Power Quality Management

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Abstract:

Any deviation of voltage or current from the ideal sinusoidal waveform is a power quality (PQ) disturbance. The economic loss caused by malfunction or destruction of equipment due to poor power quality is significant and must be avoided. Emission is the term used to describe the disturbance levels which equipment injects into the electrical network which in turn create PQ disturbances. It is not economically viable to eliminate emissions and hence PQ disturbances completely, therefore a careful balance between emissions by, and immunity of, equipment is required; this is also referred to as maintenance of electromagnetic compatibility.

Power Quality is a major concern in the relatively small island electrical network of New Zealand (N.Z.). Firstly, the relatively small size of the N.Z. system means any given emission may create a large PQ disturbance. Moreover, the influx of new technologies such as electric vehicles, heat-pumps, LED lighting, …etc, could potentially cause electromagnetic compatibility problems in the future. It is clear from the increasing number of consent applications for PV installations in NZ that PV could have a dramatic impact on PQ, as it has in Australia. The number of Electric Vehicles (EVs) in NZ is also increasing, assisted by cheap second hand imports, and their chargers will also impact PQ.

The *Power Quality (PQ) in Future Electricity Networks (NZ)* project, which was funded by the Government and Electricity Engineers' Association of NZ (EEA) developed the EEA PQ Guidelines that were released in January 2013. This paper discusses the principles of power quality management (embodied in the EEA PQ Guidelines), areas for future development, and issues on the horizon.

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1. Introduction

The New Zealand electricity network is undergoing dramatic change, brought about by new technologies and the desire to make it smarter and more efficient. With the proliferation of equipment using power electronics many more industrial loads have become nonlinear which can cause power quality disturbances. Considering the importance of power quality and the concern on the possible impact of new technologies (such as widespread use of PV and Electric Vehicles) the PQ project was initiated in 2008. This paper gives an overview of this project which was designed to manage the PQ levels into the future, especially considering the challenges of new technologies.

Earlier publications [1]-[3] gave an overview of the concepts and preliminary outcomes of the project while this paper gives an overview of the EEA PQ guidelines recently published [4]. In this the IEC concept of emission, immunity and compatibility levels was discussed. Although the above EEA Power Quality Guidelines are in use, the content will continue to be extended and improved upon over time to provide the best outcome for the electricity industry.

2. Background to the guidelines and structure of the paper

Power quality is in most cases a result of the interaction between equipment current and the network resulting in distortion of the supply voltage. This distortion may be experienced at installations close to where distorting equipment is operating and may be in the form of fundamental voltage changes, harmonics, unbalance, fluctuations and other forms of disturbances. The control of PQ within acceptable levels necessarily involves limiting the distorting current from equipment at LV or from whole installations at higher voltage levels.

The development of the guidelines has involved investigations at both the equipment and network level. Section 3 describes work on the measurement of equipment and modifications which can be made to reduce customer emission levels to acceptable levels. Studies of the network are given in Section 4 and include finding typical values of New Zealand network impedances and surveying methods which can be used to reduce network PQ levels to meet distributor requirements.

The approaches to controlling different PQ disturbances are given in Sections 5 and 6. The first of these is concerned with harmonics where some significant changes have been made to past New Zealand practices, including harmonic limits, allocation methods and allowance for short term burst. Section 6 covers steady state voltage, voltage unbalance, voltage fluctuations, voltage dips and other PQ disturbances in less detail. Power quality monitoring, which is necessary to establish network compliance to PQ standards, is also treated briefly.

Section 7 is devoted to some changes which were made to the guidelines after the draft edition was released, including the definition of point of compliance, a more detailed definition of the fault level to be used in allocation calculations and a change in terminology to match the three stage allocation process used in IEC standards.

