1-1-2013

Characteristics of power quality disturbances in Australia: voltage harmonics

S T. Elphick
University of Wollongong, elpho@uow.edu.au

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

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

S Perera
University of Wollongong, sarath@uow.edu.au

Characteristics of power quality disturbances in Australia: voltage harmonics

Abstract

Management of harmonic voltage levels can impose significant economic impacts for both electricity suppliers and customers. For the case where harmonic voltage levels are high, economic costs include damage to equipment and associated loss of production due to high voltage harmonic levels as well as the costs associated with mitigation of harmonic currents, for example, harmonic filters. In the alternate scenario, ie. the case where harmonic voltage levels are acceptable, considerable expense may be incurred mitigating harmonic currents unnecessarily due to lack of knowledge of harmonic levels and/or network capabilities. As such, there is considerable potential for industry to make large economic gains if harmonic voltage levels can be better understood. Using data collected as part of an ongoing long-term power quality monitoring project, this paper details the characteristics of voltage harmonic behaviour on Australia electricity distribution networks

Keywords

voltage, quality, power, characteristics, australia, harmonics, disturbances

Disciplines

Engineering | Science and Technology Studies

Publication Details

S. T. Elphick, V. W. Smith, V. J. Gosbell & S. Perera, "Characteristics of power quality disturbances in Australia: voltage harmonics," Australian Journal of Electrical & Electronics Engineering, vol. 10, (4) pp. 490-496, 2013.

Characteristics of power quality disturbances in Australia: Voltage harmonics*

S Elphick†, V Smith, V Gosbell and S Perera
University of Wollongong, Wollongong, NSW

ABSTRACT: *Management of harmonic voltage levels can impose significant economic impacts for both electricity suppliers and customers. For the case where harmonic voltage levels are high, economic costs include damage to equipment and associated loss of production due to high voltage harmonic levels as well as the costs associated with mitigation of harmonic currents, for example, harmonic filters. In the alternate scenario, ie. the case where harmonic voltage are acceptable, considerable expense may be incurred mitigating harmonic currents unnecessarily due to lack of knowledge of harmonic levels and/or network capabilities. As such, there is considerable potential for industry to make large economic gains if harmonic voltage levels can be better understood. Using data collected as part of an ongoing long-term power quality monitoring project, this paper details the characteristics of voltage harmonic behaviour on Australia electricity distribution networks.*

KEYWORDS: Power quality; harmonics; power quality survey; power quality monitoring.

REFERENCE: Elphick, S., Smith, V., Gosbell, V. & Perera, S. 2013, "Characteristics of power quality disturbances in Australia: Voltage harmonics", *Australian Journal of Electrical & Electronics Engineering*, Vol. 10, No. 4.

1 INTRODUCTION

Understanding the voltage harmonic behaviour has many benefits for distribution network service providers as well as customers. Improper management of harmonic voltage levels can represent a significant economic impact for both electricity suppliers and customers. Where harmonic levels are high, economic costs include damage to equipment and associated loss of production along with the costs associated with mitigation of harmonic currents, for example, harmonic filters. In other scenarios, expense may be incurred where harmonic mitigation equipment is installed to alleviate a problem that may not exist. As such, there is considerable potential for industry to make large economic gains if harmonic voltage levels can be better understood. However, in order for industry to begin to address the costs associated with voltage harmonics, an understanding of harmonic voltage levels present on electricity distribution networks is necessary.

Using data collected as part of an ongoing long-term power quality monitoring project, the Australian Long Term National Power Quality Survey (LTNPQS), this paper details the characteristics of voltage harmonic behaviour on Australia electricity distribution networks. Section 2 of this paper details the LTNPQS project and the data available for analysis. Section 3 of the paper details the low voltage (LV) and medium voltage (MV) data, which has been collected as part of the LTNPQS project. The data is displayed in a number of different formats to aid analysis. Section 4 of the paper compares the voltage harmonic levels monitored on Australian networks to data which has been collected from other studies from across the world. This comparison allows an understanding of how Australian networks compare to other distribution networks around the world.

