REV Electric Jet Ski

REVski Electrical Safety System

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Abstract

The problem of designing reliable electrical safety systems in a maritime setting is crucial in providing safe operation for personnel and for the protection of internal components within the vehicle. The electrical connections across the systems and installations elsewhere in the vehicle must adhere to the IEC 60092 Standards of Electrical Installation in ships. While the REVski is not a ship, it is a maritime vehicle and the electrical installations made within the REVski must follow these regulations. Additionally, the Australian and New Zealand Electrical Safety Standards must also be followed, as they are intended to protect persons and property from electric shock or fires that may arise from electrical installations (AS/NZS 3004.2:2014). This paper aims to design electrical safety systems in areas of the REVski that may pose a danger to personnel or hinder the performance of the vehicle in the event that a fault occurs. Should a fault occur in any of the areas outlined below, the system is designed to cut power and discontinue the operation of the REVski to prevent any further electrical hazards until they are repaired out of water to a satisfactory level.

Safe operating temperatures are considered in the battery tubes, the electric motor and the AC Curtis Motor Control Unit. Protection against high voltage lines is mitigated through the Bender Insulation Monitoring Device by measuring the resistance level of the high voltage lines before they pose a risk to personnel or neighboring equipment. Water leakage in the REVski is managed by the use of Arduino water level sensors. The state of the rechargeable lithium ion batteries housed in PVC tubes is monitored through a battery management system. Future work aims to investigate the use of a graphical user interface to relay the information of the electrical safety system to the user to be viewed from outside the REVski and for data collection. Another area for future research is into the use of depth sensors to monitor the depth at which the REVski is in the water to allow safe navigation and protection of the hull from physical damage. The implementation of mobile water quality testing will also be investigated as a project in the future.

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Nomenclature and Terminology

PVC	Polyvinyl Chloride
UWA	University of Western Australia
REV	Renewable Energy Vehicle
IP	Ingress Protection
BMS	Battery Management System
IMD	Insulation Monitoring Device
A	Amperes
V	Voltage
EPW	Electric Personal Watercraft
MCU	Motor Control Unit
BMMCU	Battery Management Master Control Unit
BMM	Battery Master Module
LV	Low Voltage
ELV	Extremely Low Voltage
ZEVA	Zero Emission Vehicles Australia
GUI	Graphical User Interface
ISO	International Organization for Standardization
OS	Open Source
IoT	Internet of Things
PCB	Printed Circuit Board

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I would also like to thank the sponsors of the REVski Project, for their support and for providing the equipment and technical information necessary for bringing this project to fruition.

Lastly, I would like to thank the REVski team for all their hard work and all the time they have put into the project, without which the completion of this project would not be possible.

1. Introduction

1.1 Background

Every piece of safety equipment that comprises an electrical system is designed to protect the user from one or more electrical safety hazards, such as electric shock and electrical fires. This is especially true for maritime vehicles, as having any type of electrical system or component in water poses a risk to personnel. With the Renewable Energy Vehicle Electric Jet Ski (REVski) being a fully electric watercraft, the need for a reliable electrical safety system to protect the user from electrical safety hazards is paramount.

Commencing 2012, the REVski project, like all REV projects, was built as a response to an increase in demand for methods of transportation that did not result in the consumption of fossil fuels. Based on the SeaDoo GTI130 model, it is the first of its kind in Australia and presents a prototype for future iterations of Electric Personal Watercraft (EPW).

There are a set of regulations and standards to follow when constructing any electrical system, and maritime electrical safety systems are no exception. These standards provide manufacturers a means to create electrical systems that not only achieve their intended purpose, but also ensure that personnel are in no way injured whilst the vehicle is operational or when performing maintenance. Design considerations for the REVski safety system require the modules used to monitor and protect areas of interest are independent of each other. Cost is also a criterion in the design for the safety system.

1.2 Objective

This report proposes a feasible electrical safety system design that is applied to areas of the REVski that may pose a danger to personnel or hinder the performance of the REVski in the event that a fault may occur. As to be expected, it is dangerous to have a fully electric vehicle, with components sensitive to water, in a marine environment. Standards, such as the IEC 60092 and the AS/NZS 3004, exist to instruct manufacturers of maritime vehicles on how to correctly produce and protect electrical connections and systems within the vehicle so as to prevent property damage and any hazards to persons that may arise. The REVski is powered by a total of 272 Lithium Iron Phosphate ($LiFePO_4$) batteries. Lithium batteries are capable of igniting when exposed to water, and thus present themselves as both a fire hazard as well as an electrical hazard when in a marine environment. Containment of the batteries within the REVski is accomplished by having them sealed in PVC pipes, and any connections to the batteries are protected by cable glands rated at IP67 (as can be seen in Figure 1 below), outlined in AS/NZS 3004. Similar processes must be undertaken to ensure other installations within the REVski are not directly exposed to water.

Figure 1. Nylon Cable Gland IP67 Rated

2. Project Timeline

The aim set before the first field test is to order and gather any required instrumentation by the 6th of January 2018 so they can be installed and tested by mid-February 2018. The first field test would then be scheduled one week after all the instrumentation has been installed and tested. A second field test is scheduled for mid-April 2018. However, a pre-water test similar to the one conducted before the first field test must be done. This pre-water test involves gathering and interpreting the data collected from the first field test, making any necessary adjustments. A Gantt chart outlining the timeline of the project is given in Appendix A.

Unfortunately, due to numerous unforeseen issues with the REVski, the project timeline could not be followed as accurately as anticipated, and almost all planned activities were delayed as a result. At some point in January 2018, a short circuit was discovered in one of the battery tubes (T1). The fault drained all the batteries, and only a handful could be successfully recharged to acceptable levels. This task was very costly and time-consuming, forcing the team to shift their focus away from thesis-specific tasks to repairing the REVski. Water tests were not conducted until the mid-semester break in April.

3. Problem Identification

The work for the REVski is currently split amongst a 4-person team, with some allocated to weight distribution, and others to electrical safety and functionality. As the objective of this report is to design a safety system for the REVski, the author’s responsibilities lie within the electrical safety and functionality aspect of the project. The jet ski is a maritime vehicle, thus the environment in which it operates in poses a high risk to not only the user, but to the components within the REVski.

As the REVski project progressed, alterations made to the vehicle, for student theses or performance adjustments, have consequently altered the circuitry within the Jet Ski. As a result, the diagrams illustrating the wiring connections of the Jet Ski are out of date and must be updated to reflect the new changes. The new safety system planned for this project will also require electrical drawings to be updated. The most recent changes to the REVski in regards to the electrical aspect include one new battery cell (making a total of 5 battery cells), 7 new temperature sensors, a battery management system (BMS) and a Bender insulation-monitoring device (IMD), model IR 155-3204.

To increase the reliability of the safety system for the REVski, the modules that form the overall safety system must be independent of each other. This means that the system designed to monitor the temperatures of the batteries, motor control unit (MCU) and motor should not be dependent or interfere with any other system in the in the REVski, for instance. The purpose of this is to ensure that if the temperature system returns a bad signal, or completely fails due to damage, the systems for the insulation protection would not be affected, while still being able to cut power to the REVski in order to protect the user and other components within the vehicle from damage.

Two sets of criteria were achieved when considering a modular design for the safety system. The first is that it can account for any changes that may be issued in the future, be it due to oversight or a genuine improvement on the design. The second is that the majority of the components that form the safety system were made using off-the-shelf products that were inexpensive and easily sourced from vendors located in Perth, WA.

3.1 Safety System Overview

The purpose of the REVski safety system is to protect the user and the equipment from damages caused either directly or indirectly by areas of potential risk in the vehicle. It accomplishes this by collecting the data from these areas and using that data to control the supply power to the REVski. The current wiring diagram for the REVski can be found in Appendix F. Doing so is not only required under electrical safety standards, such as the AS/NZS 3004, but also prevents the risk of electrocution or damage to the components within the vehicle. There are four areas of concern within the REVski: temperature, water level, battery health, and insulation levels in the low voltage (LV) and extremely low voltage (ELV) conductors.

3.1.1 Temperature

Temperature is measured in three areas of the REVski that are likely to be subjected to high levels of temperature when the vehicle is operational: the battery cells, the MCU and the motor. The temperature is measured using LM335 temperature sensors (as seen in Figure 2), for which the wiring diagram is provided in Figure 3.

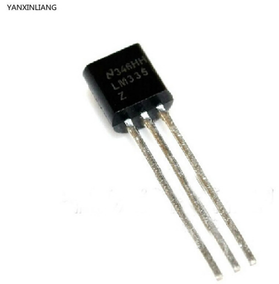


Figure 2. LM335 Sensor

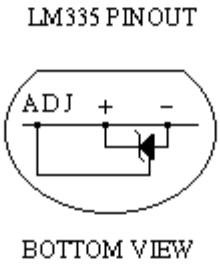


Figure 3. LM335 Pinout

All sensors are located directly adjacent to the elements they are monitoring, and thus are sealed within waterproof containers, with the exception of the motor. The data is the collected from these sensors and logged by the Arduino ATMega 2560, housed within the EWIS box designed by Woloszyn [1].

3.1.2 Water Level

Water level is measured at five points inside the hull of the REVski: four sensors positioned on the left and right-hand side of the bottom most level of the hull, and one more sensor placed within the motor control unit. The water level sensor in the motor control unit containment is to detect coolant leaks; since water is unlikely to enter this containment, the next fluid to consider would be the coolant. Measurements are taken using Arduino water level sensors. As the REVski is a maritime vehicle, the possibility of water entering the hull of the Jet Ski is high, marking this aspect of the system as a top priority.

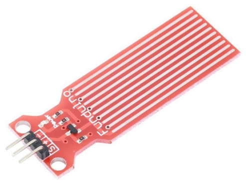


Figure 4. Arduino Water Sensor

3.1.3 Battery Management

Battery Management Systems (BMS) are monitoring systems that keep track of the battery's key parameters and act accordingly to protect the battery [2]. For example, a battery approaching a state of charge limit may turn off non-essential loads or shut down the charging source when the batteries reach a high cell voltage [2]. All 272 Lithium ion batteries that power the REVski are monitored using the ZEVA Battery Management Master Control Unit (BMMCU), used in conjunction with four ZEVA BMM8 V1.5 modules, the assembly of which was already completed previously by former student Jayden Dadleh [3].

Figure 5. ZEVA BMMCU

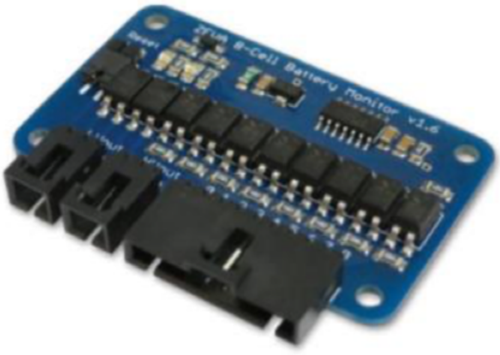


Figure 6. ZVEA BMM8 V1.5 Module

3.1.4 LV and ELV Protection

Protection against Low Voltage (LV) and Extremely Low Voltage (ELV) in electrical systems is required according to the AS/NZS 3004 Electrical Installations – Marinas and Recreational Boats. The insulation level of the LV and ELV conductors are monitored using the Bender Isometer model IR 155-3204, previously provided by former UWA student Joshua Knight.

As previously stated, the predominant goal of the safety system is to use the data collected from these 4 areas and have them shut off supply to the REVski in the event that a fault were to occur. The BMS act as relays and open the circuit when the battery voltage readings fall outside the range of acceptable values. The IMD accomplishes the same task by measuring the insulation resistance of the LV and ELV conductors and opening the circuit when this value falls below the threshold resistance value.

3.2 Water Quality Testing

The monitoring of the quality of water is to ensure that the water is safe for particular uses, such as protection of fish, drinking and swimming. Standard practice for water quality testing is to take samples of the water in the field and transport them back to a lab for analysis and testing. The REVski project aims to devise methods that would allow the analysis and testing of water quality while mobile, integrating the circuits into the electric watercraft, rather than collecting and transporting samples to a lab. Thus, in addition to the design of the REVski safety system, this report will also include proposed methods in which water quality testing can be performed out in the field. The literature review below will outline systems and standards used in monitoring water quality and conduct an analysis of pros and cons of each equipment and device used.

3.3 Water Depth Sensors

When conducting field tests, the team is reminded to drive the REVski carefully when bringing the vehicle near the jetty as the hull could be physically damaged if driven too close to the ramp. As small indications of physical damage have already been detected on the bottom surface of the vehicle, the use of water depth sensors would allow safe navigation of waters and prevent any further physical damage to the hull.

3.4 Graphical User Interface

By definition, a graphical user interface (GUI) is a visual way of interacting with electronic devices using items such as icons or menus [4]. Troubleshooting the REVski involves having the vehicle open and REVski team members having to cross-reference the electrical network of the REVski with the wiring diagrams to determine any problems. The idea of integrating a GUI into the REVski is to allow the user to interact with other electronic components installed, such as the EWIS designed by Wolosyzn [1], without having to dismantle or open the REVski. A GUI would also allow interfacing with a planned GPS to be installed the REVski.

