ADAPTIVE AGENT BASED CONTROL SCHEME

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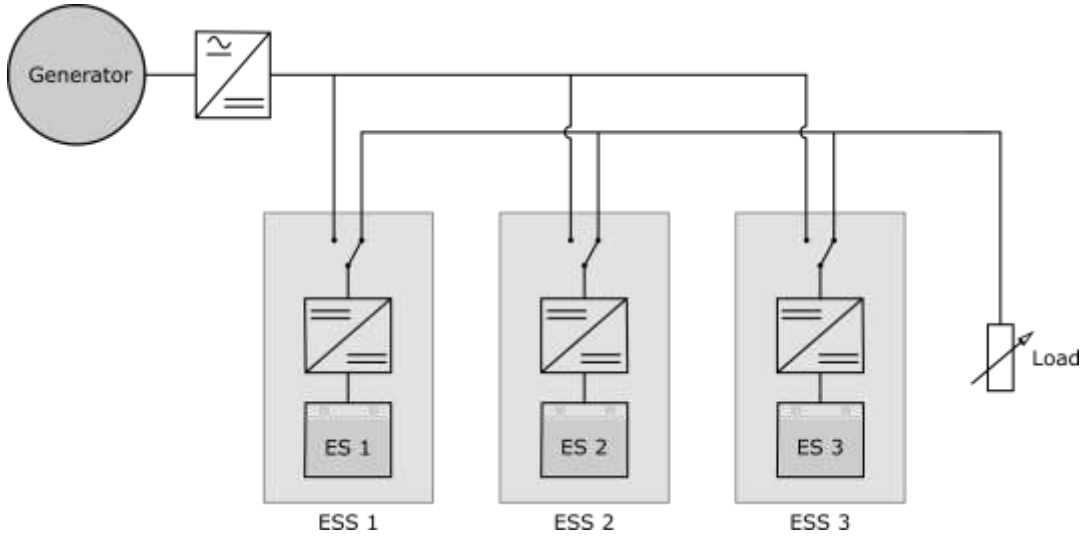
NAVAL RELEVANCE

- Increased need for high energy due to advanced energy weapons and systems.
  - Naval ships will rely on Batteries to satisfy this need.
  - Batteries should be distributed redundancy.
- Adaptive control scheme for collective control.
  - Improve redundancy.
  - Improve reliability.
  - Improve readiness.

Notional Navy DDG(X) hull design. PEO Ships Image

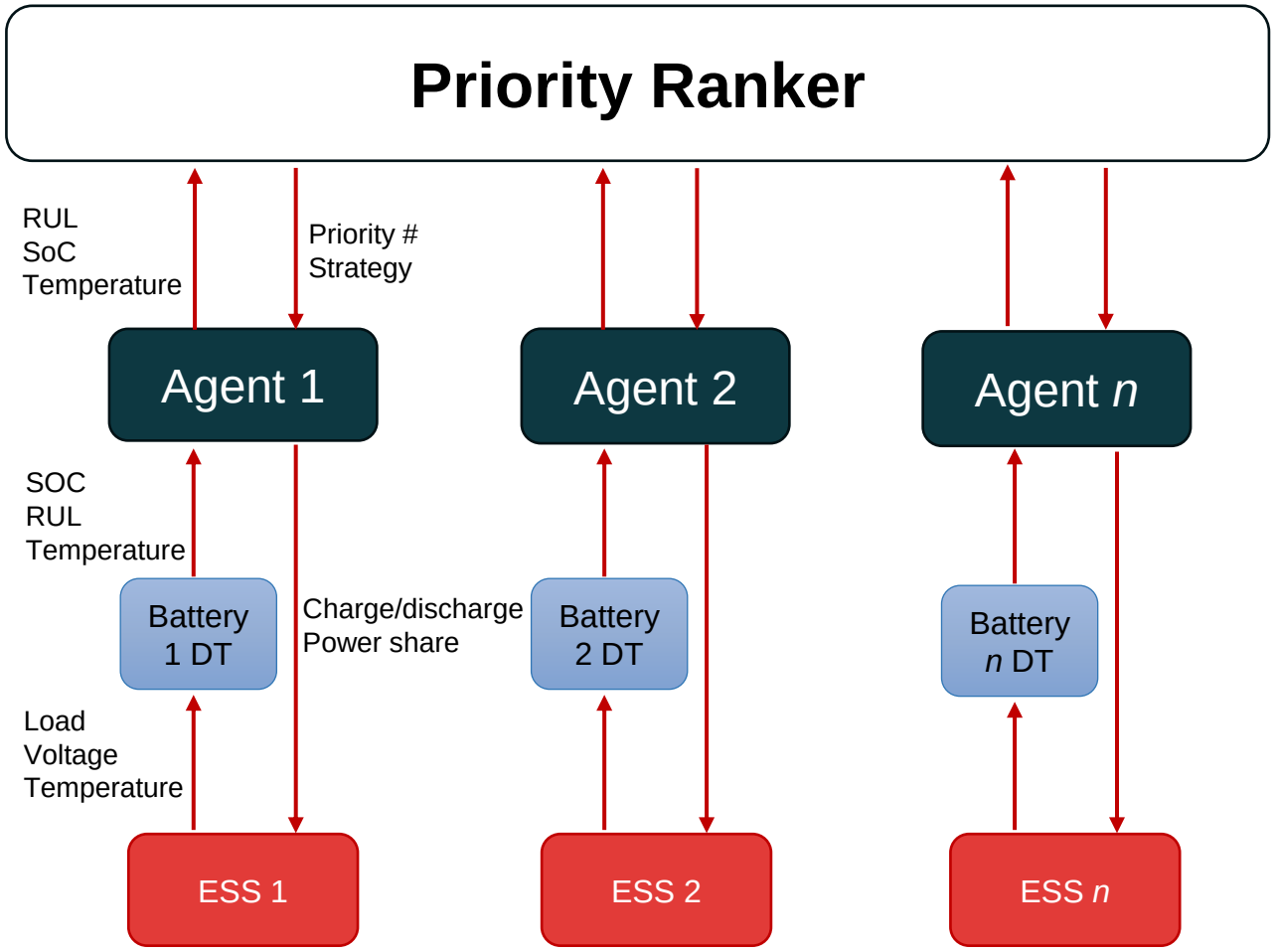
SIMPLIFIED SYSTEM CONFIGURATION

- The system configuration is made up of 3 energy storage systems (ESS) and a generator.
- ESS model
  - Provides the battery's Temperature Voltage, and Current.
- Generator model
  - Calculates the remaining useful life (start-stop cycles).
  - Sends power to the batteries when they need to charge.



