EMC-ESD association

EMC of EV Charging: a Power Quality perspective

NEDERLANDSE EMC-ESD VERENIGING

Elaadnl

EMC-ESD association

Arthur M. Hartsuiker

Chairman of the EMC-ESD association

Contact: info@emc-esd.nl

Account manager Test & Meassurement

High voltage/ PowerQuality / instrumentation

Email: ahartsuiker@cnrood.com

Linkedin: www.linkedin.com/in/arthurhartsuiker

EMC-ESD association

The objective of the association

To promote knowledge in the field of EMC and ESD and the exchange of (technical) information among its members. The association aims to achieve these goals by organizing meetings, events and activities for and with its members. In addition, the association has working and task groups that deal with various themes of EMC and/or ESD. Due to the increasing number of members with diverse backgrounds and activities in the field of EMC and ESD, the network function of the association is important.

EMC-ESD association

Approximately 150 professionals in the field of EMC and/or ESD

The Dutch EMC-ESD Association is an association for:

- Consultants
- Educational institutions
- Measurement and test houses
- Suppliers of equipment and machines
- Manufacturers of machines and electrical devices
- Installers of electrical and mechanical installations
- Students
- Medics

EMC-ESD association

- **EMC/ ESD event (once per 2 years)**
- **Lunch sessions**
- **EMC /ESD newsletters**
- **Knowledge market (Kennis markt)**
- **EMC on tour**
- **Technical Seminars:**
  - Power electronics / EMC in installations
  - Electronics design and EMC/ESD in devices
  - EMC-ESD test & measurement
  - Tools for standards and regulations

Elaadnl

NEDERLANDSE EMC-ESD VERENIGING

ElaadNL, Testlab & Power Quality research

Thijs van Wijk
Manager Elaad Testlab

Elaadnl

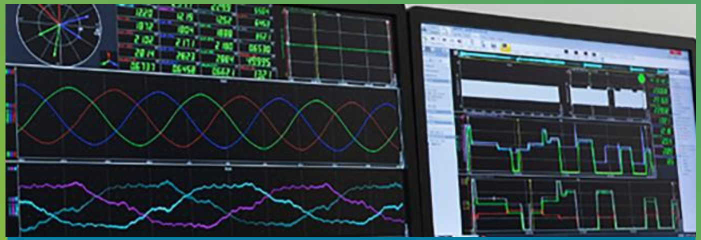
- Knowledge & innovation centre
- Non profit foundation
- Cooperation of grid operators

Our goal:
Integrating electric transportation in the electricity grid

ElaadNL


2009
stichting e-laad
3.000 public charging stations in 350 municipalities
Elaadnl
evnetnl
Klimaat-akkoord
Start knowledge- and innovation centre Elaad
Opening Elaad Testlab 2022
Elaadnl
2028

Our activities (2024)



1. Predict

- Data-analyses & Outlooks
- Grid impact analyses
- Logistic sector analysis
- Behavioral research

2. Innovate

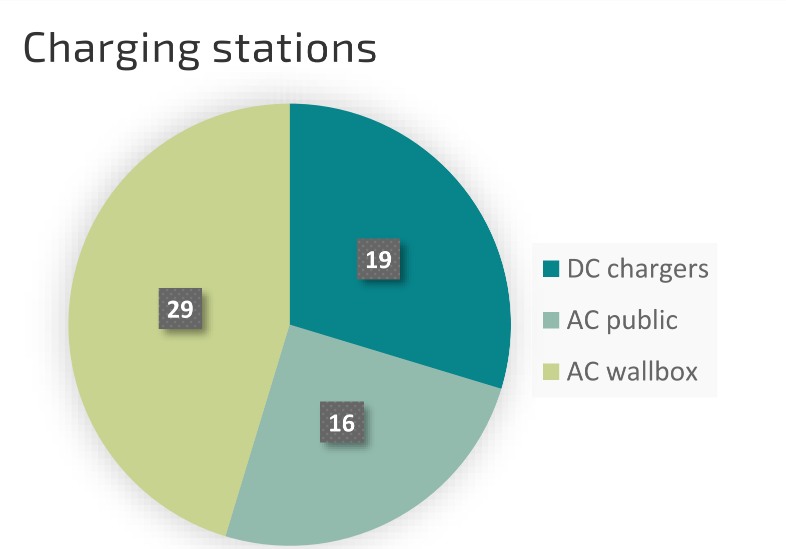
- Smart charging
- Protocols & standards
- Home energy systems
- Cybersecurity
- V2G

3. Implement

- Smart charging
- Power quality awareness
- Grid connection checks
- Improve processes
- Tender support
- Human Capital
- Charging logistics
- Testlab

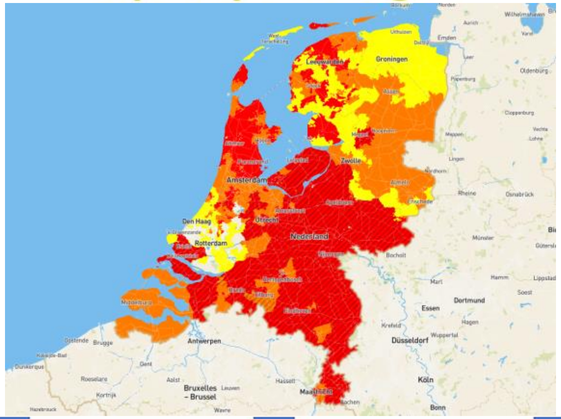
The Elaad Testlab

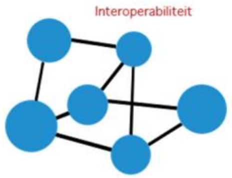
- Founded and funded by the Dutch DSOs to improve grid integration of EV charging
- Pre-certification and pre-normative testing
- Suitable for all kinds of electric vehicles including busses and trucks
- Different types of public and home AC chargers and DC chargers
- Highly accurate measurement equipment
- 360 kW bidirectional test system from Keysight
  - Bidirectional AC and DC emulators
  - EV/EVSE emulator, including 15118-20 (V2G)



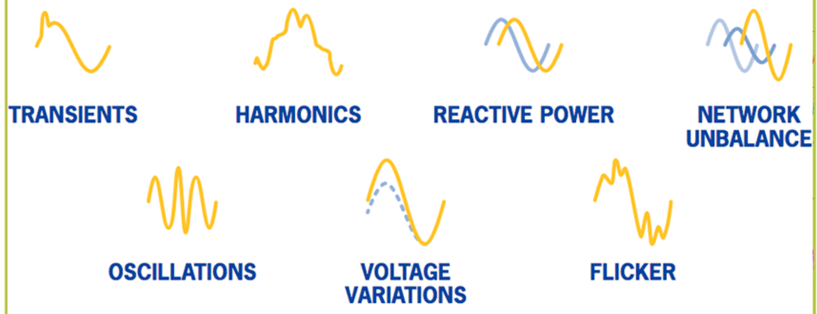
Why & what do we test

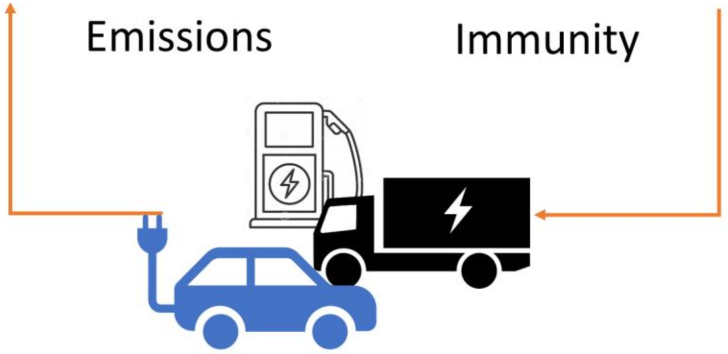
Capacity of the grid





Quality of the grid





Pre-normative

Gaps in standards

Frequentiebereik					
Harmonische	Laagfrequent bereik	Radiofrequenties door geleiding	Radiofrequenties door geleiding	Radiofrequenties door straling	Radiofrequenties door straling
50Hz - 2/2.5kHz 60Hz - 2.4/3kHz	2/2.5Hz - 9kHz 2.4/3Khz - 9kHz	9Khz - 150Khz	150kHz - 30MHz	30MHz - 1/2/3GHz	Boven 3GHz

Test proces/certification does not include everything

UNECE

ELAAD
100% ELECTRIC
DAF
T-162-BL
Z-562-LX
T-626-VD
V-81-GFD
G-908-DB
GVV-56-V
X-592-XK
X-824-SL
S-319-LN
GBN-87-L
GPD-73-P

Research

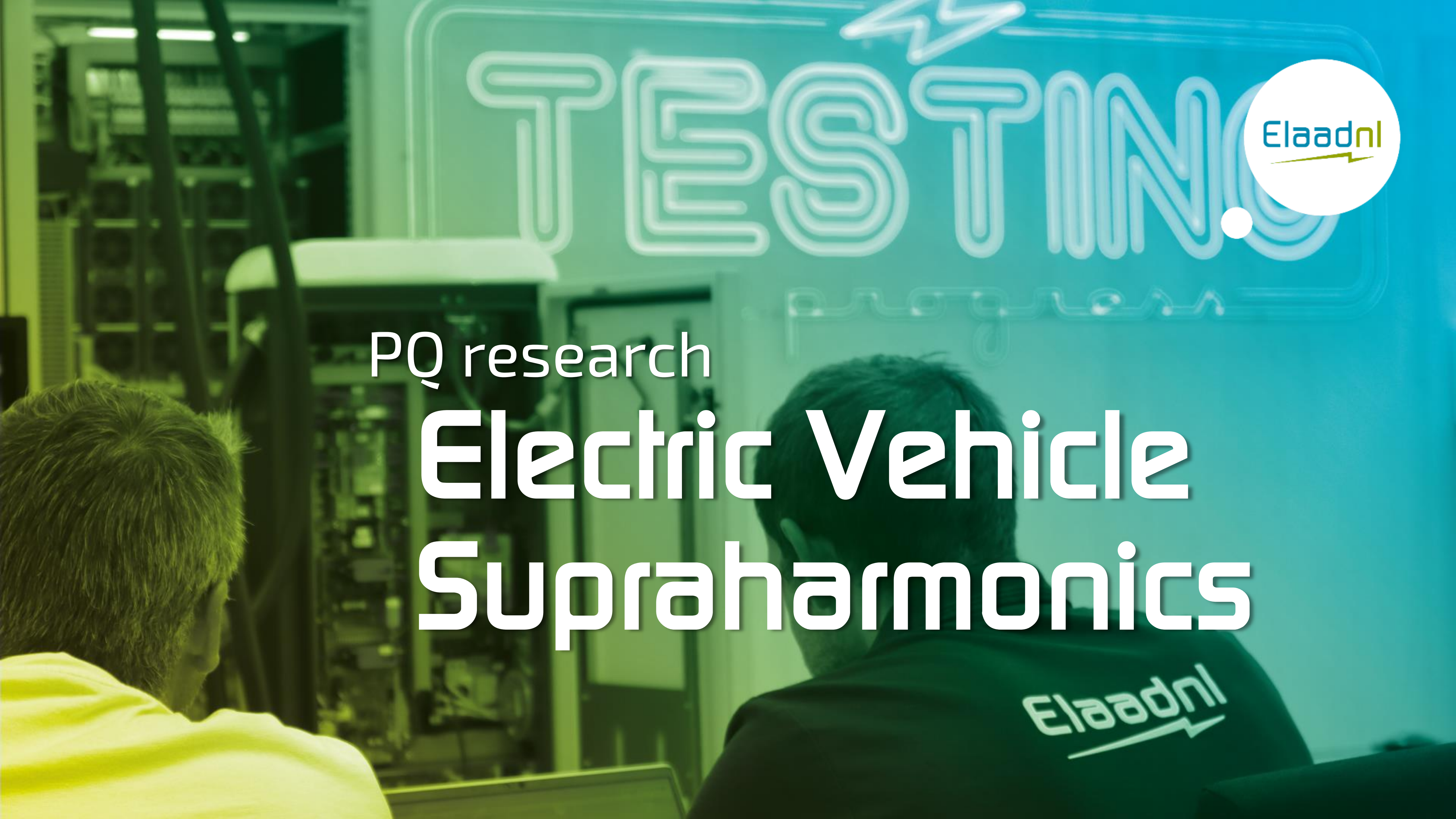
- Smart charging capabilities EVs and chargers
- Cyber security robustness chargers

&

- Power Quality research
  - Since 2017
  - Together with TU/Eindhoven, UTwente and TU Delft
  - Total of 9 students
  - Tim Slangen (TU/e); intern, graduation student, PhD
  - Tycho van Leersum (Utwente), graduation student, PhD
  - Focus Area: Supraharmonics

PQ research

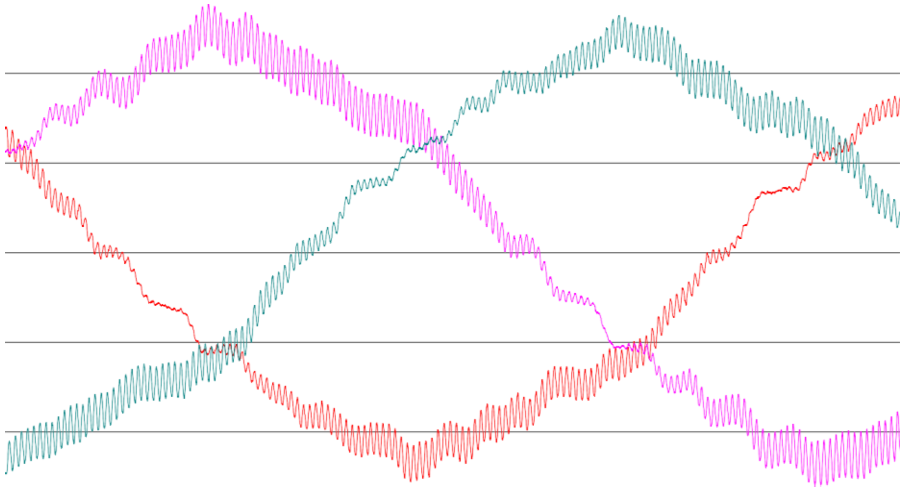
Electric Vehicle Supraharmonics



Supraharmonics explanation

Supraharmonics or *low frequency conducted emissions* (2-150 kHz)

- High frequency distortions related to switching frequency AC/DC converters
- Traditionally in between PQ (till 2 kHz) and EMC (starting at 150 kHz)
- Distortions are seen at lab and field measurements
- No full standardisation of emission & immunity levels yet



Frequentiebereik					
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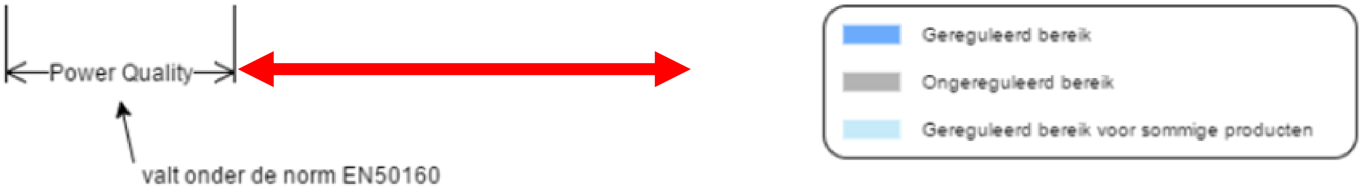
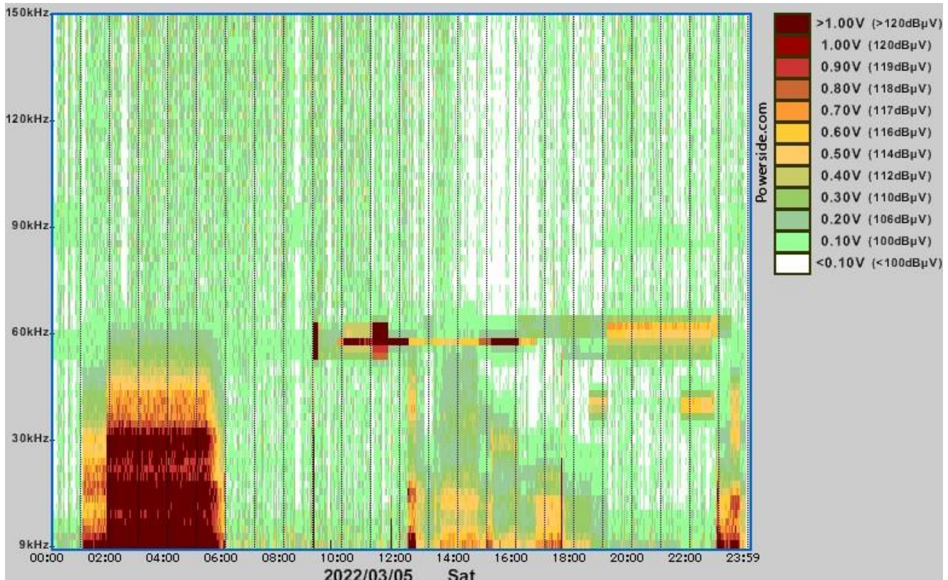


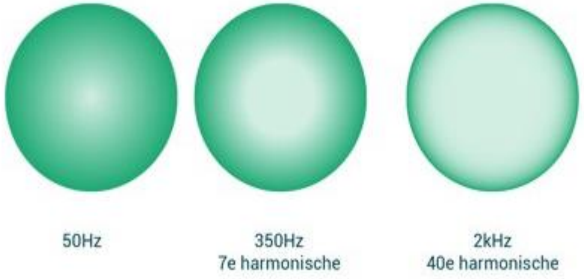


Impact

- Audible noise; high pitch noises from devices like induction cooking plates
- loss of functionality of electronic devices
- flickering lights
- Metering issues
- Impacting behaviour of RCDs
- Reduced lifespan of equipment and grid assets due to emission absorption
- Skin effect; higher frequencies travel on the edges of the conductor; increase heat loss





EV SHs emissions

First analysis in 2018;
8/9 most common Battery Electric Vehicles in NL are a source of supraharmonic currents

Vehicle	Suspected switching frequency(ies) (kHz)	Magnitude (mA)
BEV-A	10	**1080**
BEV-B	45 (15)	**199**
BEV-C	60 (30, 15)	57
*BEV-D	16	28
BEV-E	45	78
BEV-F	-	-
BEV-G	10	49
BEV-H	35	27
*BEV-I	16	27

Red: Within human hearing range (20 Hz – 20 kHz)

* Different vehicles, same OBC

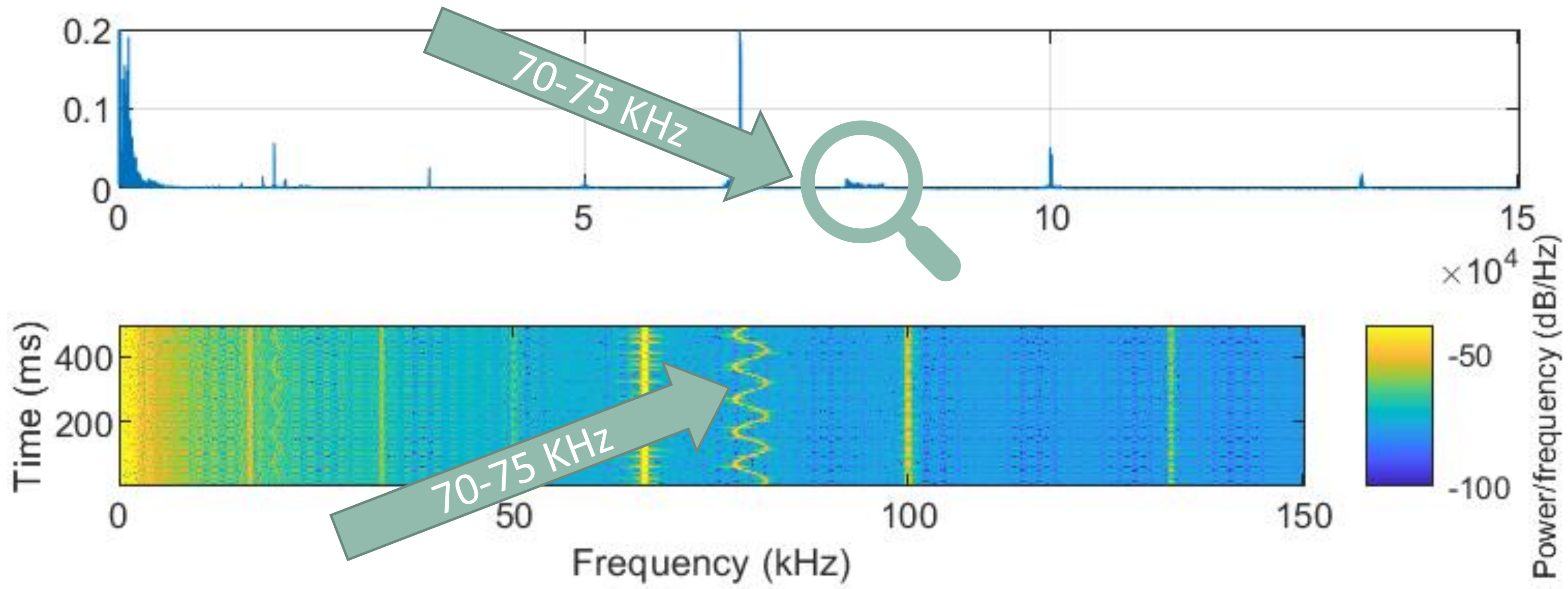
Source: Slangen, T. (2018), Potential Impact of Electric Vehicles on the Power Quality in the Low-Voltage Grid

Example SH emissions

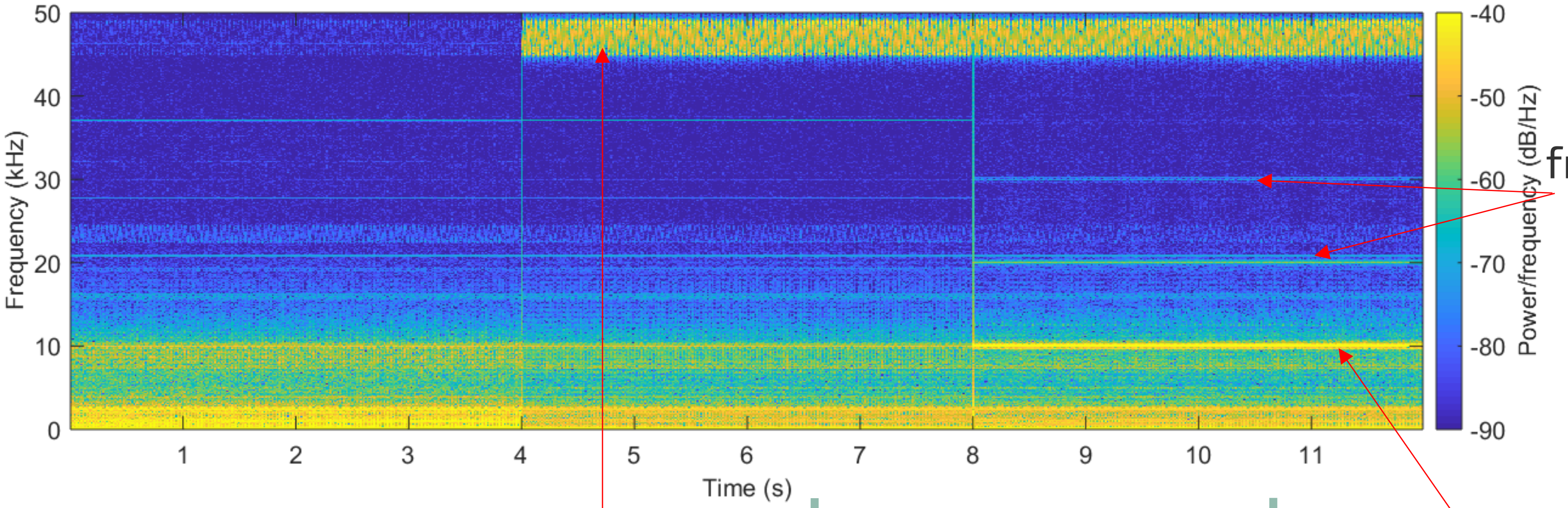
Most emissions at a single frequency, but some EVs have a time-varying broadband emission

