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Feb 20, 2017

Steve Whitmore
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Re: ENSC 405W Project Requirement Specifications for PowerPad

Dear Mr. Whitmore:

The attached document, *Disconnect Electronics PowerPad Requirements Specifications,* provides a breakdown of the requirements imposed on our ENSC 405W/ENSC 440 project. We are developing a wireless power transfer prototype specifically to be implemented for golf carts. This will be executed in conjunction with Delta-Q Technologies in order to interface with their existing technology, allowing for more intelligent battery management and charging capabilities.

This document will provide an outline of the functionalities of our product as well as justification for the requirements. We will breakdown the PowerPad into two design stages, providing requirements for each stage. This document will also provide an overview of the process details, and the engineering standards to be used, as well as addressing the issues related to sustainability and safety.

We are Disconnect Electronics and our team consists of six dedicated upper year engineering students: Connor Floyd, Amar Masalmeh, Paul Vu, Michael Hsiao, Thomas Prettejohn, and Valery Ushakov. If there are any further questions about this document, I can be reached by email at mha96@sfu.ca.

Sincerely,

Michael Hsiao

Enclosure: *Disconnect Electronics PowerPad Proposal*

School of Engineering Science
Simon Fraser University
ENSC 405W

Disconnect Electronics PowerPad Requirements Specifications

Team 2

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Contributions

Each member of the group has put in an equal amount of effort in the writing of this requirements document.

Abstract

Disconnect Electronics is developing the *PowerPad*, a wireless power transfer solution intended for mid-range electric vehicles that require charging in the range of approximately 500 watts up to 1.5 kilowatts. The *PowerPad* will transfer power from a power transmitter, connected to AC mains, to a secondary receiver, connected to an on-board battery charger. It will focus on applications concerning golf carts, since they make up a large portion of the global electric vehicle market.

The *PowerPad* is being designed with the vision of having charging stations at strategic locations around a golf course. These stations will automatically transfer power to the battery charger once the user parks, and must be completely weather resistant, sealed to foreign particles, and withstand significant mechanical forces.

The final device will have the ability to wirelessly charge at a distance of 10-20cm, and will have the ability to detect, verify, and automatically adjust terminal alignment to a small degree. Further, an obstacle detection mechanism will be implemented for safety. It will be run on 120V AC, and may also have the ability to function with 208/240V AC. The *PowerPad* is being developed in partnership with Delta-Q Technologies Corp., which develops 300-1500W wired battery chargers for OEM applications.

This document will outline the software, electronic, and mechanical specifications of the primary and secondary terminals of the *PowerPad*, as well as its non-functional specifications. Furthermore, it will outline concerns regarding sustainability and safety and the engineering standards that the *PowerPad* must adhere to.

Disconnect Electronics would like to thank Delta-Q Technologies for their support in the development of the *PowerPad*.

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List of Figures & Tables

1. Introduction

Currently, there are marketable wireless power transfer products for small scale devices, such as Qi charging pads for mobile devices, and large scale devices such as electric vehicles; for example, American manufacturer Plugless Power developed a modular product to charge electric vehicles wirelessly in 2014 [1]. However, there is market gap for applications concerning mid-range electric devices. Such mid-range devices include low speed electric vehicles such as golf carts, electric scooters, boom lifts, dirt bikes, and floor care machines.

In partnership with Delta-Q Technologies Corp., *Disconnect Electronics* intends to fill this market gap with the *PowerPad*, which will wirelessly transfer power to a battery charger mounted on or in an electric vehicle. It will consist of a primary transmitter connected directly to AC mains, and a secondary receiver connected to an on-board battery charger. The *PowerPad* is intended to be compatible with chargers developed by Delta-Q Technologies, which develops 300-1500W wired battery chargers for OEM applications.

The *PowerPad* will be an efficient and easy-to-use wireless power transfer solution. We will develop a feedback system for users to determine primary and secondary device alignment, and will implement foreign object detection, power transfer efficiency, and a small degree of automatic terminal alignment. To provide such feedback, we will need several sensors to track measurands such as current in the primary and secondary in order to calculate efficiency. Using these parameters, the device will also include automatic shutdown if unsafe conditions are detected.

In development, we will focus on applications concerning golf carts, since they make up a large portion of the global electric vehicle market. Therefore, the ultimate vision for the *PowerPad* is to have charging stations at strategic locations around a golf course, which will automatically transfer power to the battery charger once the user parks. The concept of the *PowerPad* architecture is provided in Fig. 1. However, the technology would ultimately have the capacity to be applied to any mid-range electric vehicle.