3. Equipment Characterisation

3.1 Emission Levels

With the cooperation of retailers the harmonic emissions from all the domestic appliances on their shop floor were tested to give an understanding of the performance of equipment entering the system. Monitoring equipment as well as an arbitrary waveform generator was transported to the shops and four tests were performed on each device. The first three tests were with a sinusoidal waveform (230V, 230V-6%, 230V+6%) and the fourth test was with a 230V waveform with harmonics (flat-top waveform) [5]-[6]. A small representative sample of devices were purchased and taken to the laboratory for further testing (voltage dip/sag testing and in-rush testing [7]). This was necessary due to the stress the voltage dips put on the devices and possibility of damage.

The desire for energy efficiency is driving the adoption of new technologies such as Compact Fluorescent Lamps (CFLs), LED lighting (domestic & street lighting), and heat-pumps for space-heating & water-heating. The performance of even relatively low power devices, such as CFLs, needs to be understood as the combined effect of the millions entering the system can be very significant [8].

Heat-pumps are another energy efficiency technology that is rapidly being adopted. As a result of subsidies (as well as the Canterbury earthquakes) large numbers have been install in recent years. Moreover, new generation of water-heaters are based on heat-pump technology.

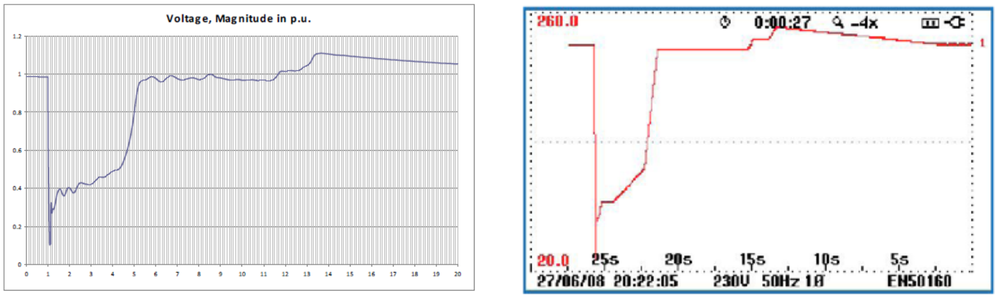
The new generation of fridges and freezers entering the market are based on inverter technology rather than the ON/OFF cycle switching controlled by a thermostat. The characteristics and emissions are very similar to the Variable Speed Drives (VSDs) used in industry and for irrigation, but at a smaller power level. VSDs are widely used in industry and are a major source of harmonic emissions from factories.

In the rural sector the high prices for dairy products and low prices for wool and lamb has resulted in many cropping and sheep farms converting to dairy farming. Often these farms are situated in dry areas where intensive irrigation is required to maintain adequate grass growth for the herds. These irrigators use submersible pumps that are fed from Variable Speed Drives (VSDs). Due to the size of these pumps, typically 100 kW up to 2.2 MW, some type of soft-starting is required. VSDs rather than soft-starters are selected due to the additional features they provide and the incremental cost. These VSDs have caused harmonic problems, which have interfered with protection equipment in the rural network [9]-[10].

Besides the aforementioned appliance testing in situ PQ measurements were made on farm irrigation pumps, dairy factories, PV installations, wind turbines, and Electric Vehicle (EV) chargers. PQ data was also gathered from installations and networks which already have PQ monitors installed (mainly wind-farms and two Utilities).

3.2 Immunity

Immunity to voltage dips/sags testing has been performed as well as quantifying the ability to harden equipment to voltage dips/sags (by adding extra dc bus capacitance). Two voltage dip/sag profiles were supplied by Transpower NZ Ltd to be used for testing heat-pump performance. Fig. 1(a) shows the supplied profile for a hard fault based on measurements of these events while Fig. 1(b) displays the digitised representation that the arbitrary waveform generator applies to the device under test. Testing has been performed at sites where malfunctions have been blamed on poor PQ.



(a) Supplied voltage profile for a hard fault

b) Voltage profile generated by an arbitrary waveform generator

Fig. 1. Voltage profile for a hard fault.

