# REVSki - Electric Jet Ski

## Electrical safety compliance of LV and ELV systems in a maritime setting


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# 1 Acronyms

| | |
|---|---|
| AC | Alternating Current |
| DC | Direct Current |
| ELV | Extra Low Voltage (Voltage not exceeding 50V AC or 120V ripple free DC) |
| HRC | High Rupture Current (Fuse Type) |
| IMD | Insulation Monitoring Device |
| $LiFePO_4$ | Lithium Iron Phosphate (Battery Chemistry) |
| LV | Low Voltage (Voltage exceeding ELV but not exceeding 1000V AC or 1500V DC) |
| PEC | Protective Earthing Conductor |
| PWC | Personal Water Craft (jetski) |
| REV | Renewable Energy Vehicle Project |
| RMS | Root Mean Square |
| SME | Submersible Motors Engineering |
| UWA | University of Western Australia |

# 2 Tale of Figures

# 3 Abstract

The concept of electric vehicles has been around for many years now, but has been many confined to the automotive market. There are now a number of commercially available electric cars on the road [1]. The application of electric vehicle technology to the boating arena is far less developed. There is some evidence of development occurring in the electric boating arena with German company Zebotec releasing a 23ft sportsboat driven by a 120kW electric motor [2]. In the area of Personal Water Craft (commonly referred to as a jetski) there are some companies who have released concepts of electric versions, however as it stands these companies are yet to release prototypes [3]. The aim of the REVSki project was to convert what was a petrol powered Personal Water Craft to electric drive. This had to be done whilst complying to relevant Australian Standards. The vehicle to be converted was a SeaDoo GTI130, this originally used a 97kW (130hp) rotary petrol engine as it's powerplant. The REVSki project replaced this petrol motor with a fully submersible 50kW (67Hp) continuous rated three-phase AC induction motor constructed by Submersible Motors Engineering Pty Ltd (SME) [4]. This motor is powered through a motor controller with an 80Ah pack of Lithium Iron Phosphate batteries delivering a nominal voltage of 96V DC. From this battery pack the motor controller generates 96V Three-Phase AC power to drive the motor. To ensure the REVSki is safe and compliant to Australian Standards These two 96V systems require the implementation of electrical safety systems. This project designed and implemented these electrical safety systems to meet or exceed what it required by the relevant standards. The systems as required under the standard include an earth fault protection system, overcurrent protection systems and protection against direct contact. As well as these systems this project implemented electrical safety procedures to ensure the project could be safely constructed, operated and maintained. As a result of this project the REVSki project has been constructed compliant to the relevant Australian Electrical Standards and was constructed safely without incident. As a result of the work of the 2015 group of students construction of the REVSki has been completed. The REVSki has been successfully operated for a number of tests and is currently in the process of being tuned to increase its performance. As the vessel is currently configured it will travel at roughly 40km/h and the battery will last for around 30 minutes on 3.5 hours of change. The performance of the REVSki is currently being improved and it should continue to improve with further testing. The vehicle concept has been successfully proven and a working prototype has been constructed that is compliant to Australian Standards. The vehicle performance is not yet comparable to the original petrol powered variant. However, the vehicle is continuing to be tuned and performance is still increasing.

# 4 Background

The REVSki project makes up part of the Renewable Energy Vehicle (REV) project at the University of Western Australia (UWA). The REV project has overseen the conversion and construction of a number of internal combustion powered vehicles to electric propulsion. To date these include a Hyundai Getz, a Lotus Elise, eleven Ford Focus, and a Formula SAE racecar [5]. Some ongoing projects include a Hub Motor Formula SAE racecar, an Electric Endurance Vehicle, and this project, a SeaDoo GTI130 personal water craft (PWC) commonly known as a jetski.

The REVSki project seeks to prove an electric recreational watercraft can be constructed to be safe, reliable and have similar performance capabilities to its petrol powered counterpart. Electric vehicles are quieter, more cost effective to run, and do not contribute tailpipe emissions during operation [6]. The application of electric vehicles to the recreational boating arena could provide for significant reductions in pollution and emissions [7] while providing comparable functionality to current petrol powered recreational vessels. Currently there is some development of electric propulsion evident in the recreational boating arena. One company developing electric recreational boats is Zebotec of Germany. Zebotec has developed a 23ft sportsboat with a 120kW electric motor which is quoted to reach speeds of up to 60km/h and have a range of over 40km at moderate speed [2]. There are amateur videos available online of what are stated to be electric PWCs and there are some companies advertising concepts of electric PWCs [3].Although currently there does not seem to be any evidence of an electric PWC being developed that is compliant to Australian or International electrical standards.

The REVSki project commenced at the UWA in Second Semester 2012 and a prototype has been under developmemnt since that time. The REVSki was originally purchased with just the internal combustion engine and fuel system removed; all other components remained in the vehicle [4]. Notably, the hull, superstructure, jet propulsion system, and steering remain unchanged from the original petrol powered model. The original 97kW (130Hp) internal combustion engine has been replaced with a fully submersible 50kW (67Hp) continuous rated three-phase AC induction motor constructed by Submersible Motors Engineering Pty Ltd (SME) [4]. Although this is a change from a 97kW engine to a 50kW motor, the electric motor is continually rated at 50kW whereas the petrol engine's maximum output rating is 97kW. The electric motor is expected to perform comparably to the original petrol engine once tuning is performed.

The REVSki employs Lithium Iron Phosphate ($LiFePO_4$) batteries as its power source [4]. These cells are arranged to give a nominal pack voltage of 96V DC and a potential maximum pack voltage of 111V DC. The DC power source is then converted into AC power via the Curtis motor controller, which outputs three phase AC at a nominal voltage of 96V suitable to drive the motor.

At the beginning of 2015 when this project commenced the REVSki was still under construction. The batteries and motor had been installed in the vehicle. Most major components had been selected and procured. 2015 has seen the installation and construction of all components of the new electrical propulsion system. A working prototype has been completed and the first water testing of the craft has been conducted. The vehicle has been launched publically through the media and has seen support from the general public.

# 5 Problem Identification

At the commencement of this project the REVSki had no protection systems designed for its Low Voltage (LV) or applicable Extra Low Voltage (ELV) circuitry. Voltage levels are defined in s1.4 of AS/NZS 3000:2007 which defines ELV as "[voltage] not exceeding 50V AC or 120V ripple free DC" and LV as "[voltage] exceeding ELV but not exceeding 1000V AC or 1500V DC." [8]. By this definition the 96V DC system is classified as ELV and the 96V AC system is classified as LV. Previous projects have been completed concerning the safety of the REVSki however these have been predominately focused on hazards surrounding the operation of the craft and have not dealt with many of the electrical hazards associated with the construction, operation and maintenance of the craft. Prior to the commencement of this project it had been assumed that the electrical systems on the vessel where not high enough potential to warrant the implementation of electrical safety systems. Upon investigation the applicable Australian Standard was identified and it was found that acceptable safe voltages were clearly defined in this standard. Recommended safety voltages are outlined in AS/NZS 3004.2:2014 any circuit operating above these voltages in a maritime setting require electrical protection systems. The safety voltages are 50V AC RMS and 50V DC between conductors, or between any conductor and earth [9]. Both the ELV and LV systems on the REVSki exceed their respective allowable safety voltages and hence suitable protection systems were required to reach compliance. In addition to the requirements under AS/NZS 3004.2:2014 a system of safety controls was to be developed to ensure the safe construction and maintenance of the vessel.

## 5.1 Relevant Standards

The REVSki is a 3.4m (11ft) PWC with a 96V nominal ELV DC system (the supply from the battery pack) and a 96V nominal LV three-phase AC system (the supply from the motor controller). The standard deemed applicable to the REVSki's DC and AC systems is AS/NZS 3004.2:2014 – Electrical Installations – Marinas and Boats – Part 2 Boat Installations. The scope of this standard is outlined in s1.1.

> *"This Standard specifies the requirements for the design, construction and installation of electrical systems in boats that have a length of up to 50 m, and are designed for use on inland waters or at sea." – s1.1 – Scope – AS/NZS 3004.2:2014 [9].*

The REVSki falls within this statement of scope as the REVSki is only 3.4m in length and the intended area of operations is predominately the inland waters of the Swan and Canning river systems, with the possibility of use at sea. Applicable DC and AC systems defined within the standard are also outlined in s1.1. Types of DC systems applicable are outlined in s1.1(a).

> *"Direct current systems that operate at a nominal voltage not exceeding 1500V." – s1.1(a) – Scope – AS/NZS 3004.2:2014 [9].*

Types of three phase AC systems applicable are outlined in s1.1(c).

> *"Three-phase alternating current systems that operate at a nominal voltage not exceeding 1000V." – s1.1(c) – Scope – AS/NZS 3004.2:2014 [9].*

The REVSki's DC and AC systems both fall within these voltage limits and as such AS/NZS 3004.2:2014 applies to these systems; in addition the REVSki must also comply to AS/NZS 3000:2007 – Electrical Installations as outlined in AS/NZS3004.2:2014 [9].

## 5.2 Requirement for Earth Fault Protection of AC Systems

Earth fault protection of AC systems is required under s4 of AS/NZS 3004.2:2014 - Protection against electric shock and earth leakage on AC systems with voltage exceeding 50V.

> *"A protective device (fuse, circuit-breaker or RCD) shall automatically disconnect the supply to the circuit or equipment in the event of a fault between a live part and an exposed non-current-carrying conductive part." - s4.2 – Automatic disconnection of supply to final sub circuits or equipment – AS/NZS 3004.2:2014 [9].*

In the event of insulation failure of part of the REVSki's LV AC system, a fault between a live part and an exposed non-current-carrying conductive part is possible. If this occurs a protective device as outlined in the standard must be in place to disconnect the supply to the equipment.

