Review of common quality obligations: Discussion on the governance and management of harmonics

Sheila Matthews, Nasser Faarooqui and Professor Neville Watson

3 July 2024

ELECTRICITY AUTHORITY
TE MANA HIKO

Introductions and what we are covering today

- Purpose of today's webinar
- Context for the consultation paper
- Making a submission
- Overview of the paper and discussion
- Questions

  Pop them into the Q&A function

Purpose of today's webinar

The Authority is consulting with interested parties on a discussion paper on the governance and management of harmonics

The Authority has published a suite of consultation papers, comprising the following four documents:

1. **Cover paper:** *Future Security and Resilience – Review of common quality requirements in the Code, Suite of three consultation papers*
2. **Consultation (options) paper:** *Addressing more frequency fluctuations in New Zealand's power system*
3. **Consultation (options) paper:** *Addressing larger voltage deviations and network performance issues in New Zealand's power system*
4. **Consultation (discussion) paper:** *The governance and management of harmonics in New Zealand's power system*

Context

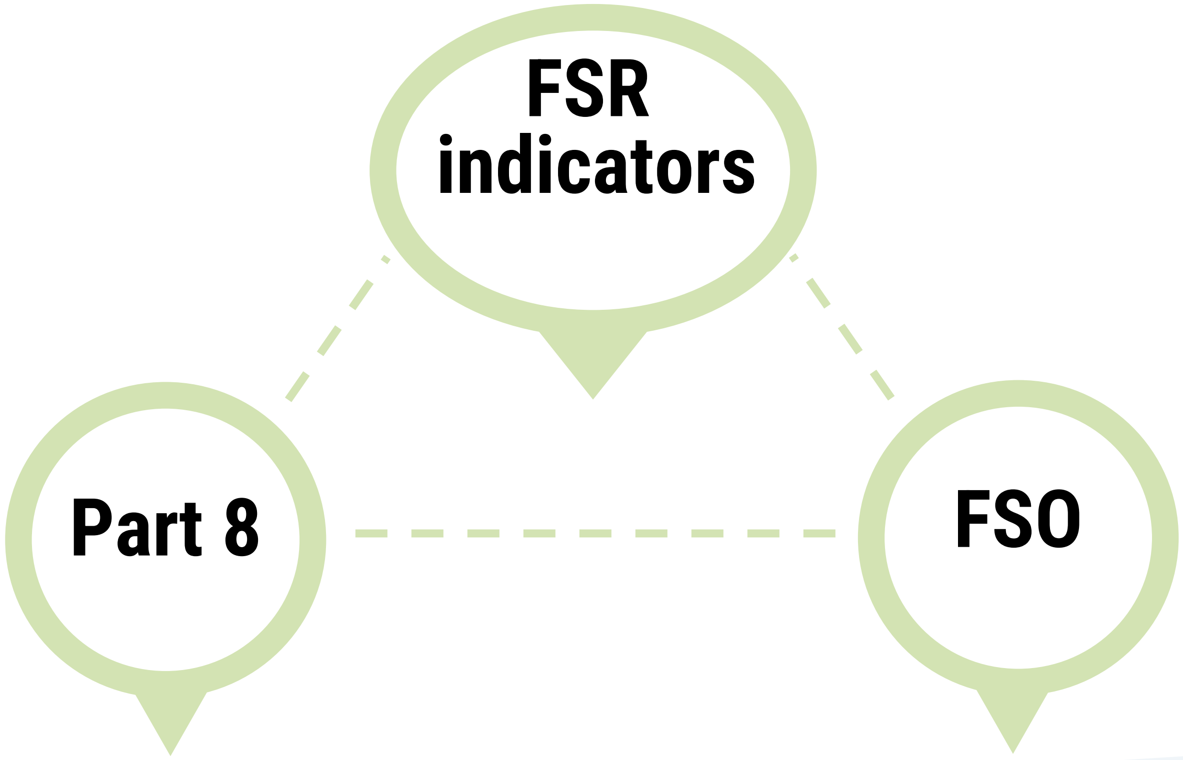
Our power system is changing

- Proportion of inverter-based resources (IBRs) is growing, and will continue to do so
- More electricity industry participants with new ways for consumers to participate
- Greater reliance on intermittent and variable wind and solar PV generation
- These changes affect the security and resilience of our power system

Future Security & Resilience Programme

Purpose

- **Ensuring New Zealand's power system remains secure and resilient as we transition to a low-emissions economy**



A secure and resilient power system promotes our objectives

Authority’s main statutory objective

- **Promote competition in, reliable supply by, and the efficient operation of, the electricity industry for the long-term benefit of consumers**

Additional objective

- Protect the interests of domestic consumers and small business consumers in relation to the supply of electricity to those consumers

Review of the Part 8 common quality requirements

Part 8 review is addressing 7 key common quality issues through a staged approach because the issues are foundational to the safe and reliable supply of electricity to consumers

We have been actively working with stakeholders and seeking input from technical experts across the industry, including:

- Common Quality Technical Group (CQTG)
- Professor Neville Watson of the University of Canterbury, a leading international expert in power system harmonics
- Electricity Engineers' Associations (EEA)
- MBIE and WorkSafe
- Overseas regulators (Australia, UK)

7 key common quality issues identified

Issue 1: Frequency

Issues 2, 3, 4: Voltage

Issue 5: Harmonics

Issue 6: Information

Issue 7: Code terminology

Our common quality consultations during 2023 & 2024

- *April – May 2023*
  - Consultation on 7 key common quality issues
- *June – August 2024*
  - Consultation on short-listed options to help address frequency and voltage issues (key issues 1 – 4)
  - Consultation on current harmonics arrangements in New Zealand (key issue 5)
- *Quarter 4, 2024*
  - Consultation on proposed Code amendments to help address some of the common quality information and Code terminology issues (key issues 6 and 7)

Making a submission

Appendix B of the consultation paper provides the format for submissions

Submissions close **5pm, Tuesday 20 August**

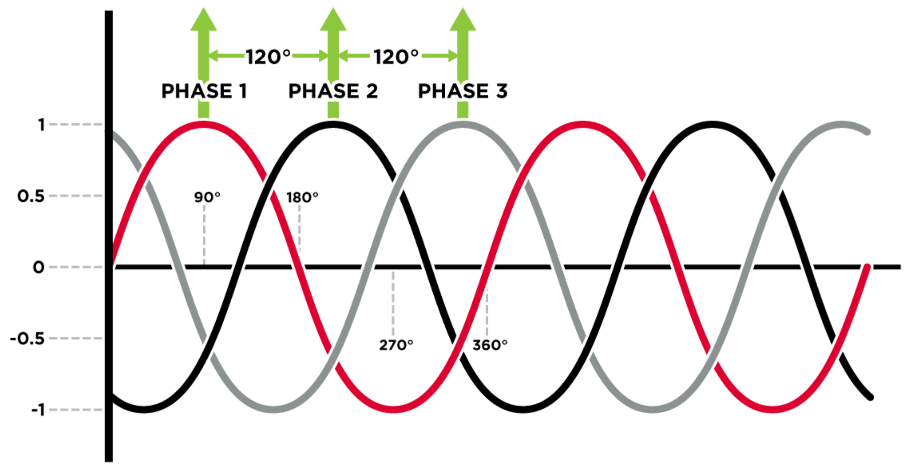
If you have any queries or would like to meet individually, email us at **FSR@ea.govt.nz**

DISCUSSION PAPER:

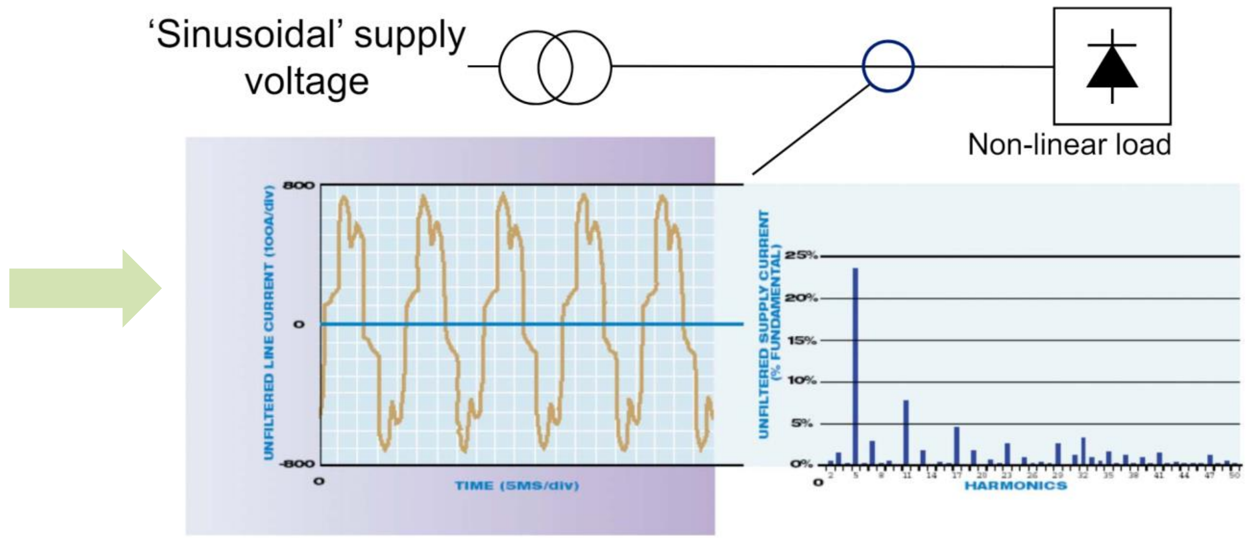
The governance and management of harmonics in New Zealand's power system

What are 'Harmonics'?

Harmonics are distortions or interruptions in the current or voltage waveforms



Ideal voltage sources are sinusoidal



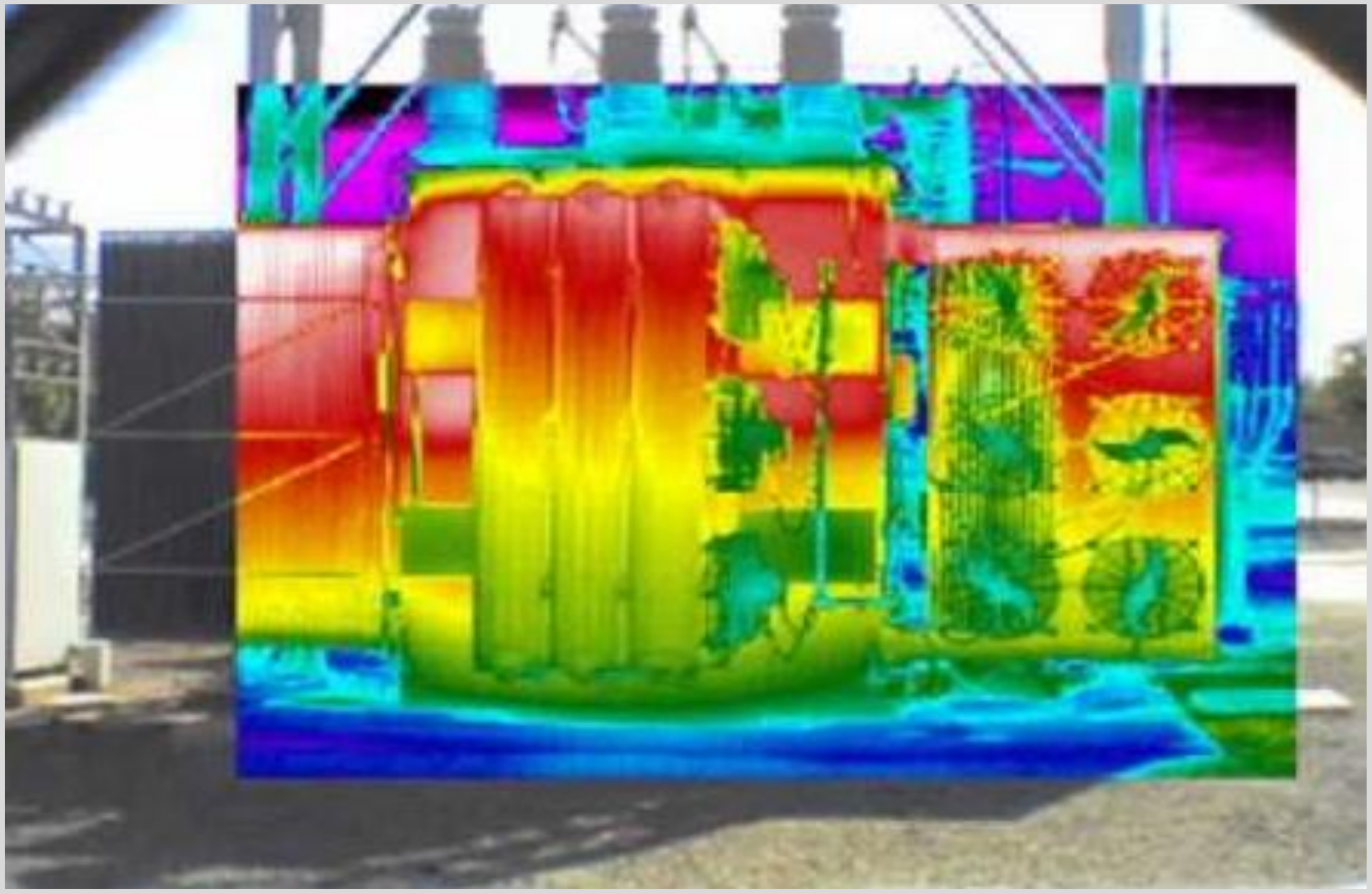
Measured voltage supply with harmonics (distortions)

Some common sources of harmonics

Harmonic Producer	Harmonic	Notes
Transformers during energization	2nd	Gone after 0.1 sec
Arc Welders and Furnaces	Broad spectrum, 2nd, 3rd, 4th, 5th, 7th, 11th	Filters usually included
Ballasts, electronic	3rd, 5th, 7th	3rd cancelled in delta transf
Plating Rectifiers	Typical 5th, 7th, 11th, 13th, etc, magnitude 1/n	Varies by number of pulses
Computers, switching power supplies	3rd, 5th, 7th	3rd cancelled in delta transf
DC Drives	Typical 5th, 7th, 11th, 13th, etc, magnitude 1/n	Varies by number of pulses
AC drives	Typical 5th, 7th, 11th, 13th, etc,	Varies by type, number of pulses, system Z
Switching Cap banks	High frequencies, depend on system	Transients, induce system resonances

What are the issues with harmonics?

