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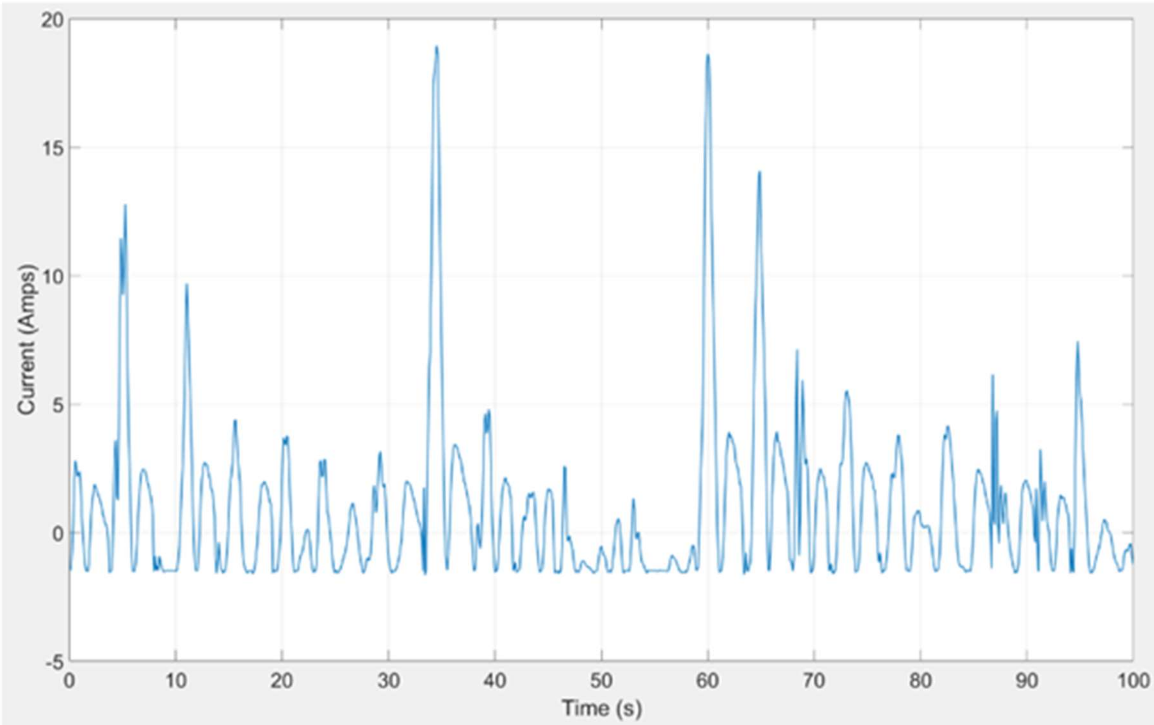

Figure 1: Battery Current at 300V.

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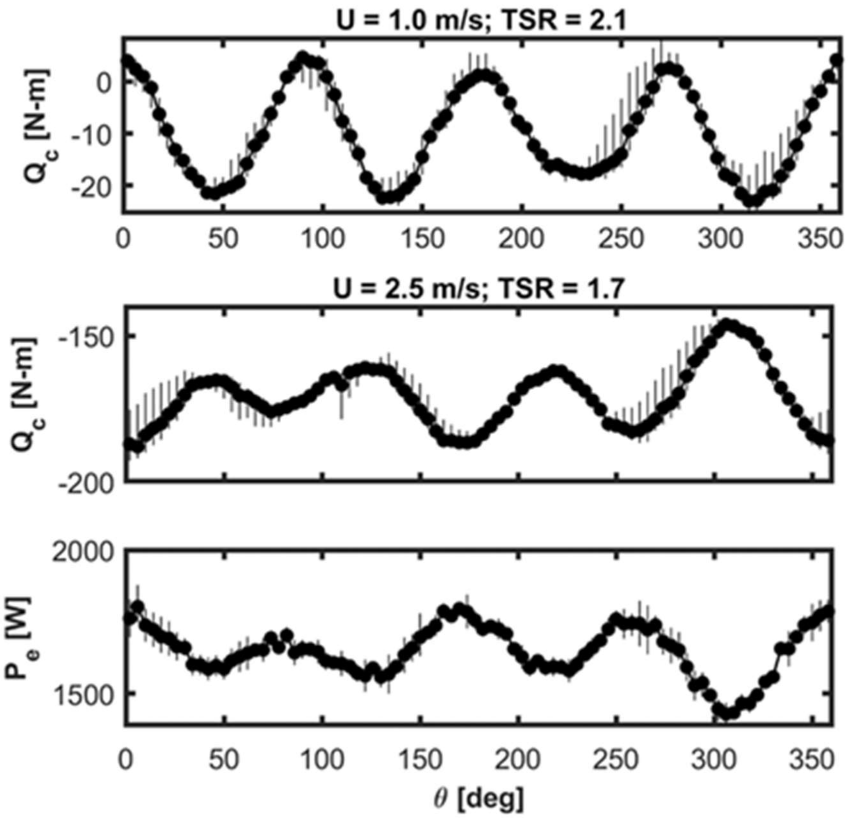

