Triton–C
Detailed Design Report: SCADA System

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Review

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Summary

The objective of this document is to broadly detail the design of the Supervisory Control and Data Acquisition (SCADA) system for the Triton-C wave energy converter. This document discusses the network design, cabinet layout, instrumentation, and control processes implemented by the SCADA. Detailed design specifications, drawings and bill of materials may be found in the supporting documents.

SCADA System

System overview

Figure 1 details the network architecture for the Triton-C SCADA system.

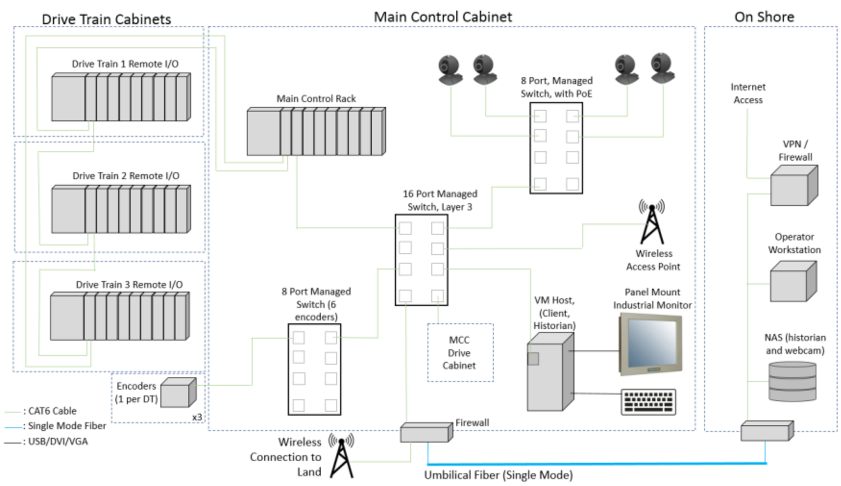

Figure 1. *Network architecture for Triton-C system*

A central control and data acquisition system connects to three remote I/O units located adjacent to each drivetrain, into which instrumentation connects. Locations of the main control cabinet (MCC) and the three drivetrain control cabinets (BCC, PCC, SCC) within the hull are shown in Figure 2.

Wiring between these remote cabinets is via Ethernet and routed via managed switches. All critical and operational data will be recorded to a local historian (Synology RS217). Data will be sampled at different rates. Dynamic quantities, such as sheave position, will be acquired with a sample rate of 20 ms whereas slowly changing quantities, like oil temperature, will be acquired at 1 s. Data will also be “live streamed” for remote monitoring of the system.

The SCADA system also includes a redundant internet connection, and on-board storage for DAQ. The system is design around a TCP-IP network with managed routers, so it becomes very easy to add additional IP based components and access them from the mainland. This also allows the DAQ to be decentralized and IO to be located at each drivetrain, substantially reducing wiring requirements.

The fiber connection provided within the umbilical cable will connect the internal TCP/IP network to an onshore network and an appropriate firewall will be put in place for security. Cellular wireless data will be provided as a temporary fall-over network connection in case of loss of primary data connection. Access to monitoring and control interfaces will be made available on board the Triton C and remotely via an internet connection.

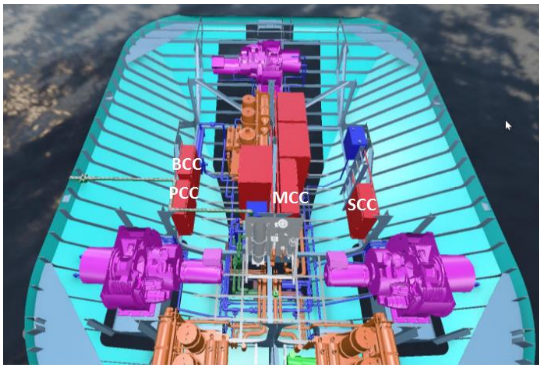

Figure 2. *Control cabinet locations within the hull*

The Triton-C battery storage system (300±50 VDC) will power a 24 VDC supply, which will provide power the SCADA cabinets and all instrumentation. The following table details the estimated max power draw for each of the cabinets in the control system.

Table 1. *SCADA power draw*

Estimated Power Draw	
Item	**Est. Power Draw**
Drive Train 1 Remote I/O Cabinet	240W
Drive Train 2 Remote I/O Cabinet	240W
Drive Train 3 Remote I/O Cabinet	240W
Main Control Cabinet	480W
Total Max Power Draw Estimate:	1200W

The programmable logic controller (PLC) will manage all of the input and output processing for the instruments in the system. The PLC (Siemens Simatic S7-1500) will be able to process all required analog/discrete inputs and outputs. Function blocks will handle the following logic processing, when applicable to the device type:

- Signal scaling (raw value to engineering unit)

- Alarm processing (high-high, high, low, low-low, and fault)
- Alarm suppression and acknowledgement.
- Mode (auto, manual, maintenance)
- Actuation (i.e., control output for an analog or discrete output)
- Interlock functionality

The following table details the weight estimate for each panel. This weight estimate includes all devices detailed in the bill of materials for each panel.

