

FEASIBILITY/CONCEPTUAL DESIGNS OF ENERGY EFFICIENT AND ENVIRONMENTALLY FRIENDLY SHIPS WITH NATURAL GAS AS A FUEL - PROJECT 4

Prof. Dr. Claudio Mueller P. Sampaio, Prof. Dr. Kazuo Nishimoto, Eng. Dr. Felipe Ruggeri, Eng. MSc. Lucas H. S. do Carmo, Eng. Cristiana Pirpiris, Bruno Mendes, Eng. Rodrigo J. do Vale
Dept. of Naval Architecture and Ocean Engineering
University of São Paulo, Brazil



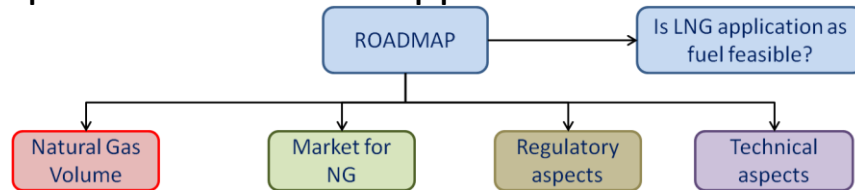
Research Centre
for Gas Innovation

cleaner energy for a sustainable future

V Workshop RCGI
University of Sao Paulo, Brazil
21 – 22 AUG, 2018

Project Structure

1st year – Roadmap on LNG as a fuel applied to Brazilian conditions



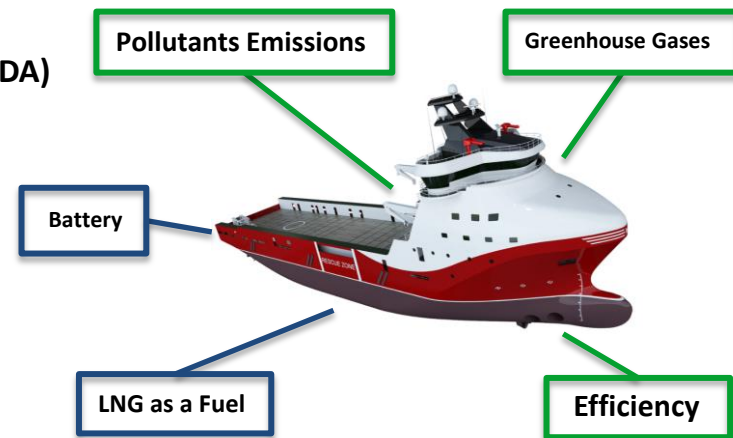
- American Bureau of Shipping - **Technical Contributor (NDA)**

2nd year – Assessment of the use of LNG as a fuel and hybrid energy systems (combustion engines and batteries) in PSV vessels.



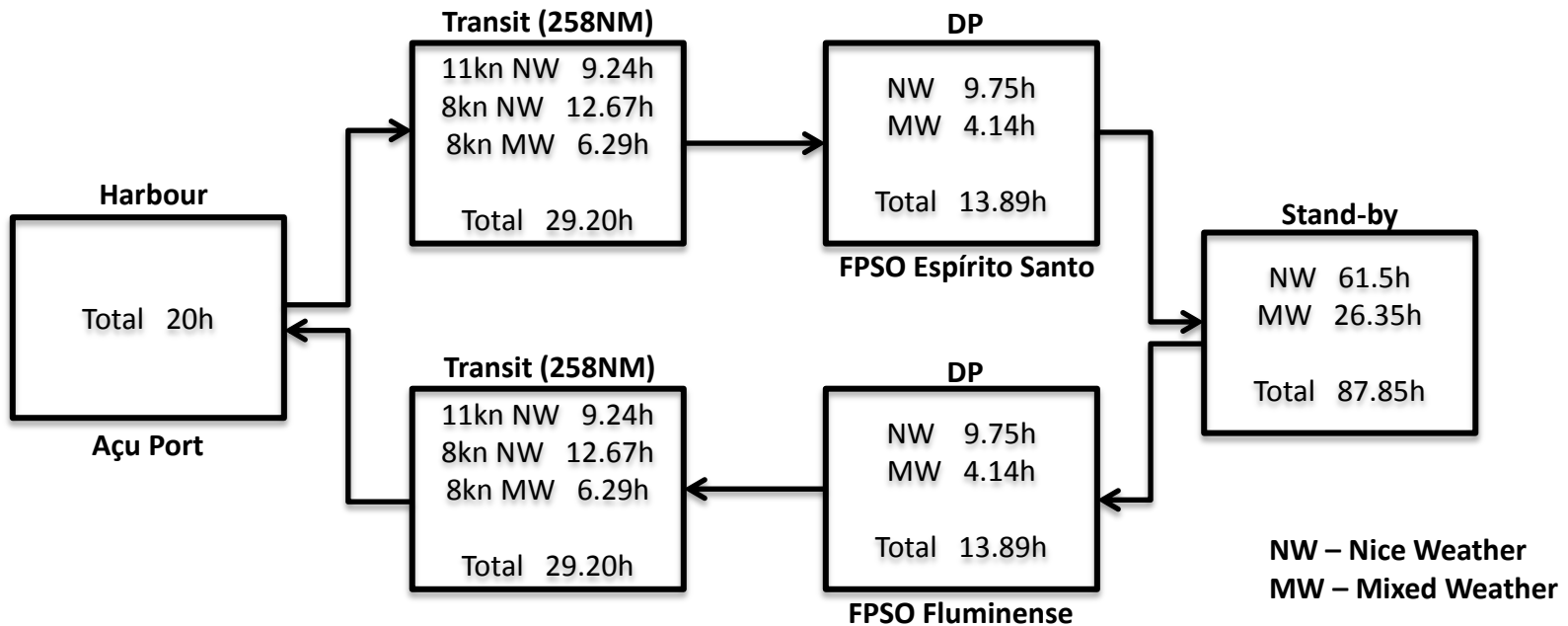
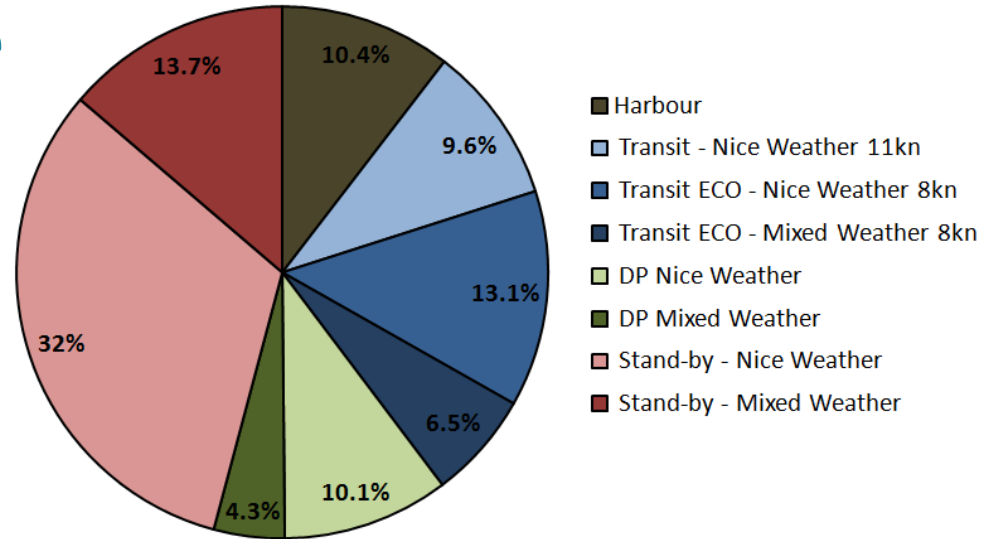
- EDISON CHOUEST OFFSHORE- **Technical Contributor (NDA)**