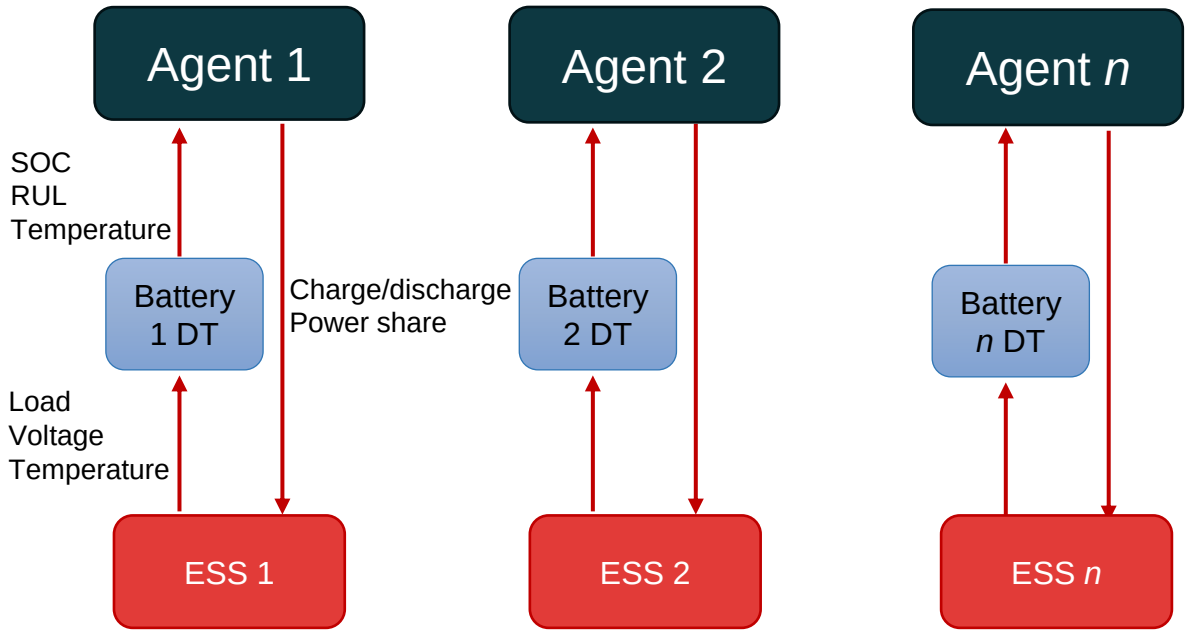
ESS is made up of a battery, converter and contactors.

ADAPTIVE AGENT BASED CONTROL SCHEME



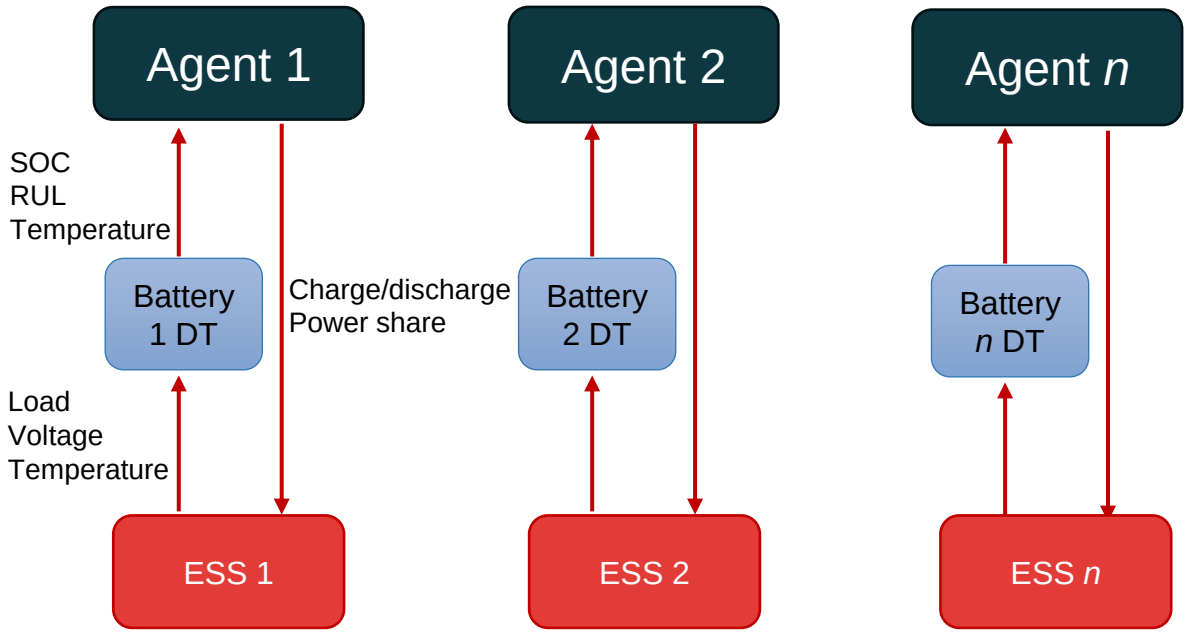
ADAPTIVE AGENT BASED CONTROL SCHEME

- Energy Storage System (ESS) is composed of batteries and converter hardware.
- Sensor measurements from batteries/power converter interfaces are passed to the battery digital twin.
- Each ESS is assigned its own agent.



