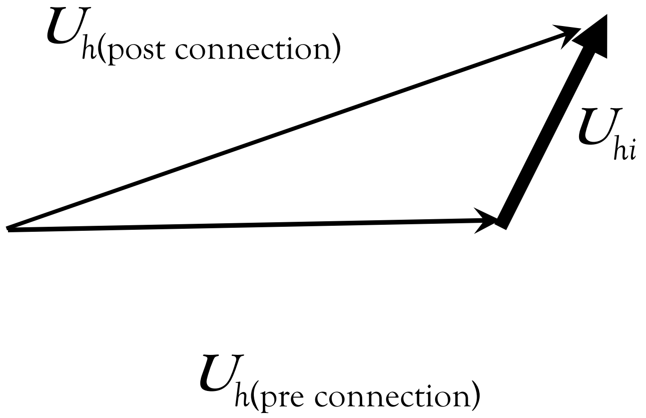
How to measure voltage THD emission: can it be done?

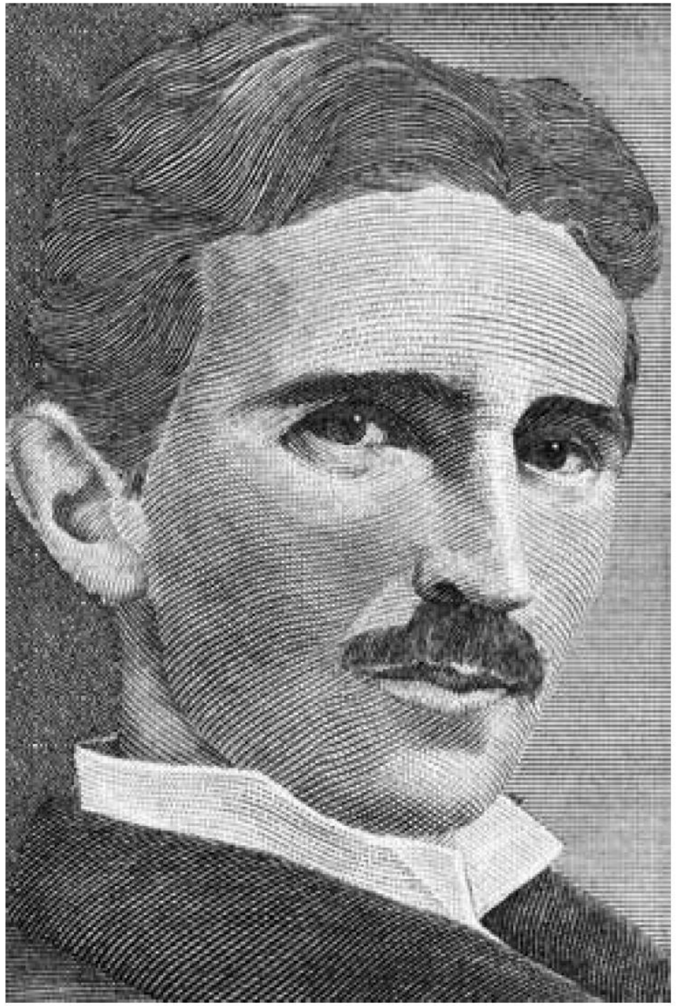
- A scientific constraint
- What to measure: Metrological requirements
- A harmonic emission agreement
- A methodology
- Estimate, not measure – we remain unsure



$$VoltageTHD(\%) = \frac{\sqrt{\sum_{h\neq 1}^{N} V_h^2}}{V_1} \times 100$$

Johan.Rens@ieee.org
March 2023

The Association of Electricity Distribution Undertakings in Namibia, AEDU Namibia



Electrical science has revealed to us the true nature of light, has provided us with innumerable appliances and instruments of precision, and has thereby vastly added to the exactness of our knowledge.

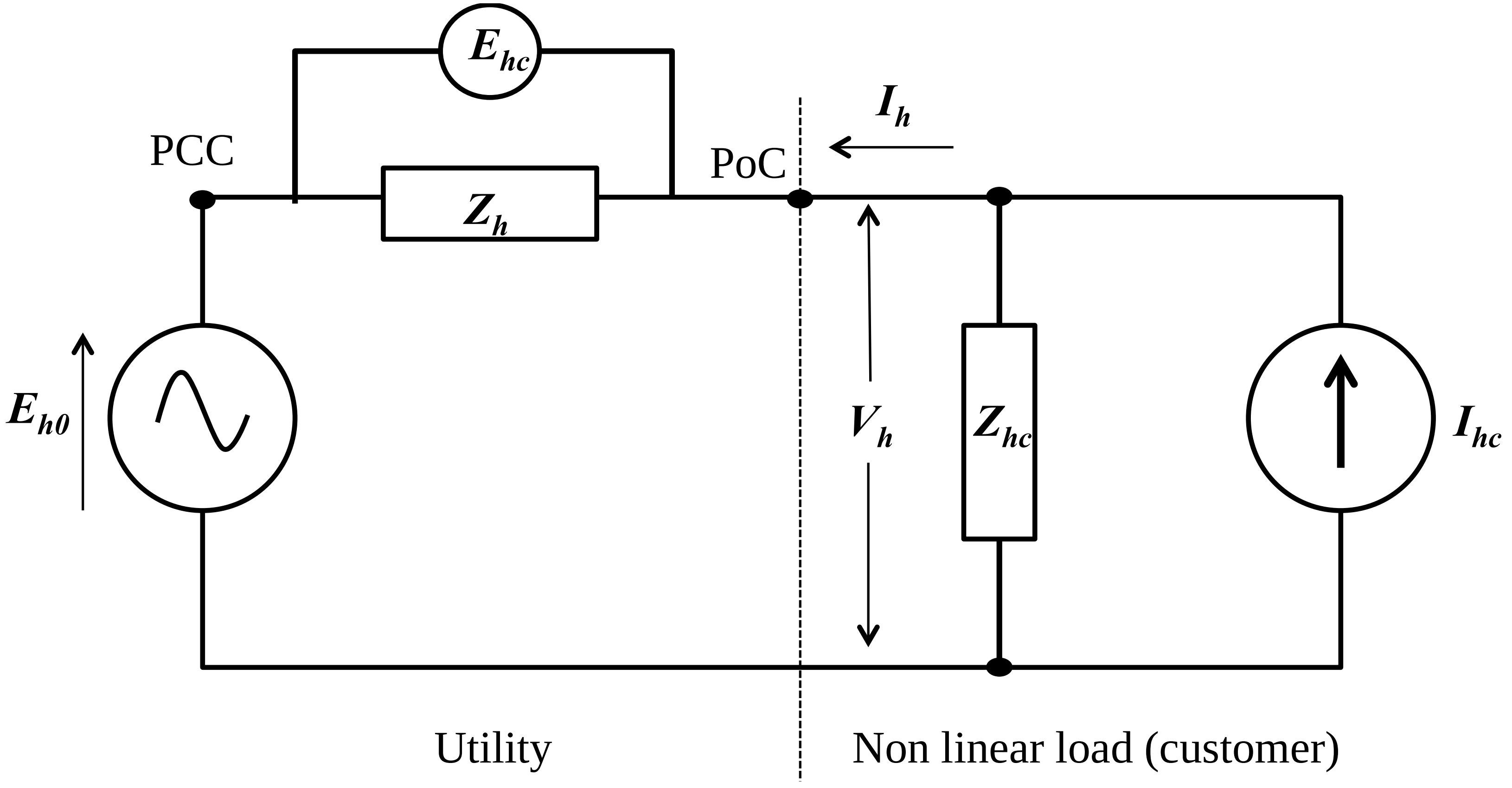
Nikola Tesla, inventor, engineer and futurist

We do not know who is doing what

- Networks are interconnected
- Sources of distortion all over
- Single-point measurements cannot measure distortion contributed from any single source
- Non-linear loads are active loads with control to optimise the local performance
- Non-linear loads interchange harmonic active power
- Rendering a single-point measurement useless
- Need to measure at ALL sources of distortion SYNCHRONOUSLY and SIMULTANEOUSLY

✓ To fully understand the impact on Voltage THD

Harmonic emission – the aim



$$E_{hc} = Z_h I_h = V_h - E_{h0}$$

Engineers need to be pragma

BELOW IS A LIST OF WAYS TO WIN AN ARGUMENT WITH A WOMAN:

- To measure at EVERY source of distortion, at same time (accurate time-stamping) – impossible/unpractical

- Single-point measurements are what engineers

- We can estimate, not assess (we never know precisely)

- We do contract on harmonic emission, we sho be able to know contractual compliance?

