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The Australian long term power quality survey project update

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The Australian Long Term Power Quality Survey Project Update

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Abstract—The Australian Long Term National Power Quality Survey (LTNPQS) is a large multi-utility power quality survey which has now been in operation for 8 years. This paper details the latest innovative developments in the reporting and analysis procedures developed for the LTNPQS. The paper also highlights the key power quality issues affecting Australian electricity networks at the present time. These include high voltage levels at LV sites and difficulties in measurement of voltage unbalance. The longevity of the survey has allowed better understanding of disturbance trend levels. Interesting results include an apparent reduction in harmonic levels in the past couple of years and no definite trend in sag levels even with 7 years worth of data.

Some of the challenges involved in conducting a survey of this type are explored and indications as to solutions presented. With the implementation of smart grid concepts it is likely that the number of sites with instrumentation capable of supplying data to the survey will increase exponentially. This presents a new set of challenges and the survey must adapt to these. Future directions taken in response include the implementation of web-based reporting systems which will provide more flexibility for participants.

***Index Terms*-- Harmonics, power quality data analysis, power quality monitoring, unbalance, voltage, voltage sags**

I. Introduction

The Australian Long Term National Power Quality Survey (LTNPQS) project was instigated by the University of Wollongong and the then Electricity Supply Association of Australian (ESAA) in 2000. Since then annual reports have been published covering the period of July one year to June the next (financial year). The 2008/2009 reports, issued in early 2010 mark the 7th issue of the reports. The LTNPQS project has irrevocably changed the power quality monitoring and reporting paradigm in Australia. At the inception of the LTNPQS project, proactive power quality monitoring and reporting was basically non-existent and quality of supply was considered a low priority for electricity distributors compared with network expansion and reliability improvement. Over time, electricity distributors have come to realise the importance of power quality (PQ) and regulators now have a strong interest in ensuring that distributors meet PQ obligations. As such, the LTNPQS project could be considered well ahead of its time at its introduction.

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The continuing support of the project by Australian electricity distributors as well as the successor to the ESAA, the Energy Networks Association (ENA), has encouraged a large quantity of research to be performed into power quality monitoring, analysis and reporting techniques, firmly positioning Australia at the forefront of these disciplines [1, 2, 3]

The operation of the survey is such that participants choose the sites they wish to monitor and instrument types which are convenient. The data from these sites is then provided to the University of Wollongong which performs analysis and reporting. The PQ disturbances accepted for and reported in the survey are steady state voltage, voltage unbalance, voltage total harmonic distortion (THD) and voltage sags. These voltage disturbances are considered the key indicators of power quality for Australia at the present time. Current data is not considered as it is more relevant to reactive power quality monitoring (problem solving).

Data is accepted from low voltage (LV) (230 V) sites and medium voltage (MV) sites. For the purposes of the LTNPQS MV is considered to be any voltage level above 230 V nominal and up to and including 132 kV. To simplify reporting, LV and MV sites are aggregated into 2 separate classes.

Reports are produced for each site, across all sites supplied by the individual participant and across all sites from all participants. The University is in a unique position in that it is considered to be an objective third party and can provide unbiased nation-wide benchmarking.

A. The LTNPQS Today

The 2008/2009 LTNPQS reports contained data from 540 distinct sites. Of these sites, 292 were LV sites and the remaining 248 were MV sites. Data was provided by 10 of a possible 14 electricity distributors across all Australian states. As such, in terms of site numbers, geographic extent and longevity, the LTNPQS has grown to be one of the largest PQ monitoring projects in the world.

II. LTNPQS Reporting Methods

A number of innovative and unique reporting techniques have been developed for the LTNPQS. At the commencement of the survey reporting techniques did not exist or were poorly defined for a number of power quality disturbances. Further, reporting methods for aggregating indices from large numbers of sites to provide high level indicators of performance useful at management level and for benchmarking had not been developed. Consequently, many of the reporting techniques utilised in early survey reports were developed from scratch. The longevity of the survey has provided scope for strong development and verification of these reporting techniques over time.

