I'll have a battery system, please!

About integrating battery systems: Sizing, ROI, AC vs DC and Power Quality

Matthijs Mosselaar – Alewijnse
Akhil Ajith – Alewijnse

11th February 2025

KNVTS

'Wie nu een thuisbatterij koopt, komt niet uit de kosten'

Evi Husson | 05 feb. 2024 | Laatste update: 06 jun. 2024

Lucas van Cappellen: "Het huidige beleid staat de thuisbatterij in de weg." (foto: NPF Photography)

Why a battery?

- Expensive
  - Battery cost
  - Converter cost
  - Integration cost
- Relatively big
- Electrical losses
- Dead within 2 years

Introduction

Matthijs Mosselaar

Background: MSc Electrical Power Engineering
TU Delft

Occupation: (Electrical) Engineer
- Hybrid systems
- Modelling/Simulation
- Power Quality / EMC

Akhil Ajith

Background: MSc Sustainable Energy Technology
TU Delft

Occupation: (Electrical) Engineer
- Hardware In Loop real-time modelling & hybrid EMS design
- Data Analyst

Agenda / Index

1. Introduction Alewijnse
2. The cost of a Battery Energy Storage System
3. Operational profile analysis
   – Less than ideal
   – Ideal
4. Optimizing the system
5. Coffee break
6. DC vs AC (hybrid systems)
7. Filter design & power quality
8. Key takeaways & Questions/discussions

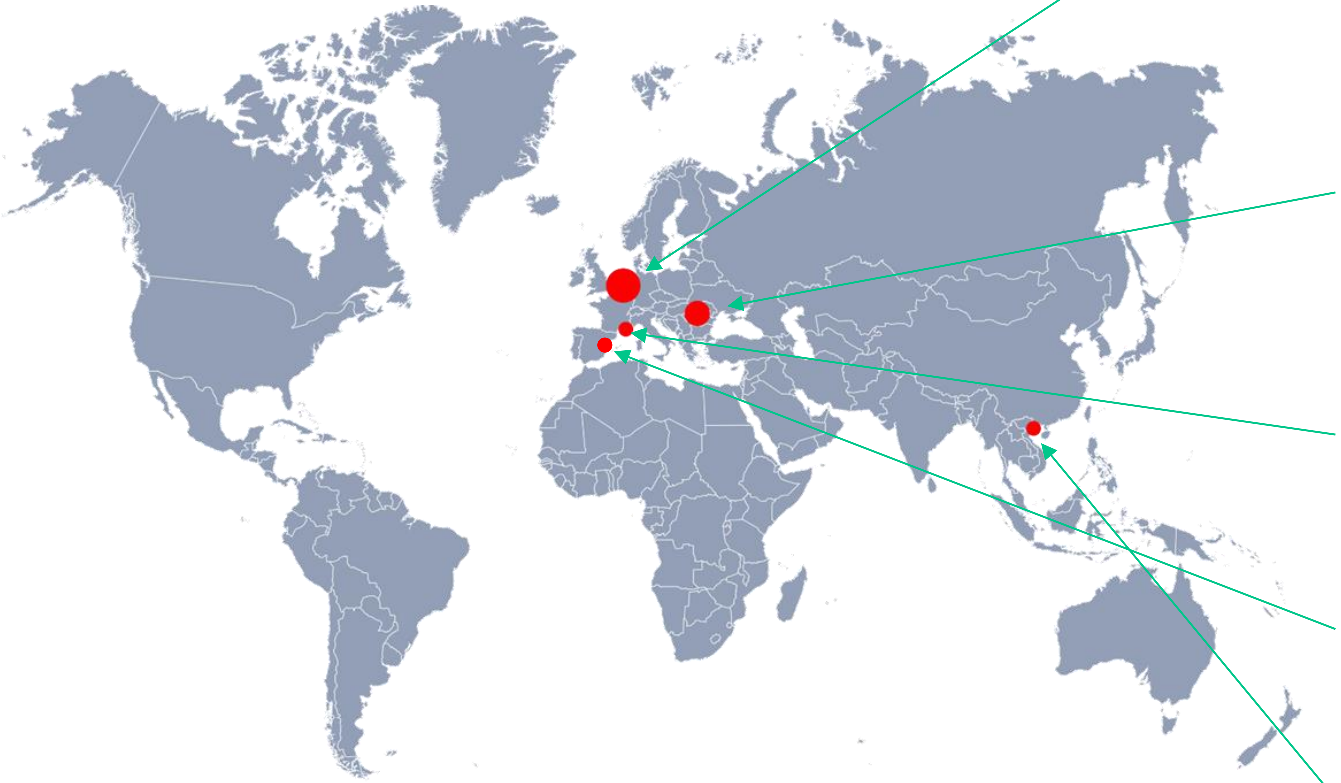
Alewijnse

- All-round technological partner with over 130 years of experience in Maritime and Industry
- Working in 4 segments:
  - Yachting
  - Dredging, offshore & transport
  - Naval & governmental
  - Industry
- New build, refit, solutions, panel-building, repair & maintenance projects
- International footprint, own branches in the Netherlands, Romania, France, Spain and Vietnam
- Competent & flexible, +/- 130 engineers, +/- 600 electrical installers

Our History – over a century of experience

1889-1899	1900-1945	1945-1962	1962-1980	1980-2002	2002-2015	PRESENT
Start: Light bulb factory Roothaan, Alewijnse & Co	Electrical installation company C. Alewijnse & Co	Strong growth in electrical installations of factories and vessels	Start and take-over companies in Vlaardingen, Tiel, Drachten, Zwolle, Zaltbommel and Delft	Emergence of ICT, start-up company in Romania, take-over company in Krimpen a/d IJssel	Internationalization and focus on engineering and automation	Take over by SRC, Common Wealth & Damen. Further focus on system integration. Tijssen Elektro added to the Alewijnse

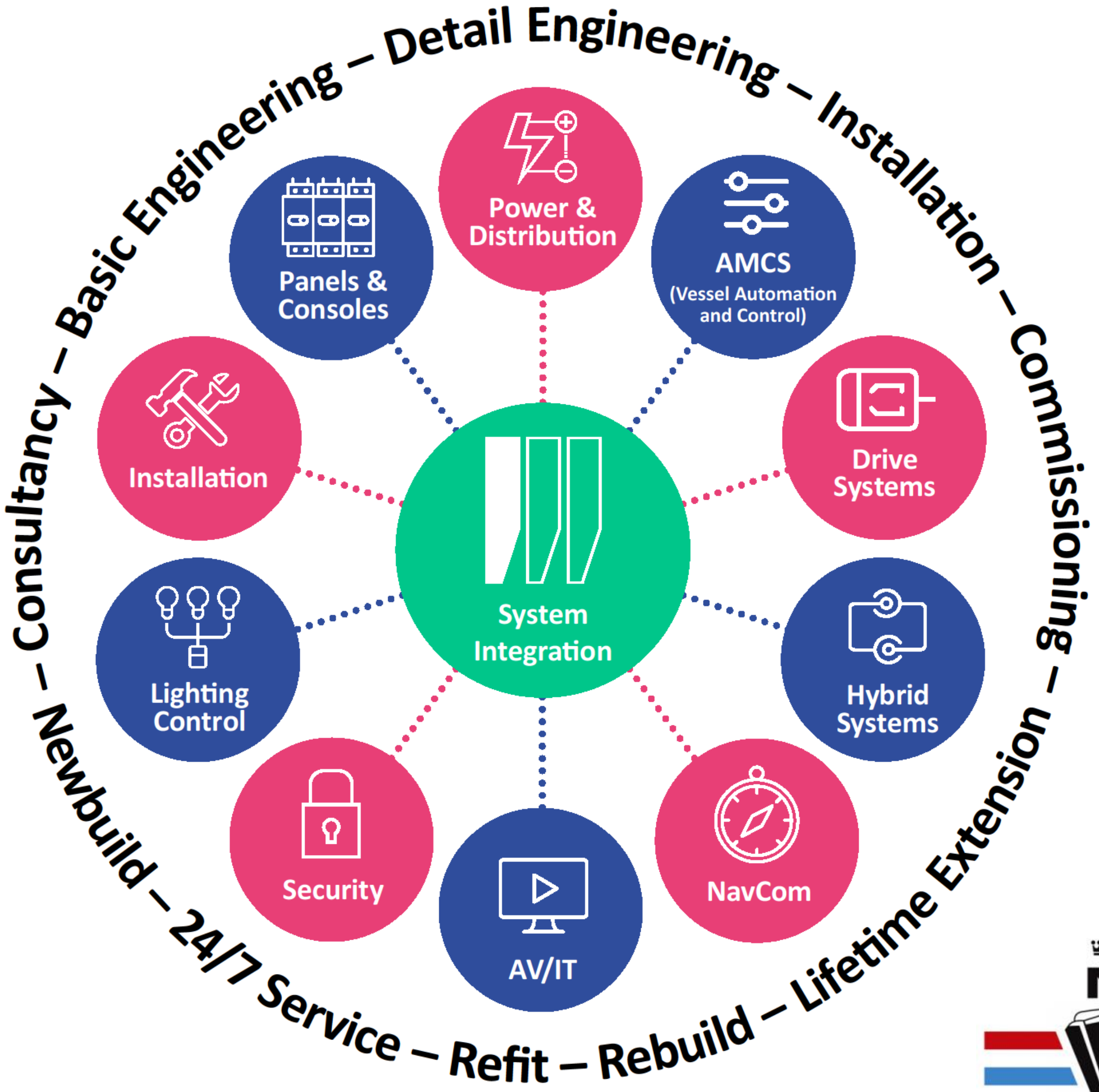
Our locations



- **The Netherlands**
  - Nijmegen (HQ),
  - Rotterdam,
  - Drachten,
  - Oss
- **Romania**
  - Galati,
  - Mangalia
- **France**
  - La Ciotat
- **Spain**
  - Vilanova
- **Vietnam**
  - Hai Phong

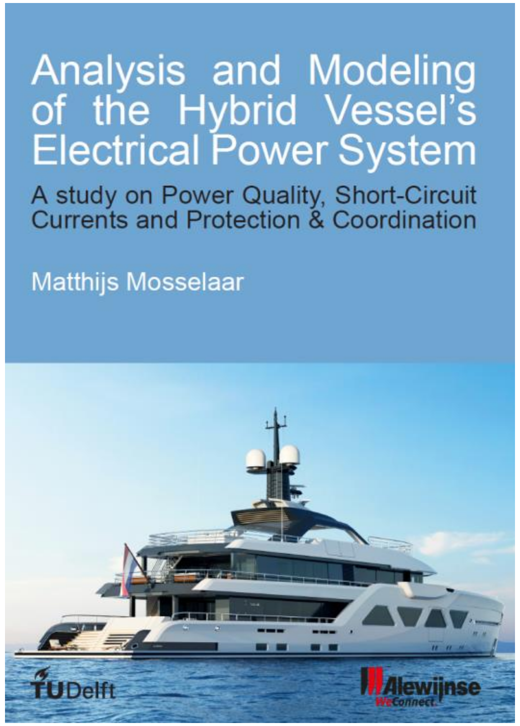
What we offer

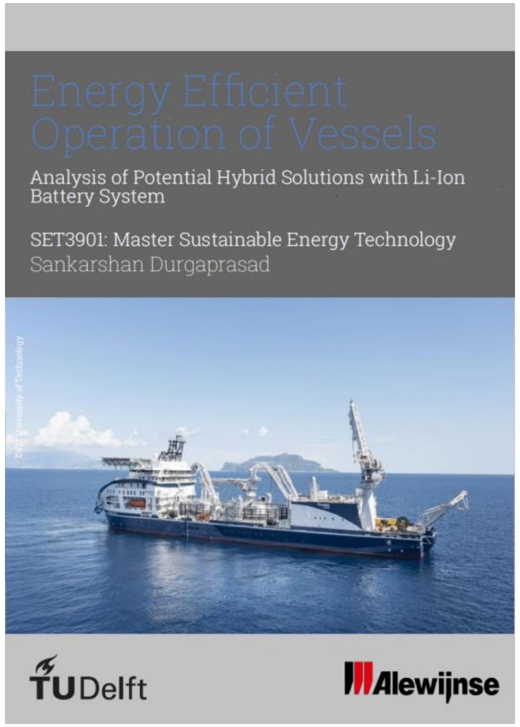
- Our solutions
  - Vessel automation
  - Process automation
  - Navigation & Communication Systems
  - Electric Installation
  - Switchboards & Consoles
  - Power Distribution
  - Drive Systems
  - **Hybrid Systems**
  - Audio/Video & IT
  - Safety & Security

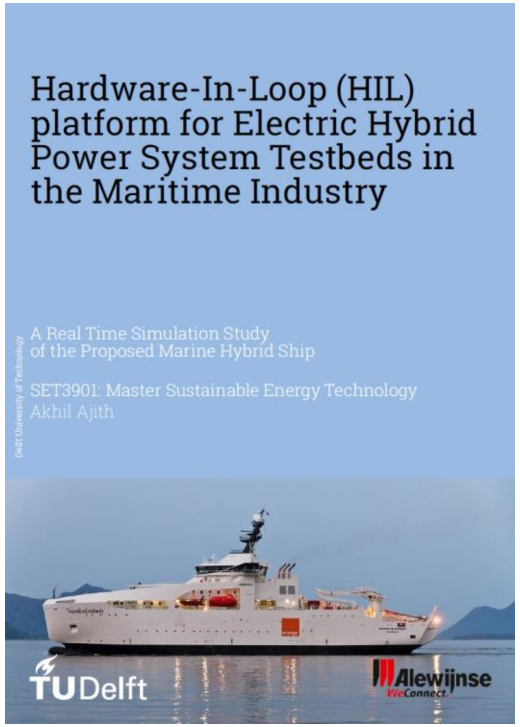


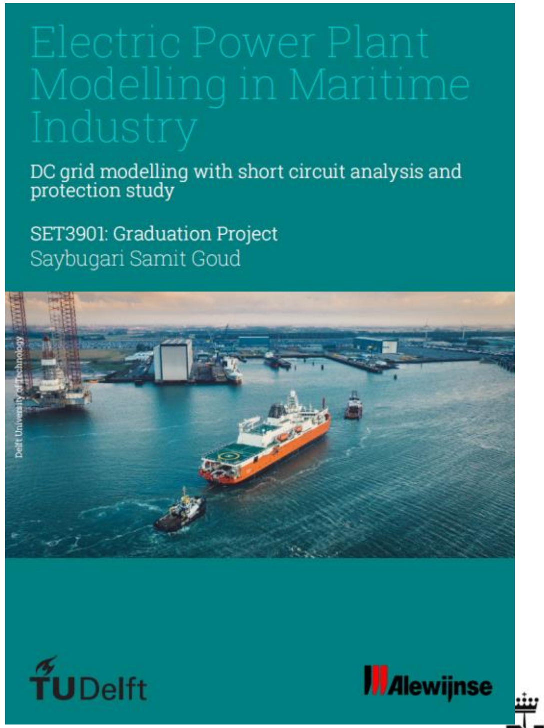
R&D

Thesis projects









R&D

Partners

Strong collaboration with universities
Multiple internships and thesis projects realised

MATLAB & Simulink simulation software
Advanced data visualisation and time domain analysis

ETAP simulation software
Advanced power system analysis studies

Consultancy

- Early involvement
- Total Cost of Ownership Analyses
- Data Analysis-Based Modelling
- Maintenance Analysis
- Improvement in Overall Equipment Effectiveness
- Bridge gap between concept design, basic design and commercial viability

Alewijnse

Our customers
Whom we connect

DAMEN

oceAnco

KONINKLIJKE DE VRIES SCHEEPSBOUW

MB92 GROUP

ROYAL HUISMAN

AMELS

DAMEN yachting

Royal IHC

GREAT LAKES DREDGE & DOCK COMPANY, LLC

THECLA BODEWES SHIPYARDS

DEME
Dredging, Environmental & Marine Engineering

LÜRSSEN

DJN

Boskalis

Van Oord

JUMBO

Allseas

Koninklijke Marine

oaseo drinkwater

VB SUSTAINABLE TOGETHER

Vitens

WEIR

Vion FOOD GROUP

HAUZER

Let's do the math

- Battery price €500,-/kWh
- Converter cost
- Integration/EMS cost
- Losses
- Limited lifetime

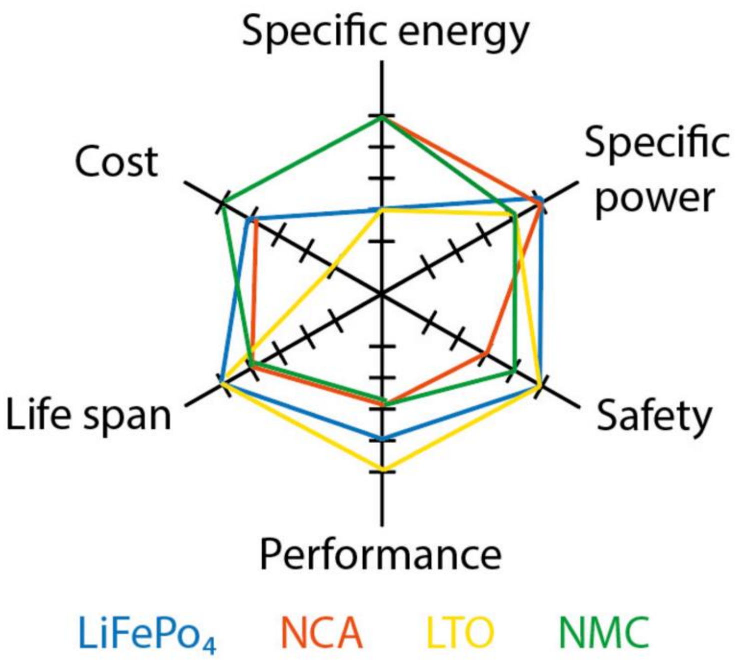
200kWh battery:	€100.000
400kW converter:	€150.000
	= €250.000
Fuel price:	€750/mt
Fuel amount:	333mt
Fuel price:	€500/mt
Fuel amount:	500mt

Battery specifications

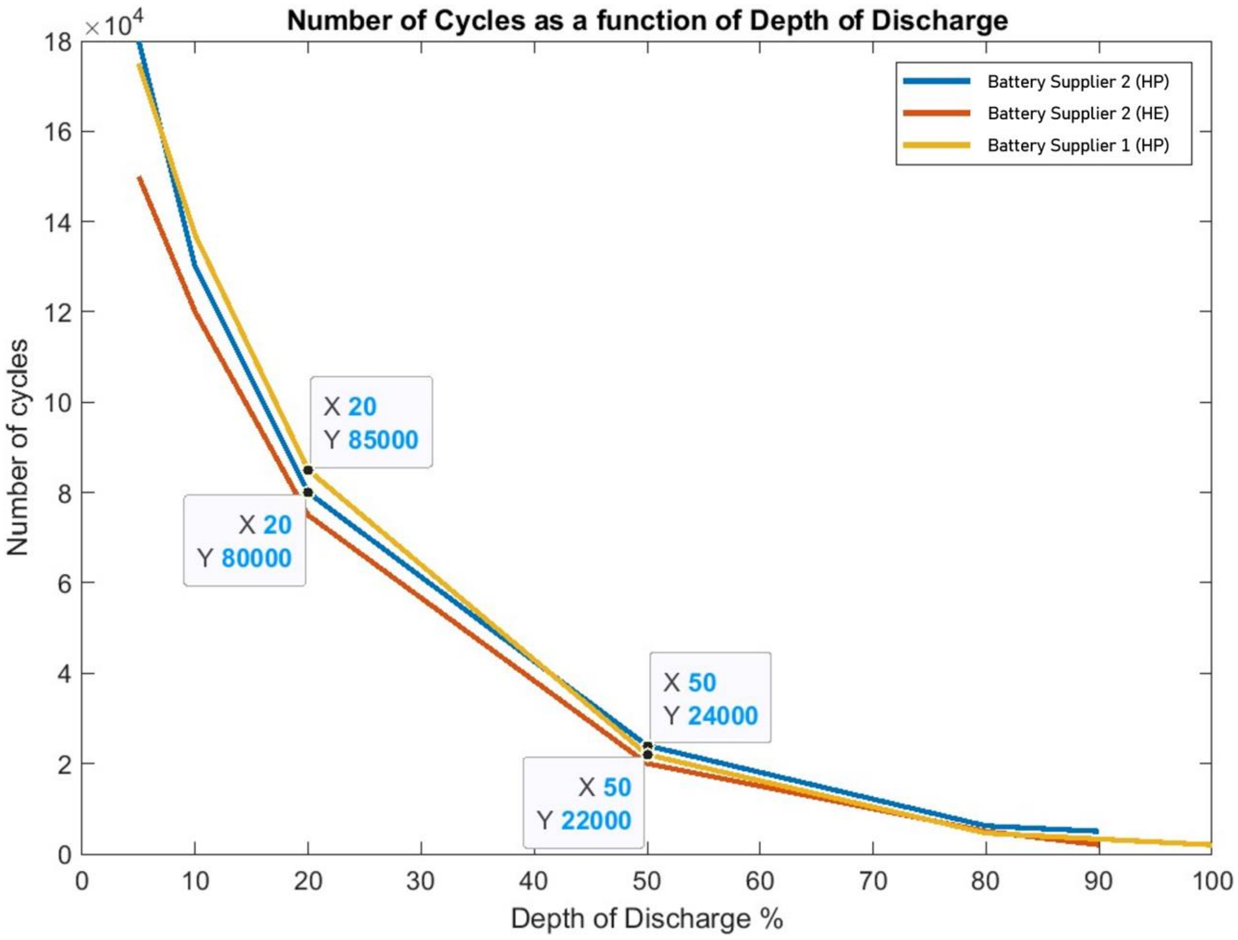
- High power
- High energy
- Chemistry
- Ageing

$$\text{C-rate} = \frac{\text{power (kW)}}{\text{energy (kWh)}}$$

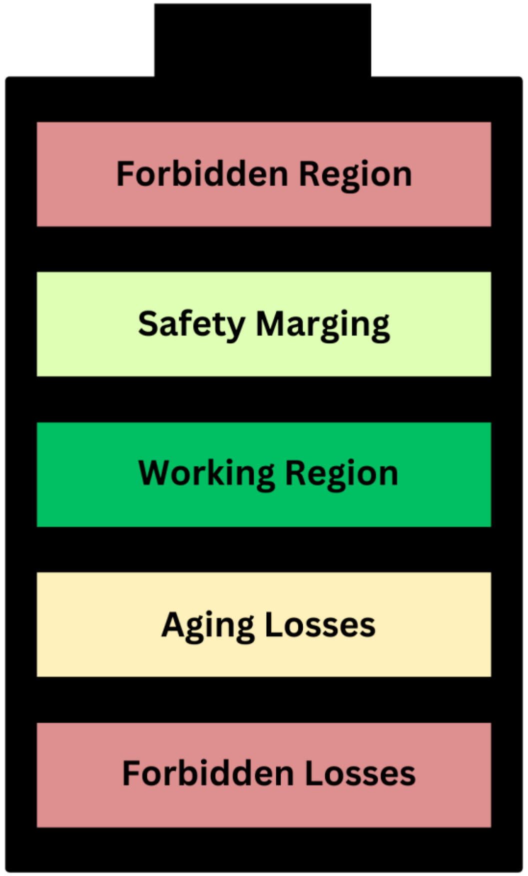
C-rate < 0,8: high energy
C-rate > 0,8: high power



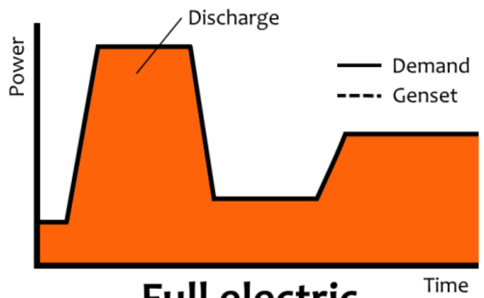
Battery specifications



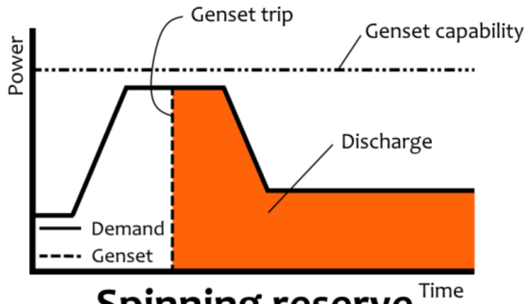
Battery specifications



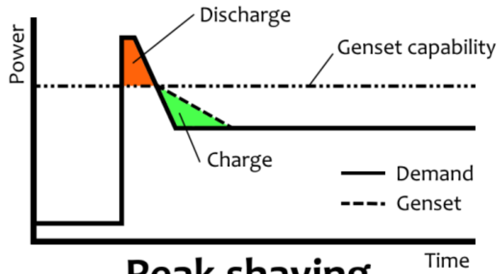
How do you use the battery?



