Grid oscillations

Insight into the 3.5 Hz issue and cross-network correlations

Tim Slangen

Introduction

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OUR SERVICE AREA

- Grid operator in provinces Utrecht, Zeeland and most of Zuid-Holland
- Construction, management and maintenance of electricity and gas networks
- 2.4 million households
- Highly urban and industrial area (Port of Rotterdam)
- Dense and complex area with high energy demand
- Responsible for grids < 110 kV

Gas service area

Electricity and gas service area

Overview

- Introduction
- First observations
- Research results
- Next steps

Part 1
Introduction

New challenges

Due to fast integration of renewables

LV-networks:

- Electric vehicles (EV)
- Heatpumps
- Solar-PV

MV- and HV-networks:

- Large solar parks
- Wind turbines
- Battery systems
- Large EV-chargers

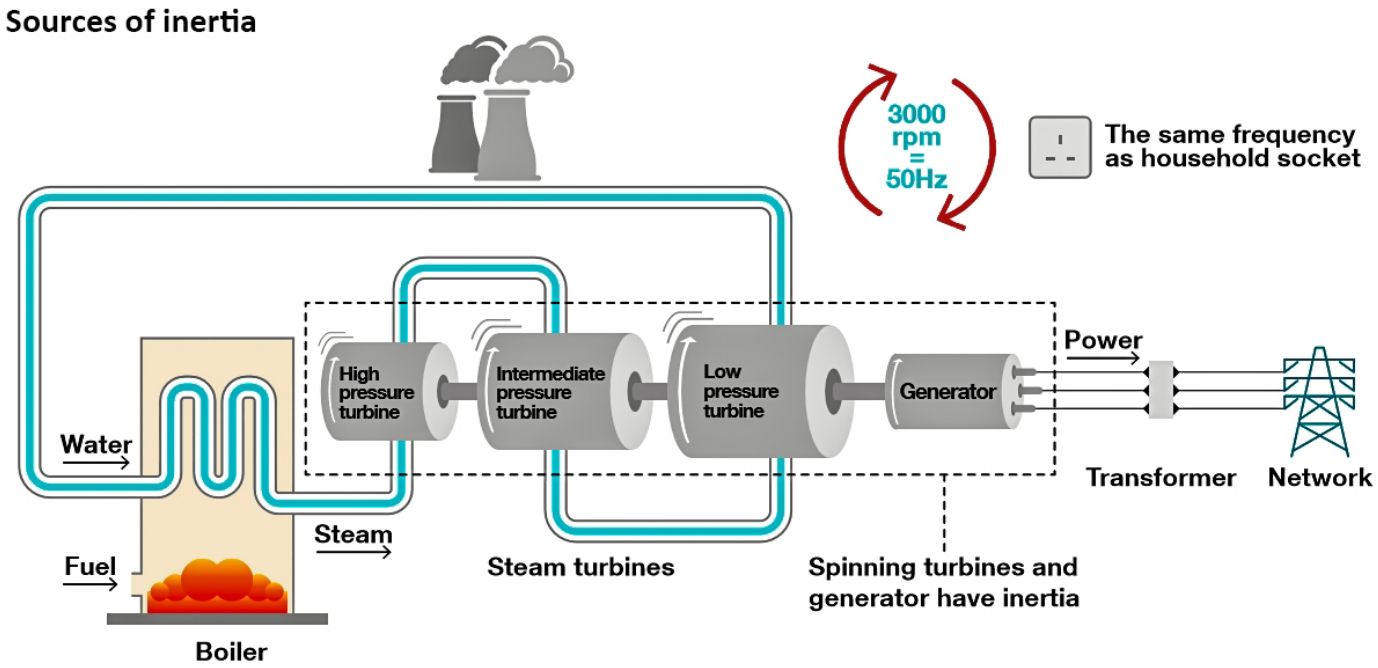
Consumption and production on all grid levels

Electricity grids in transition

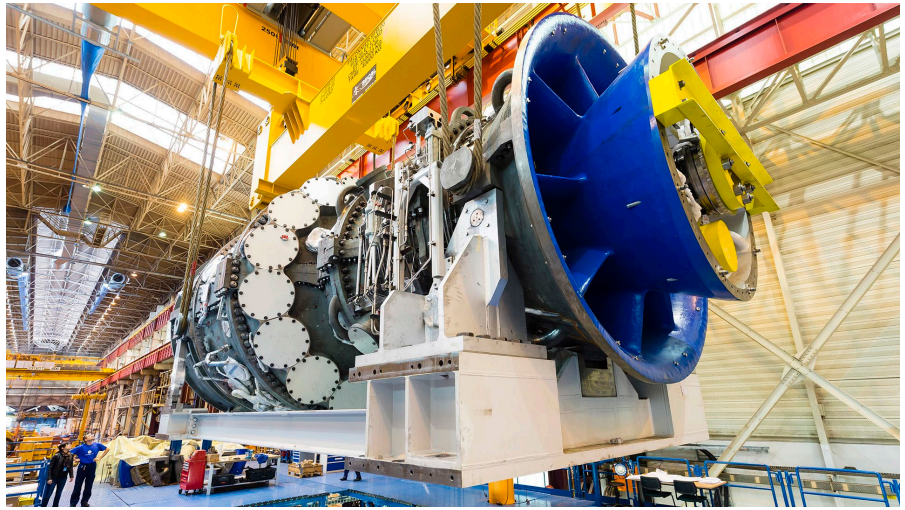
THE SYSTEM PERSPECTIVE

Conventional energy production (coal/gas/nuclear) → centralized

Thermal energy (heat) → Kinetic energy (rotation) → Electrical energy (electricity)