Table 2*. Control cabinet weight estimate*

Weight Estimate	
Item	**Weight [kg]**
Drive Train 1 Remote I/O Cabinet	60
Drive Train 2 Remote I/O Cabinet	60
Drive Train 3 Remote I/O Cabinet	60
Main Control Cabinet	280
Total Weight Estimate:	460

Any technician accessing the systems onboard the Triton C float will have wireless or wired internet access via a grace port. The main control cabinet will have a touchscreen interface to be able to troubleshoot the system. The HMI screen will show overall system graphics and display a summary of Drivetrain 1-3 and main instrumentation.

Instrumentation

A comprehensive suite of instrumentation is incorporated into the Triton-C drivetrain and hull, which will provide important validation data on performance. The complete list of instrumentation is detailed in the I/O List. The significant majority of the instrumentation is for the purpose of drivetrain control and monitoring.

Table 3. *Summary of sensor types within each drivetrain*

Parameter	Sensor (type)
Float motion	Inertial Measurement Unit
Sheave absolute rotary position	Absolute rotary encoder
Tendon Force	Shackle load pin at ring w/ subsea cable
Tendon Temperature	Thermocouple integrated into fairlead
Hydraulic Pressure	Pressure Transmitters
Hydraulic Temperature	Temperature Transmitters
Coolant Temperature	Temperature Transmitters

Additional monitoring sensors:

- Sheave winding camera

- Structural load sensors (bonded strain gauges)
- Oil quality contamination sensor
- Air tank pressure
- Air tank temperature
- Dynamic brake pressure
- Bearing accelerometer
- E-Brake pressure
- Gearbox lubricant oil level
- Gearbox oil temperature
- Hull water pressure
- Hull strain at key structural hot spots
- Mooring force
- Coolant liquid level
- Coolant pump pressure
- Load resistor temperature
- Weather (wind direction, wind speed, temperature, relative humidity, barometric pressure, dew point
- Float position and motion (GPS + IMU)
- Indoor, outdoor 360-degree camera
- Bilge water sensor
- Fire protection system
- Generator temperature, torque, voltage, current, power, absolute position, fault status (from CU-320 generator controller)

This data will be displayed on the control panel as:

- Float summary (weather condition monitoring, pressure, wave calculations, etc)
- Power Take Off (PTO) system overall summary

Instrumentation was carefully selected and designed to ensure that corrosion or external hazards do not affect the sensors, and that suitable backup is provided for critical measurements. The instrumentation suite will monitor all key loads and properties including the electrical system and the external meteorological data.

Cable harnesses will be built and run from each sensor group to the corresponding I/O cabinet. The Cable Schedule documents each of these cable runs and connector requirements for each cable. Instruments on the mast (cameras, weather station) will have cables fed through the mast vent tube to the hull interior. Cabling for each of the sheave winding cameras will be passed through the top of the hull via SubConn bulkhead connectors. The cabling for the mooring load shackles will also be passed through the hull via bulkhead connectors. The load shackles for the tendons will be submersible and rated to at least 30m. The cables for all 6 load shackle cables will tie into a single oil-filled junction box mounted on the reaction ring. A single multi-core umbilical shall run from the junction box and connect to the hull with a wet mate connector. This umbilical will be designed to be sacrificial in the event that it needs to be replaced.

State flow diagram

The Triton-C WEC has multiple 'States' of operation. Figure 3 depicts the different states of the WEC, and how each state is accessed throughout the course of the deployment. A graphic on the SCADA system HMI will allow the operator to transition between states and indicate to the operator what steps and actions are necessary to move between the states.