#### 5.2.1 Protection of Non-Neutral Earthed System

The REVSki has fully floating ELV and LV systems i.e. there is no existing connection between the current carrying conductors and any non-current carrying conductive parts. AS/NZS 3004.2:2014 defines this type of system as a "Non-Neutral Earthed System (IT Type System)" [9]. An IT type system is permitted to have a single earth fault to existing on one current carrying conductor without requiring the disconnection of final sub-circuits, instead requiring a warning to the vessel operator [9]. If an earth fault occurs on more than one current carrying conductor then final sub-circuits must be disconnected [9].

## 5.3 Requirement for Protection Against Direct Contact

Protection against direct contact with AC systems is required under s4 of AS/NZS 3004.2:2014 - Protection against electric shock and earth leakage on AC systems with voltage exceeding 50V.

"Live parts shall be protected against accidental contact by the use of enclosures in accordance with Clause 7.1.1. All exposed non-current-carrying parts shall be connected to earth either via the protective conductor or by connection directly to the hull of a steel boat." – 7.1.1 – Enclosures for electrical equipment in AC systems – AS/NZS 3004.2:2014 [9].

Clause 7.1.1 requires metallic enclosures to be connected to the boat's earth via the protective conductor [9]. Table 1 below displays the minimum degree of protection for LV electrical systems dependent on their location on the vessel[9].

**Table 1 - Minimum degree of protection of electrical equipment in accordance with AS 60529. Table 3 of AS/NZS 3004:2014 [4].**

**DEGREE OF PROTECTION IN ACCORDANCE WITH AS 60529**

| Example of location | Generators | Motors | Transformers | Switch-board and control gear | Instruments | Switches | Luminaires | Accessories |
|---|---|---|---|---|---|---|---|---|
| Control rooms (above floor) | IP22 | IP22 | IP22 | IP22 | IP22 | IP22 | IP22 | IP44 |
| Battery rooms | | | | | | | IP44+(Ex) | |
| General store; provision room | | IP22 | | | | IP44 | IP44 | IP44 |
| Closed navigation bridge; accommodation spaces | | IP22 | IP22 | IP22 | IP22 | IP22 | IP22 | IP22 |
| Machinery space rooms (above floor) | IP44 | IP44 | IP44 | IP44 | IP44 | IP54 | IP44 | IP55 |
| Machinery space rooms (below floor) | | IPX7 | | | IPX7 | IPX7 | IPX7 | |
| Open deck | | IP56 | | IP56 | IP56 | IP56 | IP56 | IP56 |

* Electrical equipment shall not be installed below floor plates in engine rooms, except as indicated above.

## 5.4 Requirement for Overcurrent Protection

Protection against overcurrent is required under s5 of AS/NZS 3004.2:2014 – Protection Against Overcurrent.

*"Every circuit, except for the starter motor (cranking) circuits, shall be protected against overload and short-circuit by a fuse or circuit-breaker located in the active conductor (non-earthed) as close as practical to the source of supply." – s5.1– General – AS/NZS 3004.2:2014 [9].*

As such every LV and ELV circuit on the REVSki will need to be protected by a suitable overcurrent protection device.

## 5.5 Requirement for Earthing Electrode

Fitment of an earthing electrode is required under s7 of AS/NZS 3004.2:2014 – Cable and Wiring Installation and Termination.

*"The protective conductor shall be connected to an earthing electrode that comprises a solid uncoated conductor having a contact area with the water of at least 0.1 m$^2$, a thickness of at least 5 mm and a width of at least 20mm secured to the outside of the hull in an area reserved for this purpose and located below the light-load water line so that it is immersed under all conditions of heel." – s7.1.2– Earthing of the protective conductor in non-metallic boats – AS/NZS 3004.2:2014 [9].*

The REVSki has systems that require a protective conductor and as such will require a suitable earthing electrode.

## 5.6 Other Electrical Hazard Controls

In addition to the electrical safety systems required by Australian Standards significant electrical hazards were identified surrounding the construction operation and maintenance of the REVSki. During the construction and maintenance of the vessel live electrical components can and do become exposed presenting an elevated risk of injury by direct contact or arc flash as well as equipment damage as a result of potential short circuit faults. Uncontrolled these hazards would present unacceptable risk to persons working on or operating the REVSki.

# 6 Previous Work

Previous work had been completed on the REVSki that was relevant to this project. Notably the design and construction of a Safety System, the procurement and installation of the induction motor, The procurement, construction and installation of the battery pack and motor.

## 6.1 Safety System

One important consideration of this project is that of safety; safety of the REVSki team, the REVSki operator, the public, the environment, and the vessel itself. As such a safety system was developed for the REVSki that monitors various hazards and provides a suitable warning to the REVSki operator and/or causes a shutdown of the ELV and LV systems. At the commencement of this project The Safety System was monitoring the following parameters:

- Battery Temperature
- Battery Management (high and low cell voltage cutoff)
- Water Ingress - vehicle hull
- Water Ingress – motor controllere
- Deadman Switch
- On/Off switch (main power switch accessible to the operator)

These were the identified potential hazards associated with the operation of the REVSki. The safety system outputs a drive enable signal which is used to control a contactor that in turn controls the ELV DC output of battery pack i.e. the main power source. This contactor will only be energized when the safety system detects “healthy” signals from the above listed parameters. During operation if any of the above listed parameters becomes “unhealthy” the safety system will de-energize the contactor shutting down all ELV and LV systems.

One safety parameter that was not being monitored by the existing safety system was that of earth faults i.e. part of the ELV or LV systems becoming exposed and causing a potential for electric shock or equipment damage.

## 6.2 Induction Motor

The REVSki utilizes a 50kW three-phase AC induction motor as its power plant. The motor has a stainless steel chassis and is designed to be fully submersible [4]. The motor has seven connections, six phase conductors and one earth protective circuit. At the commencement of this project the Induction Motor had been mounted in the REVSki however was yet to be wired to the motor controller. The motor had not yet been tested to ensure it was working as expected.

## 6.3 Battery Pack

The REVSki uses 240 3.2V nominal $LiFePO_4$ batteries arranged into 30 parallel modules of 8 cells each, these modules are then arranged in series to create a 96V nominal pack. Prior this project these batteries had been constructed into 4 separate battery containers; these containers were mounted in the REVSki and wired together into a single 96V battery pack. The BMS and temperature sensors were wired inside each container and these output to a connector on the end of each container. At the commencement of this project the battery pack was yet to be connected to any other components.

# 7 Design and Construction of Electrical Safety Systems

The aim of this project was to design and install LV and ELV system components to ensure the requirements as outlined in Section 5 of this report were achieved. By meeting these requirements the electrical safety of the REVSki can be guaranteed. As a result of this project the LV and ELV systems on the REVSki have been constructed to be compliant to the relevant Australian Standards.

## 7.1 Earth Fault Protection System

As outlined in Section 5.2 of this report AS/NZS3004.2:2014 requires an earth fault protection system to be installed on the LV systems. The REVSki utilizes a fully floating power system, and as such only requires supply to be cut off when an earth fault is present on more than one current carrying conductor at any one time.

### 7.1.1 Earth Leakage Detection

A system was required that would be able to detect earth faults of less than 30mA [9]. The earth fault detector that was selected is the Bender Isomerter® IR155-3204 Insulation Monitoring Device (IMD). This device monitors the resistance of the insulation between current carrying conductors and earth and will provide a healthy signal if this is above 500ohm/Volt. As shown in Equation 1 below, this translates to a maximum allowable fault current of 2mA regardless of operating voltage, well under the 30mA requirement. This system will Trigger if the resistance at any point of the LV or ELV system falls below this value regardless of whether there is already an existing earth fault. The ability of this system to trigger when only a single earth fault is present exceeds the requirement for earth fault cutoff as outlined in AS/NZS 3004.2:2014.

$$V = IR$$
$$V = I(500 \times V)$$
$$1 = I(500)$$
$$I = \frac{1}{500}A = 0.002A = 2mA$$

Equation 1 – Maximum allowable fault current using Bender Isometer IR155-3204 IMD.


Figure 1 - Bender Insulation monitoring device IR155-3204.

