MARCH 2017

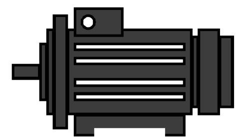
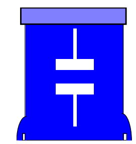
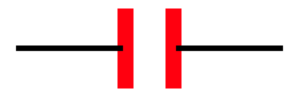
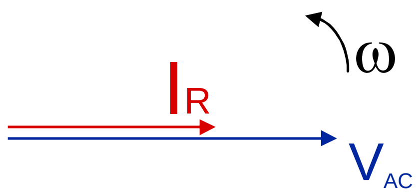
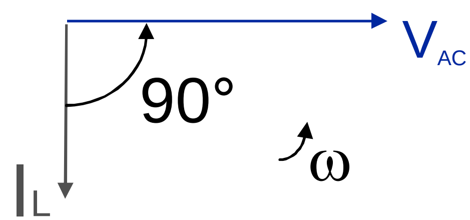
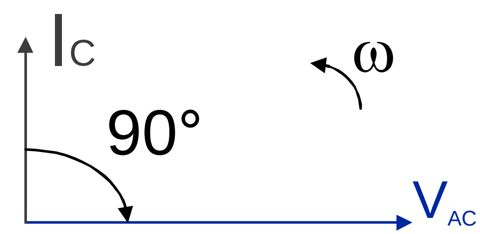
Reactive Power Compensation

First step towards improvement of power quality

Outline

1. Theory
2. Examples
3. Compensation along the power line
4. Compensation at the consumer end
5. Summary and conclusion

Summary of load categories

R	L	C
 Furnace, heater,…	 Motor, coil-based device,…	 Capacitor, cap bank,…
		
		
P **W or kW**	**Q** **var or kvar**	**Q** **var or kvar**

1. Theory

Why do we install a compensation system?

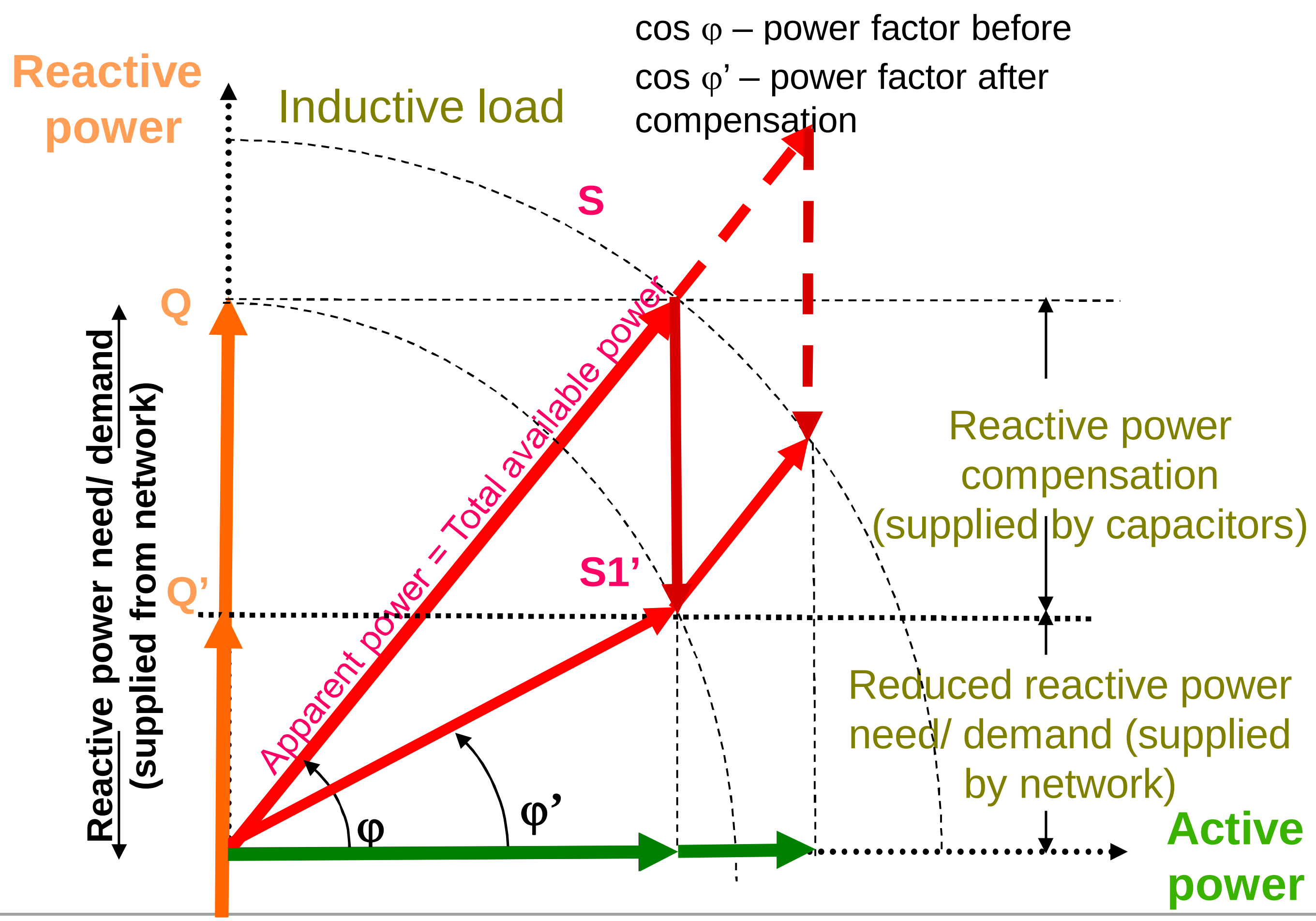
Comply with utility demands at PCC (grid code), might also include distortion demands?