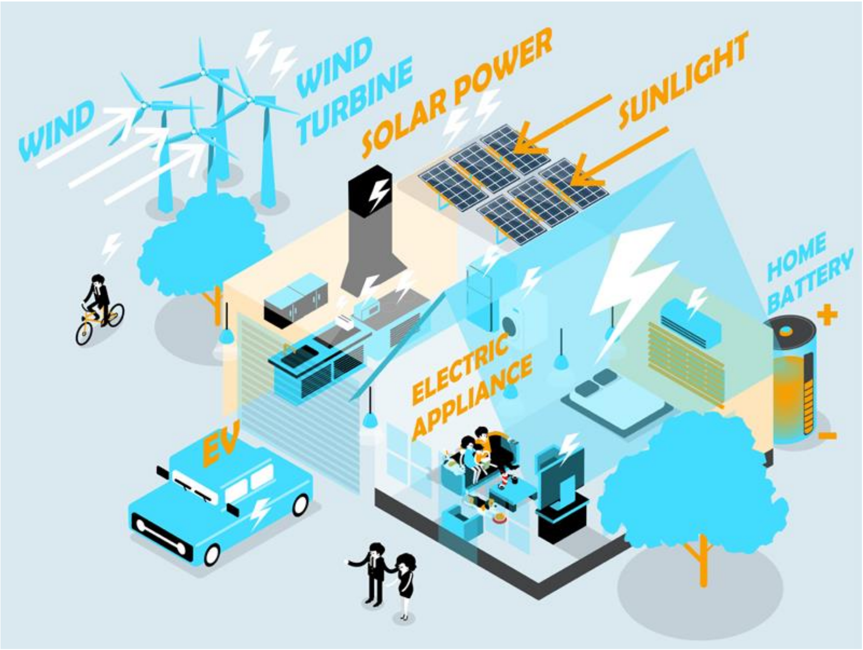
1. Poor power quality
2. Harmonic currents create heat for example in transformers is shown below
3. Harmonics may lead to resonance with line inductance and capacitance
4. Excessive harmonics distorts input voltage which may cause electrical equipment to operate erratically or result in premature failure.



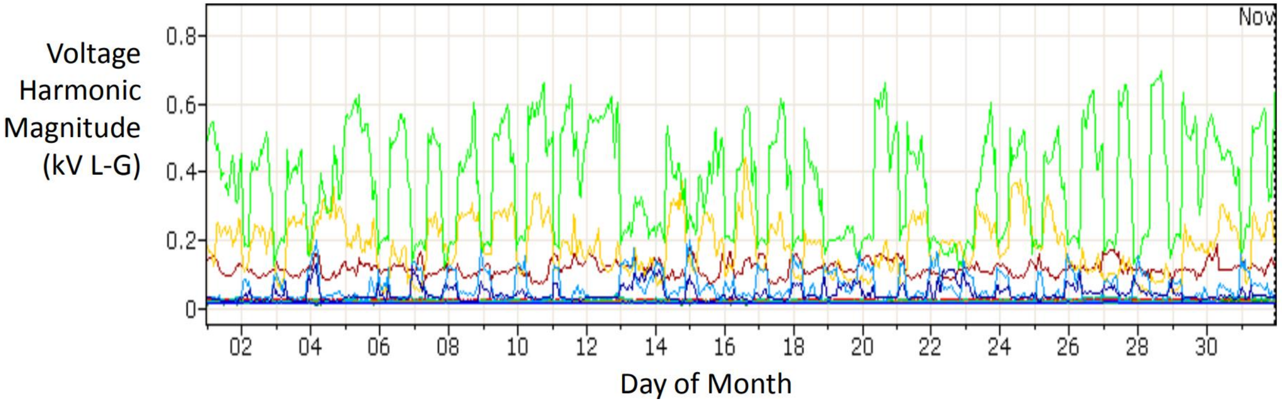
Changes to the power system

Traditionally the power system has had minimal harmonic distortions as the source of power was mainly "synchronous" based generation.

The rapid increase in 'non-synchronous' based generation is introducing increasing levels of harmonics into the power system.



Voltage harmonics measured at 110 kV Wind Farm (UK)



Green: 7th Harmonic
Yellow: 5th Harmonic
Red, **blue** etc.: Other

GOVERNANCE OF HARMONICS

Evolution of the governance of harmonics in New Zealand

ENGINEERING RECOMMENDATION G.5/3
System Design and Development Committee
September 1976
CLASSIFICATION 'C'

THE ELECTRICITY COUNCIL

CHIEF ENGINEERS' CONFERENCE

LIMITS FOR HARMONICS

IN THE

UNITED KINGDOM ELECTRICITY SUPPLY SYSTEM

NZECP 36:1993

NEW ZEALAND ELECTRICAL CODE OF PRACTICE

for

HARMONIC LEVELS

Issued by the Office of
The Chief Electrical Inspector,
Energy and Resources Division, Ministry of Commerce

Harmonic limits standard set in UK in 1976

Current Harmonic limits standardized in 1993

Harmonics governance issues

Outdated regulation

- The Code and the Electricity (Safety) Regulations 2010 both refer to the 'New Zealand Electrical Code of Practice for Harmonic Levels' (NZECP 36:1993)
- NZECP 36:1993 is based on the 1981 'Limitation of Harmonic Levels Notice'
- Harmonic emissions limits in NZECP 36:1993 were developed in the 1960s and 1970s
- Technology and the NZ power system have changed since then

Ambiguity around applicability of harmonics standards

- The Code and the Safety Regulations contain harmonics standards
  - The Code is subordinate to the Safety Regulations
  - No conflict between the two at present
  - Complying with the Code means complying with the Safety Regulations
  - But participants may not realise this – potential area of confusion
- The Safety Regulations apply two different standards (NZECP 36:1993 & IEC 61000 3 2) to equipment covered by the AS/NZS 4777.2 standard in Part 6 of the Code and in distributors' connection and operation standards for distributed generation

Scattered regulation

NZECP 36:1993

NEW ZEALAND ELECTRICAL CODE OF PRACTICE

for

HARMONIC LEVELS

Issued by the Office of
The Chief Electrical Inspector,
Energy and Resources Division, Ministry of Commerce

New Zealand standard set in 1993

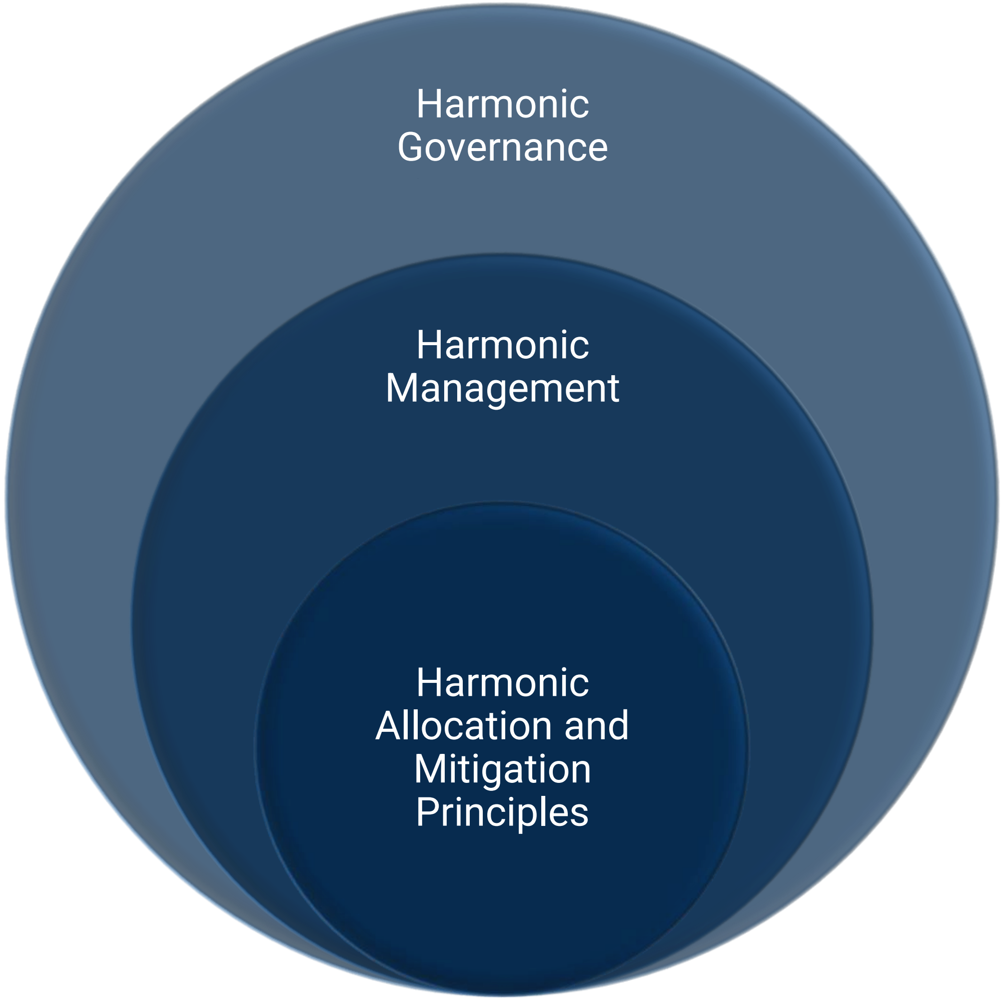
Harmonic Order	IEC 61000-3-6	IEEE Std. 519	Discrepancy (%)
5	5%	3%	67%
7	4%	3%	33%
11	3%	3%	0%
13	2.5%	3%	17%
17	1.6%	3%	47%
19	1.2%	3%	60%
23	1.2%	3%	60%
25	1.2%	3%	60%
THD	6.5%	5%	30%

	IEC 61000-3-6	IEEE Std. 519
Planning Levels	Detailed	Not Detailed
	Documented well	Not Documented well

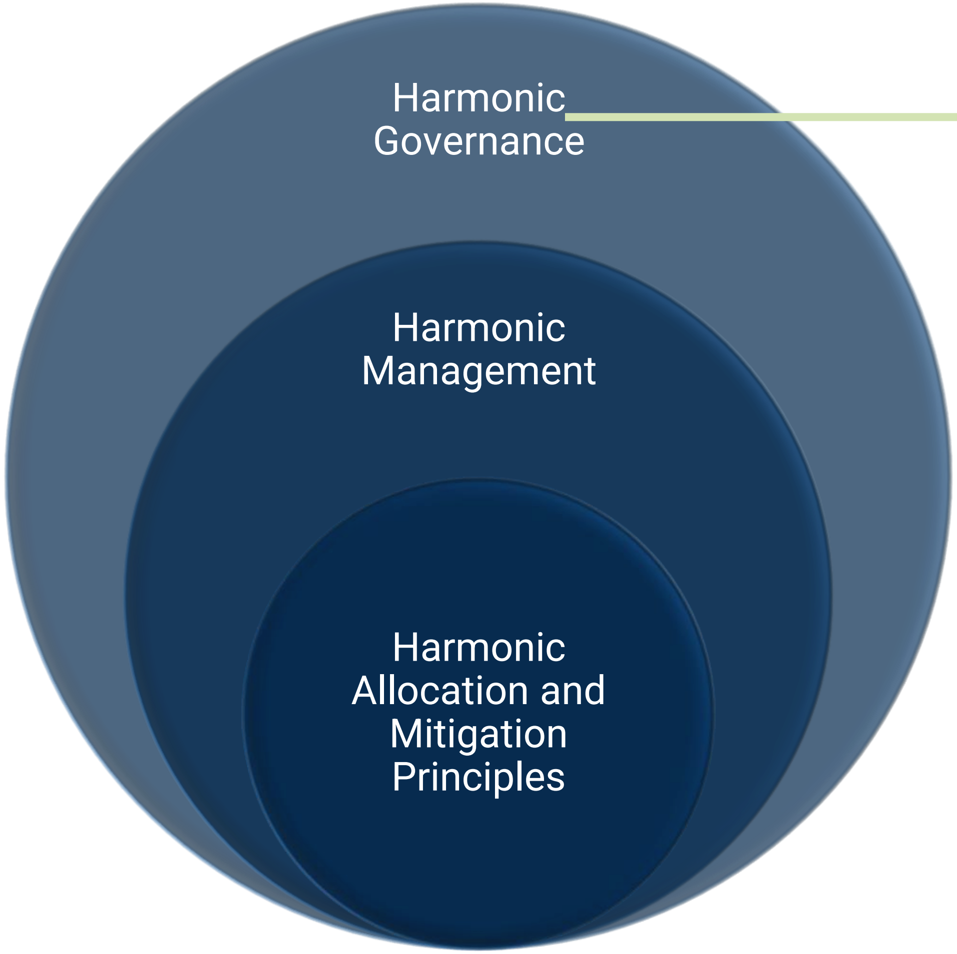
One of the differences between IEC 61000 and IEEE 519 standard – Planning levels at Medium Voltage Networks

