Eskom
Power factor: Sizing guide
Fact Sheet

1 Reducing electricity costs with improved power factor

This is the third brochure in the power factor series - the other two brochures are Power Factor: Basic Overview, and Power Factor: Technical Overview Guides. The aim of this brochure is to provide sizing and payback information for power factor correction equipment and should be read in conjunction with the rest in the series.

A facility's power factor will rarely be at 100% if the load is mainly uncompensated inductive loads. Improving poor power factor is not difficult and often a guaranteed mechanism of saving on expensive electricity supply upgrades and the existing electricity bill. Correctly sized power factor correction equipment would ensure optimal correction meaning you pay for exactly what you need and no more.

2 Determining the power factor correction requirements

The total kVAR rating of capacitors required to improve power factor to any desired value can be calculated by using the table published by leading power factor capacitor manufacturers.

Using the Table below:

To properly select the amount of kVAR required to correct a lagging power factor of a 3-phase motor; follow the following steps:

Step #1: Determine the kW and existing power factor.

Step #2: Find the existing power factor in the table on the left (in bold) – then move across the Table to the desired power factor. The number represented is your multiplier number.

Step #3: Multiply the kW by the multiplier of the desired power factor.

Capacitor correction factor

Power factor (Cos θ_2) after improvement:

Power factor (Cos θ_1) before improvement:	**1.0**	**0.99**	**0.98**	**0.97**	**0.96**	**0.95**	**0.94**	**0.93**	**0.92**	**0.91**	**0.90**	**0.85**	**0.80**
0.50	1.73	1.59	1.53	1.48	1.44	1.40	1.37	1.34	1.30	1.28	1.25	1.11	0.98
0.52	1.64	1.50	1.44	1.39	1.35	1.32	1.28	1.25	1.22	1.19	1.16	1.02	0.89
0.55	1.52	1.38	1.32	1.27	1.23	1.19	1.16	1.12	1.09	1.06	1.04	0.90	0.77
0.57	1.44	1.30	1.24	1.19	1.15	1.11	1.08	1.05	1.01	0.99	0.96	0.82	0.69
0.6	1.33	1.19	1.13	1.08	1.04	1.01	0.97	0.94	0.91	0.88	0.85	0.71	0.58
0.62	1.27	1.23	1.06	1.01	0.97	0.94	0.90	0.87	0.84	0.81	0.78	0.65	0.52
0.65	1.17	1.03	0.97	0.92	0.88	0.84	0.81	0.77	0.74	0.71	0.69	0.55	0.42
0.67	1.11	0.97	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.65	0.62	0.49	0.36
0.7	1.02	0.88	0.81	0.77	0.73	0.69	0.66	0.62	0.59	0.56	0.54	0.40	0.27
0.72	0.96	0.82	0.75	0.71	0.67	0.63	0.60	0.57	0.53	0.51	0.48	0.34	0.21
0.75	0.88	0.74	0.67	0.63	0.58	0.55	0.52	0.49	0.45	0.43	0.40	0.26	0.13
0.77	0.83	0.69	0.62	0.58	0.54	0.50	0.47	0.43	0.40	0.37	0.35	0.21	0.08
0.80	0.75	0.61	0.54	0.50	0.46	0.42	0.39	0.35	0.32	0.29	0.27	0.13	
0.82	0.70	0.56	0.49	0.45	0.41	0.37	0.34	0.30	0.27	0.24	0.21	0.08	
0.85	0.62	0.48	0.42	0.37	0.33	0.29	0.26	0.22	0.19	0.16	0.14		
0.87	0.57	0.42	0.36	0.32	0.28	0.24	0.20	0.17	0.14	0.11	0.08		
0.90	0.48	0.34	0.28	0.23	0.19	0.16	0.12	0.09	0.06	0.02			
0.91	0.45	0.31	0.25	0.21	0.16	0.13	0.09	0.06	0.02				
0.92	0.43	0.28	0.22	0.18	0.13	0.10	0.06	0.03					
0.93	0.40	0.25	0.19	0.15	0.10	0.07	0.03						
0.94	0.36	0.22	0.16	0.11	0.07	0.04							
0.95	0.33	0.18	0.12	0.08	0.04								
0.96	0.29	0.15	0.09	0.04									
0.97	0.25	0.11	0.05										
0.98	0.20	0.06											
0.99	0.14												

The following are some practical examples of calculating the required correction:

Example 1:

If a 150kW electric motor has a power factor before improvement of 0.75 (Cos θ_1), and we require a power factor of = 0.96 (Cos θ_2) – the capacitor correction factor from the Table above is 0.58. The required kVAR capacity can then be calculated as C = (150 kW) x 0.58 = ***87 kVAR***.

