Power Quality Indices

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Abstract:

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Power Quality Indices: A Review

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Abstract

Electrical Power Quality is the study of how close to the ideal sinusoid the voltage and current waveforms are. In reality the Voltage Quality is of most concern as it is through the terminal voltage that the devices interact. Any deviation, whether momentary or sustained, in the voltage a device sees at its terminal is a power quality (PQ) issue and could detrimentally affect the device.

It is the manifestation of a disturbance in the current, that flowing through the system and its impedance, results in poor voltage quality. Devices connected to the network will be subjected to this voltage waveform and potentially be adversely affected. The important concepts are of emission, disturbance level and immunity level.

This paper results from the Power Quality and GREEN Grid research programmes. It begins by reviewing the various types on power quality phenomena, their source and potential impact on generation, network of end-user loads. A critique of power quality indices is then given. Technology is ; for example the rapid uptake of photovoltaic solar power systems, EV chargers, heat pumps, and LED lights. As a consequence, the immunity of some devices is changing, which means there is a need to review and possibly change some indices. In particular voltage flicker and telephone interference indices need to be reassessed.

1. Introduction

PQ disturbances can be broadly classified into two categories. These are *variations* and *events*. Variations are disturbances which have an effect on every cycle, such as harmonics or voltage unbalance. Events are disturbances which last for a time, from a fraction of a cycle to several cycles, and then may not repeat for several hours or days, for example transients and voltage dips. Some important differences between the two are illustrated in Table 1, while Table 2 shows the category of different PQ disturbances.

Table 1: Comparison of one type of PQ Variation and PQ Event

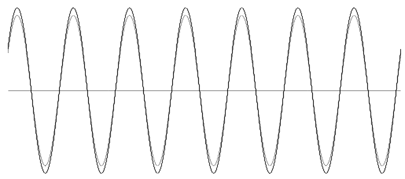
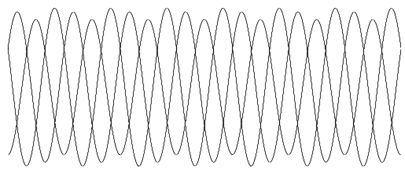
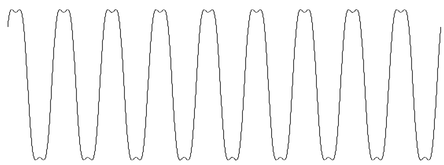
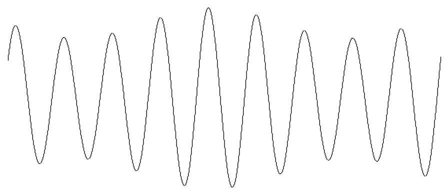
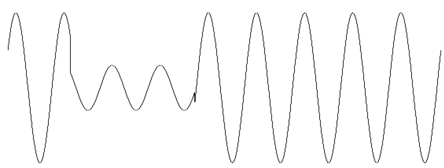
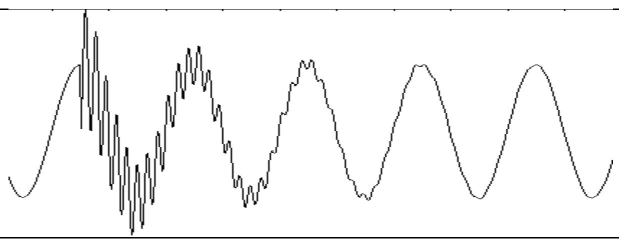
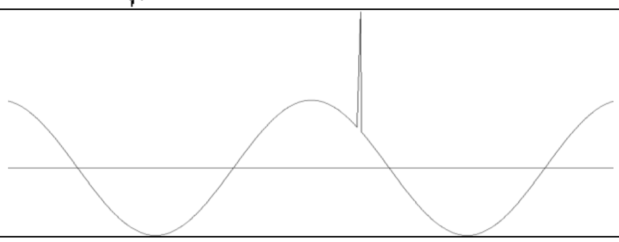
	Variation	**Event**
Example	Unbalance	Sags
Time nature	Present at all times	Occur as separate, independent events
Equipment impact	Thermal, cumulative	Mal-operation or destruction, instantaneous
Limits	Statistical	Not well developed; limit applied to worse case

2. Power Quality Disturbances and their Effects

There are many books and reports discussing power quality phenomena [1-22]. In the discussion in this section the effect of each type of power quality issue will be discussed and an indication of what part of the system it mainly affected ([G] generation, [N] network or [L] load) is given.