3rd year – Assessment LNG as a fuel for Push-Convoy – Brazilian North Inland waterway.

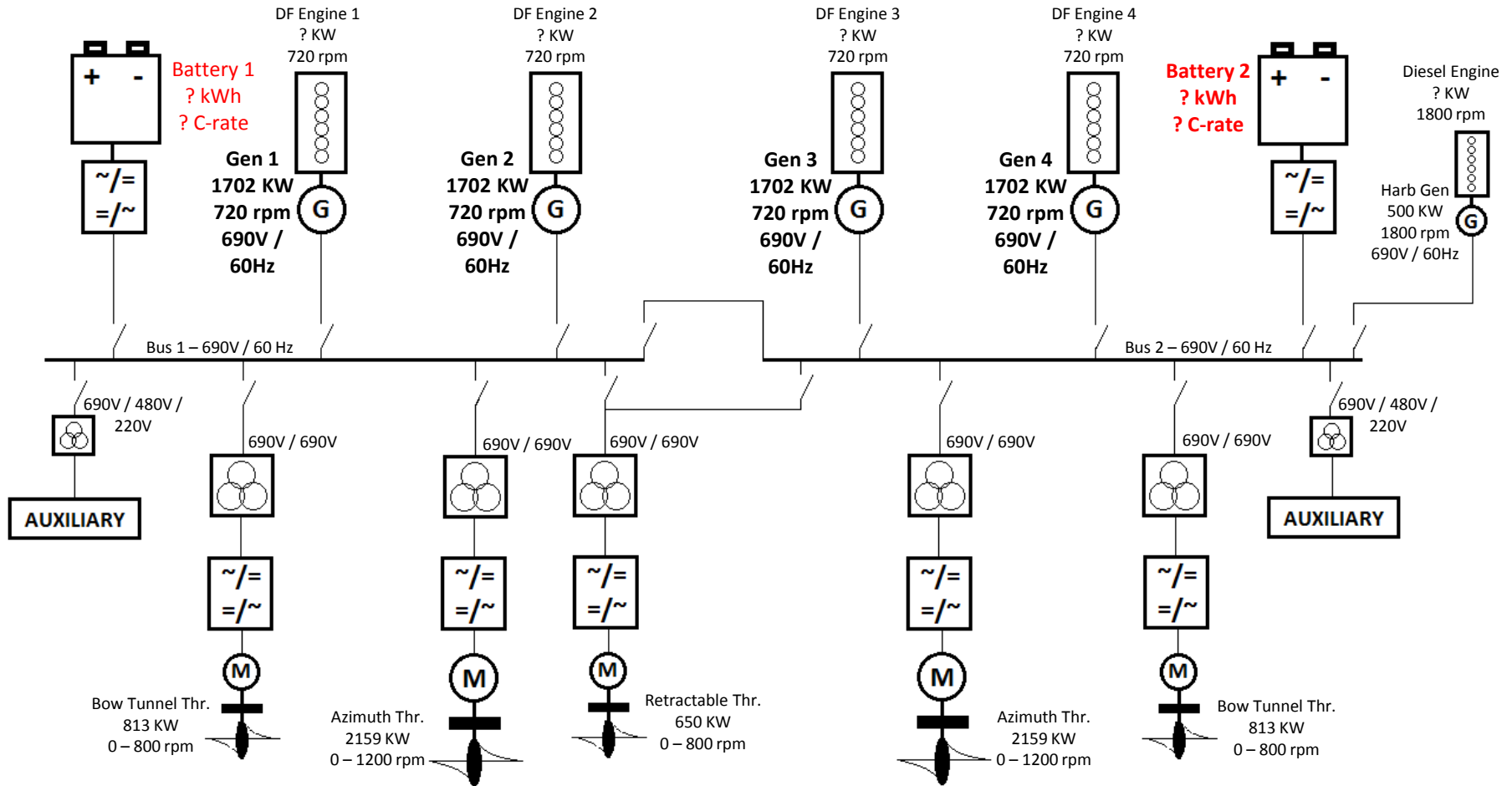


Operational profile

- PSV Operational Description
 - **Operating Region:** Campos Basin
 - **Deadweight Capacity:** 4500DWT
 - **Voyage Speed:** 11kn (Eco 8kn)
 - **Dynamic Position System:** Class 2

