2003

Harmonic Planning Levels for Australian Distribution Systems

Victor J. Gosbell
University of Wollongong, vgosbell@uow.edu.au

Victor W. Smith
University of Wollongong, vic@uow.edu.au

D A. Robinson
University of Wollongong, duane@uow.edu.au

W Miller

Publication Details

V. J. Gosbell, V. W. Smith, D. A. Robinson & W. Miller, "Harmonic Planning Levels for Australian Distribution Systems," in AUPEC2003, 2003, pp. 49-1-49-6.

Harmonic Planning Levels for Australian Distribution Systems

Abstract

A modelling technique is developed for determining the harmonic voltage distribution across a distribution system when there is an equitable distribution of harmonic emission. The harmonic voltages at the 132kV and 415V levels are fixed to values based on IEC Compatibility and Planning Levels and the intermediate voltages determined. Studies are made of six systems, typical of Australian distribution practice, to examine the effect of choice of voltage level and system parameters over the harmonic range of 2-40. Based on the study, harmonic Planning Levels are recommended for application to Australian distribution systems.

Keywords

distribution, systems, australian, harmonic, levels, planning

Disciplines

Physical Sciences and Mathematics

Publication Details

V. J. Gosbell, V. W. Smith, D. A. Robinson & W. Miller, "Harmonic Planning Levels for Australian Distribution Systems," in AUPEC2003, 2003, pp. 49-1-49-6.

Harmonic Planning Levels for Australian Distribution Systems

V.J. Gosbell[1], V.W. Smith[1], D. Robinson[1] and W. Miller[2]

[1]Integral Energy Power Quality Centre, University of Wollongong
[2]Standards Australia

Abstract

A modelling technique is developed for determining the harmonic voltage distribution across a distribution system when there is an equitable distribution of harmonic emission. The harmonic voltages at the 132kV and 415V levels are fixed to values based on IEC Compatibility and Planning Levels and the intermediate voltages determined. Studies are made of six systems, typical of Australian distribution practice, to examine the effect of choice of voltage level and system parameters over the harmonic range of 2-40. Based on the study, harmonic Planning Levels are recommended for application to Australian distribution systems.

1. INTRODUCTION

The Australian standard for the control of harmonic levels in MV distribution systems, AS/NZS 61000.3.6 [1], is a slightly modified form of International Electrotechnical Standard IEC 61000-3-6. This standard gives Utility obligations as regards voltage levels and Customer obligations as regards harmonic current emission levels. The scope of the standard is harmonics 2-40.

The fundamental concept in the standard is a Compatibility Level. This is a harmonic voltage level which can be thought of a boundary between what is permitted on the supply and the immunity level of equipment (see Table 1). Utilities are given some scope for choosing their own harmonic limits depending on local conditions - these values are given the name Planning Levels.

Table I - Compatibility Levels for Harmonic Voltages (in per cent of nominal voltage) in LV and MV power systems ([1] Table 1)

Odd harmonics non multiple of 3		Odd harmonics multiple of 3		Even harmonics	
Order h	Harmonic voltage %	Order h	Harmonic voltage %	Order h	Harmonic voltage %
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.5	15	0.3	6	0.5
13	3	21	0.2	8	0.5
17	2	>21	0.2	10	0.5
19	1.5			12	0.2
23	1.5			>12	0.2
25	1.5				
>25	0.2 + 1.3 · (25 / h)				
NOTE – Total harmonic distortion (THD): 8%.					

Some indicative values for Planning Levels are given in the standard, but it would be unsatisfactory to adopt them in Australia. One problem is that all MV levels are given the same values. Where there are two MV levels in the chain of supply, as in most parts of Australia, identical harmonic voltages would mean there is no voltage drop and therefore no harmonic current between the two voltage levels. Furthermore, no values are given for LV systems although they can be expected to be slightly less than the Compatibility Levels of Table I.