Reporting techniques have needed to evolve due to many factors including unexpected characteristics in data, changes in industry focus and development in PQ standards. Many of these techniques have been discussed in [4] and [5]. This section of the paper details the most recent innovations in reporting.

A. LTNPQS Report Structure

Any large PQ survey involving large site numbers and various PQ disturbances will produce large amounts of data. As stated above, the current survey involves 10 participant utilities submitting data for over 500 sites. This equated to 10 GB of raw data or nearly 5 million rows (1 row includes all reported continuous parameters) of variations (generally recorded at 10 or 15 minute intervals) and approximately 1.7 million rows of sag data. One of the greatest difficulties in PQ reporting is how to reduce this data to a form which is manageable without losing important detail. The LTNPQS deals with this issue through the use of a three-tiered reporting structure [6]. This reporting structure has been under continuous development since the beginning of the survey and continues to be so. The current structure of the survey is designed to be accessible to all levels of a utility business. High level data, which has the least detail, is reported at the beginning of each report. This section of the report is designed to be viewed at management level and contains a few high level indicators of overall performance. Subsequent reporting tiers include more and more detail about the performance of the network and finally each site.

B. Reporting Across Many Sites

One of the most innovative features of the LTNPQS has been methods developed to produce a single overall PQ performance indicator for each disturbance for all sites supplied by each participant. The first reports adopted an RMS averaging method to determine an indicative number for each disturbance across all sites. This method of averaging gives unnecessary weight to sites which are performing poorly. Over time it became apparent that, when this method was used, a few poor performing sites were influencing results to an unacceptable level. To address this problem, RMS averaging methods have been replaced with a median average when values across all sites are calculated.

C. Executive Summary

One of the great challenges for participants in the survey is 'selling' the importance of proactive PQ monitoring to higher management. Although management of PQ is now seen as an essential function of the modern electricity distributor, it can be a highly technical, diverse discipline and complex to understand. As such, it can be difficult for PQ managers to discuss PQ performance and make businesses cases for funding for PQ initiatives with higher management which may not be strongly technical. This is an issue that considerable effort has been devoted to in the LTNPQS project. Reporting methods have been developed to clearly show which PQ disturbances are of most importance to each participant and to illustrate where attention should be directed so that the best improvement can be made. Examples of these methods include colour coding and written commentary.

The section of the report designed for use at management level is known as the executive summary. This section of the report contains 2 key PQ performance indicators for all sites supplied by the participant. These indicators are the percentage of sites exceeding limits for each disturbance and the trend of disturbances across the years for which the individual participant has been involved in the survey. Some text is also provided which indicates the number of sites supplied by the participant along with areas of performance that require investigation for improvement.

Fig 1 shows an example of the table provided showing the percent of sites exceeding limits table. This table is formatted such that any disturbance for which there are sites exceeding the limit is shaded red. This gives the reader an immediate indication of disturbances which are of concern. In the table presented it can be seen that V High at LV sites, with 11% of sites exceeding the limit, would be the disturbance of most concern. Sags at MV sites and the primary voltage index (known as Absolute Voltage Deviation (AVD)) at LV sites are the next worst performing disturbances. A small number of sites exceed harmonic limits at both LV and MV sites. There are no sites which exceed limits for any other disturbance.

Percent of Sites Exceeding Limits			
Indices		Low Voltage Sites	Medium Voltage Sites
Voltage	AVD	5%	
	V High (V99%)	11%	
	V Low (V1%)	0%	
	V Spread	0%	
Unbalance	VUF	0%	0%
Harmonics	THD	3%	2%
Sags	SI	0%	6%

Fig. 1. Example of Percent of Site Exceeding Limits Table

Fig 2 shows an example of the trend graphs presented in the executive summary. These graphs allow the participant to easily track how PQ levels are evolving over time and provide an early indication of those disturbances which are approaching limits. For example, in the graphs shown, it can be seen that there is a strong upward trend in voltage indices and that levels are now above the limit. Also of note is the random behaviour of sag levels.