MANAGEMENT OF HARMONICS

Conceptual framework for regulating harmonics

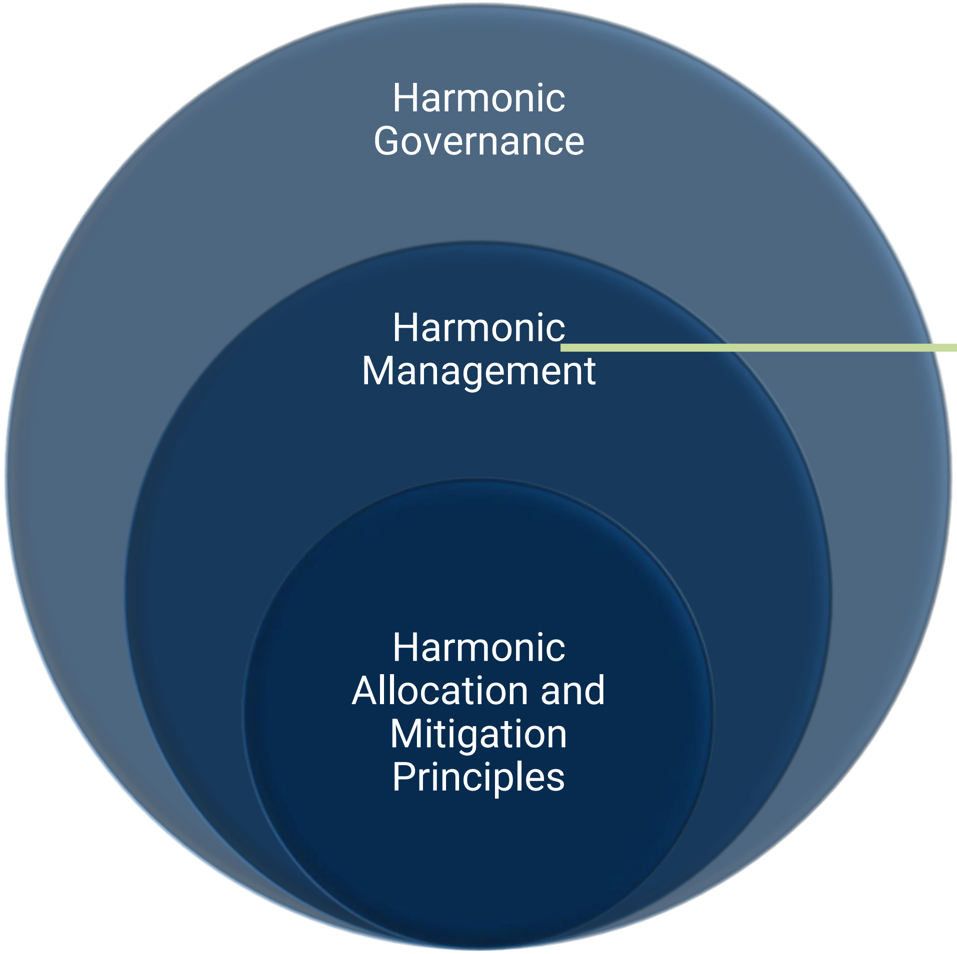


Conceptual framework for regulating harmonics



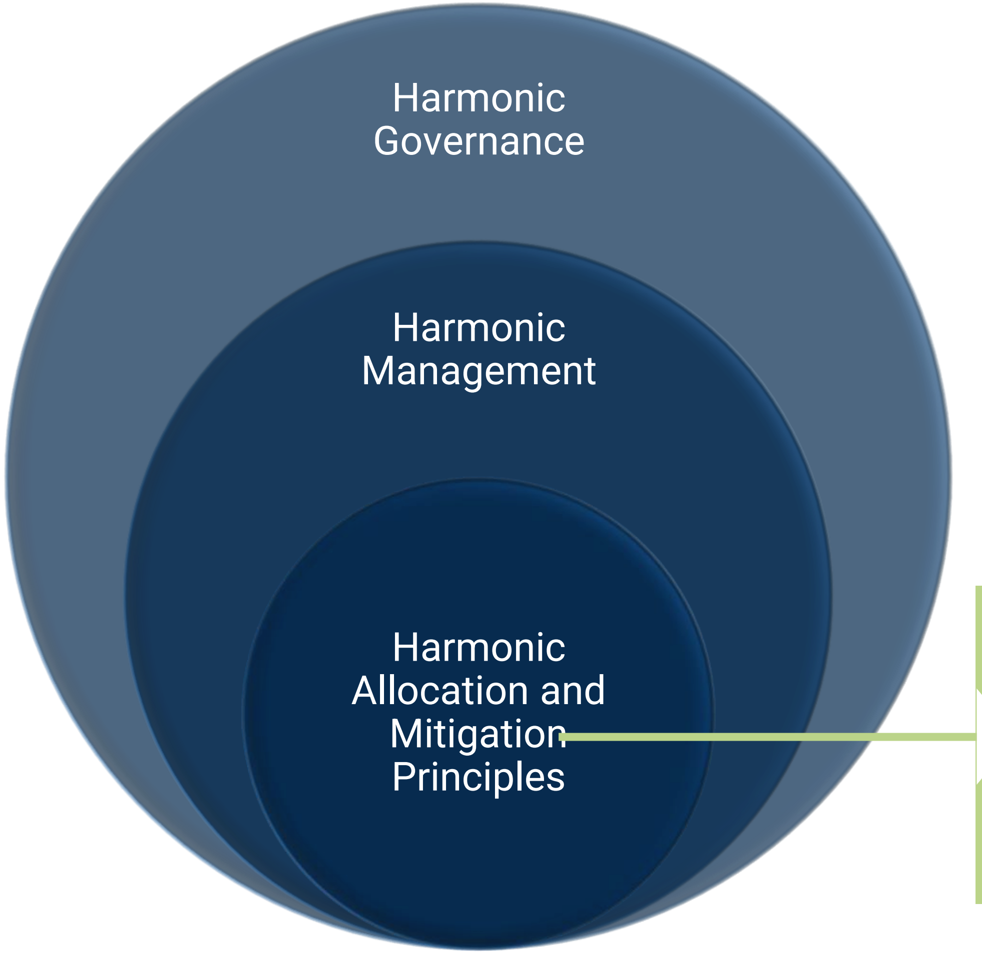
1. Limitations of existing regulation – NZECP36:1993
2. Applicability of AS/NZS 61000 suite of standards in New Zealand for harmonics regulation
3. Considerations for other standards/approaches

Conceptual framework for regulating harmonics



1. Roles and Responsibilities
2. Harmonics Measurement
3. Planning and Compatibility levels
4. Voltage levels
5. Compliance timeframes

Conceptual framework for regulating harmonics



1. Status quo
2. AS/NZS based stage wise approach
3. Other approaches for harmonic allocation and mitigation

Links to relevant documents

- Future Security and Resilience roadmap – August 2022
- Future Security and Resilience indicators
- Consultation: The future operation of New Zealand's power system
- Submissions: The future operation of New Zealand's power system
- Consultation: Review of common quality requirements in Part 8 of the Code – Issues paper
- Consultation: Review of common quality requirements in Part 8 of the Code – Options papers to address issues related to frequency and voltage issues and a discussion paper on issues related to harmonics

A DISCUSSION ON THE ISSUES OF HARMONICS

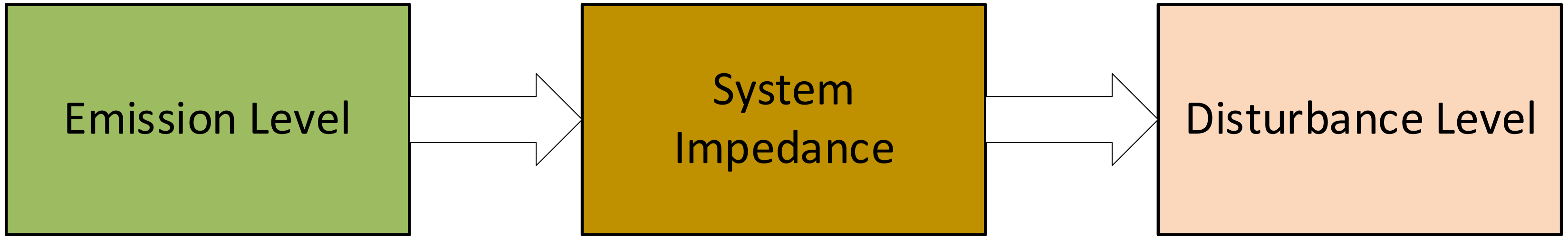
By Prof. Neville Watson

University of Canterbury

Outline

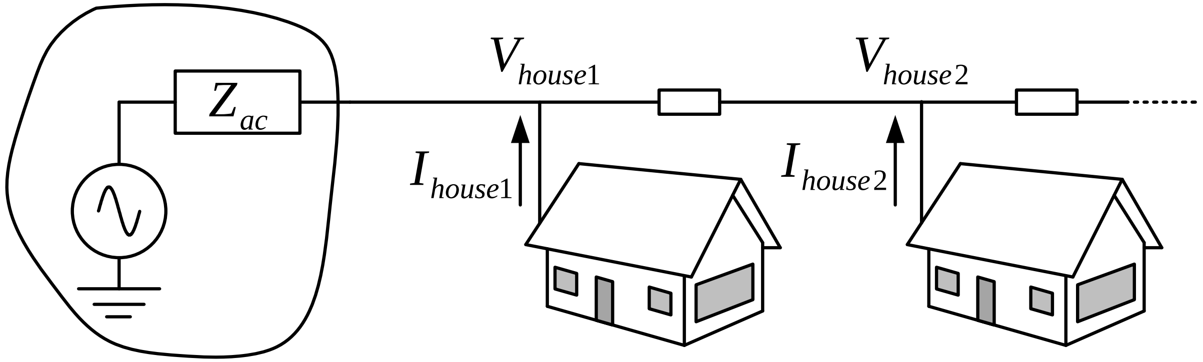
1. Fundamentals
2. Allocation
3. Complexities
4. Present day Examples
5. Mitigation

Fundamentals



Current
- Fluctuating
- Distorted

Voltage
- Fluctuating
- Distorted



Fundamentals: Types of Standards

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

1. Absolute (e.g. NZECP36)

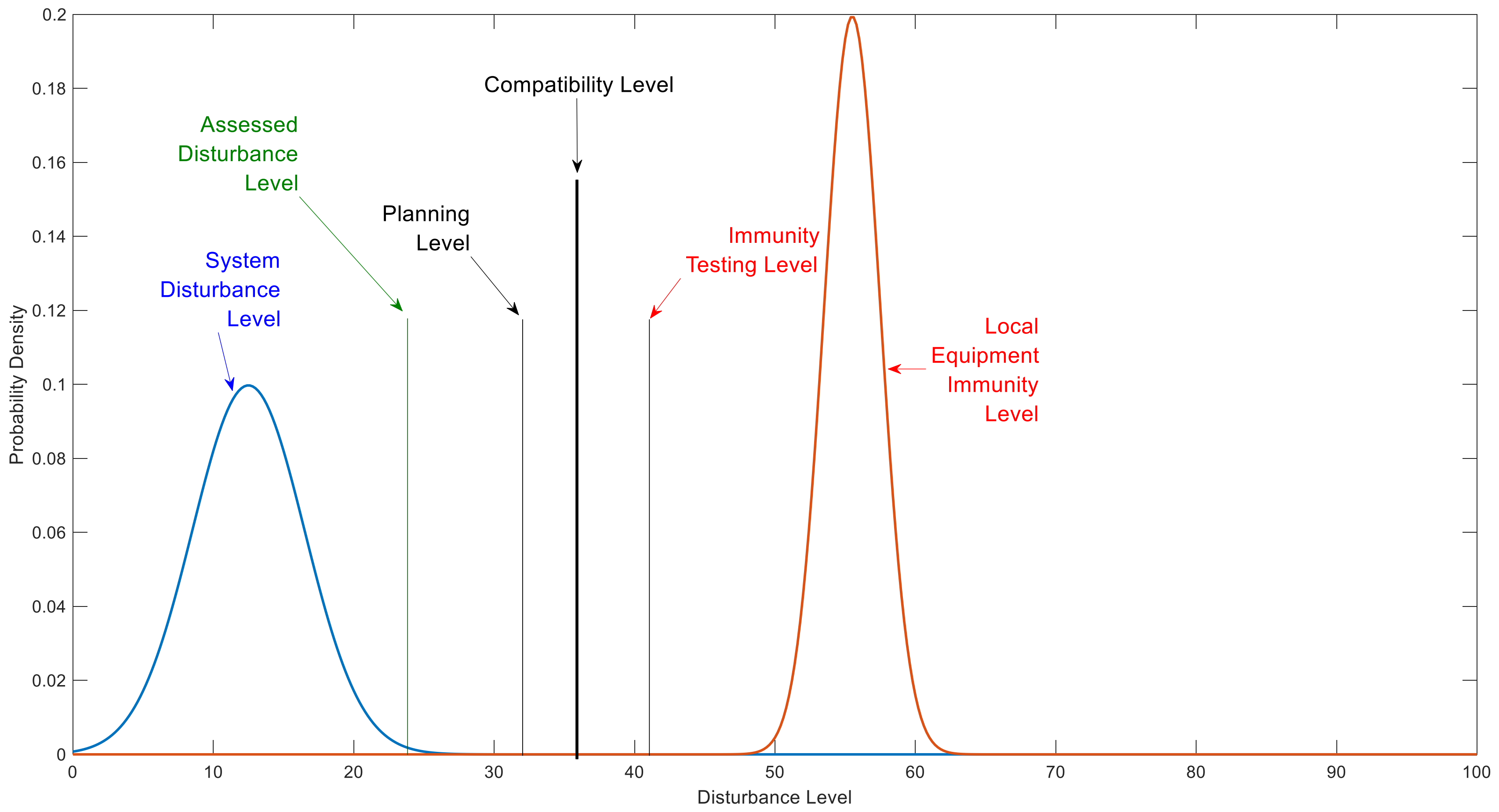
2. Probabilistic (AS/NZS and IEC Standards)

Note that there are two types:

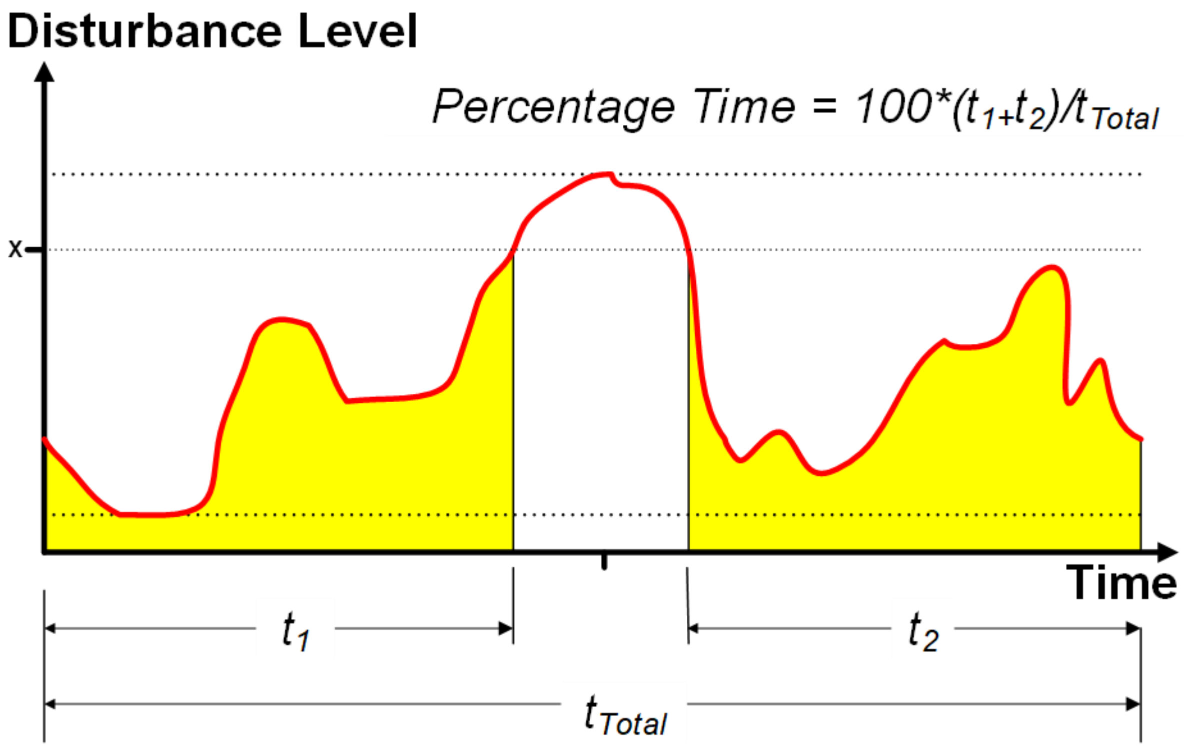
Installation standards and ***Device Standards***