In a system where the harmonic load is distributed across all voltage levels, one would normally expect that voltage levels would be highest at the extremity of LV distributors and decrease at each successive higher voltage level. Planning Levels need to be profiled similarly, and should correspond to the preferred distribution of harmonic emission across the system.

The Integral Power Quality Centre was asked by Standards Australia to determine appropriate Planning Level values for typical Australian distribution systems. This paper will discuss the methodology which was developed to determine suitable values.

2. OVERVIEW OF APPROACH

A generic system was chosen for the study. The system extended from a 132kV level to 415V as shown in Figure 1. The voltages 33kV and 11kV are shown as example voltages. 22kV is also used and in some systems there may be only one intermediate voltage level between sub-transmission and LV. The many branch circuits connected to the 33kV, 11kV and 415V busbars are indicated by the dashed lines. Parameter values were sought from several utilities to ensure that a wide range of planning and construction practices were allowed for. Key parameters included fault levels, substation loadings, number of lines, line lengths and impedances and load values and distribution.

A preferred harmonic loading needs to be defined. The loading is due to two load types subject to different standards. LV equipment has current distortion limits set for four generic equipment

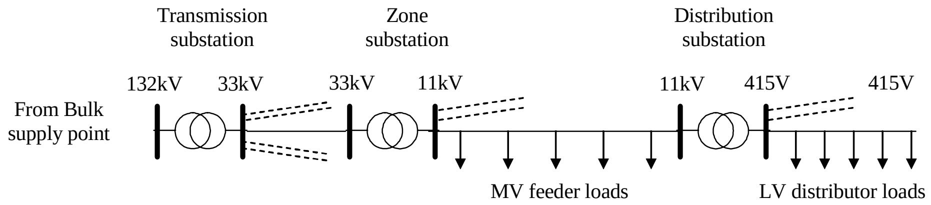

Figure 1: Test system topology

types [2]. Assumptions need to be made about the make-up of a typical domestic installation in order to determine corresponding LV customer current distortion levels. MV loads have current limits allocated by utilities in order for Planning Levels to be met, following some broad principles in [1]. A key concept in this standard is that MV customers of equal maximum demand should have equal harmonic allocation. This corresponds closely to all MV customers in a particular subsystem being allocated equal current distortion as a percentage of maximum demand current, with a slight complication due to the Second Summation Law to be described. The MV and LV load fundamental components are assumed to be equal as stated in [3].

The LV load is set at a constant harmonic level whose value is determined as described in Section 4.1. The MV load harmonic emission is increased until the 415V.R busbar reaches the 415V Planning Level. The values of the intermediate busbar voltages are then taken as the required intermediate Planning Levels.

To avoid representing the system upstream of the 132kV busbar, it is assumed that the whole power system is operating at its maximum allowed harmonic emission and the 132kV busbar voltage has reached its Planning Level which has to be determined from a preliminary study (Section 5.2). The selection of the 132kV Planning Level is to some extent arbitrary, however the resulting values do not have a major impact on the intermediate Planning Levels. The 415V Planning Level is also set independently, slightly less than the values in Table I, as described in Section 5.1.

Harmonics are generally time-varying. The maximum value of the harmonic voltage is too short in duration to give a good measure of its effects. The standard recommends the use of statistical quantities such as the 95% value and this will be used for all voltages and currents in the discussion below.

The voltages at each busbar are made up of three components

- 132kV busbar value representing transmission effects.
- Upstream LV load effects.
- Upstream MV loads effects.

The relationship between the harmonic currents from each of these components and the corresponding voltages are given by simple single-phase circuit theory techniques. However the relationship between the component and resultant voltages do not obey the Superposition Law and cannot be given by a circuit theory approach because of the use of the 95% values. The Standard recommends two approaches, of which the Second Summation Law is more general. This law uses an exponent α varying with the harmonic order as shown in Table II. If sources 1 and 2 have 95% voltage values of V_1 and V_2, the 95% of their combined voltage is

$$V = \sqrt[\alpha]{V_1^{\alpha} + V_2^{\alpha}} \tag{1}$$

Table II - Summation Law Exponent α variation with h

Harmonic order	α
$h < 5$	1
$5 \le h \le 10$	1.4
$h > 10$	2

The circuit theory calculations are not unduly complex. A spreadsheet has served as a convenient means for implementing all the calculations described in this study, including load modelling, converting harmonic currents into voltages, and combining voltage components.