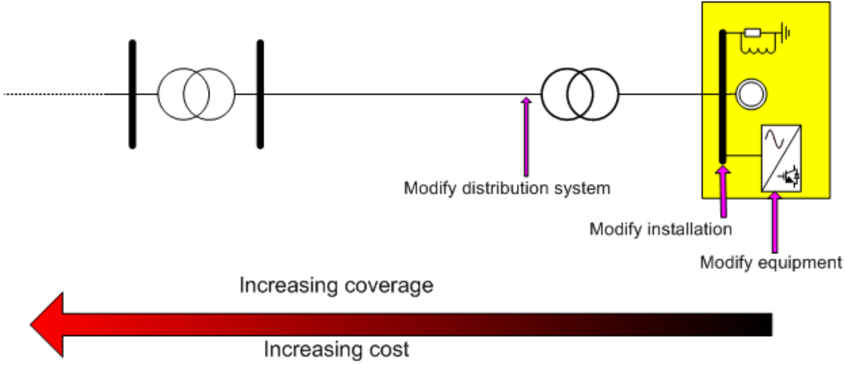


Fig. 2. Mitigation position.

3.3 Emission level reduction

As depicted in Fig. 2 the cheapest method to mitigate PQ emission is generally at the equipment level and the cost escalates as the mitigation is taken further into the system. As an example the harmonic emissions from a simple rectifier used for CFL drops from 120-200% to 30-50% by splitting the dc capacitance into two small capacitors and adding some diodes to form the well-known Valley-Fill circuit topology. Harmonic reduction can also be achieved by reducing the dc capacitance and allowing a high ripple on the DC voltage. On medium to large converters, where the cost can be justified, there are many possibilities, such as use of:

(a) Multiple bridges (with different transformer winding configurations)

(b) Reinjection techniques
(c) Multi-level techniques
(d) Pulse-Width Modulation based rectifier
(e) Active front-end to converter
(f) Artificially increasing the dc side inductance

The use of passive and active filtering is an option that may be required to meet design requirements

4. Electrical Network Characterization

4.1 Existing Disturbance Levels

A national survey of existing PQ disturbance levels has been carried out at MV & LV levels. Monitoring was also performed at customer premises. Each Lines company receives a report on their PQ disturbance levels on their network. Once the national survey has been completed a report will be produced benchmarking the different networks (identity of Lines companies will be anonymous).

4.2 System Impedance

With the help of the EEA the Lines companies were surveyed to obtain information of typical network topologies and fault levels. Supply impedances at harmonic frequencies were established employing techniques related to change in disturbance level with change in injection, capacitor switching operations, loop testing (performed by the utility) and using ball-park calculations.

4.3 Mitigation

It is always better to avoid the problem before it occurs by using equipment with lower PQ emission levels. However, sometimes it is necessary to fix the problem after it appears. Harmonic filters are the obvious answer for harmonic problems. They are not always the best option as they can be expensive, difficult to retrofit due to size considerations and continually consume power. For example mitigation of the intolerably high 5th harmonic levels in rural areas was studied [9]-[10]. Harmonic filters were investigated however the preferred solution was the use of zig-zag transformers (Dnz0). These were deployed and the improvement monitored. Dairy factories that convert milk to milk-powder use a large number of VSDs and create significant harmonics.

5. Harmonics

5.1 Setting of Compatibility and Planning Levels

Since equipment is now sold on a world market, most of this equipment will be designed in terms of emission and immunity for conformity to international standards. Therefore, a new set of limits for LV systems which are better aligned with international standards is required. The new compatibility levels for harmonic voltages are shown in Table I. The planning level at LV is set to 90% of the compatibility level. The difference between the planning levels at different voltage levels sets the allowed emission at the voltage level and is a function of the system impedances. From the survey work, five typical network configurations were identified and typical impedances were obtained. These were then used to develop the planning levels at all the other voltage levels [11]. This process is illustrated in Fig. 3. Of note is that the triplen harmonic levels in Table I are significantly higher than those specified in IEC standards. Measurements on the New Zealand system showed some triplen harmonic levels at some locations are already double IEC limits, with no adverse effects. The reasons for having lower triplen harmonic levels would have to be coupled to the fact that they are of zero sequence. Telephone interference would be one obviously consideration. There has been a long history of telephone interference with analogue circuits in New

Zealand, but with modern digital technology this problem has largely disappeared. Consequently, triplen & non-triplen odd harmonics are not distinguished in terms of approach and formulae used in the PQ Guidelines.