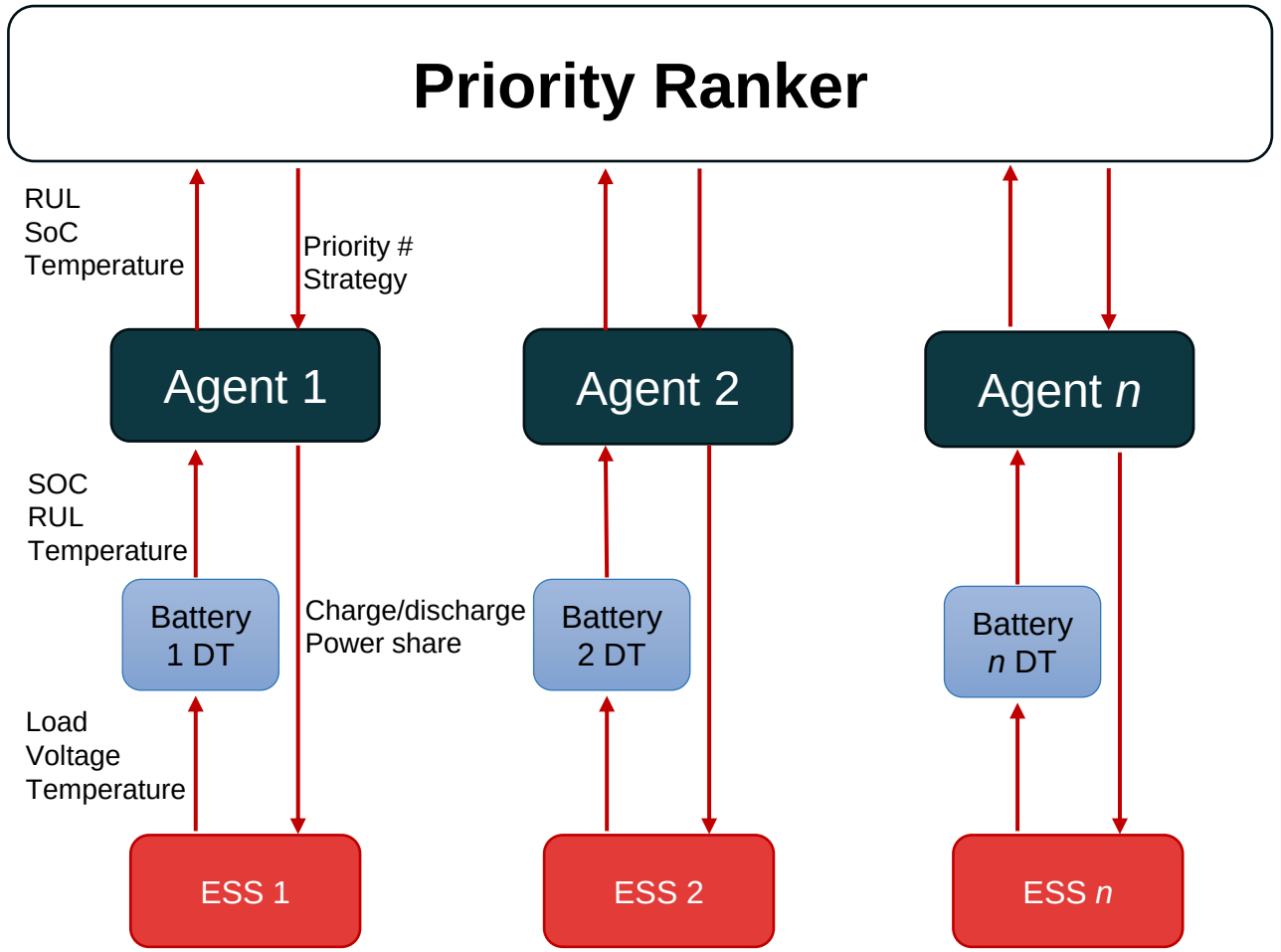
ADAPTIVE AGENT BASED CONTROL SCHEME

- Agent logic is composed of a decision tree.
- Battery digital twin informs Agent of RUL.
- Agent determines whether the battery should be charging, discharging or idle based on its status.



ADAPTIVE AGENT BASED CONTROL SCHEME

- Agents report their status.
- Priority Ranker organizes the agents based on SOC, RUL, and temperature.
- Priority order tells which agent will select its ESS outputs and when.
- Depending on the priority of the agents, their power outputs will be different.
  - 1st and 2nd priority gets to select their preferred output.
  - 3rd must make up the remaining power needed to service the load.



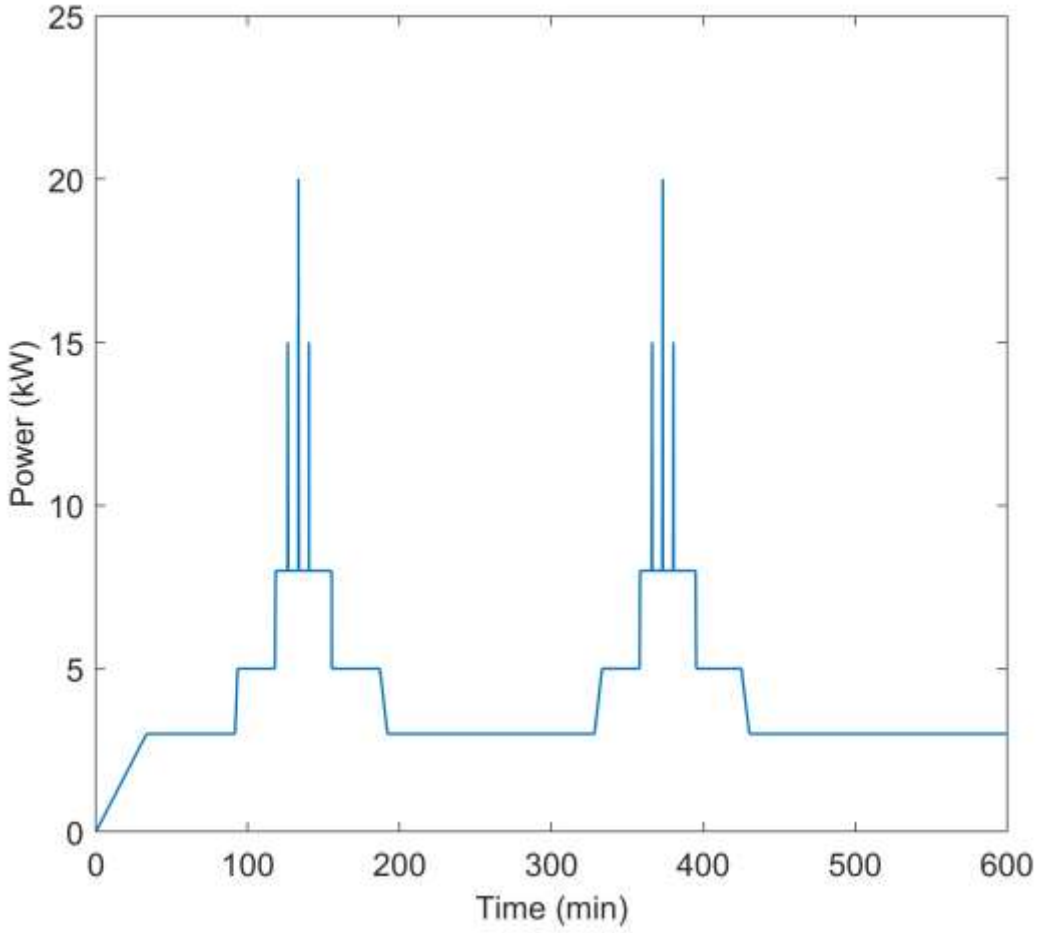
AGENT STRATEGIES

- There are 3 strategies that the batteries can align to.
- Strategy 1 (Reduced Aging)
  - Designed to maximize longevity of battery
- Strategy 2 (Ready)
  - Designed to maximize the readiness
- Strategy 3 (Aggressive)
  - Designed to maximize power output and power availability

	Strategies		
	Reduced Aging	Ready	Aggressive
max power output	1.9 kW (0.5C)	4.1 kW (1.1C)	4.1 kW (1.1C)
max temperature	40°C	60°C	60°C
SOC range	20%-80%	80% -100%	0.5% -100%
load importance weighting factor	0.6	0.7	0.9
temperature importance weighting factor	0.4	0.3	0.1