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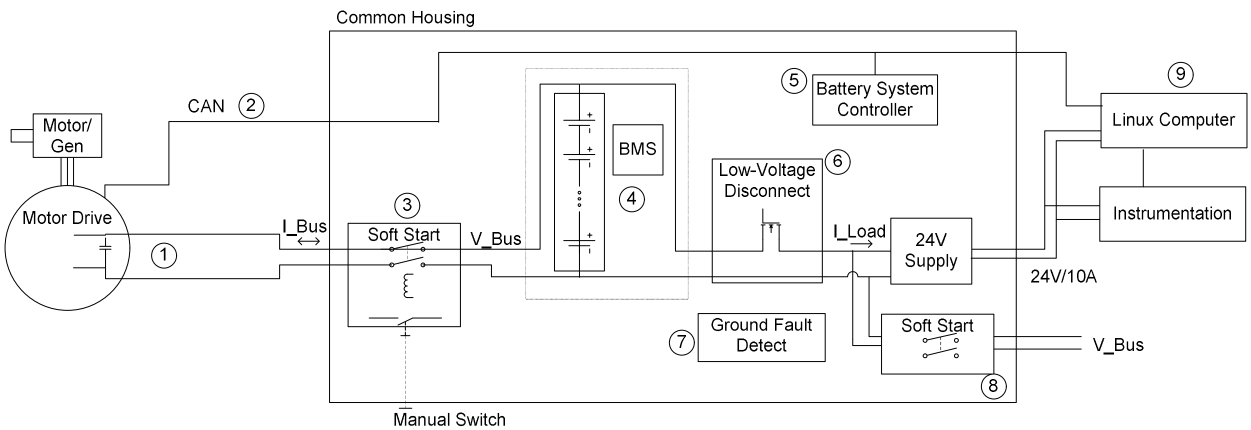

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System Components and Design Considerations

Batteries

The battery itself needs to operate at a nominal voltage of 325-375V, and be able to source/sink up to 35 Amps to be consistent with the motor drive/gen capabilities. The desired capacity range for this system is desired to be in the 6-12 kW-hr range and depending on the resulting size/weight.

Low-Voltage Disconnect and 24V supplies

The system must disconnect power to the 24V supplies when the battery state of charge drops below a suitable level, and then turn this supply back on when the state of charge increases because of subsequent charging or when a command is received from an external controller. The wave-energy device always makes a small amount of power (10's of watts) so this feature simply shuts down all non-

