JUSTIFICATION OF POWER FACTOR CORRECTION EQUIPMENT

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Abstract

Cost savings to be gained from static power factor correction as related to present day electrical energy tariffs are investigated.

Introduction

Although the value of power factor correction is generally well known the recent sharp escalation in electrical energy costs imposed by ESCOM affects most factories in the industry for at least a portion of the year and a new look at achieving power bill savings by power factor correction should be of some value to mill engineers.

The investigation that follows is based on 525 volt equipment as this seems to be the most common voltage in use in the industry, and the equipment will provide correction in evenly graded steps, switching capacitors in or out automatically to provide the optimum power factor required at all loads up to the normal maximum for the various system sizes being investigated.

In the examples that follow the switching steps vary from 4 to 12 but detailed component costs will not be provided for each installation. The figures arrived at however provide a fair estimate of the cost of each installation for budgetary purposes.

Unfortunately the derivation of a simple cost factor for capacitance for power factor correction is not possible for automatic installations as the fixed cost of panels, capacitor racks, relays, instrumentation and control equipment do not bear a constant ratio to the number of capacitors, contactors, fusegear etc., required in the varying sizes of installation. In practice the correction requirements would be calculated from electrical measurements taken and the system designed and built for the customer using standard components to suit his requirements.

The consumer's tariff

These vary with the various local supply authorities and even vary with individual suppliers depending on the voltage of supply and the cost of the installation to the supplier. In most tariffs however the consumer is penalised for poor power factor or, in other words, a higher than necessary kVA demand compared to his power requirements.

For the purposes of this exercise ESCOM's Large Power User's Tariff for 11 kV supplies will be used as being the most common supply voltage, and this is made up as follows:

1. Service charge R20,00.
2. Maximum Demand charge at R5,50 per kVA.
3. Unit (kWh) charge. (currently 0,708c per unit but this varies with ruling running expenses.)
4. A discount, presently 5% on the total of Items 1, 2 & 3.
5. The extension charge: (Based on the cost of the consumer's extension to ESCOM.)
6. Rebate at R1,00 per kVA of maximum demand. (Item 6 is subtracted from Item 5 and the sum remaining is added to the account.)

The above then makes up the monthly electricity bill.

An examination of this tariff reveals the following:

Item 1 is fixed.

Item 3 is a direct payment for goods received.

Item 4 is simply a discount.

Item 5 is diminished by Item 6, usually to zero. Negative quantities are not taken into account.

Item 2 however, which is by far the most expensive part of the tariff, can be manipulated by the consumer and often substantially reduced, if unimportant loads cannot be switched off during high demand periods, by improving the system power factor. Allowing for the 5% discount the cost for this item is effectively R5,225 per kVA.

Theory

Most engineers are familiar with the basic power vector triangle and the relevant theory but others will possibly welcome some explanation of the terms used.

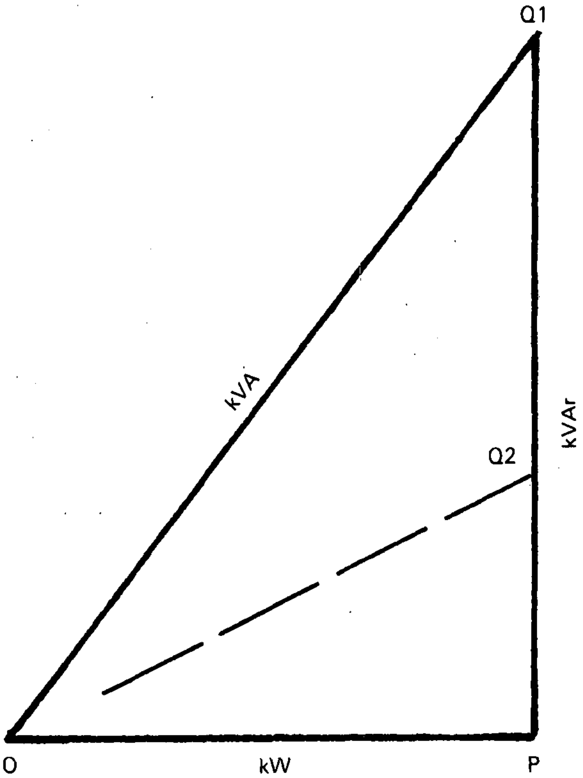

Figure 1

Referring to Fig 1

kW = Kilowatts and is a measure of the usefull power or work drawn from the system, and is represented here as a vector OP in the direction shown.

