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

Consultation paper

25 June 2024

ELECTRICITY AUTHORITY
TE MANA HIKO

Executive summary

The Electricity Authority (Authority) is reviewing the common quality requirements in Part 8 of the Electricity Industry Participation Code 2010 (Code). The Authority is undertaking this review as part of our Future Security and Resilience (FSR) work programme. 'Common quality' means those elements of the quality of electricity conveyed across New Zealand's power system that cannot be technically or commercially isolated to an identifiable person or group of persons.

Through a combination of one-on-one engagement and formal consultation with interested parties, the Authority has identified seven key issues with the common quality requirements in Part 8 of the Code.

We are publishing a suite of consultation papers on matters relating to five of these seven key issues. This paper describes the Authority's current thinking on the governance and management of electrical harmonics in New Zealand, which together have been identified as the fifth key common quality issue. Another paper contains short-listed options to address Issue 1, which relates to frequency. A third paper contains short-listed options to address Issues 2, 3 and 4, which relate to voltage. A fourth paper provides an overview of, and context for, the consultation suite.[1]

Later in 2024 we plan to consult with interested parties on addressing Issues 6 and 7.

What are harmonics?

Harmonics are electrical waveforms that have the form of a sine curve (ie, they are sinusoidal), with a frequency that is a multiple of the primary 50 Hertz (Hz) alternating current sinusoidal waveform.[2] Harmonics cause distortion of the primary 50Hz current and voltage sinusoidal waveforms.

Amongst other things, excessive levels of harmonics in electricity networks lead to poor power quality and can cause problems in electrical equipment and appliances, including premature failure.

Harmonics are typically caused by non-linear electrical loads, which are loads drawing current with a non-sinusoidal waveform (eg, computer power supplies, variable frequency drives, arc furnaces and heat pumps). However, inverter-based resources, which contain power electronic components, can cause excessive levels of (current and voltage) harmonics if the power electronic components are inadequately designed.

Inverter-based resources, such as wind generation, solar photovoltaic generation, and battery energy storage systems, are expected to become increasingly prevalent in New Zealand as various sectors of the economy electrify. For example, Transpower has estimated that 7,360 megawatts of large-scale solar photovoltaic generation and

---

1 Overview and context for the consultation suite: https://www.ea.govt.nz/documents/cqrconsultationcoverpaper

Paper 1: Addressing more frequency variability in New Zealand's power system: https://www.ea.govt.nz/documents/cqrconsultationpaper1

Paper 2: Addressing larger voltage deviations and network performance issues in New Zealand's power system: https://www.ea.govt.nz/documents/cqrconsultationpaper2

2 For example, the 3rd harmonic is 3 x 50 = 150Hz. The 5th harmonic is 5 x 50 = 250Hz, and so on.

595 megawatts of small-scale residential and commercial solar photovoltaic generation will connect to New Zealand's electricity networks by 2030.

Care needs to be taken that this large uptake of inverter-based resources does not cause problems for the power system and for consumers' appliances through excessive harmonics. This necessitates a review of New Zealand's approach to limiting and managing harmonics.

It is timely to consider the governance and management of harmonics

Regulations placing limits on harmonic levels were first introduced in New Zealand in 1981. These were based largely on recommendations from the United Kingdom over a decade earlier. Today the Code and the Electricity (Safety) Regulations 2010 both contain harmonic standards that are intended to avoid harm associated with excessive harmonics.

However, the management of harmonics receives relatively little attention in the Code and other regulatory instruments. Currently, some of the key aspects of managing harmonics, such as the monitoring of harmonics, roles and responsibilities, and the allocation of harmonics are not well defined in rules and regulations.

In April 2023 the Authority consulted with interested parties on the seven key issues with the common quality requirements referred to above. The identified issue relating to harmonics was ambiguity around the applicability of harmonics standards and who manages harmonics (including the allocation of harmonics). (**Issue 5**)

Since the close of consultation on the 2023 Issues paper, the Authority has considered how the governance and management of harmonics in New Zealand's power system might be improved, to address Issue 5. The Authority has benefitted greatly from input we have received from the Common Quality Technical Group, the system operator, the Electricity Engineers' Association, and harmonics experts such as Professor Neville Watson from the University of Canterbury.

The Authority considers it is too soon to consult on a short-list of options to be investigated to help address Issue 5. First, we want to consult with interested parties on our current thinking on the governance and management of harmonics.

We consider a better outcome will be achieved for consumers and industry participants if we describe what we see as the important elements of managing harmonics. Doing this will help facilitate having 'everyone on the same page' before we discuss options that are likely to help address Issue 5.

Your feedback is welcomed

The Authority welcomes feedback on this paper from interested parties.

The Authority acknowledges the content of this consultation paper is technical and has allowed for an 8-week consultation period. During the consultation period the Authority will be available to hold individual and group briefings with interested stakeholders.

Contents

1. What you need to know to make a submission

What this consultation is about

1.1. Through a combination of one-on-one engagement and formal consultation with interested parties, the Electricity Authority (Authority) has identified seven key issues with the common quality requirements in Part 8 of the Electricity Industry Participation Code 2010 (Code). 'Common quality' means those elements of the quality of electricity conveyed across New Zealand's power system that cannot be technically or commercially isolated to an identifiable person or group of persons.

1.2. The purpose of this consultation paper is to seek feedback from interested parties on the governance and management of harmonics in New Zealand. Together these have been identified as the fifth key common quality issue. (**Issue 5**) This consultation paper follows on from our 2023 Issues paper.

1.3. The Authority is undertaking a review of common quality requirements in Part 8 of the Code as part of our Future Security and Resilience (FSR) programme of work. An overview of the FSR work programme can be found on our website at Future security and resilience | Our projects | Electricity Authority (ea.govt.nz).

This paper is part of a suite of common quality consultation papers

1.4. The Authority is publishing a suite of consultation papers on matters relating to five of the seven key common quality issues identified in the 2023 Issues paper. This consultation suite contains:

(a) an overview of, and context for, the consultation suite

(b) options to help address the frequency-related key common quality issue (Issue 1)

(c) options to help address the voltage-related key common quality issues (Issues 2, 3 and 4)

(d) a discussion on the governance and management of harmonics (which relates to Issue 5).

1.5. The other papers being published alongside this one are available at

(a) Overview and context for the consultation suite: https://www.ea.govt.nz/documents/cqrconsultationcoverpaper

(b) Paper 1: Addressing more frequency variability in New Zealand's power system: https://www.ea.govt.nz/documents/cqrconsultationpaper1

(c) Paper 2: Addressing larger voltage deviations and network performance issues in New Zealand's power system: https://www.ea.govt.nz/documents/cqrconsultationpaper2

How to make a submission

1.6. The Authority's preference is to receive submissions in electronic format (Microsoft Word) in the format shown in Appendix B. Submissions in electronic form should be emailed to fsr@ea.govt.nz with "Consultation Paper—The governance and management of harmonics in New Zealand's power system" in the subject line.

1.7. If you cannot send your submission electronically, please contact the Authority (at fsr@ea.govt.nz or 04 460 8860) to discuss alternative arrangements.

1.8. Please note the Authority intends to publish all submissions we receive. If you consider that the Authority should not publish any part of your submission, please:

(a) indicate which part should not be published,

(b) explain why you consider we should not publish that part, and

(c) provide a version of your submission that the Authority can publish (if we agree not to publish your full submission).

1.9. If you indicate part of your submission should not be published, the Authority will discuss this with you before deciding whether to not publish that part of your submission.

1.10. However, please note that all submissions received by the Authority, including any parts that the Authority does not publish, can be requested under the Official Information Act 1982. This means the Authority would be required to release material not published unless good reason existed under the Official Information Act to withhold it. The Authority would normally consult with you before releasing any material that you said should not be published.