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Soft Start

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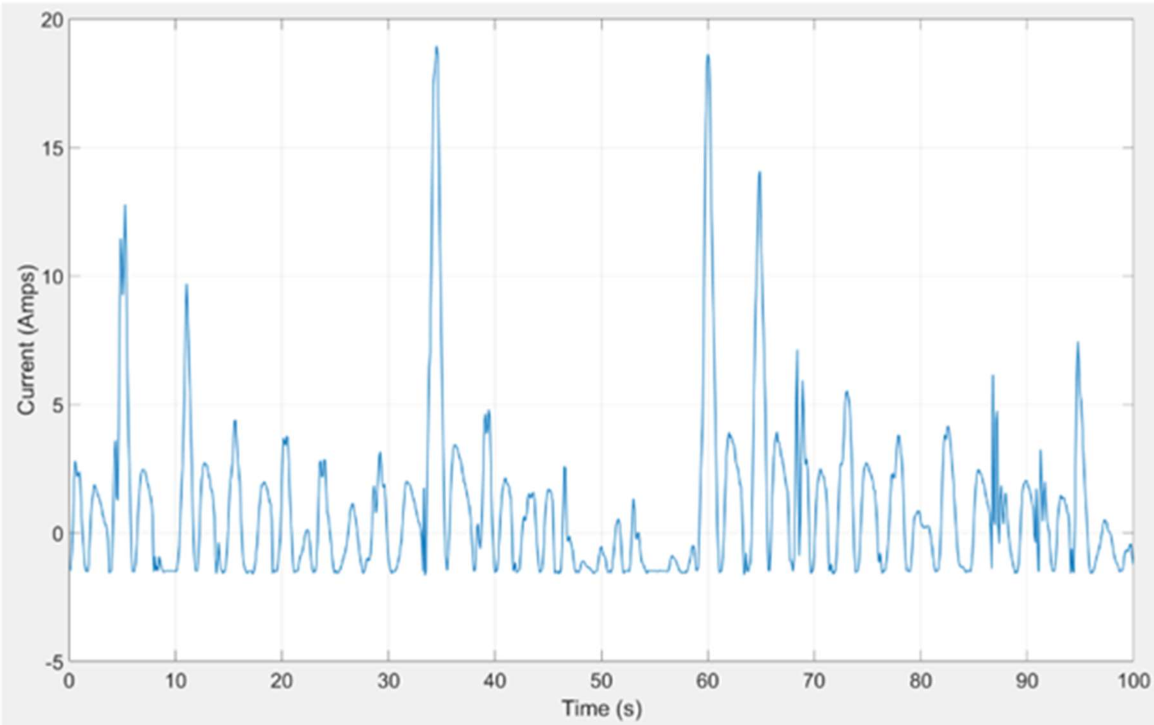

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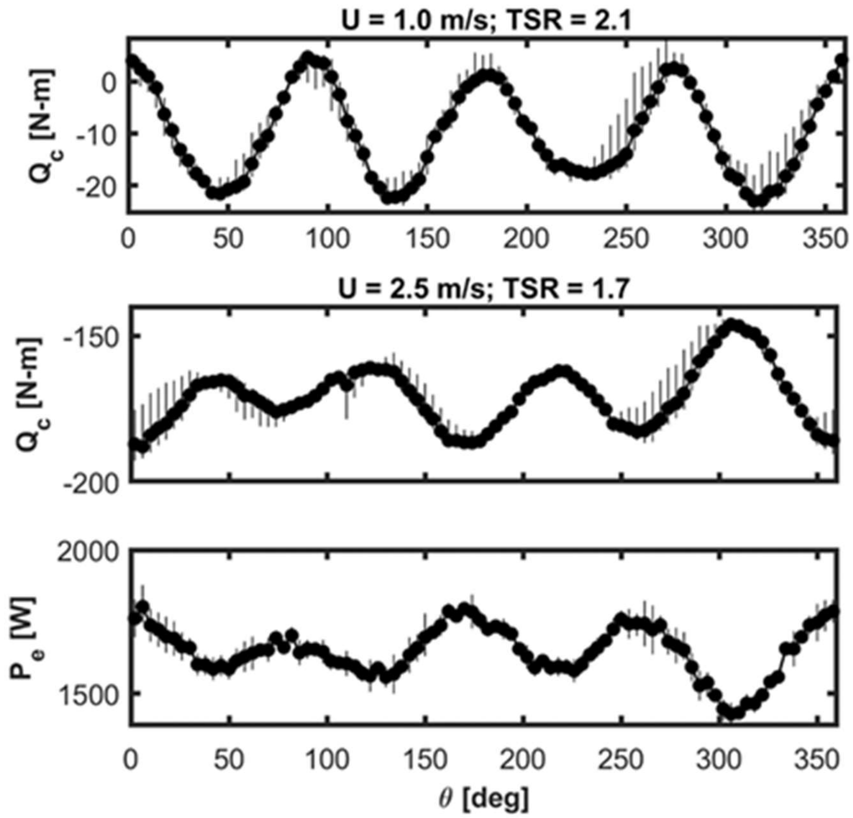