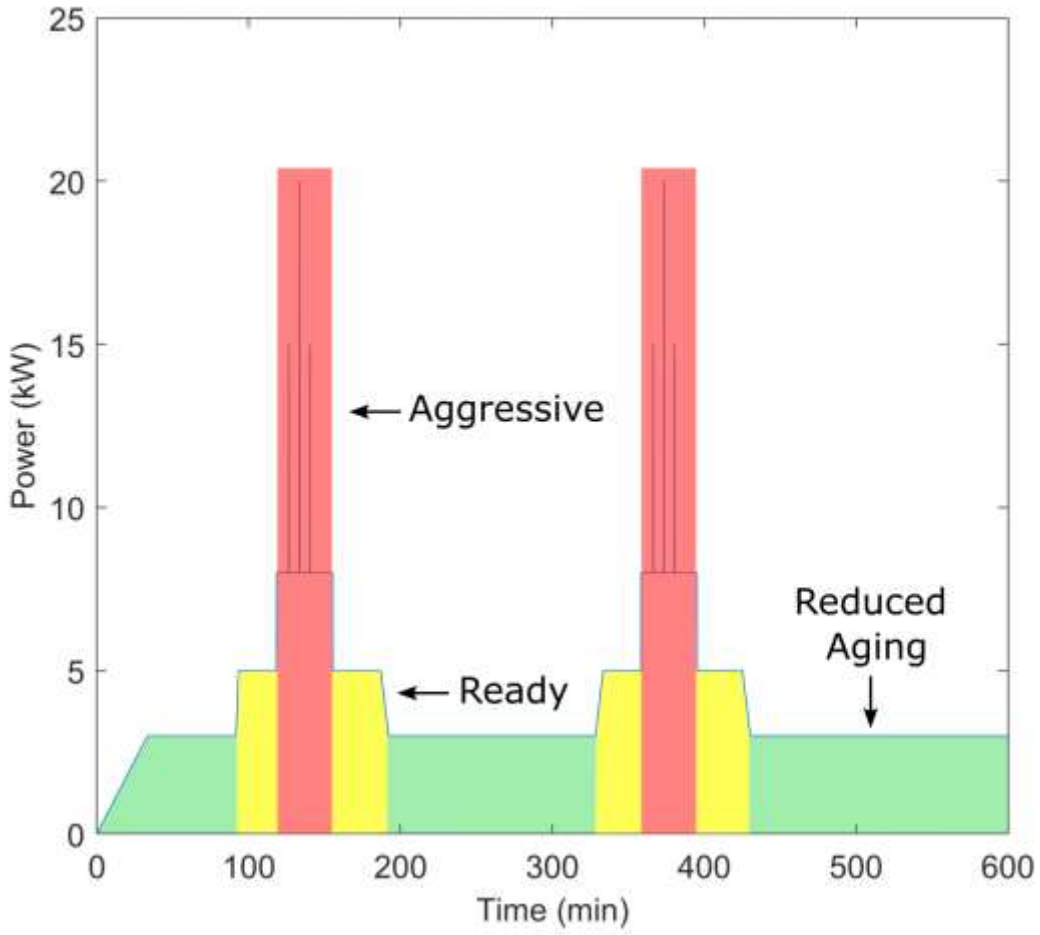
LOAD PROFILE

- The selected load profile is created to represent a 10-hour mission in which there is two brief engagements.
- The power level of the load profile is scaled to testbed power levels.
- We have three 3.8 kWh SimpliPhi batteries to satisfy the load.



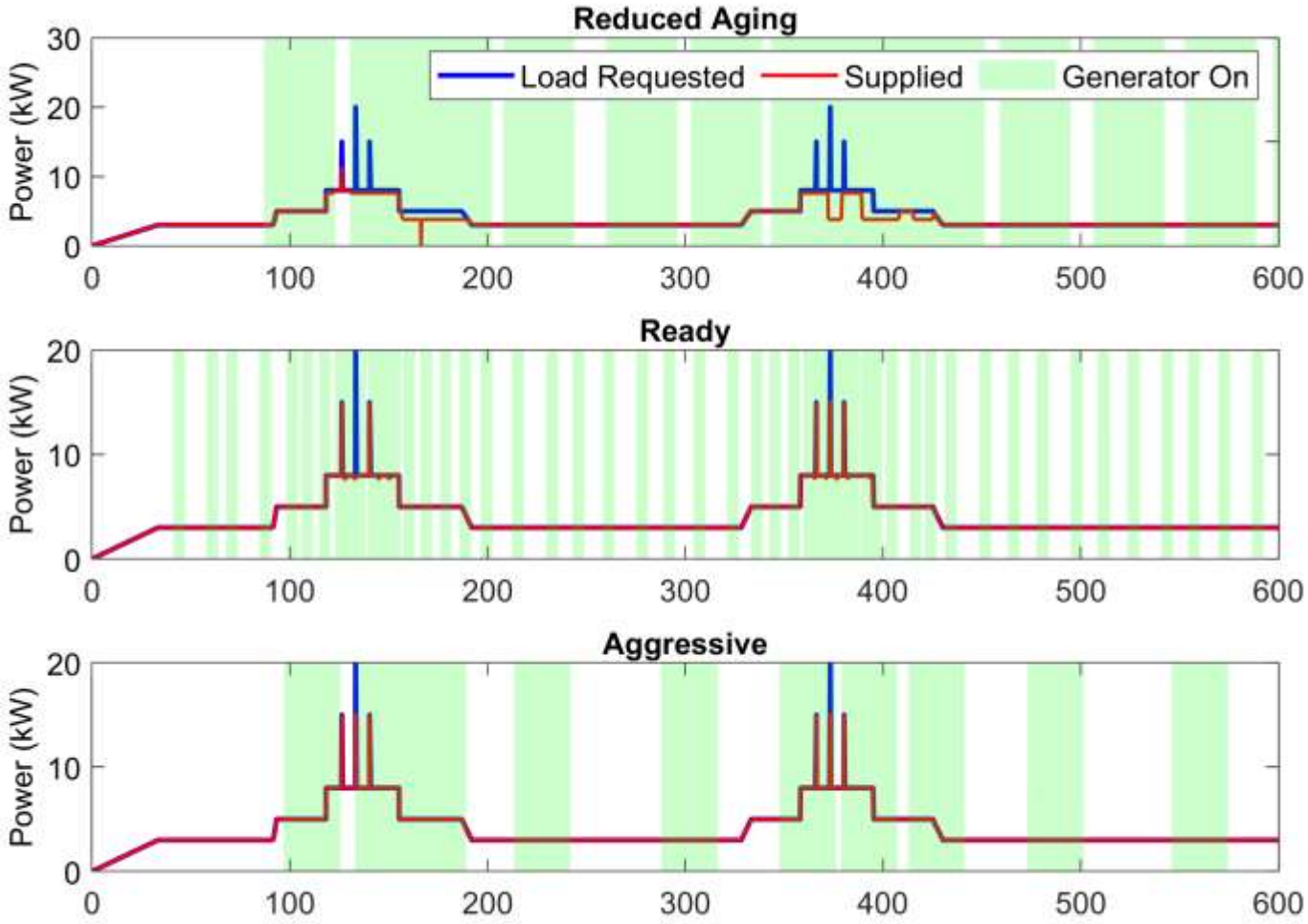
ADAPTIVE STRATEGY

- Maps the reduced ageing, ready, and aggressive strategies to level of power needed for the load.
  - Reduced Ageing: <3.8 kW
  - Ready: <5 kW
  - Aggressive: >5 kW



