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 / TU Delft

11 juni 2024

'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 and heavy
- Additional electrical losses
- Dead within 2 years if not used properly

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: Graduate intern
- Hardware In Loop real-time modelling & hybrid EMS design

Agenda / Index

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

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

KNVTS

Our History – over a century of experience

1889-1899
Start:
Light bulb factory Roothaan, Alewijnse & Co

1900-1945
Electrical installation company C. Alewijnse & Co

1945-1962
Strong growth in electrical installations of factories and vessels

1962-1980
Start and take-over companies in Vlaardingen, Tiel, Drachten, Zwolle, Zaltbommel and Delft

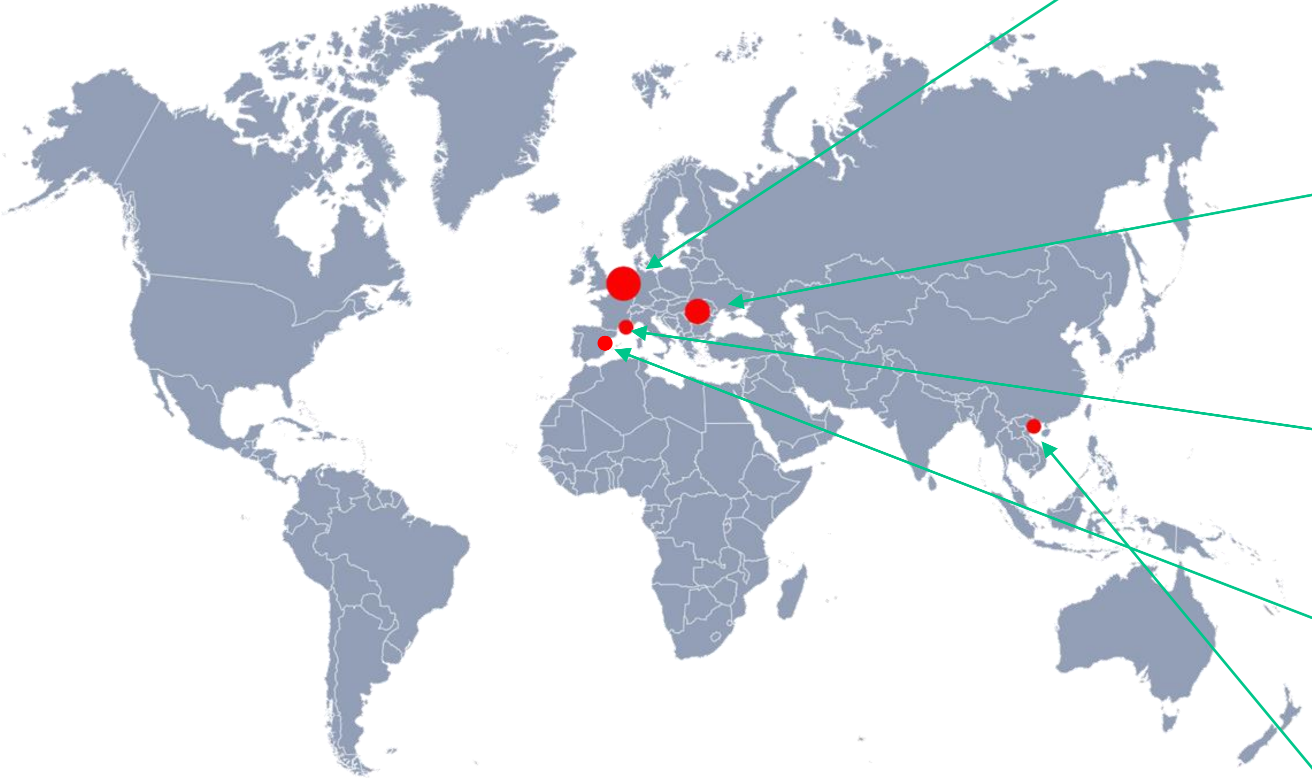
1980-2002
Emergence of ICT, start-up company in Romania, take-over company in Krimpen a/d IJssel

2002-2015
Internationalization and focus on engineering and automation

PRESENT
Take over by SRC, Common Wealth & Damen. Further focus on system integration. Tijssen Elektro added to the Alewijnse

Alewijnse

Our locations



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

KNVTS

Mission Statement

Mission

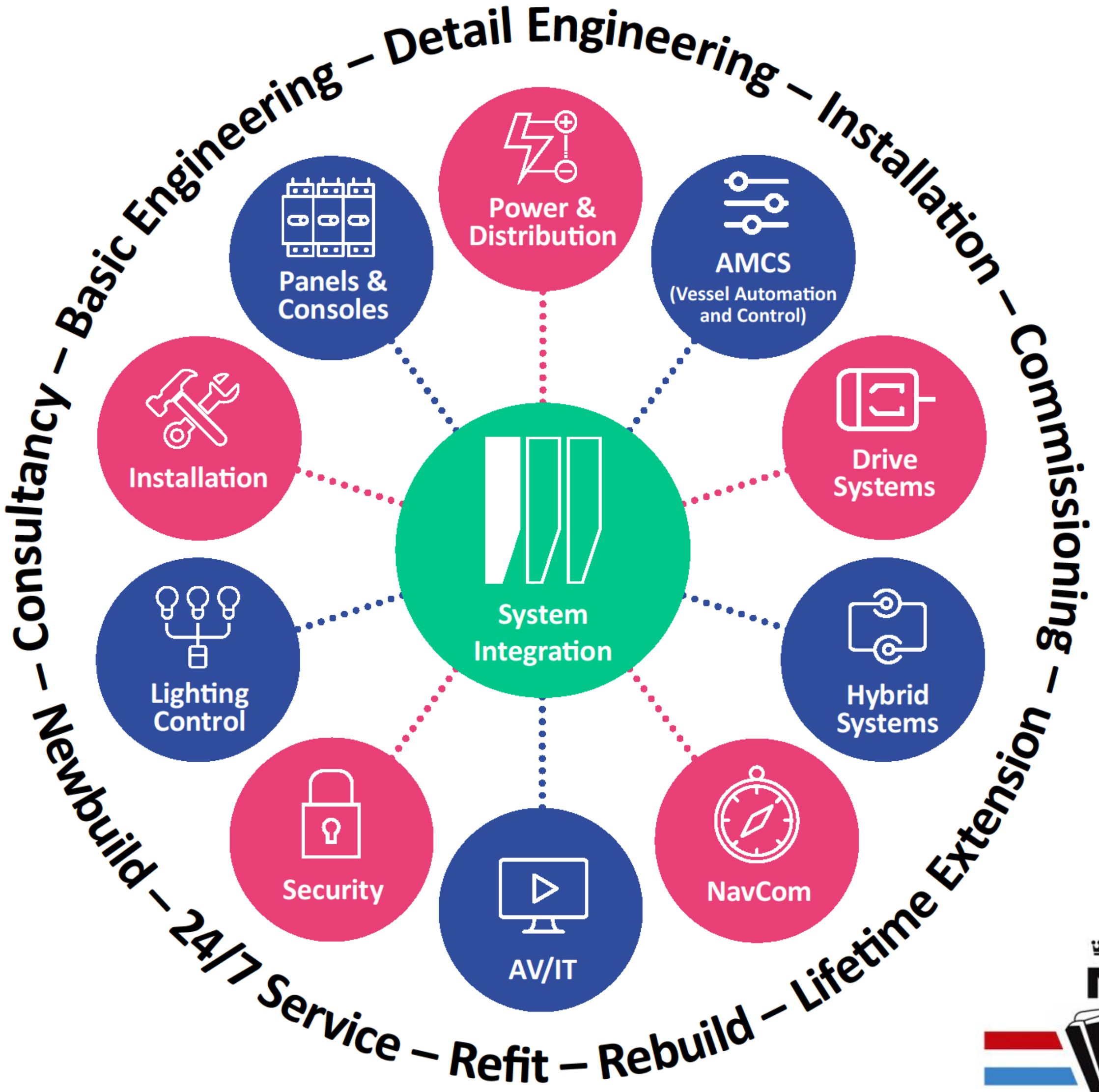
- We Connect. Our passionate teams connect people and technology.

Vision

- Our goal is to continuously create added value for our employees and our customers by stimulating developments and being a technology partner who thinks along with its co-makers from the very beginning through to delivery.
- In doing so, we strive to develop and improve electrification and automation solutions that are innovative, sustainable and of the highest quality in order to make a valuable contribution to successful projects in the maritime and industrial sectors.

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



Let’s do the math

On a hybrid installation

- Battery price: €500,-/kWh
- Converter cost
- Integration/EMS cost (not included)
- Losses (not included)
- Limited lifetime

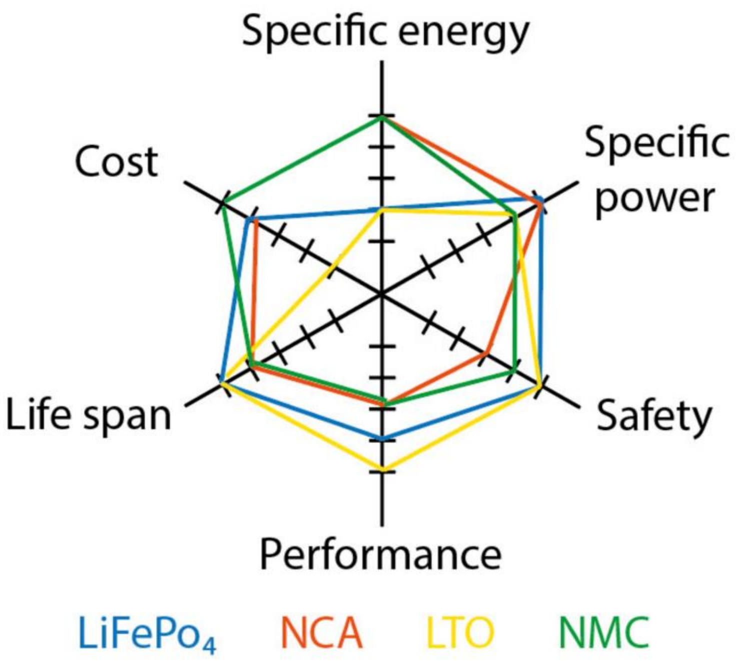
200kWh battery:	€100.000
400kW converter:	€150.000
	= €250.000
Fuel price:	€750/mt
Fuel amount to be saved:	333mt
Fuel price:	€500/mt
Fuel amount to be saved:	500mt

Battery specifications

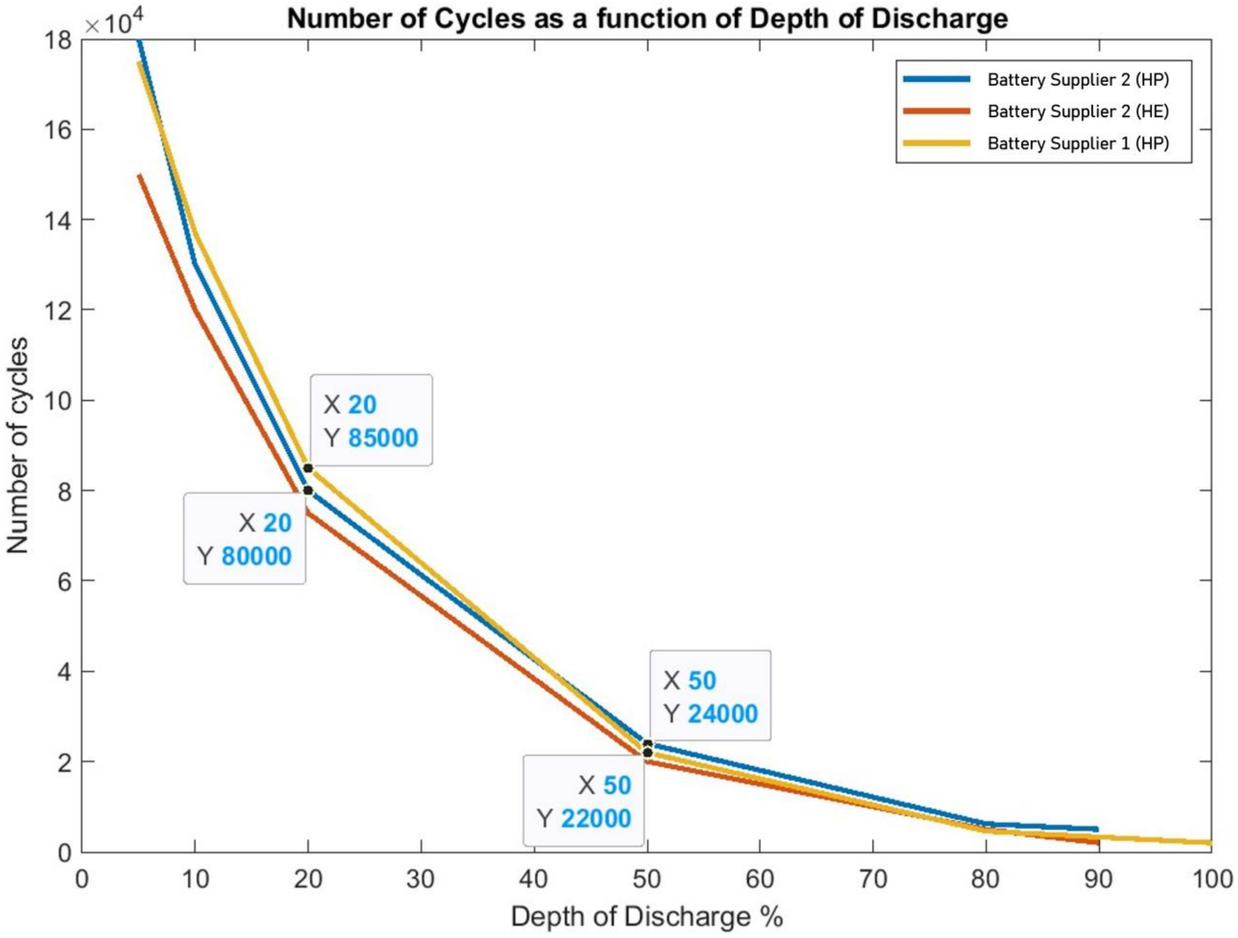
- High power
- High energy
- Chemistry
- Ageing

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

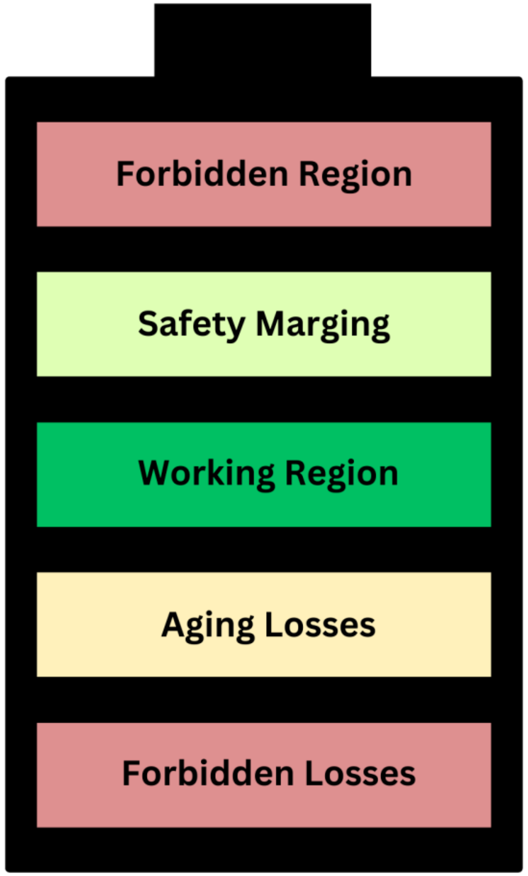
C-rate < 0,8: high energy
C-rate > 0,8: high power



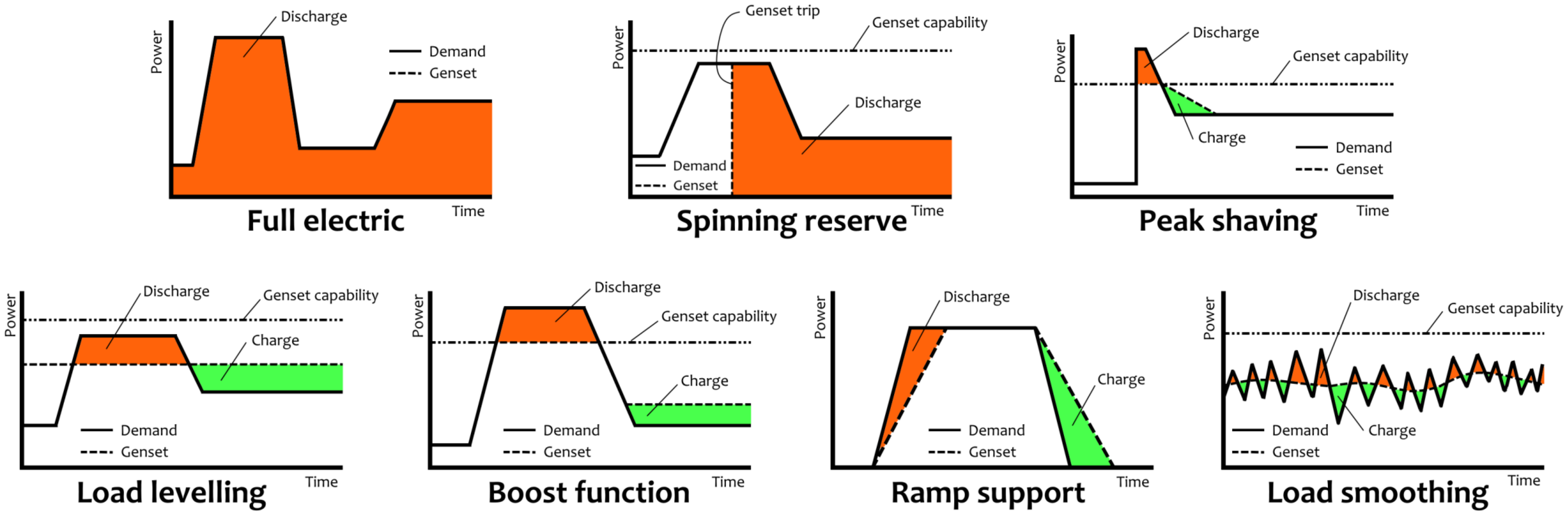
Battery specifications



Battery specifications

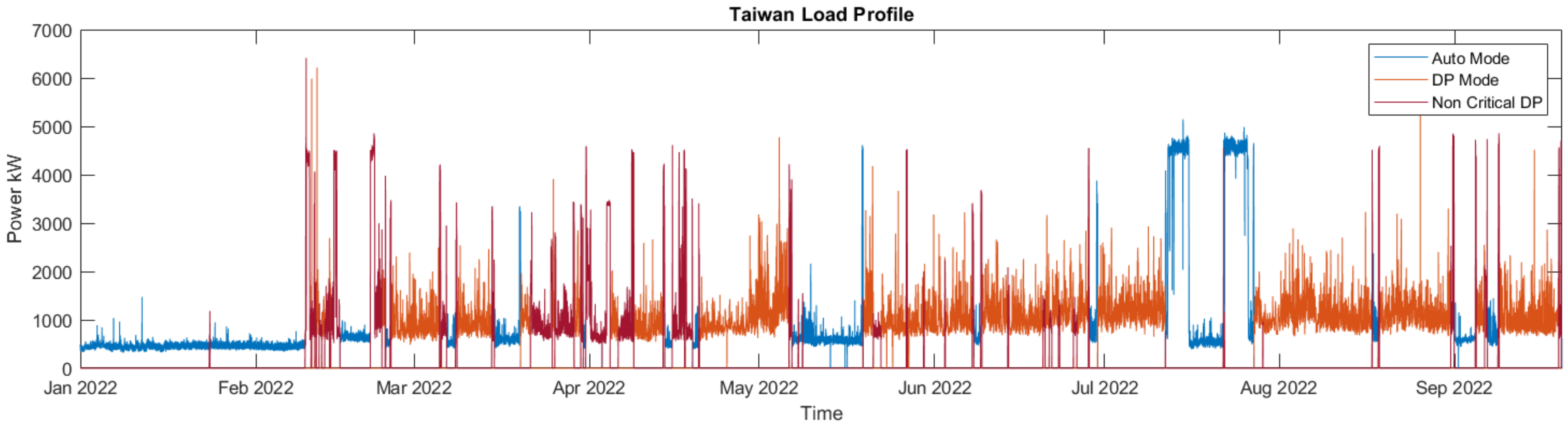


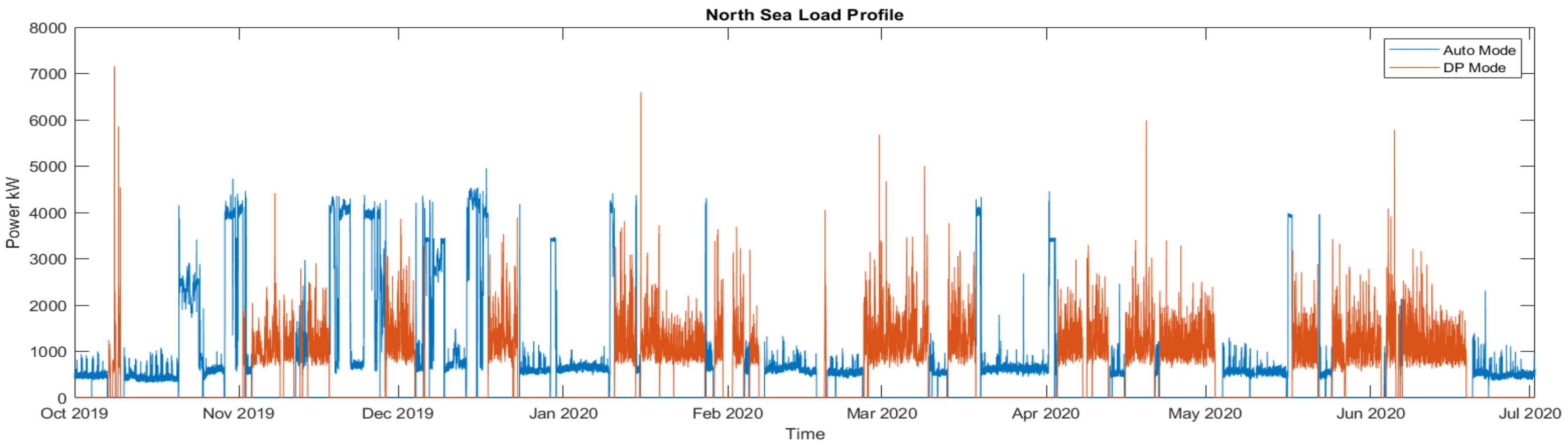
How do you use the battery?

