Australian Power Quality and Reliability Centre

Power Quality in Future Low Voltage Electricity Networks

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Endeavour Energy

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1. Executive Summary

This technical note forecasts how power quality (PQ) issues in low voltage (LV) networks may develop over the next decade or so. It has four sections to cover PQ concepts, PQ disturbances, possible developments of the network and the future of PQ. Forecasting in this area is difficult because there are several ways in which electricity networks may develop depending on whether investment will be for short term or long term returns. The present debate in Australia seems to emphasise the short term and this may increase many of the long term PQ issues. With this proviso, we conclude:

1. Maintaining the steady state voltage within acceptable limits will be the most important issue because of the new Australian voltage standard and the impact of embedded generation and electric vehicle charging. Unbalance (differences in the rms value of the three-phase voltages) could be an issue depending on how the electric vehicle charging issue is implemented.
2. Future installations will become more susceptible to voltage sags. Smart and strong grid developments can reduce these to acceptable levels.
3. Future residences will become more susceptible to transients; utilities and installers will need to develop a methodology for dealing with this.
4. The situation with harmonics is complex. Low frequency harmonics could increase depending on the scale of power factor correction and whether detuning reactors are used. Neutral cable sizing practices in large three-phase installations may need to be reassessed if there is a continuing growth in single-phase power electronic loads. High frequency harmonics will increase and will be difficult to deal with because of the uncertain effect of stray capacitance. In general, harmonics will be more of a compliance problem rather than a major cause of customer complaints.
5. Voltage fluctuations will become less of an issue.

2. Power Quality & Associated Concepts

2.1. Characteristics of Electricity Supply

The electricity supply voltage has three characteristics - the rms (root-mean-square) voltage level, the frequency and the waveshape. In Australia today these are set ideally at 230 V rms, 50 Hz with a sinusoidal waveshape. Electrical equipment can operate with its best performance (highest efficiency, rated torque, specified lumen output etc) only if these characteristics are within a narrow range close to nominal values. Electrical equipment can still operate to some extent with characteristics outside this range, but efficiency and performance cannot be guaranteed.

2.2. Power Quality

Power Quality (PQ) concerns the range of disturbances on the electricity supply such that equipment does not operate as intended. These disturbances affect the magnitude of the voltage waveform, its waveshape and its frequency. The frequency is controlled centrally by overall control of generators, and is very seldom a problem. This technical note will be concerned with the voltage magnitude and waveshape, particularly where it involves interactions within the distribution network. A good summary of PQ is to be found in [1] and [2].

2.3. Reliability

Reliability or Continuity of Supply concerns the availability of the supply with characteristics allowing useful but not necessarily optimal performance of electrical equipment.

2.4. Quality of Supply

Often both PQ and Reliability are grouped with Customer Service under the umbrella term Quality of Supply [3]. Good Quality of Supply from a distribution company requires it to deliver a supply with a small number of interruptions, with a supply voltage having tightly controlled characteristics, and to respond quickly to customer complaints when there are supply difficulties. Figure 1 shows diagrammatically the relationship between these concepts.

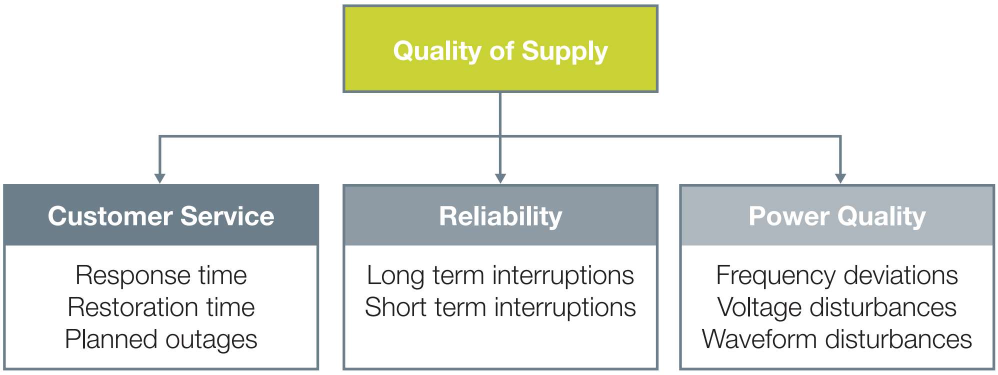

Figure 1 Relationship between Quality of Supply, Customer Service, Reliability and Power Quality

2.5. Origin of PQ Problems

Poor PQ may originate as a result of atmospheric events, utility operation, other consumer's installations or within the affected installation. It can also be caused by external events such as motor vehicle impact.