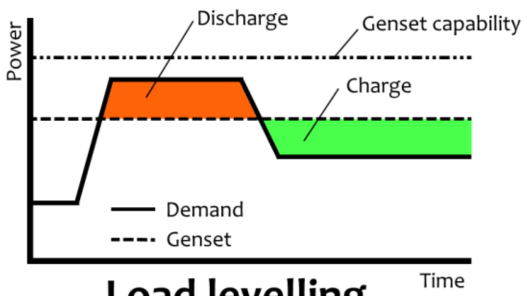
Full electric



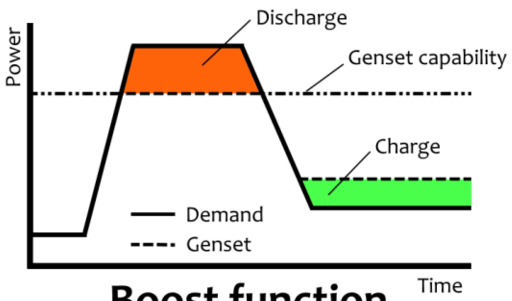
Spinning reserve



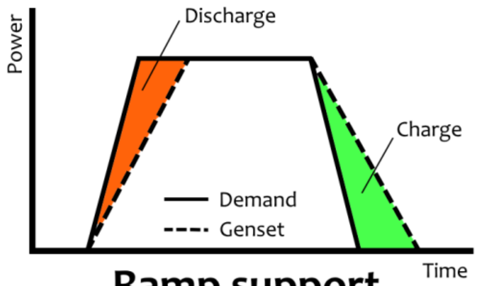
Peak shaving



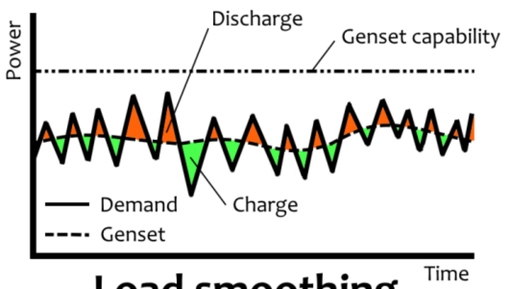
Load levelling



Boost function



Ramp support



Load smoothing

Operational profile

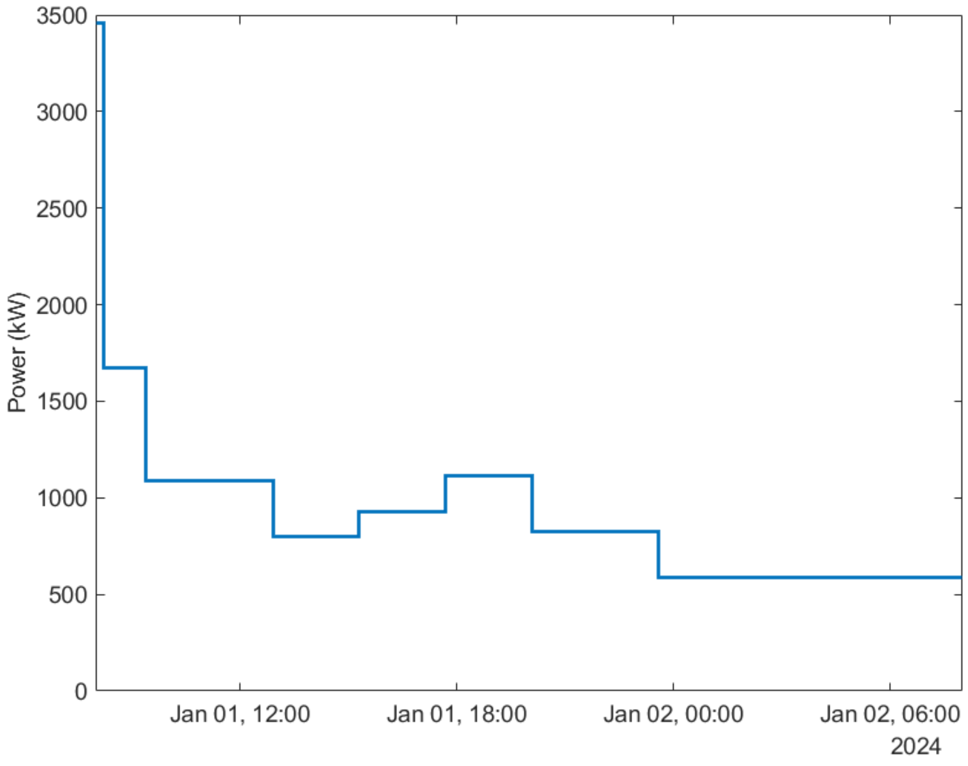
Less than ideal case

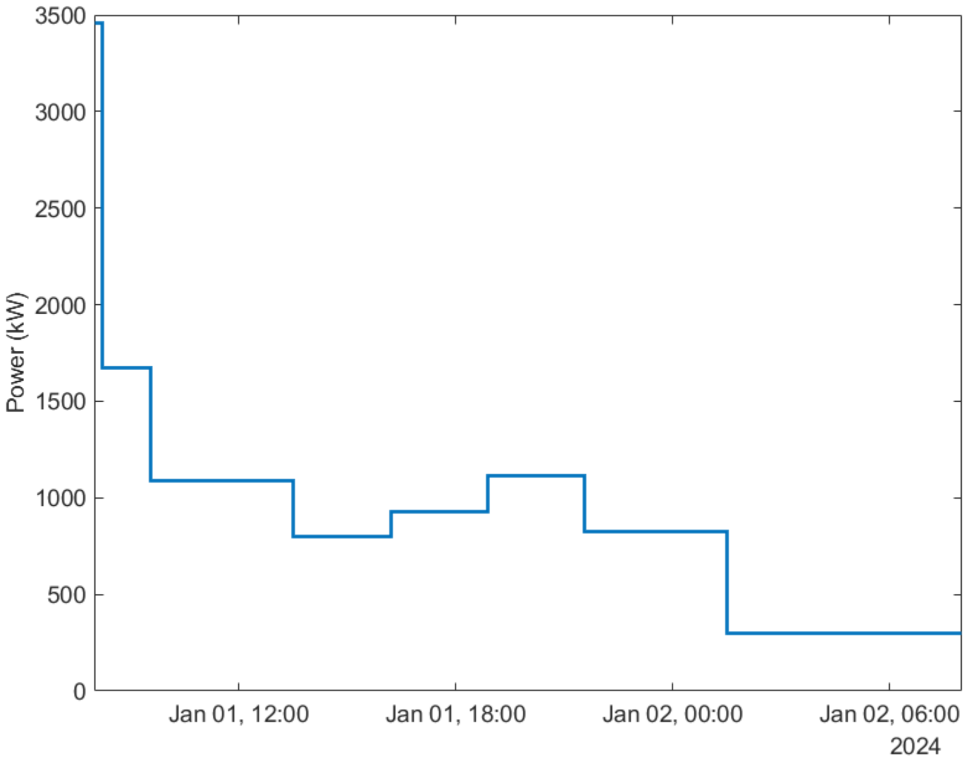
- Create operational based on operating mode power and time
- Example for an '80 percent full-electric vessel'

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	
Operating mode 1	0,21	0,21	0,21	0,21	0,21	0,21	0,24	0,21	0,21	0,21	0,21	0,21	0,21	0,24	3
Operating mode 2	1,19	1,19	1,19	1,19	1,19	1,19	1,34	1,19	1,19	1,19	1,19	1,19	1,19	1,34	17
Operating mode 3	3,51	3,51	3,51	3,51	3,51	3,51	3,94	3,51	3,51	3,51	3,51	3,51	3,51	3,94	50
Operating mode 4	2,39	2,39	2,39	2,39	2,39	2,39	2,68	2,39	2,39	2,39	2,39	2,39	2,39	2,68	34
Operating mode 5	2,39	2,39	2,39	2,39	2,39	2,39	2,68	2,39	2,39	2,39	2,39	2,39	2,39	2,68	34
Operating mode 6	2,39	2,39	2,39	2,39	2,39	2,39	2,68	2,39	2,39	2,39	2,39	2,39	2,39	2,68	34
Operating mode 7	3,51	3,51	3,51	3,51	3,51	3,51	3,94	3,51	3,51	3,51	3,51	3,51	3,51	3,94	50
Operating mode 8	8,42	8,42	8,42	8,42	8,42	8,42		8,42	8,42	8,42	8,42	8,42	8,42		101
Operating mode 9							6,5							6,5	13
	24	24	24	24	24	24	24	24	24	24	24	24	24	24	

Operational profile

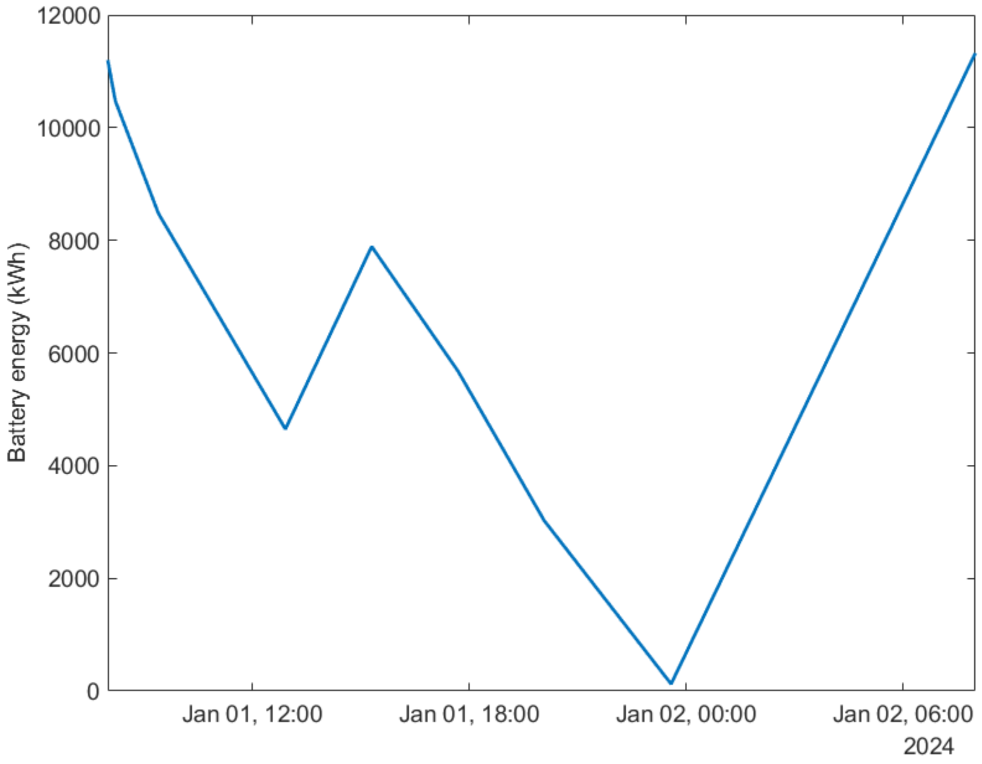
Less than ideal case

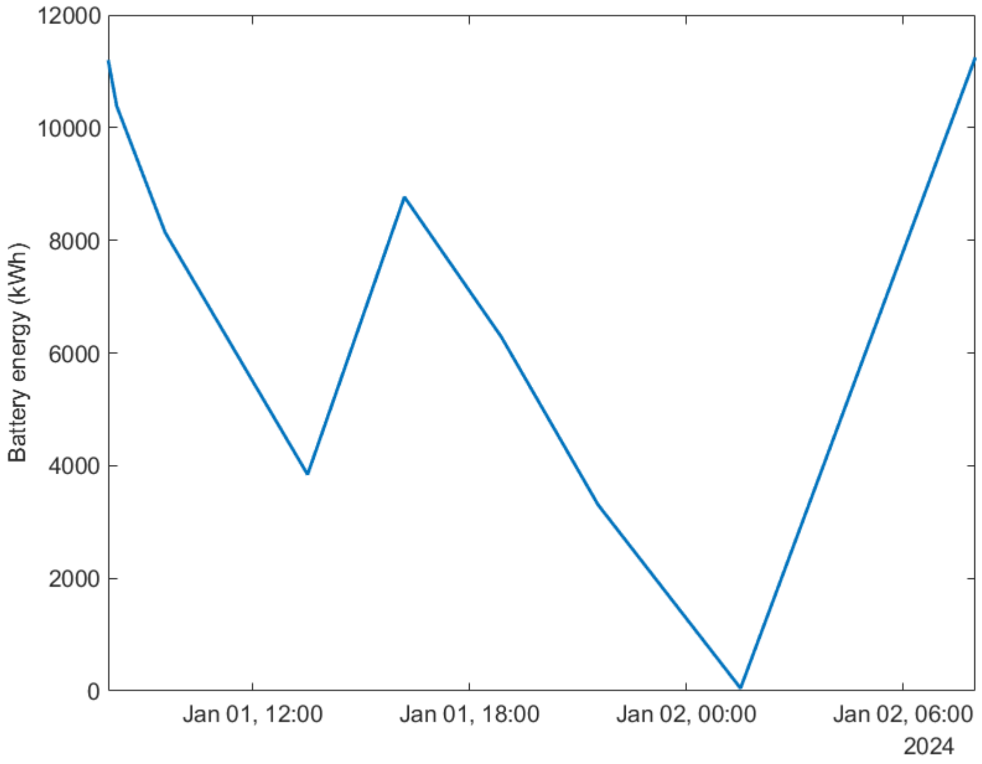




Battery energy

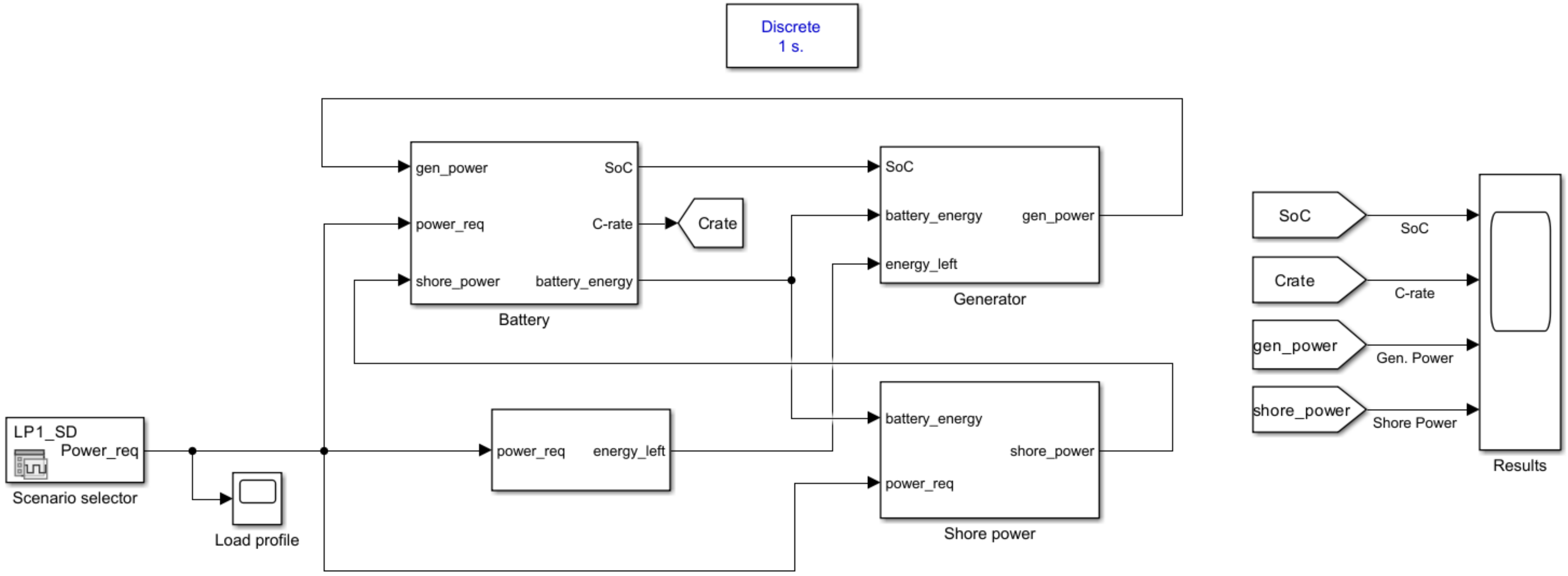
Simulation of operational profile





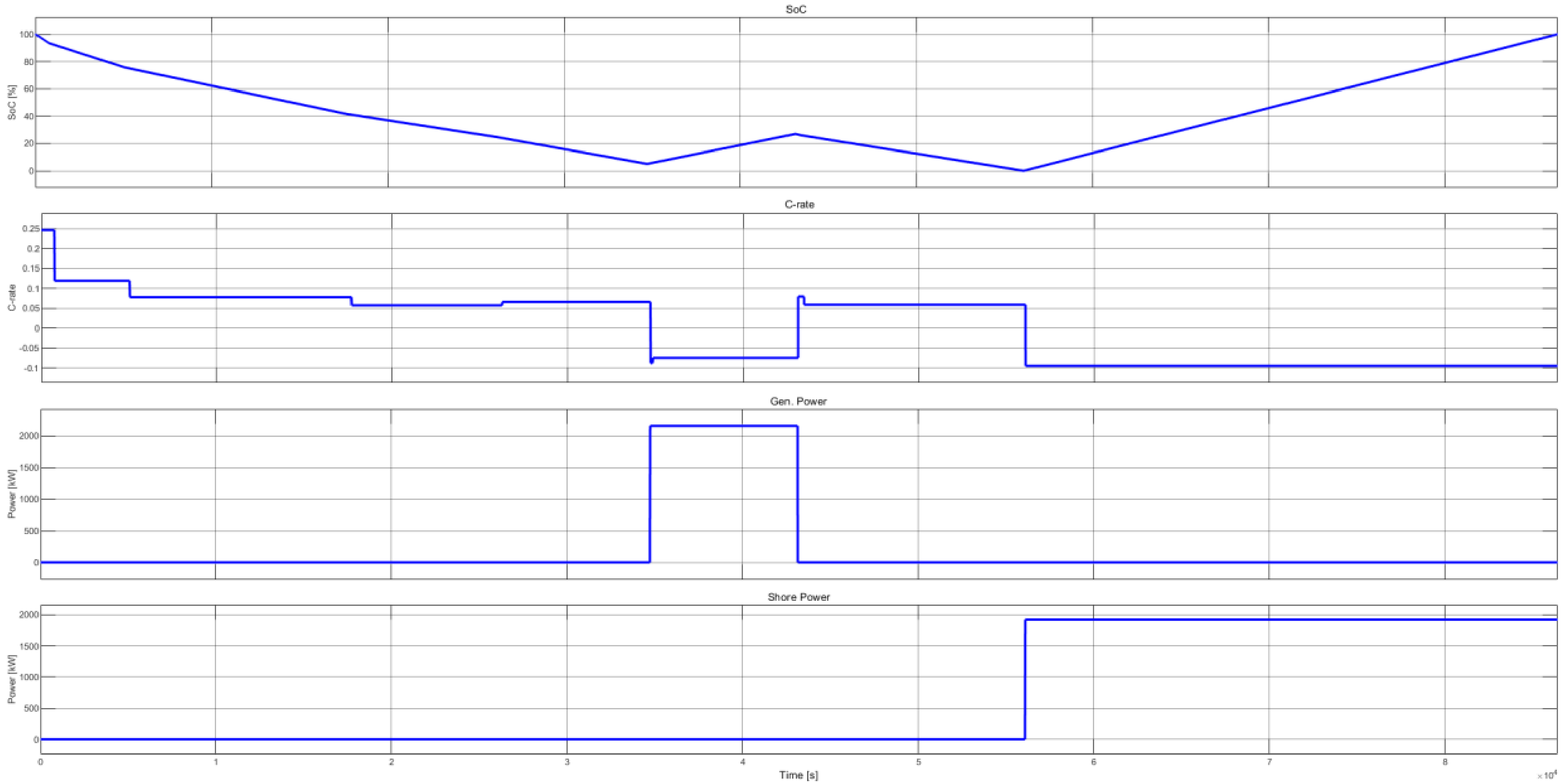
Operational profile

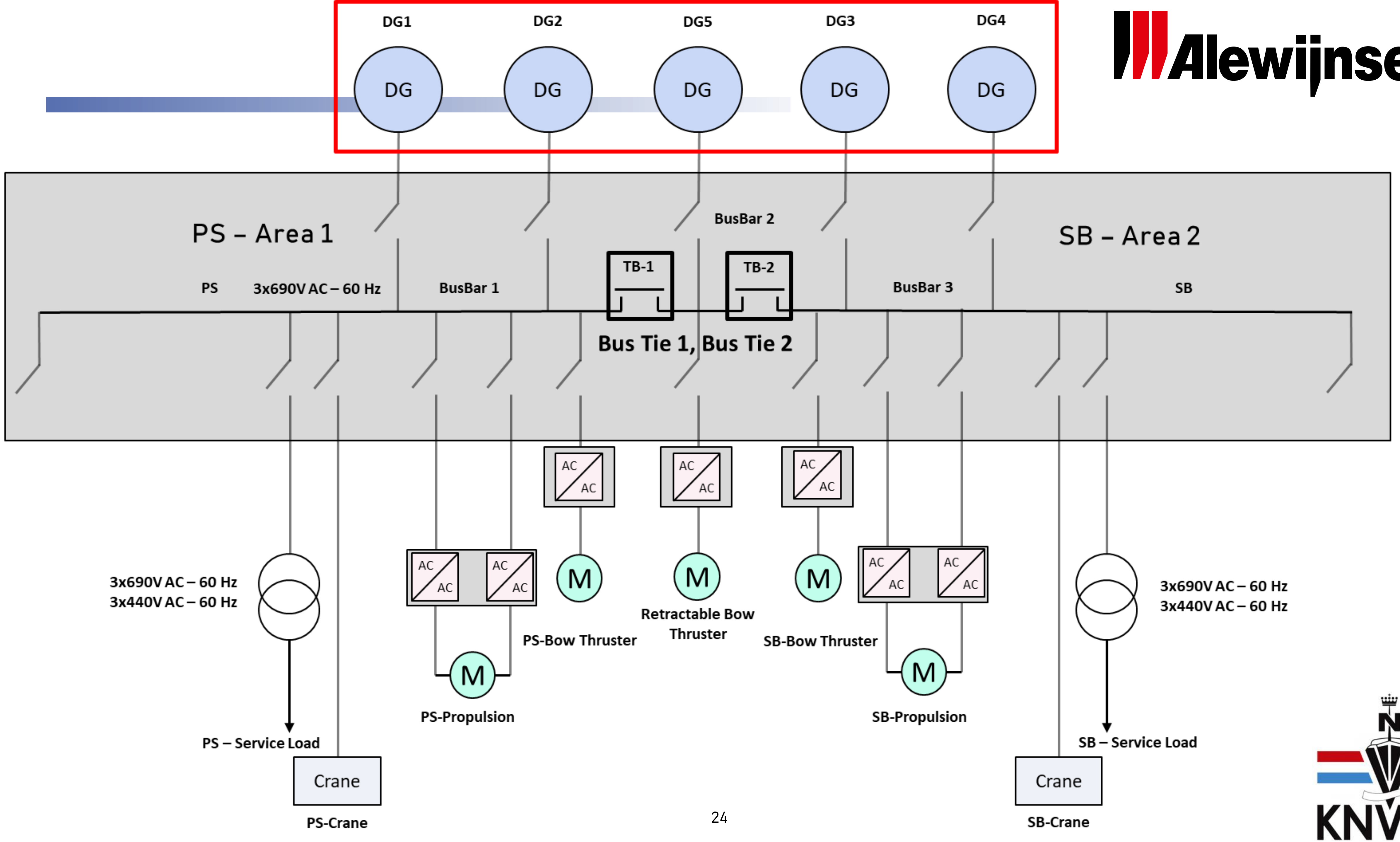
Simulation of operational profile

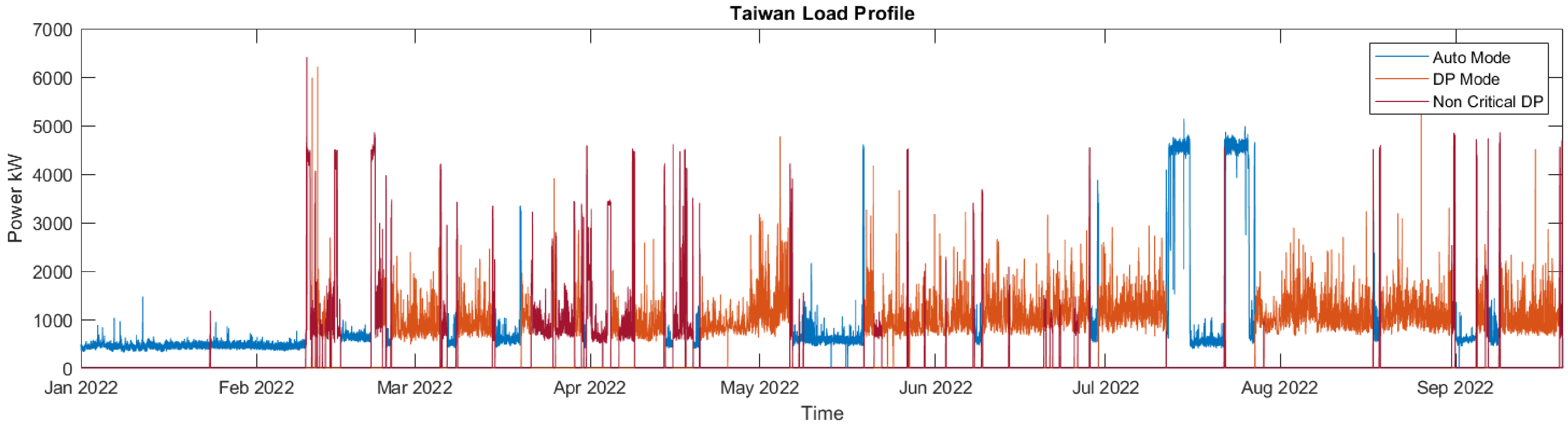


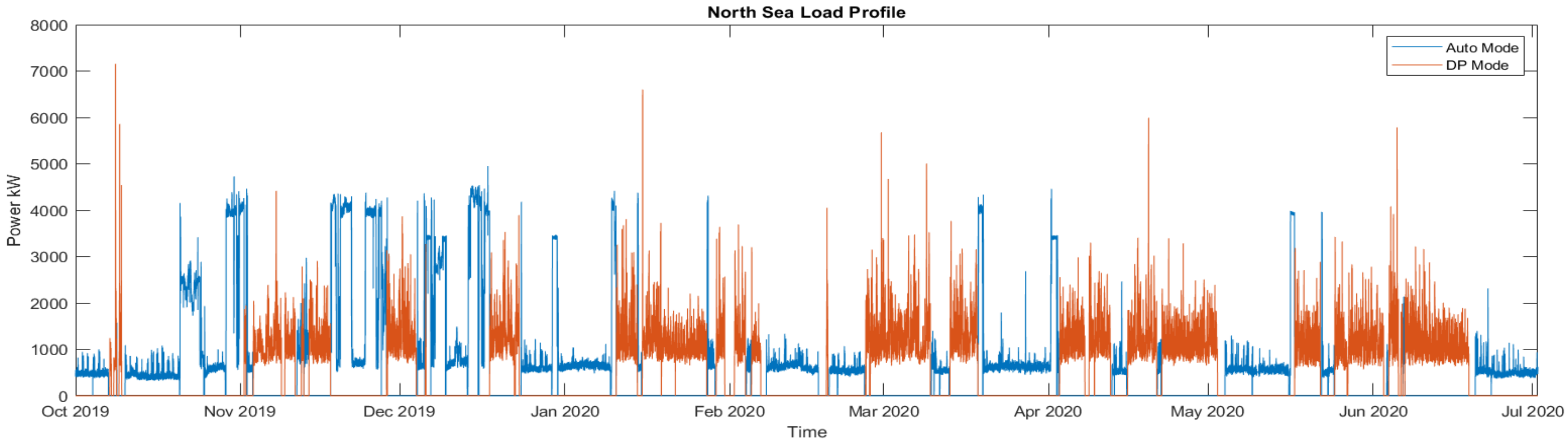
Operational profile

Simulation of operational profile

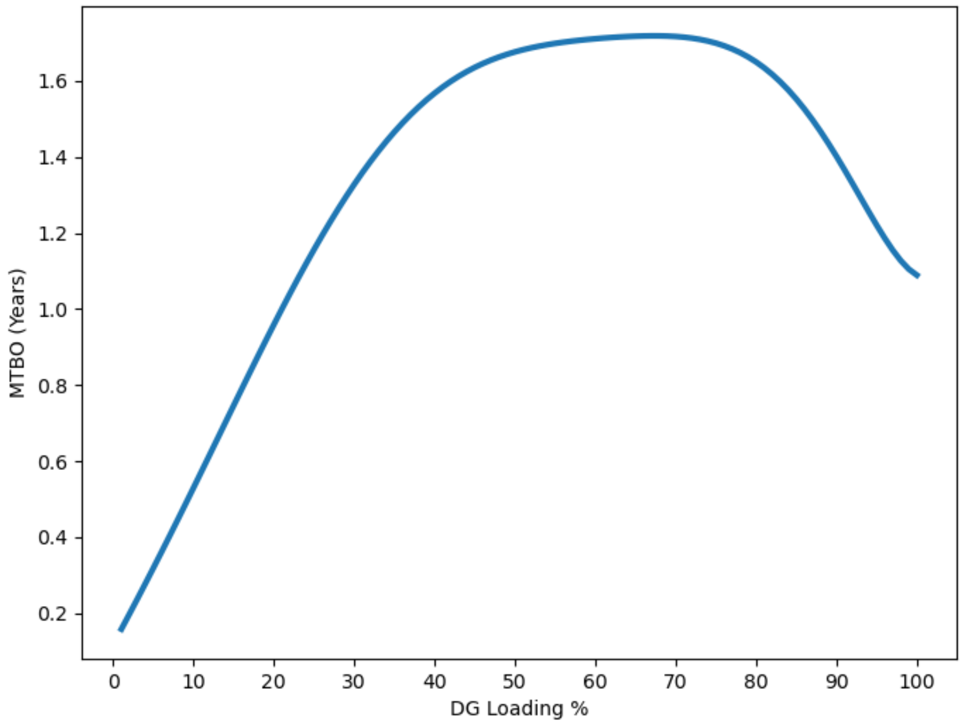



DG1
DG2
DG5
DG3
DG4
DG
DG
DG
DG
DG
PS – Area 1
BusBar 2
SB – Area 2
PS
3x690V AC – 60 Hz
BusBar 1
TB-1
TB-2
BusBar 3
SB
Bus Tie 1, Bus Tie 2
AC
AC
3x690V AC – 60 Hz
3x440V AC – 60 Hz
M
PS-Bow Thruster
Retractable Bow Thruster
SB-Bow Thruster
PS-Propulsion
SB-Propulsion
3x690V AC – 60 Hz
3x440V AC – 60 Hz
PS – Service Load
SB – Service Load
Crane
PS-Crane
Crane
SB-Crane


Taiwan Load Profile
7000
6000
5000
4000
3000
2000
1000
0
Power kW
Auto Mode
DP Mode
Non Critical DP
Jan 2022
Feb 2022
Mar 2022
Apr 2022
May 2022
Jun 2022
Jul 2022
Aug 2022
Sep 2022
Time

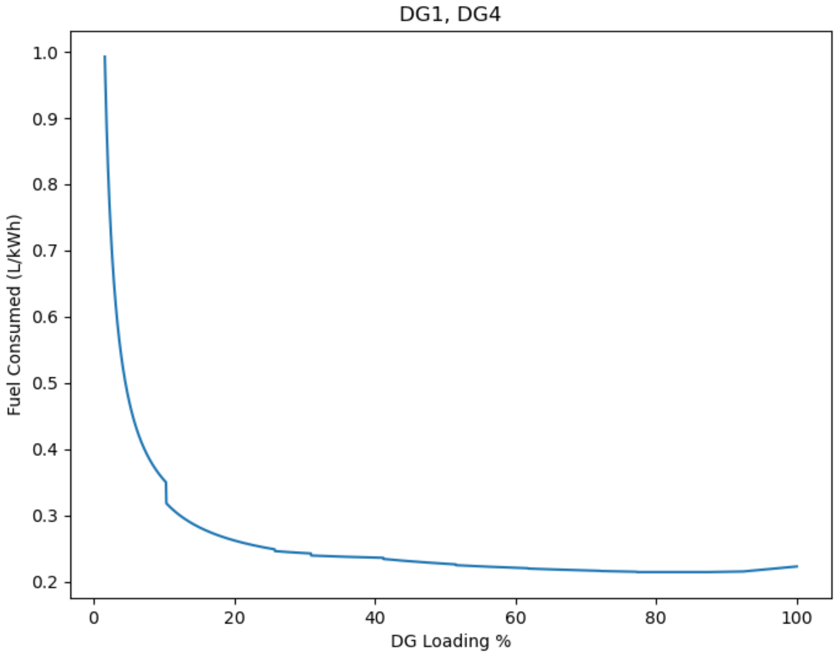

North Sea Load Profile
8000
7000
6000
5000
4000
3000
2000
1000
0
Power kW
Auto Mode
DP Mode
Oct 2019
Nov 2019
Dec 2019
Jan 2020
Feb 2020
Mar 2020
Apr 2020
May 2020
Jun 2020
Jul 2020
Time