Source: National Grid



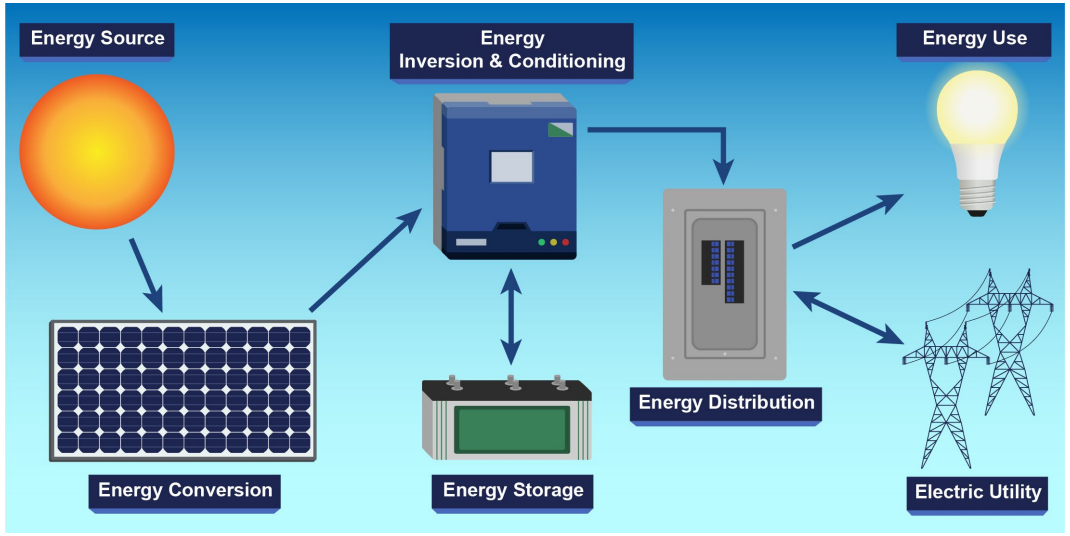
Container ship

Image: Copilot

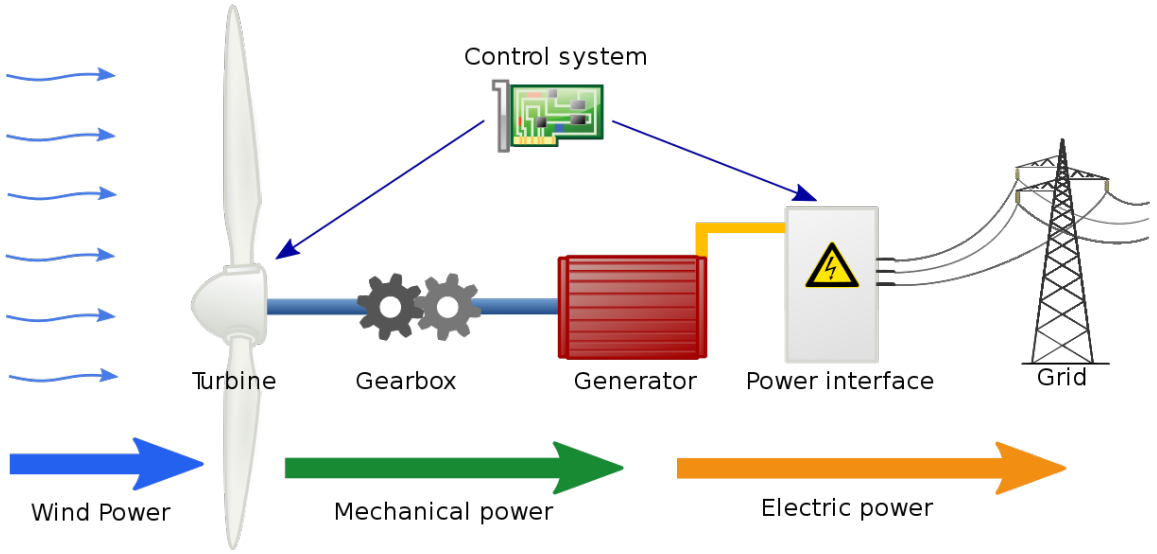
- High inertia (large, stable, steady)
- Slow response to changes (damping)
- Easily controllable (dispatchable)
- Predictable (plannable)
- Ancillary services: built-in (voltage/frequency control)
- Fossil (non-renewable) energy

Modern energy production (IBR*: sun, wind) → decentralized

"light" energy (photovoltaic) → Electrical energy (electricity)



Kinetic energy (rotation) → Electrical energy (electricity)



*IBR: inverter-based resources → renewable energy sources

Sailing boats

Image: Copilot

- Low or no inertia (more sensitive)
- Fast response, but risk of instability
- Poor controllability, dependent on weather conditions
- Limited (but increasingly better) predictable, dependent on weather conditions
- No/limited additional support services
- Renewable energy sources (wind)

Subsynchronous oscillations (SSOs)

Subsynchronous oscillations (SSOs)

Definition

- Below fundamental frequency (50 Hz)
- But above the electromechanical range (~ 3 Hz)
- Observed in the phasor domain (e.g. PMUs)

Risks

- Grid stability / System resilience
- Large-scale outages
- Power quality limit exceedance / complaints

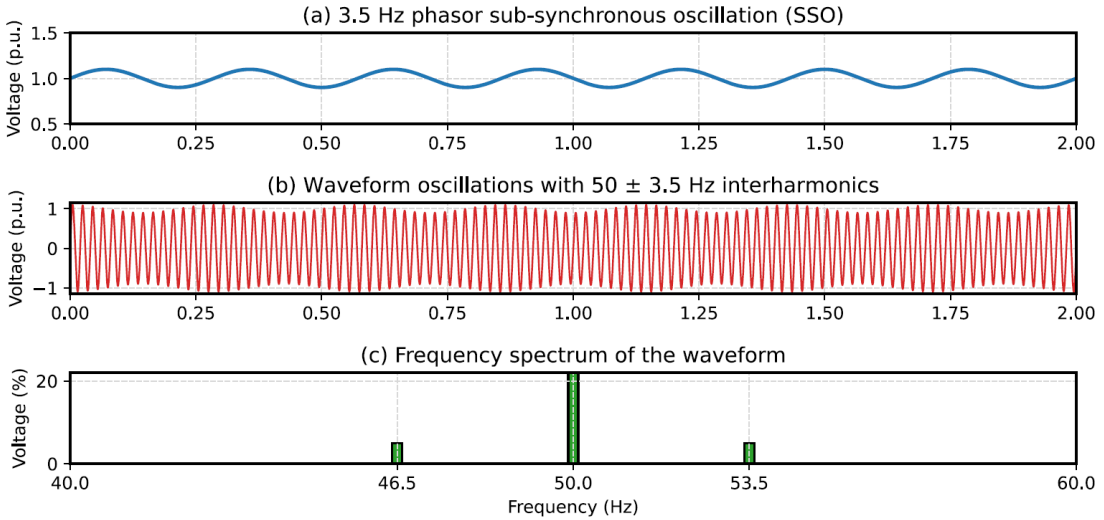
Relation with Power Quality

- Interharmonics
- Can lead to PQ flicker

The existence of interharmonics is a necessary condition to the formation of phasor oscillations in the rotating reference frame

$$sin\alpha + sin\beta = 2sin\left(\frac{\alpha+\beta}{2}\right)cos\left(\frac{\alpha-\beta}{2}\right)$$

$$2sin\left(2\pi\frac{f_1+f_2}{2}t\right)cos\left(2\pi\frac{f_1-f_2}{2}t\right)$$

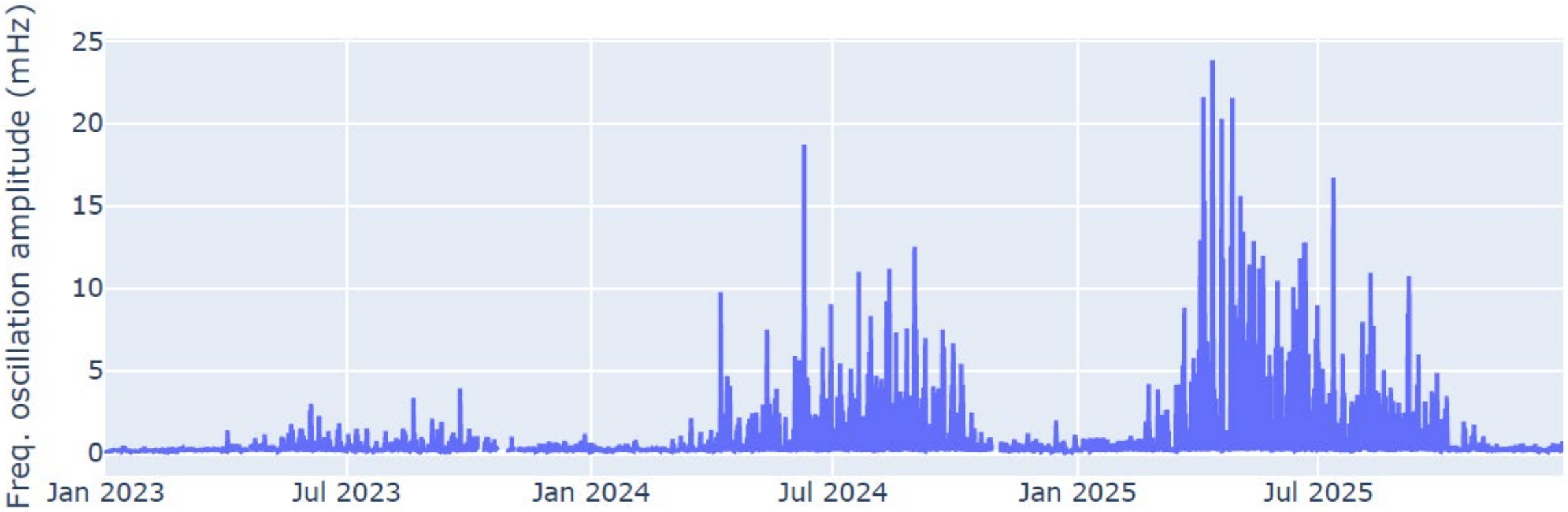


Source: T.M.H. Slangen, A. Boricic, S. Frohn, M.S. Janssen, F.J. Wensink, "Sub-synchronous Oscillations and Interharmonics with High IBR Penetration - The Dutch 3.5 Hz Case", in 2026 *22nd International Conference on Harmonics and Quality of Power (ICHQP)*, Dresden, Germany, sept 2026 (submitted)