2.6. Importance of PQ

PQ has become more important over the last 15 years because of:

- Decrease in immunity of some sensitive equipment with increasing use of electronic power supplies with inadequate filtering.
- Increase in emission of distorted current waveforms due to increased use of power electronics.
- Higher integration of manufacturing processes so that a loss of supply in one production line can result in significant delays and economic losses.
- Customers becoming more rights conscious.
- Regulator concerns and imposition of minimum PQ standards.

2.7. Structure of the Supply

The largest generators in the power system feed into a high voltage transmission system which is highly interconnected to allow flexibility of generator operation and for continuity of supply during faults or maintenance outages. The power flows to domestic LV customers through a series of step down transformers, reducing the voltage at each stage. The final stage of low voltage involves a distribution transformer situated on a pole-top or within a kiosk supplying about 50-100 residences though underground cable or overhead lines up to about 400 m long. The supply is generally three-phase requiring 4 wires, three active and one neutral. Most houses are single-phase and are connected to one of the active conductors and to the neutral. Some houses with a very large load (generally 20 kVA or more) are connected three-phase to all three active conductors as well as to the neutral.

2.8. Voltage

The voltage between an active conductor and neutral is nominally 230 V rms, corresponding to a peak value of 325 V. The voltage waveshape is sinusoidal, with a frequency of 50 Hz or 50 cycles per second. This gives a period for 1 supply cycle as 20 ms. When the three voltages in a three-phase system are equal in magnitude but time-shifted by 6.7 ms, the supply is said to be balanced.

2.9. Impedance

It will be seen that the cause of PQ problems depends in many cases on the impedance between the customer installation and the power system generators. The impedance of an electric circuit can be measured by the voltage drop required to force a current of 1 Ampere through it. One part of the impedance is called resistance and is due to the restricted cross-section of the network conductor. Another part is called reactance, only occurs in ac circuits, and is due to the setting up of magnetic fields changing at 50 cycles per second.
In general, the impedance of the supply system causes the voltage to reduce in the direction of power flow.
The impedance of a circuit can be reduced by reducing its length, increasing the conductor cross-section and reducing the spacing between the separate conductors.

3. Types of PQ Disturbances

The list below is not complete but comprises the most important PQ issues in Australia at present. Disturbances described in Sections 3.1-3.4 are voltage magnitude disturbances while Sections 3.5 and 3.6 describe voltage waveshape disturbances. Some general aspects of PQ will be discussed in Section 3.7.

3.1. Steady State Voltage (and Power Factor)

At light load, the output voltage of a distribution transformer is set by the tap setting of the transformer and the voltage control of the upstream medium voltage (MV) system. The voltage reduces with increasing customer load, especially further away from the transformer, because of the interaction of customer current with the impedance of the supply system. The reduction in voltage seen at a particular installation depends on the load current drawn by all the customers connected to the transformer and the position of the installation along the line. The maximum voltage drop occurs during peak loading particularly at the far end of the LV supply line. The specification for voltage at the point of connection is a range of 230V – 6% to 230V + 10%. Voltages greater than this may cause equipment insulation to degrade faster than intended resulting in a reduced lifespan. If voltages are less than this, equipment may fail to operate as intended. Motor-driven equipment may fail to start or motors might overheat and trip or be damaged.

Wiring within a customer's installation also has impedance and contributes to voltage drop up to the point where customers' equipment may be connected. Installations should be wired with conductors of adequate cross-section so that the maximum voltage drop from the point of connection is no more than 5%. Considering the voltage range at the point of connection, we see that equipment must be able to operate acceptably within a voltage range of 230 + -11% to 230 +10%.

Power factor is a related issue to voltage. Two types of power factor need to be distinguished – “displacement power factor” which concerns out-of-phase fundamental current and “total power factor” which concerns distortion current. In general, when the term “power factor” is used without qualification, there is a convention that total power factor is intended. The statement “the power factor can be improved by shunt capacitors” can be very misleading when there is distortion present in the current.

- One has to be very clear which power factor is intended. Shunt capacitors are only able to correct displacement power factor, not total power factor.
- Shunt capacitors have adverse effects on the impedance of the power system at high frequencies and this may amplify harmonic distortion.