4. Literature Review

When the REVski was first built in 2012, the idea of converting a conventional Jet Ski into a renewable energy vehicle was a fairly new concept, thus an extensive literature review on the systems pertaining to the REVski, particularly those concerning safety, were seldom. Since its inception, there have been a total of 3 Theses that have tackled electrical safety for the REVski.

The theory in the subsections of Section 3 is elaborated further with the literature review. Clarity will be given to the aspects that were not or could not have been made clearer in Section 3, and justifications will be given for the decisions made in regards to the safety system.

4.1 Safety Systems – Riley White

Former UWA student and REVski team member Riley White was the first to design an electrical safety system for the REVski in 2013. The majority of the safety system requirements have been met by White’s designs. The aspects covered were: temperature, water, BMS, Deadman’s switch and Safe to Charge operations.

The batteries were elected to be the component in the REVski at the most risk to high temperatures [5]. Due to spatial limitations within the REVski, the batteries do not have their own cooling system. At high temperatures, such as at 100°C, Lithium-Ion batteries are capable of exploding [5]. In Australia, where temperatures are known to reach 40°C in summer, the likelihood of this occurring is very high. The recommendation for battery storage temperature is to store them between -33°C and 55°C [6]. These limits to temperature are the basis for which the LM335 sensors in the new safety system will be set to. White chose to employ a Kemo Electronic Temperature Switch 12V/DC. White decided that the accuracy of the temperature sensors was not of the highest priority, thus the ±10°C accuracy range for the sensor readings was deemed acceptable [5]. The Kemo Temperature sensor has the added advantage of a built-in relay used to cut the supply power should the sensors detect a high enough temperature increase.

White’s work also covered water level measurement in the hull of the REVski, choosing to use a Kemo Electronic Water Level Sensor 9V/DC as the sensor [5]. Unlike the Kemo Temperature sensors, the Kemo Water Level Sensors required 9V to operate, thus needing a voltage regulator to drop the 12V provided by the DC-DC converter. Due to the complicated nature of Whites water level module, the Arduino water level sensors will replace the Kemo Electronic Water Level Sensors in the new safety system. Despite this, at the time of designing the new safety system for this project, White's water module was not in use.

The main purpose of the Deadman/ignition key switch, also done by White [5], is to cut the supply to the REVski in the event that the key is not connected. This key is to be attached to the user when operating the REVski. Should the user fall off the vehicle, the key will subsequently be pulled off with them, and the REVski will deactivate, rather than have it continue to run while the user is overboard. One of the complications encountered by the current REVski team was that the throttle would not work, and it was discovered that the connection from the Deadman switch was not properly connected, after which the REVski was fully operational and ready for a field test. This issue only served to reaffirm White's work with the Deadman switch, in that it functioned exactly the way it was intended.

4.2 Safety System Schematic - Caitlin Mitchell

Mitchell was a former UWA student that was responsible for a possible safety system design for the REVski in 2015. The system Mitchell designed follows a similar process to past efforts, employing basic electrical engineering principles to construct a single integrated module that monitored temperature, water level and the BMS.

However, no documentation was found detailing the mechanics behind Mitchell's design aside from the schematic shown in Appendix B, and it was decided that reverse engineering the circuit would be time consuming. Additionally, Mitchell's system was not in use at the time.

4.3 Electrical Safety Compliance of LV and ELV Systems in a Maritime Setting – Joshua Knight

Compliance of Low Voltage (LV) and Extremely Low Voltage (ELV) electrical safety systems in maritime vehicles is a requirement under the regulations of the AS/NZS 3004.2:2014, covered by former UWA student and REVski team member Joshua Knight in 2015. Knight's contribution to the earth leakage and protection system saw the installation of the Insulation Monitoring Device (IMD), model IR155 by Bender, which is designed to detect faults along the LV and ELV conductor lines. The IMD also has the ability to monitor the insulation resistance level of these conductors, and provides a healthy signal if this value is above 500Ω [7]. The requirements presented by AS/NZS 3004.2:2014 state that the system needs to detect fault levels below 30mA, and according to Knight's calculations and the insulation resistance level measured by the Bender IMD, this equates to a fault level of 0.002mA, thereby meeting the AS/NZS 3004.2:2014 standards. The specifications of the IMD can be viewed in Appendix E.

4.4 Safety and Battery Management Systems within an Electric Personal Watercraft – Jayden Dadleh

Former UWA student and REVski team member Jayden Dadleh was responsible for the REVski's current Battery Management System (BMS). Dadleh's installation of the ZEVA BMMCU and BMM8 modules have allowed the Lithium ion batteries to be maintained at healthy voltage levels throughout the duration of the project. The BMMCU acts as the "brains" of the batteries, with the BMM8 modules monitoring each individual battery cell. Table 1 lists the specifications of the BMM8 module.

Cell Capacity	2-8 cells
Over-Voltage Threshold	3.8V
Under-Voltage Threshold	2.5V
Sampling Rate	10Hz
Dimensions	60×37×5mm
Power Consumption	8.5mA

Table 1

Aside from maintaining battery voltage capacities within the acceptable ranges (2.5V undedrvoltage and 3.8V overvoltage), the end goal of the BMS, similar to the Bender IMD, is to cut the supply to the REVski in the event of fault detection, as is the case with a relay: if the BMM8 modules send a signal to the BMMCU indicating that the voltages are within the acceptable range, the switch is closed and the REVski will run [3], coinciding with the goals of the overall safety system. The wiring for the BMS safety system is displayed in Figure 7.

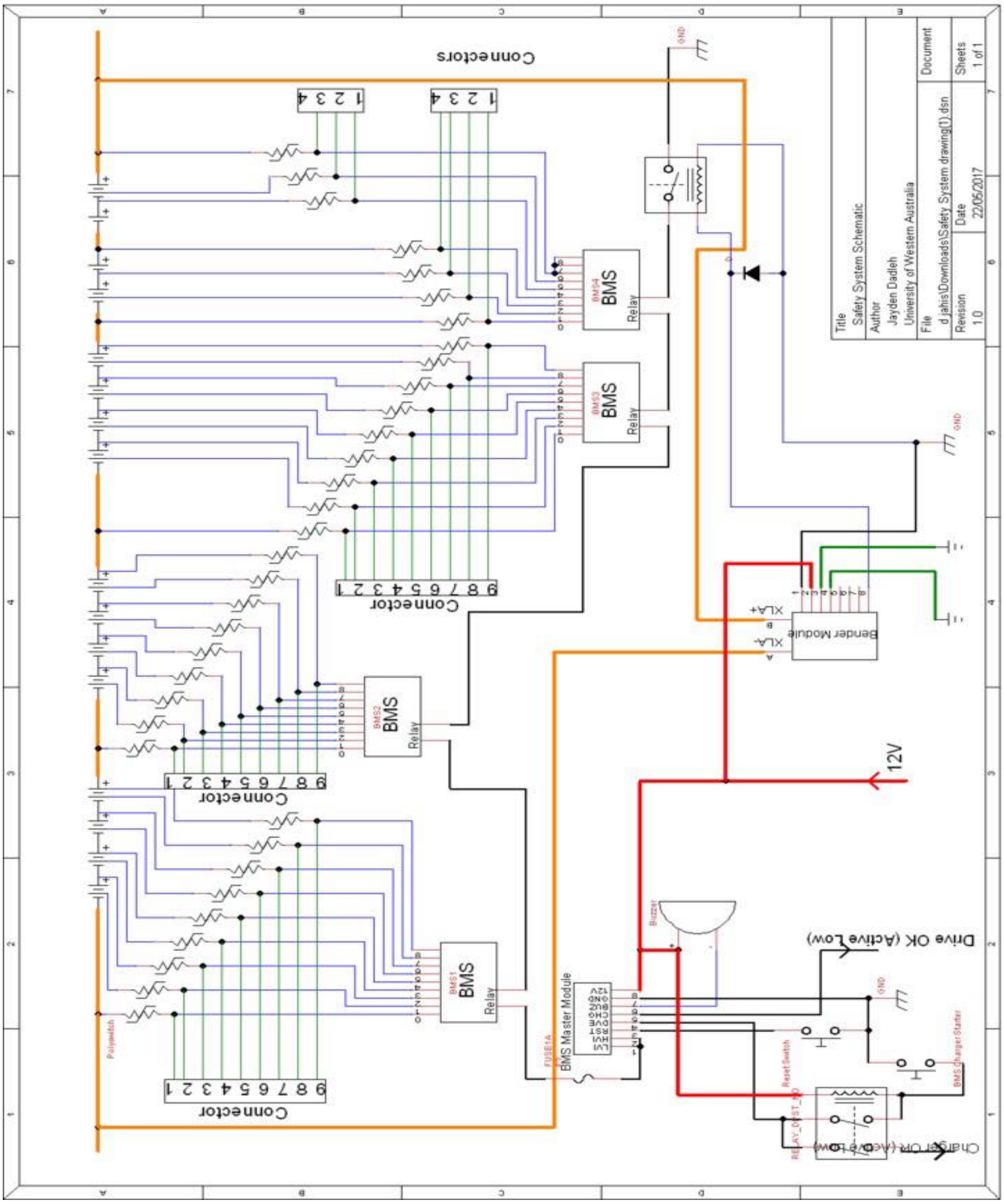


Figure 7. BMS Safety System Wiring Diagram

4.7 Water Quality Testing

4.7.1 Standards for Water Quality Testing

In a similar fashion that electrical wirings must follow a set of regulations, there are standards for which water quality testing must also follow, such as ISO 7027. While not inherently related to electrical safety, the standards for water quality testing is geared towards the collection and use of the data pertaining to the quality of water, providing instructions as to what to collect and how.

4.7.2 Open Source Mobile Water Quality Testing Platform

According to Wijnen et.al [8], there has been little development of simple and inexpensive water quality assessment instrumentation. Research into water quality testing must determine whether such methods are: (1) needed, (2) effective, and (3) reliable [8]. The design must also incur minimal cost in order to be deployed in the field. The open-source hardware approach is one such method proposed by Wijnen et.al [8].

Open-source mobile water quality testing combines Arduino electronics and RepRap 3-D printing to make an OS colorimeter – a tool used for water quality testing using the chemical oxygen demand method. The platform developed provides colorimetry for biochemical oxygen demand and nephelometry to measure turbidity using methods presented in ISO 7027 [9].

The electronics utilized are based on the Arduino platform. Software libraries facilitate integration of Arduino board features into custom code developed by the end user. The OS wiring diagram in Figure 8 bears a striking resemblance to the system used for the temperature and water level modules used for the REVski.

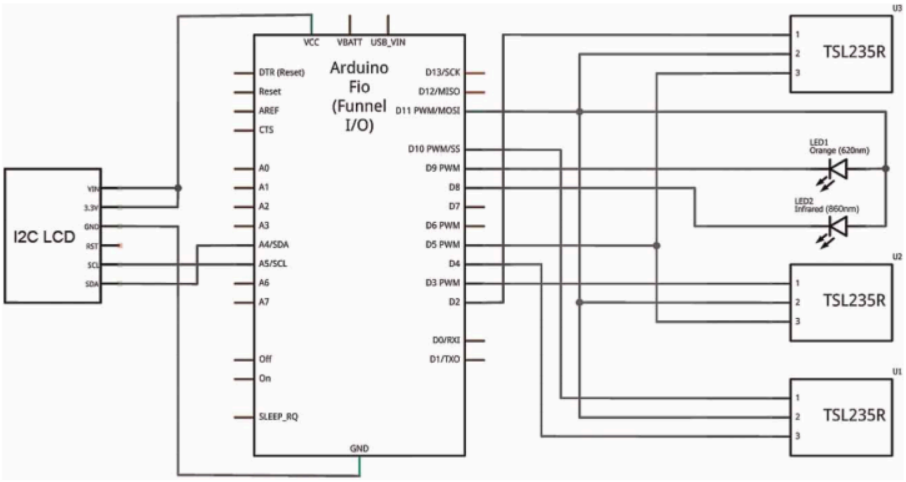


Figure 8. Open-Source Wiring Diagram

4.7.3 Real-Time Water Quality Monitoring System Using Internet of Things

An Internet of Things (IoT) is described as a network of physical objects, vehicles or buildings embedded with sensors, micro-controllers and network connectivity that enable these objects to collect and exchange data [10]. A real-time water quality monitoring system makes use of IoT's for continuous onsite testing and real-time reporting of water quality data that can be accessed via smartphones or PC's [10]. This system utilizes multiple sensors to measure the parameters of the water quality accurately and with less effort [10]. Like OS water quality monitoring [8], the set up for Real-Time Water Quality Monitoring also resembles the temperature and water level modules currently used by the REVski.

