INTEGRAL energy

Power Quality Centre

Technical Note No. 2 May 1999

POWER FACTOR CORRECTION AND ITS PITFALLS

This Technical Note considers power factor correction as applied by large customers and the possible consequences when power factor correction capacitors are incorrectly applied where there are major harmonic producing loads such as adjustable speed drives. Integral Energy, your local Network Operator or the Integral Energy Power Quality Centre can give you advice if you have particular concerns with these issues.

Summary

Large customers tend to install power factor correction capacitors because of the associated cost savings. While this is advantageous to both the customer and the electricity supplier incorrect application of capacitors can lead to equipment damage.

There are numerous customer loads, such as adjustable speed drives and computers, which draw distorted currents from the supply network adding distortion to the ideal sinusoidal voltage waveform. In particular, power factor correction capacitors should be applied in such situations with care as they can magnify distortion causing damage to capacitors themselves and other plant equipment.

Even if there are no distorting loads in a customer premises, power factor correction capacitors can cause problems if incorrectly applied, as waveform distortion can be present due to other customers connected to the same network.

Careful investigations into the supply network and the nature of the loads within customer's installation is required before connection of capacitor banks. Problems can be avoided by connecting suitable detuning inductors in series with the capacitors.

Contents

University of Wollongong

1. Basics of power factor correction

Power system loads can be generally classified into non-distorting and distorting loads. The total current drawn by most non-distorting loads consists of a component of current (i_{ip}) which is in phase with the supply voltage (v) and a component (i_{op}) of current which is out of phase as illustrated in Figure 1. The in-phase component of the current carries power to the load whereas the out-of-phase component establishes the necessary magnetic fields within equipment such as induction motors that are commonly found in many industrial and commercial installations.

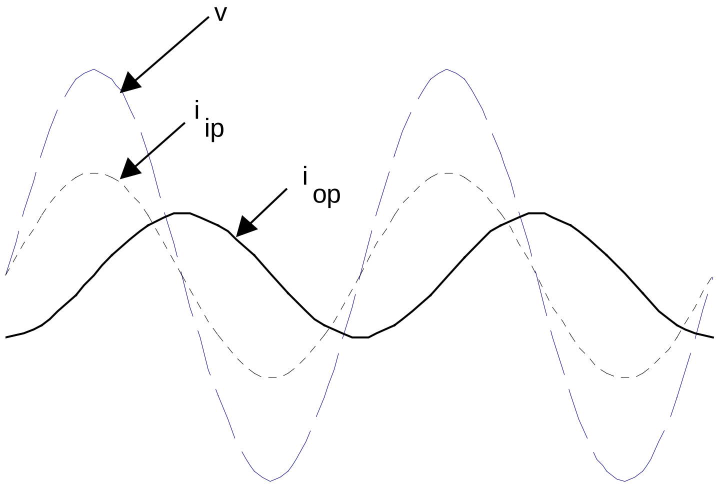

Figure 1: Voltage, in-phase current and out-of-phase current components.

Although the component current i_{op} carries no power to the load it causes extra voltage drops and heat losses in the power supply network. It also means that the electricity supplier has to accommodate this extra component of current when the size of distribution lines and transformers is determined.

The rating of equipment is given by the total current equal to $\sqrt{i_{ip}^2 + i_{op}^2}$

As a measure of the component current i_{op} the term power factor defined by the ratio of the in-phase component of current to the total current is generally used. The best possible value of power factor is unity, when i_{op} is zero. Any procedure, which reduces i_{op} increasing the value of power factor towards unity, is a form of power factor improvement and will help the electricity supplier.

The electricity tariff that is often applicable to large customers is based on two components: (a) real power - product of voltage and in-phase current (b) apparent power – product of voltage and total current (which is also called the demand). Therefore improvement of the power factor is advantageous to the customers.

One of the most common methods of power factor correction is the installation of shunt connected capacitors by the customer. The current through a capacitor (i_c) is in anti-phase with the current i_{op} as shown in Figure 2 and, if properly chosen, will lead to a reduction in the total current drawn by the customer.

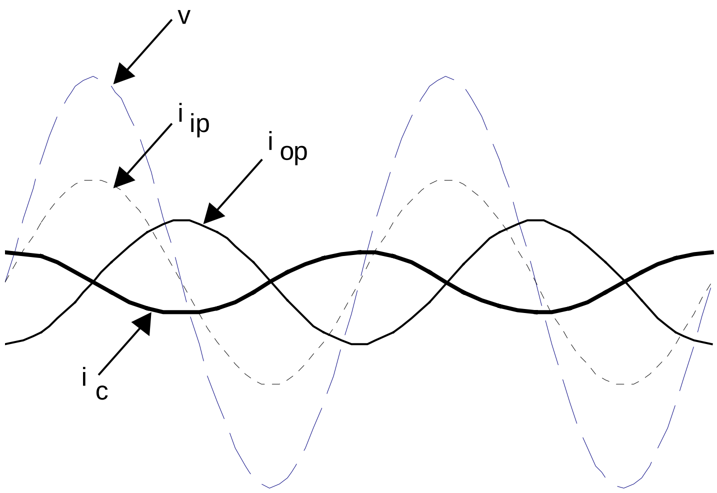

Figure 2: Capacitor current i_c voltage and the component currents i_{ip} and i_{op}