Reduce internal losses / billing charges?

Increase capacity of transformers and power lines (Raise the system capacity)

Voltage control

1. Theory



Reactive power
Inductive load
cos φ – power factor before
cos φ' – power factor after compensation
S
Q
Q'
S1'
Apparent power = Total available power
Reactive power need/ demand (supplied from network)
Reactive power compensation (supplied by capacitors)
Reduced reactive power need/ demand (supplied by network)
φ
φ'
Active power

1. Theory

Q Generation Demand

- Minimum generated power is given by system calculations
- Present and target power factor together with active power
- Distortion demands might require filter and more reactive power generation than power factor demand

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1. Theory

Power factor correction

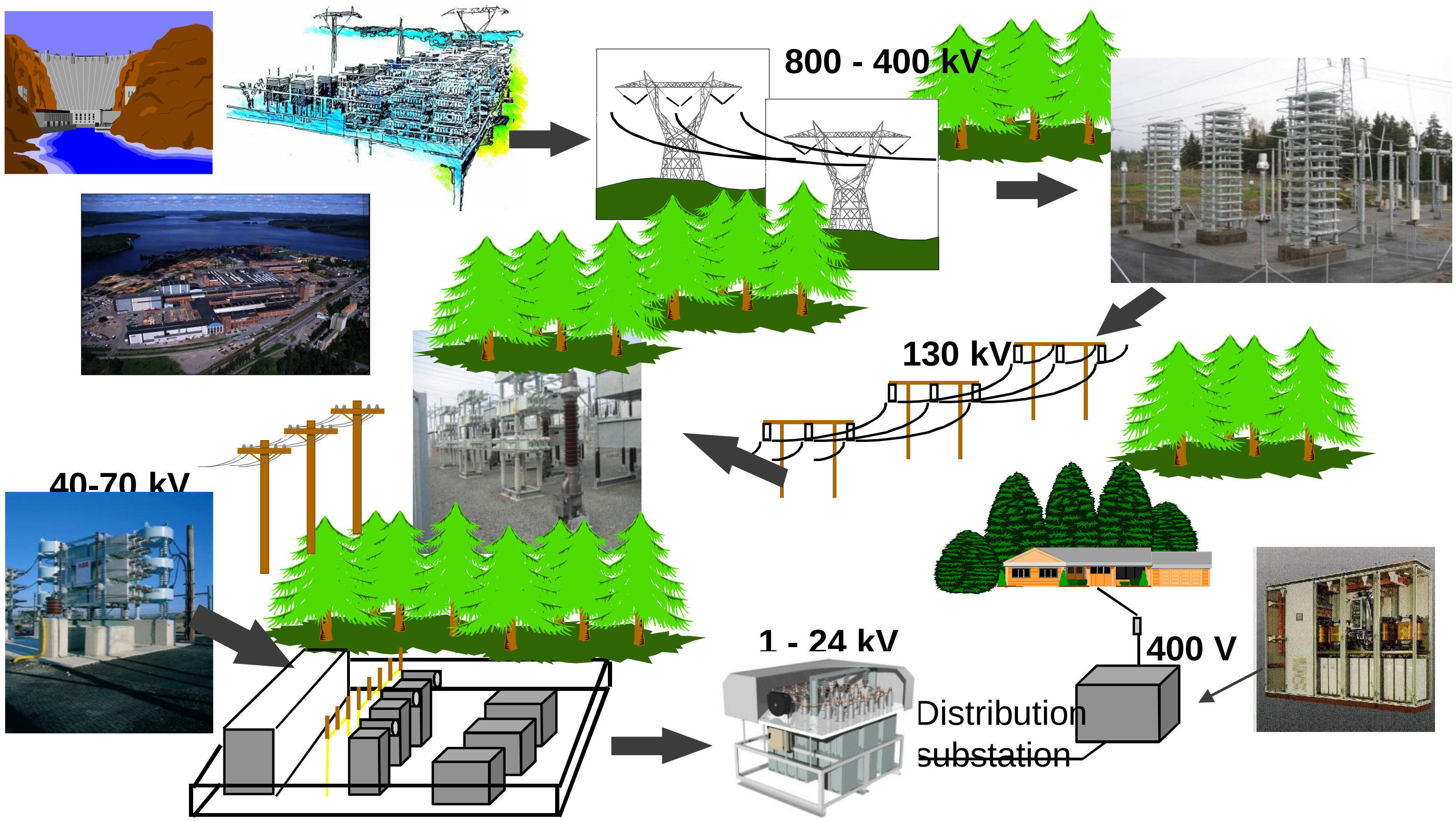
The network quality problems refers to the actual power not power factor.