Part 2
First observations

Observations TenneT PMU and WAMS

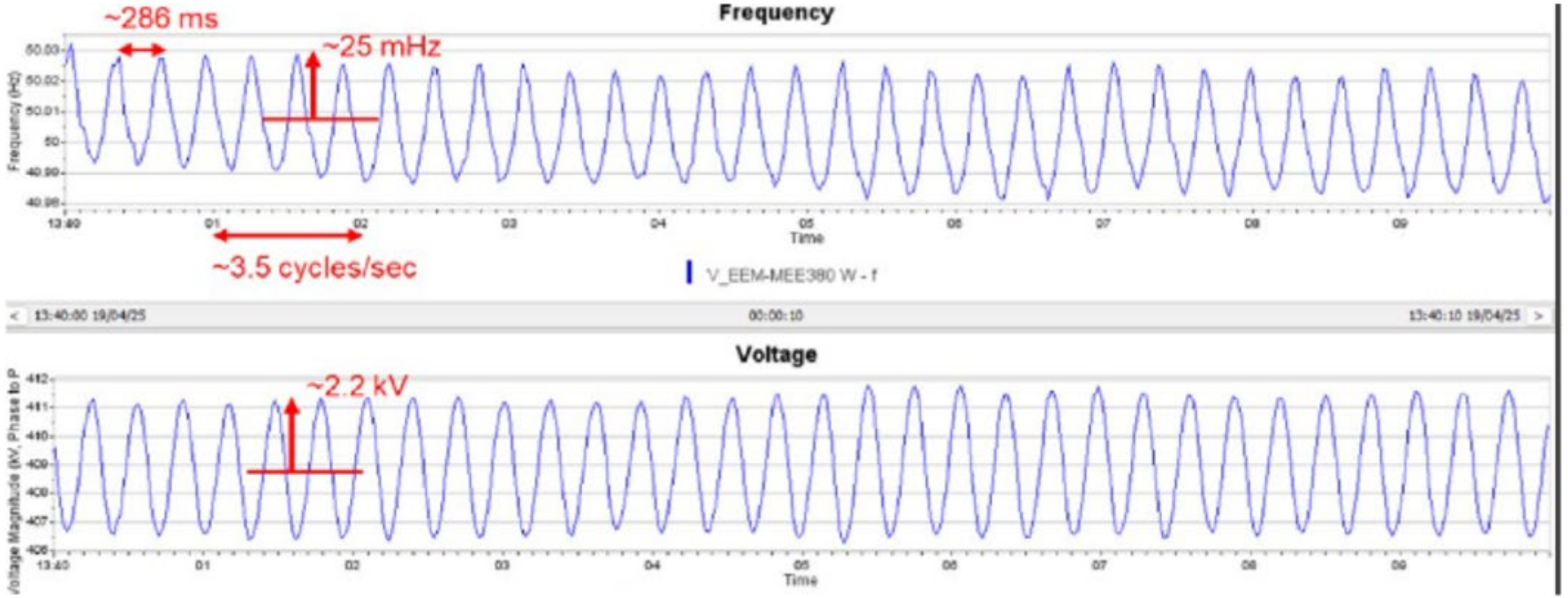
Frequency oscillations



Bron: TenneT

Observations TenneT PMU and WAMS: Eemshaven 380 kV

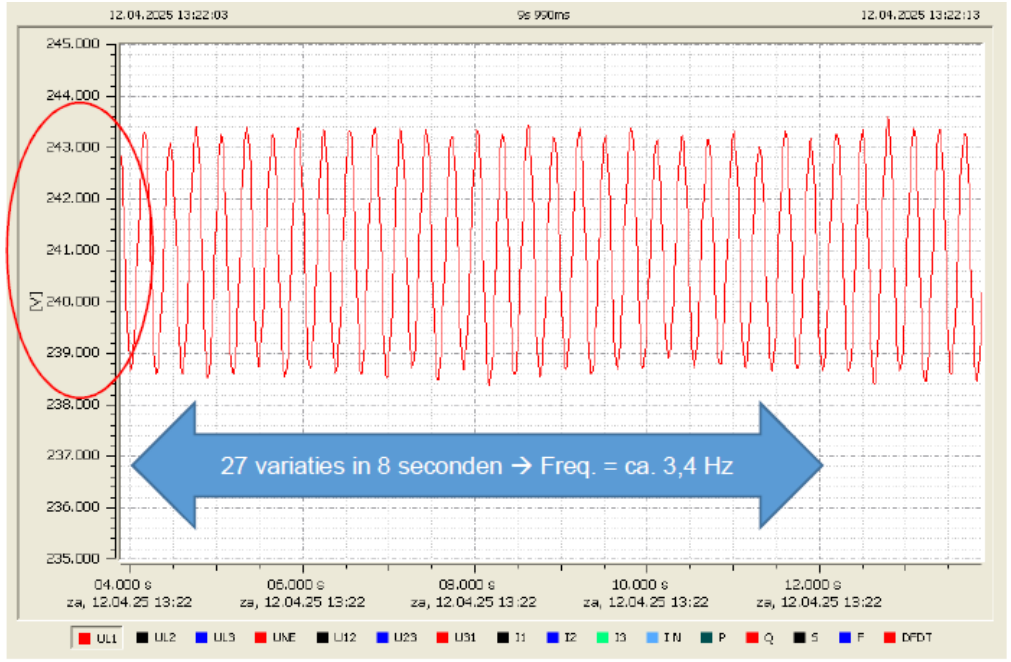
Frequency and HV voltage oscillations



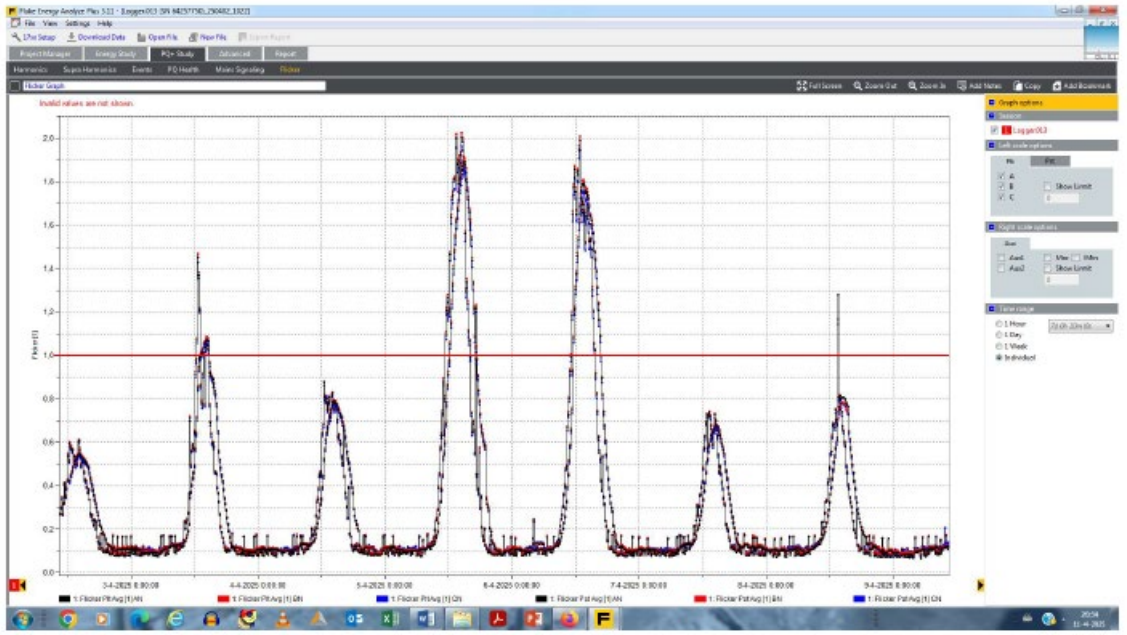
Bron: TenneT

Observation DSO PQ flicker monitors
LV Voltage oscillations

- Oscillating voltage level on LV (Utrecht)



- Exceedance of Flicker limit (Pst) on LV (Utrecht)



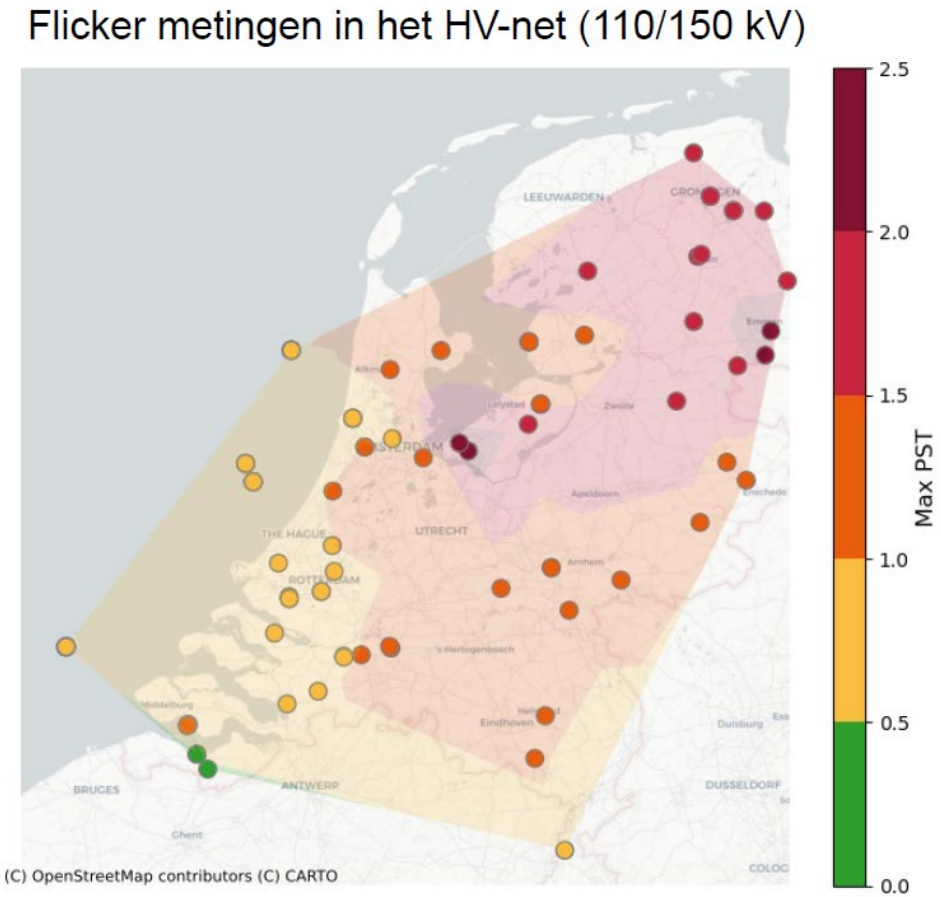
Part 3
Research results

Research consortium “3.5 Hz project”