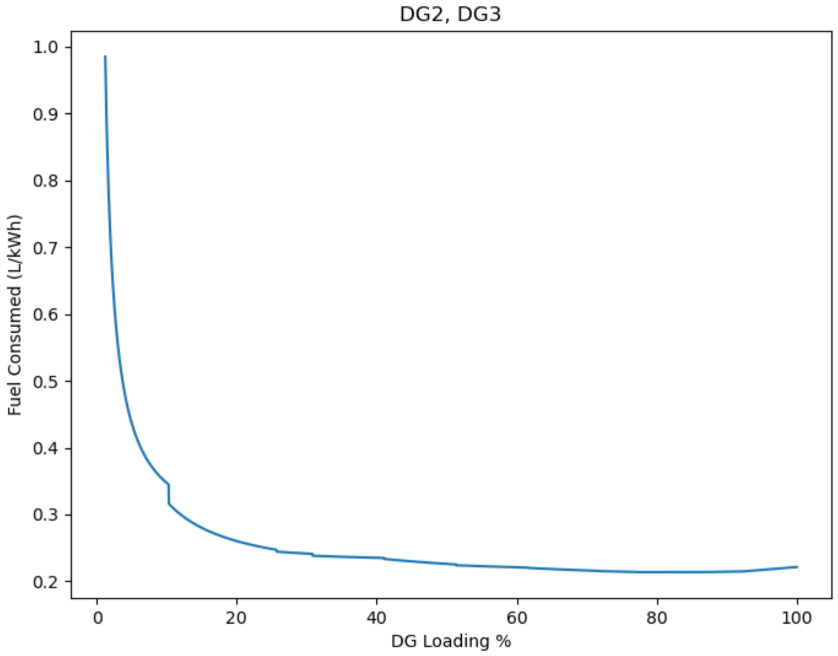
Generator maintenance



[1] Carlos Frederico Matt et al. “Optimization of the Operation of Isolated Industrial Diesel Stations”

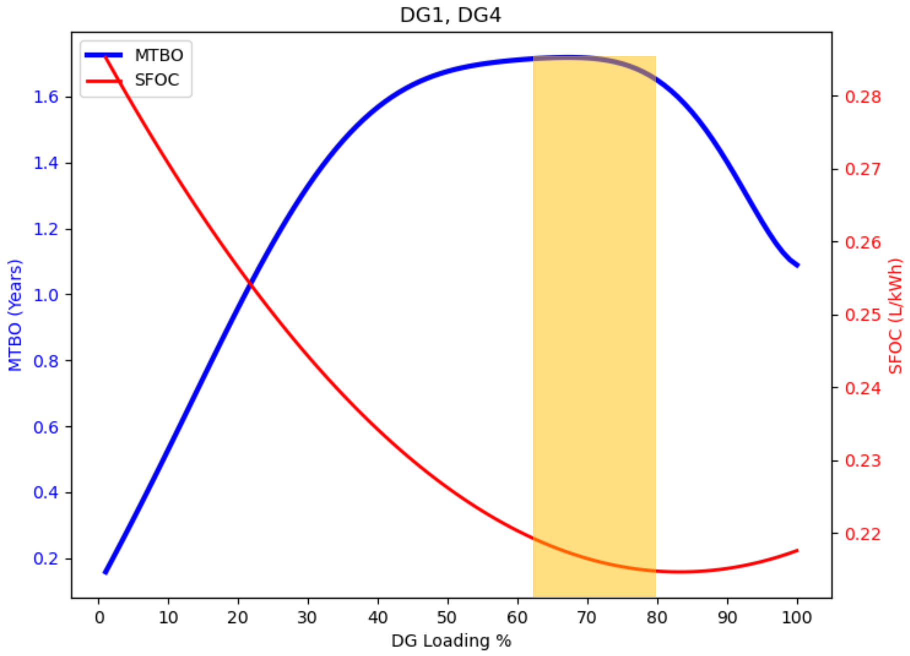
Fuel consumption

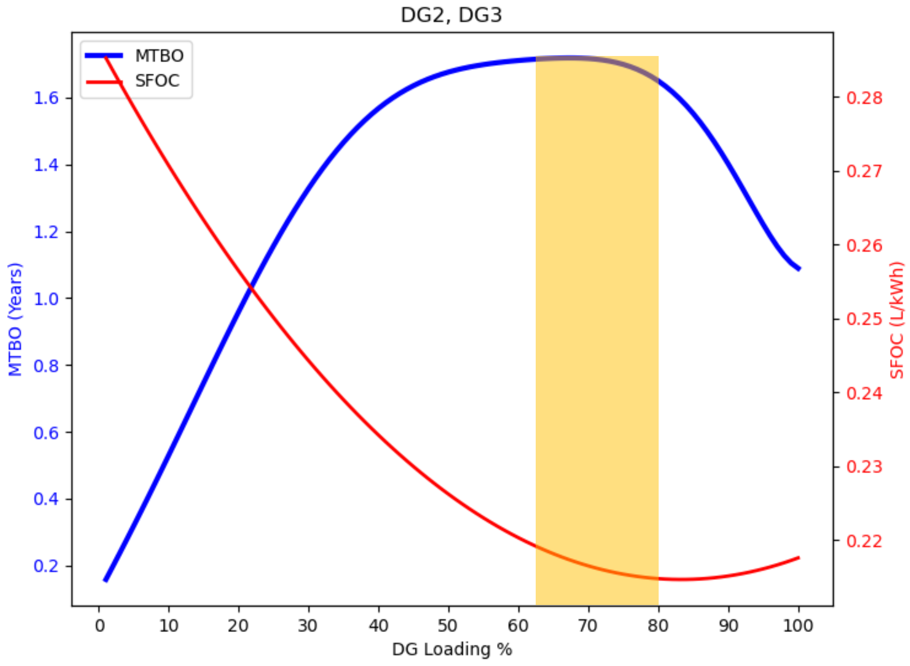




Source: Vessel Owner

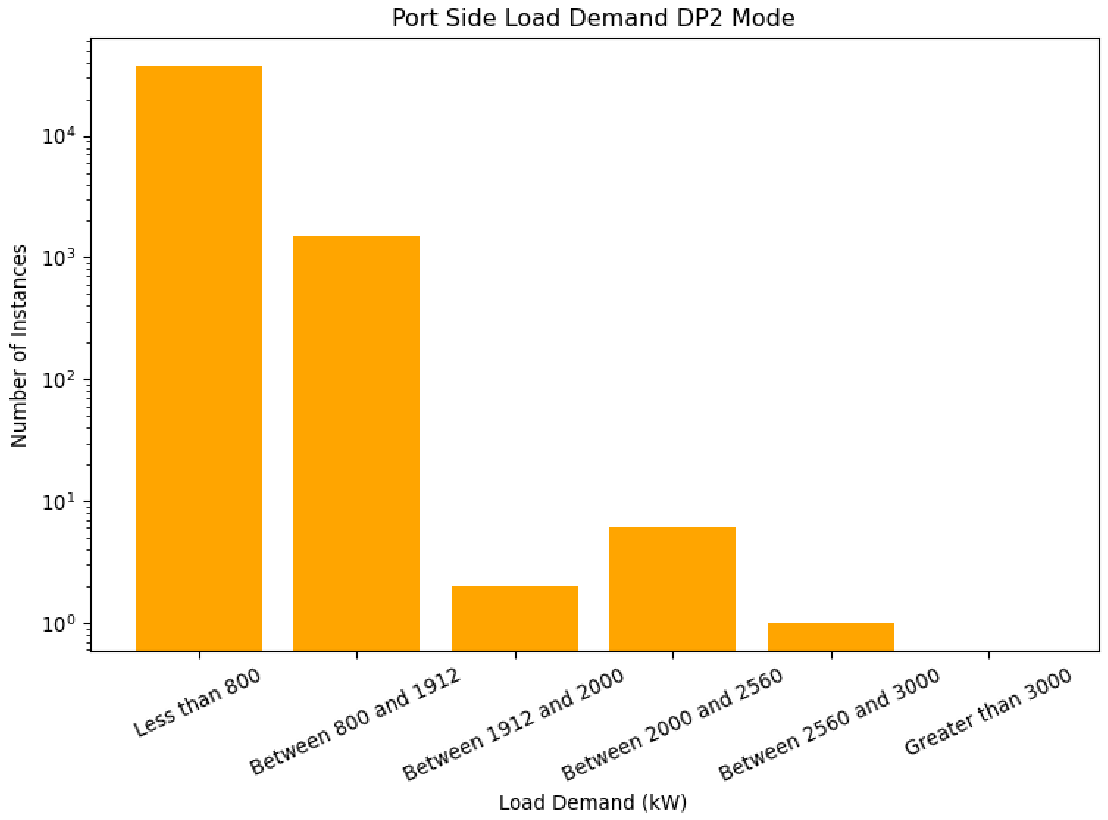
Generator maintenance





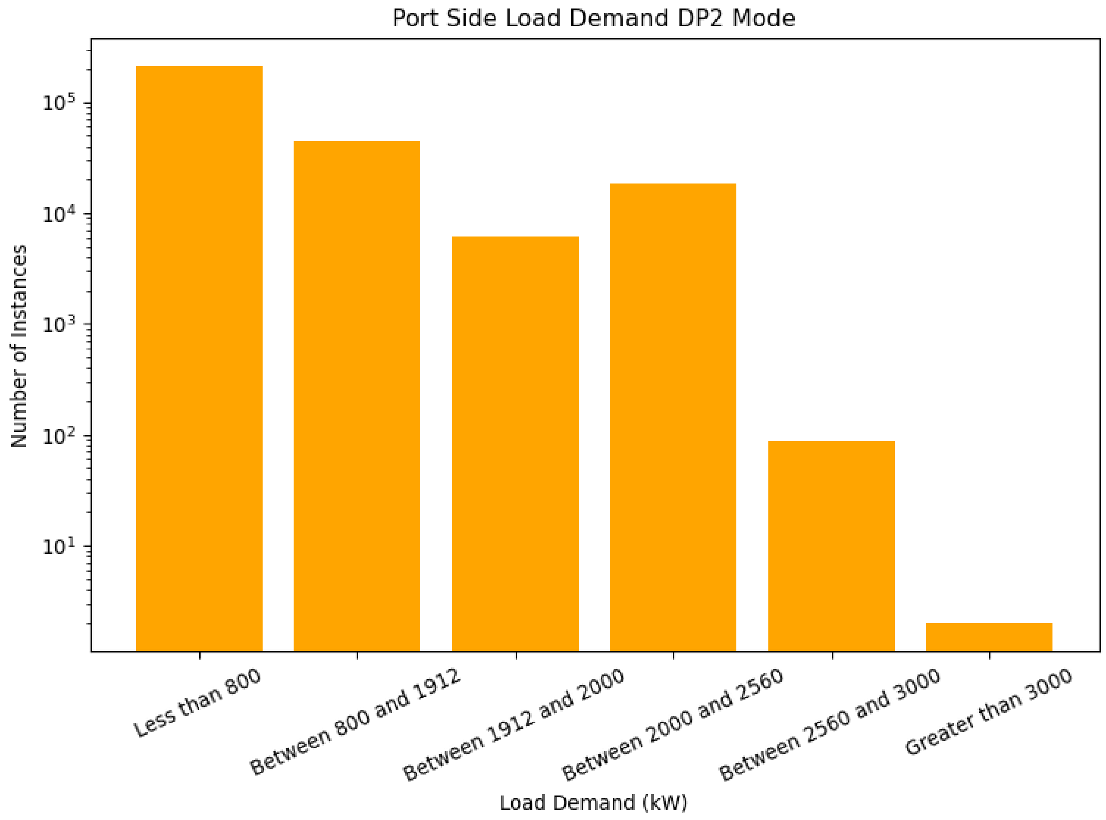
Event analysis

Taiwan Strait load profile



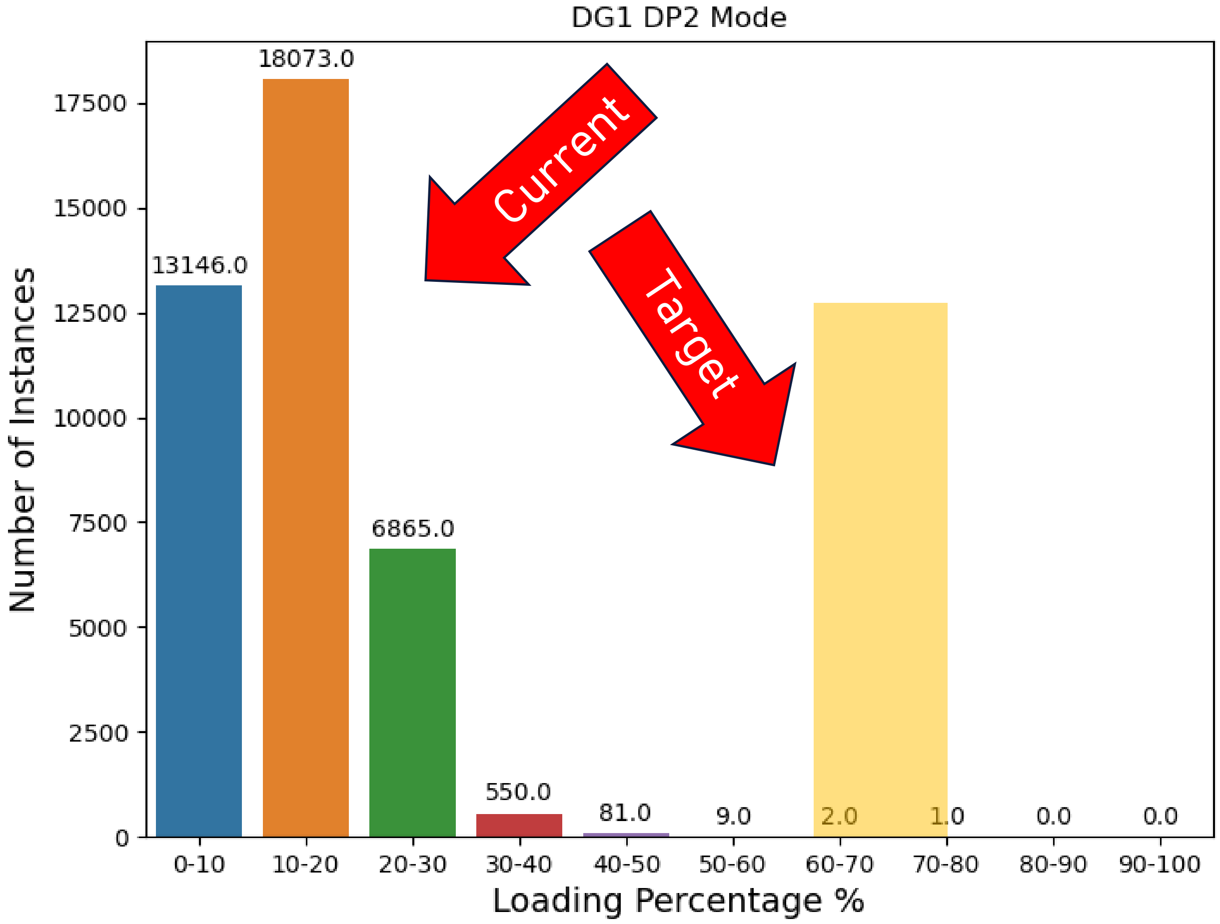
Event analysis

North Sea load profile



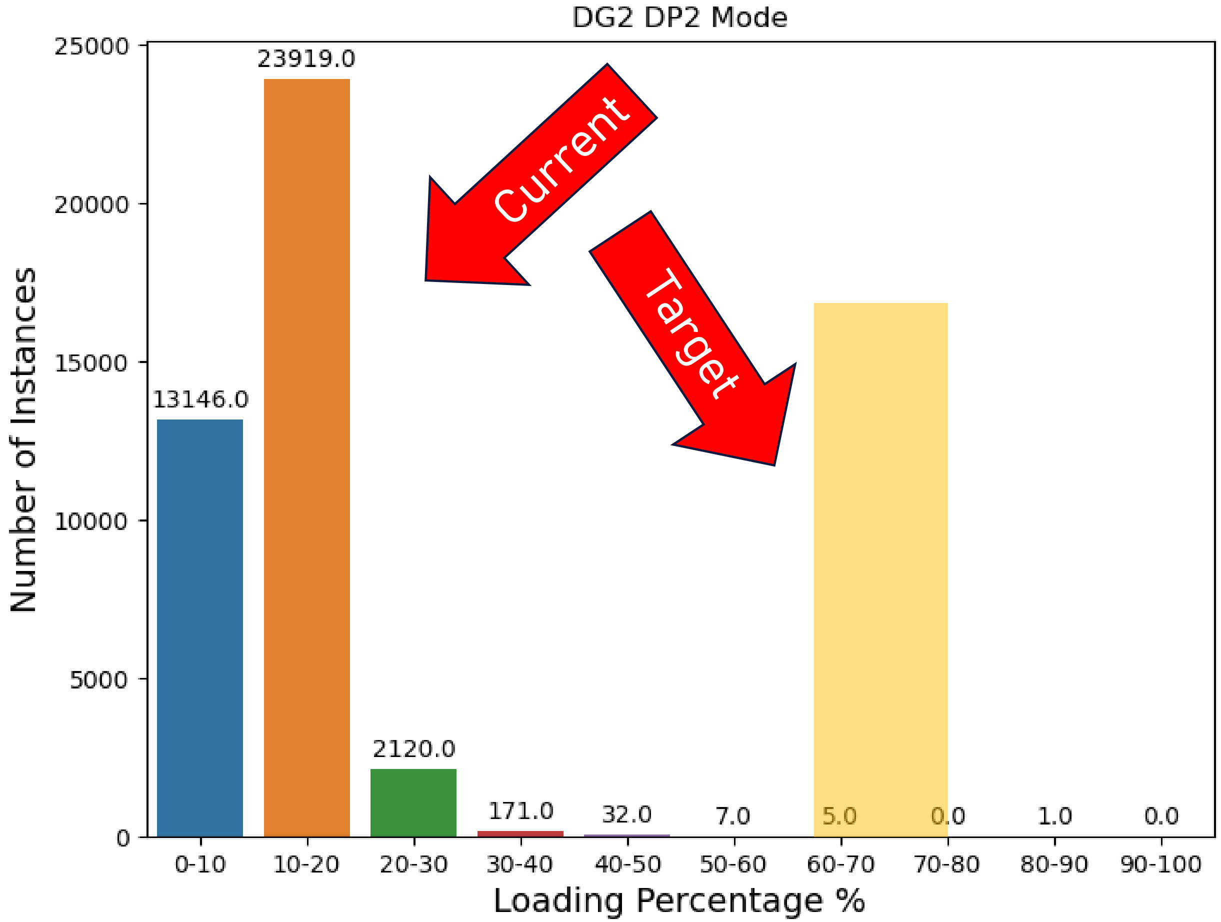
Generator loading

Taiwan load profile



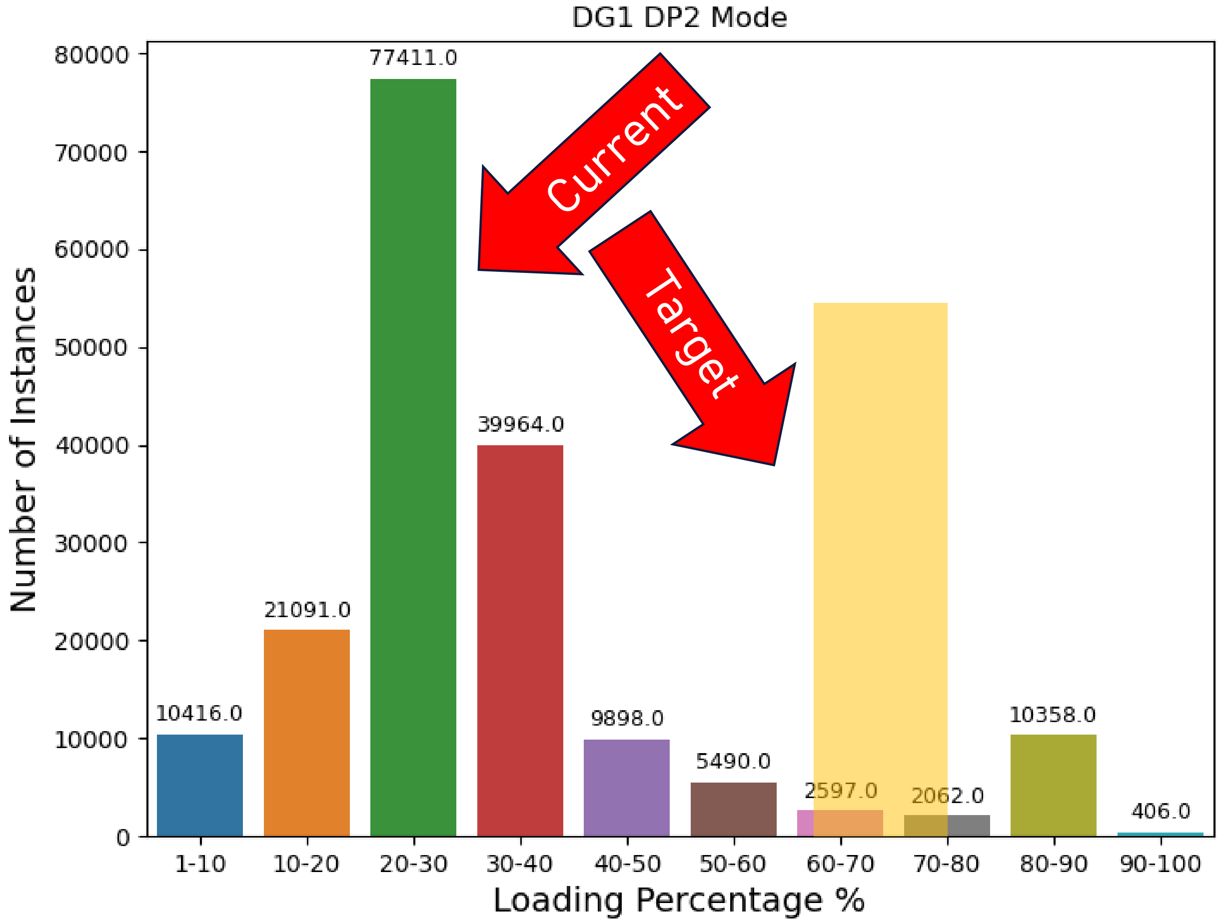
Generator loading

Taiwan load profile



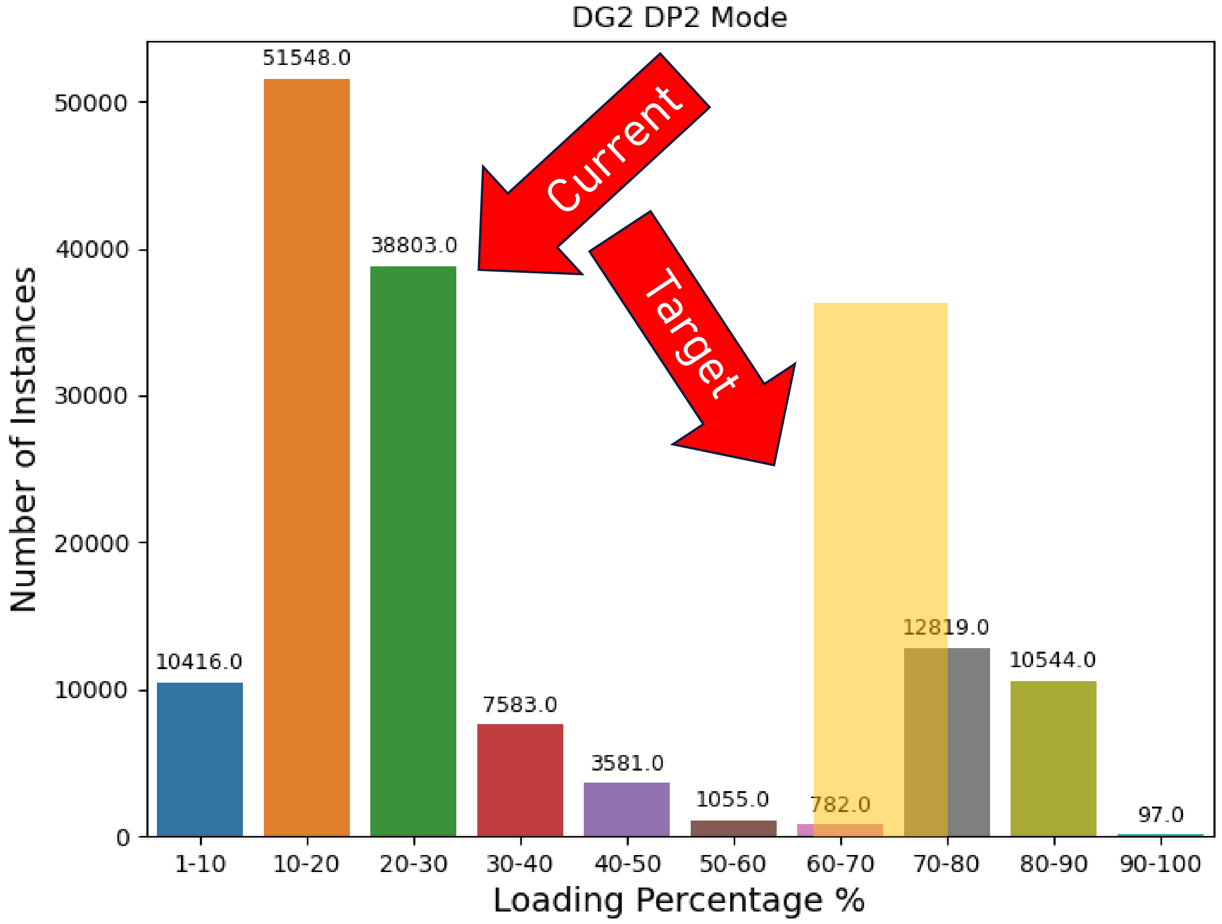
Generator loading

North Sea load profile



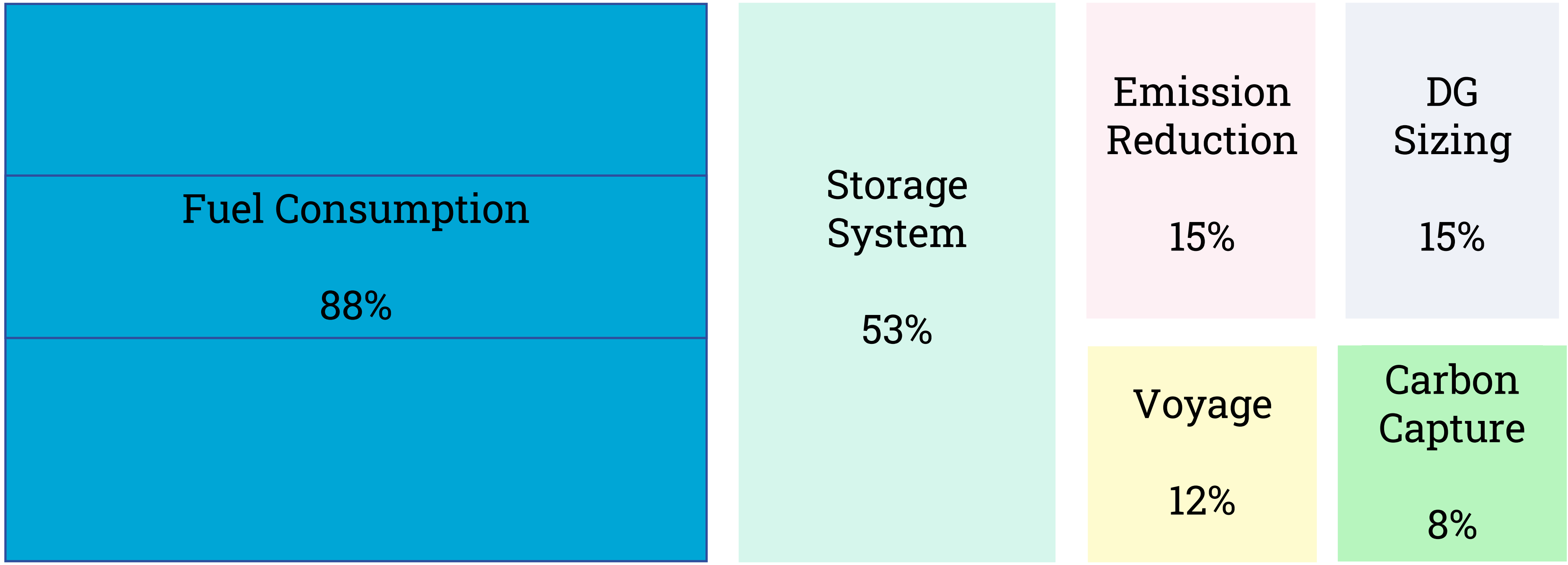
Generator loading

North Sea load profile

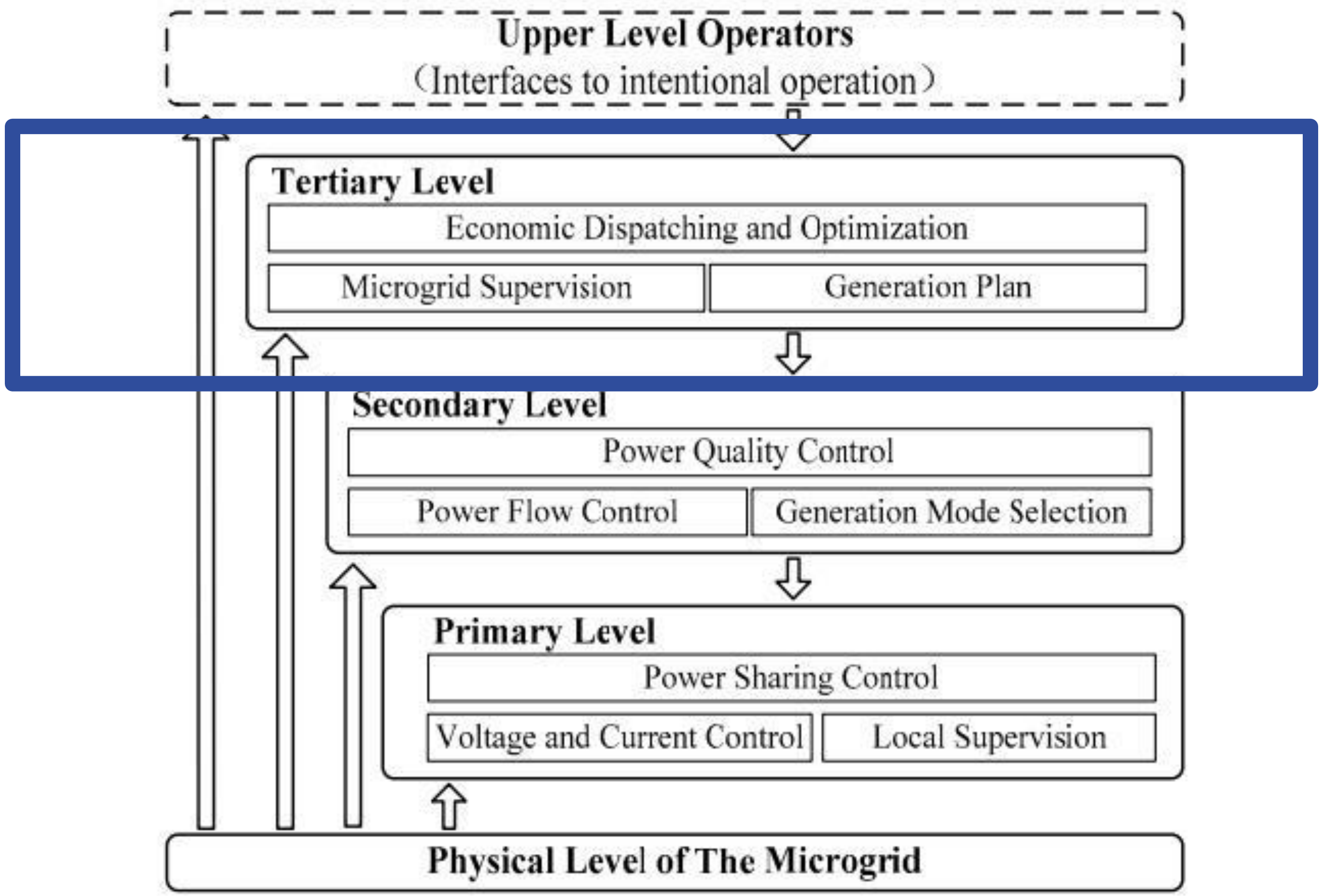


Optimizing fuel consumption & MTBO

- What are studies optimizing?