SIMULATION RESULTS

- Batteries are undersized.
  - Better demonstrate the control scheme
  - A goal to find the smallest batteries that can be used.
- Reasons for load unfulfillment
  - Static strategies
    - Reduced aging is limited to 0.5C
    - Batteries are used too evenly leading to charging at the same time
  - Adaptive
    - Switching between strategies when under the lower SOC bound causes batteries to charge



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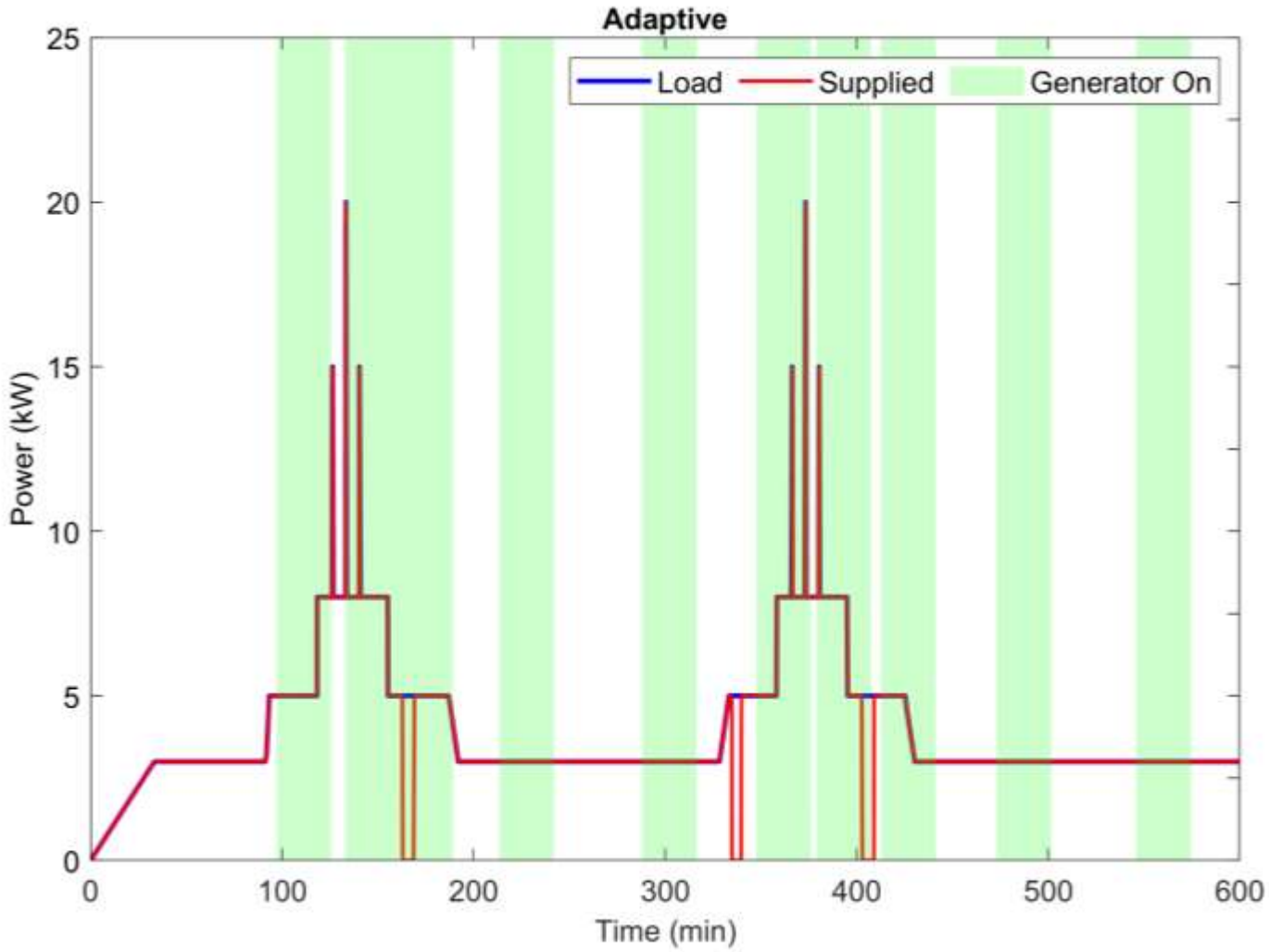
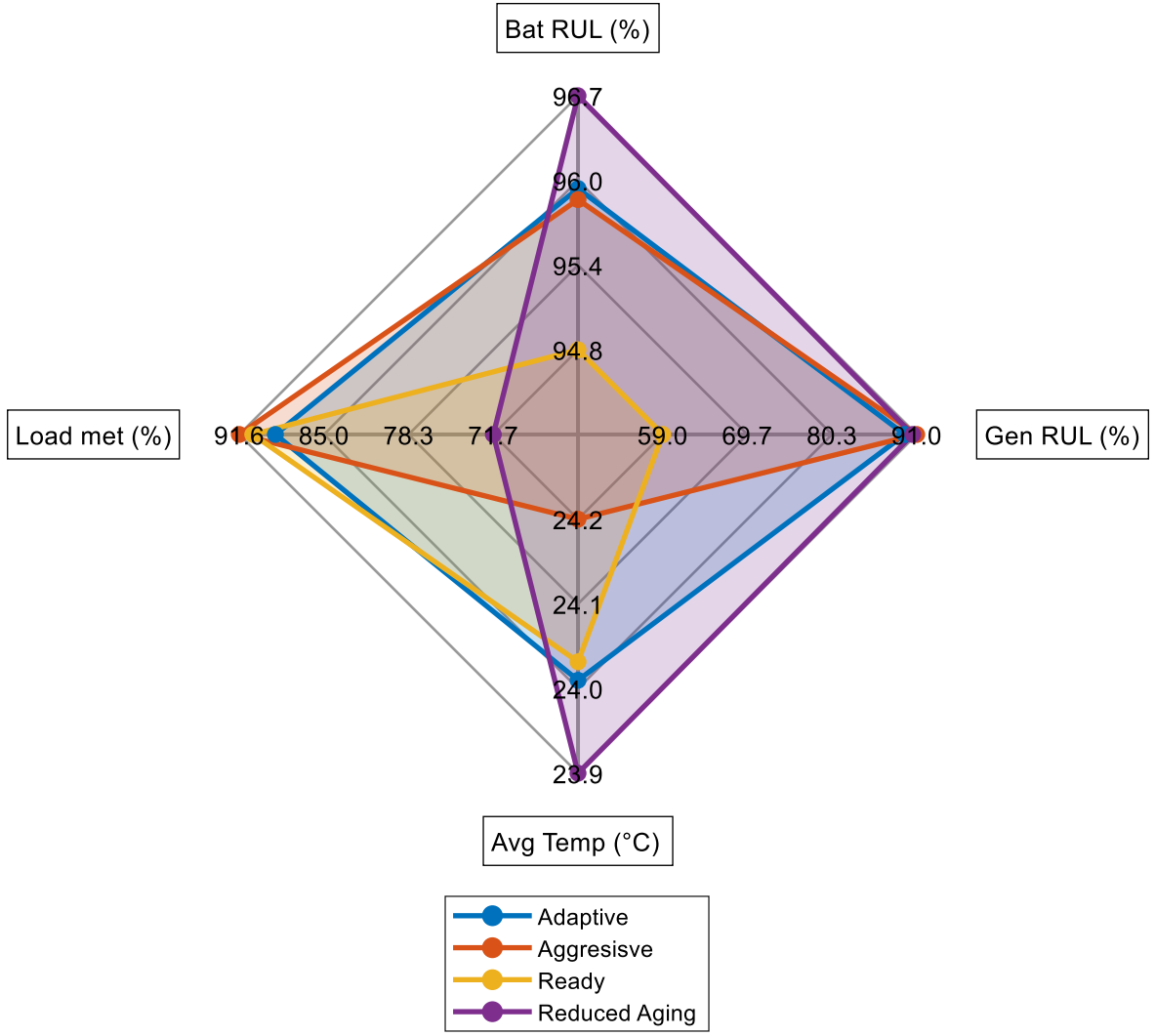