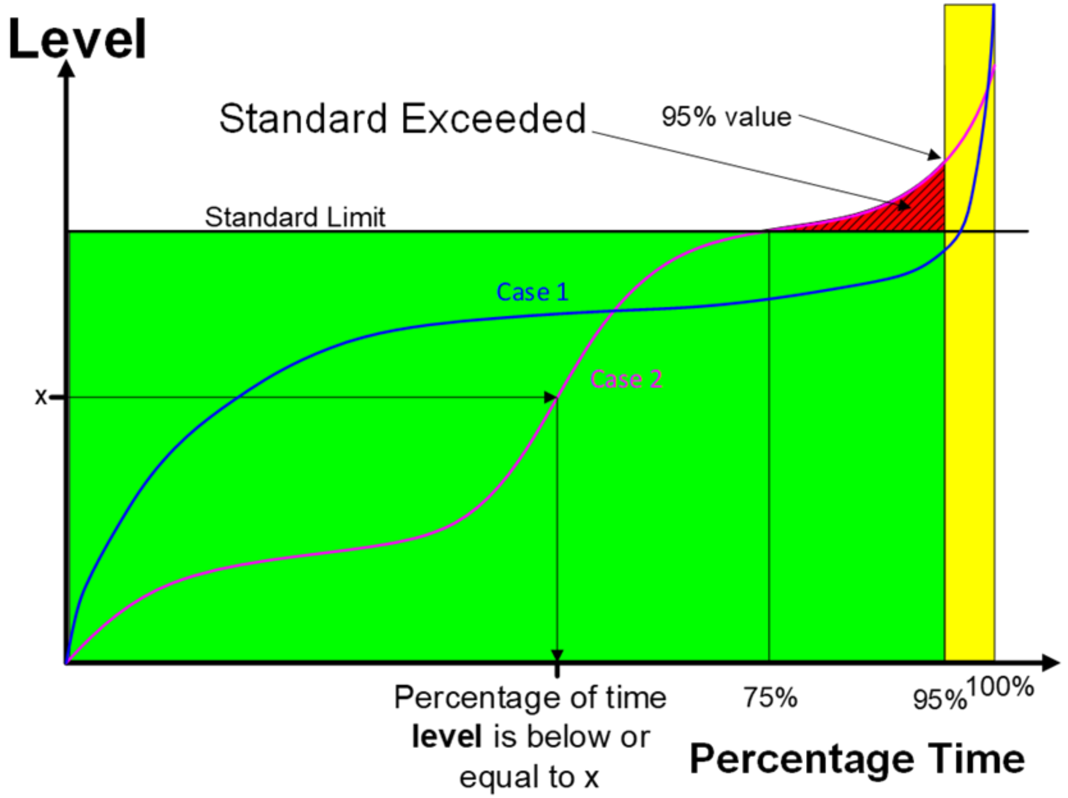
- Allow compliance of a site by 1 week measurements
- Considers different system loading/impedance

Illustration of basic voltage quality concepts with time statistics relevant to one site within the whole system

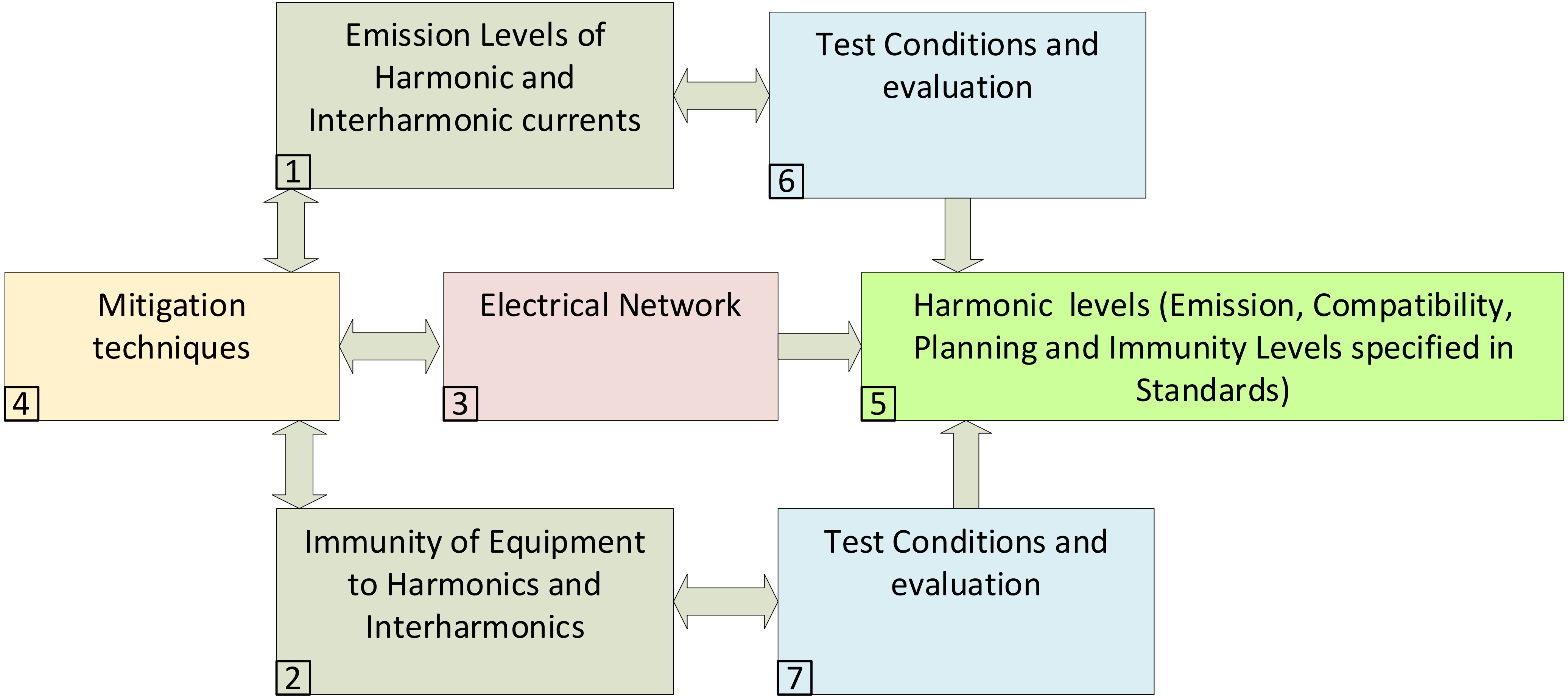


Use of Cumulative Probability Density function

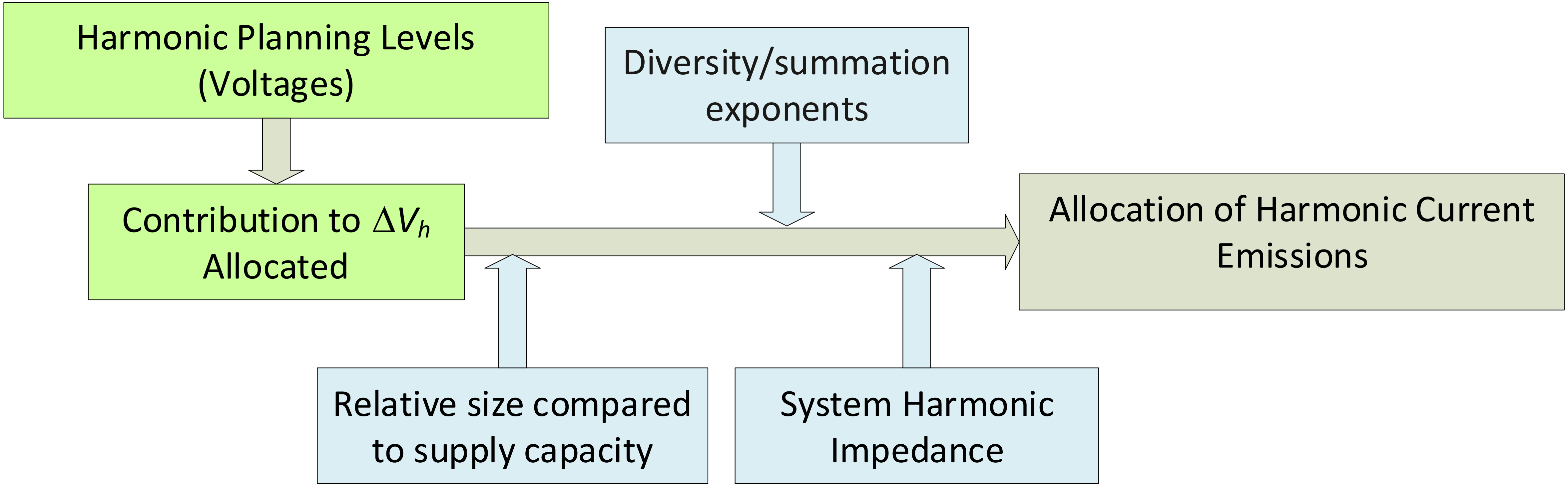




Framework for setting Harmonic Levels



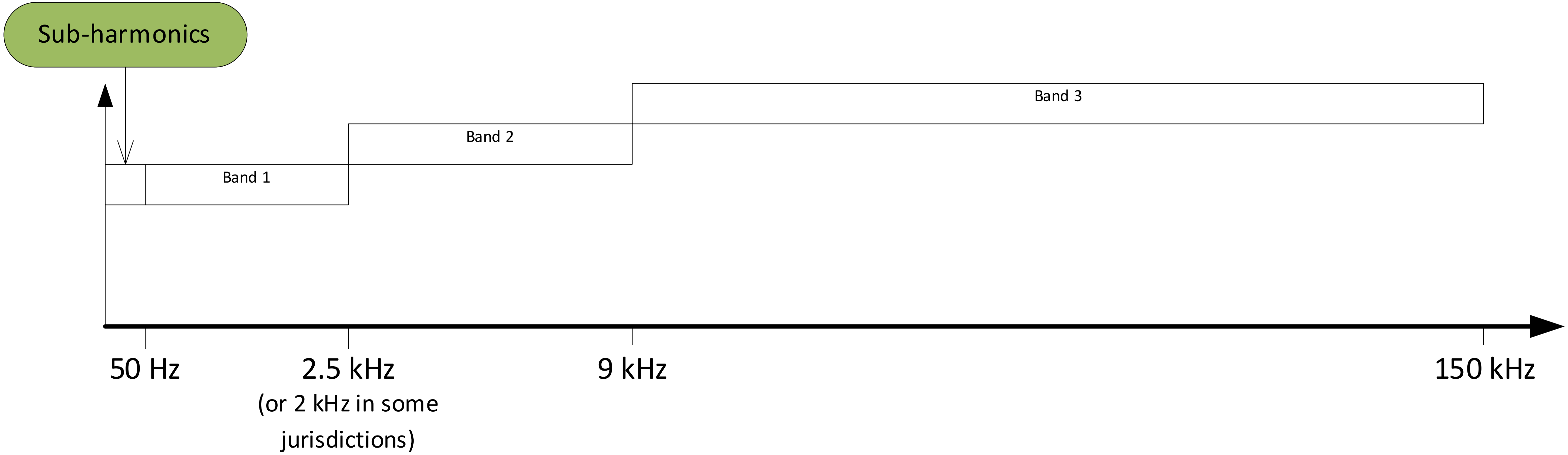
Allocation of permissible Emission Levels



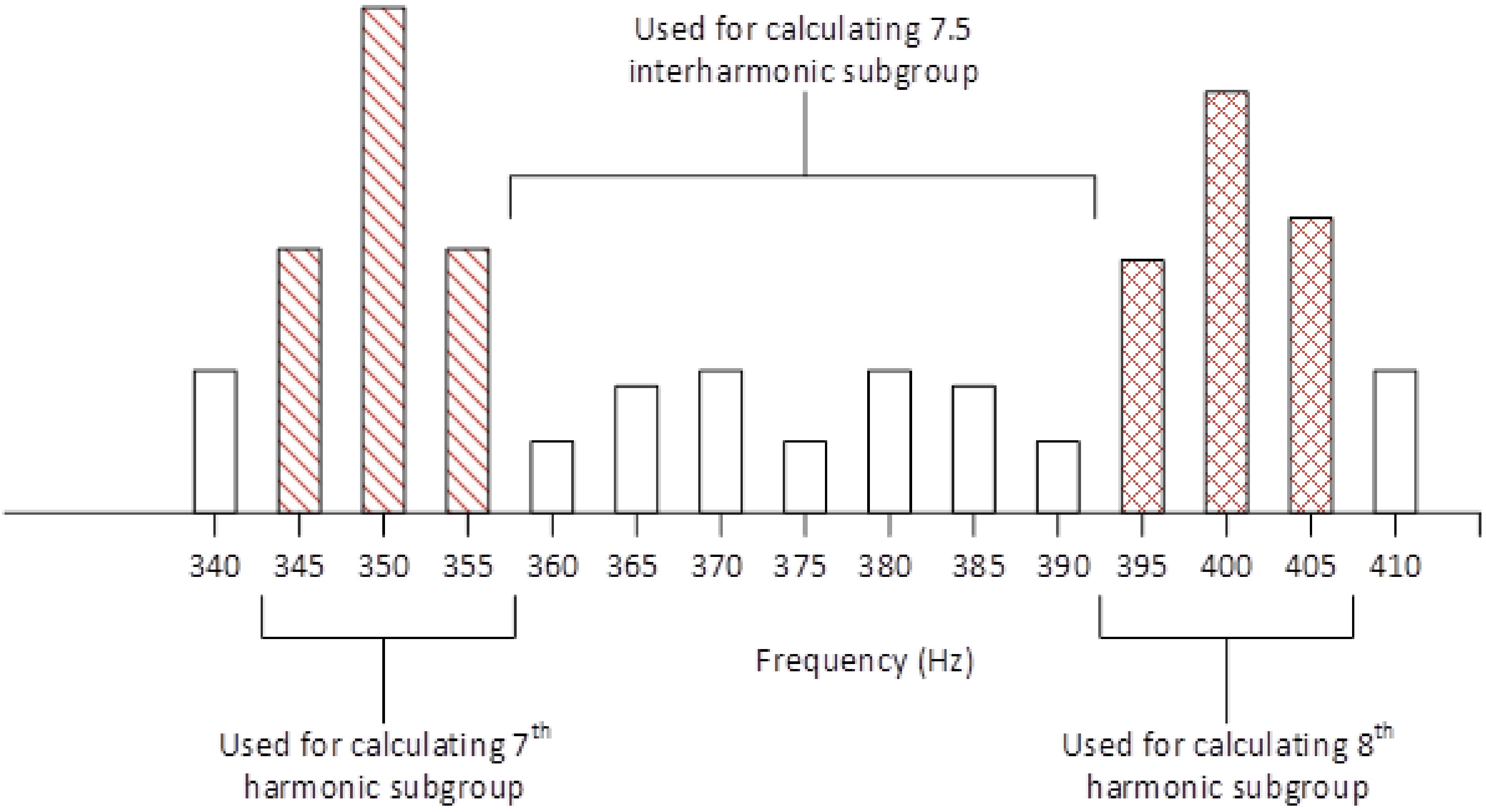
Principles for Standards

1. Limits must be matched to the compatibility level of equipment.
2. Rather than setting limits to accommodate the most sensitive devices, work on the lack of immunity for some devices. Hence the importance of immunity standards.
3. Different types of standards (e.g. Installation and Device).
4. Clarity of compliance and fairness in allocation.
5. Enforcement.