2 THE LTNPQS PROJECT

Proactive monitoring of power quality across Australia has been undertaken since 2002 through the LTNPQS as described by Elphick et al (2006; 2010a). Since inception, the database of power quality data associated with this project, which is housed at the University of Wollongong, has grown to include data from over 3300 sites provided by 12 of the 16 Australian electricity distribution utilities. These sites include a mix of low (230 V), medium/high (6.6-132 kV) voltage sites. Overall, 770 monitor-years of data available in the database. Utilities that currently participate or have participated in the LTNPQS project supply electricity to at least 90% of the population of Australia.

3 VOLTAGE TOTAL HARMONIC DISTORTION

3.1 Low voltage sites

3.11 Available data

Data for voltage total harmonic distortion (THD) from a total of 2338 distinct LV sites over a 7-year period was available for analysis. Table 1 shows a summary of the number of sites available for analysis for each year. Overall, there are 3075 monitor years of data available for analysis.

Table 1: Summary of available LV data.

Financial year (1 July to 30 June)	Sites	Monitor years
2010-2011	1287	1042
2009-2010	1717	1176
2008-2009	197	164
2007-2008	486	307
2006-2007	440	233
2005-2006	270	101
2004-2005	79	52

3.1.2 Overall site indices

Figure 1 shows a histogram of LV voltage THD site indices generated using the available data. For each site, the voltage THD index is calculated as the 95th percentile value of voltage THD readings over the period for which data was available. Overall indices for all surveyed sites can be calculated using the index for each site. The overall calculated index for the average site is 2.53%, while it is 4.25% for the 95th percentile site. These overall indices are relatively low and are well within all planning levels or regulatory limits imposed in Australia.

3.1.3 Comparison between strong and weak sites

There is a strong perception that harmonic levels will increase at sites that are further away from the distribution transformer. The study by Berthet et al (2007) indicated that this is the case for French electricity networks. The LTNPQS framework allows sites to be classified based on their position on the distribution network. This in turn has allowed for an investigation into how voltage harmonic levels behave across networks. Two classifications are available for sites in the LTNPQS: strong and weak. At LV, a strong site is considered to be one which is close to the terminals of a MV/LV distribution transformer. A weak site is one which is remote from the distribution transformer and in many cases is positioned at the end of the LV distributor. Analysis has been undertaken to investigate the differences between voltage THD levels at strong and weak sites. The results of this analysis are shown in figure 2. It can be seen that voltage THD levels at weak sites are somewhat worse than those observed at strong sites. Table 2 shows a comparison of the overall voltage THD indices based on site strength. The average and 95th percentile values shown in the table are calculated by taking the arithmetic average

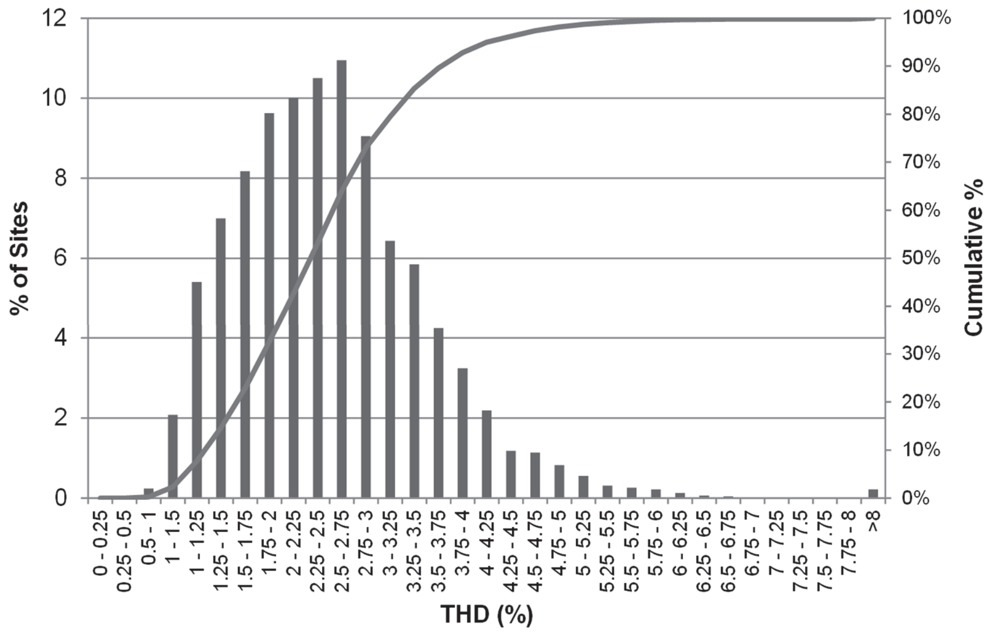

Figure 1: Histogram of LV voltage THD indices.