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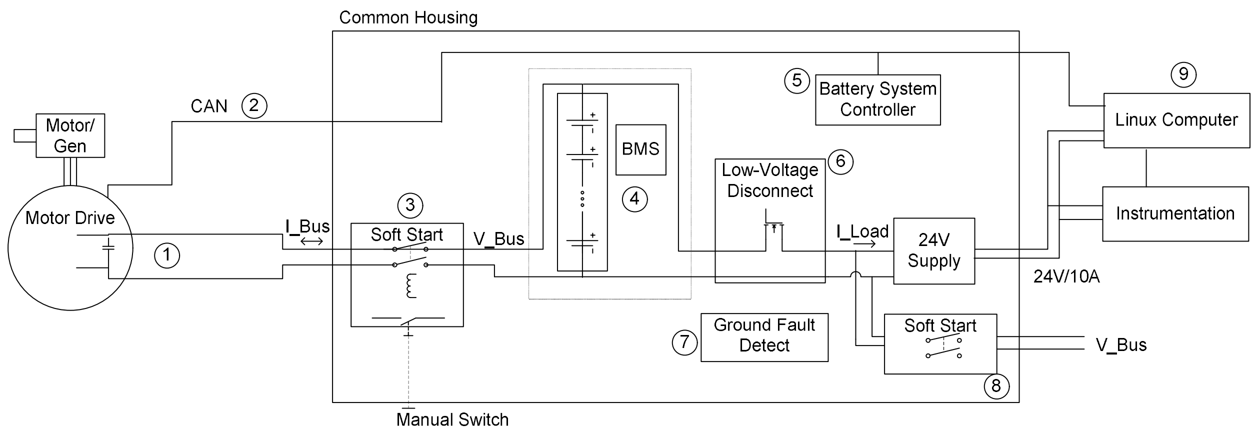

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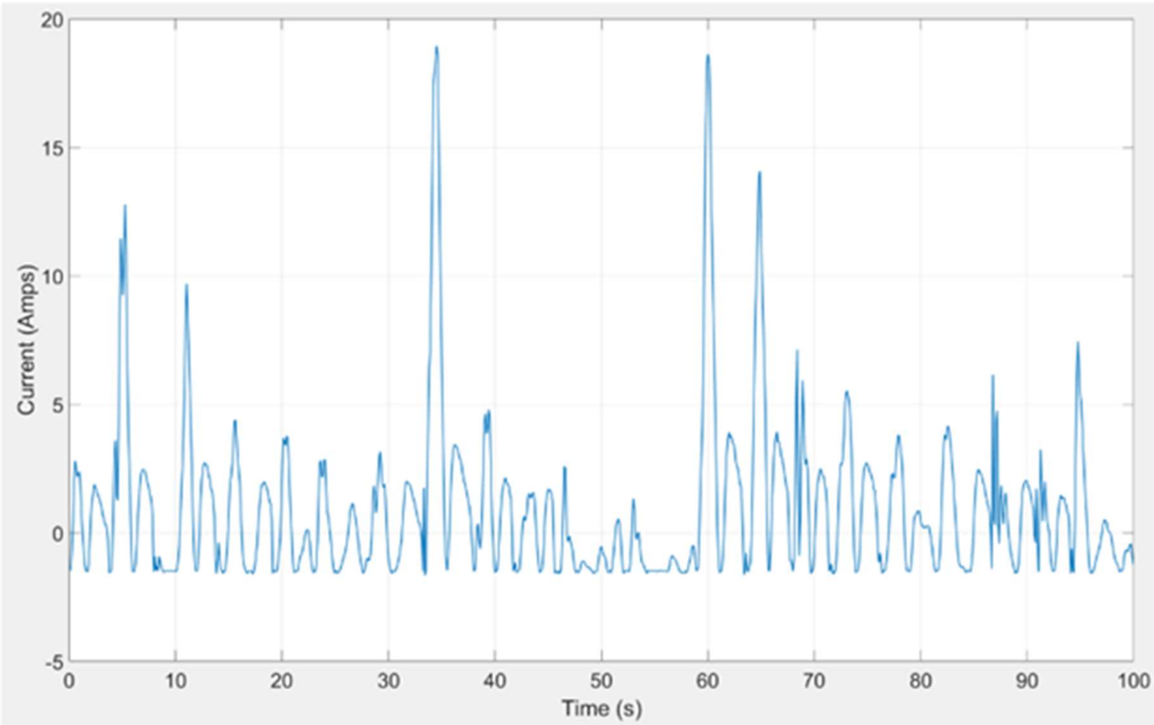