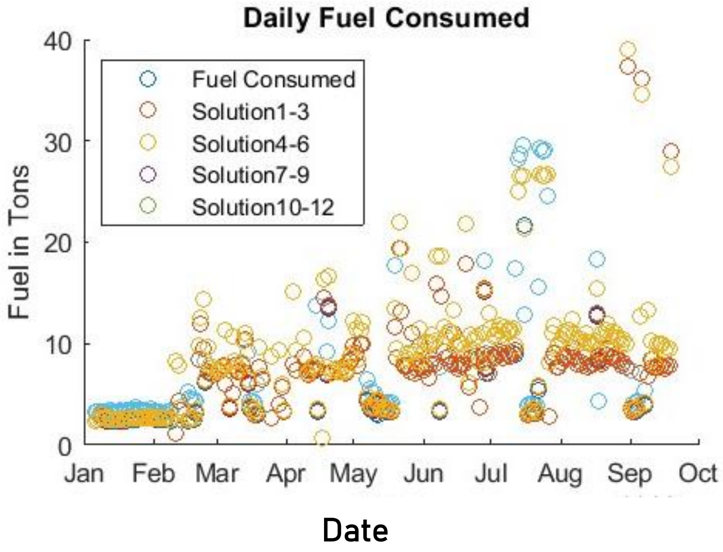
Optimizing fuel consumption & MTBO

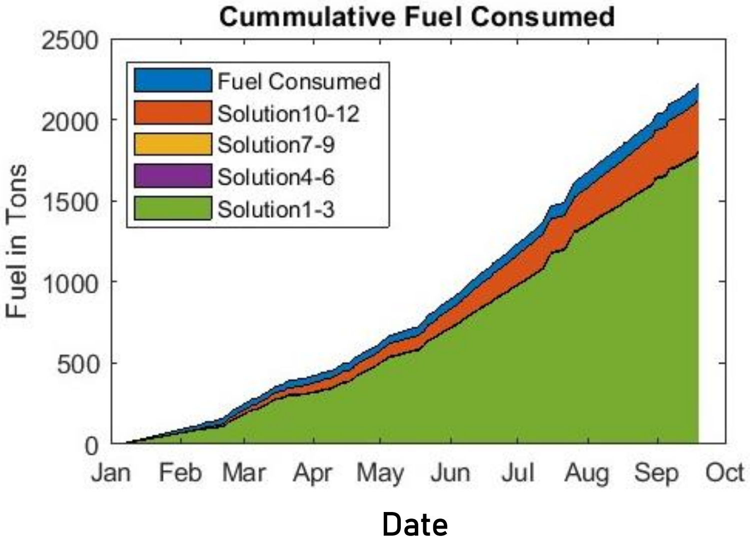


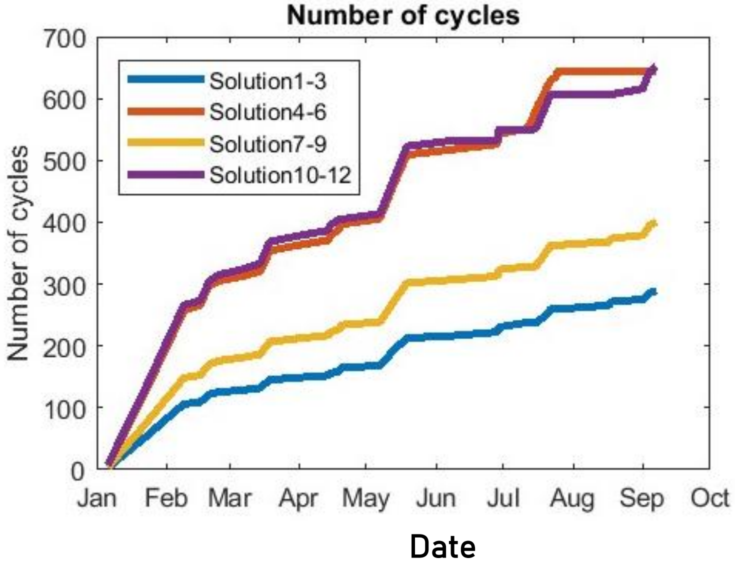
Ref: Monaaf D. A. Al-Falahi, AC Ship Microgrids: Control and Power Management Optimization

Optimizing fuel consumption & MTBO

Taiwan Result



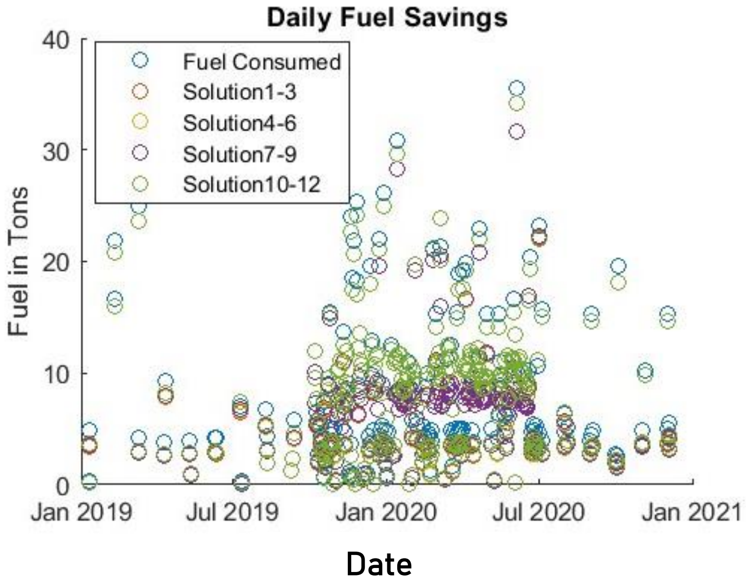


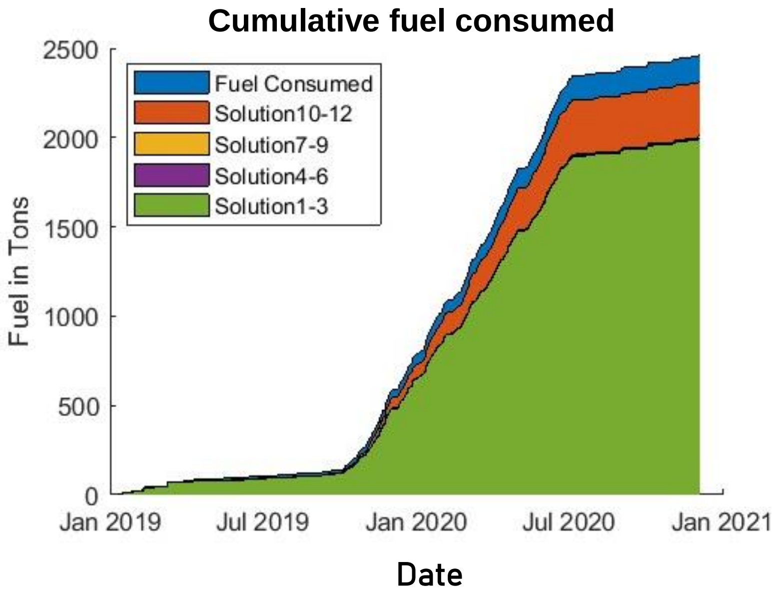


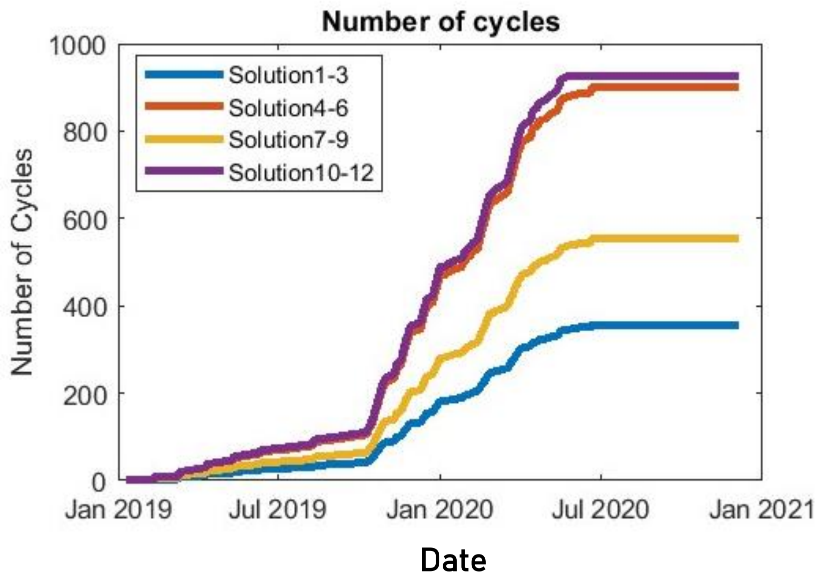
Solution Number	Fuel Savings (tons)	Number of Cycles	Time Period (days)
1-3	425.08	289.7	256
4-6	424.9	644.7	
7-9	416.3	400	
10-12	98.3	652.2	

Optimizing fuel consumption & MTBO

North Sea







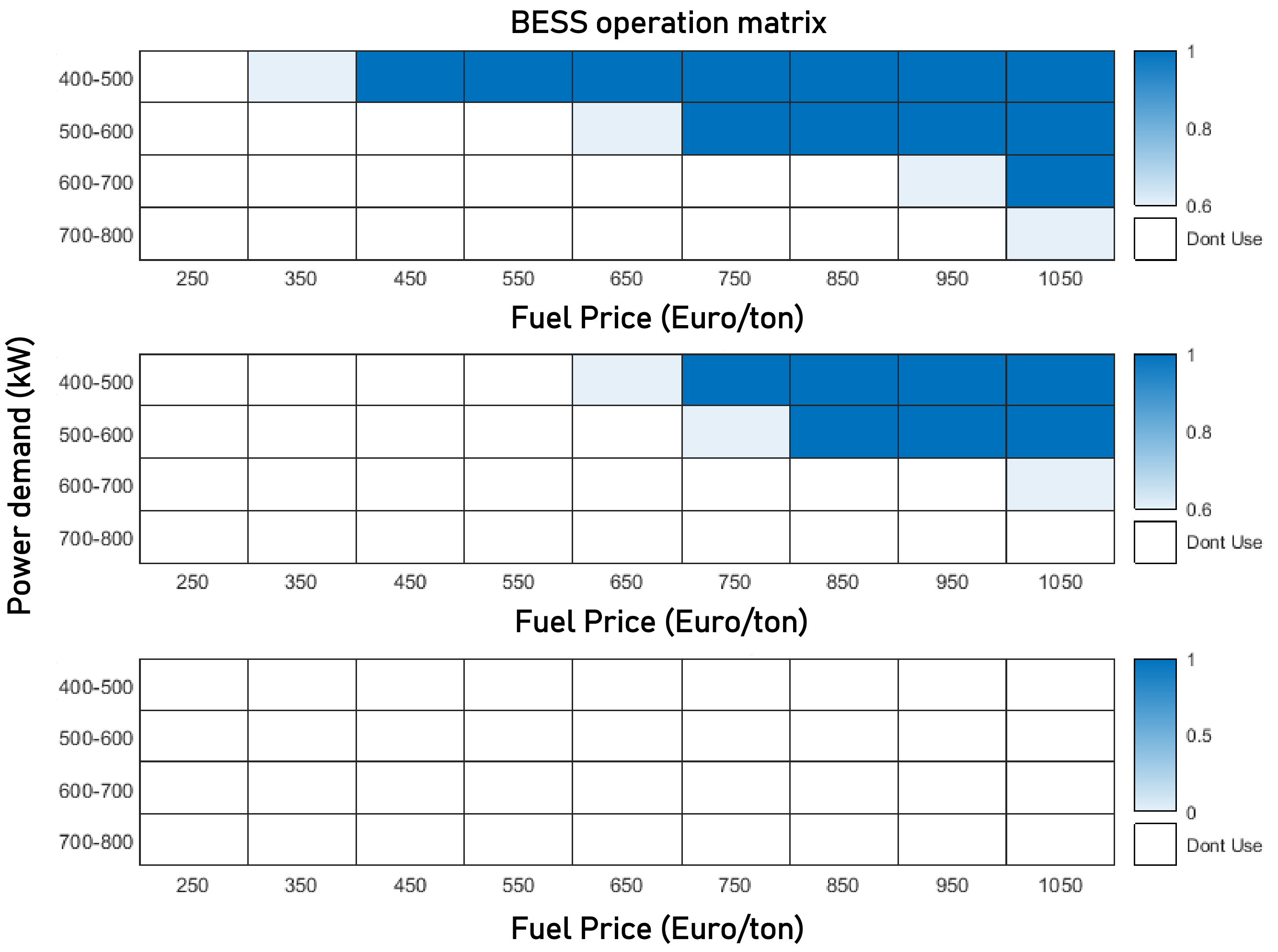
Solution Number	Fuel Savings (tons)	Number of Cycles	Time Period (days)
1-3	470.9	357.1	285
4-6	467.3	900.9	
7-9	459.6	554.1	
10-12	152.6	925.6	

Optimizing fuel consumption & MTBO

Solution number	Capital investment (Million Euros)	Payback period (years) per scenario		
		1	2	3
1	2.68	6.5	6.8	6.3
2	2.54	6.1	6.4	5.9
3	2.41	5.8	6.1	5.6
4	1.66	4.1	4.2	3.9
5	1.58	3.9	4	3.7
6	1.52	3.7	3.9	3.6
7	2.06	5.1	5.3	4.9
8	2.10	5.2	5.4	5
9	2.02	5.0	5.2	4.8
10	0.88	8.6	9	8.3
11	0.82	8.1	8.5	7.8
12	2.06	7.7	8.1	7.4

Solution	Years of profitability per scenario			ROI per scenario		
number	1	2	3	1	2	3
1	7.1	6.8	7.3	1.26	0.99	1.19
2	5.2	5	5.4	0.98	0.76	0.93
3	2.7	2.5	2.9	0.54	0.4	0.52
4	4.6	4.4	4.8	1.31	1.03	0.85
5	3.1	3.0	3.3	0.93	0.72	0.58
6	1.4	1.2	1.5	0.43	0.31	0.27
7	5.5	5.3	5.7	1.25	0.98	1.01
8	3.5	3.3	3.6	0.77	0.59	0.64
9	1.3	1.1	1.5	0.31	0.21	0.27
10	-1.2	-1.6	-0.9	-0.17	-0.18	-0.04
11	-2.3	-2.7	-2.0	-0.33	-0.31	-0.09
12	-3.6	-4	-3.3	-0.54	-0.48	-0.15

Optimizing fuel consumption & MTBO

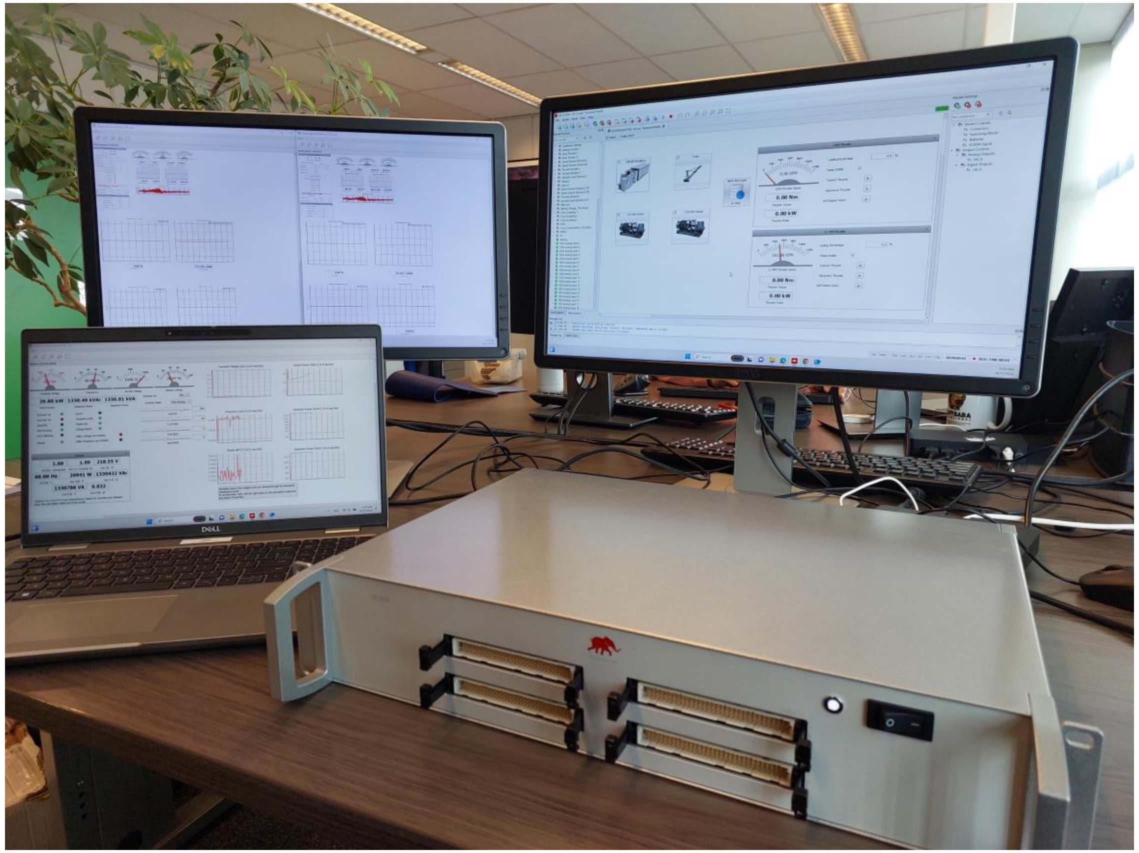


Solution 1,7,10

Solution 2,4,11

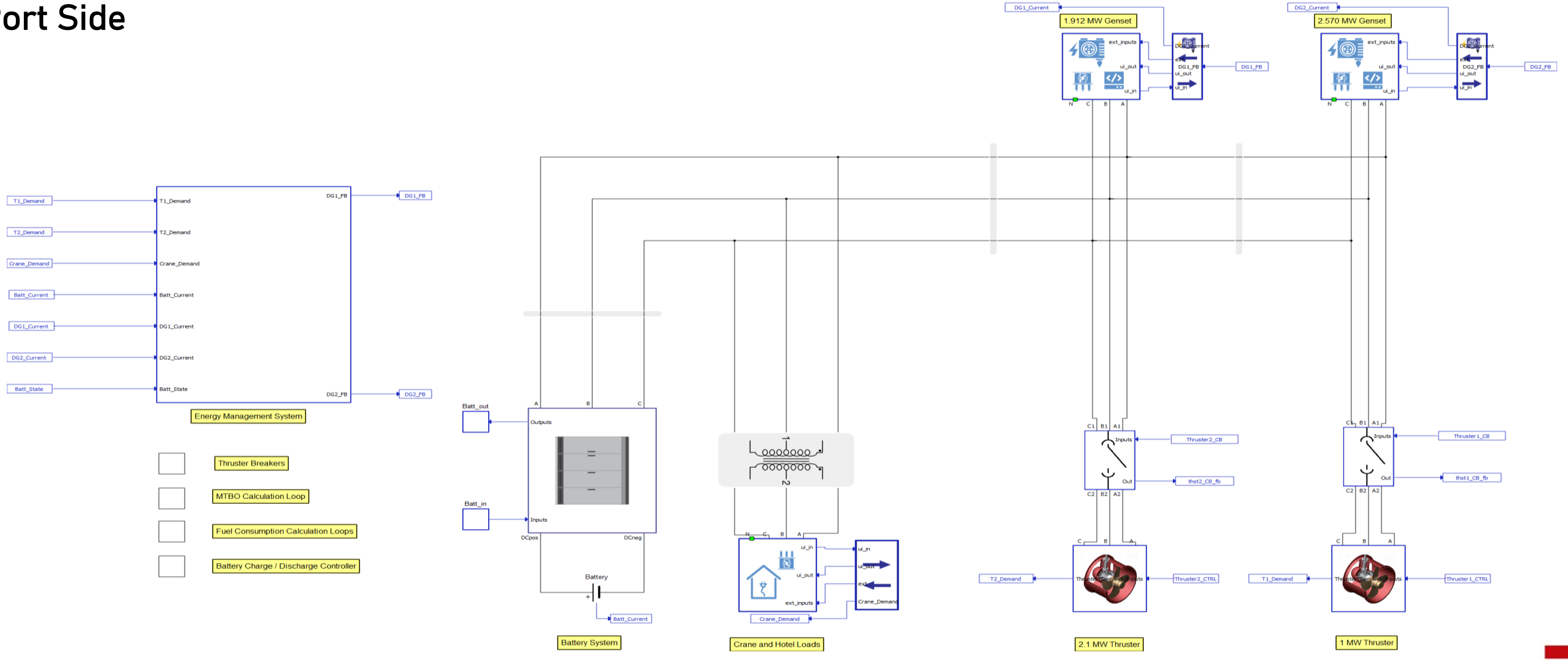
Solution 3,5,6,8,9,12

Hardware in Loop Test Setup

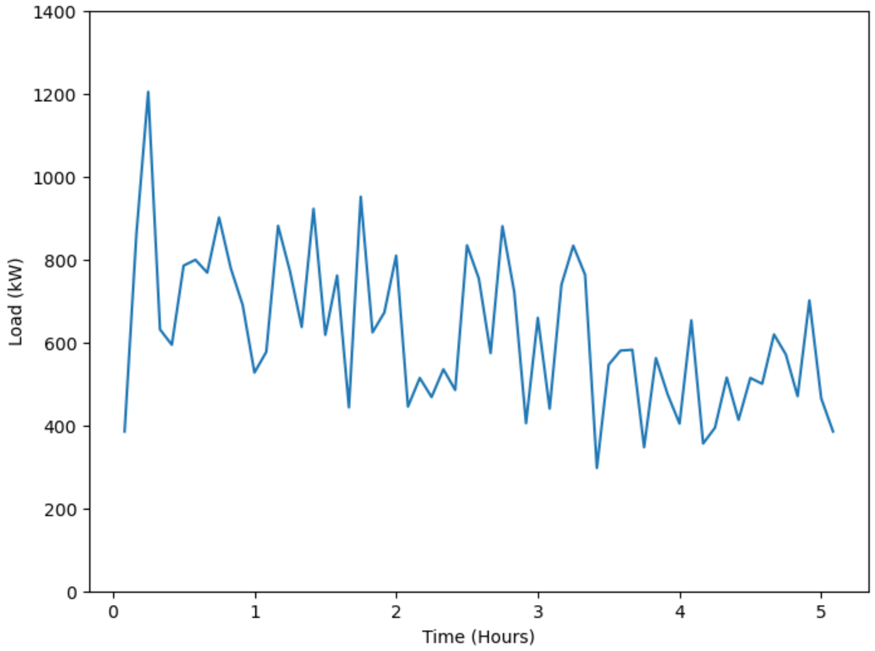


DP2 Hybrid Vessel Model on Typhoon HIL

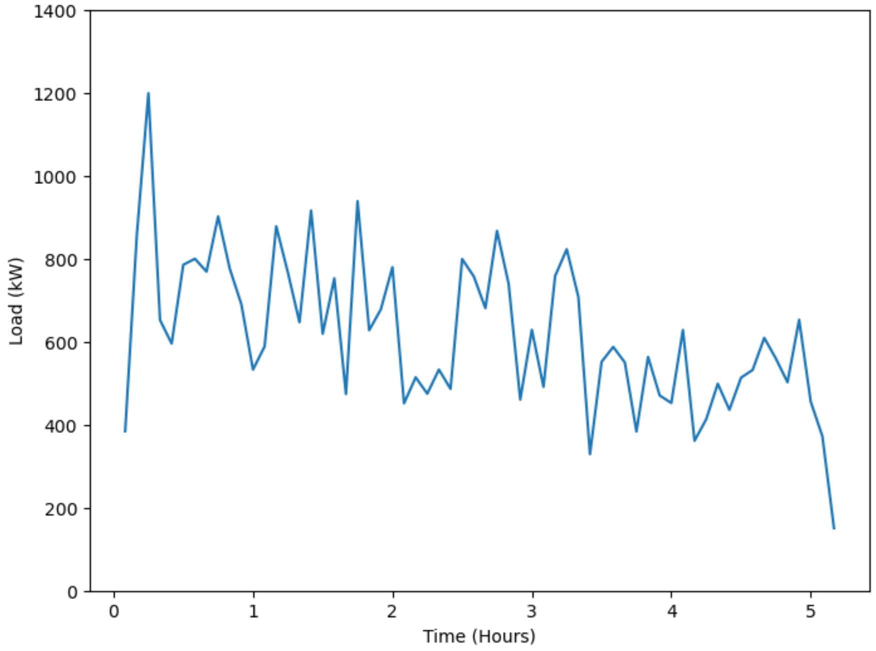
Port Side



The Taiwan Strait Load Profile in DP2 Mode (Port Side)

