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Harmonics and Flicker Levels at a Sub-Transmission Substation: A Measurement Experience

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Abstract

Proactive monitoring of power quality disturbance levels by electricity utilities is vital to allow cost-effective mitigation when disturbances are perceived to be approaching planning levels and also to protect the security of customer installations. Ensuring that disturbance levels are within limits at the HV and EHV points of supply of the network is essential if satisfactory levels downstream are to be maintained. This paper presents discussion on a power quality monitoring campaign performed at the sub-transmission point of supply of a distribution network with the objective of benchmarking background disturbance levels prior to modifications to the substation and to ensure emissions from HV customers and the downstream MV networks are within acceptable levels. Some discussion on the difficulties involved in such a study is presented.

Keywords

substation, transmission, harmonics, levels, measurement, experience, sub, flicker

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Harmonics and flicker levels at a sub-transmission substation: A measurement experience

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ABSTRACT

Proactive monitoring of power quality disturbance levels by electricity utilities is vital to allow cost-effective mitigation when disturbances are perceived to be approaching planning levels and also to protect the security of customer installations. Ensuring that disturbance levels are within limits at the HV and EHV points of supply of the network is essential if satisfactory levels downstream are to be maintained. This paper presents discussion on a power quality monitoring campaign performed at the sub-transmission point of supply of a distribution network with the objective of benchmarking background disturbance levels prior to modifications to the substation and to ensure emissions from HV customers and the downstream MV networks are within acceptable levels. Some discussion on the difficulties involved in such a study is presented.

KEY WORDS

Power quality, harmonics, flicker, measurement, distribution system, substation, planning

1. INTRODUCTION

Electrical power systems are rarely static and their physical structure and layout will often change to satisfy load growth, network improvements, application of new technologies, and replacement of equipment nearing the end of its life span. When network modifications become apparent the system parameters of the network may also change. The level of power quality is often dependent on these system parameters, thus it is important to consider possible consequences on the level of power quality disturbances existing on the system when modifications are integrated into the network. For example harmonics voltage levels may be affected detrimentally from shifts in resonant frequencies or significant increases in harmonic impedance. Increases in system impedance will also affect the magnitude of voltage fluctuations.

Integral Energy is about to commence a project to refurbish one of their larger sub-transmission substations. The proposed refurbishment included replacement of seven 132/33kV 60MVA transformers, with transformers of rating 60MVA or 120MVA, and refurbishment of one other 60MVA transformer, effectively upgrading the total capacity of the substation by approximately 30%. At the request of Integral Energy the Power Quality Centre became involved with monitoring harmonics and flicker levels at the sub-transmission substation to allow assessment of existing levels of disturbances prior to substation refurbishment, evaluation of customer contributions, and calculations of future levels for the planned upgrade of transformers.

To determine existing levels of harmonics and voltage fluctuations a two-week power quality monitoring campaign was undertaken. Assessment of harmonics and voltage fluctuation levels was carried out, where possible, as per guidelines from the relevant standards AS/NZS 61000.3.6[1] and AS/NZS 61000.3.7[2] respectively, although instrument limitations prevented an exact assessment being completed. Data from the monitoring campaign was also utilised to assist in modelling the sub-transmission substation and surrounding network to establish how the refurbishment would affect power quality disturbance levels. Some of the issues encountered with the monitoring program and assessment include

i.) Lack of accessible monitoring points in the HV and MV network,
ii) Discrepancies between monitoring instruments,
iii) Evaluating the impact of multiple combinations of switched capacitors,
iv) Lack of clearly defined planning levels for sub-transmission systems,
v) Calculation of acceptable emissions for MV customers, and
vi) Effective reporting of disturbances to benchmark results for the future.

This paper will report on the experiences of the power quality monitoring program, including a discussion on the above issues. The calculations of acceptable customer power quality disturbance contributions as per the relevant standards are presented and a summary of the modelling techniques utilised to predict future harmonic and voltage fluctuation levels will also be examined.

2. THE STUDY SYSTEM

A single line diagram of the sub-transmission substation is illustrated in Fig 1. Substation load includes three large industrial customers and Integral Energy's own 33kV network. Industrial *Customer A* is fed at 33kV via five 60MVA transformers, two other industrial customers (*Customer B* and *Customer C*) are fed at 132kV and Integral Energy's own 33kV distribution network is supplied via three 60MVA transformers. Integral Energy's 33kV network includes some smaller industrial customers and a significant amount of commercial and domestic load.

As is typical of most larger sub-transmission substations the power system equipment such as transformers, circuit breakers, busbars, etc. are located in an open air fenced off enclosure adjacent to a building containing secondaries to metering and protection circuits and substation monitoring and control systems. Interfacing to equipment and control is brought into the building via supervisory cables.