Part of newly founded **NBNL WG Systeemstabiliteit**

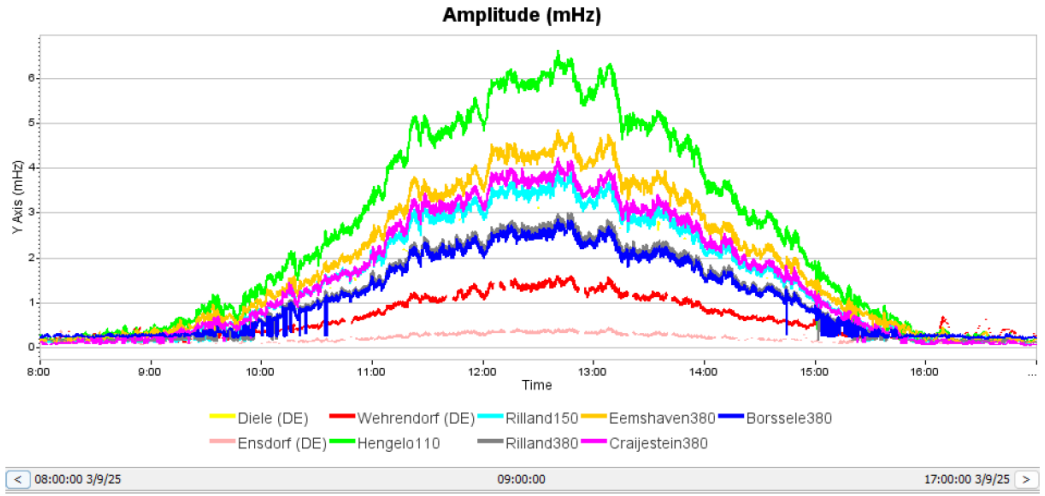
Initial analysis

Observations TenneT PMU and WAMS



Voltage oscillations

Voorbeeld 9 maart 2025

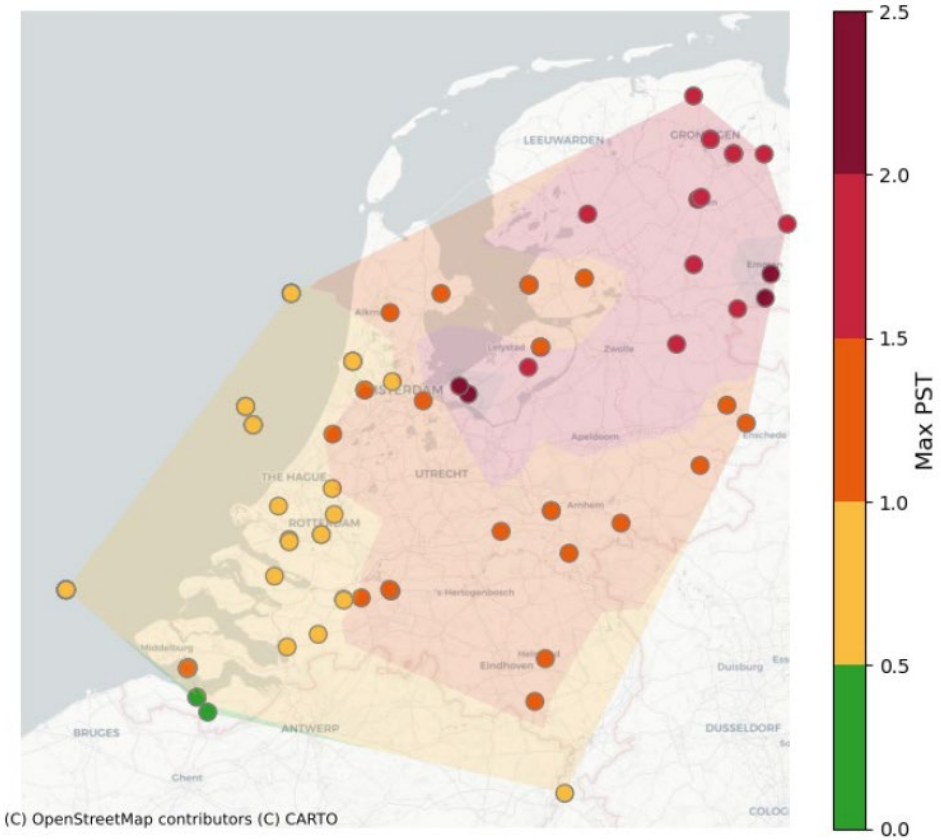


- Amplitude in NL hoger dan in omliggende landen

Bron: energieopwek.nl / 21 juni 2025

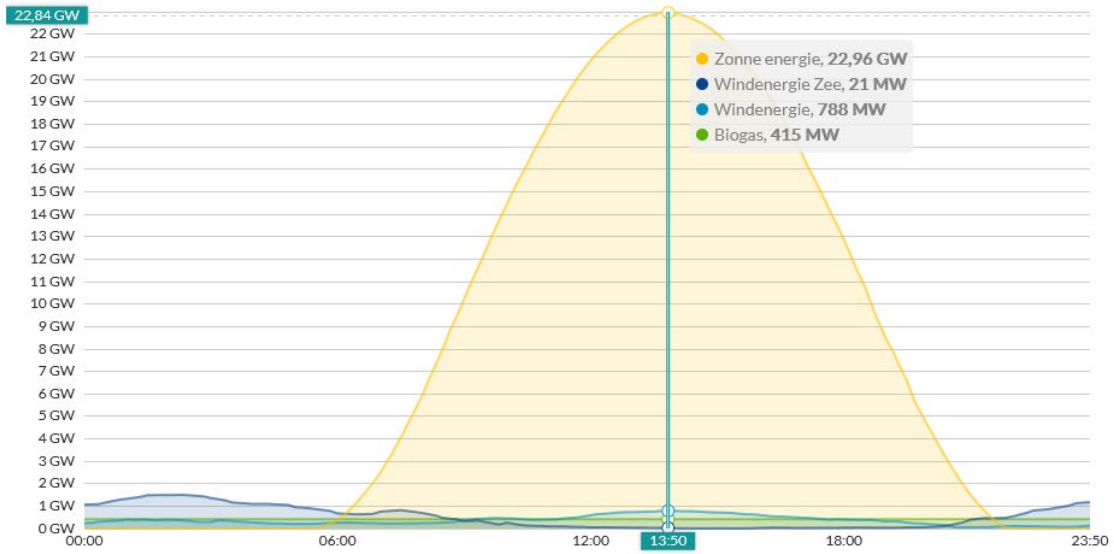
Observations TenneT PMU and WAMS

Flicker metingen in het HV-net (110/150 kV)



