A REVIEW OF THE NEW AUSTRALIAN HARMONICS STANDARD AS/NZS 61000.3.6

V. J. Gosbell[1], P. Muttik[2] and D.K. Geddey[3]

[1]University of Wollongong, [2]Alsthom, [3]Transgrid
v.gosbell@uow.edu.au

Abstract

Harmonics due to large installations in Australia will be covered at the end of 1999 by a new standard AS/NZS 61000.3.6 "Limits - Assessment of emission limits for distorting loads in MV and HV power systems" replacing AS2279.2 which has been in force for twenty years. This new standard is largely based on an IEC standard and proposes a quite different approach to the connection of harmonic loads, but this requires a greater attention to detail with a consequent increase in complexity. The paper will discuss limitations of the old standard and how these have been overcome. The key steps in the new standard will be outlined and some example applications given in both MV and HV power systems.

1. INTRODUCTION

The main power quality standard in force in Australia for the past twenty years has been AS2279 "Disturbances in mains supply networks" [1]. It was last revised in 1991 and appears in four parts, 1 and 2 concerned with harmonics and 3 and 4 concerned with fluctuations and flicker. Part 1 is in effect a product standard for household appliances rated at not more than 4.8 kVA while part 2 concerns large industrial installations, where the point of common coupling might appear in a MV or HV power systems. Part 2 "Limitations of harmonics caused by industrial equipment" is due for replacement at the end of 1999 by AS/NZS 61000.3.6, largely based on an IEC standard with an identical number.

The scope of both these standards is to give guidance in determining the maximum size of distorting electrical equipment or converter that may be supplied from high or low voltage, especially when the rating is more than 4.8 kVA or the voltage at the point of common coupling is greater than 240/415 V. The point of common coupling or pcc is defined as the nearest point in power system to which another consumer might be connected.

It should be noted that the use of the terms "high voltage" and "low voltage" in this standard is to be replaced by the IEC terms which have the following meanings for line-to-line values V_{ll}:
Low voltage: V_{ll} <= 1 kV
Medium voltage: 1 kV < V_{ll} <= 35 kV
High voltage: 35 kV < V_ll <= 230 kV
Extra high voltage 230 kV < V_{ll}

AS 2279.2 gives harmonic voltage limits which are smaller at higher voltage levels. This is meant to assure a reasonable clean system at the next lower voltage level to take up the distortion due to loads connected there. The limits are given for odd and even voltages over the range 2nd-40th harmonic and for the total harmonic distortion. Lower limits are given for the even harmonics to minimise the chance of maloperation of rectifying equipment as this may lead to dc being drawn from the power system.

Standards need to be a compromise between a full harmonic study giving accurate evaluations at the cost of much time and simplified approaches which give quick answers with poor accuracy. AS2279.2 allows most cases to be quickly evaluated by having assessment in three stages. Stage 1 is a conservative but quick assessment based on the ratio of converter rating to the fault level at the pcc. Stage 2 allows higher ratings if the existing or background harmonics have been measured. Three possible conditions arise

(i) If the background is less than 25% of the standard levels, Stage 2 allows converter size depending on fault level and converter type.
(ii) If the background is between 25% and 75% of the standard levels, converter ratings of half that given for (i) are allowed.
(iii) For higher background levels, connection must be assessed under Stage 3, that is a full harmonic investigation.

This standard was one of the first national harmonic standards to be developed. Although adequate when first developed, a number of deficiencies have become apparent in recent times.

(i) It gives no account of time variation. Normal background variation is as much as 3:1 over a day in a distribution system. Converter harmonics can vary widely when used as part of a cyclic load such as a minewinder. This was not important initially because most converters assessed were major cause of harmonics in the neighbourhood and it could be argued that the maximum harmonics produced ought to meet the standard limits, providing they lasted for a minimum time of some seconds.

(ii) The Stage 2 approach gives the largest harmonic allowance to the first converter to be connected in the neighbourhood. The allowance for subsequent converters of the same rating becomes less as the background level rises. Again this problem was not too significant at a time when converters were generally of large rating and connected sparsely in the system. It is inappropriate for the modern situation of many small converters of modest ratings.

(iii) Relatively large converters, especially those connected to the transmission and sub-transmission system, are not handled by the standard in Stages 1-2. As a result an industry rule has developed giving an allowance of 1/3 the voltage limit to such converters. This rule has not proved adequate in all cases.

(iv) The crude division of the background into three classes gave a poor treatment of installations which were close to the boundary.