In FFT not visible

But visible in time-frequency domain



Example SH emissions



Reflections from the 10 kHz distortion

Broadband distortion 45-50 kHz at lower charging speed

EV2 has a distortion at 10 kHz

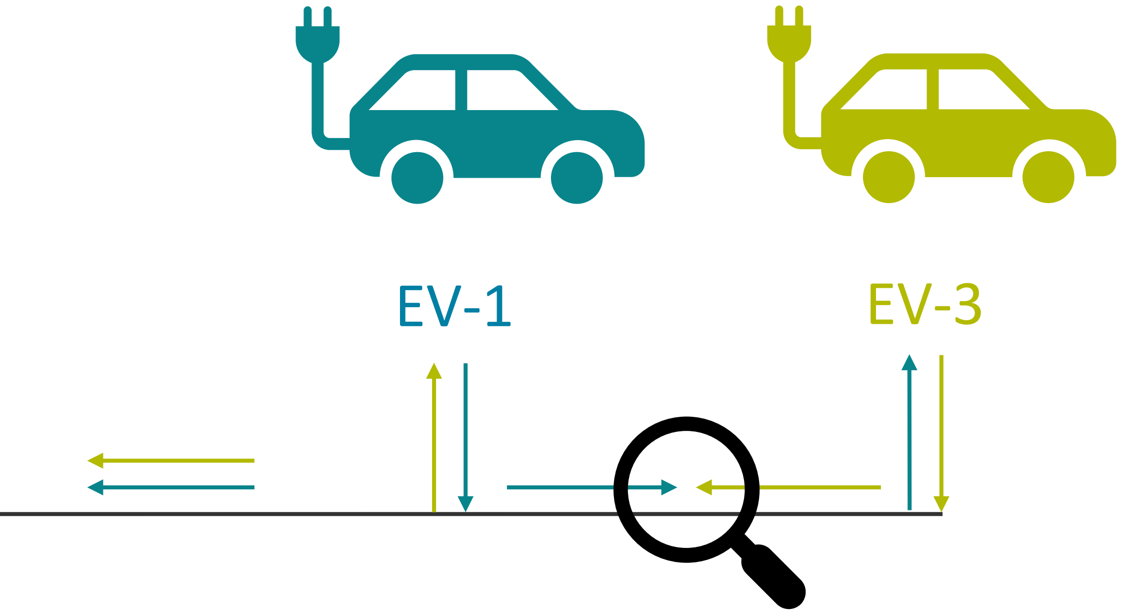
Smart charging

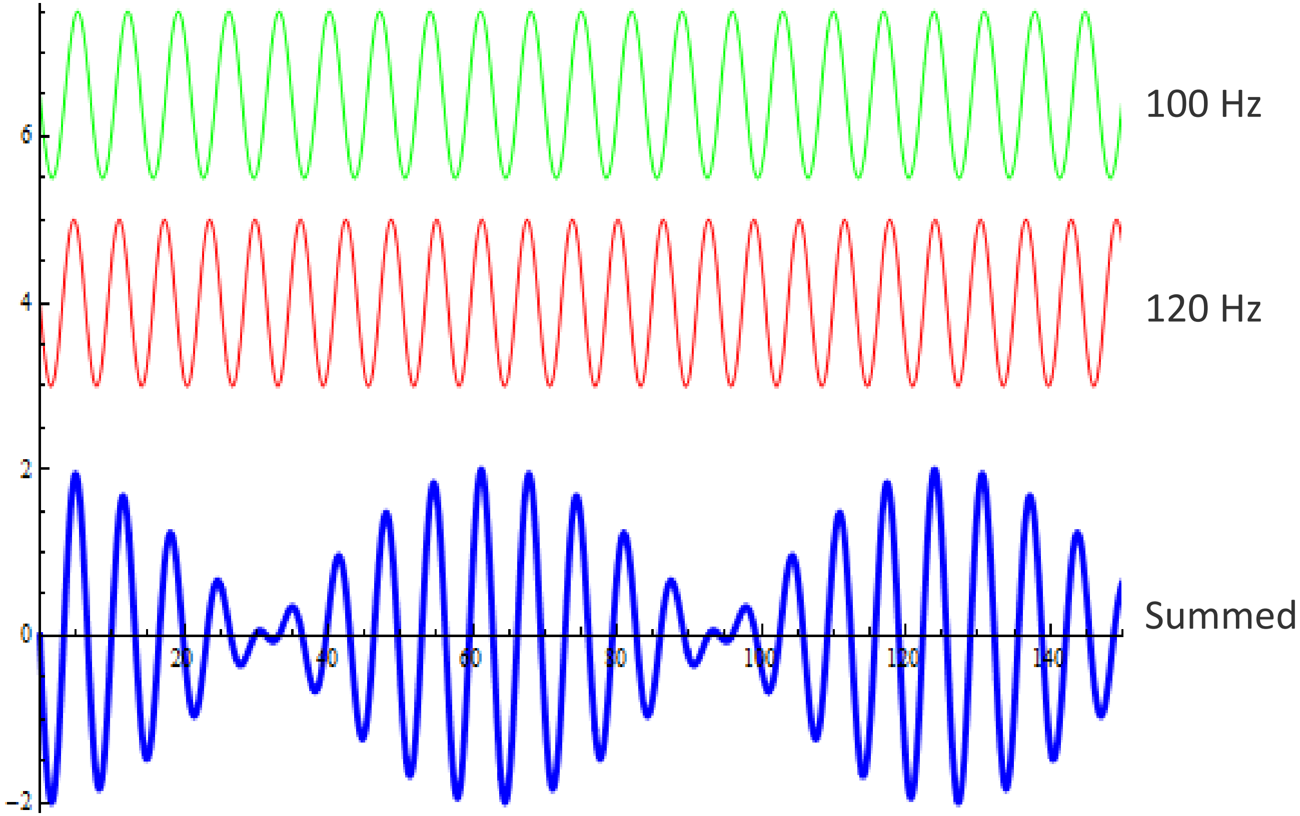
Example SH interactions

Video of total emissions from multiple EVs of same type

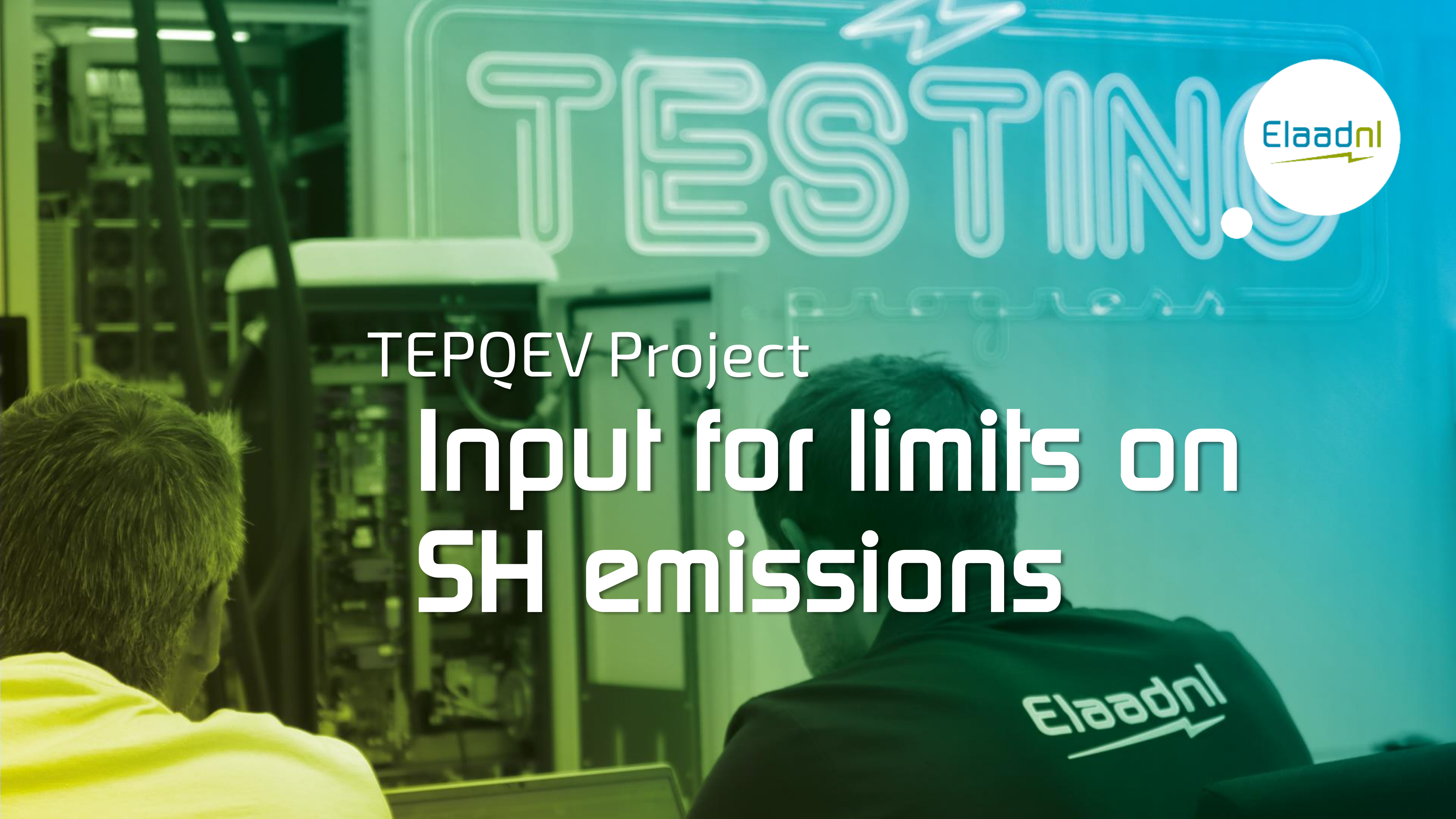
Example SH interactions

Frequency beating





Animated example



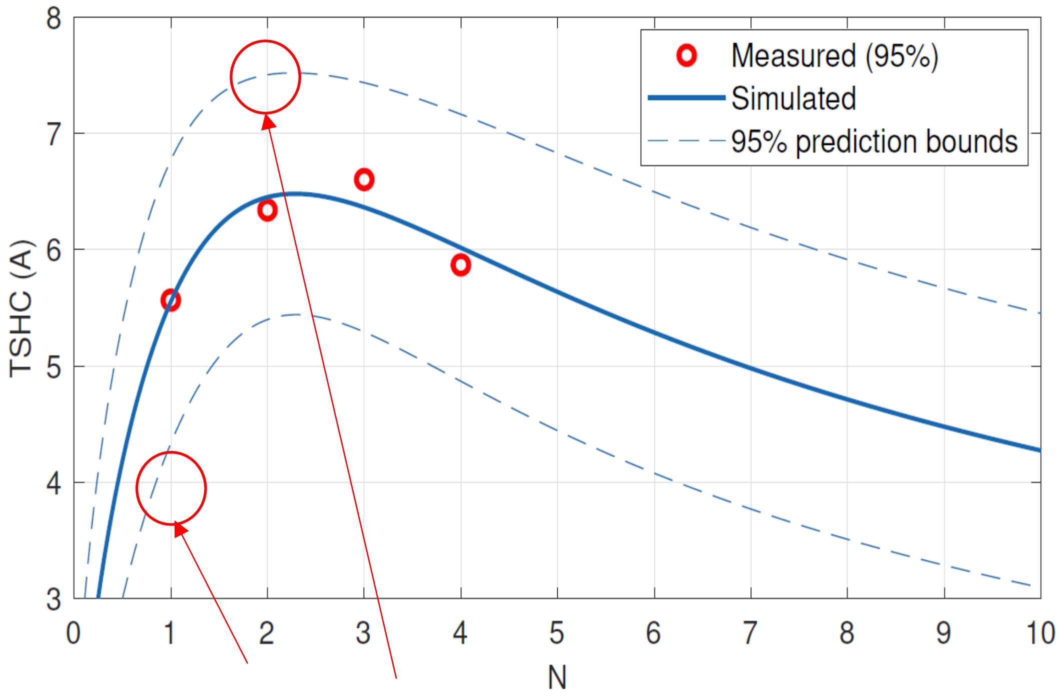
TEPQEV Project

Input for limits on SH emissions

Summation of SHs

Based on Measurements on DC chargers and simulations for up to 10 active chargers

- SH summation is not linear
- Emission to grid might even decline when more devices are connected due to absorption by the EMC filters of these
- When multiple devices are connected to a single grid connection, the Supraharmonic distortions tend to add up at first, and then start to decline.
- Using the TSHC graph per number of devices from the research, while taking the opposite 95% prediction bounds for 1 vehicle and 2 vehicles, we can see the TSHC can roughly double



lower TSHC at 1 device is 4A, upper TSHC at 2 devices about 8A

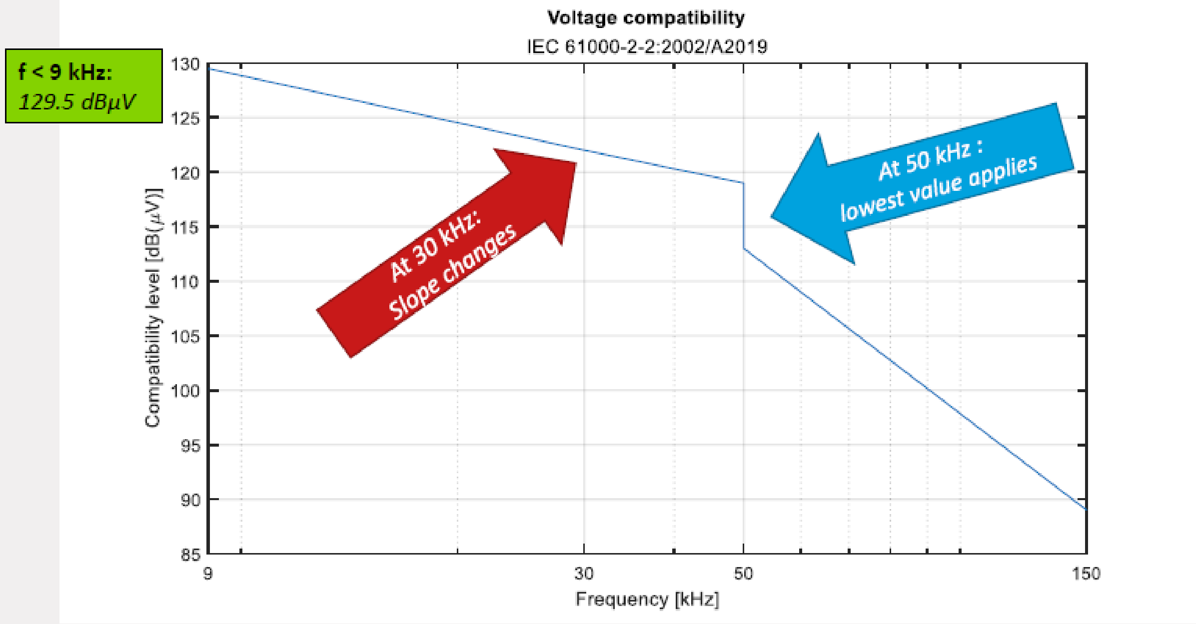
Source: Slangen, T., Cuk, V., & Cobben, S. (2023). Summation of supraharmonic currents (2–150 kHz) from EV fast charging stations.

SH Voltage compatibility

SH Voltage compatibility levels have been set in IEC 61000-2-2.

Voltage compatibility 2-150 kHz

Separate definitions for 2-9, 9-30, 30-50 and 50-150 kHz



$V[V] = 10^{(V[dB\mu V]-120)/20}$

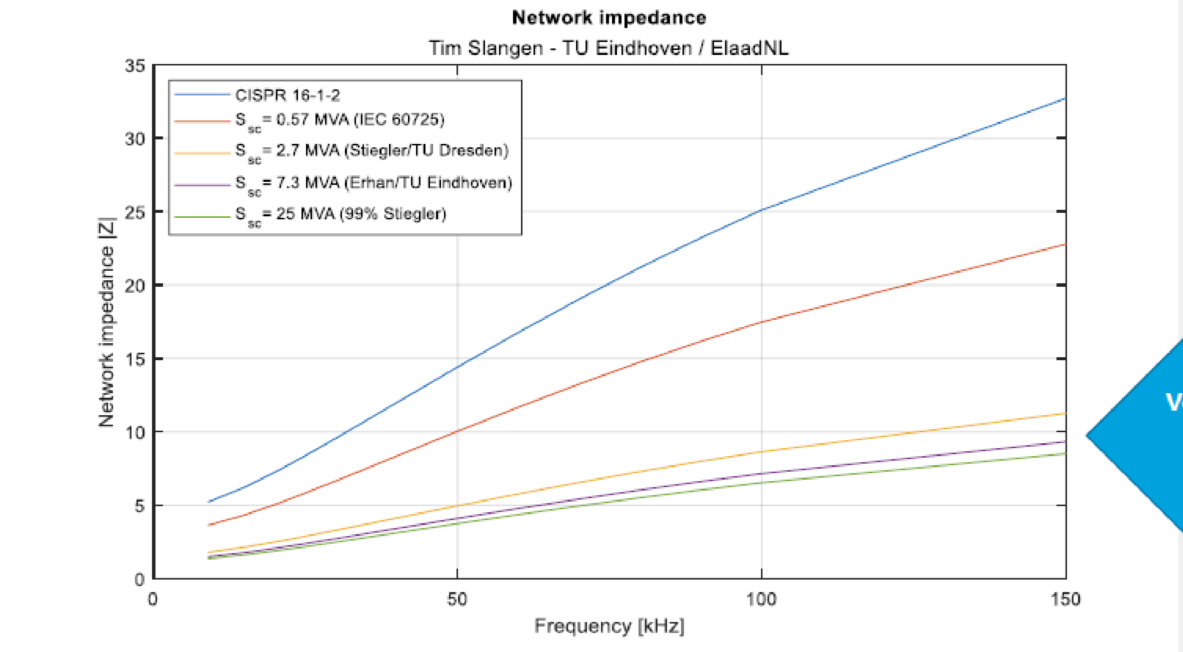
dBuV	V
129.5	3.0
120	1.0
100	0.1
85	0.02

Grid impedance 9-150kHz

To see what this means for the emission limits first the grid impedance for 9-150 kHz is needed

Impedance characteristic 9-150 kHz

CISPR and Scaled-CISPR (Stiegler method) for different Ssc values from practice

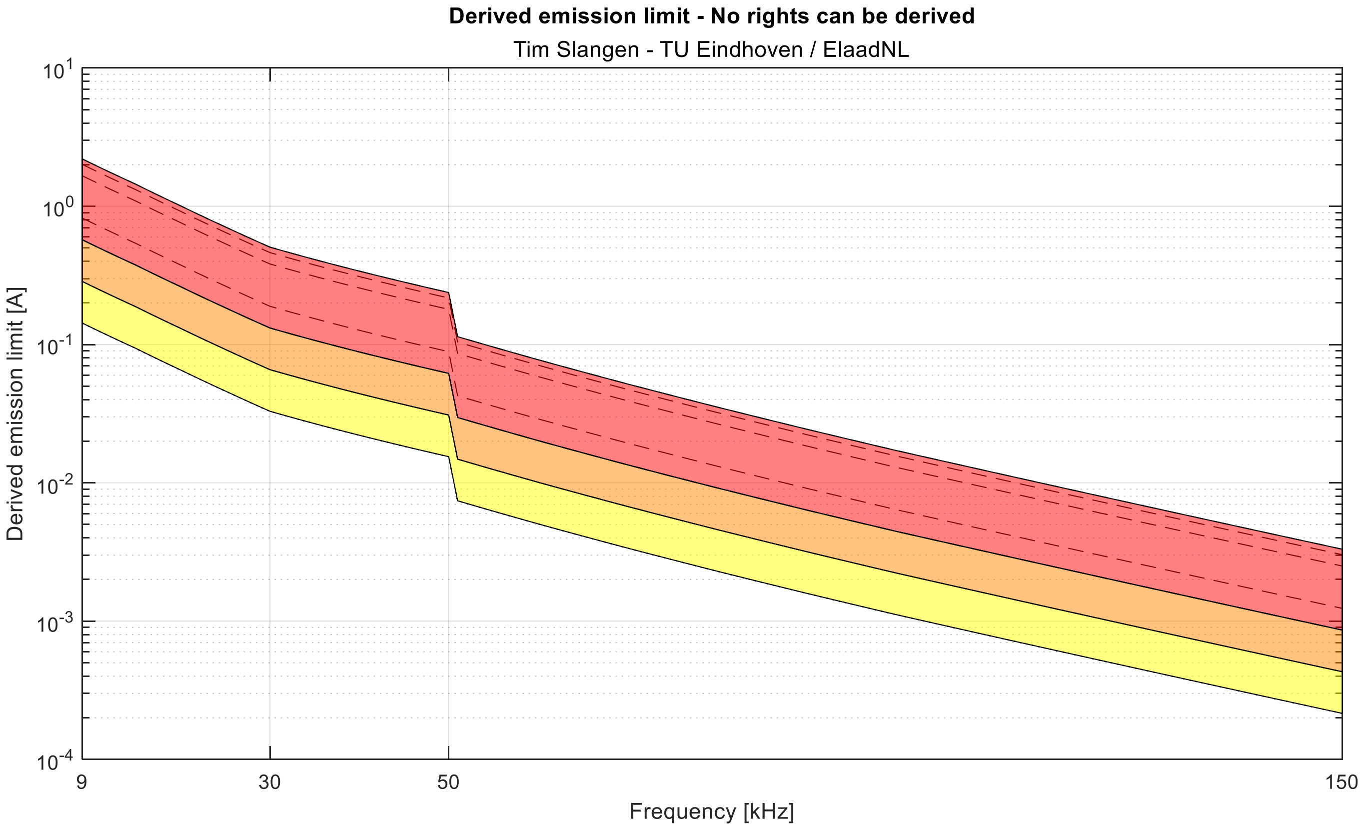


Verified by field measurements
TU Dresden (2019) /
TU Eindhoven (2022)

Grid impedance much lower for higher frequencies than defined in standards like the CISPR 16-1-2

Supraharmonic limits

Using the voltage compatibility levels and the measured grid impedance, combined with data on how distortion from multiple sources adds up (roughly times 2), results in the emission limits below



Preliminary results from TEPQEV project, more information on the ELaadNL website;

https://elaad.nl/en/projects/tepqev/

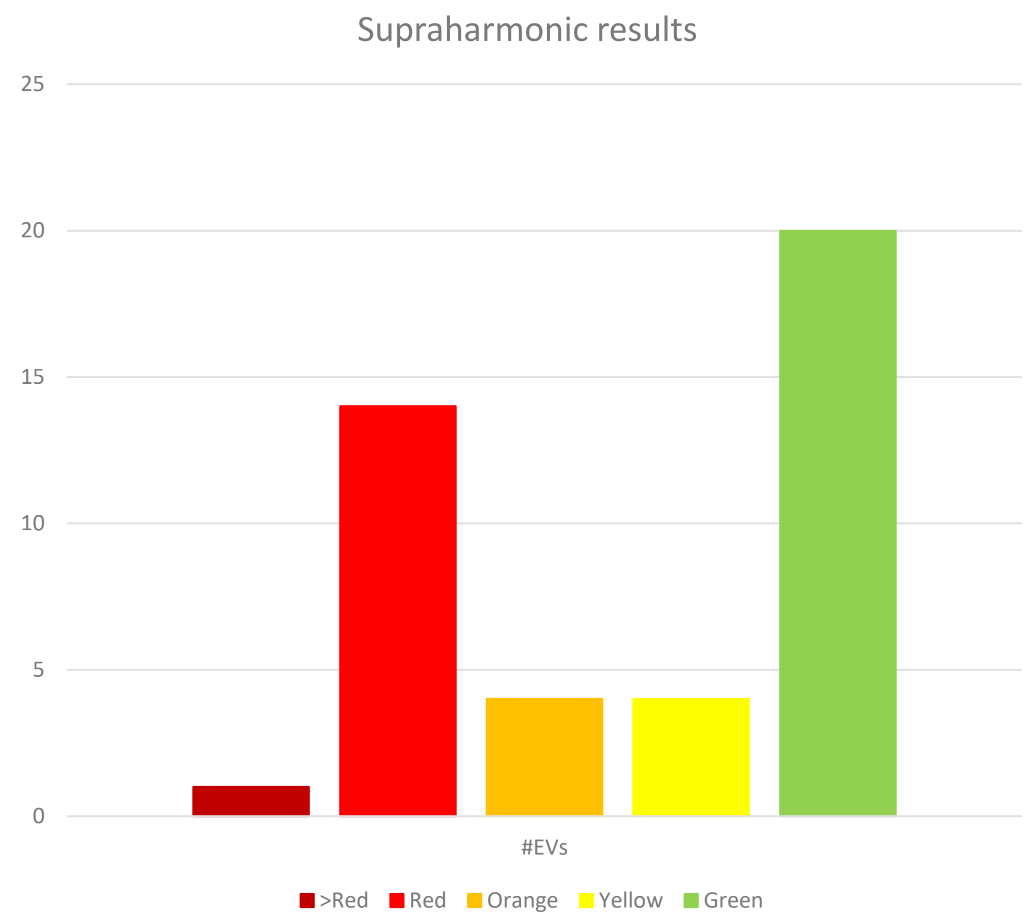
EV SH analysis

Method:

- Total number of EVs; 43
- Just observable peaks in the FFT have been measured
- The highest peak found at any charging speed was used
- No special treatment for broadband distortions

Results:

- 20 EVs seem OK, 23 seem to be in one of the limit ranges
- 14 EVs in the “red range”, even one above that range
- Moment of highest peak differ per EV; at max charging current, min charging current, 1 phase, 3 phase.