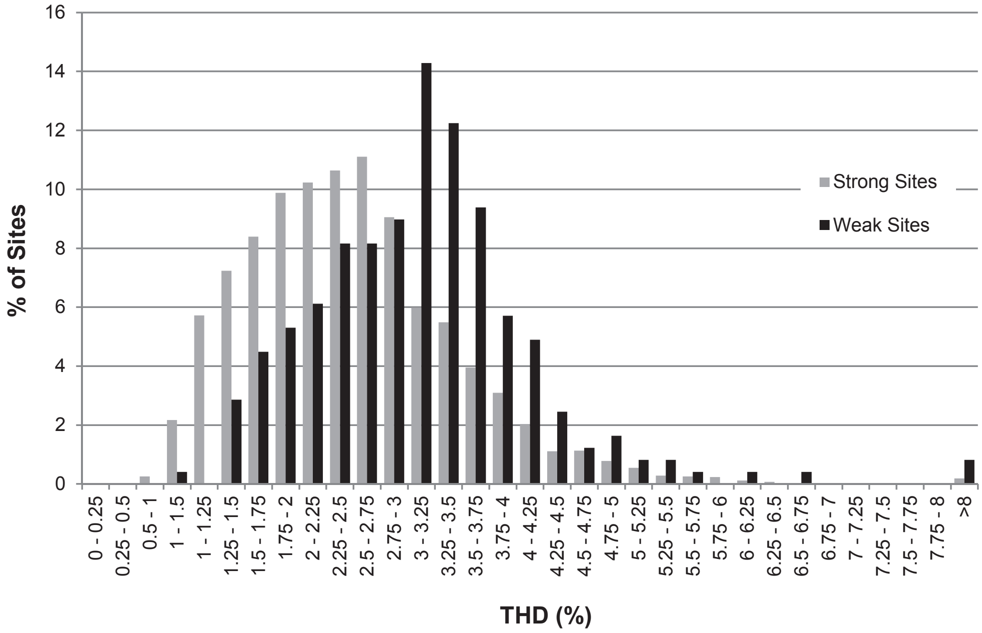

Figure 2: Comparison of voltage THD levels at strong and weak LV sites.

Table 2: Comparison of voltage THD indices for strong and weak sites.

Site strength	Average (%)	95^{th} percentile (%)
Strong	2.49	3.13
Weak	4.20	4.73
Ratio	1.69	1.51

and 95^{th} percentile values of the voltage THD values shown in figure 2 respectively. It can be seen that voltage THD levels at weak sites are approximately 1.5 times levels at strong site. While this result is significant it must be tempered by the fact that there is data available for many more strong sites than weak sites (a ratio of 17:1). As such, the data presented here should be treated as informative.

3.1.4 Seasonal trends

Analysis of the seasonal trend of the voltage THD has been completed. Figure 3 shows voltage THD values for each month of the year for the average site, while figure 4 shows voltage THD values for each month for the 95^{th} percentile site. The average and 95^{th} percentile values shown in the figures are calculated by taking the arithmetic average and 95^{th} percentile value of site indices across each month. Both figures show a similar monthly trend for voltage THD with levels peaking during the Australian spring and autumn months whereas lowest levels are recorded in summer and winter months.

The exact reasons for the relatively strong seasonal trend observed in figures 3 and 4 are unknown; however, it will be related to loading levels during the various seasons. Further investigation into these seasonal trends is an area of further research. It should be noted that similar seasonal trends were reported by Issouribehere et al (2010).