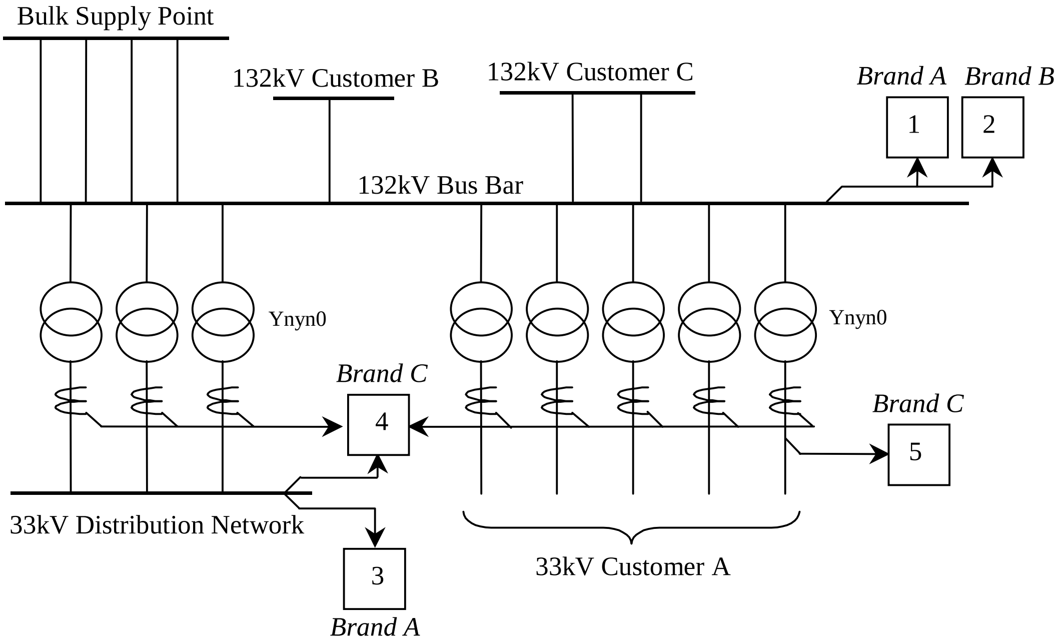


Fig 1: Sub-transmission substation single line diagram and PQ monitor locations

The eight transformers shown in Fig 1 are all to be either replaced or refurbished. After refurbishment impedances of the new transformers will be different to what already exists. Thus there is a requirement to ensure that the new network parameters do not create a rise in the level of power quality disturbances.

3. MEASUREMENT CONSIDERATIONS

3.1 Monitoring locations

The aim of the monitoring project was to benchmark background disturbances and assess emission levels from the customers that would be affected by substation refurbishment. Ideally it would be preferable to install power quality monitoring instruments, measuring both current and voltage on all three phases, on each of the incoming and outgoing feeders of the substation. This would allow disturbance emissions from all customers to be assessed both before and after refurbishment of the substation. However, this would require a significant number of power quality instruments. To limit the number of instruments used it was desired to monitor three phases of the summated currents from the three 33kV distribution network transformers, summated currents from the five *Customer A* transformers, and summated currents from other customers fed at 132kV.

Network monitoring points for this particular substation had been designed to be accessible for two purposes, protection and metering. The protection circuits metering points were available from field CTs and VTs on all three phases, however connecting into or altering protection circuits is regarded as reducing network security and hence these points cannot be accessed for power quality monitoring. Metering CTs and VTs are also installed on all three phases on each of the transformers in the field, though not all metering connections were connected via supervisory cables back into the substation building as they are not all required for metering purposes. Summation CTs were also not available on all phases for the 33kV distribution network, *Customer A* and *Customer C*. As impedance changes applied to the system were most likely to affect *Customer A* and the 33kV distribution network, measurement of background levels and emissions from these locations were of most significance.

For assessment of substation 132kV busbar flicker levels *Brand A* and *Brand B* (for comparison) power quality monitoring instruments were connected line-to-neutral to the 132kV/110V Capacitive Voltage Transformer (CVT) of the substation 132kV busbar. As the CVT has a narrow frequency bandwidth, harmonic voltage measurements could not be completed at the 132kV busbar using existing instrumentation. A second *Brand A* instrument was installed line-to-neutral to the 33kV/110V Voltage Transformer (VT) of the 33kV busbar for voltage harmonics and flicker level measurements at MV sub-transmission. Although the harmonic voltage levels could not be measured directly at the 132kV busbar an indication of levels can still be estimated by interpolating measurements from the substation 33kV busbar. For measurement of the available summated harmonic current contributions a single *Brand C* instrument was utilised measuring two phases of the 33kV distribution network and a single phase of *Customer A*. The *Brand C* instrument was also connected to measure line-to-line harmonic voltages at the 33kV distribution network busbar. An additional *Brand C* instrument was connected to the 33kV side of *Customer A* transformers to measure harmonic voltages.

3.2 Discrepancies between instruments

Three types of instruments were used to complete this study. These instruments included two *Brand A* instruments, two *Brand B* instruments, and one *Brand C* instrument. The *Brand B* instrument had previously been reported by Piekarz et al.[3] as not providing a comparable value for short term and long term flicker indices, P_{st} and P_{lt} respectively. As illustrated in Fig 1 *Brand A* and *Brand B* instruments were connected in parallel on the 132kV busbar CVT to measure flicker. A comparison of the recorded results from the two instruments for the study survey in the form of a scatter graph is presented in Fig 2.