One graph is provided for each disturbance at each voltage level (LV or MV).

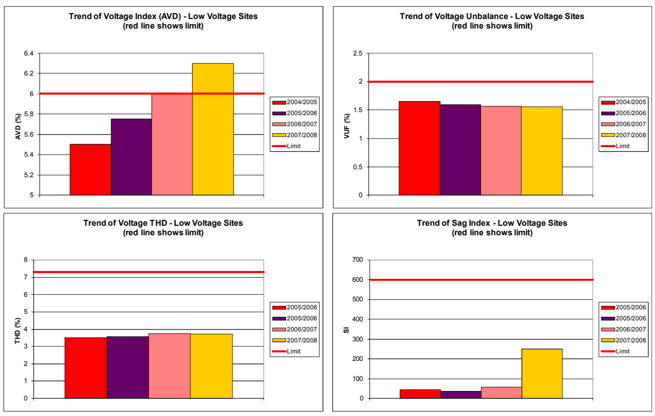

Fig. 2. Example of Disturbance Trend Graphs (LV Example Shown)

D. Reporting Harmonics

Harmonics are a multi-parameter disturbance, as there are many harmonic orders each with its own limit. To simplify reporting, THD has been selected as the key harmonic quantity for reporting. This is justified by the fact that THD will give an overall indication of harmonic levels at a site. However, THD does not indicate the individual harmonics at each site. This data may be of interest particularly if the site has high harmonic levels or is displaying abnormal harmonic behaviour. In order to give an indication of the harmonic components included in the THD, a second index known as the Harmonic Inclusiveness Index has been developed for harmonics reporting. This index has been developed based on the principle that the 5th harmonic has been shown, by measurement, to be the dominant harmonic order at the vast majority of sites. The index is the ratio of 5th harmonic to THD. If the ratio is small it indicates that harmonic behaviour at the site is atypical.

III. Important Findings So Far

A. LV Steady State Voltage

Steady state voltage levels continue to be the disturbance of most concern in the LTNPQS. Since the inception of the survey it has consistently been found that some 25 % - 30 % of LV sites record 95th percentile steady state voltage levels which are above the upper low voltage limit (230 V + 10%). This is of possible serious concern as the lifespan of appliance connected to a site with high voltage level may be considerably reduced due to dielectric and thermal stressing of components. Further analysis of voltage levels indicates that in many cases there is a serious light load problem. A first observation of a typical histogram such as the example shown in Fig 3 suggests that a change could be made to the transformer tap setting to bring the voltage at the site back within limits. However, there are considerable reservations about doing this in the industry due to the fact that almost all the sites in the survey are at the sending end of the low voltage feeder. As such, there are concerns that adjustment of tap position will lead to undervoltage problems at the remote end of the feeder due to voltage drop. This is of particular concern in Australia where LV feeder runs are considerably longer than may be the case in Europe (200 – 300 m of overhead line). Without significant amounts of data from the ends of LV runs, to ensure changing of tap position will not lead to heavy load problems, this problem is somewhat intractable. Endeavours are being made to collect data from sites at the remote ends of LV feeders, but it is not convenient to have instruments connected there and, at present, site numbers are very low.