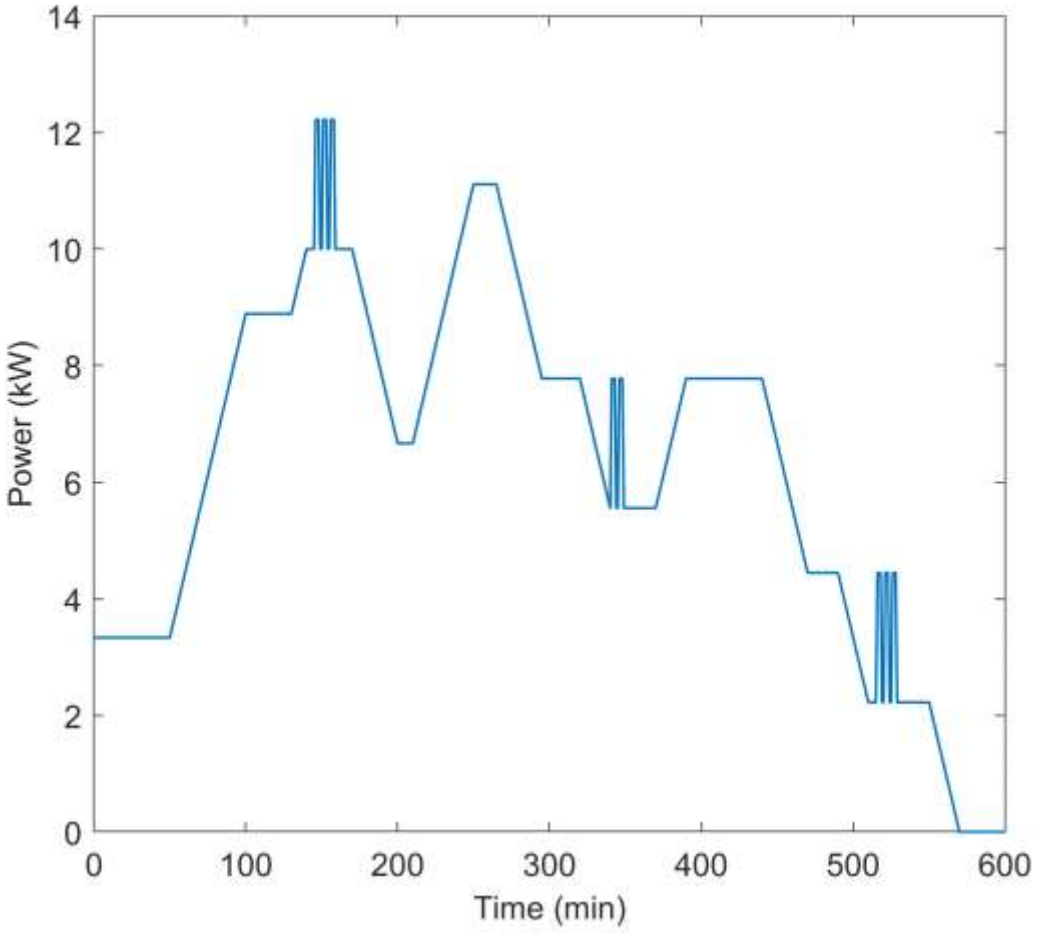
STRATEGY RESULTS

- Adaptive
  - Successfully acts as the middle ground.
- Aggressive
  - Successfully prioritizes load.
- Reduced Aging
  - Successfully prioritizes battery and generator RUL.
- Ready
  - Successfully prioritizes energy readiness.