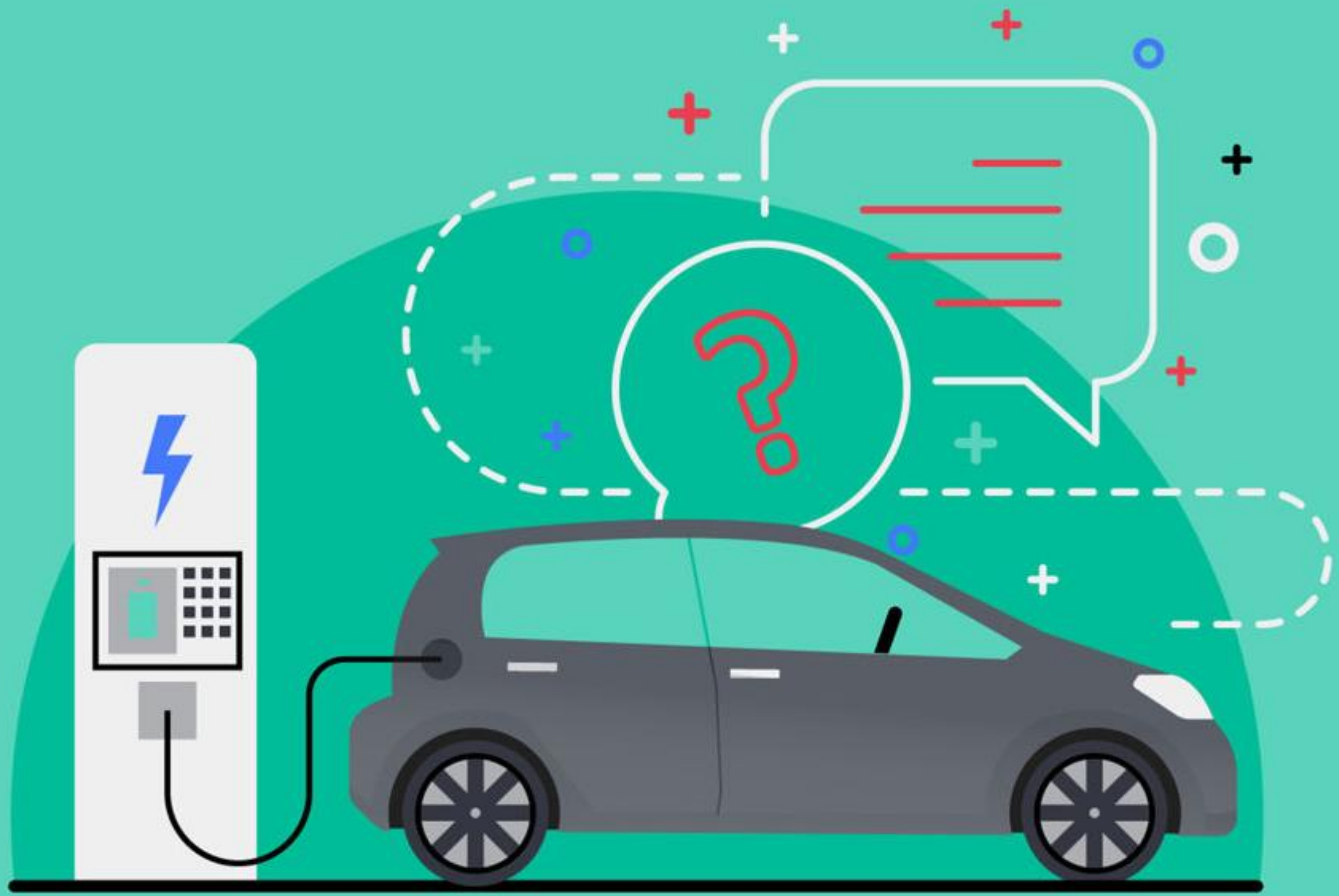
Conclusion Supraharmonic

Conclusion:

- The analysis shows EVs can be a high source of Supraharmonics
- But also, that it is possible to stay below the lowest limit!

Recommendations:

- A standard and certification is needed to get all into the green zone
- The suggested limits seem to be a good starting point
- The measurement method should include;
  - ✓ Testing at different charging speeds,
  - ✓ at 1 phase charging and 3 phase charging, and
  - ✓ include broadband emissions, f.i. via time-frequency domain analysis or using frequency bins



Thanks for your attention!

Any questions?

Power Quality in a time of great transitions

FEBRUARY 4, 2025

Prof. dr. ir. Sjef Cobben

Department of Electrical Engineering, Electrical Energy Systems

EINDHOVEN UNIVERSITY OF TECHNOLOGY

25 years ago…

Brussel dringt aan op liberalisering

Na in maart mandaat te hebben gekregen van de Lisbon European Council om de voorstellen voor versnelling van de liberalisering van de Europese energiemarkt uit te werken, nodigt de Europese

TOYOTA PRIUS (2000) - TEST

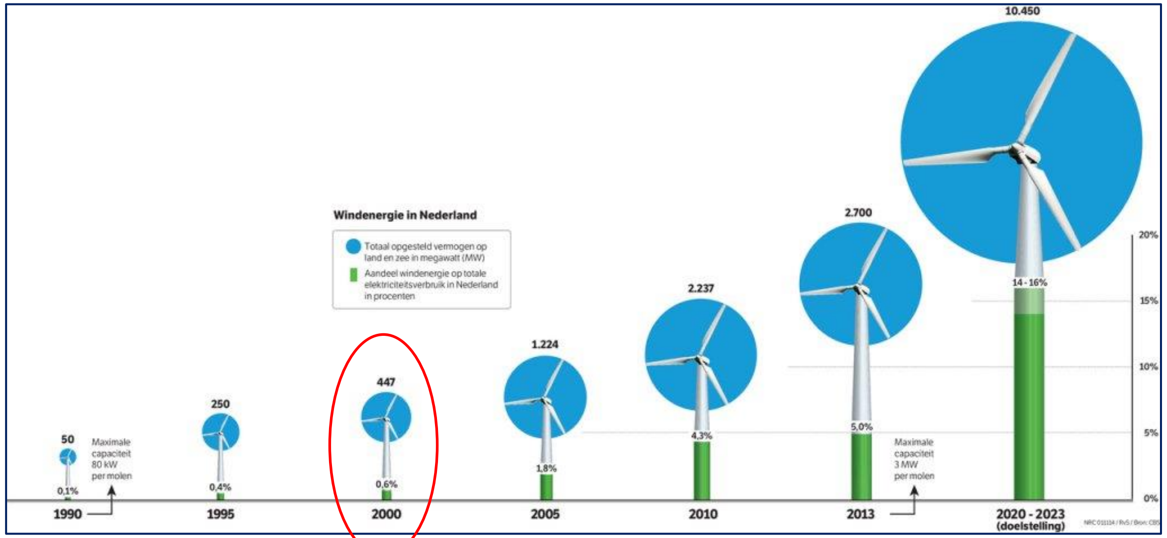
LICHTGROEN

PETER FOKKER | EERSTE RIJTEST

10 oktober 2000 om 00:00

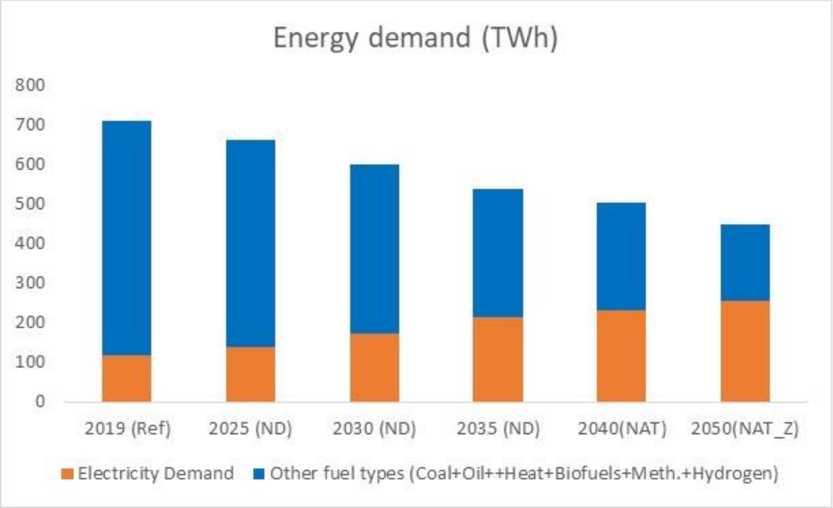
De subsidieverlening zal plaatsvinden via de Regeling energiepremies. Huiseigenaren kunnen daarbij via hun energiebedrijf de subsidie krijgen. Het subsidiebedrag zal liggen tussen de 500 en 750 gulden per zonnepaneel. Op dit moment kost een zonnepaneel van 100 W piekvermogen nog ongeveer 1500 gulden. Als blijkt dat subsidies en prestatieafspraken onvoldoende resultaat opleveren, zal worden bekeken of de toepassing van zonne-energiesystemen opgenomen moet worden in de bouwregelgeving, aldus de bewindslieden.

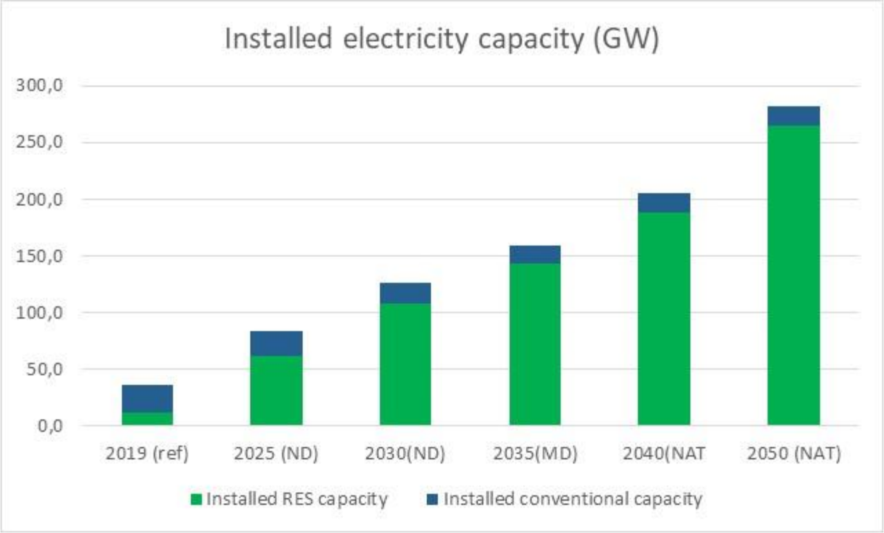
Subsidie voor PV moet marktconforme doorbraak stimuleren (foto Aris Homan)



TU/e

25 years from now…

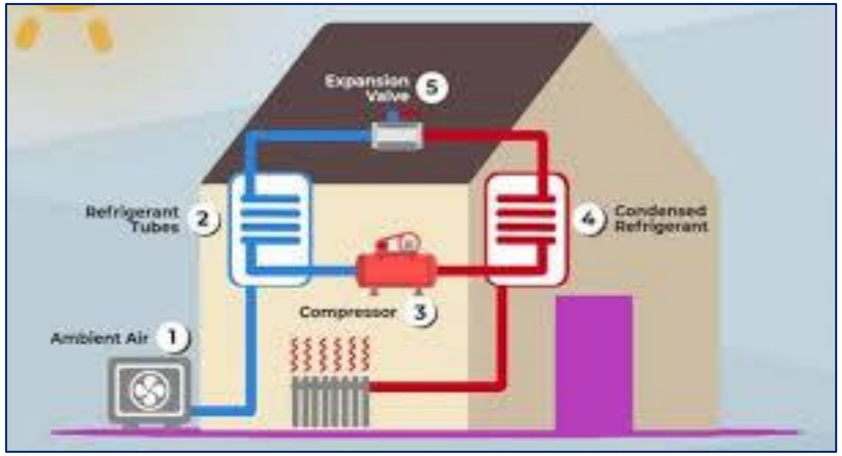




(Netbeheer Nederland Integrale energiesysteemverkenning 2030-2050)

Changes: generation of energy

Changes: more and different types of connections



- More flexible loads
- More storage devices
- More power electronics
- Electric boilers
- Heat pumps and EV
- More disturbing loads
- More sensitive loads

(Extra) High voltage networks: transmission system

Used for the bulk transfer of power

Characteristics

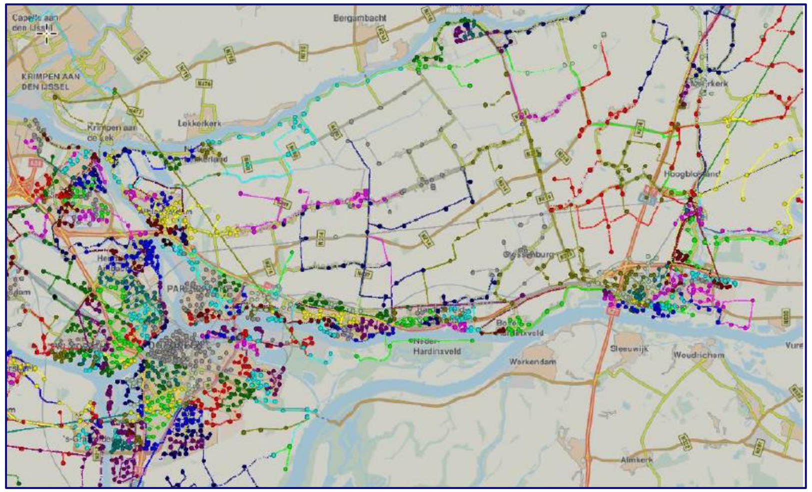
- EHV (220kV, 380kV)
  - Mostly overhead lines (OHL)
  - International connections

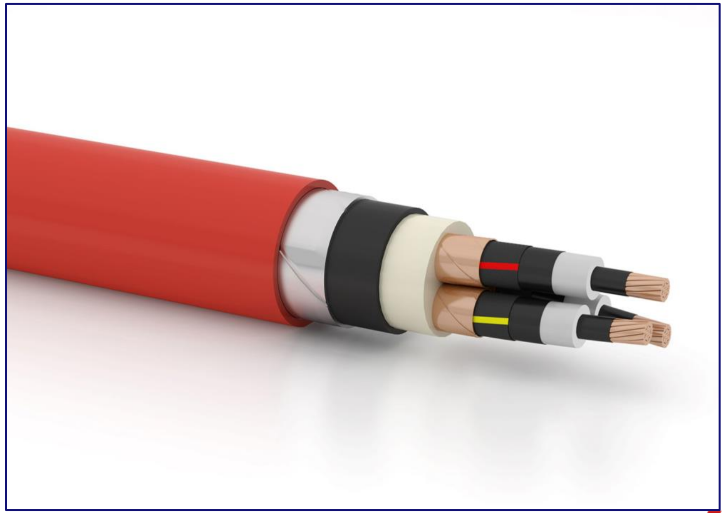
  (UK, Denmark, Norway(HVDC) Belgium, Germany (50Hz AC)
- HV (110kV, 150kV)
  - Overhead lines and new branches mostly undergr cables
- Including offshore
- Approx. 500 HV/MV substations

TU/e

Distribution networks

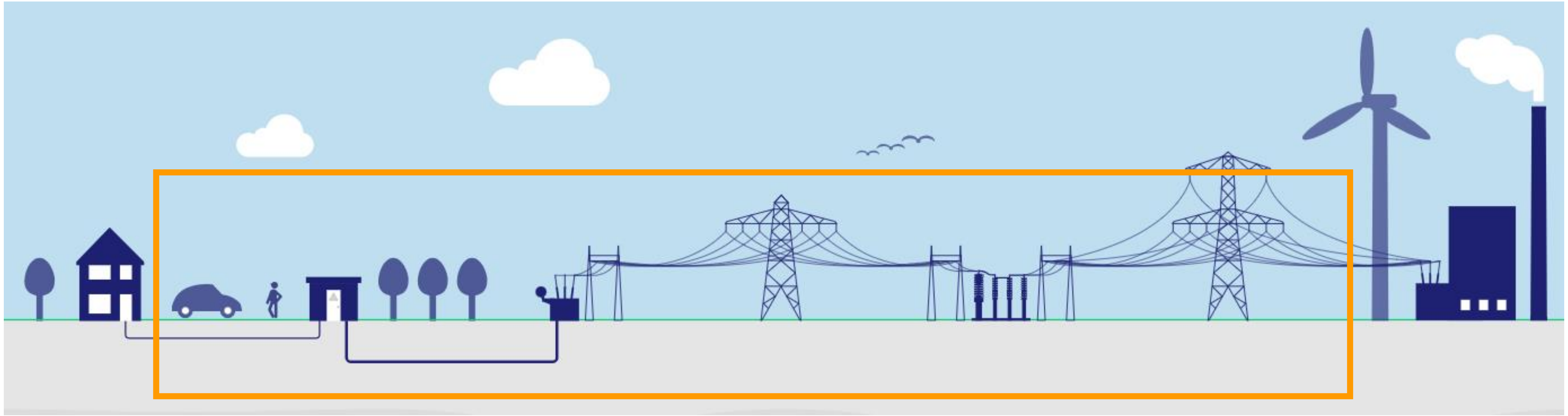
- Delivery and distribution of electricity to end users
- MV and LV networks cabled
- Approx. 200.000 MV/LV substations



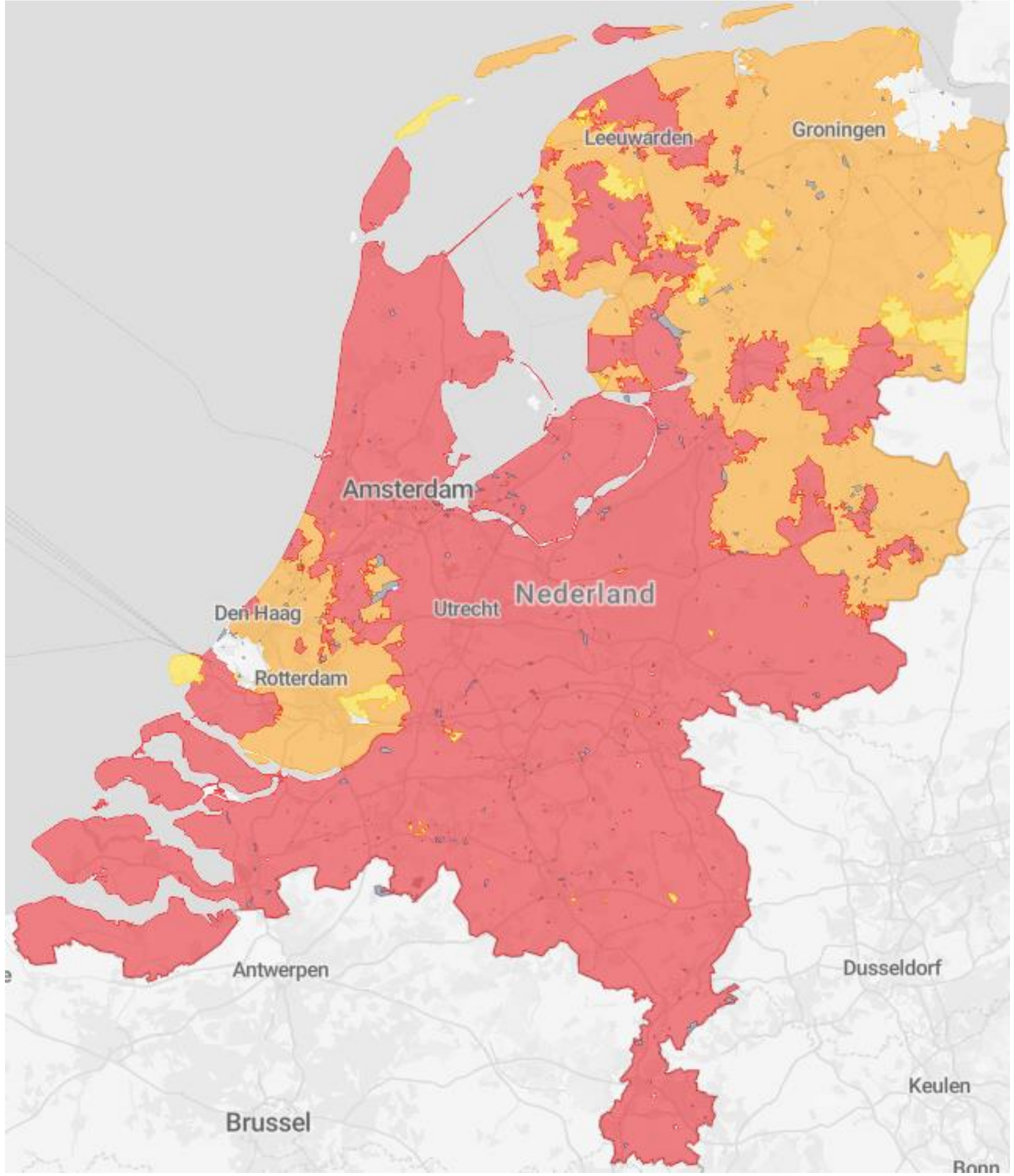


25 years from now…

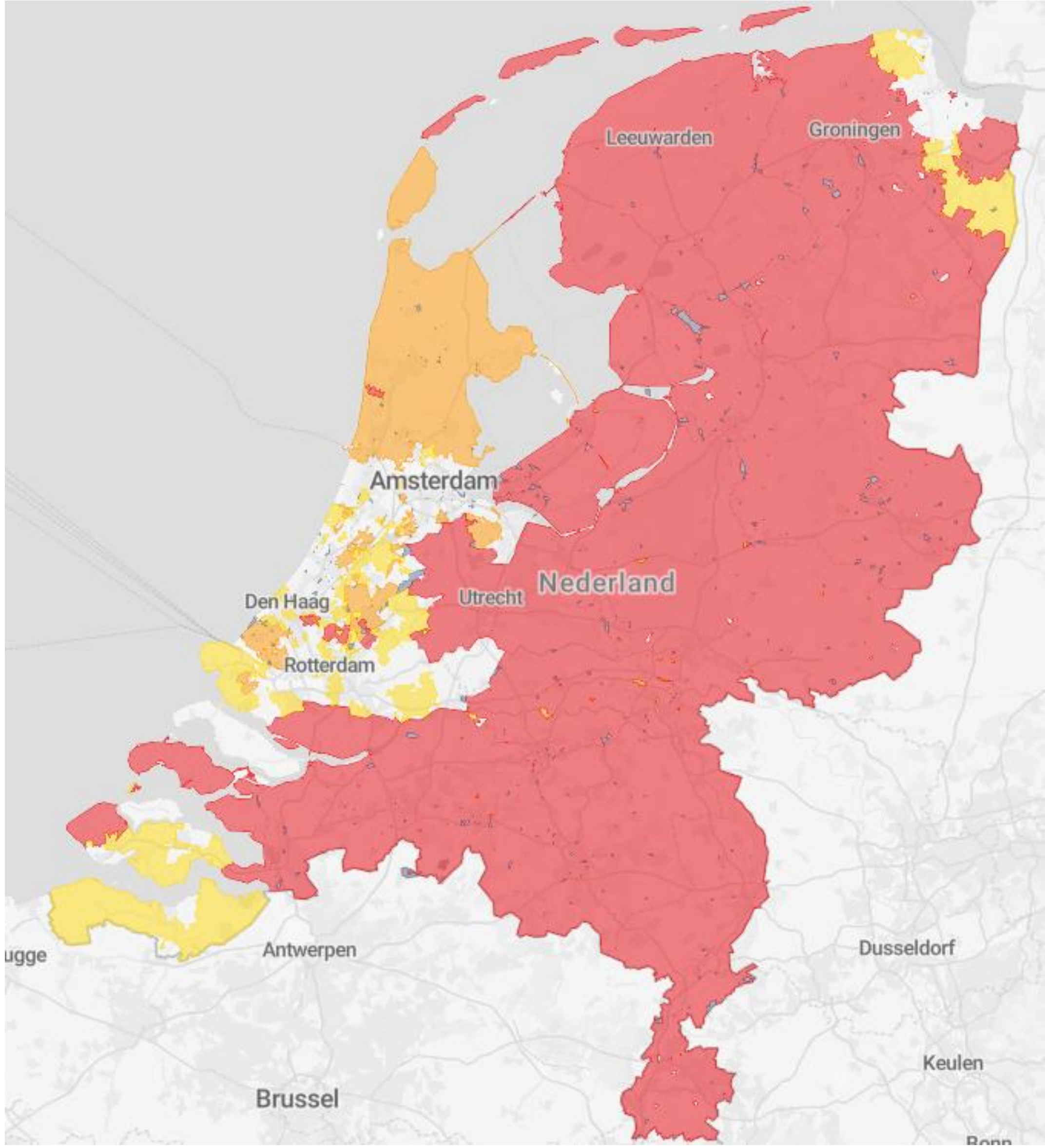
Electricity grid



Load

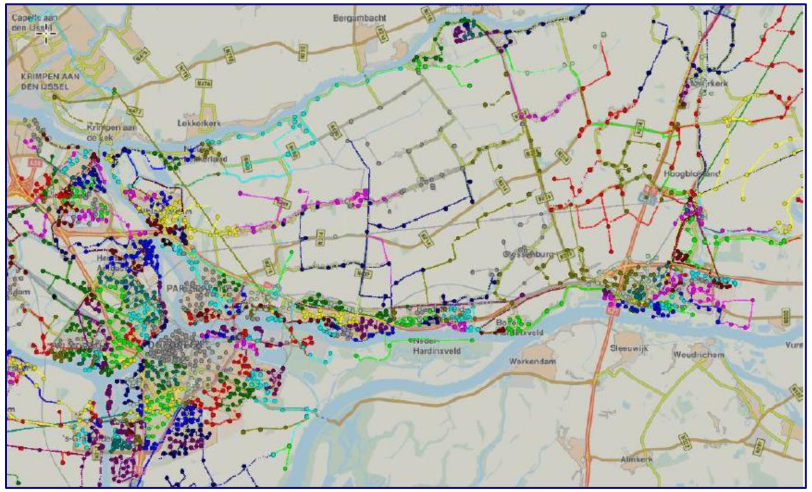


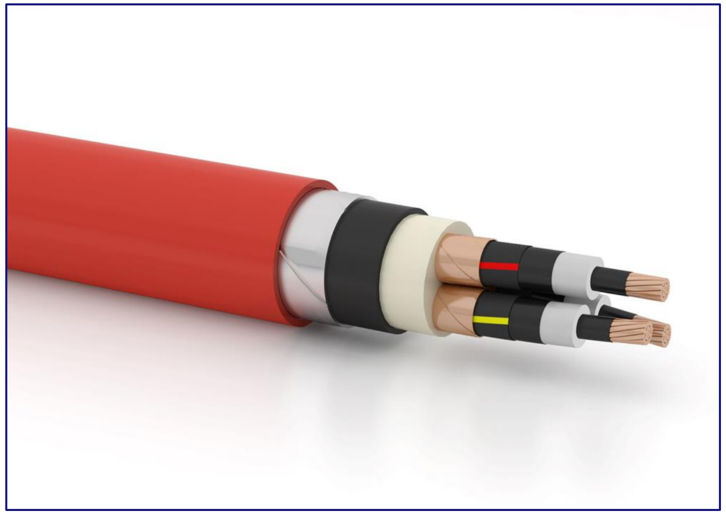
Production

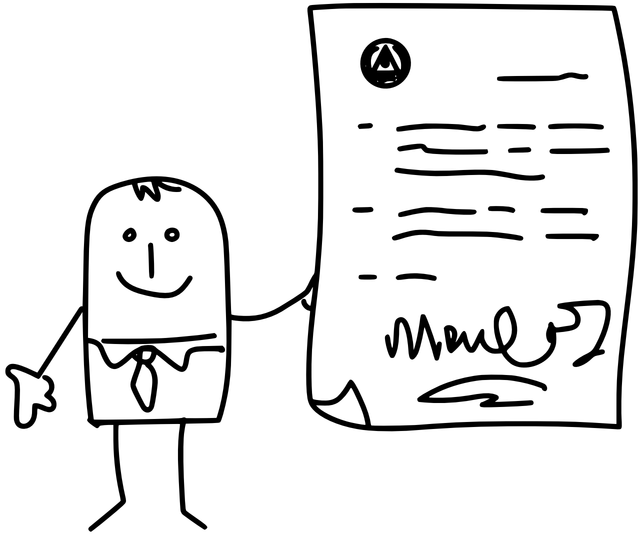


TU/e

Changes: increased usage of cables/transformers/lines/flexibility….



