DEE 3143 BASIC ELECTRICAL MACHINE & POWER SYSTEMS

CHAPTER 6
COST OF ELECTRICITY

by
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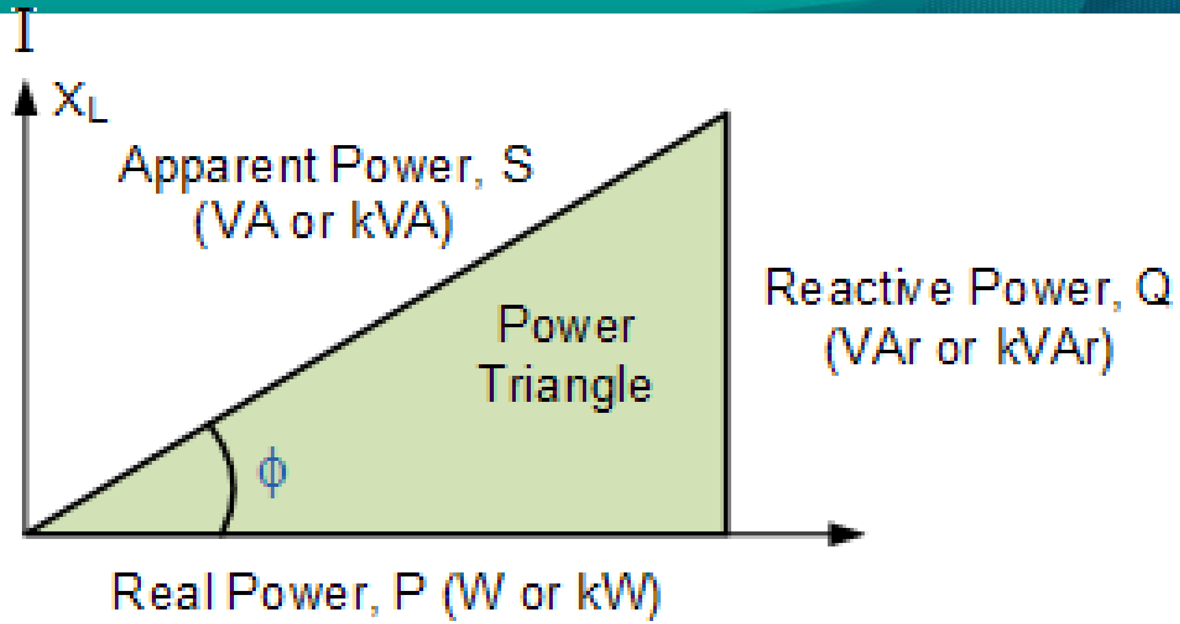
Power Factor Correction

- **Definition of Power Factor**
- Power factor is the ratio between actual (true) load power (kW) and the apparent load power (kVA)

$$pf = \frac{Actual\ load\ power(kW)}{Apparent\ load\ power(KVA)}$$

- It is a measure of ***how effectively the current is being converted into useful work output*** and ***more particularly is a good indicator of the effect of the load current on the efficiency of the supply***.

Power Factor Correction



$$P = VI\cos\phi, \quad S = VI, \quad Q = VI\sin\phi$$

$$VA = \sqrt{P^2 + VAr^2}$$

Source: http://www.electronics-tutorials.ws/inductor/ac-inductors.html

Power Factor Correction

- **Equipment Causing Poor Power Factor**
- ***Lightly loaded induction motor***. Examples of this type of equipment and their approximate power factor are:
  - ***70% power factor or better:*** Air conditioners, pumps, center less grinders, cold header, up setter, fans or blower
  - ***60% to 70% power factor:*** Induction furnaces, standard stamping machines and weaving machines
  - ***60% power factor and below:*** Single-stroke presses, automated machine tools, finish grinders, welders

Power Factor Correction

- **Reactive Power Problem (Motor)**
- **Example** that a motor is rated at 10,000W at 0.8 power factor. The resistance is 5ohm. At 415V, the motor will require the following amount of current:

  $I=10000/(\sqrt{3}x0.8x415)=\mathbf{17.39A}$

  Losses when pf =0.8 : $I^2R=(17.39)^2(5)=$***1,512W***

  The same motor rated at ***0.65 power factor*** will require:

  $I=10000/(\sqrt{3}x0.65x415)=\mathbf{21.403A}$

  Losses when pf=0.65 : $I^2R=(21.403)^2(5)=$***2290.4W***

Low Power Factor = Higher Losses

Power Factor Correction

- **Reactive Power Problem (Transformer)**
- **Example** that 11/0.433 kV 1000kVA transformer has maximum loading of 800KW and power factor of 0.45

  What is the % loading of the transformer?