Use good data

- Use a measuring instrument certified as compliant to IEC 61000-4-30
- **BUT:** Class A Edition 4 (at least Edition 3) on BOTH voltage and current measurements and respecting IEC requirements on BOTH voltage and current harmonic phasors – with PQ 10 min data in **RMS**
- Emission, in principle, requires knowledge on direction of **harmonic current phasor**
- That knowledge lost after 200 ms!
- $\boldsymbol{I}_{200ms,h} = I_{200ms.h} \angle \varphi_{200ms,h}$
- $I_{agg,h} = \left(\frac{1}{N}\sum_{i=1}^{N} I_{200ms,h,i}^{2}\right)^{\frac{1}{2}}$

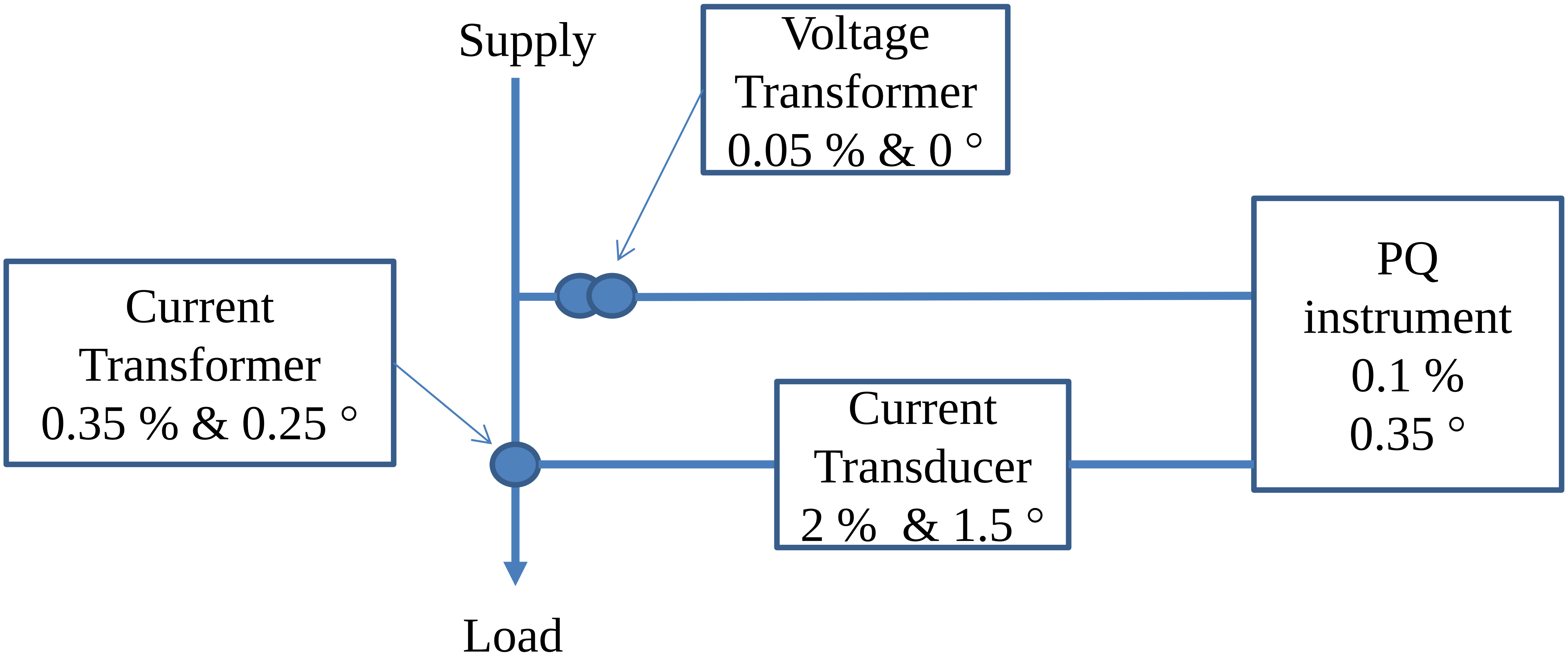
IEC 61000-4-30

Voltage harmonics: Measure, and be uncertain

- Voltage and current transformers designed for Class performance at 50 Hz, NOT AT HARMONIC FREQUENCIES – linearity
- Harmonic phasors have a relatively small amplitude
- With “lower” impact on the magnetic circuit in use
- Causing “measurement uncertainty”

- **All components in measurement chain contributes to METROLOGICAL PERFORMANCE**
- We need to assess **measurement uncertainty**
- ”How much” can we really measure?

Voltage harmonics: The metrology chain



Example of measurement uncertainty: Field application

Power Quality Instrument	Accuracy Class	Ratio
Vectograph III	IEC 61000-4-30, Class A, edition 3 on both voltage and current Harmonics: IEC 61000-4-7, Flicker IEC 61000-4-15	Not applicable
Voltage Transformer	30 VA, Class 0.2	11 kV/110 V
Current Transformer	10 VA, Class 0.2	600:1 A

TR 61869-103 © IEC:2012(E) – 43 –

Table 13 – Accuracy classes for power metering

Accuracy class	Percentage (ratio) error (+/–) at harmonics shown below				Phase displacement (+/–) at harmonics shown below							
					Degrees				Centiradians			
	2nd to 4th harmonic	5th and 6th harmonic	7th to 9th harmonic	10th to 13th harmonic	2nd to 4th	5th and 6th	7th to 9th	10th to 13th	2nd to 4th	5th and 6th	7th to 9th	10th to 13th
0,1	1 %	2 %	4 %	8 %	1	2	4	8	1,8	3,5	7	14
0,2	2 %	4 %	8 %	16 %	2	4	8	16	3,5	7	14	28
0,5	5 %	10 %	20 %	20 %	5	10	20	20	9	18	35	35
1	10 %	20 %	20 %	20 %	10	20	20	20	18	35	35	35

Example of measurement uncertainty: Technical standards

- **(IEC 61869-2:2012)/ BS EN 61869-2:2012**: Instrument transformers; Part 2: Additional requirements for current transformers
- **IEC/TR 61869-103**: Instrument transformers – The use of instrument transformers for power quality measurements.
- **BS EN IEC 61400-21-1:2019**: Wind energy generation systems (and PV)
- **IEC 61000-3-6**: Limits: Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems.