When to make a submission

1.11. Please deliver your submission by 5pm on Tuesday 20 August 2024.

1.12. Authority staff will acknowledge receipt of all submissions electronically. Please contact the Authority (at fsr@ea.govt.nz or 04 460 8860) if you do not receive electronic acknowledgement of your submission within two business days.

2. Introduction

2.1. Since the close of consultation on our 2023 Issues paper, the Authority has considered how the governance and management of harmonics in New Zealand's power system might be improved.

2.2. We have undertaken a literature review of approaches adopted in various overseas jurisdictions. The literature indicates that each jurisdiction has developed its own approach to harmonics regulation and management. For some jurisdictions we have engaged directly with people involved in the regulation of harmonics.

2.3. The Authority has also met with various subject matter experts on harmonics. We have benefitted greatly from the input we have received from members of the Common Quality Technical Group, staff from the system operator, the Electricity Engineers' Association, and experts such as Professor Neville Watson from the University of Canterbury who is an internationally renowned expert in harmonics. Together these people provide a mixture of day-to-day operational involvement in common quality matters, a range of relevant commercial and technical experience, and extensive academic and institutional knowledge. The insights provided by these people have been most valuable to us.

2.4. Unlike for frequency- and voltage-related common quality issues, the Authority considers it is too soon to consult on a short-list of options to be investigated to help address Issue 5. First, we want to consult with interested parties on our current thinking on the governance and management of harmonics.

2.5. We consider a better outcome will be achieved for consumers and industry participants if we describe what we see as the important elements of managing harmonics. Doing this will help facilitate having 'everyone on the same page' before we discuss options that are likely to help address Issue 5.

2.6. The Authority wants to ensure that our work on harmonics in New Zealand fits coherently with other such work currently being undertaken or which has recently been completed (eg, the Electricity Engineers' Association's updated set of power quality guidelines published at the beginning of 2024[3]).

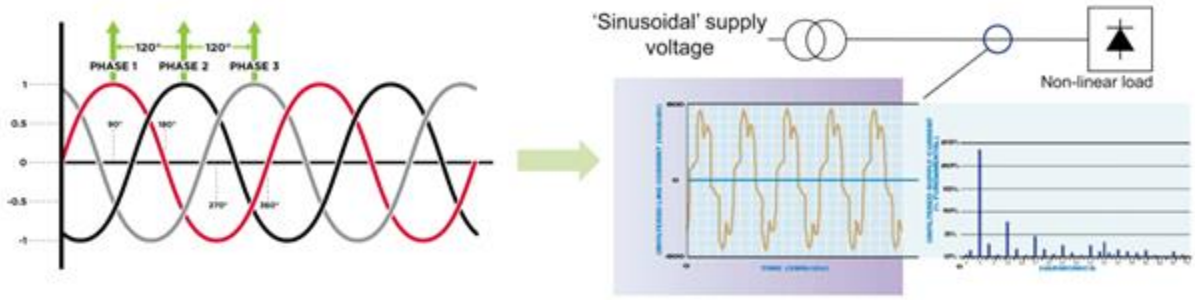
---

[3] Electricity Engineers' Association, January 2024, Power Quality (PQ) Guidelines.

3. An introduction to harmonics

3.1. Harmonics are electrical waveforms that have the form of a sine curve (ie, they are sinusoidal), with a frequency that is a multiple of the fundamental 50 Hertz (Hz) alternating current sinusoidal waveform.[4] As shown in Figure 1, harmonics cause distortion of the fundamental 50Hz current and voltage sinusoidal waveforms. This distortion is not limited to one cycle of a waveform, but rather occurs across adjacent cycles of a waveform.

Figure 1: Effect of harmonics on voltage waveforms at a consumer installation



Ideal voltage sources are sinusoidal *Measured voltage supply with harmonics (distortions)*

3.2. Electrical resonance in a network, caused by capacitors and power system impedance effectively cancelling out the effect of one another, can amplify harmonic voltages and harmonic currents to unacceptably high levels. On the flip side, harmonic currents cause a drop in harmonic voltages across the power system.

3.3. Harmonics are typically caused by non-linear electrical loads, which are loads drawing current with a non-sinusoidal waveform (eg, computer switched mode power supplies,[5] variable frequency drives, arc furnaces and heat pumps).

3.4. However, inverter-based resources, which contain power electronic components, can cause excessive levels of current harmonics and voltage harmonics if the power electronic components are inadequately designed. An 'inverter-based resource' is equipment that uses an inverter when functioning. An inverter is an electronic device that converts direct current electricity to alternating current electricity. Examples of inverter-based resources include wind generation, solar photovoltaic generation, and battery energy storage systems.

3.5. Inverter-based resources, particularly the examples in the paragraph above, are expected to become increasingly prevalent in New Zealand, as various sectors of the economy electrify. For example, Transpower has estimated that 7,360 megawatts of large-scale solar photovoltaic generation and 595 megawatts of small-scale residential and commercial solar photovoltaic generation will connect to New Zealand's electricity networks by 2030.[6]

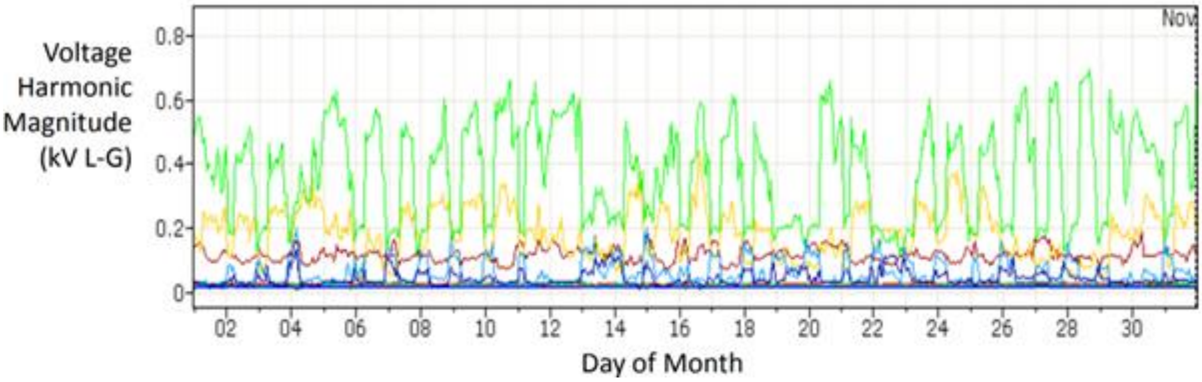
---

4 For example, the 3rd harmonic is 3 x 50 = 150 Hz. The 5th harmonic is 5 x 50 = 250 Hz, and so on.

5 A typical switched mode power supply for a computer transfers power from an alternating current source to the computer's direct current load. Thus, data centres are a major source of harmonics in an electricity network if appropriate mitigation measures are not put in place.

6 Transpower, 2023, Whakamana I Te Mauri Hiko, Monitoring Report, March 2023

Figure 2: Examples of voltage and current harmonic measurements at a wind farm[7]



3.6. Care needs to be taken that this large uptake of inverter-based resources does not cause problems for the power system or for consumers' appliances through excessive harmonics.

3.7. Excessive levels of harmonics in electricity networks can (amongst other things):

(a) lead to poor power quality, with harmonics adversely affecting power quality both within the installation in which they are generated, and also within installations that share the same (electrically close) section of network (eg, the same substation)

(b) cause problems in electrical equipment / appliances (eg, overheating, motor vibration, control equipment jitter, and premature failure)

(c) interfere with fixed line telecommunications as harmonic currents often oscillate at the same frequencies as the voice communications being transmitted over the phone line.[8]

3.8. It is difficult to quantify the cost to New Zealand's economy from harmonics causing these and other issues. This is for several reasons, including a lack of power quality monitoring devices, a lack of subject matter expertise, and a low volume of industrial trials and research. Therefore, we need to look to research undertaken overseas.