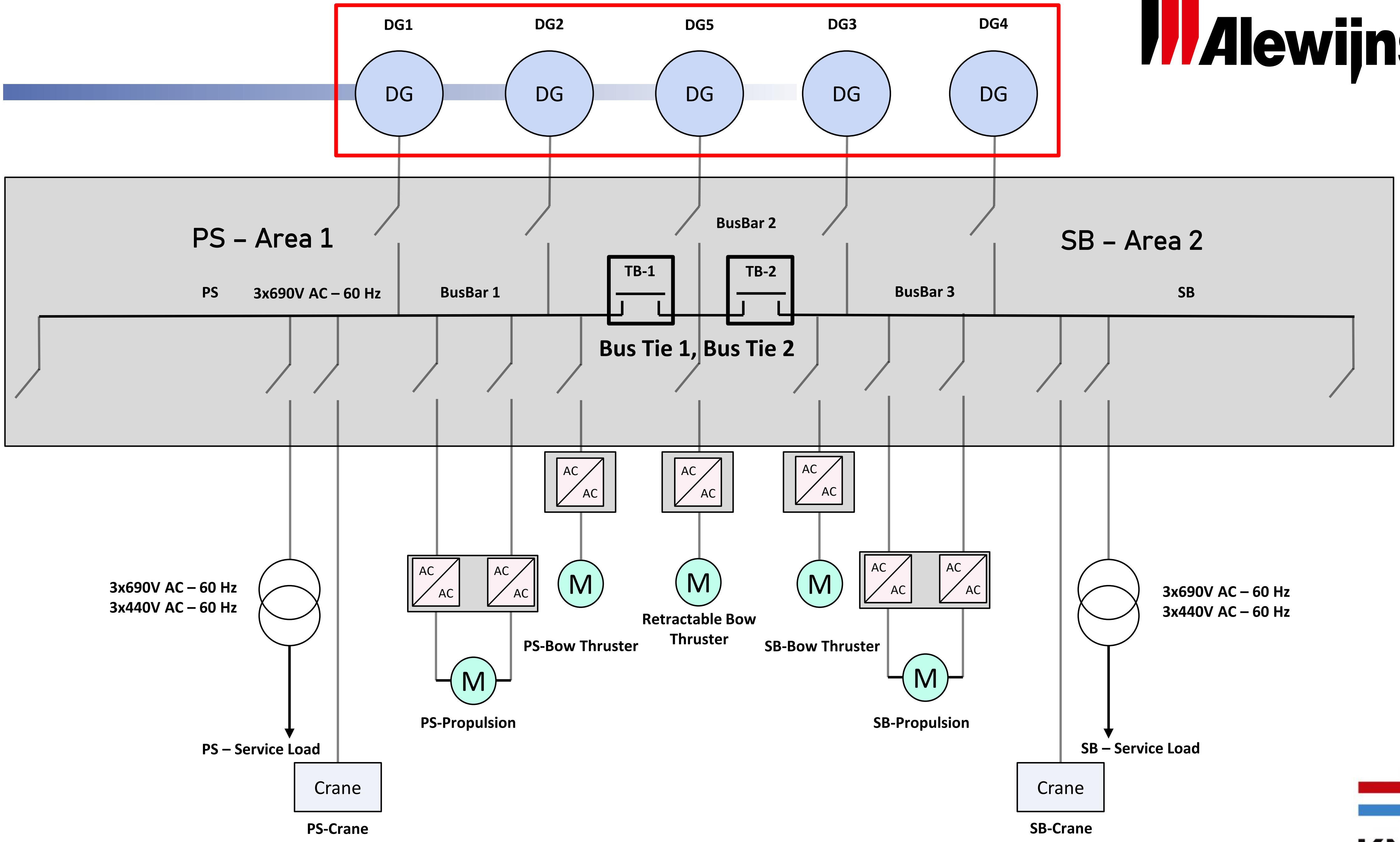


Operational profile

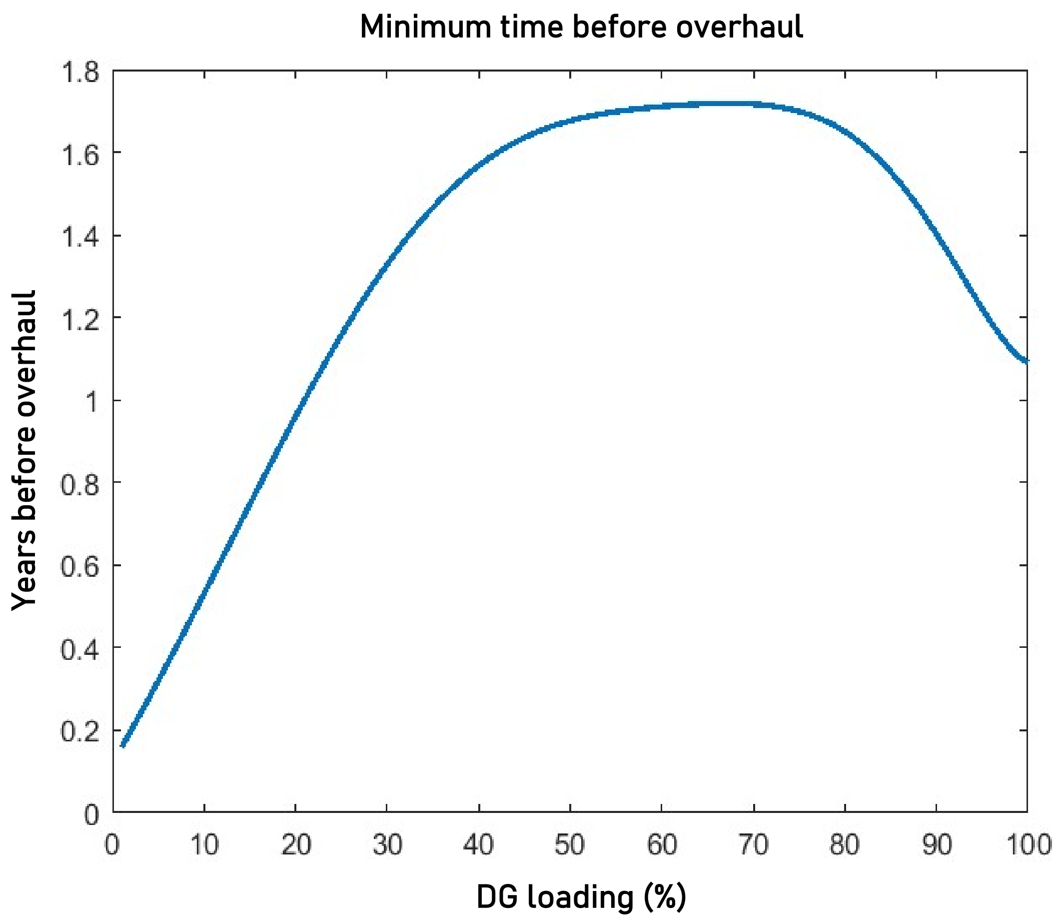
Ideal case: lots of data available






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

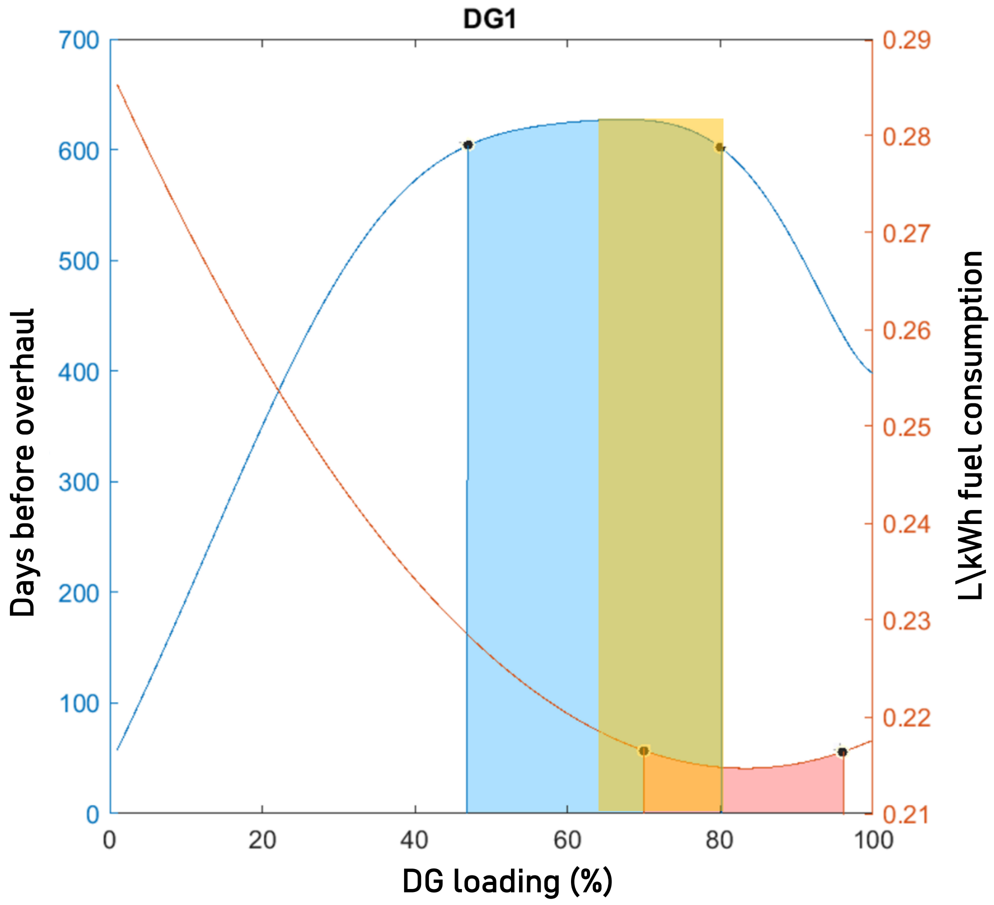
Generator maintenance



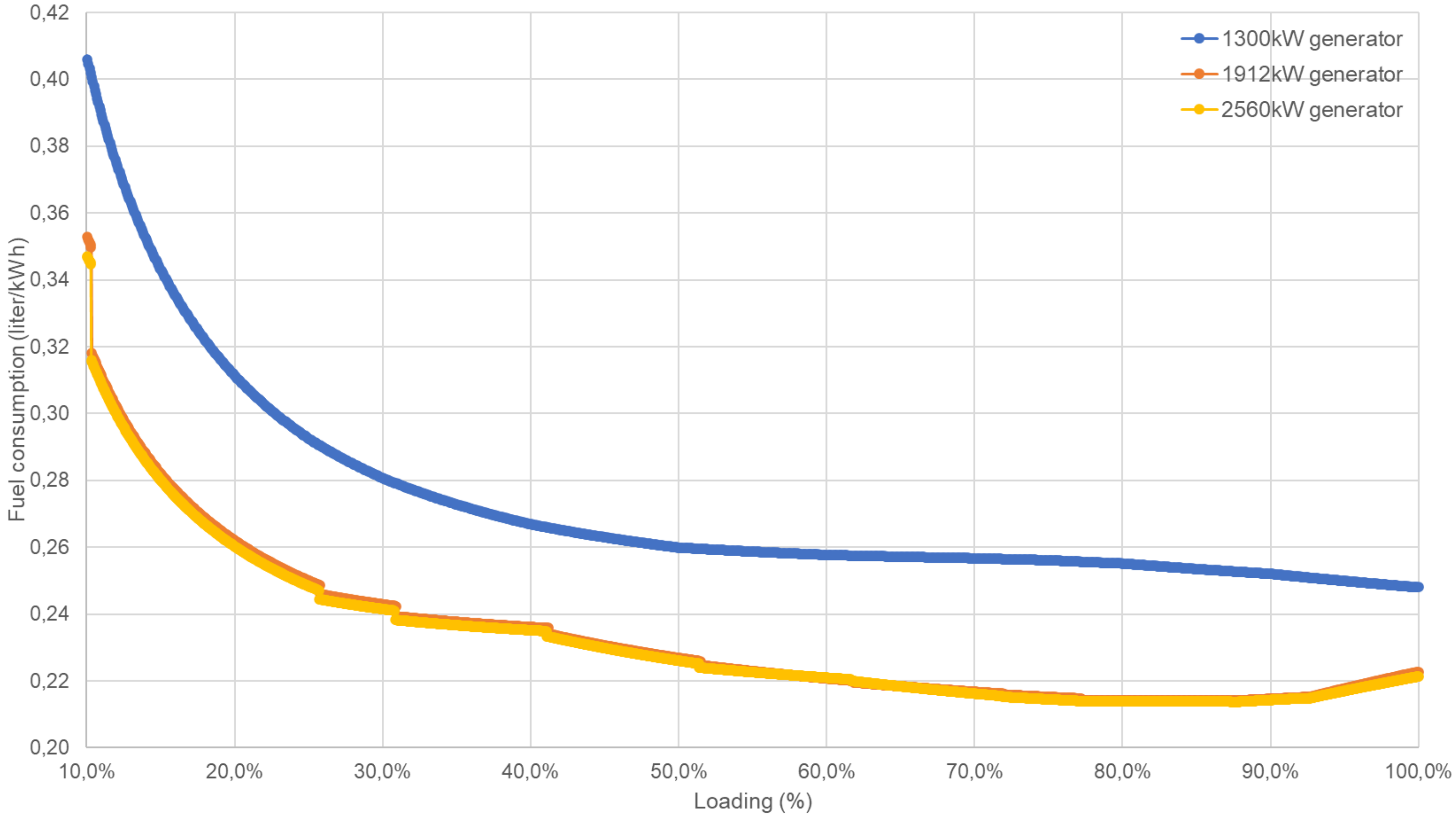
[1] Carlos Frederico Matt et al. “Optimization of the Operation of Isolated Industrial Diesel Stations