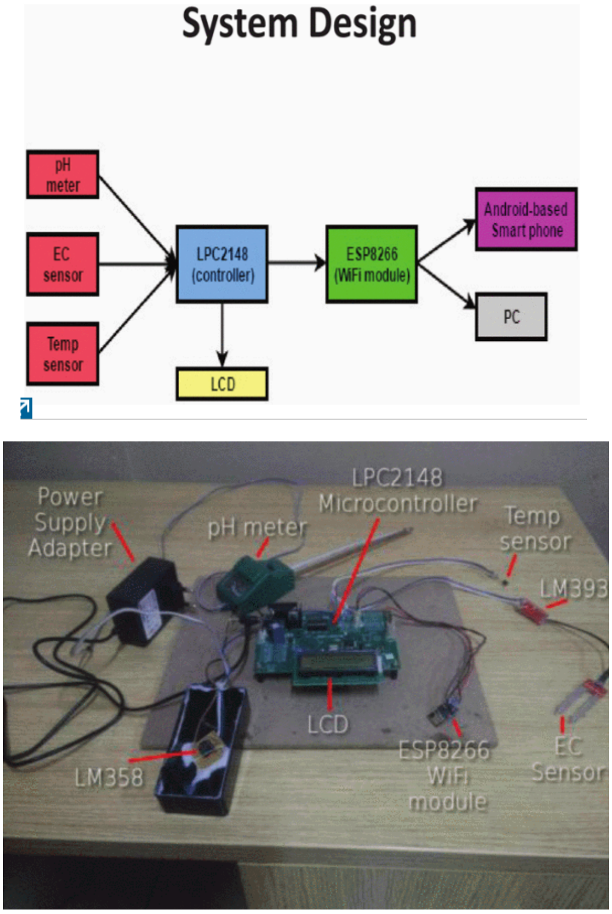


Figure 9. Water Quality Monitoring System

4.7.4 A Solar Powered Long Range Real-Time Water Quality Monitoring System by LoRaWAN

Another attempt at employing real-time water quality monitoring and IoT's is to use a LoRaWAN [11]. A LoRaWAN is described as a set of protocols designed for long-range communication networks [11]. Similar sensors used to detect water quality parameters, such as pH, conductivity, turbidity and temperature. A solar cell is used to recharge the batteries powering the system and prolong lifetime [11]. The difference between LoRaWAN and the system proposed in Section 4.7.3, are the micro-controller and Wi-Fi modules used. LoRaWAN utilizes an Arduino Nano micro-controller and a LoRa module as the Wi-Fi module. The Arduino Nano micro-controller would be consistent with the electrical safety system, and grants the option of compartmentalizing this water quality monitoring system with the safety system by using the ATMega 2560 inside the EWIS [1] instead of having a separate waterproof box housing the water quality monitoring system and consuming more of the mounting space area inside the REVski.

4.7.5 Development of Unmanned Surface Vehicle for Water Quality Monitoring and Measurement

A method for water quality monitoring for Unmanned Surface Vehicles (USV) also utilizes IoT's [12], and proves as the most promising outlook for applying a mobile platform for water quality testing using service vehicles to collect and analyze water quality, as opposed to collecting data in the field and then transporting said data back to a lab for further analysis. The USV makes use of an ARK solar powered water quality monitoring buoy [13]. Being rated at IP68, not only is it suited for a USV and any other water surface vehicle, but also complies with the AS/NZS 3004 standards for electrical systems in maritime environments. While Sections 4.7.2 to 4.7.4 provided mobile water quality monitoring systems, they did not account for how the sensors would monitor the water if all the electronics were contained within the REVski. As a buoy, this issue is eliminated, and the only concern left would be to interface with the device.

4.7.4 Sensors used in Water Quality Testing

Section 4.7.3 stated that an analog-to-digital converter (ADC) could be used to convert the signals from the sensors into digital signals, which can then be processed by the micro-controller. With the REVski safety system already following a modular design, it raises the question as to whether it is necessary to follow this implementation, or to make some alterations so as to make troubleshooting and the physical implementation easier for the REVski team.

Observing Figure 9, the temperature sensor used appears to be the same as the one currently being used to measure temperature in the REVski (as explained in Section 3.1.1). In fact, the sensors depicted in Figure 9 all seem to be ones that would first come to mind if the team were to construct this system from the bottom up. The problem lies, then, with the microprocessor. The EWIS integrates and processes all the data from the electronics currently used in the REVski using an ATMega 2560. The microprocessor used in Das and Jain's [10] proposed system is an LPC2148 founded by Philips. This presents two differing methods for processing the data collected from the sensors: incorporate every sensor and device for both the safety system and the water quality monitoring system and utilize either the Philips LPC2148 or the ATMega 2560 as its main micro-controller, or have the two systems kept separate, with the safety system in one area of the REVski and the water quality monitoring system in another.

5. Design

5.1 Requirements

The design of the safety system is to collect data from problem areas of the REVski and use said data to control the supply to the vehicle; if there is an issue in one or more of these targeted areas the supply voltage is switched off to avert danger and protect other components in the REVski. The flow chart in Figure 10 below illustrates this in an easy-to-understand picture format.

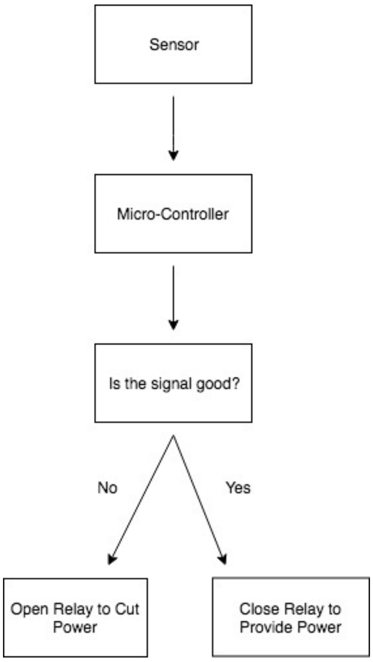


Figure 10. Safety System Flow Chart

While the overall concept for the safety system may seem relatively straightforward, physically implementing and installing the system components within the REVski has proven to be a challenge. The previous locations of the water level sensors were proven to be counter-intuitive. The height of the water level sensors lined up with the lower B1 and B2 battery tubes, along with the motor. Having the sensors detect water leaks at the same level as the very components the system is trying to protect defeats the purpose of a water level detection module. Instead, the water level sensors have now been positioned at the bottom-most level of the hull. This gives the user ample time to see the warnings displayed on the LCD and switch on the bilge pump to extract the water leaking into the REVski.

The implementation of the temperature module also proved difficult, and several different methods were considered for the physical wiring of the new LM335 temperature sensors used for the temperature module.

5.2 Temperature Sensors

A total of seven LM335 temperature sensors are used to monitor the areas of the REVski that are most affected by temperature: the five battery tubes, the motor, and the motor control unit (MCU). The choice to use the LM335 series temperature sensor over the previous sensors is trivial: the previous sensors were old and worn. Additionally, wiring the LM335 sensors and installing them into their respective areas proved to be a simple task.

The most important aspect of the LM335 sensors is its ability to be coded using Arduino Software. Due to its nature as Open Source software, there are numerous sources detailing the construction of simple temperature sensor circuits, including circuits that utilize the LM335. The code, which can be viewed in Appendix C, used for the safety system follows the one available on Instructables, with some minor alterations [14].

5.3 Water level Sensors

Water leaks within the hull of the REVski are monitored using four Arduino water level sensors. Although the water sensors are the same as the one used to monitor water level previously, the older sensors were deemed worn and thus were replaced by new ones, and as mentioned in Section 5.1, have now been relocated. The code to read the sensors, available from Instructables [15], is provided in Appendix D. Additionally, one extra Arduino water level sensor was added to the circuitry to monitor coolant leaks within the MCU. The proposed wiring diagram for both the temperature and water level modules are given in Figure 11.

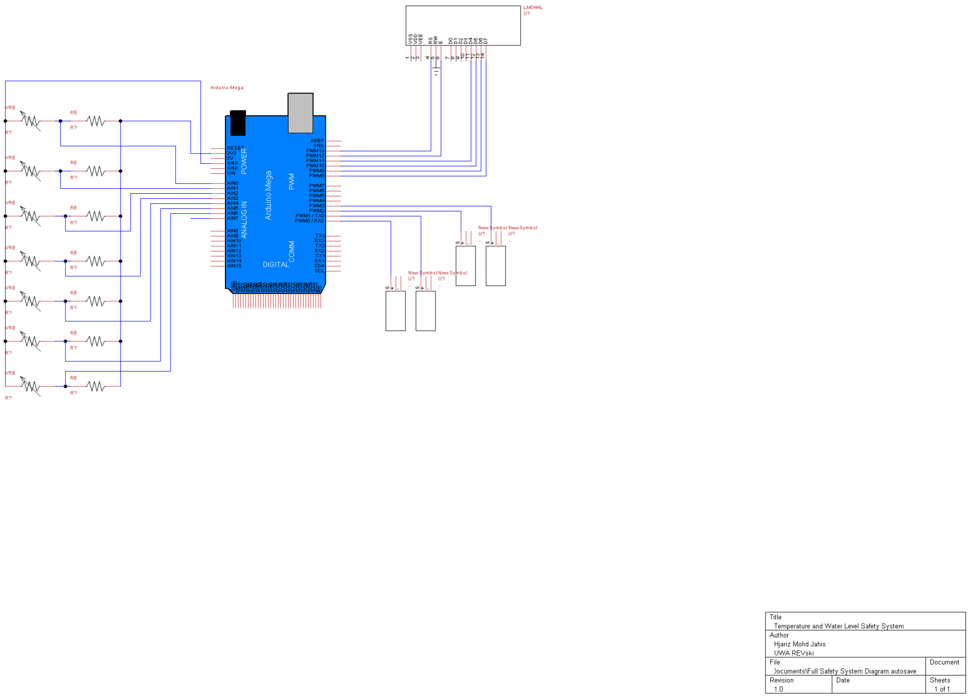


Figure 11. Temperature and Water Level Module Wiring Diagram

5.4 Battery Management system (BMS)

Battery voltage and overall health is maintained using the system developed by Dadleh [3], using a ZEVA Battery Management Master Control Unit (BMMCU) alongside four ZEVA BMM8 V1.5 modules. There have been minor changes made to the original BMS design and enclosure, most of which was to accommodate certain bypasses. One such bypass was the BMS start/stop reset. Wired to the actual start/stop button on the REVski, it allows the user to effectively reset the BMS should they cut off the supply due to low voltage readings during water tests.

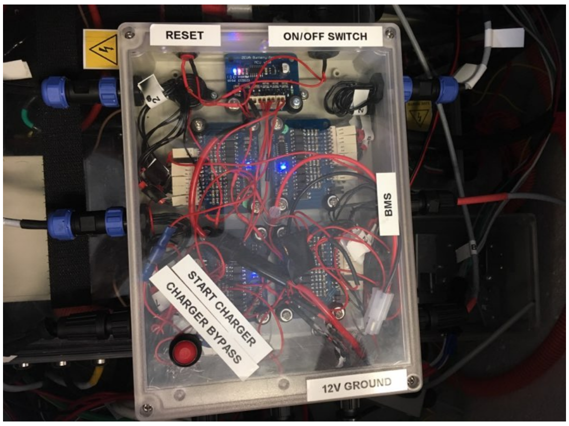
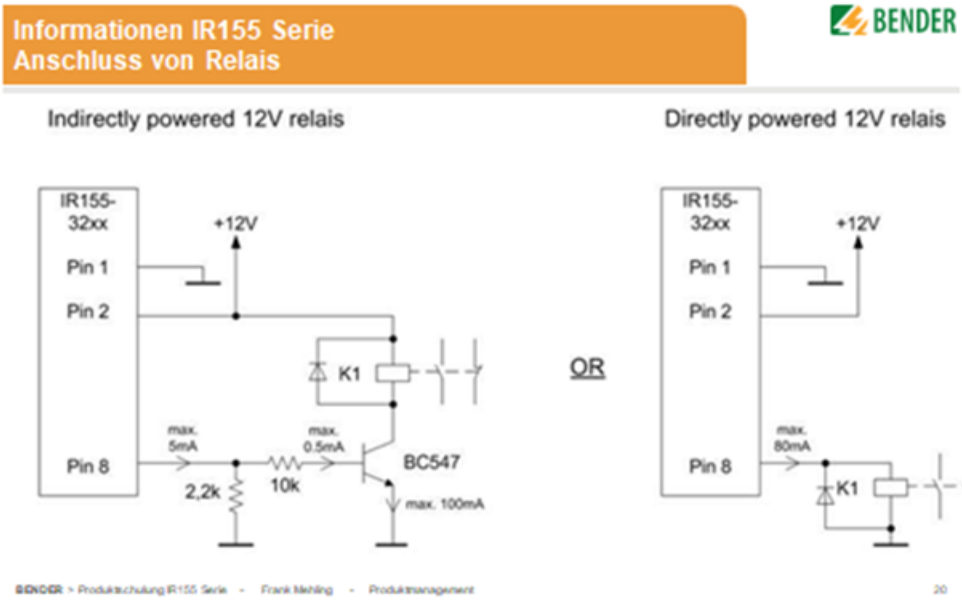


Figure 12. BMS Enclosure

5.5 Insulation Monitoring Device (IMD)

LV and ELV monitoring and protection is handled by the IMD by Bender, previously installed by Knight [7]. After contacting Bender regarding the physical wiring of the device into the REVski, Bender provided two options for which could be used in the system, depicted in Figure 12. The circuit on the left-hand side is designed for a system that does not have direct access to 12V. Since the DC-DC converter allows auxiliary equipment to have access to a 12V power source, the simpler circuit on the right-hand side can be implemented instead.