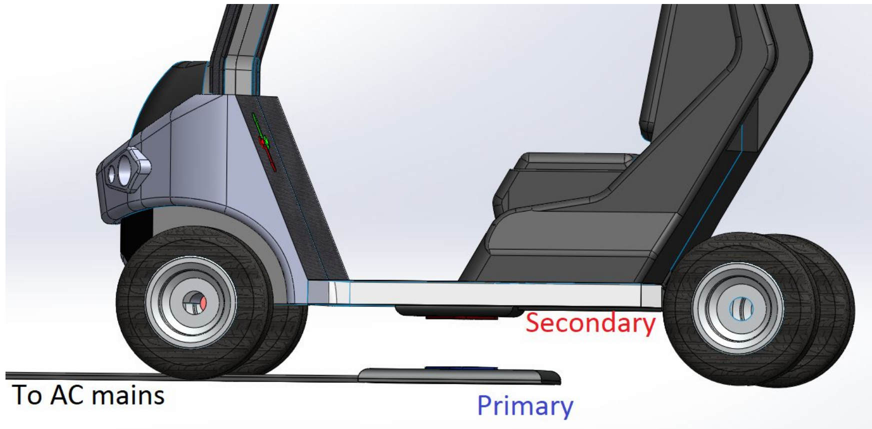

Figure 1: PowerPad concept with primary and secondary devices indicated. 3D golf cart model [2], primary, and secondary representations were modeled by Disconnect Electronics using SolidWorks.

2. Background

Wireless power transfer solutions have been developed for both small and large scale applications, such as charging for mobile phones and electric automobiles. Although large scale products have only recently entered the market, smaller scale products have proven profitable. Following market trends and demand, it is only a matter of time before mid scale wireless power transfer devices hit the market, specifically for low-speed vehicles such as electric golf carts. These vehicles have a short battery life and slow charging times, and would therefore benefit from a wireless charging solution that can be fixated around golf courses.

2.1 Growing Demand & Revenue

Inductive wireless power transfer has grown in popularity in the electronic device market over the last few years and has been forecasted as a growing demand in the next 4 years. In a 2016 research survey conducted in the UK, it was reported that wireless charging was the most requested feature for smartphones [3]. In addition, Pike Research, forecasts inductive charging revenue will eclipse $11.8 billion by 2020 [4]. Fig. 2 depicts Pike Research's study on the growth in revenue of wireless charging. This comes as no surprise as wireless charging is a convenient cable free alternative which is also more durable than a USB charging connection.

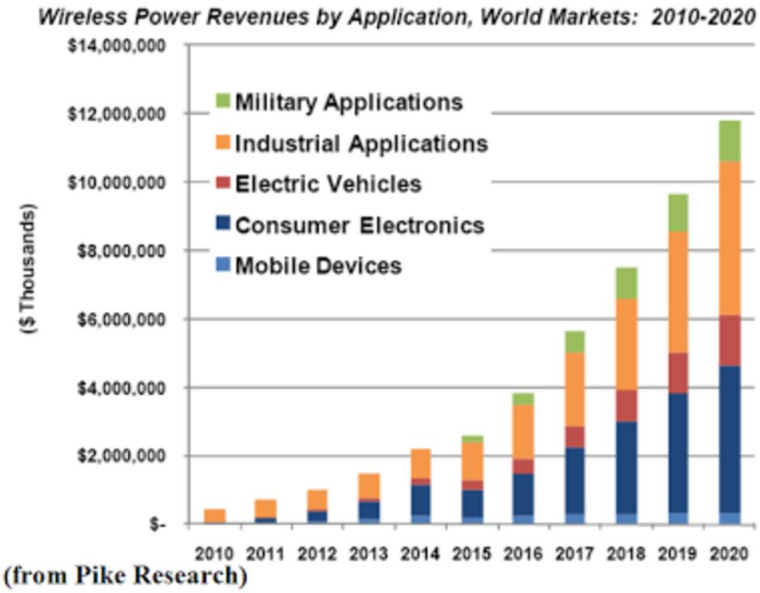

Figure 2: Projected wireless power revenues for 2020 per industry [4]. This shows how wireless power demand will increase over the coming years.

2.2 Current State of Need: Electric Golf Carts

Electric golf carts with a healthy full battery typically have a range of between 15 and 30 miles. In practical use, this can cover up to 2-3 rounds of a typical 18 hole golf course, depending on the weight of the people and golf bags on the cart. As a result, these golf carts struggle to keep up with demand during tournaments and are discharged within half a day. Unfortunately, charge time for these vehicles range from 10-14 hours depending on the battery [5]. As a result, golf course owners compensate by purchasing extra electric golf carts and cycle charges during tournaments. Additionally, in an interview with Chris Botting, Manager of Research at Delta-Q, it was noted that batteries account for approximately one-third the weight and cost of electric golf carts [6]. Therefore, a solution which reduces the costs and weight of golf carts will allow golf course owners to invest more into our product which allows for opportunity charging at every golf hole. In addition to this, having the ability to charge golf carts while playing could reduce the total amount of golf carts needed to maintain each course which further reduces costs.

2.3 Wireless Power Transfer

To wirelessly charge electronic devices, a primary transmitter and secondary receiver is required. These two devices will each have an inductive coil inside them. The primary device will be connected to an AC plug outlet and draw in voltage which will be converted to high frequency AC and transmitted through the primary coil to the receiver coil through electromagnetic induction which is passed to the secondary receiver device. Within the secondary receiver, the current induced by the coils will need to be converted to DC. Fig. 3 illustrates a typical wireless power transfer.