Generator maintenance

Optimizing fuel & maintenance

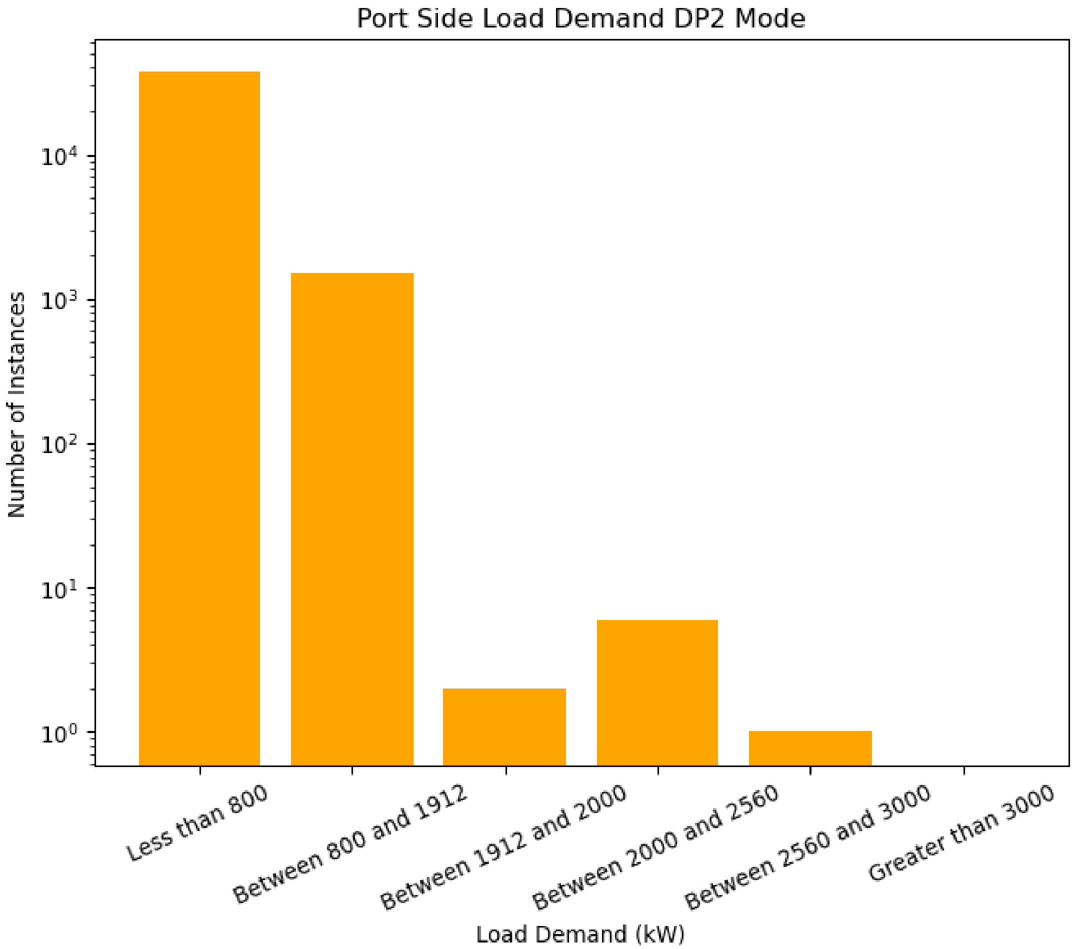


Fuel consumption



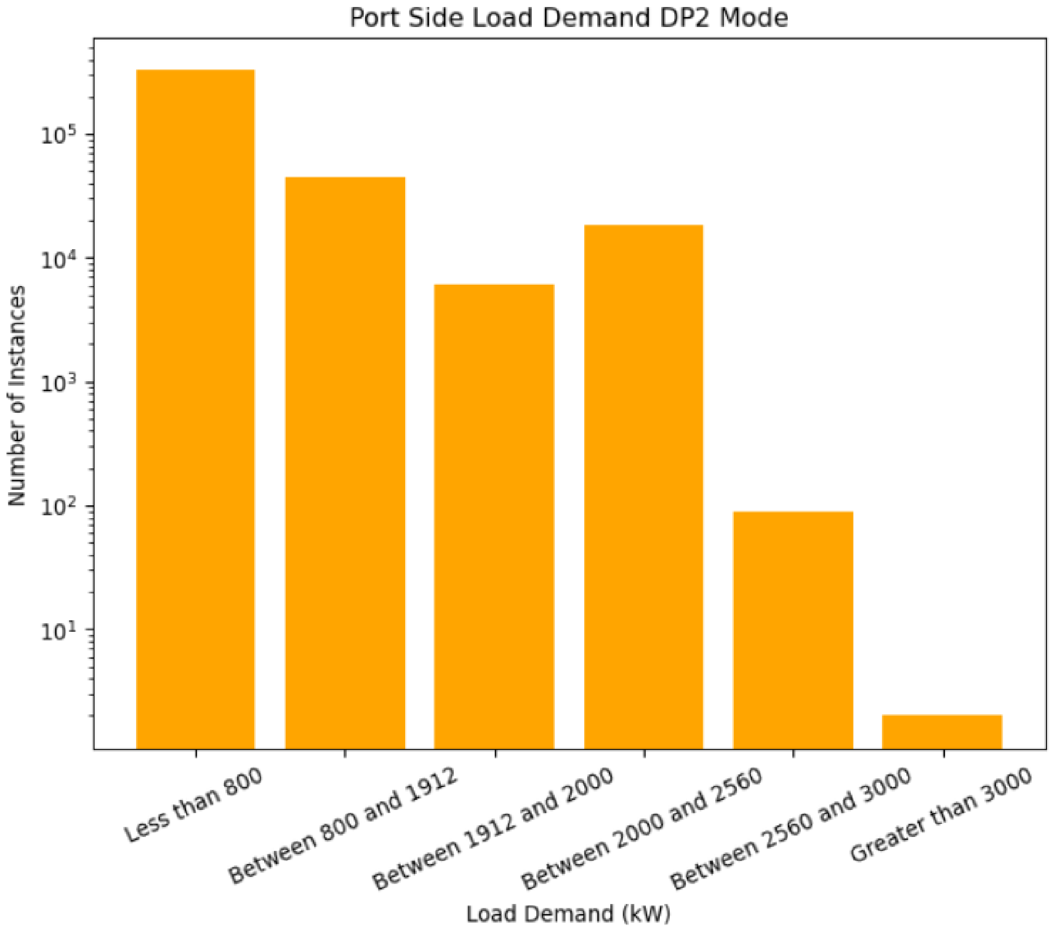
Event analysis

Taiwan load profile



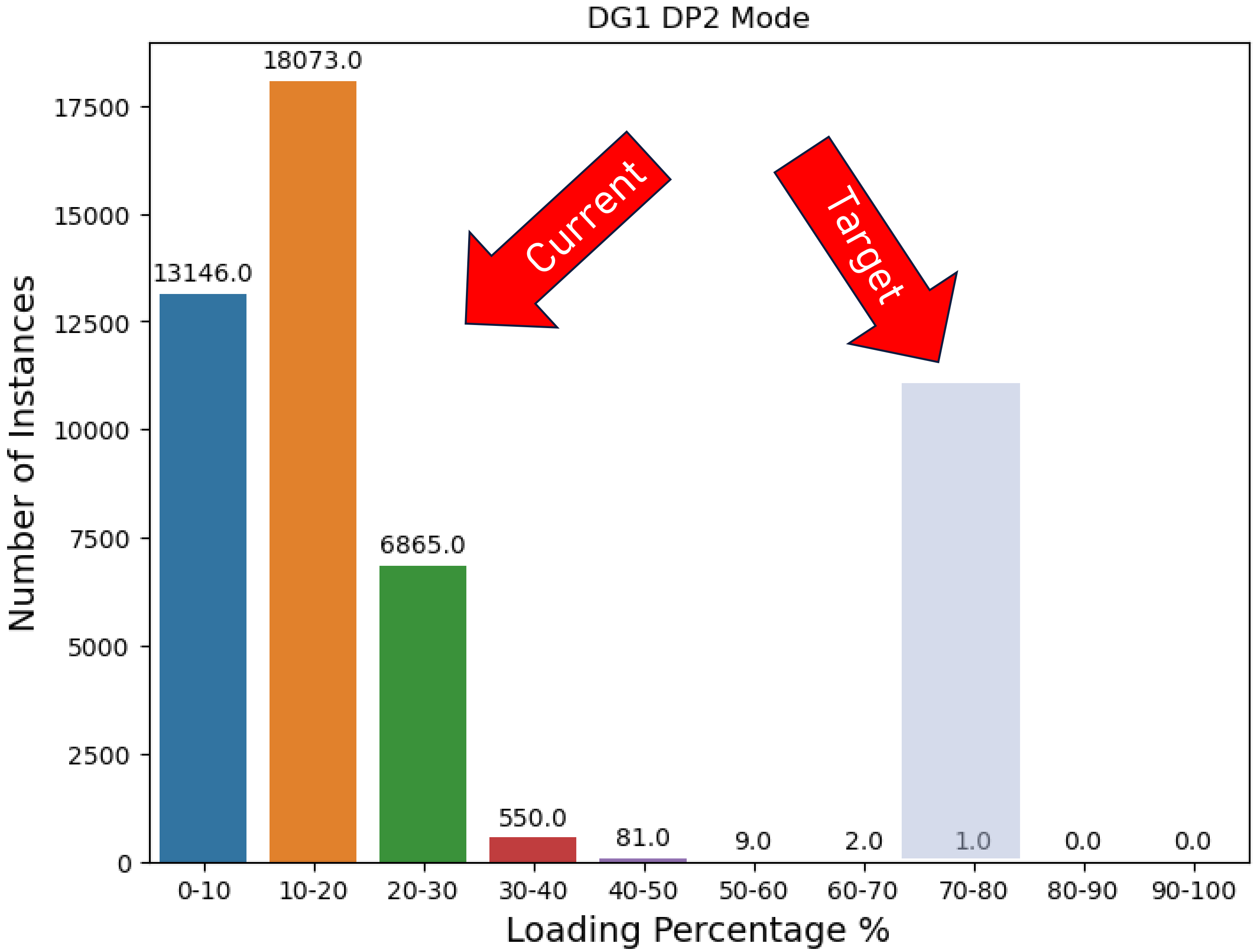
Event analysis

North Sea load profile



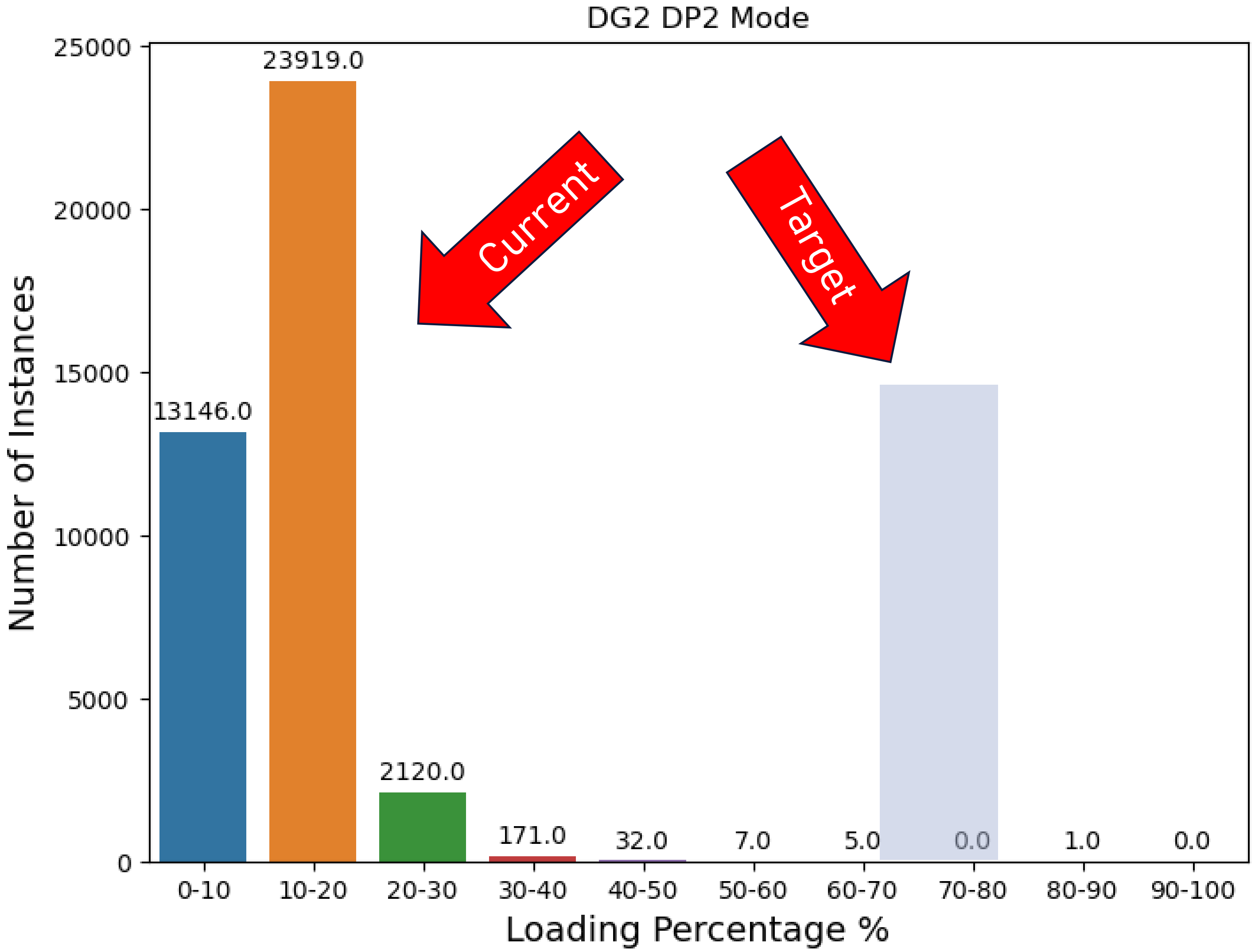
Generator loading

Taiwan load profile



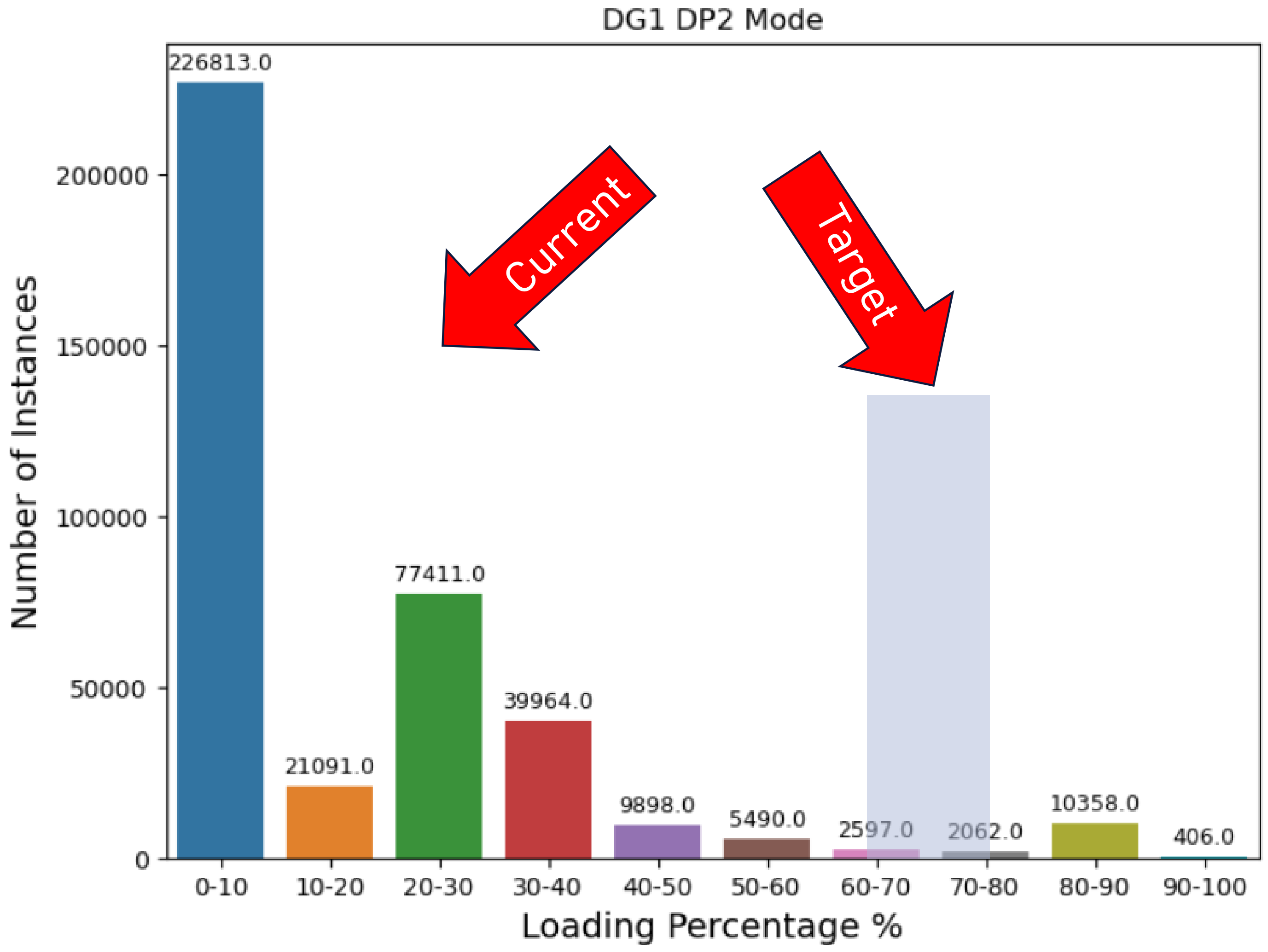
Generator loading

Taiwan load profile



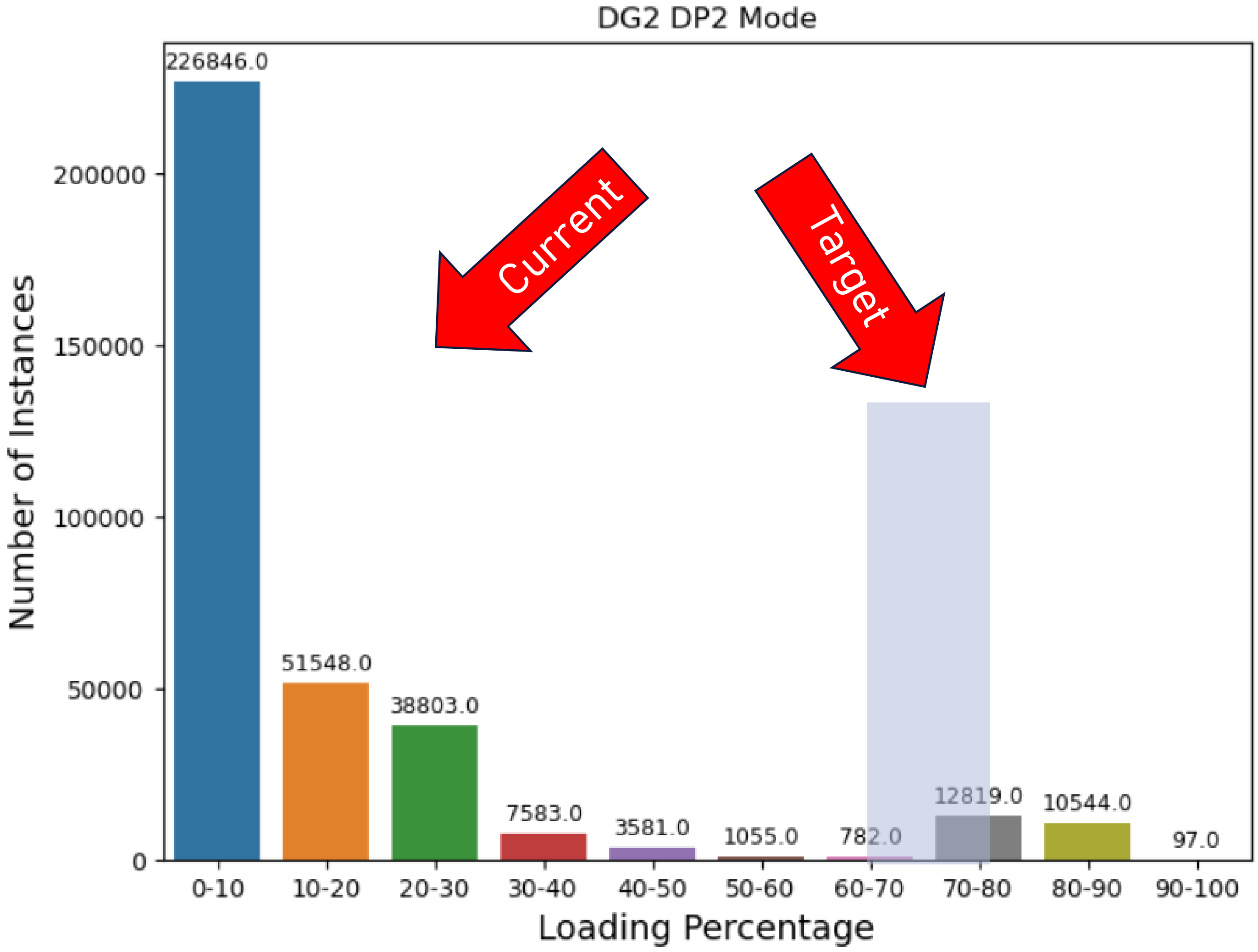
Generator loading

North Sea load profile



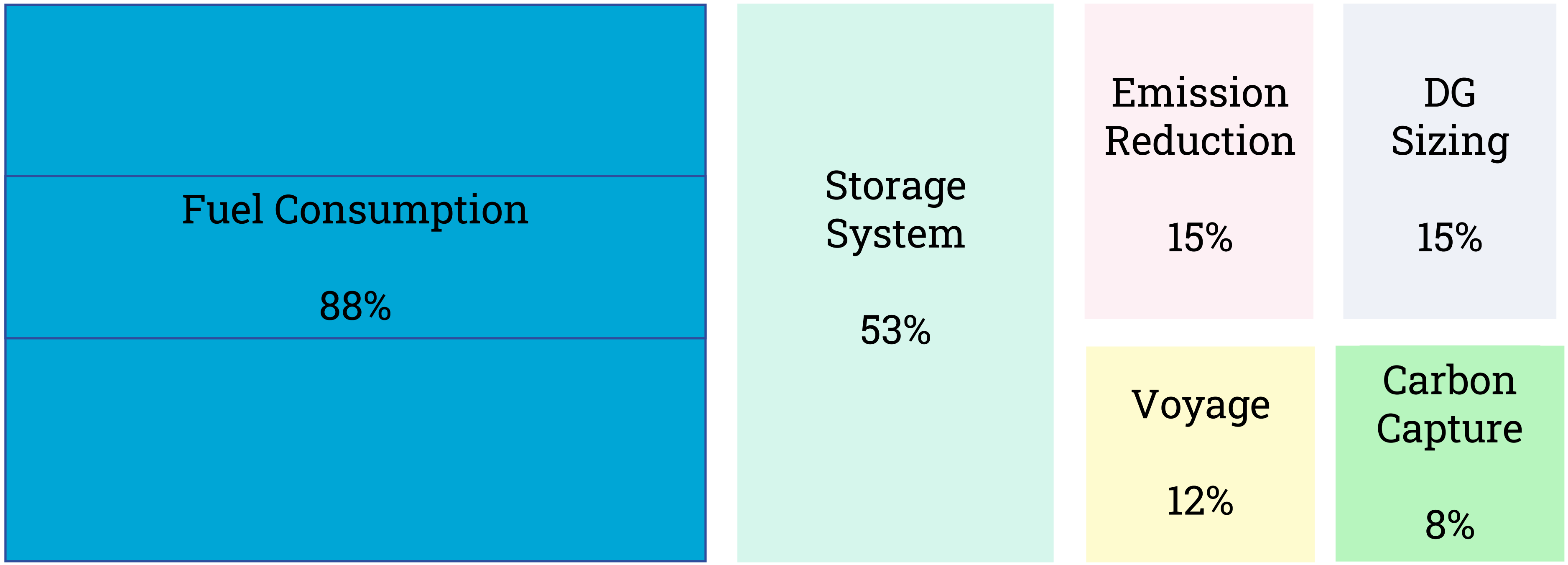
Generator loading

North Sea load profile

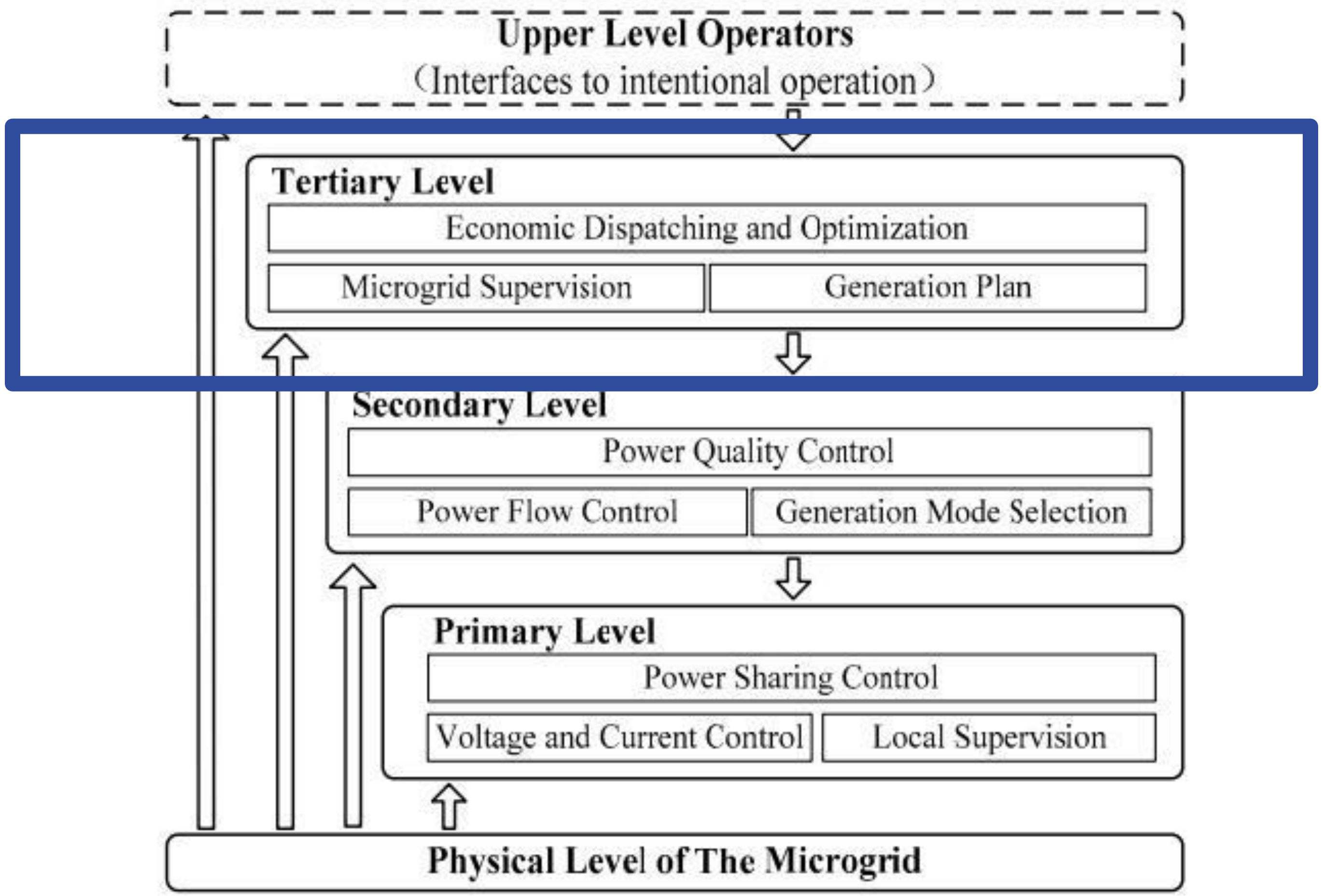


Optimizing fuel consumption & MTBO

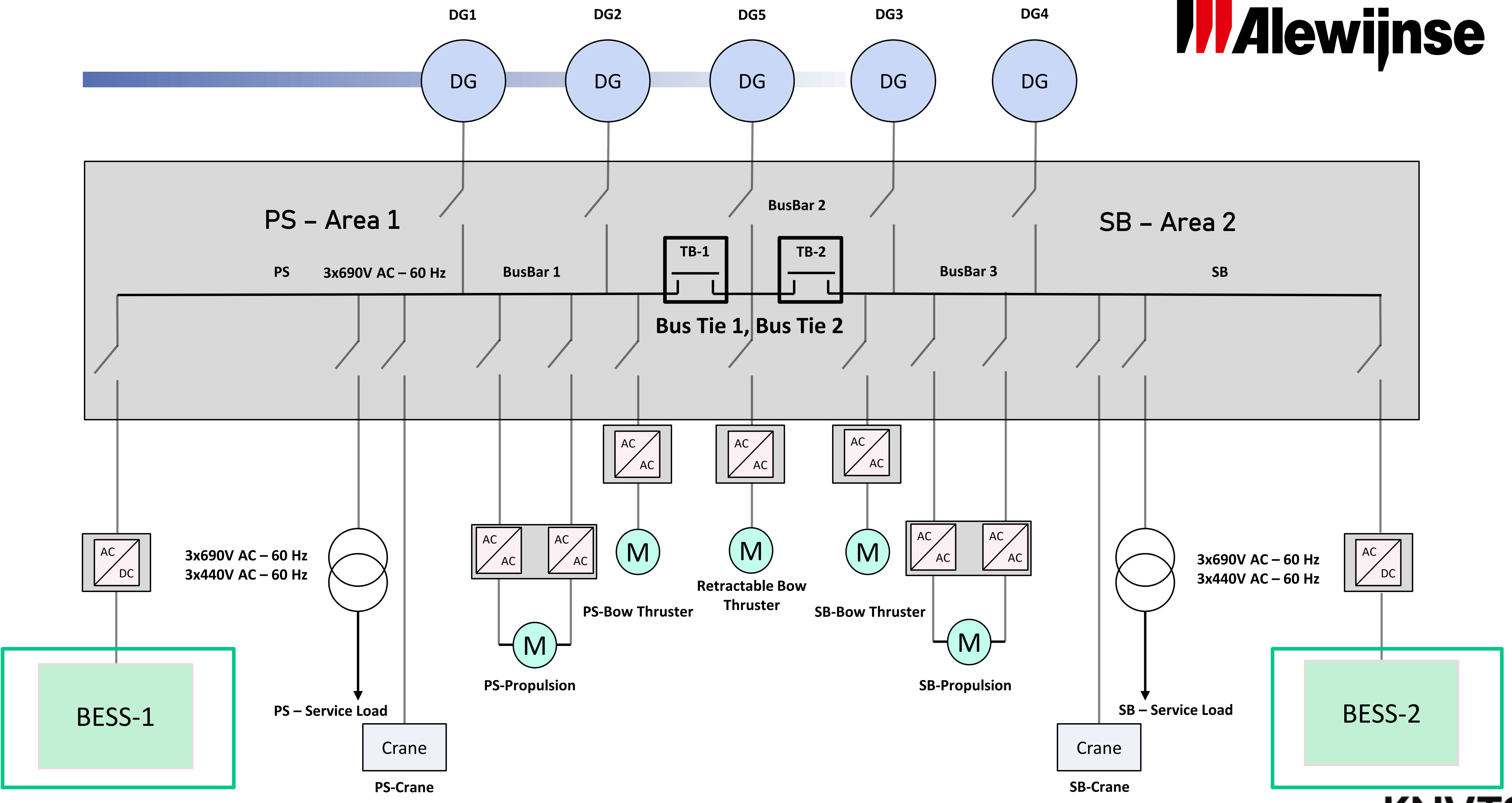
- What are studies optimizing?



Optimizing fuel consumption & MTBO



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


DG1
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AC
DC
3x690V AC – 60 Hz
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DC
BESS-1
PS – Service Load
Crane
PS-Crane
SB – Service Load
Crane
SB-Crane
BESS-2

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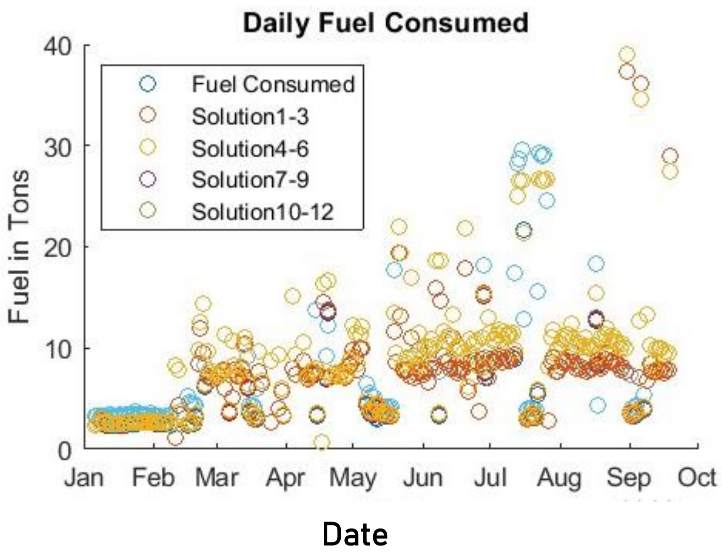
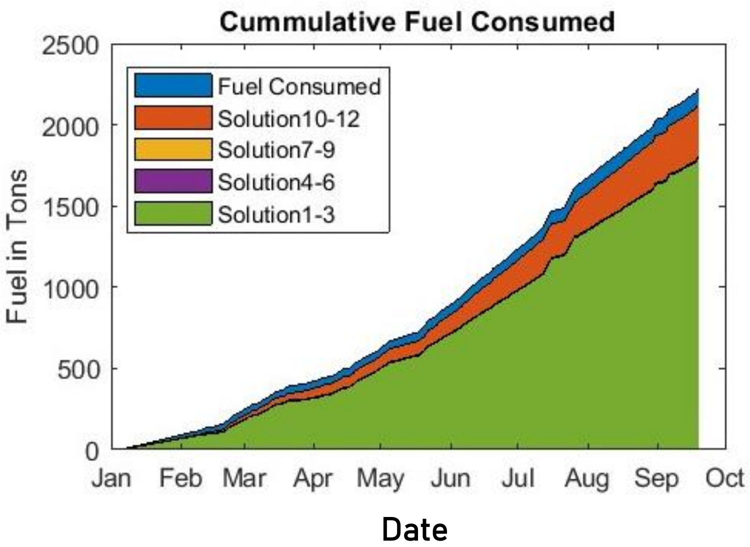
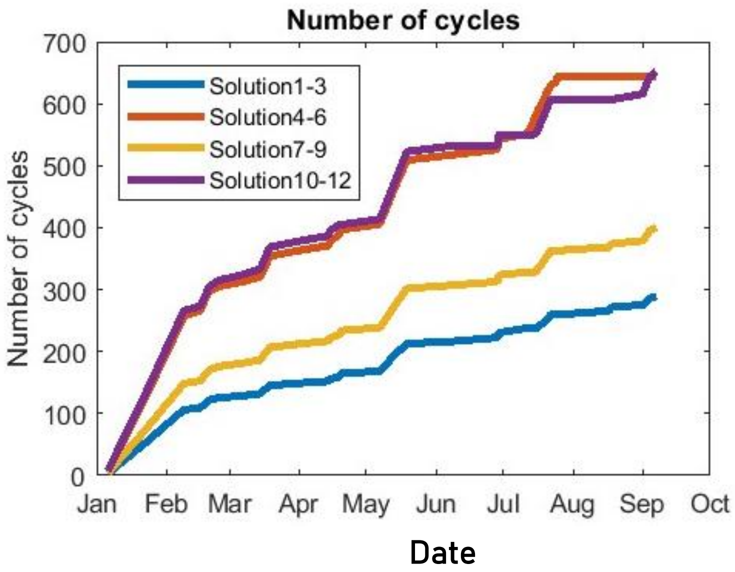