It would be time-consuming to apply this approach for the Total Harmonic Distortion (THD) and each of the 39 harmonics within the scope of [1]. It is also questionable if the methodology can be extended simply to all other harmonics. There is also uncertainty in determining LV load emissions at high harmonics. Single phase models cannot be used to analyse the propagation of triplen harmonics which must be unbalanced at the MV level where there is no neutral connection. The approach is clearly unsuited for a study of THD.

Instead the method has been applied only to the original test system at several selected harmonics across the range 2-40. It was found that the change in the voltage profile with frequency could be reasonably well approximated by a linear expression. This frequency-dependent harmonic profile is assumed to be suited to the other sets of power system data and has been extended to all harmonics and the THD, enabling Planning Levels to be determined for all MV levels studied (66kV, 33kV, 22kV, 11kV).

3. TEST SYSTEM

It is assumed that the system is homogenous, that is all the parts not shown have the same parameters, topology and loading data as the section shown. Note the symbols S (Send) and R (Receive) are used to distinguish the busbars at the two ends of the feeder and distributor.

Six sets of parameters were chosen to represent the range of distribution data obtained from utilities as shown in Table III. The key differences are given in the two right hand columns, showing that System Numbers 3 and 5 are weaker than the others at the MV level while System Numbers 1-4 are weaker at the LV level. Most numerical values used, for example those in Figure 2, are from System Number 1.

Table III - Summary of test systems

System Number	Voltage levels	22/11 kV Feeders	415V distributors
1	132-33-11-415	Length 7 km	Length 350m
2	132-66-11-415	Length 7 km	Length 350m
3	132-22-415	Length 15 km	Length 350m
4	132-11-415	Length 7 km	Length 350m
5	220-66-22-415	Length 17 km	Length 100m, ABC construction
6	220-66-11-415	Length 4.9 km	Length 100m, ABC construction

Loads distributed along feeders (11kV) and distributors (415V) are replaced by equal lumped loads at the ends of the lines. All loads have been converted to per unit on a 1MVA base which is well suited to distribution system calculations. Line resistance is ignored as usual in harmonic calculations of this type. It is assumed that lines are sufficiently short that shunt capacitance can be ignored. The 11kV and 415V line fundamental reactances can be shown by well known methods to be 0.020pu and 0.711pu respectively for the lengths given in Figure 2. Other reactances can be determined from fault level data and are shown, again for System Number 1, in Table IV.

Table IV – Lumped load and fundamental upstream reactance at each busbar – typical data

Busbar	132	33.S	33.R	11.S	11.R	415.S	415.R
Lumped load (MVA)	0	75	0	23.21	1.39	0.3	0.1
PU fundamental reactance (1MVA base)	.00033	.001	.002	.0067	0.027	0.083	0.795

4. LOAD MODELLING

4.1 LV loads

It will be assumed that most LV loads are domestic installations. There are some LV industrial and commercial installations which produce high harmonic emissions locally, but it will be assumed that they are a small part of the whole LV load in a MV subsystem. Table V summarises the harmonic current limits for LV equipment as given in AS/NZS 61000.3.2 for the 5th harmonic [2].

Table V - Summary of AS/NZS 61000.3.2 for 5th harmonic

Equipment type	Class	Current limit
Three phase balanced load & all equipment not otherwise classified	A	1.14A
Portable tools	B	1.71A
Lighting	C	10% I_1
Special waveshape	D	46% I_1 up to 1.14A maximum

The major contributions to household harmonic distortion are shown in Table VI. The major harmonic emitting equipment is an inverter-type air-conditioner present in 1 in 5 houses. Although personal computers draw a lower current, they are assumed to be present in every house and hence their average contribution/house is more. TV units draw even less current but are even more prevalent and Table VI shows that they are the major contributor in terms of Amperes/household. The estimation of 1.5 TV/house is expected to allow for the use of VCRs as well. Stereos are considered not be operating at the same time as TVs and to have a similar harmonic current. It is thought that there is unlikely to be a significant number of dishwashers operating simultaneously at the peak period. Most other residential harmonic loads are of small power and unlikely to make a significant contribution.