kVAr = Reactive or wattless power, and is the energy required to energise the windings and magnetic cores of transformers and motors in the electrical system. As this energy does not produce any useful power it is represented by a vector PQ1 at right angles to the useful power vector in the direction shown.

The vectorial sum of these two vectors OQ1 is termed the kVA vector, the magnitude of which determines the kVA demand charge.

The power factor is the ratio kW/kVA or in the more commonly used trigonometrical term is equivalent to Cos Ø and will be low if PQ1 is large with respect to OP. Cos Ø would increase or "improve" however, if the kVAr vector could be shortened to Q2 say, or Cos Ø would become unity if the kVAr vector was eliminated altogether. This also reduces the magnitude of the kVA vector until finally at unity power factor kVA equals kW and the consumer is paying for useful work only.

As the PQ1 vector is caused by what is termed the "inductance" in the system it is possible to reduce or cancel the effect of this inductance by connecting capacitance or static condensers into the system. This capacitance produces a vector opposite in direction to PQ1 and if it were equivalent to Q1Q2 kVAr the resultant reactive vector would be reduced to PQ2. If capacitance equivalent to Q2P kVAr were connected into the system the effect of the inductance would be eliminated altogether and Cos Ø would be unity.

Further, as the kW load on the system varies it becomes necessary to vary the capacitance in order to maintain the desired power factor. This is achieved by the electrical measurement of the power factor of the system, computing its deviation from the required value and automatically switching capacitance in graded steps until the required value is reached.

Referring again to Fig 1 and referring the kVA and KVAr vectors to the kW vector the following relationships, which will subsequently be used to calculate kVA demand reduction and kVAr correction required at various power factors and kW loads, are obtained.

$$\text{kVa/kW} = \frac{1}{\text{Cos } \phi} \qquad \text{Equation 1}$$

$$\text{kVAr/kW} = \text{Tan } \phi \qquad \text{Equation 2}$$

These values may also be obtained graphically or the triangles solved directly.

Calculations

All calculations will be presented in tabular form and commence at 0,7 power factor which is not uncommon in sugar factories, where motors are often lightly loaded resulting in poor power factor.

The kVA/kW and kVAr/kW factors are calculated for four values of Cos Ø, namely 0,7; 0,8; 0,9 and 1,0 and presented in Table 1. The method for the individual calculations is as follows:

$$\text{e.g. for Cos } \phi = 0{,}8 \text{ kVA/kW} = \frac{1}{0{,}8} = 1{,}25$$

$$\text{and kVAr/kW} = \text{Tan } \phi$$

$$= \text{Tan (Arc Cos 0,8)} = 0{,}75$$

TABLE 1

Cos Ø	kVA/kW	kVAr/kW
0,7	1,43	1,02
0,8	1,25	0,75
0,9	1,11	0,48
1,0	1,0	0

If the power factor is improved from, say, 0,7 to 0,9, the kVA demand per kW reduces from 1,43 to 1,11 or by 1,43 - 1,11 = 0,32 kVA/kW, or for a load of 100 kW the kVA demand would drop from 143 kVA to 111 kVA giving an improvement of 32 kVA and a saving of 0,32 x 5,225 = R1,67 per kW or 32 x 5,225 = R167 per 100 kW.

The amount of capacitance required to achieve the above improvement is obtained by subtracting the kVAr/kW for Cos Ø = 0,9 from the kVAr/kW for Cos Ø = 0,7. i.e. 1,02 - 0,48 = 0,54 kVAr/kW. For 100 kW this would be 54 kVAr.