Because of the different technology used in an area care is needed in discussing possible effects. For example generation may utilise synchronous machines (with either electromagnetic or solid-state excitation systems), induction generators, doubly-fed induction generators, permanent magnet generators with full rated power converters, or power electronic inverter. The effect of power quality issues on generators depends greatly on whether the generator is based on traditional synchronous machines or power electronic inverter technology, as each technology has its own vulnerabilities. Synchronous machines are robust and the extra heating is usually the main issue. However, gas turbine powered synchronous machines readily trip off-line due to system events so as to protect the gas turbines from excessive mechanical stresses. Hence frequency fluctuations are critical for gas-turbines.

Table 2: Classification of Power Quality Issues

Classification	Waveform	Type
Steady-state r.m.s. voltage (under- or over-voltage)		Variation
Steady-state voltage unbalance		
Harmonics		
Voltage fluctuations		
Short-term interruption, sag (dip) or swell		Event
Transient – (a) Oscillatory		
(b) Impulsive		

Power electronic inverters used for grid connecting PV and wind generation have to be synchronized to the grid. The Phase-Locked Loop (PLL) used for this is susceptible to power quality disturbances such as unbalance and inter-harmonics [23-28].

2.1 Steady-state Voltage Excursions

The main effects of steady-state voltage excursions, such as over-voltage, are:

- High voltage: reduction in lifetime for incandescent globes and Switched-Mode Power Supplies (SMPS) filtering capacitors. [L]
- Low voltage: motor current increase and possible stalling and burnout of motor if prolonged. [L]
- Some equipment may not operate as intended if the voltage is too low [L].
- Increased corona [N].
- Higher leakage currents and more insulator failures [N].

2.2 Steady-State Voltage Unbalance

The main effects of voltage unbalance, where the voltage is difference on one or more phase compared to the other phases, are:

- Heating of rotors in three-phase induction motors (due to negative sequence flux). If unbalance levels are high enough motor derating will be required [L].
- Reduction in locked-rotor torque and breakdown torque. If the voltage unbalance is extremely severe, the torque might not be adequate for the application. [L]
- Three-phase converter systems will draw unbalanced currents containing uncharacteristic harmonics. [G,L,N]
- High ripple in rectifier output. [L]
- Electromagnetic devices (such as relays may be damaged. [L,N]

2.3 Harmonics

The main effects of harmonics on the system, which are integer multiples of the 50Hz fundamental present on the voltage, are [1-2]:

- Heating of rotating machines. [G,L]
- Heating of transformers and cables, resulting in loss of lifetime or destruction [29]. This is well documented and the reason K-rating was introduced for transformers. [G, L, N]
- Destruction of capacitors not fitted with an appropriate series detuning inductor. [L,N]
- Mal-operation of electronic controlled equipment [G,N,L]
- Destruction of equipment due to increased r.m.s. currents and voltages (particularly capacitor banks) [L,N].
- Telephone interference. [N]
- Cogging and crawling of induction motors. [L]
- Acoustic noise from equipment and vibrations [G,L,N]
- Destruction of smart meters [N]

Harmonic issues can be either thermal issues or short-term effects (interfering with the operation of equipment). The high frequency sinusoidal components can have an adverse effect on induction motors, capacitors and electronic equipment. In some situations, it is too expensive or impractical to modify the equipment to make it insensitive to harmonics. Hence limits are set to allow equipment suppliers to have some confidence regarding the environment in which their equipment will need to operate.