### 7.1.2 Protective Earthing Conductors

To ensure electrical safety and compliance to Australian Standards the drive motor's protective earthing conductor (PEC) needed to be connected to a suitable earth bar which in turn was to be connected to the main earthing conductor [8]. The drive motor was supplied with a PEC installed, this is a 16mm$^2$ copper conductor with PVC insulation. The required cross sectional area for this conductor is dependent on the protective device used to disconnect supply if an earth fault occurs. The main power delivery system is protected by a 600A rated high rupture current (HRC) fuse. Equation 2 shows the calculation of the required minimum cross sectional area of this PEC [8]. With this protective device in place the PEC only needs to be 3.34mm$^2$, this indicates that the 16mm$^2$ earthing conductor can safely be utilised with this fuse. The drive motor is the only piece of equipment on the vessel that was not constructed as "Class II Equipment" as defined in s1.4.28 in AS/NZS 3000:2007 and hence is the only piece of equipment that requires a PEC [8]. To add an additional level of protection all metallic components surrounding any of the LV or ELV power delivery cables or equipment have also been connected to earth via a 16mm$^2$ PEC. This allows for earth fault detection and supply cut-off should any of these metallic components become connected to a current carrying conductor. The only other exposed metal inside the hull of the vessel is that of the auxiliary component mounting plate, located towards the front of the craft above the battery enclosures. This mounting plate is aluminum and supports the throttle, safety system, IMD, serial communication connector and the charging relays. There are four 96V cables running to this location servicing the IMD and charge relays, each fused at the point of supply, the highest rated fuse being a 30A HRC fuse on the charge line. Equation 3 shows calculation of the required minimum cross sectional area of the PEC for this mounting plate based on the highest rated fuse. The calculated cross sectional area is 0.38mm$^2$ as this is not readily available cable size a 0.75mm$^2$ cable has been used for these connections.

$$S = \sqrt{(I^2t/K^2)} \qquad (1)$$
$$I^2t = 206000 \quad (from\ datasheet)$$
$$S = \sqrt{206000/136^2} = 3.34mm^2 \quad (from\ eq. 2\ line\ 1)$$

**Equation 2 - Minimum cross sectional area of the PEC for metallic parts surrounding power delivery components, based on 600A rated FWH-600A Fuse. Datasheet available in Appendix 5.**

$$I^2t = 2678.75 \quad (from\ datasheet)$$
$$S = \sqrt{2678.75/136^2} = 0.38mm^2 \quad (from\ eq. 2\ line\ 1)$$

**Equation 3 - Minimum cross sectional area of the PEC for axuillary component mounting plate, based on 30A rated 0SPF030.T Fuse. Datasheet available in Appendix 3.**

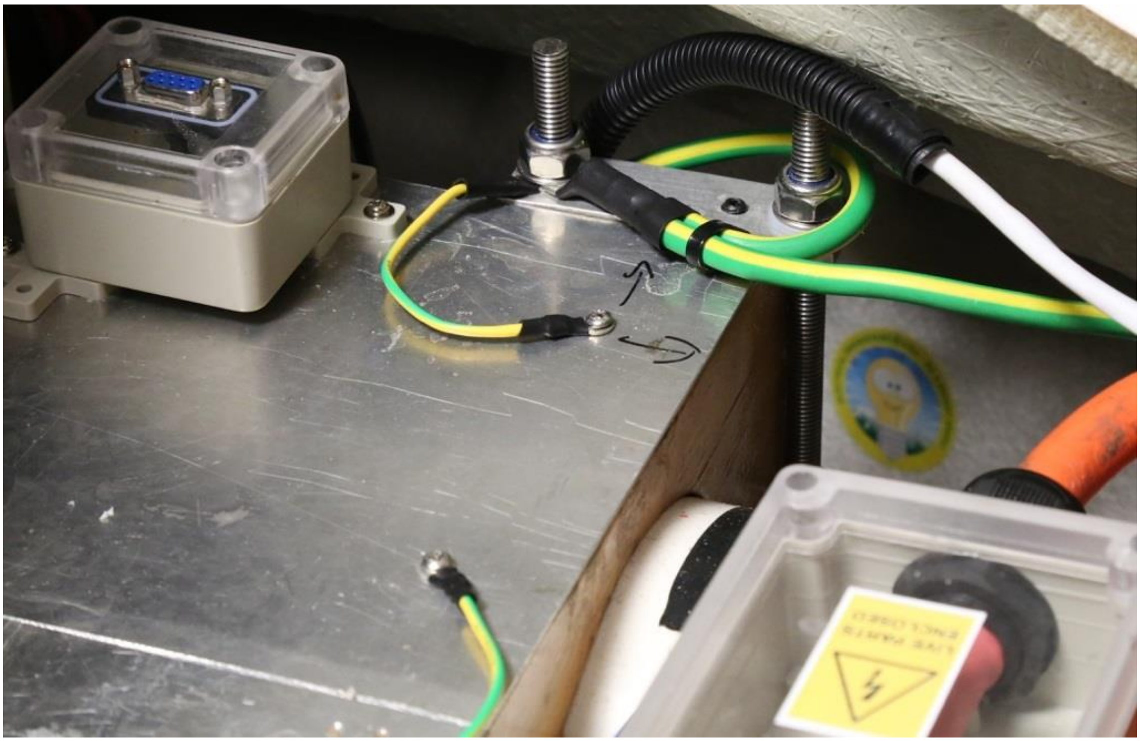


**Figure 2 – Auxiliary component mounting plate showing protective earthing conductors.**

### 7.1.3 Earth Electrode

An earth electrode is a piece of metallic hardware used to ensure good conductivity to the surrounding water. This electrode is required under AS/NZS 3004.2:2014 this plate must be mounted below the light load water line on the vessel so it is submerged at all times [9]. The plate was designed to be mounted at the stern of the craft and was moulded to the shape of the existing cooling plate. This plate is constructed from a 5mm thick solid copper plate, bent to match the shape of the cooling plate. A model of the earth electrode is presented in Figure 3 displaying its size and shape. The earth electrode is connected to the earth bar via the main earthing conductor, a 16mm² copper conductor with PVC insulation.

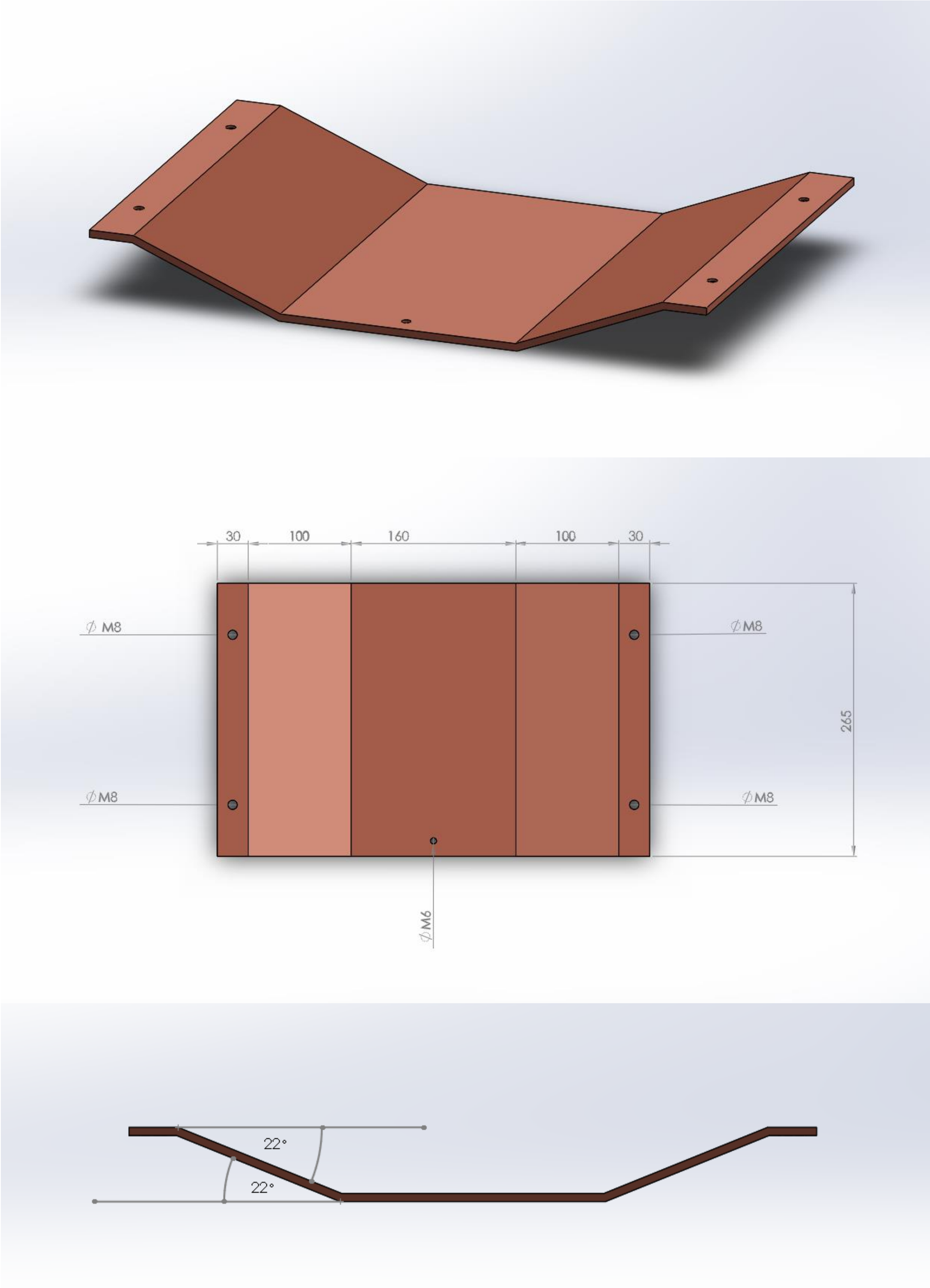



**Figure 3 - Model of earth electrode displaying size and shape dimensions are in mm.**

## 7.2 Protection Against Direct Contact

The LV systems on the REVSki are required to be protected from direct contact through the use of water resistant enclosures. For added safety this requirement was also extended to the 96V ELV systems. As outlined in Table 1 the maximum required level of protection for a machinery space room is IP55 for accessory enclosures. All of the LV and ELV system enclosures were selected to be a minimum of IP65 rated this exceeds the level of ingress protection requires by the standard. The enclosures used are all constructed from insulating material and have been mounted without the need for conductive fasteners entering the enclosure. These enclosures make up one layer of insulation as required to create “double insulated” or Class II Equipment. All current carrying components inside the enclosures are insulated through the use of heat shrink or by application of an insulating putty. The insulating putty is applied as a liquid and allows for insulation of irregular shaped components. As two layers of insulation is maintained within the enclosures all LV and ELV enclosures are Class II Equipment, and do not require additional earth protection.

