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Methods for Harmonic Analysis and Reporting in Future Grid Applications

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Abstract

The rollout of advanced metering infrastructure, advanced distribution automation schemes, and integration of generation into distribution networks, along with a raising of awareness of power quality (PQ), means that there is an increase in the availability of power system monitoring data. In particular, the data for harmonics, whether it is voltage or current harmonics, is now available from a large number of sites and from a diverse range of PQ instruments. The traditional analysis and reporting of power quality examines harmonic orders to the 50th. This means that the harmonic data available for analysis are significantly larger than, for example, steady-state voltage variations where only a few parameters are examined (e.g., the voltage on each phase). Higher frequency components, sometimes called high-frequency harmonics, in the 10-250 kHz range arising primarily due to power-electronic interfaced generation are also becoming significant. Given the vast amount of harmonic data that will be captured through grid instrumentation, a significant challenge lies in developing methods of analysis and reporting that reduces the data to a form that is easily understood and clearly identifies issues but does not omit important details. This paper introduces a number of novel methods of analysis and reporting which can be used to reduce vast amounts of harmonic data for individual harmonic orders down to a small number of indices or graphical representations which can be used to describe harmonic behavior at an individual site as well as at many sites across an electricity network. The methods presented can be used to rank site performance in order for mitigation strategies. The application of each method described is investigated using real-world data.

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Methods for Harmonic Analysis and Reporting in Future Grid Applications

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***Abstract*—The rollout of advanced metering infrastructure, advanced distribution automation schemes and integration of generation into distribution networks, along with a raising of awareness of power quality (PQ), means that there is an increase in the availability of power system monitoring data. In particular, the data for harmonics, whether it be voltage or current harmonics, is now available from a large number of sites, and from a diverse range of PQ instruments. The traditional analysis and reporting of power quality examines harmonic orders to the 50th. This means that the harmonic data available for analysis is significantly larger than, for example, steady state voltage variations where only a few parameters are examined (e.g. the voltage on each phase). Higher frequency components, sometimes termed high frequency harmonics, in the 10–250 kHz range arising primarily due to power electronic interfaced generation are also becoming significant. Given the vast amount of harmonic data that will be captured through grid instrumentation, a significant challenge lies in developing methods of analysis and reporting that reduces the data to a form that is easily understood and clearly identifies issues but does not omit important details. This paper introduces a number of novel methods of analysis and reporting which can be used to reduce vast amounts of harmonic data for individual harmonic orders down to a small number of indices or graphical representations which can be used to describe harmonic behaviour at an individual site as well as at many sites across an electricity network. The methods presented can be used to rank site performance in order for mitigation strategies. The application of each of the methods described is investigated using real-world data.**

***Index Terms*—power system harmonics, power system management, power system measurements, power quality.**

I. INTRODUCTION

THE impact of poor power quality (PQ) on consumer equipment has been well documented [1], [2]. Distributors of electrical energy generally have a regulatory requirement to ensure that the quality of the supply to individual customers remains within operational guidelines and national standards. One of the key mechanisms for ensuring compliance with national guidelines is for utilities to monitor a wide range of sites within the boundaries of their respective networks, measuring parameters such as steady state voltage, voltage unbalance, voltage sags and waveform distortion. Much of this monitoring infrastructure has been made available through the roll-out of new grid infrastructure [3]. With regard to waveform distortion, voltage distortion rather than distortion of the current waveform tends to be the metric of choice. Current distortion is useful for source identification and mitigation design for individual sites rather than the assessment of the overall PQ state of a power distribution network.

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In some cases, the analysis of data obtained from monitoring activities involves the determination of the voltage total harmonic distortion (VTHD) in order to gain a preliminary overview of the harmonic performance at a monitored site. However, there are two main drawbacks of this approach. Firstly, if a site has poor VTHD performance (i.e. the overall VTHD is beyond that which is defined by relevant standards or operational requirements), the VTHD does not give an indication of the individual harmonic order(s) which is (are) causing a problem. Secondly, a VTHD value which is below a set limit does not automatically ensure that all harmonic orders are below their respective limits.

Researchers and practitioners worldwide have developed ways for reducing large quantities of data [4], obtained from monitoring instruments, to simple indices, graphical representations and reporting formats that do not require specialist technical knowledge [2]. In [5], the authors have devised a novel method of visualising the compliance of the voltage magnitude at individual sites as well as across an entire network. The method is restricted to RMS voltage levels and is quite effective in displaying both typical and atypical performing sites. However, the analysis falls short of easy identification of the atypical sites.

