The significance of High Speed Power Factor Correction

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Although most plant managers will be aware of the concept of Power Factor Correction, relatively few are implementing PFC systems. This is surprising, because, for many industrial environments, it is a straightforward and inexpensive process. And the benefits can be enormous, not only to power users themselves, but to the environment also.

Take, for example, Wincanton Logistics. Part of Unigate plc, Wincanton Logistics is one of the UK's leading providers of complete supply chain solutions, and boasts a genuinely blue-chip client base which includes names such as BA, BP, Littlewoods, Nestle, SmithKline Beecham and Tesco. Handling £2.5 billion worth of goods annually, the company has 52 warehouses across the country, totalling some 8.5 million ft^2 of storage capacity. And, in June 1999, the company reported a reduction of some £6,500 per annum on electricity bills at a *single warehouse*, through the use of an advanced PFC system. Although this was one of Wincanton's larger sites - a 40,000-location automatic warehouse - it's not unreasonable to suppose that the potential savings from such an implementation across the company could be an order of magnitude bigger, at least.

Or take another kind of calculation - not for power saving, this time, but pollution cutting. A recent report for one of our customers - a large manufacturer of plastic film - showed that the installation of PFC equipment can reduce its CO_2 emissions by some 6,000 tonnes per annum! This takes on real significance when you consider that power generation is largely responsible for the greenhouse gas (principally, but not solely, carbon-dioxide) emissions generally agreed to be at the root of a slow, but steady - and potentially catastrophic - increase in the temperature of the earth. According to a US study, Britain contributed 2.4% of the world's (1997) $C0_2$ total - a figure all the more notable for resulting from about 1% of the world's population. Citizens of the UK, therefore, make over double the average global per capita contribution to greenhouse gas emissions!

The calculations above are typical. But, although we have chosen examples from the logistics and manufacturing industries, all industrial environments could benefit from the use of PFC. Here, we look in some detail at PFC, and explain why this is the case.

Before doing so, however, it is worth reminding ourselves of some basic definitions. Essentially, Power Factor is a simple notion. It's a measure of the efficiency of a power supply (that is, the proportion of its energy which is available for useful work in a machine, or "load"). Such a calculation can be made for all electrical circuits, but it is particularly relevant in the industrial and commercial sector, where machinery and fluorescent lighting is heavily used. The reason does not lie with the power supply itself, but a result of electrical theory which dictates that pretty well all machinery, to one extent or another, introduces a phase difference between current and voltage. This means that the electrical load cannot convert all the supplied electricity into useable mechanical energy. To make up for this, the load takes more electricity than it really needs. The extent of this inefficiency varies with the size and nature of the load, but is often quite high. For example, it is very common for industrial plant to be working with a PF of between 0.5 and 0.7 (a PF of 0.5 means 50% efficient - half the supplied electricity services reactive power). As a mechanical analogy, think of pulling a barge, say, along a canal. If you can exert your pull directly in the line of intended motion, you will use it all. Otherwise (which would be the case, if you're on the towpath), there is some component of force not acting in the direction of motion - you are wasting energy. The bigger this component, the more energy you waste. You have a "power factor" of less than 1.

For those looking for a more formal definition of electrical PF, we need to recall that the total power (KVA) supplied by electricity utilities consists of two components: real power (KW) which produces energy, and reactive power (KVAr) generated by inductive machines which decreases the capacity and effectiveness of the supply system. The Power Factor is defined as the ratio between real and total power. And, in almost all situations, a low PF (less than 0.9, say) is quite easy to improve significantly (thereby increasing the efficiency of the power supply) by adding a suitably configured capacitative component to the load. This, effectively, brings the current and voltage back into (near) phase (see fig.1).

But while conventional PFC equipment can be extremely effective, it does have limitations. Why? well, some environments - those which have rapidly switching loads - require a rapidly switching system. But conventional PFC systems achieve reactive power compensation by means of controllers with a limited reaction time which utilise electromechanical switching elements - which cannot maintain high switching rates without rapid wear and tear. Conventional PFC systems can therefore correct the power factor of stable loads but are unable to cope with rapid and frequent load variations.

Such conditions are far from uncommon, however, particularly in plants with large numbers of unsynchronised machines such as injection machines, lifts etc, and in plant with rapidly changing loads such as spot welding. But now there is a solution, even to this – High Speed PFC. This uses a high speed capacitor-switching unit, designed to replace conventional switching equipment in power factor control systems. By utilising electronic switching, capacitor groups can be connected to the network without transients. The connection is made during the capacitors' voltage zero crossing, providing smooth introduction of the capacitor groups. There is no limit to the number of switching operations, since the electronic switching elements do not wear out or deteriorate during the switching process. This rapid response can therefore compensate and provide variation in the reactive *power within one cycle of the network* (i.e. of the order of 20milliseconds).