Where capacitors are required to correct displacement power factor, it is possible to prevent them amplifying harmonic distortion by the addition of an appropriately sized series reactor, commonly called a “detuning reactor”. The only way to correct total power factor when there is distortion is to filter out the distorting current.

3.2. Unbalance

The three voltages of the active conductors (Sections 1.7, 1.8) are ideally similar in magnitude and time-shifted by 1/3 of a period or 6.7 ms. If the single-phase residences are drawing roughly equal current and are properly distributed across the three-phases, the voltages will be balanced along the LV supply line. In practice this is hard to achieve and the downstream voltages will in general be different in the three active conductors. Such a set of voltages is said to be unbalanced and can cause three-phase induction motors to overheat. A limit of 2% unbalance is often set to avoid this.

3.3. Voltage Fluctuations

Some loads such as welders and rolling mills change in a cyclic manner with a period from a fraction of a second to several minutes. This gives an approximately cyclical change in the voltage magnitude over a similar timescale.

The effect of voltage fluctuations on incandescent lamps is to cause annoying light flicker. This has been studied and limits have been set based on the annoyance to typical individuals. The limit depends on the cycle time, being about 0.3% fluctuation in the voltage for a 0.1 second period.

3.4. Voltage Sags (also known as Voltage Dips)

Voltage sags are short term reductions in the rms voltage. There are two main causes:

- Faults within the power system give a short term reduction in voltage to all loads connected nearby. The most onerous voltage sags are due to faults within the distribution system as transmission system faults are cleared more rapidly.
- The starting of very large induction motors can cause reduction in voltage at nearby loads. The voltage reduction is generally less than for power system faults.

Power system faults can be caused by:

- Lightning strikes
- Wind borne debris
- Animals or birds
- Interference by man (car accidents, trench diggers)
- Failure of equipment

Most faults such as those due to the first three causes above are temporary. They are accompanied by breakdown of air insulation and arcing which can be removed by short-term de-energisation of the local power system. Faults resulting from physical damage to the power system are permanent and require a line crew to correct the damage before proper operation can be resumed.

The power system is designed to recover from temporary short-circuit faults. This is done by upstream protection circuits which open the appropriate circuit breaker for a few seconds. This usually removes short-circuits caused by the first three causes in the above list. The circuit-breaker is inhibited from operating for a substantial portion of a second to allow other downstream fuses to operate first.

When a fault occurs and protection operates as described above, the effect on customers depends on whether they are connected to the faulted feeder or a neighbouring one. In the former case, they will experience a short drop in voltage while the breaker is inhibited, then complete loss of supply for the few seconds that the breaker is opened. If the breaker operation is successful, their supply will then return to normal. This disturbance to the voltage is called a momentary interruption. Customers connected to a neighbouring feeder will see a voltage sag until the faulted feeder circuit breaker opens after which the voltage returns to normal. A voltage sag is formally defined as a reduction in voltage to 10-90% for a time of a fraction of a second to a minute.

The depth of the voltage sag depends on the position of the fault along the feeder. The duration of the voltage sag depends on the short-circuit current. For faults close to the supply point, the sag is deep and of short duration.

Voltage sags can cause equipment to fail if the duration is long enough. The effect is complex and depends on the reduction in voltage during the sag, the sag duration and equipment design. For electronic equipment, in many cases the immunity to voltage sags depends on the size of the power supply filtering capacitor. The most common effect is on electrical clocks which can lose time and blink. Computers may reboot. TVs can suffer temporary loss of picture and/or sound. The effect on a production line can be the temporary loss of the normal operating sequence which can lead to damage to equipment and wastage of material.

3.5. Harmonics

In the past, customer equipment drew a current waveform which was sinusoidal, the same shape as the voltage waveform. The effect of network impedance was to give a voltage drop with no change in the voltage waveshape. Modern equipment is mainly electronic and draws a current with a waveshape which is usually a series of positive and negative pulses which are narrower than would be expected from a sinusoid. The effect is to both reduce the voltage as before and also to change the waveshape, an effect called harmonic distortion. The resultant voltage waveshape is usually like a sinusoid which has been flattened slightly.

There is no complete agreement as to the effect of this on equipment, but it can lead to motors overheating and affect the operation of electronic equipment. The magnitude of voltage harmonics can be measured by many parameters, one of which is THD (total harmonic distortion) which should be limited to 5.5%.