Voltage drops and fluctuations

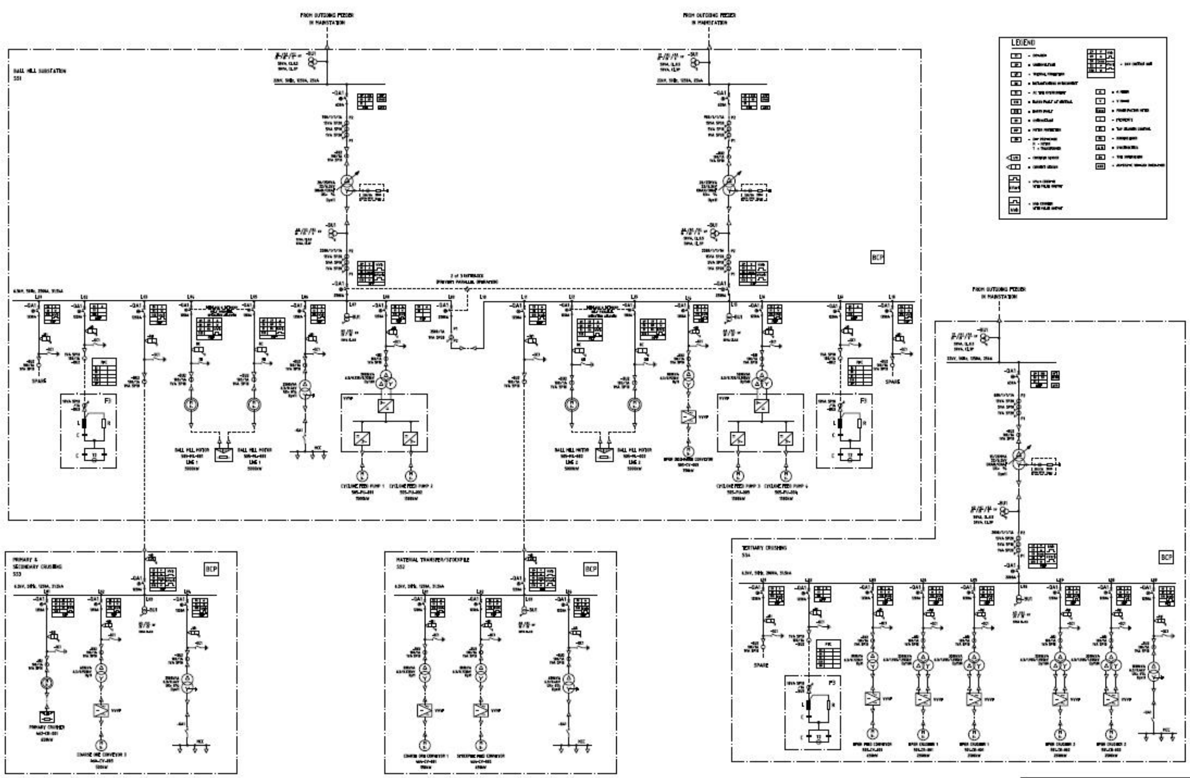
Bad utilization of present transmission systems.