TABLE I

COMPATIBILITY LEVELS FOR HARMONIC VOLTAGES (RMS VALUES AS PERCENTAGE OF R.M.S. VALUE OF THE FUNDAMENTAL COMPONENT) IN LV & MV POWER SYSTEMS

Odd harmonics non-multiple of 3		Odd harmonics multiple of 3		Even harmonics	
Order h	Harmonic Voltage %	Order h	Harmonic Voltage %	Order h	Harmonic Voltage %
5	6	3	5	2	2
7	5	9	3.0	4	1
11	3.5	15	2.0	6	0.5
13	3	21	1.5	8	0.5
17≤ h ≤49	2.27×(17/h)-0.27	21< h ≤45	1.5	10≤ h ≤50	0.25×(10/h)+0.25
Note: Total Harmonic Distortion (THD): 8%					

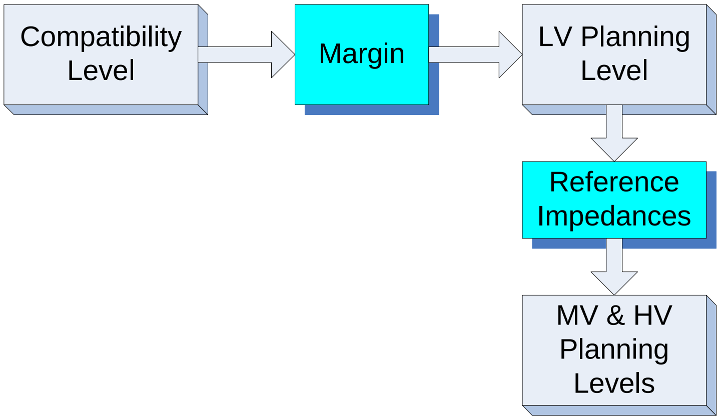


Fig. 3. Process of setting planning levels

5.2 Allocation of Emissions

Any emission allocation method needs to be:

- Fair
- Well defined
- Have a sound technical basis
- Practical

The voltage droop philosophy [12]-[14] fulfils these criteria and has been adopted in the guidelines. Customers and equipment manufacturers can control the time variation of their installations/products better than utilities can control their harmonic voltages. Because of this it is justified to compare the installation or device's 100% (maximum) current with the allocated value whereas the harmonic voltage is based on the 95% level.

The allocated harmonic voltage contribution an installation is:

$$E_{Vhi} = \frac{L_h}{(V_d SCR)^{1/\alpha}} \tag{1}$$

where:

L_h - is the relevant planning level.

SCR – the Short-Circuit Ratio

V_d – Voltage droop (proxy for the system impedance) [$V_d = \max(0.3, 2/SCR)$]

The harmonic current allocation is:

$$E_{Ihi} = \frac{E_{Vhi}}{X_{ih}} \tag{2}$$

In the absence of resonances and if not a triplen harmonic the impedance can me approximated by:

$$X_{ih} = \frac{h}{FL_i} \tag{3}$$

giving:

$$\frac{E_{Ihi}}{S_i} = \frac{L_h SCR^{1-1/\alpha}}{hV_d^{1/\alpha}} \tag{4}$$

5.3 Short-term Harmonics

For short-term harmonics the major limitation is not thermal effects but interference with neighbouring equipment. The compliance based on 10 minute reading can allow intolerably high harmonic levels for a short time. For this reason both voltage harmonics and current harmonics have short-term limits that are separate to the statistical limit of 10 minute readings taken over 1 week. The short-term harmonic voltage limit is 150% of the steady-state value. Many instruments give for each 10 minute reading the ratio of the maximum 3 second value to the average, hence the maximum 3 second value is available. Each 3 second recording must be below 150% of the steady-state limit.