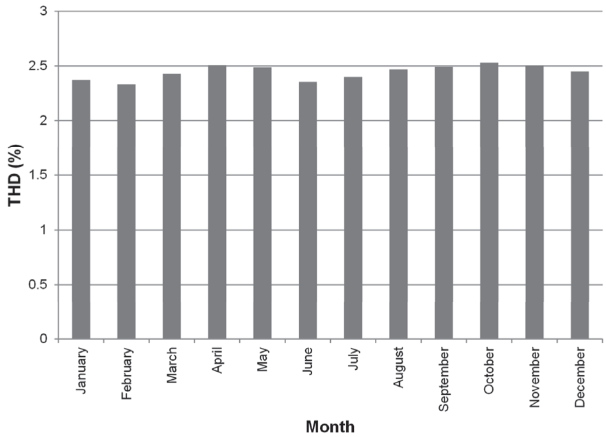

Figure 3: Monthly values of LV voltage THD for the average site.

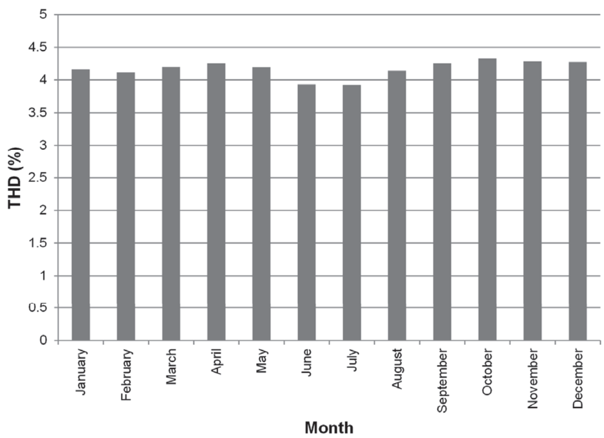

Figure 4: Monthly values of LV voltage THD for the 95^{th} percentile site.

3.1.5 Long-term trends

As stated in table 1, data for voltage THD is available for the past 7 years. Using this data, long-term trends for the average and 95th percentile sites have been calculated. Figure 5 shows the yearly voltage THD trend for the average site, while figure 6 shows the yearly trend for the 95th percentile site. In both figures it can be seen that the voltage THD shows a long-term downward trend. For the average site, voltage THD levels are seen to decrease at a rate of 0.17% per year, while for the 95th percentile site, THD levels are seen to decrease at a rate of 0.2% per year.

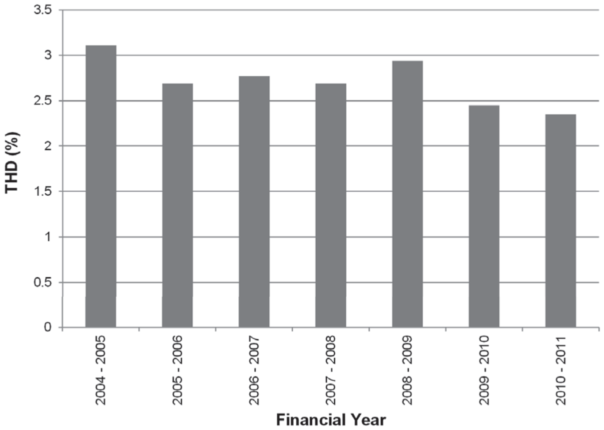

Figure 5: Yearly LV voltage THD trend for the average site.

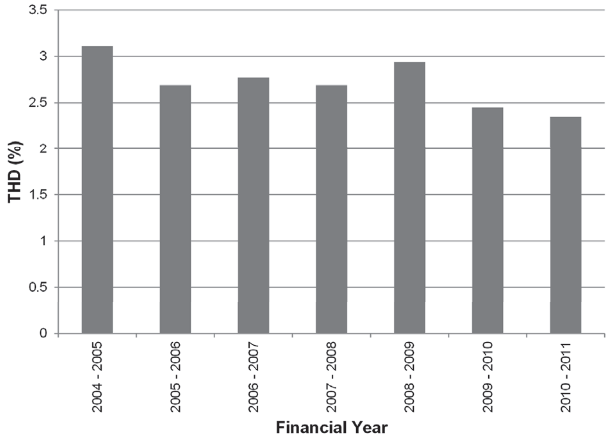

Figure 6: Yearly LV voltage THD trend for the 95th percentile site.