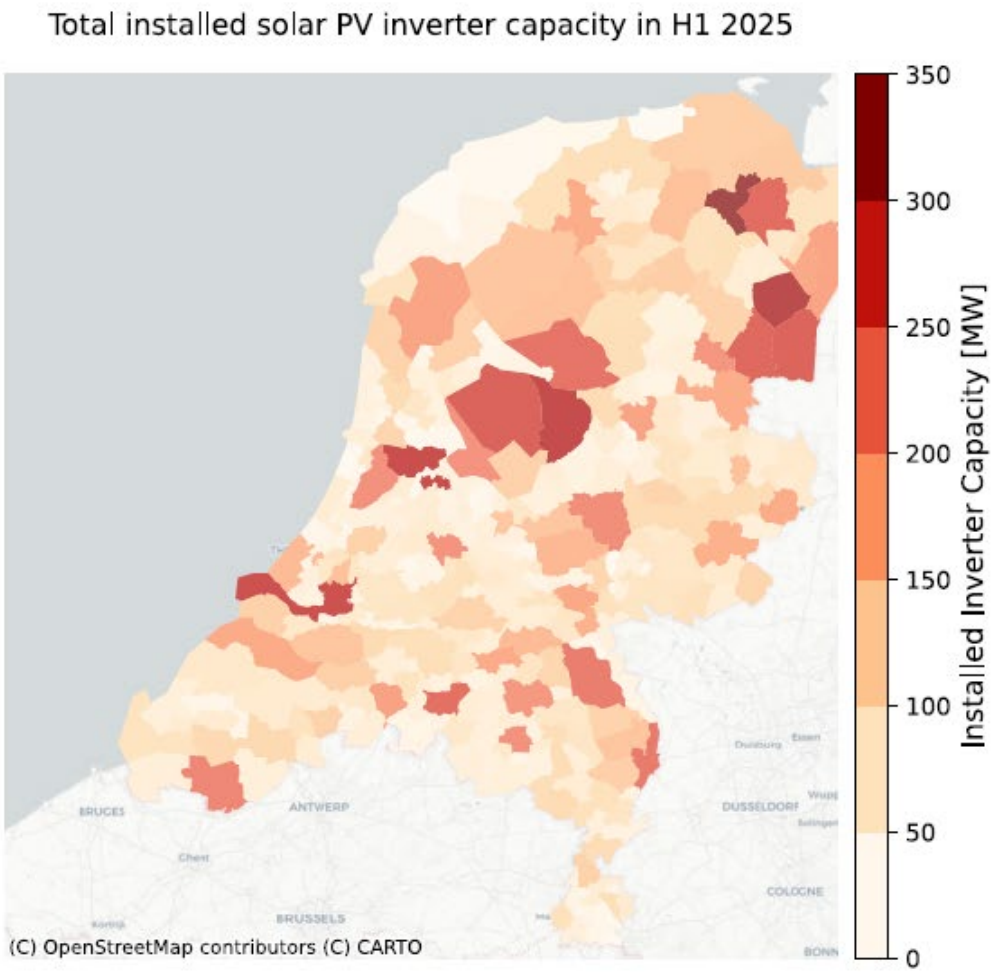
Voltage oscillations

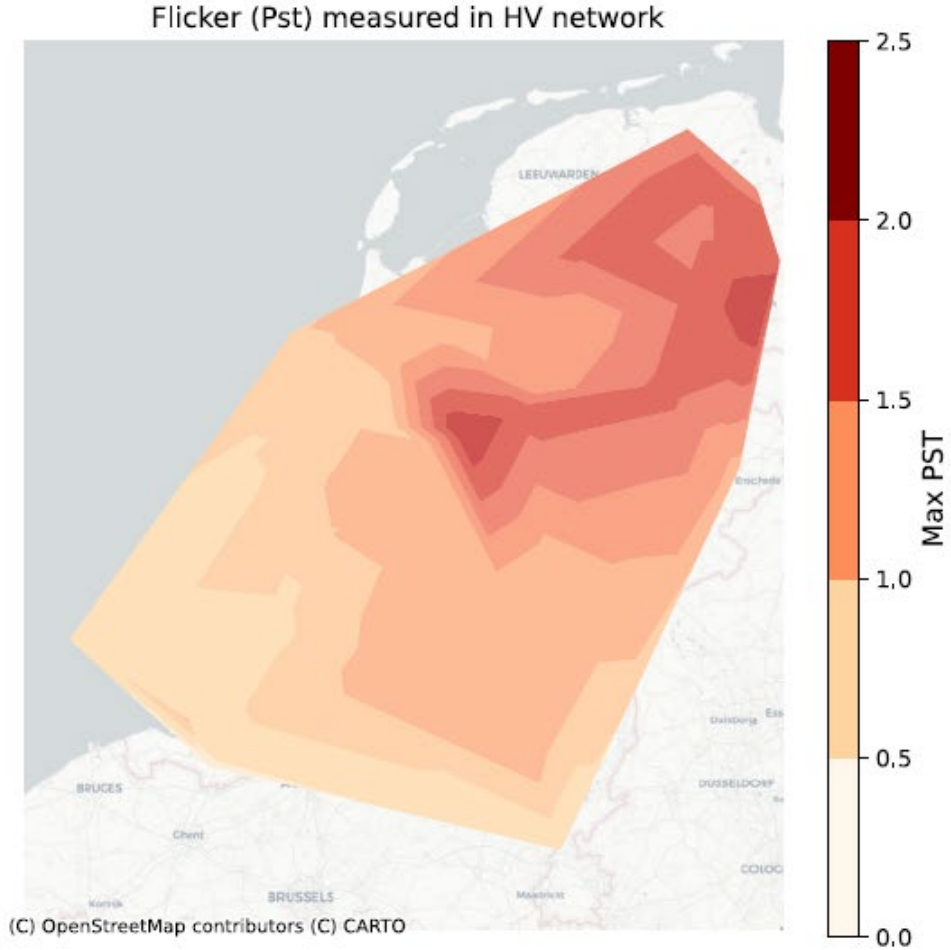
PV generation. Days with 99% PV (of renewable output)



Bron: energieopwek.nl / **21 juni 2025**

Correlation with PV generation capacity