(v) It was assumed in the Stage 2 formulation that converters had a current harmonic spectrum which fell off as 1/n. For example 6-pulse converters had 20% 5th harmonic current, 14% 7th harmonic current and so on. This applies to inductively filtered rectifiers such as the dc drives which were common twenty years ago, but is inaccurate for ac drives which are now proliferating and which are capacitively filtered. Studies have shown that the 5th harmonic current can be as much as 80% of the rated current [2] so that assessment under AS2279.2 can lead to harmonic overvoltages four times larger than expected.

The paper will discuss how the replacement standard AS/NZS61000.3.6 [3] overcomes these problems. The standard is more comprehensive but at the expense of complexity and the use of new concepts which will be explained. Some examples will be given to show how the standard can be applied to typical problems. Finally some aspects of the standards which are not clearly described and where there is scope for uncertainly will be described.

2. THEORETICAL BACKGROUND TO THE NEW STANDARD

2.1 Compatibility levels

The new standard accounts for time variation by limiting a statistic associated with the time variation of the harmonic rather than just the maximum value. The measure chosen in general is the 95% probability level, that is the value which is exceeded for only 5% of the time.

Figure 1 shows and ideal distribution of system disturbances over many points in the power system and taken over many days. In principle, disturbances can occur at very high levels although with low probability. Equipment immunities have a similarly shaped distribution. Compatibility is achieved if the two distributions are sufficiently separated that their overlap occurs at the distribution tails. The compatibility level is the key limit given in the standard and is defined as that level which

(i) is rarely encountered in the system,

(ii) is lower than the immunity level of most connected equipment.

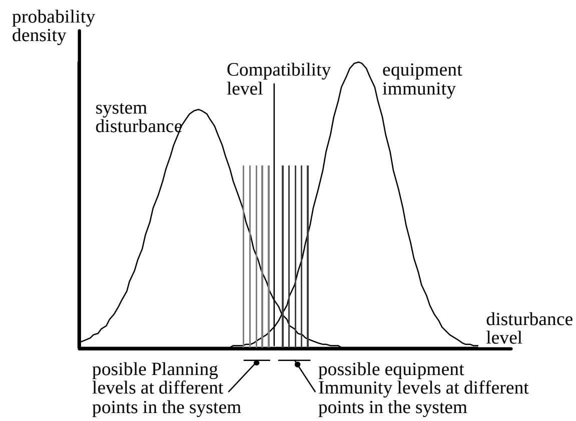

Figure 1. Relationship between compatibility level and the distributions of disturbances and immunities (adapted from IEC 61000.3.6 Figure 1)

2.2 Planning levels

The utility has to achieve a distribution of disturbances lying below the compatibility level. It does so by choosing a value less than the compatibility level, called the planning level, limiting all disturbances to this value. Planning levels may differ in different parts of the power system – for example they may be allowed to be larger in rural areas where there is less equipment that may be affected. The standard suggest typical values of planning levels as summarised in Table I.

Compared with AS 2279.2, a key feature of the new limits is that they are larger for low order harmonics and fall off with increasing frequency to smaller values. The even harmonics are limited to less than half the nearby odd harmonics. A new class of triplen harmonics has been introduced with limits between the nearby odd and even harmonics. The high voltage limits are still about half the medium voltage values.

Table I – Suggested planning levels

Odd harmonics non-triplen			Triplen harmonics			Even harmonics		
Order h	Harmonic voltage %		Order h	Harmonic voltage %		Order h	Harmonic voltage %	
	LV/ MV	HV		LV/ MV	HV		LV/ MV	HV
5	5	2	3	4	2	2	1.6	1.5
7	4	2				4	1	1
11	3	1.5	9	1.2	1	6	0.5	0.5
13	2.5	1.5				8	0.4	0.4
17	1.6	1	15	0.3	0.3	10	0.4	0.4
19	1.2	1				12	0.2	0.2
37	0.5	0.5	39	0.2	0.2	40	0.2	0.2
THD MV: 6.5%, HV: 3%								

2.3 Assessment of disturbance and emission levels

The main steps in assessing the acceptability of a utility's harmonic voltage levels are as follows:

(i) Measure the harmonic voltage continuously over a period of at least a week (the details of the measurement instrument are given in [4]).

(ii) Determine the 95% cumulative probability value, that is the value which is not exceeded for 95% of the time, and confirm that it is not greater than the planning level.

Since consumers may have several converters, the standard limits the total harmonic of the consumer installation rather than the current drawn by a particular converter. The acceptability of a consumer's installation is assessed by comparing current harmonics against an emission standard calculated as will be described later. Time variation is accounted for by a similar approach to that used in assessing a utility's disturbance levels.