Informationen IR155 Serie
Anschluss von Relais

BENDER

Indirectly powered 12V relais

Directly powered 12V relais

BENDER > Produktschulung IR155 Serie - Frank Mehling - Produktmanagement 20

Figure 13. IMD Wiring Diagram by Bender

6. Implementation

6.1 Temperature Module

As stated in Section 5.1, the physical implementation of the temperature sensor module into the REVski proved to be difficult. Since the sensors are placed directly on the batteries within the tubes, data cables, specifically 9-core cable, that carry the signals from the sensor would have to be strung through the tubes by means of cable glands, rated at IP67. The physical implementation of this design is displayed in Figure 14.

This configuration with the sensors, data cables and resistors all soldered together is applied to all seven LM335 sensors. As displayed in Figure 11, it is evident that all the sensors utilize the 5V and GND pins on the Arduino Microcontroller. It was then dictated that all seven sensors share the same lines that connect to 5V and GND for simplicity sake. Several ideas were proposed to how this wiring configuration could be accomplished. One method was to solder all the cables together, using heat shrink to cover any exposed cables. The downside, however, is that, because the “signal” wires do not share the same pin on the Adruino board, they would be completely exposed within the hull of the REVski, and at risk of physical damage due to their small dimensions and short circuit due to water leakage in the REVski. Another proposed solution was to have a watertight box, rated at IP67, containing a wire terminal block that collected like wires. This was deemed the most efficient solution, the physical implementation of which is shown in Figure 14.

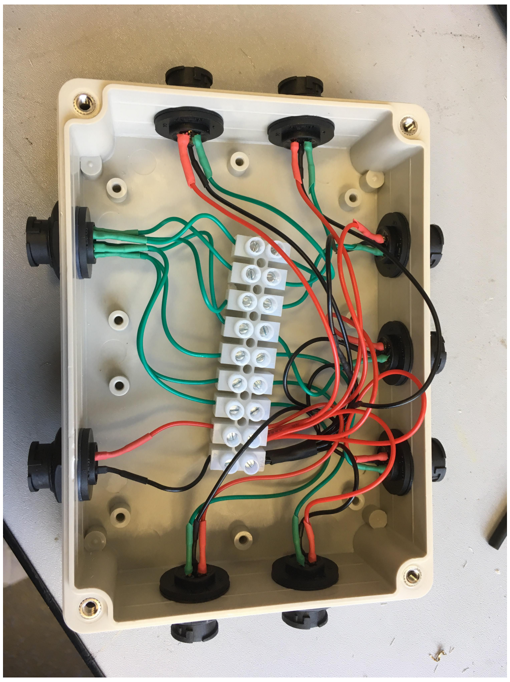


Figure 14. Temperature Connection Box

Observing the temperature connection box, it can be seen that the seven sensor cables from all the targeted areas of the REVski meet and connect to the box. The individual wires within the cored data cables are separated, with the red 5V wires joining together, and the black GND wires joining together. The green "signal" wires are kept separate as they each carry their own individual signals from their respective sensors. Although the entire structure is constructed using off-the-shelf components that can be sourced locally from vendors in Perth, Western Australia, some complications arose in acquiring components. Originally, it was intended to have all the wires from the front end of the terminal block (left-hand side in Figure 14) converge into a single 9-pin male chassis head (7 signal wires + 1 5V wire + 1 GND wire = 9). However, this particular pin was not available from Altronics, and thus the decision was made to have two different male connector heads, one 2-pin head carrying the red 5V and black GND wires, and one 7-pin head carrying all seven green signal wires.

6.2 Water Level Module

The implementation of the water level module is very much the same as previously established. The only marked difference is that the sensors have been moved to different locations. Before, the water level sensors were positioned at approximately the same level as the lower B1 and B2 battery tubes and motor. Since the purpose of the water level sensors is to detect when water enters the hull of the REVski, this placement of the sensors proved counter-intuitive. The sensors have since been moved to the bottom-most level of the hull and placed vertically rather than horizontally. The water sensor box with an Arduino Nano, used to process the data collected from the sensors, is no longer in use. Instead, the Arduino ATMega in the Electric Watercraft Instrumentation System (EWIS) box, designed by UWA student and REVski team member Maximillian Woloszyn [1], will now be used to collect data from the water level sensors.

The intended use of the sensors is to use the data collected from said sensors and implement Arduino code to instruct a set of relays, wired in series to the emergency cut-off switch, to open the circuit and cut the supply to the REVski in the event that water is detected at a height that may start to damage the more sensitive components in the hull, such as any of the components on the mounting system situated at the front end of the REVski. Before this occurs, however, the Arduino code, provided in Appendix D [15], is structured in a manner that grants the user adequate time to take action against any water leaks in the REVski. Should any of the sensors come into contact with water, the ATMega Microcontroller is instructed to send a message to the LCD screen on the compartment, warning the user of a potential leak and instructing them to switch on the bilge pump to eject the water. The effect of the bilge pump can be seen in Figure 15.

Figure 15. Bilge Pump in Effect

6.3 BMS

No drastic physical changes have been made from Dadleh's [3] original BMS enclosure. The only marked differences are the Velcro straps attached to the bottom surface of the enclosure box providing a strong hold to the mounting system at the front end of the REVski, yet easily detachable by personnel. The BMS cables connecting the battery tubes to the BMS enclosure were repaired due to minor physical damage. A switch was added to bypass the charger, as there were some complications when attempting to use the charger module to charge all battery tubes. The electrical drawings have since been updated to provide an accurate representation of the circuitry within the BMS enclosure, as seen in Figure 7.

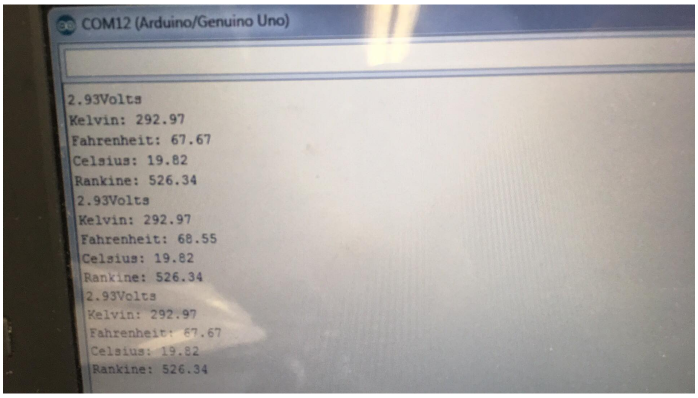
6.4 IMD Module

Due to the small size and simplicity of the circuitry of the Bender IMD, the wiring for the device (shown in Figure 13) was combined with the circuitry for the BMS and housed in the BMS enclosure. The PCB holding all the components of the IMD circuit was wrapped in electrical tape for safety. There was some consideration to have the circuit housed in a separate waterproof box, but due to the lack of space in the front of the REVski, this could not be achieved.

7. Testing

7.1 Temperature

Following the code provided by Instructables [14], testing the temperature sensors yielded the results shown in Figure 16



```
2.93Volts
Kelvin: 292.97
Fahrenheit: 67.67
Celsius: 19.82
Rankine: 526.34
2.93Volts
Kelvin: 292.97
Fahrenheit: 68.55
Celsius: 19.82
Rankine: 526.34
2.93Volts
Kelvin: 292.97
Fahrenheit: 67.67
Celsius: 19.82
Rankine: 526.34
```

Figure 16. Temperature Sensor Test

While it is clear that the sensors work, it is worth noting that the accuracy of the sensors is not 100% precise. This constraint has been addressed by the manufacturer in that the sensors are accurate to 1°C. When the code specifying supply voltage (line 42 of the LM335 Temperature sensor code in Appendix C) and the actual voltage of the supply were the same, the readings from the sensor were almost perfectly accurate. Another slight variation to the code is the removal of the measurements for the Rankine, Fahrenheit and Kelvin temperature scales, as they were deemed unnecessary.

7.2 Water Level

Although the code to read the Arduino Water Level sensors is provided in Appendix D [15], at present time, the sensors themselves have not been fully tested to the same extent as the temperature sensors. Future work would include testing the code against the sensors by holding them vertically and slowly submerging them in a small body of water. Once it has been confirmed that the sensors work, the next step would be to wire a relay in series with the power supply of the REVski and adjust the code to instruct the ATMega 2560 to send a low signal to open said relay in the event of a water leak.

7.3 BMS

Upon conducting the field tests, the batteries needed to be fully charged. As outlined in Section 4.4, the threshold voltage allowed by the BMS is between 2.5V and 3.8V. Tables 2 to 6 displays the voltages of the batteries at a full charge and also the voltage readings taken after a successful field test in a tabulated format, while Figures 17 to 21 represent these results in the form of easy-to-read histograms.

T1				
Cell Number	Charged 4th April	Charged After Previous Record	13hrs Fully Charged	After Driving 6th April
1	3.27	3.29	3.30	3.18
2	3.28	3.30	3.31	2.94
3	3.28	3.30	3.34	3.23
4	3.28	3.30	3.34	3.24
5	3.28	3.30	3.34	3.22
6	3.27	3.29	3.33	3.22
7	3.29	3.31	3.35	3.24
8	3.29	3.31	3.34	3.22

Table 2

T2			
Cell Number	Charged 4th April	13hrs Fully Charged	After Driving 6th April
1	3.31	3.33	3.27
2	3.32	3.34	3.27
3	3.32	3.34	3.27
4	3.32	3.34	3.26
5	3.31	3.34	3.27
6	3.32	3.34	3.26
7	3.32	3.35	3.28
8	3.30	3.35	3.27

Table 3

T3			
Cell Number	Charged 4th April	13hrs Fully Charged	After Driving 6th April
1	3.32	3.33	3.27
2	3.28	3.34	3.23
3	3.28	3.34	3.25
4	3.28	3.33	3.24
5	3.28	3.33	3.24
6	3.27	3.33	3.24
7	3.29	3.35	3.26
8	3.29	3.35	3.27

Table 4

B1			
Cell Number	Charged 4th April	13hrs Fully Charged	After Driving 6th April
1	3.31	3.33	3.26
2	3.32	3.33	3.27
3	3.32	3.34	3.27

Table 5

B2			
Cell Number	Charged 4th April	13hrs Fully Charged	After Driving 6th April
1	3.31	3.33	3.26
2	3.32	3.34	3.27
3	3.31	3.33	3.26