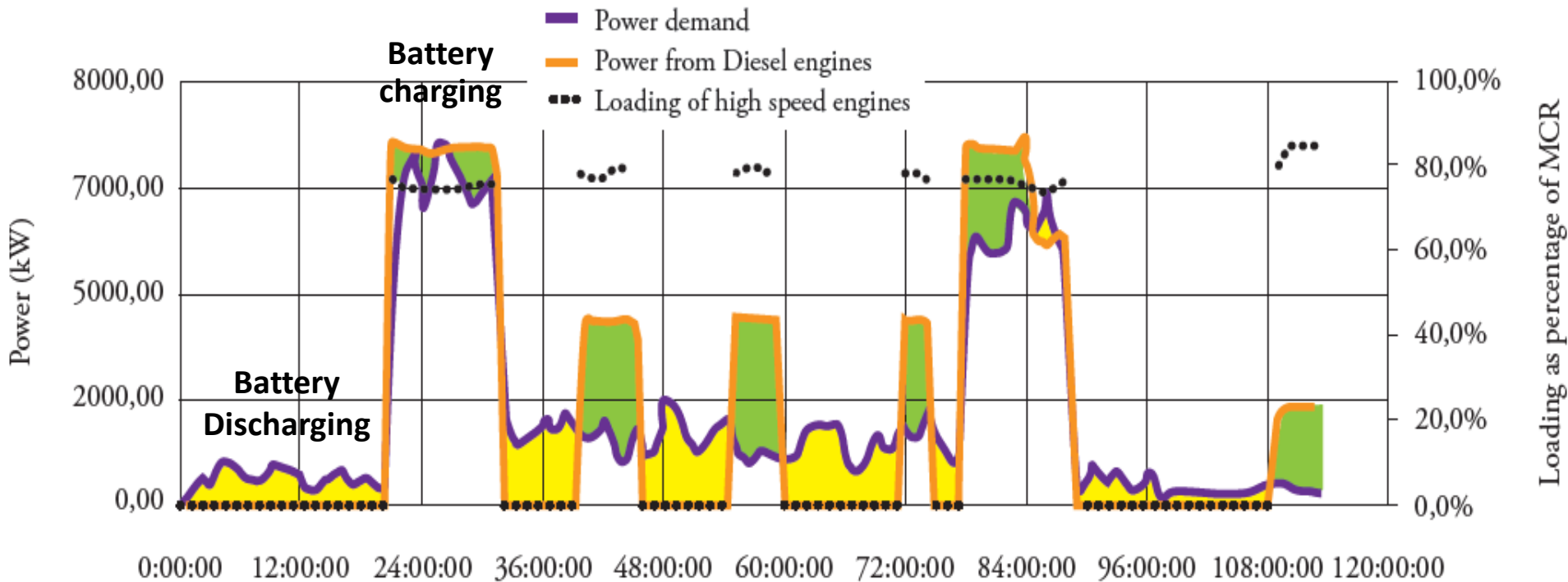


Diesel Electric System – Single Line Diagram



Battery - Performance Analysis Problem

Battery as energy to increase the average load on engines (**Battery Strategic Loading**) (High kWh)



(Vasquez, 2016)

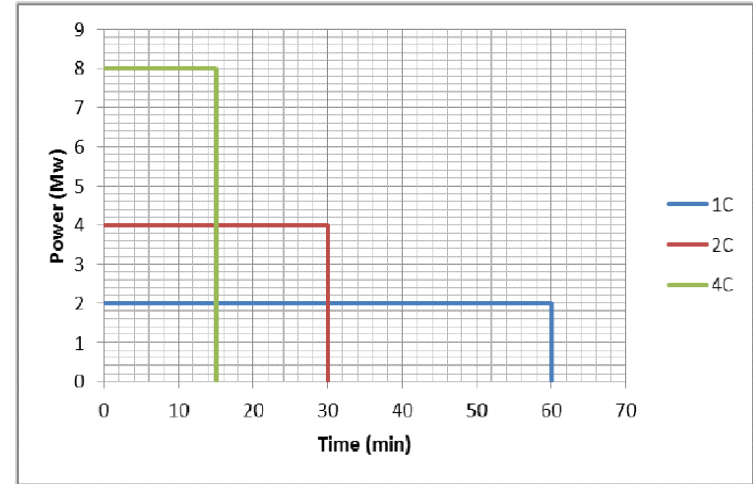
C-rate / SOC – State of Charge

Definition

$$\text{C-rate} = (\text{Dis})\text{charge} / \text{hour}$$

C-rate:

- ❑ C-rate is a measure of the rate at which a battery is discharged relative to its maximum capacity.
- ❑ C-rate 1C means that the discharge current will discharge the entire battery in 1 hour.



C-rate for charging with respect to the time of fully charged (Mjøhus, 2017).

State of Charge – SOC [%]:

- ❑ An expression of the present battery capacity as a percentage of maximum capacity.
- ❑ It is assumed the battery voltage is fixed and the charge stored is directly proportional to energy stored.

$$\text{SOC}(t) = \text{SOC}(0) + \int_{t_j}^{t_{j+1}} \frac{P_{\text{battery}}(t)}{E_{\text{battery}_{\text{max}}}} dt$$

$$\text{SOC}_{\text{max}} = 80\%$$

$$\text{SOC}_{\text{min}} = 20\%$$

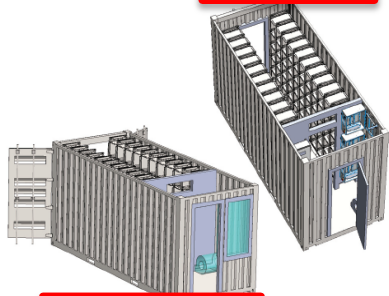
Above SOC_{max}, the energy efficiency is decreasing

Below SOC_{min}, occur rapid degradation (the batteries can deteriorate rapidly)

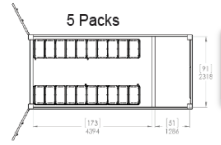
Battery specifications (Corvus Energy)