2.4 Notching

There is no explicit limit on notching. It is possible to show that the fall of voltage limit with increasing harmonic order provides an indirect limit on nothing. Notches more than 5° wide are limited to a depth of about 20% as in AS 2279.2. For narrow notches, the standard limits the notch area. This is a sensible approach as the difficulty in filtering a narrow notch is proportional to the notch area.

2.5 Summation laws for combining harmonics

The combined effect of harmonic voltages from several different sources is not simply the arithmetical sum of the individual voltages. The voltages are 95% probability levels of distributions which are unlikely to be identical and there will be phase differences between the voltages which can become significant at higher frequencies. Two summation laws are proposed in the standard

(i) First summation law: makes use of diversity factors, similar to AS 2279.2, but taking more factors into account.

(ii) Second summation law: this is a power law recommended as being more general and will be described here in more detail.

The net effect U_h of voltages U_{h1}, ... U_{hn} is

$$U_h = \sqrt[\alpha]{\sum_i U_{hi}^{\alpha}} \qquad (1)$$

where α is selected as shown in Table II.

Table II – Summation exponents

Harmonic order	**α**
h < 5	1
5 h 10	1.4
h > 10	2

2.6 Harmonic impedance

If there is no resonance below the 13th harmonic, it is suggested that

$$Z_h = hZ_{sc} \qquad (2)$$

Where resonances exist and the network is known in detail, the harmonic impedance can be calculated by well-known methods such as those given in Appendix B of the standard. Where the network is not known in detail, a worse-case impedance curve approach is recommended such as given in Appendix I. For the particular case of a typical 11 kV system, this simplifies to the approach given in Appendix A, ie for h 8, use twice the value of eqn(2), otherwise use this equation unchanged.

2.7 Consumer's share of emission

Central to the implementation of the standard is the concept of agreed power S_i, a number which describes the size of a particular consumer load. Although not defined clearly in the standard, it is believed that it could be measured by the maximum half hour demand. A premise of the new standard is that every consumer with the same point of common coupling and having the same agreed power has the right to draw equal distorted current from the supply.

Suppose that after allowing for background harmonics, at a particular supply point there is a voltage G_h available to be distributed to all connected and potential future consumers. A strategy is needed to allocate a portion of G_h to each consumer to satisfy the equal rights criterion and to take up G_h fully when the supply is fully loaded. Define the available power S_t as maximum possible sum of the consumer agreed powers.

$$S_t = S_1 + ... + S_n \qquad (3)$$

If the second summation law is assumed, a suitable strategy is

$$G_{hi} = \left(\frac{S_i}{S_t}\right)^{1/\alpha} G_h \qquad (4)$$

This can be verified by adding G_{hi}^{α} due to every consumer and making use of eqn(3).

Eqn(4) gives a larger proportion to each consumer than if the allocation was simply proportional to S_i/S_t. In particular, smaller consumers get a considerably greater share. For example, a customer taking 1% of the supply capability is allocated 3.7% of the available 5th harmonic voltage (α = 1.4) and 10% of the available 11th harmonic voltage (α = 2).

3. EMISSION LIMITS IN MV SYSTEMS

3.1 Overview

Assessment is made in three stages, as with AS 2279.2. Stage 1 has three tests, any one of which can give acceptance if passed. Stage 2 combines Stages 2 and 3 of the old standard and contains a number of tests of increasing complexity, the choice of which depends on how much is known about the system. Stage 3 does not correspond to any Stage in AS 2279.2 and is meant to allow connection with a greater than normal share of the emission allocation on a temporary basis when not all loads are connected or the loads already connected have not taken up their full share. This Stage has no tests and will not be considered further.

3.2 Stage 1

Test 1 is passed it the condition S_i/S_{sc} 0.1% is met. This test is unfair to very large installations which might have a small fraction of distorting load. Tests 2 and 3 are intended to cope with this situation.

In test 2, the distorting load MVA is summed with weighting factors of 0.7-2.5 as given in Table 6 of the standard, depending on converter type, to give the weighted distorting power S_{Dwi}. When the converter characteristics are unknown, a weight of 2.5 can be used. The test is passed if the condition $S_{DWi}/S_{sc} < 0.1\%$ is met.

Test 3 can be used if the current harmonic distortion is known for the installation for each harmonic order of interest.

3.3 Stage 2

This stage has several tests of increasing complexity and only a broad outline can be given here. We will concentrate on the simplest case where the installation supply point is close to all loads and the LV load varies in a similar manner to the MV load, ie there is no diversity. The next step then depends on the choice of summation law. We shall adopt the second law as generally recommended.