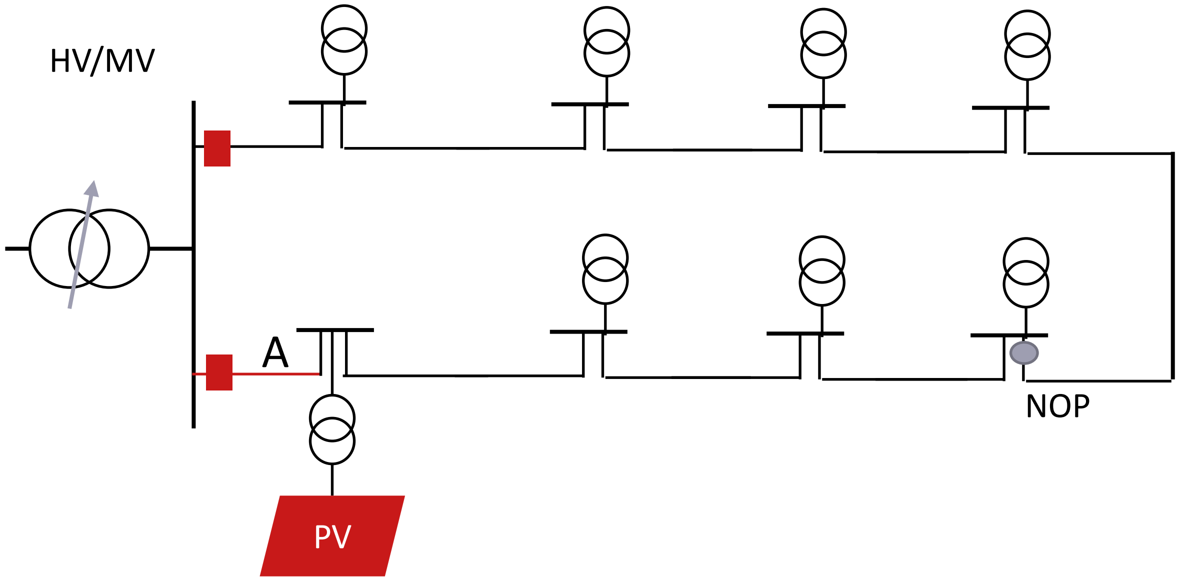




Flexibility in contracts

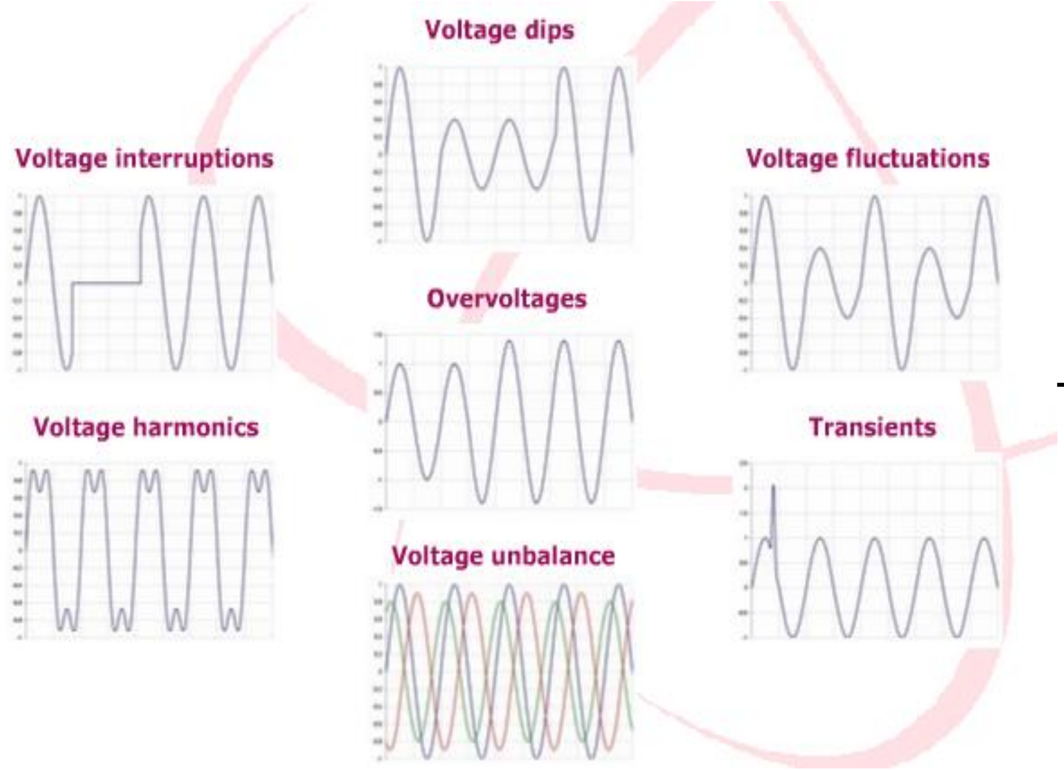
More flexibility in regulation

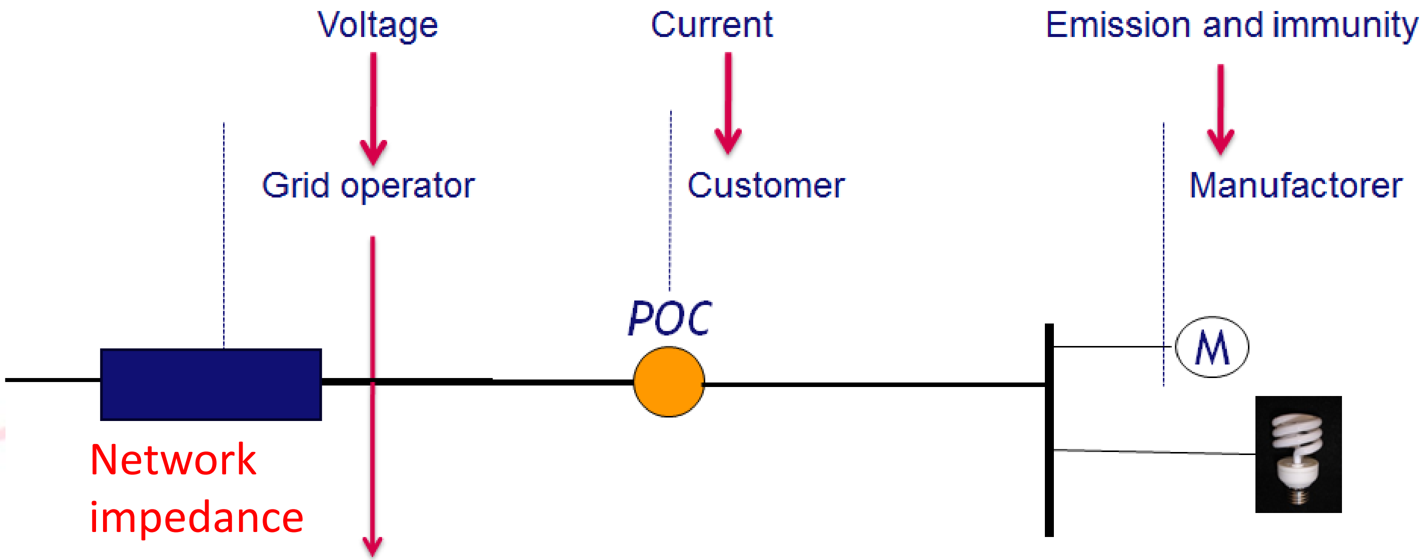
Not always using N-1



PV close to substation (no voltage problem)
Disconnect when cable A is out of order

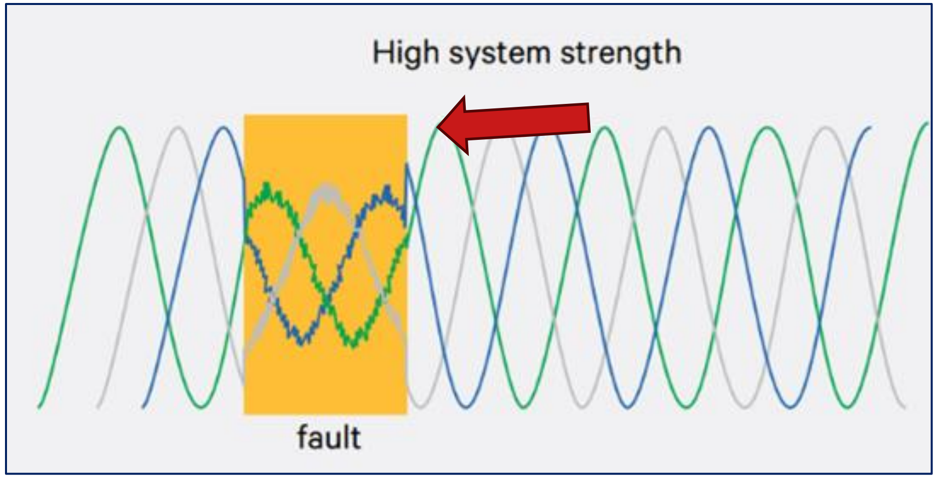
Power Quality: Phenomena and Responsibilities

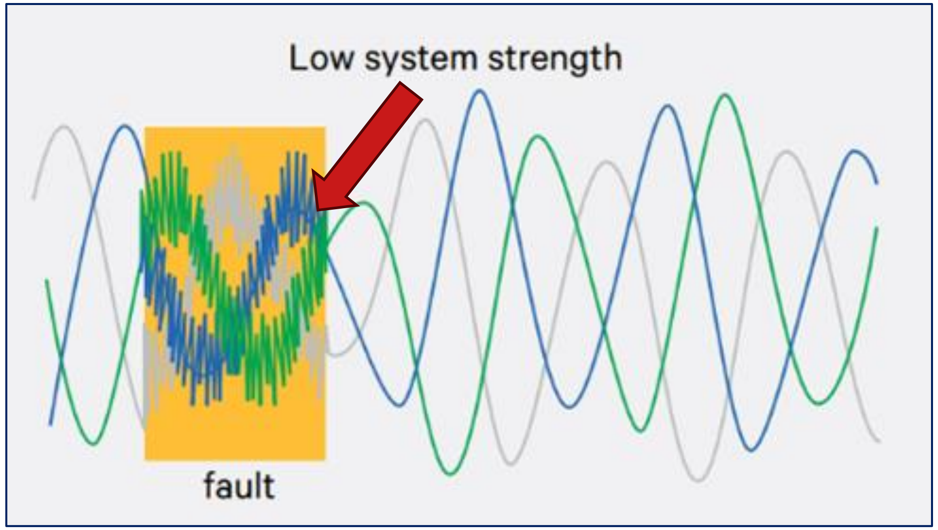




Voltage level
Fast voltage variations (dips, flicker)
Unbalance
Harmonics
……

Changes in the system may result in a lower System Strength



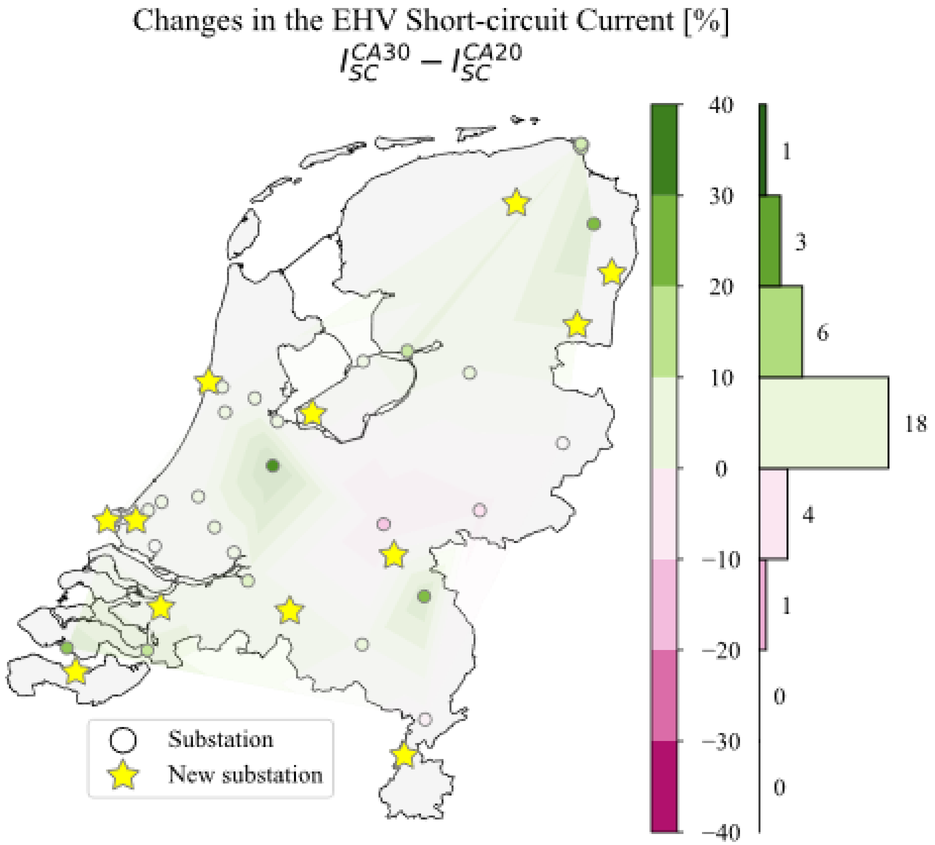


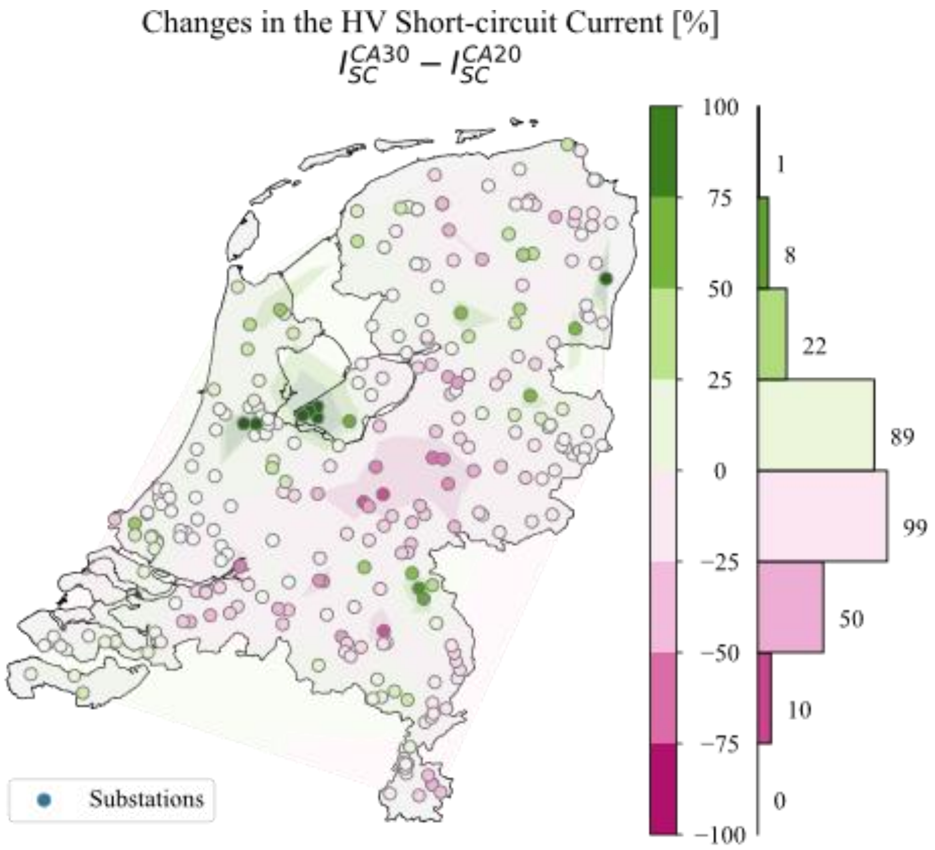
What is an acceptable network impedance?

Impedance sweep in frequency domain?

What is the impedance in emergency situation?

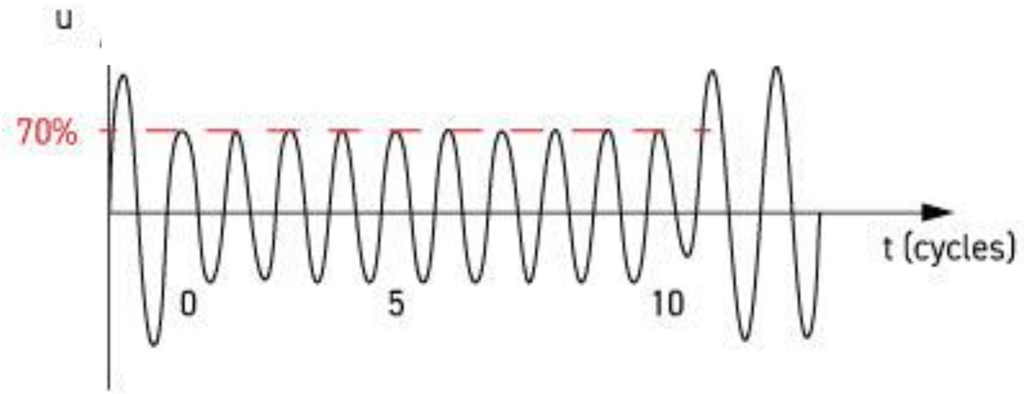
How to quantify the impact of the changes?





(R. Torkzadeh, G Mulder)

Voltage dips



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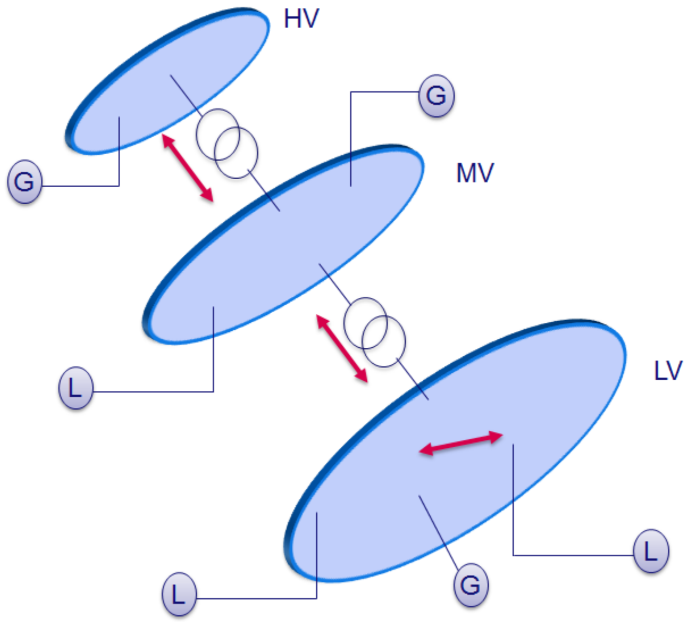
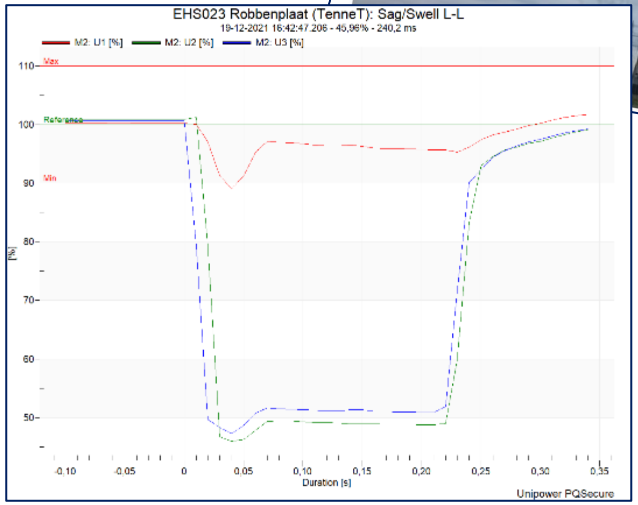
<tr><th rowspan="2">RESIDUAL VOLTAGE (p.u.)</th><th colspan="4">DURATION (ms)</th></tr>
<tr><th>10 to 200</th><th>200 to 500</th><th>500 to 1000</th><th>1000 to 5000</th></tr>
<tr><td>0.80≤U<0.90</td><td colspan="4">Class A</td></tr>
<tr><td>0.70≤U<0.80</td><td></td><td></td><td colspan="2" rowspan="4">Class C
(MV:4/(E)HV:0.4)</td></tr>
<tr><td>0.40≤U<0.70</td><td></td><td rowspan="3">Class B2
(MV:4/(E)HV:1.2)</td></tr>
<tr><td>0.05≤U<0.40</td><td rowspan="2">Class B1
(MV:3/(E)HV:1.2)</td></tr>
<tr><td>0.01≤U<0.05</td></tr>
</table>

Voltage dips

- Event on 19-12-2021 in the 220kV grid
- Led to disconnection of both generators and load at various voltage levels