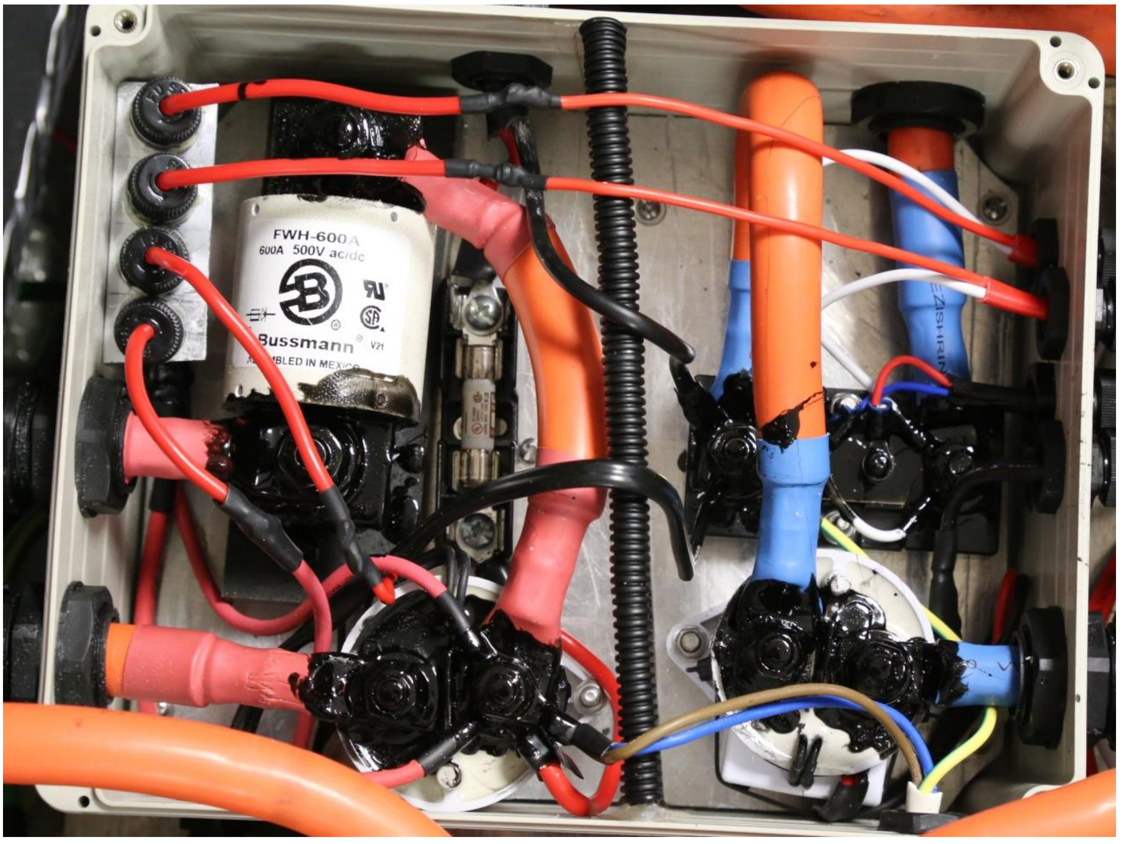



**Figure 4 - ELV Switchgear and fuse box showing double insulation by use of heatshrink and putty.**

## 7.3 Overcurrent Protection

The LV and ELV system on the REVSki require protection from overcurrent. The main power supply from the battery pack is protected by a 600A rated HRC fuse that will ensure circuit disconnect in the event of the main supply current exceeding 600A. The only component that is connected directly to this fuse is the motor controller. All other circuits are protected by their own additional fuse, selected as per the equipment’s rated capacity.

# 8 Electrical Safety Controls

It was identified that the construction, maintenance and operation of the REVSki could present significant hazards to persons and equipment. The REV project is a multidisciplinary engineering project, the 2015 REVSki team was comprised of three mechanical engineering final year project students, and two electrical and electronic engineering final year project students. The makeup of this team meant there was a range in levels of electrical experience and competency. In addition, at the start of the year the students were still familiarising themselves with the project. The potential lack of electrical experience along with this lack of familiarity was identified as a substantial risk at the commencement of this project. As the project continued into the construction phase, the assembly of the LV and ELV would present electrical risks if not performed with adequate controls in place. As part of this project safety controls were developed to manage these risks and ensure construction, operation and maintenance could occur without risk of injury or equipment damage

## 8.1 Isolation of Power Supply

### 8.1.1 Prior to Main Isolator Switch install

At the commencement of this project the vessel's power supply i.e. the 96V battery pack had been installed in the vessel but no other power delivery components had been installed for this to be connected to. The battery pack is arranged into four individual enclosures which are connected by cable and junction boxes. To ensure the battery pack could not be inadvertently short circuited all cable terminations were insulated with heat shrink tubing and the termination placed inside a IP65 rated enclosure displaying a hazard label reading "live parts enclosed". The positive battery termination was marked with an "out of service" tag indicating that it was the point of isolation and connection could only be reinstated by a suitably authorized person. The positive battery termination remained the point of isolation until the point at which the main isolator switch could be installed.

### 8.1.2 Post Main Isolator Switch Install

A main isolator switch was installed that would allow isolation of all LV and ELV systems from a single point. The main isolator switch selected is a HBD41 hermetically sealed battery disconnect, the level of ingress protection exceeds IP69. This switch is able to be conveniently mounted on the REVSki's dash within reach of the vessel operator and is easily accessible and visible to persons performing construction or maintenance tasks. Once installed the main isolator switch provided a reliable point of isolation that could be maintained by the use of a padlock. When performing construction of maintenance works on any of the vessels electrical systems an isolation/lock out procedure is to be followed (available in Appendix 6) this allows work to be performed safely without risk of accidental re-energisation. Once work is complete an energisation procedure is performed by an authorised person to ensure the power supply can be safely reinstated.

## 8.2 Safety Tags

In 2015 the REVSki project had a number of persons working on the vessel at one time and this is likely to be the case in years to come. In order to effectively communicate potential electrical hazards to other members of the REVSki team a system of safety tags was implemented. When one member of the team is to perform work on any of the electrical systems they would need to ensure the isolation/lockout procedure was followed. Once isolated the team member would then complete an "out of service" tag noting the reason for isolation and their details. Once isolated, additional tags can be added by other members to prevent the supply from being re-instated until their works are also completed.

## 8.3 Operating Procedures

Once the REVSki was operating pre-operation and post-operation procedures (available in Appendices 1 and 2) were developed to minimize the risk of failure during operation. These procedures assist with confirming the vessels readiness for on-water testing and outline what tasks are to be preformed upon completion of on-water testing.

# 9 Results and Discussion

## 9.1 On-Water Testing

The vessel was completed and for the first time since the REVSki project commenced in 2012 it was subject to on-water testing. Since completion of the craft four successful water tests have been performed over consecutive weeks. The first water test was at reduced power and had the primary aim of testing stability, buoyancy and drive. The installation of the electrical components has altered the vessels centre of mass placing it slightly forward and making the craft sit slightly nose down in the water. Drive was achieved on the first water test and was sustained for more than 30 minutes at reduced power. It was found that some water had entered the hull during the testing, this was later found be another member of the team to be a simple problem with the vessels bilge draining system. The second water test was performed at increased power and the vessel was taken to its maximum speed at which it reached around 25km/h. The vessel again ran for over 30 minutes but performance was still hampered. The third water test was intended to test some tuning of motor controller parameters, this test saw the vehicles speed increase to around 30km/h the battery was not ran flat for this test and was only run for approximately 15minutes. The fourth water test again tested some updated parameters and in this test the vehicle was able to reach 40km/h and again achieved around 30 minutes run time. This on water testing has allowed the vehicle concept to be proven successful and subsequent tests will allow for further tuning to increase the vehicles performance.

### 9.1.1 Electrical Safety for On-Water Testing

The electrical safety systems have been functioning during all on water testing. The systems have not triggered to indicate any unhealthy state at any point during operation. The electrical safety system triggering would indicate a path from the current carrying conductor to earth. This type of fault would most likely be a result of poor enclosure insulation or cable ware. The enclosures were inspected before and after each on water test to check for water ingress, or mechanical damage and have shown no sign of disrepair. The positive inspections and the lack of any detectable insulation faults would suggest the enclosures and insulation are performing to the required level.

## 9.2 Electrical Compliance

The LV and ELV electrical systems installed on the REVSki have been designed to be compliant to the applicable Australian Standards AS/NZS 3000:2007 and AS/NZS 3004.2:2014. At the time of completion of this project there exists nom standard for the application of electrical drive systems to boats or PWCs. AS/NZS 3004.2:2014 is predominately targeted at persons installing electrical power systems in boat and does not specifically mention considerations for vessels with electric propulsion. As this is the case I would expect the standards to which the vessel has been constructed to exceed the requirements of a standard that was written for this application. As a result of this project the vessel can be shown to be compliant to the relevant Australian Standards with respect to its electrical systems this being a major goal for the REVSki project.

## 9.3 Electrical Safety

The electrical safety systems and procedures used during the construction and operation of the REVSki have resulted in no incidents involving the LV and ELV systems. Prior to the commencement of this project there has been at least one overcurrent failure during construction when a tool was dropped across bus bars shorting out the battery pack. Since the implementation of the electrical safety procedures outlined in this project the project has not been any incidents.