Example of measur

The “GUM”

Assessment of measurement uncertainty		Formulas from the GUM	Sensitivity Coefficient	$\frac{\partial f}{\partial x_i}$
Coverage Factor *k* from the Guide to Uncertainty in Measurements (GUM)	1.65	$u_c^2 = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i}\right) u^2\,(x_i)$	Square of equipment variance (obtained from specification sheet)	$u^2(x_i)$

Uncertainty in Current Measurements							
Symbol	Source of Uncertainty	Reference	Value of relative expanded uncertainty	Value of absolute expanded uncertainty	Divisor	Sensitivity coefficient	Relative Standard Uncertainty
I_m	Metering Equipment	Calibration Certificate	0.10%	'	1.73	1	0.06%
a_I	Current Transformer at Substation	Accuracy Class	0.35%	'	1.73	1	0.20%
b_I	Current Transformer supply cable	Assessed	0.05%	'	1.73	1	0.03%
$u_c(I)$	Combined Standard Uncertainty (relative)						0.21%
U	Expanded Uncertainty (relative)						0.35%

Measurement uncertainty: From where?

GUM: Guide to the Expression of Uncertainty in Measurement

JCGM 100:2008(E) – in English
Evaluation of measurement data (2008)

JCGM 100:2008(F) – Version française
Évaluation des données de mesure (2008)

JCGM 101:2008
Supplement 1 – Propagation of distributions using a Monte Carlo method (2008)

JCGM 102:2011
Supplement 2 – Extension to any number of output quantities (2011)

JCGM 104:2009
An introduction to the "GUM" and related documents (2009)

JCGM 106:2012
Evaluation of measurement data – The role of measurement uncertainty in conformity assessment (2012)

https://www.bipm.org/en/committees/jc/jcgm/publications

We can apportion harmonic emission

NRS 048 Part 4 -2021

Annex F
(informative)

A methodology for assessing contractual emission levels based on the IEC apportioning procedures

This equation allows for a fair distribution of allowable harmonic voltage distortion by all connected customers at the PCC. It also makes provision for the connection of future prospective clients, ensuring that the total allowable distortion capabilities of the PCC be used to their full capacity once all customers are connected. The minimum value accepted will be 0,1 % even if lower values are calculated.

We

T

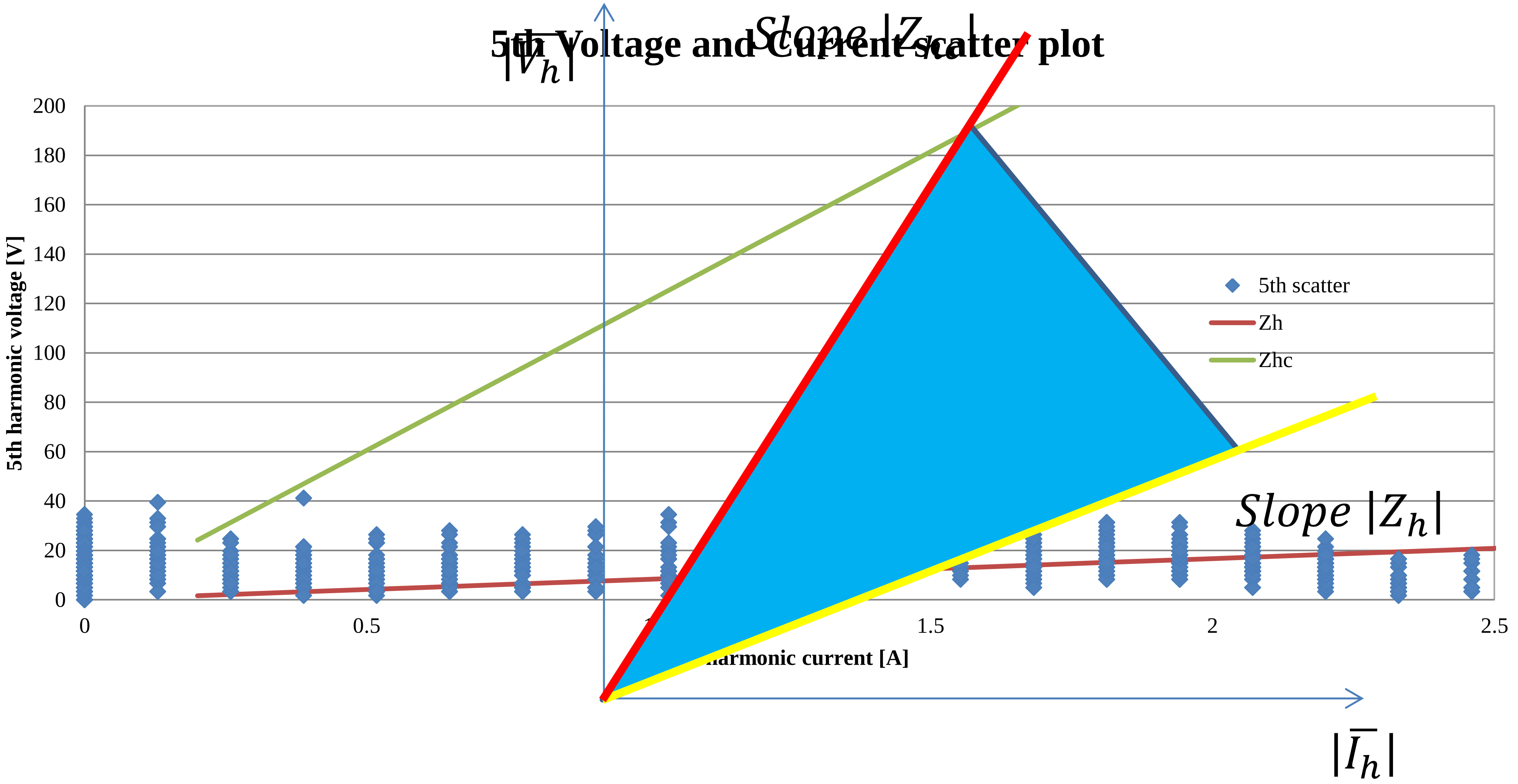
Harmonic order	I
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	

