MAKING ELECTRICAL TECHNOLOGY WORK

Power Factor Correction

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Power Factor Correction

1.0 Introduction

Power factor correction is an increasingly important element of an electrical installation. Not only because of the year-on-year increase in energy costs, but also because it can reduce the production of greenhouse gases. Companies anxious to demonstrate their green credentials to customers, shareholders and staff will want to review the power factor of their building. The green element of power factor correction encourages improvement closer to unity than simple return on capital considerations.

Recent changes to Part L of the Building Regulations recognise the importance of power factor correction in reducing the carbon footprint of an enterprise, important in the fight against global warming.

In installations with inductive and/or capacitive loads, power factor correction can:

i) reduce the maximum demand (kVA) of an installation: reducing electricity demand and charges for customers on a maximum demand tariff.

ii) reduce currents in cables and equipment: reducing voltage drop and copper losses and so improving performance and reducing energy consumption (kWh).

The reduction in the demand and the reduction in current can sometimes allow the selection of installation equipment of lower rating.

Operators of electrical installations with inductive loads such as motors (including air conditioning compressors) and on an energy tariff that incorporates a kVAr authorised supply capacity (Asc) charge and reactive penalty charge, would benefit from any improvement in Power Factor.

2.0 The Building Regulations

Part L of the Building Regulations 2010 sets minimum energy performance targets for new buildings. The carbon emission targets are reduced by 25% as compared with those of the 2006 Building Regulations.

The installation of power factor correction that improves the power factor to 0.9 for the whole building allows a 1% reduction in this target, and if the power factor is corrected to 0.95, a 2.5% reduction in the target is allowed.

If automatic monitoring of energy use is installed with alarms, a further 5% reduction in the energy target is allowed.

The result is that if a high level of power factor correction and monitoring is installed, the target reduction is reduced from 28% to 20.5% for buildings with air conditioning and from 23% to 15.5% for naturally ventilated buildings.

Enhanced management and control features

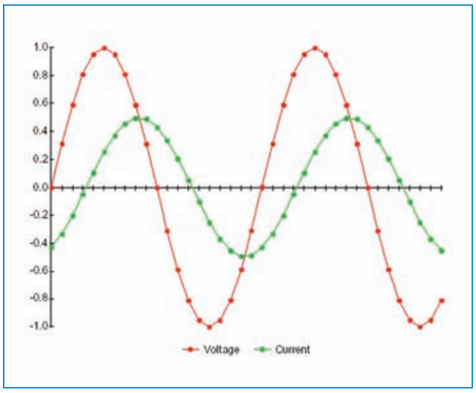
Feature	Adjustment factor
Automatic monitoring and targeting with alarms for out of range values[1]	0.050
Power factor correction to achieve a whole building power factor >0.90[2]	0.010
Power factor correction to achieve a whole building power factor >0.95[2]	0.025

Notes: 1. Automatic monitoring and targeting with alarms for out of range values means a complete installation that measures, records, transmits, analyses, reports and communicates meaningful energy management information to enable the operator to manage the energy it uses. 2. The power factor adjustment can be taken only if the whole building power factor is corrected to the level stated. The two levels of power factor correction are alternative values, not additive.

3.0 The theory

The current taken by most electrical installations, and much electrical equipment, lags the voltage. Figure 1 shows a voltage sine wave, with a lagging or inductive current.

Figure 1 Voltage sine wave with a lagging (inductive) current



The relationship between the voltage and current can also be shown using vectors and this approach allows easy calculation of the rating of power factor correction equipment.

Figure 2a below shows an inductive current lagging the voltage by the power factor angle ø. The current vector (I) can be resolved into a resistive vector (I.cos ø) in phase with the voltage and an inductive vector (I.sin ø), lagging the voltage by 90°.

In situations where the operating reactive load is capacitive, it may be necessary to consider special equipment to compensate from a leading Power Factor to unity.