Table 6

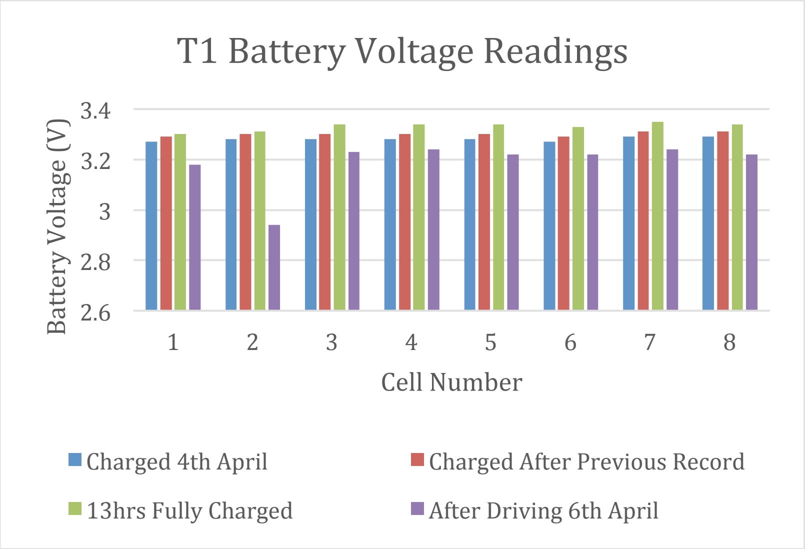


Figure 17. T1 Battery Voltage Readings

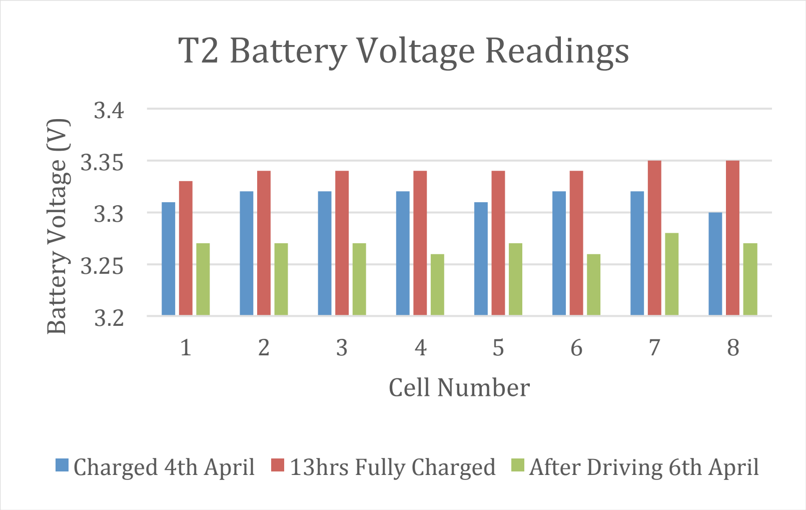


Figure 18. T2 Battery Voltage Readings

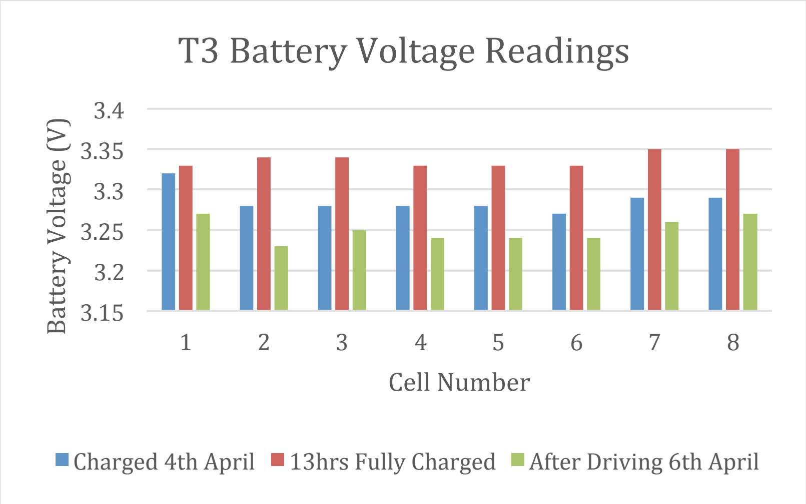


Figure 19. T3 Battery Voltage Readings

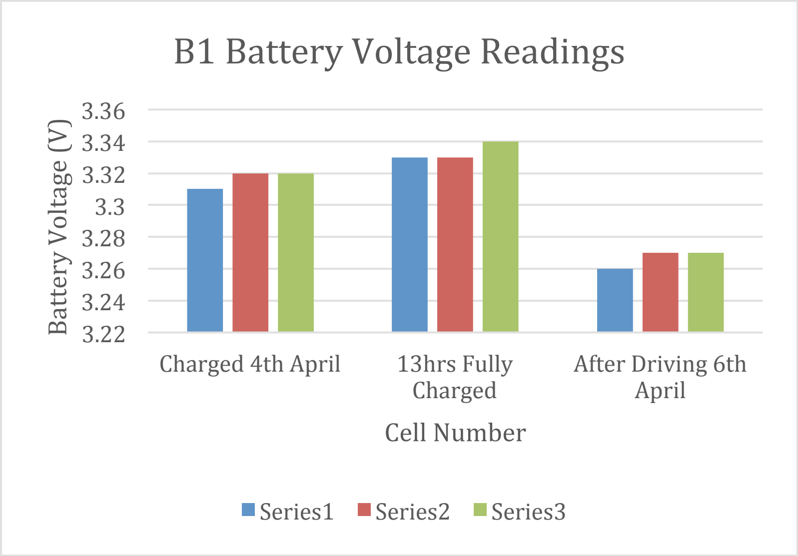


Figure 20. B1 Battery Voltage Readings

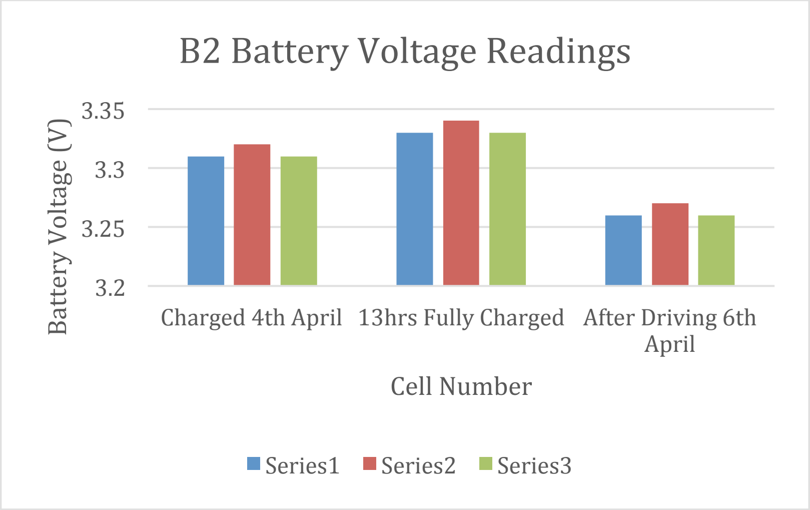


Figure 21. B2 Battery Voltage Readings

7.4 IMD

As stated in Section 2, unforeseen complications with the REVski prevented many tasks from being accomplished, including testing the IMD. Testing the IMD would involve mimicking a drop in resistance along the LV and ELV conductors and observing if the result triggers an unhealthy signal from the IMD, which would then lead to a cut in supply power. Despite this, there have been no issues with the insulation resistance of the conductors thus far.

7.5 Discussion

7.5.1 Temperature Sensors

With the LM335 sensors functioning, it is now a matter of adjusting the code to instruct the ATMega 2560 to use the information to achieve two outcomes. The first is to direct a low signal to a relay wired in series with the REVski power supply in the event that the sensors read a temperature of ~55°C, as that is the recommended upper temperature limit for the battery's operation. The second is to display the messages on an LCD screen to indicate to users the condition of the battery's temperature. At present time, only the LCD has been installed, while the wiring of the relay in series with the power supply is still in progress.

7.5.2 Battery Readings

As seen in Figures 17-21, it is evident that there is an imbalance between the cells, resulting in the BMS cutting power upon reading a low voltage from one cell, while others remain above the threshold. While the REVski team works tirelessly to charge these cells individually to approximately the same voltages, ultimately a handful of cells are unable to achieve the same level. Due to their high cost, replacing all the cells with brand new ones is not a feasible solution. Attention can then be drawn to a new, more robust BMS, one that has the capability of balancing the cells while charging.

7.5.3 REVski Work Lifecycle

The life cycle of work done on the REVski has followed a particular formula: disassembly for improvements or thesis-related works, assembly, troubleshooting and finally the field test. The one process in this cycle that proves the most difficult and stressful is troubleshooting. During the completion of this report, there have been three major field tests. On the first two field tests, during the troubleshooting phase, connectivity issues were encountered that were time-consuming and stressful. The first field test, performed some time in November 2017, saw issues with charging. The second and third field test in April and June 2018 saw an issue with the throttle. In all three instances, the source of the problems stemmed from a simple missed connection. The installation of LED's at certain points of the electrical network will greatly assist in the troubleshooting process by highlighting points along the circuitry that may have not been properly connected. Unfortunately, due to time constraints, this solution is yet to be implemented. This task also falls under general REVski work and not completely related to any Theses, yet holds a significant priority as without passing the troubleshooting phase, field tests cannot be performed and data collection is delayed.

8. Conclusion

This project aimed to design an electrical safety system for an Electric Jet Ski that monitored areas of interest in the vehicle that may pose a risk to equipment and personnel in the event of a fault. The system for the REVski is now capable of monitoring temperature, water level, battery voltage and insulation resistance of LV and ELV conductors. However, out of the four areas of safety, only the BMS and IMD are capable of cutting power to the supply in the event of a fault. The tools necessary for the temperature and water level modules to achieve this same outcome are ready to be installed, but are yet to be done.

9. Future Work

The modular design of the safety system allows for future improvements to problems in the REVski that may either be unidentified or overlooked. While most of the equipment used in the REVski are off-the-shelf products mostly available from vendors in Perth, some improvements planned for the REVski may require equipment that is above any projected budget assigned to the Jet Ski. A clear example in this report would be the Bender IMD, with an estimated price tag of $1000 AUD.

As stated in Section 7, the troubleshooting phase of the REVski assembly cycle proves the most difficult and at times a great source of stress. The LED's used to assist in identifying the sources of any issues during this phase have yet to be installed, and hold a high degree of importance to the troubleshooting phase of the REVski lifecycle.

Testing the water sensors to confirm functionality would be a task assigned to any future students that may wish to take this project. Wiring of the relay in series with the power supply must also be completed.

Future work will continue the investigation into the implementation of a low-cost mobile water quality testing system. The installation of more sensors, such as waterproof depth sensors for safe navigation of waters is another area in which future work can be conducted. A GUI for interfacing with a planned GPS and the EWIS should also be taken into consideration.

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water quality monitoring and measurement", in *IEEE Conference*, pp. 566-569. doi: 10.1109/ICASI.2018.8394316

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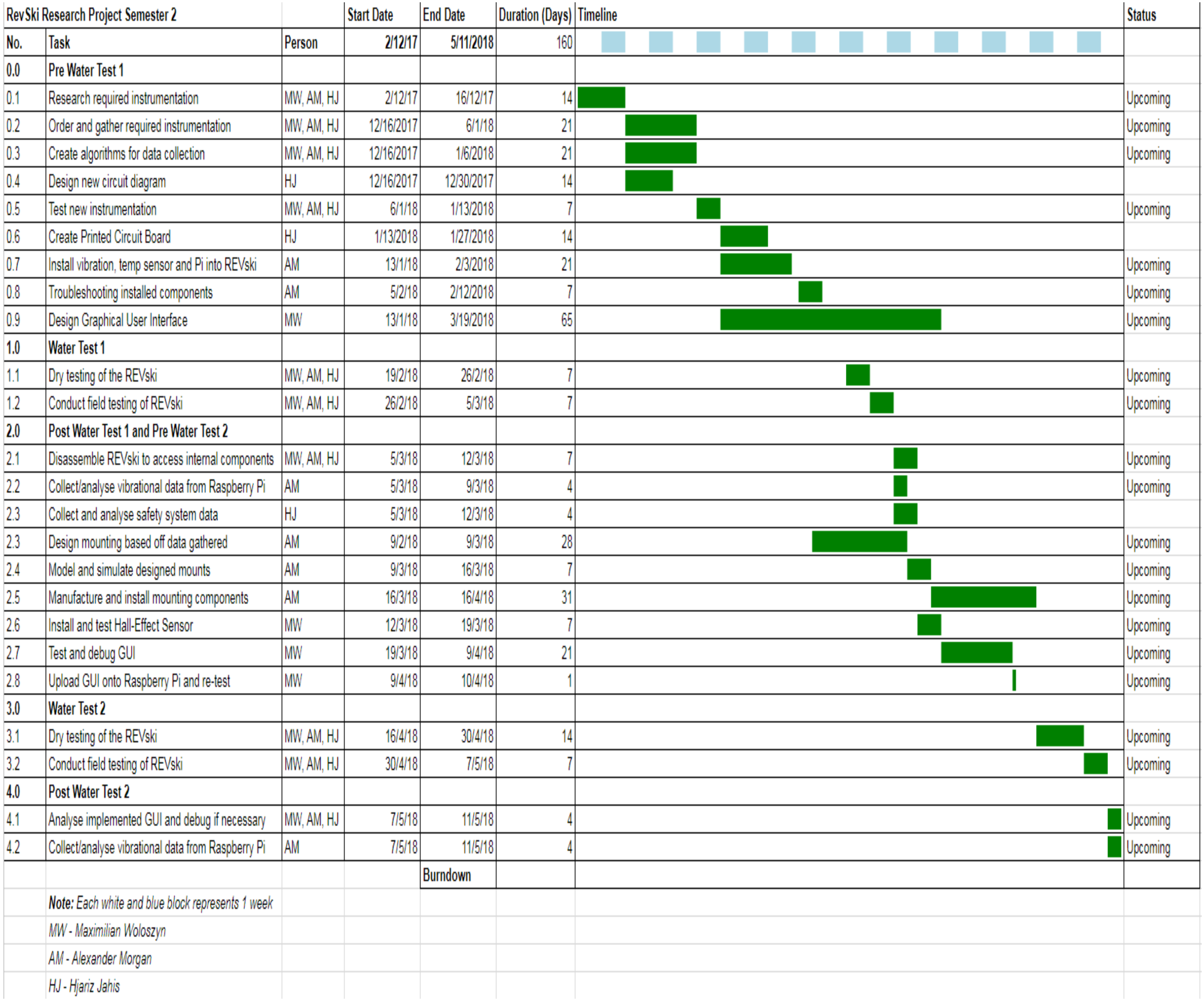
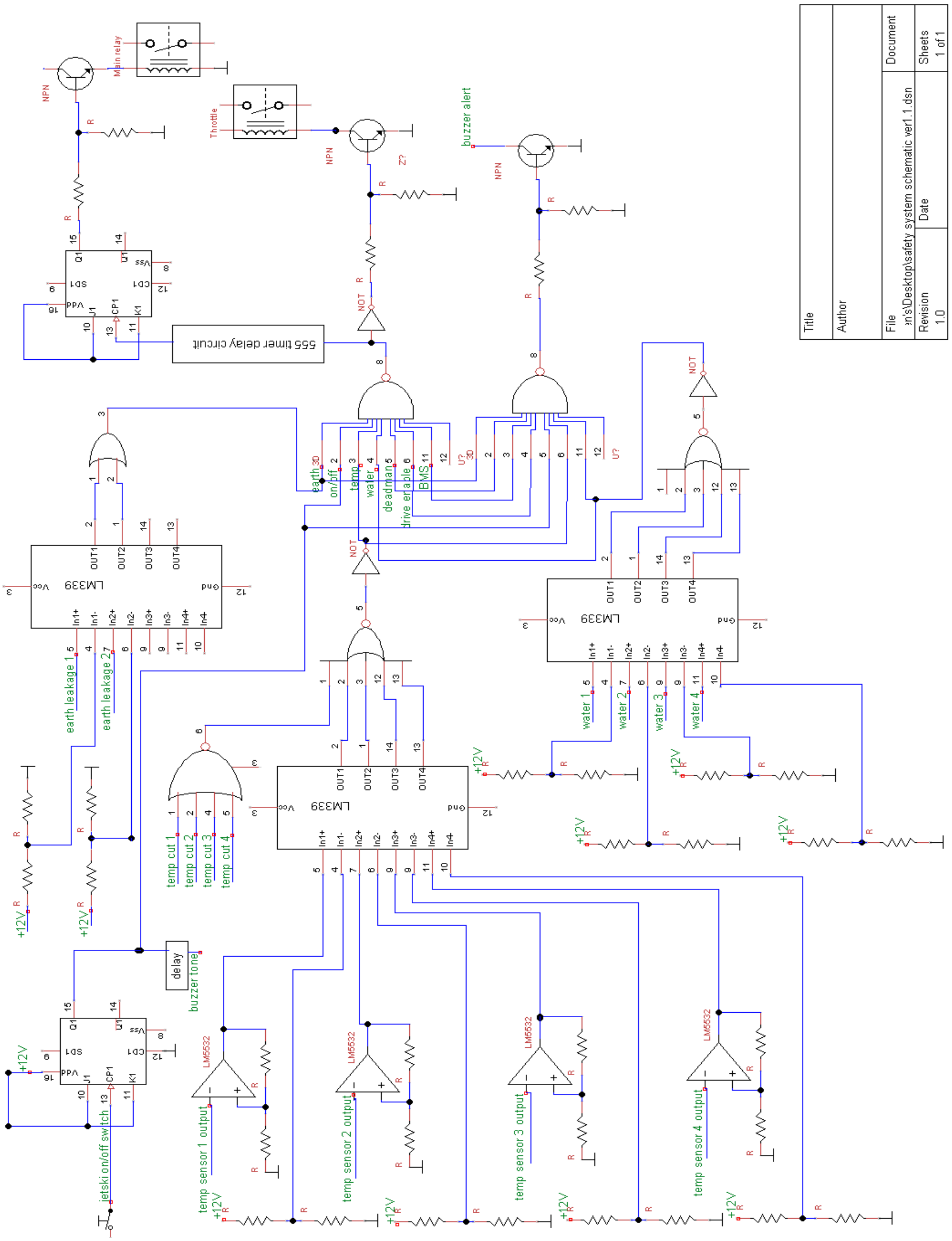
Appendices