3.2 Medium voltage sites

3.2.1 Available data

Data for voltage THD is available from 203 distinct MV sites over a 7-year period. On the whole, 727 monitor years of data has been analysed. Table 3 shows a summary of the MV data collected each financial year. The vast majority of data from MV sites has been monitored at strong sites; that is, sites close to supply transformer terminals. Many of the MV sites are zone substations.

3.2.2 Overall site indices

Figure 7 shows a histogram of MV voltage THD site indices based on all survey data. The indices for

Table 3: Summary of available MV data.

Financial year (1 July to 30 June)	Sites	Monitor years
2010-2011	172	124
2009-2010	155	117
2008-2009	144	128
2007-2008	137	118
2006-2007	121	87
2005-2006	114	84
2004-2005	85	68

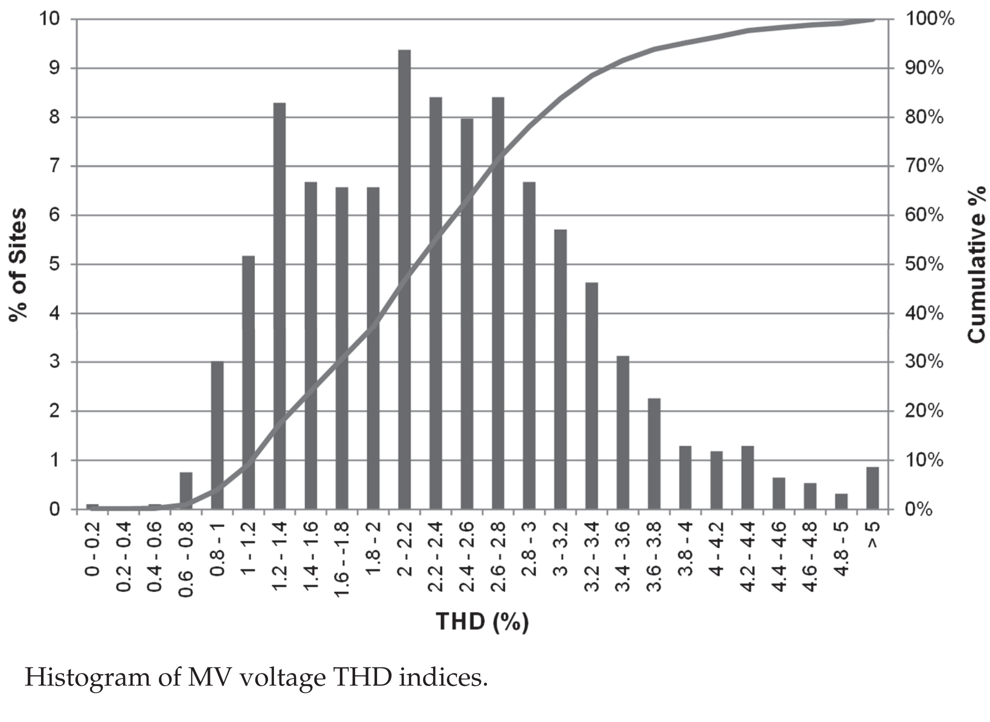

Figure 7: Histogram of MV voltage THD indices.

each site plotted in this histogram are calculated by determining the 95th percentile voltage THD level across the survey period. The overall calculated index for the average MV site is 2.34% while the overall calculated index for the 95th percentile site is 3.96%. As was the case for LV sites, overall harmonic levels are relatively low and well within all Australian planning levels or regulatory limits.

3.2.3 Seasonal trends

Figure 8 shows voltage THD values for each month of the year for the average site, while figure 9 shows voltage THD values for each month for the 95th percentile site. The average and 95th percentile values are calculated using the same method as was applied to the LV data in figures 3 and 4. Both figures show a similar monthly trend for THD with a distinct reduction in voltage THD levels during the Australian winter months.