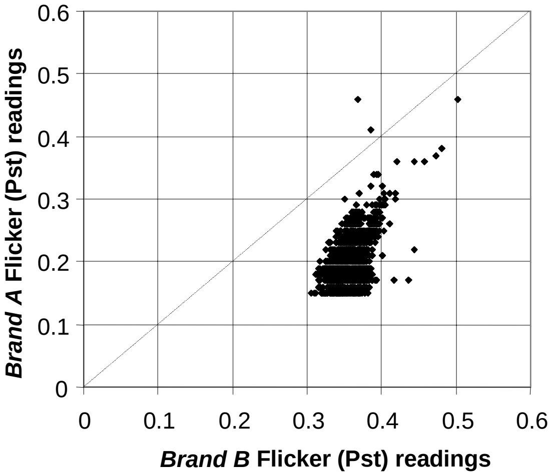
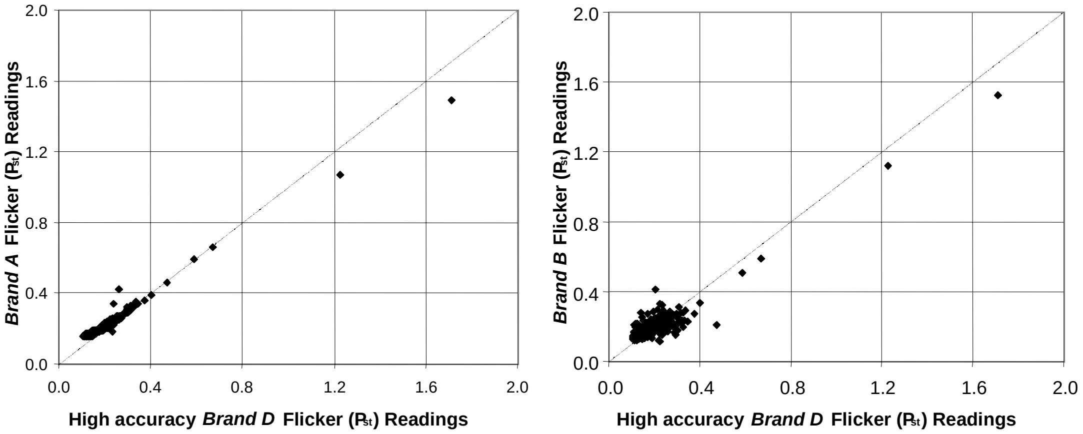


Fig 2: Scatter graph of short term flicker (P_{st}) measured by *Brand A* and *Brand B* instruments (Correlation coefficient = 0.54)

The scatter graph in Fig 2 is produced to illustrate the correlation between *Brand A* and *Brand B* instruments. The correlation coefficient was calculated from the data in Fig 2 to be 0.54. As a correlation coefficient of value of 1 or –1 indicates strong correlation and zero indicates no correlation, in this instance at least one of the meters was not recording the correct value. After the study survey was completed two laboratory tests were carried out with two additional instruments of high accuracy to determine which instrument was not reading incorrectly or poorly. During laboratory tests the *Brand B* instrument was placed in parallel with *Brand A* instrument to once again establish a comparison of results, and with at least one of two other high accuracy instruments, referred to here as *Brand D* and *Brand E* instruments.

The first laboratory test included monitoring short term flicker, P_{st}, appearing from a general power outlet over a period of one week. The second laboratory test utilised a waveform generator[4], owned by the Integral Energy Power Quality Centre, as a controlled flicker source. The results of the first laboratory test are presented in Fig 3(a) and 3(b) as scatter graphs. Fig 3(a) compares *Brand A* instrument against the high accuracy *Brand D* instrument, while Fig 3(b) compares *Brand B* against *Brand D* instrument.



(a) Correlation coefficient = 0.99 (b) Correlation coefficient = 0.92

Fig 3: Scatter graph of flicker readings during laboratory tests

Fig 3(a) and 3(b) suggest that all three instruments show good correlation for P_{st} at higher values, i.e. greater than 0.5. And correlation coefficients for scatter graphs compliment this. However problems with the *Brand B* instrument outlined by Piekarz et al.[3] suggest the instrument will have greatest error for lower P_{st} values. The poorer correlation between the *Brand B* instrument and other instruments at lower flicker values, i.e. less than 0.4, is evident in Fig 3(b) where the correlation coefficient is given as 0.92 if values of $P_{st}>0.5$ are considered, but if these values are removed the correlation coefficient reduces to 0.75. If the same values are removed from Fig 3(a) the correlation coefficient remains high at above 0.96.

The second laboratory test had the second high accuracy instrument, *Brand E*, connected in parallel with the three above mentioned instruments while connected to controlled flickers levels being produced by the waveform generator. Various points on the flicker curve[5] were selected and produced by the waveform generator while P_{st} values determined by each of the instruments were recorded. A selection of some of the results from these tests is provided in Table 1.