Optimizing fuel consumption & MTBO

Taiwan Result



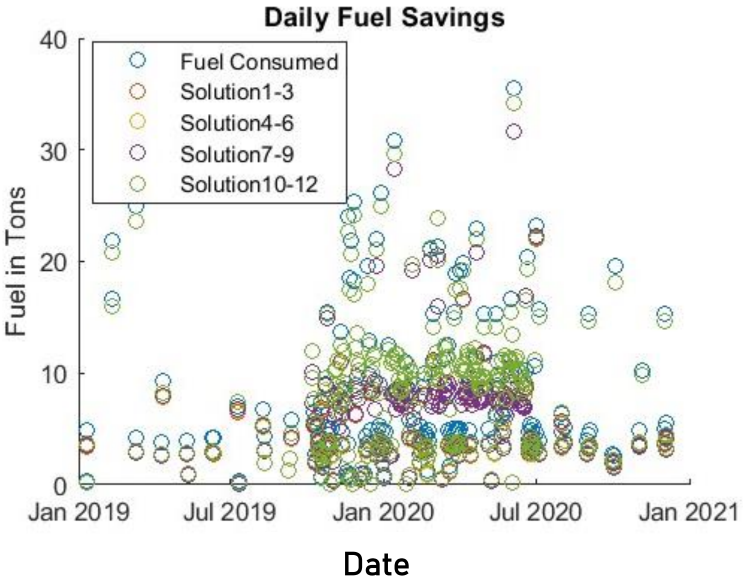


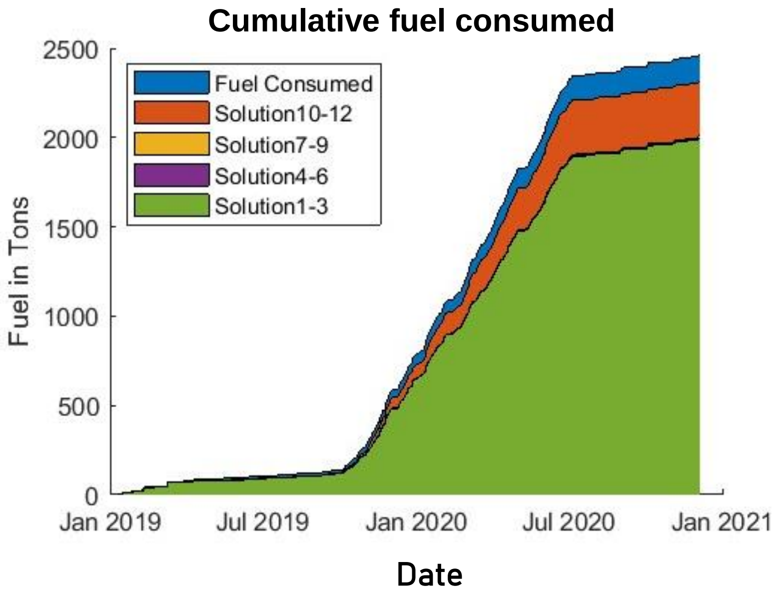


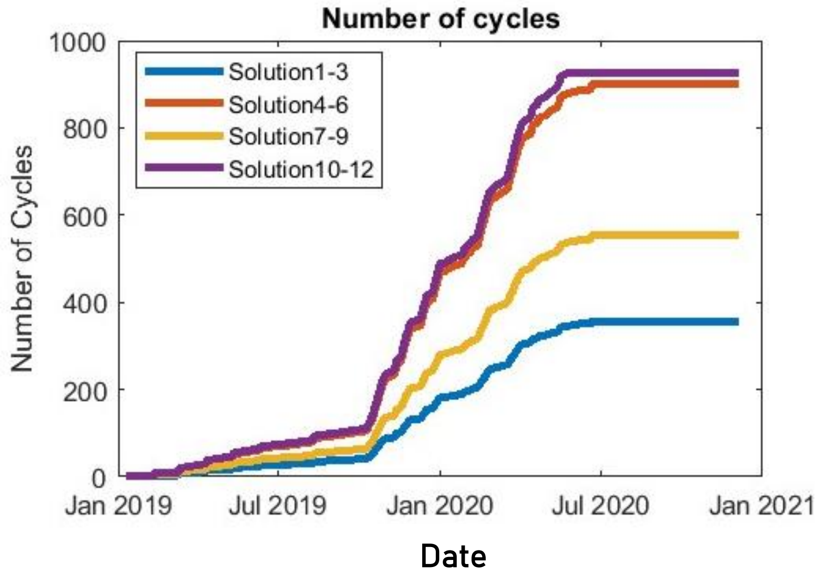
Solution Number	Fuel Savings (tons)	Number of Cycles	Time Period (days)
1-3	425.08	289.7	256
4-6	424.9	644.7	
7-9	416.3	400	
10-12	98.3	652.2	

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	

Analysis results

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 number	Years of profitability per scenario 1	2	3	ROI per scenario 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

A negative ROI is also possible!

Operational profile

Less than ideal case: no measurement data available

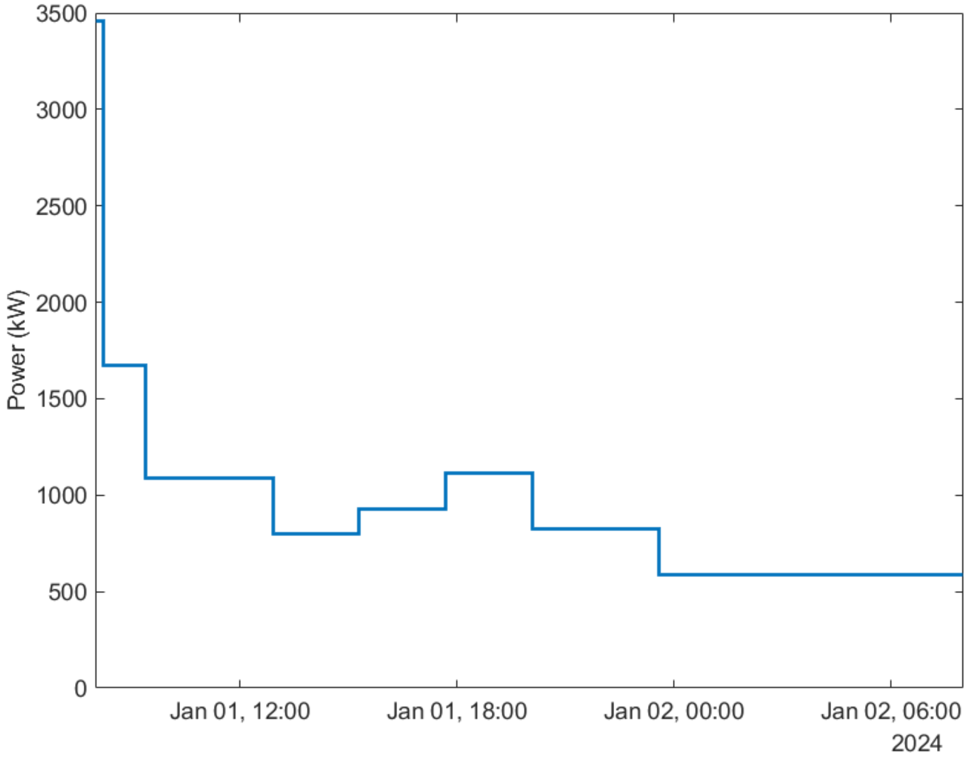
80% full-electric vessel (with diesel generators as back-up power source)

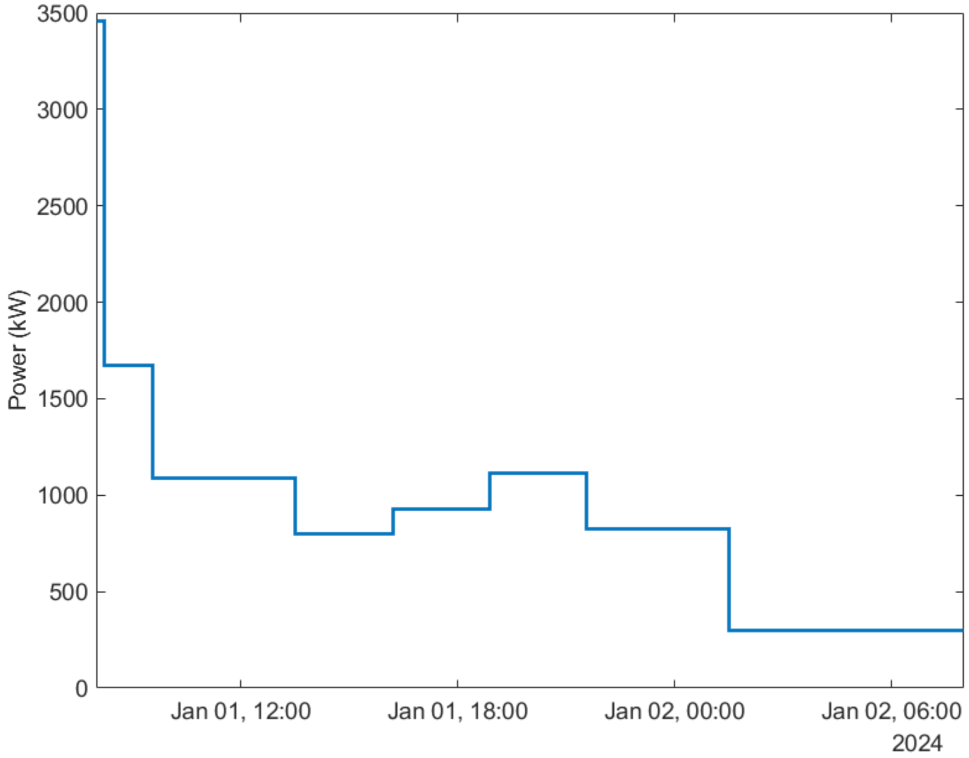
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	
Operating mode 1	0,21	0,21	0,21	0,21	0,21	0,21	0,24	0,21	0,21	0,21	0,21	0,21	0,21	0,24	3
Operating mode 2	1,19	1,19	1,19	1,19	1,19	1,19	1,34	1,19	1,19	1,19	1,19	1,19	1,19	1,34	17
Operating mode 3	3,51	3,51	3,51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

A 14-day operational profile based on various operating modes. All numbers are hours.
Operating mode 8 & 9 are for charging.