Large industrial and commercial installations are usually connected to a three-phase supply. Ideally, about 1/3 of the appliances in the installation should be connected to each of the three active conductors (see Section 1.7). In the absence of distortion, this results in a cancellation of most of the current in the neutral conductor and it can often be reduced in cross-section relative to the active conductors. When there is harmonic distortion of the current, this cancellation is very poor and there can be an unexpectedly large neutral current. This can result in overheating of the neutral and the risk of fire damage.

3.6. Transients

A very high current is injected into a power line during a direct lightning strike causing high voltages of up to several hundred kV for a duration of 100 μs or more. This voltage transient propagates along the distribution system changing shape and reducing in magnitude. Nevertheless it can still be of sufficient magnitude when it reaches a customer's installation to cause damage to sensitive electronic equipment. It can also induce voltages in other circuits such as control and communication circuits causing damage or false signals. At present there is not much attention given to transients by utilities mainly because measurement instrumentation is complex and expensive and there are no clear limits given.

3.7. Overall Aspects of PQ

Relative Cost

A study presented in [4] looks at the relative economic cost of the above disturbances and estimated relative importance and annual costs as shown in Figure 2. Voltage sags give the largest economic loss. Installations experience roughly ten times as many voltage sags as interruptions and even a short voltage sag can cause as much economic loss as an interruption of ½ hour or so. The steady state voltage inevitably has a wide variation throughout the day and is important as it causes loss of service life. Harmonics and unbalance lead to similar problems but their values at present are sufficiently small to be ignored. Voltage fluctuations are an issue only close to disturbing sources and these are not common. In any case incandescent lamps are being phased out and the new generation of lighting is less susceptible to rapid voltage changes.

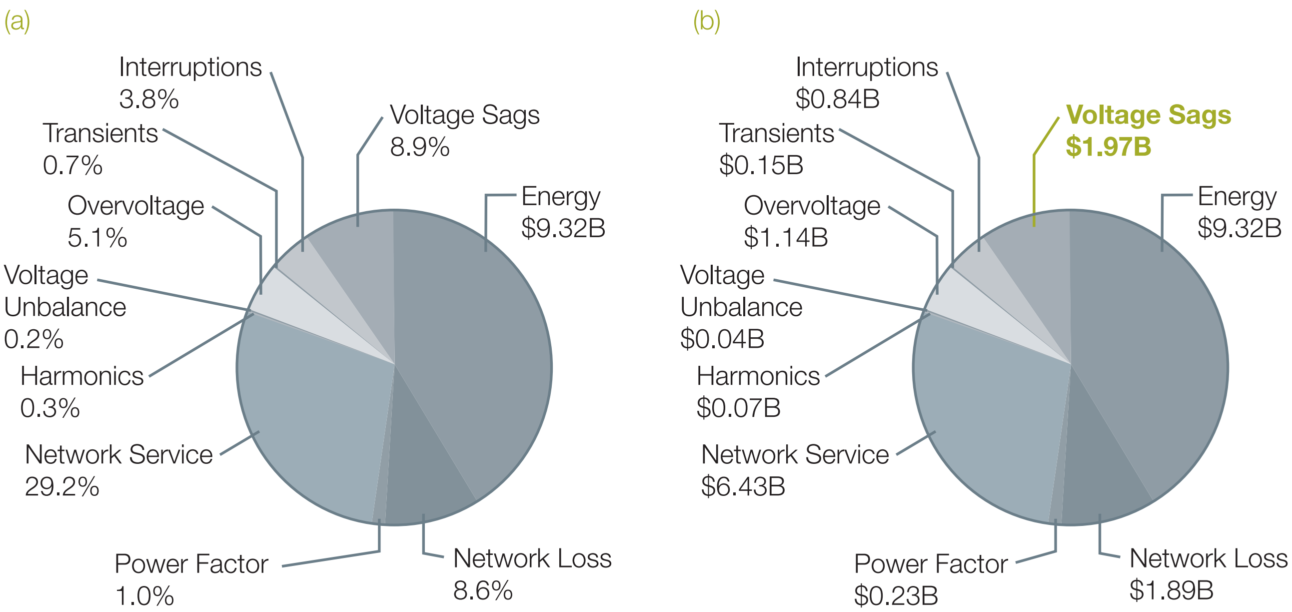

Figure 2 Comparison of PQ disturbances: (a) Relative importance, (b) Estimated annual cost

Electromagnetic Compatibility (EMC) Principles and Responsibilities

All disturbances discussed, except for voltage sags and transients, are due to the flow of customer current in the network impedance. These disturbances are controlled using principles of Electromagnetic Compatibility EMC. The key concepts are planning levels, equipment emission levels and equipment immunity levels which are set in Australian PQ standards following IEC (International Electrotechnical Commission) documents.