Appendix A – Project Timeline

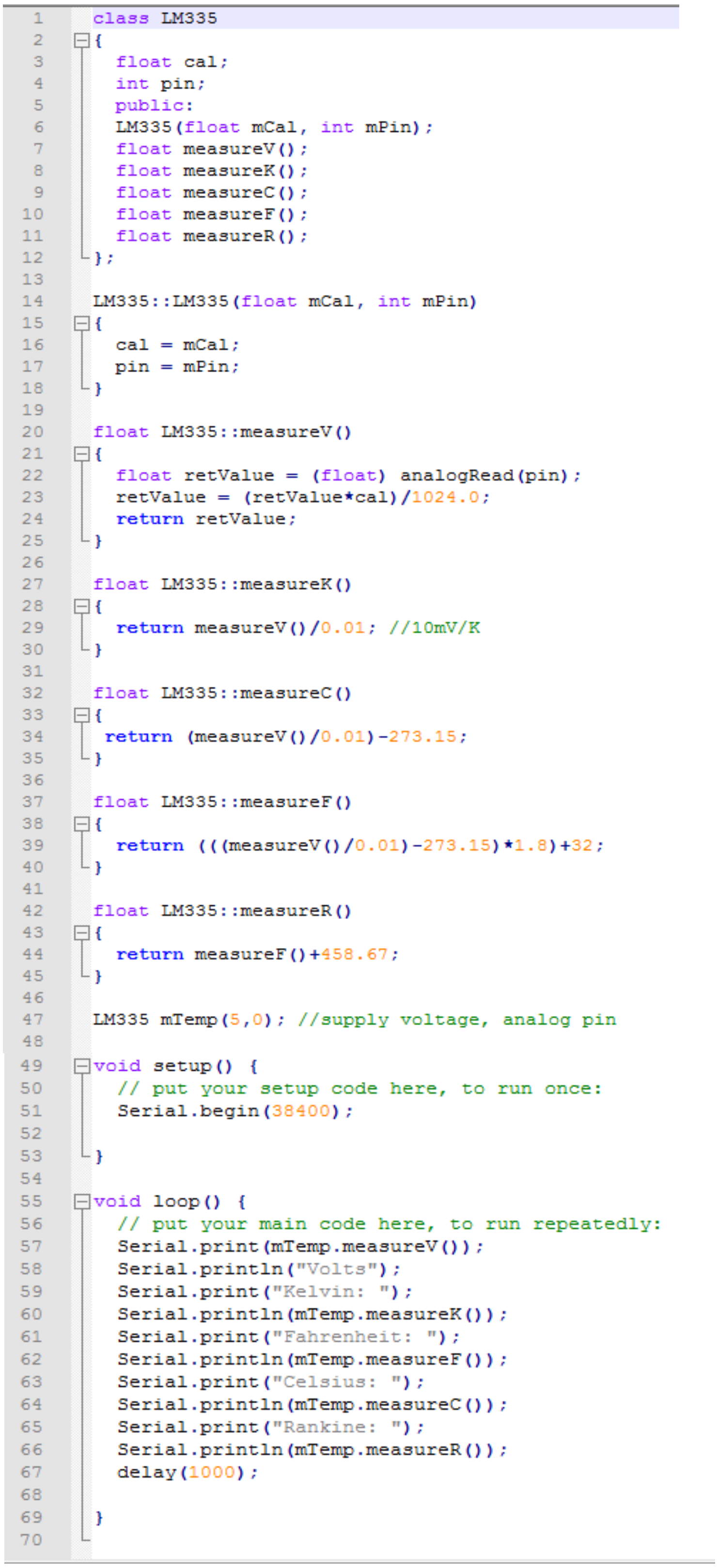


RevSki Research Project Semester 2			Start Date	End Date	Duration (Days)	Timeline	Status
No.	Task	Person	2/12/17	5/11/2018	160		
0.0	**Pre Water Test 1**						
0.1	Research required instrumentation	MW, AM, HJ	2/12/17	16/12/17	14		Upcoming
0.2	Order and gather required instrumentation	MW, AM, HJ	12/16/2017	6/1/18	21		Upcoming
0.3	Create algorithms for data collection	MW, AM, HJ	12/16/2017	1/6/2018	21		Upcoming
0.4	Design new circuit diagram	HJ	12/16/2017	12/30/2017	14		
0.5	Test new instrumentation	MW, AM, HJ	6/1/18	1/13/2018	7		Upcoming
0.6	Create Printed Circuit Board	HJ	1/13/2018	1/27/2018	14		
0.7	Install vibration, temp sensor and Pi into REVski	AM	13/1/18	2/3/2018	21		Upcoming
0.8	Troubleshooting installed components	AM	5/2/18	2/12/2018	7		Upcoming
0.9	Design Graphical User Interface	MW	13/1/18	3/19/2018	65		Upcoming
1.0	**Water Test 1**						
1.1	Dry testing of the REVski	MW, AM, HJ	19/2/18	26/2/18	7		Upcoming
1.2	Conduct field testing of REVski	MW, AM, HJ	26/2/18	5/3/18	7		Upcoming
2.0	**Post Water Test 1 and Pre Water Test 2**						
2.1	Disassemble REVski to access internal components	MW, AM, HJ	5/3/18	12/3/18	7		Upcoming
2.2	Collect/analyse vibrational data from Raspberry Pi	AM	5/3/18	9/3/18	4		Upcoming
2.3	Collect and analyse safety system data	HJ	5/3/18	12/3/18	4		
2.3	Design mounting based off data gathered	AM	9/2/18	9/3/18	28		Upcoming
2.4	Model and simulate designed mounts	AM	9/3/18	16/3/18	7		Upcoming
2.5	Manufacture and install mounting components	AM	16/3/18	16/4/18	31		Upcoming
2.6	Install and test Hall-Effect Sensor	MW	12/3/18	19/3/18	7		Upcoming
2.7	Test and debug GUI	MW	19/3/18	9/4/18	21		Upcoming
2.8	Upload GUI onto Raspberry Pi and re-test	MW	9/4/18	10/4/18	1		Upcoming
3.0	**Water Test 2**						
3.1	Dry testing of the REVski	MW, AM, HJ	16/4/18	30/4/18	14		Upcoming
3.2	Conduct field testing of REVski	MW, AM, HJ	30/4/18	7/5/18	7		Upcoming
4.0	**Post Water Test 2**						
4.1	Analyse implemented GUI and debug if necessary	MW, AM, HJ	7/5/18	11/5/18	4		Upcoming
4.2	Collect/analyse vibrational data from Raspberry Pi	AM	7/5/18	11/5/18	4		Upcoming
				Burndown			
	Note: *Each white and blue block represents 1 week*						
	MW - Maximilian Woloszyn						
	AM - Alexander Morgan						
	HJ - Hjariz Jahis						

Appendix B – Safety System Schematic (Caitlin Mitchell)

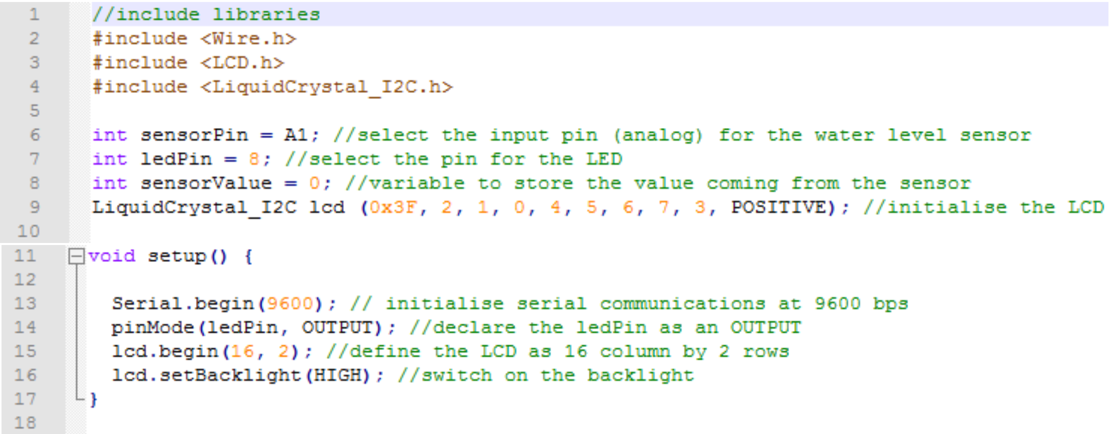


Appendix C – LM335 Temperature Sensor Arduino Code

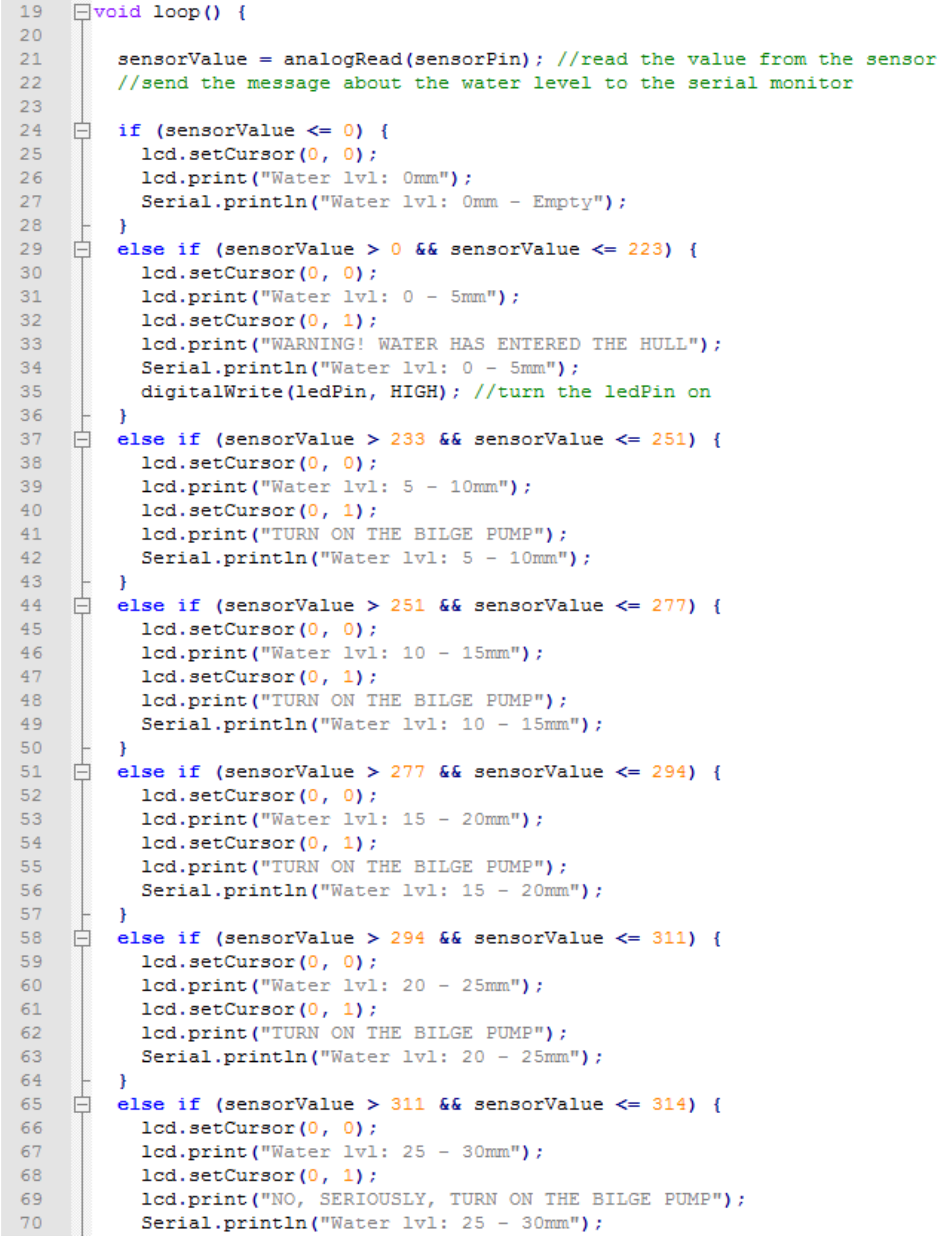


```
class LM335
{
  float cal;
  int pin;
  public:
  LM335(float mCal, int mPin);
  float measureV();
  float measureK();
  float measureC();
  float measureF();
  float measureR();
};

LM335::LM335(float mCal, int mPin)
{
  cal = mCal;
  pin = mPin;
}

float LM335::measureV()
{
  float retValue = (float) analogRead(pin);
  retValue = (retValue*cal)/1024.0;
  return retValue;
}

float LM335::measureK()
{
  return measureV()/0.01; //10mV/K
}

float LM335::measureC()
{
 return (measureV()/0.01)-273.15;
}

float LM335::measureF()
{
  return (((measureV()/0.01)-273.15)*1.8)+32;
}

float LM335::measureR()
{
  return measureF()+458.67;
}

LM335 mTemp(5,0); //supply voltage, analog pin

void setup() {
  // put your setup code here, to run once:
  Serial.begin(38400);

}

void loop() {
  // put your main code here, to run repeatedly:
  Serial.print(mTemp.measureV());
  Serial.println("Volts");
  Serial.print("Kelvin: ");
  Serial.println(mTemp.measureK());
  Serial.print("Fahrenheit: ");
  Serial.println(mTemp.measureF());
  Serial.print("Celsius: ");
  Serial.println(mTemp.measureC());
  Serial.print("Rankine: ");
  Serial.println(mTemp.measureR());
  delay(1000);

}