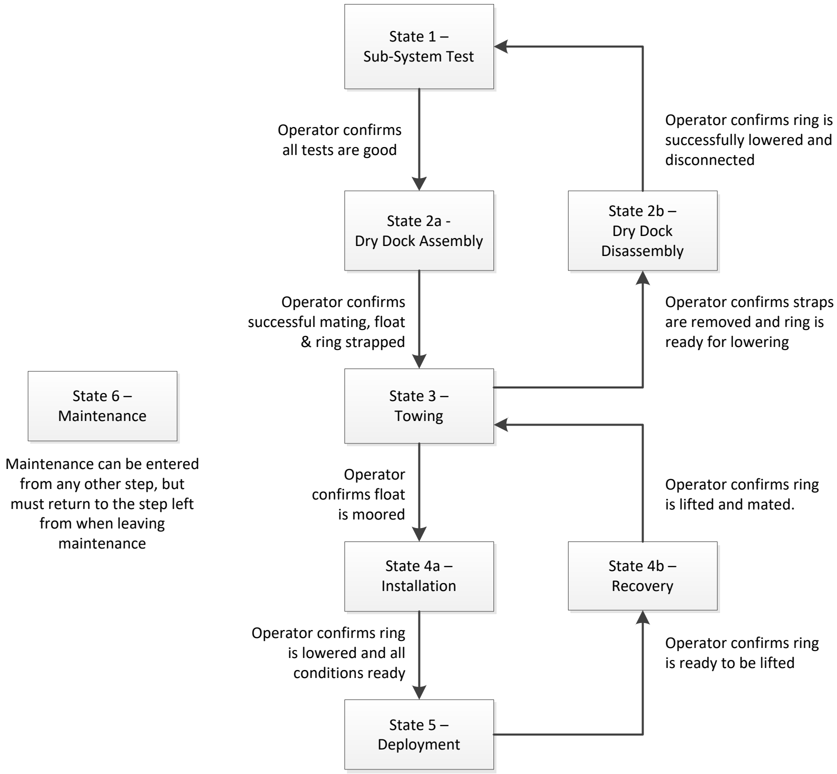

Figure 3. *Triton-C state flow diagram*

The system state will be set to one of states 1-6 manually by the operator. A brief description for each of the different states are described below, and a complete specification may be found in the Functional Spec. In addition to these states, there are several sub-states and interlocks that will be triggered/entered autonomously by the SCADA based on instrument readings.

- **State 1 – Sub-system Test**: The SCADA software will initiate in this state. Before deploying the WEC, the operator will be able to individually test the operation of each subsystem. This includes all generators, valves, pumps, brakes, and sensors. In this state, the WEC will be onshore and power will be supplied externally. All instrumentation/video signals will be live-streamed so the operator can confirm cameras are functional, and all of the equipment will be in manual mode to allow operators full control. Once the operator confirms that all systems are functional, the SCADA may be placed in State 2a.

- **State 2a – Dry-Dock Assembly**: In this state, the system will be in the dry dock to attach the reaction ring, and the reaction ring will be lifted and mated with the surface float.
- **State 3 – Towing**: In this state, the float and ring will be attached via the lashings, and the WEC will be towed to site. All powered systems including generators will be shut down. The on-board battery will provide temporary power to the SCADA so that it can continue to log data.
- **State 4a – Installation**: In this state the system will be on-site and the reaction ring will be lowered to operational depth. Installation will be performed in small waves only (H_s < 1 m).
  - **4A:** Power failure: If power is lost during either the lowering or raising operation, the hydraulic E-brakes on the hydraulic motors will be automatically engaged.
- **State 5 – Deployment**: In this state, the WEC is in its operating configuration in a wave environment. This state can only be entered from State 4 or State 6. The following interlocks shall be monitored while in state 5.
  - **5A:** Insufficient wave energy: The SCADA system will continuously monitor net power exported by the WEC. If the average power is less than 100 W (on a 100s rolling average basis), the E-Brakes will be engaged, and the system will no longer generator power
  - **5B:** Operating normally
  - **5C:** Fault state. The codes below indicate which fault(s) are present
    - **5C1:** Loss of generator damping (power production): If the generator torque is less than 80% of the demand torque, an alarm will notify operators of the loss of damping
    - **5C2:** Loss of grid connection: The generator controller will be able to detect a grid loss via the voltage sensing module. In the event of a grid loss, the cooling pumps will be set to 100% to remove heat from the load bank.
    - **5C3:** Water ingress: If the bilge water sensor goes high, the SCADA will activate the bilge pump until the bilge sensor goes low.
    - **5C4:** Encoder failure: If a fault detected on the encoder, the corresponding generator will be set to zero torque and an alarm will be sent to the operator
    - **5C5:** Cooling failure: If the cooling pump VFD setpoint is greater than 0% but the flow rate is zero, an alarm will be sent to the operator to notify a VFD failure
    - **5C6:** Severe hydraulic loss/loss of spring: If the recharge manifold pressure drops below 100 bar, the E-Brakes will be engaged, the generators will be set to zero torque, and the operator will be notified of a pump failure.
- **State 4b - Recovery:** In this state the system will be on-site and the reaction ring will be raised to the float for mating. This operation will be performed in small waves only

(H_s < 1 m). Once completed, the operator shall be able to set the system state into state 3 (towing). Interlock 4A shall also be applied while in this state.