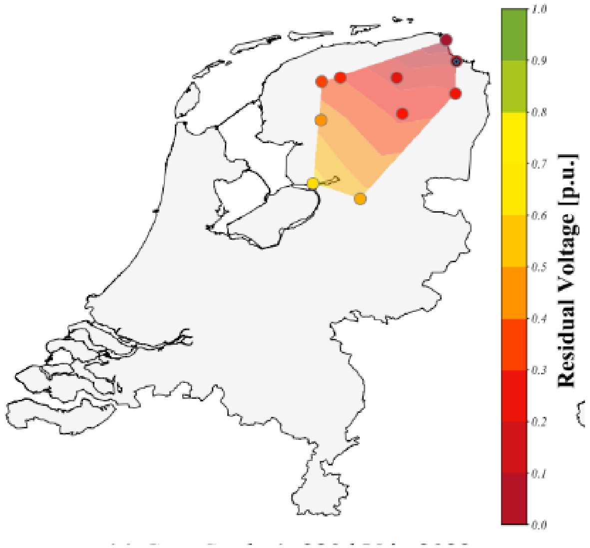


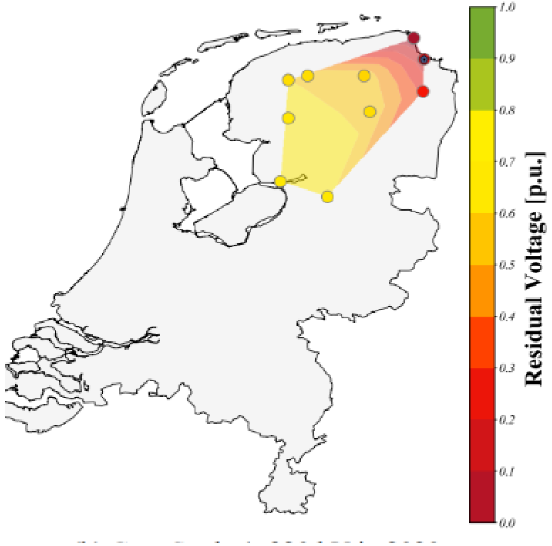


Voltage dips

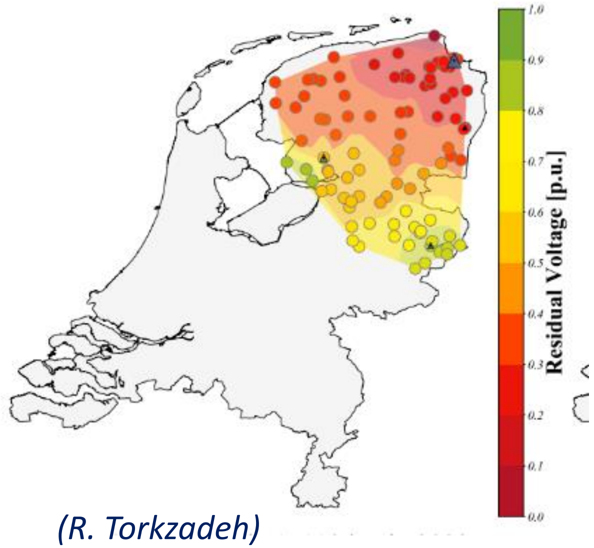
2020 | 2030

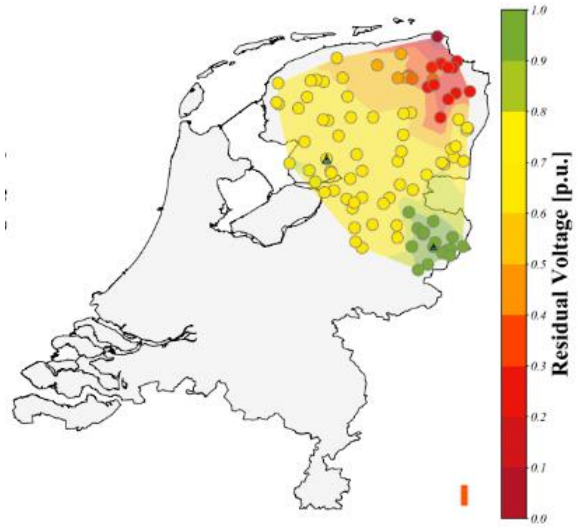
220kV





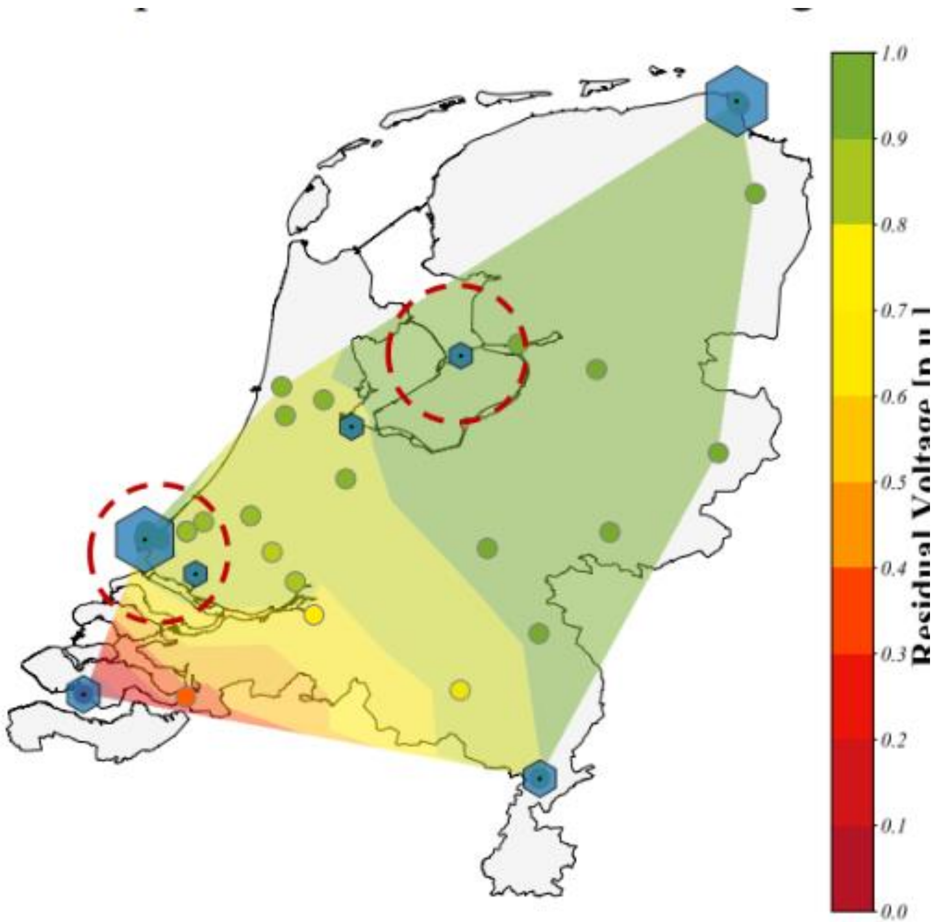
110kV



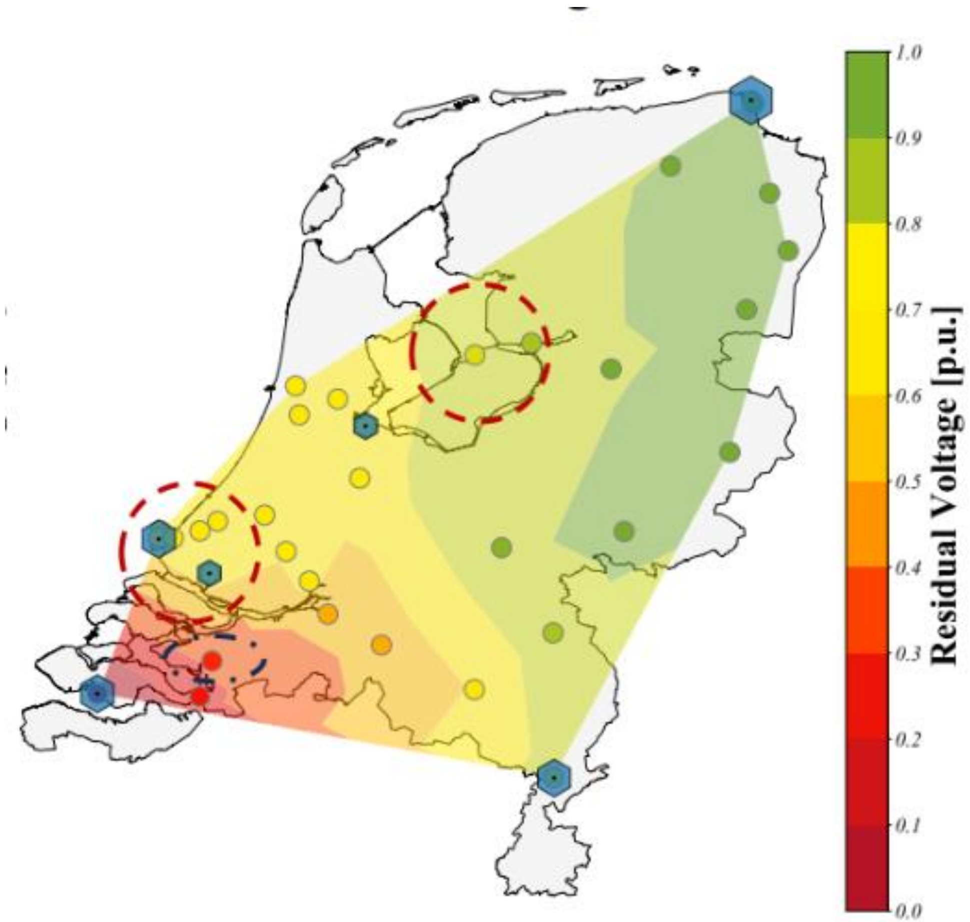


(R. Torkzadeh)

Voltage dips



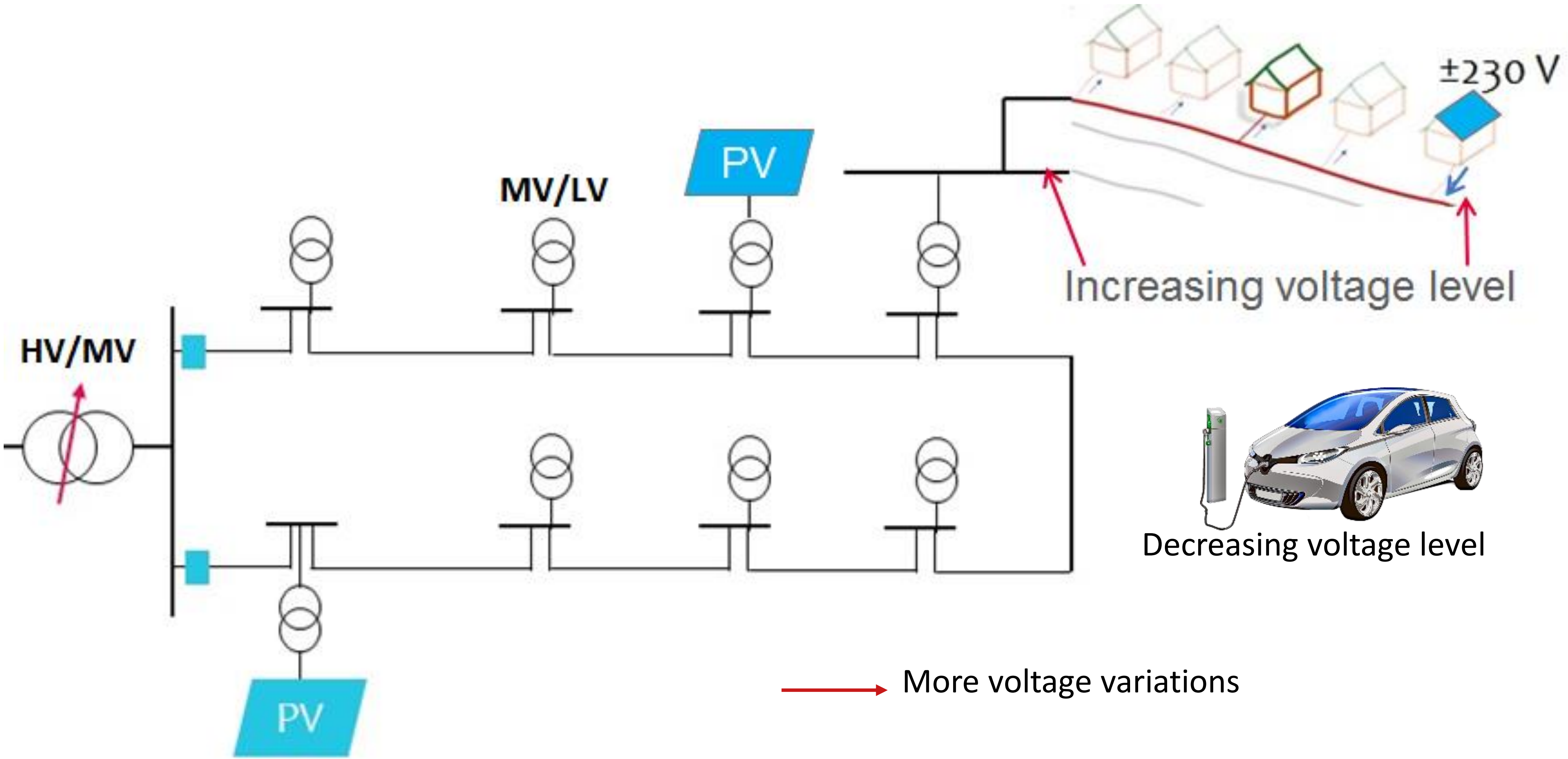
(a) Case Study 2, 380 kV in 2022



(b) Case Study 2, 380 kV in 2030

(R. Torkzadeh)

The impact of DG/EV on voltage level (MV and LV-level)



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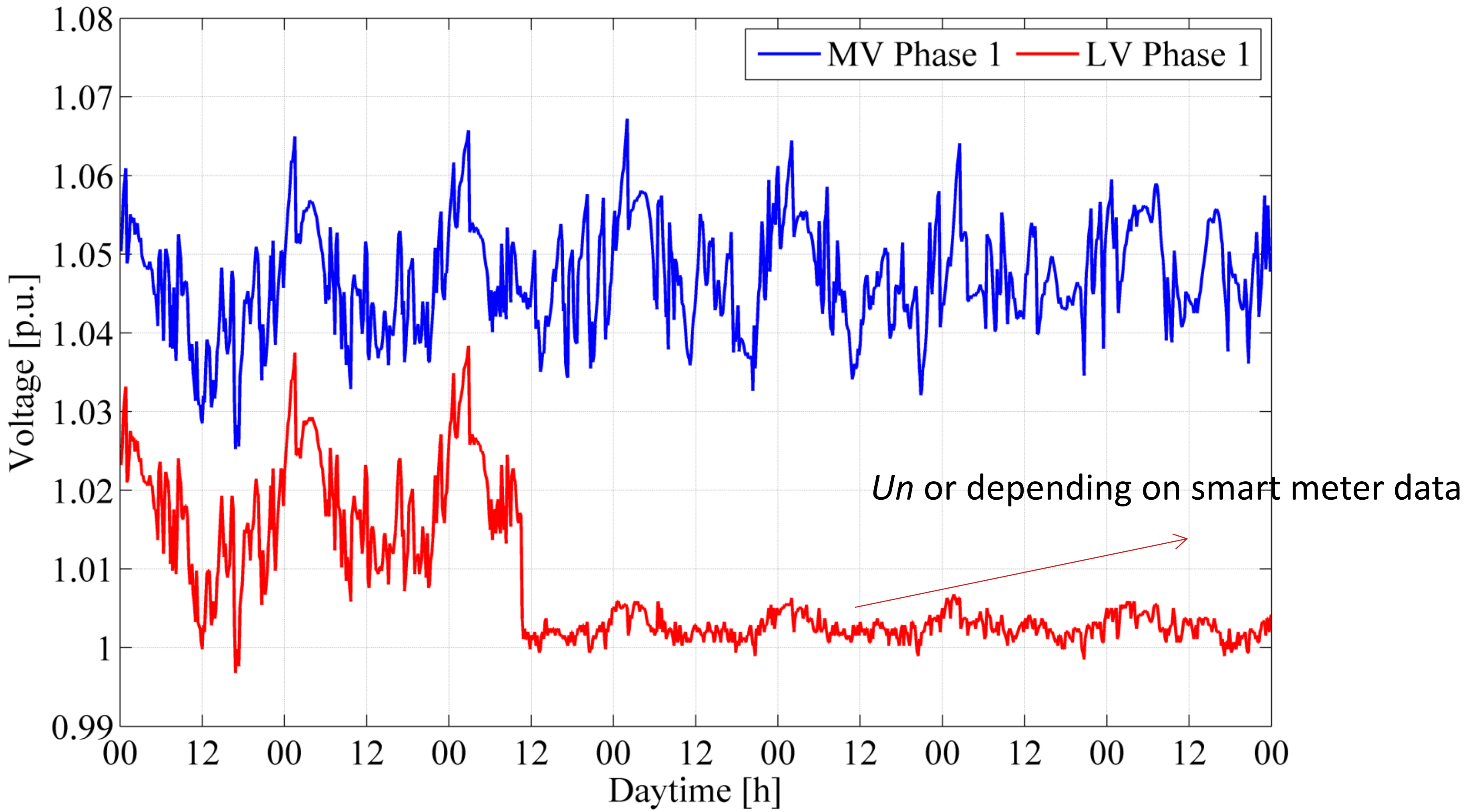
The biggest problem for the DSO at the moment

17-05-2022

Zonnepanelen vallen bij 75.000 eigenaren uit tijdens volle zon

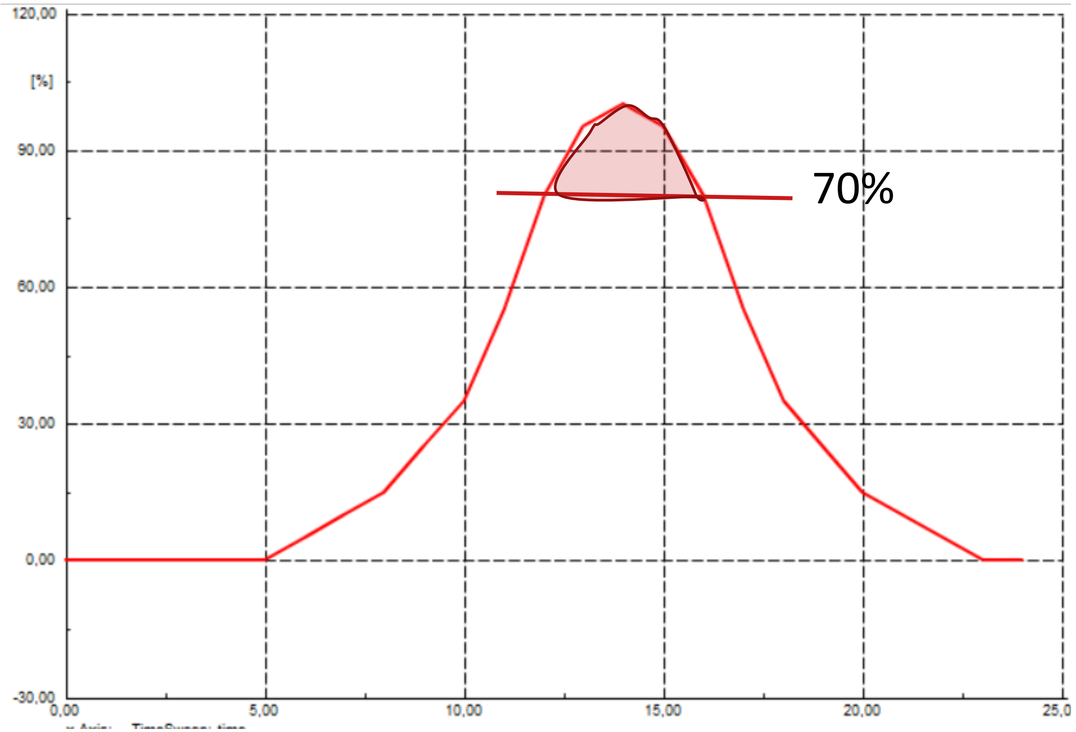
3 min. leestijd Delen

Possible solutions (1): The smart transformer

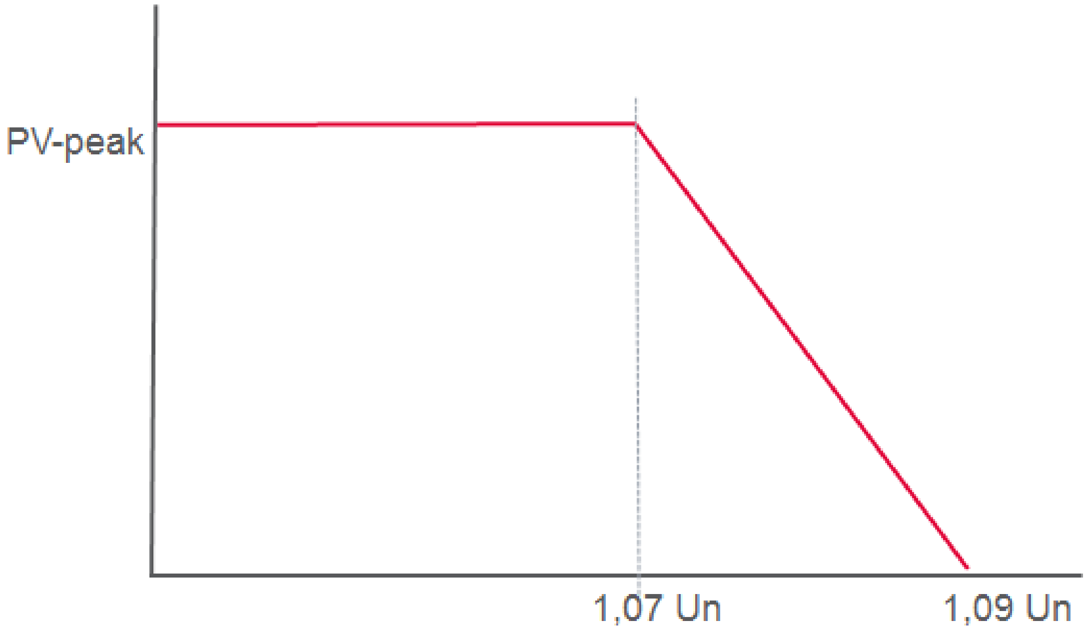


Possible solutions (2): Curtailment of active power

Passive curtailment (70% of PV-peak)



Depending on voltage level



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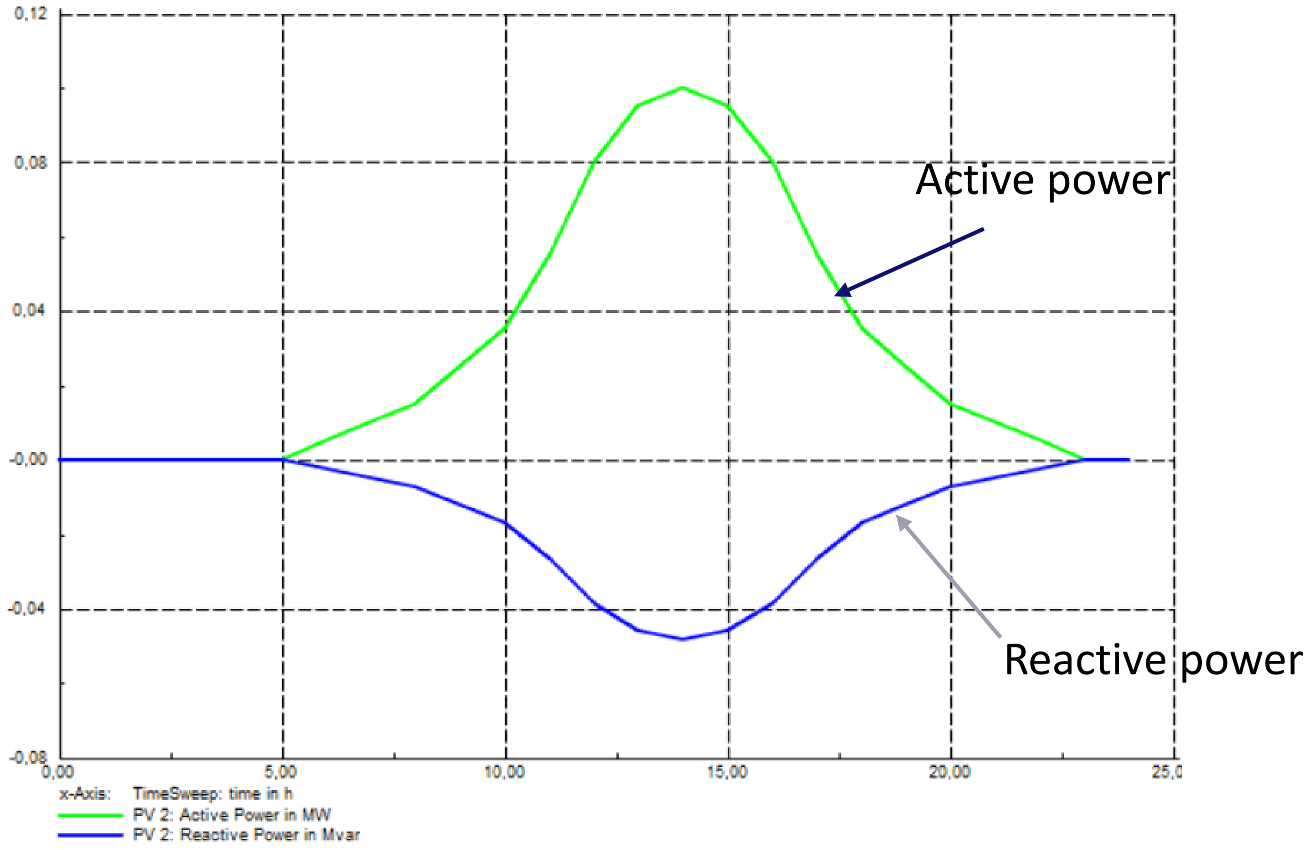
Possible solutions (3): Reactive power when R/X is small



- Only effective when R/X is small
- More losses in network
- Higher S needed for inverter

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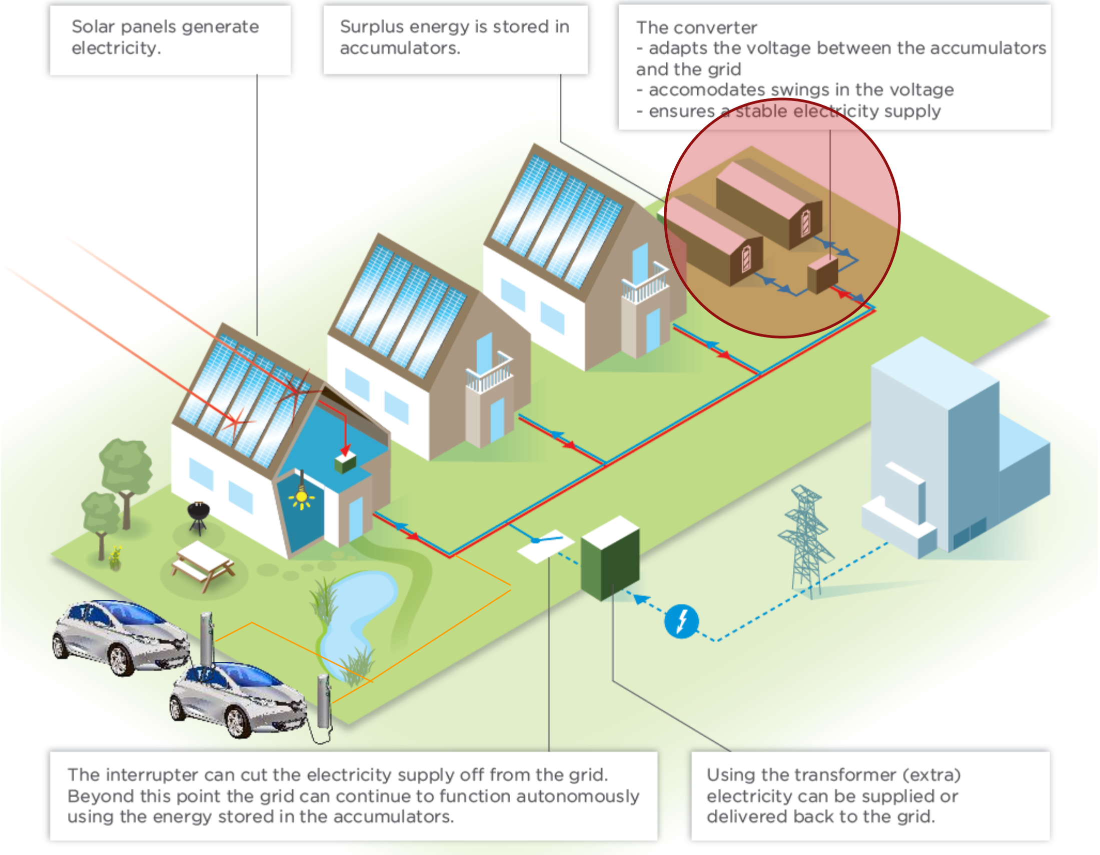
Possible solutions (4): Demand response/storage