20 foot

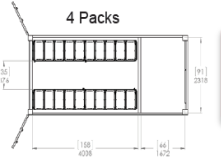
2 man doors, 650 kWh



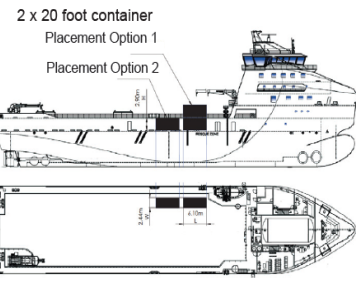
STD 20ft Container, 546 kWh



5 Packs of 20 Modules
Voltage: 1008 VDC max
Capacity: 6500Wh x 100 = 650 kWh



4 Packs of 21 Modules
Voltage: 1058 VDC max
Capacity: 6500Wh x 84 = 546 kWh



Orca™ ESS C-Rate Performance

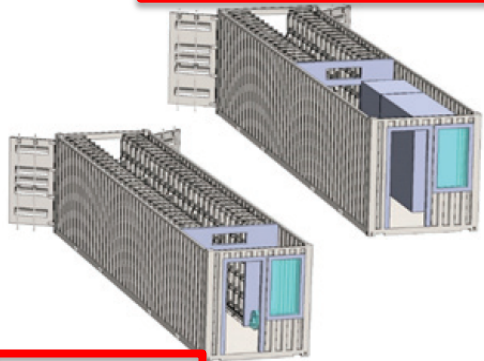
Performance Specifications*		Orca Energy	Orca Power
C-Rate – Peak ¹	Discharge	6C	15C
	Charge	3C	13C
C-Rate – Continuous ²	Discharge	3C	10C
	Charge	3C	5C
C-Rate – RMS ³		2.5C	6C

¹ Peak – maximum rating for 10 seconds
² Continuous – complete charge or discharge
³ RMS – indefinite alternating charge and discharge

* Specifications subject to change without notice

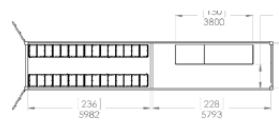
40 foot

Battery & Power Electronics, 819 kWh



Battery Only, 1365 kWh

Battery & Power Electronics – 6 Packs

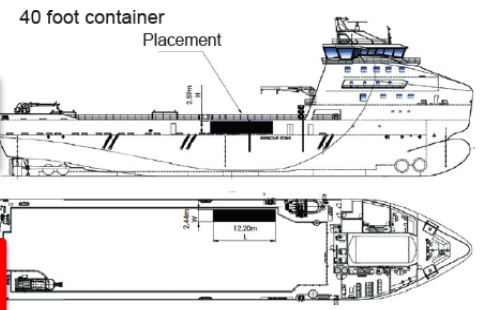


6 Packs of 21 Modules
Voltage: 1058 VDC
Capacity: 6500Wh x 126 = 819 kWh

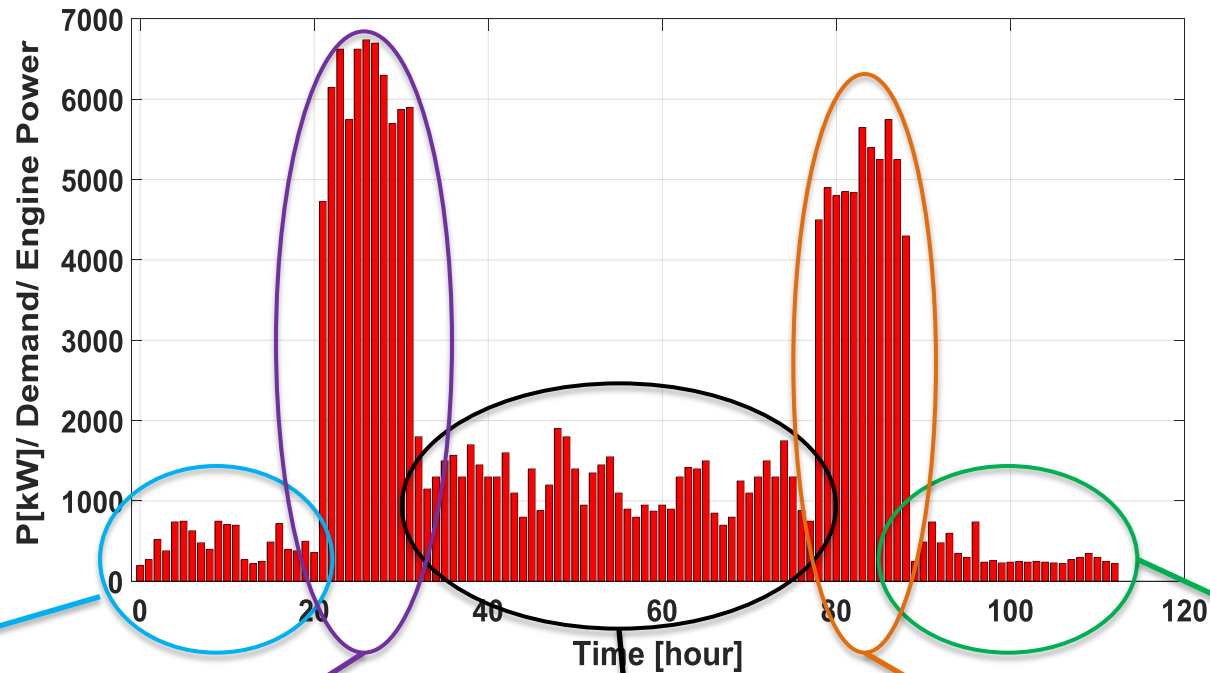
Battery Only



10 Packs of 21 Modules
Voltage: 1058 VDC
Capacity: 6500Wh x 210 = 1365 kWh



Battery dimensioning for PSV hybrid Operation Profile - Vasquez (2014)