Table 1: Waveform generator voltage fluctuations test results.

Instrument P_{st} values				
Test	*Brand A*	*Brand B*	*Brand D*	*Brand E*
1	0.98	0.79	1.00	1.20
2	3.19	2.69	3.22	3.27
3	0.78	0.78	0.79	0.95
4	4.95	4.10	5.15	5.24

As with the first laboratory test Table 1 shows reasonably good agreement between P_{st} values recorded by *Brand A*, *Brand D* and *Brand E* instruments and somewhat less correlation with the *Brand B* instrument. Previous field measurements by Integral Energy had also found discrepancies between the *Brand B* instrument and other instruments when reporting voltage fluctuations[6]. It is suggested by Piekarz et al.[3] that the discrepancy of the *Brand B* instrument is due to an incorrect interpretation of the relevant standard, IEC 61000-4-15[5], which specifies the functionality of flickermeters. The problem of open interpretation has since been rectified in the latest amendment of the standard[7] and should ensure future power quality monitors (and instrument firmware upgrades) provide consistent results.

A comparison between instruments for harmonic voltage measurements was also made during the monitoring program where meters were connected in parallel. Reasonably good correlation of recorded results between all instruments at the more significant lower order harmonics was found, including the *Brand B* instrument during later laboratory tests, even though the sample periods of the instruments differed, i.e. some instruments used an rms average over a 10 minute period, while others used much shorter time interval. The scatter graph in Fig 4 shows that for the 5th harmonic voltage *Brand A* and *Brand C* instruments gave reasonably comparable results with a correlation coefficient of 0.93.

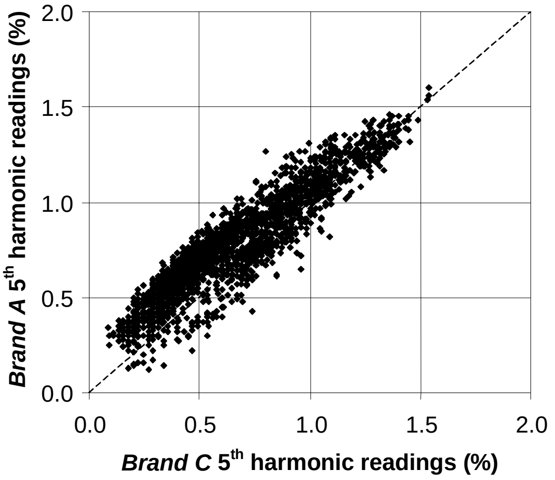


Fig 4: Scatter graph of 5th harmonic voltage measured by *Brand A* and *Brand C* instruments (Correlation coefficient = 0.93)

4. ASSESSMENT OF LEVELS AND EMISSIONS

4.1 Planning levels

AS/NZS 61000.3.6 and AS/NZS 61000.3.7 suggest that topology of a network is an important consideration when selecting harmonic voltage and flicker planning levels. Indicative planning levels for both MV and HV are provided by the standards. For effective harmonic management MV planning levels should be assessed at the most extreme points on the system where it is expected harmonic levels will be highest, i.e. the end of distribution feeders for harmonics, thus utilising MV planning levels for this sub-transmission study was not perceived practical. There is no clear indication given by the standard on how to select planning levels for points in the network between transmission and extremes of distribution. The substation 33kV busbar in this study is defined as being sub-transmission, and accordingly planning levels should, in principle, appear somewhere between the HV and MV planning levels. However, fault levels at the 33kV busbar were closely matched to that of the 132kV busbar, and thus for this project the HV planning levels were used for both transmission (132kV busbar) and sub-transmission (33kV busbar). Using HV planning levels at sub-transmission is a suitable method to ensure fewer harmonics and flicker problems occur at the extremes of the distribution system (MV and LV).

4.2 Power factor correction capacitor considerations

A study of the effects of power factor correction (PFC) capacitors at and 'electrically nearby' the sub-transmission substation was required to ensure no critical harmonic resonance would occur that might cause excessive harmonic voltages. The simulation study was completed for the substation before and after refurbishment, with the altered harmonic impedance of the transformers the most significant modification. As there were nine capacitor banks in the vicinity of the sub-transmission substation the number of possible combinations of capacitors connected at any one time could be up to 512 combinations suggesting an excessive number of iterations of simulations. A number of capacitor banks were time and load switched and thus it was possible to reduce the number of possible capacitor combinations by a factor of 10 based on the normal operating conditions of the substation before simulations were implemented.

MATLAB® was used to model the entire study system creating Tableau matrices calculated at each increment of frequency with individual power system components modelled as per recommendations in Robert et al.[8]. Simulations under various loading conditions were carried out to identify possible harmonic resonances. Fig 5 illustrates the resulting harmonic impedance curves at the 33kV distribution network bus bar for six different capacitor combinations with no load damping considered.