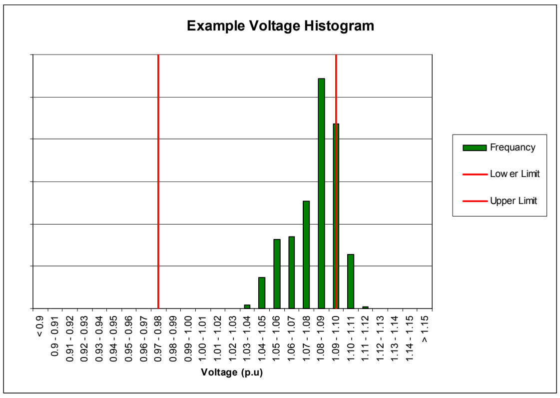

Fig 3. Example Voltage Histogram

B. Voltage Unbalance

While voltage unbalance magnitude has not generally been a problem at most sites, problems with the calculation of unbalance, leading to very high levels of unbalance, have been identified with some monitoring instruments. For consistency, in the LTNPQS, unbalance is calculated from three-phase voltages using the IEC formula shown in (1) and (2).

$$\beta = \frac{V_{ab}^4 + V_{bc}^4 + V_{ca}^4}{(V_{ab}^2 + V_{bc}^2 + V_{ca}^2)^2} \tag{1}$$

$$Unbalance = \sqrt{\frac{1 - \sqrt{3 - 6\beta}}{1 + \sqrt{3 - 6\beta}}} \tag{2}$$

Use of this method eliminates any vagaries in calculation of unbalance resulting from the monitoring hardware. The method relies on all instruments measuring voltages to a high accuracy. However, it has become apparent over time that high accuracy measurement of voltage cannot be guaranteed. A specific case exists where certain smart revenue meters supplying voltage data have been found to report incorrect voltages. This occurs when the instrument is connected using the two wattmeter method for measurement of energy. This method is often used at MV where often only 2 voltage phases are available on metering transducers. Under this circumstance, the instrument calculates the values of the remaining phase voltage. It has been shown that some instruments get this calculation incorrect and as such report an erroneous voltage. When the three voltages are used in (1) and (2) it leads to unbalance levels which appear to be very high but are not reflective of actual operating conditions.

C. Harmonic Trends

In [4] a distinct upward trend of harmonic (THD) levels was detailed. This was in line with the trend of harmonic levels reported in Europe [7]. The latest data indicates that this upward trend in harmonics has either stabilised or reversed. Fig 4 shows the trend of 95th percentile harmonic levels for LV sites while Fig 5 shows the same information for MV sites. These graphs clearly show that the upward trend of THD has been arrested and that 95th percentile harmonic levels are now trending downward. Whether this is a long term trend or an aberration will only become clear as the survey continues. Similar uncertainties in the trend for harmonics have been observed for the average values across all sites.