2.4 Inter-harmonics

Inter-harmonics are frequencies that are not integer multiples of the fundamental. Inter-harmonics that are below the fundamental frequency are also known as sub-harmonics. Inter-harmonics are often used for ripple control (e.g. 175Hz or 317 Hz). The main effects are:

- Light flicker. The two mechanisms are; (a) the interharmonic voltages combining with the fundamental (or occasionally harmonics) to give rise to a beat frequency with a modulation frequency in the visible range and (b) the frequency translation that naturally occurs between the ac and dc sides of a power electronic converter (i.e. electronic ballast) causing modulation of the light output in the perceivable frequency range (which can be an issue with modern LED lights). [L]
- Unwanted currents in the supply network generating additional energy losses. [N]
- Disturbed operation of electronic equipment such as fluorescent lamps and television receivers. Devices which use the crest voltage or the zero-crossing can be disturbed if the combination of unwanted frequencies present alters these attributes of the supply voltage. [L]
- Disturbance of Distributed Generation (due to the sensitivity of the PLL used in grid-tie inverters). [G]
- Acoustic noise and vibrations [G,L,N]
- Temperature increase and unwanted torques in induction motors [L]
- Interference causing mal-operation of equipment. [L]
- Overloading or disturbance of equipment due to amplified voltage distortion. With a greater range of frequencies there is a greater the risk of resonant effects. [L]
- Interference with the operation of protection relays (alteration of operating time or pickup current). Both electro-mechanical and solid-state protection relays may be affected [4]. [N]

2.5 Voltage Fluctuations and Flicker

- The main effect of voltage fluctuations is light flicker in lighting equipment causing eye irritation. Flicker occurs as result of amplitude modulation of the voltage envelope. The human eye-brain connection has different sensitivity to different modulation frequencies, hence there is the need to weight these voltage fluctuations based on frequency (repetition rate). The human perceptibility to fluctuations has been evaluated using a large sample group and this found fluctuations in the range 1 to 35 Hz were significant and the human eye is most sensitive to light fluctuations at a modulation frequency of 8.8Hz (~16 changes/second). [L]
- Other effects of voltage fluctuations include: voltage being outside accepted normal tolerance, interference with communication equipment, spurious tripping of relays and electronic equipment and mal-operation of equipment with control systems which depend on the phase angle of voltage waveform. [L, N]

2.6 Voltage Dips/Sags

Voltage dips/sags are events whereby there is a sudden drop in voltage level for a period of time. For example a voltage dip/sag occurs when a fault in the system occurs. The duration is dictated by the time it takes for the protection to isolate the fault from the network. The starting of large motors also can cause voltage dips/sags. The main effect is the loss of production due to one or more of the following:

- Digital clocks reset. [L]
- Computers and PLCs reset. [L]
- AC contactor drop-out. [L]
- Variable Speed Drives (VSDs) stopping. [L]
- Incorrect deposition in manufacturing. [L]
- Product outside acceptable manufacturing tolerance. [L]
- Tripping of loads. [L]
- Tripping of generators (thermal plants). [G]

Device hardening involves making changes to increase the immunity of equipment to power quality disturbances. Some changes are quite cheap and easy to implement. Ref. [30] looks at device hardening by increasing the smoothing capacitance on the dc busbar.

2.7 Transients

Transients may be oscillatory in nature or sudden voltage spikes, and are also transient in nature. The effects can be attributed to three mechanisms:

- Increased component and insulation stress due to elevated crest voltage. This will cause degradation of the insulation and components in equipment. Repetition of these events will shorten the life-time of equipment. [G,L,N]
- Malfunction due to high *dv/dt*. False switching of solid-state devices (e.g. thyristors) causing malfunction or destruction of equipment. [G,L,N]
- Multiple zero-crossings causing timing issues. Affects time related devices (clocks, magnetic tapes and disks). [G,L,N]

2.8 Voltage Swells

A voltage swell is an event related increase in voltage, typically due to load rejection. The effects are:

- Over-stressing equipment and their associated components, this may lead to reduced life time or destruction. [G,L,N]
- Tripping of grid-tie inverters. [G]
- Tripping of Loads (e.g. VSDs). [L]

2.9 Voltage Notches

A voltage notch involves the loss of voltage time area within a cycle due to the commutation process in a power electronic converter. The main effects are:

- Mal-operation of equipment due to the voltage-time area reduction in part of the cycle (due to commutation process). [L]
- Destruction of solid-state equipment. The high *dv/dt* can cause false triggering (turn-ON) of devices such as thyristors. The charging current of the inherent capacitance of the semiconductor junction can be seen as a triggering current, turning the device ON at the wrong time.