# 10 Conclusion

At the commencement of this project the REVSki had only the batteries and electric motor installed in the hull and had many of the major components procured but not assembled or procured. The work outlined in this report pertains to the electrical safety around the construction, maintenance and operation of the vessel. In addition to this work all LV and ELV systems were installed in the craft, connected and commissioned to permit the vehicle to successfully reach completion. The REVSki project commenced in 2012 at the completion of this project the vessel has been successfully tested on water and has been launched publicly to sponsors and the general public through the media. The vehicle concept has been proven to be viable and it has been proven that an electric PWC can be constructed to be compliant to Australian Standards. The vessel is currently still in the development stage and as yet cannot match the performance of it's petrol powered counterpart. By conducting further testing and continuing to tune the motor controller the performance could be further increased. Testing to date has indicated the battery life of the craft to be around 30 minutes. This figure could be improved through the addition more batteries or through further tuning. With the current charging arrangement the battery pack can be charged in roughly 3.5 hours, though through the use of DC fast charging this figure could be significantly reduced to 30 minutes with the current batteries or as little as 7 minutes with newer battery technology. The project has received promising support from the public since the media launch, indicating that the public would like to see further development in this new application of electric vehicle technology. The objective of the REVSki project is to prove an electric recreational watercraft can be constructed to be safe, reliable and have comparable performance to petrol powered watercraft. The prototype that has been constructed is compliant to Australian Standards and has proven to be safe and reliable when tested on water. Performance does not currently match the petrol powered alternative however the vehicle performance is being improved.

# 11 Future Work

The working REVSki prototype has been completed and been successfully operated on-water. There are a number of areas in which future work can be undertake on the REVSki project to continue to develop its performance and usability.

## 11.1 Motor Controller Tuning

The motor controller on the REVSki is currently using many of the default parameters. Further testing needs to be conducted and parameters set to best match the motor. Currently there is no system to monitor motor controller status while the vessel is operating. In order to do this a wireless serial interface needs to be procured. Once the wireless interface is operational on-water testing needs to be completed and the motor controller status monitored. By recording the controller status while performing different manoeuvers the team will be able to begin characterising the motor and can set the controller parameters accordingly.

## 11.2 Weight Distribution Adjustment

As a result of the current positioning of electrical components the centre of mass has been shifted forward. This has resulted in the craft sitting slightly nose down in the water and this seems to have affected the vessels handling. The weight distribution needs to be assessed and redistributed to move the centre of mass toward the stern. One possible way of achieving this would be to move some of the batteries from their current forward mounting position to the rear of the craft.

## 11.3 Dashboard Display

Currently there is no dashboard display available to the operator. The dashboard screen is the original SeaDoo dash cluster. This can be written to via CAN BUS protocol, and various parameters can be displayed. This display needs to be setup to display speed and rpm to allow the vessel operator to effectively operate the craft.

## 11.4 Impellor Investigation

The original impellor is being used with the REVSki, this impellor was designed to work with a rotary petrol engine and not an electric induction motor. The impellor needs to be investigated to determine if it is suitable for this use or if this needs to be modified to maximize the performance of the jet pump.

## 11.5 High Level Safety System

Currently the safety system on the REVSki only monitors the deadman switch and the earth fault protection system. The high level safety system is yet to be installed, this system monitors battery temperature, water ingress sensors, the on/off switch and the battery management system. The system also has a display which will alert the operator as to what safety function has failed when an error is detected. This system has not been installed due to time constraints. Safety functions that ensure the safe operation of the prototype were prioritised over other non-critical safety functions.

# 12 References


[1] Tesla_Motors. (2015, 22nd October). *Tesla Motors Web page*. Available: http://www.teslamotors.com/en_AU/

[2] Zebotec. (2015, 20th May). *zero emission technology Cobalt ZET*. Available: http://www.zebotec.de/en

[3] DiMoraMoto. (2015, 24th October). *Electric Jet Skis*. Available: http://www.dimoramotorcar.com/ecowatercraft.html

[4] A. Beckley, "Drive Train for an Electric Jet Ski Conversion," Bachelor, Engineering, University of Western Australia, Perth, 2013.

[5] The REV Project. (2015, 19th May). *The Renewable Energy Project, University of Western Australia*. Available: http://therevproject.com

[6] M. Baumann, B. Simon, H. Dura, and M. Weil, "The contribution of electric vehicles to the changes of airborne emissions," in *Energy Conference and Exhibition (ENERGYCON), 2012 IEEE International*, 2012, pp. 1049-1054.

[7] M. Bannan, C. E. Adams, and D. Pirie, "Hydrocarbon emissions from boat engines: Evidence of recreational boating impact on Loch Lomond," *Scottish Geographical Journal,* vol. 116, pp. 245-256, 2000/01/01 2000.

[8] Australian Standards/New Zealand Standards, "AS/NZS 3000:2007 - Electical Installations (known as the Austrlian/New Zealand Witing Rules)," ed: SAI Global, 2007.

[9] Australian Standards/New Zealand Standards, "AS/NZS 3004.2:2014 Electrical Installations - Marinas and Boats," in *Boat Installations*, ed. Australia: SAI Global, 2014.

# 13 Appendices

## 13.1 Appendix 1 - Pre-Operating Procedure

**REVSKI PROJECT**

**REVSKI PROJECT**

| PRE-OPERATING PROCEEDURE | ID: SOP 01 |
|---|---|

THIS PROCEEDURE SHOULD BE UNDERTAKEN BY AUTHORISED PERSONNEL ONLY. IF YOU ARE UNSURE WHETHER YOU RE AUTHORISED DO NOT PROCEED. SEEK ADVICE FROM FACULTY STAFF. THE FOLLOWING PROCEEDURE MUST BE COMPLETED IN NUMERICAL ORDER.

| STEP | TASK | COMPLETED |
|---|---|---|
| 1. | Check main isolator lock for safety tag<br><br>**DO NOT OPERATE IF:**<br>• Safety tag indicates that the jetski is unsafe for operational use.<br><br><br><br>**If does not apply proceed to step 2. If safety tag indicates unsafe END PROCEEDURE.** | ☐ |
| 2. | Check if charge cable is connected. If yes:<br>• Turn off charger at power outlet<br>• Remove charge cable by twisting the retainer ring anti-clockwise and pulling it towards you. | ☐ |
| 3. | Open front hatch and remove seat | ☐ |
| 4. | Inspect condition of:<br>1. Orange LV/ELV cables<br>2. Green/yellow earth cables<br>3. Equipment enclosures<br>4. Mounts and mounting hardware | ☐ |
| 5. | Remove isolation lock and switch on main isolator | ☐ |
| 6. | Ensure deadman switch cord is connected | ☐ |
| 7. | Turn on DC-DC output switch<br>A tone will sound for roughly 2 seconds to indicate | ☐ |
| 8. | Turn on coolant pump and listen for operation<br>Turn off coolant pump once operation is confirmed | ☐ |
| 9. | Turn on bilge pump and listen for operation<br>Turn off bilge pump once operation is confirmed | ☐ |
| 10 | Ensure bungs are screwed in place | ☐ |
| 11. | End of procedure | ☐ |

## 13.2 Appendix 2 - Post-Operating Procedure

| POST-OPERATING PROCEEDURE | ID: SOP 02 |
|---|---|
| THIS PROCEEDURE SHOULD BE UNDERTAKEN BY AUTHORISED PERSONNEL ONLY. IF YOU ARE UNSURE WHETHER YOU RE AUTHORISED <u>DO NOT PROCEED</u>. SEEK ADVICE FROM FACULTY STAFF. THE FOLLOWING PROCEEDURE MUST BE COMPLETED IN NUMERICAL ORDER. | |

| STEP | TASK | COMPLETED |
|---|---|---|
| 1 | Turn on bilge pump until water is no longer exiting outlet<br>Turn off bilge pump once complete | ☐ |
| 2. | Ensure main isolator is switched off | ☐ |
| 3. | Check DC-DC output is switched off<br>Check Coolant pump is switched off | ☐ |
| 4. | Wash salt water off of outside of hull and superstructure | ☐ |
| 5. | Wash salt water off trailer, ensure wheel bearings are washed from both sides | ☐ |
| 6. | Open seat and front hatch and inspect for water<br>If present place hose inside hull and with bungs removed slowly flush salt water out of hull | ☐ |
| 7. | Ensure all water has drained out of hull before returning to lab | ☐ |

## 13.3 Appendix 3 – Charge Fuse Datasheet

**POWR-GARD® Fuse Datasheet**

Littelfuse
Expertise Applied | Answers Delivered

# SPF SERIES SOLAR FUSES

1000 VDC • 1-30 A

### Specifications

| | |
|---|---|
| **Voltage Rating** | 1000 VDC |
| **Amperage Rating** | 1, 2, 3, 3.5, 4, 5, 6, 8, 10, 12, 15, 20, 25, 30 |
| **Max. Interrupting Rating** | 20 kA |
| **Time Constant** | ≤ 2ms |
| **Material** | Body: Melamine<br>Caps: Copper Alloy |
| **Approvals** | UL 2579 Listed (File: E339112)<br>IEC 60269-6 (1-25 A)<br>VDE Certified (No. 40033098)*<br>see specifications on pg. 2<br>CSA Certified (File: 029862_0_000) |
| **Environmental** | RoHS Compliant |
| **Country of Origin** | Mexico |

### Description

The SPF Solar Protection Fuse series has been specifically designed for the protection of photovoltaic (PV) systems. This family of Midget style fuses (10 x 38 mm) can safely protect PV modules and conductors from reverse-overcurrent conditions.

As PV systems have grown in size, so have the corresponding voltage requirements. This increase in system voltage has typically been intended to minimize power loss associated with long conductor runs. Standard circuit protection devices are not designed to completely protect photovoltaic panels. However, the SPF series is UL Listed to safely interrupt faulted circuits up to this demanding voltage level.

Littelfuse offers 14 ampere ratings to match specific requirements in a variety of applications.