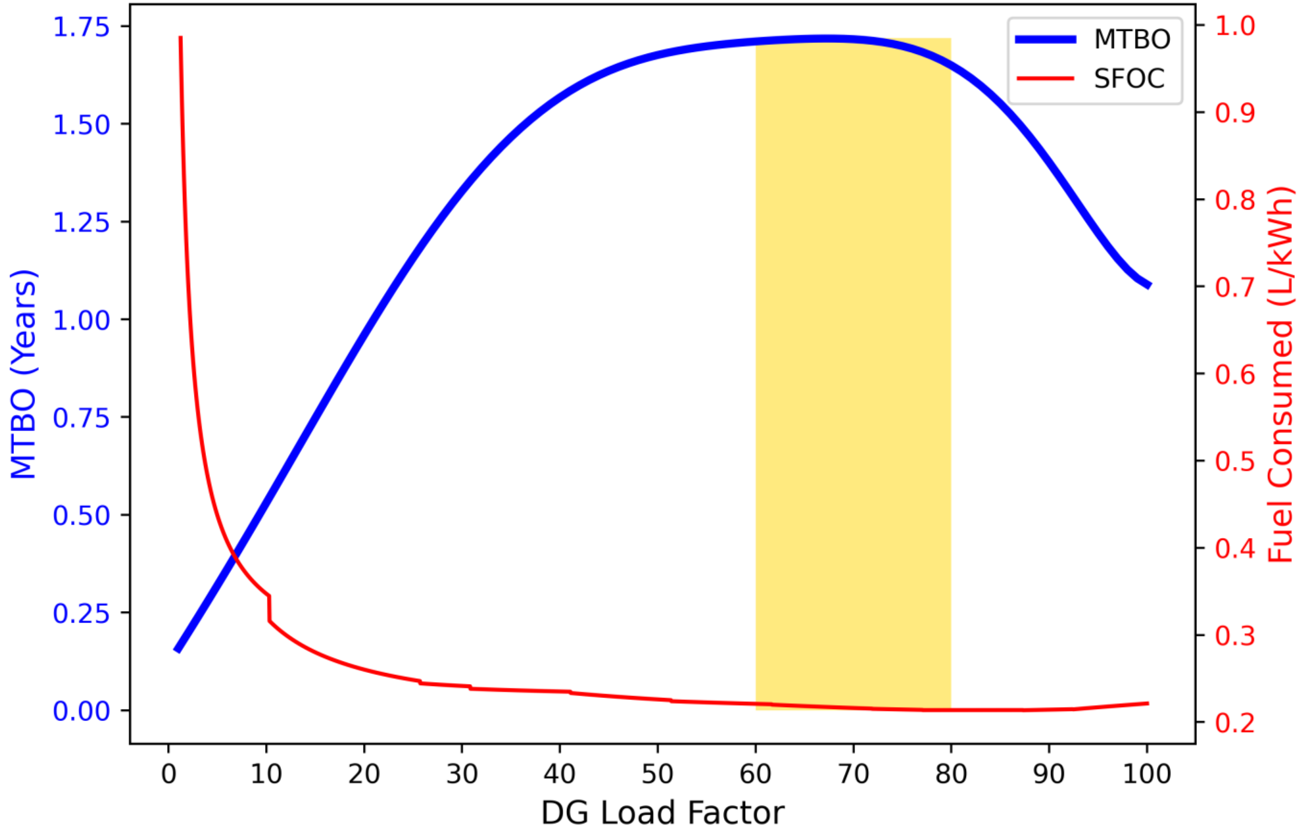


Source: Vessel Owner



Simulated Vessel on Typhoon HIL

EMS Control Philosophy

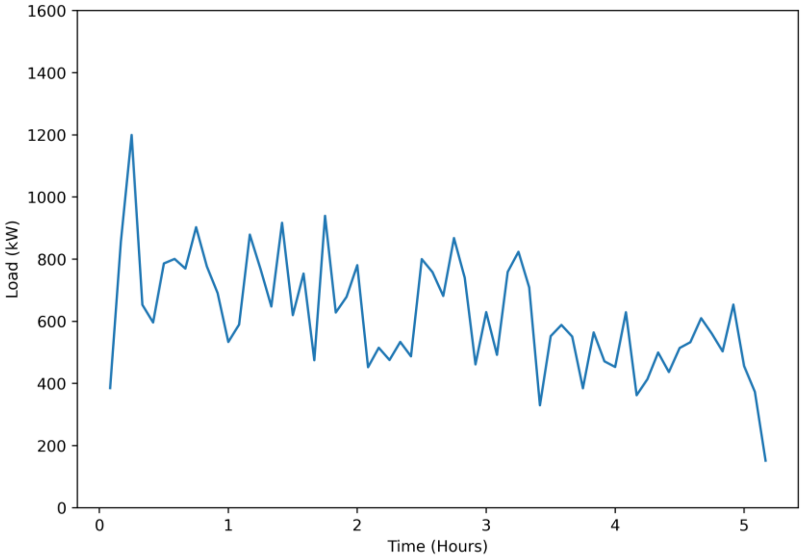


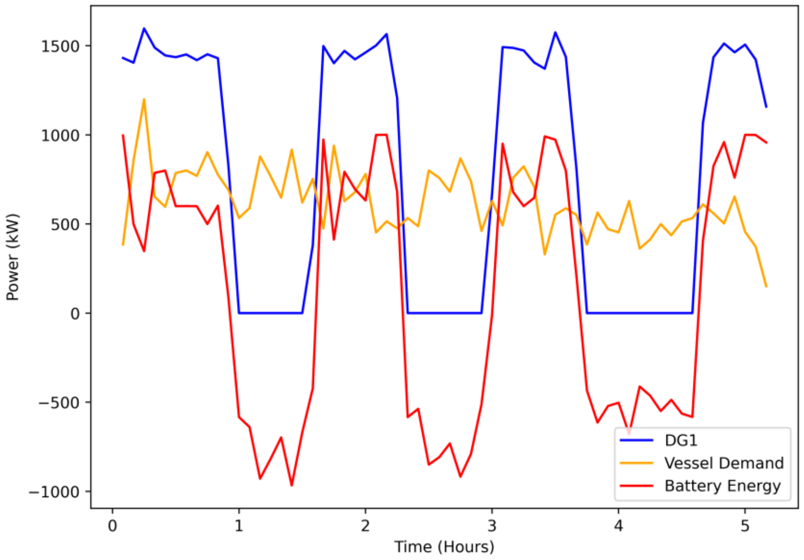
What is different in a Hybrid Vessel?

- The Battery is an additional load.
- The extra power (charge power) demand will *change* the original load profile.
- The extra load will push the operation to a high efficiency region, but:

i. It is demanding more power

ii. Some extra fuel will be consumed due to more energy being delivered.





Analysis Approach

- Consider the Hybrid Vessel only
  However,

- **With EMS** Control
  Optimized Control of Diesel Gensets

- **Without EMS** Control
  Synchronous Control of Diesel Gensets

Comparison

Parameter	With EMS	Without EMS
Net Fuel Consumption in Cycle	908 L	966.39 L
DG1 Loading %	73.4 %	29.51 %
DG2 Loading %	Standby	30 %
DG1 MTBO	1.71 years	1.29 years
DG2 MTBO	Standby Mode	1.29 years
DG1 Annual Maintenance Cost	€ 50,904	€ 67,084
DG2 Annual Maintenance Cost	Standby Mode	€ 67,084

Savings Estimate with EMS Control

- The EMS control has better fuel savings opportunity. The saved fuel with EMS : 966.39 – 908.65 L = 57.75 L or 5.98 % improvement.

- Assuming a 10-hour operation per day, fuel saved in 1 year on Port and Starboard Side (80% of the time in DP2 mode):

  57.75*2*2*365*0.8 = 67,448.5 L

  Data from Chevron suggests MGO has fuel density of 860 kg/m^3

  Fuel Saved = 58,005 kg of MGO

- Taking a market price of approx. $ 758.5/ton of MGO.
  Money saved = $ 758.5*58 = $ 43,997 = € 40,697 per year

Savings Estimate with EMS Control

- Approximate Annual Maintenance Cost of Gensets (Non-Hybrid Vessel) per year = € 108,173.07
- With EMS Control:
- DG1 Annual Maintenance Saving = € 108,173 – € 50,904 = € 57,268
- DG2 was on Standby. It is assumed, due to lesser use of DG2, maintenance cost of DG2 = € 40,000.
- DG2 maintenance savings = € 108,173 – € 40,000 = € 68,173

Net Saving = € 40,697 (Fuel) + € 114,536 (DG1 PS & SB) + € 136,346 (DG2 PS & SB)
= € 291,579 per year.

Emissions Savings

- Estimated Emission Factor for MGO = 3.206 tons CO_2 / ton MGO
- Net Emissions Offset = 58*3.206 = 185.96 tons CO_2 per year.

- Scenarios:

Tax € / ton CO_2	€ 30/ton	€ 67/ton	€ 150/ton
Saved Costs (Annual)	€ 5,578	€ 12,459	€ 27,894

Source: Leestemaker, Louis. "Maritime shipping and EU ETS An assessment of the possibilities to evade ETS costs." (2022).

Battery Technology Investment

- 2x1MWh High Energy Batteries + Power Converter Investment
- CAPEX = (2* €714,286) + (2 *€250,000) = € 1,928,572
- At a fuel price of $758.5/ton MGO, Simple Payback Time = 6.34 years

- Scenarios:

Fuel Price	€ 700/ton	€ 800/ton	€ 900/ton
Net Savings and Maintenance (year)	€ 303,946	€ 309,746	€ 315,547
Simple Payback Time (SBT)	6.34 years	6.22 years	6.11 years

Return on Investment

- With an assumption of 10 years lifetime.
- Return on Investment = € 304,039 * 3 = € 912,117

Conclusions of this study

- Installing BESS and operating them in DP2 mode in combination with the DGs, with the new EMS control is profitable.

- The new EMS control creates the opportunity for greater fuel savings and delaying the Minimum Time Before Overhaul (MTBO).

- The BESS solution for this ship has an estimated return on investment, of 0.912 million euros in an assumed lifespan of 10 years.

- In this control approach, the BESS lifetime will be limited to about 10 years. Expecting a useful life beyond this time-period is unfeasible, due to aging and the large number of cycles it would have operated. This can be seen as disadvantage, due to the long payback timeframe.

Key differences between these two studies

- Global optimization solutions such as the MILP require knowledge of future events. In this case, the load demand profile. This is often difficult to predict for ships, when they operate in modes such as Dynamic Positioning due to variable weather patterns and the task they are performing.

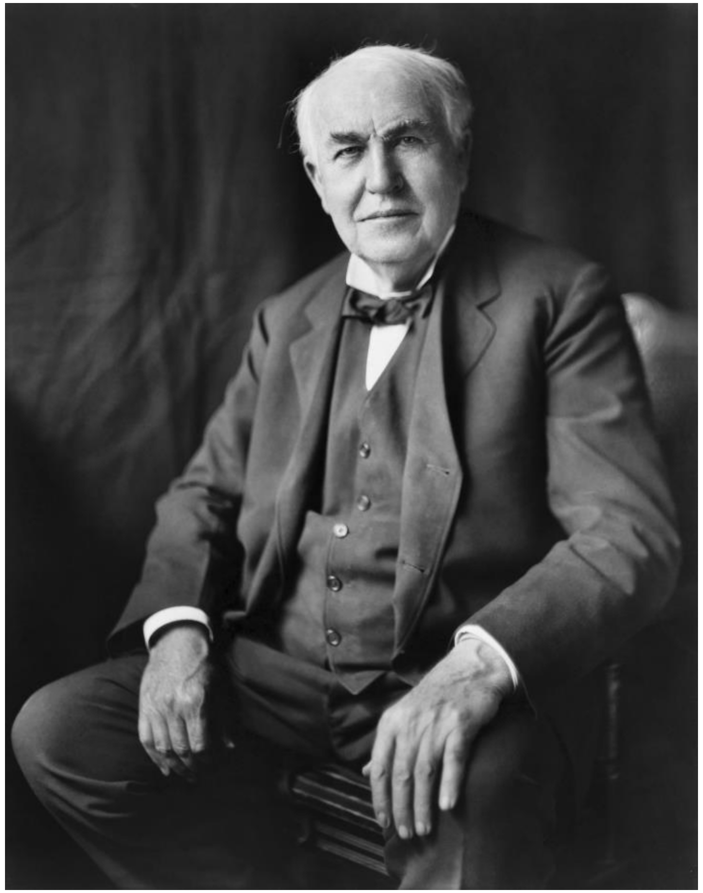
- The Simple Rules Based Control approach does not require this knowledge.

- However, from the performance front, global optimization performs better.

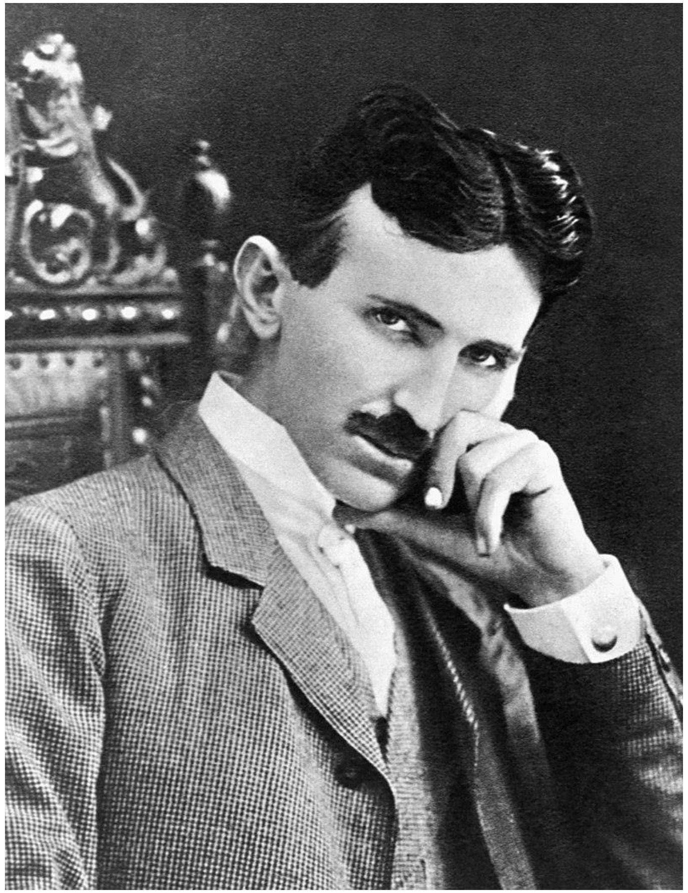
Solution?

- Need to investigate ways in which some knowledge of future load demand can be incorporated into the EMS, so that it can make better decisions using global optimization.

DC vs AC



Thomas Edison

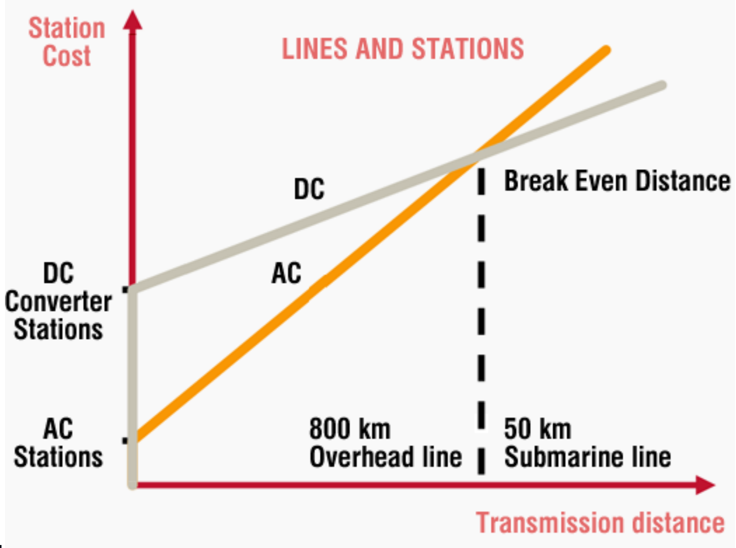


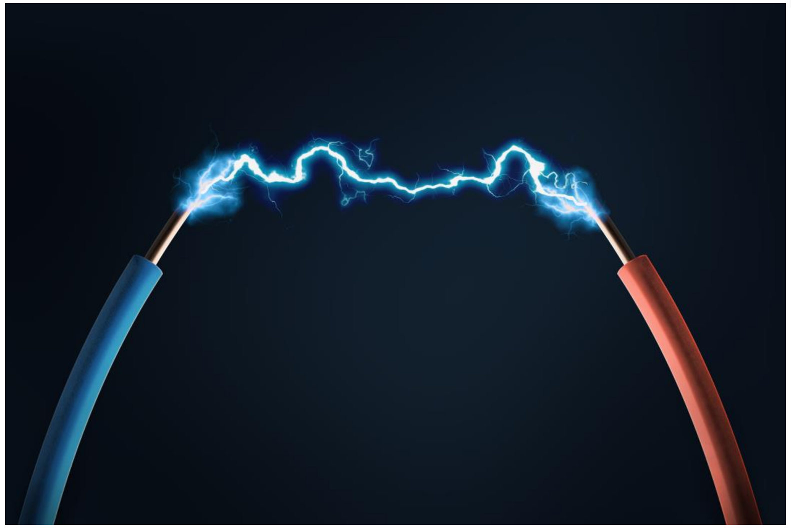
Nikola Tesla

DC vs AC

Why did AC win?

- Easier transformation to different voltage levels
- Lower losses during long distance transmission
- Easier to interrupt (safety)
- You can plug it in both ways



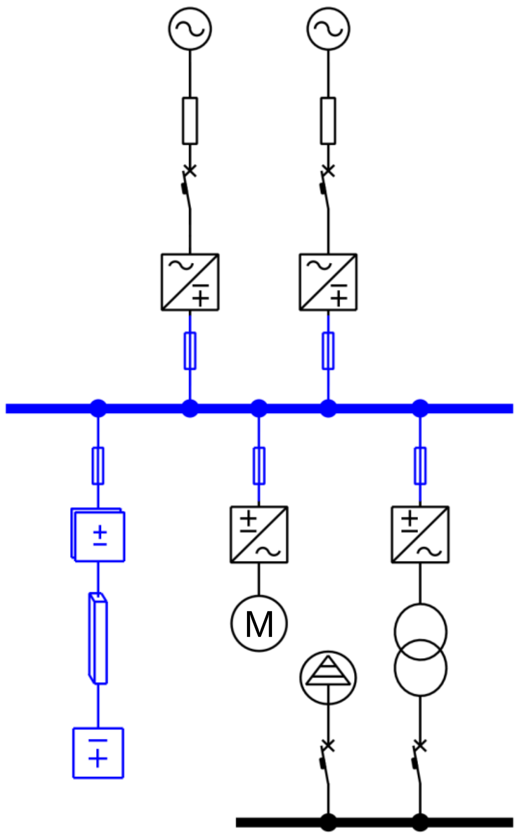


DC vs AC

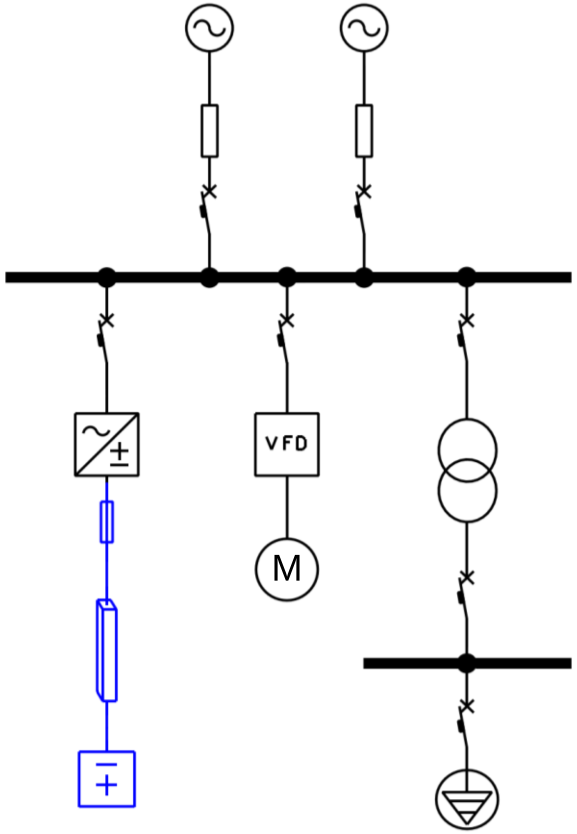
Modern appliances are often based on DC

DC vs AC

In maritime systems



'Typical' DC system

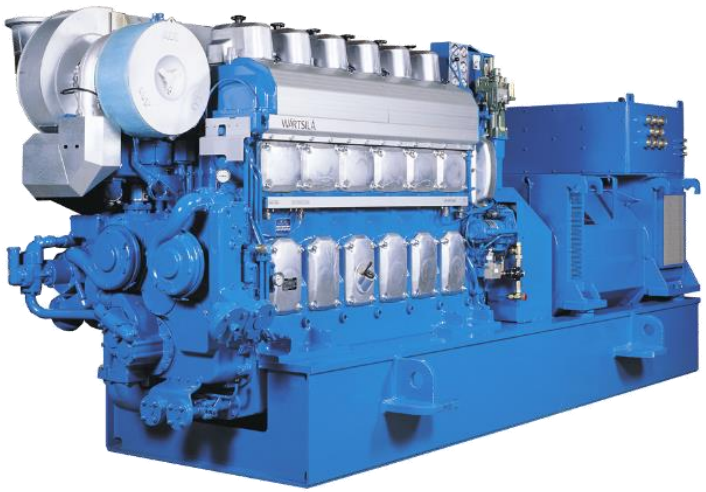


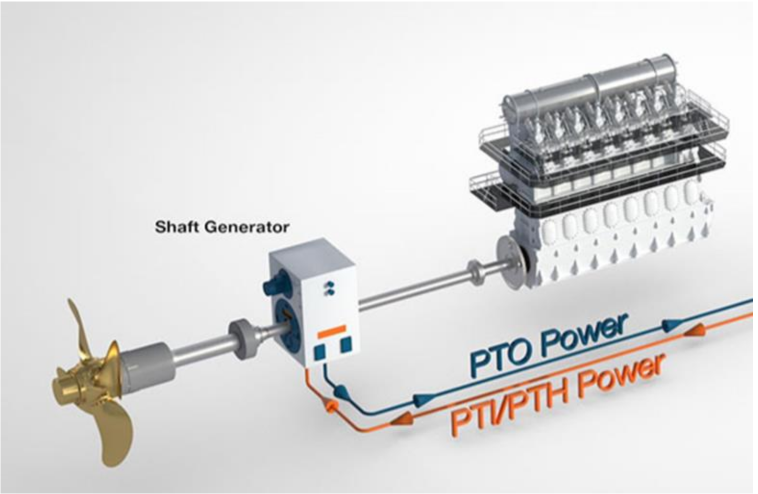
'Typical' AC system

DC vs AC

Which makes most sense?

1. **Equipment**
2. Technical limitations
3. Technical challenges
4. Operational profile

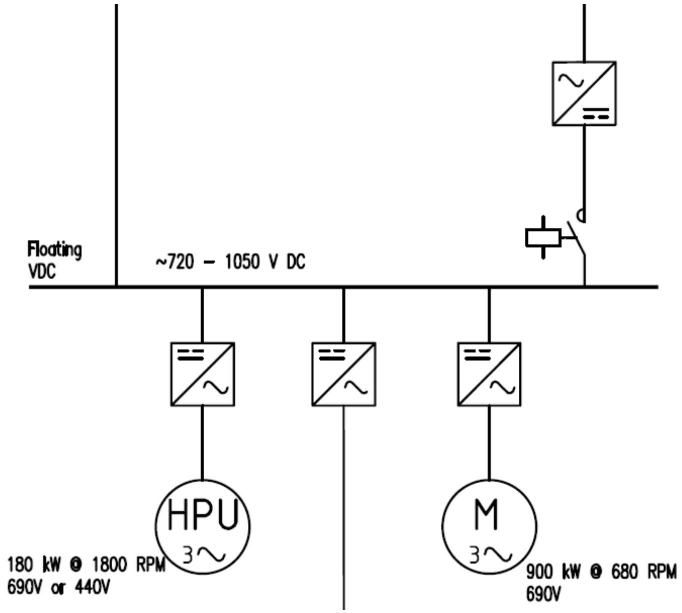




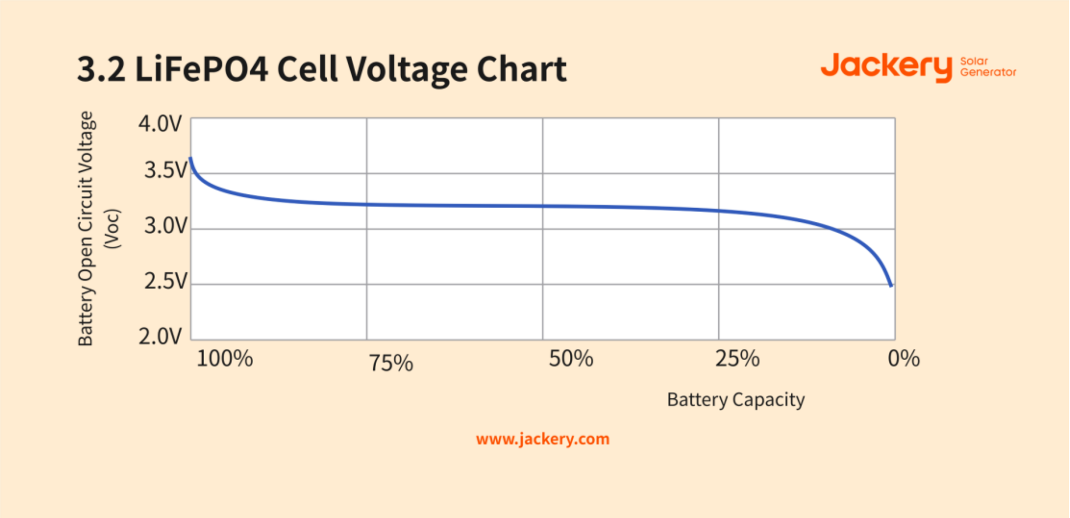
DC vs AC

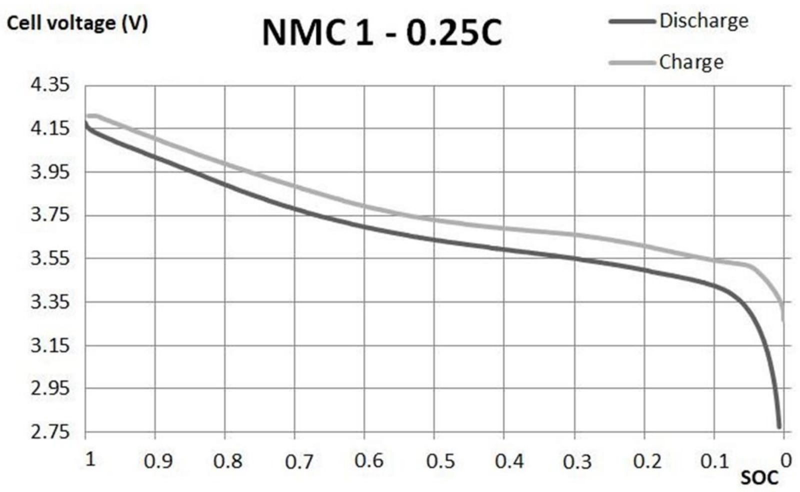
Which makes most sense?