Figure 2a Voltage and lagging current vectors

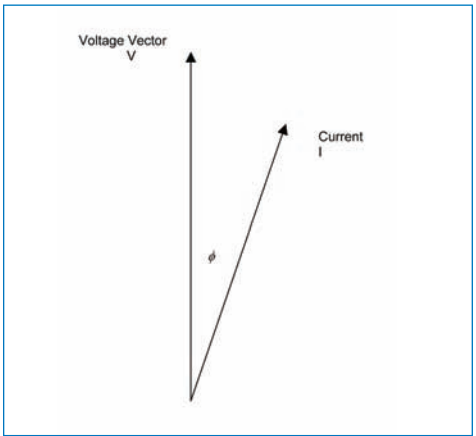
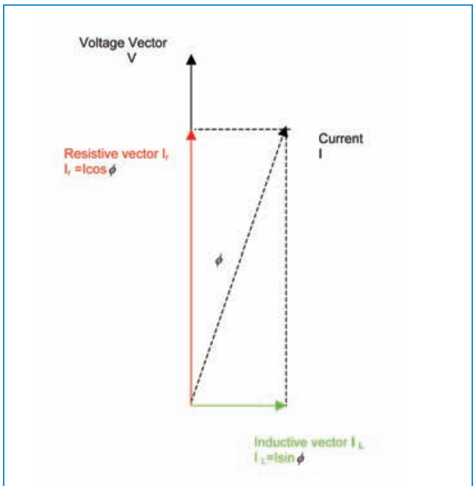


Figure 2b Current vector resolved into a resistive vector and a reactive inductive vector



The cosine of the angle ø between the current (I) and the voltage vector (V) is called the power factor.

For example, if the current lags the voltage by 30 degrees, that is ø = 30, then:

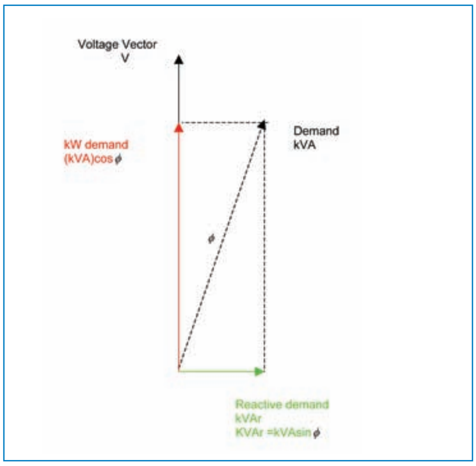
$$\text{power factor, cos } 30 = 0.866 \text{ (or } \frac{\sqrt{3}}{2} \text{).}$$

This cosine is very useful for determining the resistive element from the total current and vice versa, or the kW demand from the kVA demand.

Figure 3 is a vector diagram that shows the maximum demand in kVA, the kW demand and the reactive demand in kVAr, obtained by multiplying the current vectors by the voltage:

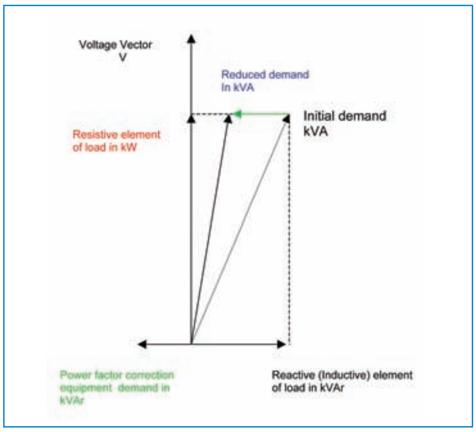
> V_{phase} for single-phase installations or equipment, or
> $\sqrt{3}\ V_{line}$ (or 3 V_{phase}) for three-phase installations.

Figure 3 Vector diagram of demands



By installing a capacitor bank to draw capacitive (leading) current, the inductive or lagging element of current can be reduced and the resultant total current (and kVA demand) can be reduced. See Figure 4.

Figure 4 Reduction in maximum demand by power factor correction



4.0 Electricity tariffs

4.1 Introduction to tariffs

Electricity tariffs for larger users who are metered half-hourly and billed monthly could include the following elements:

- A fixed standing charge.
- A capacity charge, per kVA, for agreed available system capacity (ASC – Authorised Supply Capacity).
- Charges per kWh for day and night usage.