### Features/Benefits

- Meets UL, IEC and VDE photovoltaic standards
- UL 2579 Listed 1000 VDC maximum
- 1-30 A ratings available
- 20,000 A Interrupting Rating
- Both PCB mount and dead-front holder options available

### Applications

- Inverters
- Combiner boxes
- Battery charge controllers

### Recommended Fuse Holders

LPHV 1000 VDC POWR-Safe Series

### Web Resources

Downloadable CAD drawings and other technical information: **Littelfuse.com/spf**

### Part Numbering System

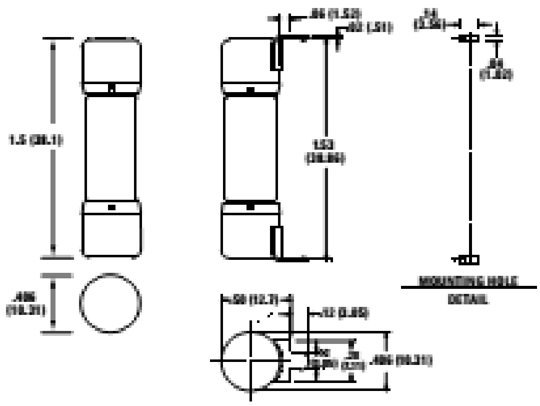
0SPF xxxx H XR

- **Series**
- **Amp Code** – Refer to Amp Code Column in Electrical Specifications Table
- **Package Quantity** – T = 10, H = 100
- **Mounting Options** – Blank = Ferrule, XR = PCB

| SERIES | AMP | PACKAGE QUANTITY | MOUNTING METHOD | CATALOG NUMBER | ORDERING NUMBER |
|---|---|---|---|---|---|
| SPF | 2 | 10 | FERRULE | SPF002 | 0SPF002.T |
| SPF | 3.5 | 10 | FERRULE | SPF03.5 | 0SPF03.5T |
| SPF | 30 | 100 | PCB TABS | SPF030R | 0SPF030.HXR |

### Dimensions Inches (mm)

Ferrule Version PCB Version




Look for this logo to indicate products that are used in solar applications. Visit our website Littelfuse.com/solar for the latest updates on approvals, certifications, and new products.

Littelfuse.com 1 of 4 © 2013 Littelfuse POWR-GARD® Products Rev:4-D-052413

# SPF SERIES SOLAR FUSES

## Electrical Specifications
### Ferrule Version

| AMPERAGE | AMP CODE | ORDERING NUMBER | UPC | VOLTAGE | INTERRUPTING RATING | | NOM COLD RESISTANCE (ohm) | WATTS LOSS AT 100% RATED CURRENT (W) | WATTS LOSS AT 80% RATED CURRENT (W) | TOTAL CLEARING I²t (A²s) 10 kA | TOTAL CLEARING I²t (A²s) 20 kA | AGENCY APPROVALS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | DC | AC | DC | | | | | | UL | VDE | CSA |
| 1 | 001. | 0SPF001.T | 07945816907 | 1000 | – | 20 kA | 0.394 | 0.602 | 0.410 | 0.554 | 0.554 | • | | • |
| 2 | 002. | 0SPF002.T | 07945816910 | 1000 | – | 20 kA | 0.237 | 1.586 | 0.851 | 1.175 | 4.755 | • | • | • |
| 3 | 003. | 0SPF003.T | 07945816913 | 1000 | – | 20 kA | 0.11 | 1.504 | 0.824 | 5.007 | 7.882 | • | • | • |
| 3.5 | 03.5 | 0SPF03.5T | 07945880087 | 1000 | – | 20 kA | 0.07787 | 1.365 | 0.778 | 11.297 | 11.297 | • | | • |
| 4 | 004. | 0SPF004.T | 07945816916 | 1000 | – | 20 kA | 0.06127 | 1.491 | 0.839 | 23.031 | 23.031 | • | • | • |
| 5 | 005. | 0SPF005.T | 07945816919 | 1000 | – | 20 kA | 0.04086 | 1.465 | 0.859 | 42.600 | 42.600 | • | • | • |
| 6 | 006. | 0SPF006.T | 07945816922 | 1000 | – | 20 kA | 0.0281 | 1.348 | 0.769 | 76.270 | 80.254 | • | • | • |
| 8 | 008. | 0SPF008.T | 07945816925 | 1000 | – | 20 kA | 0.0178 | 1.610 | 0.914 | 193.323 | 198.960 | • | • | • |
| 10 | 010. | 0SPF010.T | 07945816928 | 1000 | – | 20 kA | 0.0125 | 1.760 | 1.000 | 395.556 | 401.208 | • | • | • |
| 12 | 012. | 0SPF012.T | 07945816931 | 1000 | – | 20 kA | 0.00993 | 1.965 | 1.109 | 599.198 | 641.940 | • | • | • |
| 15 | 015. | 0SPF015.T | 07945816934 | 1000 | – | 20 kA | 0.00799 | 2.282 | 1.382 | 457.740 | 504.770 | • | • | • |
| 20 | 020. | 0SPF020.T | 07945816937 | 1000 | – | 20 kA | 0.0045 | 2.810 | 1.574 | 1173.990 | 1312.850 | • | • | • |
| 25 | 025. | 0SPF025.T | 07945817596 | 1000 | – | 20 kA | 0.00353 | 2.981 | 1.745 | 1937.430 | 2371.140 | • | • | • |
| 30 | 030. | 0SPF030.T | 07945817598 | 1000 | – | 20 kA | 0.00284 | 3.923 | 2.125 | 2209.480 | 2678.750 | • | | • |

## Electrical Specifications
### PCB Version

| AMPERAGE | AMP CODE | ORDERING NUMBER | UPC | VOLTAGE | INTERRUPTING RATING | | NOM COLD RESISTANCE (ohm) | WATTS LOSS AT 100% RATED CURRENT (W) | WATTS LOSS AT 80% RATED CURRENT (W) | TOTAL CLEARING I²t (A²s) 10 kA | TOTAL CLEARING I²t (A²s) 20 kA | AGENCY APPROVALS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | DC | AC | DC | | | | | | UL | CSA |
| 1 | 001. | 0SPF001.HXR | 07945816909 | 1000 | – | 20 kA | 0.394 | 0.602 | 0.410 | 0.554 | 0.554 | • | • |
| 2 | 002. | 0SPF002.HXR | 07945816912 | 1000 | – | 20 kA | 0.237 | 1.586 | 0.851 | 1.175 | 4.755 | • | • |
| 3 | 003. | 0SPF003.HXR | 07945816915 | 1000 | – | 20 kA | 0.11 | 1.504 | 0.824 | 5.007 | 7.882 | • | • |
| 3.5 | 03.5 | 0SPF03.5HXR | 07945880089 | 1000 | – | 20kA | 0.07787 | 1.365 | 0.778 | 11.297 | 11.297 | • | • |
| 4 | 004. | 0SPF004.HXR | 07945816918 | 1000 | – | 20 kA | 0.06127 | 1.491 | 0.839 | 23.031 | 23.031 | • | • |
| 5 | 005. | 0SPF005.HXR | 07945816921 | 1000 | – | 20 kA | 0.04086 | 1.465 | 0.859 | 42.600 | 42.600 | • | • |
| 6 | 006. | 0SPF006.HXR | 07945816924 | 1000 | – | 20 kA | 0.0281 | 1.348 | 0.769 | 76.270 | 80.254 | • | • |
| 8 | 008. | 0SPF008.HXR | 07945816927 | 1000 | – | 20 kA | 0.0178 | 1.610 | 0.914 | 193.323 | 198.960 | • | • |
| 10 | 010. | 0SPF010.HXR | 07945816930 | 1000 | – | 20 kA | 0.0125 | 1.760 | 1.000 | 395.556 | 401.208 | • | • |
| 12 | 012. | 0SPF012.HXR | 07945816933 | 1000 | – | 20 kA | 0.00993 | 1.965 | 1.109 | 599.198 | 641.940 | • | • |
| 15 | 015. | 0SPF015.HXR | 07945816936 | 1000 | – | 20 kA | 0.00799 | 2.282 | 1.382 | 457.740 | 504.770 | • | • |
| 20 | 020. | 0SPF020.HXR | 07945817594 | 1000 | – | 20 kA | 0.0045 | 2.810 | 1.574 | 1173.990 | 1312.850 | • | • |
| 25 | 025. | 0SPF025.HXR | 07945817597 | 1000 | – | 20 kA | 0.00353 | 2.981 | 1.745 | 1937.430 | 2371.140 | • | • |
| 30 | 030. | 0SPF030.HXR | 07945817600 | 1000 | – | 20 kA | 0.00284 | 3.923 | 2.125 | 2209.480 | 2678.750 | • | • |

POWR-GARD® Fuse Datasheet

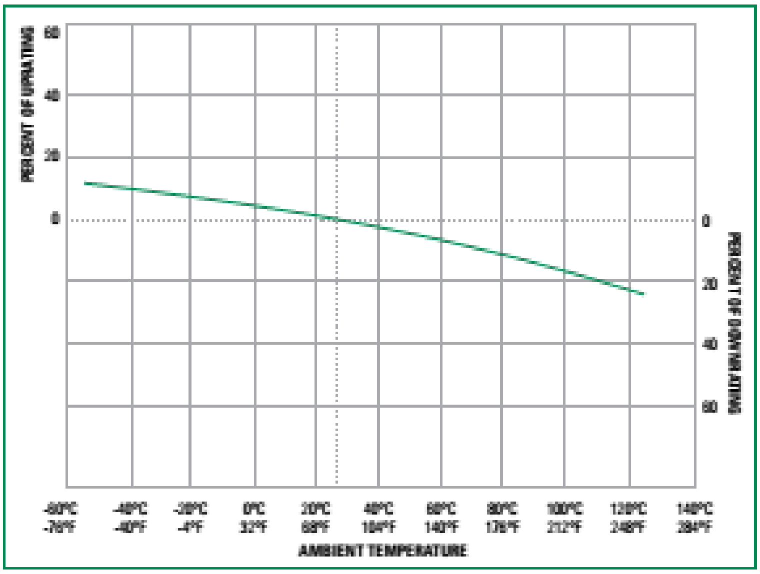
Littelfuse®
Expertise Applied | Answers Delivered

