

The hybrid power plant in Graciosa island - a pioneer project in the Azores islands

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1. Introduction

- Graciosa Island belongs to the archipelago of the Azores (Portugal)
- It has an area of 60,65 km² and around 4300 inhabitants
- HPP started its commercial operation in August 2019
- This pioneer project introduces a new paradigm in the way a small island can run its power system relying mainly on renewable energy sources combined with storage solution.



2. Graciosa island power system overview

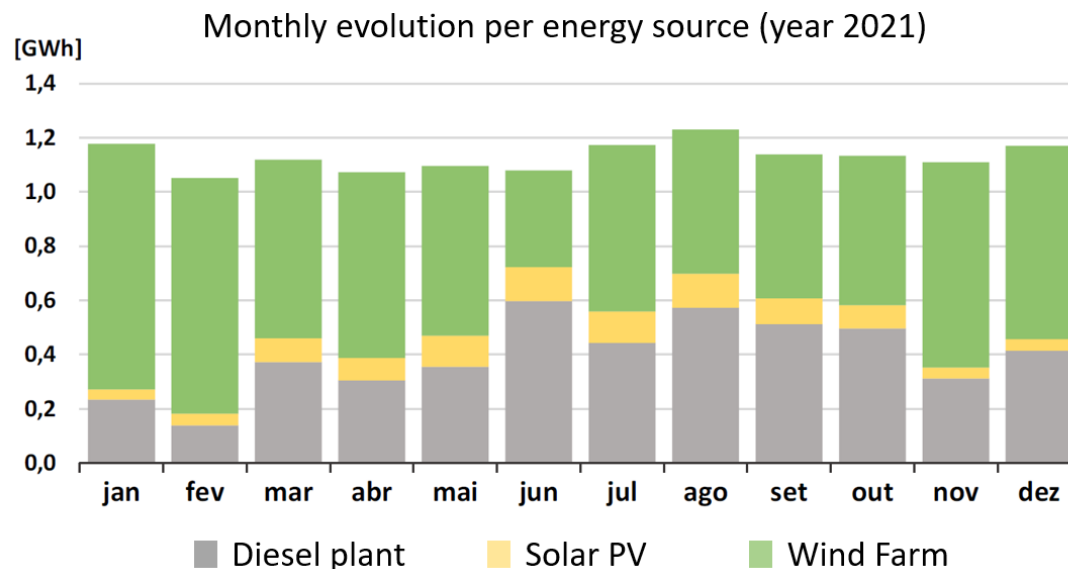
- In April 2022, Graciosa Island generation power system is composed by two main electricity sources:

1. Conventional Diesel Power Plant (DPP)
2. The recent Hybrid Power plant (HPP)

- Electricity produced in 2021: 13,55 GWh



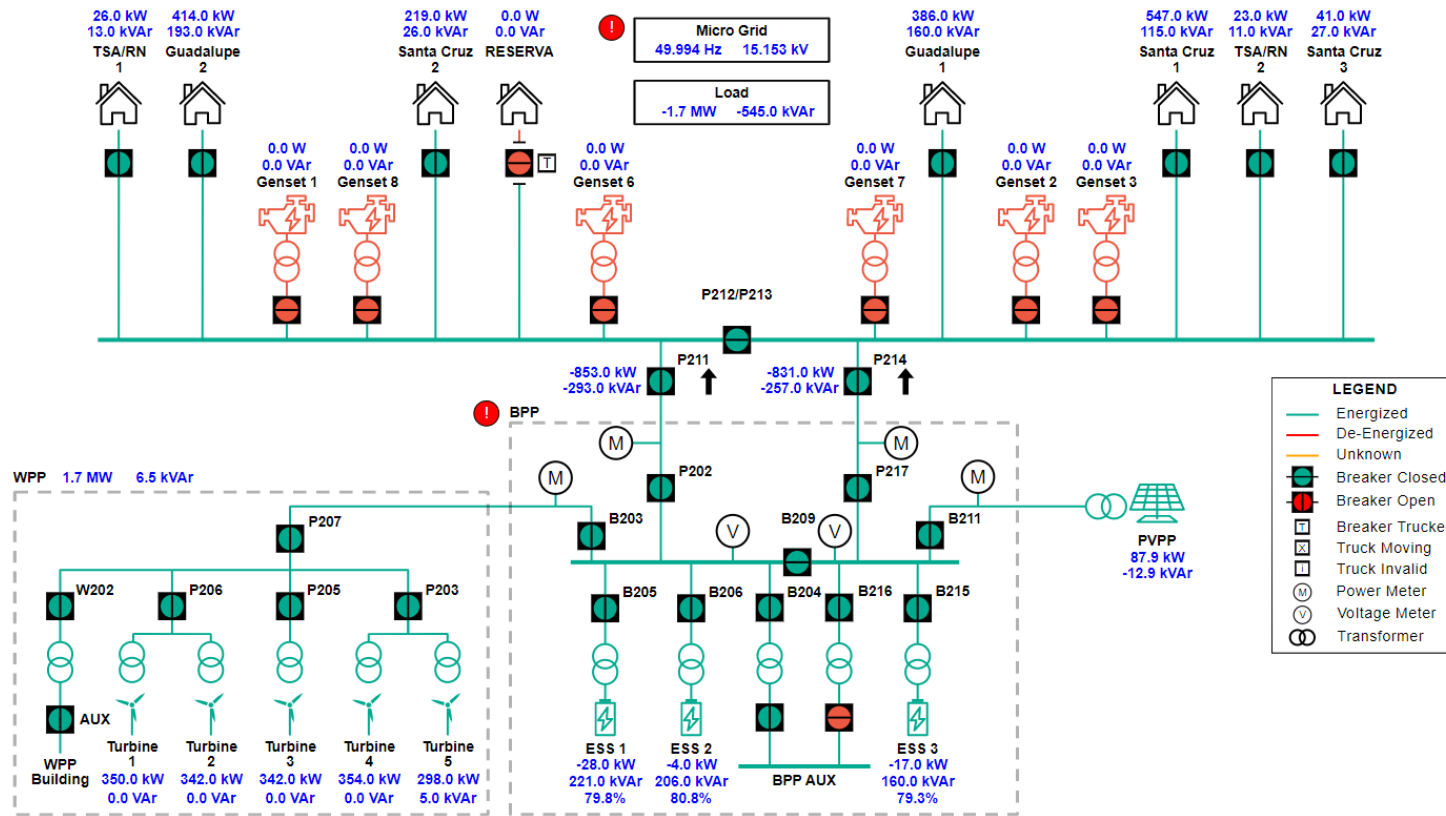
HPP accountable for
65% and DPP for 35%



Island peak load: 2,36 MW, registered in December 2021

Valley load: 0,97 MW, registered in September 2021

3. Graciosa hybrid power plant



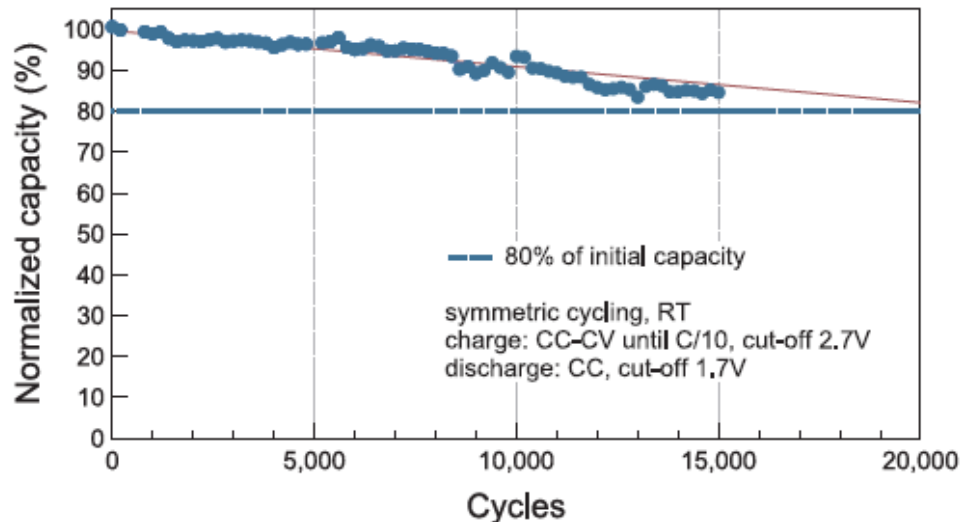
- 4,5 MW Wind Power Plant (5x 900 kW)
- 1 MW PV Power Plant
- 7,425 MW Battery Power Plant/Battery Energy Storage System (3x 2475 kW) with a usable capacity of 2,6 MWh
- 4,6 MW Diesel Power Plant (3x 600 kW, 1x 810 kW, 2x 1000 kW)
- Autonomous EMS