- Planning levels are the maximum acceptable limits for the disturbances. They are set according to the damage done to equipment and the cost of equipment immunity.
- Emission levels are the maximum allowable disturbance levels allowed from equipment. They are set according to the assumed power level and usage of individual equipment types.
- Immunity levels are the maximum levels of disturbances which equipment can tolerate and should be larger than the planning levels.

Voltage disturbances are the responsibility of the appropriate distribution companies.

For LV installations equipment emission levels are set in Australian standards. In Europe they are the responsibility of equipment manufacturers but no mechanism has been set up in Australia to enforce compliance. Most equipment sold in Australia is built for a world market and is compliant, but there is the possibility that non-compliant equipment could be dumped on the Australian market. There is some evidence that some early cheaper CFLs (compact fluorescent lamps) which were unacceptable in Europe were being sold in Australia. Installations must also be wired according to AS 3000 including the provision that voltage drops within the installation not be excessive.

MV installations can contain non-compliant equipment provided that the overall disturbing current is acceptable. It is the role of distribution companies to determine this level for each installation depending on the maximum demand of the installation and the fault level at the point of connection. Customers are responsible for meeting these installation limits.

Voltage sags have to be handled differently to the other disturbance types. They are not in general caused by equipment emission and their nature is too complex to allow the setting of immunity levels in any simple fashion. The number of sags per year is limited by low line fault rates, similar to the control of Reliability. The depth of voltage sags is affected by relative fault levels and it is important not to have fault levels unnecessarily high at substations. Sag duration is determined by protection operation and this should be made as short as possible, consistent with the operation of downstream fuses.

Impact on Different Types of Customers

LV customers can be broadly classified as residential, commercial and industrial. Residential customers are generally single-phase and can be connected some distance from the supply transformer. They will be affected most by steady state voltage, harmonics and voltage sags. Customers close to the supply transformer will also be affected by transients.

Commercial and Industrial LV customers are generally three-phase and connected close to the supply transformer. Steady state voltage and harmonics are expected to be of less concern. Unbalance will be an issue for installations where there are three-phase motors. Voltage sags and transients will also be a concern.

4. Likely Future Developments of the Electricity Supply Network

It is difficult to forecast the immediate future of the grid because of competing forces. Many technical developments in power system equipment, instrumentation and communication systems are now becoming more affordable and offer many advantages in terms of efficiency and reliability. However increasing electricity tariffs and accusations of "gold-plating the network" may mean that these developments will not occur as rapidly as was thought a couple of years ago.

Factors which will lead to changes in the network are discussed in the following sub-sections. There are strong connections between some of these items and they are not as independent as the discussion might suggest.

4.1. The Need to Reduce Greenhouse Gas Emissions

This is prompting utilities to look for alternative renewable generation sources. Power systems need to be operated with lower losses. Assets need to be operated with greater utilisation prompting a drive to reduce system peak demand encouraging demand management. Customer loads will incorporate power electronics for higher efficiency.

4.2. Embedded Generation

This comes about because of the need for sustainable generation and regulator pressures to give open access to the grid. The main forms at present are wind at MV and solar photovoltaic units (PV) at LV. These forms of generation are not generation-on-demand and give greater uncertainty as to the load to be met by the large power stations. There are voltage control issues at MV as wind generation is often situated away from load centres where the transmission system is weak. There are different voltage control issues at LV as the system is designed for power flow only in one direction. When PV reverses this flow, there can be undesirable voltage rises and these may be sufficient to trip out some PV inverter units. Embedded generation is often connected to the system via power electronics and this may give increasing harmonic issues particularly at the higher frequencies associated with power switching. Protection systems are not designed to account for embedded generation and may need redesign. There are opportunities for embedded generation to support the system during large disturbances and this may contribute to reducing sag severity.