In Fig 5 it can be seen that one of the capacitor combinations creates a resonance at both the 5th and 7th harmonic. It was found that this particular condition only exists for a very short time interval as capacitors within the same bank are gradually switched in. The harmonic voltage for the very short interval for which this capacitor combination existed was examined in conjunction with the appropriate block of survey data and an insignificant rise in 5th and 7th harmonic voltage levels was found. The harmonic resonance is possibly reduced greatly due to effects of load damping which essentially trim down the peak of the harmonic resonance. A simulation of the same capacitor combinations with a very light loading of 30% of normal load was considered and results are illustrated in Fig 6. For the simulations the load was represented by an inductor in parallel with a series combination of inductor and resistor, as per the recommendations in Robert et al.[8].

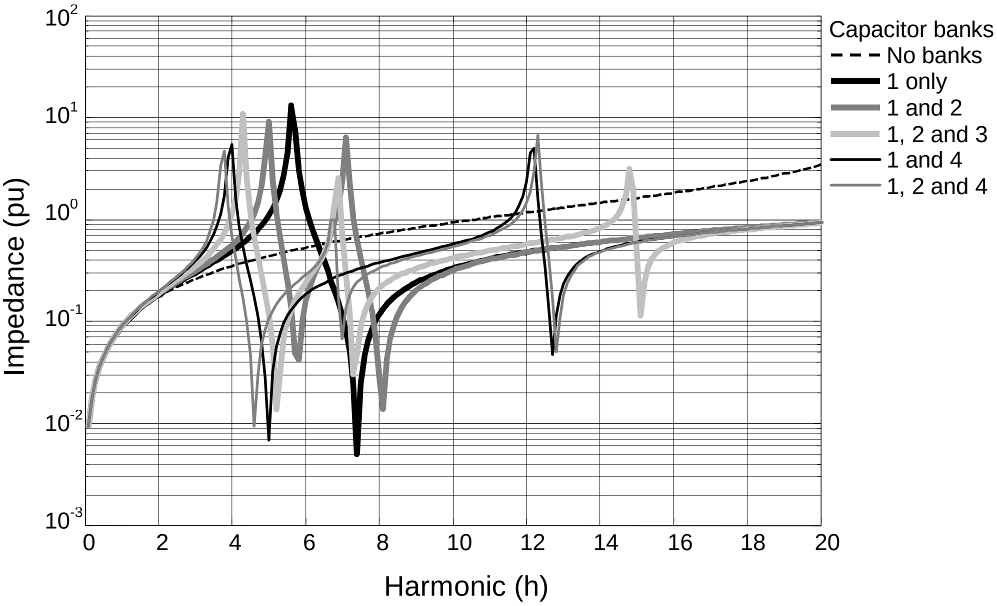


Fig 5: Harmonic impedance seen at 33kV bus for six capacitor combinations and no load damping

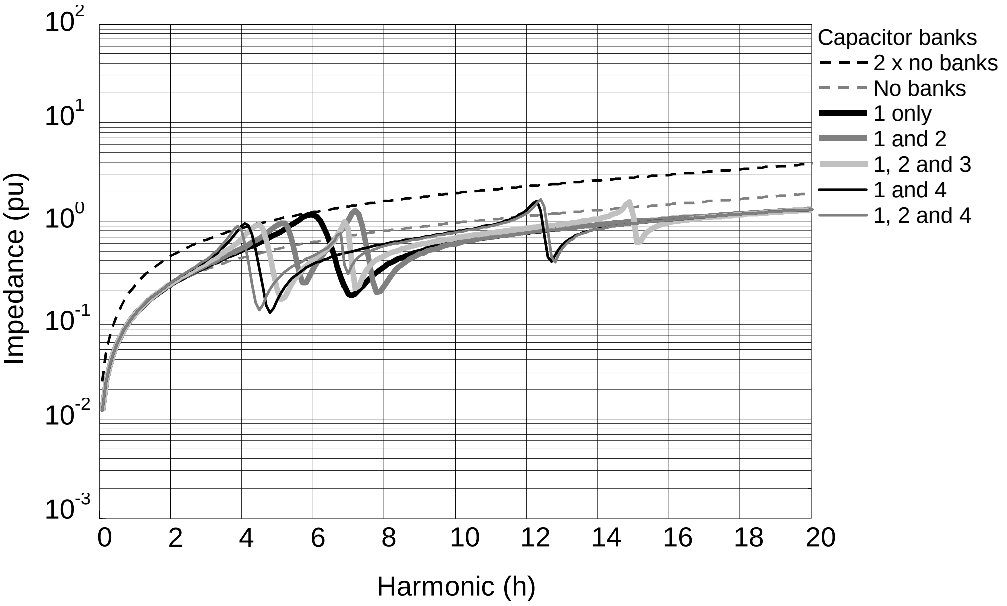


Fig 6: Harmonic impedance seen at 33kV bus for sample capacitor combinations and 30% load damping

As can be seen in Fig 6 harmonic resonances are greatly attenuated by even a small amount of load damping. The level of attenuation in fact reduces the magnitude of resonances to below twice that of the case with no capacitors present (Upper line in Fig 6). This seems to align with recommendations provided in AS/NZS 61000.3.6 and Robert et al.[8] of using twice the harmonic impedance with no capacitors to provide a pessimistic approximation of harmonic impedance with capacitors present. The simulations completed indicated that the shift in resonant frequencies due to the changing impedance of substation transformers did not create any new problematic harmonic resonances.