- **State 2b – Dry Dock Disassembly:** In this state, the system will be in the dry dock to remove the reaction ring; The reaction ring will be lowered and decoupled from the float. In this state, all of the equipment shall be in manual mode to allow operators full control. Once completed, the operator shall be able to set the system state into state 1 (sub-system test). This state can only be entered from state 3 (towing). Interlock 2A will also be applied while in this state.
- **State 6 – Maintenance**: This state can be entered from any state but must return to the prior state. In this state, the WEC is at sea and is being inspected/maintained. This will be performed in small waves (H_s < 1m) only. The operator will have access to the full maintenance tools in State 1.

Controlled systems

In addition to monitoring and recording all instrumentation signals, the SCADA system is responsible for the high-level control of multiple systems and processes during WEC operation. These include: the hydraulic recharge system, the generator torque control, the return spring system, the cooling system, the E-Brake system, the dynamic brake system, the cooling system, the bilge system, and the ring lifting/lowering operation. Detailed procedures for controlling these systems are described in the Function Specification, however, brief descriptions are summarized below.

Hydraulic recharge system

The SCADA system will supervise and manage the hydraulic recharge system in order to maintain the correct average oil levels in the high and low-pressure accumulators. This will allow the drivetrain to maintain a consistent mean sheave position and hence reaction ring deployment depth.

There are two separate control loops on the high-pressure and low-pressure sides. On the high-pressure side, the SCADA will monitor the sheave rotation over a 50 second moving average. If the mean reaction ring position is lower than the operator setpoint (due to hydraulic oil leakage), the control system will actuate a valve to connect the high-pressure system to the recharge accumulator, thus charging up the high-pressure side and raising the ring to the equilibrium setpoint.

On the low-pressure side, another control loop will maintain a mean pressure of approximately 15 bar. The SCADA will monitor the low-pressure side over a 50 second moving average. If the mean pressure is below a lower limit, the control system will actuate a valve to charge the low-pressure side from the auxiliary accumulator. If the mean pressure is above an upper limit, the control system will actuate a valve to drain the low-pressure side to tank.

Generator torque control

The torque profile provided by the power take-off is critical for maximizing power capture. The Triton-C platform will enable testing and implementation of a suite of control strategies, ranging from proportional control to more advanced 'active control' strategies. Control will be implemented through the electrical side of the drivetrain. The generator control units are capable of providing full four quadrant control (i.e. the generators can be motored, if required, to provide reactive control).

The implementation of these control strategies is somewhat challenging as CPU resources are required in addition to those needed to enable data acquisition. These control algorithms are managed by the SCADA system to provide a torque demand signal for each generator in real time (on a ~20 ms time basis). The operator will have the ability to select either baseline proportional control or advanced active control. These two controls approaches will be handled differently by the SCADA system.

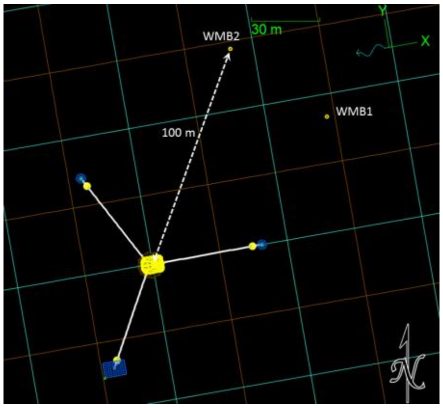

Figure 4. *Spotter wave buoys WMB1 and WMB2*

For baseline proportional control, the generator demand torque will be calculated internally by the PLC as a linear function of the instantaneous sheave encoder velocity. The tuning parameter (damping coefficient) will be determined through a lookup table, populated based on OPI numerical model results, describing optimal damping coefficient as a function of sea state. The current sea state will be retrieved every 30 minutes by querying the Wavespotter wave buoys [1], located ~100 meters up-wave of the Triton-C (Figure 4). In the event of loss of internet, or if the wave buoys are offline for maintenance, the onboard IMU system will be used to estimate the wave state. This will be done by processing the heave measurement once every 30 minutes for the previous 30-minute window. The demand torque for all three generators will be calculated by the PLC every 20 ms, which will be then sent to the control unit (Siemens CU320-2). The control unit performs a feedback loop to achieve the demand torque for the three generators.

Figure 5. *Speedgoat hardware for active control implementation*

For advanced active control, the real-time calculations will be offloaded from the main Siemens PLC to a devoted Speedgoat machine that can handle the more intensive calculations. The Speedgoat machine will also have the ability to implement baseline proportional control, allowing OPI to confirm that the approach works correctly and to permanently offload from the PLC (if needed). The Speedgoat hardware will be located in the Main Control Cabinet aboard the float and will run a real-time Matlab/Simulink hardware in the loop simulation. When active control is implemented, the PLC will send the Speedgoat instantaneous data from several I/O channels including the hull motion, the tendon tensions, and the sheave position and velocity. The Speedgoat will run a real-time control algorithm and send back a desired torque value for each of the generators. Depending on the control strategy, the algorithm would involve solving a series of equations or optimization functions to calculate the desired generator torque. The algorithm running on the Speedgoat machine will have the ability to be updated remotely from OPI's office in Seattle over the course of the deployment.

