Power Quality Monitoring and Disturbance Investigations
Power Quality Monitors and Instrumentation

Technical Note 20
October 2021
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1. Introduction

This Technical Note describes the instrumentation required to accurately measure and assess power quality phenomena. It complements Technical Note 19 Power Quality Monitoring and Disturbance Investigations: Characterisation of Power Quality Disturbances and Investigation Methodology.

In this Technical Note, power quality instrument requirements and standards are initially described. Considerations when selecting a power quality monitor are then discussed and an overview of the various types of power quality monitoring instruments is given.

The Technical Note concludes by presenting the different types of voltage and current transducers and their applications.

2. Instrument Requirements and Considerations

An instrument for measuring power quality disturbances is called a power quality monitor (or analyser). These instruments must be able to identify and record the characteristics of many types of disturbances changing on a timescale of microseconds (transients) to hours (steady state voltage variations). Fast transients require high sample rate analogue-to-digital converters (e.g. 1-4 MHz) giving a large data throughput. Operating over a long timescale this gives an enormous amount of data to be handled. As such, these instruments must either retain very little of the data, have large storage facilities (e.g. hard disk, compact flash card, SD card) or communicate the data to a storage facility by means of a modem or integrated communications system such as a local area network and/or fibre connection.

Good quality power quality monitors have to meet stringent standards for instrumentation and processing methods. Since transients require the measurement of voltages larger than the peak supply voltage while flicker requires the resolution of voltages of 0.3% or less, their input must have a wide dynamic range with accurate analogue-to-digital converters (generally 16-bit or better).

2.1 AS/NZS 61000.4.30

AS/NZS 61000.4.30 [3] which is a clone of the IEC version of the standard is the internationally accepted standard for specifying the methodology for how power quality phenomena should be measured and interpreted. It is important to note that the standard is a performance specification, not a design specification. It describes instrument performance requirements, in particular, instrumentation accuracy (by defining instrument accuracy classes), time intervals for measurement and assessment (by defining time aggregation periods), and the concept of “flagging” to warn when event type disturbances might influence the assessment of variation type disturbances. The standard also provides informative guidelines on minimum assessment periods and recommended reporting intervals. The standard does not define specific instrument design criteria (e.g. sampling rates). These aspects are at the discretion of the instrument manufacturer and there are many designs which may meet the requirements of the standard.
Power quality disturbances covered directly by AS/NZS 61000.4.30 are:

- Voltage and current variation
- Voltage unbalance
- Frequency
- Voltage sags and swells

The standard calls AS/NZS 61000.4.7 [4] for measurement protocols and accuracies for harmonics and interharmonics and AS/NZS 61000.4.15 [5] for flicker measurement protocols and accuracies. The only major power quality disturbance not covered by AS/NZS 61000.4.30 is transient overvoltages and there is currently no standardised method for measuring and evaluating transient overvoltages.

AS/NZS 61000.4.30 specifies three instrument accuracy classes – A, S and B (in order of specified accuracy). A summary of the instrument classes is as follows:

- **Class A** instruments are the most accurate (accuracy to 0.1% of nominal voltage) and must comply with strict methods of data sampling and time aggregation. They are used where precise measurements are necessary e.g. contractual applications, verifying compliance with standards.
- **Class S** instruments (accuracy to 0.5% of nominal voltage) have lower processing requirements than Class A instruments and are used for statistical applications e.g. surveys or power quality assessment.
- **Class B** instruments (accuracy to 1% of nominal voltage) are largely manufacturer defined and covers legacy instrument designs.

Most modern dedicated power quality monitors are Class A and can be effectively used for site surveys and the identification of plant power quality problems.

AS/NZS 61000.4.30 specifies a range of aggregation intervals to be used for the evaluation of power quality levels. These aggregation intervals apply only to Class A and Class S instrumentation. The AS/NZS 61000.4.30 aggregation intervals are shown in Table 2.1.1. These aggregation intervals are in turn derived from a number of shorter intervals. For 50 Hz systems, the basic interval is 10 cycles. From these basic intervals, longer evaluation periods may be calculated by averaging (arithmetic or RMS) and statistical measures can then be used to evaluate power quality levels.