3.2.4 Long-term trends

Figure 10 shows the yearly trend of MV voltage THD for the average site. Figure 11 shows the same information for the 95th percentile site. The average and 95th percentile values are calculated using the same method as was applied to the LV data in figures 5 and 6. Both figures show a distinct downward trend in voltage THD levels. This result is similar to that observed for LV sites. For the average site, voltage THD is seen to decrease at a rate 0.1% per year while for the 95th percentile site, the rate of decrease is 0.23% per year.

3.3 Discussion of long-term voltage THD trends

There is strong evidence to suggest that voltage harmonic levels were increasing quite rapidly in Europe up until the early 2000s (Iglesias, 2002; Berthet et al, 2007). This increase in harmonic voltage levels was attributed to the proliferation of non-linear equipment being connected to electricity distribution networks. Although, there is no data available showing harmonic trends for Australia through the 1990s it is reasonable to assume that harmonic levels on Australian networks showed a similar increasing trend to those seen in other parts of the developed world.

While voltage harmonic levels increased during the 1990s, data collected as part of the LTNPQS project

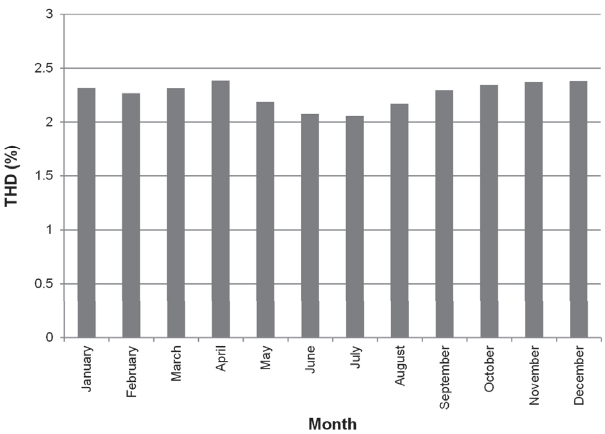

Figure 8: Monthly values of MV voltage THD for the average site.

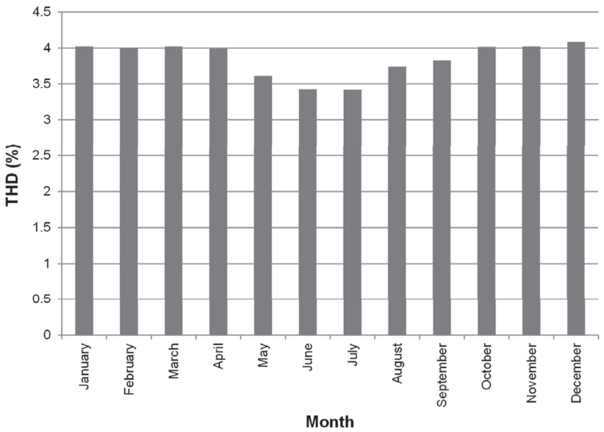

Figure 9: Monthly values of MV voltage THD for the 95th percentile site.

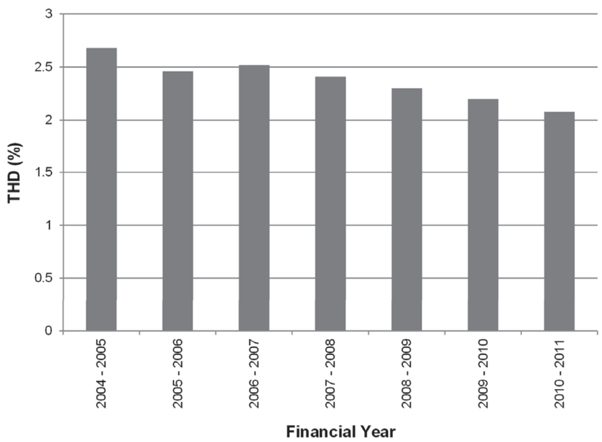

Figure 10: Yearly MV voltage THD trend for the average site.