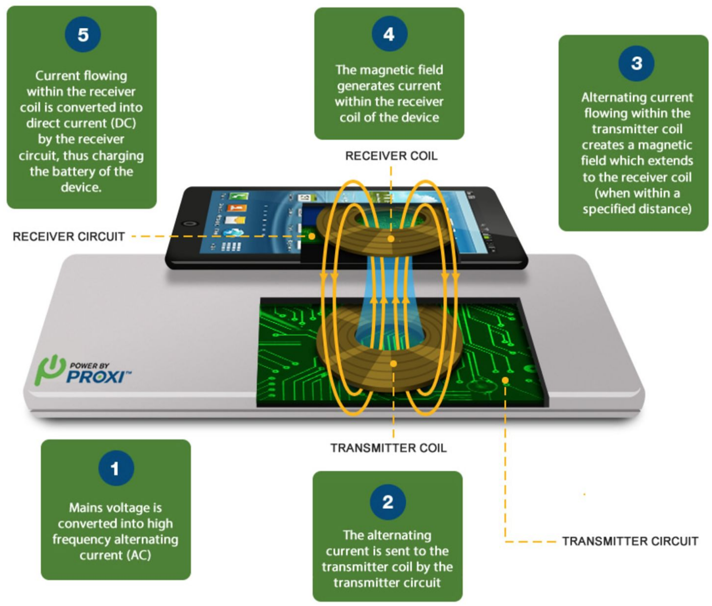

Figure 3: The concept of wireless power transfer in cellular devices [7]. Here oscillating current induces magnetic fields which couples into the secondary coil.

2.4 Implementation of the PowerPad

In this context, a reasonable vision for a wireless power transfer system would be to simply power an existing battery charger. Such a device would require minimal effort to implement, since it would not be necessary to consider battery management requirements in the design; this would be carried out by the charger and the battery`s own battery management system (BMS). In addition, this solution could be applied to existing golf carts and chargers, and customers would not necessarily need to purchase entirely new golf carts in order to use the product. However, it would admittedly be optimal if this design were integrated into the golf cart by the OEM so that the charger could be completely sealed into an on-board environment. Ultimately, the vision is to place *PowerPad(s)* at strategic points around a golf course to allow a few minutes of automatic charging when the golf cart is stopped during use. It is necessary to burden the user as little as possible to make this solution feasible. Therefore, the *PowerPad* must be able to automatically transfer power to the golf cart if the user parks within a reasonable distance. The concept of opportunity charging, where the golf cart can be charged when stopped on the course, will allow for a lower capacity battery and will ultimately reduce the weight and cost of each individual golf cart.

3. Process Details

The *PowerPad* will consist of a primary transmitter (or primary terminal) and a secondary receiver (or secondary terminal). The primary transmitter will be connected to the AC line indefinitely, and will resemble a large pad either on, inset to, or buried under the ground. It will require signifiers to indicate where the user must park to allow for power transfer. This pad will transmit power to the secondary receiver when the secondary is in range; however, it will not do so if there is a not a valid secondary terminal in proximity for obvious safety and efficiency reasons. Because the primary terminal may be outside for the span of the product's life, it must withstand adverse and potentially severe weather conditions, as well as daily golf course maintenance such as frequent activation of sprinklers and mowing of the grass. Further, it is reasonable to expect physical stresses such as golf carts driving over the *PowerPad*, people walking, jumping, or stomping on it, and golf balls and clubs striking it; these are all examples of forces that the *PowerPad* must be able to withstand.

The secondary receiver will be mounted on the golf cart, though ultimately a marketable product would be sealed inside the golf cart. This receiver must inform the primary of its proximity in order to initiate power transfer. Furthermore, it must continuously report measured power values to the primary terminal for the purposes of efficiency calculations, alignment, obstacle detection, and safety shutdown.

Both the primary and secondary terminals will require microcontrollers to manage the overall system and terminal-to-terminal communication. The primary microcontroller will be powered by the AC line, while the secondary will be powered by the golf cart battery. Potential design problems that must be addressed include behaviour when the two terminals are not in proximity, and behaviour as the terminals come into proximity with each other. Charging when the golf cart battery is completely dead is not an issue we have to consider because the maximum safe discharge amount for a lead acid battery is 80%. Any further discharge will damage or kill the battery meaning it should not be charged in that state [5]. Lithium ion batteries have a BMS to manage battery discharge and also will not allow a 100% battery discharge, meaning our secondary will always have available power if the battery is in a safe charging state.

The requirements for the *PowerPad* are described in the section below. They are separated into three main components: the primary transmitter requirements, the secondary receiver requirements, and the non-functional system requirements. The primary and secondary have been further split into software, electrical, and miscellaneous requirements for ease of understanding. The overall non-functional requirements have also been divided into cost, dimensions, and efficiency requirements. In addition, each section will provide an explanation for potentially vague requirements or those that are not self-explanatory.

Each requirement is categorized using the following notation:

[Rn - x] The requirement.
i.e: [R1-A] The PowerPad must track the input voltage in order to monitor efficiency

In this convention, ***n*** represents the requirement number and ***x*** represents the design stage for which the requirement applies to. The design stage, ***x***, can either be ***A*** for the alpha prototype that proves the validity of the *PowerPad*, or ***G*** for the gamma prototype, which is a pre-production version of the *PowerPad*.