Return spring control

The return spring subsystem offers an additional tuning parameter that enables the WEC to maximize power absorption in small and normal operational waves, or alternatively, ensure survivability (i.e. reduce PTO travel and velocity) in more extreme waves. The SCADA system will first query the Wavespotter buoy for the current sea state and then use a lookup table to identify the optimal return spring rate for that sea. This process will occur every 30 minutes. The look up table will initially be populated based on OPI numerical model results and will have the ability to be slightly refined throughout the course of the deployment to fine tune to the optimal return spring parameters for each sea state.

The desired spring rate is achieved by changing the volume of gas connected to the gas side of the high-pressure accumulators. After determining the optimal return spring rate for the current wave condition, the SCADA will open and close the three gas bottles per drivetrain in a binary manner to create a given total air volume for the return spring subsystem. A smaller air volume corresponds to a 'stiffer' spring, and a larger air volume corresponds to a 'softer' spring. The gas bottle settings, as a function of spring rate, will be programmed into the controller using an additional look-up table.

E-Brake System

When the power output is too low to sustain operation, the Triton-C enters a de-activated state. The SCADA system continuously monitors the power output from the power electronics as a rolling mean average. When the rolling mean average is below an operator set value, the SCADA will initiate steps to lock the drivetrains by engaging the E-Brakes, i.e. isolating the high-pressure accumulators, and powering off the recharge pump.

The float will stay in the de-activated state until the sea state measured by the Wavespotter buoys is above an operator set threshold, after which the SCADA will unlock the E-Brakes and re-start the recharge system. Nominally, this will correspond to a significant wave height greater than 1 meter, but this will be tuned by OPI throughout the deployment as exact WEC power output is quantified.

Dynamic Brake

The dynamic brake attached to each drivetrain provides supplemental damping to the system to prevent overspeed of the generator. The torque applied by each brake will be controlled in real time by the SCADA system. There are two separate situations in which the dynamic brakes will be used.

1. Generator functioning: the dynamic brake will be applied once the speed of the generator exceeds 800 RPM, after which the generator torque starts to decrease due to field weakening. The dynamic brake will apply a torque to keep the total damping torque (generator + dynamic brake) at 62 kNm. The SCADA system will monitor the sheave velocity and the generator torque to determine the braking amount required to keep the net torque constant with velocity beyond the generator knee point.
2. Generator not functioning: the brake will apply a damping characteristic where the braking torque is dependent on the sheave speed.

In both cases, the dynamic brake torque is controlled via a proportional valve between the recharge accumulator and each of the hydraulic brake powerheads. The proportional valve will be controlled based on the sheave speed and the pressure on the powerhead via a lookup table that will be experimentally determined in advance of the deployment.

Cooling system

The SCADA system will constantly monitor the temperatures of the hydraulic oil, the dynamic brakes, the generators, and the resistor load bank in addition to the coolant throughout the drivetrain. All temperature signals will be recorded in the historian for reporting purposes. The motor start and stop status, and the motor speed for the three cooling pump Variable Frequency Drives (VFD) (two freshwater and two seawater) will also be recorded in the historian for reporting purposes.

Commented [KS1]: Updated from one to two

To conserve power, the SCADA system will take a reactive response to the cooling requirements in the system. As the cooling demand fluctuates, this involves controlling the speed of the cooling pump VFDs and the proportional valve openings for the dynamic brake and resistor bank cooling loops. The cooling requirements for different operating scenarios are summarized in Table 4.

Table 4. *Summary of cooling requirements for different operating scenarios*

	Low waves	**Moderate waves**	**Moderate waves. Grid loss**	**Extreme waves**	**Extreme waves. Grid loss**	**Moderate - Extreme waves. Grid loss. Generator fail**
Cooling Requirements	None	Hydraulic oil	Hydraulic oil	Hydraulic oil	Hydraulic oil	Hydraulic oil
		Generator	Generator	Generator	Generator	Dynamic brake
			Resistor bank	Dynamic brake	Dynamic brake	Resistor bank
					Resistor bank	