2.10 Frequency Deviations

Deviations of the fundamental frequency from 50Hz, usually major, and related to a contingency in the power system such as the loss of a generator or the HVdc link. The main effects are:

- Affects time related devices (clocks, magnetic tapes and disks). [G,L,N]
- Tripping of gas-turbines. [G]
- Tripping of loads. [L]

3. Power Quality impact on Distributed Generation (DG)

High steady-state voltage has been a major problem in the past with inverter-based DG (particularly PV installations in Australia). The significant DG injection of power, coupled with the characteristics of the DG, has resulted in the steady-state voltage reaching a level that causes tripping of the inverters and hence loss of DG generation into the network. The use of Volt-VAr, Volt-Watt characteristics, Volt-cos(theta) and/or f-Watt (whichever is deemed most appropriate for a given network) specified in the draft AS/NZS4777.2 will alleviate this problem.

New Zealand is experiencing a rapid increase in the uptake of PV generation [31]. In order to avoid problems occurring due to poor power quality, some restrictions may be required on DG. The restrictions may be in terms of rating, inverter characteristics, and/or whether single or three-phase. Traditionally the 11kV/415V transformer tap is set so that the LV voltage is on the high end of the allowable voltage range so as to ensure that the end customer's voltage is still within allowable range at times of heavy loading. The injection of power from PV units can further increase the voltage that is already on the high-side at times of light loading. In the residential case the peak generation often coincides with when there is low local load (empty house in the middle of the day). In a distribution system the conductor often changes to reflect the loading it serves (smaller further down the network). This can result in areas where the LV network is weak in terms of ability to cope with DG injection of power. This congestion of the network may require constraints to be placed on DG generation to avoid expensive network reinforcing in these areas. Moreover, the DG may also have to be constrained because of the network's susceptibility to voltage fluctuation and voltage unbalance.

Voltage Unbalance in a PLL results in a second harmonic component which hinders the control of the inverter. If sufficiently large it will cause loss of injected power by the DG. This is because of wrongly timed switching of the converter which will at its best reduce power transfer, cause the inverter to shutdown, or possibly damage the inverter.

Inter-harmonics cause frequency components in the PLL which also hinder the control of the inverter. The impact is very similar to the problem of voltage unbalance.

Harmonics also impact the inverters and their control, but normally they are not as sensitive to characteristic harmonics as to inter-harmonics and voltage unbalance.

Voltage Dips/Sags are well known for causing DG to drop off the system (hence losing their generation). As this exasperates the problem many papers have been written of fault ride through (FRT) capabilities (particularly for wind power) and ways of enhancing it.

Voltage stressing and potential damage of either electrical insulation of generation equipment or electronic controls are the main issues with transients, whether switching or impulsive. The rate of change of voltage can also cause false triggering of power electronic devices (e.g. thyristors) which will cause mal-operation or destroy of generation equipment such as solid-state exciters in generators using a synchronous machine.

Voltage swells are more severe for generation equipment than loads as the voltage rise is more significant at the generator for a load rejection event. Insulation withstand level is still the main issue.

Voltage notches have similar issue to transients regarding the potential false triggering of power electronic devices (e.g. thyristors) which will cause mal-operation or destroy of generation equipment such as solid-state exciters in generators using a synchronous machine. The loss of voltage-time area can also adversely affect the power electronic controllers. However, voltage notches do not usually put a high voltage stress on the generation equipment insulation (unless it is compounded by a resonance).

Frequency deviations may cause loss of generation due to gas-turbines dropping-off the system. They may also interfere with the synchronisation of inverter-based DG which will influence the injected power.

4. Power Quality impact on Electrical Networks

The impact of poor power quality on the electrical supply network is often insidious and often its root cause is not correctly identified. The reduction in an assets lifetime is difficult to prove as is the need for increased maintenance. It is questionable whether these are due to the quality of the materials used, or quality of the design and construction of the asset or whether the cause is outside in terms of the power quality.

