INTEGRAL energy

Power Quality Centre

University of Wollongong

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POWER QUALITY MONITORING - PLANT INVESTIGATIONS

This Technical Note discusses power quality monitoring, what features are required in a power quality monitor and how it can be used to identify specific problems in an electrical installation. Integral Energy, your local Network Operator or the Integral Energy Power Quality Centre can give you advice if you have particular concerns with these issues.

Summary

Power quality (PQ) is the generic name given to a range of disturbances on the electrical network. Each PQ disturbance has a defining characteristic waveshape. By identifying the type or types of disturbances, the cause and possible solution can be found.

PQ monitoring instruments are needed to determine what type of PQ disturbance is present as disturbances are not always obvious. Many types of PQ monitors are available and as a general rule, the more expensive the instrument, the more disturbances it can record with a high degree of accuracy. However, less expensive monitoring instruments can be utilised provided some basic features are included.

Ensuring optimum use of a PQ monitoring instrument requires flexibility in its application on Low Voltage (LV) and Medium Voltage (MV) systems. This will require current transformers for current measurement on LV. Higher voltages require correctly installed Current and Voltage Transformers (CTs and VTs) for connection of monitoring equipment. Transducers should be selected based on the frequency response required.

Investigation of plant disturbances requires several questions to be answered to define the problem and highlight possible mitigation methods. Typical plant investigations require some knowledge of possible causes for specific symptoms. An easy to use table is included in this Technical Note to aid problem identification.

Contents

1. Introduction

Power Quality (PQ) is the study of the sources, effects and control of disturbances which propagate via the electric power supply. The disturbances change the supply rms voltage or its waveshape (or very occasionally the frequency) and may originate from various sources, for example

- upstream transmission system
- switching operations in the local supply
- atmospheric disturbances
- car accidents
- in neighbouring plant
- distorting equipment or faults within the affected plant.

There are two main reasons for making power quality measurements:

(i) plant investigations to solve specific problems in an installation;

(ii) utility measurements to obtain the general PQ levels in a part of the network. We will concentrate on the first in this technical note.

The major disturbance types are covered in Table I.

Table I – Main disturbance types listed in order of increasing frequency content
1. Excessive steady state voltage variation
2. Unbalance
3. Flicker
4. Harmonics
5. Sags and short-term interruptions
6. Swells (temporary overvoltage)
7. Oscillatory transients
8. Impulsive transients

Disturbance types 1-4 are caused mainly by the emission of disturbing loads and are present continuously, although in varying degrees. They are usually recorded as a trend graph such as the one in Figure 1. Other disturbance types such as 5-8 in Table I occur as individual events. This type is recorded as a set of journal entries with the time of each instance of the disturbance and its associated parameters. For example, for each short-term interruption one could record the duration in cycles.

In the remainder of the technical note we will look at how to characterise (or parameterise) the different types of PQ disturbances and see what are the levels which equipment should be able to tolerate. Power quality monitors and associated transducers will be described. We shall conclude by discussing how to use PQ monitors to solve plant problems.

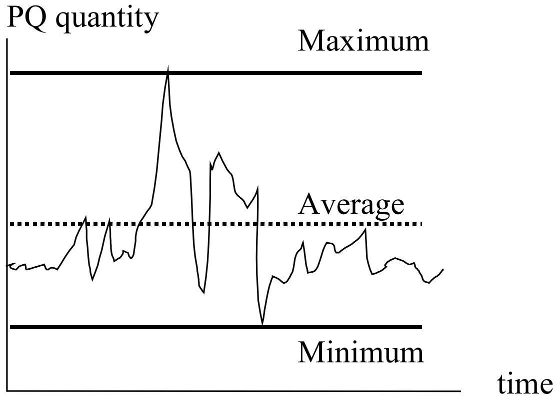

Figure 1: Trend graph

2. PQ Disturbances and Their Characterisation

Equipment usually has a specified voltage range over which it can operate. Incandescent light globes for example can fail when subjected to high voltage.

2.1 Excessive Steady State Voltage Variation

Voltage can be measured by a handheld voltmeter if it is not changing very much. When it changes significantly, it should be logged continuously by a more sophisticated PQ monitor capable of giving a display as shown in Figure 1. It is common to determine and display the average rms value every 10 minutes. Maximum and minimum values need to be compared with utility objectives. Until recently, voltages within LV installations could vary from 240V +6%/-11%. We are now moving gradually to a new standard which is likely to be 230V +10%/-11%.