Normally it is not a technical problem with low power factor at low load conditions

1. Theory
Locations in network



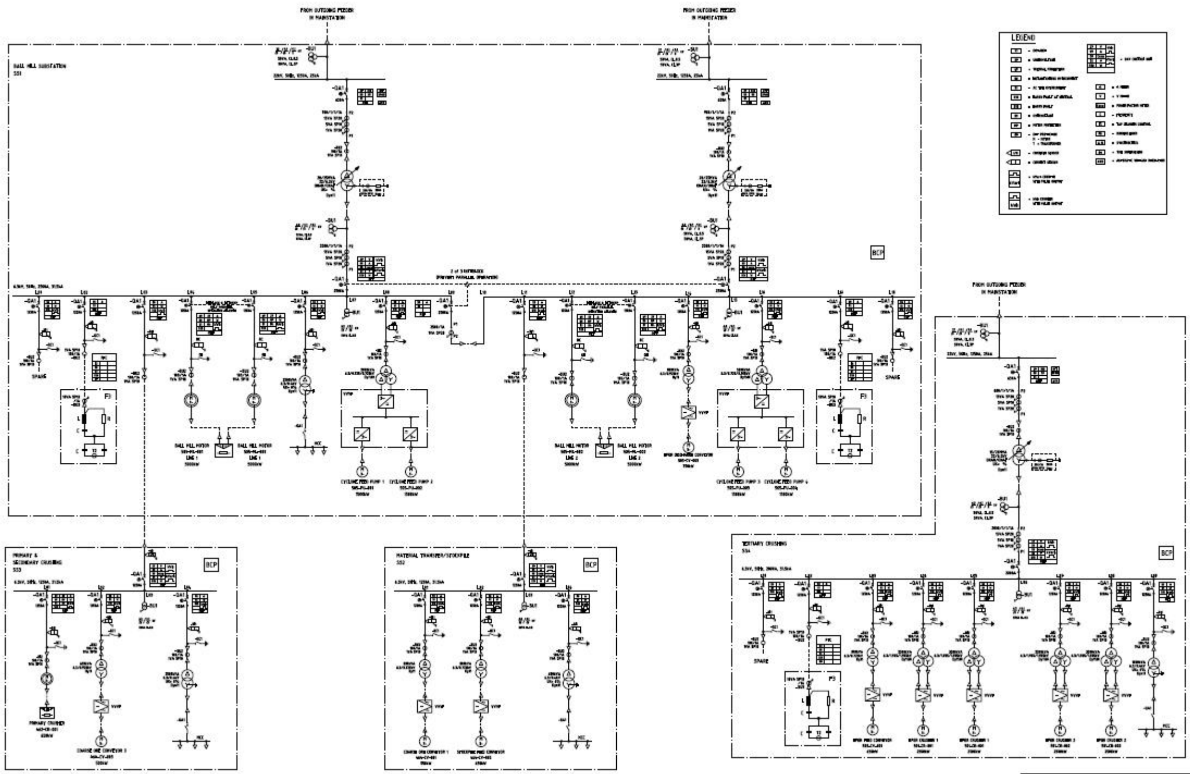
1. Theory
Static compensation/Location?



Main objective of compensation

Compensation location is many times a compromise

1. Theory
Static compensation/Location?



- Best result close to the load but might imply several systems
- Higher switching frequency
- For filters might imply limitations regarding operation

1. Theory
Generation demand

The main concerns when installing small capacitor banks are not optimized banks and switchgear cost (including the protection) and the cost of the installation.