If kW or present power factor is not known you can calculate the required compensation using the following formulas (applicable for 3 phase supply only) to get the 3 basic pieces of information required for calculating kVAR:

$$P.F. = \frac{kW\ (Real\ Power)}{kVA\ (Apparent\ Power)}$$

$$\text{kVA} = \frac{1.73 \times \text{I} \times \text{E}}{1\ 000}$$

$$kW = \frac{1.73 \times \text{I} \times \text{E} \times \text{P.F.}}{1\ 000} \quad \text{or} \quad kW = \frac{\text{H.P.} \times 0.746}{\text{efficiency}}$$

Example 2:

What kVAR compensation is required to correct an existing power factor of 62% to 95% for a three phase induction motor operating at 500V and 62A:

Where
I = full load current in amps
E = voltage of motor/equipment
P.F. = present power factor as a decimal (80% = 0.80)
H.P. = rated horsepower of motor/equipment
eff. = rated efficiency of motor as a decimal (83% = 0.83)

NOTE: If the desired power factor is not provided; 95% is a good economic power factor for calculation purposes

Solution

i) Actual power:
kW = 500 x 62 x 0.62 x 1.732/1 000 = ***~33 kW***

ii) The leading reactive power kVAR necessary to raise the power factor to 95% is calculated by multiplying 33kW with the factor found from the correction Table for capacitor selection (refer above), which would be 0.937.
33kW x 0.937 = ***30.92 kVAR***
Use **30 kVAR**

Example 3:

An energy audit for a facility provides the following measurements at the load side of the transformer; 480V, 1 200A and 800kW operating load.

i. Calculate the power factor, and,

ii. Calculate the reactive power (kVAR) in the system

Solution

i) To calculate the power factor, first calculate the KVA in the system.

$$kWA = \frac{V \times A \times \sqrt{3}}{1\ 000} = \frac{480 \times 1\ 200 \times \sqrt{3}}{1\ 000} = \mathbf{1\ 000\ kVA}$$

Substitute the kVA into the power factor formula

$$P.F. = \frac{kW}{kVA} = \frac{800}{1\ 000} = \mathbf{0.8}\ \textit{or}\ \mathbf{80\%\ P.F.}$$

ii) To calculate the reactive power (kVAR) in the system requires re-arranging the formula $\text{kVA}^2 = \text{kW}^2 + \text{kVA}^2$ and solving for kVAR.

Example 4:

The measurement at the main distribution board of a manufacturing facility measures 1 000 kVA and 800 kW. Determine the system kVAR and power factor of the facility. Also determine the kVAR required for achieving a power factor of 0.95 while providing the same power load of 800 kW.

Solution

Measured kVA = 1 000
Measured kW = 800

i) The system kVAR and power factor of the facility

$$\text{kVAR} = \sqrt{(\text{kVA}^2 - \text{kW}^2} = \sqrt{1\ 000^2 - 800^2} = \mathbf{600}\ \boldsymbol{kVAR}$$

$$P.F. = \frac{kW}{kVA} = \frac{800}{1\ 000} = \mathbf{0.8}\ \textit{or}\ \mathbf{80\%\ P.F.}$$

ii) The system kVAR after power factor correction to 0.95

- System kVA after correction

$$kVA. = \frac{kW}{P.F.} = \frac{800}{0.95} = \mathbf{843}\ \boldsymbol{kVA}$$

- System kVAR after correction

$$kVAR = \sqrt{(kVA^2 - kW^2} = \sqrt{843^2 - 800^2} = \mathbf{265}\ \boldsymbol{kVAR}$$

ii) iii) The power factor correction kVAR rating

Power Factor Correction kVAR
= kVAR (uncorrected) – kVAR (corrected)
= 600 – 265 = ***335 kVAR***

Use the multiplier table for capacitor selection (refer Table above) when the kW load, uncorrected power factor and the desired power factor are known; as shown in examples above.

Example 5:

Billing based on kW demand charges

An industrial plant has a demand of 1 000 kW and operates at 80% power factor. The electricity utility supplying power to this facility requires a minimum power factor of 85% and levies a kW demand charge (penalty) of R80.00 in the electricity bill. Determine the savings possible by improving the power factor to the minimum required target of 0.85 along with the payback period when investing on power factor correction.