2.2 Unbalance

There are two definitions of Unbalance Factor (UF) used in Australia. The two agree within 30% of each other for normal levels of unbalance (0-3%). The simpler for everyday applications is the IEEE definition which applies to line-line voltage measurements only and involves three steps

(i) Calculate V_{avg}, the average line-line voltage

(ii) Calculate ΔV_{max} maximum deviation of the line-line voltages from the average calculated in (i) above

(iii) Then $UF = \Delta V_{max}/V_{avg}$

Unbalance affects three phase induction motors which should be able to tolerate 2% if properly chosen.

2.3 Flicker

Voltage fluctuations give light flicker which can annoy because of its distracting visual stimulation. AS/NZS 4376:1996 and 4377:1996 define an instrument for measuring voltage fluctuations based on a model of the light source/eye/brain system. The instrument output is P_{st}, the short term flicker index over a 10 minute interval, defined such that $P_{st} = 1$ corresponds to the threshold of perceptibility. A long term flicker index P_{lt} is also defined over a 2 hour interval and is calculated from the 12 consecutive values of P_{st} which occur. Flicker can only be measured with expensive PQ monitors. The P_{lt} value should be less than 1 for 95% of the time.

2.4 Harmonics

Harmonic distortion gives a waveform which is non-sinusoidal and repetitive. Such a waveform can be resolved into a fundamental V_1 and harmonics V_2 , etc. Usually only harmonics up to the 20th order are of interest in power systems studies as the higher order ones are extremely small. In this case the rms voltage is

$$V = \sqrt{(V_1^2 + V_2^2 + \ldots + V_{20}^2)}$$

The Harmonic Voltage is defined as

$$V_H = \sqrt{(V_2^2 + \ldots + V_{20}^2)}$$

Hence it can also be calculated as

$$V_H = \sqrt{(V^2 - V_1^2)}$$

The Total Harmonic Distortion (THD) is defined as

$$THD = V_H/V_1\ (\%)$$

Excessive harmonics are a concern as they may cause heating in synchronous/induction machines, interference in communication systems or damage to capacitors and computers.

Harmonics can be measured with a dedicated handheld meter or a PQ monitor. The second is preferable when harmonics are changing. A common limit is 6.5% total harmonic distortion for 95% of the time.

2.5 Sags and Short-term Interruptions

This category concerns voltage drops to 90% or less for less than 1 minute. A sag is a drop to more than 10% while an interruption is a drop to less than 10%. There are no clear guidelines at present as to "normal" levels of sags. Equipment may operate incorrectly or fail to operate as a result of a sag (e.g. switched mode power supplies, variable speed drives, induction motors).

A sag waveform can be shown as the variation of rms voltage over the sag duration as shown in Figure 2. Sags are recorded as a logged event described by two parameters

- Sag depth: maximum deviation of the rms voltage from nominal
- Sag duration: time below threshold, often chosen as 90%.

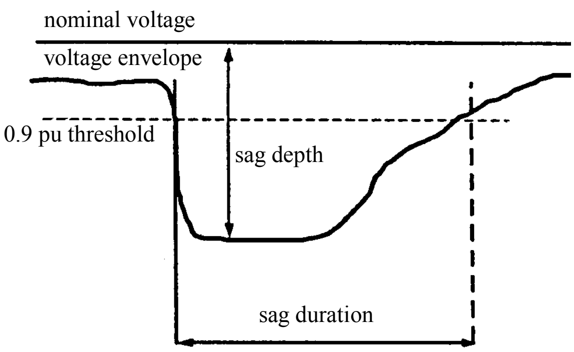

Figure 2: Sag characterisation

A sag can be represented graphically as a point on axes where the horizontal axis is duration and the vertical axis is depth (or equivalently sag voltage). There have been attempts to show the sag immunity of some types of equipment on the same axes. The most popular is the ITIC curve (Information Technology Industry Council - 1996), shown in Figure 3, developed for single phase 120 V information technology equipment (eg pc, copier, fax). This has been developed from an earlier graph formulated by CBEMA (Computer and Business Equipment Manufacturers Association) and this name is sometimes applied to the more modern graph. The Lower line gives recommended equipment sag immunity; the Upper line gives recommended equipment swell and transient immunity.