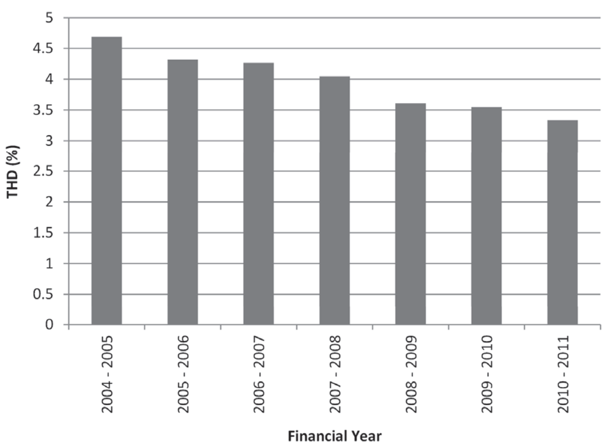

Figure 11: Yearly MV THD trend for the 95th percentile site.

since 2004 suggests that this trend has been arrested and the voltage THD levels are now decreasing over time. This is the case for both LV and MV sites. The results presented by Berthet et al (2007) showed a similar trend of harmonic voltage levels on French LV networks; a stabilisation since the early 2000s.

There are a range of possible explanations for the decrease in harmonic levels. The first is the adoption of IEC 61000-3-2 (IEC, 2009) and its Australian counterpart AS/NZS 61000.3.2 (Standards Australia, 2003). These standards define limits for current harmonic emissions of LV equipment of rated current ≤ 16 A per phase. Although these standards are not mandated in Australia, they are in other jurisdictions, especially Europe. As manufacturers are unlikely to specially design equipment for sale in a market as small as Australia it is fair to assume that much of the equipment being imported into Australia is designed and built to European specifications and as such complies with the IEC standard. Evidence was presented by Elphick et al (2010a) that showed that harmonic current emission levels from a variety of LV appliances, especially televisions and air conditioners, have decreased over time. The study presented by Berthet et al (2007) also proposed the adoption of IEC61000-3-2 as an explanation for reduction in harmonic voltage levels on LV electricity distribution networks.

The second explanation is the adoption of connection agreements and more sophisticated harmonic emission management plans by distribution utilities for MV networks. Many Australian distribution utilities now require connection agreements to be put in place between the utility and large distorting loads. Under such connection agreements, the customer is allocated a specific limit for each current harmonic order. If emissions are deemed to be above the allocated level, harmonic mitigation strategies must be implemented. There are a number of methods of determining current allocation, but the majority utilise methods similar to those described in IEC 61000-3-6 (IEC, 2008).

As the levels of non-linear load continue to increase on networks, the study presented by Berthet et al (2007) suggested that harmonic levels will begin to rise again when all applicable older style appliances have been replaced by those complaint with IEC 61000-3-2. Continued monitoring will be required to determine whether or not this occurs in Australia.

4 COMPARISON OF AUSTRALIAN DATA WITH OTHER SURVEYS

Although a large volume of data is not available for comparison, based on available literature, there is considerable evidence to suggest that voltage harmonic levels measured on Australian electricity distribution networks are lower than those observed in Europe. There is also limited evidence to suggest that these Australian harmonic levels may be significantly higher than those observed in other regions such as Asia and South America.

For LV sites, the data presented by Berthet et al (2007) and CEER (2008) can be used to develop an indication of voltage harmonic levels on European networks. In Berthet et al (2007), the data presented was for 5th harmonic. As such, no direct comparison can be made to the THD data presented in this paper. However, 5th harmonic levels presented in this study are significantly higher than the THD levels observed for the LTNPQS. As the 5th harmonic value is only one component of the THD it is fair to assume that THD values will be higher than those observed for the LTNPQS. The data presented by CEER (2008) were statistical measures of harmonic values from Norwegian distribution networks. The data indicated that based on median site values, the overall 95th percentile level for voltage THD is approximately 4.5%. Analysis of median site values was not undertaken for the LTNPQS, instead 95th percentile site values were evaluated. As stated above, the overall 95th percentile level across all LTNPQS sites was 4.25%. Given that any indices evaluated using 95th percentile site values will be higher than those evaluated using median site values, it is clear that LTNPQS values are less than those presented by CEER (2008). The study presented by Issouribehere et al (2010) presented LV harmonic voltage levels for three Argentinian networks. Based on 95th percentile site values, the overall average value for voltage THD ranged between 1.7% and 2%, while the overall 95th percentile value ranged between 2.5% and 2.8%. Compared to the LTNPQS values of 2.53% and 4.25%, respectively, it is evident that the voltage THD levels presented by Issouribehere et al (2010) are less than those observed in the LTNPQS.