2. Power factor of an installation having distorting loads

As the demand changes during the day capacitor banks have to be switched in and out. Normally the power factor correction capacitors are selected so that power factor established after installing the capacitors is still lagging but close to unity.

The above discussion has been based on the assumption that the customer load is non-distorting (load current is sinusoidal) but most industrial loads these days tend to draw currents having waveforms that are distorted. Such loads include adjustable speed motor drives that are powered by power electronic systems and electronic office equipment. The waveform of the AC supply side current of an adjustable speed *ac* induction motor drive is shown in Figure 3.

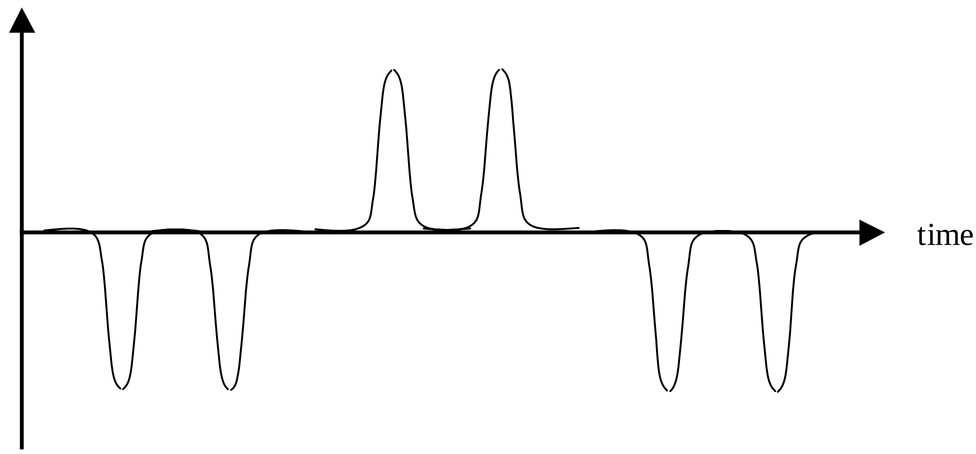

Figure 3: AC supply side current waveform of an adjustable speed induction motor drive.

This current waveform can be considered to consist of a large number of sinusoidal current waveforms of differing frequencies including the fundamental frequency which is 50Hz. The other frequencies present in the waveform are integer multiples of 50Hz and are called harmonics (See Technical Note 1). These harmonics take the frequencies 250Hz, 350Hz, 550Hz, 650Hz, 850Hz, etc. The ratio of these frequencies to the fundamental frequency is called a harmonic order (n), ie harmonics are of the order 5, 7, 11, 13, 17, etc. Normally, as the order increases the magnitude of the corresponding current decreases, Figure 4 illustrates the spectrum of these currents expressed in the form of a bar graph for the waveform of Figure 3.

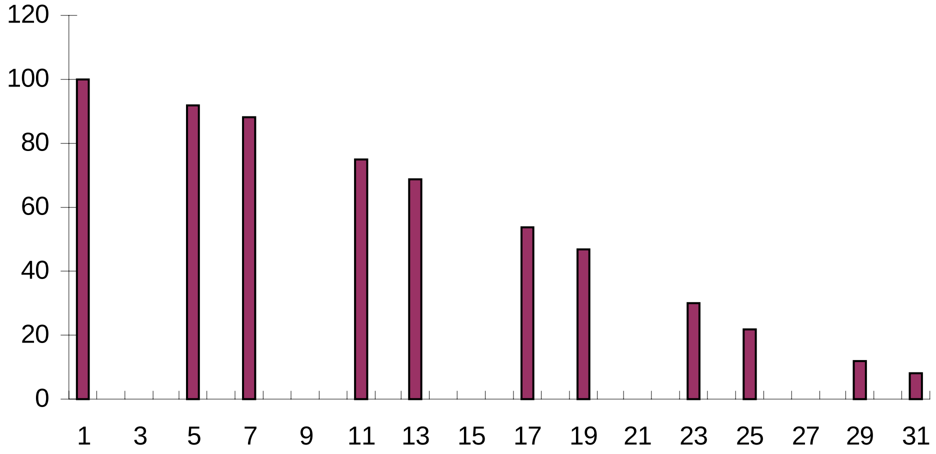

Figure 4: Spectrum of harmonics of the AC side input current waveform of an adjustable speed induction motor drive.