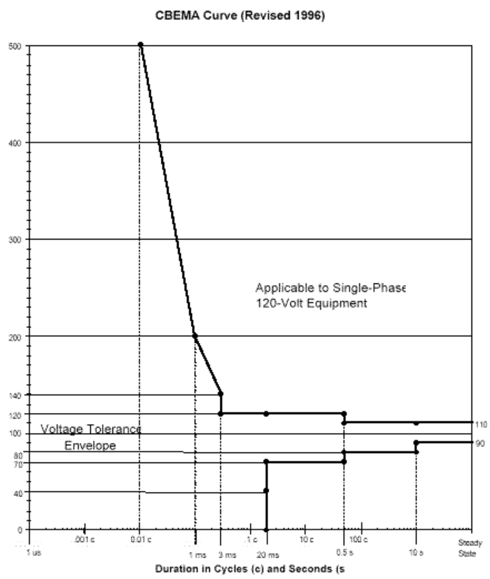

Figure 3: ITIC Curve

2.6 Swell (Temporary Overvoltage)

These are not currently of great interest and there is not much information on their characterisation. They can have values of up to 170% nominal voltage for one minute. Equipment may be damaged if subjected to voltage higher than its short time withstand rating e.g. capacitors.

2.7 Oscillatory Transients

These can be set up by the switching in of power factor correction capacitors. Figure 4 shows that they have the form of a sudden voltage fall towards zero followed by an oscillation in the range 500Hz-2kHz for up to a couple of supply cycles. Characterisation has not been formally defined, but 130% peak can trip variable speed drives.

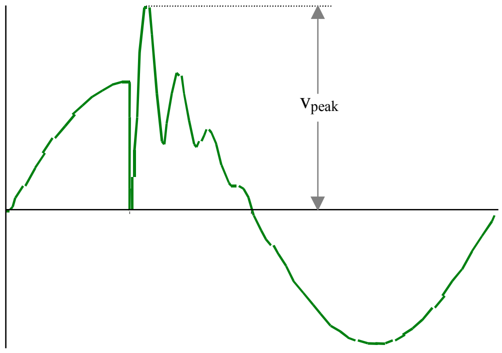

Figure 4: Characterisation of oscillatory transient

2.8 Impulsive Transients

Equipment susceptible to impulsive transients includes electronic equipment such as computers. Impulsive transients are characterised by (1) rise time, (2) decay time & (3) peak value as shown in Figure 5. The rise time is measured between the instants when the front edge rises from 10% to 90% of its peak value. The decay time is measured from the start of the waveform to the time when the tail value is half the peak. Typical limits are rise times of µs-to-ms with a peak not exceeding 6 kV for 415 V systems.

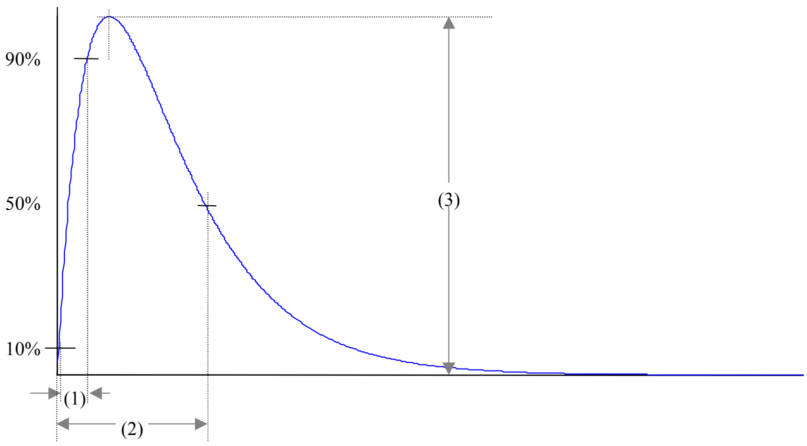

Figure 5: Characterisation of impulsive transient

3. PQ Monitors

Power Quality Monitors are intended to give all necessary information about significant PQ disturbances over a long period varying from weeks to months. These instruments have to 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 (eg 1-4

MHz) giving a large data throughput. Operating over a long timescale this gives an enormous amount of data to be handled. These instruments must either record very little of the data handled or have large storage facilities (eg hard disk) or communicate the data to a storage facility by means of a modem or similar.

To prevent overloading of memory with discrete event type disturbances, monitors have adjustable thresholds which determine the level at which a disturbance is recorded. For example, one may set a sag threshold only to record sags with a depth of more than 15%.

Some basic instrument specifications to watch are the following.