In order to limit the short-term THD level, the short-term harmonic current emission must be limited. The multiplication factor for short-term harmonic current emission is:

$$F = \frac{20}{1 + 19 * \left(\dfrac{S_i}{S_t}\right)} \tag{5}$$

Where S_i / S_t is the ratio of the installation size to supply capacity.

With an aim of limiting the harmonic voltage to 1.5 times the steady-state limit, if five 10 minute readings are at the limit and one at 1.5 times the limit then the average of the r.m.s. values is approximately 1.05 times the limit (with rounding). Therefore if a load is very small then F is approximately 20 and the short-term harmonic current limit is 21×1.05=21 times their steady-state limit. If a load is large the F is approximately 1 and their short-term limit is 1×1.05=1.05 times their steady-state harmonic current limit.

5.4 Inter-harmonics

Due to the negative consequences inter-harmonics need to be limited. Noted negative effects of inter-harmonics are; interference with equipment causing them to malfunction (protection relays, grid-tie inverters, PLC, and home appliances), acoustic noise and vibration, increased thermal heating, and in the case of resonant excessive voltages and/or currents. One additional consequence is light flicker in fluorescent lamps.

The main frequency divisions are:

<50 Hz (sub-harmonics)
50 to 2.5 kHz
2.5 to 9 kHz
9 to 150 kHz
>150 kHz

Disturbances in the frequency range 2.5 to 150 kHz are classified as; Narrowband, Broadband or Recurring oscillations. The indicative planning levels for inter-harmonics and other high frequency components from the guidelines are reproduced in Table II.

TABLE II
Inter-harmonic and High Frequency Limits
Indicative Planning Levels

Frequency	Applied to		Reference Level ($\%V_1$)
0 – 100 Hz	Inter-harmonics	Discrete frequency	0.2%
Ripple frequency		Discrete frequency	0.1%
100 Hz to 2.5 kHz	Inter-harmonics	Discrete frequency	0.5%
2.5 to 9 kHz	Harmonics/ inter-harmonics	Discrete frequency	0.2%
2.5 to 9 kHz	n/a	Band of frequencies	0.3%
9 to 150 kHz	Harmonics/ inter-harmonics	Discrete frequency	0.2%
9 to 150 kHz	n/a	Band of frequencies	0.3%

5.5 Ripple Control Systems

In New Zealand ripple control is widely used and these use both harmonic and inter-harmonic frequencies. Therefore compatibility with ripple control is important. Since ripple receivers may respond to as little as 0.3% of the nominal supply voltage any inter-harmonics above this can disturb if its frequency is the same as the operational frequency of the receivers. Hence the reference value is set to 0.1% of the nominal supply voltage. This limit is location specific as different regions will have different ripple frequencies.

One issue was whether control signals such as ripple control should be called out as an exception to the limits or made to comply with the short-term emission limits. The latter approach was taken.

6. Other PQ issues

The EEA PQ Guidelines also address (to varying degrees):

- Steady-state voltage
- Voltage unbalance
- Voltage fluctuations and flicker
- Voltage dips/sags
- Voltage swells
- Frequency deviation
- Telephone Interference
- D.C. current injection
- Wiring and contact defects
- PQ monitoring

For these PQ issues either international or local standards have been drawn upon.

6.1 Steady-state voltage

Except for momentary fluctuations, the voltage magnitude supplied to an installation must be kept within ±6% of the nominal voltage (230 V for phase-to-neutral LV). Hence the maximum range is 216.2 Volts to 243.8 Volts. The immunity of equipment is expected to ±10%, giving a margin between the disturbance level and immunity level. Assessment is made of the 99th percentile and 1st percentile of 10 minute rms readings over a one week period.