Table VI – Expected 5th harmonic current/household for major appliances

Appliance	P(kW)	Class	I_5/appliance (A)	Penetration Factor	I_5/household (A)
Air-conditioner	3.5	A	1.14	0.20	0.23
Personal Computer	.3	D	0.6	1	0.6
TV	.25	D	0.475	1.5	0.71

Using the Second Summation Law gives I_5 = 1.2A. Assuming 5kVA house demand (21A at 240V) gives the percentage 5th harmonic current as 6%. Some households might be expected to have larger installations of harmonic equipment, but their maximum demand is likely to be larger giving a similar percentage of 5th harmonic current relative to the maximum demand current.

It is assumed that every 5kVA of single phase LV load has 6% 5th harmonic current. Taking three such households distributed across the three phases gives a 15kVA three phase LV load with 6% of 5th harmonic current. Using a 1MVA base, 1.2A is 0.000864pu.

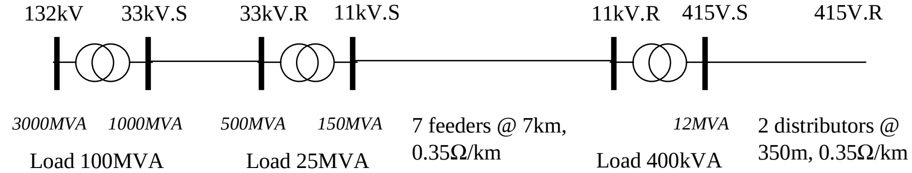

Figure 2: Test system data – Fault levels shown in italics

Now consider an LV load of S_{LV} distributed across three phases. The number of 15kVA blocks is

$$N = S_{LV}/0.015 \qquad (2)$$

Using the Second Summation Law, the 5th harmonic current of S_{LV} is

$$I_{LV5} = 0.000864\times N^{1/\alpha} = 0.000864\times(S_{LV}/0.015)^{1/\alpha}$$

Hence $$I_{LV5} = 0.017S_{LV}^{1/\alpha} \qquad (3)$$

In general $$I_{LVh} = k_{LVh}S_{LV}^{1/\alpha} \qquad (4)$$

It is assumed that the limits in LV equipment standards have been determined to give household contributions to harmonic voltages which fall off at higher frequencies in the same way as the Compatibility Levels. Hence k_{LVh} can be determined for other values of h by scaling depending on the ratio of Compatibility Levels for the hth and 5th harmonics.

For a 400kVA pole-top transformer, the model given by eqn(3) predicts a 5th harmonic current is 12A or 2% of the load fundamental current. This is consistent with readings taken by the Integral Energy Power Quality Centre at one such transformer.

Since several questionable assumptions have to be made to deduce values for k_{LVh}, a sensitivity study was made which demonstrated that the harmonic voltage profile across the study system was not very sensitive to values of this constant.

4.2 MV loads

The preferred harmonic allocation given in the Standard is a harmonic current which increases with load maximum demand S_{MV}. It is shown, because of the use of the Second Summation Law, that the mathematical treatment is simplified if the allocation follows the form

$$I_{MVh} = k_{MVh}S_{MV}^{1/\alpha} \qquad (5)$$

where α is the Second Summation Law exponent and k_{MVh} is the allocation constant. As part of the procedure for determining Planning Levels, k_{MVh} will be increased until harmonic voltages at the end of the 415V distributor in the test system reach the LV Planning Level value. S_{MV} should be the design maximum demand taking into account planned load growth.