3.1 Primary Transmitter Requirements

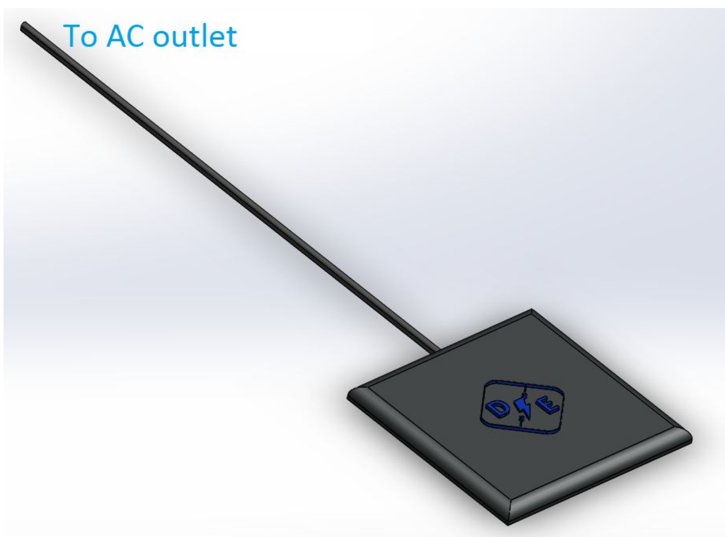

Figure 4: The concept design for the primary terminal of the *PowerPad*

3.1.1 Overview & Justifications

Fig. 4 shows the overall design concept for the primary terminal of the *PowerPad*. Fig. 5 and Fig. 6 show the relationship expected from the primary coil side for the *PowerPad*. The square wave in Fig. 6 shows the input rectified voltage that oscillates between 0 and 120 volts pk-pk. A 10 Ohm resistor was used to simulate the concept of a load being reflected into the primary side from the secondary and then simulated the current through the resistor using PSIM. Since the coils will be operated with large separation between the primary and secondary, a large portion of the magnetic field generated by the primary will be lost. This limits the current that is able to run through the primary (and therefore secondary) at any time. This is where the resonant capacitor comes in. At a certain frequency, a certain value of capacitance will cause the effective reactance of the equivalent LC circuit to drop to zero. This allows the primary transmitter to 'pump' more apparent current (shown in red in Fig. 6) through to the secondary receiver. This closely relates to the requirement R-14A about minimal efficiency of 80%. Since the *PowerPad* will be used with a Delta-Q Technologies battery charger, the temperature operating range has been set to match that of the typical Delta-Q Technologies battery charger in order to allow for charging in all situations where the charger is functional.

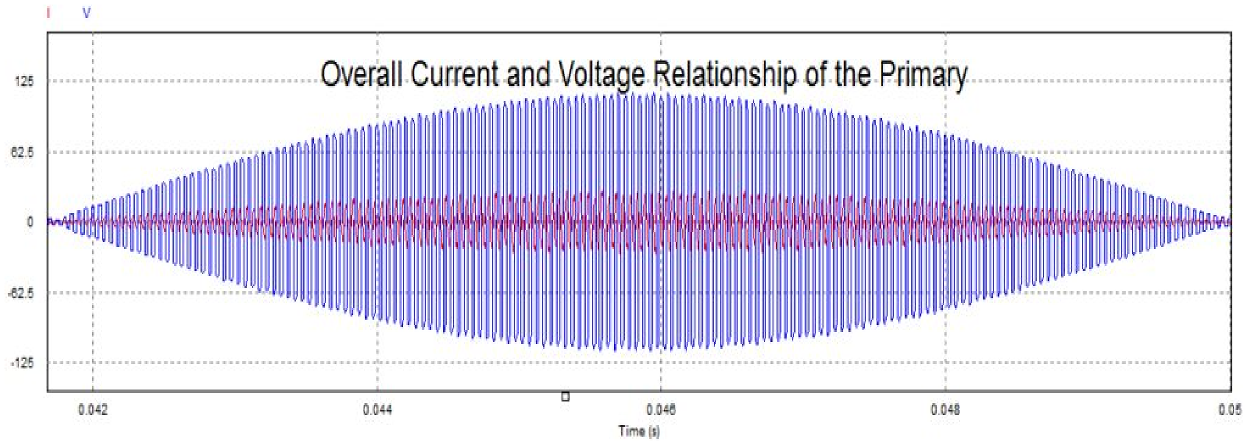

Figure 5: *PowerPad* primary transmitter voltage vs current relationship. Here voltage is the blue line and current is in red. The envelope oscillates at 60Hz, while the smaller frequency oscillates at 20kHz