4.3 Assessment of emissions

Acceptable harmonic emissions from *Customer A* and the 33kV distribution network were calculated as per Stage 2 Test 1 of AS/NZS 61000.3.6. Fig 7 illustrates acceptable harmonic emission limits calculated for *Customer A* plotted against maximum harmonic current measured during the monitoring campaign. Although the 5th harmonic current in Fig 7 is shown as exceeding the acceptable emission limit this may be regarded as acceptable by the utility due to the following

i) The harmonic impedance used for the allocation was approximated as twice the impedance with no PFC present. This is conservative considering the amount of load damping illustrated in Fig 6.

ii) Harmonic emissions from other customers (*Customer B* and *Customer C*) are lower than their allowances.

iii) Harmonic voltage levels are not approaching the recommended HV planning levels.

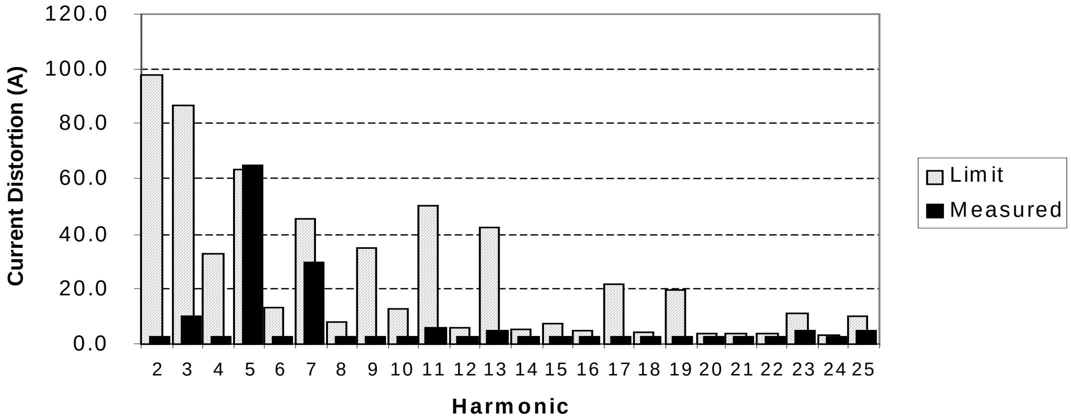


Fig 7: *Customer A* allocated and measured maximum harmonic current.

It was found that if the maximum harmonic impedance from simulations described in Section 5 were used the allocated harmonic limit would increase by a factor of 50% suggesting that the *Customer A* harmonic contribution was not at the limit of their allocation. Theoretically, after substation refurbishment the allocation of harmonic emissions would require recalculation, as the total capacity of the sub-transmission substation is to increase. This would mean a slight reduction in current allocation to *Customers A*, *B*, and *C* but an increase for the 33kV distribution network. It would be very difficult and perhaps unrealistic for utilities to impose such changes in allocations if previous emission agreements with customers had been established.

HV planning levels were also used for voltage fluctuation assessments at both transmission and sub-transmission. AS/NZS 61000.3.7 contains indicative 99th percentile values of planning levels for short term P_{st} and long term P_{lt} flicker in HV systems. Table 2 shows a comparison of values of $P_{st99\%}$ and $P_{lt99\%}$ obtained from the *Brand A* instrument on the 132kV busbar and indicative planning levels from AS/NZS 61000.3.7. It was noted that flicker indices levels at the busbar of the 33kV distribution network were also within the less generous HV planning levels.

Table 2: Assessment of sub-transmission substation 132kV busbar flicker levels

Quantity	Maximum of all phases from *Brand A* instrument	HV planning levels from AS/NZS 61000.3.7	Proportion of planning level
$P_{st99\%}$	0.38	0.8	48%
$P_{lt99\%}$	0.54	0.6	90%

Proposed changes in transformer impedances after refurbishment suggested that there will be little change to the system impedance seen by *Customer A* at the sub-transmission substation. Thus flicker level contributions from *Customer A* loads should remain almost the same before and after refurbishment. Similarly the substations fed at 132kV should also see no change in flicker levels after refurbishment. The reduction in system impedance seen by loads connected via the three 33kV distribution network should actually improve flicker levels for downstream customers. However the magnitude of improvement will probably not be significant, as most of the system impedance seen by the loads exists downstream from the 33kV busbar.

A study of the increasing harmonic currents due to changes in short circuit ratio (SCR) was also completed. If harmonic sources are primarily of the capacitor filtered rectifier type (as is common in ac variable speed drives and electronic switch mode power supplies) then it is possible that harmonic currents may increase with a decrease in source impedance. As the impedance of the transformers supplying the 33kV distribution network were to reduce after substation refurbishment, loads downstream may see a change in source impedance and thus SCR. Using the theory outlined by Gosbell et al.[10] an estimate of the extent of increases in harmonic currents due to changes in SCR was obtained. However, as most of the non linear loads in the 33kV network were connected further down stream from the sub-transmission substation the change in impedance at their point of connection may not be significant. The nearest downstream point of common coupling (PCC)[11] of significant non linear loads were to experience a 3% increase in the SCR after refurbishment of the sub-transmission substation giving a rise of approximately 1% in 5th harmonic current from the non linear loads according to Gosbell et al.[10]. Thus no significant increases in harmonic currents due to increasing SCR are expected after refurbishment of the substation.