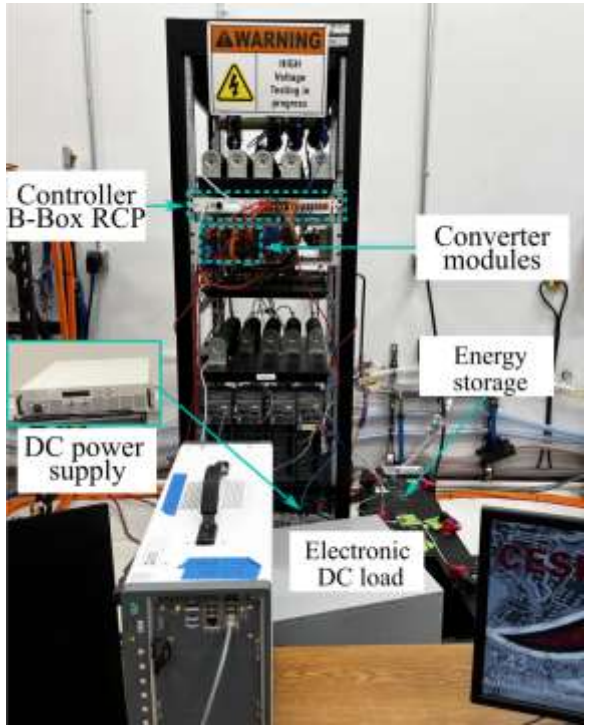
NEXT STEPS MODELING

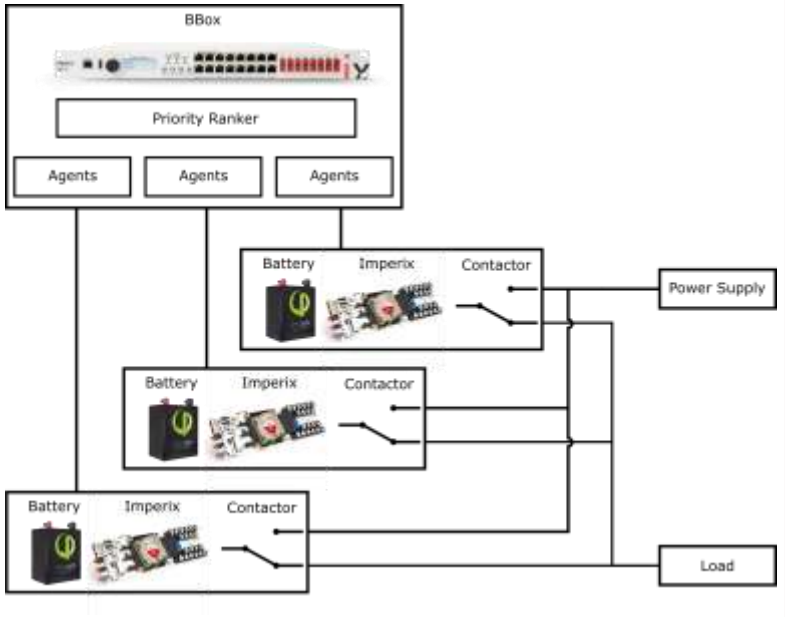
- Use more aggressive load profiles.
- Use more detailed battery & generator RUL digital twins.
  - Add nonlinearity to strategy results



NEXT STEPS HARDWARE

- Validate the adaptive agent experimentally.
  - Deploy the priority ranker and agents on the BBox.
  - Battery subsystems are the Imperix/ Simpliphi batteries.





CONCLUSION

- Future ships will further incorporate distributed energy storage systems.
- An adaptive agent-based control scheme was created.
- Strategies were developed to align the agents to a common goal.
  - Reduced Ageing- Longevity of the battery
  - Ready- maximize readiness of energy
  - Aggressive- maximize power output and power availability
  - Adaptive- switches strategies based off power level of the load
- The control scheme was tested against a simulated microgrid.
- Results show Adaptive strategy performed successfully as a middle ground.

THANKS!

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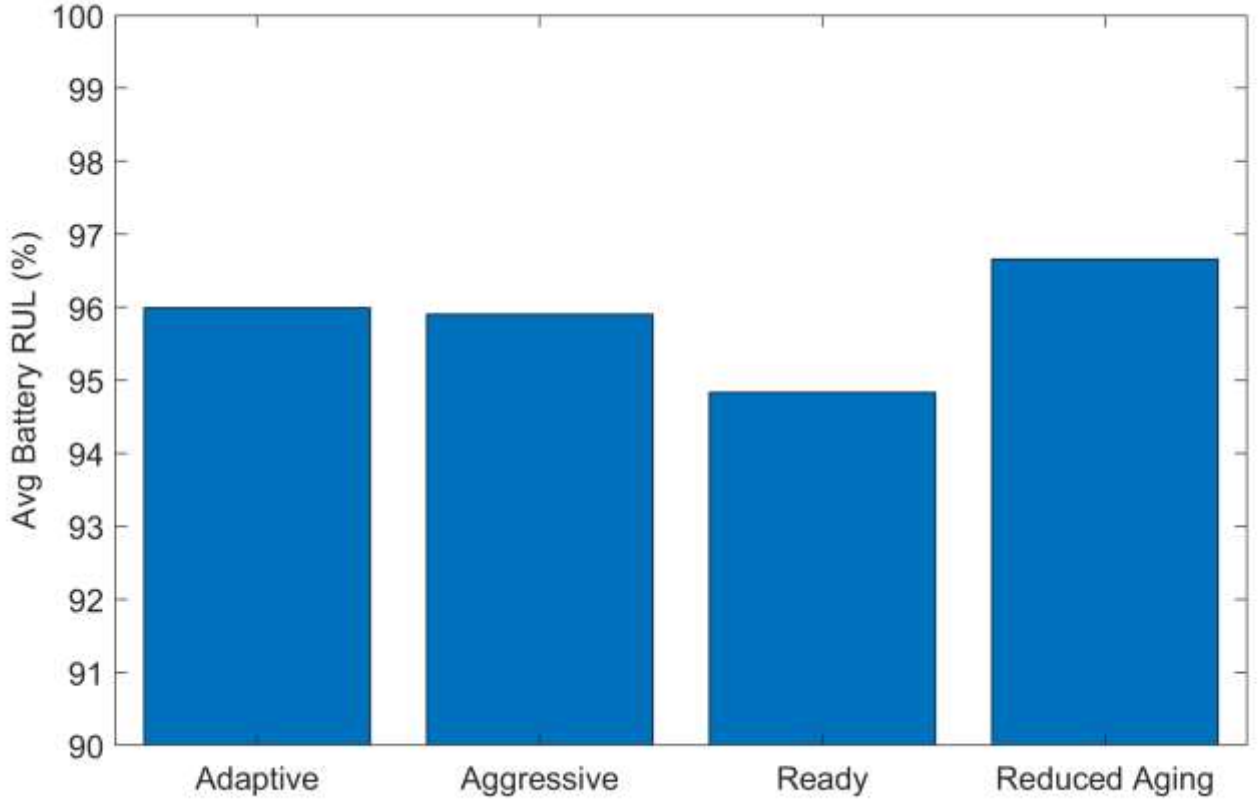
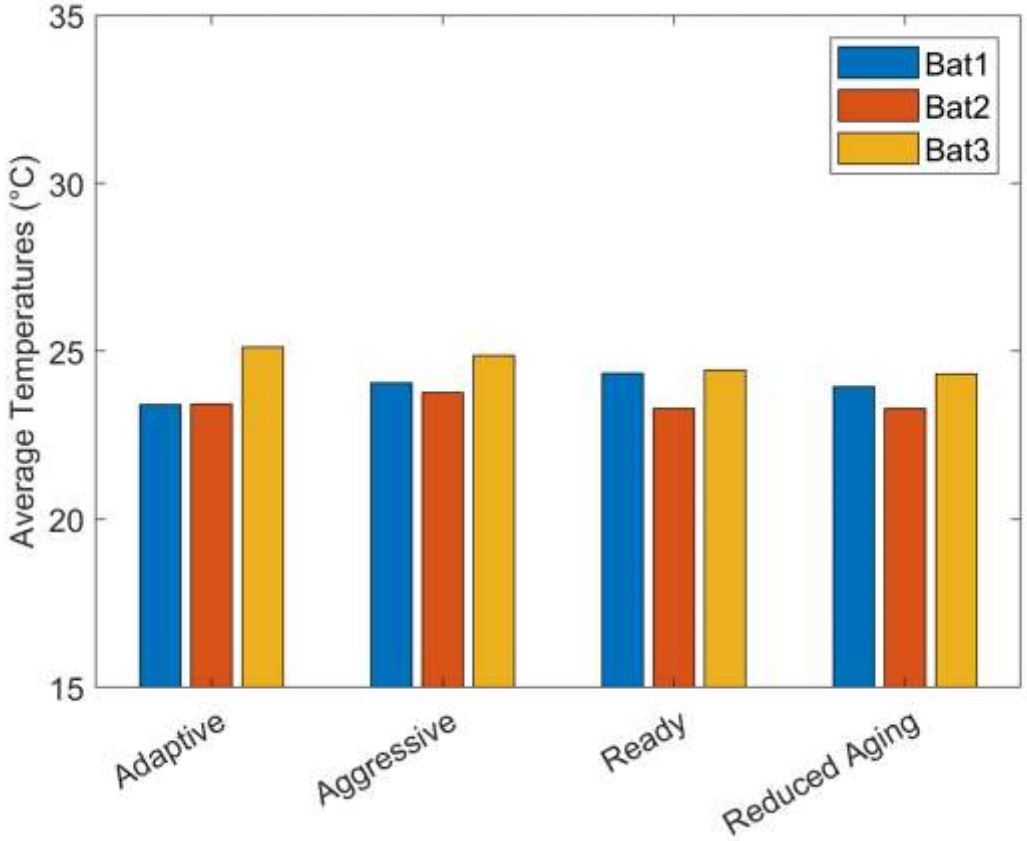
SIMULATION RESULTS (BACKUP)