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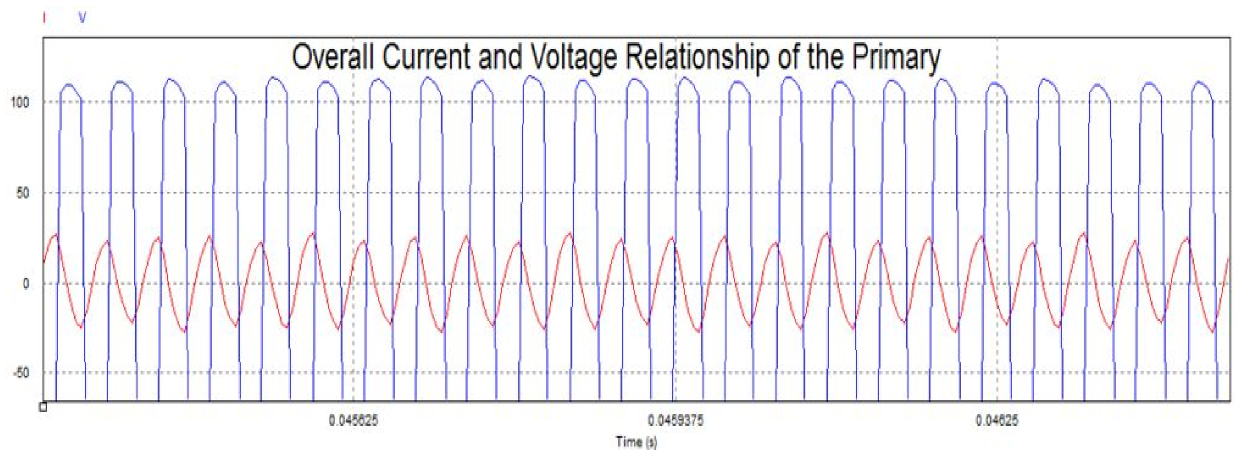

Figure 6: *PowerPad* primary transmitter voltage vs current relationship with a smaller scale. Here voltage is the blue line and current is in red. The envelope oscillates at 60Hz, while the smaller frequency oscillates at 20kHz.

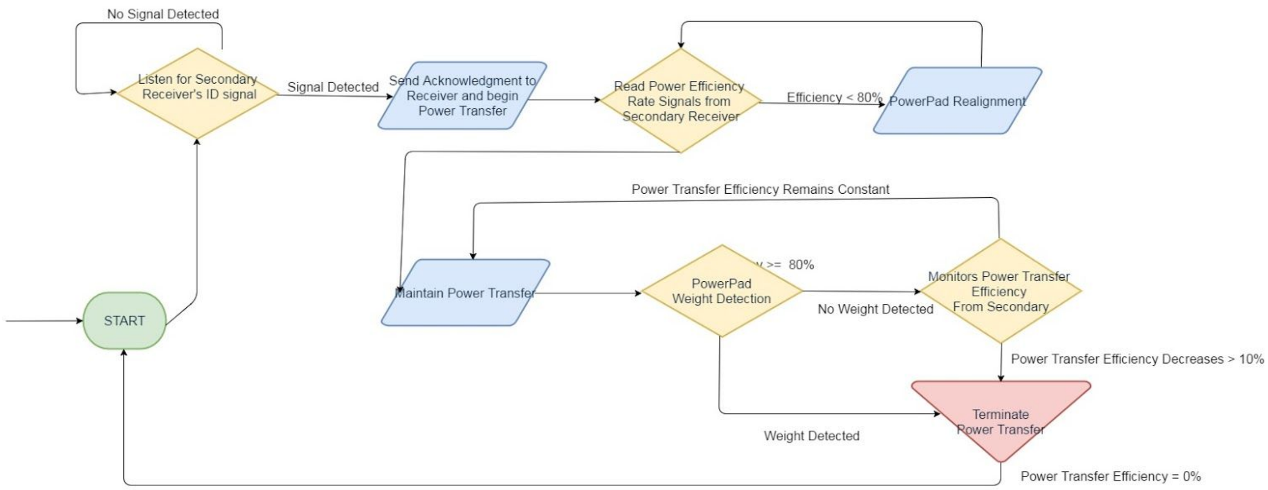

Figure 7: *PowerPad* primary transmitter software block diagram describing the basic algorithm

3.1.2 Software

[R1-G] The PowerPad must track the input voltage in order to monitor efficiency

[R2-G] Continuous communication with secondary terminal during power transfer

[R3-G] Determines proximity of secondary terminal based on efficiency

[R4-G] The primary terminal will use motors to fine-tune the alignment

[R5-A] Embedded application must manage the IGBT switching rate

[R6-G] The PowerPad must not output power if a foreign object is between the primary and secondary terminals

[R7-G] The PowerPad must not output power if the primary and secondary terminals are misaligned

[R8-A] The PowerPad must indicate when it is transferring power

[R9-G] The PowerPad must indicate if a foreign object is obstructing power transfer

[R10-G] The PowerPad must enter an idle state when the secondary terminal is not detected

3.1.3 Electrical

[R12-A] The PowerPad must be usable with a wall supply of 120V at 60 Hz AC, which is typical of North American wall outlets [8]

[R13-A] The AC power needs to be converted to DC in order to provide the microcontrollers with necessary input voltage (3-5V) [9]