5. EFFECTIVE REPORTING OF POWER QUALITY INDICES

Power quality monitoring campaigns usually lead to large amounts of data needing to be analysed and reported in an effective way such that network planners and regulators can easily obtain the required summary indicators and other relevant information[12]. While reporting will vary with the user, the key concepts addressed for this power quality study included

i) Ensuring that correlation between phases was sufficient to allow a single phase to be reported as indicative of all three,
ii) Comparing disturbance levels with known power system events (e.g. capacitor switching), and
iii) Benchmarking measurements against the relevant standard.

Ensuring correlation between phases is best realised through illustrative methods such as scatter graphs or a simple trend plot as illustrated in Fig 8. As seen in Fig 8 the voltage Total Harmonic Distortion (THD) on each phase of the 33kV distribution network is rising and falling in unison even though the magnitude of each is slightly different. This suggests good correlation between phases and a minimalist approach for reporting might be to only give and account of parameters such as maximum, 95th percentile etc. for a single phase. Alternatively the maximum value of all three phases may also be used.

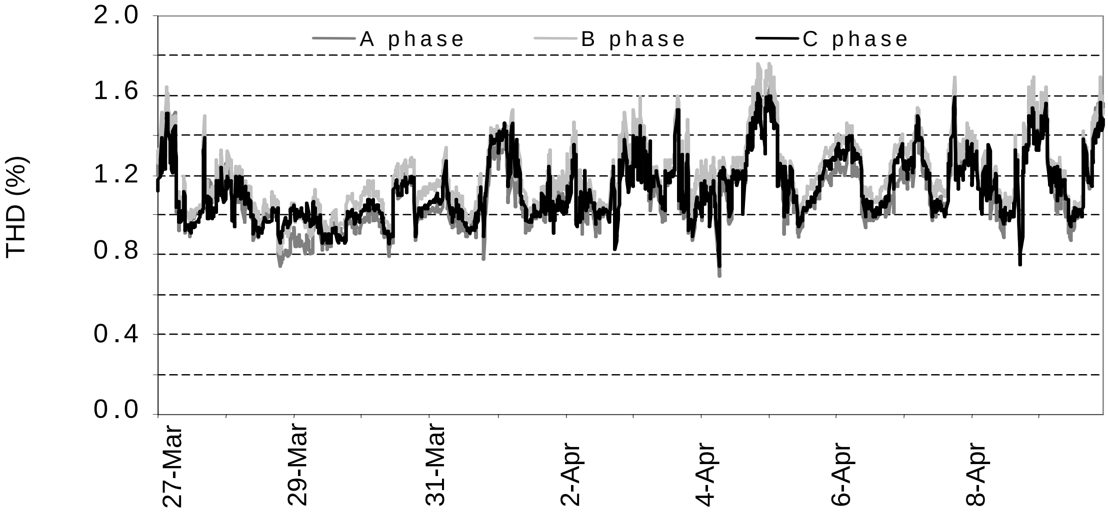


Fig 8: 33kV distribution network total harmonic voltage distortion levels from *Brand A* instrument

If required, the harmonic voltages on the 132kV busbar can be interpolated from the 33kV distribution network results by combining the 33kV harmonic voltage, currents and impedance using the second summation law given in AS/NZS61000.3.6. It is expected that harmonic voltages on the 33kV busbar would be higher than that of the 132kV busbar, thus there is no need to complete such a calculation in this instance as the levels of distortion do not approach the limit of the planning levels.

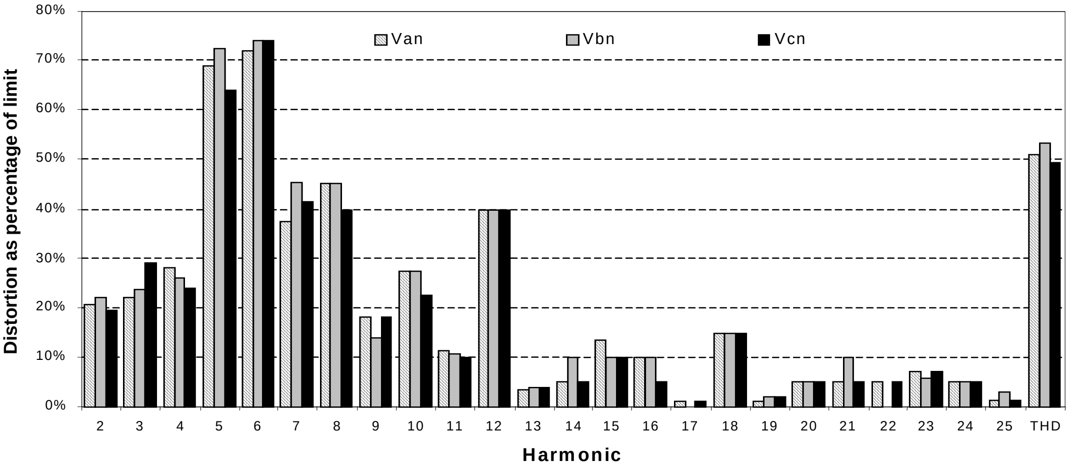


Fig 9: 33kV distribution network harmonic distortion expressed as percentage of HV planning levels