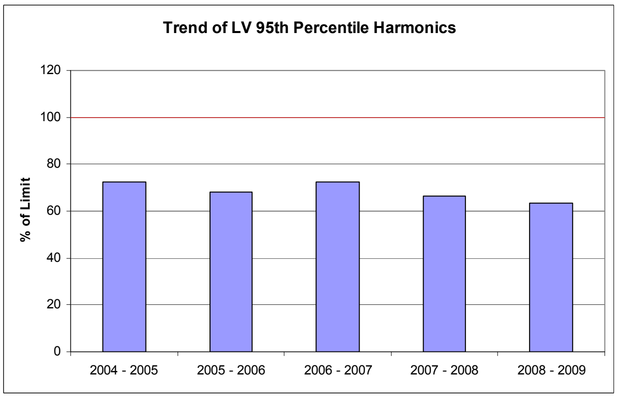

Fig. 4. Trend of LV 95th Percentile Harmonic Levels

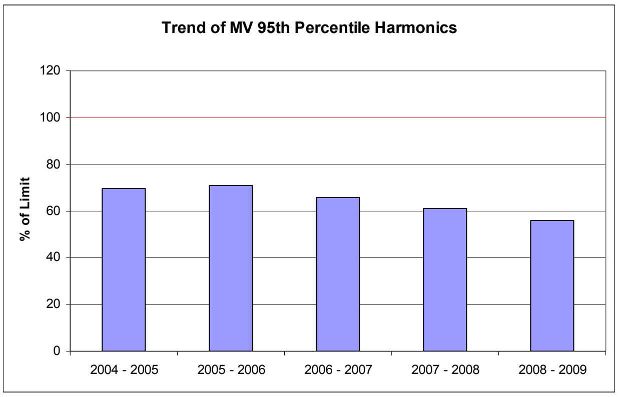

Fig. 5. Trend of MV 95th Percentile Harmonic Levels

D. *Sag Trends*

Another trend of significant interest to the industry is the trend of sags. Studies such as [8] have shown that many years of data is required before any meaningful sag trend may be available. This is due to the fact that sag levels are highly variable and strongly dependant on climatic conditions. The University of Wollongong has developed a special index for reporting sags which is detailed in [9] and this index is used for reporting sag levels here. There is now 7 years worth of sag levels available, calculated using this index, and there still does not appear to be any strong trend in sag levels. Figs 6 and 7 show 95th percentile sag trends for LV and MV sites. In these graphs, sag levels are presented as a percentage of the 2002/2003 value, which is the first year for which data is available.

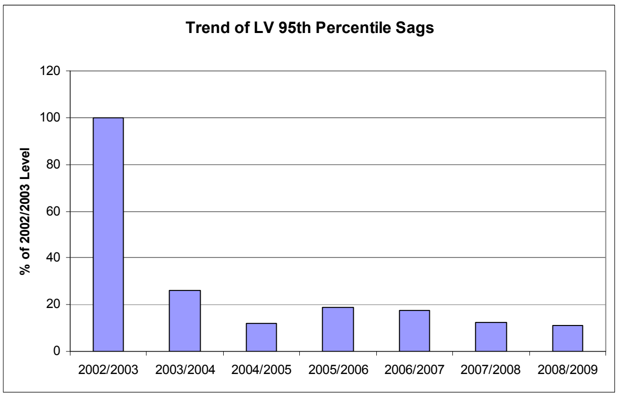

Fig. 6. Trend of LV 95th Percentile Sag Levels

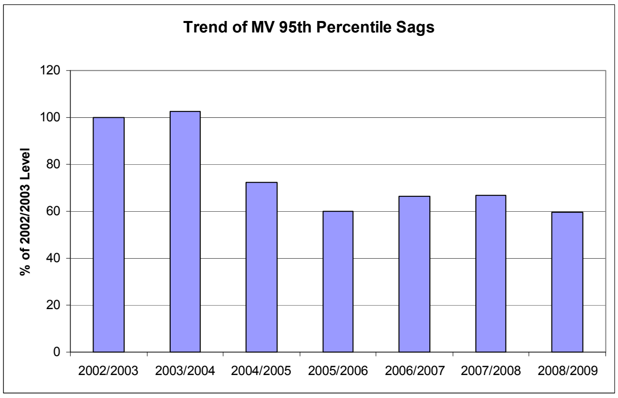

Fig. 7. Trend of MV 95th Percentile Sag Levels

Figs 6 and 7 clearly show the variation in sag levels throughout the duration of the LTNPQS. It can be seen that LV sag levels were particularly high at LV in 2002/2003. This was due to severe windstorms experienced across the Australian eastern seaboard. These windstorms also created a spike in reliability indices illustrating the strong link between sags and reliability due to weather events. Sag levels have decreased significantly since. At MV, the first 2 years of the survey showed high sag levels, which have not been repeated since. Overall, there is still no discernable trend for sags.

IV. Future Directions

A. *Strong Growth in Site Numbers*

Many Australian electricity distributors are now rolling out extensive proactive power quality monitoring schemes. For many this will involve placement of monitoring devices at all zone substations along with other monitoring sites throughout the network. In some cases it is proposed that monitoring devices be placed at every distribution (MV/LV) substation. Combined with smart grid initiatives which will likely see smart metering installed at most customers there is huge potential for growth in the site numbers with PQ monitoring available.