As long as the system is generating power, the primary freshwater cooling pump will have a minimum flow rate that will always be active. The minimum flow rate will initially be set to 10% of pump maximum, but this be able to be adjusted if needed during the deployment. This ensure that there is some circulation so that the coolant temperature can be monitored. As the wave height and WEC power absorption increase, the temperatures in the system will also increase. To keep up with the cooling requirement, the SCADA will implement an automatic temperature controlled PID loop. This controller will monitor the return temperature of the heat exchanger and adjust the coolant flow rate to keep this temperature at 38°C. As heating demands increase, the speed of the primary freshwater VFD will increase to keep the heat exchanger output at 38°C. If the primary freshwater cooling pump is running at more than 50% of its maximum speed, the seawater pump speed will be ramped to 10% and the speed of both pumps will subsequently increase at the same rate. If the seawater cooling pump is running at 50% of its maximum speed, the secondary freshwater pump will be ramped to 10% and all pumps will increase speed at the same rate to keep the heat exchanger return temperature at 38°C. All pumps will plateau at 80% max speed to avoid potential damage. The cooling control law described above will have the be ability to be manually adjusted over the course of the deployment as the system is better understood. As the cooling demand decreases, the SCADA will execute the above steps in reverse. The pump speeds will also have the ability to be manually controlled and can be set to 100% in the event of an emergency.

Commented [KS2]: I believe this was related to the HP, seem to remember as more like 52%. Maybe we should revisit this.

Commented [B3R2]: Can you point to this spec? The numbers I listed are a rough starting and will have the ability to be fine tuned as we learn more throughout the deployment.

Commented [KS4R2]: Got it, makes since now with how the other parts of the document read.

To balance the relative flow rates and cooling capacity in each hydraulic oil and generator branch of the cooling system, proportional globe valves will be placed in the cooling lines upstream of each oil cooler and generator. These globe valves will nominally be 100% open; however, they can be manually closed by the operator (via the HMI) to throttle the flow in each branch. These throttling valves are expected to be fine-tuned by the operator at the beginning of the deployment in order to balance the flow rates, after which they should rarely need to be adjusted.

The dynamic brakes will be actuated intermittently when the Triton-C is in larger waves. The amount of cooling flow supplied to each brake will be regulated by a proportional ball valve that will be controlled by the SCADA through another PID loop. This PID loop will monitor the output temperature of the dynamic brake coolant and adjust the proportional ball valve position to keep this temperature below 60°C. In order to mitigate the risk of overheating the brakes, the SCADA will take preemptive action and increase the flow to the brakes as waves start to build and the brakes are on the verge of being used. The SCADA will monitor the time trace of each generator velocity, and if the generator velocity exceeds 700 RPM at least once in the previous 10 minutes, the overall flow rate provided by the cooling system will be increased by 10% and the brake proportional ball valve will be opened 10%.

In the event the brake powerhead overheats and cracks, this will result in leakage of cooling fluid, which will be collected in a drip pan installed underneath each brake. A water level switch in the drip pan will be used to diagnose this issue. Upon activation of the level switch signal, the SCADA system will alarm the operator of brake damage and close the coolant isolation ball valves on each side of the brake.

Electrical power will be transmitted to a resistor bank under two conditions: firstly, when the net power absorbed by the Triton-C is more than can be transmitted to the grid (30 kW), in which case the excess electricity needs to be burned off, or secondly, when the grid connection is lost. In the first situation, the SCADA will open the resistor proportional cooling valve to 10% once the mean electrical exported by Triton-C exceeds 15 kW[1]. Afterwards, the SCADA will control the proportional cooling valve to keep the resistor coolant outlet temperature below 80 °C, with a maximum temperature rise of 20°C. In a grid loss situation, where the WEC is producing power, both freshwater pumps and a seawater pump (secondary as backup) will be activated and ramped to 80% speed and the dynamic brake and resistor proportional ball valves will be opened to 100%. This will provide maximum cooling to the hydraulic oil, generator, dynamic brakes, and resistor bank.

Bilge system

The bilge pump is used to remove any water that has entered the float and is expected to be used very infrequently. A water level switch will be used to monitor the level of water in the bilge. Upon activation of the level switch signal, the SCADA system will alarm the operator of water ingress in the float and activate the bilge water pump, running it until the level switch is cleared.

Ring lifting/lowering operation

The reaction ring lifting and lowering processes will be executed manually by an operator from inside the hull. The SCADA HMI interface will walk the operator through each step of the lifting and lowering processes. A rotary dial (incremental encoder) on the main control cabinet accessible to the operator will allow the operator to monitor and finely control the reaction ring position. The rotary dial will enable control of both the recharge pump pressure and the pressure to each of the three dynamic brakes.