Solution

i) The monthly kW billing amount is determined with the ratio of the target power factor to the existing power factor, times kW demand.
kW billing on power factor is 0.80.
The monthly kW billing: *1 000kW x 0.85 target P.F. / 0.80 existing P.F.* = ***1 062 kW***
Total demand charge @ R80.00 = 1 062kW x R80.00
= **R84 960**

ii) kVAR required to increase the power factor from 0.8 to 0.85
The multiplying factor = 0.13 (from the capacitor estimation Table above)
Therefore kVAR required = *0.13 x 1 000* = ***130 kVAR***

iii) Power factor correction investment
Cost of 130 kVAR power factor correction (on a 480 volt system, installed power factor cost is assumed to be R150 per kVAR)
130 kVAR x R150.00 = ***R1 950***

iv) The kW billing on the new power factor of 0.85
The monthly kW billing: *1 000kW x 0.85 target P.F. / 0.85 modified P.F. = 1 000 kW*
Modified demand charge @ R80.00
= *1 000kW x R80.00* = ***R80 000***

v) The payback period
Monthly savings on demand charge
= R84 960 - R80 000 = **R4 960**
Investment on power factor correction = R1 950
Simple payback = cost/ savings = R1 950 / R4 960
= **approx 3.9 months.**
(NOTE: The savings will continue thereafter)

Example 6:

Billing based on KVA demand charges

An industrial plant is operating at 400 kW and maximum demand of 520 kVA. The facility has electricity contract based kVA demand charges, which will reduce as the power factor is improved. The demand charges rate is fixed @ R30.00 per month per kVA.

Determine the savings possible by improving the power factor along with the payback period of the investment in power factor correction.

Solution

The kVA demand can be reduced if the power factor is raised. Usually, 95% is a good economic power factor when the demand charges are based on kVA charges.

i) The present power factor = *kW / kVA = 400 / 520* = ***77%***

ii) Present demand charge = *520 x R30* = ***R15 600***

iii) Assume the target new power factor to be 95%. This would reduce the present 520 kVA demand down to 421 kVA.
The calculation as follows:
Reduced kVA = *kW / modified power factor = 400 / 0.95*
= ***421 kVA***

iv) Modified demand charge = *421 x R30* = ***R12 630***

v) Likely Savings = *R15 600 - R12 630* = ***R2 970***

vi) The kVAR required to increase the power factor from 0.77 to 0.95
The multiplying factor = 0.5 (from the capacitor estimation Table above)
Therefore kVAR required = *0.5 x 400* = ***200 kVAR***

vii) The power factor correction investment
Cost of 200 kVAR power factor correction (on a 480 volt system, installed power factor correction cost is assumed to be R150 per kVAR)
200 kVAR x R150.00 = ***R30 000***

viii) The payback period
Monthly savings on demand charge = R2 970
Investment on power factor correction = R30 000
Simple payback = cost/ savings = R30 000 / R2 970
= ***approx 10 months.***
(NOTE: The savings will continue thereafter).

In addition, by installing the 200 kVAR power factor correction **an additional 20% capacity is immediately available for new electrical loads** without installing any new transformers, power lines or distribution equipment. This is important because in critical times the new transformers and power lines may be difficult to get in time, and their costs, in most cases, would exceed the R30 000 spent for power factor correction.

Example 7:

Billing based on kW and KVAR demand charges

A hotel complex with majority of HVAC and lighting loads has a contract with power factor which includes an energy charge for kWh, a demand charge based on kW and another demand charge based on kVAR. The kVAR charge is R15 per month for each kVAR demand in excess of 1/3 (33.3%) of the kW demand. The operating electrical characteristics involved are 1 800 kVA, 1 350 kW and 1 200 kVAR. Calculate the possible savings on reducing the kVAR demand charges with the correction of the power factor along with the simple payback.