5. CHOICE OF PLANNING LEVELS FOR 132kV AND 415V SYSTEMS

5.1 LV Planning Levels

The Standard gives identical Compatibility Levels for LV and MV systems (Table I). Table 2 in [1] gives Indicative Planning Levels for MV systems which are 80-90% of the Compatibility Levels. The LV Planning Levels will need to be larger than these values but not higher than the Compatibility Levels. They have been chosen to be the average of the LV Compatibility Levels and the Indicative MV Planning Levels as shown in Table VII.

5.2 132kV Planning Levels

The Standard gives indicative Planning Levels for HV-EHV which look broadly suitable for applying to Australian 132kV systems. However, not all the values are well thought out. For example, the values are equal to the LV Compatibility Levels at the 4th harmonic and many higher harmonics. If 132kV systems were loaded to these levels, there would be no scope for harmonic emission at MV or LV levels at the harmonic frequencies involved.

It is noted that, at the important harmonic orders of 5, 7, 11, 13, the HV-EHV indicative Planning Level is 36%, 44%, 46% and 55% of the LV Planning Level

Table VII - Recommended Planning Levels (Voltages given in percent of nominal)

	Voltage level							Voltage level					
h	132KV	66kV	33kV	22kV	11kV	415V	h	132KV	66kV	33kV	22kV	11kV	415V
2	1.1	1.3	1.3	1.7	1.7	1.8	22	0.12	0.13	0.13	0.18	0.18	0.20
3	2.0	2.6	2.8	4.3	4.3	4.5	23	0.70	0.77	0.79	1.18	1.18	1.35
4	0.60	0.70	0.73	0.96	0.96	1.00	24	0.12	0.13	0.13	0.18	0.18	0.20
5	2.0	2.8	3.1	5.1	5.1	5.5	25	0.51	0.54	0.55	0.76	0.76	0.85
6	0.30	0.35	0.36	0.48	0.48	0.50	26	0.12	0.13	0.13	0.18	0.18	0.20
7	2.0	2.6	2.7	4.2	4.2	4.5	27	0.12	0.13	0.13	0.18	0.18	0.20
8	0.27	0.31	0.32	0.43	0.43	0.45	28	0.12	0.13	0.13	0.18	0.18	0.20
9	0.81	0.92	0.95	1.27	1.27	1.35	29	0.46	0.47	0.48	0.67	0.67	0.76
10	0.27	0.31	0.32	0.42	0.42	0.45	30	0.12	0.12	0.13	0.17	0.17	0.20
11	1.5	1.8	1.9	3.0	3.0	3.3	31	0.44	0.45	0.45	0.63	0.63	0.73
12	0.12	0.13	0.14	0.19	0.19	0.20	32	0.12	0.12	0.12	0.17	0.17	0.20
13	1.5	1.7	1.8	2.5	2.5	2.8	33	0.12	0.12	0.12	0.17	0.17	0.20
14	0.12	0.13	0.14	0.19	0.19	0.20	34	0.12	0.12	0.12	0.17	0.17	0.20
15	0.18	0.20	0.20	0.28	0.28	0.30	35	0.40	0.40	0.40	0.57	0.57	0.67
16	0.12	0.13	0.14	0.18	0.18	0.20	36	0.12	0.12	0.12	0.17	0.17	0.20
17	1.0	1.1	1.2	1.6	1.6	1.8	37	0.38	0.38	0.38	0.54	0.54	0.64
18	0.12	0.13	0.13	0.18	0.18	0.20	38	0.12	0.12	0.12	0.17	0.17	0.20
19	0.81	0.88	0.90	1.23	1.23	1.35	39	0.12	0.12	0.12	0.17	0.17	0.20
20	0.12	0.13	0.13	0.18	0.18	0.20	40	0.12	0.12	0.12	0.17	0.17	0.20
21	0.12	0.13	0.13	0.18	0.18	0.20	THD	3.0	4.1	4.4	6.6	6.6	7.3

recommended here. It is recommended that the HV-EHV Planning Level should not exceed 60% at any harmonic frequency to give adequate scope for harmonic loading at lower voltage levels. Because of the use of a summation law with α =2 at higher frequencies, this will allow MV and LV loads to contribute about 80% of the 132kV harmonic voltage level. The recommended values shown in Table VII are the minimum of the indicative Planning Levels from [1] Table 2 and 60% of the recommended LV Planning Level.