The lifting operation from the dry dock will be performed when the operator sets Triton-C to State 2a. Once the operator confirms that the tendons are securely connected to the reaction ring, the operator will use the HMI to start the recharge system at low pressure (25 bar). Once the recharge system is started, the SCADA system will automatically engage the dynamic brakes to 100% for each drivetrain. The operator will then use the HMI to disengage the E-Brakes. Once E-Brakes are disengaged, the operator will use the incremental encoder to

[1] *This value will depend on the actual performance of the electrical system and will be adjusted based on measured performance.*

gradually reduce the mechanical brake pressure until all three are at 0%. The tendons will then tighten at this point. After the mechanical brakes are at 0% and the tendons are tight (as confirmed by divers), the operator will gradually increase the recharge pressure using the encoder until the rings start to move. The recharge pump will pump oil through the recharge system into the HP system, which drives the Poclain pumps and lifts the ring. Once the ring reaches the desired height (~1m before mated with the float), operators will increase the mechanical brakes to 100% to stop the rise. The operator will then slowly reduce the mechanical brake to raise the ring to gently mate with the float. Once the ring is mated with the float, the operator will re-engage the E-Brake for each drivetrain. After E-Brake is engaged, the hydraulic system will be powered down. At this point, the float has completed State 2a and is ready to be moved into State 3 – Towing.

For the lowering process, power will be supplied from the installation vessel to the WEC via the hull access hatch (the umbilical needs to remain disconnected until the lowering operation is complete). Once the operator confirms that power is live and system is powered up, the operator will place the float in State 4a. The operator will first disengage the E-brakes for each drivetrain. For the lowering of the reaction ring, oil will be pumped from LP to HP and on the HP side, and the speed of the lowering operation is controlled through a proportional valve on each drivetrain. The reaction ring will be lowered at constant speed set by the operator and measured by the encoders. This will be controlled via PID control by the proportional lowering valves. Each valve will have a common setpoint determined by the operator. Once the installation depth is nearly reached (within one meter of expected depth, as indicated by the encoders), the three proportional control valves will be set to 0%. The leakage in the hydraulic system will allow the float to slowly creep down to final depth. Once the exact depth is reached, the E-Brakes will be engaged by the operator. The power umbilical will then be connected to the surface float

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Drivetrain_Combined_FEED_R1-0
FEED Report – Mechanical R1-0
Electrical System FEED R1-0
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Triton-C Detailed Design Report: Power Take Off_R1
Triton-C Detailed Design Report: Surface Float_R1
Triton-C Detailed Design Report: Reaction Ring_R1

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Appendix A

Hotel loads

For each piece of power generation equipment, there exists an auxiliary system to support the powering, monitoring, and conditioning of integrated systems. The Triton-C's sources of power draw have been termed as a 'hotel load'. All above hotel loads for the AEP calculation as were applied as a sum. In this section, we will further detail these internal system loads—hydraulics, cooling system, SCADA, and overall instrumentation and electronics. These system and their associated hotel loads are described in the Summary and Surface Float Reports as included in the Reference section of this report.

Table 5. *Source of subsystem hotel loads*

System	Component	Hotel Load	Power Range [kW]
Hydraulics Common Skid			
	Recharge pump	Two pump motors which have variable loads depending on sea states and operation, motor runs at ~60% capacity during normal operations	0-11.19
Cooling System			
	Freshwater pump	Two pump motors (one of which is a backup pump). During normal operation only one pump will operate which have variable loads depending on sea states. It will run at 10-50% capacity during normal operations. This duty cycle will increase capacity to 80% of max speed during extreme states. The freshwater pump will only operate at max during <1% at extreme operation states or fault case.	0-0.82
	Seawater pump	A single pump motor will have variable loads depending on sea states and operation, it will also operate at ~60% capacity during extreme sea states with the freshwater system. The seawater pump will very rarely increase flow beyond this and only during <1% of extreme operation states.	0-0.82
	Bilge pump	A single pump motor will only operate will significant water ingress. No planned use of this during operation.	0-0.82

		Only anticipated use during maintenance and initial install testing.	
SCADA			
	Controller monitoring system	Will have two mode of operation during idle and operation state. During idle most of instrumentation will be offline.	0.24-1.2
Generator			
	Generator parasitic loads	Internal system loads during standby and operation for each generator.	0.03-0.26
Electrical			
	Resistor bank	By design this subsystem turn generated power into heat to burn off max loads generated during grid loss events to protect grid conversion electronic power equipment. Control will be designed to relief load before max power or fault case, limited to 30kW.	0-10, 30 kW
	Auxiliary parasitic loads	This is the sum of all remaining minor electrical subsystem requirement such as internal cooling fans and other power drawing equipment within the electrical system. This load will only be on during extreme wave states.	NC
Monitoring			
	Cameras	Internal and external 360 cameras to be powered at all times.	0.2
	Internal lighting	Lighting to be use by cameras to monitor interior of the hull. Cameras are to be powered 24/7.	0.04
	Location and weather	GPS location monitoring and weather data system to be powered 24/7.	0.2
Maintenance			
	Fans and power tools	Auxiliary power needed during maintenance internal to the hull for fans, power tools, or charging devices. This load will be only used during maintenance periods.	2.0

Commented [KS5]: Tim - not sure how to include this as it is maybe just a part of electrical system efficiency but would like to confirm this.