However, some catastrophic failures of equipment have conclusively been shown to be due to poor power quality. Harmonic content has been shown to destroy capacitor banks, over-heat transformers and overload neutral connections. Without detuning chokes the capacitor banks provide a low impedance path to harmonic frequencies which can cause the capacitor’s voltage & current ratings to be exceeded. Transformer fires in low power transformers was the reason UL (USA) developed the K-rating system for transformers to de-rate the transformers based on the harmonic currents flowing in them. Harmonics have also been shown to interfere with control, telecommunication and protection system causing false-tripping and erratic behaviour.

Storm related damage is a major source of poor power quality. Damage due to transients, such as impulsive lightning induced transients, are also well documented.

There are unconfirmed reports that new devices such as Smart Meters, can be adversely affected by higher order frequencies but this is a subject of research at present. These higher order frequencies are generated by devices with active front-ends, Active front-ends are used to meet the harmonic current limits without the use of harmonic filters (avoiding their inherent cost and energy losses).

Frequency deviations cause loss of generation due to gas-turbines to drop-off the system. It may also interfere with the synchronisation of inverter-based DG which will influence the injected power.

5. Power Quality impact on End User Equipment

Low steady-state voltage and voltage dips are a major cause of disruption to end users. The dropping out of electrical contactors (due to reduced solenoid force) causes loss of supply to motors and plant equipment. PLCs and other control equipment also shut-down under these conditions, as they look at the input voltage and perform a controlled shutdown. Many loads (motor and power electronic loads) draw more current at low voltage and this can cause excessive losses and heat build-up that is damaging to equipment. Therefore, failure to disconnect under low voltage conditions can destroy equipment (hence often dropping off is a design feature).

High steady-state voltage stresses the insulation of equipment. Even if by itself it is within the capability of the equipment the presence of harmonics or transients can cause the stress level to exceed the withstand capability of the insulation.

Voltage Unbalance is a problem for three-phase equipment. The main impact is the increase losses, and hence heating of three-phase motors as well as reduction in torque. More audible noise is evident also. Equipment such as variable speed drives (VSDs) may trip off.

Harmonics have a variety of effects depending on the type of equipment. The main issues are:

- extra losses and hence heating (thermal effect) in cables, transformers and machines (motors or generators) connected to the system.
- increased rms current and hence voltage across capacitors. This often causes destruction of capacitors in fluorescent light fittings and in power-factor correction units.
- Mal-operation of equipment that have timers (often in conjunction with ICs controlling a process), cooking equipment. This poses a fire hazard.
- Mal-operation of control equipment (causes fails triggering and hence spurious turn-ON or turn-OFF of equipment).
- Induction motors not motoring up to their normal operating speed by running at a fraction of their normal operating speed.
- Increased acoustic noise from equipment such as transformers and machines (motors and generators), and vibrations.
- Telephone interference in analogue telephone circuits.

Although there are other possible causes, a few symptoms of poor power quality in electrical motors are:

- Nuisance tripping of a motor-protective device.
- Difficulty in a starting motor or the motor not getting to full speed.
- Higher than expected maintenance of motor & control equipment.
- Not getting expected lifetime from motors or unusually high number of motor failures.

The loss of life could be due to harmonics or voltage unbalance, both of which increase the heating of the motor insulation, thereby accelerating its degradation and ultimately its failure. Another mechanism is harmonics causing a higher crest factor (depends of the phase angle of the harmonics) increasing partial discharge (PD) damage. Events can stress the insulation and accumulation of damage can lead to catastrophic failure of the motor insulation. White residue or powder is a sign of problems in motors and generators. There are two main causes. The first is a result of partial discharge and generation of ozone. This PD will gradually erode the insulation and may result in phase-to-phase stator failure. It only occurs where the electric field are highest, i.e. on coils or near the phase terminals. The second is due to fretting because of inadequate support of the coils, particularly in the end-winding area. The relative movement between the coils and support rings and at the blocking between coils leads to fretting of the insulation and a characteristic white powder.

Inter-harmonics have similar impact to harmonics in terms of extra losses (thermal effect) and potentially causing mal-operation of equipment, however, the biggest impact is light flicker. Harmonics themselves do not cause light flicker. The inter-harmonic levels are typically a lot lower than harmonics hence the thermal affect and mal-operation is not as big an issue as light flicker. This is because the eye is very sensitive to light variations and only a small level can cause perceptible flicker. Having said that there is an increasing number of reported incidents internationally of inter-harmonics causing mal-operation of equipment.