6. 5TH HARMONIC PROFILES

The aim of the study to find a compromise voltage profile that can be applied to all the test systems without undue loss of harmonic absorption capability. The value of k_{MVh} from eqn(5) was increased until the 415V Planning Level was met and the voltages at the intermediate MV buses then determined.

The voltages were then expressed in terms of their percentage span between the HV Planning Level and the LV Planning Level. For example, if the HV Planning Level is 1% and the LV Planning Level is 5%, a harmonic voltage of 2% is expressed as 25% since it is 25% of distance between 1% and 5%. This method was chosen with the aim of finding a standard set of ratios which could be applied to the HV and LV Planning Levels for all harmonics. The value determined in this way is called a "voltage ratio".

The above six systems gave voltage ratios for the 5th harmonic as shown in Table VIII. The table also shows the MV allocation constant as a measure of the system's harmonic absorption capacity. Larger values indicate a system which can absorb a larger harmonic current for a given maximum demand.

Table VIII - Harmonic voltage ratios for different test systems at 5th harmonic

	Voltage level						
System Number	220/132kV	66kV	33kV	22kV	11kV	415V	k_{MV5}
1	0		32		83	100	0.126
2	0	24			83	100	0.134
3	0			83		100	0.177
4	0				83	100	0.157
5	0	19		96		100	0.141
6	0	35			96	100	0.204
Recommended ratios	0	25	32	85	85	100	

In determining ratios which can be applied to all systems, the following need to be considered

(i) Since the choice of a ratio different to that found in the table will reduce the harmonic absorption of the system, the weaker systems 1-2 should be given greater weight.

(ii) 11kV and 22kV Planning Levels should be chosen too low rather than too high, else the LV harmonic voltages might be excessive.

Based on these criterion, the ratios given in the bottom row of Table VIII are recommended for the 5th harmonic voltage.

7. VARIATION OF PLANNING LEVELS WITH HARMONIC FREQUENCY

There would be a large effort required to perform the analysis of Section 6 for all harmonics in the range 2-40 for the six test systems. This effort would not have much value at the higher frequencies where the accuracy of system reactance and LV load modelling are suspect. Instead the voltage profile is examined for System Number 1 only since it is the weakest (see the value of k_{MV} in the right hand column of Table VIII) for several frequencies in the range. The aim of the study is to check if the ratios in the bottom row of Table VIII can be applied at all harmonic frequencies.

Simulations have been made at the 5th, 7th, 11th, 19th, 29th and 37^{h} harmonics. The 5th and 7th harmonics were chosen because they are dominant harmonics in practice. The other harmonics were chosen as being the important harmonics (those of the form 6k±1) with value closest to 10, 20, 30 and 40. The different harmonic voltage ratios are shown plotted in Figure 3.

Linear regression has been applied to find a straight-line approximation. In forming the sum of the errors squared, a higher weighting is applied to the lower frequency values where more accuracy is required. The variation of harmonic voltage ratio with harmonic order was found to be

$$\text{Voltage\_Ratio}_{11kV}(h) = \text{Voltage \_Ratio}_{11kV}(5)\times(1.1 - 0.01h) \quad (6)$$

$$\text{Voltage\_Ratio}_{33kV}(h) = \text{Voltage \_Ratio}_{33kV}(5)\times(1.1 - 0.03h) \quad (7)$$

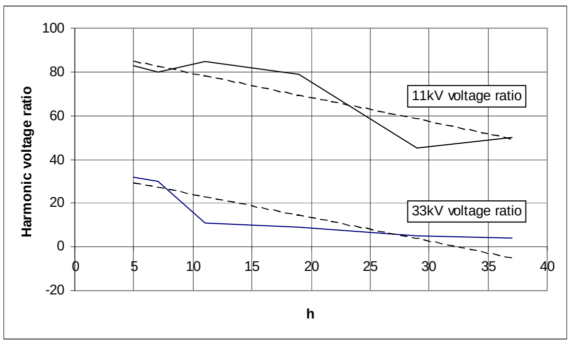

Figure 3- Voltage ratio variation with harmonic order (solid line: from computed results; dashed line: linear approximation)

The first law has been applied to the 11kV and 22kV recommended ratios in Table VIII while the second has been applied to the 33kV and 66kV ratios.