1. Equipment
2. **Technical limitations**
3. Technical challenges
4. Operational profile



$$690 \cdot \sqrt{2} = 976V$$

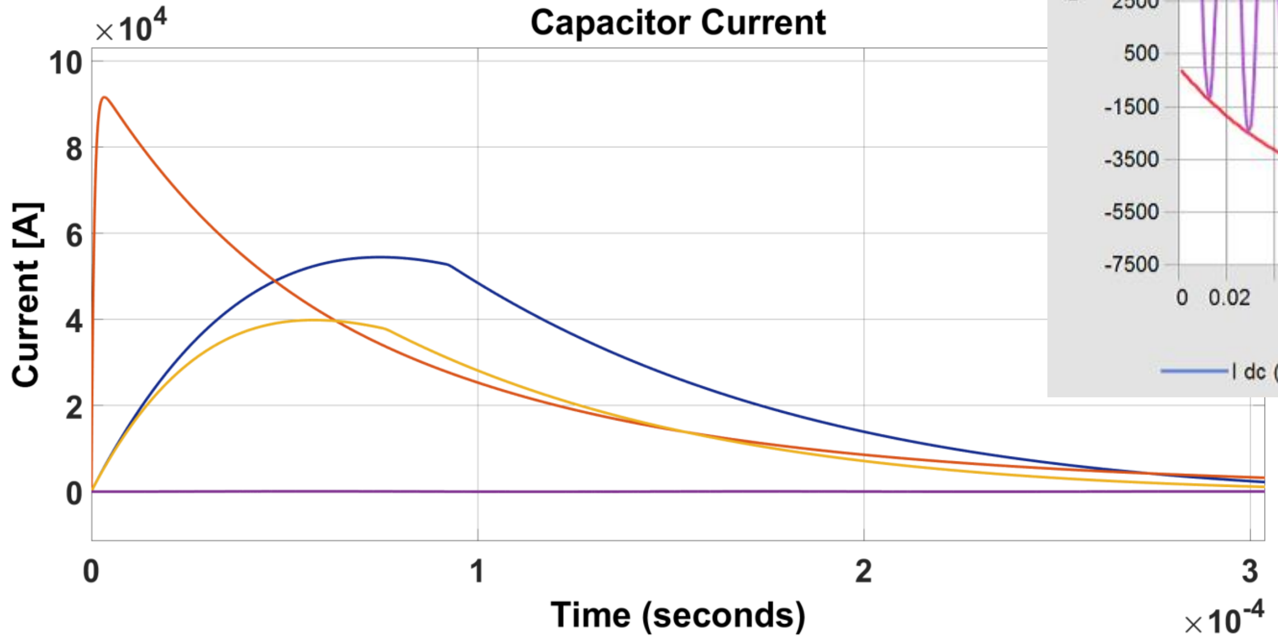


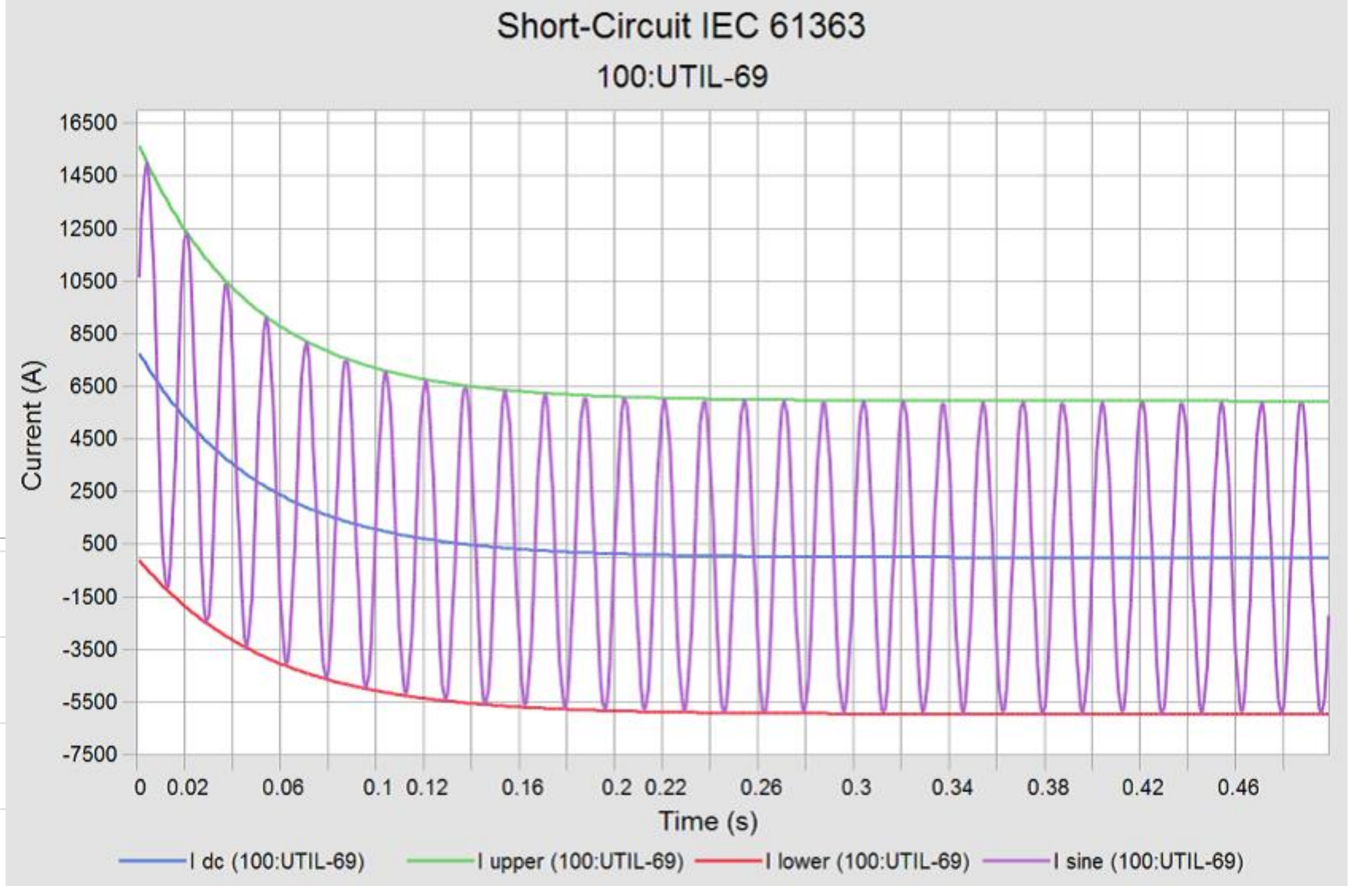


DC vs AC

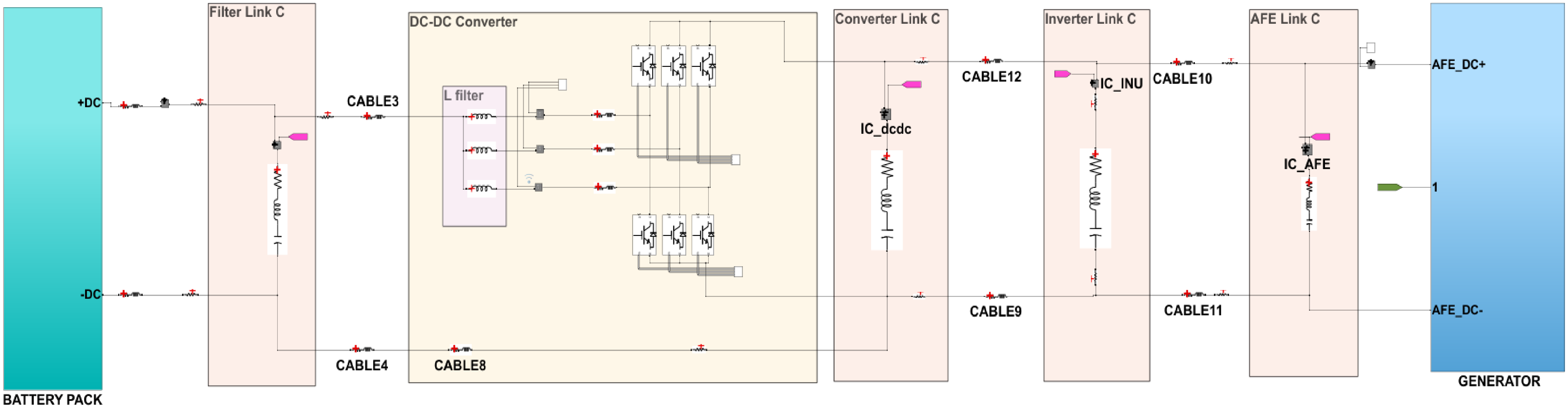
Which makes most sense?

1. Equipment
2. Technical limitations
3. **Technical challenges**
4. Operational profile

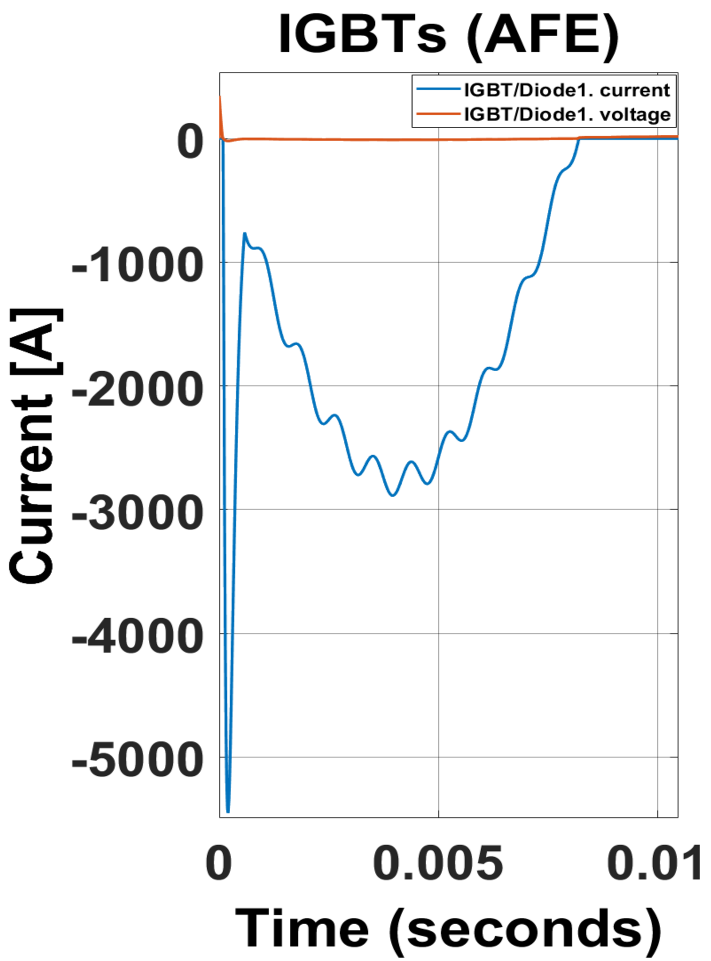


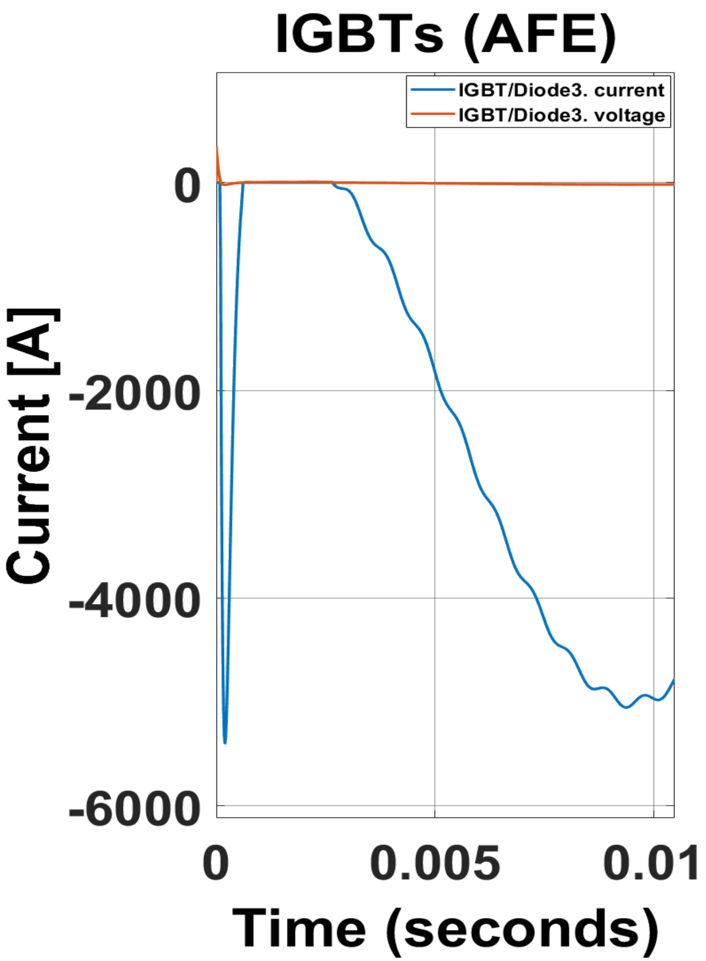


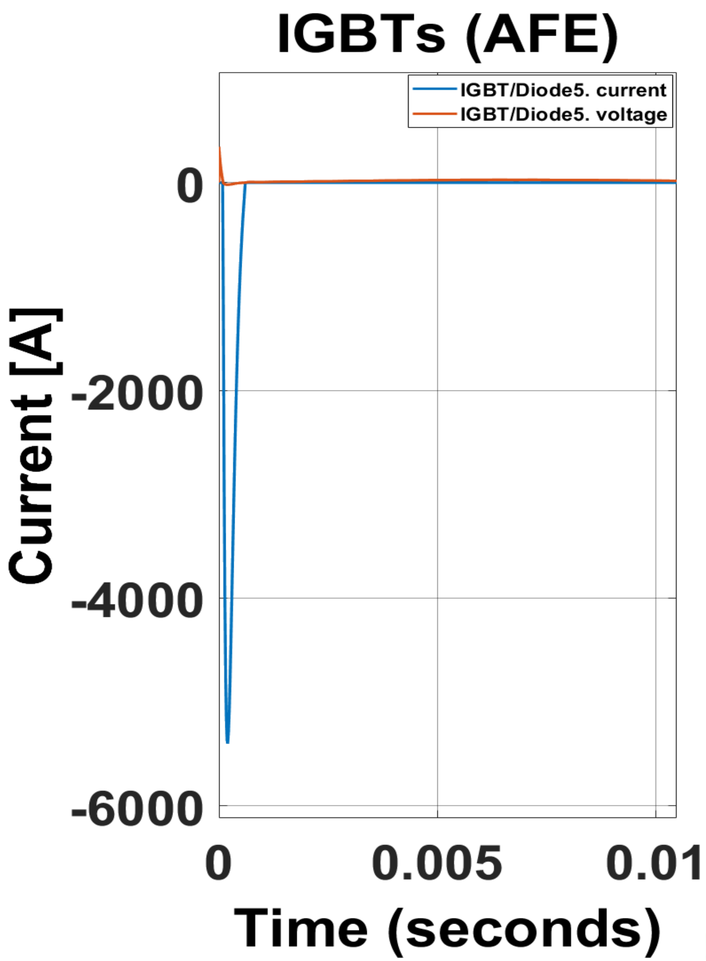
DC Grid Modelling



DC Grid Modelling

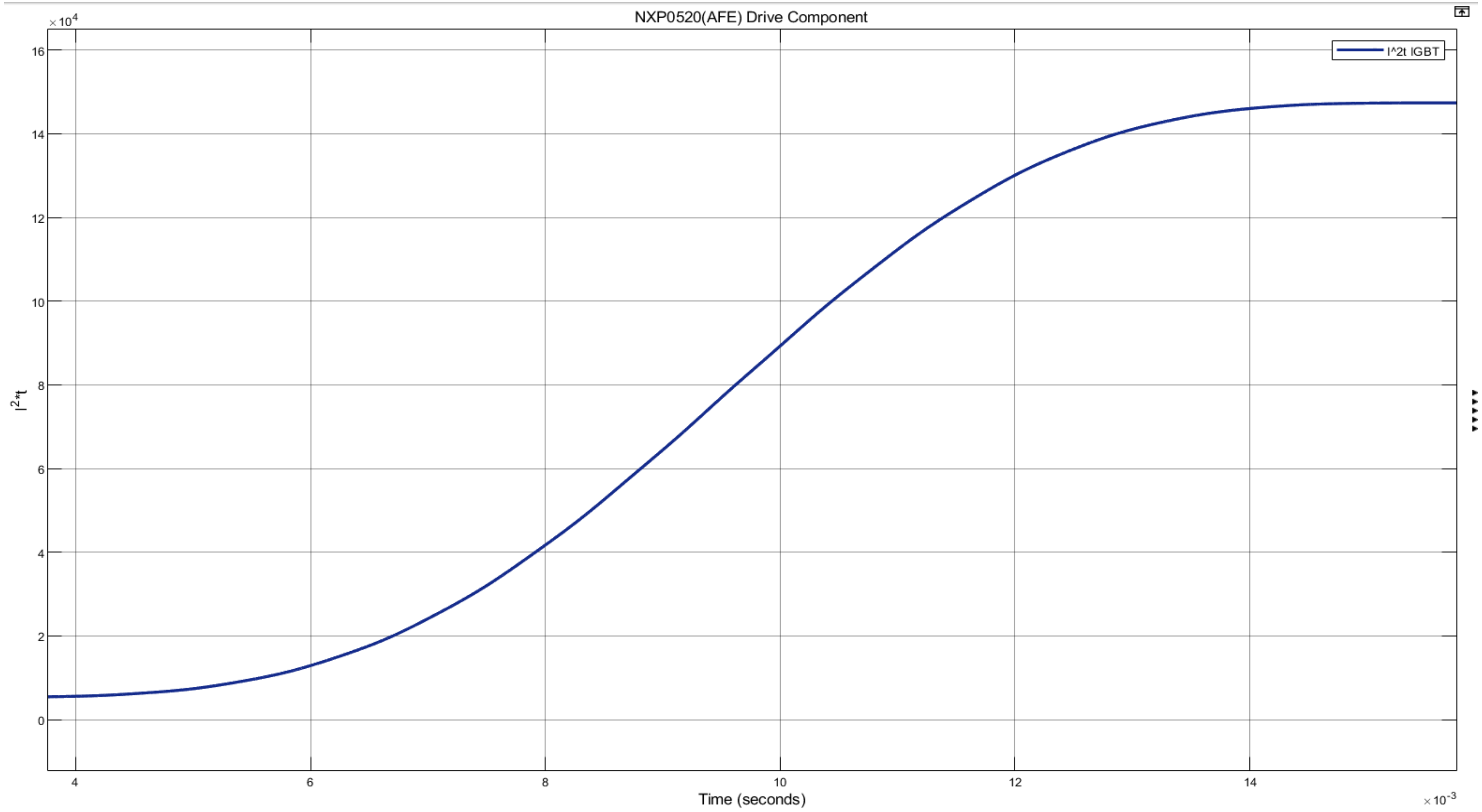




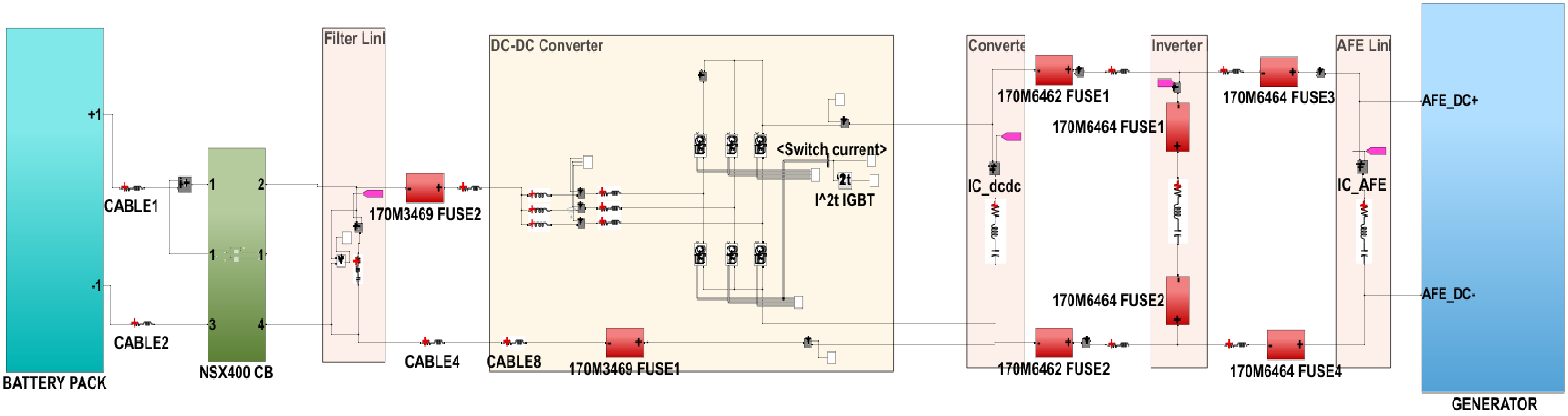


DC Grid Modelling

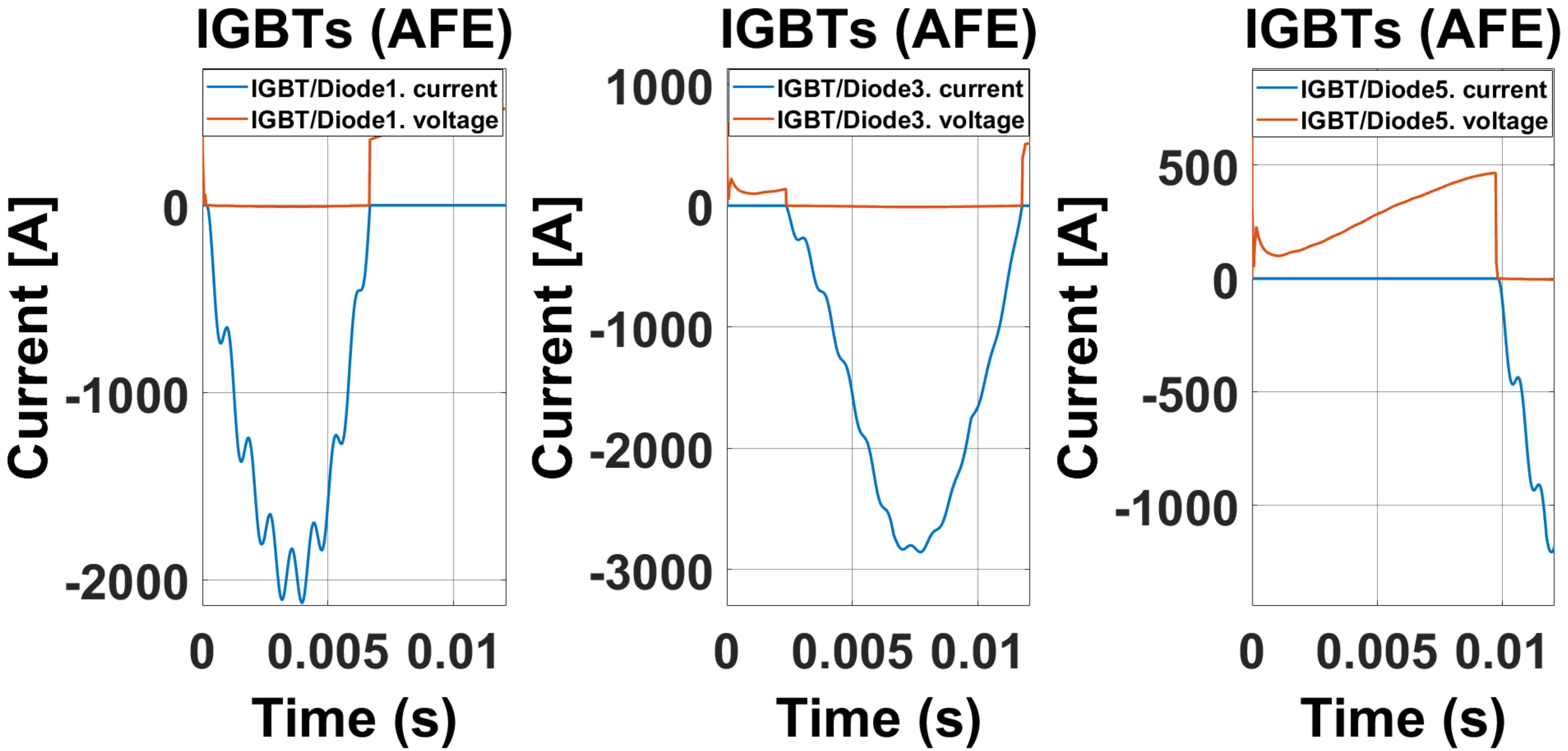
- Inverse Diode I²t = 93000A²s
- Inverse Diode IFSM = 4320A (10ms)



DC Grid Modelling



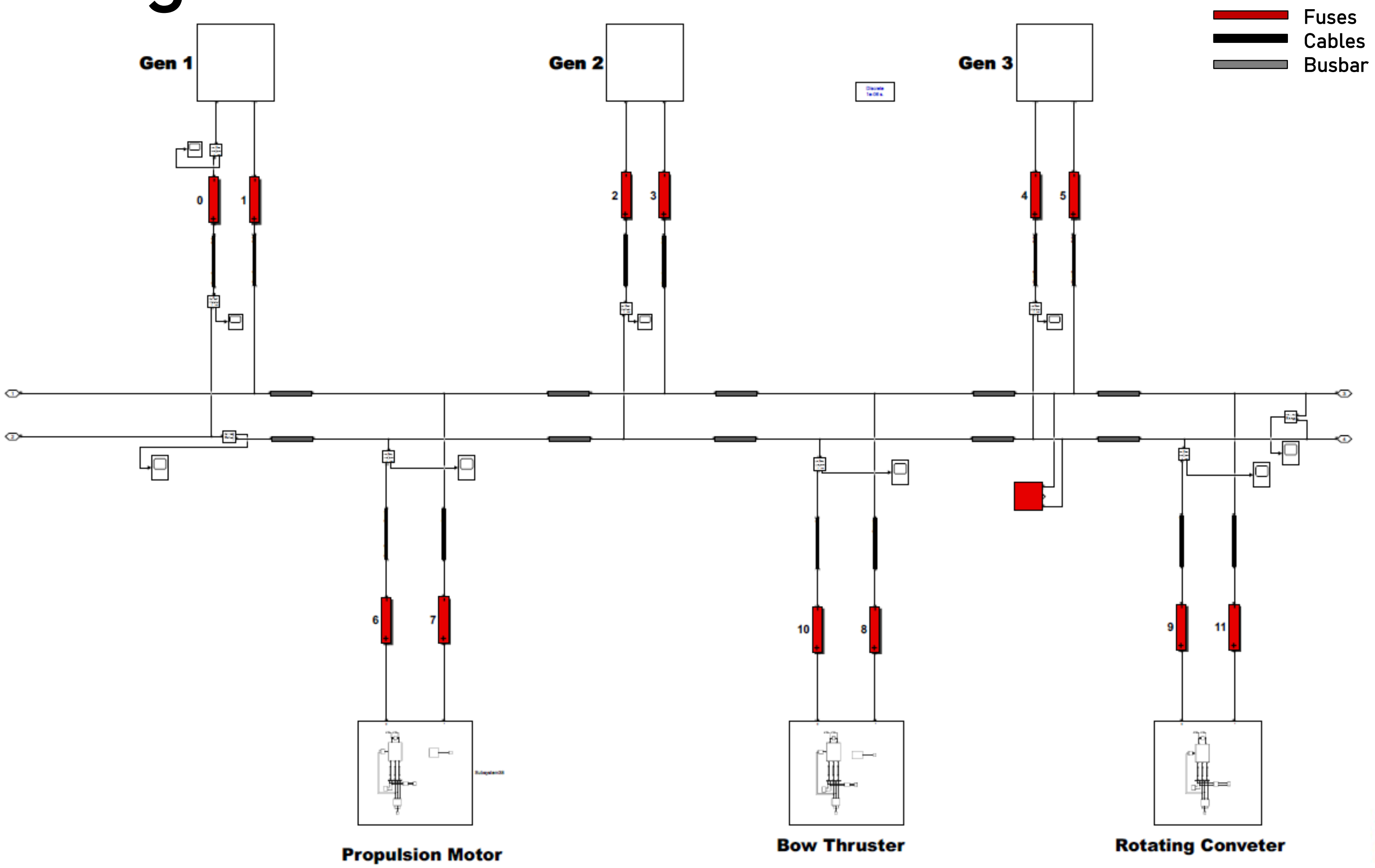
DC Grid Modelling



- Inverse Diode I^2t = 93000A²s
- Inverse Diode IFSM = 4320A (10ms)

DC Grid Modelling

A different vessel



DC vs AC

Which makes most sense?