Table 2: Apportioned harmonic current emission limits expressed in %

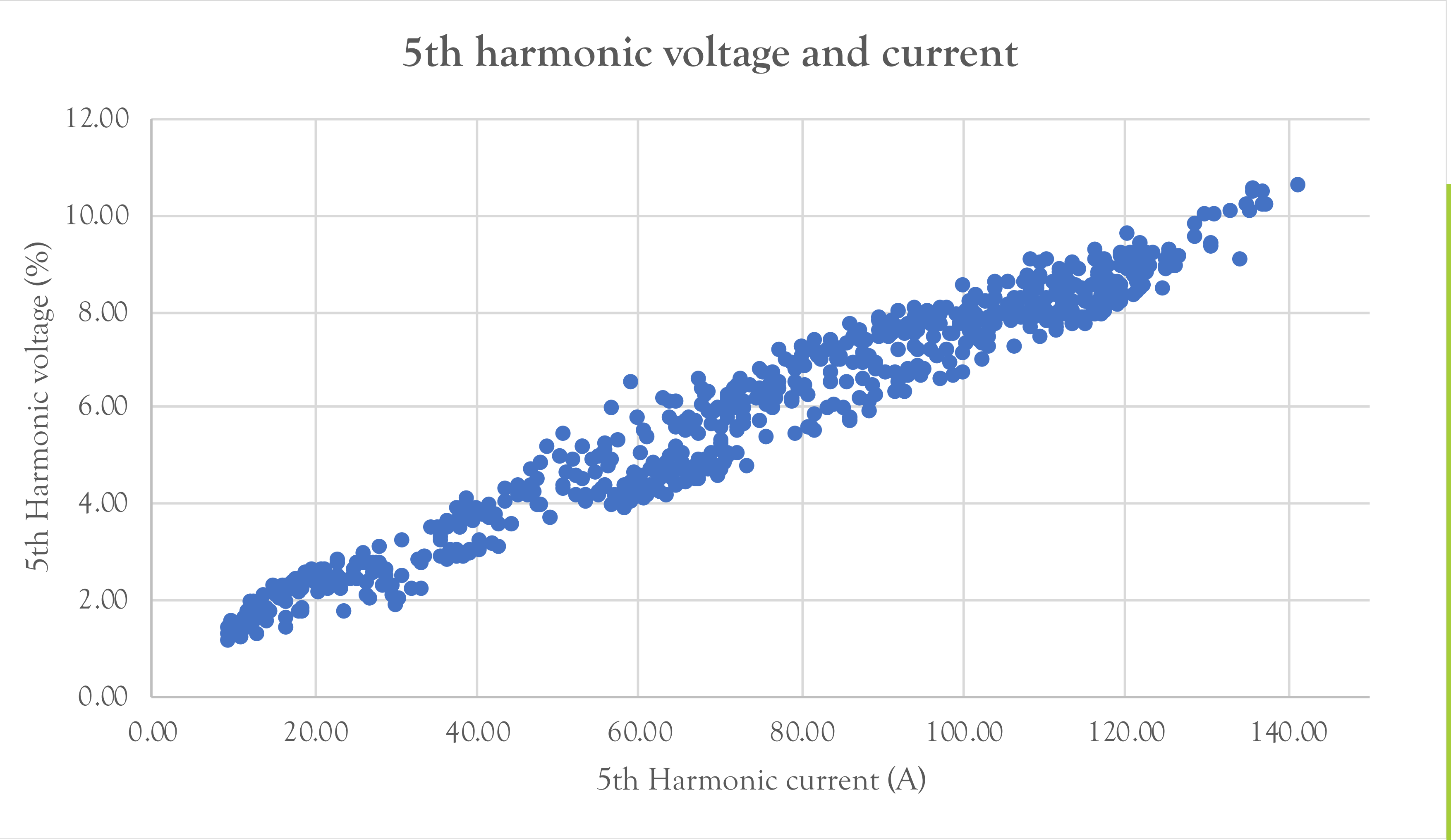
Harmonic order	Current emission [A]	Current emission [%]	Harmonic order	Voltage emission [%]	Current emission [%]
2	0.93	0.09%	26	0.10	0.07%
3	1.96	0.20%	27	0.10	0.07%
4	0.71	0.07%	28	0.10	0.07%
5	2.89	0.29%	29	0.23	0.07%
6	0.71	0.07%	30	0.10	0.07%
7	1.56	0.16%	31	0.22	0.07%
8	0.71	0.07%	32	0.10	0.07%
9	0.71	0.07%	33	0.10	0.07%
10	0.71	0.07%	34	0.10	0.07%
11	1.11	0.11%	35	0.21	0.07%
12	0.71	0.07%	36	0.10	0.07%
13	0.76	0.08%	37	0.20	0.07%

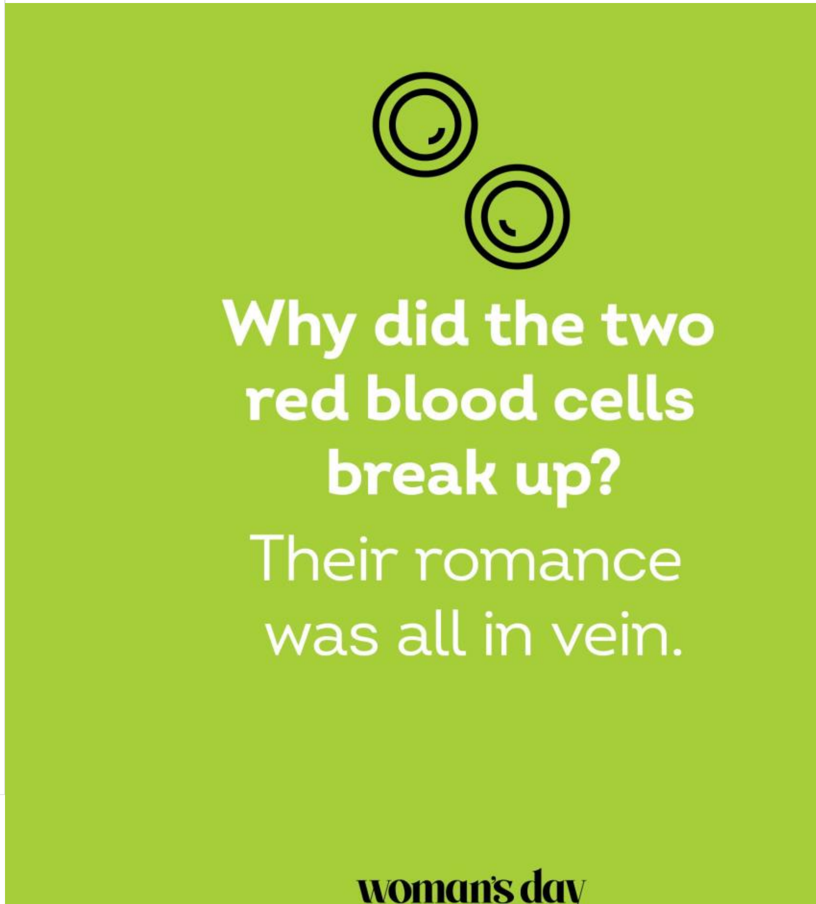
How do harmonic emission behave? (a)

Cigre/Cired C4-109 method: accepted in SA grid code compliance assessment methodology

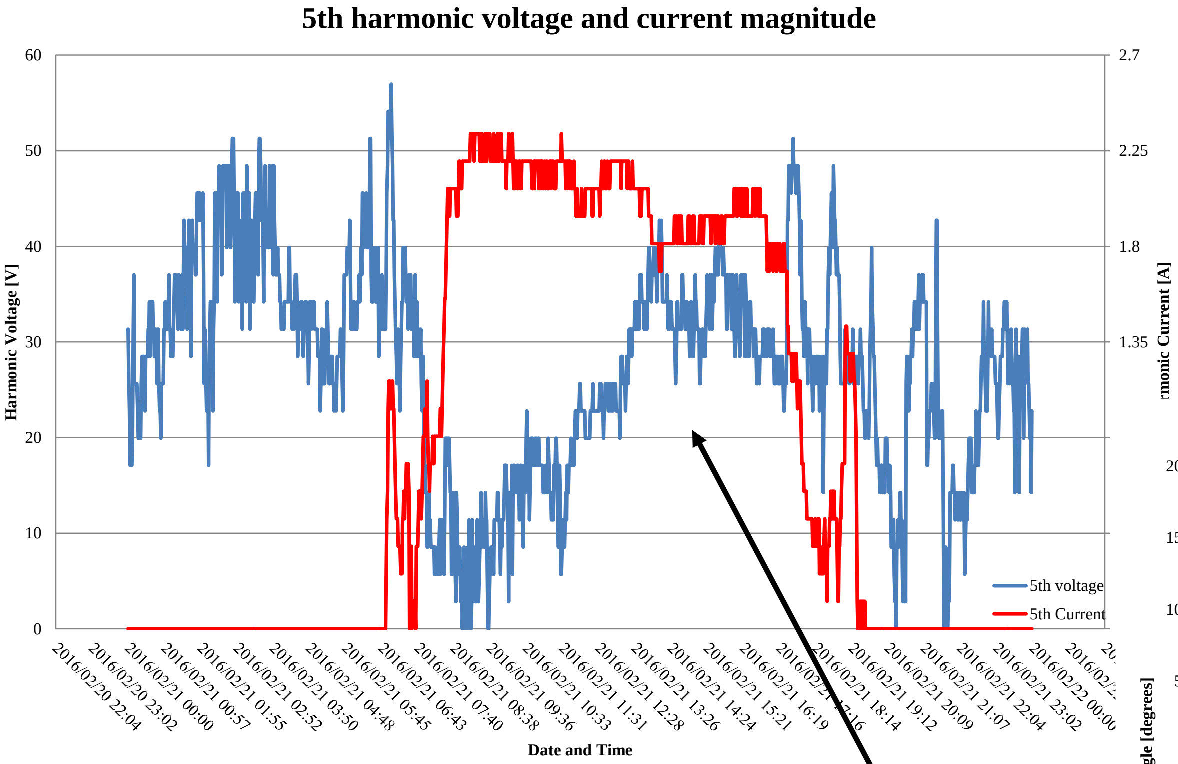


How do harmonic emission behave? (b)