This huge growth in site numbers presents opportunities and challenges. Addition of more sites to the survey has obvious advantages such as enhanced statistical confidence in the results. Large growth in site numbers will also allow improved factor analysis. Current reports contain some analysis based on site characteristics such as the load supplied by the site and the construction of the network (e.g. overhead, underground) supplying the site. However, to date, factor analysis has not been effective due to the fact that the majority of sites that have PQ monitoring available tend to be from a select subset of site characteristics. In general, the sites in the survey tend to be at zone substations for MV and at large industrial or commercial customers at LV.

While growth in site numbers has obvious advantages, challenges will be presented in the areas of data storage, analysis and reporting. With potentially hundreds or thousands of sites being added to the survey the computer software and hardware will require optimisation so that analysis can be performed within an appropriate timeframe. Reporting techniques must also be optimised so that the necessary data can be easily accessed.

B. *Web-Based Reporting*

From the 2009/2010 report, it is planned that a significant component of the LTNPQS reports will be available online. This online reporting system will provide participants with much greater flexibility to generate individualised reports. This will include options and reporting structure that are not available in the traditional printed reports. If data is provided on an ongoing basis, a web-based system will allow reporting of the most up to date data without the need to wait till the end of the survey period for the traditional report. There is also potential to design online systems which could include algorithms which would report site behaviour according to evaluation methods outlined in various PQ standards. This would allow the LTNPQS to be used to prove compliance with limits and other regulatory requirements.

Online reporting will also greatly assist with many of the reporting challenges presented in preparing a traditional paper-based report.

C. *Greater Numbers of 'Weak' Sites*

Weak sites are defined as sites which are remote from transformers. One of the ongoing weaknesses of the LTNPQS is the lack of weak sites, particularly weak LV sites. Weak sites are important as it is at these sites where the power quality disturbance levels are at their worst. Most LV domestic customers are connected at sites which would be considered to be weak. The current survey is heavily biased toward data from strong sites. As such, current power quality levels in the reports may be considered as a best case for many disturbances and disturbance levels are expected to be somewhat higher in general.

Without data from a statistically valid number of weak sites, the survey does not give a complete picture of power quality levels throughout Australian electricity distribution networks. As LTNPQS data is now being used by participants to manage power quality and also for submissions to regulators and standards bodies, the lack of data from weak sites is a serious concern.

Another issue stemming from the lack of weak sites is the control of steady state voltage at LV sites. Data from strong sites has shown that there is a systemic high voltage problem at Australian strong LV sites. Data shows that many MV/LV distribution transformers may need adjustment to tap positions. However, without having data available showing voltage levels at the end of the LV feeder run, tap positions cannot be changed with certainty as correcting the high voltage at the sending end may result in a undervoltage problem at the end of the LV feeder run.

V. Important Considerations for Undertaking Large PQ Monitoring Projects

A. *What to Report*

There are many different disturbance types included under the PQ umbrella. These include steady state voltage, unbalance, waveform distortion, rapid voltage variations and flicker, sags, swells and transients. With so many potential disturbances to be reported it is not feasible to include all of them in a long term proactive survey and report. One of the key decisions that must be made when a survey project is launched is what should be reported. In some cases this will be determined by practical restrictions such as what participants are currently measuring and what their instrument have the potential to measure. Further decisions must take into account which disturbances are the most prevalent and have the most impact on consumers. If the survey is designed to be proactive then there is little value in measuring any current parameters as these are more useful for problem solving.