Spectrum


Sub-harmonics
Band 3
Band 2
Band 1
50 Hz
2.5 kHz
(or 2 kHz in some
jurisdictions)
9 kHz
150 kHz

Subgroups

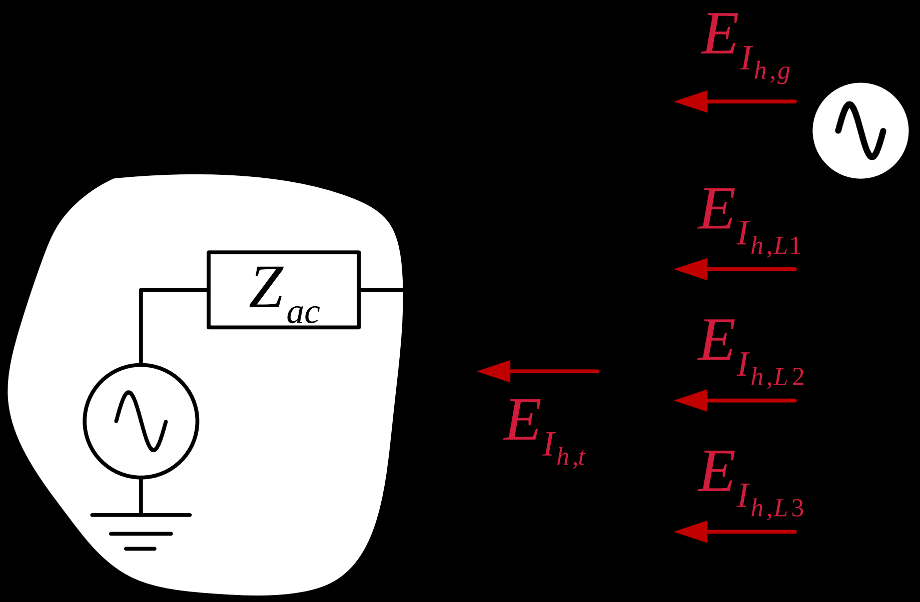


Inaccuracies in the spectral component magnitudes cause spill-over to neighbouring spectral components either side of the harmonic.

The international community is moving towards the use of the interharmonic subgroup concept of *IEC 61000-4-7 Ed. 2* instead of individual interharmonic components.

Wrinkles

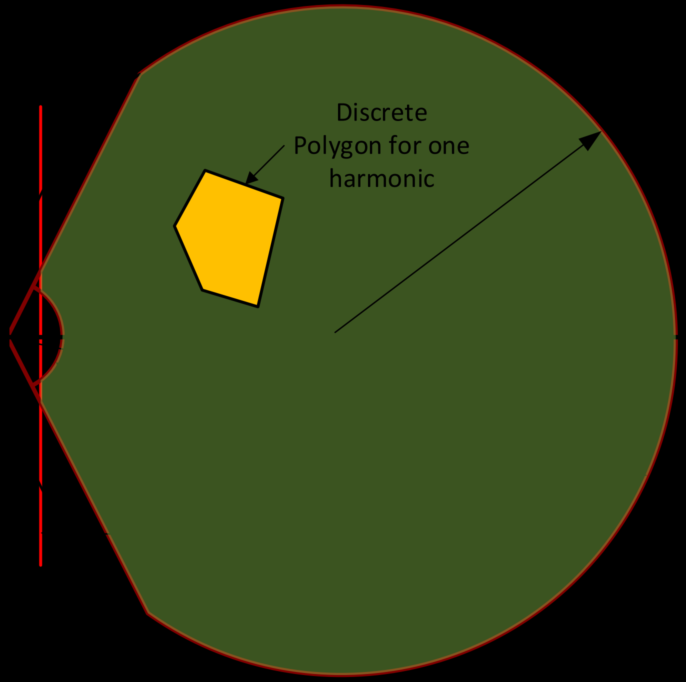
1. Allocation with Embedded generation

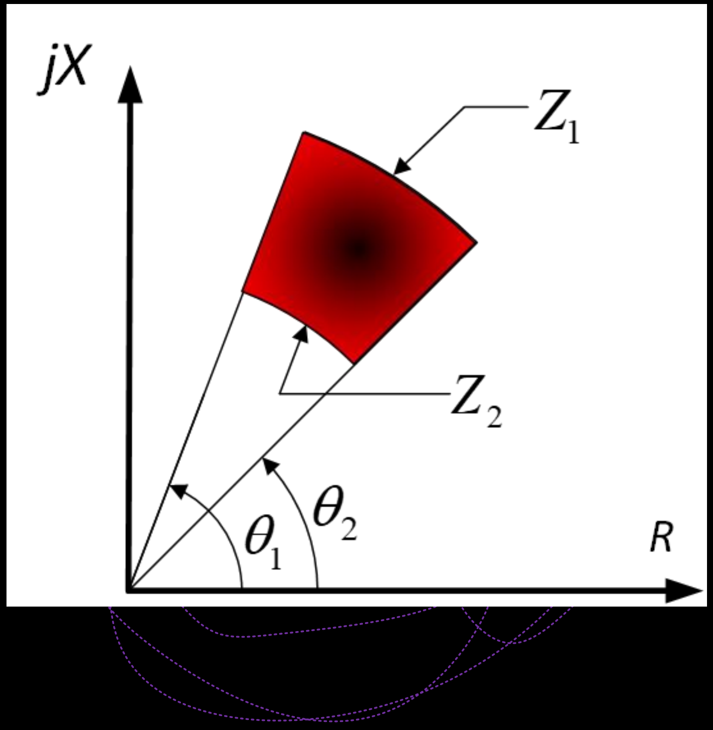


2. Harmonic impedance variation

3. What is the appropriate diversity/summation exponents for modern power electronic equipment. How to deal with spread-spectrum devices.

Impedance loci





Parallel
Resonance

Diversity/Summation exponents

Diversity/Summation exponents incorporate two types of diversity:

- **Phase angle and time diversity**

Indicative values **means typical but can be changed based on the situation and knowledge of the situation. Note 1 of AS/NZS 61000.3.6 makes this clear.**

Extract from AS/NZS 61000.3.6:2012

On the basis of the information available to date, the following set of exponents can be adopted in the absence of further specific information:

Table 3 – Summation exponents for harmonics (indicative values)

Harmonic order	α
h < 5	1
5 ≤ h ≤ 10	1,4
h > 10	2

NOTE 1 When it is known that the harmonics are likely to be in phase (i.e. phase angle differences less than 90°), then an exponent α = 1 should be used for order 5 and above.

NOTE 2 Conversely, some low order non-characteristic harmonics (e.g. 3^{rd}) may have different causes that are unlikely to produce in-phase harmonics, therefore an exponent higher than 1 could be used for these cases (e.g. α =1,2).

NOTE 3 Higher summation exponents can be used for even harmonics that are less likely to be in phase (for h ≤ 10).

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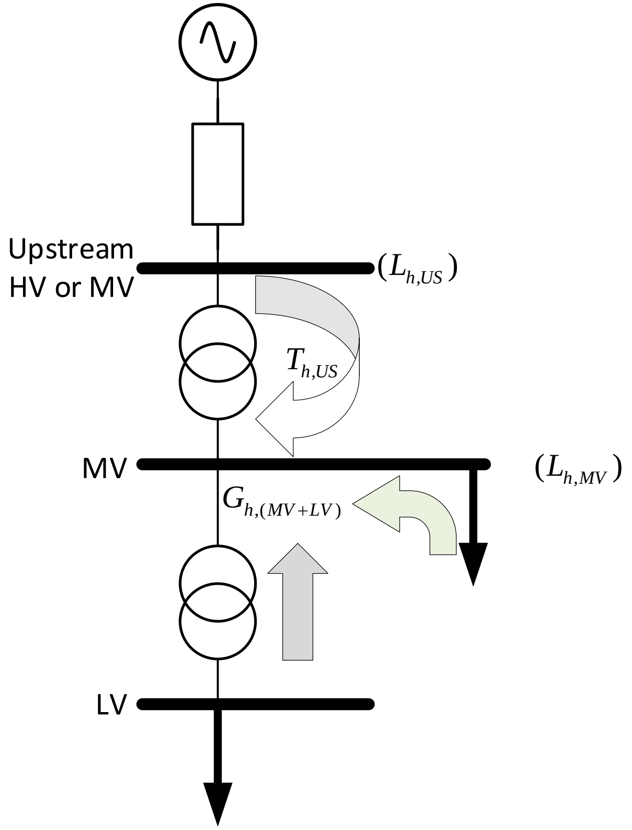
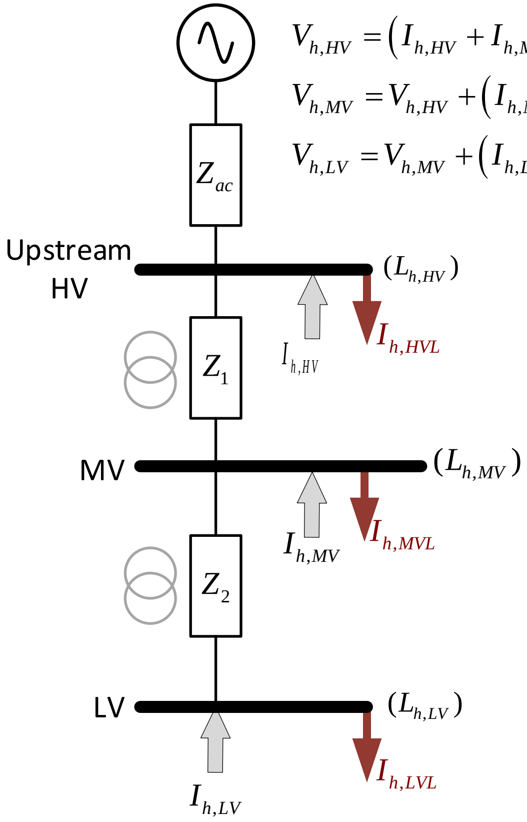
3. Complexities
4. Present day Examples
5. Mitigation

Transfer of Harmonic Distortion between different Voltage levels



Transfer of Harmonic Distortion between different Voltage levels



$$V_{h,HV} = \left(I_{h,HV} + I_{h,MV} + I_{h,LV}\right) Z_{ac}$$
$$V_{h,MV} = V_{h,HV} + \left(I_{h,MV} + I_{h,LV}\right) Z_1$$
$$V_{h,LV} = V_{h,MV} + \left(I_{h,LV}\right) Z_2$$

Ignoring the damping of loads

$$L_{h,HV} = \left(I_{h,HV} + I_{h,MV} + I_{h,LV}\right) Z_{ac} \Rightarrow I_{h,HV} = \frac{L_{h,HV}}{Z_{ac}} - I_{h,MV} - I_{h,LV}$$
$$L_{h,MV} - L_{h,HV} = \left(I_{h,MV} + I_{h,LV}\right) Z_1 \Rightarrow I_{h,MV} = \frac{L_{h,MV} - L_{h,HV}}{Z_1} - I_{h,LV}$$
$$L_{h,LV} - L_{h,MV} = I_{h,LV} Z_2 \Rightarrow I_{h,LV} = \frac{L_{h,LV} - L_{h,MV}}{Z_2}$$

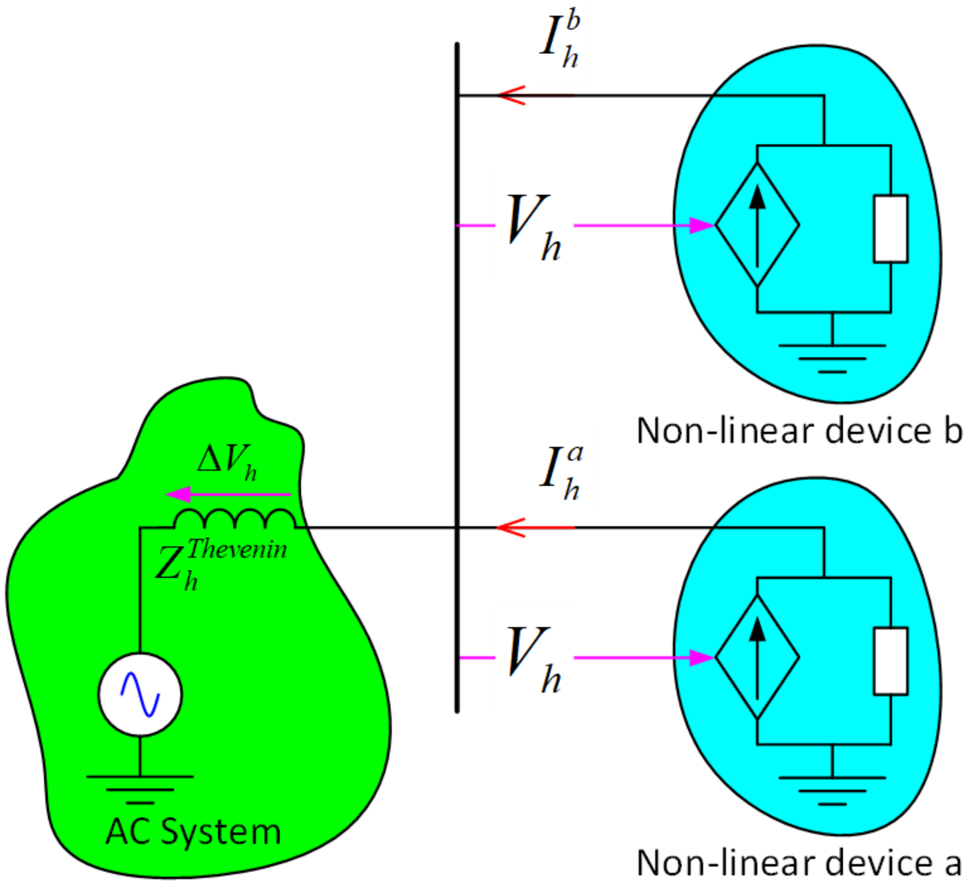
Harmonic current allocation at a voltage level as a function of planning levels

If damping of loads is considered.

$$V_{h,HV} = \left(\left(I_{h,HV} - I_{h,HVL}\right) + \left(I_{h,MV} - I_{h,MVL}\right) + \left(I_{h,LV} - I_{h,LVL}\right)\right) Z_{ac}$$
$$V_{h,MV} = V_{h,HV} + \left(\left(I_{h,MV} - I_{h,MVL}\right) + \left(I_{h,LV} - I_{h,LVL}\right)\right) Z_1$$
$$V_{h,LV} = V_{h,MV} + \left(I_{h,LV} - I_{h,LVL}\right) Z_2$$

Complexities:
Interaction in through the Voltage Waveform

Voltage quality is maintained within allowable limits by restricting the emissions (Harmonic currents injected into the power system)