Operational profile

Less than ideal case: no measurement data available

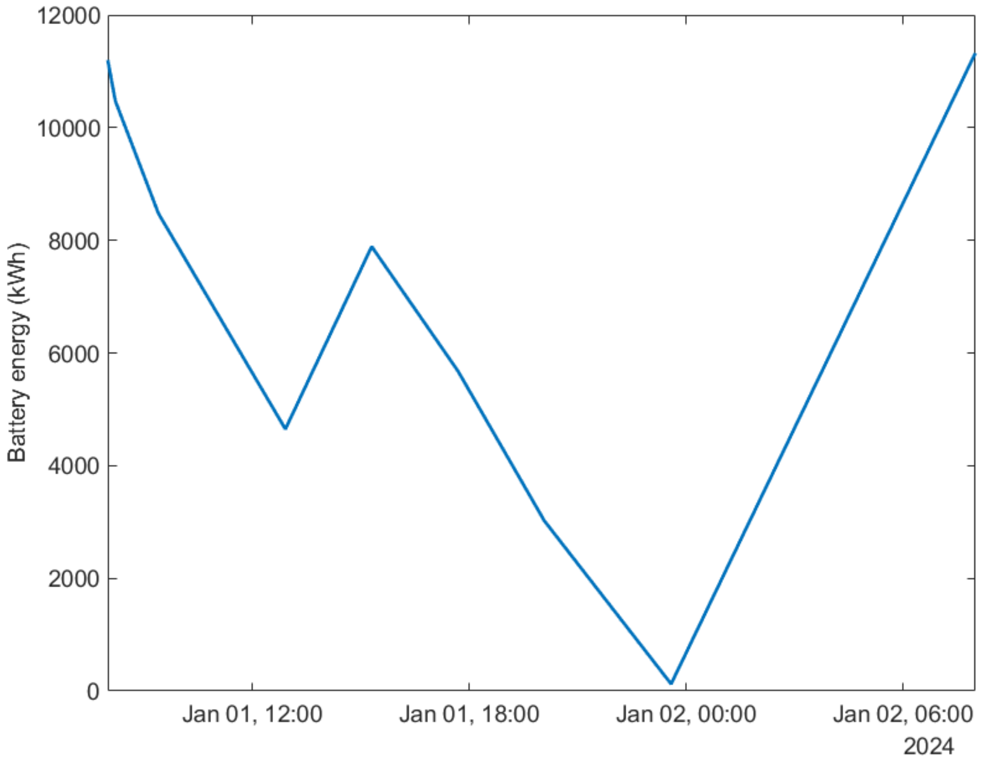


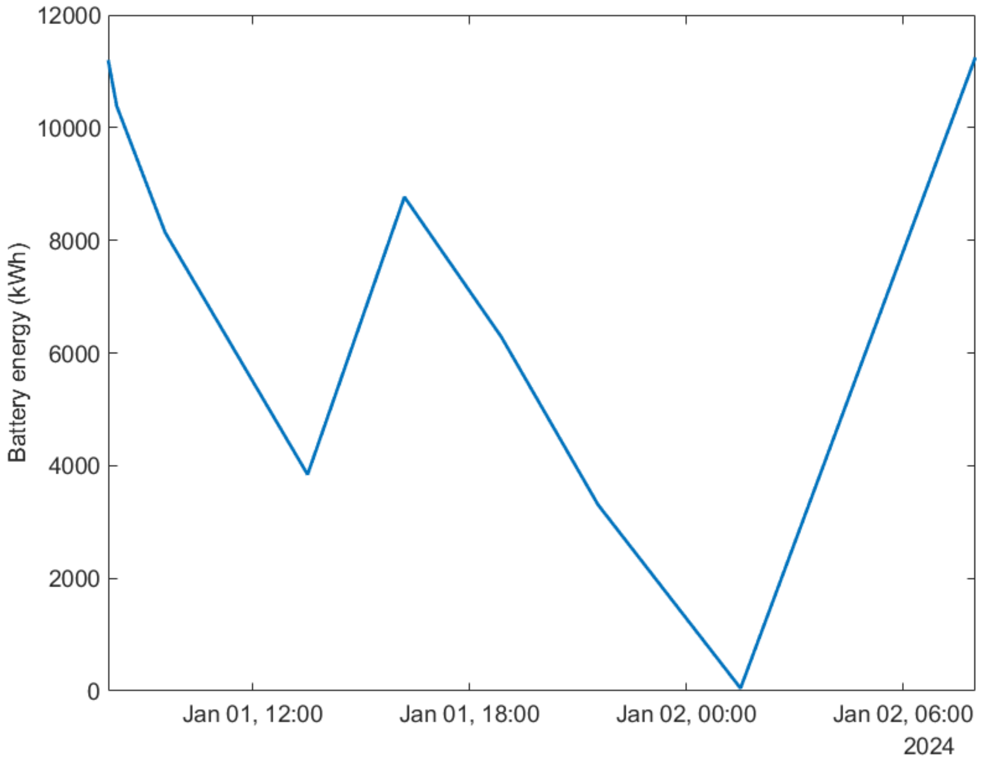


24-hour operational profile with power demand levels.

Battery energy

Simulation of operational profile

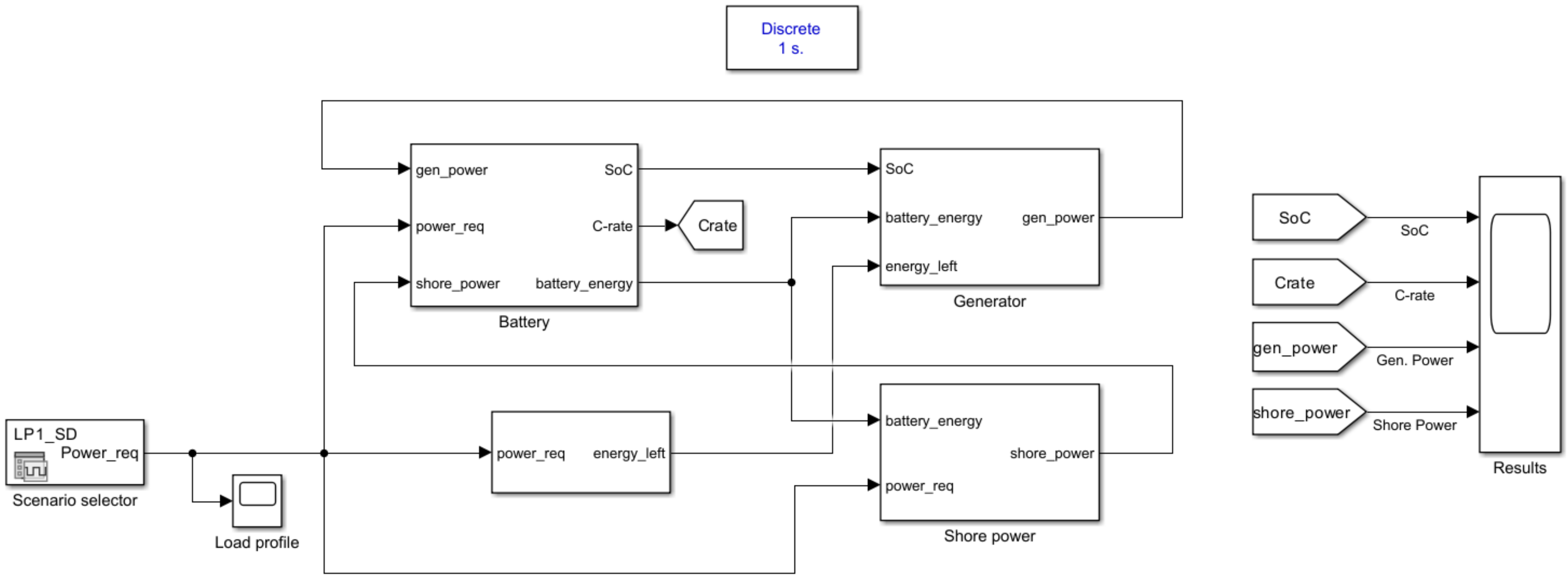




In this case, generators are charging the BESS to be able to make it to the end of the day.

Operational profile

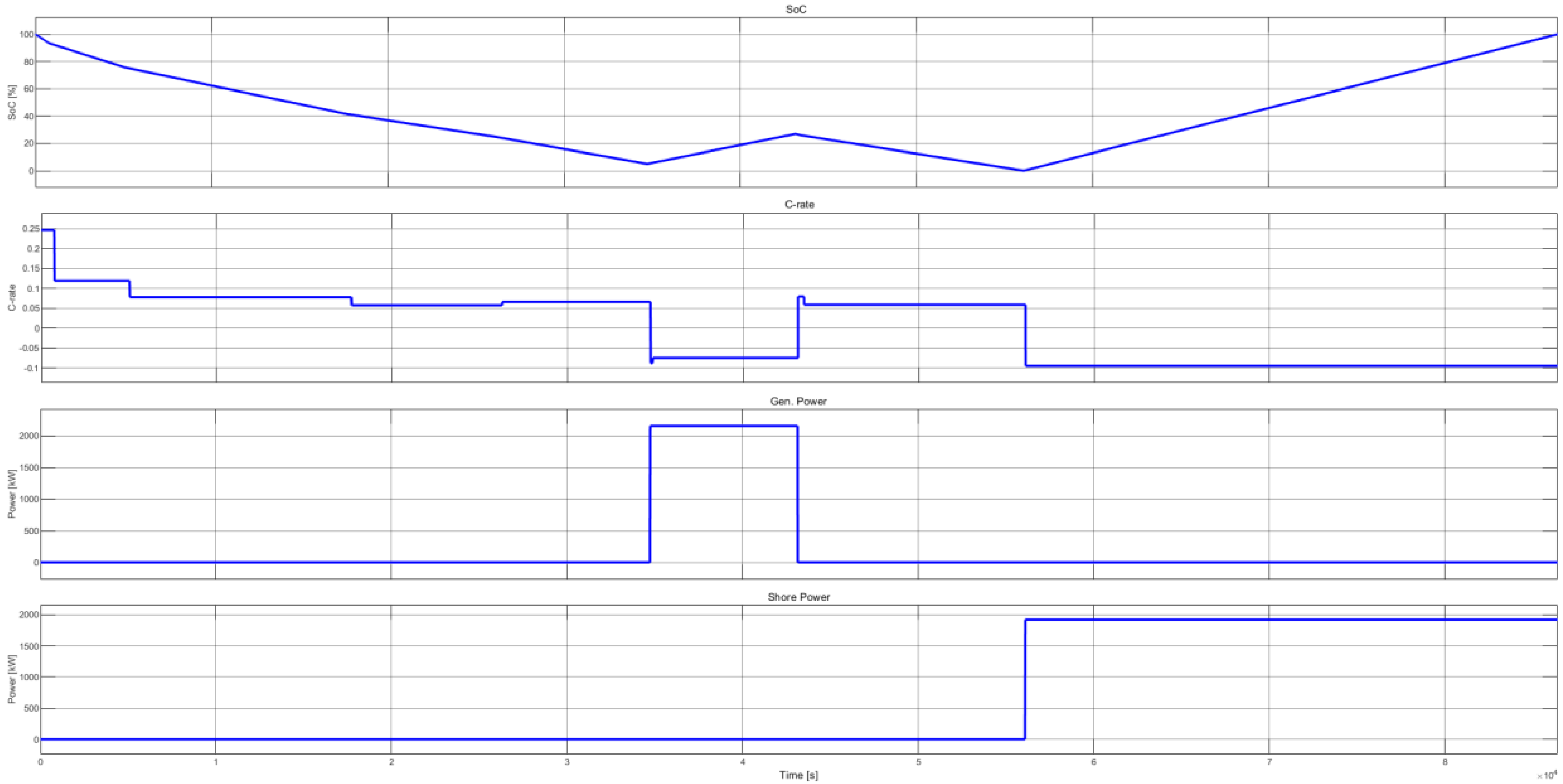
Simulation of operational profile



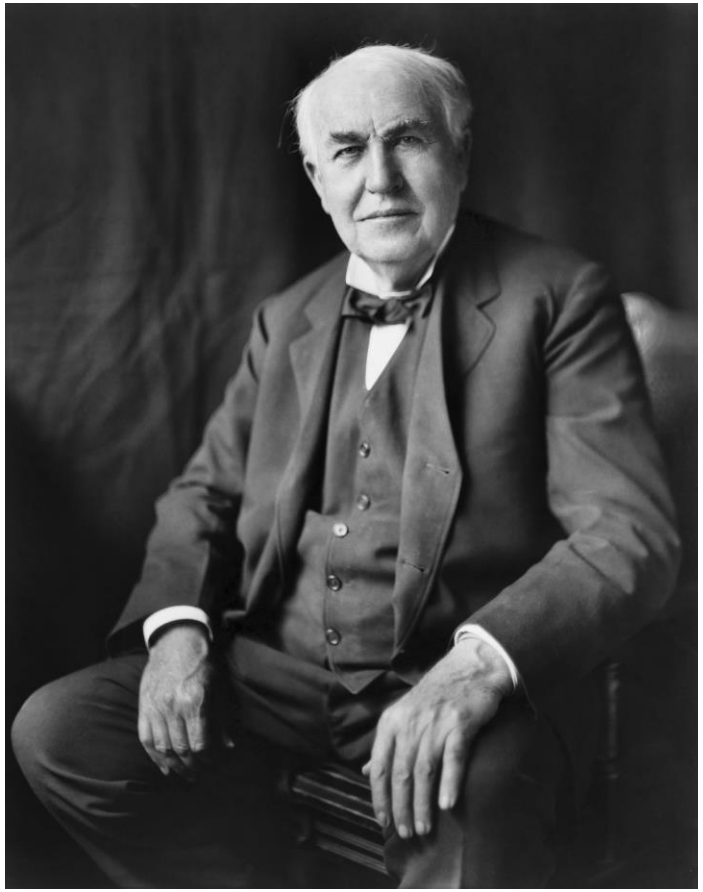
Various parameters such as battery and generator size, DoD and shore power available can be varied.

Operational profile

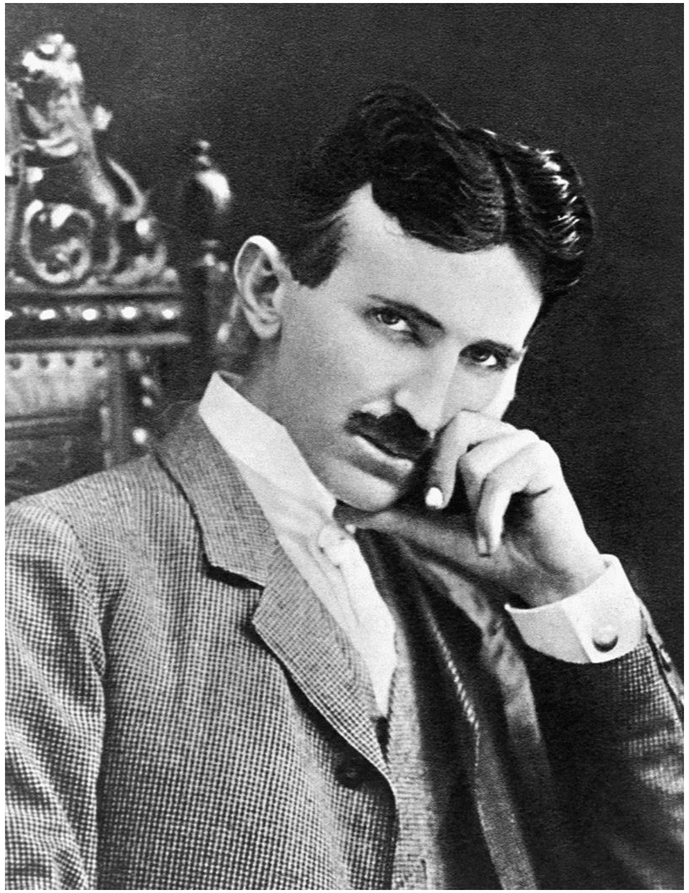
Simulation of operational profile



DC vs AC



Thomas Edison

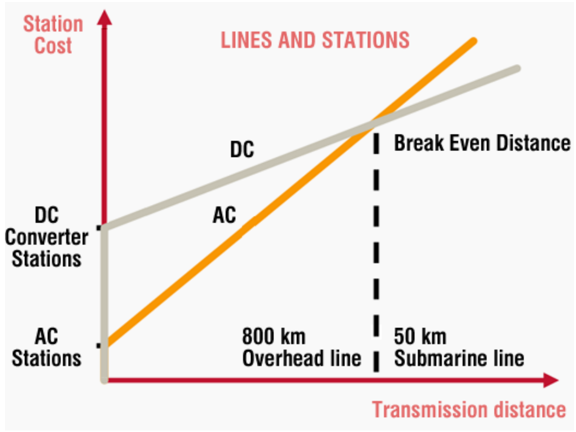


Nikola Tesla

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

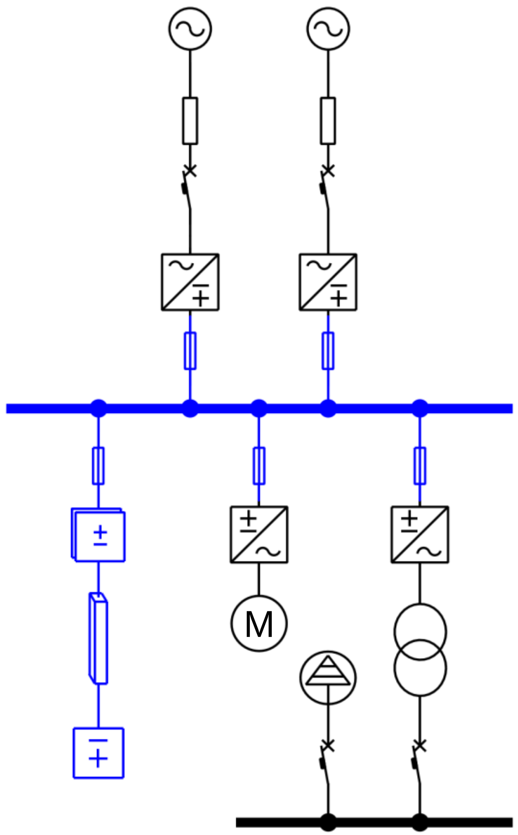


DC vs AC

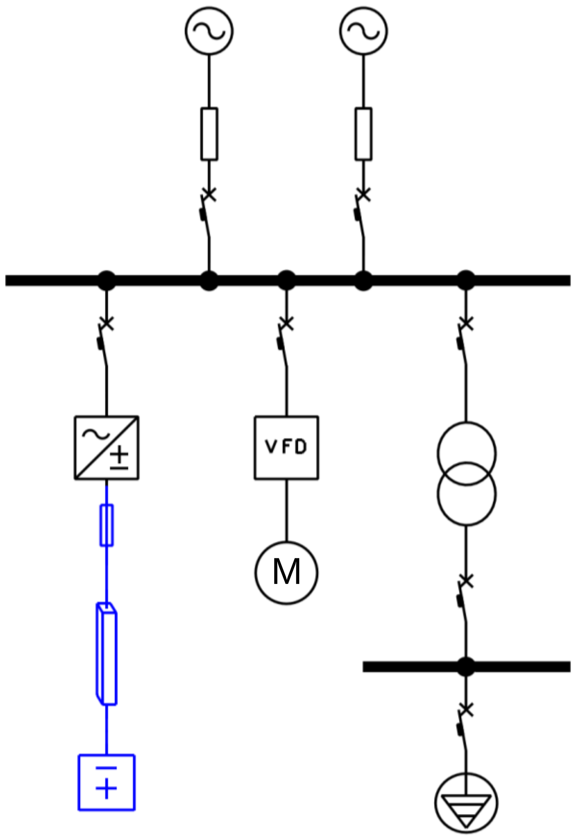
More and more modern applications are DC