4.3. Customer Load Technologies

More power electronics is being introduced to make appliances with higher efficiency, smaller volume and lower weight. There is greater use of digital control operating at lower signal levels. This may result in a greater sensitivity to voltage sags. This can be avoided with adequate design if the extra cost is acceptable. Higher harmonic frequencies and interharmonics may result from this growth in power electronics depending on the choice of front-end power conversion technology. Demand management may give customers access to more information from utilities through smart meters and this might result in some customers having overall energy management systems which control lighting, heating and non-critical loads to optimise time-of-day tariff charges. Such systems may be very susceptible to PQ issues from voltage sags, harmonics and transients unless very well designed.

4.4. Electric Vehicle Charging

Electric cars are predicted to be a significant load on the future network, requiring high energy demand which can only be met by continuous charging over many hours. It is likely that most users will want to charge their vehicles at night and so there will be very little diversity. This load will give both voltage drop and current loading problems for the LV network. Harmonic issues at high frequency will again be a problem. Vehicle charging stations do have the capability to contribute energy storage support for the network. Some customers may wish to participate in this if an attractive tariff can be offered.

4.5. Customer Expectations

Changing customer expectations will impact on the operation of the power system. There will be a greater range of loads. Customers will expect a “plug and play” power network where loads and local generation can be connected without special arrangements. Time-of-day tariffs will be offered as a means of reducing electricity bills. Some customers will adopt energy management systems to manage their non-critical loads according to changing tariffs. They will expect greater Quality of Supply, especially Customer Service, Reliability, better regulated voltage and reduced voltage sags. They will be looking for electric energy at the lowest possible rate requiring more to be achieved with the existing infrastructure. This may be taken up by politicians and lead to the usual under-investment/over-investment cycle. A serious consequence is to avoid investment for the long term which will hold up both smart and strong grid developments to give a system which is not robust and which is very vulnerable to a critical event.

4.6. Australia’s Adoption of a 230 V Standard

For many years most Australian utilities had adopted an LV voltage specification of 240 V ±6%. In 2000, Standards Australia published AS 60038 [5] which changed the nominal voltage to 230 V. This standard, based very closely on an IEC standard, gives a very wide range for the allowable voltage and does not specify that a utility’s voltage range must be centred at 230 V. As an interim measure, many Australian utilities adopted the minimum compliance with this standard by redefining their voltage range as 230 V +10%/-2%.

It appears now that there are good reasons to try to reduce the voltage range seen at the point of connection. One reason is to give headroom for solar PV installations to operate as generators without suffering an overvoltage trip. Furthermore it is felt that there will be international convergence to 230 V over the next decade or so and that equipment designed for a world market will be optimised to give best performance, efficiency and service life at this voltage level.

In December 2011 the Australian Standards Power Quality Committee published AS 61000.3.100-2011 [6] which defines a voltage range centred close to 230 V. Voltage readings are taken every 10 minutes over one week and the statistical values $V_{1\%}$, $V_{50\%}$ and $V_{99\%}$ are calculated. $V_{1\%}$ is to be more than 230V – 6%, $V_{50\%}$ is to lie between 230 V 2%/+6% and $V_{99\%}$ is be less than 230 V + 10%. It is expected that utilities will progressively move to this new voltage range over the next decade, with priority given to new sites and where transformers are to be replaced.

For constant power loads, the impact of lower voltages will be to increase currents and network losses. In practice there are many types of loads and there seems to be no clear statement as to the impact that adoption of this standard will have. There may be a need to revisit distribution planning practices to see if losses remain acceptable and to revisit voltage management practices to assure that the new and old voltage standard parts of the power system will coexist without conflict.

4.7. Smart Grid Technology

The power grid of today is a development of a system first used almost a hundred years ago. There have been many new requirements put on it in the last decade in particular and it is clear to many that the existing basic design will soon become inadequate. Power systems equipment, such as lines and transformers, are expensive and people are looking to communications, IT and control to enhance their performance. Hence the emphasis in this approach is on “brain” rather than “muscle”. Many of the associated technologies have become cheaper in the last few years to the extent that trial demonstration sites are affordable, but it will still be very expensive to incorporate smart grid technology throughout the whole network. Some consider that each local part of the power system will have its own particular requirements and that each part will develop its own flavour of “smartness” as required. In this view, the smart grid is mainly an idealised model from which various components are to be taken and added to the real system as particular local problems arise.