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Complexities

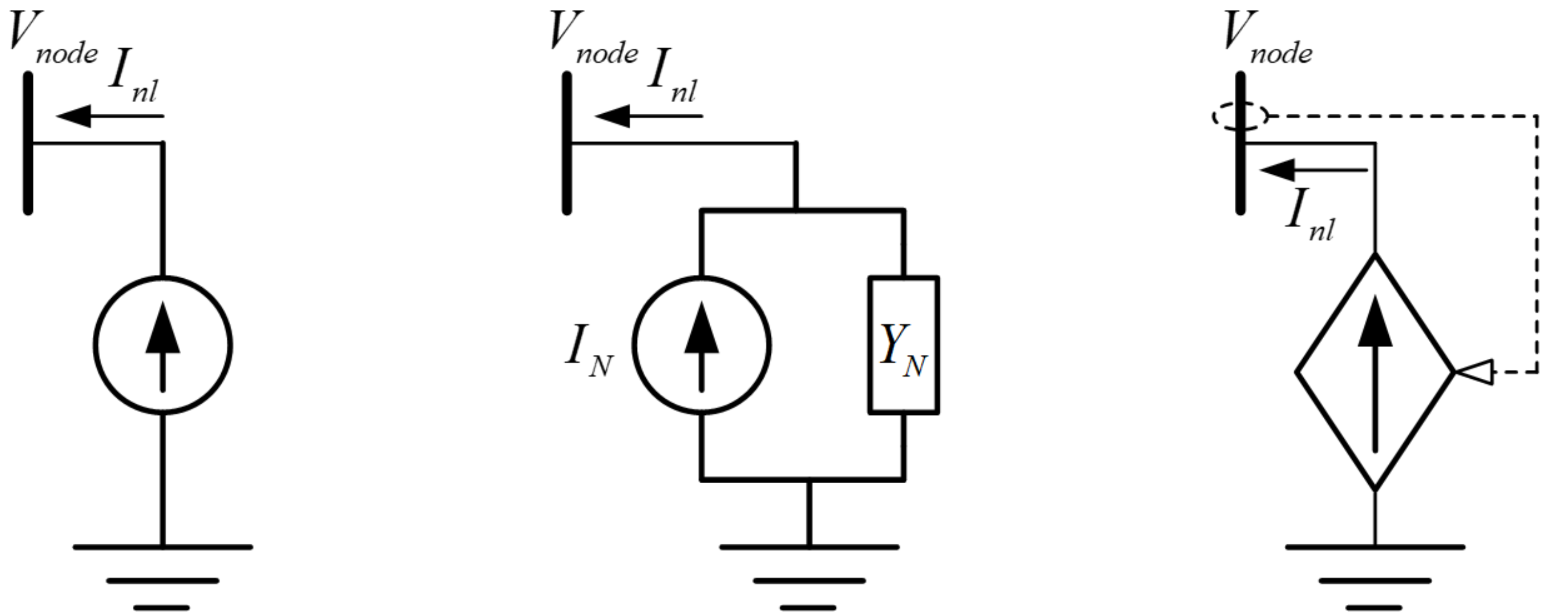
Harmonic penetration studies (Fixed harmonic current sources)

- Gives the harmonic impedance as seen from a prospective connection point for credible scenarios and captures parallel and series resonances excited by harmonic current injection.

Harmonic power-flow (Tensor representation). The harmonic current emission will vary due to:

- There will be voltage waveform distortion. This could be due to the nonlinear device's interaction with the AC system (i.e. the device's harmonic current through the system impedance). It could also be partly due to the voltage distortion caused by the current of other nonlinear devices flowing through the AC system and adding to the voltage distortion.
- There is the influence of the phase angle of the harmonic voltage distortion at the terminals. The harmonic current emission from nonlinear devices can be quite sensitive to the phase angle even though the harmonic voltage magnitude remains unchanged.
- There is coupling between harmonic frequencies. What happens at 5^{th} harmonic influences the 7^{th} harmonic.
- Even an imbalance ac system (in voltage or impedance) can generate what are called uncharacteristic harmonics.

Representation of Harmonic producing Equipment

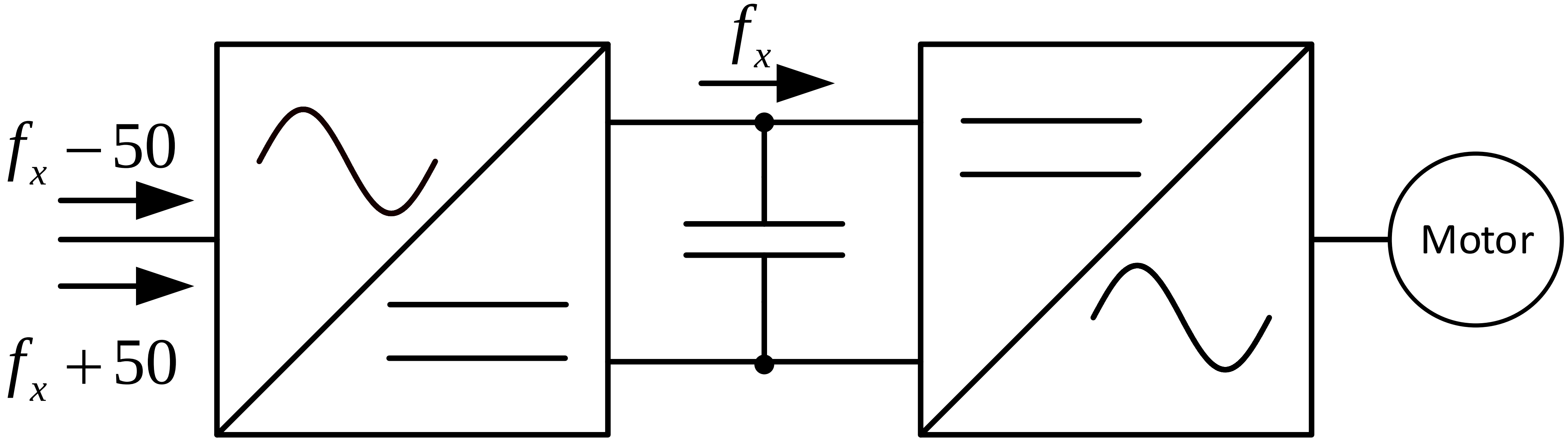


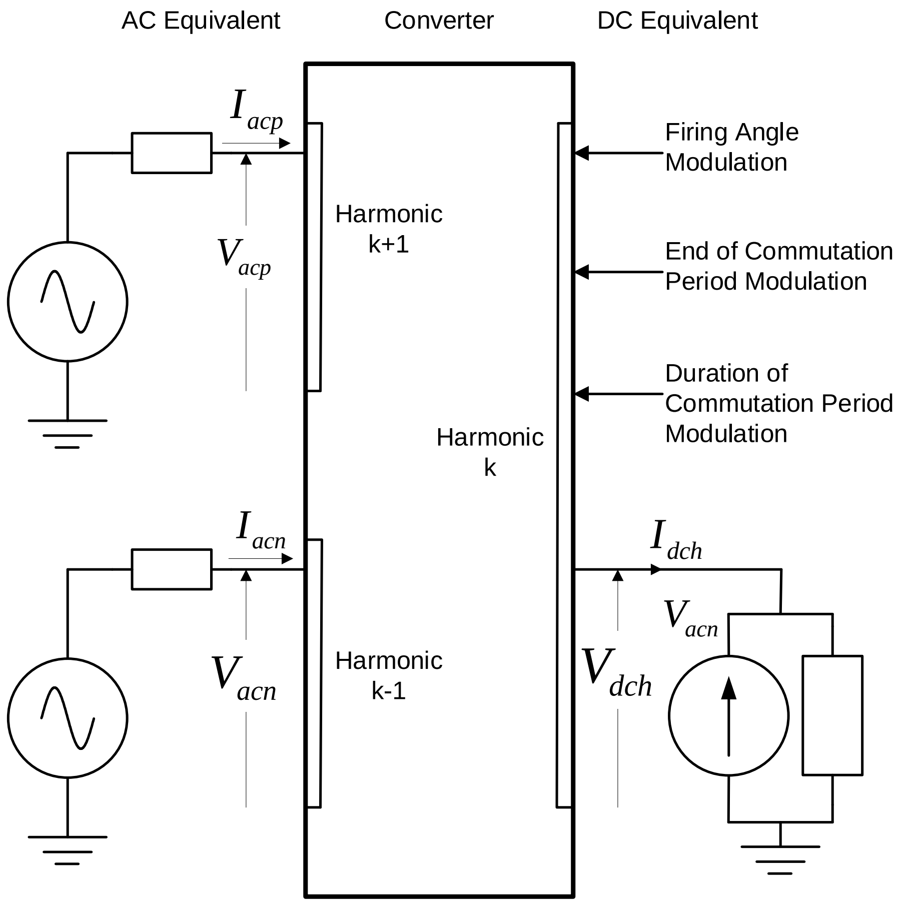
(a) Fixed Current Injection

(b) Norton Equivalent

(c) Dependent Current Source

Converter as a Modulator (translates frequencies)




AC Equivalent
Converter
DC Equivalent
I_{acp}
V_{acp}
Harmonic k+1
Firing Angle Modulation
End of Commutation Period Modulation
Duration of Commutation Period Modulation
Harmonic k
I_{acn}
V_{acn}
Harmonic k-1
I_{dch}
V_{acn}
V_{dch}

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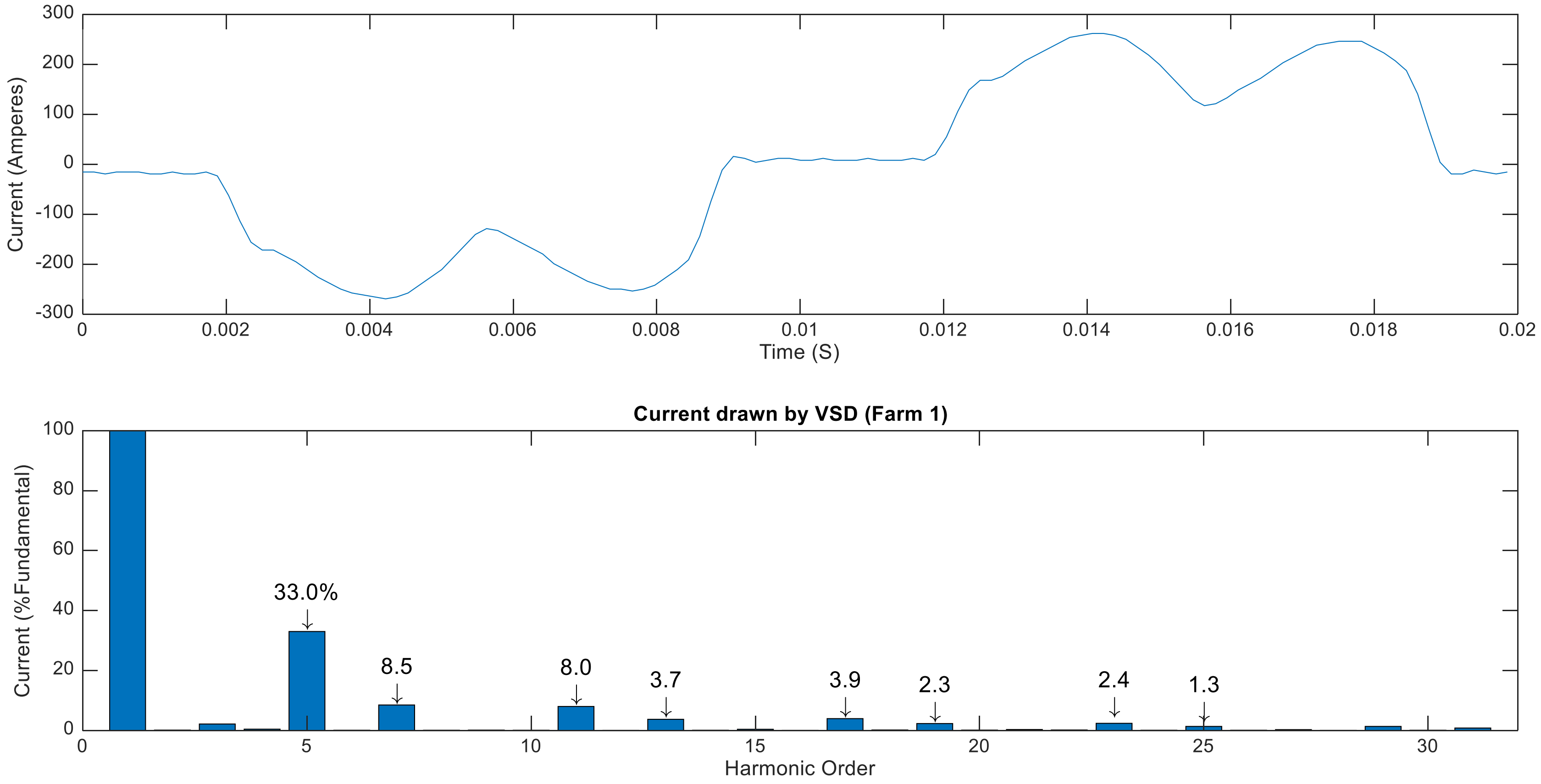
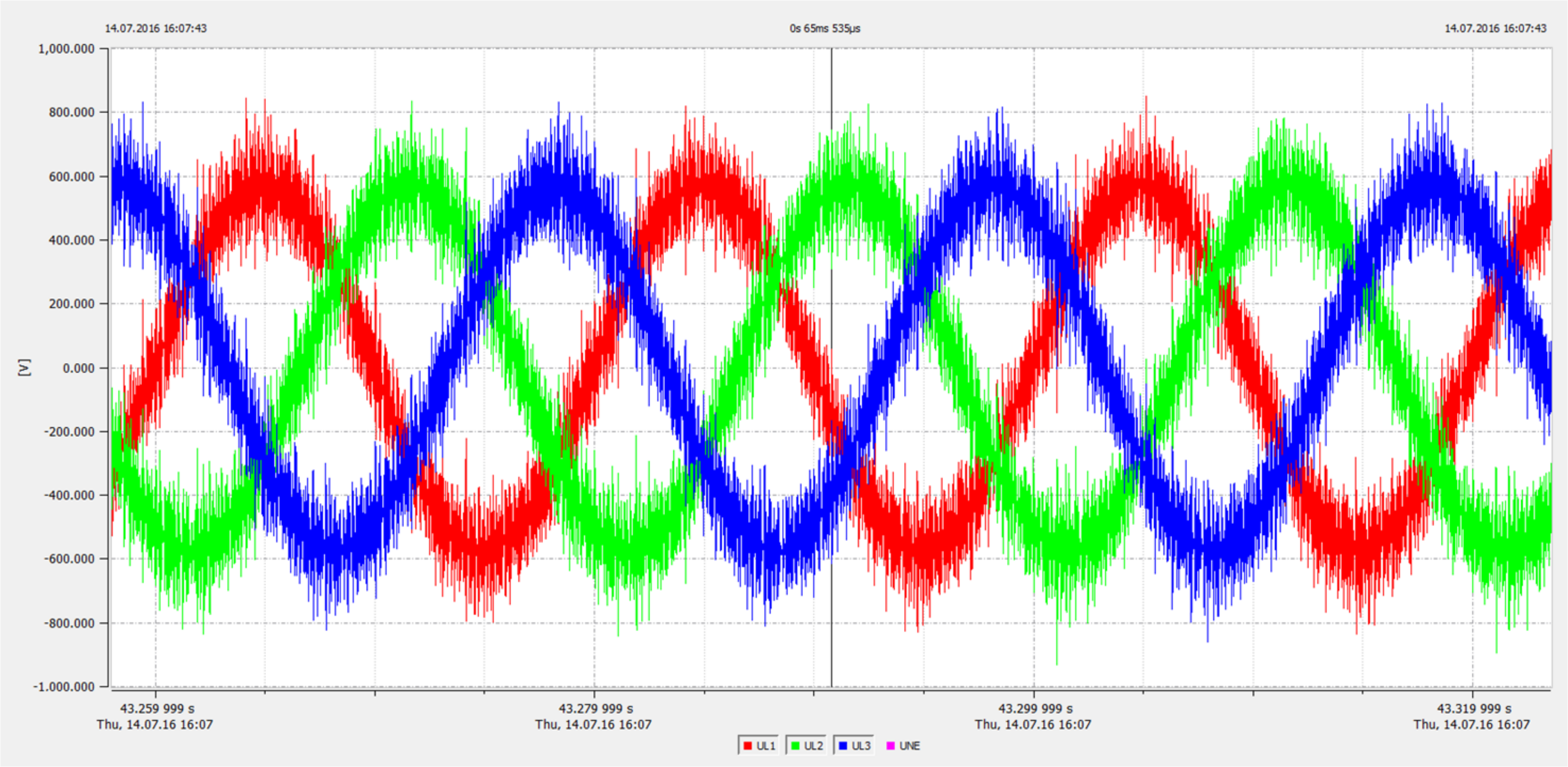
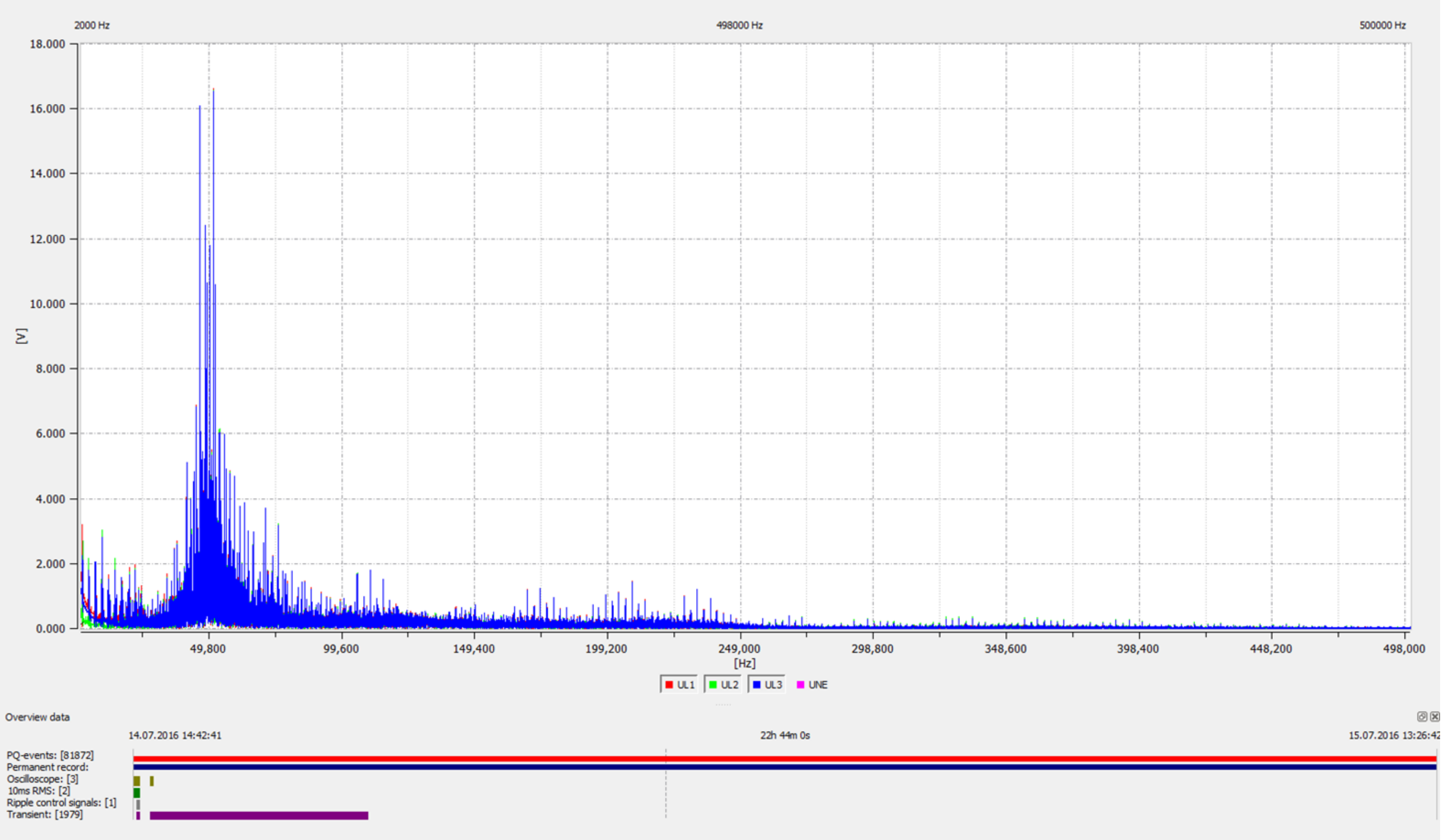
Waveform example 1