```

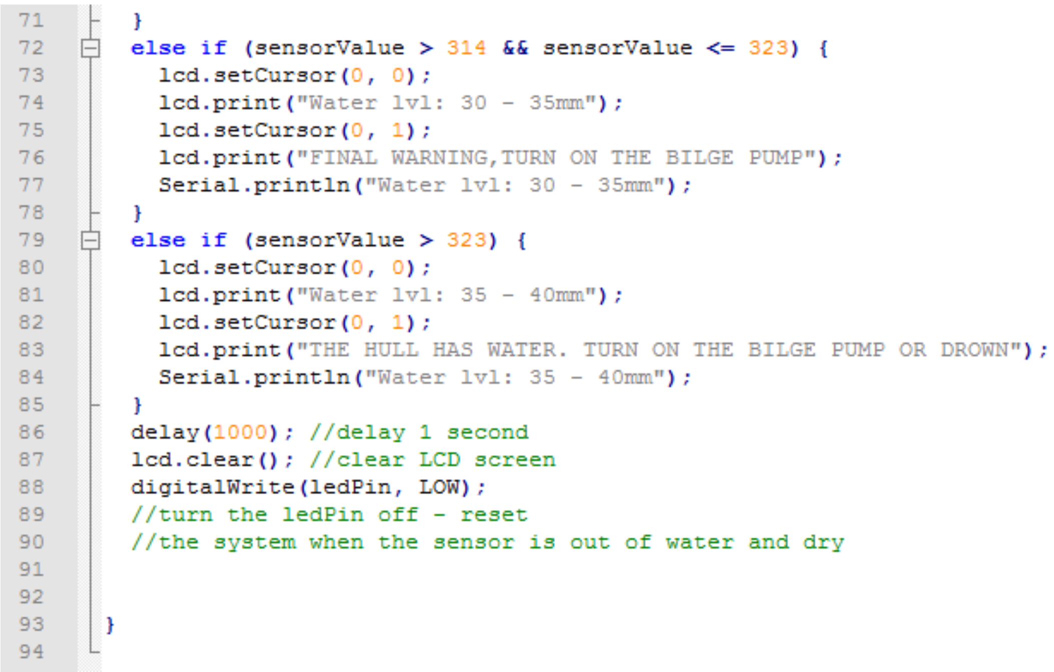
Appendix D – Arduino Water Level Sensor Code



```
//include libraries
#include <Wire.h>
#include <LCD.h>
#include <LiquidCrystal_I2C.h>

int sensorPin = A1; //select the input pin (analog) for the water level sensor
int ledPin = 8; //select the pin for the LED
int sensorValue = 0; //variable to store the value coming from the sensor
LiquidCrystal_I2C lcd (0x3F, 2, 1, 0, 4, 5, 6, 7, 3, POSITIVE); //initialise the LCD

void setup() {

  Serial.begin(9600); // initialise serial communications at 9600 bps
  pinMode(ledPin, OUTPUT); //declare the ledPin as an OUTPUT
  lcd.begin(16, 2); //define the LCD as 16 column by 2 rows
  lcd.setBacklight(HIGH); //switch on the backlight
}

```

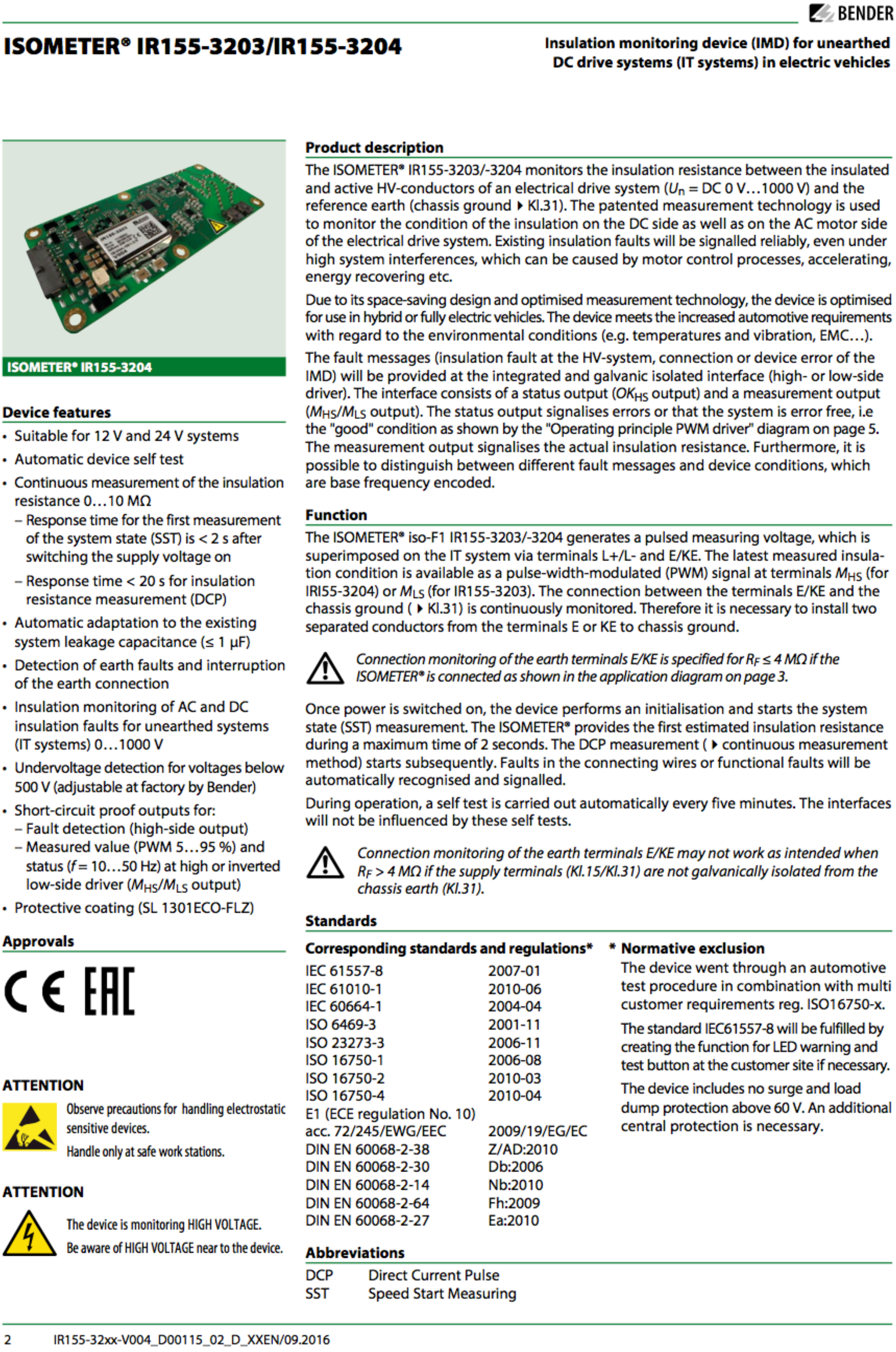


```
void loop() {

  sensorValue = analogRead(sensorPin); //read the value from the sensor
  //send the message about the water level to the serial monitor

  if (sensorValue <= 0) {
    lcd.setCursor(0, 0);
    lcd.print("Water lvl: 0mm");
    Serial.println("Water lvl: 0mm - Empty");
  }
  else if (sensorValue > 0 && sensorValue <= 223) {
    lcd.setCursor(0, 0);
    lcd.print("Water lvl: 0 - 5mm");
    lcd.setCursor(0, 1);
    lcd.print("WARNING! WATER HAS ENTERED THE HULL");
    Serial.println("Water lvl: 0 - 5mm");
    digitalWrite(ledPin, HIGH); //turn the ledPin on
  }
  else if (sensorValue > 233 && sensorValue <= 251) {
    lcd.setCursor(0, 0);
    lcd.print("Water lvl: 5 - 10mm");
    lcd.setCursor(0, 1);
    lcd.print("TURN ON THE BILGE PUMP");
    Serial.println("Water lvl: 5 - 10mm");
  }
  else if (sensorValue > 251 && sensorValue <= 277) {
    lcd.setCursor(0, 0);
    lcd.print("Water lvl: 10 - 15mm");
    lcd.setCursor(0, 1);
    lcd.print("TURN ON THE BILGE PUMP");
    Serial.println("Water lvl: 10 - 15mm");
  }
  else if (sensorValue > 277 && sensorValue <= 294) {
    lcd.setCursor(0, 0);
    lcd.print("Water lvl: 15 - 20mm");
    lcd.setCursor(0, 1);
    lcd.print("TURN ON THE BILGE PUMP");
    Serial.println("Water lvl: 15 - 20mm");
  }
  else if (sensorValue > 294 && sensorValue <= 311) {
    lcd.setCursor(0, 0);
    lcd.print("Water lvl: 20 - 25mm");
    lcd.setCursor(0, 1);
    lcd.print("TURN ON THE BILGE PUMP");
    Serial.println("Water lvl: 20 - 25mm");
  }
  else if (sensorValue > 311 && sensorValue <= 314) {
    lcd.setCursor(0, 0);
    lcd.print("Water lvl: 25 - 30mm");
    lcd.setCursor(0, 1);
    lcd.print("NO, SERIOUSLY, TURN ON THE BILGE PUMP");
    Serial.println("Water lvl: 25 - 30mm");
```



```
  }
  else if (sensorValue > 314 && sensorValue <= 323) {
    lcd.setCursor(0, 0);
    lcd.print("Water lvl: 30 - 35mm");
    lcd.setCursor(0, 1);
    lcd.print("FINAL WARNING,TURN ON THE BILGE PUMP");
    Serial.println("Water lvl: 30 - 35mm");
  }
  else if (sensorValue > 323) {
    lcd.setCursor(0, 0);
    lcd.print("Water lvl: 35 - 40mm");
    lcd.setCursor(0, 1);
    lcd.print("THE HULL HAS WATER. TURN ON THE BILGE PUMP OR DROWN");
    Serial.println("Water lvl: 35 - 40mm");
  }
  delay(1000); //delay 1 second
  lcd.clear(); //clear LCD screen
  digitalWrite(ledPin, LOW);
  //turn the ledPin off - reset
  //the system when the sensor is out of water and dry


}

```

Appendix E – Bender IMD Information and Data Sheet



ISOMETER® IR155-3203/IR155-3204

Insulation monitoring device (IMD) for unearthed DC drive systems (IT systems) in electric vehicles

ISOMETER® IR155-3204

Device features

- Suitable for 12 V and 24 V systems
- Automatic device self test
- Continuous measurement of the insulation resistance 0…10 MΩ
  - Response time for the first measurement of the system state (SST) is < 2 s after switching the supply voltage on
  - Response time < 20 s for insulation resistance measurement (DCP)
- Automatic adaptation to the existing system leakage capacitance (≤ 1 µF)
- Detection of earth faults and interruption of the earth connection
- Insulation monitoring of AC and DC insulation faults for unearthed systems (IT systems) 0…1000 V
- Undervoltage detection for voltages below 500 V (adjustable at factory by Bender)
- Short-circuit proof outputs for:
  - Fault detection (high-side output)
  - Measured value (PWM 5…95 %) and status (f = 10…50 Hz) at high or inverted low-side driver (M_{HS}/M_{LS} output)
- Protective coating (SL 1301ECO-FLZ)

Approvals

CE EAC

ATTENTION

Observe precautions for handling electrostatic sensitive devices.