It is assumed that the harmonic voltage at the MV level is the combination of that allocated to the MV and LV loads G_{hMV+LV} and that propagating down from the HV supply system. Assume that the HV system is fully distorted to the planning level L_{hHV} and that a fraction T_{hHM} appears in the MV system. From the second summation law

$$G_{hMV+MV} = \sqrt[\alpha]{L_{hMV}{}^{\alpha} - (T_{hHM} L_{hHV})^{\alpha}} \qquad (5)$$

T_{hHM} is usually taken as 1. This has to be allocated to each customer using eqn(4) giving

$$E_{Uhi} = \left(\frac{S_i}{S_t}\right)^{1/\alpha} G_{hMV+LV} \qquad (6)$$

The harmonic current allocated to consumer "i" is then found from Z_h as discussed in Section 2.6

$$E_{Ihi} = E_{Uhi}/Z_h \qquad (7)$$

This approach can be further developed to take into account some inconsistencies which can sometimes arise. When the LV load is significant and has its maximum at a different time to the MV load, the above approach is conservative. If the coincidence between the peaks of the MV and LV loads is known, then an approach described in Appendix J.2.1 can be used to give a more generous allowance.

Another problem occurs when the MV loads are spread along a long feeder with a significant impedance. The approach of using eqns(6, 7) gives less harmonic allowance to loads towards the end of the feeder, sometimes by a factor of four, and it may be argued that principle of equal rights is violated. There are a couple of modifications to the above approach, given in Appendix D, which boost the allowance at the end of the feeder and reduce it at the sending end. There is a general trend in these approaches that increasing the equity for consumers reduces the harmonic absorption capability of the power system compared with the original approach.

3.4 Example - Connection of a large inductively filtered rectifier in a MV network

The following example has some simplifications to make clear the approach of the new harmonic standard and compare it with that used in AS 2279.2. In particular we shall concentrate only on the 5th harmonic. Strictly, similar calculations need to be made on all harmonics up to the 40th as well as the THD, although with some experience only a few of these need be made. A 10 MVA base is used.

We shall consider the case of a 10 MVA zone substation supplying a small industrial estate with no significant LV loads. The fault level at the 11 kV bus is 150 MVA. A consumer proposes to establish a factory with a total demand of 3.5 MVA. All of this load has a low harmonic content except for a 1.8 MVA induction furnace. Its front end is a six-pulse thyristor rectifier with inductive filtering. The furnace can be operated up to 24 hours non-stop, depending on the production demand.

A harmonic survey (required for AS 2279.2 Stage 2) shows that the existing background harmonics vary with time with a 95% value of 2%.

3.4 1 AS 2279.2 Assessment

Stage 1: Is $S_{converter}/S_{sc} < 0.3\%$?

$$S_{converter}/S_{sc} = 1.8/150 = 1.2\%$$

and the installation fails to meet Stage 1

Stage 2: AS 2279.2 is vague regarding time variation. Let us assume the background can be taken as the 95% value of 2%. 2% is between 25% and 75% of the value in Table 1 of the standard. Hence a converter can be connected up to the rating shown in the standard's Figure 1. For a 6-pulse controlled converter this is 1% of the fault level or 1.5 MVA. As

$$S_{converter} = 1.8 \text{ MVA} > 1.5 \text{ MVA},$$

the installation fails to meet Stage 2 and a full Stage 3 study is required.

3.4.2 AS/NZS 61000.3.6 Assessment

We shall use the second power law with a value

$$\alpha = 1.4$$

for the 5th harmonic.

Stage 1: Is $S_i/S_t < 0.1\%$?

$$S_i/S_t = 3.5/10 = 35\%$$

and the installation fails this part of Stage 1.

Stage 2: First calculate the voltage emission available to all MV loads.

$$G_{5MV+LV} = \sqrt[1.4]{5^{1.4} - 2^{1.4}} = 4\%$$

Calculate the portion of the voltage emission available to this load.

$$E_{U5i} = \left(\frac{S_i}{S_t}\right)^{1/1.4} G_{hMV+LV} = \left(\frac{3.5}{10}\right)^{1/1.4} 4 = 1.9\%$$

Calculate the system impedance at the 5th harmonic.

$$Z_5 = 5 \times Z_{sc} = 5 \times (10/150) = 0.333 \text{ pu}$$

Calculate the harmonic current available to the installation.

$$E_{I5i} = E_{U5i}/Z_5 = 1.9/0.333 = 5.7\% \text{ or } 0.057 \text{ pu.}$$

The actual 5th harmonic current can be estimated from

$$I_5 = I_1/5 = 0.18/5 = 0.036 \text{ pu.}$$

The installation passes Stage 2. The new standard is more generous than the old in this case and does not require a harmonic survey.