3. Graciosa hybrid power plant

Battery Energy Storage System (BESS)

Individual lithium titanate oxide (LTO) cells

- Nominal capacity: 30 Ah measured at 0,1 C discharge rate;
- Nominal voltage: 2,7 V
- Charge and discharge rates up to 4 C
- 45600 LTO cells with a battery module architecture of 60 cells, 3P20S.



The LTO cell technology advantages:

- Excellent lifetime characteristics
- High charge/discharge rates
- Superior safety features
- Wide temperature range
- Symmetrical system design

3. Graciosa hybrid power plant

Battery Energy Storage System (BESS)

Grid-forming power converter system (PCS):

- Operates with frequency and voltage droop curves emulating the behaviour of a diesel engine;
- Run in standalone or in parallel with diesel engines
- Provides black-start to the HPP
- Tuned to provide an I_{cc} up to 1,5 times their rated current for 600 milliseconds, plus $1,25 \times I_{cc}$ for an additional 4 seconds
- Contribute to any type of fault on the grid (line-to-line, phase-to-ground, three-phase)

Response to transient events

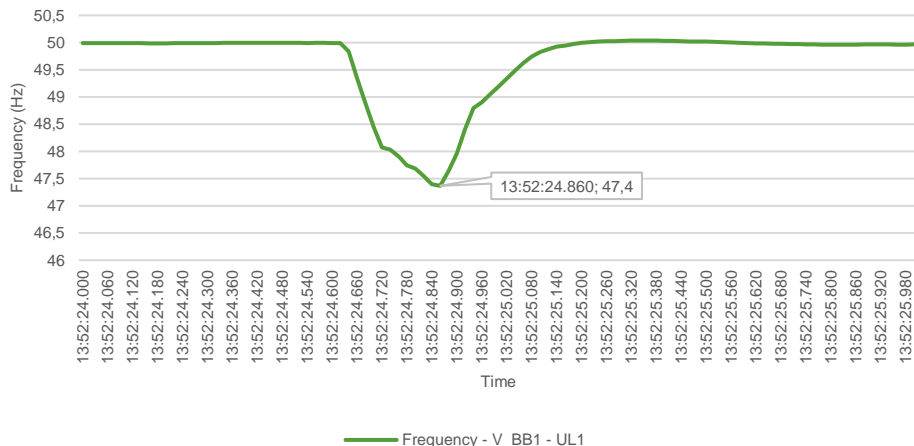
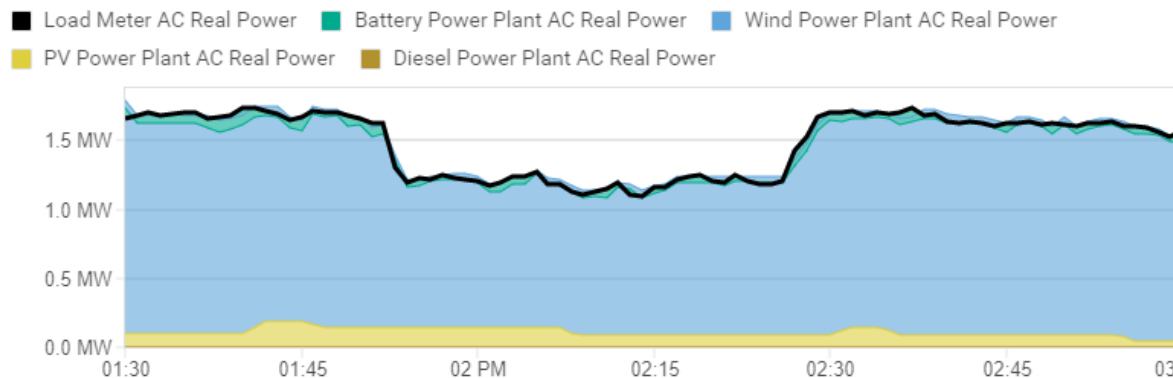
- Coordinated response between the BESS and the EMS is necessary to ensure that the frequency and voltage are recovered to their nominal value
- Only the DPP and the BESS provide short-circuit current to clear faults.
- The solar and wind farm were set to operate in zero power mode during short-circuits