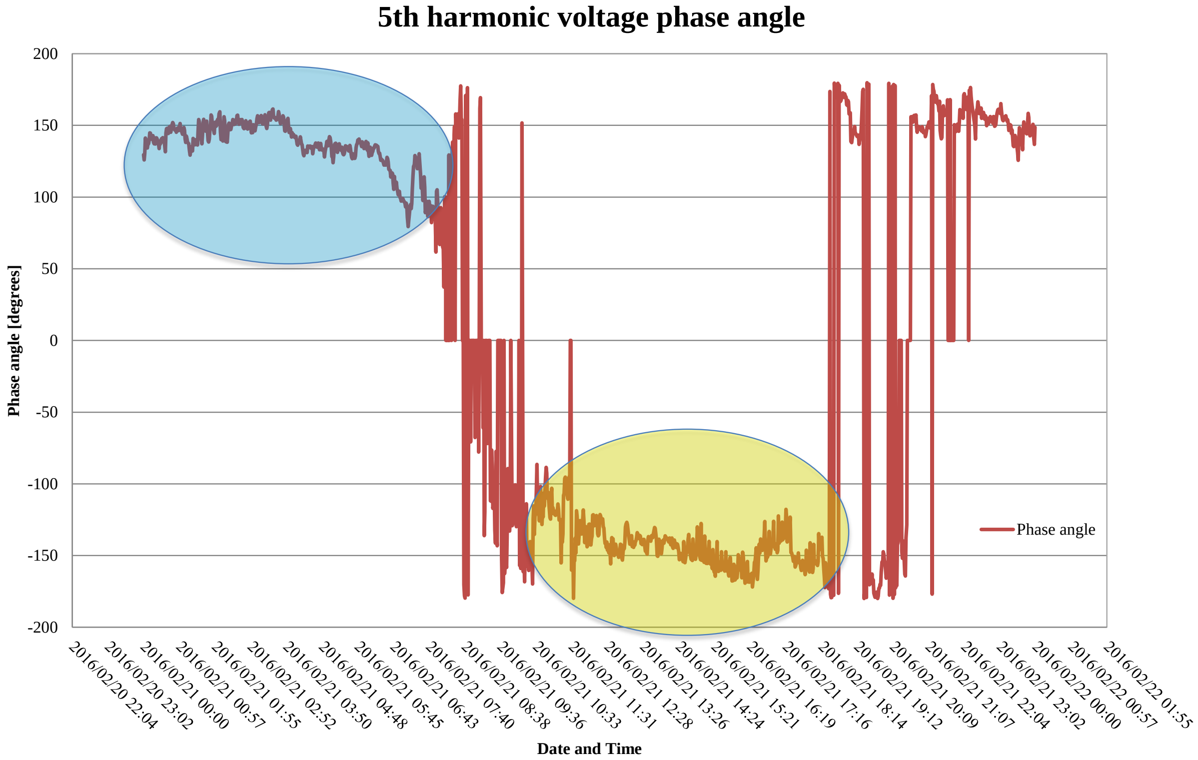




How do harmonic emission behave? (c)