1. Equipment
2. Technical limitations
3. Technical challenges
4. **Operational profile**

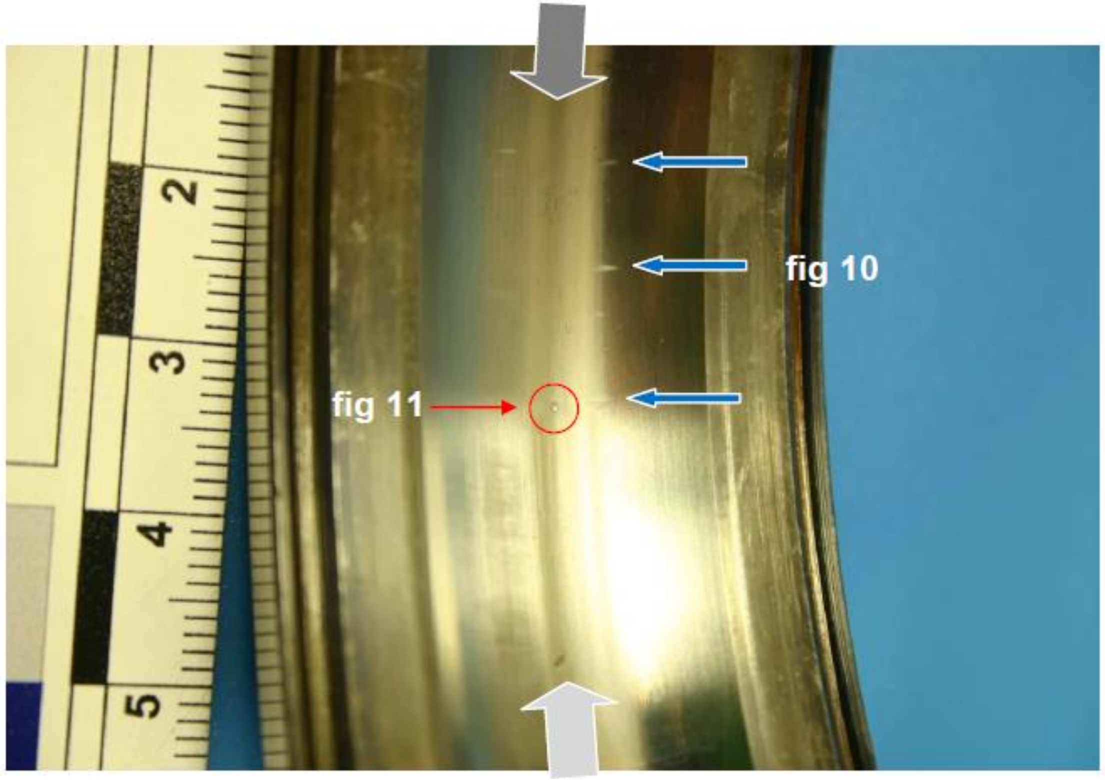
DC	
Motor inverter	97.5-98%
Grid converter	98.5-98.9%
DC/DC converter	98.5-99%
AC/DC converter	97-98%
AC	
Variable Frequency Drive	97%
Grid converter	98.5-98.9%

	DC – total power train loss [kW]	AC – total power train loss [kW]
Charging from shore	82.03	81.10
Charging from generator	54.23	60.87
Discharging	54.07/46.76	63.16

Filter design & Power Quality

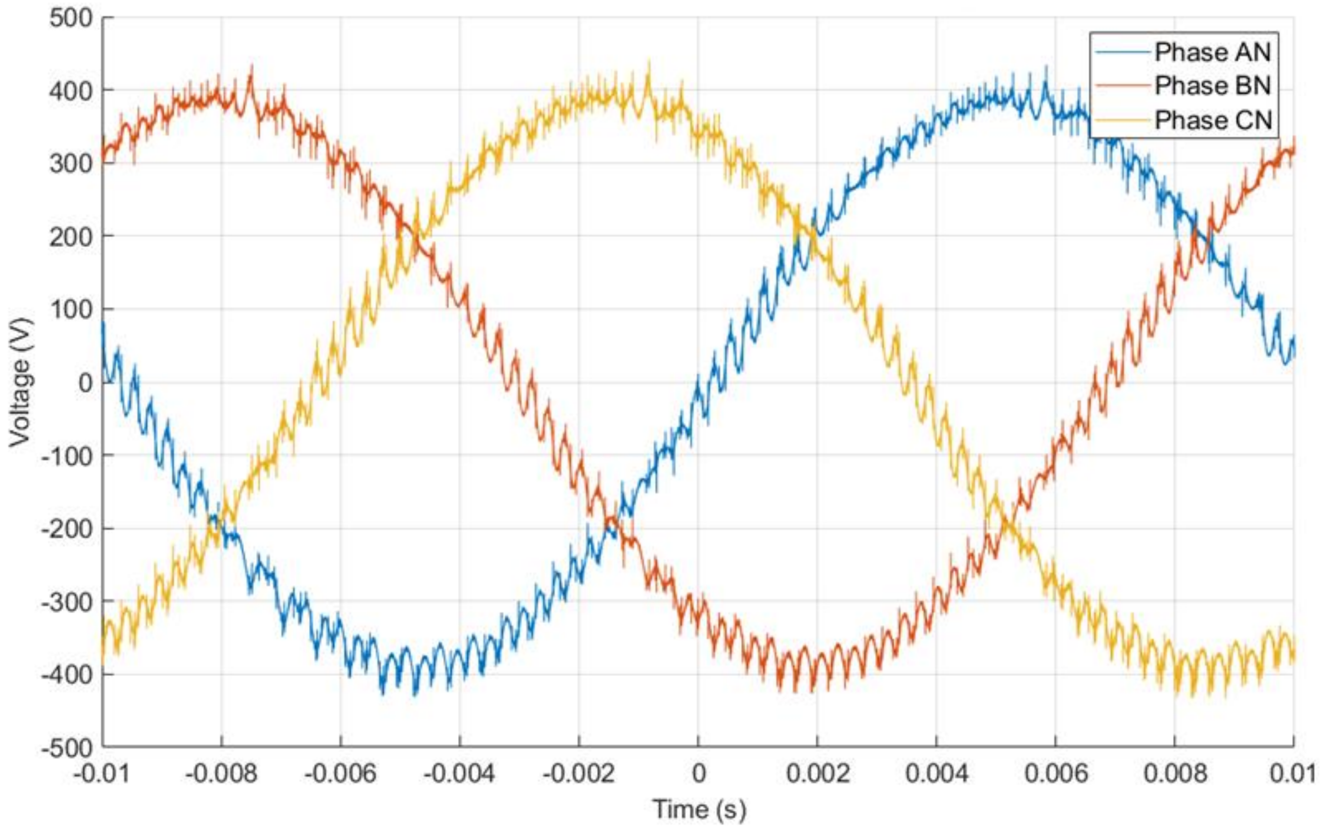
Complaints:

- High maintenance cost generator
  - Bearing replacement every 2000 hours
  - Isolation failure
- Often replace filter capacitors
- Often leakage on the filter inductances



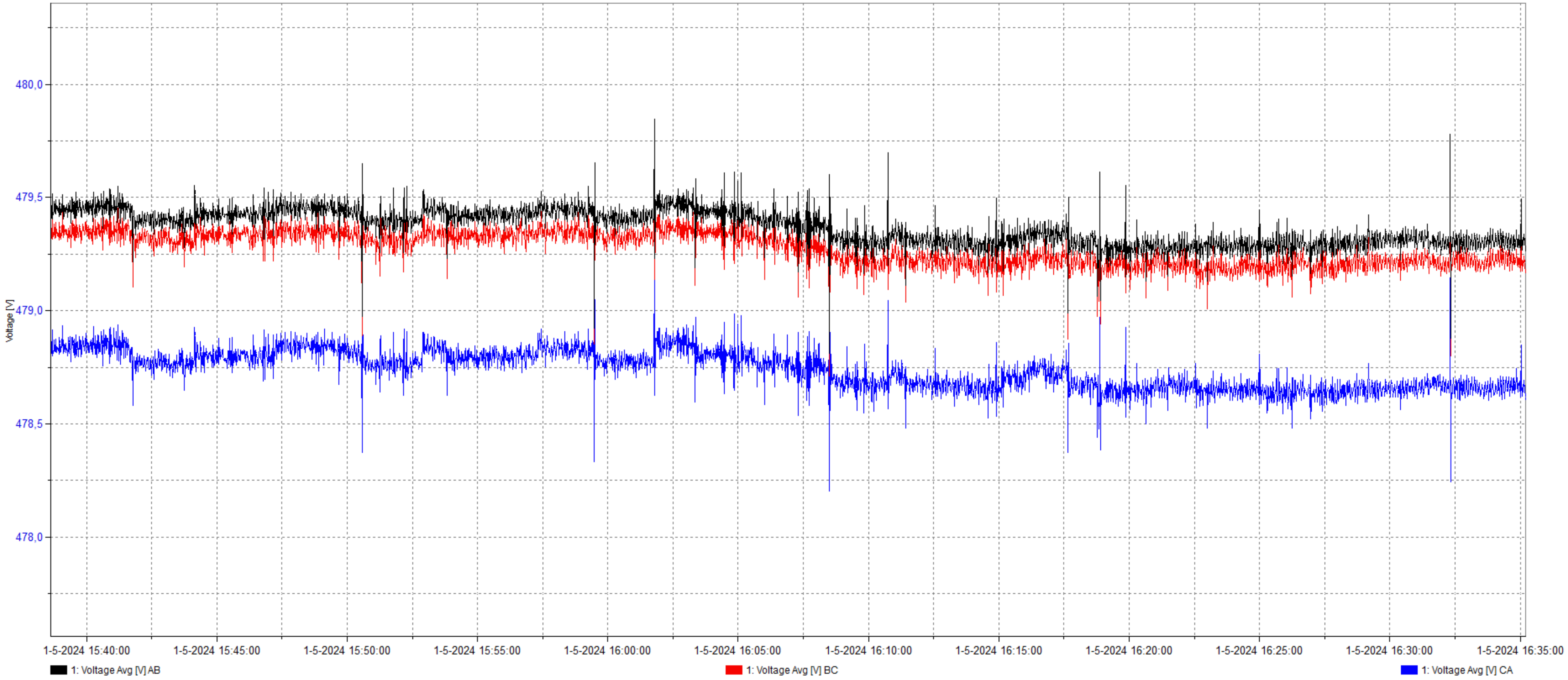
Filter design & Power Quality

A measurement result



Filter design & Power Quality

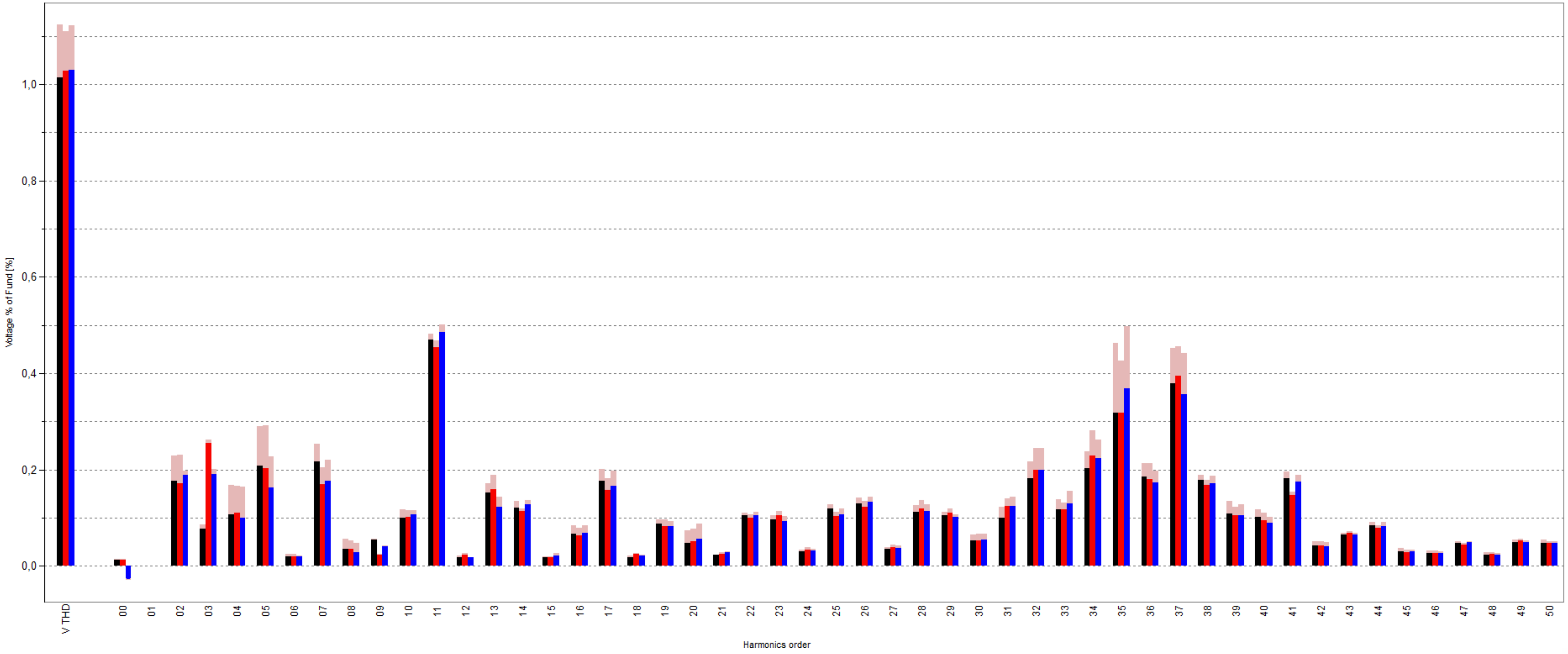
A measurement result



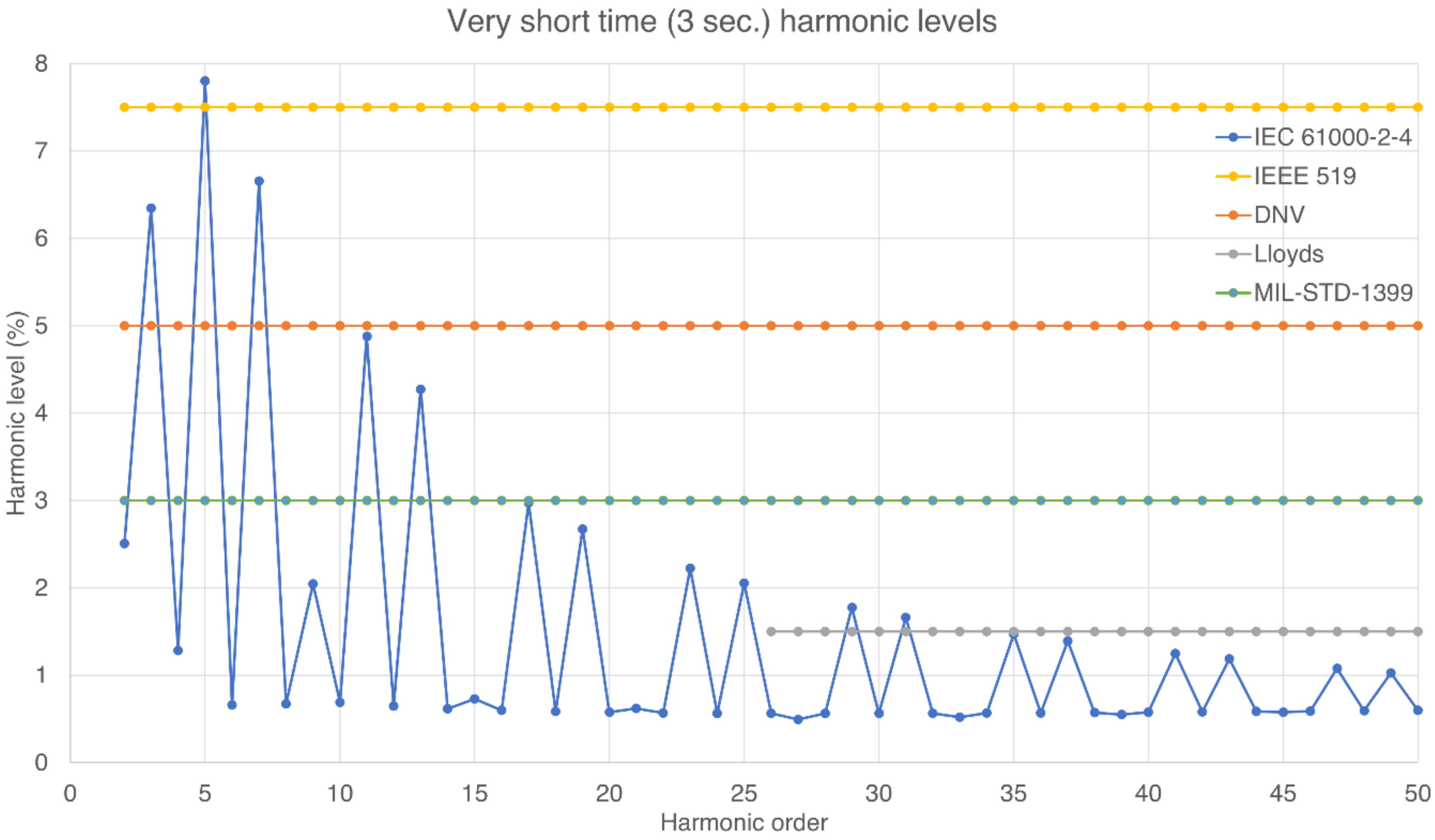
Filter design & Power Quality

A measurement result

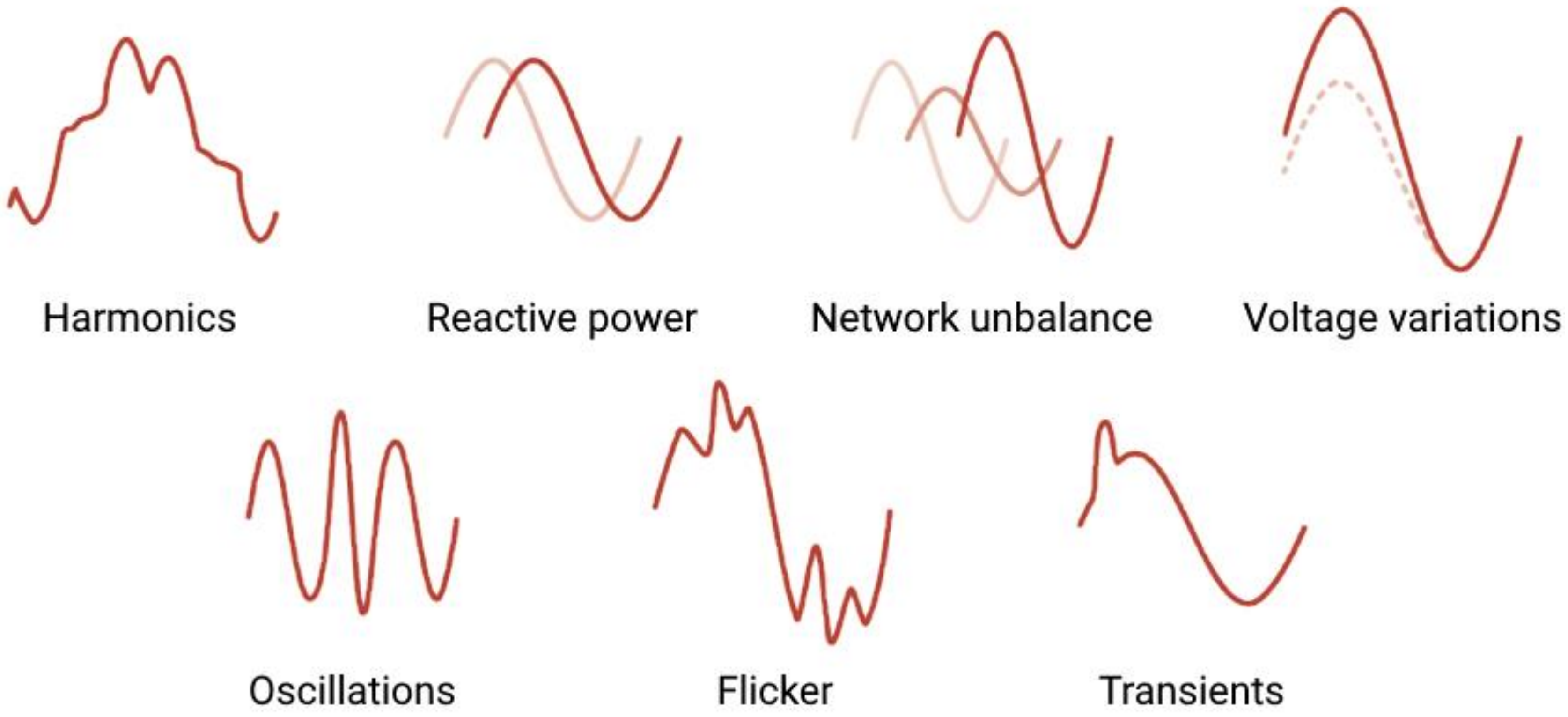
Filter design & Power Quality



Filter design & Power Quality



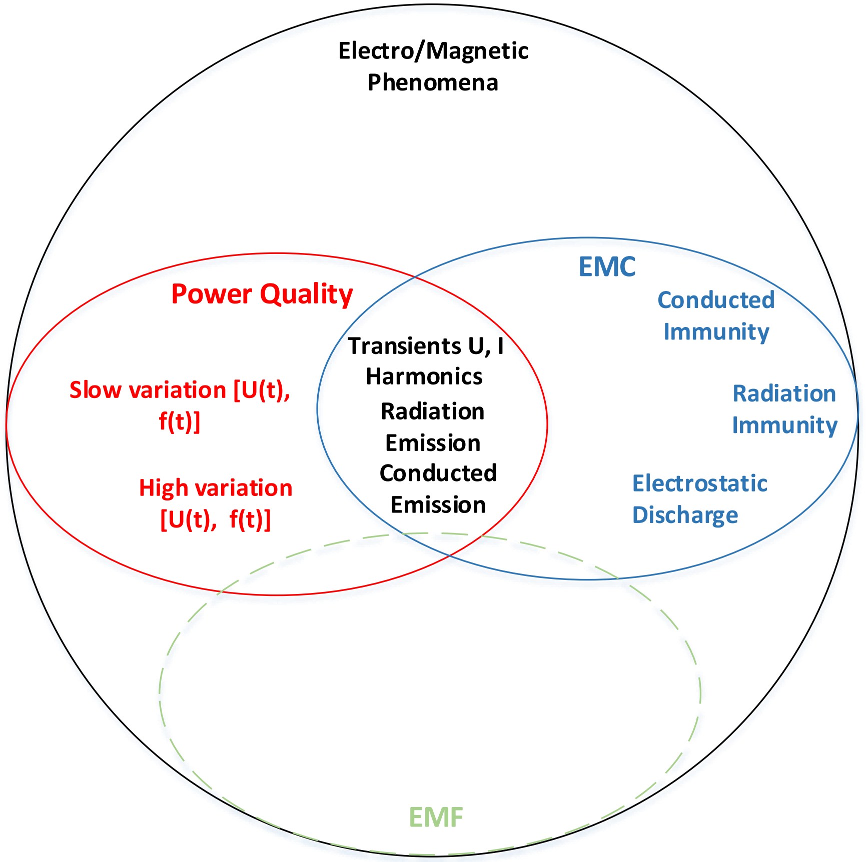
Power Quality



Power Quality and other phenomena

Class requirements
*IEC 61000-3-3
*IEC 61000-2-4
*IEC 61000-4-15
*IEEE 519
*EN 50160

*Land standards



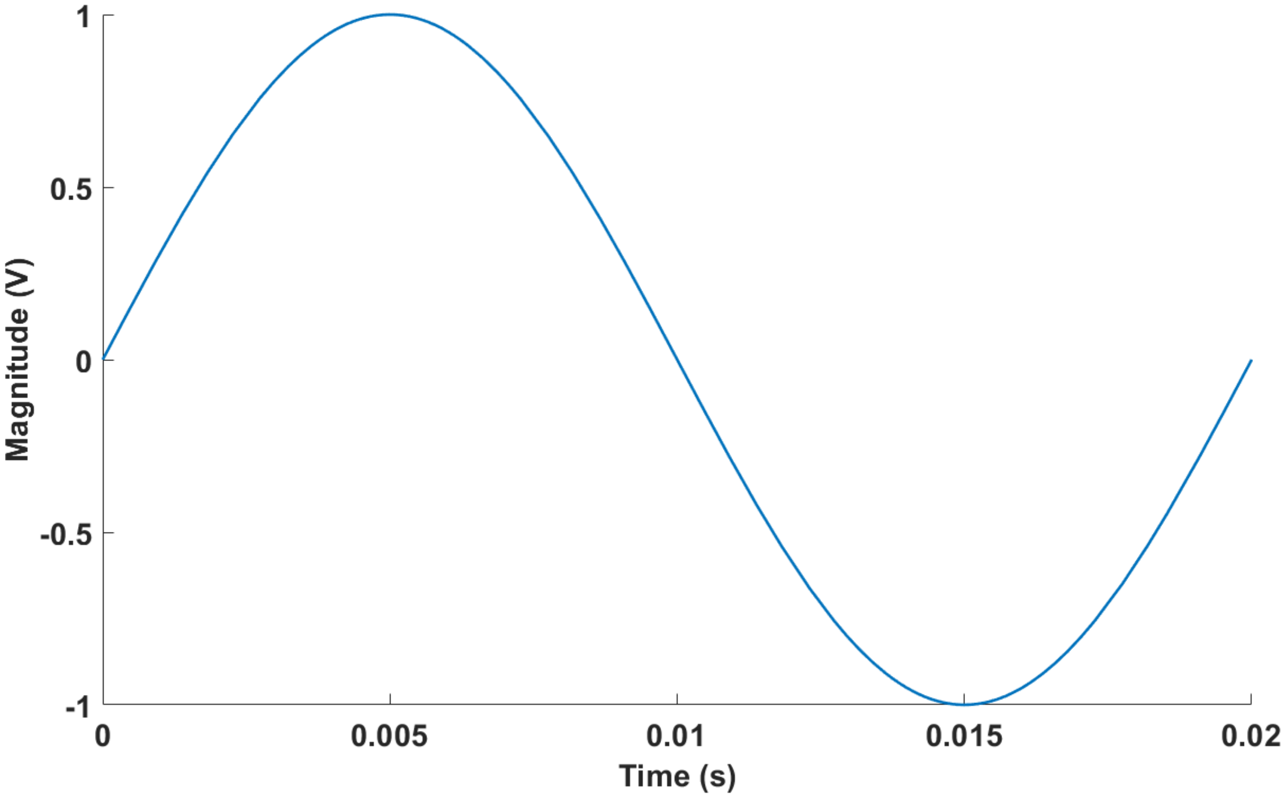
Class requirements
IEC 60533
IEC 60092
*IEC 61800-3