The diagram illustrates the switch structure, showing the relationship between switch and capacitor stage. The firing circuit includes zero crossing detection to ensure transient free connection of the transient stages. A typical system design would use a 50kVAr detuned capacitor stage (using 189Hz reactors), which would include 462 microF (between phases) of 525V rated capacitors. A typical single transformer installation of HSPFC units vary between 360kVAr and 800kVAr.

And HSPFC is not only useful for steady state operation of unstable loads (such as welders, and unsynchronised operation of large numbers of machines). There are other conditions under which HSPFC can deliver benefits, too. For example, transient electrical condition such as motor start-up. Rapid and large variations in reactive power normally occur during motor start-up, where current consumption of a motor is 6 to 7 times greater than the running current. The main component of this current is the reactive power. Conventional PFC cannot compensate for this due to the short time involved. HSPFC, however, reacts quickly enough to reduce the current to desirable levels. The following is then achieved:

- Mains protection against voltage drops caused by momentary high consumption of reactive current and by the phase shift between voltage and current.

- Central compensation of all loads reducing the number of special starters required. Star-Delta, auto transformers and soft-start devices are no longer necessary.

Furthermore, HSPFC is unique in that maximum torque can be obtained when a motor is connected directly to the mains. All types of starters reduce the current going through the motor, thereby reducing the torque. If a supply is weak the voltage drop will cause motors to operate in a lower torque. Associated equipment such as PLCs and controllers are adversely effected by voltage drop. Also, higher network loading can be achieved due to optimum reduction of reactive current.

In short, an HSPFC system minimises the negative effects of these rapidly varying loads, resulting in improved power quality and system capacity. Smooth connection of the capacitor groups is also utilised to operate the capacitor bank in a Scan mode, in which the capacitor groups are connected and disconnected continually in a First In-First Out (FIFO) order. The Scan mode is used to limit the capacitor over-current caused by supply power harmonics and over voltage to nominal value of the capacitor current. The HSPFC system immediately disconnects the capacitors from the mains in the event of resonance between capacitors and the main transformer.

In summary, therefore, HSPFC provides the following:

- Optimum utilisation of total capacity rating of transformer, generators and distribution networks.
- Cost effective upgrading of electrical services for plants which have outgrown the installed capacity.
- Reduction of losses in generators, transformers and distribution systems.
- Reduction of mains voltage flicker

Of course, even after all this, the question remains: if PFC is so straightforward, and offers such significant benefits, why don’t companies do it? Well, some do. Many more, however, don’t - mainly because they aren’t aware of the problem. Or, if they are, they don’t appreciate the scale of it. Others are fully aware of the problem, but labour under the misapprehension that there is no solution, or that such solutions are prohibitively expensive. Neither is true. Arcotronics is at the leading edge of the technology and can demonstate perfectly viable solutions for a wide range of industry environments.

Box out 1: phase difference and power factor

The mathematics behind power factors can be found in most texts on AC theory. Here is a quick refresher of the basics.

First, we need to recall that in a purely resistive circuit, carrying an alternating (sinusoidal) current, R=V/I, where I and V are in phase. However, in a purely inductive circuit, V leads I by 90^{o}, whereas in a purely capacitative circuit, V *lags* I by the same amount. Also recall that the "resistance" of a capacitor varies with both C and ϖ (frequency), and is therefore given the term "reactance", numerically equal to $1/\varpi C$. The reactance of an inductance is ϖL.

But what happens when we mix R, C and L in a simple (series) circuit? The resultant phase angle between V and I will be a function of the total reactance in the circuit (i.e. a function of ϖ, C and L). This can be seen by the figures (d, e, f), which use vectors to show the total impedance, Z (sum of reactance and resistance), in an RL, and RC and an RLC circuit. The diagrams show that the addition of C can help reduce the phase angle in a circuit carrying L.

Fig d

Fig e

Fig f

The fact that there is a phase difference between V and I in an RCL circuit leads to the concept of a power factor. This can be seen through the use of simple mathematics.

Power = IV

Assuming V is sinusoidal, we have:

$$P = (V_o\cos\omega t) \times (V_o/Z)\cos(\omega t - \phi)$$

$$= (V_o^2/Z)[\cos^2\omega t\cos\phi + \cos\varpi t\sin\varpi t\sin\phi]$$

This can be easily shown to give a mean power dissipation of

$$P_{ave} = ½I_o^2Z\cos\phi$$

Taking the RMS value of I, this becomes $P_{ave} = I_{rms}^2Z\cos\phi$.

Cosϕ is called the *power factor* of the circuit, and represents the fraction of the product $V_{rms}I_{rms}$ which is dissipated as heat in the load. Clearly, it makes sense to make the power factor as close to unity as possible. This, by the above argument, can be achieved through the addition of suitable capacitative elements of a circuit.

It boils down to this: the addition of capacitors to a network supplies the reactive energy component of the load,. Upstream of the capacitors, therefore, reactive demand is therefore reduced. The result is the reduction of total power and an improvement in power factor.