<table>
<thead>
<tr>
<th>ABBREVIATION</th>
<th>NAME</th>
<th>DURATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>vs</td>
<td>Very short</td>
<td>150/180 cycles (~3 seconds for a 50/60 Hz system)</td>
</tr>
<tr>
<td>s</td>
<td>Short</td>
<td>10 minutes</td>
</tr>
<tr>
<td>l</td>
<td>Long</td>
<td>2 hours</td>
</tr>
</tbody>
</table>

**2.1.1 AS/NZS 61000.4.30 Flagging Concept**

The flagging concept described in AS/NZS 61000.4.30 aims to prevent one disturbance type from being reported more than once – for example a sag being counted as both a steady state voltage variation and...
a sag. The flagging concept is only applicable to Class A instrumentation and states that during the survey period, if an event disturbance is detected, the variation type data recorded during the interval in which the event was detected should be flagged. This flag allows quick identification of data that may not be reliable. Flagging as a concept is useful in preventing a single disturbance influencing other disturbances and to separate out events from variation data.

### 2.2 Summary of Instrumentation Requirements

Table 2.2.1 summarises the instrumentation requirements for the different power quality disturbance types. Voltage, harmonics, sags and swells are relatively standard features. Unbalance requires three voltage channels and direct measurement of line-line voltages or measurement of the phase angles of the line-neutral voltages. Measurement of voltage fluctuations requires high accuracy analogue-to-digital converters and complex processing. Transient measurement also requires high performance analogue-to-digital converters.

<table>
<thead>
<tr>
<th>DISTURBANCE</th>
<th>LOGGING/EVENTCAPTURE</th>
<th>SPECIAL REQUIREMENTS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>Log</td>
<td>Voltage</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Unbalance</td>
<td>Log</td>
<td>3 phase</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Harmonics</td>
<td>Log</td>
<td>FFT to 20-40th</td>
<td>Maybe 2 kHz</td>
</tr>
<tr>
<td>Fluctuation</td>
<td>Log</td>
<td>0.1% resolution</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Sag/interruption</td>
<td>Event</td>
<td>Threshold</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Swell</td>
<td>Event</td>
<td>Threshold</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Transient</td>
<td>Event</td>
<td>Threshold</td>
<td>5 kHz-5 MHz</td>
</tr>
</tbody>
</table>

The following considerations are required when choosing a power quality monitor:

i. They are available in a range of costs and performances so it is necessary to understand performance requirements well.

ii. Which monitoring standards does the instrument comply with, if any.

iii. In general it is desirable that they measure 3 phase voltage and preferably current, especially if they are to be used in fault-finding.

iv. The instrument should have sufficient memory capacity to store all required data for the survey period or be able to be interrogated before memory fills. Modern instruments have memory capacities of up to 32 GB using compact flash cards.

v. There should be adequate filtering, surge protection and battery back-up to be able to be unaffected by disturbances on their own supply leads.

vi. It is most important that the instrument can give trends for voltage and harmonics, with unbalance and fluctuations as desirable options. Statistical values, e.g. 95% probability levels, should be available from the instrument or its software, or it should be possible to export the trend data to Microsoft Excel for subsequent processing.
vii. The instrument should be able to recognise and characterise sags, interruptions and swells. There should be adjustable thresholds for each.

viii. It should at least give a count of transients above a known threshold level.

ix. For fault-finding, it is essential that it can store some waveforms with time and date stamps.

x. The instrument should have a ruggedised case if it is to be installed in an uncontrolled environment and be weatherproof if used outdoors i.e. it should have a suitable Ingress Protection (IP) rating.

xi. The reporting software should be easy to use and flexible. Flexibility is not so important if it is easy to export the data to other analysis packages such as Microsoft Excel or MathWorks MATLAB.

Table 2.2.2 below illustrates the key features of one Australian designed and manufactured power quality monitor while Figure 2.2.1 shows a photograph of the device.

<table>
<thead>
<tr>
<th>FEATURE</th>
<th>PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channels</td>
<td>3 (isolated)</td>
</tr>
<tr>
<td>Measuring Range (RMS)</td>
<td>10% to 150% of nominal value</td>
</tr>
<tr>
<td>Instrument Accuracy</td>
<td>Class A (accuracy of ±0.1% of nominal value)</td>
</tr>
<tr>
<td>Sample Rate</td>
<td>19.2 kHz synchronised to mains (384 samples per cycle at 50Hz)</td>
</tr>
<tr>
<td>ADC Accuracy</td>
<td>16 bit</td>
</tr>
<tr>
<td>RMS Calculated</td>
<td>Every 1/2 cycle (10ms at 50 Hz)</td>
</tr>
<tr>
<td>Log Intervals</td>
<td>All AS/NZS 61000.4.30 intervals simultaneously plus adjustable interval from 1s to 3600s</td>
</tr>
<tr>
<td>Harmonics</td>
<td>AS/NZS 61000.4.7, Class I (up to 50th harmonic) Voltage and current magnitude and angle THD (up to 50th harmonic)</td>
</tr>
<tr>
<td>Other Features</td>
<td>Transient recording, RMS capture, waveform capture, 8GB logged data memory, built in GPS, IP66 (all weather housing)</td>
</tr>
<tr>
<td>Disturbance Types</td>
<td>Voltage, unbalance, harmonics, flicker, mains signalling, sag/interruption, swell, transients</td>
</tr>
</tbody>
</table>