[R14-G] The efficiency of the power transfer must be at least 80%

[R15-A] Convert the input 60Hz AC to the higher frequency of 20 kHz
[R16-G] The voltage and current of the primary terminal should follow a relationship similar to that of Fig. 1
[R17-A] Proper fusing is required to prevent the current drawn by the primary terminal from exceeding 30 Amps

3.1.4 Mechanical

[R18-G] The PowerPad will consist of a primary transmitter enclosed in a larger casing
[R19-G] The PowerPad will be sealed with epoxy
[R20-G] The primary transmitter must have the ability to move within the casing for the purposes of terminal alignment
[R21-G] The primary transmitter must be able to move up to 15 cm in each direction

3.1.5 Miscellaneous

[R22-A] The power cord must be durable and stable to avoid electric shocks
[R23-G] The PowerPad must withstand forces and daily physical treatment
[R24-G] The PowerPad must be durable, and resist defects under standard operating conditions
[R25-G] The PowerPad must conform to an Ingress Protection rating of 66 (IP66) [10]
[R26-G] The PowerPad must operate under temperatures from -40 to 65℃ to match the typical Delta-Q Technologies battery charger [11]

3.2 Secondary Receiver Requirements

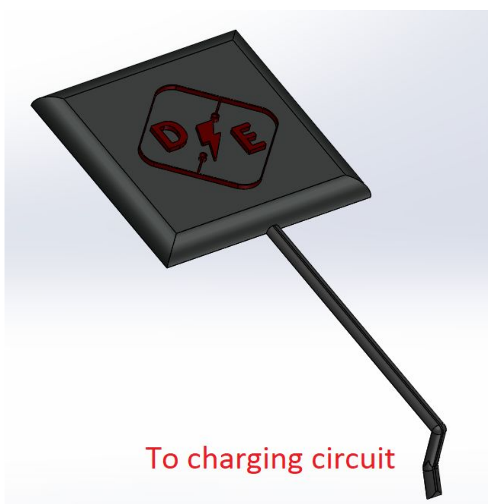

Figure 8:The concept design for the secondary terminal of the *PowerPad*

3.2.1 Overview & Justifications

In Fig. 8, the design concept of the *PowerPad*s secondary terminal is shown. The secondary receiver takes the power transmitted from the primary transmitter and passes it to the on-board battery charger. In order to minimize the idle power usage of the *PowerPad*, the secondary receiver must transmit a signal to alert the primary terminal that the terminals are nearby. In order to ensure optimal power transfer, the secondary terminal must track and report power measurements in order to measure efficiency. An indicator panel similar to the one shown in Fig.10 will be connected to the secondary terminal to display information on the alignment, efficiency, and also to alert the user to foreign objects disrupting the power transfer. The indicator panel will be placed in an easily viewable area, in order to simplify the user experience when using the *PowerPad*. Since the secondary receiver will be mounted directly to the vehicle, it must provide safe power transfer for the sake of the consumers. As such, the secondary receiver must be electrically and mechanically robust in order to ensure that it can stay protected from the stress associated with being permanently mounted to a vehicle. For the alpha prototype, the secondary receiver will be able to transfer the power from the transmitter to the battery charger, and will also be able to display when there is sufficient power transfer to easily communicate that the *PowerPad* is functional. Fuses will be used in order to avoid unexpected behaviour of the circuit. Fig. 9 shows the software block diagram for the secondary receiver.

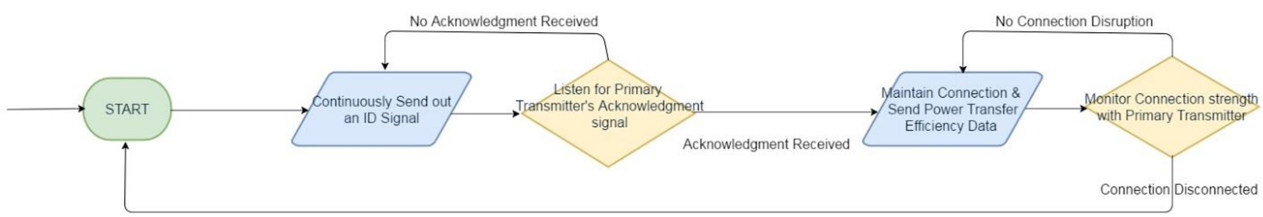

Figure 9: *PowerPad* secondary receiver software block diagram describing the basic algorithm

3.2.2 Software

[R27-G] The secondary terminal must continuously report power measurements to the primary terminal

[R28-G] The secondary terminal must broadcast an ID signal that is recognisable by the primary terminal

[R29-G] The indicator panel must indicate the direction required for repositioning by the user

[R30-G] The indicator panel must indicate when there is successful power transfer