6.2 Voltage Unbalance

A compatibility level of 2% has been adopted and the indicative planning levels as per IEC 61000-3-13 used (Table III).

TABLE III
Indicative Planning Levels

Voltage level	VUF - Planning level (%)
MV	1.8
HV	1.4
EHV	0.8

6.3 Voltage Fluctuations and Flicker

The compatibility levels of P_{st} and P_{lt} for LV power systems of 1.0 and 0.8 have been adopted (as per IEC 61000-2-2). The indicative planning levels of AS/NZS61000.3.7, shown in Table IV, were also adopted. It is acknowledged that this approach is inappropriate for newer technologies and flicker based on direct light measurements is being developed but not yet at a stage ready for incorporation into standards or regulations.

TABLE IV
Indicative values of planning levels for P_{st} and P_{lt} (L_{Pst} and L_{Plt})

	MV	HV & EV
L_{Pst}	0.9	0.8
L_{Plt}	0.7	0.6

Flicker problems have been experienced due to inter-harmonics. Power electronic converters act like a modulator that couples frequencies between the ac and dc sides. For example 175 Hz ripple signal can cause a 25 Hz component in the light from fluorescent lights. The strength of this coupling is design dependent and choosing a different model of ballast often removes the problem. On the other hand flicker in incandescent lamps can be solved by replacing them with CFLs.

6.4 Voltage Dips/Sags

The ITIC curve is a voltage tolerance curve which shows the dip/sag depth and duration region which equipment should be able to tolerate. It covers both voltage dips and voltage swells. Therefore the lower limit of the ITIC Curve is a measure of the voltage dip/sag envelope which equipment should withstand. Although designed for computer and electronic business equipment (its predecessor was the CBEMA curve), the immunity of other equipment is often tested against ITIC Curve. This is due to the lack of internationally accepted limits for immunity of other class of equipment to voltage dips (the one exception is SEMI 47). A recent contribution gives 230V voltage dip/sag tolerance of 230V equipment [15].

Many sources of voltage dips are unplanned events in which an emission allocation is inappropriate. However, for events for which an emission allocation is appropriate (e.g. motor starting), in accordance with the practice of 10% margin between the compatibility limit and planning level, the deviation from nominal voltage is multiplied by 0.90 to give a planning level as a deviation from nominal voltage. This is then converted to a retained voltage limit (see Table V). Both voltage dip/sag time and phase aggregation are dealt with.

The measurement of existing disturbance levels have clearly shown that faults cause the voltage dips which are outside of the voltage dip/sag limits and this is due to the slow operating speed of distribution system protection equipment.

TABLE V
Voltage Dip/Sag Limits

Duration of Event	**Deviation from Nominal**		**Retained Voltage**	
	Immunity (ITIC Curve)	**Planning Level**	**Immunity (ITIC Curve)**	**Planning Level**
< 2 ms	100%	90%	0%	10%
20 ms to 0.5 s	30%	27%	70%	73%
0.5-10 s	20 %	18%	80%	82%
> 10 s	10%	9%	90%	91%

6.5 Voltage Swells

Voltage swells occur when the r.m.s. voltage rises to more than 110% of nominal for a period of 1 minute or less. As with Voltage dips/sags many sources of voltage swells are unplanned events in which an emission allocation is inappropriate. However, for events for which an emission allocation is appropriate (e.g. load rejection) , in accordance with the practice of 10% margin between the compatibility limit and planning level, the deviation from nominal voltage (from ITIC curve) is multiplied by 0.90 to give a planning level as a deviation from nominal voltage. This is then converted to a percentage voltage level limit (as is done for voltage dips/sags). As based on the ITIC curve there are four timeframes: 0.1 ms to 1 ms, 1 ms to 3 ms, 3 ms to 0.5 s and > 0.5 s.