3.9. Surveys and studies from Europe and North America have concluded that these regions incur billions of dollars of cost per annum from poor power quality.[9] Closer to home, reports out of Australia have indicated the losses due to poor power quality, especially as a result of harmonics, can amount to several million dollars per annum.[10] While harmonics are just one aspect of power quality, and these regions are much larger than New Zealand, it appears reasonable to expect that the cost of harmonics on New Zealand's economy could be material.

---

7 Potential Solutions for Mitigating Technical Challenges Arising from High RES-E Penetration of the Island of Ireland: A Technical Assessment of 2030 Study Outcomes, p. 80.

8 Noting this is becoming progressively less of an issue with the ongoing change to fibre of New Zealand's telecommunication network cables.

9 Targosz, Roman and John Michael Manson, 2007, Pan European LPQI Power Quality Survey

D.Lineweber, S.R. MCNulty, 2000, The cost of power disturbances to Industrial and digital economy companies.

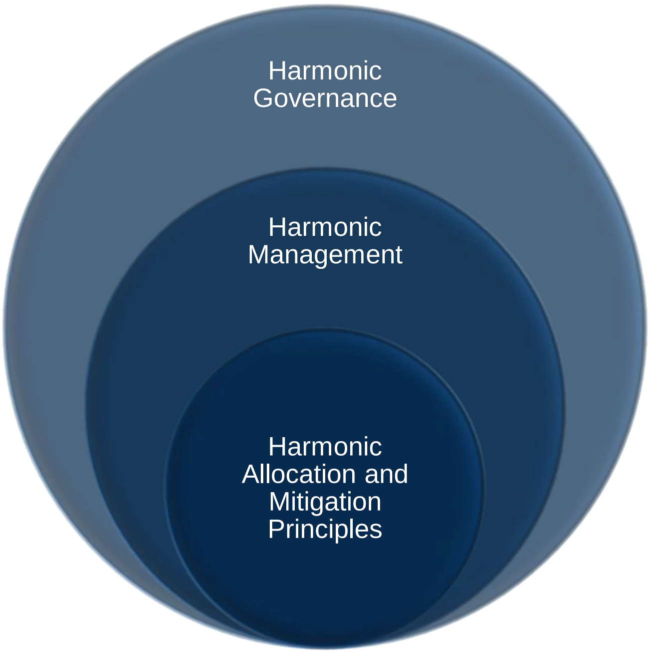
10 S. T. Elphick, P. Ciufo, V. W. Smith and S. Perera, "Summary of the economic impacts of power quality on consumers," in Power Engineering Conference (AUPEC), Wollongong, 2015

3.10. It is generally accepted that harmonics in the range of 100Hz to 2.5kHz (ie, 2 to 50 times New Zealand's 50Hz supply frequency) are of most interest when identifying the cause of problems such as those listed in paragraph 3.7. However, harmonics up to 150kHz may be emitted from some modern power converters that transfer charge to an electrical load by frequently switching a conductor on and off.

4. The governance of harmonics in New Zealand

4.1. When we refer to the governance of harmonics, the Authority is referring to the rules and regulations for limiting and managing harmonics in New Zealand.

Figure 3: Conceptual framework for the governance and management of harmonics



4.2. For the good part of 30 years leading up to 2008, there was relatively little change in the regulatory requirements for limiting harmonics in New Zealand. Standards for harmonics that were put in place in 1981 were revised only once – in 1993.

4.3. In 2008, the former Electricity Governance Rules (which were superseded by the Code in 2010) permitted industry participants to comply with harmonics standards other than the New Zealand standard that had been in place since 1993. Two years later the Electricity (Safety) Regulations 2010 also permitted industry participants to do likewise.

A brief history of the governance of electrical harmonics in New Zealand

In 1967, the Chief Engineers' Conference in the United Kingdom issued 'Engineering Recommendation G 5/2'. This specified limits for the emission of harmonic currents at the point of connection between a harmonics emitter and the electricity network. Based on industry feedback, this was revised and issued later that same year as 'Engineering Recommendation G5/3'.

In 1981, the 'Limitation of Harmonic Levels Notice 1981' was gazetted in New Zealand, under which the Secretary of Energy prescribed limits in the level of harmonics from any apparatus or appliance. This notice, which was based on the United Kingdom limits of 1967, imposed limits on the level of harmonics in New Zealand's power system. At the time there were only a few sources of harmonics in the power system, and these were large – being the high voltage direct current (HVDC) link between the South Island and the North Island, and the aluminium smelter at Tiwai Point in Southland.

In 1993, the Minister of Energy approved the New Zealand Electrical Code of Practice for Harmonic Levels (NZECP 36:1993), pursuant to section 36 of the Electricity Act 1992. NZECP 36:1993 set acceptable levels of harmonic voltages and harmonic currents that were permitted to be introduced into an electrical supply system by a consumer's installation. NZECP 36:1993 was based on the 1981 Limitation of Harmonic Levels Notice.

In 2003, the Electricity Governance Rules were established. These contained a principal performance obligation on the system operator to, upon request, identify the cause of the problem where the NZECP 36:1993 standard was not being met at a point of connection to New Zealand's transmission network. The system operator was empowered, upon request, to take any practicable action available to it under the Electricity Governance Rules to resolve the problem.

In 2008, the Electricity Governance Rules were amended to require Transpower and its customers to comply with the same standards referred to today in the default transmission agreement template in Schedule 12.6 of the Code.

In 2010, the Electricity (Safety) Regulations were made. While still citing compliance with NZECP 36:1993 as a way of being compliant with their harmonics requirements, the regulations permitted compliance with harmonics standards other than NZECP 36:1993 to be used as a means of achieving compliance with their harmonics requirements. The 2010 regulations contained the same harmonics standards referred to in today's version of the regulations.

In 2015, the Code was amended to permit small-scale distributed generation applying for connection to a distributor's network to use the simplified one-stage application process in Part 1A of Schedule 6.1 of the Code, if amongst other things, the generation incorporated an inverter that complied with the standard AS/NZS 4777.2:2020.

The regulation of harmonics by the Code

4.4. The Code contains harmonic standards that are intended to avoid harm associated with excessive harmonics.

4.5. The default transmission agreement template in Schedule 12.6 of the Code forms the basis for transmission agreements between Transpower and its customers (ie. generators, distributors and direct consumers). This default agreement template requires the parties to a transmission agreement to comply with:

(a) the New Zealand Electrical Code of Practice for Harmonic Levels (NZECP 36:1993), as amended from time to time, or

(b) any other equivalent or similar Australian Standards and New Zealand Standards (AS/NZS) standard, International Electrotechnical Commission (IEC) standard, Institute of Electrical and Electronics Engineers (IEEE) standard, or

(c) any other requirements specified by Transpower (acting reasonably) that cover similar matters to those set out in NZECP 36:1993.[11]

[11] Clause 4.7 of Schedule 8 (Connection Code) of the default transmission agreement template.

4.6. In relation to these requirements, the Authority notes:

(a) the NZECP 36:1993 standard applies only to harmonic voltages and harmonic currents emitted by consumer installations[12]

(b) the AS/NZS 61000 standard series is based on the IEC 61000 standard series

(c) IEEE standard 519 is relatively specialised compared with the other standards referred to in the default transmission agreement template. This standard describes IEEE recommended practices and requirements for controlling harmonics in power systems.

4.7. The Code does not require other persons connecting, or connected, to the power system to comply with a harmonics standard, with one exception. Small-scale distributed generation[13] applying for connection to a distributor's network using the simplified one-stage application process in Part 1A of Schedule 6.1 of the Code must incorporate an inverter that complies with the standard AS/NZS 4777.2:2020.