Table 2.2.2: Key features of CHK Power Quality MIRO PQ35 three phase power quality logger

Figure 2.2.1: Photograph of CHK Power Quality MIRO PQ35 three phase power quality logger
3. Additional Types of Monitoring Instruments

In addition to the dedicated power quality monitors mentioned above, other types of instruments may be able to assist with plant site surveys and investigations. These instruments are outlined below.

i. Handheld/Spot Check Instruments

Some simple power quality investigations can be made without a fully equipped power quality monitor. Handheld instruments include the following:

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MULTIMETER</td>
<td>Used to perform simple checks on voltage and unbalance levels. Many can also measure current. It is important that true RMS multimeters be used for power quality purposes as shown here in the Fluke 117 True RMS Multimeter.</td>
</tr>
<tr>
<td>PORTABLE HARMONIC METER</td>
<td>Useful when harmonics are not time-varying; some can store data and download to computer and are thus useful in time-varying situations as shown here with the RS PRO IPM6300 Power Quality Analyzer.</td>
</tr>
</tbody>
</table>
ii. Smart Tariff Meters

Smart tariff meters are essentially electricity metering devices with some added power quality functionality. They are often seen as a fiscally attractive option for routine power quality monitoring as they are generally installed at installations for metering purposes, and are significantly less expensive than power quality monitors. Adding power quality functionality generally does not present a major additional cost.

| SMART TARIFF METER | Laboratory testing has shown that smart tariff meters perform well for basic parameters such as fundamental voltage and current and low order harmonics. The drawback of smart tariff meters is that they generally don’t comply with monitoring standards and instrument accuracy becomes a major problem at higher order harmonics. In addition, the functionality of smart tariff meters is often limited with regards to the amount of on-board memory, the number and types of disturbances that can be measured and the sampling rates. Shown here is the Schneider Electric PM5000 Smart Meter with Basic Power Quality Monitoring Functionality. |

iii. Other Instruments

| DIGITAL OSCILLOSCOPES | Digital oscilloscopes (preferably with FFT features) are useful for continuous disturbances under steady state and possibly under time-varying conditions as well depending on memory requirements. Flexible triggering modes and very high sampling rates may make them very useful for capture of events such as switching transients. Shown here is the Tektronix DPO7000 Series Digital Storage Oscilloscope. |

| BLACKBOX | Another class of modern instrument continually logs waveform data over time [6]. These devices sample and store waveforms over long time periods using large on-board data storage (many GBs) in conjunction with data compression algorithms. Analysis and reduction of data for reporting is completed using software after the data has been captured. These devices have the advantage that events will not be missed due to incorrect trigger settings. In addition, it is sometimes useful to capture many cycles of waveform and these devices accomplish this task much better than traditional power quality monitors. Shown here is the Elspec G4500 Blackbox. |
4. Transducers

Transducers play an important role in power quality monitoring. Transducers are necessary to reduce the magnitude of the signal to be monitored down to levels which can be directly connected to the monitoring instrumentation. Signal levels should use the full scale of the instrument without distorting or clipping the desired signal and should stay above instrument noise levels [1]. Power quality monitors usually come equipped with voltage measurement circuits which can be connected directly to LV circuits (generally up to 600 V RMS). For higher voltages, they must be connected to a transducer such as the secondary of a substation metering transformer.

Investigation of particular plant problems usually require current as well as voltage measurements. Some instruments may directly measure small current inputs (e.g., 5A). Many modern instruments often use current transducers (e.g., clamp-on CTs) which convert current signals to voltage inputs.

The accuracy of the transducers used to perform power quality measurements can have a significant impact on the measurement outcomes. For harmonics, the frequency response of the transducer must be adequate up to the frequency of the harmonic of interest. Transient measurement also requires frequency response adequate to resolve the transient without the loss of important detail.