Loading in Port

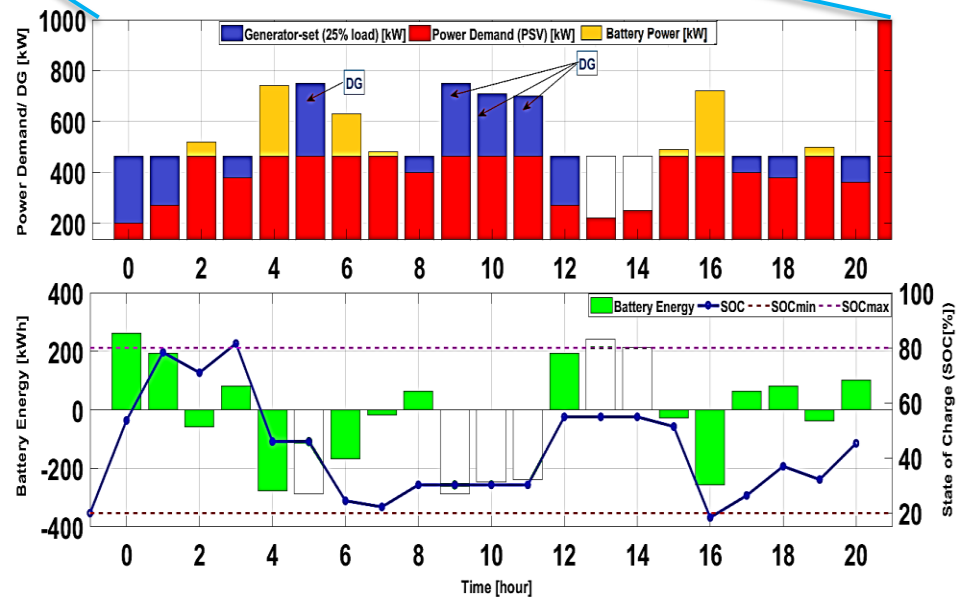
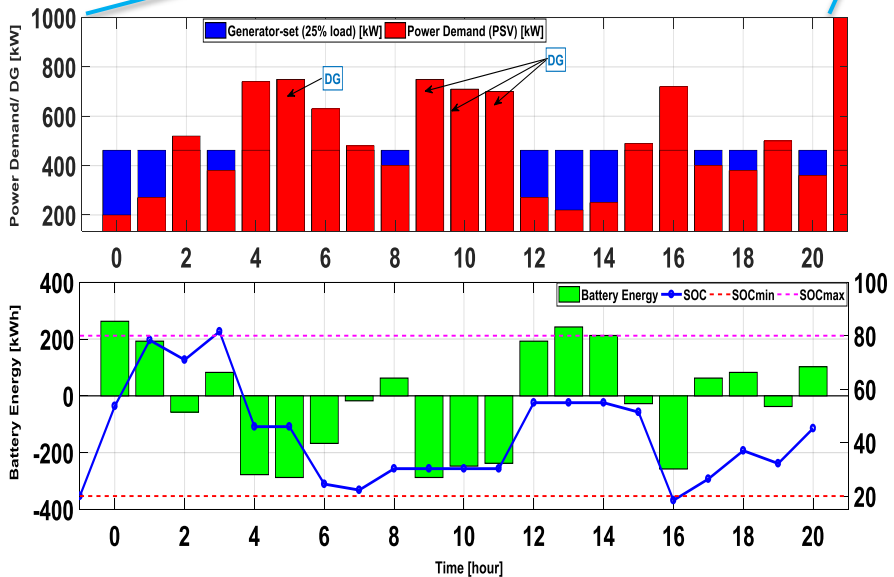
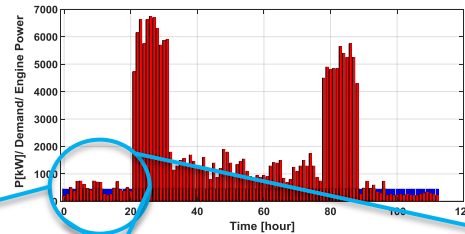
Laden Voyage

DP operation

Partial Load Voyage

Stand-by

Battery dimensioning for PSV hybrid Loading in Port (Generator-set 25%)



Battery dimensioning for PSV hybrid DP (Genset 1246,19 kW – Average demand)

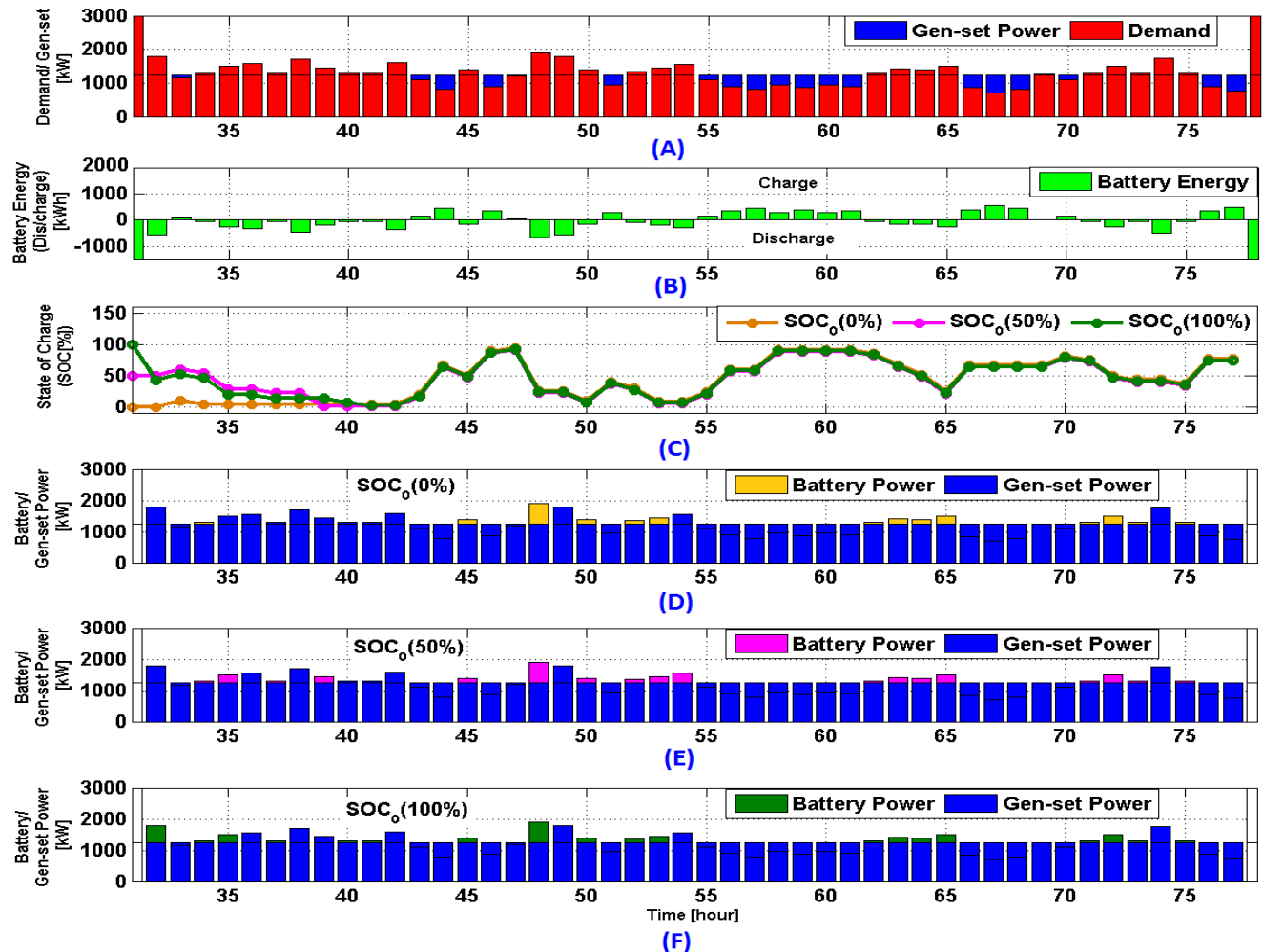
Battery operation study with $P_{\text{gen-set}} = 1246,19 \text{ kW}$ and $E_{\text{battery}} = 950 \text{ kWh}$ (based on the Operational Profile presented in Vasquez (2014)).