Triplen harmonics cannot be analysed directly by the method described which is based on a single phase network representing positive sequence effects. As there appears little scope for a soundly based mathematical analysis, it will be assumed that the triplen harmonic Planning Levels can be allocated using the same proportions as for the other harmonics.

Now let the 415V and 132kV Planning Levels at harmonic order h be $V_{PLh}(415V)$ and $V_{PLh}(132kV)$. The Planning Levels between 11kV and 66kV for harmonic voltages at any harmonic number can be determined from the recommended ratios in Table VIII and the higher harmonic factors given in eqns(6) and (7).

Let
$$K_1(h) = 1.1 - 0.01h \quad (8)$$

$$K_2(h) = 1.1 - 0.03h \quad (9)$$

Then
$$V_{PLh}(11kV) = V_{PLh}(132kV) + 0.85K_1(h)(V_{PLh}(415V)-V_{PLh}(132kV)) \quad (10)$$

$$V_{PLh}(22kV) = V_{PLh}(132kV) + 0.85K_1(h)(V_{PLh}(415V)-V_{PLh}(132kV)) \quad (11)$$

$$V_{PLh}(33kV) = V_{PLh}(132kV) + 0.32K_2(h)(V_{PLh}(415V)-V_{PLh}(132kV)) \quad (12)$$

$$V_{PLh}(66kV) = V_{PLh}(132kV) + 0.25K_2(h)(V_{PLh}(415V)-V_{PLh}(132kV)) \quad (13)$$

The same approach is used to find Planning Levels for voltage THD. Since THD is dominated by the 5^{th} harmonic, the recommended voltage ratios from Table VIII are applied without the frequency dependent factors in eqns(8) and (9). These values are shown in Table VII.

8. CONCLUSION

A modelling technique has been developed for determining the harmonic voltage distribution across a distribution system for a equitable distribution of harmonic emission across the different voltage levels. The harmonic voltages at the 132kV and 415V levels are fixed to values based on IEC Compatibility and Planning Levels and the intermediate voltages recorded in the form of voltage ratios. Studies were made of six systems to examine the effect of choice of voltage level and system parameters. Important harmonic orders in the range 5-37 were studied. A compromise set of harmonic ratios, having a simple variation with harmonic order, is recommended as being suitable for typical distribution systems.

The study requires assumptions regarding

(i) Reactances and loadings of the power system
(ii) Summation of harmonic currents
(iii) Harmonic emission of LV loads
(iv) Proportion of LV to MV load demand

From the investigation, it is recommended that the Planning Levels shown in Table VII be adopted.

9. REFERENCES

1. AS/NZS 61000.3.6 “Limitations of emission of harmonic currents for equipments connected to medium and high voltage power supply systems”, Standards Australia 2001.
2. AS/NZS 61000.3.2 “Limits for harmonic current emissions (equipment input current <=16A per phase)”, Standards Australia 1998.
3. P. Meynaud et al , “Equipment producing harmonics and conditions governing their connection to the mains power supply” CIGRE Working Group 36.05, Electra, No 123, March 1989, pp. 21-37.

10. LIST OF SYMBOLS

α	Second Summation Law exponent
H	Harmonic order
K_1, K_2	Constants describing changes in voltage profile with harmonic order in eqns(8, 9)
k_{LVh}	LV load emission constant
k_{MVh}	MV load current emission allocation constant
S	Voltage-amperes
V_{PL}	Planning Level for harmonic voltage