DC vs AC

In maritime systems



'Typical' DC system

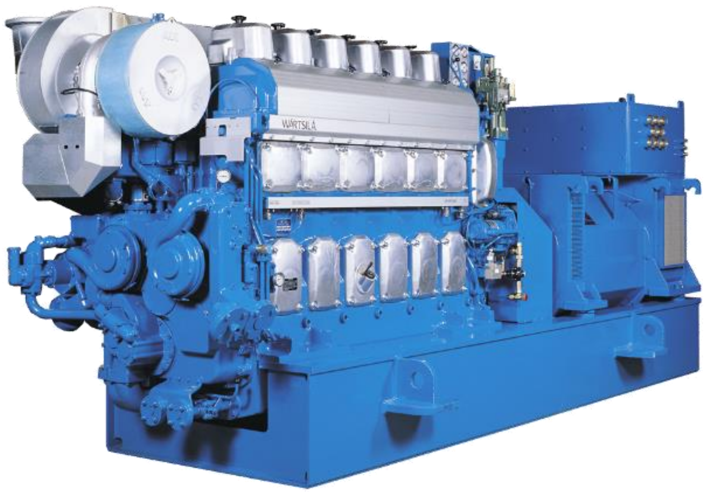


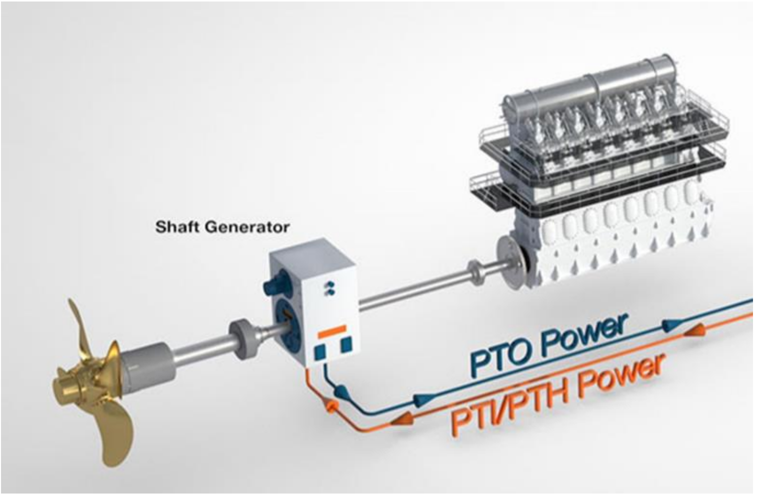
'Typical' AC system

DC vs AC

Which makes most sense?

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

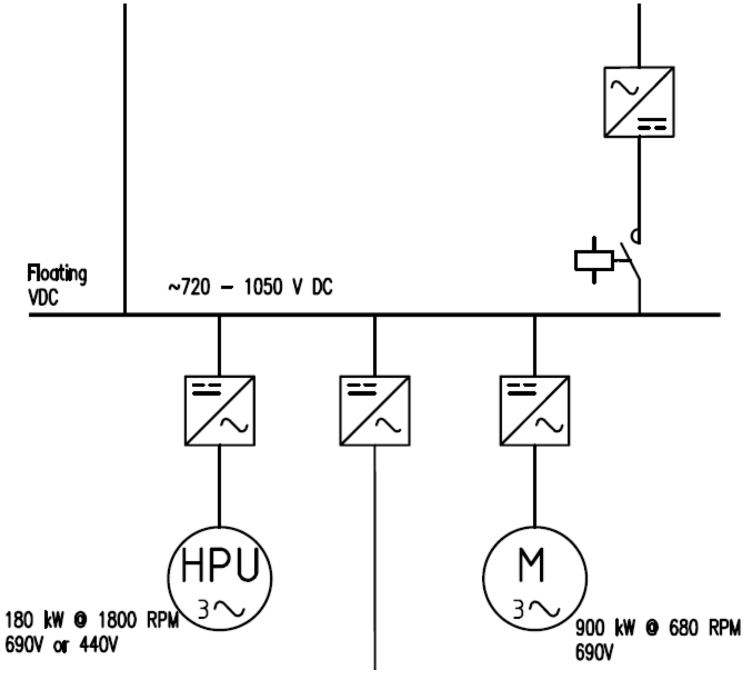




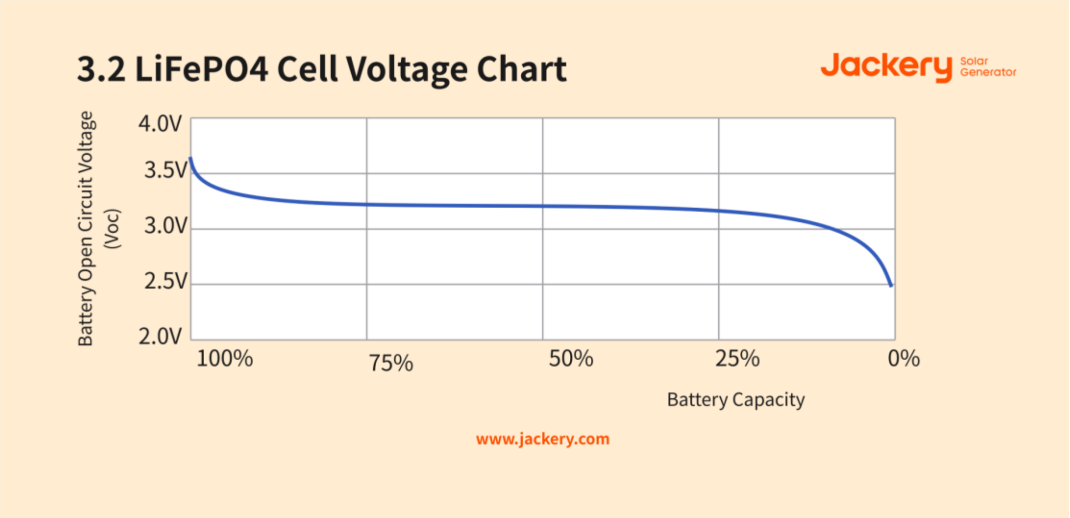
DC vs AC

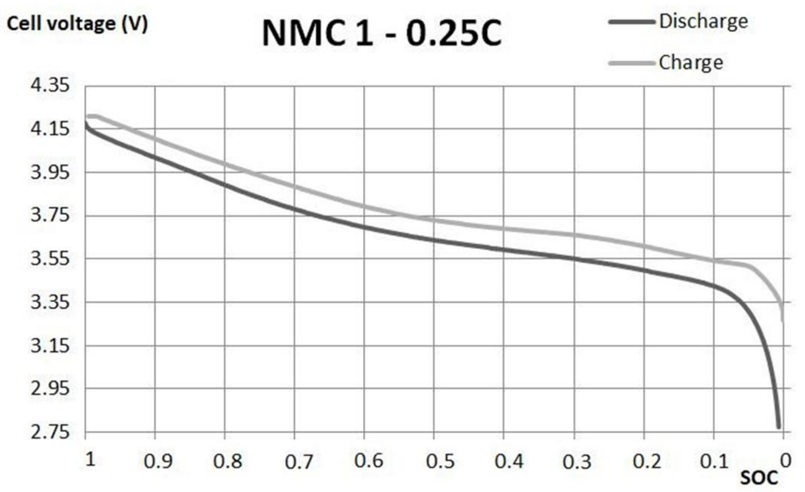
Which makes most sense?

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



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





DC vs AC

Which makes most sense?

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

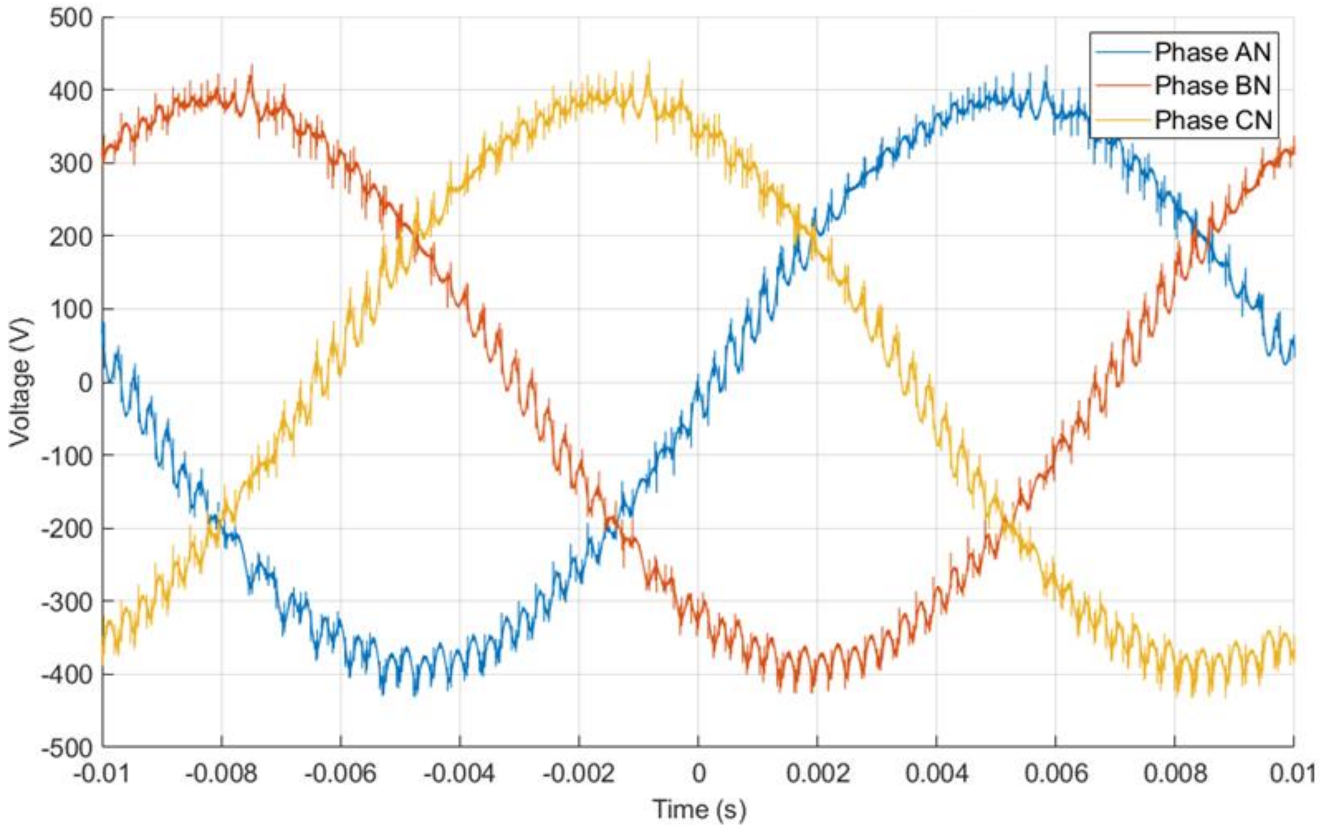
DC	
Motor inverter	97.5-98%
Grid converter	98.5-98.9%
DC/DC converter	98.5-99%
AC/DC converter	97-98%
AC	
Variable Frequency Drive	97%
Grid converter	98.5-98.9%