3. Graciosa hybrid power plant

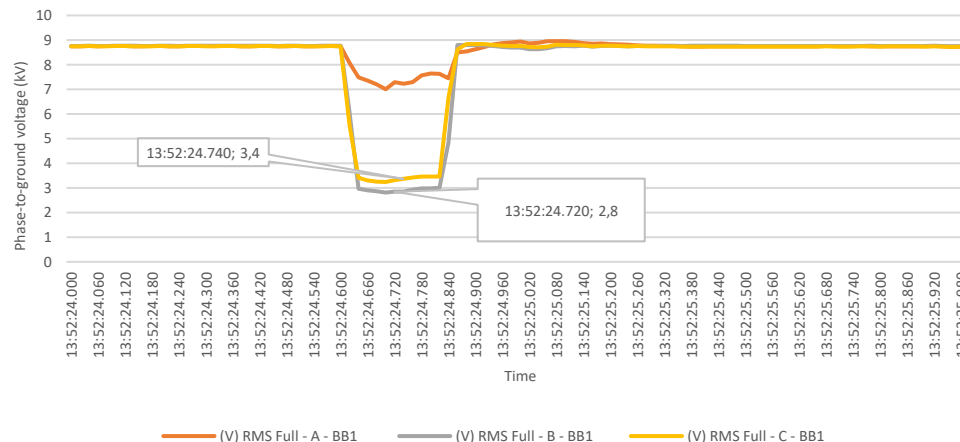
BESS response to transient events

- Operation scenario of 23rd of September, 2020
- Short circuit detected at one of the Island load feeders, causing a load drop of 500 kW at 01:52 pm
- Frequency and voltage restored within 300 ms

Microgrid Stacked Power Plot



Frequency measured at BPP busbar during short-circuit event (sampling rate of 256 per cycle)



Phase-to-ground voltage measured at BPP busbar during short-circuit event (sampling rate of 256 per cycle)

3. Graciosa hybrid power plant

Energy Management system (EMS)

Main objectives:

1. Maintain grid stability and security of supply (N-1)
2. Maximizing renewable penetration by forecasting load and renewable generation
3. Minimizing DPP operating costs
4. Enhancement of power quality

DPP operation restrictions:

1. Power factor requirements
2. Voltage and frequency operating range
3. N-1 operation criteria
4. Active and reactive power loading steps
5. Minimum stop and run time
6. Daily number of individual engine starts
7. Daily number of total engine starts

4. Hybrid Power Plant operation performance results

Operation indicators from 1st of August, 2019 until 1st of March, 2022

Availability

Full connection of the HPP to the Island grid: **934** days out of 942, uptime of **99,2 %**

Renewable penetration: 60%

Cumulative days operating with 100% renewable penetration: **338** days, 36% of the analysed period