Handle only at safe work stations.

ATTENTION

The device is monitoring HIGH VOLTAGE.

Be aware of HIGH VOLTAGE near to the device.

Product description

The ISOMETER® IR155-3203/-3204 monitors the insulation resistance between the insulated and active HV-conductors of an electrical drive system (U_n = DC 0 V…1000 V) and the reference earth (chassis ground ▸ Kl.31). The patented measurement technology is used to monitor the condition of the insulation on the DC side as well as on the AC motor side of the electrical drive system. Existing insulation faults will be signalled reliably, even under high system interferences, which can be caused by motor control processes, accelerating, energy recovering etc.

Due to its space-saving design and optimised measurement technology, the device is optimised for use in hybrid or fully electric vehicles. The device meets the increased automotive requirements with regard to the environmental conditions (e.g. temperatures and vibration, EMC…).

The fault messages (insulation fault at the HV-system, connection or device error of the IMD) will be provided at the integrated and galvanic isolated interface (high- or low-side driver). The interface consists of a status output (OK_{HS} output) and a measurement output (M_{HS}/M_{LS} output). The status output signalises errors or that the system is error free, i.e the "good" condition as shown by the "Operating principle PWM driver" diagram on page 5. The measurement output signalises the actual insulation resistance. Furthermore, it is possible to distinguish between different fault messages and device conditions, which are base frequency encoded.

Function

The ISOMETER® iso-F1 IR155-3203/-3204 generates a pulsed measuring voltage, which is superimposed on the IT system via terminals L+/L- and E/KE. The latest measured insulation condition is available as a pulse-width-modulated (PWM) signal at terminals M_{HS} (for IRI55-3204) or M_{LS} (for IR155-3203). The connection between the terminals E/KE and the chassis ground (▸ Kl.31) is continuously monitored. Therefore it is necessary to install two separated conductors from the terminals E or KE to chassis ground.

⚠ *Connection monitoring of the earth terminals E/KE is specified for $R_F \leq 4$ MΩ if the ISOMETER® is connected as shown in the application diagram on page 3.*

Once power is switched on, the device performs an initialisation and starts the system state (SST) measurement. The ISOMETER® provides the first estimated insulation resistance during a maximum time of 2 seconds. The DCP measurement (▸ continuous measurement method) starts subsequently. Faults in the connecting wires or functional faults will be automatically recognised and signalled.

During operation, a self test is carried out automatically every five minutes. The interfaces will not be influenced by these self tests.

⚠ *Connection monitoring of the earth terminals E/KE may not work as intended when $R_F > 4$ MΩ if the supply terminals (Kl.15/Kl.31) are not galvanically isolated from the chassis earth (Kl.31).*

Standards

Corresponding standards and regulations*

IEC 61557-8	2007-01
IEC 61010-1	2010-06
IEC 60664-1	2004-04
ISO 6469-3	2001-11
ISO 23273-3	2006-11
ISO 16750-1	2006-08
ISO 16750-2	2010-03
ISO 16750-4	2010-04
E1 (ECE regulation No. 10)	
acc. 72/245/EWG/EEC	2009/19/EG/EC
DIN EN 60068-2-38	Z/AD:2010
DIN EN 60068-2-30	Db:2006
DIN EN 60068-2-14	Nb:2010
DIN EN 60068-2-64	Fh:2009
DIN EN 60068-2-27	Ea:2010

*** Normative exclusion**

The device went through an automotive test procedure in combination with multi customer requirements reg. ISO16750-x.

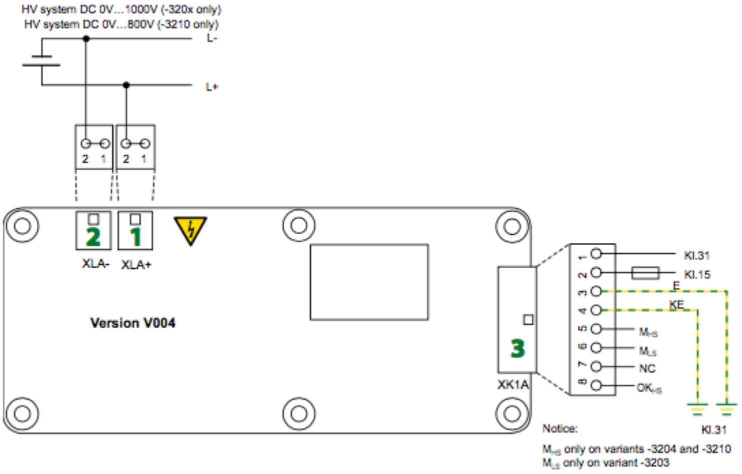
The standard IEC61557-8 will be fulfilled by creating the function for LED warning and test button at the customer site if necessary.

The device includes no surge and load dump protection above 60 V. An additional central protection is necessary.

Abbreviations

DCP	Direct Current Pulse
SST	Speed Start Measuring

Wiring diagrams



Notice:
M_{HS} only on variants -3204 and -3210
M_{LS} only on variant -3203

1 - Connector XLA+

Pin 1+2	L+	Line Voltage

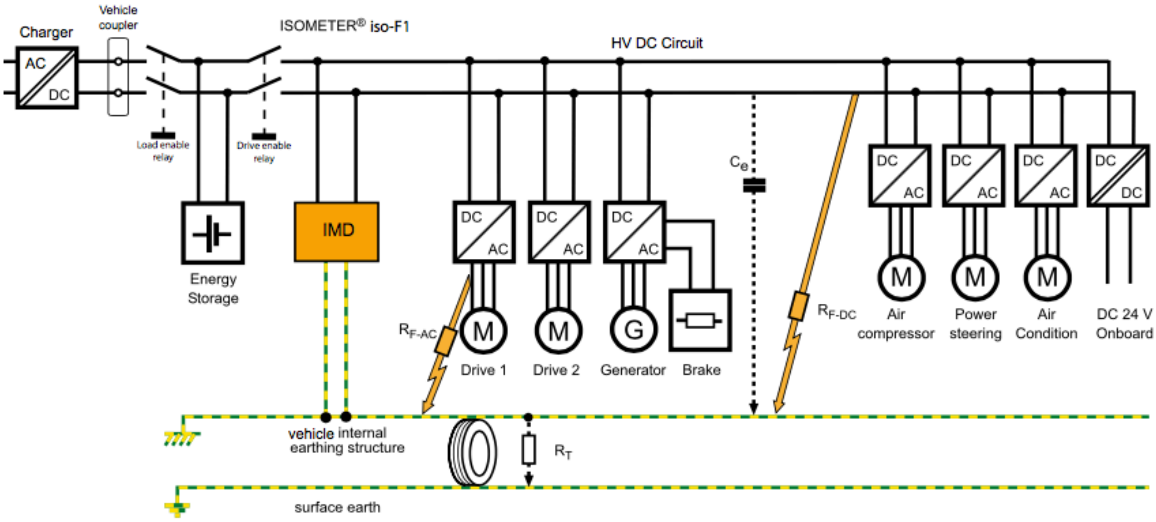
2 - Connector XLA-

Pin 1+2	L-	Line Voltage

3 - Connector XK1A

Pin 1	Kl. 31	Chassis ground/ electronic ground
Pin 2	Kl. 15	Supply voltage
Pin 3	Kl. 31	Chassis ground
Pin 4	Kl. 31	Chassis ground (separate line)
Pin 5	M_{HS}	Data Out, PWM (high side)
Pin 6	M_{LS}	Data Out, PWM (low side)
Pin 7	n.c.	
Pin 8	OK_{HS}	Status Output (high side)

Typical application



Output

Measurement output (M)

M_{HS} switches to U_S – 2 V (3204)
(external pull-down resistor to Kl. 31 necessary 2.2 kΩ)

M_{LS} switches to Kl. 31 + 2 V (3203)
(external pull-up resistor to Kl. 15 reqired 2.2 kΩ

0 Hz ▸ Hi > short-circuit to U_b + (Kl. 15); Low > IMD off or short-circuit to Kl. 31

10 Hz ▸ Normal condition
Insulation measurement DCP;
starts two seconds after power on;
First successful insulation measurement at ≤ 17.5 s
PWM active 5…95 %

20 Hz ▸ undervoltage condition
Insulation measurement DCP (continuous measurement);
starts two seconds after power on;
PWM active 5…95 %
First successful insulation measurement at ≤ 17.5 s
Undervoltage detection 0…500 V
(Bender configurable)

30 Hz ▸ Speed start measurement
Insulation measurement (only good/bad evaluation)
starts directly after power on ≤ 2 s;
PWM 5…10 % (good) and 90…95 % (bad)

40 Hz ▸ Device error
Device error detected; PWM 47.5…52.5 %

50 Hz ▸ Connection fault earth
Fault detected on the earth connection (Kl. 31)
PWM 47.5…52.5 %

Status output (OK_{HS})

OK_{HS} switches to U_S – 2 V
(external pull-down resistor to Kl. 31 required 2.2 kΩ)

High ▸ No fault; R_F > response value

Low ▸ Insulation resistance ≤ response value detected;
Device error; Fault in the earth connection
Undervoltage detected or device switched off

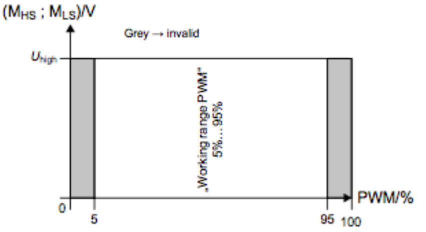
Operating principle PWM driver

- Condition "Normal" and "Undervoltage detected" (10 Hz; 20 Hz)

Duty cycle 5 % = > 50 MΩ (∞)
Duty cycle 50 % = 1200 kΩ
Duty cycle 95 % = 0 kΩ

$$R_F = \frac{90\,\% \times 1200\,k\Omega}{dc_{meas} - 5\%} - 1200\,k\Omega$$

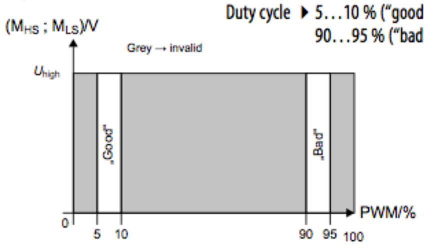
dc_{meas} = measured duty cycle (5 %…95 %)



Operating principle PWM driver

- Condition "SST" (30 Hz)

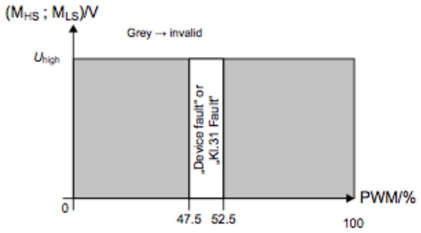
Duty cycle ▸ 5…10 % ("good")
90…95 % ("bad")



Operating principle PWM driver

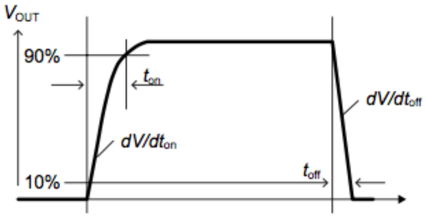
- Condition "Device error" and "Kl.31 fault" (40 Hz; 50 Hz;)

Duty cycle ▸ 47.5…52.5 %



Load current I_L	80 mA
Turn-on time ▸ to 90 % V_{out}	max. 125 µs
Turn-off time ▸ to 10 % V_{out}	max. 175 µs
Slew rate on ▸ 10…30 % V_{out}	max. 6 V/µs
Slew rate off ▸ 70…40 % V_{out}	max. 8 V/µs

Timing 3204 (inverse to 3203)



EMC

Load dump protection	< 60 V
Measurement method	Bender-DCP technology
Factor averaging	
F_{ave} (output M)	1…10 (factory set: 10)

ESD protection

Contact discharge – directly to terminals	≤ 10 kV
Contact discharge – indirectly to environment	≤ 25 kV
Air discharge – handling of the PCB	≤ 6 kV

Connection

On-board connectors	TYCO-MICRO MATE-N-LOK 1 x 2-1445088-8 (Kl. 31, Kl.15, E, KE, M_{HS}, M_{LS}, OK_{HS} 2 x 2-1445088-2 (L+, L-); The connection between the respective connecting pins at L+ or L- may only be used as redundancy. Cannot be used for looping through!
Crimp contacts	TYCO-MICRO MATE-N-LOK Gold 14 x 1-794606-1 Conductor cross section: AWG 20…24
Enclosure for crimp contacts	TYCO-MICRO MATE-N-LOK receptor HSG single R -1445022-8 TYCO-MICRO MATE-N-LOK receptor HSG single R -1445022-2

Appendix F – REVski Wiring Diagram