The authors of [6] present an evaluation of a number of different PQ indices, including those which can be used for harmonic analysis. However, as reported, the focus is on total harmonic distortion (THD), either averaged across sites, or compartmentalised into a histogram to give a "world view" of the network under investigation. The shortfall of this approach has already been highlighted; it fails to identify individual harmonic orders. The method described may identify an atypical site, but further investigation is required to determine of there is a problematic harmonic order.

In [7], the authors apply Cochrane's theorem for sample size in order to determine the required number of measurement locations. The focus on the measurement method with regard to harmonics is the use of THD at each of these sites. This approach is problematic in two ways. Firstly, it assumes that there is a uniformity of harmonic distortion across the distribution network and secondly, the reliance on THD means that individual harmonic orders that may be exceeding compliance limits are not identified unless the THD index is excessive.

Many other authors have addressed aggregation of large volumes of harmonic data. In most cases, the research is focussed on a large site or a distribution zone that has several large polluters. A PQ survey conducted at a large educational site is presented in [8]. The authors explore a method for identifying atypical buses within the site by assessing VTHD. Once again, this raises the possibility of out-of-limit values for individual harmonic orders masked by the THD calculation. The study presented in [9] presents a world view of a distribution zone with the intent of determining mitigation methods for harmonic pollution levels. The focus is on THD, but there is also an attempt to address the levels of individual, lower-order harmonics (predominantly 5th and 7th) for harmonic filter requirements. The approach identifies the worst affected system bus but will not identify typical and atypical buses in the distribution zone.

In their discussion of the PQ compatibility, the authors of [10] focus on how a large customer provides evidence of compliance prior to connection. They provide a well developed procedure in which simulation and measurement are used. However, with the focus being on a single site, the effect on other customers in the same distribution zone is not addressed.

This paper introduces a number of novel methods which can be used to reduce large amounts of harmonic data for individual harmonic orders down to a small number of indices or graphical representations which can be used to describe harmonic behaviour at an individual site as well as at many sites across an electricity network. The methods presented can identify poor performing sites and therefore provide a means by which to rank site performance, and can be used to determine sites which require further investigation. It is also possible to classify sites and investigate site clustering to determine if particular loads or other factors are present.

The remainder of this paper is organised as follows. In Section II, indices will be introduced which describe the harmonic performance of a site. The first index is designed to indicate the overall compliance performance of the entire harmonic spectrum with respect to harmonic limits. Further indices, which aren't related to compliance, are designed to describe the characteristics or 'shape' of the harmonic spectrum which can be used to determine if there is unusual harmonic behaviour at a site. Following the discussion of individual site indices, Section III presents a method which may be used to indicate the harmonic performance of many sites within a network. In all cases, the application of each of the methods described is investigated using data from the Australian Long Term Power Quality Survey [11], [12]. Finally, conclusions and further work will be presented in Section IV.

II. Novel Harmonic Indices for Individual Sites

When data is to be examined from a very large number of sites, as may be the case for data provided by advanced metering infrastructure, an individual site will usually not be of interest unless there is unusual behaviour at the site; i.e. limits are being exceeded or there is an unusual harmonic spectrum. In order to find sites of interest, indices are needed which can be used to identify and rank quickly, in terms of disturbance severity, sites that require further investigation. The two indices described in Sections II-A and II-B provide a ready indication of whether or not harmonic behaviour at an individual site is of concern. This multi-stage approach to identifying and then investigating problematic sites provides a means of easily recognising sites that require additional analysis.

A. Harmonic Compliance Index

The harmonic compliance index (HCI) is designed to indicate the compliance of individual harmonic orders at a site with relevant limits. As discussed in Section I, due to lack of data or other resources, THD has previously been used as an indicator of compliance with limits. However, it is possible to have a THD value which is well below the THD limit but still have individual harmonic orders that exceed individual harmonic order limits. The HCI addresses this shortfall by providing an immediate indication of whether any harmonic order at a site is above the limit and if so, to what extent. The HCI is calculated using (1);

$$HCI = \max\left(\frac{H_{THD}}{H_{THD\ \mathrm{limit}}}, \frac{H_2}{H_{2\ \mathrm{limit}}}, \frac{H_3}{H_{3\ \mathrm{limit}}}, \ldots, \frac{H_n}{H_{n\ \mathrm{limit}}}\right) \times 100\%, \quad (1)$$

where H_{THD} represents the THD of the signal under investigation, $H_{THD\ \mathrm{limit}}$ represents the maximum allowable THD, H_n represents the magnitude of harmonic n and $H_{n\ \mathrm{limit}}$ represents the allowable limit of harmonic n (variable for different compliance requirements).