4.8. However, Part 6 of the Code does empower distributors to specify, via their connection and operation standards for distributed generation, a harmonics standard for distributed generation connecting, or connected, to their networks.[14] A recent informal review of distributors' connection and operation standards for distributed generation found that several distributors cite a version of AS/NZS 4777.2:2020 for distributed generation of 10kW or less.

4.9. The Authority also notes that the Electricity Engineers' Association published an updated set of power quality guidelines at the beginning of 2024.[15] Amongst other things, these guidelines contain information on supraharmonics[16] and interharmonics.[17] Distributors are a key intended audience for these guidelines.

The regulation of harmonics by the Electricity (Safety) Regulations

4.10. As with the Code, the Electricity (Safety) Regulations also contain harmonic standards that are intended to avoid harm associated with excessive harmonics.

4.11. The Electricity (Safety) Regulations require that the use of fittings and appliances must not unduly interfere with the satisfactory supply of electricity to any other person, or impair the safety of, or interfere with the operation of, any other fittings or appliances. In relation to interference from harmonics, this obligation is deemed to be complied with by complying with whichever of the following standards is applicable:[18]

(a) NZECP 36: 1993

---

12 See page 2 of NZECP 36:1993.

13 Being generating stations with a nameplate capacity of 10kW or less in total.

14 See, for example, clauses 6.1(a), 6.2, 6.3(2) of the Code, clauses 1D, 3(2), 9F and 18(2) of Schedule 6.1 of the Code, and clauses 3 and 11 of Schedule 6.2 of the Code.

15 Electricity Engineers' Association, January 2024, Power Quality (PQ) Guidelines.

16 These are high frequency harmonics (>50th harmonic order).

17 Interharmonics are waveform components that are at frequencies that are not a multiple of the supply frequency (being 50Hz in New Zealand). Interharmonics that are below the supply frequency are called subharmonics. See p. 58 of the Electricity Engineers' Association's 2024 Power Quality (PQ) Guidelines.

18 See regulation 31.

(b) IEC 61000–3–2[19]

(c) IEC/TS 61000–3–4[20]

(d) IEC 61000–3–12.[21]

Challenges with the existing arrangements for governing harmonics

4.12. The management of harmonics has received relatively little attention in the Code and other regulatory instruments over the years. In part this has led to some challenges with the existing arrangements for governing harmonics in New Zealand.

NZECP 36:1993 has some limitations

4.13. The harmonic emissions limits in NZECP 36:1993, which is New Zealand's main regulatory standard for harmonics, were developed in the 1960s and 1970s. These emissions limits do not account for modern inverter-based resources with power converters that transfer charge by frequently switching a conductor on and off. These power converters are becoming increasing prevalent in New Zealand. They are used in solar photovoltaic generating stations, wind generating stations, battery energy storage systems, and industrial, commercial, and consumer electronic loads.

4.14. The high switching frequency of the power converters used in inverter-based resources is a source of harmonics. So too is any nonlinear behaviour from generating units that are machine-based (ie, that convert mechanical energy to electrical energy).[22]

4.15. NZECP 36:1993 does not address:

(a) power quality disturbances such as supraharmonics and interharmonics, from new generation / non-linear load types

(b) harmonic monitoring and roles and responsibilities

(c) the justification for the defined harmonic levels.

4.16. The restrictive compatibility limits associated with NZECP 36:1993 impose significant harmonic mitigation costs on affected parties. These costs are primarily in the form of equipment costs and conducting detailed engineering studies. Additionally, the equipment added to mitigate harmonic emissions may also introduce additional electrical losses, leading to higher operational costs for the asset owner.

There is some ambiguity around the applicability of harmonics standards

4.17. As noted above, at present harmonic standards are located in the Electricity (Safety) Regulations and in Schedule 12.6 of the Code. In addition, distributors can also

---

19 'Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤16 A per phase)'.

20 'Electromagnetic compatibility (EMC) - Part 3-4: Limits - Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A'.

21 'Electromagnetic compatibility (EMC) - Part 3-12: Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase'.

22 Preciado, V., et al., 2015, 'Harmonics in a wind power plant.' 2015

specify harmonic standards in their connection and operation standards for distributed generation, under the empowering provisions in Part 6 of the Code.

4.18. The Code is subordinate to Acts and regulations,[23] so any harmonic standards in the Code, or authorised by it, are subordinated to the harmonic standards in the Electricity (Safety) Regulations should the Code and these regulations conflict. At present there is no such conflict as complying with the harmonics standards listed in regulation 31(2) of the Electricity (Safety) Regulations is just one way of meeting the obligation in regulation 31(1). Complying with the harmonics standards in the Code might be expected to also meet the obligation in regulation 31(1). However, the Authority considers there may be some ambiguity for industry participants around this interaction between the harmonic standards in the Electricity (Safety) Regulations and the standards in the Code. We believe this has the potential to cause confusion for participants.

4.19. A further source of potential ambiguity for harmonic standards is the Electricity (Safety) Regulations applying two different standards (NZECP 36:1993 and IEC 61000 3 2) to equipment that are covered by the AS/NZS 4777.2 standard in Part 6 of the Code and in distributors' connection and operation standards for distributed generation. Since NZECP 36:1993 applies to all consumer installations, it applies to the same inverter equipment as does AS/NZS 4777.2. So too does the standard IEC 61000 3 2, which applies to electrical and electronic equipment with a rated input current up to and including 16 amps per phase and intended to be connected to public low-voltage distribution systems.[24]

4.20. Lastly, the Electricity (Safety) Regulations refer to a standard that is in fact not to be regarded as an International Standard (IEC/TS 61000–3–4) according to the International Electrotechnical Commission.[25]

4.21. The absence of a nationally consistent set of harmonic regulations is causing ambiguity for various stakeholders including utilities, developers, original equipment manufacturers and consultants.

4.22. In addition, the lack of a consistent set of harmonic standards and a management framework across New Zealand creates considerable difficulty for electricity network companies to develop an approach for the management of harmonics within their respective networks. Consequently, approaches throughout the country vary widely.

A suggested way forward

4.23. To help address the challenges with the existing arrangements for the governance of harmonics, it would appear desirable for New Zealand to adopt a set of harmonic standards that promote consistency in the limitation and management of harmonics. This would include consistency in the treatment of generation and consumer loads, as well as consistency of application across electricity network companies.

---

23 See section 33(2) of the Electricity Industry Act 2010.

24 Arc welding equipment that is not professional equipment, with a rated input current up to and including 16 amps per phase, is included in IEC 61000-3-2. Arc welding equipment intended for professional use, as specified in IEC 60974-1, is excluded from IEC 61000-3-2 and can be subject to installation restrictions as indicated in IEC 61000-3-12.

25 Correctly referred to as IEC TS 61000-3-4:1998.

4.24. The Authority notes the AS/NZS 61000 series may be a suitable set of harmonics standards. This series is based on the IEC 61000 series of harmonic standards and could be modified to suit the Australian and New Zealand electricity industry arrangements. This offers the benefit of applying international best practice to local conditions.

4.25. The Authority considers guidelines are likely to be helpful to aid industry participants and other relevant stakeholders in using the adopted standard(s).

4.26. Changes to the Code and the Electricity (Safety) Regulations may be needed to give effect to this way forward.

Q1. Do you consider the Authority has accurately summarised New Zealand's existing key regulatory requirements for harmonics? If you disagree, please explain why.

Q2. Do you agree the Authority has identified the main challenges with the existing arrangements for the governance of harmonics? If there are any additional challenges, please set these out in your response.

Q3. Do you consider the existing regulatory framework for the governance of harmonics in New Zealand is compatible with the uptake of inverter-based resources? Please give reasons for your answer.

Q4. Do you have any feedback on the Authority's suggested way forward to help address the challenges with the existing arrangements for the governance of harmonics?