The present LTNPQS includes analysis and reporting of steady state voltage variation, voltage unbalance, voltage THD and voltage sags. The three continuous disturbances are considered to be the key indicators of voltage behaviour while sags are easy to measure and may have the largest impact on customers of all the PQ disturbances. Rapid voltage variations and flicker are not included in the survey as levels of these tend to be small and problems tend only to be observed in specific areas such as near large variable loads (e.g. arc furnaces). For harmonics, only THD, along with a check against 5^{th} harmonic as detailed in Section II above, is reported. In many cases, little benefit is obtained from reporting further harmonic orders. Voltage swell are ignored as these are rare and reporting methods and limits are poorly defined. Transients, while less rare are ignored for many of the same reasons as swells. Transients also present significant measurement issues including the fact that many instruments which currently supply data to the LTNPQS do not have transient measurement functionality.

B. *Data Formats and Error Checking*

In an ideal world, all PQ data from all instruments would be in a common format. However, this would require adoption of a standard format by all manufacturers. In practice such a format does not exist, let alone be produced by all instruments. As a consequence, if a power quality survey is to be conducted using the same methods as that of the LTNPQS (i.e. participants selecting sites and supplying data) it is highly likely that a range of data formats and integrity problems will be encountered. It is unlikely that all participants will operate the same monitoring hardware and, as such, the project must be able to accommodate a range of data formats. Considerable effort has been undertaken during the LTNPQS project to develop systems of transforming data from either text or proprietary formats to a common format suitable for storage in a database. In the early years of the survey a preferred format for data was developed and distributed to participants. However, as time went on, it became apparent that participants were having considerable difficulty in converting data from a range of formats into the preferred format. In many cases this was due to a lack of IT support or skills. In some cases, attempted conversion to the preferred format led to unexpected errors or problems with data. Experience has shown that it is often less time consuming and that greater data integrity can be ensured if data conversion is performed by the survey host as opposed to the individual participant. A wide range of data formats are now accepted for the LTNPQS ranging from simple text through to proprietary formats. A number of data transforms have been written to accommodate this data and new transforms must be written to facilitate data in any new format.

Once the data has been converted to an acceptable format, checks must be made to ensure data integrity. Problems with data can include duplicate records, obviously incorrect values and changes to instrument configuration mid survey. The purpose of the LTNPQS is proactive power quality monitoring. This means that the survey is most interested in normal network operating conditions. The LTNPQS relies on a number of filters and data integrity assurance algorithms to ensure that only data which has been verified is reported.

C. *Database and Reporting Software Development*

The LTNPQS has now grown to include many hundreds of sites. With this amount of data, manual analysis and reporting become untenable. Instead, automated processes must be designed for analysis and reporting. The first step in this process is the selection of an appropriate database software platform and hardware. The software must have the capacity and querying facilities to handle many millions of rows of data. Some of the queries executed in the LTNPQS take up to hours to execute even on modern hardware. Consequently, the hardware on which the database is installed must have the speed to query the data quickly.

Reporting software must also be developed as manual report generation is extremely time consuming and may not even be viable if site numbers are high. Even after 7 years, reporting software is still being developed for the LTNPQS indicating how long it can take to develop software particularly if the project is being conducted on a low budget. Any reporting software which is developed must be highly flexible in order to allow easy changes to report formats and to respond to outside influences such as changes to standards.

D. Ensuring Confidence in Reported Values

As stated above, the purpose of the LTNPQS is to provide an indication of PQ levels during normal operating conditions and over a relatively long time period. The LTNPQS is not specifically designed to locate power quality problems nor as a method of compliance with limits (although it can be used for this). One of the key benefits of the LTNPQS is the ability to benchmark the performance of all participants against a range of criteria. This benchmarking is achieved through the calculation of high level indices that take into account performance across a large number of sites. In order to ensure confidence in these high level indices it is necessary to be sure that the data provided does represent normal operating conditions and has been collected over a significant proportion of the survey period (in the case of the LTNPQS , the survey period is one year). The proportion of the survey period for which a site has data available has been termed 'coverage'. For the LTNPQS, a system is applied which requires a site to have coverage of greater than 25% of the survey period before results from that site are included in any high level indices. There are several reason why data with low coverage should not be included in high level indices. These include the survey period being too short to take into account normal PQ cycles such as weekly cycles or seasonal variation. Further, if the coverage is low, it is possible that the data collected was obtained during a period of atypical behaviour.