In considering the application of (1), if all harmonic orders at a site are below their respective limits as defined by standards or operational requirements, the HCI value will be less than 100%. In this case, the index also indicates the margin available before any harmonic order reaches its limit. If any harmonic order is above its limit, the HCI will be greater than 100 and it will indicate how far above the limit the worst performing harmonic order is.

The HCI can be used to rank sites in order to determine the sites which require attention. Fig. 1 shows a sample of a graphical representation of the HCI, showing how it can be used to rank sites.

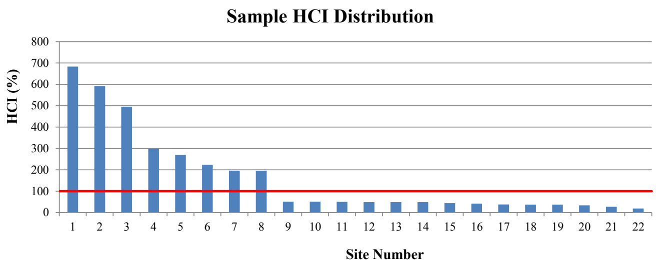


Fig. 1. Sample HCI Distribution

B. Methods to Describe Harmonic Spectrum 'Shape'

While the HCI will give an indication of whether any particular individual harmonic order is above the relevant limit at a site, it provides no information regarding the exact harmonic order(s) which is (are) above the limit and whether or not the harmonic spectrum is atypical.

Three new parameters to describe the shape of a harmonic spectrum are proposed. The first parameter gives a type of average, highlighting where the harmonic orders are centred. This parameter is hereafter referred to as the Average Harmonic, h_{av}. The other two parameters give an indication of where the significant lower and upper bounds of the harmonic spectrum occur. These parameters are hereafter referred to as h_{low} and h_{high} respectively. With the use of such indicators, it is easy to determine the sites which have a harmonic spectrum rather different to what would be considered normal. For instance in an LV network, the traditional dominant harmonic orders are low orders, specifically, 3rd and 5th. If the shape of the spectrum using the above method was found to centre on, say the 15th harmonic, this would indicate a site that is not performing as expected. It is clear that the standard THD calculation does not provide the same level of insight.

1) Calculation of Average Harmonic: The aim of the Average Harmonic calculation is to produce an indicator of where most of the harmonic spectrum is concentrated. In the first instance this can be achieved by the calculation shown in (2):

$$h_{\text{av}} = \frac{\sum h_i H_i}{\sum H_i}, \quad (2)$$

where h_{av} is the Average Harmonic, h_i is the harmonic order for the i^{th} harmonic and H_i is the magnitude of the i^{th} harmonic.

As an example, consider two cases, A and B, as illustrated in Fig. 2. In Fig. 2, and all subsequent figures presenting harmonic spectrum), the vertical-axis represents the percentage magnitude of the harmonic relative to the fundamental.

For Case A, the application of (2) leads to;

$$h_{\text{av}} = \frac{(5 \times 1) + (7 \times 2) + (25 \times 0.5)}{1 + 2 + 0.5} = 9$$

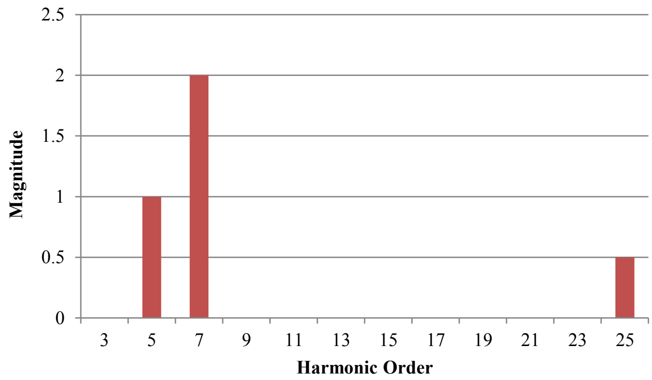
and for Case B, $h_{\text{av}} = 15.5$. A property of the definition for Average Harmonic given in (2) is that many low magnitude components will have as significant an impact as one large magnitude component. The large magnitude components can be emphasised by replacing H_i in (2) by H_i^n, where n is 2 or larger. This substitution results in (3).