- Average battery RUL rankings:
  - Reduced Aging
    - 1st battery RUL
  - Ready
    - 4th battery RUL
  - Aggressive
    - 3rd in battery RUL
  - Adaptive
    - 2nd in battery RUL



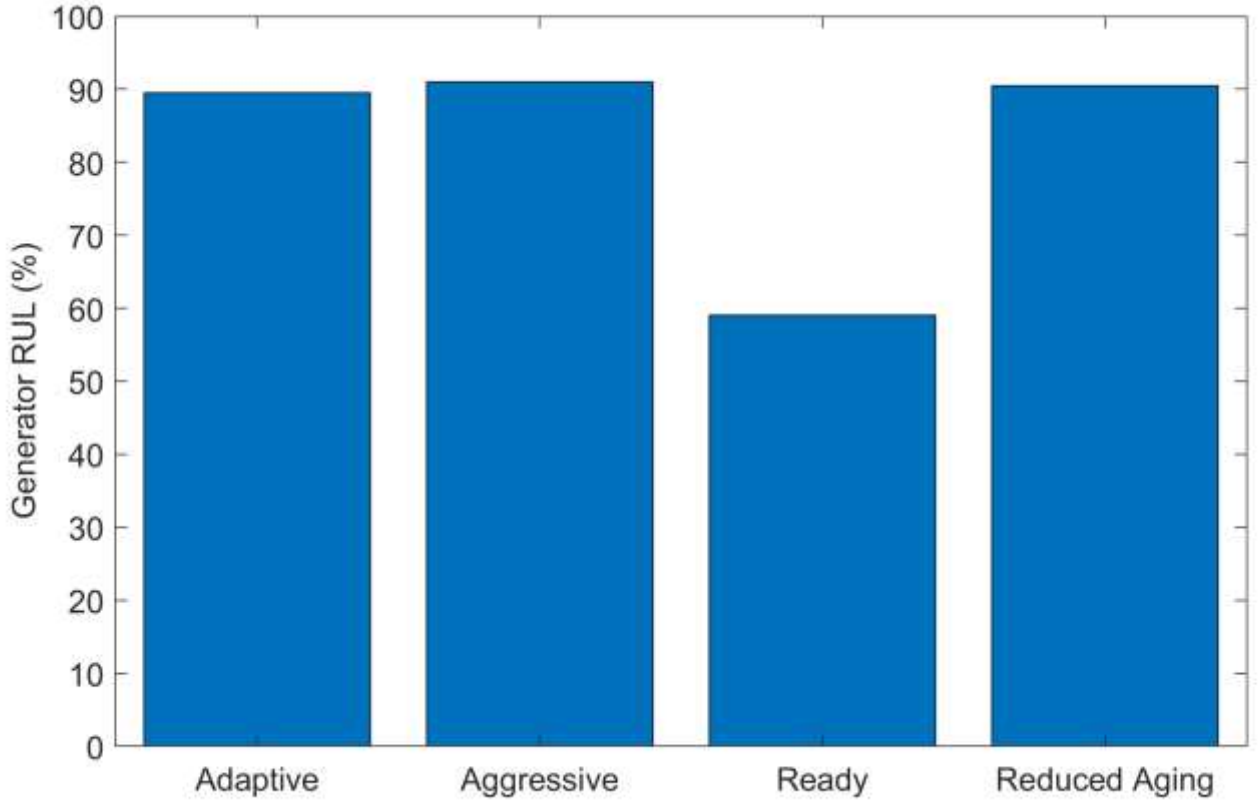
SIMULATION RESULTS (BACKUP)

- Reduced Aging
  - Lowest temperatures
- Ready
  - 2nd highest temperatures
- Aggressive
  - 1st highest temperatures
- Adaptive
  - 3rd highest temperatures



SIMULATION RESULTS (BACKUP)

- Reduced Aging
  - 2nd Generator RUL
- Ready
  - 4th in Generator RUL
- Aggressive
  - 1st in Generator RUL
- Adaptive
  - 3rd in Generator RUL



SIMULATION RESULTS (BACKUP)

- Reduced Aging
  - 4th in satisfying the load.
- Ready
  - 2nd in satisfying the load.
- Aggressive
  - 1st in satisfying the load.
- Adaptive
  - 3rd in satisfying the load.