E. Participant Liaison

Success of a large multi-participant survey such as the LTNPQS requires strong links to be forged between participants and the survey operators. This is essential due to the fact that there will always be some problems with supplied data which must be addressed before reporting can proceed. One of the key challenges with participant liaison is locating the correct contact person in what can be a very large organisation. Experience has proved that communication through superiors of those doing the actual work is often ineffective. As such, if successful liaisons are to be achieved, direct communication with the individuals collecting and providing the data for each participant organisation is essential.

F. Data Transfer Systems

Where participants supply large amounts of data it is essential that robust data transfer and receipt systems are developed. For the LTNPQS data is received in many ways. These include by emails, on physical disc and by FTP server. FTP server has been found to be one of the best methods as this can be automated by participants and receipts issued once the data has been received correctly. Experience has shown that it is of immense benefit if data is supplied on a regular basis as opposed to in one large submission at the end of the survey period. Ongoing regular supply of data ensures that data is available and pre-checking of data integrity can be performed. There have been instances where participant data storage systems have failed resulting in the loss of data for the entire survey period. If data had been provided more regularly, failure of these systems may have been mitigated.

VI. CONCLUSIONS

After 7 years the Australian LTNPQS is as relevant as ever. The success and longevity of the survey has allowed strong ongoing development of innovative power quality reporting and analysis techniques in Australia. The LTNPQS is one of the main reasons that Australia stands at the forefront of power quality research and assessment.

The survey has permitted an excellent understanding of the key power quality issues for Australian distribution networks at the present time. These issues include high voltage levels at LV sites and difficulties with reporting of unbalance. Ongoing implementation of the survey has also brought to light some of the weaknesses of the survey. Chief amongst these is the importance of monitoring data at all points of the network particularly remote ends of feeders. This is highlighted by the difficulties in adjusting LV voltage levels without understanding the impact of the change at the remote end of the LV feeder.

Over time a great deal of experience has been gained with regard to the difficulties in conducting a survey like the LTNPQS. Some solutions to these have been presented here, while some are ongoing.

With the implementation of smart grid concepts it is likely that the number of sites with instrumentation capable of supplying data to the survey will increase exponentially. This presents a new set of challenges and the survey must adapt to these. Future directions taken in response include the implementation of web-based reporting systems which will provide more flexibility for participants.

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VIII. BIOGRAPHIES

Sean Elphick graduated from the University of Wollongong with a BE (Elec)(Hons) degree in 2002. He commenced employment with the Integral Energy Power Quality Centre in 2003. Initially employed to work on a Strategic Partnerships with Industry - Research and Training Scheme (SPIRT) project dealing with power quality monitoring and reporting techniques. His current activities include delivery of the Long Term National Power Quality Survey, a first of its type in Australia as well as various other power quality related research and consulting projects.

Vic Smith graduated from the NSW Institute of Technology in 1979. In 1981, he studied for his MSc degree at the University of Manchester Institute of Science and Technology (UMIST), UK. In 1995, Dr Smith received his PhD from Sydney University. Dr Smith joined the Integral Energy Power Quality Centre at the University of Wollongong in 1997. He has an interest in measurement and reporting of power quality disturbances, network transient phenomena and their control, and power quality aspects of distributed generation.

Vic Gosbell (M' 1975) obtained his BSc, BE and PhD degrees from the University of Sydney. He has held academic positions at the University of Sydney and the University of Wollongong where he became the foundation Professor of Power Engineering. He is now an Honorary Professorial Fellow and Technical Advisor to the Integral Energy Power Quality and Reliability Centre. He is currently working on harmonic management, power quality monitoring and standards. He is a member of Australian standards and CIGRE sub-committees and is a Fellow of the Institution of Engineers, Australia.

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