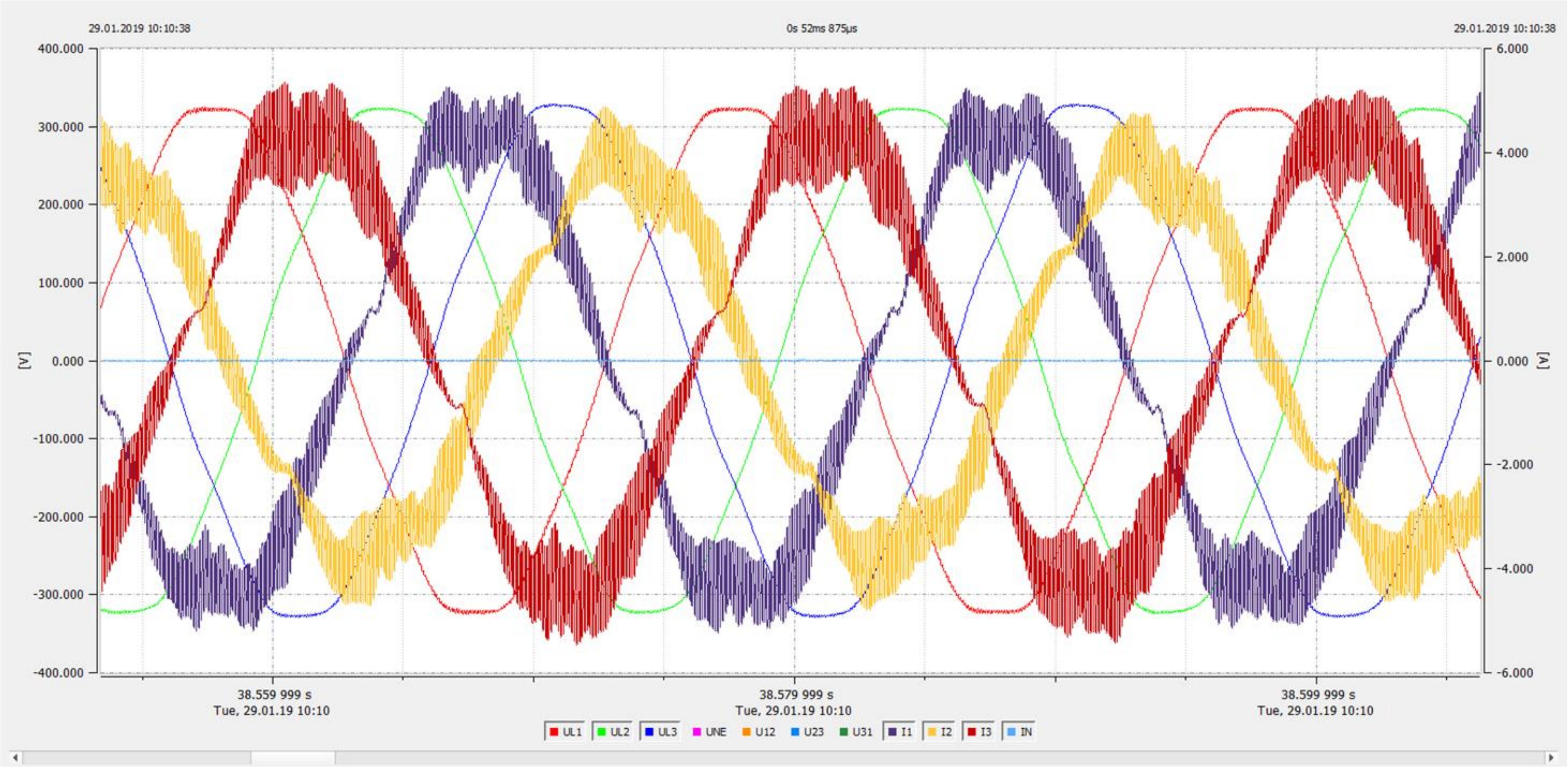
Waveform example 2



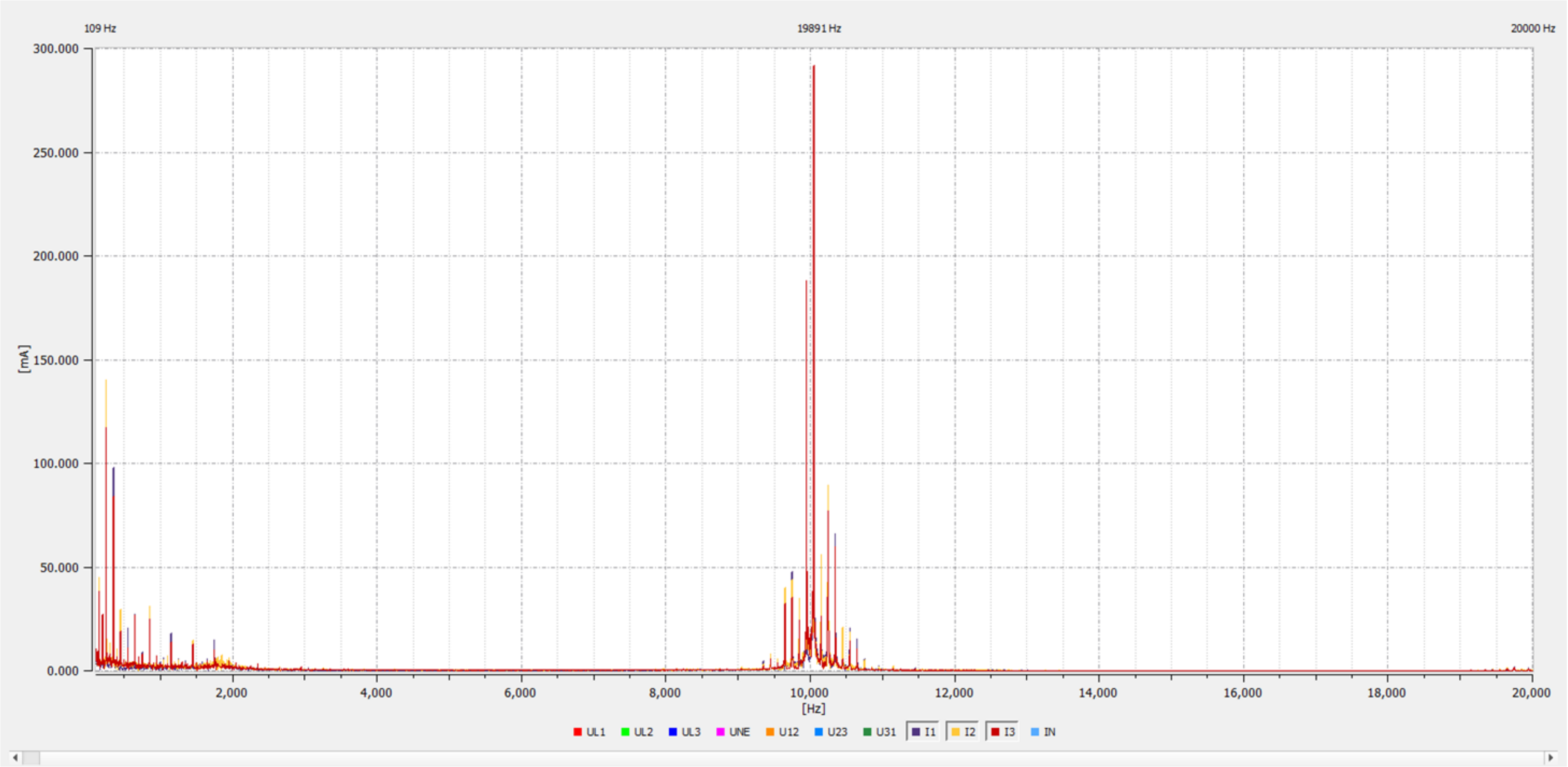
Waveform example 2 Spectrum



Waveform example 3

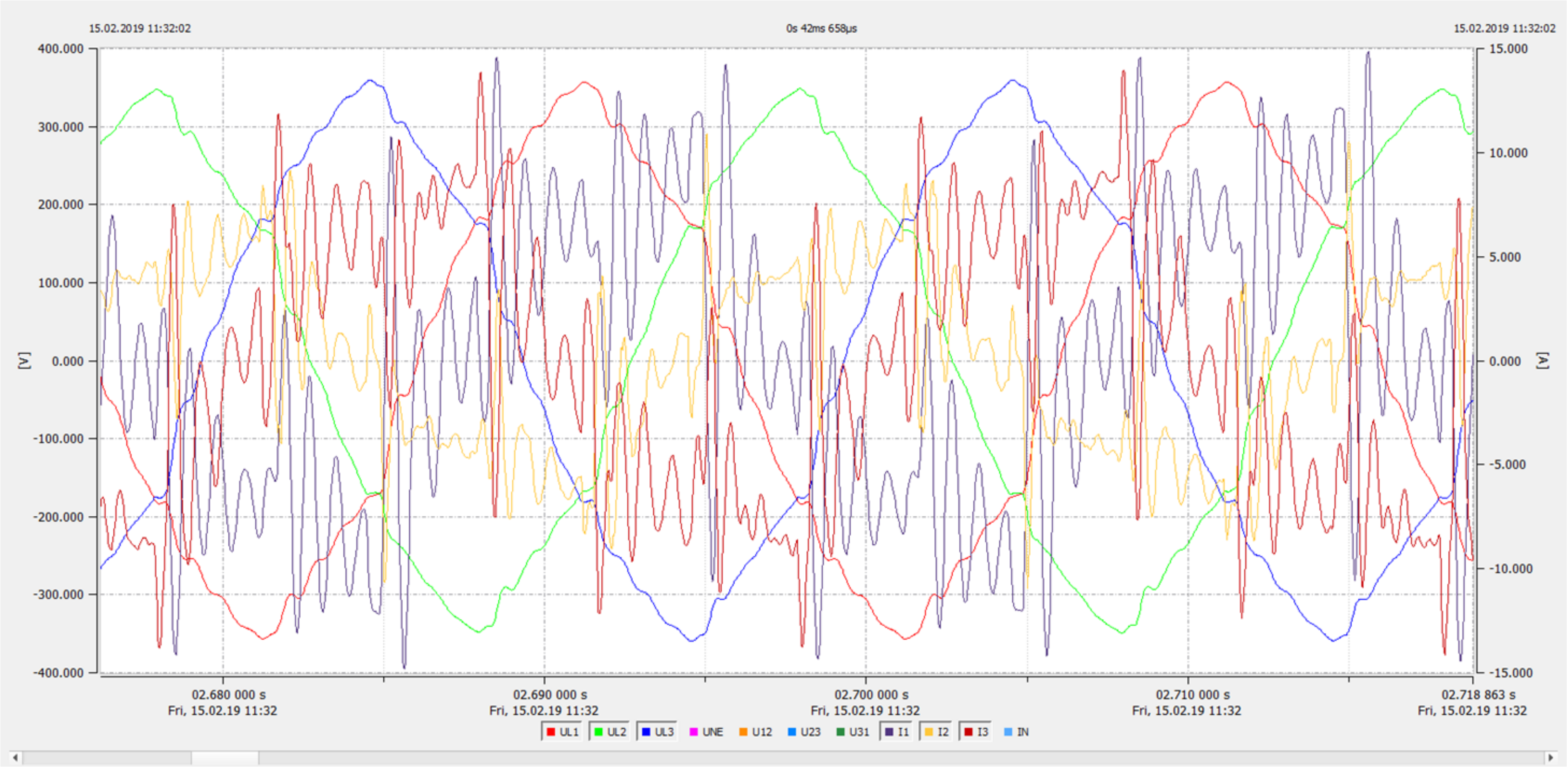


Waveform example 3 Spectrum



Waveform example 4

Waveform example 5



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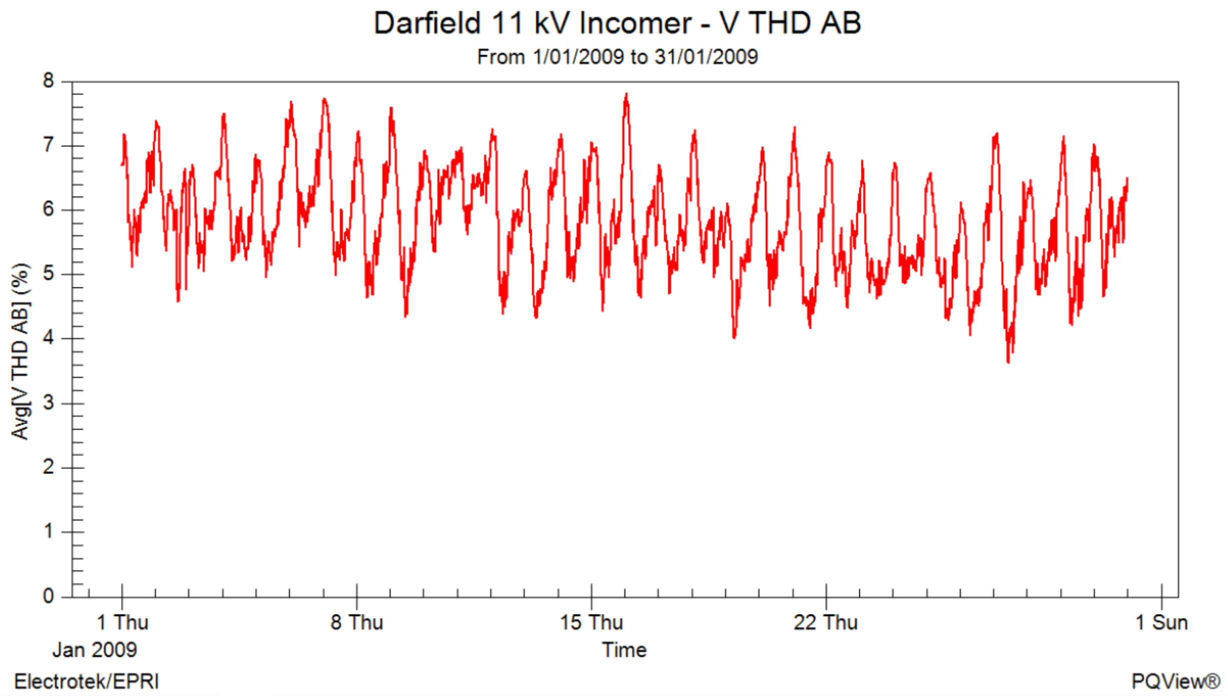
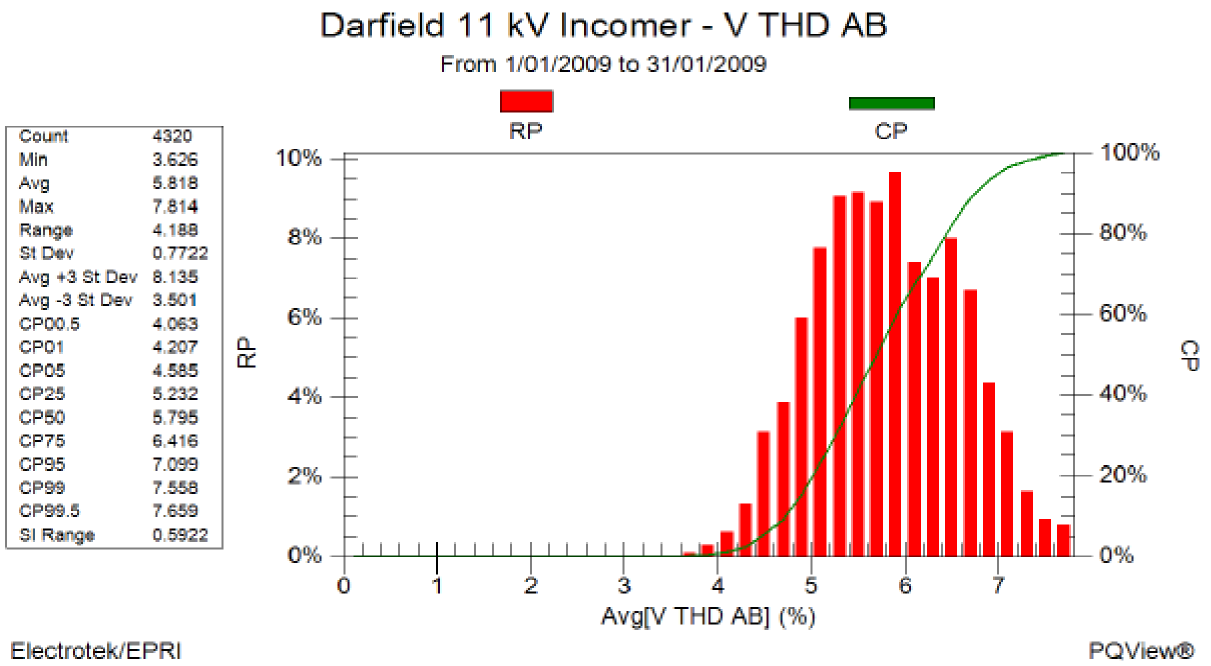
Mitigation

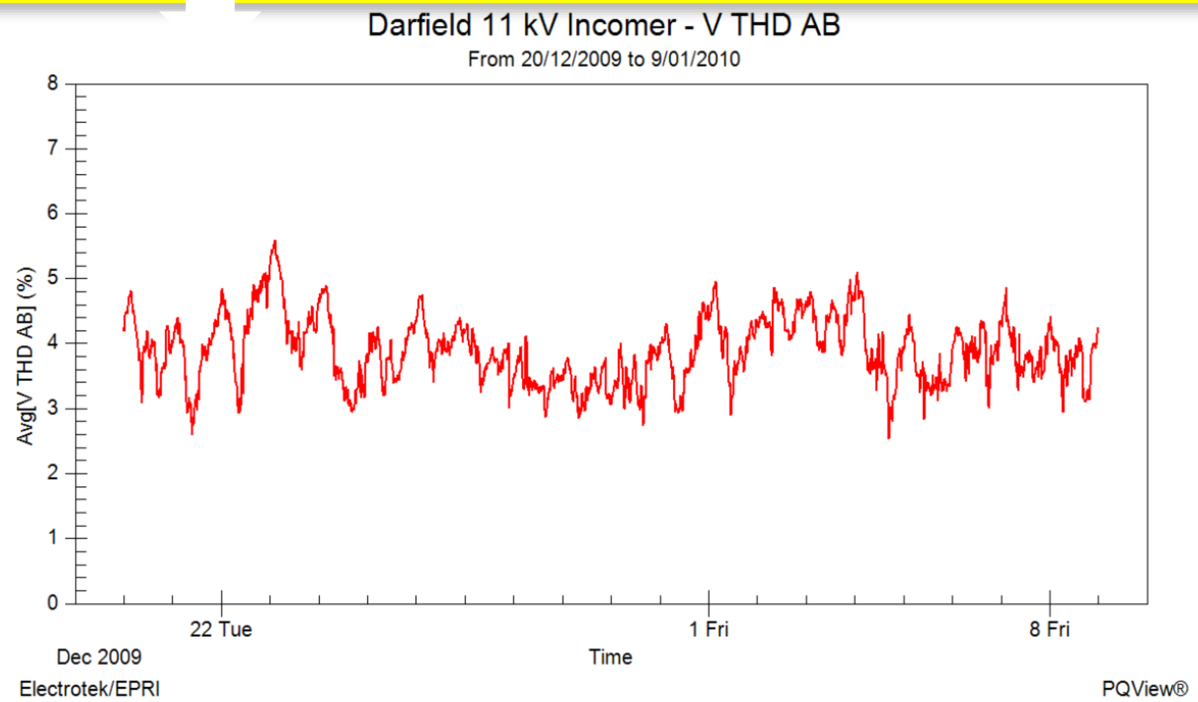
- The use of harmonic filters should be seen as a last step to obtain compliance. They can be costly, incur losses and can cause unwanted resonance.
- The best approach is to use equipment that employs a better design with lower harmonic current emission. This may involve hardware change or simply the way it is controlled.
- The next step is to try and add diversity as has been achieved for irrigators and dairy companies in Orion’s network [1,2].
- Failing these two approaches harmonic filters can be considered.