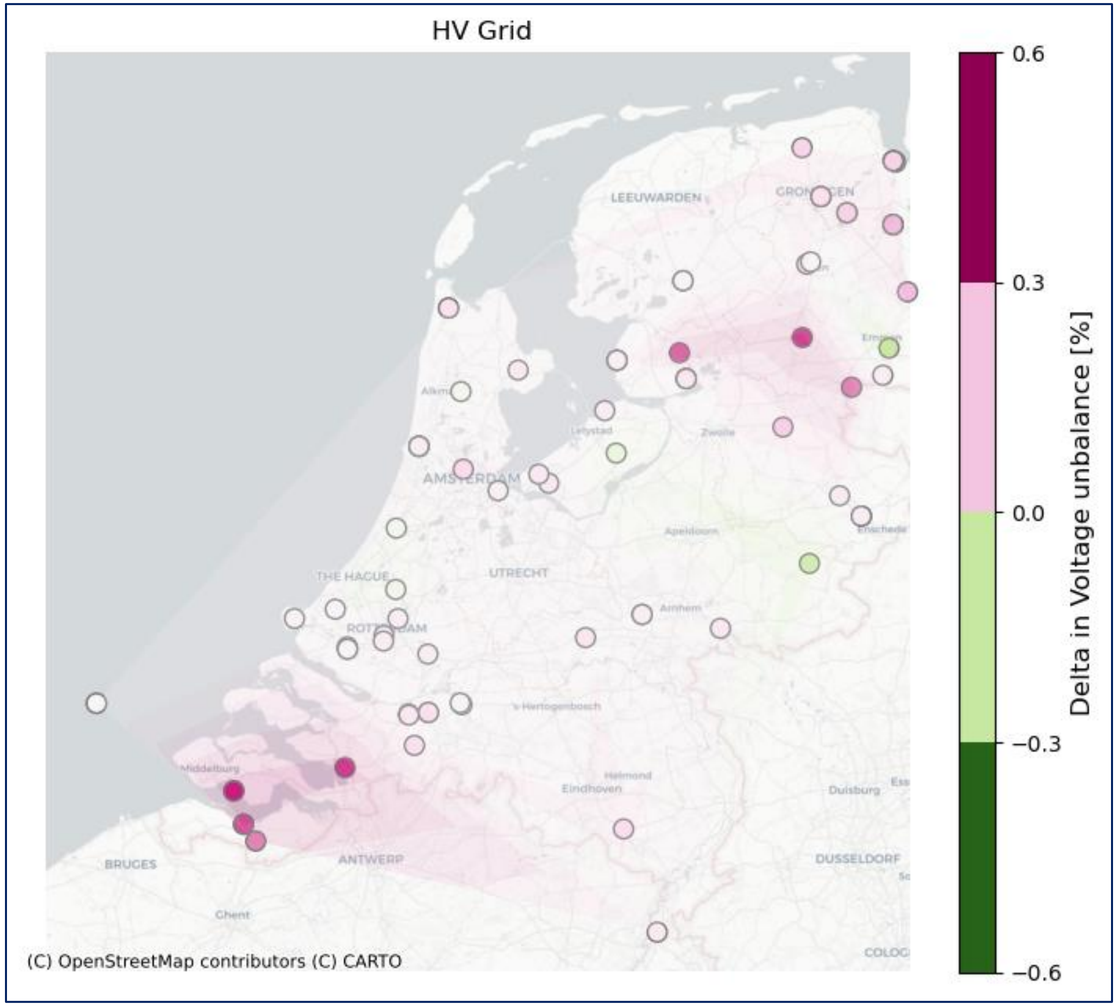


- Balancing production and load
- Energy management
- No-break system
- Harmonic filter
- Reducing voltage variations

- MMM

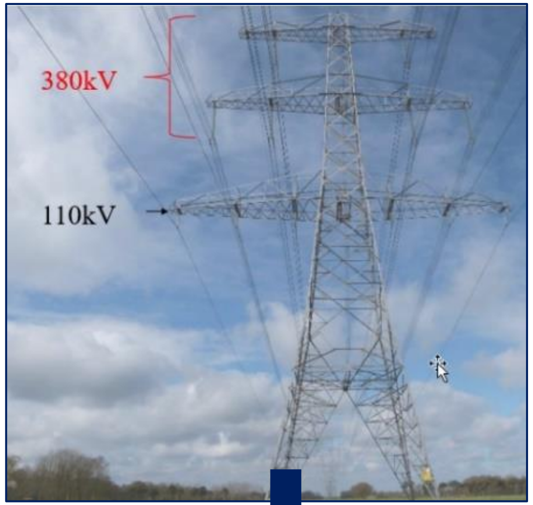
Voltage unbalance trends

- Measured trends in the 110kV and 150kV grids: 2023 vs 2019

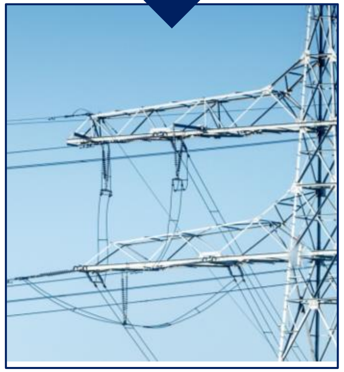


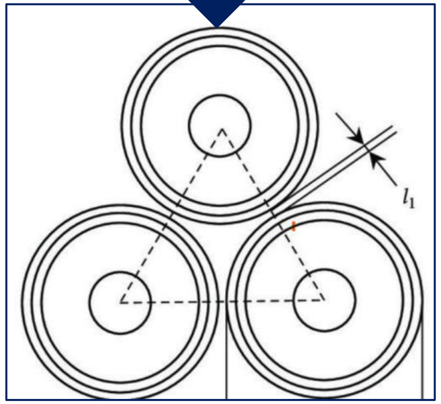
(TenneT/Krado)

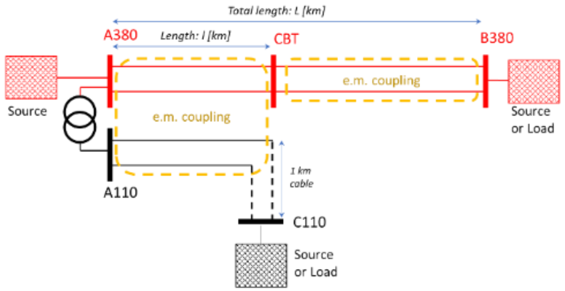
Main causes measured voltage unbalance



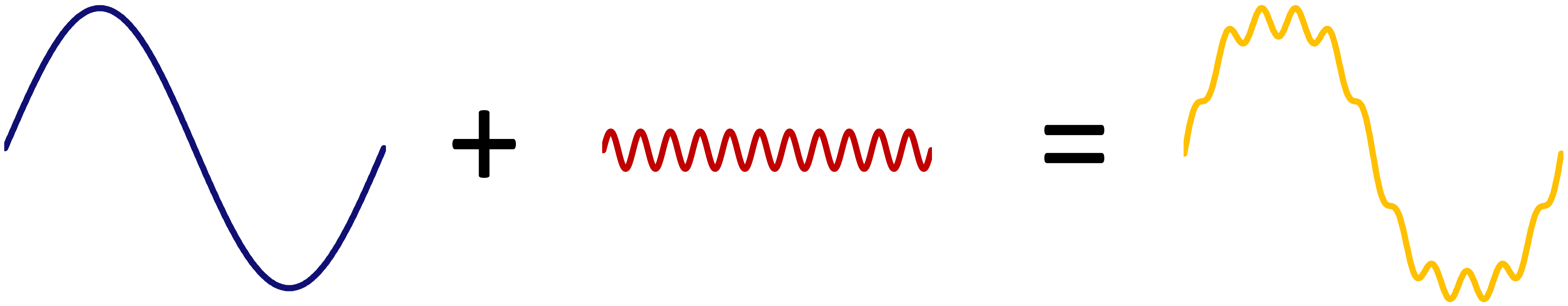
(DNV)







Harmonics

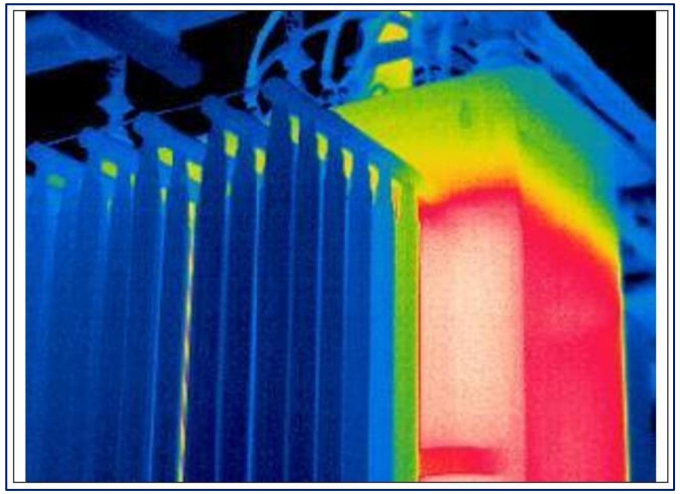


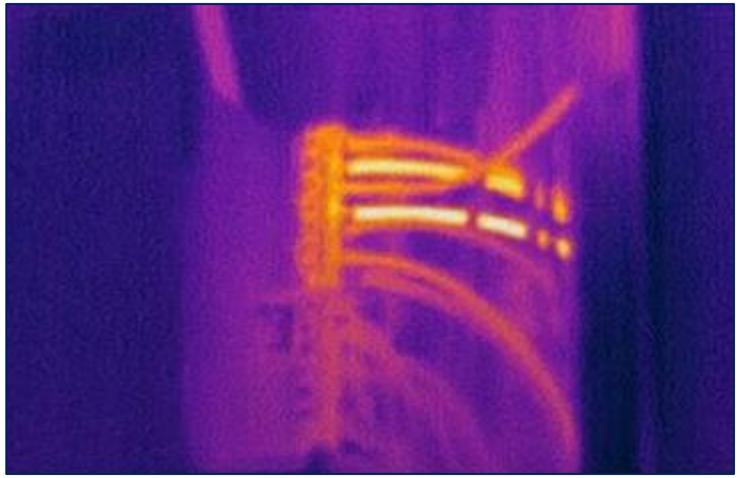
Ideal waveform (fundamental)

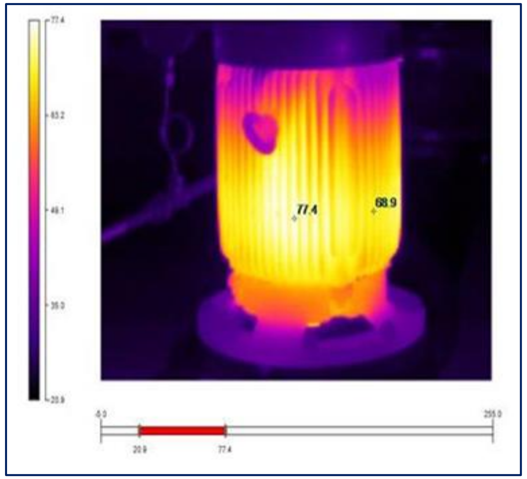
Distortion component (harmonic or supraharmonic)

Resulting waveform (fundamental + distortion)

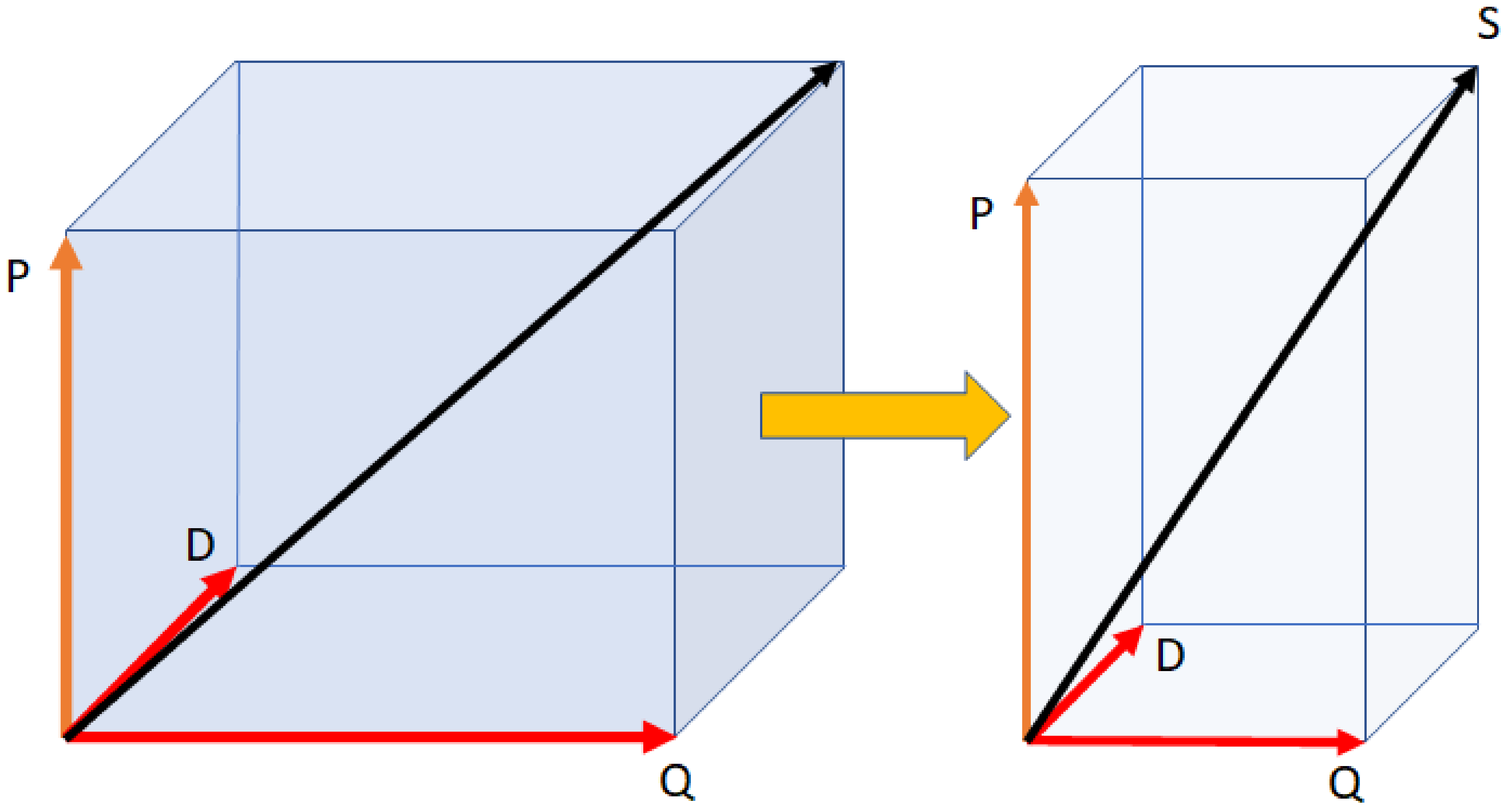
Problems related to Harmonics







Power factor (carefull with capactorbanks)



$$S = \sqrt{P^2 + Q^2 + D^2}$$

Regulation of harmonics

Odd harmonics				Even harmonics	
Not multiples of 3		Multiples of 3			
h	Relative voltage	h	Relative voltage	h	Relative voltage
5	6	3	5	2	2
7	5	9	1,5	4	1
11	3,5	15	0,5	6…24	0,5
13	3	21	0,5		
17	2				
19	1,5				
23	1,5				
25	1,5				

Table 3 – Limits for Class D equipment

Harmonic order n	Maximum permissible harmonic current per watt mA/W	Maximum permissible harmonic current A
3	3,4	2,30
5	1,9	1,14
7	1,0	0,77
9	0,5	0,40
11	0,35	0,33
$13 \leq n \leq 39$ (odd harmonics only)	$\frac{3,85}{n}$	See Table 1

Regulation of harmonics

Odd harmonics				Even harmonics	
Not multiples of 3		Multiples of 3			
h	Relative voltage	h	Relative voltage	h	Relative voltage
5	6	3	5	2	2
7	5	9	1,5	4	1
11	3,5	15	~~0,5~~	6…24	0,5
13	3	21	~~0,5~~		
17	2				
19	1,5				
23	1,5				
25	1,5				

1
0,75

Table 3 – Limits for Class D equipment

Harmonic order n	Maximum permissible harmonic current per watt mA/W	Maximum permissible harmonic current A
3	3,4	2,30
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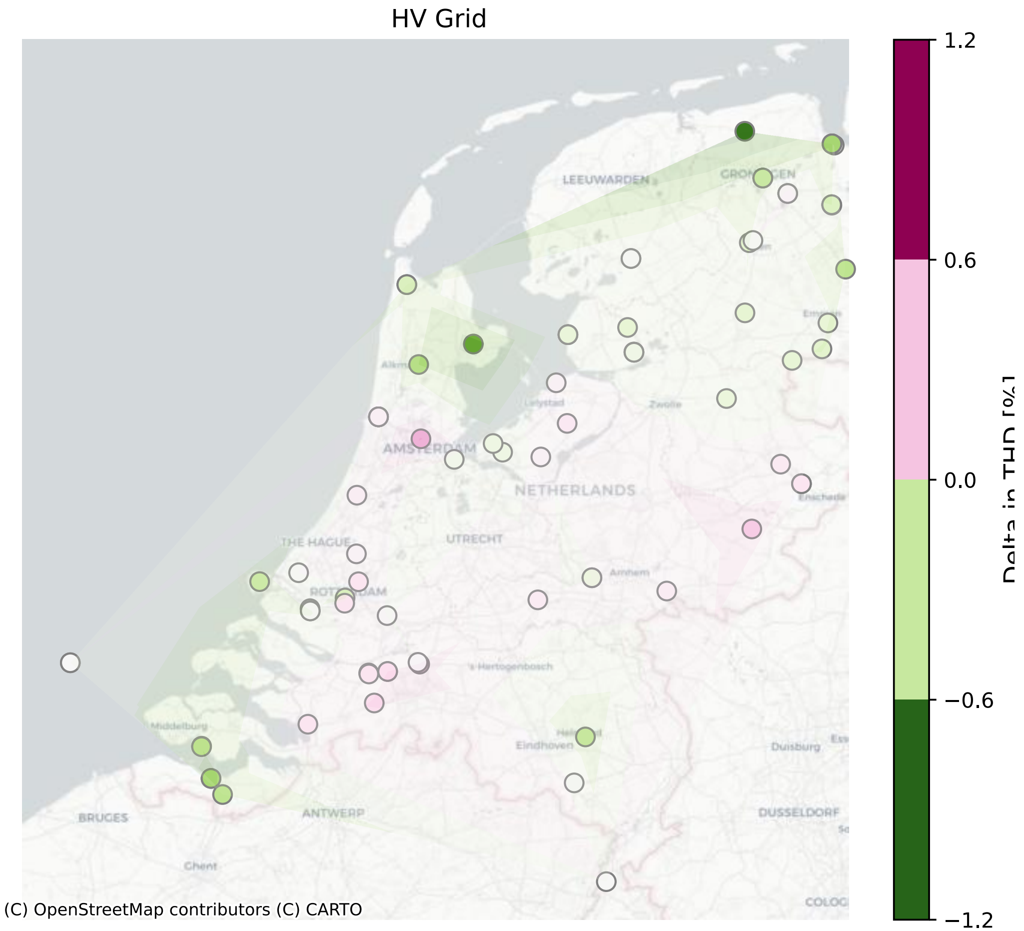
9	0,5	0,40
11	0,35	0,33
$13 \leq n \leq 39$ (odd harmonics only)	$\frac{3,85}{n}$	See Table 1

THD in the HV grid

Measured trends in the 110kV and 150kV grids: 2023 vs 2019*

Trends in MV- and LV-network is slightly increasing



*based on max value during 1 week over 1 calendar year

(Krado/TenneT)

TU/e

Supraharmonics

Harmonics	LF range	Conducted RF range	Conducted RF range	Radiated RF range	Radiated RF range
50Hz - 2/2.5kHz 60Hz - 2.4/3kHz	2/2.5Hz - 9kHz 2.4/3kHz - 9kHz	9kHz - 150kHz	150kHz - 30MHz	30MHz - 1/2/3GHz *	Above 3GHz

Regulated range

Unregulated range

Regulated range for some products

* Upper limit depends on product

Definition of frequency ranges

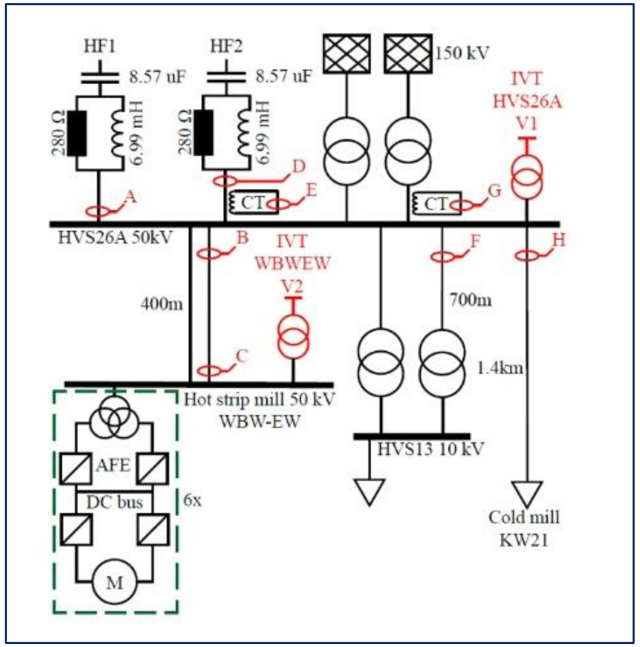
Supraharmonics

- False positive or false negative operation of protection devices
- Interference with power line communication (PLC)
- Failing of cable terminations and connections (in MV/HV)
- Appliance specific problems:
  - Coffee machines, printers, dimmers, touch sensitive controls, internal clocks (77.5 kHz), measuring devices, induction cooking plates, EV chargers

(Tim Slangen)