5. The management of harmonics

5.1. The Authority defines the management of harmonics to mean the arrangements in place to set limits on the amount of harmonics in electricity networks and to maintain harmonics within these limits.

5.2. Currently, some of the key aspects of managing harmonics, such as the monitoring of harmonics, roles and responsibilities, and the allocation of harmonics are not well defined in the Code and regulations.

5.3. This section summarises good industry practice in relation to a framework for the management of harmonics. The following elements of a framework are covered:

(a) principles for the management of harmonics

(b) planning and compatibility levels

(c) voltage levels

(d) measurement of harmonics

(e) roles and responsibilities

(f) timeframes for various steps required in managing harmonics

(g) a methodology for allocating harmonics.

5.4. Overseas harmonic management frameworks that we have reviewed generally do not specify potential harmonic mitigation options. Nor do they provide solutions to increase the capacity of an electricity network to accommodate additional harmonic distortion from new connections. However, we found that overseas frameworks may explain the situations where some form of mitigation is required, and what the timeframe for this mitigation should be.

5.5. Internationally, the most commonly used standards for the management of harmonics appear to be the IEC 61000 series of engineering standards and technical reports, and the IEEE 519 standard. However, some overseas jurisdictions have developed their own harmonic management frameworks based on engineering standards. For example, the United Kingdom has adopted the engineering standard G5/5, and Germany has adopted the VDE 0838, 4130, and 4105 technical connection rules.

5.6. The Authority notes that some of the elements of a harmonics management framework listed in paragraph 5.3 are well-defined in the AS/NZS 61000 series of standards.

Principles for the management of harmonics

5.7. The Electricity Engineers' Association's 2024 power-quality guidelines set out some principles of harmonic management.[26] We summarise these as follows.

5.8. Limits on harmonic voltages are determined by what is cost-effective for the community.

26 See p. 47 of the guidelines.

5.9. Limits are set on individual harmonics up to the 50th harmonic, interharmonics, and the total harmonic distortion.[27] These limits vary within the power system, being generally larger towards the low voltage part of the power system.

5.10. There is some scope for electricity network companies[28] to determine their own limits as they deem appropriate, provided there is some margin to ensure low voltage compatibility levels are not exceeded (see Appendix A for an explanation of compatibility levels).

5.11. Harmonic voltages are the response of harmonic currents flowing in the network harmonic impedance. Controlling harmonic voltage requires limits to be placed on the harmonic currents of connecting parties and network harmonic impedance.[29]

5.12. Low voltage harmonic emissions are controlled by generic limits on equipment current emissions determined according to the equipment's pattern of use and its power rating.

Planning and compatibility levels

5.13. Planning and compatibility levels are the reference values used to co-ordinate the background harmonic emission level on an electricity network with the immunity level of equipment and appliances connected to the network.

5.14. The planning levels and compatibility levels specified in the NZECP 36:1993 standard differ from the levels specified in the IEC 61000 series.

5.15. The Electricity Engineers' Association has published planning and compatibility levels in its 2024 power-quality guidelines.[30]

Voltage levels

5.16. As a general principle, when specifying harmonic planning levels, limits on harmonic voltages should vary as the network voltage varies.

5.17. Voltage levels differ across countries and the IEC 61000 series of standards acknowledges this. The IEC 61000 series specifies the following voltage levels relevant to New Zealand:

(a) Low voltage refers to U n ≤ 1 kilovolt (kV)

(b) Medium voltage refers to 1kV < U n ≤ 35kV

(c) High voltage refers to 35kV < U n ≤ 230kV.[31]

---

27 Total harmonic distortion is the ratio of the root mean square value of all the individual harmonic currents / harmonic voltages to the root mean square value of the fundamental current / voltage (ie, at 50Hz).

28 The terms 'electricity network company' and 'network company' are used interchangeably in this paper. The Authority is using these terms rather than 'system operator', 'network operator', 'transmission network owner', and 'distributor' as part of keeping an open mind to what roles and responsibilities relating to the management of harmonics sit with the network owner and the network operator.

29 The Authority notes the connecting party and the network company can work together to recognise location-specific impedance characteristics of the network that influence permissible harmonic emissions by the connecting party.

30 See p. 77 of the guidelines.

31 IEC TR 61000–3–6:2008 – Electromagnetic compatibility (EMC) - Part 3-6: Limits - Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems.

Measurement of harmonics

5.18. The measurement of harmonics is a key aspect of any harmonic management framework. Measurements of harmonics provide a baseline for determining the acceptability of proposed connections of non-linear equipment to an electricity network. These measurements enable estimation of the cumulative effect of new non-linear connections and existing harmonic sources.

5.19. It is common practice to measure harmonics for a period of at least one week during the (historic) peak and trough load seasons, to capture a representative range of variations in harmonic emissions throughout the year.

5.20. In accordance with IEC61000-4-30, it is recommended that 3-second aggregation and/or 10-minute aggregation measurement data is collected by the network company, depending on the company's technical and economic capabilities. The 95% value from the cumulative probability function should be used in the assessment process.

5.21. Where possible,[32] electricity network companies should publish their background harmonic data and other relevant statistics for various nodes on their networks. This could include a register of inverter types and sizes. This has the following benefits:

(a) it assists new applicants to make more informed investment decisions and decisions regarding harmonic compliance

(b) it promotes innovation by enabling new and existing connected parties to explore more efficient ways of addressing any harmonic issues (eg, selecting alternative power electronics with a greater diversity to the harmonic characteristics of existing equipment connected to the network).

Roles and responsibilities

5.22. The roles and responsibilities set out in this subsection are drawn from domestic and overseas industry practices.

The electricity network company

5.23. The electricity network company:

(a) should create a guideline to specify the information needed by someone wanting to apply for a new connection or to modify an existing non-linear load/generator.

(b) must decide on the extent to which studies are required by parties who wish to connect their non-linear load / generating station to the network or modify their already-connected non-linear load / generating station. This decision should be based on a high-level assessment of the potential impact of the connecting party's non-linear load/generator on the network's existing background harmonics.

(c) is responsible for the overall co-ordination of harmonic disturbance levels both under normal operating conditions and during contingent scenarios, and must refer to the compatibility levels.

---

32 So long as proprietary and/or commercially sensitive information is not revealed through this process.

(d) should record the power quality at key sites. These sites can be selected based on the existing identified sites with power quality issues, substations close to the point of connection of generating stations and large[33] industrial loads. The recorded power quality data should be published, along with relevant statistics showing the changed harmonics over different periods. Making such data publicly available will help in monitoring changes in the harmonic profile and assessing the impact of non-linear load / generation on the network over time.

(e) monitors the background harmonics prior to the connection of a new generating station or large non-linear load. This provides a baseline for the network company to assess the harmonic emissions from the new generator / load.

(f) is responsible for defining how harmonic compliance shall be assessed post commissioning, including specifying what supporting evidence will be required. Sufficient time should be allowed to enable the connected party to carry out robust monitoring, the preparation of a compliance assessment, and the necessary investigation and development of mitigation measures (if the initial assessment indicates non-compliance).

Network users

5.24. Network users:

(a) should conduct harmonic compliance assessment studies based on the background harmonics data and impedance ranges, for 'normal' and 'contingency' system scenarios (ie, impedance polygons) provided by the electricity network company.

(b) should continuously monitor the power quality at their network connection points and share this information with the electricity network company.

(c) should have a harmonic management plan in place, which details the resolution process the user will follow if the emissions from its generating station / non-linear load were to increase above the specified limits.

Timeframes for various steps required in managing harmonics

5.25. Harmonics are dynamic phenomena, varying over time as network operating conditions change. Therefore, it is important to have timeframes in place for various steps required in managing harmonics.