3. Harmonic distortion

For an installation which contains a load such as an adjustable speed induction motor drive it has to be noted that the total current includes the harmonic current components as well as the fundamental. For example consider a situation where the fundamental current is 50A, 5th harmonic is 35A and the 7th harmonic is 10A. Also assume that the above fundamental current has an in-phase component of 40A.

The power factor in this situation is given by: $\frac{40}{\sqrt{50^2 + 35^2 + 10^2}} = 0.65$

Harmonic currents drawn by a load can lead to further distortion of the voltage waveform at the customer entry point in addition to the already existing background voltage distortion on the supply network. In most situations, although the current distortion can be high as seen from the waveform of Figure 3, the voltage waveform may show only a little distortion. For example, the voltage waveform shown in Figure 5 is typical, having distortion in the form of a flat top.

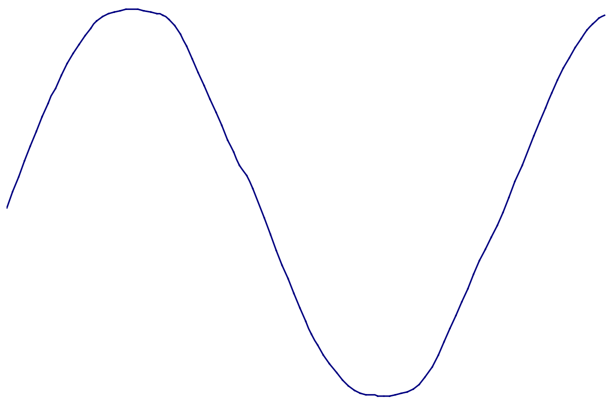

Figure 5: Waveform of the voltage on a low voltage network of a commercial premises.

The level of voltage distortion at the customer entry point depends on (a) the level of distortion of the current drawn from the power system (b) the impedance of the supply system at the customer. Normally the magnitude of the impedance seen by the harmonic currents will increase linearly as the order of the harmonic increases. For example, for a power supply network which has an impedance of 0.1 ohm at 50Hz, the impedance seen by the 5th harmonic current is 0.1x5 (0.5) ohm If the 5th harmonic current is 20A then the 5th harmonic voltage is 0.1x5x20 (10) volts.

4. Overloading of power factor correction capacitors in the presence of harmonic currents

As noted above without power factor correction capacitors the harmonic currents see a power system impedance which is linearly proportional to the order of the harmonic. Hence the harmonic currents will find it difficult to propagate through the power system as the harmonic order increases. However, this is not the case when there are power factor correction capacitors in the power system as the impedance of capacitors is inversely proportional to the harmonic order. Thus, the power factor correction capacitors which were meant to draw a component of current at 50Hz would now offer a reduced impedance to the harmonic currents. As a result, higher order harmonic currents will easily flow through the capacitors overloading them and causing damage to the capacitor banks if care is not taken.

5. Power factor correction capacitors and harmonic resonance

A further aspect which needs careful consideration in the use of power factor correction capacitors in a situation where there are strong harmonic currents is the phenomena known as parallel resonance leading to an amplification of harmonic currents. In the presence of power factor correction capacitors the total impedance seen by the harmonic currents is the parallel combination of the normal power system impedance (which is linearly proportional to the harmonic order) and the impedance of capacitors (which is inversely proportional to the harmonic order) as shown in Figure. 6.

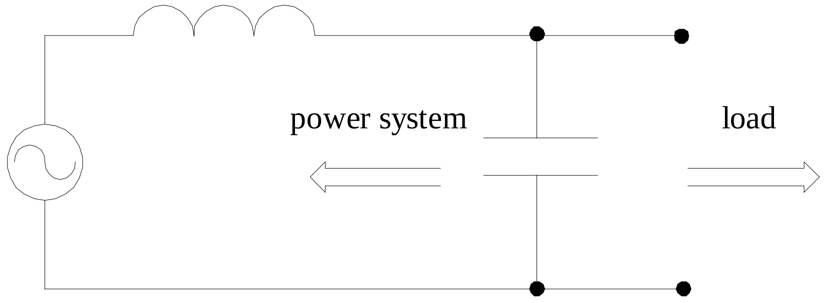

Figure 6 Parallel combination of power system impedance with power factor correction capacitors

These impedances have the opposite signs and so total impedance increases with the harmonic order quite rapidly to a high value and then falls off as the harmonic order further increases. This is illustrated in Figure 7 for a power supply network for different sizes of power factor correction capacitor banks. The Figure also shows the impedance of the same network with no capacitors connected. It is clear that if there is a load current harmonic which is close to the peaky sections of the curves a substantial voltage can be developed causing serious voltage distortion.