TU/e

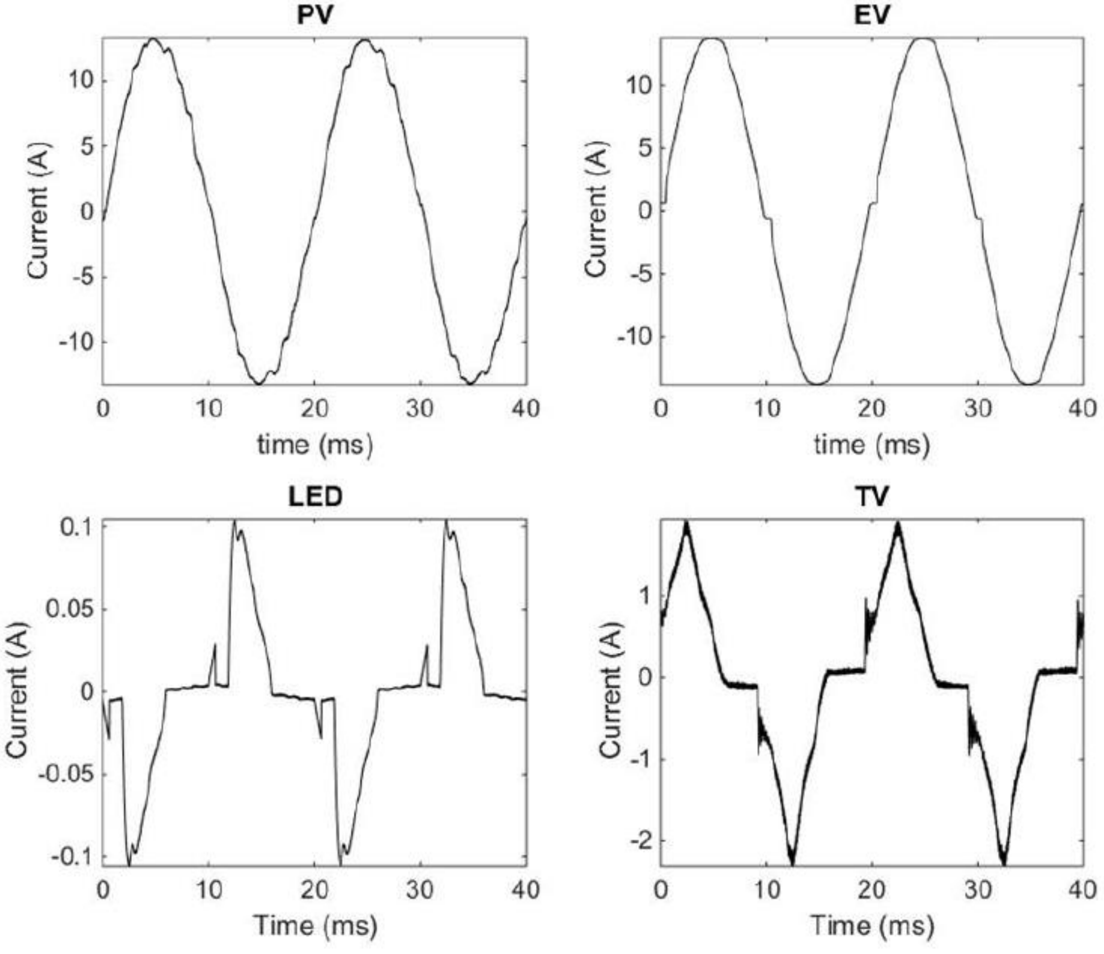
Supraharmonics

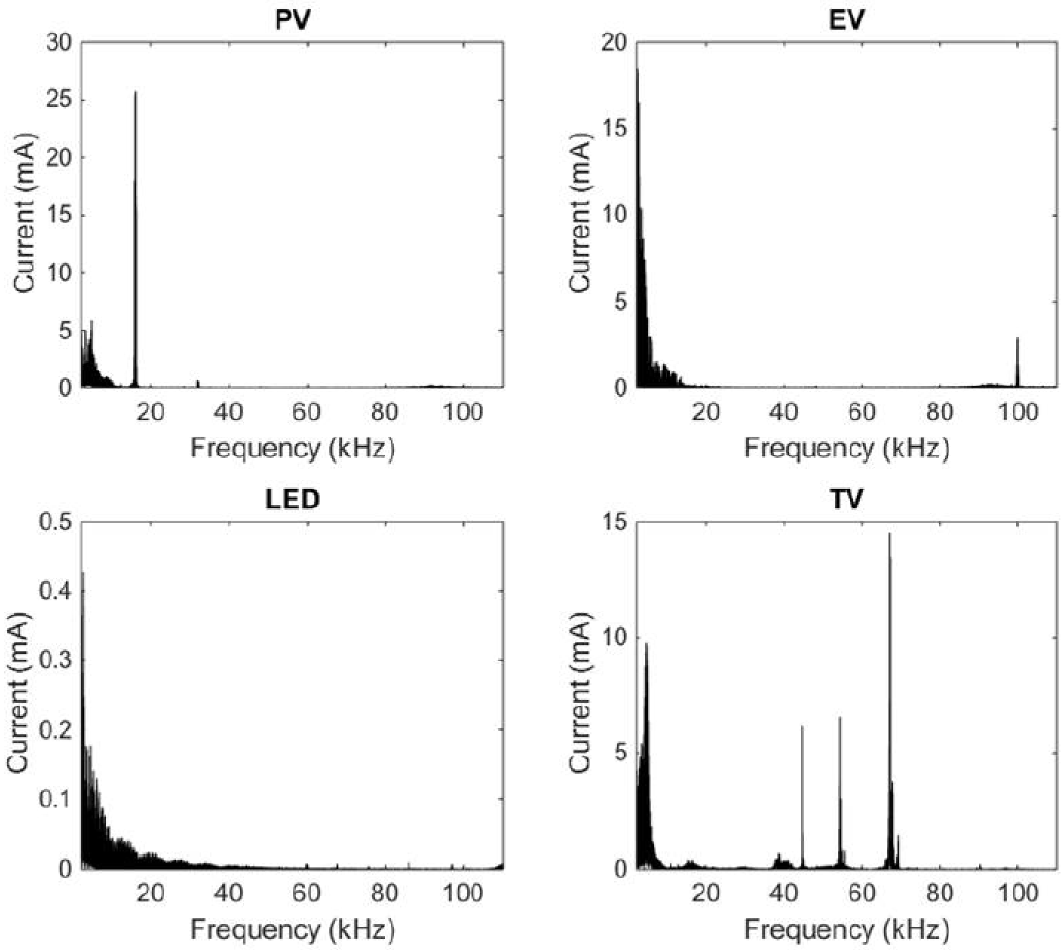


(TATA Steel/ Menno Spitteler)

Examples of sources of supraharmonics

PV-system, EV, LED and TV





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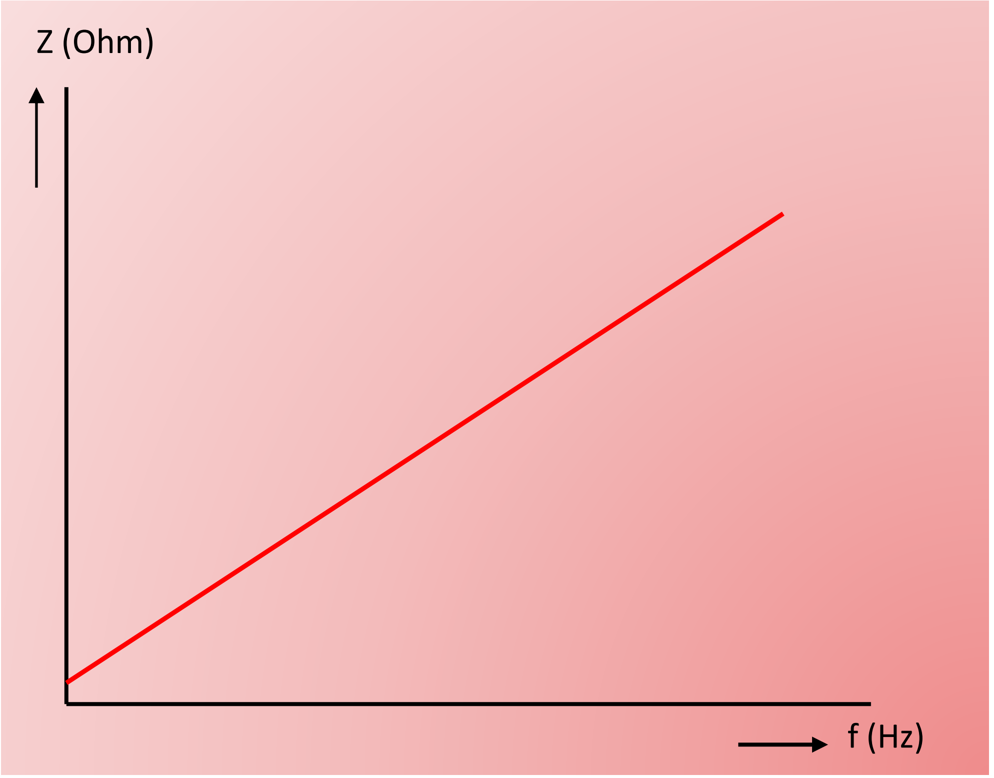
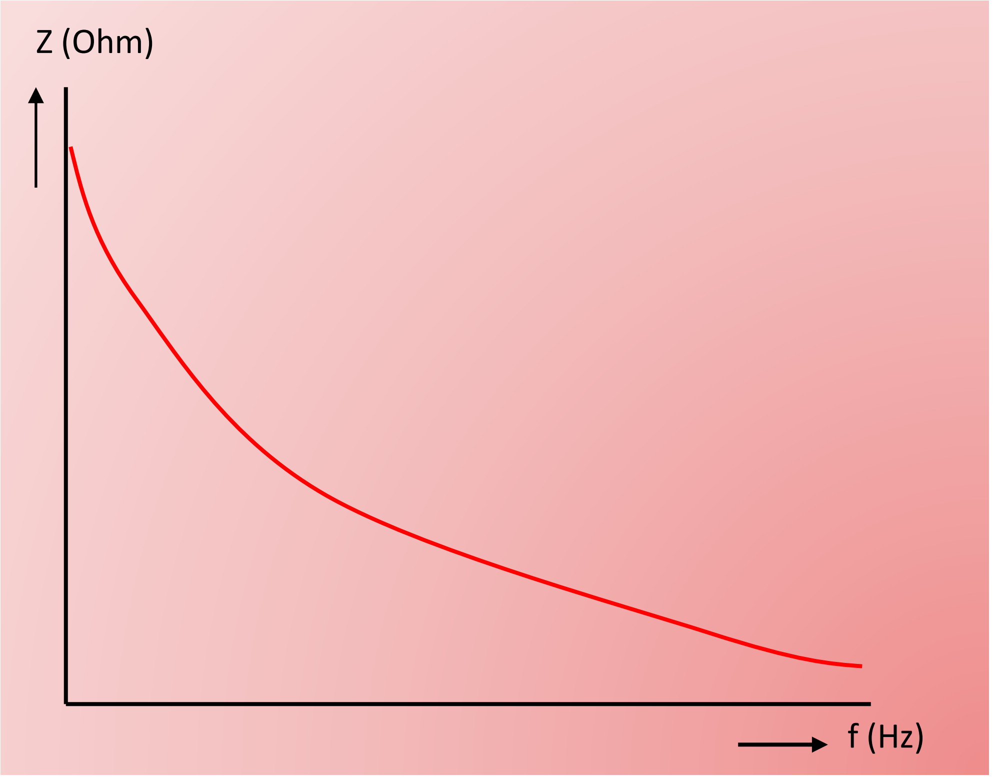
Propagation of supraharmonics

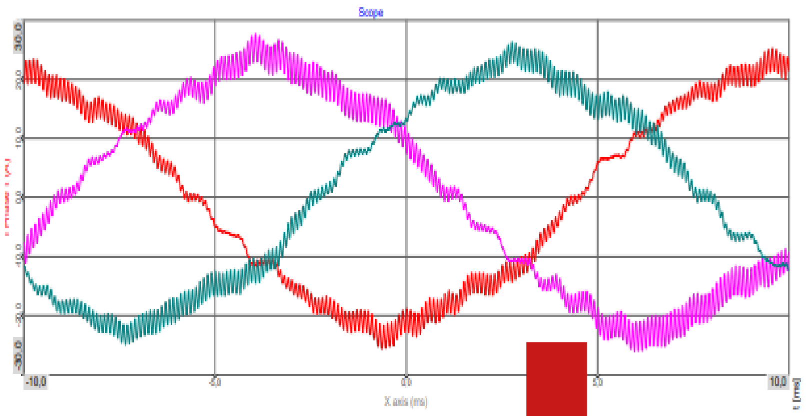
Inductivity L

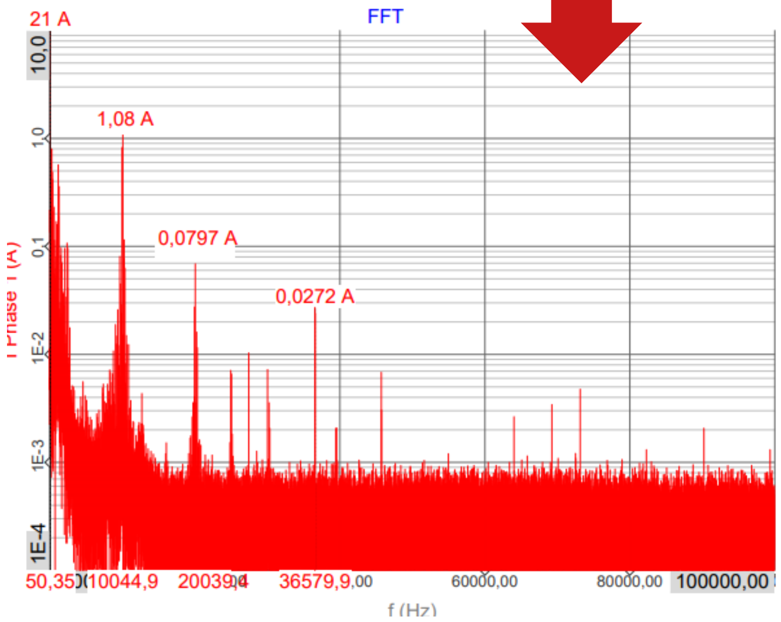


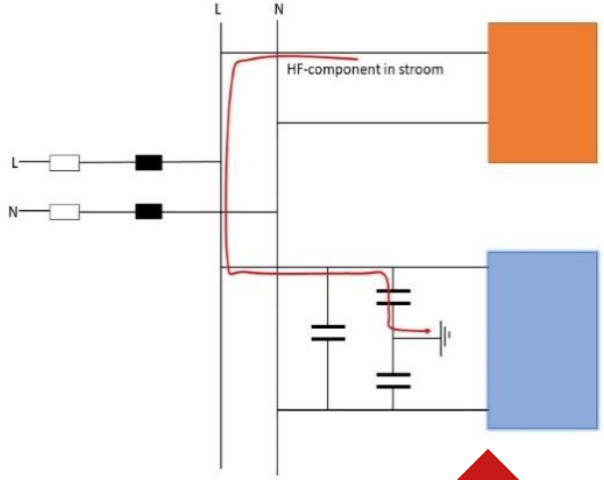
Capacity C

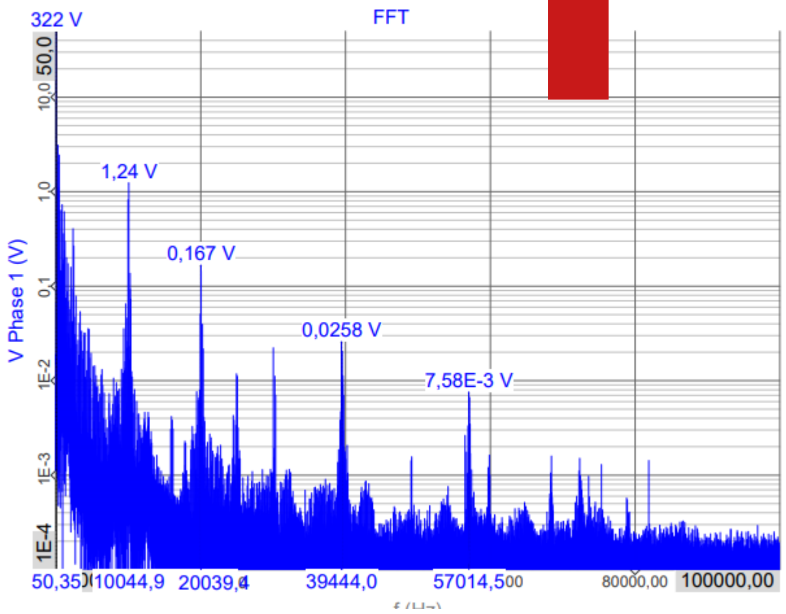


Propagation of supraharmonics

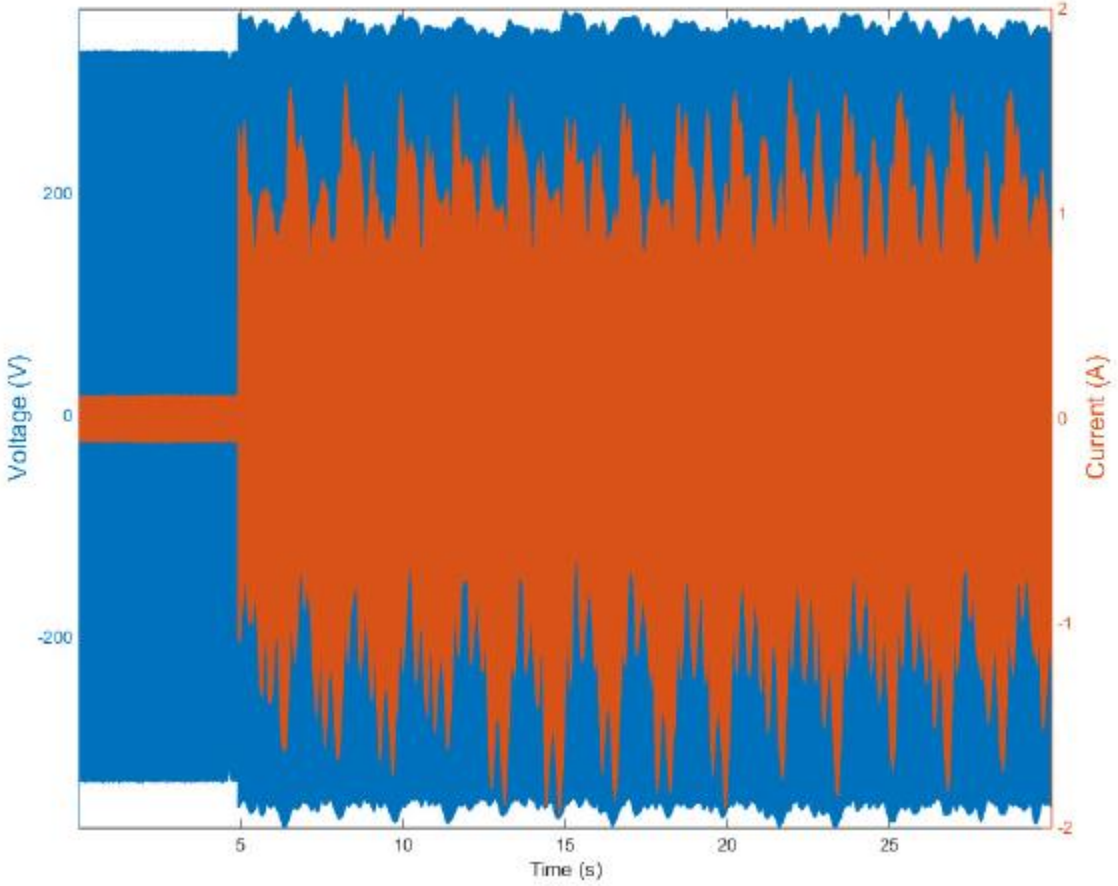


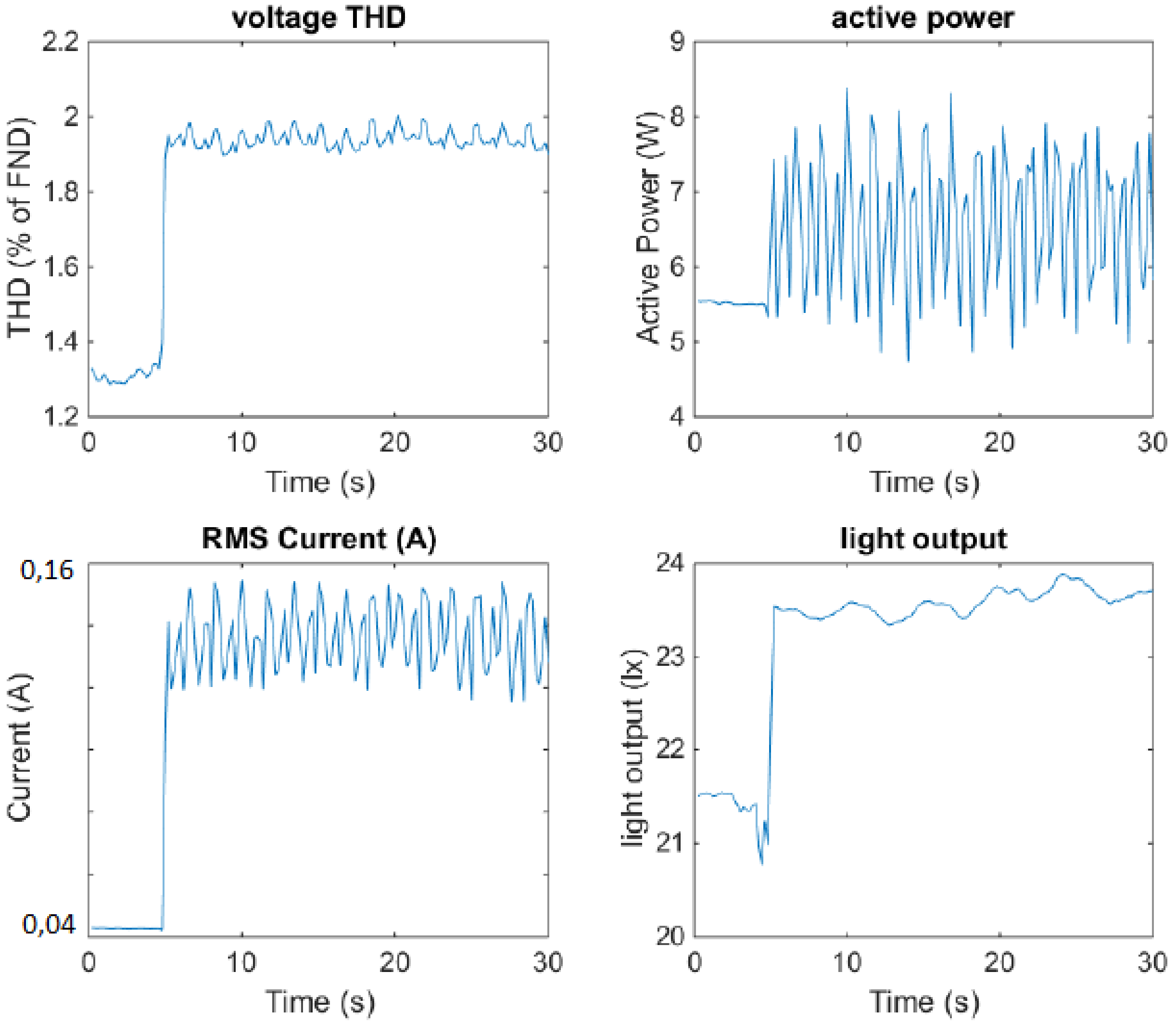






Voltage and current 6W-led





Flicker

- Variable light production from a light source generally caused by voltage variations in the electric power source
- 100 Hz variations are invisible for us
- Perceivable regular variations
- Range about 1 – 30 Hz
- In the past around 50% of all complaints

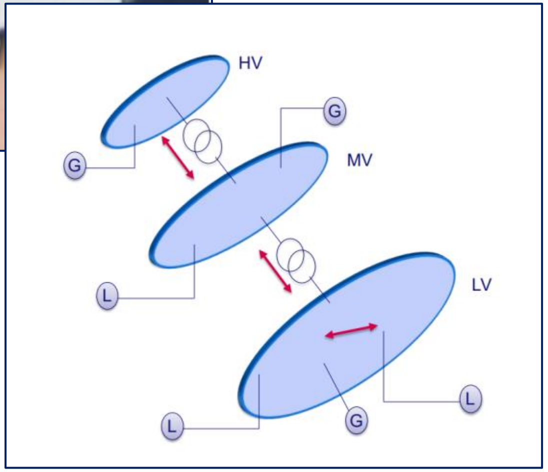
Stakeholders

- Regulator
- Network operator
- Connected parties

Also:

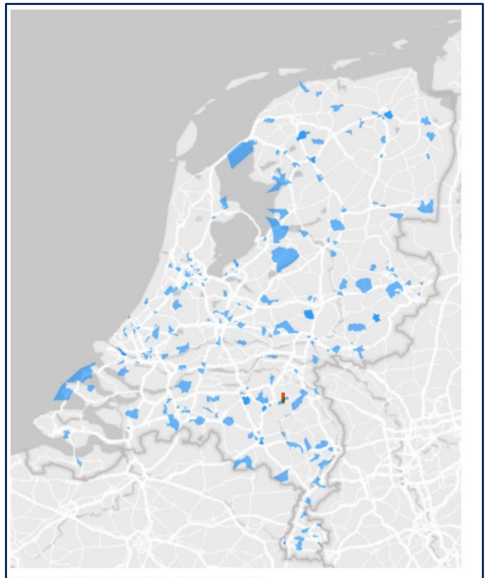
- Manufactorers
- Installation companies

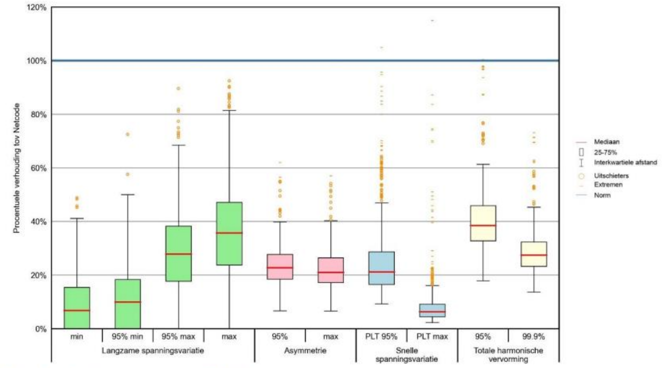
The mutual obligations are laid down by law in the Dutch Electricity Grid Code



Measurements

- Voltage quality is measured at each voltage level since 90s
- in 2014, 2015 increase in measurements
- network operators publish an annual report


Figuur B.1: Grafisch overzicht meetlocaties MS, 2023



Figuur 2.1: Continue verschijnselen LS, 2023


Spanningskwaliteit in Nederland

Resultaten 2023

Versie: 2.0
Kenmerk: HY-2024-02
Datum: 17 april 2024

Netbeheer Nederland, vereniging van energienetbeheerders in Nederland
De vereniging Netbeheer Nederland is de belangenbehartiger van de landelijke en regionale elektriciteit- en gasnetbeheerders. Netbeheer Nederland is het aanspreekpunt voor netbeheerders aangelegenheden. De netbeheerders hebben twee hoofdtaken: zij faciliteren het functioneren van de markt en zij beheren de fysieke net-infrastructuur. Lid van deze vereniging zijn de wettelijk aangewezen landelijke en regionale netbeheerders voor elektriciteit en gas. Netbeheer Nederland organiseert het overleg met marktpartijen over aanpassingen van de marktfacilitering. Netbeheer Nederland doet namens de gezamenlijke netbeheerders voorstellen voor aanpassingen van de wettelijk verankerde codes voor onder meer de structuur van de nettarieven. Netbeheer Nederland stelt ook de algemene voorwaarden op voor aansluiting en transport.

Netbeheer Nederland

HyTEPS ENERGY SAVING POWER QUALITY

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How are we doing in the Netherlands?