5.26. *Measuring harmonics*: As noted above, measurements of harmonics provide a baseline to determine the acceptability of proposed connections of non-linear equipment to an electricity network. Various standards define the timeframe for recording harmonics at points on a network (eg, NZECP 36:1993 and the IEC 61000 series of standards).

5.27. *Exchanging harmonic information*: To improve the efficiency of the connection process, it is desirable to specify timeframes for:

(a) the electricity network company's provision of information on the network's background harmonics to the party wanting to connect

---

33 The Authority considers 'large' non-linear loads to be three phase non-linear loads (400V and above).

(b) a connecting party to provide the network company with harmonic emission data and the results of harmonic simulation studies that assess the impact of the connecting party's harmonics on the network's existing background harmonics and resonance.

5.28. *Mitigating harmonics*: Mitigating harmonics is a complex process that often requires the installation of harmonic mitigation devices (eg, harmonic filters). Having clear timeframes around the mitigation of harmonics is important because typically the lead times for harmonic mitigation devices are long.

Existing allocation methods used in New Zealand to limit harmonic emissions

5.29. One approach employed in managing harmonics is to limit the harmonic emission levels for an electricity network by allocating a limited amount of the harmonic headroom in the network to a connecting party. This applies both to generating stations and (non-linear) loads.

5.30. Transpower (in its role of transmission network owner) has applied NZECP 36:1993 for assessing the harmonic emissions of its customers and allocated one third of the available headroom to a new connection. This is in line with the IEEE 519 standard.

5.31. Some distributors also use the same allocation methodology as Transpower.

5.32. The Electricity Engineers' Association's power-quality guidelines contain a three-stage approach for allocating harmonic current based on principles contained in AS/NZS 61000.3.6 and AS/NZS 61000.3.7. This approach uses a very conservative voltage droop-based methodology for allocating harmonics. This approach has been applied on some distribution networks, though its suitability for use on the transmission network has not been investigated.

5.33. The voltage droop approach was designed to be a practical method for distributors to adopt. Most distributors do not have computer models to generate harmonic impedance information for large parts of their network (typically the 400V, 11kV and 22kV parts of their networks).

5.34. If an electricity network company has the necessary computer models of their network, then using these to generate a range of harmonic impedances is likely to be a better way to allocate harmonic current than the voltage droop method.

5.35. Given the wide range of methodologies in use, it seems desirable to take a 'whole of system' approach to the allocation of harmonics. Any differences in harmonic allocation methodologies across the electricity industry (eg, between transmission and distribution networks) should not cause harmonics to exceed electricity network companies' planning levels. A 'whole of system' approach would require broad industry participation.

Alternative approaches to limiting harmonic emissions

5.36. There are alternative approaches to limiting harmonic emissions. Set out below are some examples that have been developed through the Authority's work with the Common Quality Technical Group.

5.37. Table 1 summarises some identified pros and cons of these alternative approaches.

An ‘open access’ approach

5.38. An open access approach to the allocation of harmonics focuses solely on compliance with planning levels, ensuring measured harmonic levels remain below equipment compatibility levels.

5.39. Routinely published harmonic data for large nodes across New Zealand would allow harmonic trends to be observed over time, so the network company could anticipate in advance the nodes where harmonic planning levels are likely to be breached.

5.40. As noted above in paragraph 5.21, the publication of background harmonic data and other relevant statistics also offers other benefits (eg, improved investment decision-making, innovation, and compliance).

5.41. An open access approach is already used for new generation connecting to New Zealand’s power system, in relation to the power transfer capacity available at the generating station’s point of connection. In this context, a prospective generator may be given permission to connect their generating station to the transmission network, though this permission does not guarantee the ability to generate maximum power output at all times. Network thermal or voltage constraints may limit the amount of energy that can be exported from the generating station’s location on the network. Network constraints are identified and communicated to stakeholders via the network owner’s asset management plan or the transmission system security forecast, thereby enabling generation investments to be planned accordingly.

5.42. In the context of harmonics, an open access approach would make the network company responsible for co-ordinating harmonic management on their network. Co-ordination would involve the network company monitoring and assessing harmonic levels across their network, publishing the collected data in a central location, and giving advance warning to an owner (or owners) of generating stations / load to indicate when the owner(s) might need to take further action to reduce their harmonic emissions.

5.43. An open access approach would help to avoid pre-emptive investment in infrastructure that is not directly related to the supply of electricity. Investment in harmonic mitigation measures (such as installation of harmonic filtering equipment) would be deferred until after the equipment at the new connection has been commissioned, at a time when planning levels are nearing their limits.

5.44. The sole purpose of an open access approach is to keep harmonics at a level that generation, transmission, distribution, and consumption equipment can tolerate, rather than allocating emissions amongst network users.

5.45. An open access approach would not allocate harmonic emissions. Rather it would allow the electricity network company to identify the largest emitters in advance, and give them adequate notice to reduce their emissions, before harmonic planning limits are exceeded (in the same way as future thermal constraints are managed). Parties that are considering connecting to the network can then weigh up the risk of curtailment against their approach to mitigating emissions as specified in their management plan. This reduces the electricity network company’s burden of responsibility for managing harmonics.

5.46. The level of effort required to identify large emitters will be equivalent to the effort required to assess whether a given generator or load is exceeding its allocated harmonic emissions.

5.47. An open access approach is an agile approach, which potentially lowers the cost of harmonic management.

Require connecting parties to be a net absorber of harmonic emissions

5.48. Under a 'net absorbing harmonic emitter' approach, connected parties must ensure that their contribution to the harmonic levels seen on the electricity network is net-absorbing when summed across a range of frequencies. Specifically, their net harmonic real-current (real relative to the prevailing harmonic voltage) across all frequencies is negative.

5.49. Thus, if a generating station or load installs a filter at a frequency, the station / load is credited with reducing the harmonic levels at that frequency, and the credit can then be applied at another frequency where the station / load is an emitter.

5.50. This method could work well with prescribing a cost associated with failures to meet harmonic standards. For example, if an installation has a small net-production of harmonics, it may be more economical for the connected party to pay a one-off harmonic contribution than to install a harmonic filter.

Apply charges to the emitters of harmonics

5.51. Under this option, charges would be applied to voltage-distorting generating stations and loads connected to a network, to pay for measures taken to manage the harmonics in the network caused by these parties. The aim is to promote the efficient management of harmonics by providing appropriate financial incentives on harmonics emitters to account for the harmonics-related costs they impose on other parties.

5.52. Some overseas jurisdictions apply penalties on consumers with harmonic emissions exceeding defined limits. For example, the Tamil Nadu Electricity Board in India has a penalty structure comprising incremental 1% steps up to a maximum of 10%, levied on monthly consumption charges.

Pre-emptive installation of harmonic filters

5.53. The pre-emptive installation of harmonic filtering on renewable energy projects is an option used in some overseas jurisdictions.

5.54. Pre-emptive installation of broad-spectrum harmonic filtering (eg, a C-type filter) helps reduce the risk of exceeding allocated limits and increases confidence in harmonic compliance. This approach has been used to manage limitations in the accuracy of input information used in harmonic studies, where they are prepared in advance of the generating station / load being commissioned.

5.55. The cost of filtering to the project will depend on the headroom between existing harmonic distortion levels and the respective planning limits, as well as the amount of uncertainty in the available harmonics information provided.

5.56. Installation of larger filters is likely to increase the operational complexity of the surrounding network, as they will affect system voltages and reactive power flows.

5.57. Recent experience in Australia indicates that the amount of filtering required to achieve compliance could be minimised by refining the filter design in the months following commissioning, as some equipment manufacturers are being very conservative in their power quality measurements.