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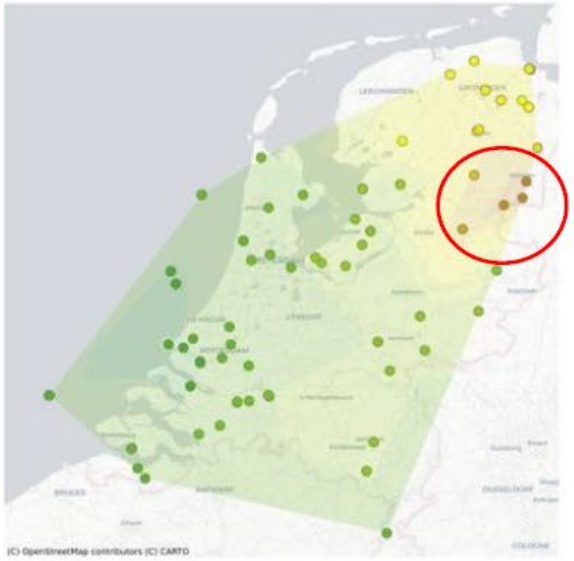
Correlation measurement data DSO / TSO

Example Sat 19 April 2025 13h40, with DNO Enexis data

EHV

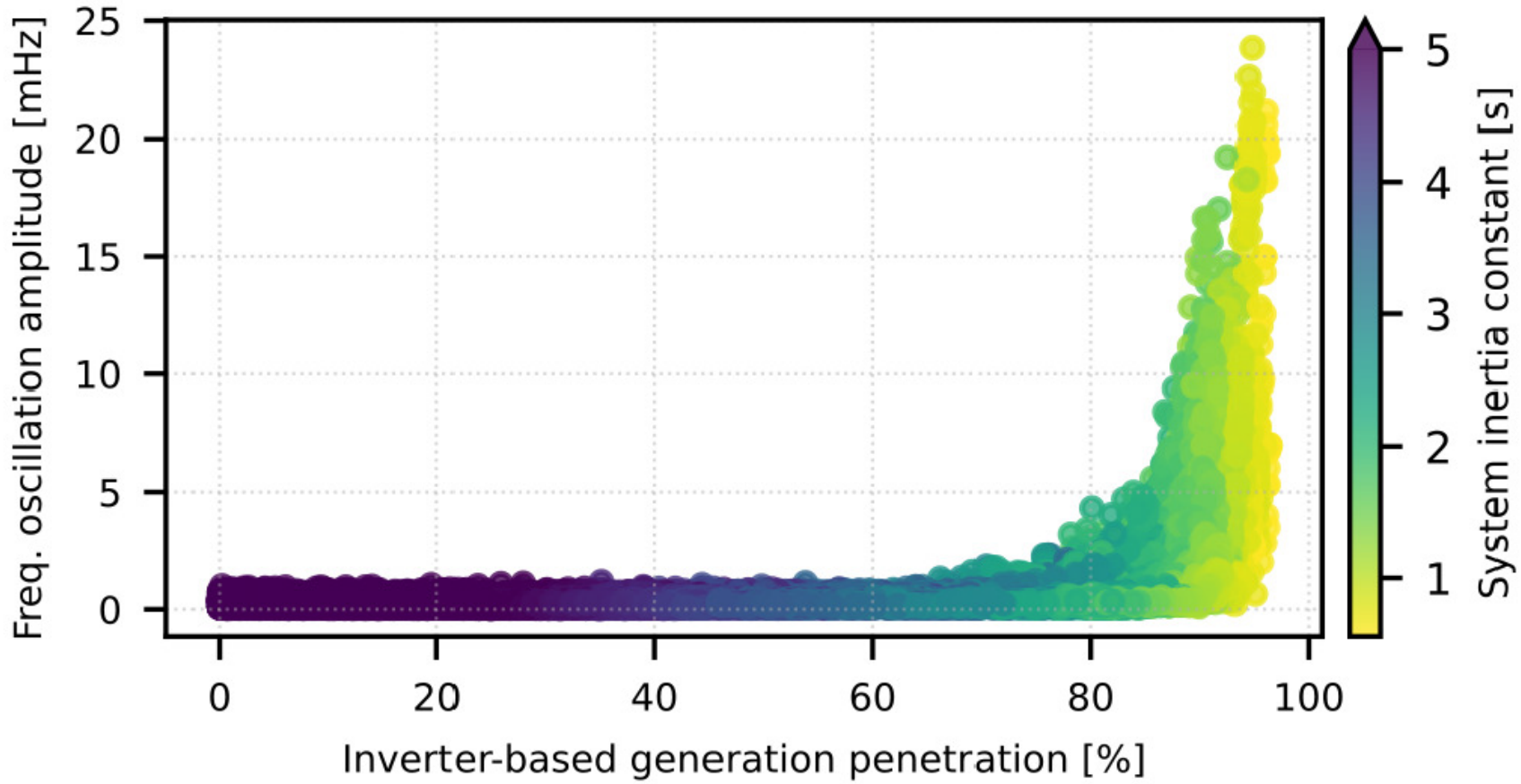
HV



MV (Enexis)