Operating hotel load cases

During operation, these loads do not significantly detract from the overall power generation of the wave energy device. However, during fault cases, these loads can become quite substantial and must be managed by the control system. To design the electrical system and connection to the grid, these loads must be analyzed in detail. This analysis also influences the float's battery system design.

For this load analysis, the four major sea states of operation were studied and are shown in **Table 6**: low, operational, and extreme waves, as well as, static cases during installation and assembly. Within these states the listed fault cases express operational failure modes possible (13 different fault cases during operational states and 6 during a static state).

Table 6. *Hotel load cases*

Case ID	Wave Condition	Fault Case	Hotel Load [kW]
1	Low Waves	None	1.78
2	Low Waves	Grid loss	0.82
3	Low Waves	Single generator failure	1.78
4	Low Waves	Two generator failure	1.78
5	Low Waves	All generator failure	1.78
6	Low Waves	Single recharge pump failure	1.78
7	Low Waves	All recharge pump failure	1.78
8	Low Waves	Freshwater pump failure	1.78
9	Low Waves	Saltwater pump failure	1.78
10	Low Waves	Severe hydraulic loss/loss of spring	1.78
11	Low Waves	Water ingress	2.53
12	Low Waves	Hydraulic failure max	5.77
13	Operational Waves	None	6.50
14	Operational Waves	Grid loss	7.84
15	Operational Waves	Single generator failure	7.34
16	Operational Waves	Two generator failure	7.56
17	Operational Waves	All generator failure	7.00
18	Operational Waves	Single recharge pump failure	6.50
19	Operational Waves	All recharge pump failure	2.62
20	Operational Waves	Freshwater pump failure	6.39
21	Operational Waves	Saltwater pump failure	6.50
22	Operational Waves	Severe hydraulic loss/loss of spring	3.07
23	Operational Waves	Water ingress	7.24
24	Operational Waves	Hydraulic failure max	15.61
25	Extreme Waves	None	7.34
26	Extreme Waves	Grid loss	8.06
27	Extreme Waves	Single generator failure	7.34
28	Extreme Waves	Two generator failure	7.56
29	Extreme Waves	All generator failure	7.73
30	Extreme Waves	Single recharge pump failure	7.34
31	Extreme Waves	All recharge pump failure	3.40
32	Extreme Waves	Freshwater pump failure	6.39
33	Extreme Waves	Saltwater pump failure	7.51
34	Extreme Waves	Severe hydraulic loss/loss of spring	3.40
35	Extreme Waves	Water ingress	8.08
36	Extreme Waves	Hydraulic failure max	15.78
37	Pre operation	Wet dock system test	9.79
38	Pre operation	Dry dock system test	9.73
39	Pre operation	Towing	0.74
40	Pre operation	Installation/recovery	5.66

41	Pre operation	Power failure during lifting	2.68
42	Pre operation	Maintenance: subsystem and component testing	8.36

Understanding the hotel loads allows for a thorough design of both the control system, the power electronics package, and other parts of the energy generation equipment to mitigate operational risks or component failures during a fault case. The fault case that yields the maximum hotel load happens during extreme waves with a max hydraulic failure (Case 36 in **Table 6**) at 15.8 kW. This hotel load is large; however, this value reflects this mode of failure when the device is still connected to grid power and the braking systems can be utilized. A combative measure might include drawing power from the grid as needed to power hotel loads and maximize pump systems as needed. Either way this risk can be managed through the power electronics to supply hydraulics, braking, and the cooling systems power.

Another output of this analysis is defining parameters for the battery storage system. Pre-operation fault cases can also produce maximum loads on the batteries if not connected to shore power: specifically, the unitization of all subsystems during testing (i.e. Case 42 in **Table 6**) at 8.4 kW. Again, this is during grid connection and power to the electrical system and DC bus can be maintained. Another case is long term grid loss. This can be a compounding failure cases must also be accounted for within the battery system. More details on the design of the battery system will be described in Triton-C Detailed Design Report: Power Take Off.

The team has designed auxiliary subsystems to try and minimize hotel loads. By designing minimal hotel loads, this increase the overall device's efficiency and performance, feeding more energy back to the grid. This performance must also be balanced with mitigating component failure risks to reduce maintenance time and cost, the effects of oversizing components, and keep the Triton-C running in operational state. In the next section, we will discuss mass and touch on the effect of mass on performance.