Voltage Dips/Sags are one of the most common power quality issues experienced by consumers. This is because there will always be the inevitable faults (such as storm related faults) that will depress the voltage until the protection equipment isolated the fault. Most end user equipment will stop or stall during the dip (and draw a high current) and resume operation when the voltage is restored. Provided the duration is not too long no damage will be suffered. Many industrial processes will need to be restarted manually with loss of time and wastage of materials and defective product as motor contactors drop-out.

Transients, whether switching or impulsive, stress the equipment insulation and electronic control boards resulting in damage. For example , televisions and other home entertainment equipment and internal vacuum cleaners, and a number of other appliances are typically on standby mode ready to be activated for use. Hence they are energised all the time. When a transient occurs the control board can be damaged. This may in turn lead to a fire risk.

Voltage Swells potentially damage equipment. In practice, in New Zealand, swells have not been a major issue as the supply voltage is kept reasonably well with ±6% of nominal voltage, while immunity standards require equipment to withstand +10%.

Voltage notches are known to cause mal-operation of power electronic equipment. Frequency Deviations can adversely affect time based equipment.

6. Power Quality Indices

The power quality indices have developed to give a quantitative measure of the disruptiveness of disturbances. However, technology has been changing and the susceptibility to some disturbances has also changed and the appropriateness of some PQ indices needs re-evaluating.

6.1 Flicker

The IEC flickermeter has been the standard for flicker measurements. Although it has been revised and updated (e.g. the number of test waveforms increased to ensure better conformity between flickermeter implementations) the fundamental concept has not been changed. It is based on voltage measurements and models both the incandescent lamp and the eye-brain perceptibility of a person. It is clearly unsuitable for modern luminaries such as fluorescent, CFL and LED lighting. This has spurned work on flickermeters based on direct light output that will work for any lighting technology. Although this has achieved a lot the problem is consistency. A laboratory test chamber can achieve consistency but a flicker measurement at different places is problematic. Any handheld light-based flicker meter is very sensitive to orientation, environment (reflections,…etc) and difficult to get a consistent, meaningful value.

6.2 Telephone Interference

The PQ indices for limiting the interference in telephony (telecommunication services for the purpose of electronic transmission of voice, fax, or data, between distant parties) are based on the induction of noise (either inductive coupling or capacitive coupling) into analogue telephone circuits from the electrical network. Weighting factors are used to represent the sensitivity of the human ear to different frequencies. In New Zealand psophometric weighting is used while in North America C-message weighting (comparison is shown in Figure 1). It is clear that this approach is inappropriate for digital telephony as the application of these weightings does not reflect the disturbance level that occurs. It is still important to limit the induced levels of voltage. Below a threshold the induced noise will not impact the quality of the voice, however, above the threshold bit-errors will occur cause a dramatic degradation in quality.

6.3 Simplified Harmonic Voltage Limits

A recent paper [32] has attempted to both simplify the limits as well as link them more closely to the physical phenomena. The main reason identified for limiting low frequency harmonics is to manage the additional heating losses in induction and synchronous machines. To keep the harmonic losses to less than 0.4% of the motor's rating then:

$$\sqrt{\sum_{h=2}^{n}\frac{V_h^2}{h}} < 6.3\% \tag{1}$$

The higher harmonics (typically h>13) are more of concern for capacitors due to both the elevated stress (voltage) on the capacitor insulation as well as the elevated heating. A high frequency weighted V_{THD} index is proposed with an indicative limit being:

$$\sqrt{\sum_{h=2}^{n}h^2V_h^2} < 90\% \tag{2}$$

The third limit is aimed to preserve the voltage waveshape. The typical flattening of the top and bottom of the voltage waveform will cause a reduction of DC voltage in equipment employing rectification and possible malfunction. This is controlled by setting a V_{THD} limit. This also will limit excursions (over-voltages) in the waveform also. The proposed limit is:

$$\sqrt{\sum_{h=2}^{n}V_h^2} < 7.5\% \tag{3}$$

The final limit is to preserve voltage waveform symmetry. Asymmetry in the voltage waveform is very undesirable as it causes DC currents to flow that will saturate power transformers, causing high magnetising currents and higher network losses. Moreover, the protection system will see this and trip equipment. Asymmetry manifests itself as even order harmonics, therefore a V_{THD} index using only the odd order harmonics is used to limit it, i.e.