$$h_{\text{av}}(n) = \frac{\sum h_i H_i^n}{\sum H_i^n} \quad (3)$$

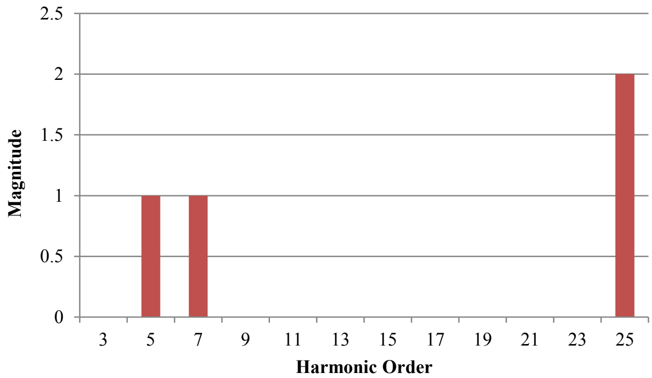
The effect of various values of n on h_{av} for the two example cases shown in Fig. 2 is demonstrated in Table I. The reader will observe that with $n = 10$, only the largest value of H

TABLE I
h_{av} FOR VARIOUS VALUES OF n

n	Case A	Case B
1	9	15.5
2	7.5	18.7
3	7.0	21.2
5	7.0	23.9
10	7.0	25.0



(a) Case A



(b) Case B

Fig. 2. Sample Harmonic Spectrums - Cases A and B

determines h_{av}. As the impact of any particular harmonic on equipment is proportional to the square of the magnitude [11], it is recommended that an n value of 2 be selected. This will reduce the weight that small harmonic magnitudes give to the result.

2) Lower and Upper Boundaries (h_{low} and h_{high}) - Preliminary:

a) Lower boundary: The lower boundary (h_{low}) is a measure of the harmonic orders at the lower frequency end where the spectrum begins to be significant. This requires an emphasis of the low frequencies in the spectrum in (3). In the first instance, this can be achieved by weighting each term with $1/h_i$, by multiplying the numerator and denominator terms by $1/h_i$ as shown in (4).

$$h_{\text{low}}(n)' = \frac{\sum H_i^n}{\sum H_i^n / h_i} \quad (4)$$

b) Upper boundary: For the upper boundary, it is necessary to emphasise the higher frequency components of the spectrum by weighting each term in (3) with h_i; that is, multiplying the numerator and denominator terms by h_i giving;

$$h_{\text{high}}(n)' = \frac{\sum h_i^2 H_i^n}{\sum h_i H_i^n} \quad (5)$$

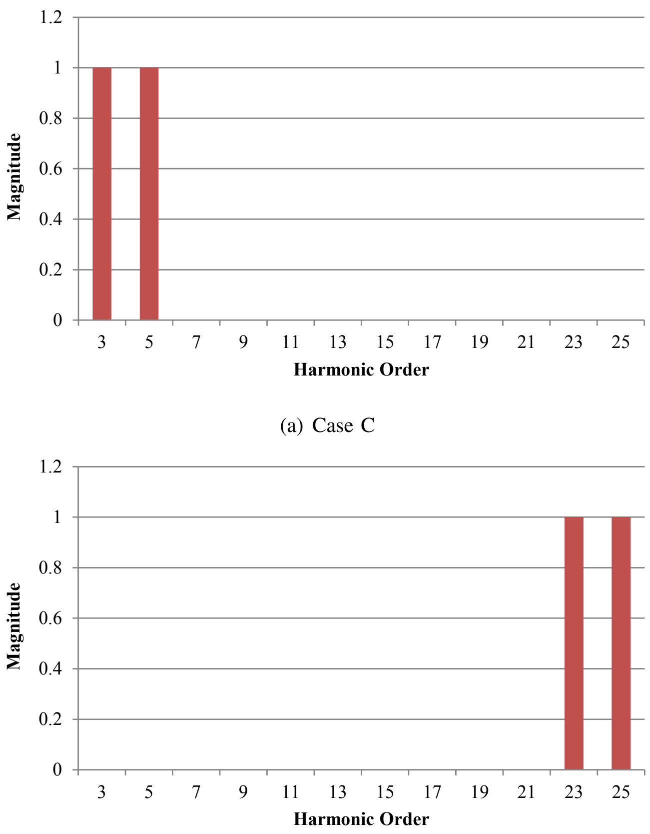
From the preceding discussion, it would seem that a reasonable definition of bandwidth is;

$$BW' = h_{\text{high}}(n)' - h_{\text{low}}(n)' \quad (6)$$

Applying these definitions to Cases A and B as shown in Fig. 2, gives the results in Table II. In the first instance, the values in Table II appear to be reasonable. However, if Cases C and D in Fig. 3 are examined, identical bandwidths would be expected for both cases. However, as the calculation values for the relevant parameters which are shown in Table III indicate, this is not the case.