Efficiencies

	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

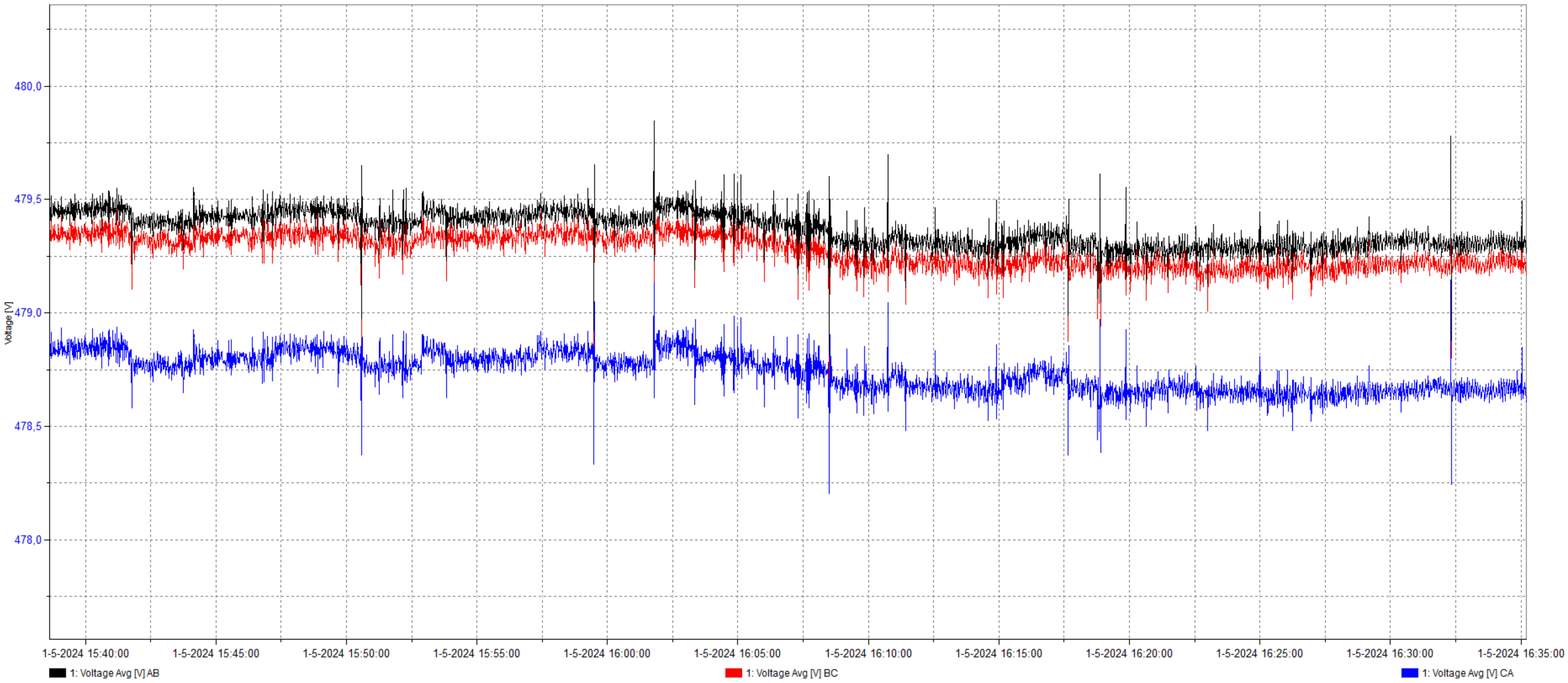
Filter design & Power Quality

A measurement result



Filter design & Power Quality

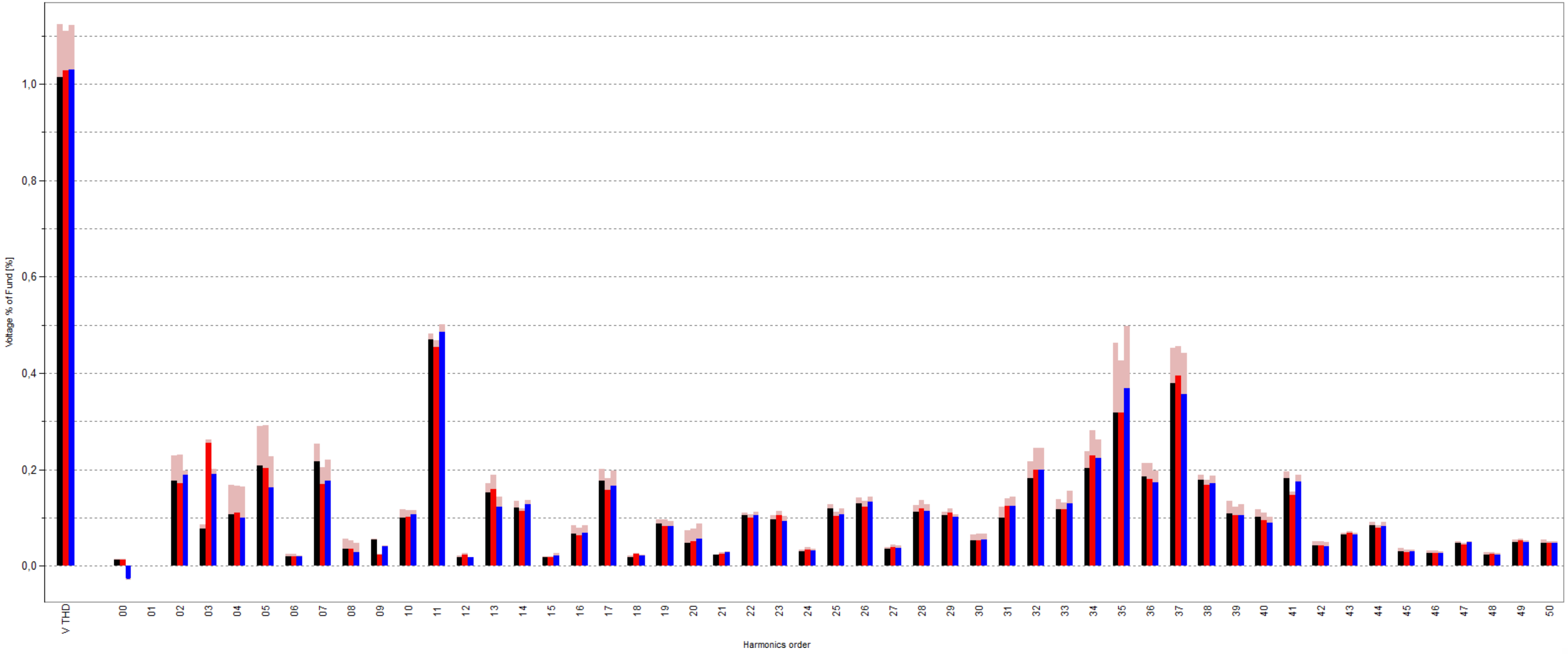
A measurement result



Filter design & Power Quality

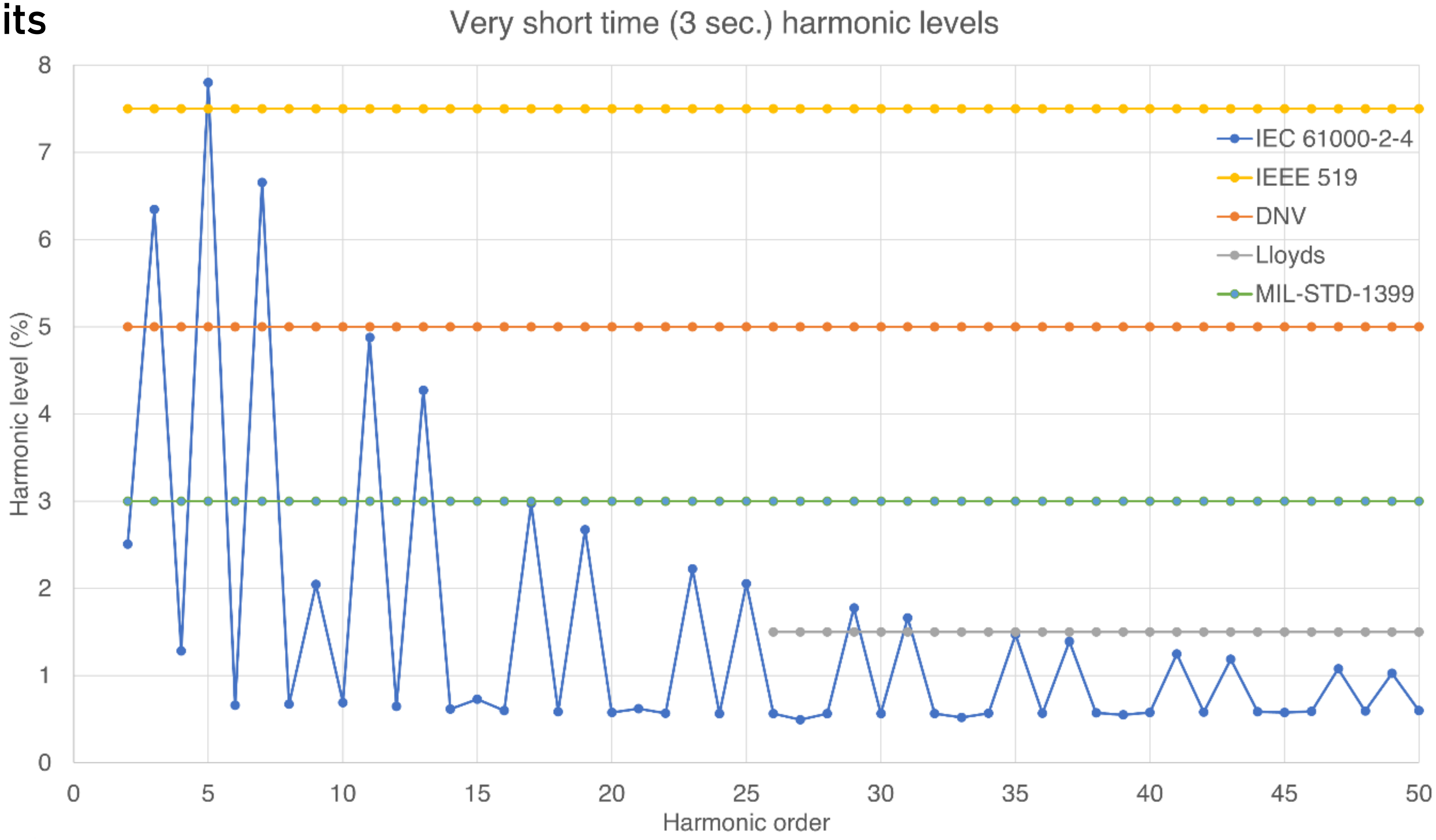
A measurement result

Filter design & Power Quality



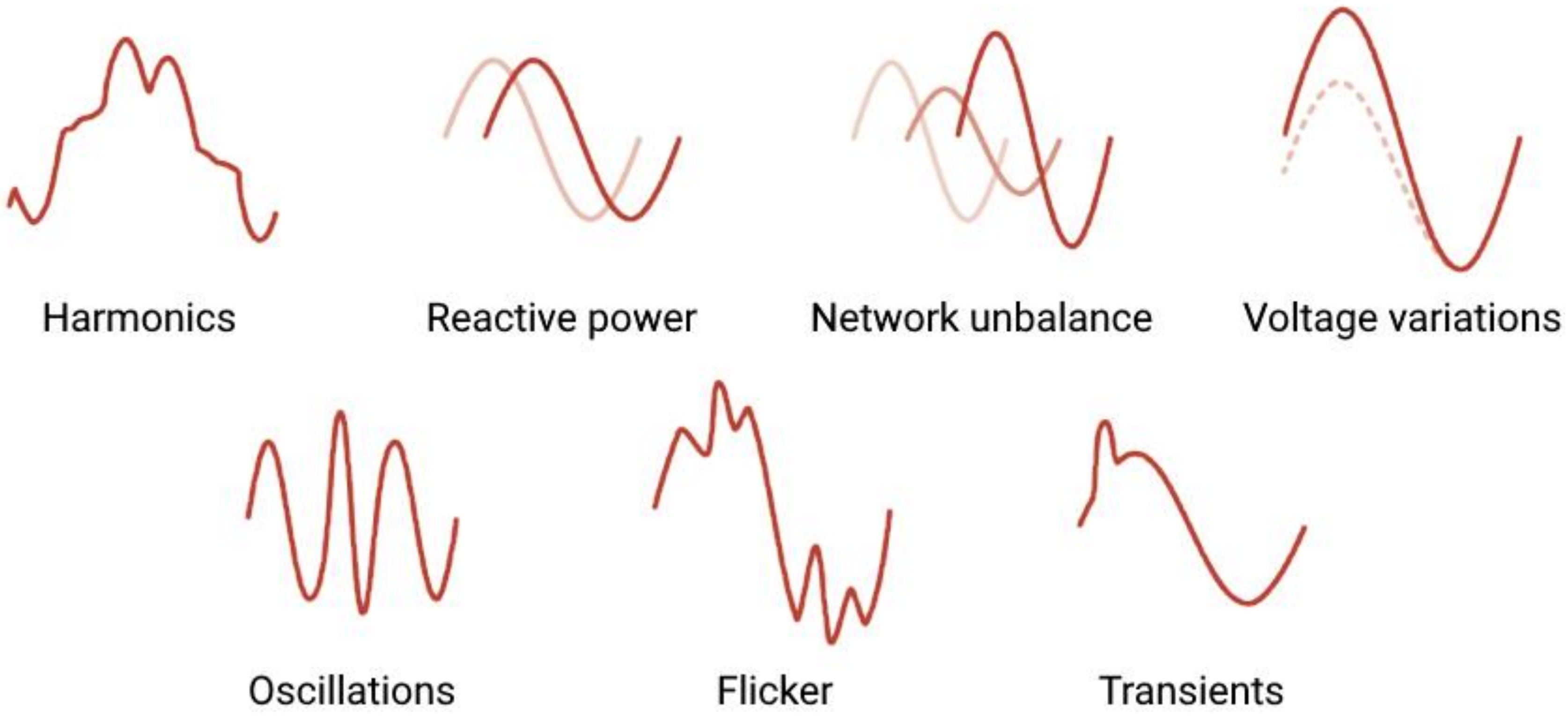
Filter design & Power Quality

Regulatory limits



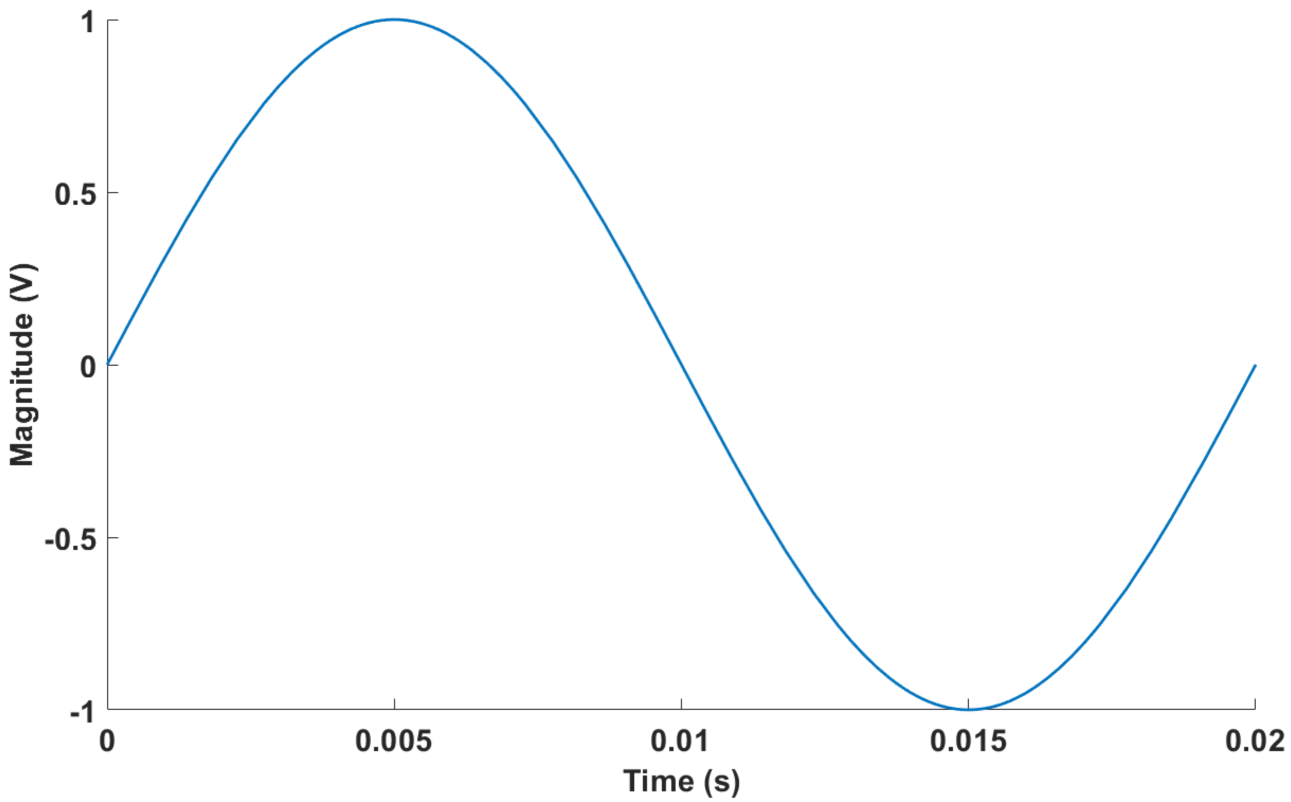
Power Quality

What is it?



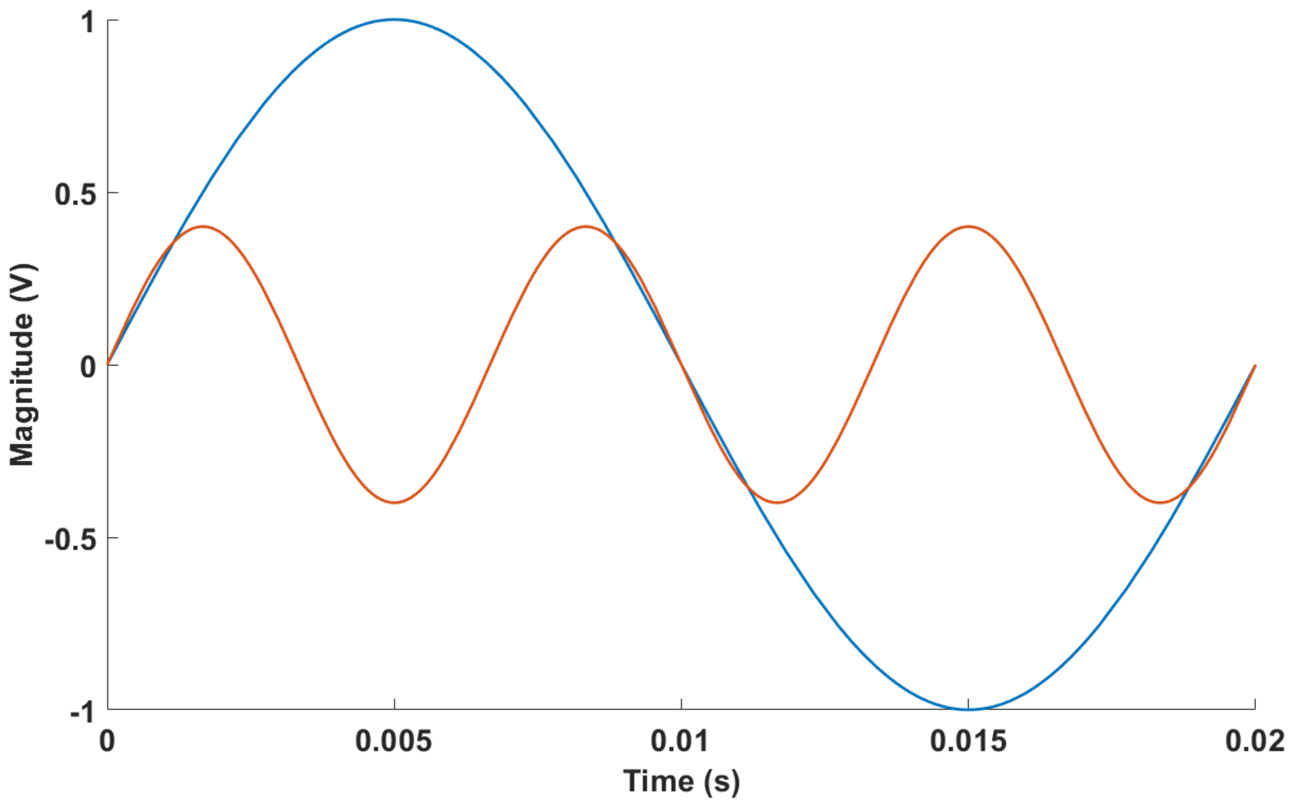
Harmonics

1st (base harmonic)



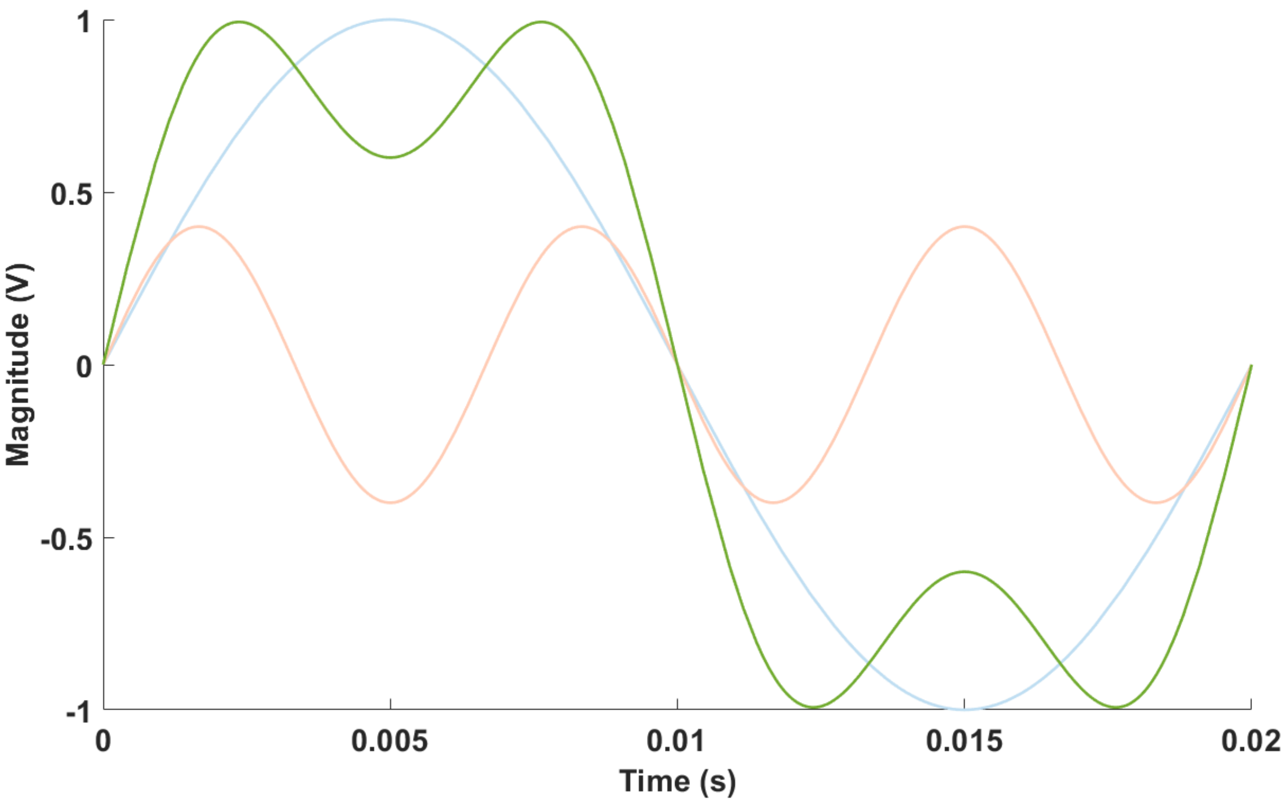
Harmonics

Introducing a 3rd harmonic

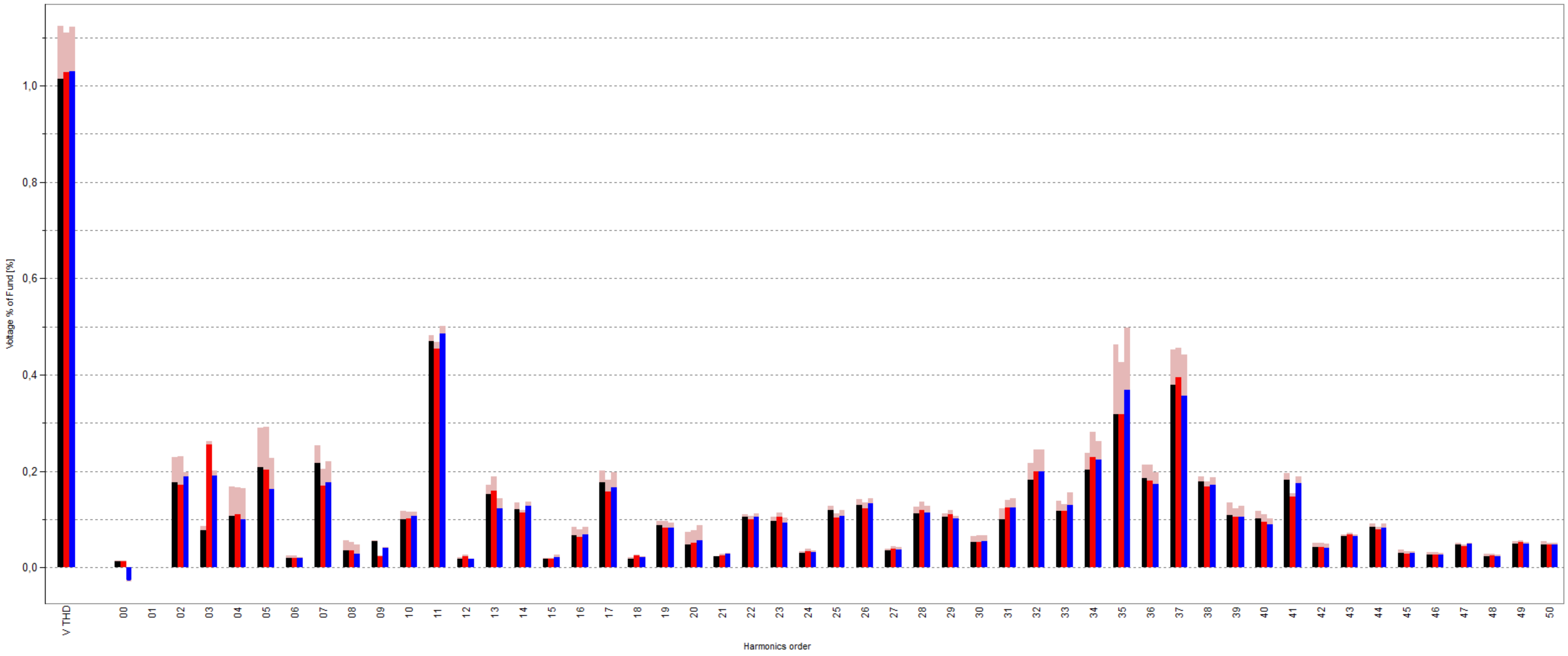


Harmonics

The result when summed up



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
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43
44
45
46
47
48
49
50
Harmonics order

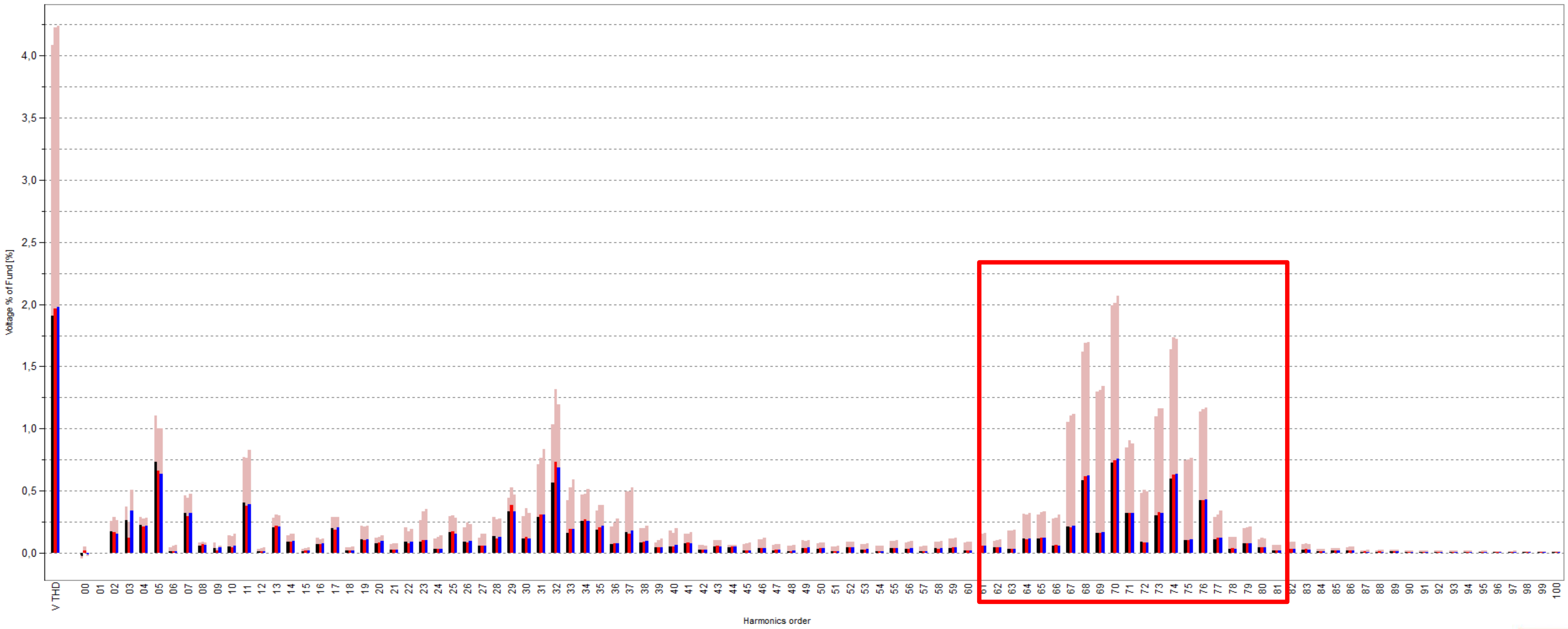
Filter design & Power Quality

Complaints:

