[R58-A] The monitoring circuit must be able to enable and disable power delivery to the loads.

[R59-B] The monitoring circuit shall have adequate thermal dissipation.

[R60-B] The monitoring circuit shall not consume more than 300mA.

[R61-B] The monitoring circuit shall have a current limiter to protect the loads.

[R62-A] The monitoring circuit must allow 500mA of current to the load continuously.

[R63-B] The monitoring circuit shall monitor humidity and send a warning signal when the humidity is above 50% [11].

[R64-C] The monitoring circuit shall be able to operate for 1 hour on back up battery power.

[R65-C] The backup battery shall charge when the main batteries are connected.

5.5 Communication Requirements

[R66-A] The BMS must periodically transmit data about the state of the batteries to the ISM-band transmitter, including temperature and state of charge.

[R67-A] The BMS must have Ethernet capability in order to communicate with the ISM-band transmitter.

[R68-A] The BMS must transmit an emergency signal through the ISM in the event of a battery module failure or disconnect beyond 15 minutes.

[R69-B] The emergency signal shall specify the cause of a battery module failure or disconnect.

[R70-C] The BMS shall receive communication from the ISM-band transmitter to perform actions such as reconnecting the battery and overriding any emergency states.

5.6 Reliability and Durability Requirements

[R71-B] The BMS shall be able to function independently for 1 hour in the event of a battery disconnect or failure.

[R72-A] The BMS must be able to disconnect the battery in case of unsafe temperatures, and to reconnect the battery when the conditions are once again safe.

6. DESKTOP APPLICATION

6.1 Communication Requirements

[R73-A] The desktop application must communicate with the ISM-band transmitter to receive and display battery state information.

[R74-A] The application must clearly display any emergency alert sent from the ISM-band transmitter and the reasons for the alert.

[R75-B] The emergency alert shall indicate the location of the faulting unit and which battery module has failed.

[R76-B] The application shall be able to communicate with the ISM-band transmitter in a selected location.

6.2 Usability Requirements

[R77-B] The application shall display current state of charge and temperature for each battery pack.

[R78-B] The application shall display the status of all batteries based on GPS location.

[R79-C] The application shall display historical data of charge levels of battery packs.

[R80-A] Any emergency alert on the application must clearly display the cause of the fault.

[R81-B] The application shall allow the user to select a unit in a particular location and to override any emergency flags and protocols as deemed necessary.

7. System Test Plan

7.1 Hardware

In the early stages of the design, the monitoring circuit will be built up of smaller modules/evaluation boards. Each module or evaluation board will be tested individually and then as an integrated system. Some functions and requirements will have very simple testing methods such as the on/off switch, and the enable/disable of power delivery. The primary objective will be to simulate all breaking conditions to test if the circuit is able to detect faults and shutdown appropriately.

There are three main hardware tests that will be conducted:

1. Overcurrent Conditions
    - The system will be connected to a load that draws an abnormally high current (1A).
    - The system must disable the power delivery to the load and send a warning signal to the ISM unit.
2. Thermal Shutdown
    - The temperature sensors will be exposed to a heater.
    - At dangerous temperatures, the system will disable the power delivery to the load and send a warning to the ISM unit.
3. Dangerous Humidity Levels
    - Utilize ambient humidity levels to verify sensor's accordance with its datasheet.
    - The system will send the humidity level to the BMS.

7.2 Software

The BMS will be tested for both detection and communication functionality iteratively during implementation. The BMS must be able to detect unsafe levels of humidity in both its own container as well as the battery container. Additionally, the BMS must detect the temperature and state of charge of the battery, and disconnect the battery if it reaches above or below the acceptable threshold temperatures. When the battery is disconnected, the BMS must consistently monitor the battery state for at least 1 hour to determine when the battery has returned within safe operating conditions, and can be reconnected. Various conditions of the sensors will be tested in order to ensure correct functioning of the BMS. Communication tests with the BMS can be executed using a standard laptop with an Ethernet interface and packet sniffer. BMS interfacing with the ISM-band transmitter will be tested with the ISM unit directly connected to both the hydrophone and BMS, and to the desktop application running on a computer. In order to detect the additional battery status signals, all of the messages from the ISM-band transmitter will be detected and decoded as needed.

The desktop application will be tested for both communication functionality and usability by both the designers and the end user (DFO). Communication will be checked by having the BMS send messages through the ISM-band transmitter. Once the ISM transmitter has transmitted a message, any changes in status should display clearly on the desktop software. In the event that a battery experiences an emergency shutdown, the user will have the option to manually override certain procedures. This will be tested by simulating numerous conditions for shutdown in a controlled lab environment, and observing if a software command for override is correctly received by the ISM unit and interpreted by the BMS to resume normal operation.

7.3 Integrated System Test Plan

The system will be tested by placing it into its waterproof containers and attaching it to a buoy. This will ensure that the buoy is anchored and balanced.

The system will be placed in a water-based environment (either a water tank, a pool, or out at sea) for several days to ensure that the system remains functional. Functionality will be verified by listening to the data being received from the transmitter – both the hydrophone and the battery data must be received without any problems. The battery conditions must also remain stable. The system is expected to continue functioning even in unfavorable weather. In a water tank or a pool, rain can be simulated by pouring water over the charging module. In both test environments, water currents can be produced to test the mechanical stability of the units. The water temperature can be altered by either heating it, or placing ice cubes into it.

The minimum time for the battery pack to last without recharging can be tested by manually disconnecting the charging module from the battery pack. At sea, the ease of detaching the battery packs will be tested by having scuba divers going under the buoy and detaching the waterproof housing units containing the battery packs. The same can be done in a pool.

8. Sustainability

The system will be designed to minimize environmental impact during the lifetime and end of life of the product. For the end of life of the designed system, the batteries chosen may be returned and recycled at proper recycling facilities. Additionally, all electrical components will be chosen so that they are RoHS compliant, and must also be recyclable [12].

The system will also have safeguards in place to mitigate any accidental failures in its watertight enclosures. These safeguards include: automatic system shutdown capabilities, self-enclosed watertight battery packs, and the encasement of all exposed components in an additional waterproof coating.

[R82-B] All components shall have a useable lifetime of at least 10 years and should be recyclable at their end of life.

[R83-B] All electrical components shall be RoHS compliant where applicable.

9. Conclusion

The functional specification clearly details the primary subsystems of the solar powered aquatic battery charger and their respective capabilities. The requirements have been divided into three categories, based on priority. 'A' level requirements are of critical priority, and their functions are expected to be fully developed and validated prior to integration testing. 'B' level requirements are necessary for the final product, but can come at a later stage. The 'C' category requirements are desirable features, but not essential for the final product.

The clear divisions of the components will allow for independent testing to ensure the full functionality of each part prior to integration. With this document, the priorities of the product are clearly outlined and will guide the team in the design and implementation of the proof-of-concept.

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