4.1 Voltage Transducers

The frequency response of voltage transducers depends on their type and the burden connected to them. For many measurement applications, inductive voltage transducers are used. For high impedance burdens, frequency response should be adequate to approximately 5 kHz. Figure 4.1.1 shows the frequency response (Ratio Correction Factor) of a high impedance (1MΩ) voltage transducer. Figure 4.1.2 shows the frequency response (Ratio Correction Factor) of a low impedance (100Ω) voltage transducer. The reduced burden can be seen to have quite a detrimental effect on the frequency response and the usable frequency range. Hence, care must be taken when connecting transducers to instruments.

![Figure 4.1.1: Frequency Response of High Impedance Voltage Transducer [1]](image-url)
For magnetic voltage transducers, the nominal voltage level of the transducer also affects the measurement accuracy of the transducer. At high voltage, the transducer frequency response may only be adequate up to a few hundred Hertz. Figure 4.1.3 shows the tested percentage of inductive voltage transducers which complied with the accuracy requirements of IEC 61000-4-7 (for harmonics measurement) [7] by voltage level. As can be seen, the percentage of voltage transducers suitable for harmonics measurements decreases with increasing nominal voltage rating. A range of magnetic voltage transducers is shown in Figure 4.1.4.
At high voltage, in addition to inductive (magnetic) voltage transducers, voltage divider type transducers are often used. There are two main types of divider, the most commonly used consists of a capacitive divider connected to a magnetic (inductive) tuned circuit. The other more infrequently used type of divider is a resistive or capacitive divider without the inductive tuned circuit. Figure 4.1.5 shows a comparison of the two types of dividers. Voltage dividers without a tuned circuit are suitable for harmonic measurements; however, dividers with a tuned circuit are not suitable since these devices are tuned to have an accurate response close to the fundamental frequency only. However, it should be noted that technologies now exist which allow capacitive dividers with tuned circuits to be used for measurement of harmonics. These technologies use measurement of currents in capacitive voltage transducers (CVT) and values of capacitor elements in the CVT to determine harmonic components. A range of CVTs is shown in Figure 4.1.6.

Figure 4.1.5: Two Types of CVT (modified from [1])
There are many types of current transducer (CT) used for measurement purposes ranging from those in fixed locations (e.g. within substation switchyards and feeder switchgear panels) to portable devices mainly used for investigation purposes (see Figure 4.2.1). All can be useful for investigating power quality problems.

Standard metering class CTs in substations are generally adequate for frequencies up to 2 kHz (although phase error may start to become significant before this) [1]. They generally have accuracies from 0.1% to 0.5%, depending on accuracy class. For higher frequencies, window-type CTs (including clamp-on types) with high turns ratios should be used (e.g. Figure 4.2.2). Figure 4.2.3 shows the equivalent circuit and frequency response of a window-type CT.
The 500 A portable clamp-on CT (Hioki 9661) shown in Figure 4.2.1 is typical of that used with power quality monitors. It converts primary current to a small AC voltage (1 mV AC per primary amp) for processing by the monitor. Accuracy is 0.3% at 50 Hz and within 1% up to 5 kHz. Some clamp-on CTs have an AC current output.

Care should be taken with current connections. Four common problems when using clamp-on CTs are [2]:

a. The conductor is not properly positioned within the clamped area (increased measurement error if not in centre);

b. The split core ends do not make a solid contact (increased measurement error plus make affect waveshape);

c. The wrong type or number of conductors are enclosed within the CT e.g. including the neutral conductor when measuring active conductors;

d. Improper CT polarity (leads to incorrect phase issues).

Other types of CTs available are:

- Hall-effect: Suitable for most measurements of DC quantities (used in some clamp-on type probes). Figure 4.2.4 shows a 500 A hall-effect clamp-on CT made by CHK Power Quality. This has an accuracy of 2% with a -3 dB point at 10 kHz. Hall-effect probes require a power source to operate. In many cases, these probes use batteries as the power source. Care should be taken to ensure that these batteries do not run flat during monitoring otherwise current data will not be measured.

- Rogowski coil: These devices can be fitted around cables in difficult locations and have good high frequency response but are unsuitable for DC (used in many “flexible” CTs). The output of a Rogowski coil system is a voltage directly proportional to the rate of change of current and requires a power supply for its integrator circuit. The accuracy of Rogowski coils is more sensitive to position error than other types of CT (i.e. the position of the primary conductor within the coil). The flexible CT shown in Figure 4.2.5 has a calibrated accuracy of 1% and a frequency range to 5 kHz.
5. Summary

In this Technical Note, power quality instrument requirements and standards have been described. Considerations when selecting a power quality monitor were also outlined and an overview of the various types of power quality monitoring instruments was given.

To conclude, the different types of voltage and current transducers and their application were presented.

6. References

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