$$\sqrt{\sum_{h=2,4,6\ldots even}^{n}V_h^2} < 3\% \tag{4}$$

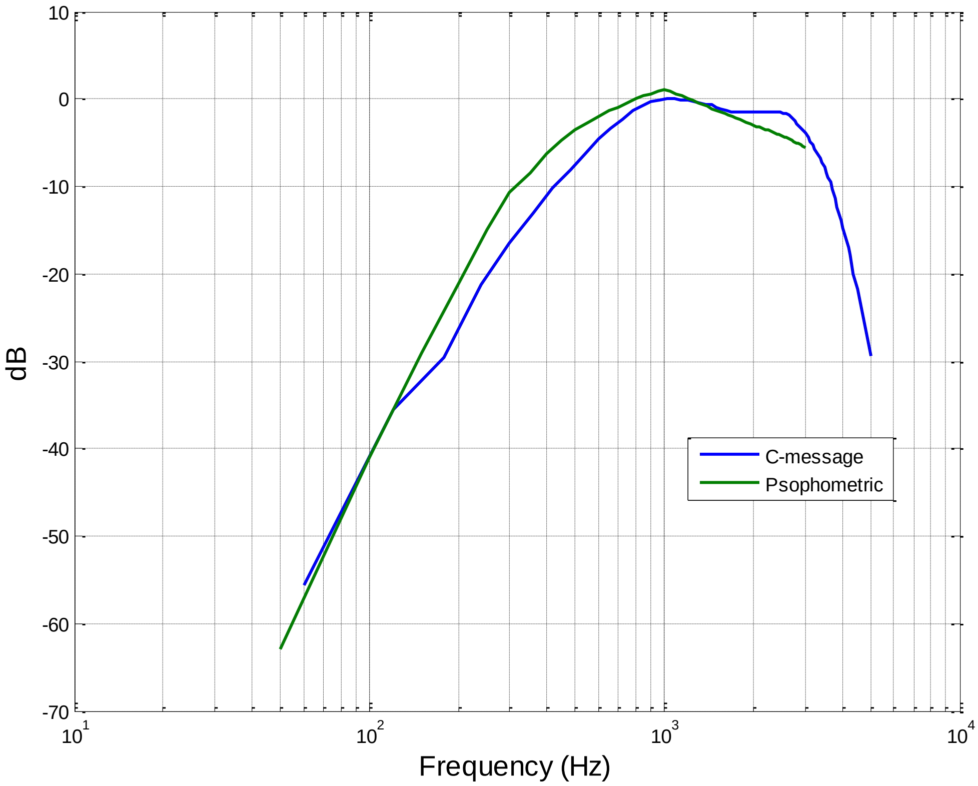


Figure 1: Comparison of CCITT Psophometric weights and C-Message weighting

7 Economic Cost of Poor Power Quality

Studies here and overseas unanimously indicate that poor power quality has a major economic impact. However, quantifying the impact is very difficult as often the root-cause of loss of production is not identified. Without pinpointing to a particular power quality issue it is never correctly attributed to it. Some consequences are long-term, such as loss of life. It is impossible to say with surety that a transformer that faulted at 25 years old rather than 40 years old was due to the power quality it was subjected to or a manufacturing issue when it was first made.

7.1 Customer Perspective

In an attempt to understand the economic losses in a New Zealand context a survey was conducted [33]. This was a sample survey as representative companies in each industrial sector were surveyed. The nett impact on New Zealand was then obtained by scaling this by the size of the industrial sector in New Zealand

The following industry sectors were chosen to be examined as part of this study. They were chosen due to their reliance on electricity of a high quality and overseas studies showing power quality heavily impacts them:

- Petroleum, Chemical, Polymer and Rubber Manufacturing
- Food, Beverage and Tobacco Manufacturing
- Textile, Leather, Clothing and Footwear Manufacturing
- Metal Product Manufacturing