- An excess capacity charge, if a site exceeds its authorised supply capacity.
- An excess reactive power charge payable where the average power factor is less than 0.95 lag.
- Climate Change Levy.

4.2 Authorised Supply Capacity (ASC)

ASCs are usually agreed with end-consumers at the time of connection and incorporated as part of the formal Connection Agreement that the DNO has with the consumer.

Typically Authorised Supply Capacity is granted in blocks of kVA as follows:

- 0 - 100kVA in multiples of 5kVA
- 100 - 250kVA in multiples of 10kVA
- 250 - 500kVA in multiples of 25kVA
- 500 - 1000kVA in multiples of 50kVA
- Above 1000kVA in multiples of 100kVA

4.3 Reactive Power Charge

The excess reactive power charge typically applies when a site's total reactive power (measured in kVArh) exceeds 33% of total active power (measured in kWh) in a billing period. This threshold is equivalent to an average power factor of 0.95 during the period. Any reactive units in excess of the 33% threshold are charged at the rate appropriate to the particular tariff.

The chargeable reactive power is calculated as follows:

Chargeable kVArh = Total kVArh – (0.33 x Total kWh). This is chargeable only where the above equation results in a positive number.

Average Power Factor is calculated as follows:

Cos ø = Power Factor = Total kWh units / $\sqrt{(\text{kWh}^2 + \text{kVArh}^2)}$

All charges can vary by Distribution Network Operator (DNO), Electricity Supply Company and if the customer is fed via either a LV or HV supply.

Typical Electricity Account
A maximum demand tariff may take the following form:

SUPPLY CHARGES	
Monthly Standing Charge	173.88 £ / month
Chargeable Supply Capacity	1.559 £ / kVA
Reactive Charge	0.0012p / kVArh
(Applicable where the average power factor is <0.95)	
Climate Levy	0.47p / kWh
UNIT CHARGES	
Day 07.30 – 23.59	9.31p / kWh
Night 00.00 -7.30	6.8p / kWh

Example of savings
If taken from the electricity account data or where a site survey has been undertaken, consider the following maximum demand:

665kW 842kVA
at a calculated power factor of 0.7897 lag.

Billing Information

Total kWh used:	235302
Total kVArh used:	229186
Average Power Factor:	0.7164 lag
Excess reactive kVArh	151537

Useful calculation data
Power Factor or cos ø = kW / kVA
ie 665/842 = 0.7897 lag

kvar reactive demand = kVA x sin ø

(if cos ø = 0.7897, then ø = 37.84 degrees and sin ø = 0.613 or cos ø = 0.7897, sin ø = $\sqrt{}$ (1- $\cos^{-1}$ ø) = 0.613)

Alternative Method
kVAr = $\sqrt{(\text{kVA}^2 - \text{kW}^2)}$
ie kVAr = $\sqrt{(842^2 - 665^2)}$ = 516kVAr

To improve the maximum demand power factor to 0.97 lag, the capacitance required can be calculated as follows:

Capacitance required:
kvar = kW demand ((tan($\cos^{-1}$ existing PF) - tan($\cos^{-1}$ target PF))

ie kvar = 665 ((tan($\cos^{-1}$ 0.7897) - tan($\cos^{-1}$ 0.97)) = 350

The installation of 350 kvar and subsequent improvement in power factor would reduce the kVA max demand as follows:

New corrected kVA demand = kW demand / 0.97 = 665/0.97 = 686kVA

A reduction of (842 – 686) = 156kVA

Based on the above tariff details, the improvement in power factor would remove the excess reactive power charges and also enable the existing ASC to be reduced (with agreement of the Regional Electricity Company) giving the following potential financial saving:

Excess reactive charges = 151537 x 0.0012p x 12 = £2182.13p pa.

Reduction of ASC = 150 x 1.559 x 12 = £2806.20p pa.

Therefore potential financial saving = £2182.13p + £2806.20p = £4988.33p pa.

It is recommended that to ensure the correct solution is installed, ie taking into consideration where harmonic generating equipment is being utilised, consultation should be made with a recognised Power Factor Correction manufacturer registered with BCMA (BEAMA Capacitor Manufacturers' Association).