Pros and cons of alternative approaches to limit harmonic emissions

5.58. Table 1 sets out the pros and cons of the above alternative approaches to limit harmonic emissions.

Table 1: Pros and cons of alternative approaches to limit harmonic emissions

Method	Pros	Cons
1. An 'open access' approach	1. The initial cost for managing harmonics is reduced. 2. The resources of the electricity network company can be directed to the nodes/regions that have observed harmonic issues. 3. Expedites the connection timeframe for projects as the downtime to complete the harmonic compliance process is avoided.	1. Provision of largest harmonic distortion allowance to the first non-linear load / generating station to be connected might appear to facilitate first mover advantage. However, the intention is to make large emitters aware in advance that they are using a large proportion of the available harmonics headroom and require them to reduce their emissions. 2. An increasing volume of non-compliant equipment connecting to the network will place a large demand on the network company in terms of planning, network design, installation and maintenance of harmonic filters. 3. The open access approach lends itself to a 'tragedy of the commons' outcome, whereby the inability to identify individual causers of harmonic emissions removes or reduces the incentive on individual parties to manage their harmonics. The outcome is rapid exhaustion of the total harmonic distortion allowance and negative effects of harmonics being felt more quickly and keenly than otherwise would be the case. 4. This approach could be problematic for real-time operation of the power system if the approach necessitates constraining generation that has not reduced its harmonic emissions sufficiently after being asked to. 5. This approach could be costly in periods of tight electricity supply if the approach necessitates constraining generation that has not reduced its harmonic emissions sufficiently after being asked to. 6. More complex to monitor, assess and execute generation curtailment.

2. Require connecting parties to be a net absorber of harmonic emissions	1. No allocations necessary. No first-mover advantage, and no issues if the harmonic levels are currently near or above limits pending investigation. 2. Filtering installed is based on actual measured harmonic levels, and generally fixes the worst one (or as specified by the electricity network company.) 3. Avoids installation of unnecessary filtering caused by harmonic loci calculations and/or per-harmonic allocation which is not being used by other installations.	1. The harmonic emissions from the inverter-based resources and other sources are not steady throughout the year. This might cause the solution to be ineffective in some cases. 2. Requires further studies to be undertaken to evaluate the effectiveness of this approach.
3. Apply charges to the emitters of harmonics	1. Reflects that harmonic issues are cumulative. 2. Clear and transparent, avoids rebating complexity.	1. Difficult to formulate a charging mechanism that accurately applies charges to harmonics emitters. 2. A key challenge in applying this methodology is that in some cases no individual connected parties are solely responsible for the adverse effects of harmonics on the electricity network. Instead, harmonic issues result from an aggregation of distributed harmonic sources. 3. Increases the cost burden on connecting parties, as the cost for connecting and operating their assets increases. However, this additional cost to connecting parties could be avoided through network companies using an efficient harmonic management practice.

4. Pre-emptive installation of harmonic filters	1. This method mitigates harmonic emissions at the source.	1. New harmonic components arise in the electricity network due to the addition of new non-linear loads / generating stations. These harmonic components may be far from the filter tuning frequency thus making the investment in the filter ineffective. 2. With ever-increasing amounts of inverter-based resources connecting to an electricity network, average harmonic levels increase in the network, thus overloading the existing filters and making them ineffective. 3. Modifying an electricity network (eg, adding new lines or reactive power compensation equipment) can affect the effectiveness of the existing filters in the network. 4. Active filters operate on fast switching of high currents in the power circuit. This causes high frequency noise which may cause electromagnetic interference in the network. 5. Filters increase operational complexity. A traditional capacitor bank may be switched in when additional volt amperes reactive are needed. Bringing in a C-type filter at times of high system voltages requires more equipment to compensate for that filtering. 6. Alternate, cheaper options can be used instead (eg, with the right control system, a smart inverter can be a load at 250Hz, and then return power to the network at 50Hz). 7. Increasing the number of harmonic filters connected to the network increases system losses.

Q5. Do you have feedback on any of the elements of good industry practice relating to a framework for managing harmonics? This may include feedback relating to elements you consider are missing from the summary provided in section 5 of this paper.

Q6. Do you agree with a ‘whole of system’ approach to allocating harmonics, so that any differences in harmonic allocation methodologies between electricity networks do not cause excessive harmonics? If you disagree, please explain why.

Q7. Do you have any feedback on the suitability for New Zealand’s power system of the harmonics standard NZECP 36:1993, or the AS/NZS 61000 series of harmonics standards?

Q8. Do you have any feedback on the alternative approaches to limiting harmonic emissions, including alternative approaches you consider to be appropriate for New Zealand’s electricity industry?

6. Next steps

6.1. Once the consultation period closes, the Authority will consider options to improve the governance and management of harmonics in New Zealand.

Appendix A Further information on electrical harmonics

A.1. This appendix expands on the description of electrical harmonics provided in section 3 of the paper. The material in this appendix draws on material in the Electricity Engineers' Association's 2024 power-quality guidelines and on material provided by members of the Common Quality Technical Group.

Sources of harmonic distortion

A.2. The main sources of harmonic distortion are:

(a) non-linear power electronic loads

(b) the saturation of iron cores.

A.3. In the past, the main sources of harmonic distortions in New Zealand were large and well known – the HVDC link and metallurgic processes such as the aluminium smelter at Tiwai Point and the steel mill at Glenbrook (with its arc furnaces).

A.4. The use of electronic and power electronic equipment throughout the economy means there are now a multitude of smaller sources capable of causing harmonic currents on a wider range of frequencies.

A.5. Today most harmonic distortions in New Zealand are caused by switching devices. These are devices that transfer charge to an electrical load by frequently switching a conductor on and off. Examples of switching devices include diodes, thyristors and insulated-gate bipolar transistors, which are synchronised with the (50Hz) supply frequency. These switching devices are found in a range of electronic devices, such as computers, compact fluorescent lamps, and variable speed drives.

A.6. In future, large-scale wind and solar photovoltaic generating stations, and battery energy storage systems, will contribute to an increase in overall harmonic distortion. This is because of their use of power electronic inverters to interface with the electricity network to which they are connected. The effect on harmonics from these inverter-based resources may be exacerbated if traditional synchronous machine-based generation is displaced. At present, this generation (beneficially) absorbs harmonics from electricity networks.

Effects of harmonic distortion

A.7. The main effects of harmonics on equipment at all voltage levels in the power system are:

(a) Mal-operation of electronic controlled equipment.

(b) Acoustic noise from equipment and vibrations.

(c) Cogging[34] and crawling[35] of induction motors.

(d) Heating of the rotor in three-phase induction motors.

---

[34] When an induction motor experiences difficulty starting because of the alignment forces between the induction motor's stator and rotor magnets being greater than the accelerating torque forces being applied at the instant of start-up.

[35] When an induction motor operates at a speed that is slower than the speed associated with operating at the motor's synchronous speed (ie, 50Hz in New Zealand).

(e) Heating of capacitors not fitted with an appropriate series detuning inductor.

(f) The high frequency sinusoidal components can accelerate the failure of induction motors, capacitors and electronic equipment.

(g) Deterioration of equipment insulation, and premature failure of electrical components due to increased root-mean-squared currents and voltages (particularly in capacitor banks).

(h) Telephone interference, although the risks associated with this issue have been reducing over time with the ongoing change to fibre of telecommunication network cables.

A.8. Careful management of harmonics is required to minimise impacts such as those described above. The inequitable management of harmonics can result in additional non-optimal investments in electricity networks, resulting in increased costs to electricity consumers.

Some common ways of mitigating harmonics in New Zealand

A.9. Ideally harmonics should be minimised at the source as much as practicable. If not, they could flow to other parts of the power system, where they can have detrimental effects or necessitate additional non-optimal network investments.

A.10. Filters (which are tuned capacitor-reactor circuits) are a common method for absorbing harmonics from alternating current networks, to improve voltage quality. Large installations such as the HVDC link and the aluminium smelter at Tiwai Point have filters tuned to absorb the characteristic harmonics generated by the process for converting alternating current to direct current. Inverter-based resources may also include filters as part of their design (either within each inverter unit or implemented at a system level).