TABLE II
PRELIMINARY INDEX VALUES FOR CASES A AND B

	Case A	Case B
h_{av}	9	15.5
h'_{low}	6.9	9.5
h'_{high}	13.8	21.4
BW'	6.9	11.9



(b) Case D

Fig. 3. Sample Harmonic Spectrums - Cases C and D

TABLE III
TESTING DEFINITIONS USING CASES C AND D

	Case C	Case D
h_{av}	4	24
h'_{low}	3.8	24.0
h'_{high}	4.3	24
BW'	0.5	0.08

Examining the results in Table III further, although the lower and upper bounds appear reasonable, the bandwidths are not identical. The reason for this can be seen by examining the examples given, in the following section.

c) Discussion of method: Assuming a spectrum with harmonics present at h_1 and h_2, each of unit magnitude and using $n = 1$. From (3);

$$h_{\text{av}}(n) = \frac{\sum h_i H_i^n}{\sum H_i^n} = \frac{h_1 + h_2}{2} \tag{7}$$

From (4);

$$h_{\text{low}}(n)' = \frac{\sum H_i^n}{\sum \frac{H_i^2}{h_i}} = \frac{2}{1/h_1 + 1/h_2} = \frac{2h_1 h_2}{h_1 + h_2} \tag{8}$$

From (5);

$$h_{\text{high}}(n)' = \frac{\sum h_i^2 H_i^n}{\sum h_i H_i^n} = \frac{h_1^2 + h_2^2}{h_1 + h_2} \tag{9}$$

This can be re-expressed as (10);

$$BW' = \frac{(h_1 - h_2)^2}{2h_{\text{av}}} \tag{10}$$

We see that the definition of BW' increases as the square of $(h_1 - h_2)$ and decreases with h_{av} as shown in Table III. Eqn (10) suggests that a better definition of bandwidth is:

$$BW = \sqrt{2h_{\text{av}} BW'} = \sqrt{2h_{\text{av}}(h'_{\text{high}} - h'_{\text{low}})} \tag{11}$$

Further simplification of (11) leads to (12)

$$BW = \sqrt{2\left(\frac{\sum h_i^2 H_i}{\sum H_i} - \frac{\sum h_i H_i}{\sum \frac{H_i}{h_i}}\right)} \tag{12}$$

From (12), it is possible to determine the final values of h_{low} and h_{high} as follows:

$$h_{\text{low}} = h_{\text{av}} - BW/2 \tag{13}$$

$$h_{\text{high}} = h_{\text{av}} + BW/2 \tag{14}$$

The results of applying these revised definitions to all of Cases A-D (Figs 2 and 3) are shown in Table IV.

TABLE IV
TESTING DEFINITIONS USING CASES A-D

	Case A	Case B	Case C	Case D
h_{av}	9	15.5	4	24
h_{low}	3.4	5.9	3	23
h_{high}	14.6	25.1	5	25
BW	11.2	19.2	2	2

3) Further Improvements: In the previous treatment, there was an assumption that h_{low} and h_{high} are symmetrically placed around the average, but there are many spectra in which this is not so, such as Case A in Fig. 2. The lowest frequency calculated is 3.4 which is less than any harmonic present. The problem is that the bandwidth was assumed to be equally placed around the average.

A better solution is to assume that the bandwidth, BW, is placed so that the spectra above the average is related to the spectra below by a ratio r, to be determined rather than given the default value of 0.5 as implied in (13) and (14). The expression for r can be found from the preliminary values of $h_{\text{high}}(n)'$ and $h_{\text{low}}(n)'$.

$$r = \frac{h_{\text{high}}(n)' - h_{\text{av}}}{h_{\text{av}} - h_{\text{low}}(n)'} \tag{15}$$

Whence better values for h_{high} and h_{low} can be determined.

$$h_{\text{low}} = h_{\text{av}} - \frac{1}{r+1} BW \tag{16}$$

$$h_{\text{high}} = h_{\text{av}} + \frac{1}{r+1} BW \tag{17}$$

The change in the parameters for Case A are presented in Table V.