PF=KW/KVA=0.45

KVA(Load) = kW/PF=800/0.45=1777

%Tx Load = kVA (Load) / Tx Capacity

= (1777 / 1000) x 100 = **177%**

Power Factor Correction

- **Reactive Power Problem (Transformer)**
- Example that 11/0.433 kV 1000kVA transformer has maximum loading of 800KW and power factor of 0.9

What is the % loading of the transformer?

PF=KW/KVA=0.9

KVA(Load) = kW/PF=800/0.9=888.88

%Tx Load = kVA (Load) / Tx Capacity

= (888.88 / 1000) x 100 = **88.88%**

Power Factor Correction

- **Reactive Power Problem (Transformer)**
- ***Condition 1***
  - ***PF=0.45***
  - TX Size=1000kVA
  - Load KVA=1777 KVA
  - ***%TX Load=177%***
- ***Condition 2***
  - ***PF=0.9***
  - TX Size=1000kVA
  - Load KVA=888 KVA
  - ***%TX Load=88%***

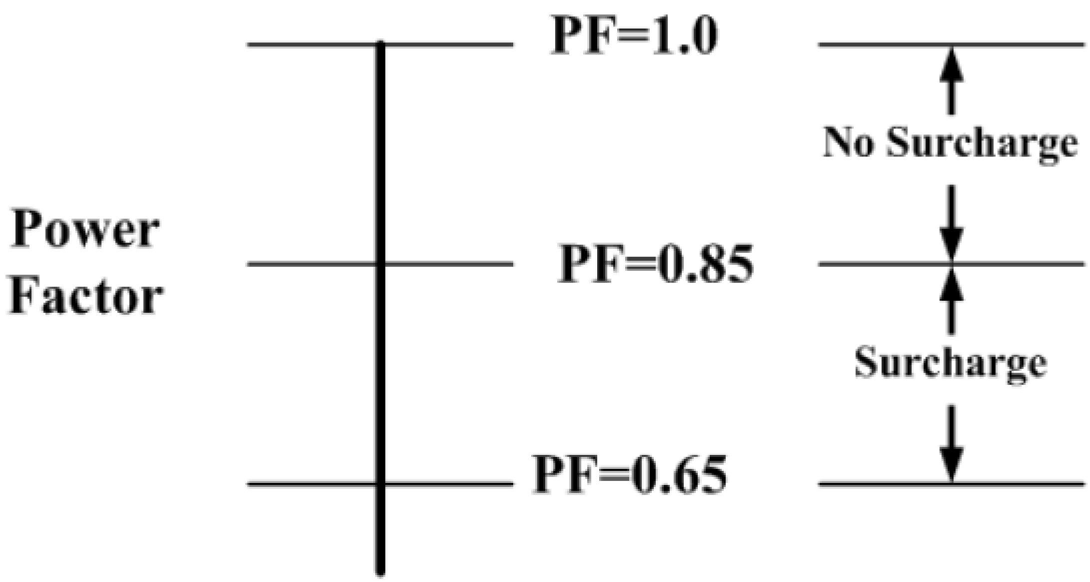
Low Power Factor

=

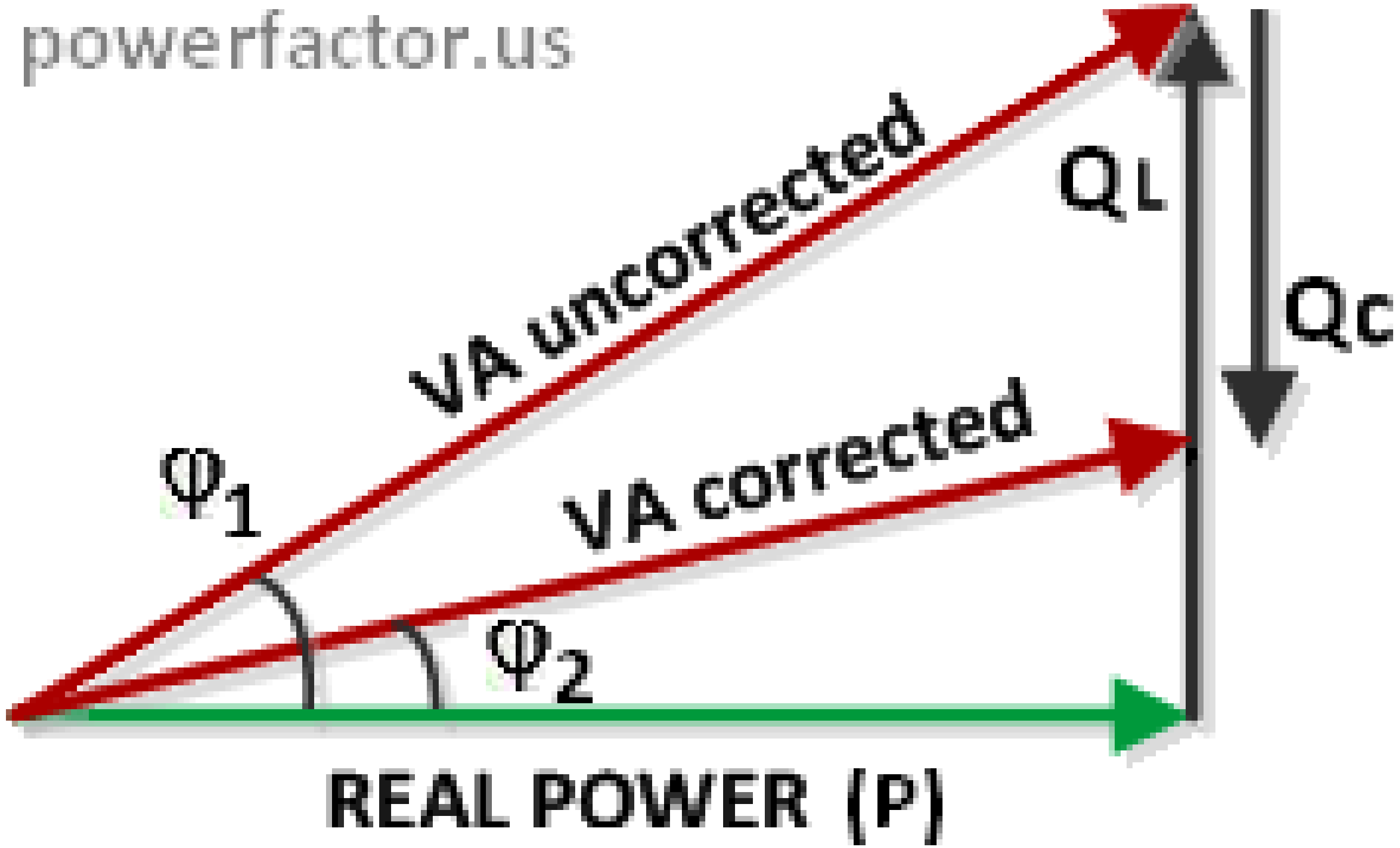
Increase Tx Loading

Power Factor Correction

- **Minimum Power Factor**
- Customers are advise to maintain power factor at minimum of 0.85



Power Factor Correction



Source: http://www.powerfactor.us/pfc-calc.html

Power Factor Correction

A factory draws an apparent power of 300kVA at a power factor of 0.65 (lagging). The minimum power factor specified by the electrical utility company is 0.85. The power factor can be improved by installing capacitors at the main switch board at the service entrance of the factory.

Calculate the kvar capacity of the capacitor bank that must be installed to bring the overall power factor to

i) Unity.
ii) 0.85 lagging.
iii) How much less would the capacitor bank cost (in percentage) if the power factor is only raised to 0.85 percent instead of unity?

Power Factor Correction

- **Example 1**
- An industrial plant has an active power demand of 500kW at a power factor of 0.76 lagging. Determine the reactive power rating of the capacitor bank required to improve the power factor to the following:

  a) 0.8 lagging

  b) 0.9 lagging

  c) Unity

  Assume the capacitor steps are available in 50 kVar increments

Power Factor Surcharge

Percent of surcharge from the current bill	Condition
1.5%	For every 0.01 less than 0.85 power factor
3%	For every 0.01 less than 0.75 power factor

The penalty surcharge is calculated based on the value of power factor below:

a) For end user customer with power factor between 0.75 and 0.85 lagging, a supplementary charge of 1.5% of the bill for the month for each one-hundredth part (0.01) will be added to the bill for that month.

b) For end user customer with power factor below 0.75 lagging, in addition to the charge payable under (a) above, a supplementary charge of 3% of the bill for that month for each one-hundredth (0.01) below 0.75[0.80] lagging power factor will be added to the bill for that month.