Energy

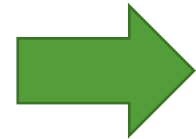
Island load: **34,7** GWh

Net renewable energy delivered to grid: **21,5** GWh

Solar farm: **2,46** GWh, 12%

Wind farm: **18,91** GWh, 88%

Technically available RE curtailed: **14,5** GWh



14864 tons of CO2 emissions avoided

BESS

AC energy charged (GWh): **1,94**

AC energy discharged (GWh): **1,71**

AC round-trip efficiency (%): **80**

DC average battery cycles/day: **0,83**

DPP

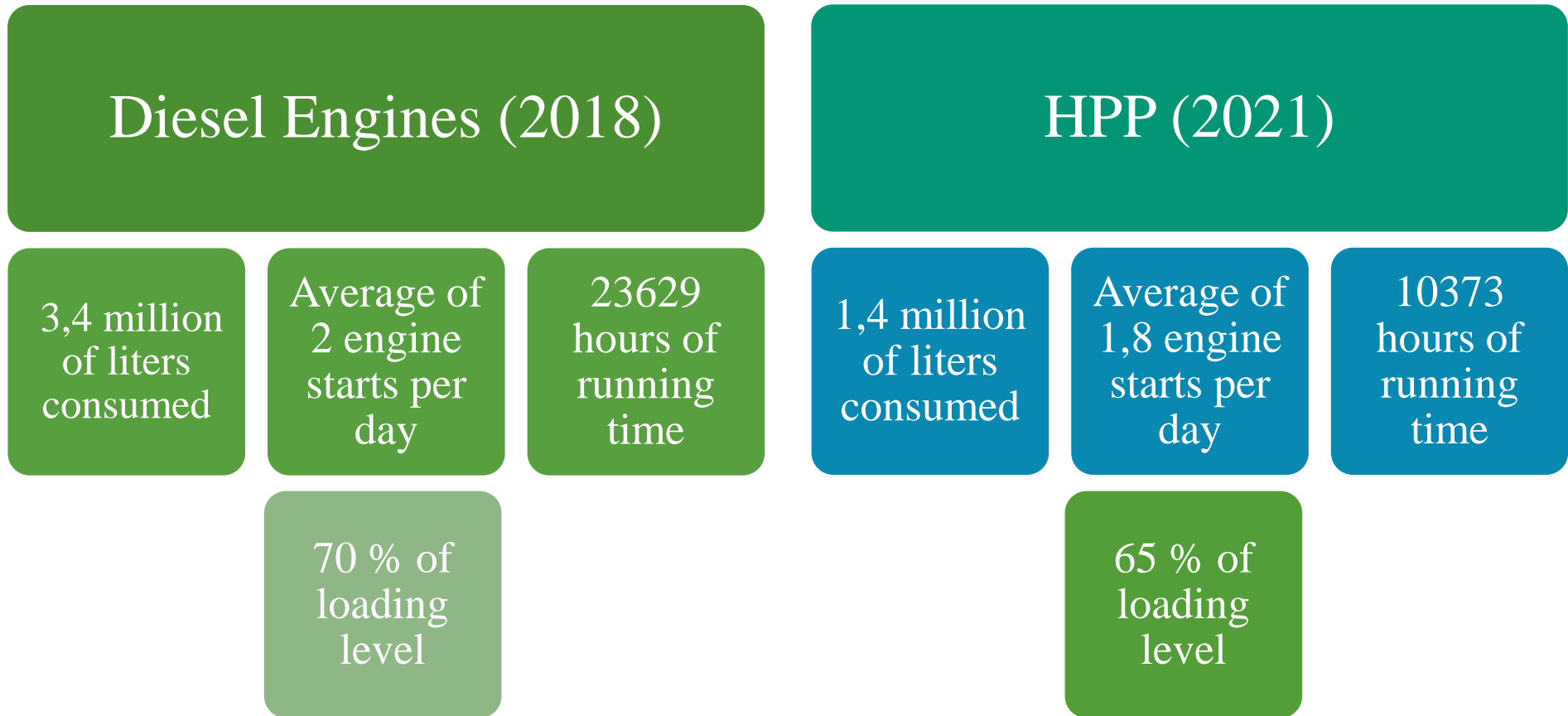
Monthly average number of engines starts: **54**