# SPF SERIES SOLAR FUSES

## Electrical Specification – Agency Requirements

| AMPERAGE RATING | OPENING TIME (MINUTES) | | | | |
|---|---|---|---|---|---|
| | 100% of Amp Rating per UL | 113% of Amp Rating per IEC | 135% of Amp Rating per UL | 145% of Amp Rating per IEC | 200% of Amp Rating per UL |
| 1-30 | Temperature Stabilization | 60 Min | 60 Max | 60 Max | 4 Max |

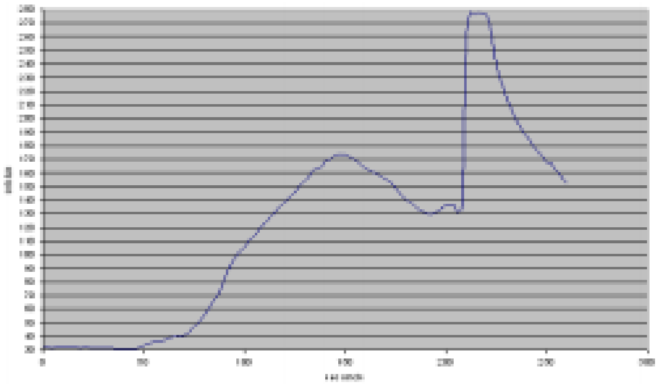
## Temperature Derating Curve (Temperature of Air Immediately Surrounding Fuse)




## Recommended Process Parameters

| WAVE PARAMETER | LEAD FREE RECOMMENDATION |
|---|---|
| PREHEAT: | (Typical Industry Recommendation) |
| TEMPERATURE MINIMUM: | 130° C |
| TEMPERATURE MAXIMUM: | — |
| PRE-HEAT TIME: | 75 Seconds Maximum |
| SOLDER POT TEMPERATURE: | 280° C Maximum |
| SOLDER DWELL TIME: | 270° C for 8 Seconds Maximum |
| COMPLETE CYCLE TIME: | 250 Seconds Maximum |

## Soldering Parameters



POWR-GARD® Fuse Datasheet

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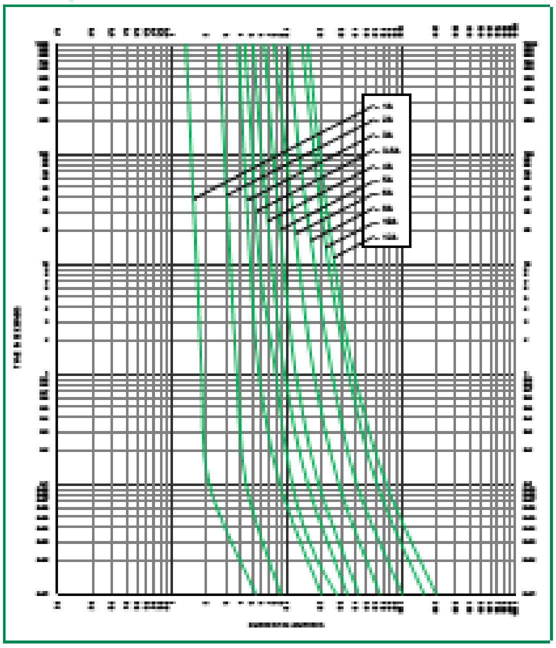
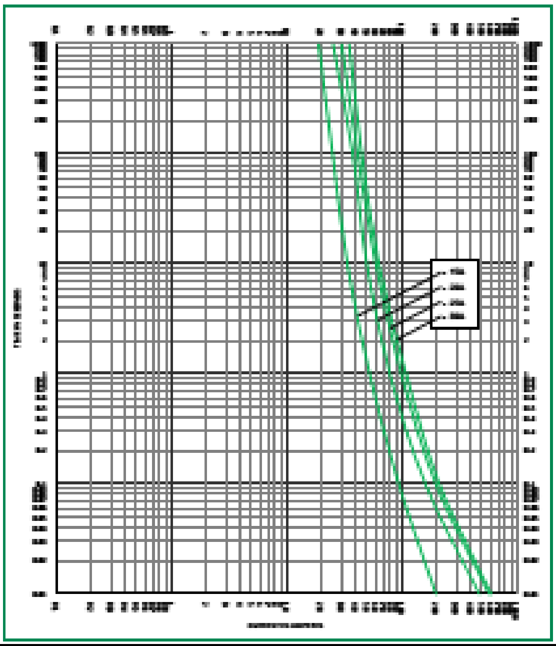
# SPF SERIES SOLAR FUSES

## Time Current Curve (1-12 A)



## Time Current Curve (15-30 A)

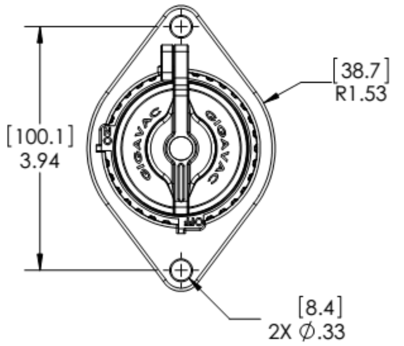


## 13.4 Appendix 4 – Main Isolator Switch Datasheet

Hermetic Battery Disconnect **HBD41**

## PRODUCT SPECIFICATIONS

| Specifications | Units | Data |
|---|---|---|
| **Contact Arrangement** | Form X | SPST |
| **Voltage, Test Max, 1 Minute** | Vdc | 5000 |
| **Voltage, Operating Max**[1] | Vdc | 1000 |
| **Current**<br>Continuous Carry, Max<br>Overload, 1 Minute<br>Make and Break, 400A @ 24Vdc | <br>A<br>A<br>Cycles | <br>400<br>2,000<br>5,000 |
| **Voltage Drop, Max** | mV | 50 |
| **Vibration, Sinusoidal (18-500Hz Peak)** | G | 20 |
| **Temperature, Operating Range** | °C | -55 to +85 |
| **Weight** | g | 500 |
| **Environmental Seal (Exceeds IP69)** | | Hermetic |

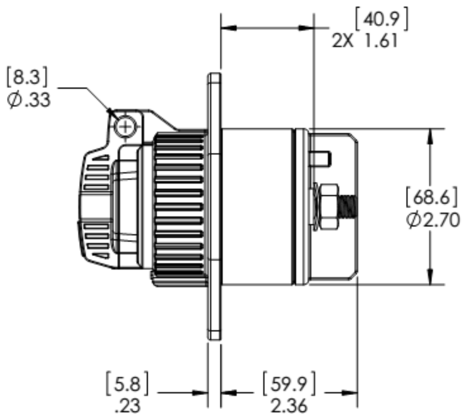


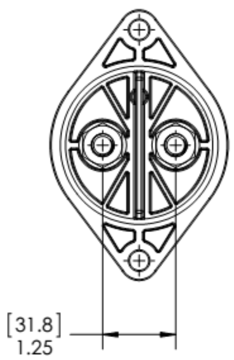

## PART NUMBER SYSTEM

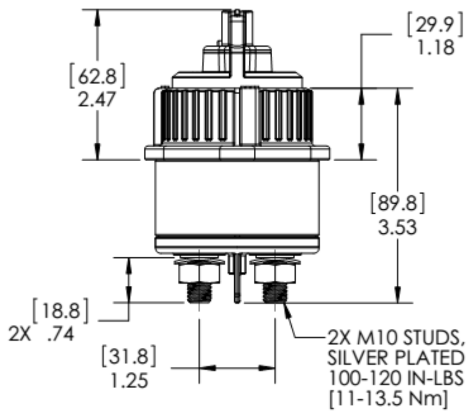
| HBD41 | A | A |
|---|---|---|
| **Mounting** | **A**=Flange, 100mm | |
| **Handle** | | **A**=Red, non-removeable |
| | | **B**=Black, non-removeable |