*Land standards

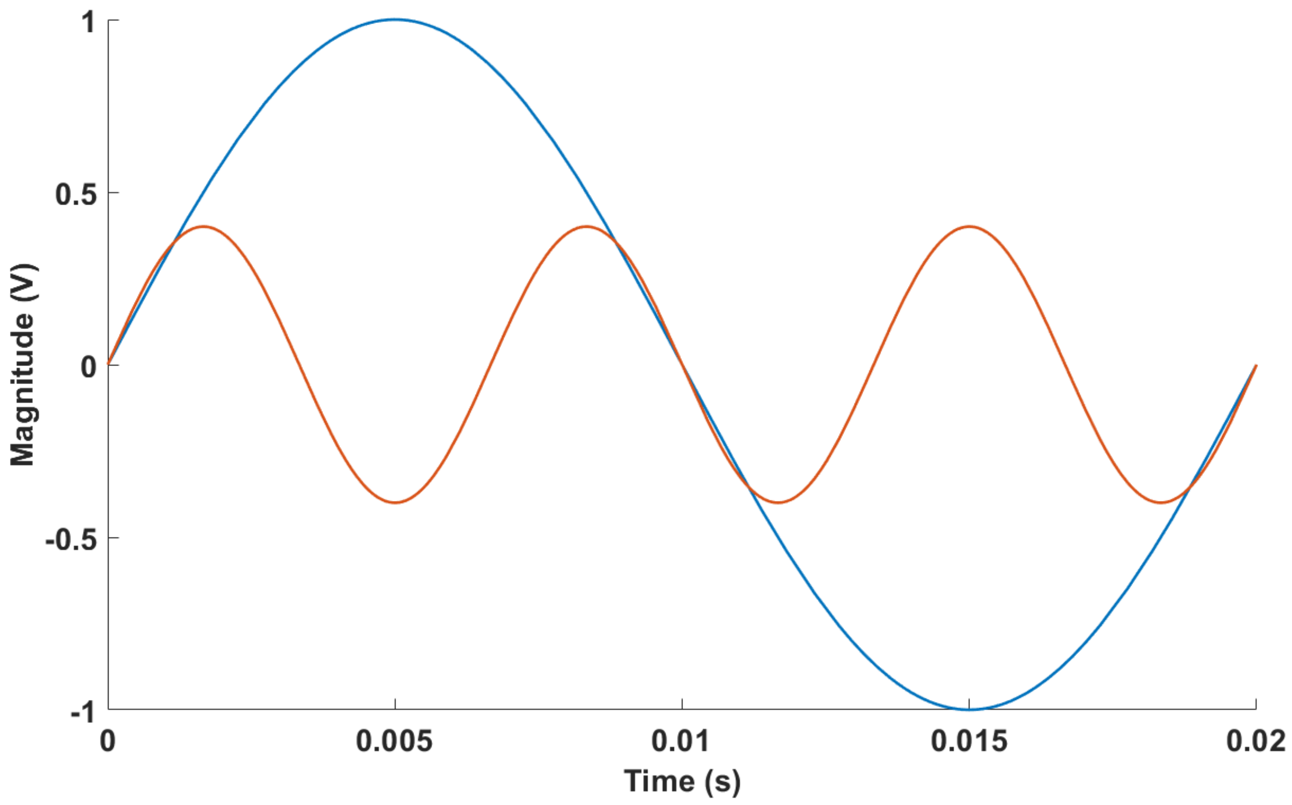
Class requirements
*IEC 62305

*Land standards

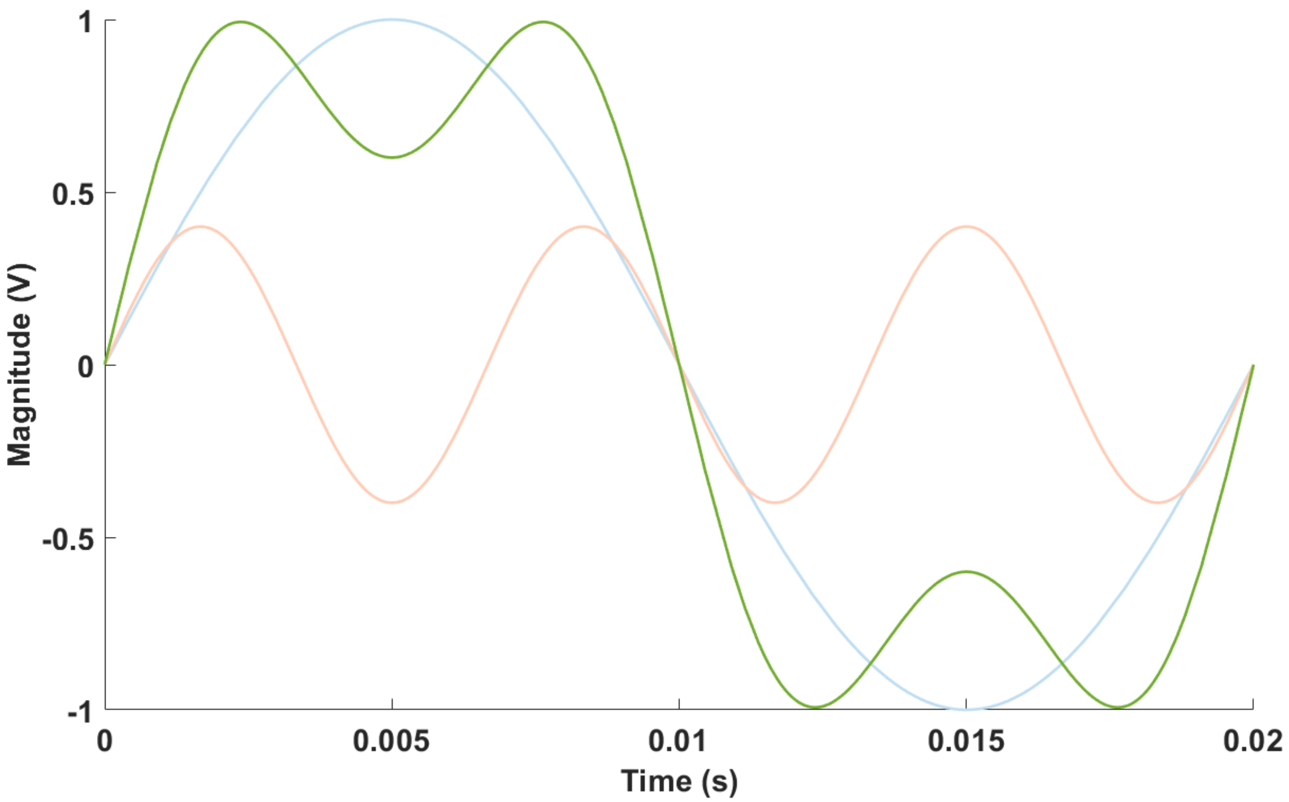
Harmonics



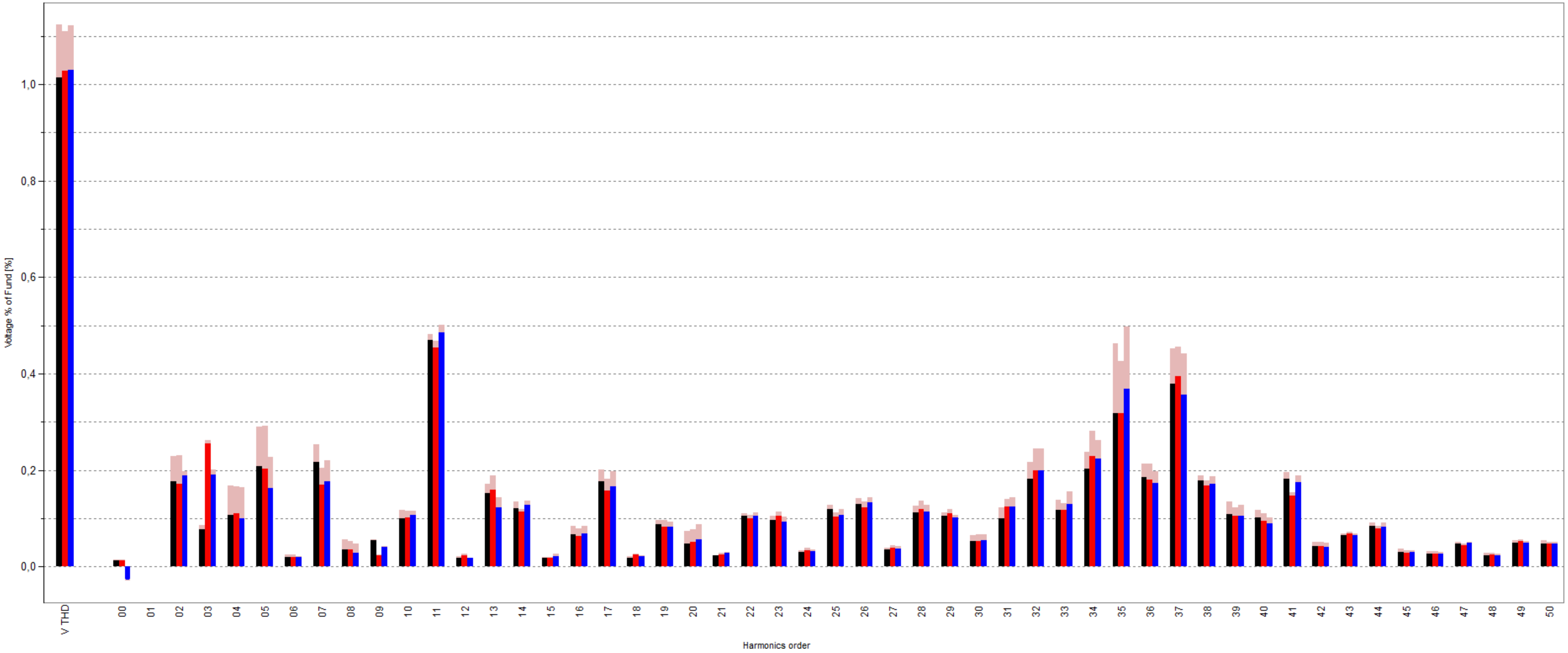
Harmonics



Harmonics

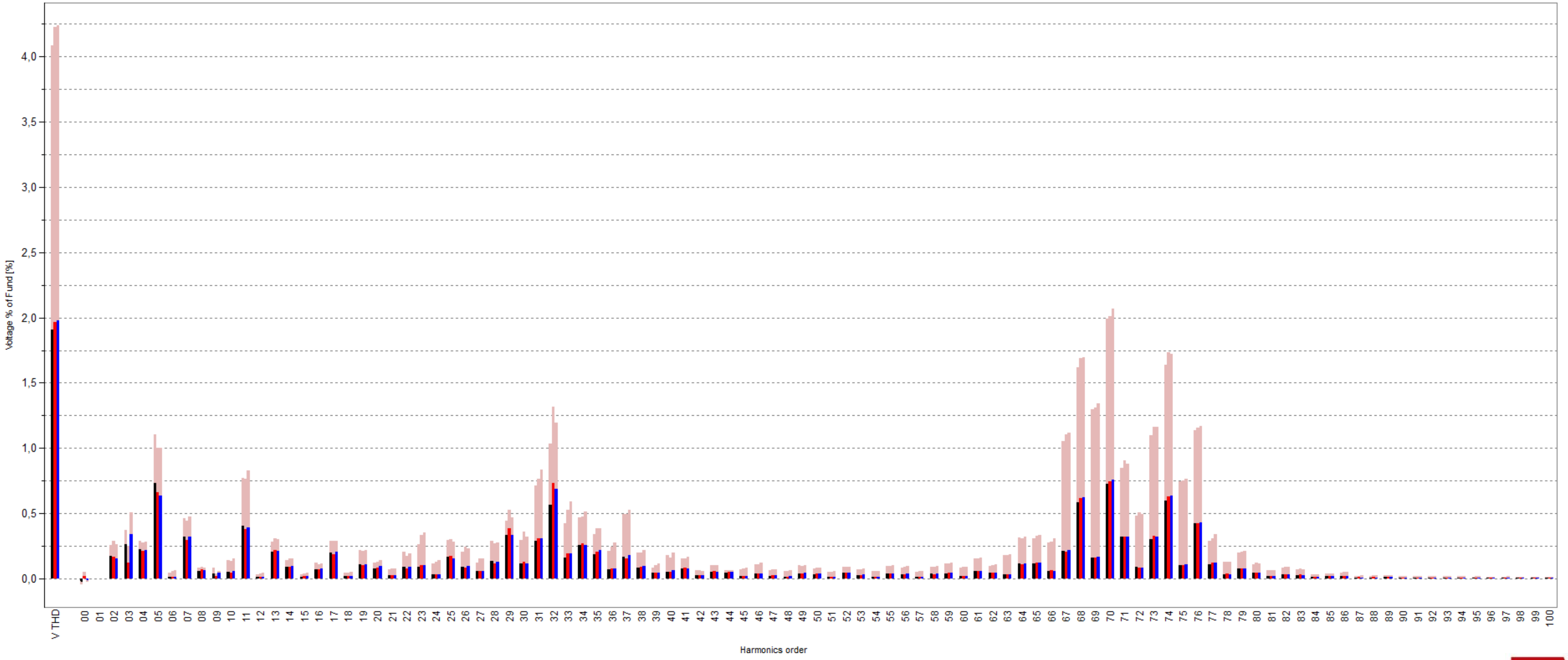


Harmonics

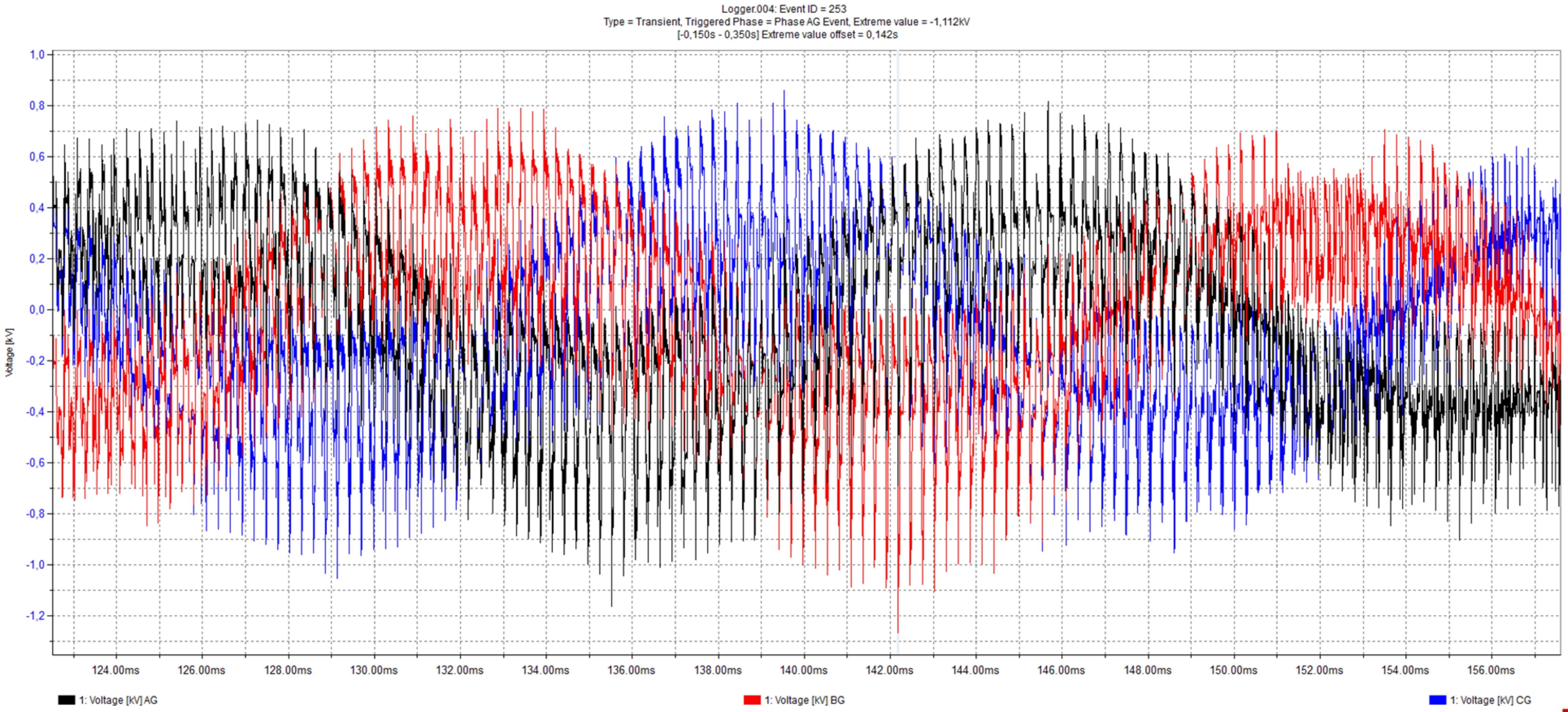


Voltage % of Fund [%]
1,0
0,8
0,6
0,4
0,2
0,0
V THD
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50
Harmonics order

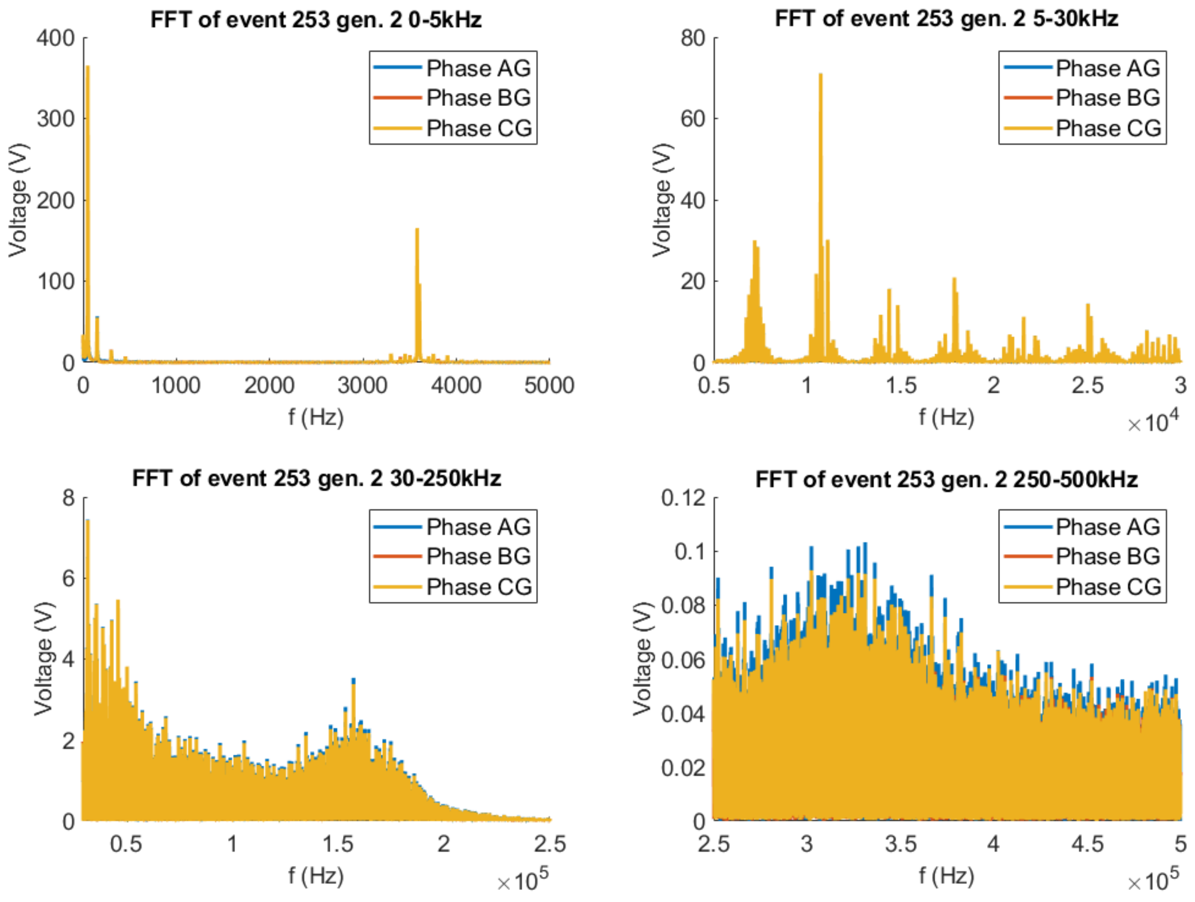
Filter design & Power Quality



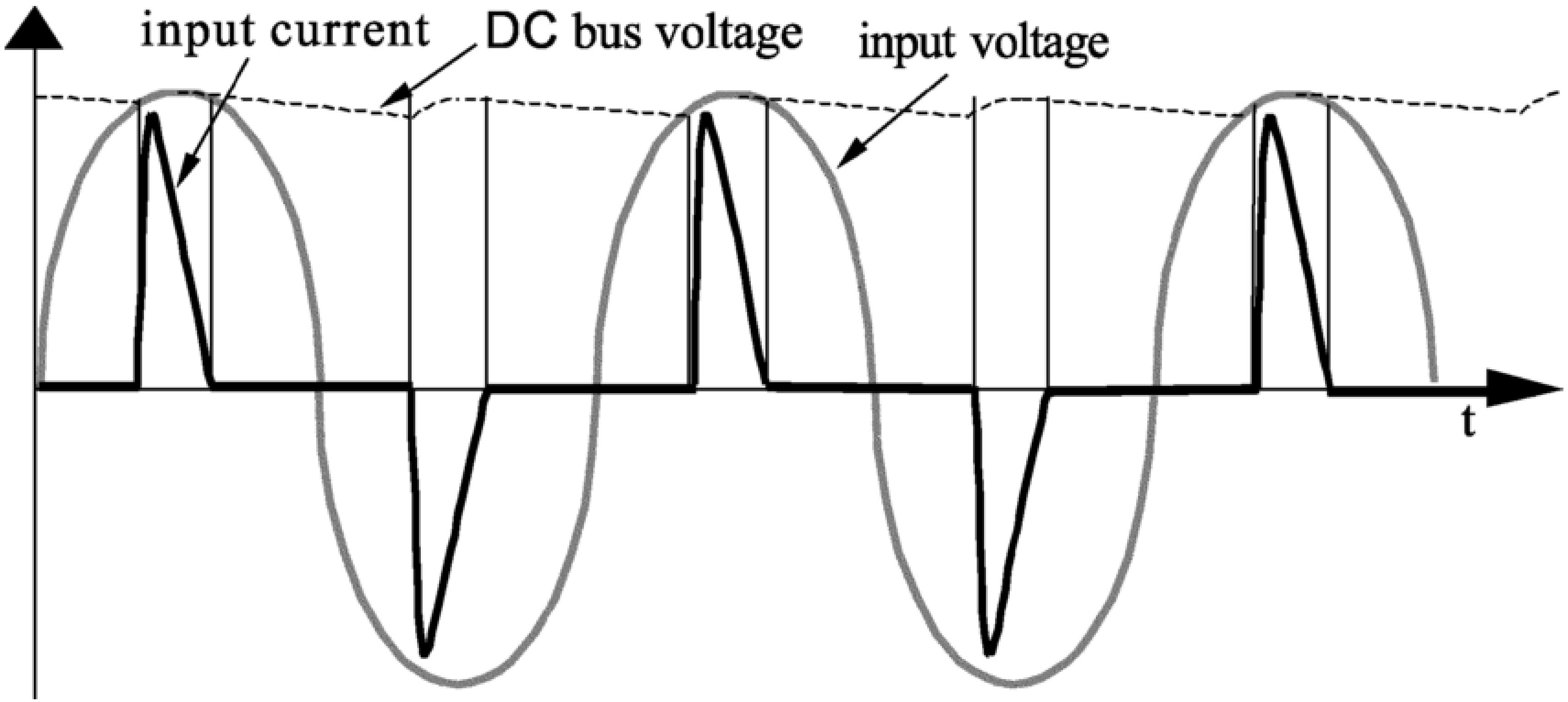
Filter design & Power Quality



Filter design & Power Quality



The effect of switching converters



$$Voltage = current \cdot impedance$$

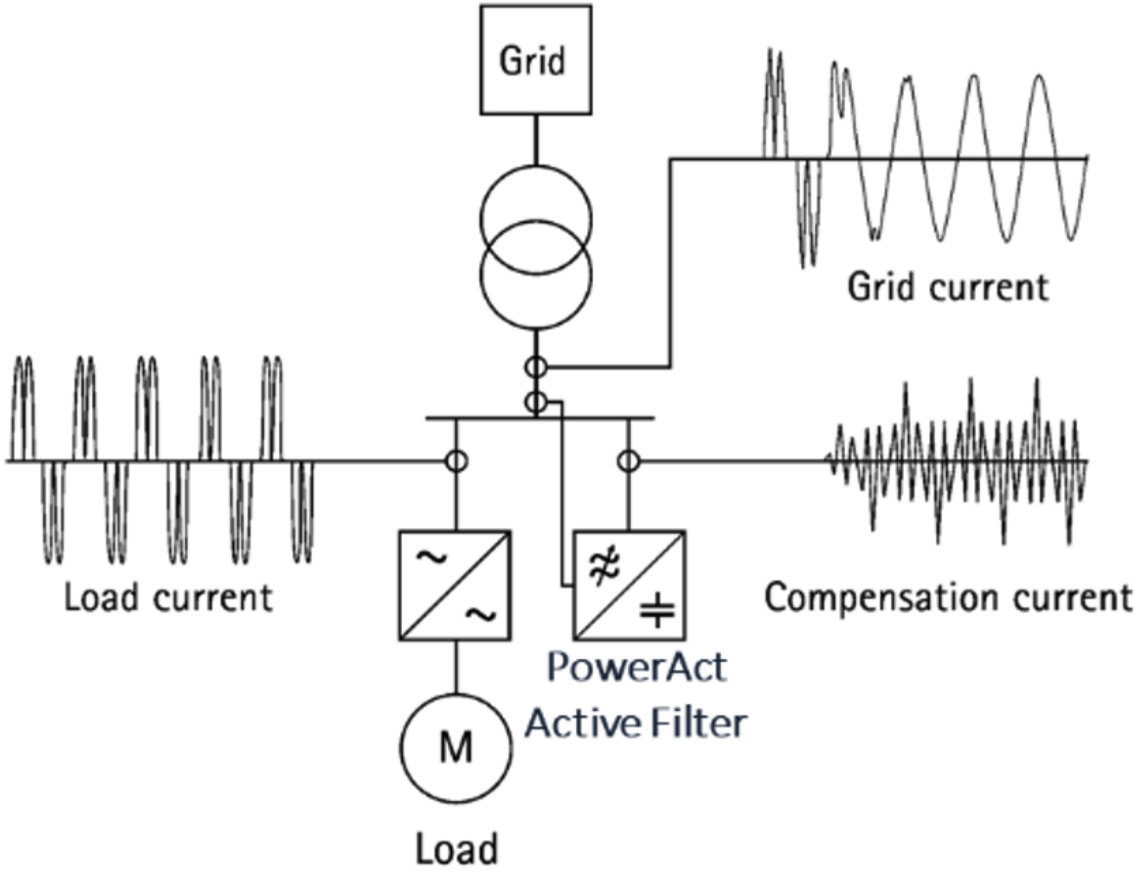
Filter design & Power Quality

What can we do?

- LCL filter
- High frequency (EMC) filter (30kHz – 300kHz)
- High frequency grounding
- Active Harmonic Filter (< 49th harmonic)

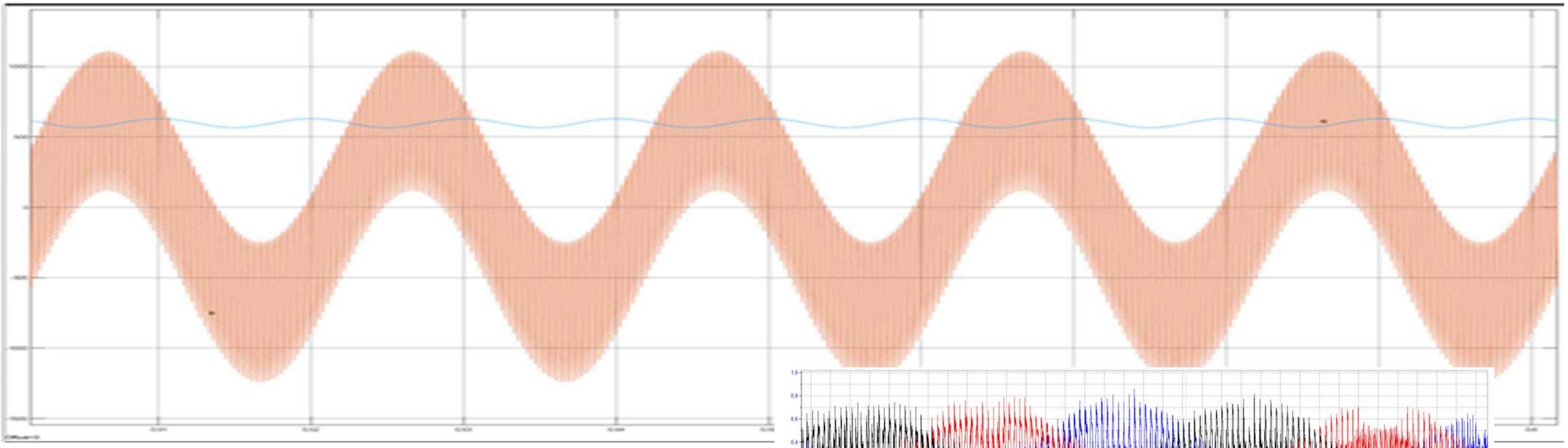
Filter design & Power Quality

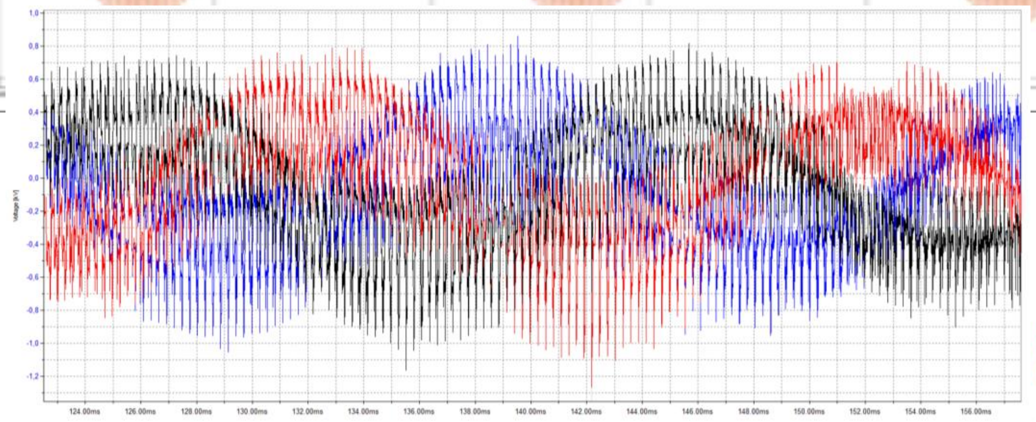
Active Harmonic Filter



Filter design & Power Quality

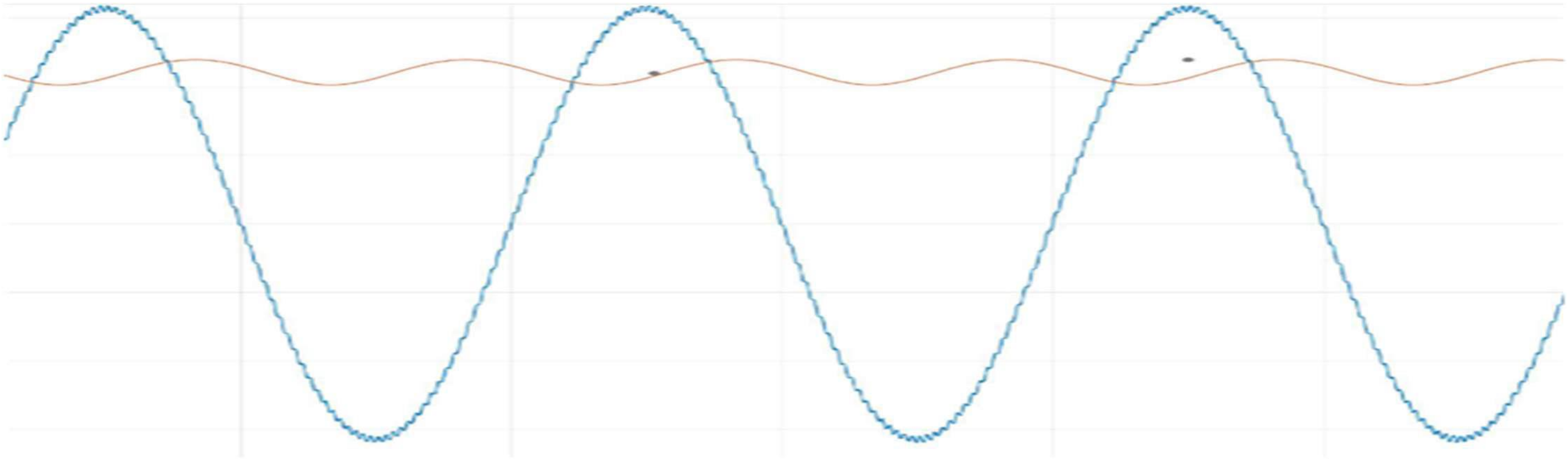
Recreating the measured signal





Filter design & Power Quality

After improving the filter



Key takeaways

- Improper filtering and earthing is the main cause for power quality and EMC issues that can show in decision-making.
- There are many factors that have to be taken into account when choosing for an AC or DC electrical topology.
- A BESS along-with a well-designed EMS, can ensure diesel generators operate at an optimal loading point, reduce fuel consumption and increase maintenance savings.
- A well-designed EMS needs to have intelligent decision-making capabilities.
- Choosing a battery size for your vessel is not a trivial decision. Many factors have to be taken into account for it to be profitable.

Thank you for your attention!

Questions?

WeConnect.