Monthly average of engines running time (hours): **982**

Running engines loading level average (%): **66**

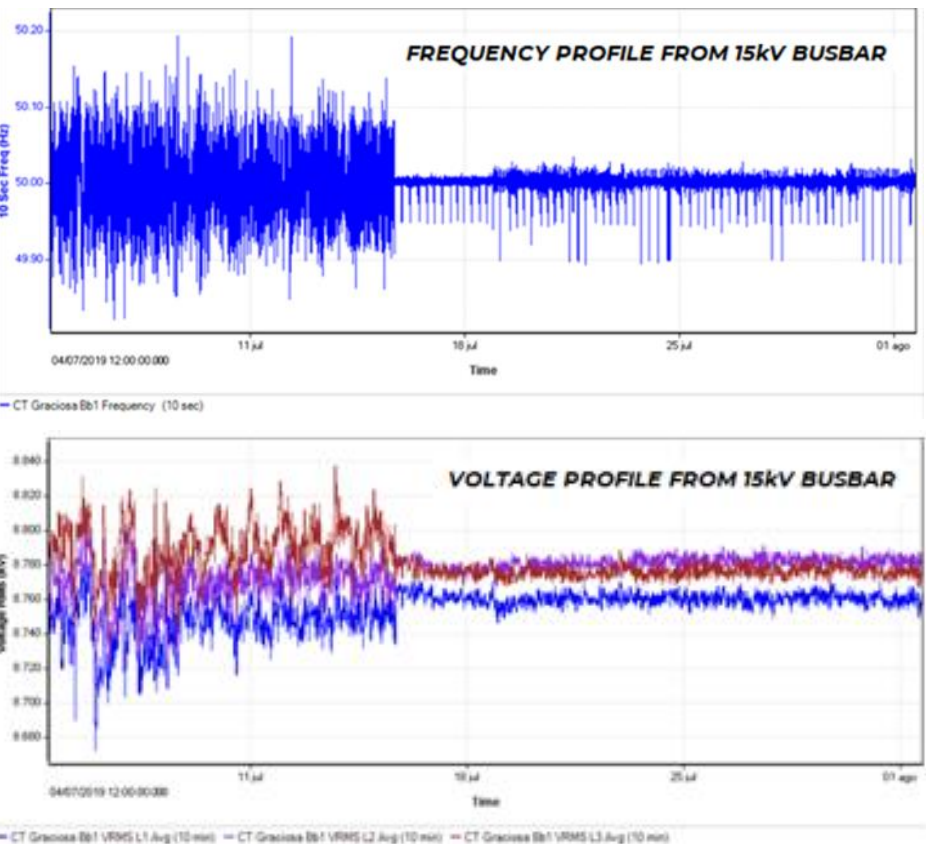
4. Hybrid Power Plant operation performance results