[1] Stewart Hardie, Neville R. Watson and Vic Gosbell, “An Investigation of Excessive Rural Network Harmonic Levels caused by particular Irrigation Pumps”, EEA Conference, Christchurch, 19-20 June 2009.
[2] Neville R. Watson, Stewart Hardie, Tas Scott and Stephen Hirsch, “Improving Rural Power Quality in New Zealand”, EEA Conference, Christchurch, 17-18 June 2010.

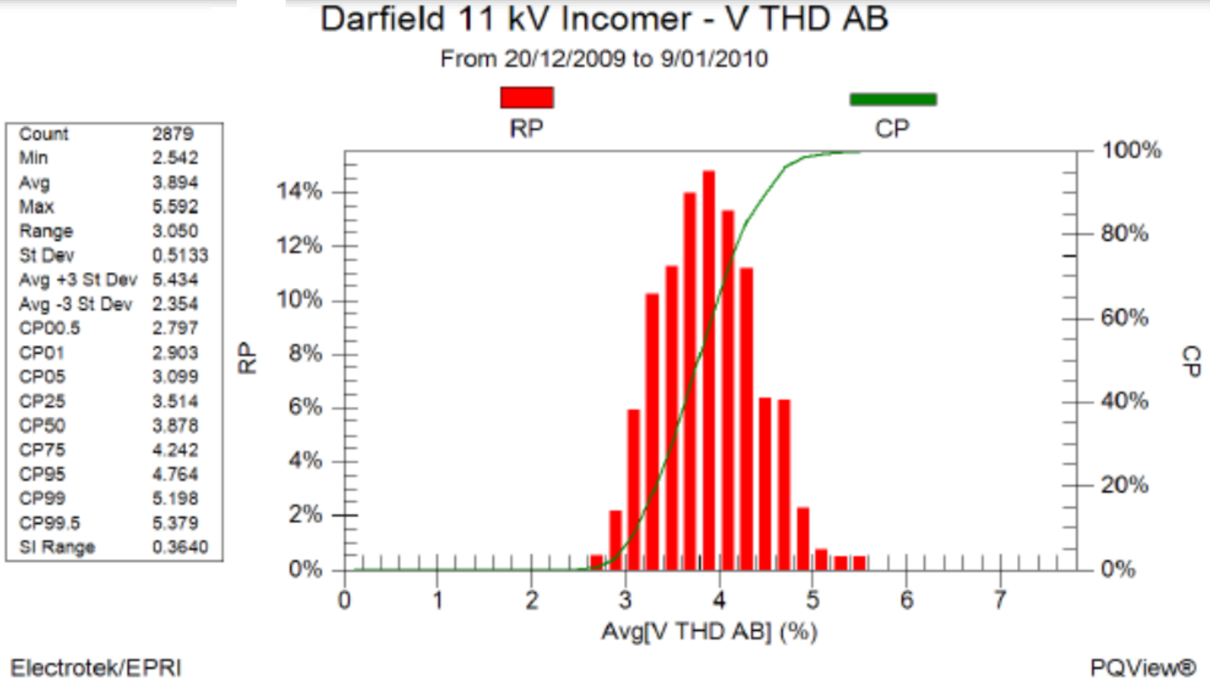


Count	4320
Min	3.626
Avg	5.818
Max	7.814
Range	4.188
St Dev	0.7722
Avg +3 St Dev	8.135
Avg -3 St Dev	3.501
CP00.5	4.063
CP01	4.207
CP05	4.585
CP25	5.232
CP50	5.795
CP75	6.416
CP95	7.099
CP99	7.558
CP99.5	7.659
SI Range	0.5922





Count	2879
Min	2.542
Avg	3.894
Max	5.592
Range	3.050
St Dev	0.5133
Avg +3 St Dev	5.434
Avg -3 St Dev	2.354
CP00.5	2.797
CP01	2.903
CP05	3.099
CP25	3.514
CP50	3.878
CP75	4.242
CP95	4.764
CP99	5.198
CP99.5	5.379
SI Range	0.3640



Thank you for your attention!

QUESTIONS

ELECTRICITY AUTHORITY
TE MANA HIKO

THANK YOU