6.6 Transients

Transients can be classed in different ways. Common classifications are:

(a) Shape of transient (oscillatory or impulsive)
(b) Source of energy for the interaction (electromagnetic transient or electromechanical transient
(c) Time-scale of the phenomena (fast, medium or slow transient), which is linked to the objective of the analysis (insulation coordination, switching study, over-voltage study, transient stability).

The transient 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.
- Malfunction due to high dv/dt.
- Multiple zero-crossings causing timing issues.

Due to the diversity of transient responses there is no straightforward way of specifying and imposing transient limits. As a first step for switching transients the peak voltage should not exceed the recommended levels shown in Table VI.

The frequency of oscillation needs to be estimated and dv/dt compared to the immunity of all equipment subjected to it. Likewise the immunity of equipment to multiple zero crossings needs to be ascertained.

TABLE VI

Recommended limits on peak voltages

Peak as percentage of normal steady-state crest voltage	Duration of event
200	< 1 ms
140	1 to 3 ms
120	3 ms to 0.5 s
110	> 0.5 s

6.7 Frequency deviations

The frequency is to be maintained within ±1.5% of 50 Hz, except for momentary fluctuations. The momentary fluctuation clause is to cover those inevitable system events (fault or loss of generation) over which there can little or no control. The expected frequency swing in a major event is ±10%. This has been observed during system events that have seen frequency in one island going to 55 Hz and the other 45 Hz. Both spinning reserve and automatic under-frequency load shedding (AUFL) are essential to maintain transient stability as N.Z. has no neighbouring electrical system to interconnect with. Historically a minimum of two 16% blocks of load in each island could be automatically disconnected to ensure restoration of the system. Because the nature of the power system is changing over time it is essential that the AUFL is reviewed periodically. Due to the makeup of the generation in each island, and historical reasons, the trip frequencies are different, as shown in Table VII.

The ability of generation to remain connected when the frequency drops due to real power deficit is essential to maintain stability. Historically the frequency swing of the North Island was 45 to 55 Hz, however, with deregulation and investment in generation coming from companies non-compliant plant has been built (particularly combined-cycle thermal plant). This has necessitated the need to reduce this frequency range.

TABLE VII

Drop-off Frequencies for AUFL

	Block 1		**Block 2**	
	SI	NI	SI	NI
Frequency (Hz)	47.5	47.8	45.5	47.5

6.8 Power quality monitoring

Many utilities currently restrict themselves to short-term reactive PQ monitoring as a response to a particular customer complaint. This gives no insights as to the general level of PQ in a network or feedback as to the effectiveness of PQ management strategies. It also ignores some PQ effects such as harmonic heating which operates over a long-term period and may not be identified as a power supply issue. A better approach is long term proactive PQ monitoring, involving fixed monitors measuring all PQ parameters of interest at a sample of sites. This not only indicates the present PQ health of the system but can show the evolution of future problems such as may be caused by increasing penetration of electric vehicle charging or other new load and renewable generation technologies. It is important to recognize the strict measurement protocols which are necessary for consistent PQ measurements across a network. The guidelines discuss the applicable standards and issues associated with the measurement of particular disturbances.

7. Refining of the EEA PQ Guidelines

The project was extended for 1 year after the PQ Guidelines were released and in this period the following were performed:

- Electricity industry personal were educated on how to use the PQ Guidelines (through workshop and ongoing communication).
- Feedback sought on improvements.

- Additional studies performed on identified issues (impact of harmonic resonances).

This was definitely beneficial and the final EEA PQ Guidelines was issued early 2013 [14].

The idea of Point of Compliance (POC) or Point of Evaluation (POE) was introduced. For most customers the Point of Common Coupling (PCC) will be the point of compliance, however, for some customers this does not give enough certainty. This is because the location of the PCC will depend on the location of the nearest neighbour, which can change over time and a customer has no control over where the PCC is, and when it changes. This complication here arose due to the case of a new factory which was being built in a rural area. Transmission lines were installed from the closest substation. The PCC was at the substation but it was acknowledged that other customers will be connected to the line over time. Therefore in makes sense to make the POE at the end of the MV line and design the installation for this.