Further investigation relation with renewables

Relation between 3.5 Hz oscillations, IBR penetration and system inertia



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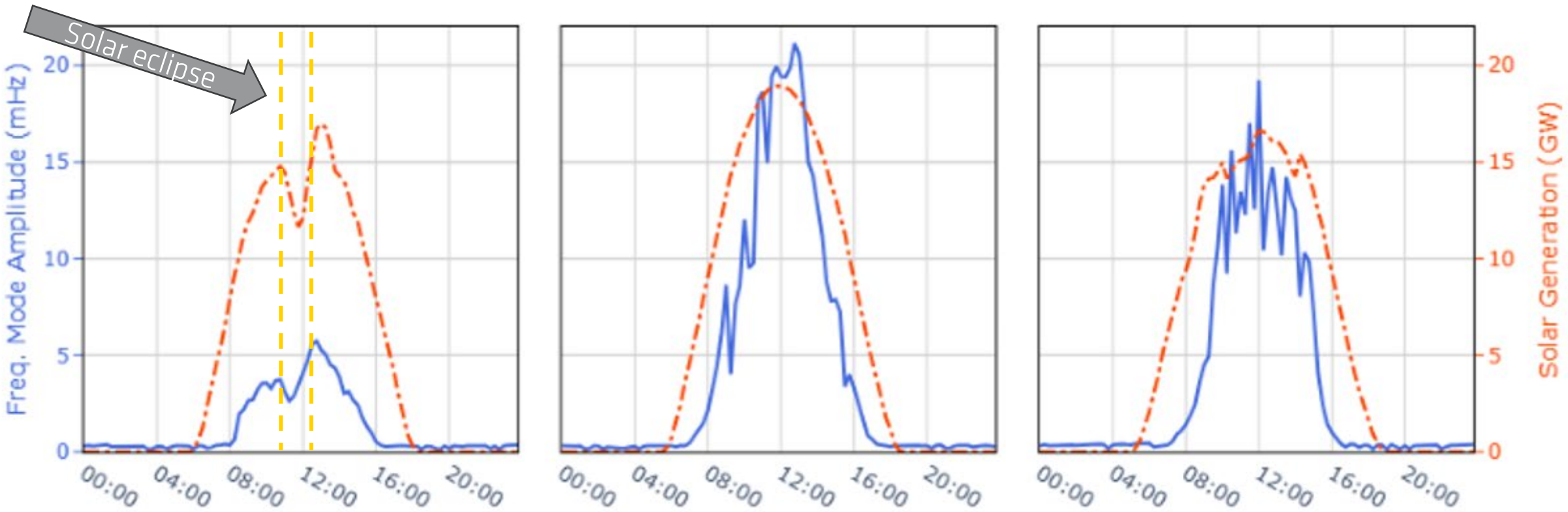
Relation between 3.5 Hz oscillations and solar PV generation



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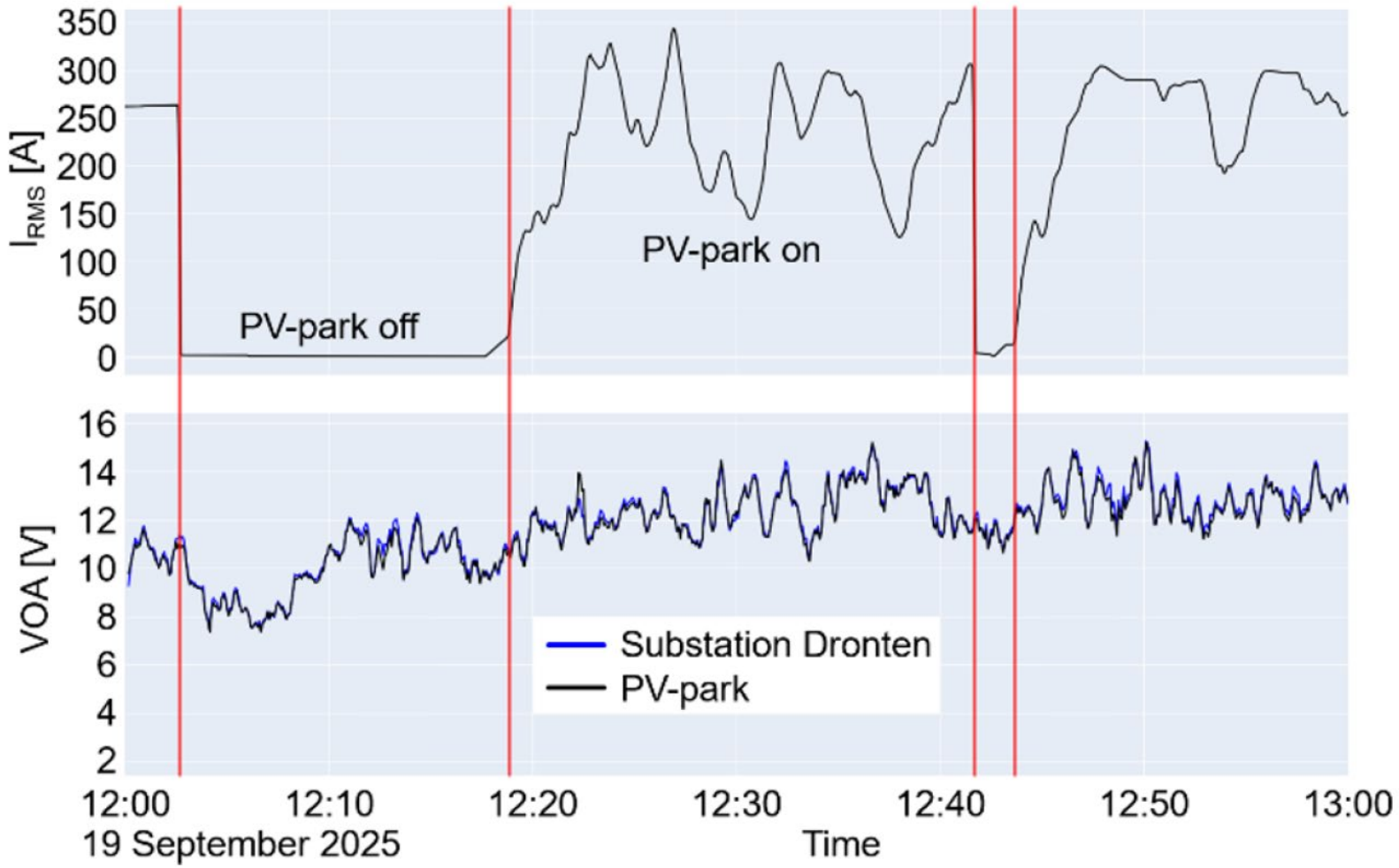
DSO Measurements large PV park: no (significant) relation