Table 3: Survey Results

		(A)	(B)	(C)	(D)	(E)
PQ Issue	Flicker	40%	35%	42%	25%	8%
	Erratic Process equipment	0%	18%	28%	25%	30%
	Reduced Life-time	10%	35%	14%	0	16%
	Equipment tripping	80%	45%	56%	50%	50%
	Computers locking up or shutting down	40%	9%	14%	37%	41%
	Data loss	0%	9%	0%	0%	8%
	Pumps/motor speed not constant	40%	0%	14%	0	16%
Technology	Computers	100%	100%	100%	100%	100%
	network servers	90%	90%	90%	90%	90%
	Electric motors/pumps/compressors	100%	100%	100%	100%	100%
	VSDs	90%	100%	84%	63%	75%
	Computer automated production systems	90%	100%	70%	75%	100%
	Electrical heating or drying systems	100%	100%	41%	38%	50%
Mitigation	UPSs	80%	80%	84%	38%	50%
	Surge Protection	80%	80%	70%	38%	75%
	Filters or Power-factor correction	70%	80%	58%	38%	58%
	backup generators	20%	35%	0	0	0

Key to Columns:

(A) Petroleum, Chemical, Polymer and Rubber Manufacturing

(B) Food, Beverage and Tobacco Manufacturing

(C) Textile, Leather, Clothing and Footwear Manufacturing
(D) Metal Product Manufacturing
(E) Transport Equipment, Machinery and General Equipment Manufacturing

The high costs of power quality are associated to the following problems:

- VSDs causing equipment to trip out. Tripping out of equipment at various stages can be very costly as it damages product and can cause a whole process line to shut-down.
- Process speeds fluctuating causing excess/shortage of raw material or incorrect temperature reached. This results in wasted raw material or off specification product.
- A short interruption in a continuous processing industry can cause material to be exposed to conditions that degrade its quality.
- It appears that processing plants in rural areas are affected by a larger range and more frequent power quality events.

The main power quality issues in the non-continuous sector were found to be:

- Process variations in the manufacturing of equipment requiring high precision.
- A lot of equipment appeared to trip out on occasion, although the economic impact of this was relatively low. VSDs were attributed to be the main cause of equipment tripping.
- Power Quality can have a large effect on companies practising Just in Time (JIT) methods as it can cause significant delays in production.

To calculate the economic cost of each issue, the costs were broken into the following areas:

A. Cost of labour for idle employees (overhead costs added)
B. Cost of material damaged/spoilt
C. Cost of recycling or disposing of material
D. Restart costs
E. Equipment damage cost
F. Lost sales

7.2 Utility Perspective

Table 2 shows a summary of the power quality issues handled by Orion in the 2012/2013 year. They categorise the enquiry but do not record the effect the PQ disturbance has on customer equipment. They are mainly concerned with responsibility (whether the problem is internally created or from the network).

Table 4: 2012/2013 Power Quality Enquires handled by Orion (219)

Category	Percentage	Description
Proven Faults within installation (including service mains)	5.9%	Equipment failure, erratic operational issues, faulty wiring, circuit breaker operation and voltage variation effecting sensitive equipment and internal harmonic issues.
Termination Failures on supply network	4.1%	Fuse termination, connectors, and aging fuse issues and burnt up joints.
Enquiries within regard to Regulations	21.5%	General enquiries to prove within regulatory limits, customers wanting to eliminate supply as an issue
Network outside Regulatory standards	18.3%	High voltage due to incorrect local transformer tap settings, 11kV voltage regulation, Voltage dips/sags, phase changes and faulty network equipment / conductors.
General Surveys	50.2%	Harmonic, EMF, distributed generation, network / loading and investigations for new connections.

CONCLUSIONS

It is clear from the power quality survey that there is significant economic loss due to poor power quality, even though it is impossible to accurately estimate this loss. This is because the root-cause is often not identified, or not identified correctly. This paper has outlined the typical impact poor power quality has on generation, network infrastructure and load equipment. A discussion on power quality indices has been given and the need to rethink some. The indices must be linked to an impact as they should give a quantitative measure of the likelihood of a tangible problem being experienced. As technology changes the susceptibility and immunity of equipment changes and these requires the appropriateness of some indices to be questioned.

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