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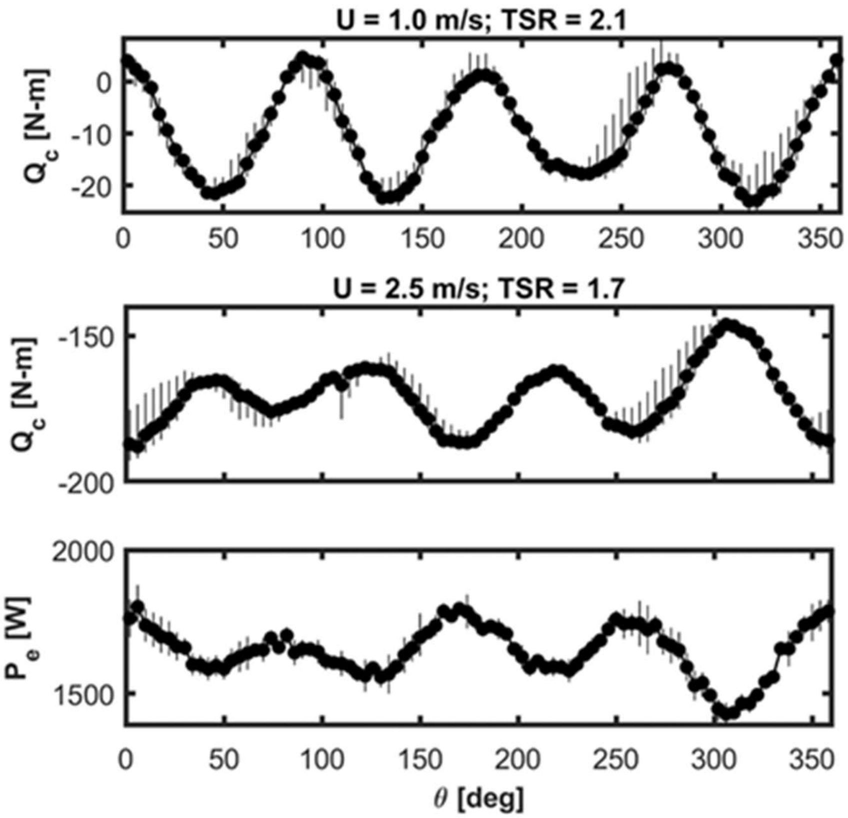

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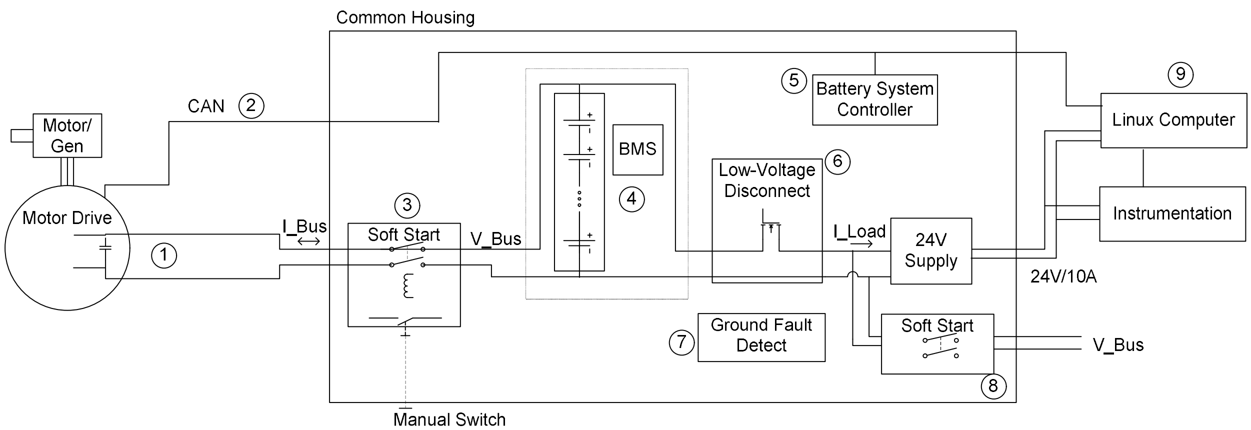

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Currently the 24V power supply is housed with the batteries to preclude the need to send battery bus voltage out of the enclosure un-necessarily. This allows transistors to be used to perform the needed switching. It would also be possible to put these 24V supplies external to the battery (which would provide size flexibility), but the low-voltage disconnect would then need to be implemented with electro-mechanical contactors due to a requirement of galvanic isolation for the higher voltages. A convenient feature for the low-voltage disconnect system would be a data connection that would alert attached computers of the pending power disconnection using typical techniques used in the UPS industry.