The aims of the ideal smart grid are:

- Better, more efficient, and more flexible use of the network
- Price reduction for network use
- Introduction of more customer options including time-of-day tariffs
- Better PQ, especially in voltage control and voltage sag impact
- Self-healing to give better reliability

This is achieved by:

- Parallel communications networks with two-way communications, remote sensors, and distributed processing
- Large data storage, analysis and fast simulation capabilities
- Some additional distributed actuators such as switches, reclosers, on-load tap changers
- Faster protection

4.8. Strong Grid

The strong grid is an enhancement of the basic elements of the present day grid. The main aim is to make a grid which will be very reliable and robust under extreme circumstances including cyber-attack, terrorist attack, and widespread events such as hurricanes and multiple bushfires. Proponents of this concept have expressed the view that a smart grid is too dependent on overall coordination, and in making it smarter it has been made less strong [7]. Elements of the strong grid include:

- Physical strengthening, e.g., metal poles and deeply buried, armoured cables
- Increased redundancy with widespread meshing and parallel paths
- Widespread dispersal of generation including portable generators for use in local emergencies
- Decentralised control which can form stable independent islands
- Use of energy storage, static Var compensators, distributed voltage regulators
- HVDC interconnections

The cost of the strong grid is high because of the size of electric power equipment and the need to acquire line easements and real estate for substations, etc. It is considered necessary if electric power supply to essential services is to be guaranteed under all circumstances.

Of course there are many intermediate stages combining some features of each of these two extremes. In the case of NSW, one might consider a strong grid system for Sydney CBD and interconnections with the Hunter Valley, with a smart grid overlay which can be replaced by decentralised control in extreme emergencies. Aspects of the smart grid might be applied to other cities and the major towns. Some aspects of the strong grid could be applied to important rural areas, for example distributed voltage regulators in long lines.

4.9. Regulator Requirements

It is the nature of government bodies to increase their scrutiny of activities and this is expected in the case of electricity regulators. In the past they have concentrated on Reliability, and this has led to utilities putting much effort in this direction at the expense of PQ. It is expected that regulators will extend their interest to PQ, with some interest already in voltage and voltage sags and with interest in other disturbance types growing in later years.

The S-factor incentive used by some regulators rewards electricity distribution businesses that exceed pre-established Reliability targets and this concept may be applied to PQ as well. It can be applied just to one disturbance type such as voltage or voltage sags or to some weighted combination of different disturbance types.

4.10. PQ Monitoring

At present Australian distributors monitor a sample of their sites with PQ monitoring of voltage, unbalance, harmonics and voltage sags with reporting on a yearly basis. The installation of smart meters with two way communications will be a good opportunity to gather data from many more sites with PQ reporting possible in real time. There will be additional opportunities for extensive data analysis to see if PQ problems are developing and for post-mortem analysis of major events.

It is inevitable that customers will insist that they have access to PQ data collected from their own meterboard. They will then have the opportunity to see data in real time, including the full range of 10 minute values rather than a single summary value taken over a year. Some will react when 10 minute harmonic or unbalance levels, for example, are seen to lie outside the maximum acceptable limits. This may encourage utilities to concentrate on compliance rather than on reducing customer complaints. This can skew the expenditure on improving the PQ performance of the grid if there is a large gap between the PQ limits and the level at which serious problems occur. For example, there might be substantial expenditure on reducing voltage fluctuations even though there might be very few incandescent lights remaining in installations.

4.11. PQ Standards

Some PQ standards are better developed than others. For example the standard on voltage unbalance is reasonable with little further development required. Conversely the standard on harmonics has limits which cannot be justified and the method for allocating harmonic current to MV customers is poorly specified. There is no detailed standard on transients. It is expected that further work will lead to better understanding which will flow into the IEC standard drafting process and later contribute to the design of LV networks and installations.

5. Future PQ Challenges

5.1. Voltage

Voltage control is expected to be the major issue. The new Australian voltage standard will require extensive retuning of the whole distribution system. Voltage retuning has to be done simultaneously at the zone-substation and downstream distribution transformers since there are interactions both upstream and downstream. Embedded generation at all voltage levels will give power flows and voltage increases for which the present system is not designed. At LV, the dominant PV solar cell units will encourage high voltages in the day time, particularly at times of light load. Conversely, electric vehicle charging will reduce the voltage at night. The length and cross-section of LV conductors will need to be re-evaluated for future LV system construction. The use of distributed voltage regulators simplifies the technical challenges but may impose an unacceptable additional cost in most situations.