TABLE V
REVISED DEFINITION FOR LOWER AND UPPER FREQUENCIES, CASE A

	Case A Previous Definition	Case A Revised Definition
h_{av}	9	9
h_{low}	3.4	5.6
h_{high}	14.6	12.4
BW	11.2	11.2

4) Examples: Harmonic spectrum data collected from medium voltage (MV) sites as part of the Australian Long Term National Power Quality Survey (LTNPQS) [12] [13] have been used to give an indication of how the calculations present data from spectrums with a range of shapes. The first selected spectrum, as shown in Fig. 4, is a typical shape for an MV site connected to an Australian distribution network. The second and third spectrums selected for investigation, shown in Figs 5 and 6, have higher than normal 21$^{\text{st}}$ and high 15$^{\text{th}}$ harmonic levels respectively. Table VI shows the calculated shape parameters for the three sites using $n = 2$. Examination of Table VI shows that the final methodology

TABLE VI
CALCULATED INDICES FOR SITES 1, 2 AND 3

	h_{av}	h_{low}	h_{high}	BW
Site 1	5.50	4.60	7.08	2.48
Site 2	8.68	4.93	15.19	10.26
Site 3	8.37	4.74	13.04	8.30

gives results which are reasonably intuitive. In all cases, h_{low} is approximately 5. This is accurate as all sites have a similar spectrum for lower harmonic orders. The reader will observe that h_{high} accurately ranks the sites based on Site 2 having a

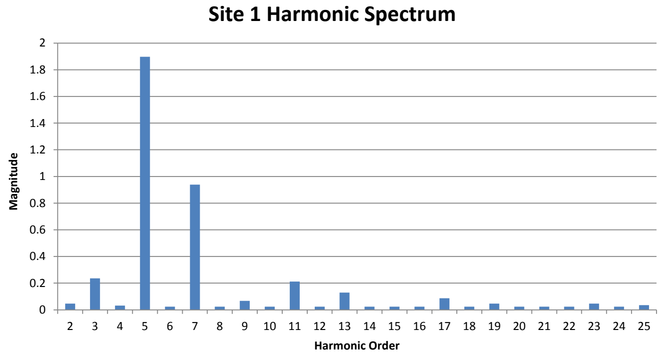


Fig. 4. Site 1 Harmonic Spectrum

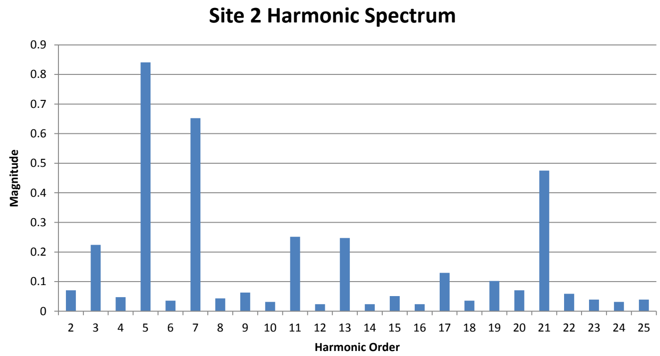


Fig. 5. Site 2 Harmonic Spectrum

higher than expected 21$^{\text{st}}$ harmonic level and Site 3 having a higher than expected 15$^{\text{th}}$ harmonic level. The calculation for the bandwidth also correctly predicts that Site 2 will have a spectrum which has significant harmonic magnitude at a larger harmonic order than Site 3 or Site 1.

5) Application of Methodology - Typical and Atypical Sites: The key purpose of this analysis is to determine which of many sites are performing poorly or otherwise need attention. This poses the question; if the sites are assessed by h_{low} and h_{high}, how can the indices be used to determine site performance and provide a method of identifying sites which are atypical or in need of attention? Answering this question requires a methodology to separate typical and atypical sites.