- Audit Laborelec in 2023

Rapport: Onderzoek Spanningskwaliteit Elektriciteitsnetwerken

Ons kenmerk	: LBE3-973173434-4092
Zaaknummer	: Laborelec NV – BE0400.902.582
Datum	: 29 juni 2023
Auteur	: Anne Dabin, Stijn Uytterhoeven, Ralf Bosch
Versie	: Definitief
Aantal pagina's	: 87

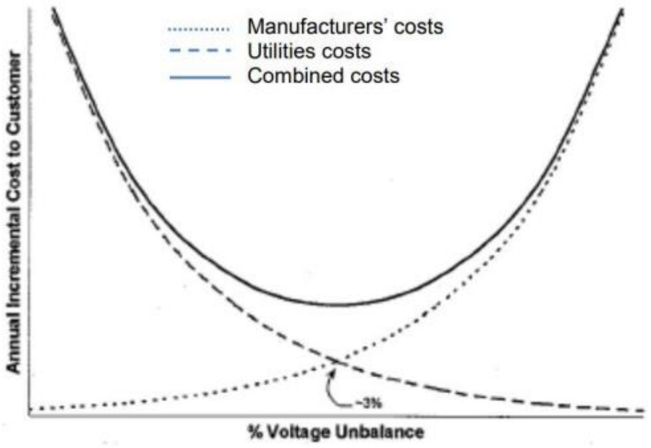
c. *Zijn er aanpassingen in het meetprogramma noodzakelijk of wenselijk?*

De netbeheerders in Nederland voeren al een zeer goede spanningskwaliteit monitoring uit met de metingen, de analyses, het ter beschikking stellen van de gegevens op het internet voor het publiek en de jaarlijkse rapportage. Nederland zit duidelijk bij de beste leerlingen van de klas voor PQM ten opzichte van andere Europese landen.

Future developments also recommendations auditor

Are the Dutch regulations not too strict?

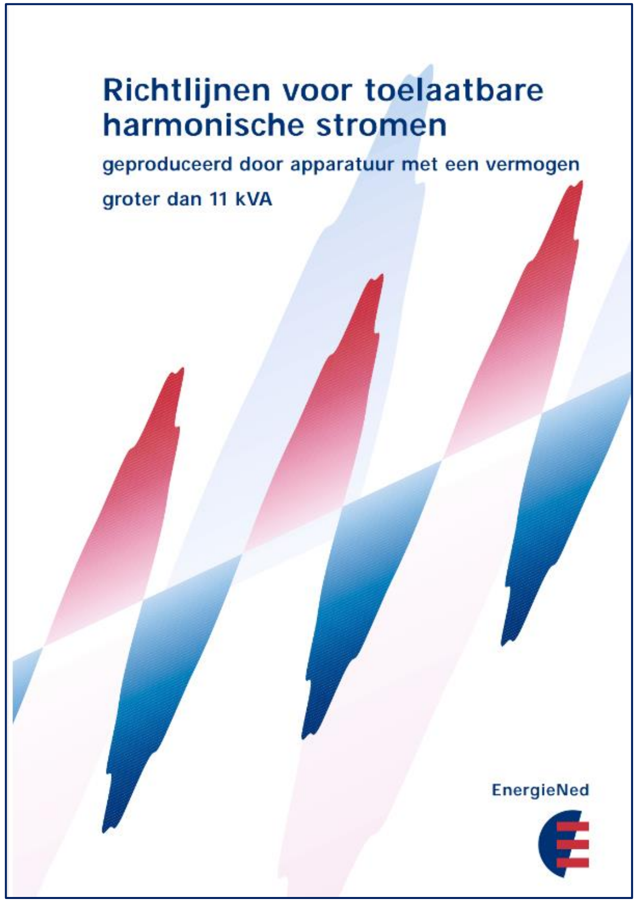
- Consider update regulations
  - Rapid voltage variations
  - Voltage unbalance



Figuur 7: jaarlijkse incrementele kost voor de klant voor verschillende spanningsasymmetrielimieten

Future developments also recommendations auditor

- Connection requirements harmonics
- Improve measurement and analysis tools
  - Automated analysis
- Improve transparency
  - sharing via automatic notifications



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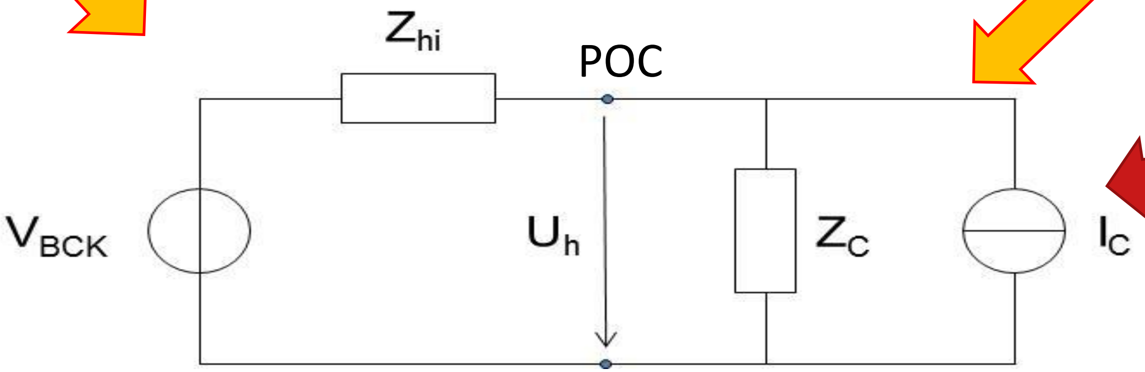
Future challenges

- How good are our models?
- How to deal with risks and make decisions?

E.g. Harmonic filters, apply transpositions in towers or other measures?

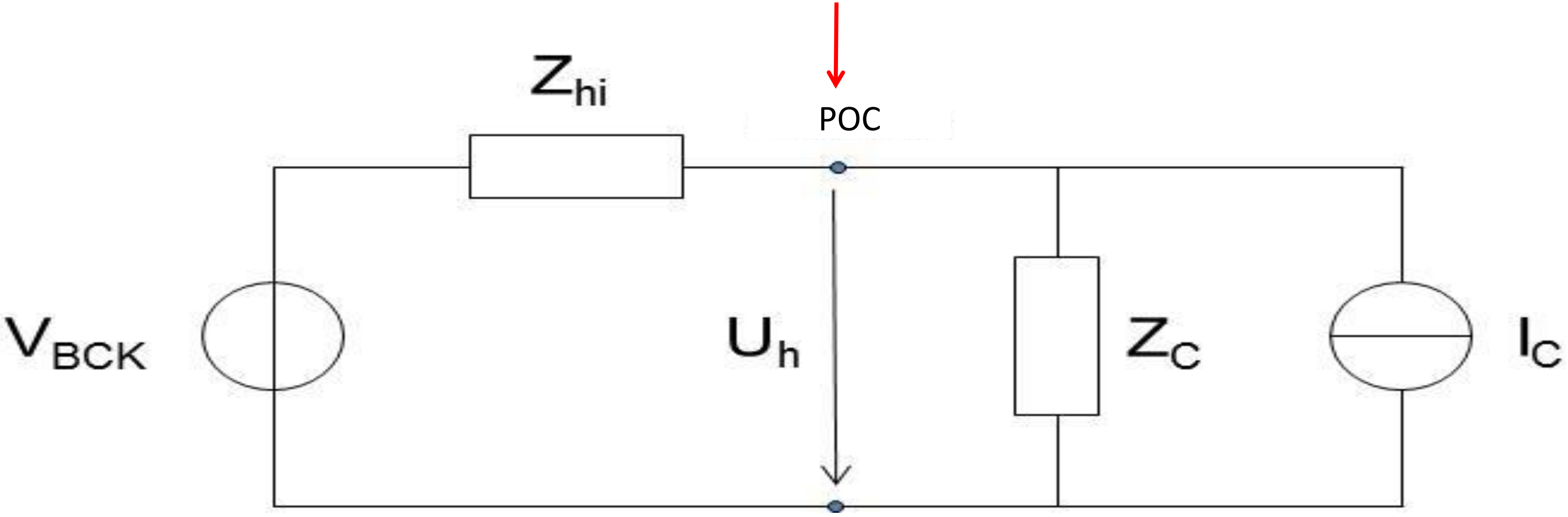
Impact on harmonics: Calculating acceptable contribution



Harmonic contribution at PCC

There are 2 contributions

1) Emission connected party (due to Ic)
2) Background harmonic voltage (Vbck)



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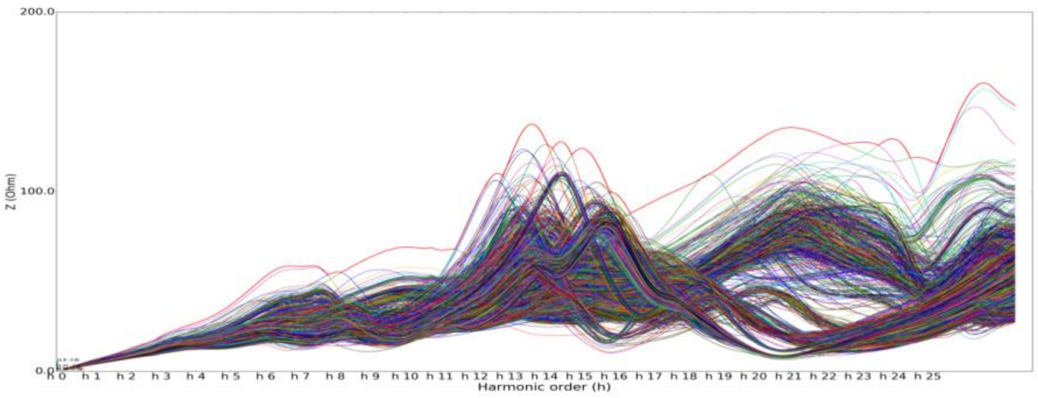
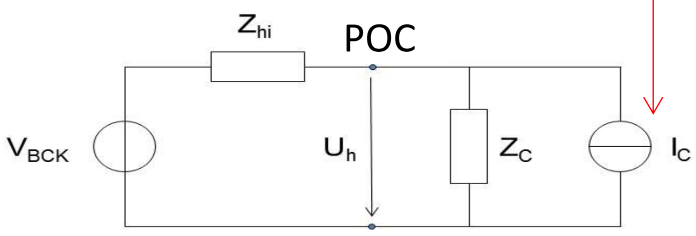
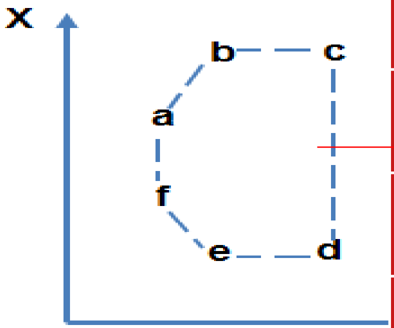
Calculating the contribution to harmonic voltages

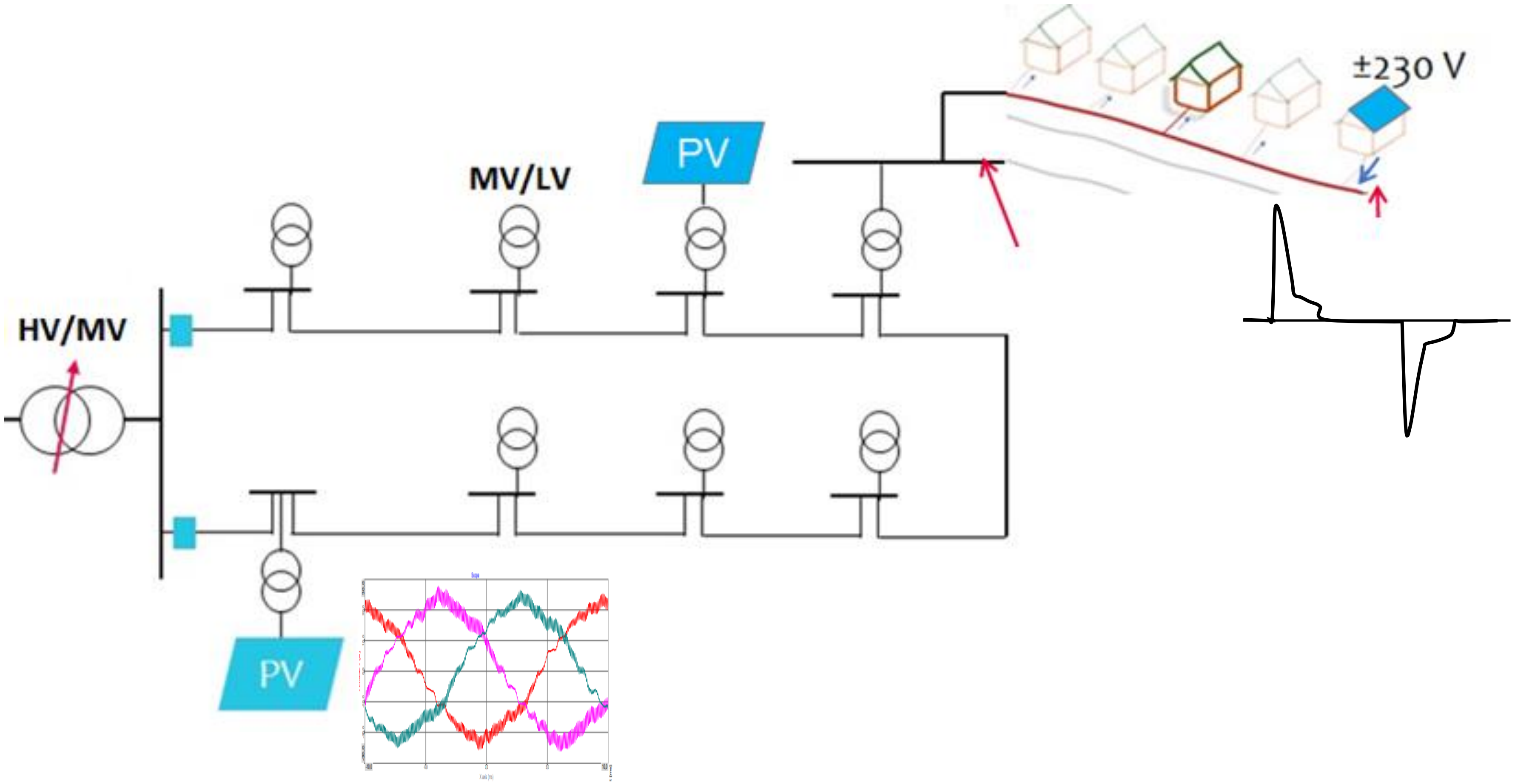






H order	fmin	fmax	a-R	a-X	b-R	b-X	c-R	c-X	d-R	d-X	e-R	e-X	f-R	f-X
1 ≤ h < 5	10	250	0.2	7.2	9.2	33.5	25.5	33.5	25.5	0.7	0.2	0.7	0.2	0.8
5 ≤ h < 10	200	500	3.9	31.2	26.3	55.5	60.2	55.5	60.2	-5.6	15.3	-5.6	3.9	12.0
10 ≤ h < 18	450	935	6.3	48.9	46.2	85.1	144.1	85.1	144.1	-57.6	52.4	-57.6	6.3	-20.0
18 ≤ h < 23	810	1210	4.9	51.8	48.1	91.4	137.5	91.4	137.5	-47.4	32.4	-47.4	4.9	-5.9
23 ≤ h ≤ 25	1035	1375	4.9	43.9	25.5	91.4	161.1	91.4	161.1	-24.9	43.2	-24.9	4.9	-2.3

Approach of harmonic calculation in MV- and LV-networks



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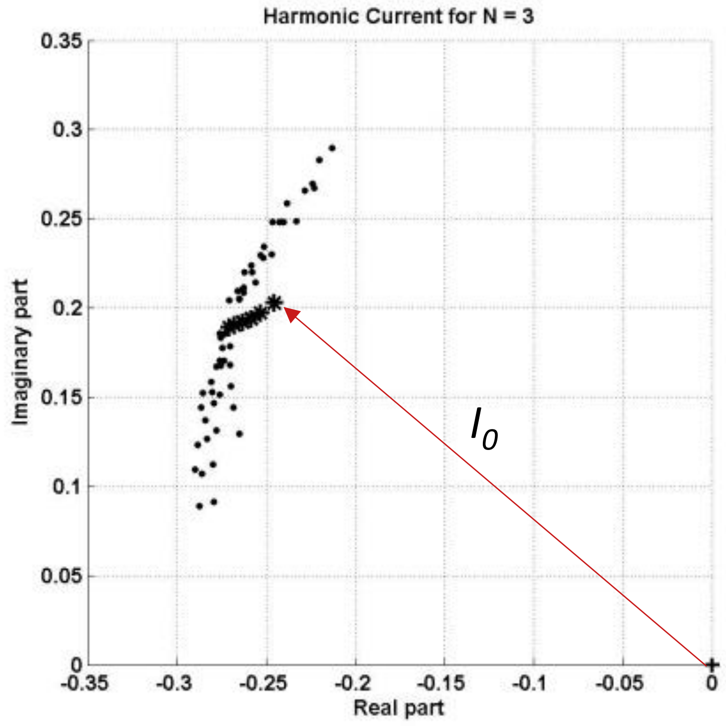
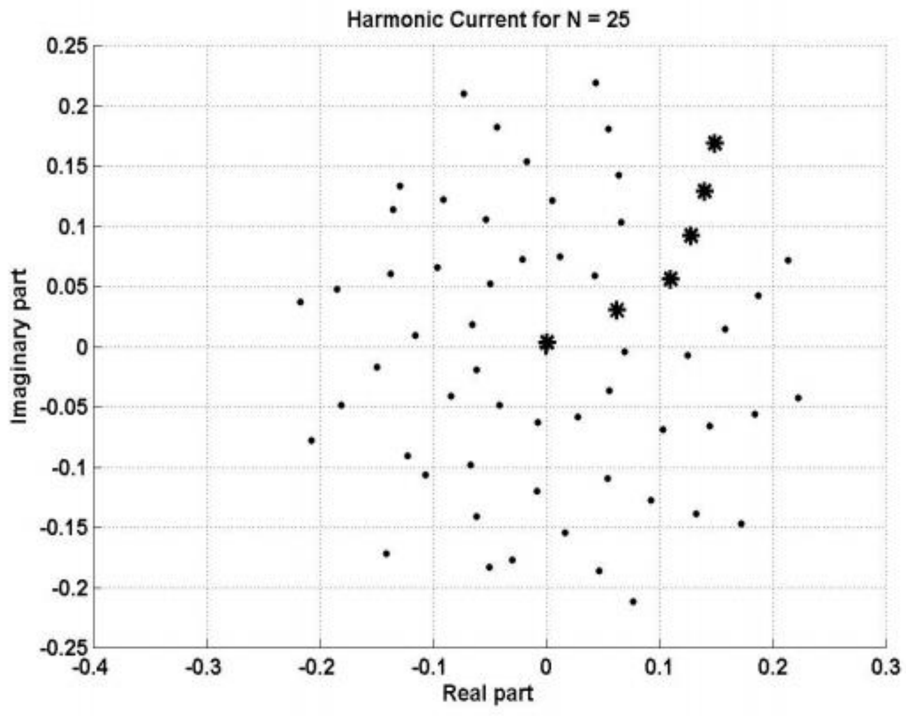
Modeling the devices: Harmonic fingerprint

- Inrush currents
- Harmonic currents
- Influence of harmonic background voltage





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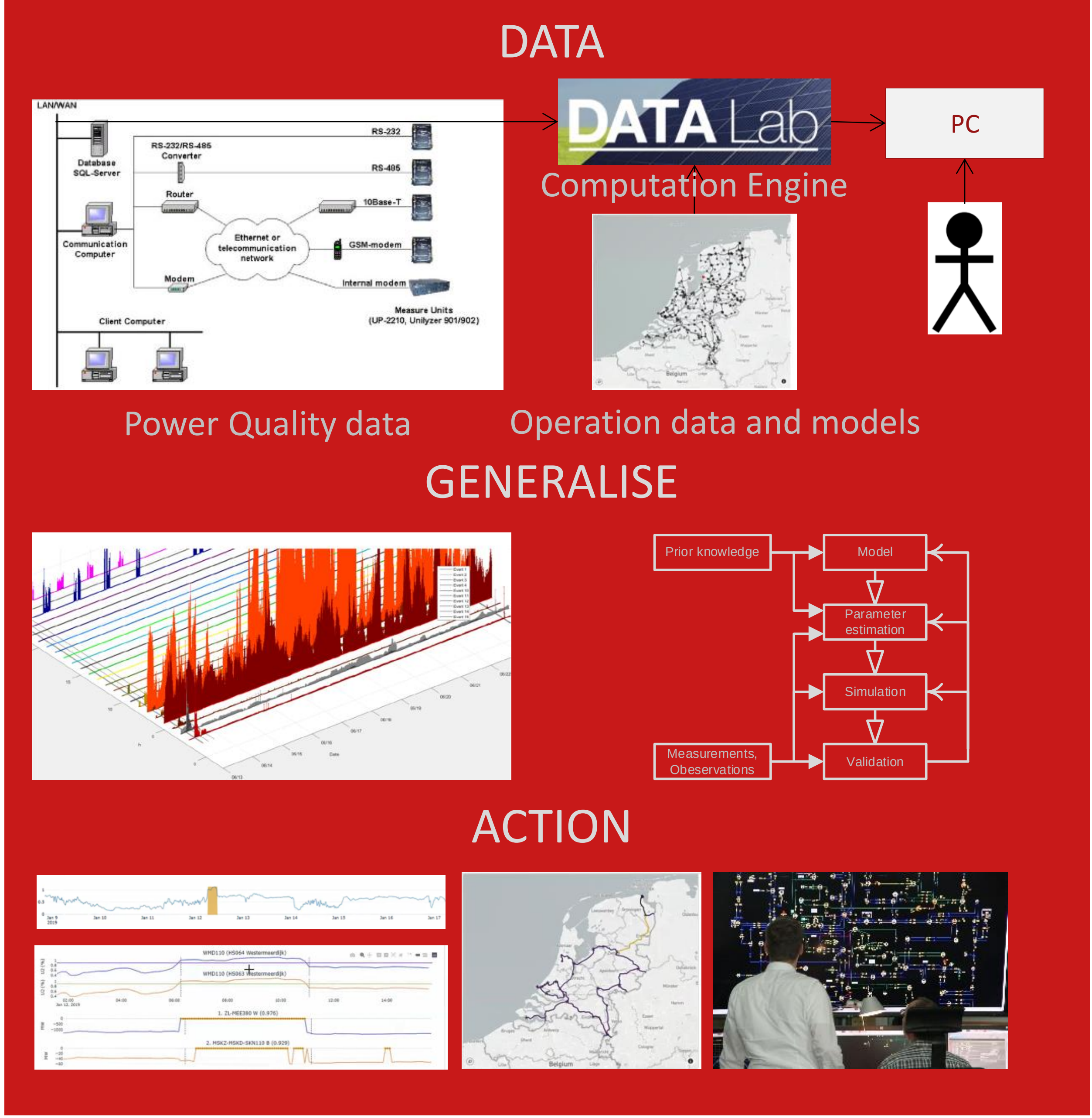
Machine learning

- Gather and combine data from various information sources/databases
- Find correlations/disturbing source
- Translation to knowledge/validate models
- Come to rules for policies & action (action)

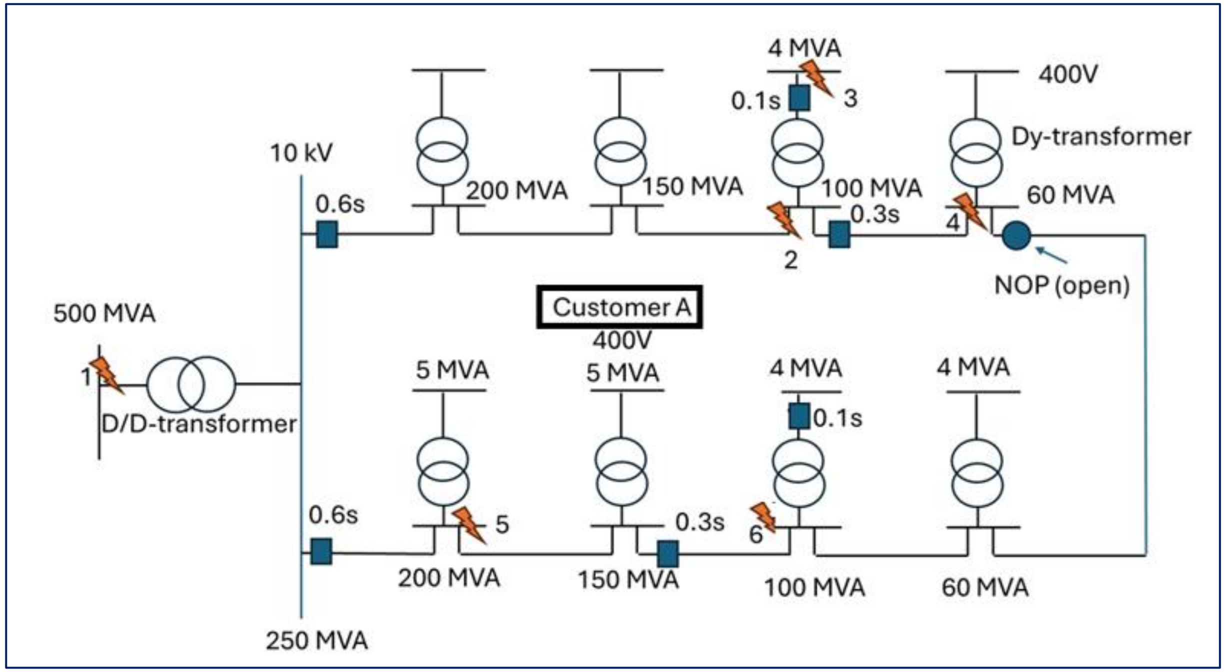


(TenneT: F. van Erp, J. van Veen, J. Buitenhuis)

Education

Course Power Quality Phenomena

- Lectures + instructions
- Practical assignment



The quality you give is the quality you get!

FEBRUARY 4, 2025

Prof. dr. ir. Sjef Cobben

Department of Electrical Engineering, Electrical Energy Systems

EINDHOVEN UNIVERSITY OF TECHNOLOGY