5.2. Unbalance

It is pointed out in [8] that if electric vehicle chargers are single-phase units, they will constitute a load with little diversity but which might impose significant unbalance on the system. This could limit the maximum power taken through the distribution transformer below the firm capacity. He gives the results of a probabilistic simulation which shows that for 50% of the charging scenarios the maximum power taken from the network is no more than 50% of the maximum available under balanced conditions. This is an issue which could be addressed to some extent with smart grid features.

5.3. Voltage Fluctuations

At present the most significant impact of voltage fluctuations is on incandescent lamps. As these are phased out, it is expected that higher levels of voltage fluctuations will be able to be tolerated on the network. There has been some discussion suggesting that CFLs might show a low immunity to interharmonics [9].

5.4. Voltage Sags

It needs to be stressed that the voltage sag immunity of a complex system is determined by the least immune part, not the most immune part. The increasingly sophisticated equipment within residential customer installations in particular, being made up of many components, is expected to show a greater susceptibility to voltage sags. Grid developments of both the smart and strong type have the improvement of Reliability as one of their goals and this should improve sag rates as well. Voltage sag durations will be greatly reduced if the smart grid is developed to give unit protection with fast breaker operation for MV feeders.

5.5. Harmonics

The harmonic situation is rather complex. One needs to think separately about low frequency (LF) harmonics (up to about the 20th order) and high frequency (HF) harmonics. There will be some growth in lf harmonics due to increasing use of electronics with front-end capacitor-filtered rectifiers. The use of embedded generation will lead to a growth in harmonic generating loads without a corresponding increase in fault level. This will increase the system impedance relative to the total load giving an increase in harmonic voltages [8]. If power factor correction is widely used without detuning inductors, there will be harmonic resonances at the important harmonic orders 5-9. This could give a further increase in harmonic voltages at these frequencies. There is some uncertainly in this since it has to be assumed in this argument that power supplies draw the same harmonic current irrespective of the value of system impedance. Attention will have to be given to the sizing of neutrals in large commercial and industrial installations where there is an increase in the use of single-phase electronic loads relative to non-distorting loads.

At higher frequencies, it is expected that there could be a large increase in harmonic current because of the increasing use of front-end active circuits for wave-shaping such as is used in more expensive CFLs and in all modern PV inverter systems. The system impedance at these frequencies depends on stray capacitance and there is no reliable data on its value. Hence there is a risk of unacceptably high harmonic voltages, especially as the limits at these frequencies are comparatively low. It will be difficult to determine reliable harmonic management strategies at these frequencies because of the uncertainty in the system impedance. There is a risk of HF harmonics inducing disturbing signals into energy management, communications and computer networks within installations. There may be a need to give greater attention to circuit screening and earthing in order to minimise these effects.

5.6. Transients

Most household equipment appears to be robust against the level of transients currently experienced on the distribution system. Increased undergrounding of LV lines should reduce the levels even more. However future residential installations will be much more complex with the possibility of energy management systems, distributed media and computer networks. All of these operate at low voltage levels which will be very sensitive to incoming transients. There needs to be a management process developed for transients at LV installations involving suppression at the main switchboard coordinated with suppression at all power outlets and possibly involving screening and earthing practices as well.

6. Summary

Power quality concerns variations in the supply voltage as regards its rms voltage, voltage waveshape and frequency. Over the next decade it will be affected by several developments of which the significant ones will be reduction in greenhouse gas emissions, the growth in embedded generation, changes in customer load technology including electric vehicle charging and a growth in energy management systems, the adoption of the new 230 V LV standard and changes in design and operation of the supply network. Depending on how much is spent on developing the network, the likely power quality problems are voltage, voltage sags and transients, with harmonics a problem in some special cases. Customers with sensitive equipment can maximize their immunity to these PQ problems by the following steps:

1. Adequate cross-section conductor should be used within the installation to minimise voltage drops due to the maximum projected load which might be installed. Three-phase installations with significant single-phase distorting loads will need to review neutral cable sizing.
2. Consumers should consider the installation of a circuit dedicated to critical loads with the provision for the future installation of a UPS system if voltage sags become more of an issue.
3. The application of surge suppression at the main switchboard should be considered if equipment is susceptible to transients.
4. All communications cabling should be well screened and properly earthed to minimize interference from transients and high frequency harmonics on electricity supply cables.

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