Example

A high voltage voltage industrial consumer having the following data from its monthly bill:

Maximum demand (kW) : 600 units
Monthly active energy consumption (kWh) : 216,000 units
Monthly reactive energy consumption (kVarh) : 190,000 units

The electricity consumption during peak hour is between 8.00 am to 10.00 pm every day. The off- peak consumption is at least 30% of the total electricity consumption. Based on **Tariff E3s – Special Industrial Tariff,** analyze

- The monthly load factor of the consumer.
- The power factor of the consumer (assume 30 days per month).
- The total penalty charge due to poor power factor (if any) and the total monthly bill charge for this consumer.
- The size of capacitor, in Kvar, would raise the PF to be 0.9.
- How many months they need to pay back for power factor improvement if the buying cost and installing of shunt capacitor are RM300/kVar.

Example

Tariff E3s – Special Industrial Tariff

RATE	UNIT	
For each kilowatt of maximum demand per month during the peak period	RM/kW	29.00
For all kWh during the peak period	sen/kWh	31.70
For all kWh during the off-peak period	sen/kWh	17.50
The minimum monthly charge is	*RM 600.00*	

Solution

i) Monthly load factor, LF

$$Average\ \ Load = \frac{Total\ \ Connected\ \ Load(kWh)}{Period(h)}$$

$$Average\ \ Load = \frac{216{,}000\ \ kWh}{30days \times 24h} = 300\ \ kW$$

$$Load\ \ Factor = \frac{Average\ \ Load}{Maximum\ \ Demand} = \frac{300\ \ kW}{600\ \ kW} = 0.5\ \ @\ \ 50\%$$

Power factor, PF

$$S = \sqrt{P^2 + Q^2} = \sqrt{(216{,}000kWh)^2 + (190{,}000kVarh)^2} = 287{,}673.426kVAh$$

$$pf = \cos \theta = \frac{P}{S} = \frac{216{,}000kWh}{287{,}673.426kVAh} \approx 0.75$$

Total penalty charge

For each kW of maximum demand per month:

$$= RM\,29.00 \times 600$$

$$= RM\,17{,}400.00$$

Electricity consumption during peak period
= 70% of Total electricity consumption
= 70% x 216,000 kWh
= 151,200 kWh

For all kWh during the peak period:

$$= RM\,0.317 \times 151{,}200\ \ kWh$$

$$= RM\,47{,}930.40$$

Electricity consumption during off-peak period
:
= 30% of Total electricity consumption
= 30% x 216,000 kWh
= 64,800 kWh

For all kWh during the off-peak period:

$$= RM\,0.175 \times 64{,}800\ \ kWh$$

$$= RM\,11{,}340.00$$

Total penalty charge

Total monthly electricity charge (**without surcharge on poor PF):**

= Maximum demand charge + peak period charge + off-peak period charge

= RM17,400 + RM47,930.40 + RM11,340

= **RM76,670.40**

Total penalty charge

$$= \left[RM\,76{,}670.40 \times \left[\frac{0.90 - 0.80}{0.01} \right] \times 1.5\% \right]$$

$$+ \left[RM\,76{,}670.40 \times \left[\frac{0.80 - 0.75}{0.01} \right] \times 3\% \right]$$

$$= RM\,11{,}500.56 + RM\,11{,}500.56$$

$$= RM\,23{,}001.12$$

Therefore, the total monthly electricity charge:

$$= RM\,76{,}670.40 + RM\,23{,}001.12$$

$$= RM\,99{,}671.52$$

The Rating of Compensation in kVar

$$Q_{CAP} = P_{LOAD} \times \left[\left(\sqrt{\left(\frac{1}{PF_1^2} \right) - 1} \right) - \left(\sqrt{\left(\frac{1}{PF_2^2} \right) - 1} \right) \right]$$

$$Q_{CAP} = 300\ kW \times \left[\left(\sqrt{\left(\frac{1}{(0.75)^2} \right) - 1} \right) - \left(\sqrt{\left(\frac{1}{(0.9)^2} \right) - 1} \right) \right]$$

$$Q_{CAP} = 119.280\ kVar$$

Payback period

Cost of installed capacitor is = RM300/kVar x 119.28 kVar = RM35,784.00

$$payback\ \ period = \frac{capacitor\ \ \cos t}{saving} = \frac{RM\,35{,}784.00}{RM\,23{,}001.12\,/\,month} = 1.556\ \ month$$

$$\therefore\ \ payback\ \ period \approx 1\frac{1}{2}\ \ month$$

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Research interest: Reliability, Distribution network, smart grid, risk assessment