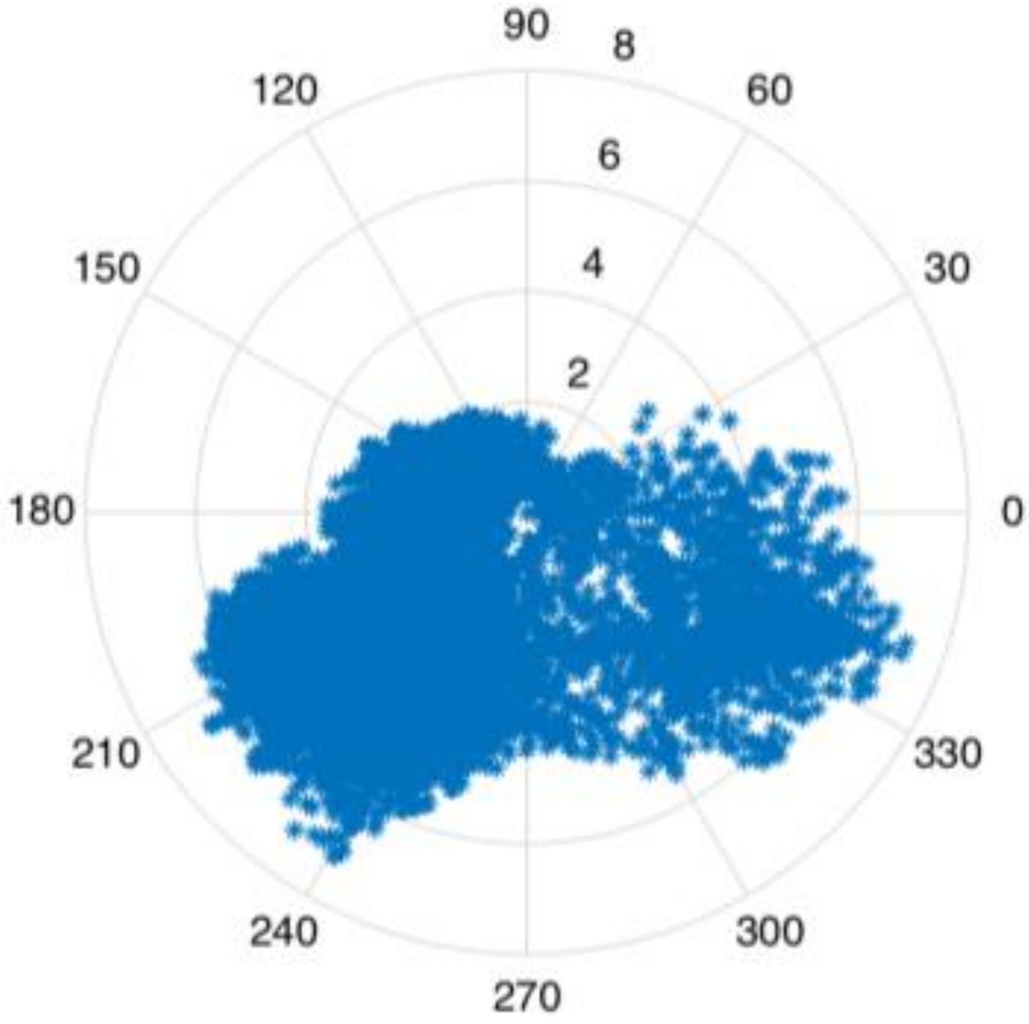


PV Plant 5th harmonic voltage and current profile

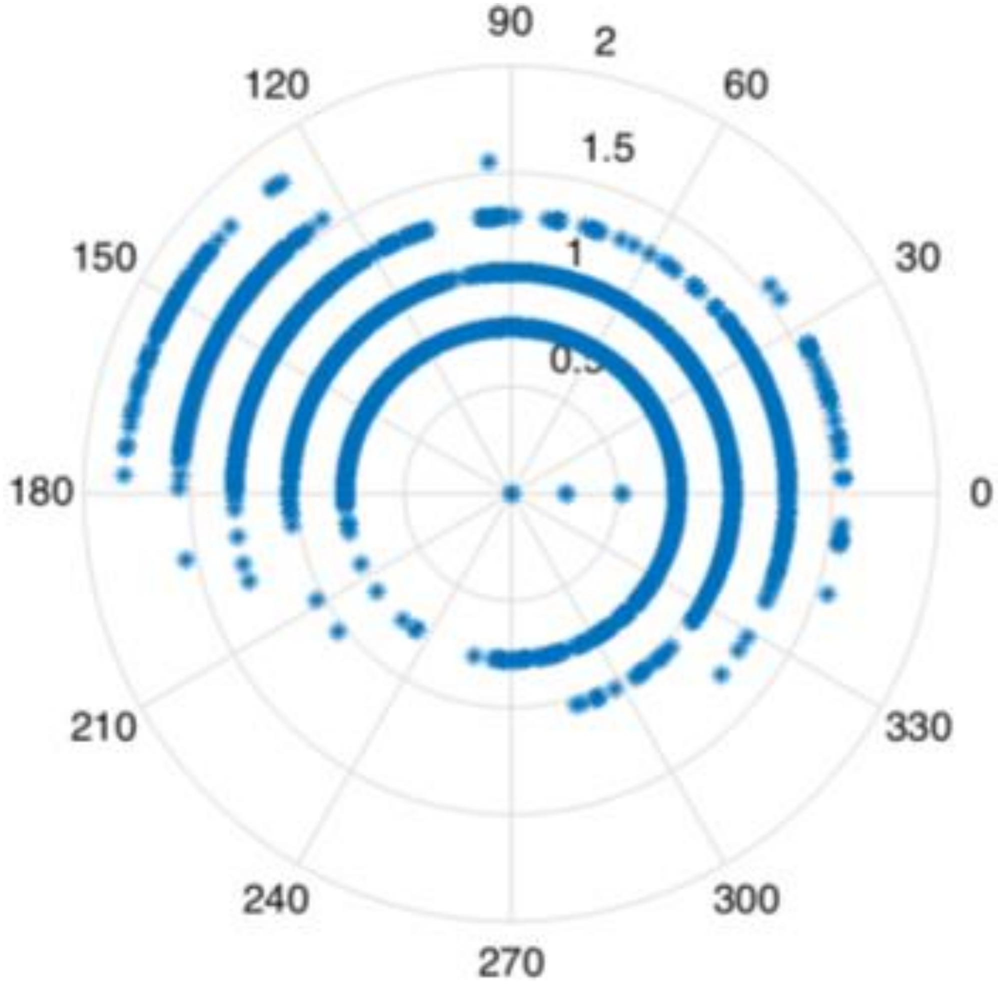


PV Plant 5th harmonic voltage phase angle profile

Not all harmonic current phasors are emission



5th harmonic current



7th harmonic current

Aggregate current harmonic phasors

Amplitude

$$Y_{prv,h} = \sqrt{\frac{1}{m}\sum_{j=1}^{m}\left(Y_{agg,h,j}\right)^2}$$