(i) Number of channels, sampling rate and accuracy: 7 channels are necessary for the recording of three phase voltage, current and neutral current as is desirable for investigation of plant problems. Another channel for measuring neutral – earth voltage can also be useful.

(ii) Appropriate variable thresholds for all required PQ disturbances – eg for transients do you require a voltage or a dv/dt threshold?

(iii) Range of disturbance types recorded – flicker and impulsive transients are both expensive because of their special technical requirements (resolution/sampling rate and peak value respectively).

(iv) Type and amount of data stored – raw data or parameters, sufficient for the desired logging period?

(v) High crest value needed to avoid clipping and modifying overvoltages in the monitored waveform.

(vi) Can ride through disturbances (eg battery support or battery operated).

(vii) Good reporting software.

(viii) Associated large database capabilities.

(ix) Easy to use.

A general instrumentation standard which is very useful is IEEE Std 1159-1995, "IEEE Recommended Practice for Monitoring Electric Power Quality"[3]. In summary, it covers

- definition of power quality terms
- monitoring objectives
- measurement instruments and practices
- choice of threshold settings
- interpreting waveforms.

4. Transducers

Low Voltage

Voltage measurement at LV can be achieved by direct connection of leads. Current measurement is obtained by current tongs or flexible CTs.

Medium and High Voltage
For voltage measurements, magnetic voltage transformers are acceptable to about 5 kHz. For higher frequencies (transients), resistor or capacitor voltage dividers are required.

Tests at the University of Wollongong [4] have shown that normal CTs are suitable for most harmonic measurements. Other types of CTs available are

- Hall effect: suitable for most measurements down to dc (used in many clip-on type probes).
- Rogowski coil: very good hf response but unsuitable for dc (used in many "flexible" CTs).
- Shunt: must be low inductive for hf readings.

5. Plant Fault-Finding

When investigating a plant problem, one should seek answers to the following questions:

- What is affected? Is it a variable speed drive (susceptible to sags and capacitor switching transients) or a computer (susceptible to sags and transients)?
- What is the disturbance type? This may be obvious from the nature of the problem (see Table II) or may require monitoring over a period to capture a couple of maloperations.
- Is the disturbance within allowable limits (utility and plant immunity standards)? If it is, some item of plant equipment is at fault. If not, the utility may have to instigate mitigation methods.
- From where does disturbance originate? This can sometimes be determined by simultaneous measurement of voltage and current. For example, if a sag is always accompanied by a large current increase, it is caused by a motor start within the plant.

Table II - What type of disturbance to look for

Symptom	Possible cause
Overloaded neutral	Harmonics
Trip-out of motor drive or PLC	Sag or oscillatory transient
Destruction of electronic equipment	Impulsive transients
Clock resetting	Sag
Racing clock	Harmonics
Light flicker	Voltage fluctuations
Capacitors fail	Harmonics
Overheating motor	Low voltage, unbalance, harmonics
Light globes fail excessively	High voltage
AC contactors trip out	Sag

Much information on waveform interpretation and problem identification can be found in [5, 6].

When the source of the disturbance has been identified, responsibility has to be determined if the disturbance originates outside the plant. The utility may be responsible if the level of the disturbance is greater than the utility's objectives, usually specified in a customer service agreement. Some idea of these levels has been given in this technical note for voltage, unbalance, flicker, harmonics and transients, with sags and swells needing to be specified more comprehensively.

6. List of References

1. AS/NZS 4376:1996, "Flickermeter - Functional and Design Specification".
2. AS/NZS 4377:1996, "Flickermeter - Evaluation of Flicker Severity".
3. IEEE Std 1159-1995, "IEEE Recommended Practice for Monitoring Electric Power Quality".
4. V.J. Gosbell and G.J. Sanders, "Frequency response of distribution CTs", Proc. AUPEC'96, pp. 77-82
5. Dranetz, "The Dranetz Field Handbook for Power Quality Analysis", 1991.
6. BMI, "Handbook of Power Signatures", BMI, 1993.

7. Integral Energy Power Quality Centre

In July 1996, Integral Energy set up Australia's first Power Quality Centre at the University of Wollongong. The Centre's objective is to work with Industry to improve the quality and reliability of the electricity supply to industrial, commercial and domestic users. The Centre specialises in research into the control of distortion of the supply voltage, training in power quality issues at all levels, and specialised consultancy services for solution to power quality problems. You are invited to contact the centre if you would like further advice on quality of supply.

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