**Notes:**

**1** For make/break switching above 100V, please contact GIGAVAC.



## 13.5 Appendix 5 Main Fuse Datasheet

**Bussmann®**

# FWH 500V 35-1600A

| | Electrical Characteristics | | | | Ordering Information | | | Dimensions | Curves |
|---|---|---|---|---|---|---|---|---|---|
| | | $I^2t$ ($A^2$ Sec) | | | | | | | |
| Type | Rated Current RMS-Amps | Pre-arc | Clearing at 500V | Watts Loss | Part Number | Carton Qty. | Carton Weight (lbs) | Figure Number | BIF # |
| FWH 500V | 35 | 34 | 150 | 8 | FWH-35B | 5 | 0.71 | Fig. 1 | 35785304 |
| | 40 | 76 | 320 | 7.5 | FWH-40B | | | | |
| | 45 | 105 | 450 | 7.5 | FWH-45B | | | | |
| | 50 | 135 | 670 | 7.5 | FWH-50B | | | | |
| | 60 | 210 | 900 | 9.9 | FWH-60B | | | | |
| | 70 | 210 | 900 | 10.6 | FWH-70B | 1 | 0.21 | | |
| | 80 | 305 | 1400 | 12.7 | FWH-80B | | | | |
| | 90 | 360 | 1600 | 15 | FWH-90B | | | | |
| | 100 | 475 | 2000 | 17 | FWH-100B | | | | |
| | 125 | 800 | 3500 | 25 | FWH-125B | | 0.33 | | |
| | 150 | 1100 | 4600 | 30 | FWH-150B | | | | |
| | 175 | 1450 | 6200 | 35 | FWH-175B | | | | |
| | 200 | 1900 | 8500 | 40 | FWH-200B | | | | |
| | 225 | 4600 | 23300 | 39 | FWH-225A | | 0.57 | | 360 |
| | 250 | 6300 | 32200 | 41 | FWH-250A | | | | |
| | 275 | 7900 | 40300 | 46 | FWH-275A | | | | |
| | 300 | 9800 | 49800 | 51 | FWH-300A | | | | |
| | 325 | 13700 | 63800 | 53 | FWH-325A | | | | |
| | 350 | 14500 | 72900 | 58 | FWH-350A | | | | |
| | 400 | 19200 | 96700 | 65 | FWH-400A | | | | |
| | 450 | 24700 | 127000 | 74 | FWH-450A | | 1.00 | | |
| | 500 | 29200 | 149000 | 84 | FWH-500A | | | | |
| | 600 | 41300 | 206000 | 108 | FWH-600A | | | | |
| | 700 | 55000 | 298000 | 120 | FWH-700A | | 2.14 | | |
| | 800 | 76200 | 409000 | 129 | FWH-800A | | | | |
| | 1000 | 92000 | 450000 | 145 | FWH-1000A | | 4.62 | | 35785304 |
| | 1200 | 122000 | 600000 | 180 | FWH-1200A | | | | |
| | 1400 | 200000 | 1000000 | 210 | FWH-1400A | | 11.66 | Fig. 2 | |
| | 1600 | 290000 | 1400000 | 230 | FWH-1600A | | | | |

†U.L. Recognition on 35 through 1200 amperes only.
CSA Component Acceptance: 35 - 1600A.

1 kg = 2.2 lbs 1 lb = 0.45 kg

- Interrupting rating 200kA RMS Symmetrical.
- Watts loss provided at rated current.
- (500 Vdc/Interrupting rating 50kA) U.L. Recognition on 35 through 800 amperes only.

COOPER Bussmann
7-11-01 SB01191

Form No. FWH 500
Page 1 of 2
BIF Doc #720007

Bussmann

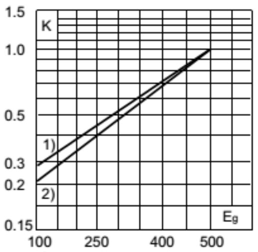
# FWH 500V 35-1600A

## Electrical Characteristics

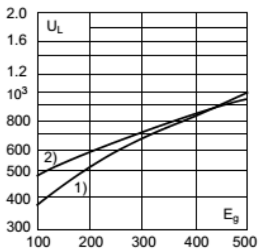
**Total Clearing I²t**
The total clearing I²t at rated voltage and at power factor of 15% are given in the electrical characteristics. For other voltages, the clearing I²t is found by multiplying by correction factor, K, given as a function of applied working voltage, $E_g$, (RMS).

**Arc Voltage**
This curve gives the peak arc voltage, $U_L$, which may appear across the fuse during its operation as a function of the applied working voltage, $E_g$, (RMS) at a power factor of 15%.

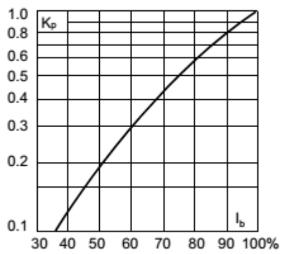
**Power Losses**
Watts loss at rated current is given in the electrical characteristics. The curve allows the calculation of the power losses at load currents lower than the rated current. The correction factor, $K_p$, is given as a function of the RMS load current, $I_b$, in % of the rated current.




1) 35-800 Amp Range
2) 1000-1600 Amp Range




1) 35-200 & 1000-1600 Amp Range
2) 225-800 Amp Range




## Dimensions

Fig. 1: 35-1200 Amp Range

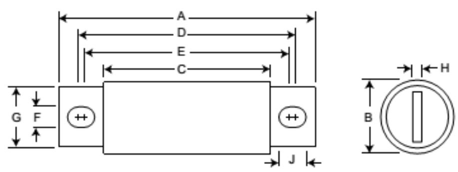
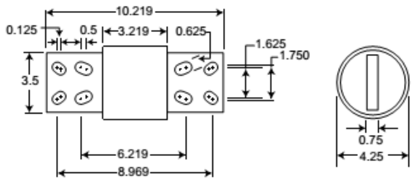



Fig. 2: 1400-1600 Amp Range




| Order # | Fig. | A | B | C | D | E | F | G | H | J |
|---|---|---|---|---|---|---|---|---|---|---|
| FWH-35B-60B | 1 | 3.188 | 0.813 | 1.593 | 2.541 | 2.193 | 0.344 | 0.719 | 0.125 | 0.518 |
| FWH-70B-100B | 1 | 3.625 | 0.947 | 1.736 | 2.853 | 2.807 | 0.352 | 0.750 | 0.125 | 0.375 |
| FWH-125B-200B | 1 | 3.625 | 1.156 | 1.836 | 2.892 | 2.768 | 0.344 | 1.000 | 0.188 | 0.406 |
| FWH-225A-400A | 1 | 4.340 | 1.500 | 2.090 | 3.440 | 2.750 | 0.410 | 1.000 | 0.250 | 0.750 |
| FWH-450A-600A | 1 | 4.340 | 2.000 | 2.090 | 3.530 | 2.780 | 0.410 | 1.500 | 0.250 | 0.780 |
| FWH-700A-800A | 1 | 6.340 | 2.500 | 2.090 | 4.970 | 3.440 | 0.530 | 2.000 | 0.380 | 1.300 |
| FWH-1000A-1200A | 1 | 6.969 | 3.000 | 3.219 | 5.465 | 4.475 | 0.625 | 2.375 | 0.438 | 1.120 |
| FWH-1400A-1600A | 2 | | | | See Drawing | | | | | |

Dimension in inches.
1mm = 0.0394" 1" = 25.4mm



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Form No. FWH 500
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## 13.6 Appendix 6 – Isolation and Lockout Procedure

| REVSKI PROJECT | |
|---|---|
| ISOLATION PROCEEDURE | ID: SOP 03 |
| THIS PROCEEDURE SHOULD BE UNDERTAKEN BY AUTHORISED PERSONNEL ONLY. IF YOU ARE UNSURE WHETHER YOU RE AUTHORISED DO NOT PROCEED. SEEK ADVICE FROM FACULTY STAFF. THE FOLLOWING PROCEEDURE MUST BE COMPLETED IN NUMERICAL ORDER. | |

| STEP | TASK | COMPLETED |
|---|---|---|
| Section 1 – Primary Isolation At Main Isolator Switch<br>THIS PROCEEDURE MUST BE ATTEMPTED FIRST. A POSITVE BATTERY TERMINAL ISOLATION MUST NOT BE PERFORMED IF MAIN ISOLATOR SWITCH IS CONNECTED | | |
| 1 | Remove seat check the positive battery terminal is connected to the main isolator switch<br>DO NOT PROCEED WITH ISOLATION IF THIS IS NOT CONNECTED<br>If main switch is not connected perform positive battery terminal isolation | ☐ |
| 2. | Switch off main isolator<br>If main isolator is already locked out and tagged go to step section 2 | ☐ |
| 3. | Secure padlock, or hasp with padlock through lock tab on isolator | ☐ |
| 4. | Attach “out of service tag” displaying reason for isolation and details of person isolating | ☐ |
| 5. | If primary isolation is being performed this is end of procedure<br>If secondary isolation is being performed CONTINUE TO SECTION 2<br>End of Procedure Section 1 | ☐ |
| Section 2 – Secondary Isolation | | |
| 1. | Attach additional “out of service tag” and lock to isolator displaying reason for isolation and details of person isolating | ☐ |
| 2. | End of Procedure Section 2 | ☐ |
| | | |
| Isolation At Positive Battery Terminal<br>THIS PROCEEDURE CAN ONLY BE PERFORMED BY PROJECT LEADER.<br>THIS PROCEEDURE MUST ONLY BE COMPLETED IF A MAIN ISOLATOR SWITCH ISOLATION CANNOT BE PERFORMED. A POSITVE BATTERY TERMINAL ISOLATION MUST NOT BE PERFORMED IF MAIN ISOLATOR SWITCH IS CONNECTED | | |
| 1 | Remove seat check the positive battery terminal is connected to the main isolator switch<br>DO NOT PROCEED WITH ISOLATION IF THIS IS CONNECTED<br>If main switch is not connected continue with procedure | ☐ |
| 2. | Check negative battery terminal is connected to equipment<br>IF NOT CONNECTED COVER WITH HEATSHRINK AND PLACE IN JUNCTION BOX | ☐ |
| 3. | Remove positive terminal from equipment | ☐ |
| 4. | Cover Positive Terminal with heat shrink and place inside junction box | ☐ |
| 5. | Attach “out of service tag” displaying reason for isolation and details of person isolating. | ☐ |
| 6. | End of Procedure | |
| Secondary Isolation | | |
| 1. | SECONDARY ISOLATION IS NOT TO BE PERFORMED<br>SEEK ADVICE FROM PROJECT LEADER | ☐ |
| 2. | End of Procedure | ☐ |