4. EMISSION LIMITS IN HV SYSTEMS

4.1 Overview
4.2 Stage 1
4.3 Stage 2
4.2 Example -

Similar descriptions as for MV will be presented.

5. DISCUSSION POINTS

It is intended that IEC standards should be adopted by Australia with minimum change. In general some slight changes are made to IEC standards to clarify expression. In this case there has been a more extensive change is the removal of sections from the main text to new Appendices I-K. This arises because the IEC recognise a hierarchy of documents with international standards as the most important, followed by Technical Reports Types I to III. IEC 61000.3.6 is classified as a Type III report, a collection of data, the lowest IEC classification. Within Standards Australia, there is only the two classifications of Standard or Technical Report. It was felt by the Standards Australia Committee that much of the main body of the IEC document warranted full standards classification. However there were parts that were not based on well-known engineering practices and contained several alternative approaches without a clear recommendation. These were removed to the Appendix to emphasise that they were for information only.

Some utilities have been unhappy with AS 2279.2 for several years and have adopted all or parts of IEEE 519 [5]. The standard is called up by the Victorian Office of the Regulator-General in their Distribution Code [6]. An attractive feature of this standard is that there is a table giving the harmonic current to a consumer depending on their power demand and the short-circuit rating at the pcc, and little further calculation is required. Care must be used with this standard in Australia since the currents have been calculated to be compatible with a different set of voltage limits and with a distribution system not necessarily having the same design practices as out own. A particular issue is the level of short-circuit current for a given supply capacity.

The proposed new Australian standard is better in that it gives a general calculation technique which can be adapted to a wide variety of practices. The use of equations and general principles avoids the "quantization" problem that occurs when data is presented in a table. It also allows for issues such as the long feeder mentioned at the end of Section 3.3.

There has been some discussion in the industry regarding the relative merits of allocating customers voltage limits or current limits. The advantages of current limits are

(i) The current drawn by an installation can be measured unambiguously irrespectively of background effects (but see (ii) in the next paragraph).
(ii) They can be estimated at the equipment design stage by calculation or by readings taken in the manufacturer's testing laboratory although supply conditions might differ from those of the final installation.

The problems are

(i) An acceptable installation at one time can create problems later on if there is a change in the network impedance, especially if there is a change in a resonance condition
(ii) There can be differences between consumers and utilities as to which part of the harmonic current is caused by their load and which part is due to the background. For example an induction motor or capacitor can draw a large harmonic current although they are not harmonic sources.

6. CONCLUSIONS

The review has given the theoretical background to the proposed harmonic standard showing the key concepts of compatibility levels, the treatment of time-varying disturbances by cumulative probability levels, the summation laws for combining disturbances and the allocation of rights as a function of agreed power. The MV and HV approaches have been summarised showing the three Stage approach, somewhat modified from that in the old standard. Within each Stage there are a variety of approaches depending on the need for accuracy and the availability of system data.

Two examples show that the application of the standard to routine cases is not too difficult. There is no need for a preliminary harmonic survey and the allocation procedure is more fair and generous than in AS 2279.2.

Various codes are being developed in Australia at State and Commonwealth level to address the issue of power quality including harmonics. There will need to be close contact between these bodies and the appropriate Standards Australia Committees as a large number of IEC standards are adopted over the next few years.

7. REFERENCES

[1] AS 2279.2-1991 "Disturbances in mains supply networks Part 2: Limitation of harmonics caused by industrial equipment" Standards Australia, 1991

[2] Gosbell, V.J. and Mannix, D.J., "Distortion load modelling for distribution system harmonic studies", AUPEC98, Hobart, Sep. 1998, pp. 57-62

[3] AS/NZS 61000.3.6 (Draft) "Electromagnetic Compatibility. Part 3.6: Limits- Assessment of emission limits for distorting loads in MV and HV power systems"

[4] AS/NZS 61000.4.7:1999 "Electromagnetic compatibility. Part 4.7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto", Standards Australia, 1999

[5] IEEE Std 519-1992, "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems"

[6] Office of the Regulator-General, Victoria, "Electricity Distribution Code", April, 1999

8. LIST OF SYMBOLS

The symbols used are the standard ones used in IEC documents, excluding obvious ones.

Main symbols	**Subscripts**
E: Emission limit	h: Harmonic order
G: Global allowance	HM: From HV to MV
L: Planning level	I: Current
S: Apparent power	i: Index of single consumer
T: Transfer coefficient	MV+LV: Combined MV & LV loads
Z: Impedance	sc: Short circuit
α: Summation law exponent	t: Total available
	U: Voltage
	DW: Weighted distorting