Solution:

i) The excess kVAR demand can be eliminated by correcting the power factor. kVAR demand in excess of 1/3 (33.3%) of the kW demand can be calculated as:

$$\mathit{1\,200\ kVAR} = \frac{\mathit{1\,350\ kW}}{\mathit{3}} = \mathbf{750\ kVAR \times 1}$$

This implies that a 750 kVAR supply, if corrected with Power Factor correction, can do away with the extra demand charges.

ii) Estimated annual electricity bill savings
R15 demand charge x 750 kVAR x 12 months = ***R11 250 savings per annum***

iii) Estimated cost of 750 kVAR power factor correction
The assumed cost of 480 volt, 50 Hz power factor correction is R150 per kVAR.
Therefore, the total investment for 750 kVAR power factor correction will be
750 kVAR x R150 = ***R112 500***

iv) The simple payback period
R11 250 annual savings against the R112 500 power factor correction investment:
The power factor correction will **pay for itself in 10 months**, and NOTE: will continue to produce the savings thereafter.

Example 8:

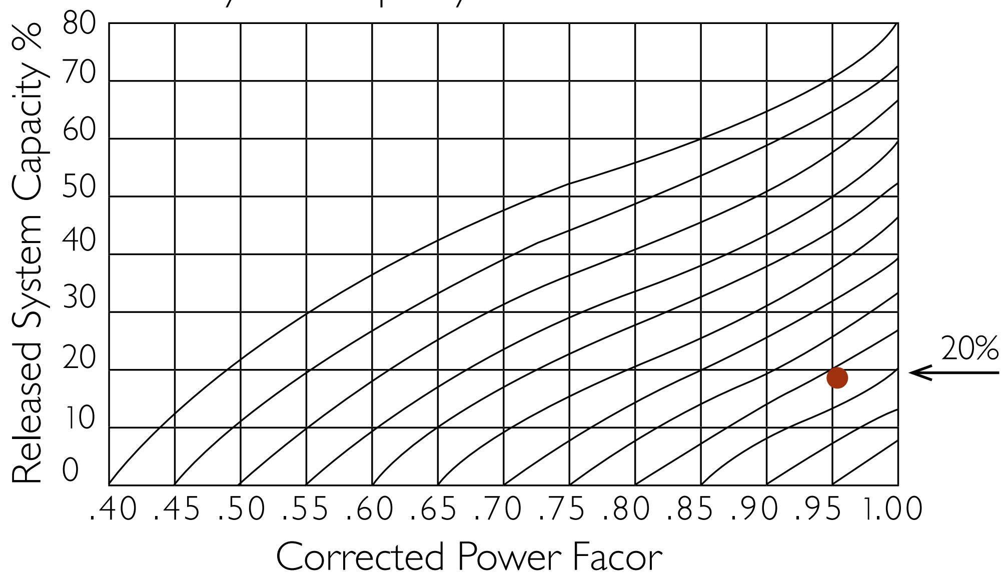
Increased system capacity

A facility electrical system is operating with the following electrical characteristics:
kVA = 1 000 kW = 800 kVAR = 600 P.F. = 0.80.
Calculate how much spare capacity can be released by improving the power factor to 0.95.

Solution

The uncorrected system can only support 800 kW loads at a power factor of 0.80.
The graph below (taken from the Technical Overview brochure) shows the empirical relationship of the system capacity against the existing factor. From the graph it is found that improving the power factor from 0.8 to 0.95 will release approximately 20% system capacity.

System Capacity vs Power Facor



800 kW + 20% = **960 kW**
The corrected system will now be capable of supporting **960 kW loads.**
Hence, the system capacity has been increased by **160 kW (20%).**

Example 9:

Lowering losses

Assume the facility system wide losses = 5%, with a current power factor of 0.80. Estimate the reduction in losses when the power factor correction is made at the load points to unity. (Unity = 1.0 = 100%).

Solution:

Improving the power factor at the load points will relieve the system of transmitting reactive current. Less current will result in lower losses in the facility distribution system since losses are proportional to the square of the current (I^2R). Therefore, fewer kilowatt-hours will need to be purchased from the electricity utility.

An estimate of the reduction in electricity losses can be made using the following equation:

% Reduction of Power Losses

$$= 100 - 100 \left(\frac{\text{Original Power Factor}}{\text{Improved Power Factor}}\right)^2$$

or

$$= 100 - 100 \left(\frac{0.80^2}{1.0}\right)$$

$$= 100 - 100\ (0.64)$$

$$= \mathbf{36\%}$$

The original facility system losses of 5% are then reduced by *5 x 36 / 100 =* ***1.8%***

As a result the monthly **kWh bill is reduced by 1.8%**, in additional savings.

An MS Excel spreadsheet to automatically calculate most of the above is available

http://www.eskom.co.za/sites/eas/Energy%20solutions/Pages/Power-Factor.aspx.

It is important to note that these calculations is indicative and the design needs to be done by a professional.