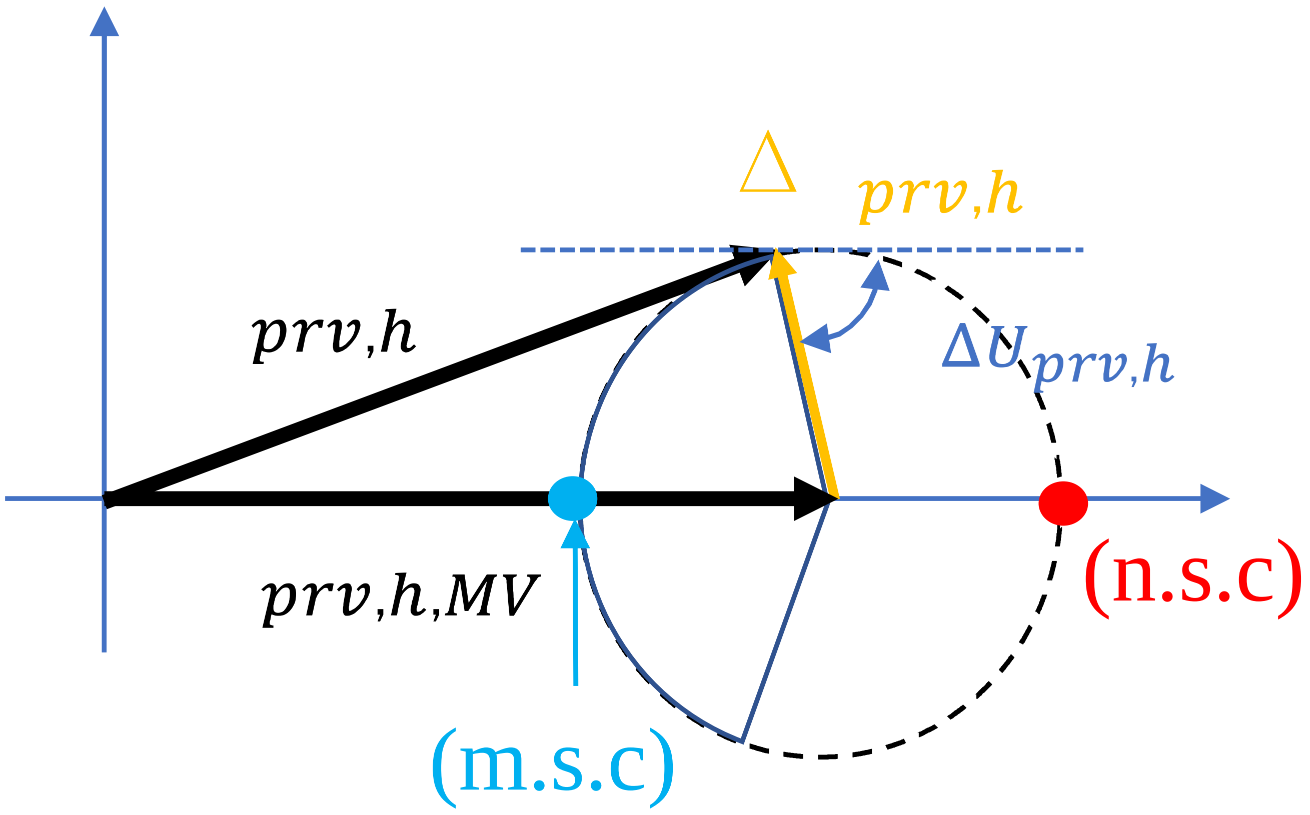
Phase angle

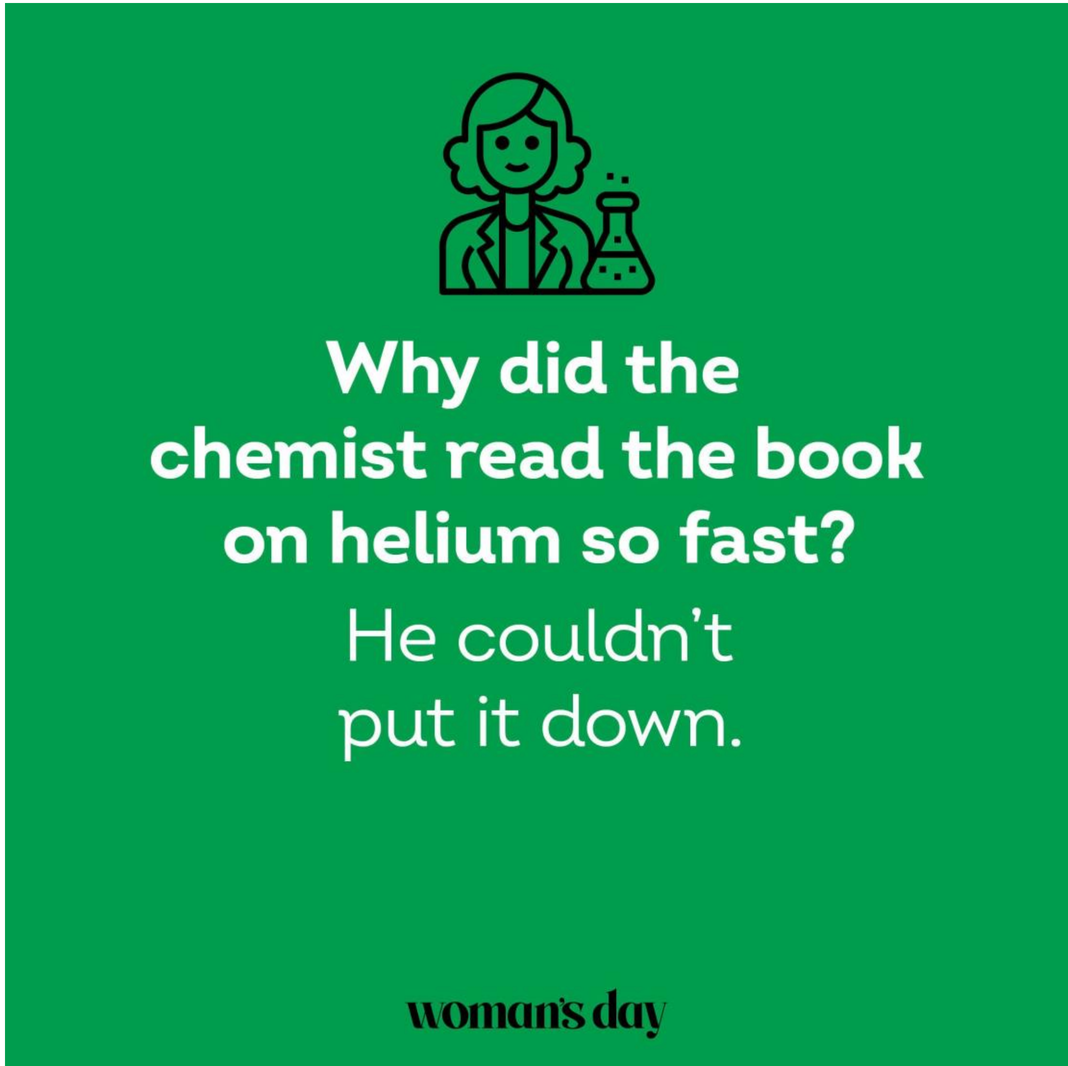
$$j_{prv,h} = \arg\left(\sum_{j=1}^{m}\bar{Y}_{agg,h,j}\right)$$

Test for stability: “prevalence” - using the 200 ms phasors

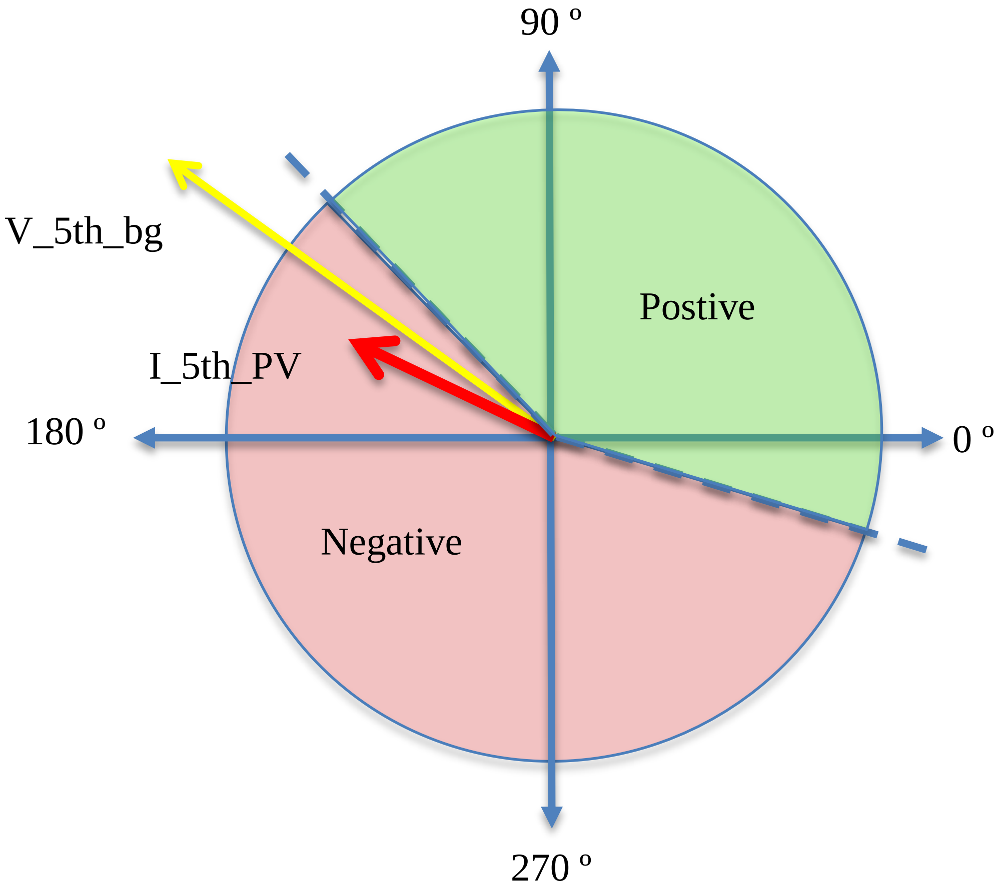
$$PR_{agg,h} = \frac{\left|\sum_{i=1}^{n}\boldsymbol{Y}_{H,h,i}\right|}{\sum_{i=1}^{n}\left|\boldsymbol{Y}_{H,h,i}\right|}$$