Benchmarking of results is achieved by reporting harmonic voltage or flicker levels as a percentage of recommended planning levels. If emission levels from all customers are at their limits and voltage disturbance levels are well below the planning levels, there may be scope for allowing an increase of customer emissions if requested. Fig 9 illustrates the harmonic voltage levels expressed as a percentage of HV planning levels for each phase of the 33kV distribution network.

It is noticeable in Fig 9 that the 6th harmonic voltage is at an unexpectedly large percentage of recommended planning level. The values illustrated in Fig 9 were obtained from line-to-neutral measurements using the *Brand A* instrument. The high value of 6th harmonic could be attributed to the presence of zero sequence created by measuring the system line-to-neutral. This was confirmed by low line-to-line measurements using the *Brand C* instrument. This is consistent with the system being reasonably balanced and the 6th harmonic appearing as a zero sequence triplen harmonic and thus cancelling in the line-to-line voltages. It is proposed that line-to-neutral measurements may not provide an adequate representation of three wire systems for harmonic assessment.

6. CONCLUSION

A harmonics and flicker study has been completed in relation to refurbishment of a sub-transmission substation. The study included a power quality monitoring campaign to benchmark present levels of background disturbances and customer emissions. Predictions of changes in disturbance levels due to refurbishment were completed using simulations incorporating some of the survey results. Some important issues to be considered when completing a study that predicts future levels of harmonic voltages and flicker levels include:

i) Ensuring monitoring is appropriate (including instruments providing the correct values for indices as per the required standards, and suitable instrument transformers)
ii) Selection of appropriate planning levels,
iii) Inclusion of the effects of harmonic resonances due to PFC capacitors,
iv) Inclusion of load and system damping in harmonic models,
v) Possible increases in harmonics due to variable short circuit ratio, and
vi) Effective reporting of power quality data for benchmarking.

Results from the power quality study have allowed a projection of the possible effects that substation refurbishment might have on future disturbance levels.

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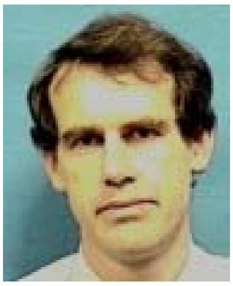
8. AUTHORS' BIOGRAPHIES

Duane Robinson graduated from the University of Wollongong with a BE (Hons I) degree in 1998 after completing a seven year cadetship with BHP Port Kembla Steelworks. Mr Robinson is currently completing a Lectureship at the University of Wollongong sponsored by the Integral Energy Power Quality Centre. He is a member of the Institute of Engineers, Australia.

Vic Gosbell obtained his BE degree in 1966 and his PhD in 1971 from the University of Sydney. He has held academic positions at the University of Sydney and the University of Wollongong, where he is foundation Professor of Power Engineering and Technical Director of the Integral Energy Power Quality Centre. He is currently working on harmonic management and power quality monitoring methodologies. He is a Fellow of the Institution of Engineers, Australia.

Sarath Perera graduated from the University of Moratuwa, Sri Lanka with a BSc (Eng) degree (1974) specialising in Electrical Power. He obtained his MEngSc degree (1978) from the University of New South Wales and the PhD degree (1988) from the University of Wollongong. He is now a Senior Lecturer at the University of Wollongong. His research interests are in the area of Power Quality.



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9. FIGURE CAPTIONS

Fig 1: Sub-transmission substation single line diagram and PQ monitor locations

Fig 2: Scatter graph of short term flicker (P_{st}) measured by *Brand A* and *Brand B* instruments (Correlation coefficient = 0.54)

Fig 3: Scatter graph of flicker readings during laboratory tests

Fig 4: Scatter graph of 5th harmonic voltage measured by *Brand A* and *Brand C* instruments (Correlation coefficient = 0.93)

Fig 5: Harmonic impedance seen at 33kV bus for six capacitor combinations and no load damping

Fig 6: Harmonic impedance seen at 33kV bus for sample capacitor combinations and 30% load damping

Fig 7: *Customer A* allocated and measured maximum harmonic current

Fig 8: 33kV distribution network total harmonic voltage distortion levels from *Brand A* instrument

Fig 9: 33kV distribution network harmonic distortion expressed as percentage of HV planning levels

10. TABLE HEADINGS

Table 1: Waveform generator voltage fluctuations test results

Table 2: Assessment of sub-transmission substation 132kV busbar flicker levels