Diesel Power Plant operation indicators comparison



5. Enhancement of Power Quality

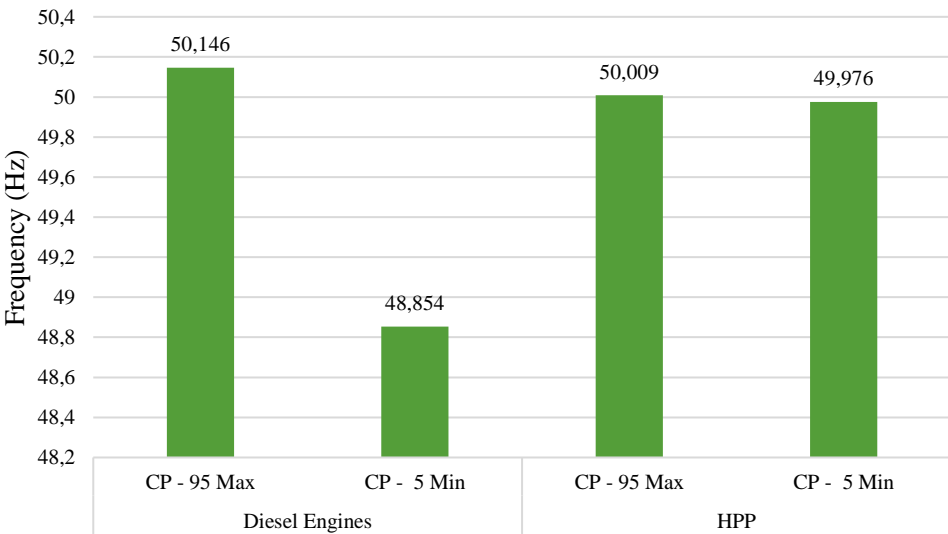
Frequency and voltage profile



PQ parameters comparison based on the EN 50160

August 1st, 2017, until January 31st, 2018: **Diesel Engines**

August 1st, 2019, until March 1st, 2022: **HPP (EMS, BESS, PVPP, WPP, DPP)**

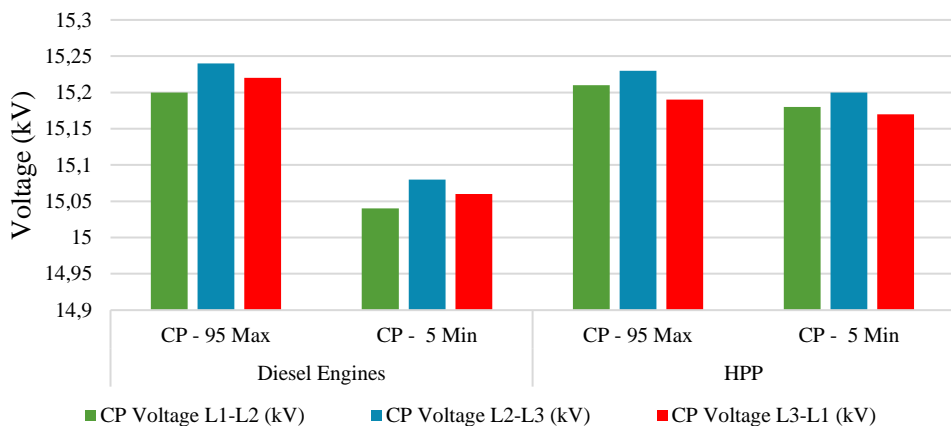


Frequency limits as per EN 50160: 49 and 51 Hz

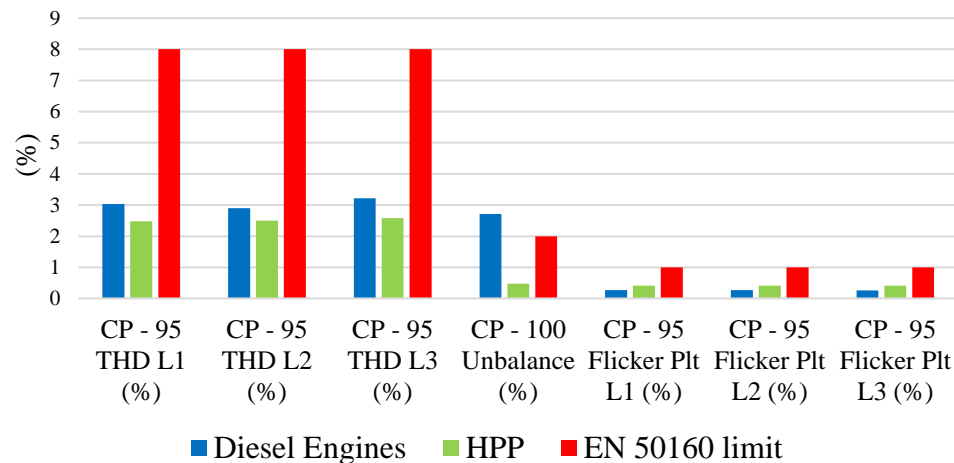
5. Enhancement of Power Quality

PQ parameters comparison based on the EN 50160

Island operating voltage level: 15,15 kV



THD, Unbalance and Flicker Plt



Voltage limits as per EN 50160: 13,63 and 16,6 kV

5. Next targets and challenges

Project Summary

- Project has been matching the initial expectations in terms of achieved RP
- 60 % of RP achieved in the first two years and 7 months of operation
- 65 % of RP achieved only in 2021

Strategies to improve renewable penetration rate

1. Greater relaxation of the diesel engines constraints
2. Integration of an additional renewable source, for instance biomass
3. The practical use of the 14,5 GWh of technically available RE curtailed in the HPP

Thank you for your attention