Total capacity (battery) = 950 kWh

Estimated capacity (battery) = 808 kWh (based Operation Profile)

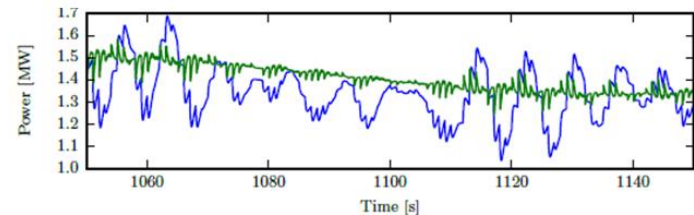
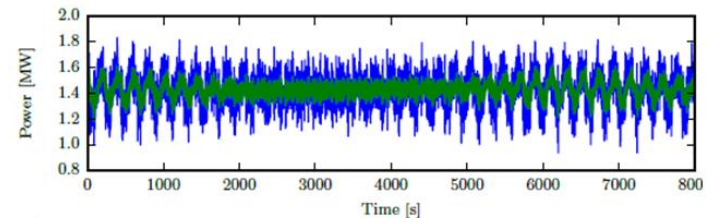
Maximum Power (battery) = 654 kW

C-rate = 0,69 (about 87 min)



Strategic Uses of Batteries in PSV Vessels

- 1) *Enhanced Dynamic Performance (Energy Applications)*
- 2) *Peak Shaving (Power Applications)*
- 3) *Spinning Reserve (Energy Applications)*
- 4) *Strategic Loading (Power and/or Energy Applications)*
- 5) *Zero Emissions Operation (Energy Application)*