5.0 Total installation power factor correction

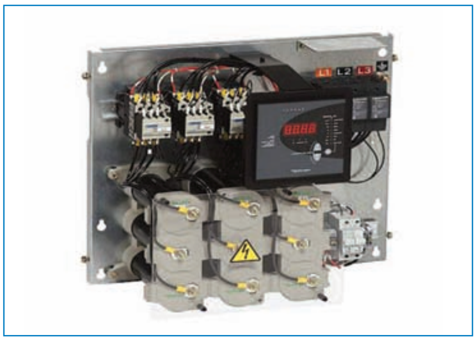
Power factor correction equipment can be installed adjacent to the meter position or local to the equipment with the lagging power factor. An electrical installation may have both equipment with lagging power factor (motors) and equipment with a leading power factor (e.g. some lighting). It is usual to install the power factor correction equipment at the meter position because this allows advantage to be taken of the equipment with a leading power factor, allowing a reduced installed kVAr. It is also simpler to do so; one capacitor bank only is required. The equipment will need to be automatically controlled to avoid overcorrection at low loads.

However, installing the correction at the meter position will not change currents or demands downstream of the meter position, and as a consequence will not reduce copper losses within the installation.

This approach can provide the best percentage return on capital expenditure and, for customers requiring a short payback period, can be most attractive.

Central automatic power factor correction equipment

6.0 Local equipment correction



Power factor correction equipment

Power factor correction equipment located at the main incomer position does provide a cost effective solution to removing kVArh reactive units and the reduction of the kVA maximum demand. However, this system does not reduce currents within the system itself.

Power factor correction equipment installed adjacent to the equipment producing the lagging power factor will contribute to reducing the reactive units used, kVA maximum demand and reduce currents in the cables supplying the equipment and, as a consequence, reduce copper losses and energy consumption.

As mentioned above, in situations where the operating reactive load is capacitive, it may be necessary to consider special equipment to compensate from a leading Power Factor to unity.

Copper losses are the losses arising from the heating effect of current in a conductor. A conductor with resistance r and current I will generate heat equal to I^2r. This is wasted energy paid for in the electricity bill. These are called copper losses, to distinguish them from the iron losses associated with magnetic circuits in transformers and similar equipment (the rise and fall of the magnetic field in an iron choke produces heat. Iron losses are proportional to voltage and frequency).

Local equipment correction can be particularly beneficial for intermittently loaded motors, for the magnetising currents that cause the poor low power factor flow both when the motor is on load and off load (but not when switched off). This means they cause copper losses even when the motor is unloaded.

The capacitive currents of power factor correction equipment can cancel out these inductive magnetising currents.

Locally installed correction equipment need not be sophisticated, as it usually requires no automatic regulation. It will typically be connected via the motor control centre.

Where correction is connected directly onto the motor terminals/motor windings, the output of the capacitor should not exceed 85% of the no-load magnetising kVA of the motor to ensure self excitation does not occur. Where the individual correction of a motor requires a higher corrected power factor to be achieved, such that the 85% no-load magnetising kVA may be exceeded, it is recommended that the correction be switched into circuit via a contactor switched by an auxiliary contact on the motor contactor.

Example

Consider a 30kW 3-phase motor with a full-load power factor of 0.85 and efficiency at full load of 95.4%, supplied by a 50m length of 10mm^2 copper cored armoured cable (from Table 4D4A of BS 7671, for 10mm^2 cable rating is 62A, and volt drop is 3.8mV/A/m, {from which conductor resistance is 3.8 mΩ/m}).