The approach taken is to consider h_{low} and h_{high} separately at first. In the case of h_{low}, a histogram of the site values from lowest to largest can be constructed. The lowest 5% and the highest 5% of site can be considered as the atypical sites. This approach can then be repeated for h_{high}. Sites may then be classified into 4 types:

- Normal
- Atypical h_{low} and typical h_{high}
- Atypical h_{high} and typical h_{low}
- Atypical h_{low} and atypical h_{high}

Once again, data from the LTNPQS has been used to give an indication of typical and atypical sites for Australian distribution networks. Harmonic data up to the 25$^{\text{th}}$ order has been analysed from a total of 79, 11 kV sites. For each site the h_{av}, h_{low}, h_{high} and BW have been calculated. Fig. 7

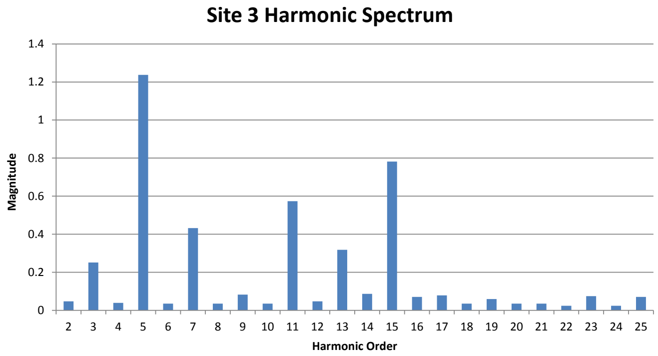


Fig. 6. Site 3 Harmonic Spectrum

shows a scattergraph of the calculated h_{high} and h_{low} values for the 79 sites. The reader will observe that most sites have a similar h_{low} value, however, there is considerable variation in h_{high} values. Some clustering of sites can be identified near the 8$^{\text{th}}$ harmonic. This indicates sites that have predominately low order harmonics. A number of the sites analysed had significant 15$^{\text{th}}$ and 21$^{\text{st}}$ harmonic levels due to load control ripple frequency injection signals. It is for this reason that a significant number of sites show h_{high} values up to the 21$^{\text{st}}$ harmonic.

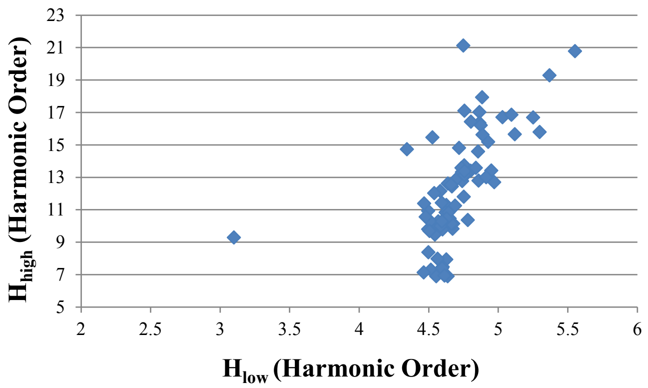


Fig. 7. Scattergraph of h_{high} and h_{low} for 79, 11 kV Sites

Statistical analysis was performed on the site data shown in Fig. 7 to produce the results shown in Table VII.

TABLE VII
STATISTICAL INDEX VALUES CALCULATED ACROSS 79 SITES

Statistic	h_{av}	h_{low}	h_{high}	BW
5$^{\text{th}}$ Percentile	5.5	4.5	7.1	2.6
Average	7.3	4.7	12.3	7.6
95$^{\text{th}}$ Percentile	9.9	5.1	17.2	12.4

Table VII indicates that for the sites shown, the harmonic spectrum for the 11 kV sites assessed predominately begins at the 5$^{\text{th}}$ harmonic. From the 95$^{\text{th}}$ percentile values for h_{high}, the highest harmonic order with significant magnitude is the 17$^{\text{th}}$. From the values shown in Table VII it is possible to determine preliminary limits for each of the indices based on the 5$^{\text{th}}$ and 95$^{\text{th}}$ percentile values. For example, a site with a h_{av} value of less than 5.5 or greater than 9.9 would be considered atypical and deserving of attention. Similar statements may be made for the other indices.

As a further explanation, this method of analysis identifies the atypical sites readily. Clearly, the site with an h_{high} approximately equal to 9.2 and h_{low} of 3.1, lies outside the typical range identified in Table VII. Additionally, the sites with h_{high} over 19 are also identified as atypical.