A clarification of what fault level is to be used for allocation purposes was made. The MVA fault level will fluctuate based on system loading and most utilities when asked give the maximum fault level as this is what they are geared-up for, yet it is the normal minimum that should be used for harmonic allocation. Hence the fault level to be used is: *"the minimum fault level that occurs over a reasonable percentage of the time. (less than one week a year should be ignored)."*

Initially the PQ Guidelines had a two stage allocation process so that all installations had to comply regardless of size. There was a consensus to realign the stages in the PQ Guidelines to AS/NZS and IEC three stages. This means allowing connection if the Short-Circuit Ratio (SCR – ratio of fault level to load power) is sufficiently high (i.e. $S_i/S_{SC}<0.2\%$).

The effect of harmonic resonances caused by power-factor correction capacitor banks was investigated as this will influence allocations. These studies investigated directly connected capacitor banks as well as capacitor banks with a 7% detuning reactor. The effect of power-factor correction capacitors on the 317 Hz ripple frequency has also been examined.

The Guidelines will be expanded and refined over time based on feedback from those using the guidelines. Critiques and reviews by practitioners are appreciated [15]. This feedback is essential to process of improving the guidelines as it informs where further work is needed,

8. Conclusion & Recommendations

The issuing of the *EEA Power Quality (PQ) Guidelines* is a first step in having a national requirement for PQ. The guidelines are at present instigated through the Electrical Network companies adopting it as part of their connection codes.

These guidelines represent a comprehensive approach to all PQ disturbances of interest in New Zealand combining material from many IEC and other documents. A discussion had been given of its approach to some specific PQ disturbances, emphasizing harmonics where many changes have been made to past New Zealand practices, including harmonic limits, determining harmonic current allocations to large customers and allowing for short term currents in excess of allocations. Some of the other significant issues are steady state voltage, voltage unbalance, voltage fluctuations and voltage dips.

Recommendations:

Equipment standards need to be examined carefully so as to reduce the number of devices connecting to the network with unacceptably high PQ emission levels. This has been completed AS/NZS61000.3.2 but is needed for the other AS/NZS standards. Better methods of informing suppliers and policing the AS/NZS standards are also required.

Section 31 "*Requirements relating to quality of supply*" of the Electricity (Safety) Regulations 2010 urgently needs revisions [16]. The statement "*whichever of the following standards is applicable is deemed to be compliance with subclause (1):*" is far too broad and open to a range of interpretations. Moreover, the incorrect standards are cited (IEC rather than the AS/NZS version). There are differences!

9. Future Work

Work is continuing on ferro-resonance, to identify the cable lengths and situations where ferro-resonance is likely to occur and the mitigation methods possible. In particular verification of the Baitch Ferro-resonance critical cable length formula [17] is being performed.

Much more work on emission and immunity of equipment at the higher frequency ranges is urgently needed. This is because the newer technology uses higher switching frequencies (2 to 9 kHz and now moving to 9 to 150 kHz range) and hence produces emissions in these frequency bands. Many devices use a switching frequency in the range 10 to 40 kHz while some equipment use as high as 100 kHz. However, the immunity of equipment at these frequencies is sometimes lacking as there has not been any requirement for testing at these frequencies in the past. Moreover, some devices do not use a fixed switching frequency but more a spread spectrum. Although this lowers the emission levels it is more likely that it will have emission at a frequency that will adversely affect another device. The specification of inter-harmonics and band of harmonics needs to be developed more and harmonised better with the Meister curve for ripple control.

In due time typical voltage dip/sag rates are to be added to give a benchmark that utilities can gauge their network's performance against. In order to develop this more comprehensive data on the existing voltage dip/sag rates is required.

In addition to allocation of PQ disturbances to installations, their compliance assessment also has to be given due consideration. In this regard the work presented in the CIGRE C4.109 report may have to be given due consideration in addition to ongoing and recently completed work [19]-[21].

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