Conclusions

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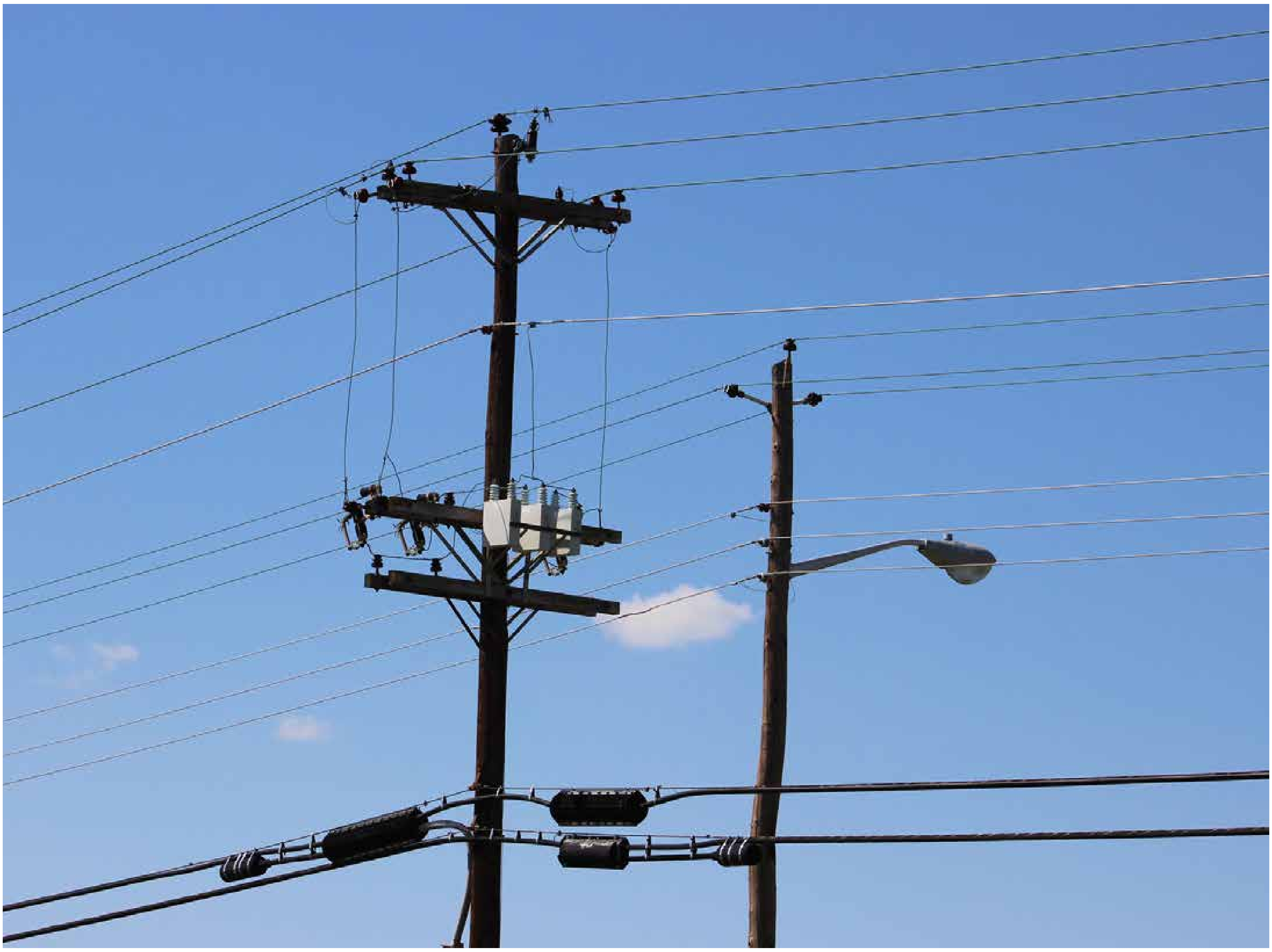
Improving power factor is a proven way of increasing the efficient use of electricity by utilities and consumers.

Economic benefits for consumers may include reduced energy costs, lower cable and transformer losses, improved voltage conditions and benefits due to released and additional system capacities.

Power Factor Correction is an effective, proven, and efficient means of improving electricity consumption.



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Issued by Energy Advisory Service February 2020
Eskom Holdings SOC Ltd Reg No 2002/015527/30
Job 3431