III. Network Reporting of Harmonics

A graphical method has been developed which effectively shows the distribution of harmonic magnitudes for each order across all sites of a utility. The graphical reporting method involves displaying the harmonic performance of sites in decile bands. The values for each decile band are based on the 95% harmonic level at each site and are normalised by the limits so that all harmonic orders can be shown on the same scale (without normalisation, some harmonic orders such as the 5th would have a magnitude much larger than others which would mask issues such as excessive high order, even harmonics). An example of this graphical method is shown in Fig. 8. Observing the graph for the 3$^{\text{rd}}$ harmonic, 10% of the sites have levels of 3$^{\text{rd}}$ harmonic that are greater than the acceptable 95% probability limit. The graph also indicates that the 3$^{\text{rd}}$, 5$^{\text{th}}$, 15$^{\text{th}}$ and 21$^{\text{st}}$ harmonics require attention.

The graphical representation of Fig. 8 has the advantage that it will clearly indicate the harmonic orders which are of concern, the percentage of sites which may be above the limit for a particular harmonic order and the distribution of values across the entire network for each harmonic order. This distribution of values is important as it can be used to indicate if systemic problems exist across all sites, or if harmonic issues are only present at just a small number of outlier sites. For example, for the 3$^{\text{rd}}$ harmonic shown in Fig. 8, the even distribution of values tends to indicate that there are a large number of sites affected by 3$^{\text{rd}}$ harmonic. Similarly, the 21$^{\text{st}}$ harmonic has an even distribution with more than 50% of the sites exceeding the recommended value. These harmonic orders may require a network-wide solution. However, for the 5$^{\text{th}}$ harmonic, the compact spread and large maximum value indicates that specific issues at relatively few sites are the cause of the harmonic exceeding the recommended value for this harmonic order. Hence, any solutions would be more localised.

IV. Further Developments and Conclusions

This paper introduced novel harmonic-analysis and reporting techniques that can be used determine the harmonic site and network performance using data collected at a large number of measurement locations. The volume of data produced as a consequence of the high number of measurement points means that traditional methods of evaluating the level of harmonic distortion that exists in a network are no longer suitable, and fail to produce a user friendly visualisation method. The techniques described in this paper address the issues associated with the large volume of data and are able

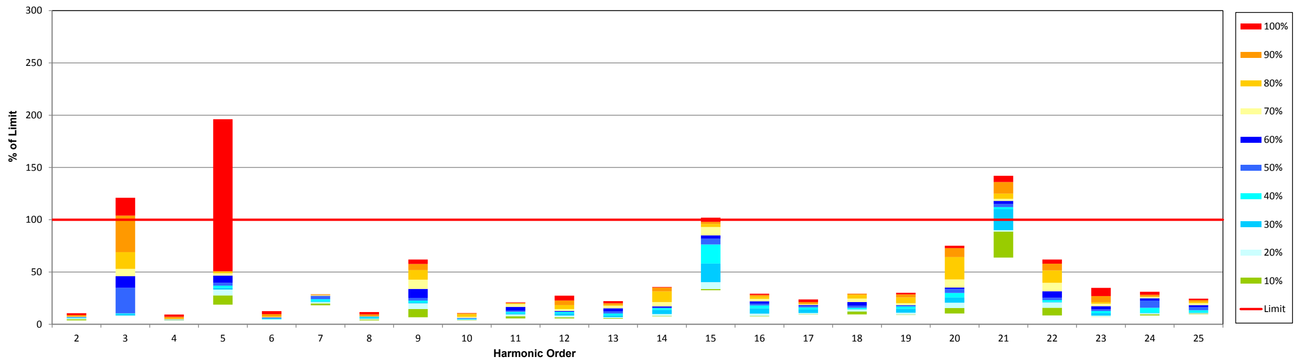


Fig. 8. Example of a Graph for Network Reporting of Harmonics

to produce a small number of meaningful indices, even for a large number of harmonic orders.

The concept of the harmonic compliance index (HCI) has been introduced to give a quick indication of whether or not any individual harmonic order is above the limit at any particular site. The current HCI is limited with respect to site ranking in that it may rank a site with a single large harmonic worse than a site with many harmonic orders above the limit. Refinement of the index to solve this issue is the subject of further work.

Novel indices to describe the shape of the harmonic spectrum at a site have been presented. In this study, raw harmonic magnitudes have been used. It is possible to perform similar calculations using normalised harmonic values (i.e. harmonic values divided by their respective limits). Again this is an area of future work and ultimately may prove more insightful than the methods presented in this paper. Finally, a graphical method of network reporting of harmonics has been presented which shows extensive detail of the harmonic performance across many sites in a compact form.

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