As the electricity account is submitted monthly the above savings would naturally be in rand/kW/month.

These factors are now calculated for improvement of power factor from 0,7 - 0,8; 0,7 - 0,9 and 0,7 - 1,0 and are given in Table 2.

TABLE 2

Power Factor improvement	kVa reduction per kW	Saving/kW/month @ R5,225 per kVa	required kVar correction/kW
0,7 - 08	0,18	R0,94	0,27
0,7 - 0,9	0,32	R1,67	0,54
0,7 - 1,0	0,43	R2,25	1,02

Various kW load values are now chosen and the required kVAr correction calculated for the three levels of pf improvement for each load. e.g. Correction for 500 kW = 500 x 0,27 = 135 kVAr for an improvement from 0,7 to 0,8.

These values are shown in Table 3.

TABLE 3

	kVAr correction required for			
Power Factor improvement	500 kW	750 kW	1 000 kW	1 500 kW
0,7 - 0,8	135	203	270	405
0,7 - 0,9	270	405	540	810
0,7 - 1,0	510	765	1 020	1 530

Savings per month for the same loads are calculated e.g. the saving for 500 kW corrected from 0,7 to 0,8 would be 500 x 0,94 = R470,00.

These figures are given in Table 4.

TABLE 4

	Savings per month in Rand			
Power Factor improvement	500 kW	750 kW	1 000 kW	1 500 kW
0,7 - 0,8	470	705	940	1 410
0,7 - 0,9	835	1 253	1 670	2 505
0,8 - 1,0	1 125	1 688	2 250	3 375

The equipment required for each of the kVAr quantities listed in Table 3 is now designed and the cost estimated. A 10% contingency allowance has been added to the material costs to allow for price adjustments and factory installation costs. Connections from the panel to the factory busbars have not been included as this could vary somewhat at different factories. Approximately 1,5 amps per kVAr of capacitance should be allowed for.

The relation of equipment cost to monthly saving is given in table 5 for the same loads and pf improvement as above.

TABLE 5

	Equipment cost/Monthly saving			
Power Factor improvement	500 kW	750 kW	1 000 kW	1 500 kW
0,7 - 0,8	3 700/470	4 650/705	4 850/940	7 050/1 410
0,7 - 0,9	4 850/835	7 050/1 253	8 350/1 670	12 250/2 505
0,7 - 1,0	7 450/1 125	10 350/1 688	13 200/2 250	19 000/3 375

By simple division of the costs by the savings in Table 5 the payback periods are obtained. These are given in Table 6.

TABLE 6

Power Factor improvement	500 kW	750 kW	1 000 kW	1 500 kW
0,7 - 0,8	7,9	6,6	5,2	5,0
0,7 - 0,9	5,8	5,6	5,0	4,9
0,7 - 1,0	6,6	6,2	5,9	5,6

Conclusions

Whereas in the past when kVA demand charges were considerably lower it was not deemed economical to correct power factor much beyond 0,95, the recent substantial increase in kVA demand charges now makes it highly advantageous to correct to unity power factor in almost every case. The only exception which comes to mind is the case where the tariff structure lays down a minimum kVA demand and to correct below this figure would bring no financial benefit.

Practical observations

The estimates tabled above are based on completely automatic full range installations. Equipment savings may be achieved by the direct connection of capacitance to large motors and transformers and then adding a smaller automatically controlled installation to achieve the optimum control required for the remaining smaller motors.

Control equipment components must be of the highest quality and reliability. Remember that a half hour breakdown in the correction equipment could eliminate the kVA demand saving for that month. As an added safeguard manual switching of the capacitance banks is highly desirable should repair work or replacement of faulty control relays or other components become necessary.

Correction equipment is also beneficial to mill power stations in that it reduces the reactive load on the alternators and permits them to run at designed power factors and excitation currents.