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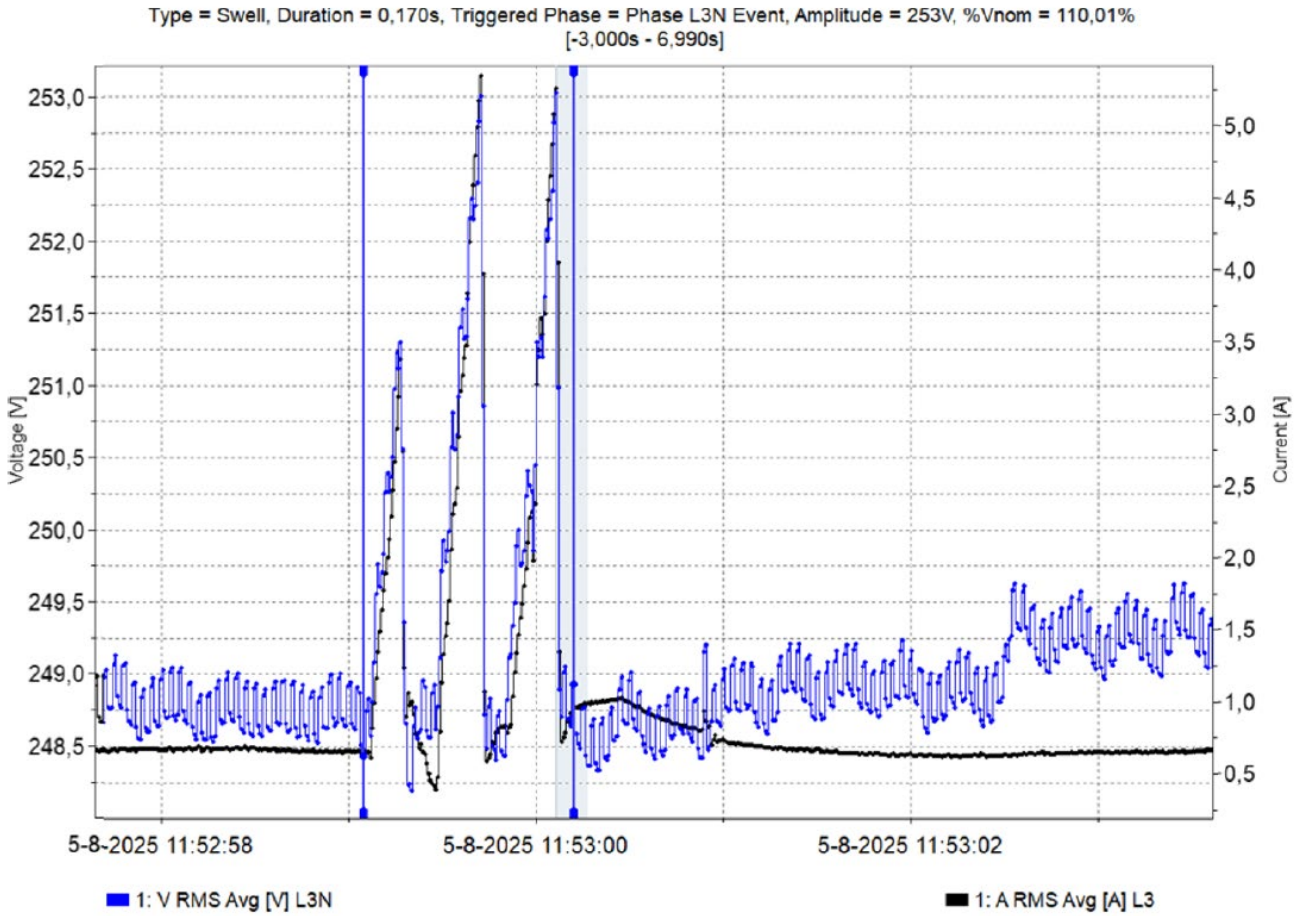
DSO Measurements residential LV PV-inverter: oscillations visible due to overvoltage triggering (possible source)



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Part 4
Next steps

Next steps

Additional measurement campaign

- To find sources and propagation of oscillations
- To verify hypotheses

Collaboration with inverter manufacturers

- Understanding control mechanisms

Collaboration with ElaadNL Testlab and Powerlab (HAN/ElaadNL)

- Lab testing different PV-inverters for different grid and operation conditions
- Characterizing inverter behaviour

Defining mitigation measures for minimizing risk

- What methods are available to control the oscillations

Informing and consulting relevant stakeholders

- Customers, inverter manufacturers, PV-park owners

Paper submitted to ICHQP'26 Dresden

Sub-synchronous Oscillations and Interharmonics with High IBR Penetration - The Dutch 3.5 Hz Case

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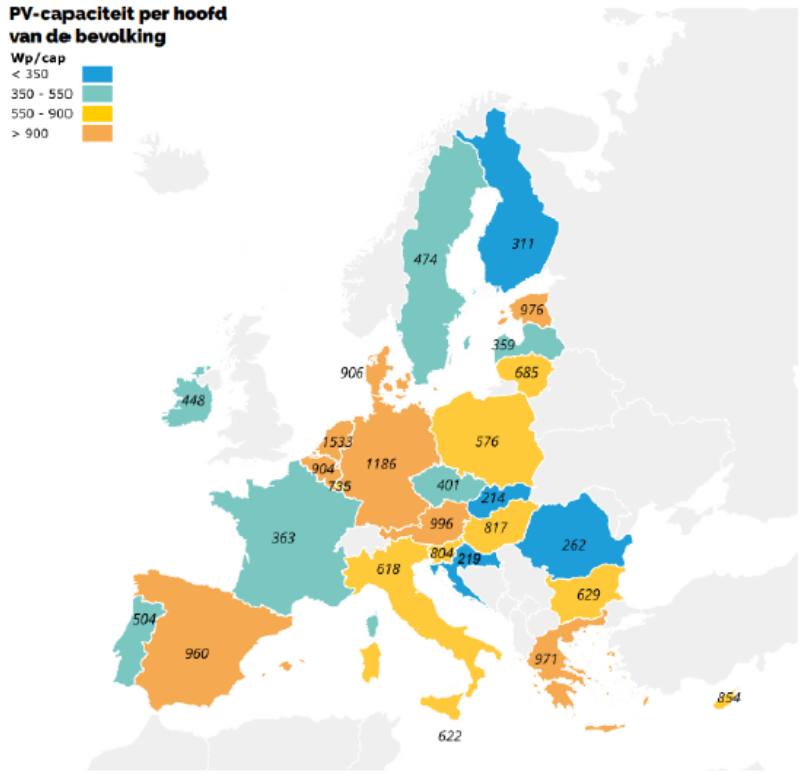
ICHQP 2026
22nd International Conference on Harmonics and Quality of Power
August 31 - September 3, 2026
Dresden, Germany

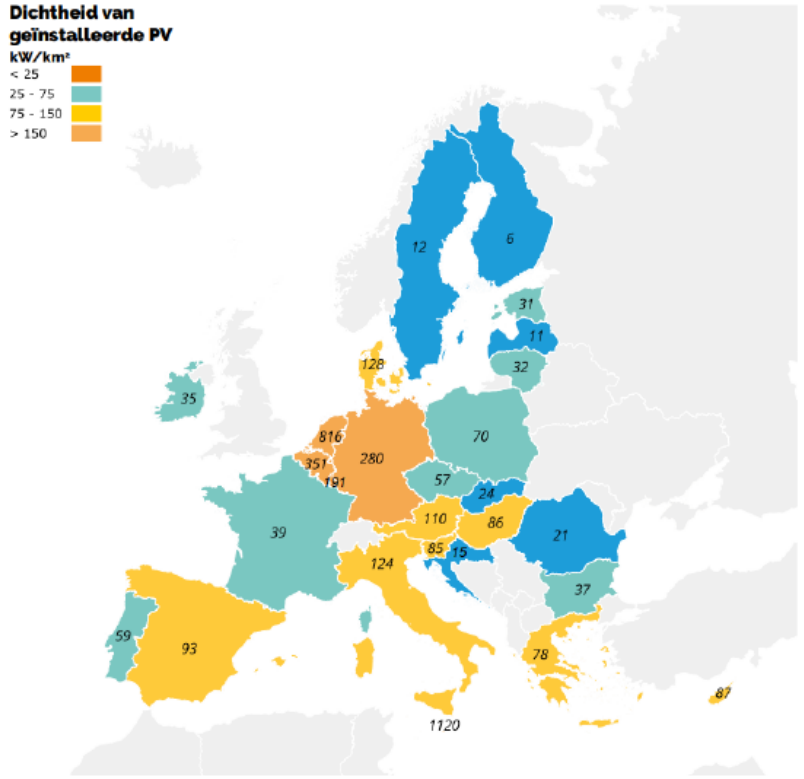
What makes NL unique

"The Netherlands has the highest density of installed solar PV in Europe"

- PV-capacity per capita



- PV-capacity density per area



BRON: NATIONAAL SOLAR TRENDRAPPORT 2025 - DNE

Thanks!

Questions? tim.slangen(at)stedin.net

VOOR DE NIEUWE **ENERGIE**GENERATIE