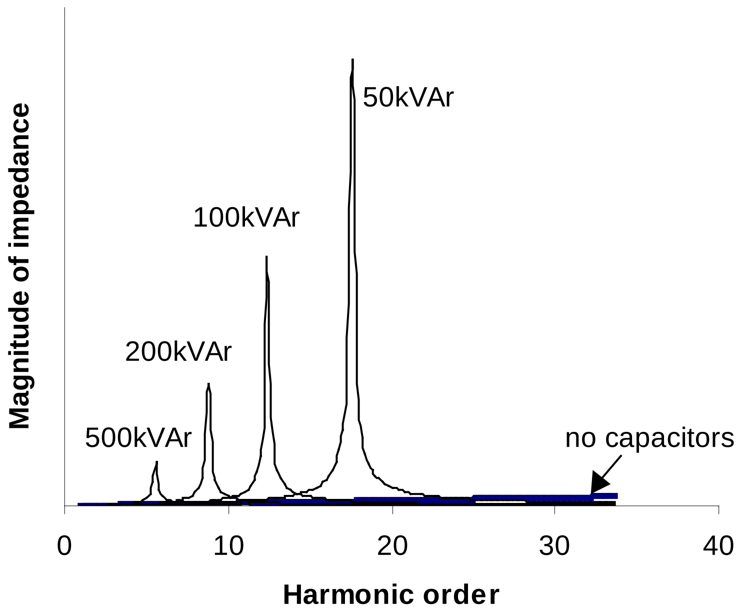

Figure 7: Variation of the impedance with harmonic order for different capacitor banks

The harmonic order at which the parallel resonance takes place can be worked out using the following expression:

$$n = \sqrt{\frac{S_{FL}}{S_C}}$$

where S_{FL} = fault level at the customer entry point, kVA

S_c = capacitor kVAr

which suggests that the parallel resonance frequency reduces as the capacitor kVAr rating increases and vice versa as shown in Figure 7.

For example, at a customer entry point of an industrial installation where the fault level is 2.5MVA with a 100kVAr capacitor bank parallel resonance will take place at 250Hz (ie n = 5).

6. Detuning the power factor correction capacitors

It is important to avoid parallel resonance at a frequency which is close to a frequency of a harmonic current of the distorting load. The common practice is to detune the capacitor bank so that the lowest order load current harmonic sees a very small impedance. This is achieved by adding an inductor in series with the power factor correction capacitors leading to a situation commonly known as series resonance. At the frequency where series resonance takes place the impedance seen by the harmonic currents is small (see Figure 8) and hence the power factor correction capacitors together with the detuning inductor work as a harmonic filter reducing the voltage distortion. As seen in Figure 8, although parallel resonance still takes place, it happens at a frequency which does not correspond to the lowest frequency of the current harmonic (n=5 in this case) that is present in the load current and hence there will be no serious voltage distortion.

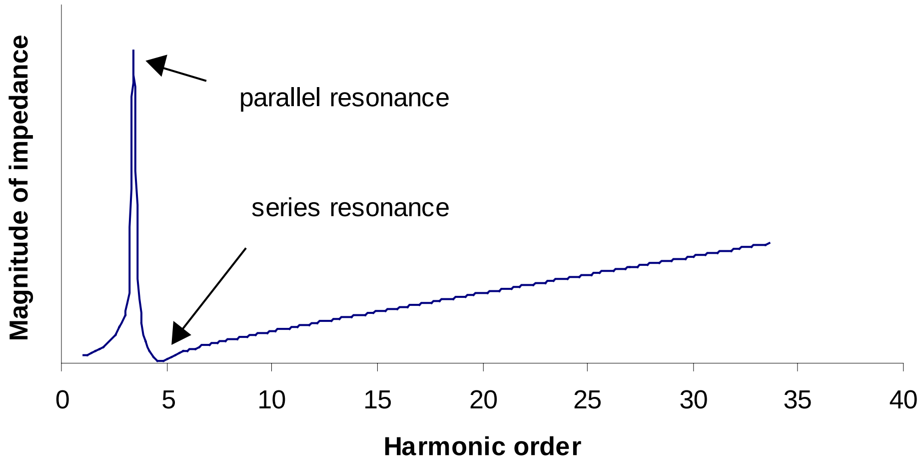

Figure 8: Variation of the impedance with detuning inductor

It has to be noted that the capacitor still provides the fundamental reactive power while working as a harmonic filter. This is quite favourable in a situation where both power factor correction and harmonic filtering is required. However, proper selection of capacitor and detuning inductor is essential for the success of the installation.

Careful system studies covering all configurations of the network and the load must be undertaken before installing power factor correction capacitors even if there are no major harmonic current producing loads in a premises as capacitors can absorb network harmonics thus creating situations not expected in the first place.

7. Integral Energy Power Quality Centre

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

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