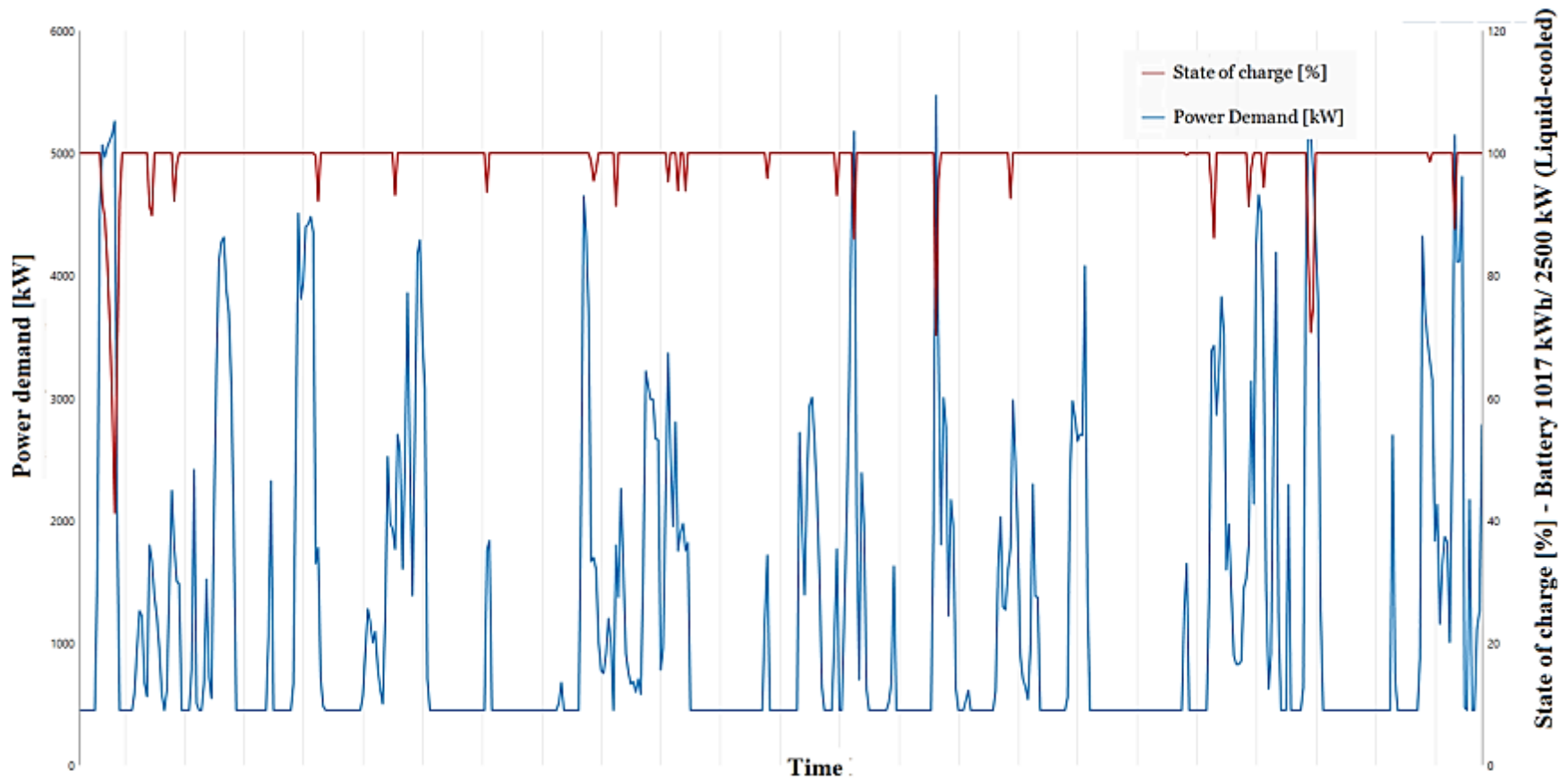


— Without peak-shaving
— With peak-shaving

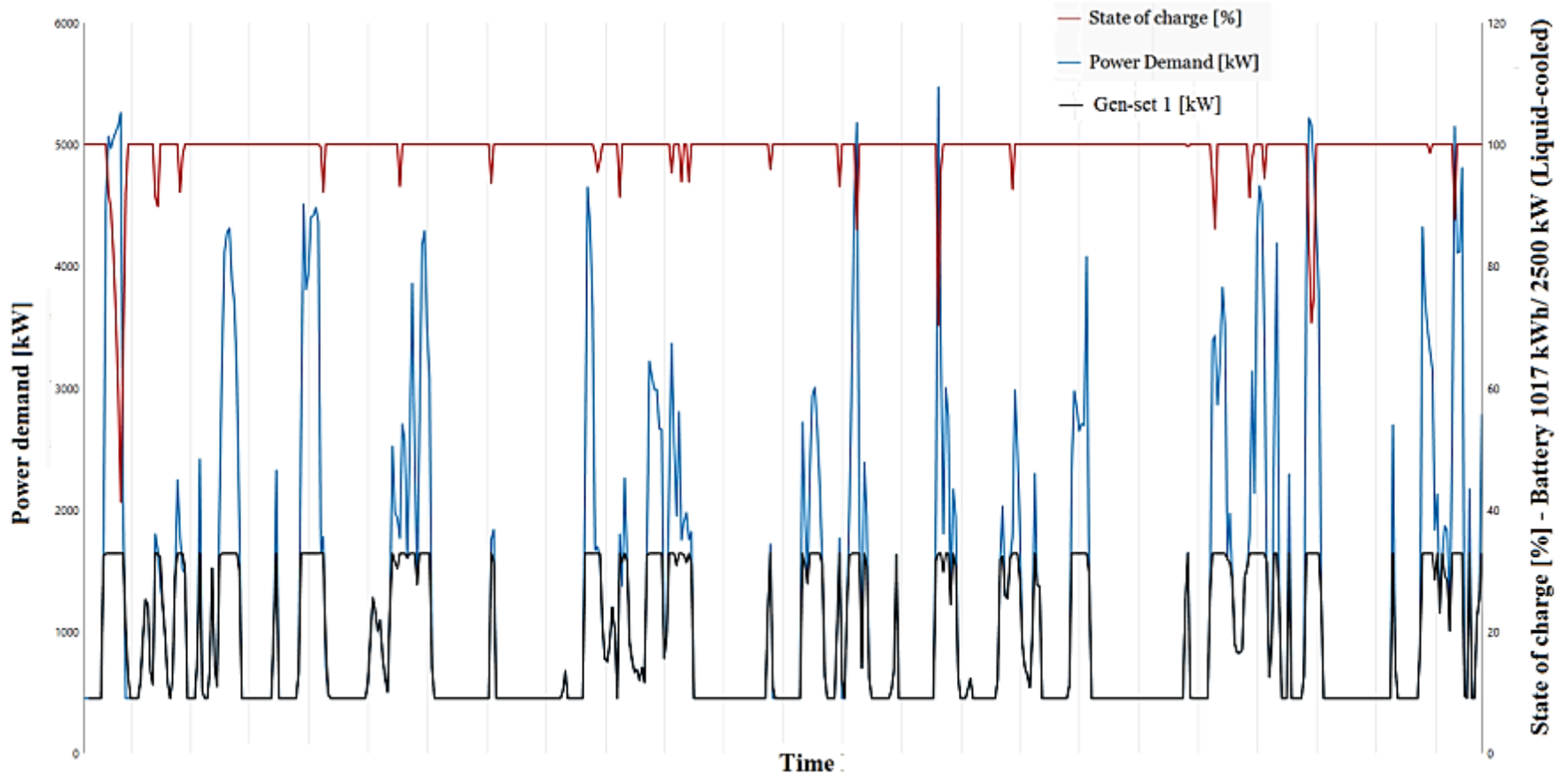
Peak Shaving concept for a hybrid vessel.