[R31-G] The indicator panel must indicate if an obstacle is detected

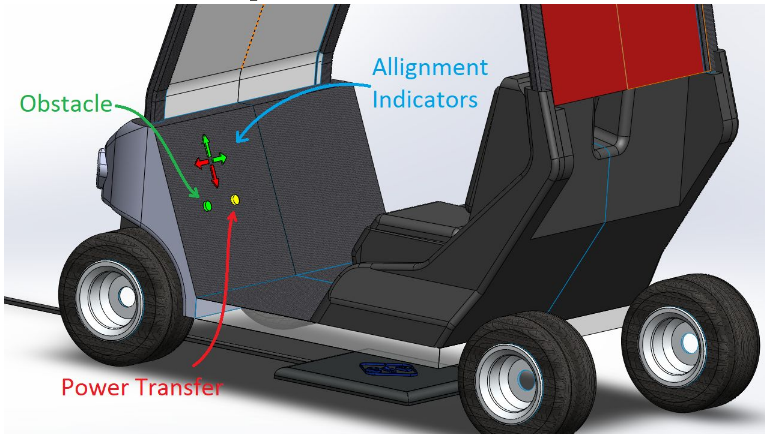

Figure 10: The concept for the *PowerPad* user interface highlighting the various LED indicators. 3D golf cart model [2], primary, and secondary representations were modeled by Disconnect Electronics using SolidWorks.

3.2.3 Electrical

[R32-G] Provide safe transfer of received power to the battery charger

[R33-A] Fuse the AC input in order to avoid unexpected spikes in voltage

3.2.4 Miscellaneous

[R34-G] The indicator panel must be visible to the user during operation
[R35-G] The indicator panel must indicate nominal alignment
[R36-A] The secondary terminal will not move within the golf cart
[R37-G] The secondary terminal will be electrically and mechanically robust

3.3 Non-Functional System Requirements

3.3.1 Overview & Justifications

When considering the cost of the *PowerPad*, the defending product was the main consideration. Since AC cords are relatively cheap, the *PowerPad* needed to minimize its price in order to stay competitive. With the dimensions of the *PowerPad*, the size of an average golf cart had to be considered, in order to ensure that the *PowerPad's* terminals would accommodate as many vehicles as possible. The weight requirements are essential since added weight would require golf carts to use more energy as well as potentially requiring larger batteries. Since the intended use of the *PowerPad* is for charging at a golf course, the *PowerPad* must emit minimal noise, in order to allow golfers to fully concentrate on their game. The efficiency requirement is set in order to minimize the chances of a golf cart depleting its charge and leaving the user stranded.

3.3.2 Cost

[R38-G] The retail price of the PowerPad shall be under $300 CDN

TABLE I
PowerPad cost requirements

System Component:	Cost (CDN):
Primary Transmitter	$220
Secondary Receiver	$80
Total:	$300

3.3.3 Dimensions

[R39-G] The PowerPad primary transmitter must be no larger than 49000 cm^3
[R40-G] The PowerPad primary transmitter must not exceed 10 kg
[R41-G] The PowerPad secondary receiver must be no larger than 6125 cm^3
[R42-G] The PowerPad secondary receiver must not exceed 3 kg

TABLE II
PowerPad dimension requirements

System Component:	Dimensions: Length x Width x Height (cm):
Primary Transmitter	70 x 70 x 10
Secondary Receiver	35 x 35 x 5

3.3.4 Efficiency

[R43-G] The PowerPad must be silent when not in use
[R44-G] The efficiency of the power transfer must be at least 80%

3.4 Engineering Standards

3.4.1 Overview & Justifications

The *PowerPad* will need to conform to many regulatory standards from various governing bodies. These standards will allow our customers to purchase our product knowing that it will operate safely and effectively. These standards will all need to be implemented into the production unit, but will not be required for the alpha prototype. The relevant standards are listed below and categorized by the regulatory body.

UL
101 - Leakage Current for Appliances [12]
943B - Standard for Appliance Leakage-Current Interrupters [13]
248-1 - Low Voltage Fuses (<1000V) [14]

CSA
C22.2 NO. 61980-1:16 - Electric Vehicle Wireless Power Transfer [15]
C22.2 NO. 107.1-16 - Power Conversion Equipment [16]

IEC
60143-1:2015 - Series Capacitors for Power Systems [17]
60364-7-722:2015 - Low Voltage Electrical Installations for Electric Vehicles [18]
61000-4-8:2009 RLV - Electromagnetic Compatibility [19]
61000-6-4:2006 - Electromagnetic Compatibility [20]
60320 - Appliance Couplers for Household and Similar General Purposes [21]

CISPR
16-1-2:2014 - Specification for Radio Disturbance and Immunity [22]
14-2:2015 - Electromagnetic Compatibility [23]

ISO
9001 - Quality Management [24]

Connector Requirements
NEMA 5-15 (120V)
NEMA 6-15 (208, 240V)

Ingress Protection
NEMA 4
IP66

3.5 Sustainability & Safety

3.5.1 Overview & Justifications

Since the *PowerPad* will rely on existing battery chargers to recharge batteries, the efficiency must be maximized in order to allow battery charger manufacturers to meet or maintain their existing standards for efficiency. Requirements imposed upon the enclosures of the *PowerPad* are vital to ensuring a long lifetime for the product. To help with this, the *PowerPad* will be built following the specifications of many industry standards such as ISO 9001, IP66, and more. Keeping the safety of our consumers in mind, the *PowerPad* will meet several safety requirements that can alert the user to the status of the *PowerPad* as well as requirements that will minimize interfering with other electronic devices. Finally, the primary and secondary devices will be composed of modular circuits such that if a component were to fail, the consumer could order replacement components to repair the *PowerPad*. As a result, the environment will benefit from reduced circuitry waste.