Soft Start

The motor drive contains a 500uF DC-link capacitor that draws a significant inrush current when voltage is applied. This inrush is larger than can be tolerated by the output switch components of the motor drive. In the current system, a pair of electro-mechanical contactors are used to switch in a current limiting resistor prior to the main contactor being closed, this allows the voltage between the capacitor and the batteries to equalize before larger currents are allowed to flow. Currently this is an entirely independent circuit from the BMS that is powered directly from the battery bus, and needs to remain connected even at low battery voltages to allow autonomous charging from a low-voltage condition. If needed to protect the batteries, this contactor could turn off at some low shut-down battery voltage, but in that case at sea, a trip would need to be made out to charge the battery by another means to re-start the system, so this shouldn't be a typical occurrence.

Ground Fault and Environmental Monitoring

Because the battery voltages travel through several undersea cables, there is a requirement for ground fault detection. Currently this is implemented using a commercially available unit (Bender) and simply reports the state of the insulation of the battery circuit from earth ground. No ground fault interruption is currently implemented. Similarly, battery housing temperature and humidity are convenient to monitor, although not absolutely necessary.

BMS

In addition to battery balancing and under/over voltage protections, the system requires V_Bus, I_Bus, I_Load, and ground-fault to be available on the CAN Bus for monitoring and logging. The motor drive/generator system can monitor these values and change output voltage in response as needed, but the system must also operate if this data link is not available. There is flexibility with regard to if the BMS itself handles all functions, or if some such as the soft-start are handled by separate systems. If at all possible, the BMS should run directly from the battery bus, independent of the 24V system on the buoy as that defeats the usefulness of the low-voltage disconnect.

Enclosure and connectors

The battery system itself does not need not be housed/sealed to the ocean environment by the vendor. Separate housings and connectors will be developed for each application of the battery depending on depth of use, etc. Safety to touch is sufficient. There is also flexibility with regard to if the 24V power supplies are housed with the battery. As noted above, moving these outside the housing introduces some flexibility, but also isolation challenges that would still need to be discussed. The packaging configuration becomes an important area of discussion for sub-sea use as cylindrical (or spherical) housings become much more efficient than rectangular housings at any appreciable depth.

Modularity/Parallelization

Although initial use of these systems will be single pack installations, the ability to utilize one or more of these systems in parallel is attractive. In that case the ancillary features of ground-fault detection, soft-start, and low-voltage disconnect would not need to be replicated in each system. Similarly, there are applications for rechargeable batteries of this capacity/chemistry that would be at a bus voltage of 48V nominally. We understand this simply may be a different system but are interested if any options exist around modular series/parallel configurations.

Chassis/Housing

A battery unit deployed in support of one of the tidal turbine devices may need to be deployed at depths of 10’s or even 100+ meters. For structural reasons, cylindrical housings are generally preferred, but aren’t strictly necessary. The requirements here are ultimately related to size. In contrast, a unit deployed in a wave energy converter will be housed inside of a buoy where housings will not need to withstand the significant ambient pressures. Despite these differences, our preference is to establish a general chassis design/aspect ratio that allows a single design to be effectively integrated in either of these scenarios (or others that may be envisioned). Without being overly prescriptive, a rectangular chassis suitable for sliding into cylindrical form factor housings would be ideal.

Chemistry

Optimal battery chemistry is driven by the suitability to meet charge/discharge profiles, safety concerns, and performance at relatively cool temperatures. Depending on the specific deployment, the battery housing will be deployed where ambient seawater is less than 10°C while a deployment where temperatures approach 0°C is possible. During these deployments there are generally high rates of heat transfer through the housing due to high flow rates of cold seawater over it. In contrast, in other deployments the battery could housed inside of a buoy with ambient temperatures similar to those outside. In balance, we think $LiFePO_4$ likely represents the best balance of performance, stability, and other factors.