A.11. Zig-Zag transformers are deployed in some distribution networks. These transformers cancel harmonics generated by specific types of loads that generate their harmonics coherently (eg, irrigation pumps that use diode rectifiers).

A.12. Some types of loads (eg, residential heat pumps) from different manufacturers have a natural diversity, which cancels harmonics and minimises their collective voltage distortion. Other types of resistive loads (eg, water heaters or electrode boilers) absorb harmonic current when connected.

A.13. Shunt capacitor banks are installed at transmission voltages in major load centres (eg, Auckland and Christchurch) to provide reactive power to support higher megawatt transfers from generating stations. These capacitor banks can provide a secondary benefit by being tuned to absorb harmonics from the power system, thereby improving voltage quality. However, they are usually switched out when there is light loading on the transmission network, to prevent voltage at the fundamental frequency (50Hz) from rising too high. This means they are not always in service and therefore cannot always be absorbing harmonics. If capacitor banks were to be permanently connected, then other investments may be needed to bring the 50Hz voltage down to within acceptable levels. This would add cost and complexity.

A.14. Power transformer leakage reactance provides a natural blocking mechanism to high frequency harmonics. Power cable capacitance can provide a natural filtering to high frequency components. The parameters of these elements may be refined to resonate at a frequency that has low harmonic emissions.

A.15. Design choices for equipment used in inverter-based resources (eg, transformer configurations, switching patterns, and the number of converter power module levels) can be made to minimise harmonic emissions.

Emission level, immunity level, planning level and compatibility level

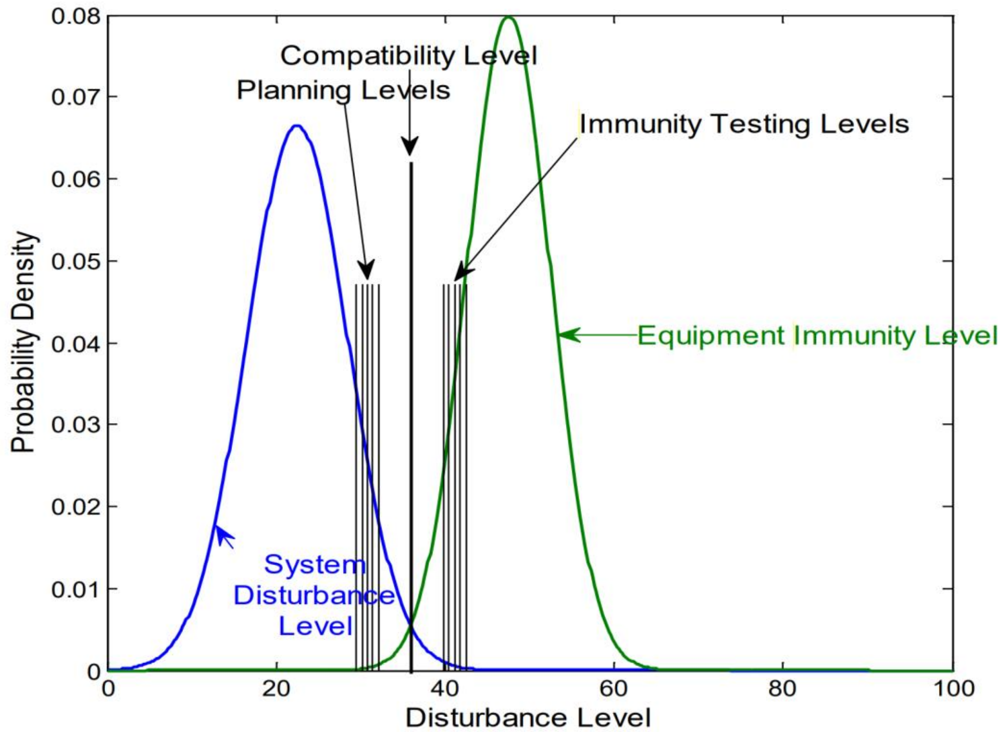
A.16. The contribution to harmonic disturbance from a piece of equipment is the equipment's *emission level*. This can be measured by a voltage or current parameter.

A.17. The minimum level of a power-quality parameter that causes equipment to malfunction is the equipment's *immunity level*.

A.18. An electricity network company achieves satisfactory power-quality levels on its network by, amongst other things, limiting harmonic disturbances on its network to a *planning level*. This is a target electromagnetic disturbance level that is below the *compatibility level*. The *compatibility level* is the electromagnetic disturbance level used as a reference level in a specified environment for co-ordinating the setting of emission limits for given immunity limits.

A.19. Figure 4 illustrates the interaction between immunity level, planning level, and compatibility level.

Figure 4: Illustration of interaction between immunity level, planning level and compatibility level



Appendix B Format for submissions

Submitter	

Questions	Comments
Q1. Do you consider the Authority has accurately summarised New Zealand's existing key regulatory requirements for harmonics? If you disagree, please explain why.	
Q2. Do you agree the Authority has identified the main challenges with the existing arrangements for the governance of harmonics? If there are any additional challenges, please set these out in your response	
Q3. Do you consider the existing regulatory framework for the governance of harmonics in New Zealand is compatible with the uptake of inverter-based resources? Please give reasons for your answer.	
Q4. Do you have any feedback on the Authority's suggested way forward to help address the challenges with the existing arrangements for the governance of harmonics?	
Q5. Do you have feedback on any of the elements of good industry practice relating to a framework for managing harmonics? This may include feedback relating to elements you consider are missing from the summary provided in section 5 of this paper.	
Q6. Do you agree with a 'whole of system' approach to allocating harmonics, so that any differences in harmonic allocation methodologies between electricity networks do not cause excessive harmonics? If you disagree, please explain why.	

Q7. Do you have any feedback on the suitability for New Zealand's power system of the harmonics standard NZECP 36:1993, or the AS/NZS 61000 series of harmonics standards?	
Q8. Do you have any feedback on the alternative approaches to limiting harmonic emissions, including alternative approaches you consider to be appropriate for New Zealand's electricity industry?	

Glossary of terms

Background harmonic level	The level of harmonic voltage distortion in a network, defined in terms of the individual and total harmonic voltage levels, that exist before the connection of the non-linear or resonant plant and equipment being assessed
Compatibility level	The level of harmonic voltage distortion, defined in terms of the individual and total harmonic levels, within which the network should be operated.
Harmonic headroom	The difference between the background harmonic level and a defined reference level, such as the planning level or compatibility level.
Incremental harmonic voltage	The harmonic voltage change produced by an applicant's asset at its point of connection to the network resulting directly from any and all harmonic emissions from the asset's non-linear components.
Incremental harmonic voltage limit	The maximum permitted harmonic voltage change that an applicant may produce at its point of connection to the network due to harmonic emissions from the asset's non-linear components
Individual harmonic distortion	The root-mean-square value of an individual harmonic voltage or current expressed as a percentage of the fundamental root-mean-square voltage or current.
Low voltage	A nominal root-mean-square value of less than or equal to 1kV.
Medium voltage	A nominal root-mean-square value of greater than 1kV and less than or equal to 36kV.
High voltage	A nominal root-mean-square value of greater than 36kV and less than or equal to 230kV.
Planning level	The level of harmonic voltage distortion, defined in terms of the individual and total harmonic voltage levels, against which the connection of non-linear or resonant plant and equipment is assessed.
Total harmonic current distortion (THDi)	The ratio of the root-mean-square value of all the individual harmonic currents, to the root mean square value of the fundamental current.
Total harmonic voltage distortion (THDv)	The ratio of the root-mean-square value of all the individual harmonic voltages, to the root mean square value of the fundamental voltage.