Maximum demand in kW = $\frac{\text{(motor rating in kW)}}{\text{(efficiency)}}$

= $\frac{30}{0.954}$

= 31.45kW

Maximum demand of the motor in kVA = $\frac{\text{(motor rating in kW)}}{\text{(power factor) (efficiency)}}$

= $\frac{30}{0.85 \times 0.954}$ kVA

= 37kVA

Reactive demand kVAr = kVA demand x sin ø

= 370.527

= 19.5kVAr

(if cos ø =0.85 then ø = 31.79 degrees and sin ø =0.527)

If 15kVAr of capacitive correction is installed then the inductive element of the demand is reduced to:

Reduced inductive demand

= (19.5-15)

= 4.5kVAr

The improved power factor angle ø = $\tan^{-1}$ (inductive demand) / (kW demand)

= $\tan^{-1}$ (4.5/31.44)

= $\tan^{-1}$ (0.143)

= 8.1 degrees

and cos = 0.99

New maximum demand

= $\frac{\text{(max, demand in kW)}}{\text{(new power factor)}}$

= $\frac{31.45}{0.99}$kVA

= 31.77kVA

At full load, the demand is reduced from 37kVA to 31.77kVA; that is a maximum demand reduction of 5.23kVA.

The demand saving using the tariff in 4.2 is:

Demand saving = £5.23 (4.5+4.5+2.5+2.5) per year

= £73.22 per year.

This reduction in demand could have been realised by correction at the meter position, perhaps at a lower cost. However, local correction reduces the maximum current in the cable supplying the equipment.

Uncorrected current = $\frac{37 \times 1000}{\sqrt{3} \times 400}$ = 53.4A

Corrected current = $\frac{31.77 \times 1000}{\sqrt{3} \times 400}$ = 45.9A

Saving at full load = (No. of phases) x (reduction in current)^2 x (cable resistance)

= 3 x (53.4 - 45.9)^2 x (3.8/1000Ω/m) x (50m)

= 32 watts

At no load, the motor current is reduced as follows:

Uncorrected reactive current = $\frac{19.5 \times 1000}{\sqrt{3} \times 400}$ = 28.14A

Corrected reactive current = $\frac{4.5 \times 1000}{\sqrt{3} \times 400}$ = 6.5A

Saving at no load = 3 x (28.14 - 6.5)^2 x (3.8/1000Ω/m) x (50m)

= 267 watts

If the motor is switched on for 12 hours a day, 5 days a week for 45 weeks (12 x 5 x 45 = 2700 hrs) and is at full load for 50% of the time, the savings are:

At full load in kWh

= 32W x 2700hrs x (50/100) / (1000)

= 43.2kWh at 13p

= £6 per year

At no load in kWh

= 267W x 2700hrs x (50/100) / (1000)

= 360kWh at 13p

= £47 per year

Total saving including demand saving = £73 + £6 + £ 47 = £126

If the motor is at full load for only 10% of the time, as is not uncommon, the savings become:

At full load = 32 x 2700 x (10/100) / (1000)

= 9kWh at 13p

= £1 per year

At no load = 267 x 2700 x (90/100) / (1000)

= 649kWh at 13p

= £84 per year

Total saving including demand saving = £73 + £1 + £84 = £158

The illustrated kWh unit cost will vary according to the electricity supplier tariff.

7.0 CO_2 Reduction

By increasing the efficiency of the plant, it could be equated to an approximate reduction in CO_2 emissions of 0.105 Tonne CO_2 per KVAr pa, based on BCMA data, and an average operating time of 6000 working hours per annum. Based on these figures, with 350KVAr of capacitance in circuit for a period of approx 6000 hours, an approximate reduction of 36.75 tonnes per annum could be realised.

8.0 Summary and action plan

In installations with inductive loads, the installation of power factor correction equipment can save energy and reduce electricity bills. Whilst central automatically controlled equipment is likely to give the best payback, locally installed equipment has the potential to also save copper losses within the installation. However, it should be noted that the individual correction method of correction does have its limitations, such that the overall power factor of 0.95 lag or better may not be achieved necessitating in the installation of automatic correction at the main incomer position.

ACTION PLAN

- Confirm installation maximum demand and power factor
- Identify loads having low power factor
- Determine scope for improvement of power factor
- Decide appropriate means of correction, in consultation with provider of power factor correction equipment
- Implement procurement/installation of equipment
- Monitor demand and/or energy savings, from billing.

This guidance document has been compiled by ECA in conjunction with BEAMA. For further information visit;

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