Emission – some phase angles are angels

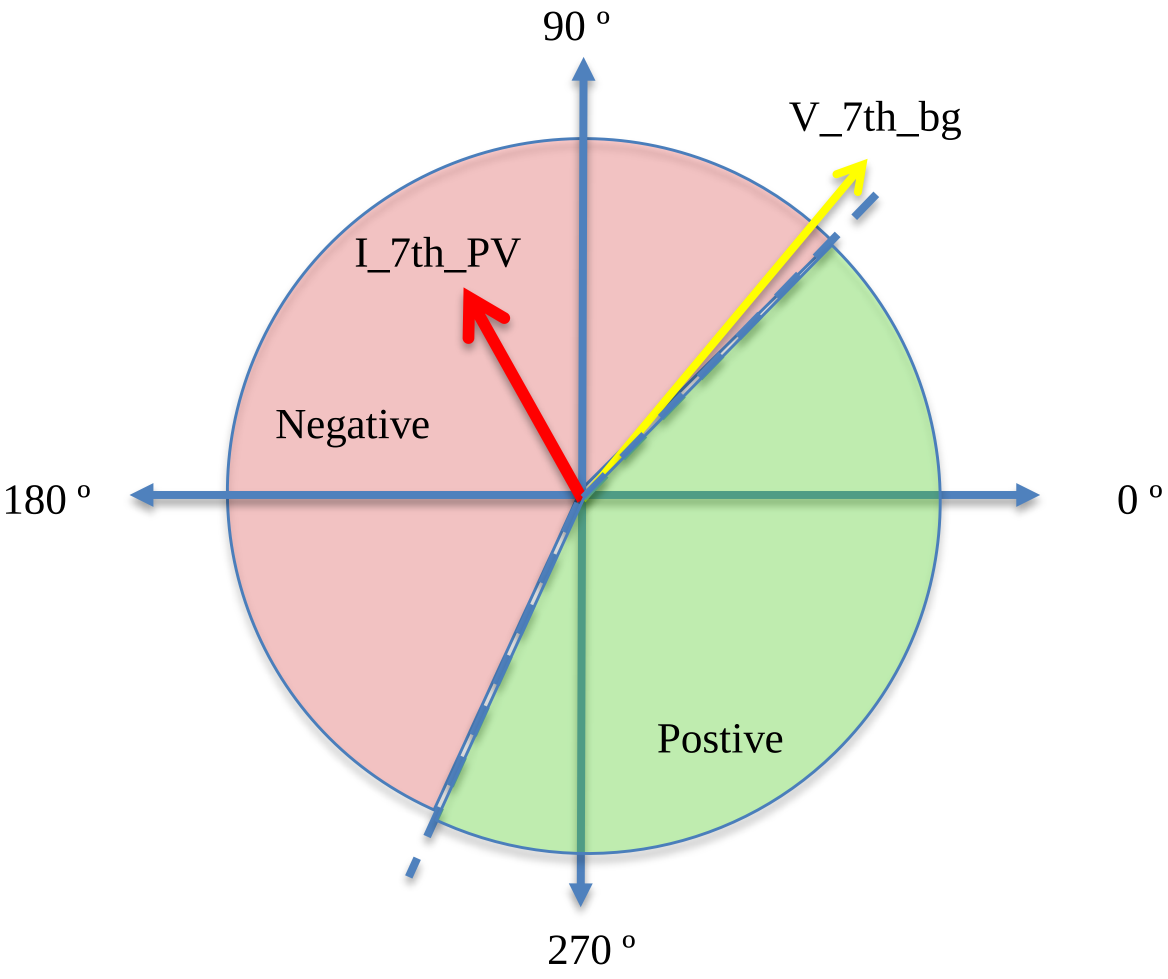




Emission becoming visual: Tracking harmonic emission – Continuous assessment is needed

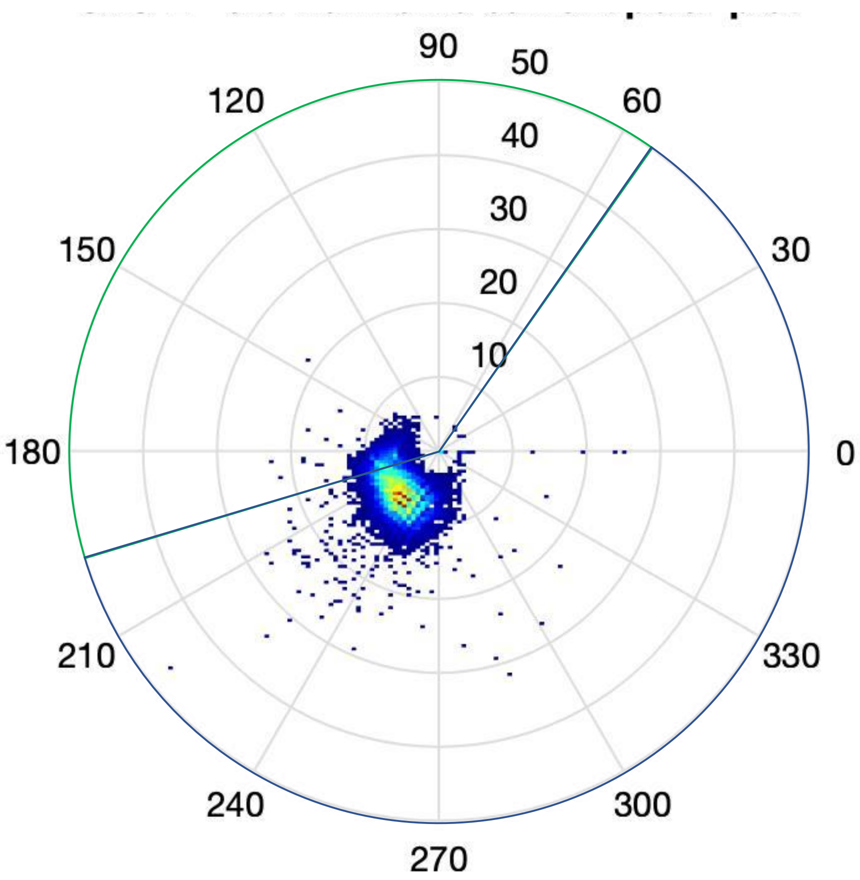


5th harmonic, range of emission

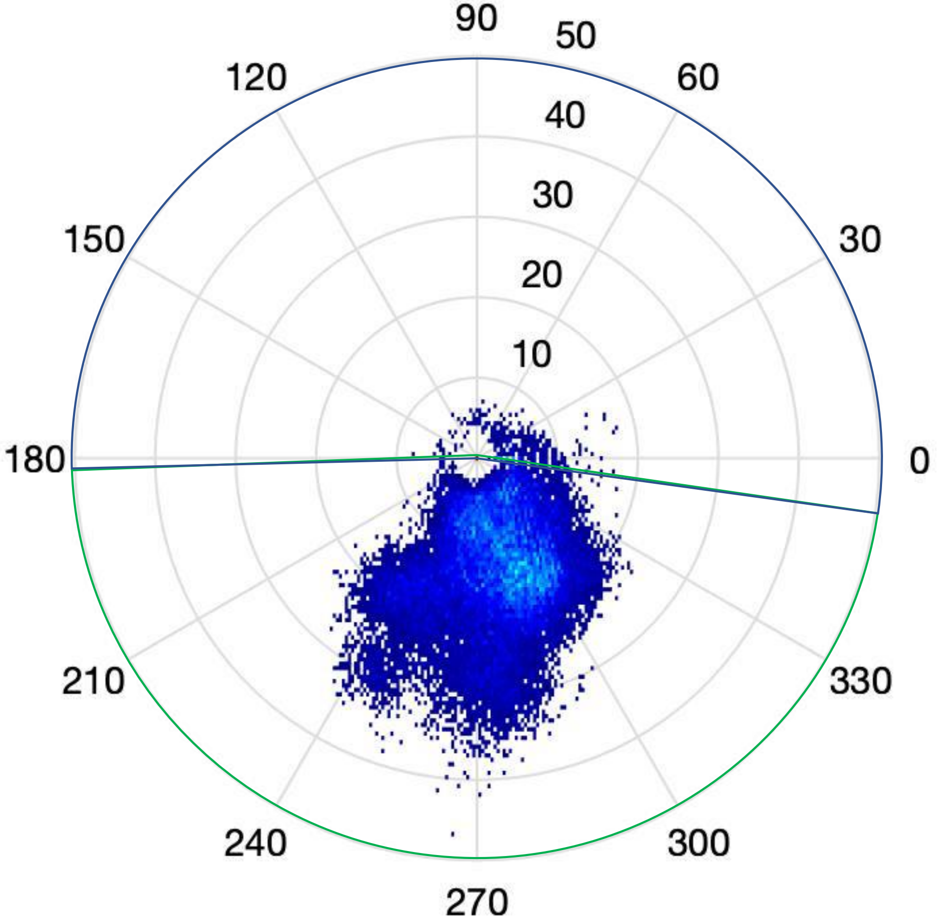


7th harmonic, range of emission

It also works for filters- track performance over time



3rd harmonic current being filtered not well all of the time



5th harmonic current being filtered well most of the time

Conclusion

- Renewable power plants to use utility grid in a contracted manner
- Compliance to grid code requirements, to be known/"tested"
- Assessment of compliance, every few years, but compliance in a dynamic distribution grid could be a time-variant feature
- Assessment of compliance to harmonic emission (and flicker and unbalance) constrained by fundamental scientific principles
- Pragmatic solutions available to engineers as a compromise
- Which are not fully "pseudo-scientific"
- Extend principles of IEC 61000-4-30 to phasors when searching for "most guilty" culprit: Aggregate harmonic phasors

to 23 September 2022
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