- High maintenance cost generator
  - Bearing replacement every 6 months
  - Isolation failure
- Often replace filter capacitors
- Often leakage on the filter inductances

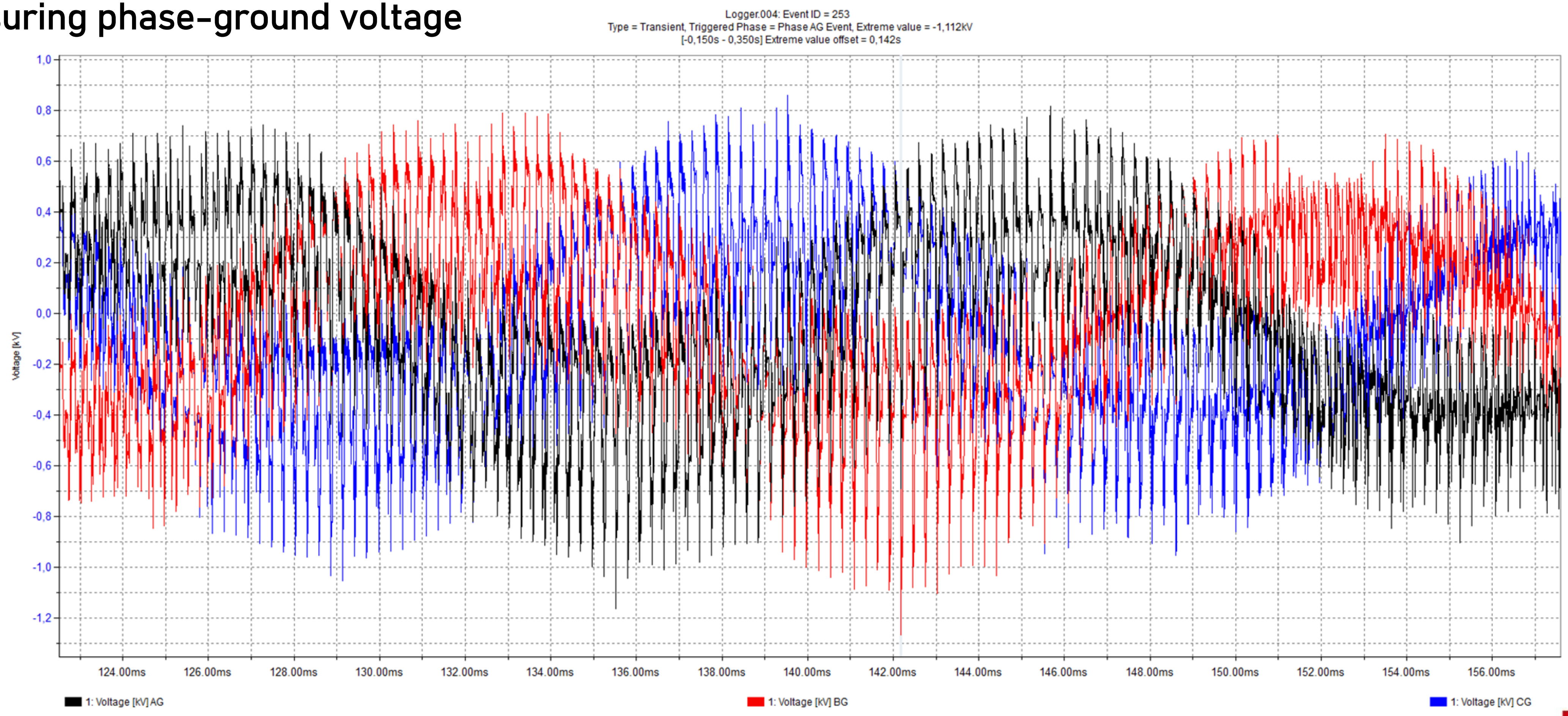
Filter design & Power Quality

Look further than 'the length of our nose'



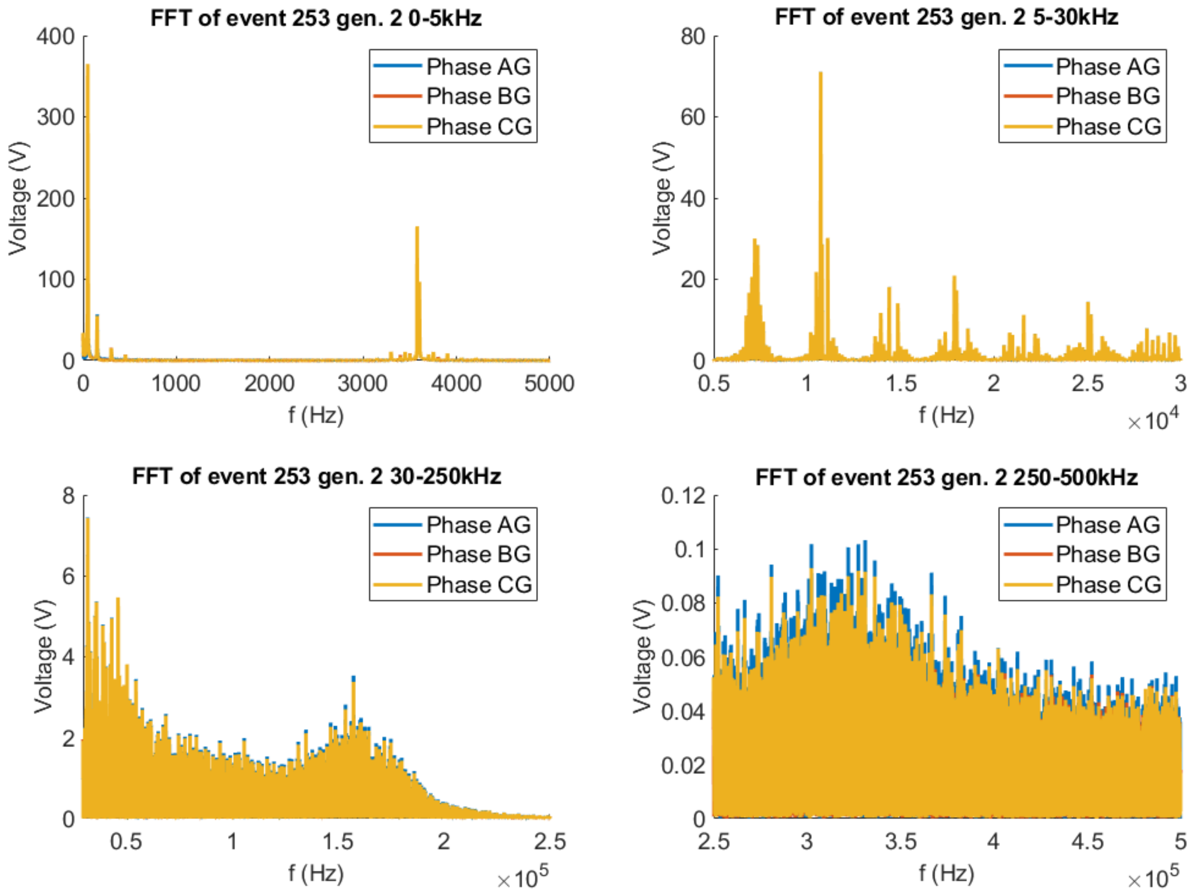
Filter design & Power Quality

Measuring phase-ground voltage

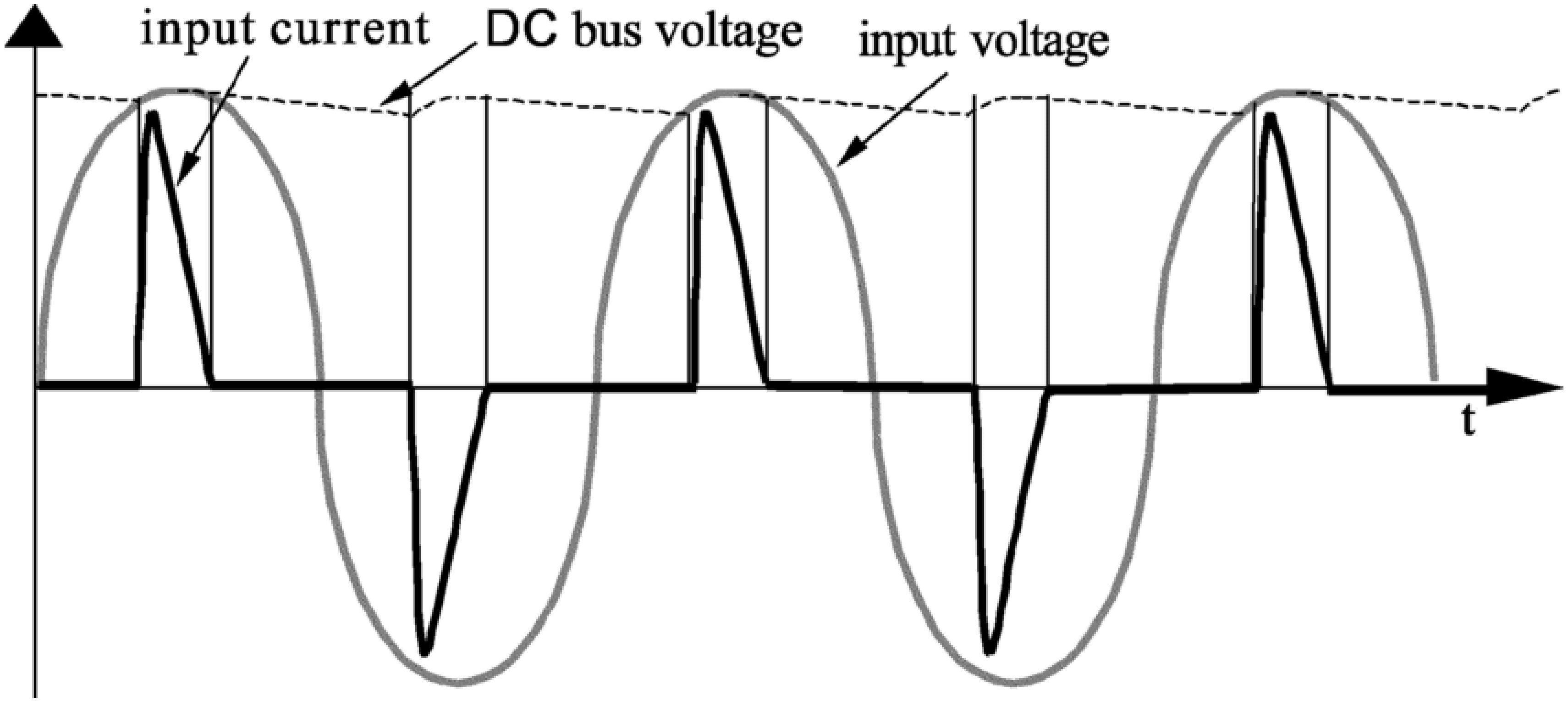


Filter design & Power Quality

Looking at higher frequencies



The effect of switching converters



$$Voltage = current \cdot impedance$$

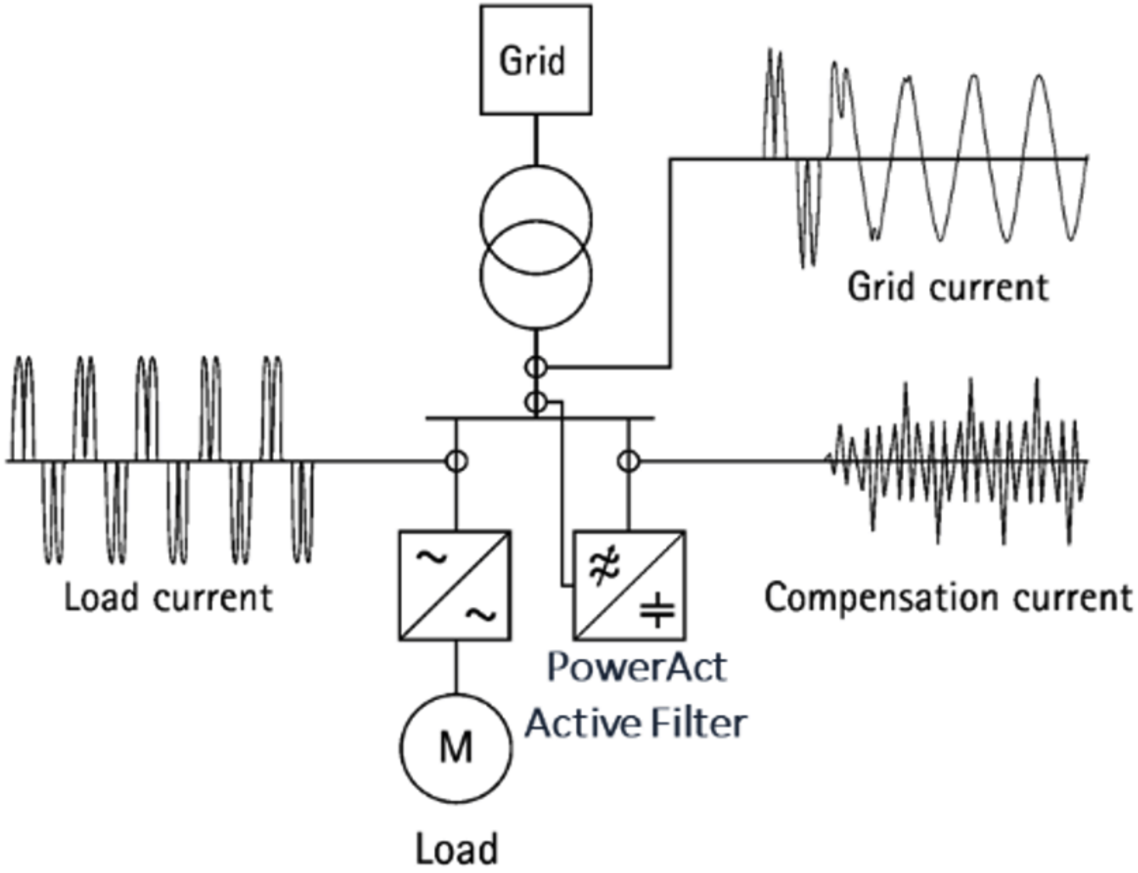
Filter design & Power Quality

What can we do?

- LCL filter
- High frequency (EMC) filter (30kHz – 300kHz)
- High frequency grounding
- Active Harmonic Filter (< 50kHz)

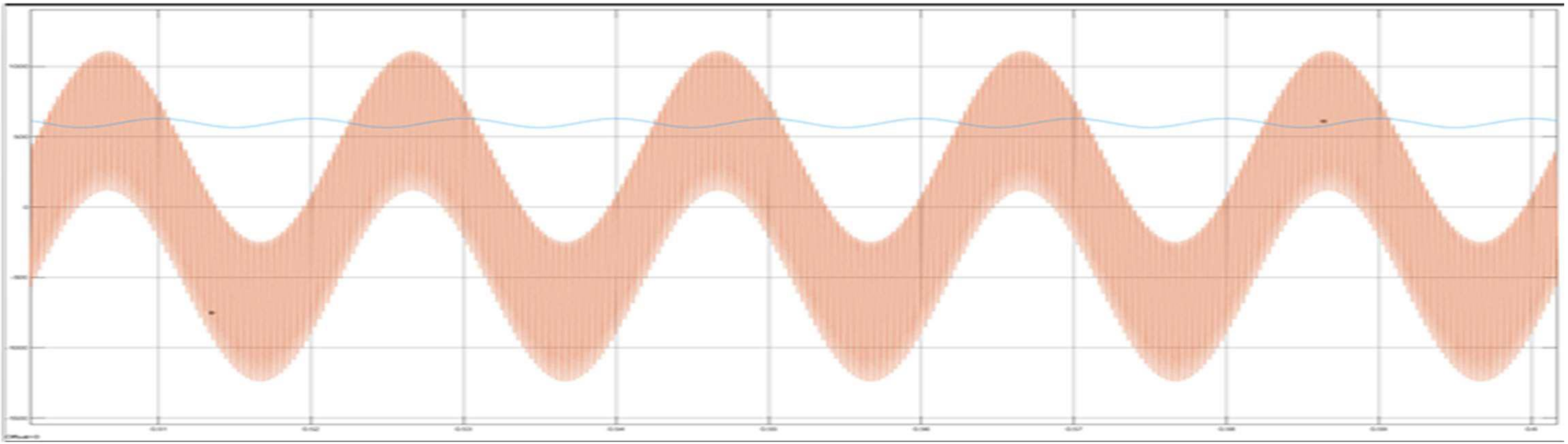
Filter design & Power Quality

Active Harmonic Filter



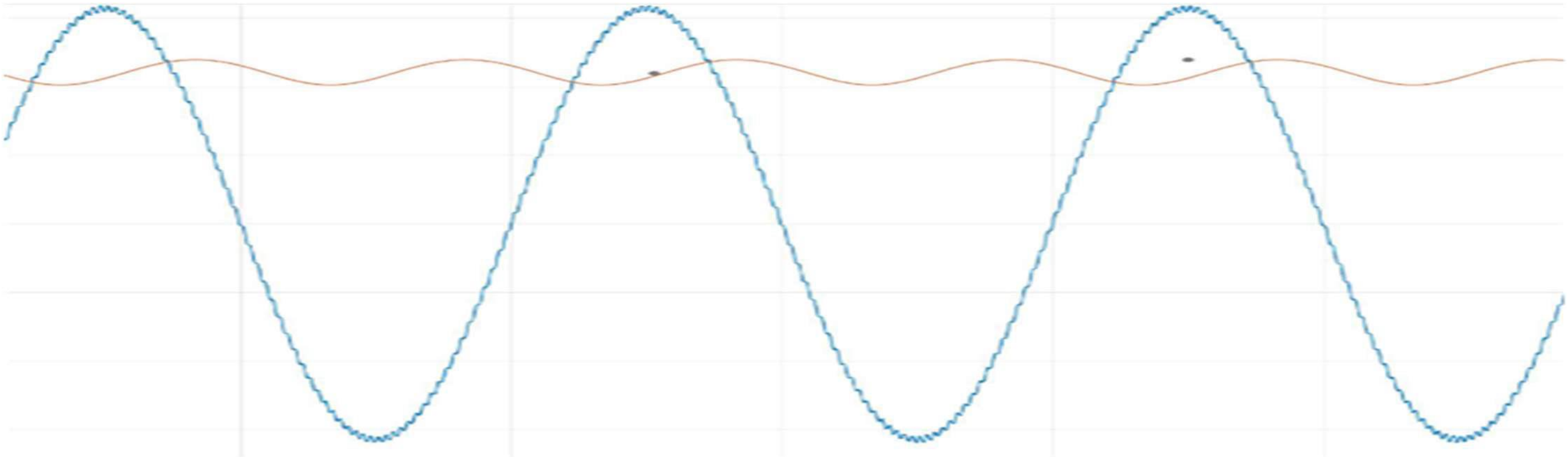
Filter design & Power Quality

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 many different ways.
- 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.
- 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.