3.5.2 Efficiency

[R45 - G] An efficiency of at least 80% must be achieved to minimize power losses in surrounding objects

[R46 - G] Automatic coil alignment will ensure maximum power transfer

[R47 - G] In standby, the microcontrollers (both primary and secondary) shall be in a low-power consumption (idle) mode, and power transfer will cease to occur

[R48 - G] Off road vehicles utilizing wireless power transfer (and the means with which they achieve it; the PowerPad) shall meet the efficiency levels described by the CSA C22.2 NO. 61980-1:16 safety standard [25]

3.5.3 Durability

[R49 - G] The primary and secondary coils must be enclosed in a magnetically opaque durable plastic

[R50 - G] The secondary receiver must be firmly attached to the vehicle in order to avoid damage in bumpy terrains

[R51 - G] The PowerPad must operate between temperatures from -40 to 65 to match Delta-Q Technologies battery charger specifications [11]

[R52 - G] The enclosure of the primary transmitter must withstand high pressures due to vehicles running over it

[R53 - G] Extreme weather conditions must not cause enclosure erosion or degradation of power transfer

[R54 - G] Build quality of the secondary side of the PowerPad must comply with the ISO 9001 standard [24]

[R55 - G] The PowerPad must be dust resistant in compliance with the safety standard (IP66, NEMA4) [10]

[R56 - G] The PowerPad must be water resistant, even in the case of a low pressure nozzle (such as a sprinkler in a golf course) (IP66, NEMA4) [10]

[R57- A] The PowerPad must be serviceable by Disconnect Electronics technicians and engineers

3.5.4 Safety

[R58 - A] Resonance in the primary and secondary coils must occur at frequencies higher than the audible spectrum of a human ear

[R59 - G] The PowerPad shall halt power transmission if foreign objects are detected in path

[R60 - G] The user shall be notified if foreign objects are detected between the two coils via an indicator on the dashboard

[R61 - G] The user shall be informed when power transmission commences through an indicator on the dashboard of the vehicle

[R62 - G] The enclosure of the primary and secondary terminals shall not become too hot to touch due to the circuit (>65°C)

[R63 - A] In the case of a short circuit or input current draw which exceeds specifications, a fuse conforming to UL 248-1 standards will protect the circuitry from damage

[R64 - A] The secondary side shall not be close (<50cm) to the battery pack in order to avoid potential interference

[R65 - A] Electronic components used in the PowerPad will have large rating margin to withstand startup spikes in voltage/current

[R45 - G] Pacemakers shall not be used in very close proximity to the power transmission equipment (riding in a golf cart shall be acceptable)

[R66 - G] Disconnect Electronics shall test and demonstrate the capabilities of the PowerPad prototype in a clear space with all necessary safety precautions available

3.5.5 Environment and Reuse of Parts

[R67 - A] The proof of concept device shall make use of breadboard/protoboards and bare wiring without enclosures

[R68 - G] The PowerPad will contain modular circuit components that can be replaced in the case of failure

[R69 - G] The enclosures for the PowerPad prototype shall be 3D printed with PLA (polylactic acid) plastic as it comes from plant-based origins and is biodegradable

[R70 - A] The PowerPad shall not emit any toxic fumes under the operating temperature range

[R71 - G] The primary side shall be embedded close to existing power lines in order to minimize the need to disrupt turf/cement

[R72 - A] Wireless power transfer from the PowerPad will terminate to prevent possible radiation (CISPR 16-1-2:2014)

4. Conclusion

This documents lists the functional requirements for the *PowerPad* wireless power solution. It entails a in-depth overview of the software, mechanical, electrical and non functional requirements for the primary transmitter and secondary receiver. In addition, our product will satisfy various engineering standards such as UL, CSA, IEC, CISPR and ISO. By ensuring our product meets our defined durability and safety requirements, our end users can trust in a high quality product which is also touch safe. *PowerPad* is intended to be a wireless bridge between an AC mains connection and an existing golf cart battery charger, such as those manufactured by Delta-Q Technologies. This product will be developed in two phases: an alpha prototype to be completed by April 2017, and a gamma pre-production unit to be completed by August 2017.

5. References

[1] Plugless Power. (2017) "About | Plugless Power" [Online] Available: https://www.pluglesspower.com/about/. [Accessed: Jan 24, 2017].

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6. Glossary

AC - Alternating current
DC - Direct current
EV - Electric vehicle
IP66 - An Ingress Protection rating of 66
NEMA4 - A set of standards for electrical enclosures that are intended for outdoor use
PSIM - Software for power electronics simulations
PWM - Pulse width modulation
OEM - Original equipment manufacturer
On-board charger - A charger that is mounted onto the vehicle or machine that it will charge
Opportunity charging - Recharging a battery whenever possible, in order to maintain the highest charge possible