Battery 1017 kWh/2500 kW - Peak-Shaving

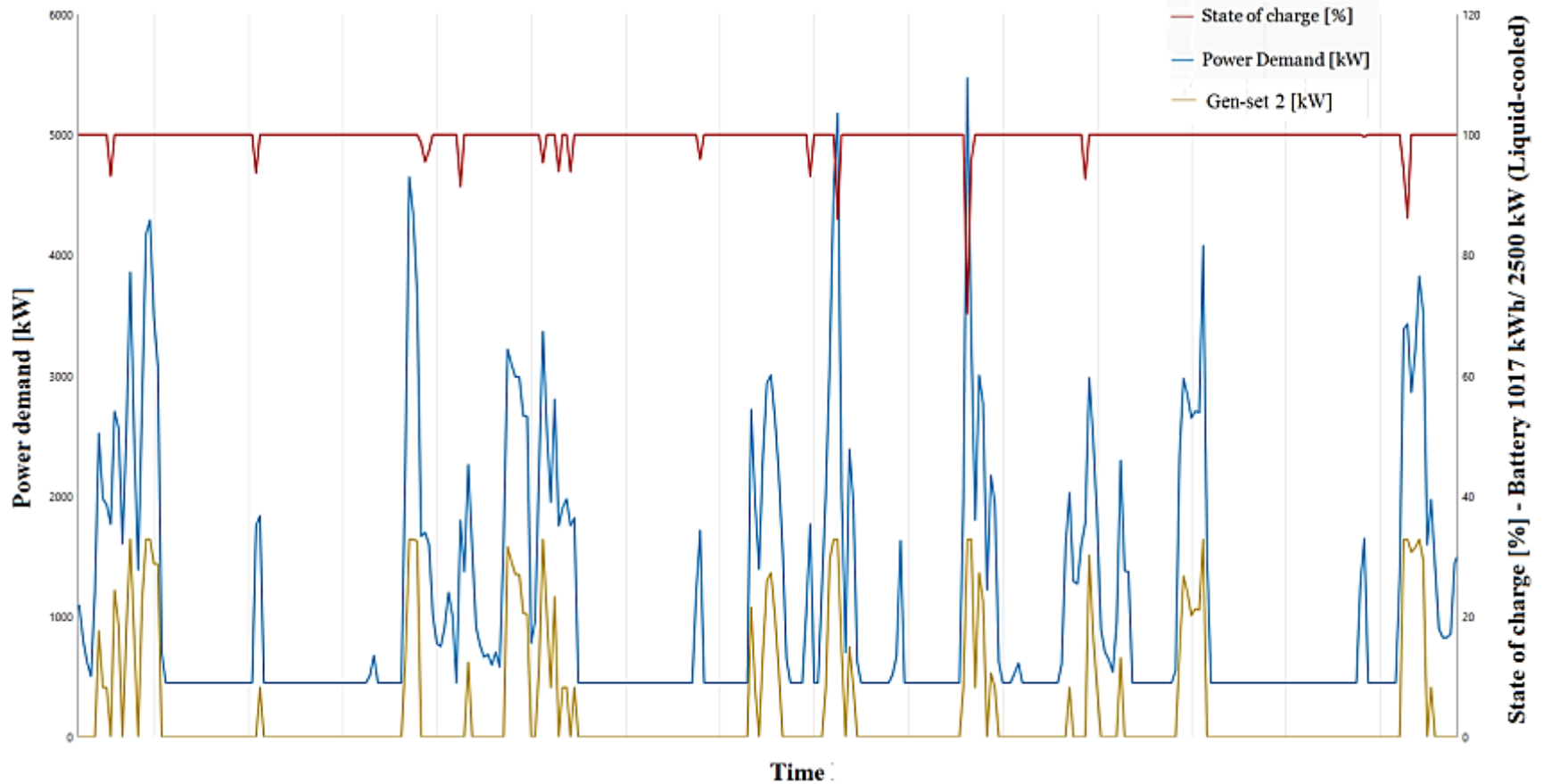
Power demand [kW] and State of charge [%]



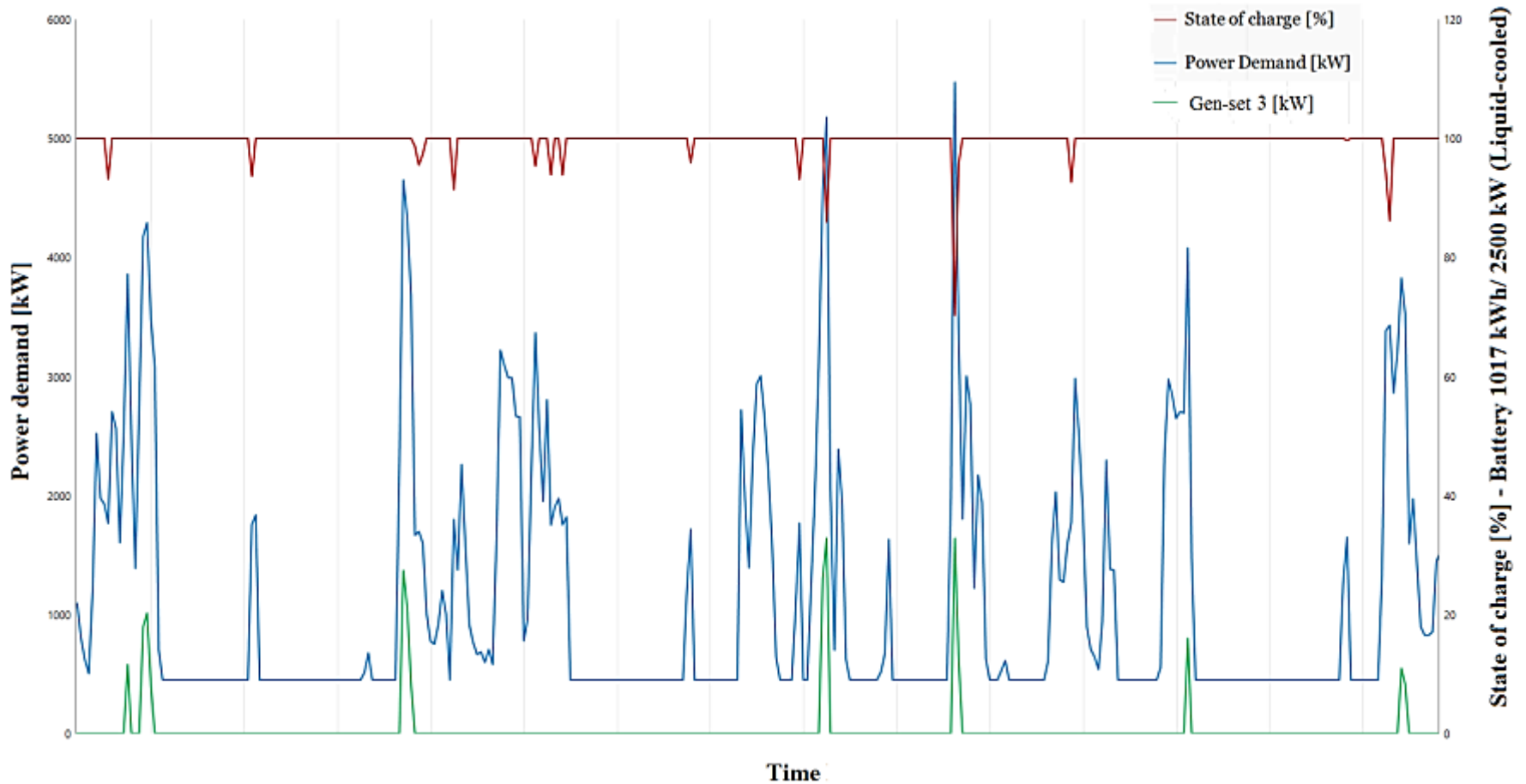
Battery 1017 kWh/2500 kW - Peak-Shaving – Gen-set 1 [kW]



Battery 1017 kWh/2500 kW - Peak-Shaving – Gen-set 2 [kW]



Battery 1017 kWh/2500 kW - Peak-Shaving – Gen-set 3 [kW]





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