Data presented by the Cigre (2004) showed the mean value of voltage THD for 95th percentile site indices to be 6.5% for MV sites with nominal voltage between 1 and 35 kV, and 3% for sites with nominal voltage above 35 kV. These values are significantly higher than the values of 2.42% and 1.36% for LTNPQS sites with the same nominal voltage levels. The study by Wang & Lu (2005) showed results for a Taiwanese electricity network. At 1.17%, the mean value of 95th percentile site indices is less than the value obtained from the LTNPQS. The study presented by Kushare et al (2007) detailed harmonic levels on an Indian electricity network. Harmonic levels observed were significantly lower than those obtained in the LTNPQS.

5 CONCLUSION

Using data collected by a large ongoing power quality monitoring project, this paper has broadly described the characteristics of voltage harmonics on Australian electricity distribution networks. In general, it is seen that voltage THD levels are quite low and well within limits imposed by Australian standards. Of particular note is the long-term trend of voltage THD which has been decreasing over the past 7 years. For LV sites it has been shown that voltage THD levels at the end of LV feeders are considerably higher than those observed at the LV distribution transformer.

A comparison has been made between voltage THD levels observed on Australian networks with voltage THD levels measured on a number of other networks around the world. The results of this comparison are mixed, with Australian levels being lower than those observed in Europe but higher than those observed in other parts of the world such as Taiwan and India.

REFERENCES

Berthet, L., Eyrolles, P., Gauthier, J. & Sabeg, S. 2007, "Harmonic Level Measurements on French Low-Voltage Networks", *CIRED 19th International Conference on Electricity Distribution*, Vienna, Austria.

Cigre, 2004, *Power Quality Indices and Objectives – Final WG Report*, Joint Working Group Cigre C4.07.

Council of European Energy Regulators (CEER), *4th Benchmarking Report on Quality of Electricity Supply*.

Elphick, S., Gosbell, V. & Barr, R. 2006, "The Australian Power Quality Monitoring Project", EEA Annual Conference, Auckland, New Zealand, June.

Elphick, S., Gosbell, V., Smith, V. & Barr, R. 2010a, "The Australian Long Term Power Quality Survey Project Update", 14th International Conference on Harmonics and Quality of Power, ICHQP'10, Bergamo, Italy, 26-29 September.

Elphick, S., Ciufo, P. & Perera, S. 2010b, "Laboratory Investigation of the Input Current Characteristics of Modern Domestic Appliances for Varying Supply Voltage Conditions", 14th International Conference on Harmonics and Quality of Power, ICHQP'10, Bergamo, Italy, 26-29 September.

IEC, 2008, *IEC61000-3-6, Electromagnetic compatibility (EMC) – Part 3-6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems*.

IEC, 2009, *IEC 61000-3-2, Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤16 A per phase)*.

Iglesias, J. G., Bartak, G., Baumier, N., Defait, B., Dussart, M., Farrell, F., Graser, C., Sinclair, J., Start, D. & Mazzoni, M. 2002, *Power Quality in European Electricity Supply Networks*, 1st edition, report prepared for Eurelectric.

Issouribehere, P., Barbero, J., Barbera, G., Issouribehere, F. & Mayer, H. 2010, "Assessment of Power Quality Indices Over a Decade of Control in Argentinian Distribution System", *2010 IEEE Power and Energy Society Meeting*, Minneapolis, Minnesota, USA.

Kushare, B. E., Ghatol, A. A. & Date, T. N. 2007, "Power Quality Survey of 33 kV Indian Industrial Supply system: Results and Remedial Actions", *The 8th International Power Engineering Conference (IPEC 2007)*, Singapore.

Standards Australia, 2003, *AS/NZS 61000.3.2:2003, Electromagnetic Compatibility, Part 3.2: Limits – Limits for harmonic current emissions (equipment input current less than or equal to 16A per phase)*.

Wang, A. C. & Lu, C. N. 2005, "A Survey of Distribution Feeder Power Quality", *IEEE Power Tech 2005*, Russia.