The cost of the installation may be reduced by installing the capacitor on the low voltage side

1. Theory
Generation demand

Maximum bank size is controlled by allowed voltage rise at connection.
Voltage raise at connection

$dU=dQ/S_{sc}$ typically < 3%

Resonance risk $n = \sqrt{(S_{sc} / Q_{gen})}$
(n harmonic order)

OBSERVE!

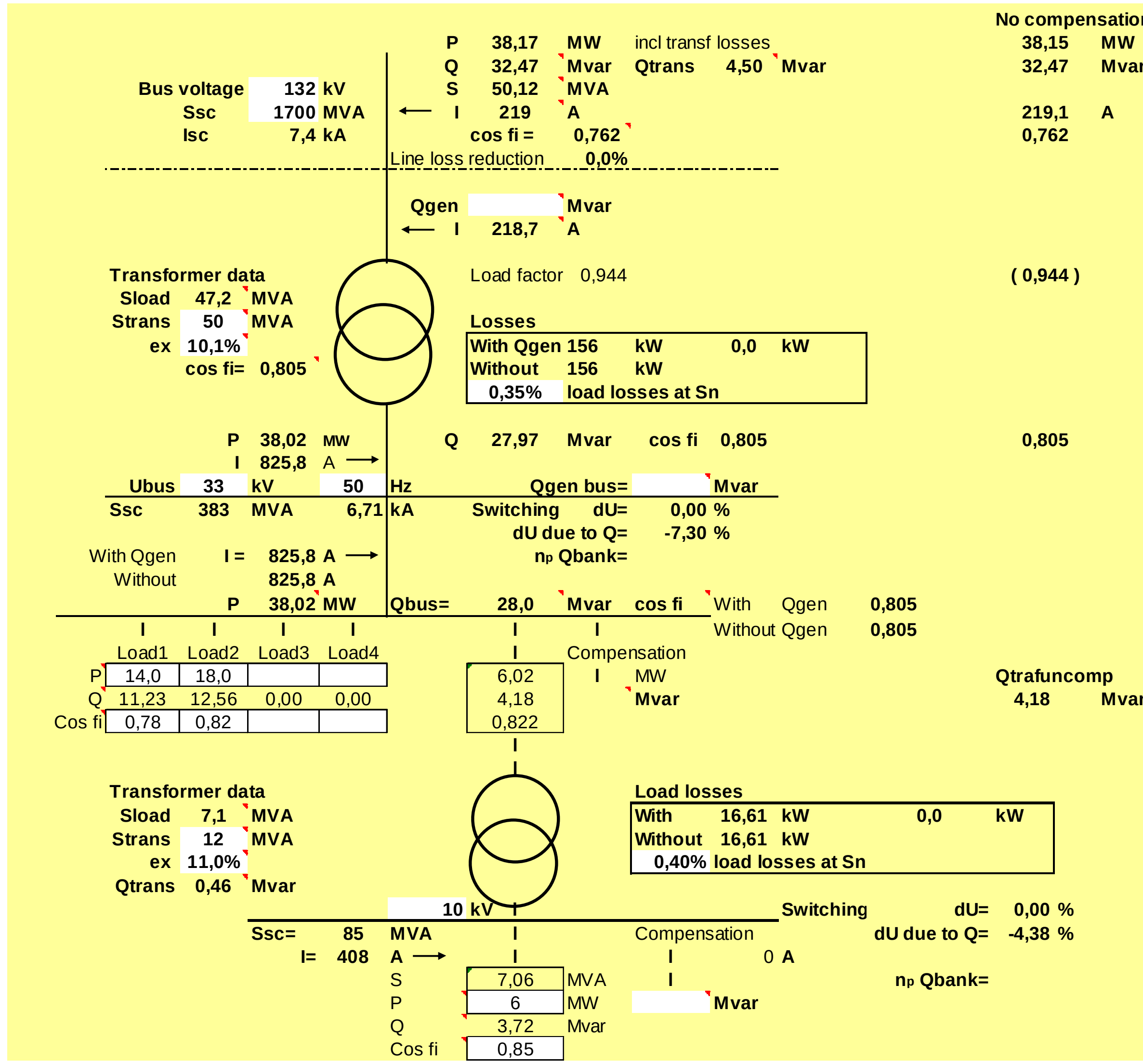
S_{sc} is used for calculation of system performance and that it is the impedance of the system giving the short-circuit power that is of interest

1. Theory

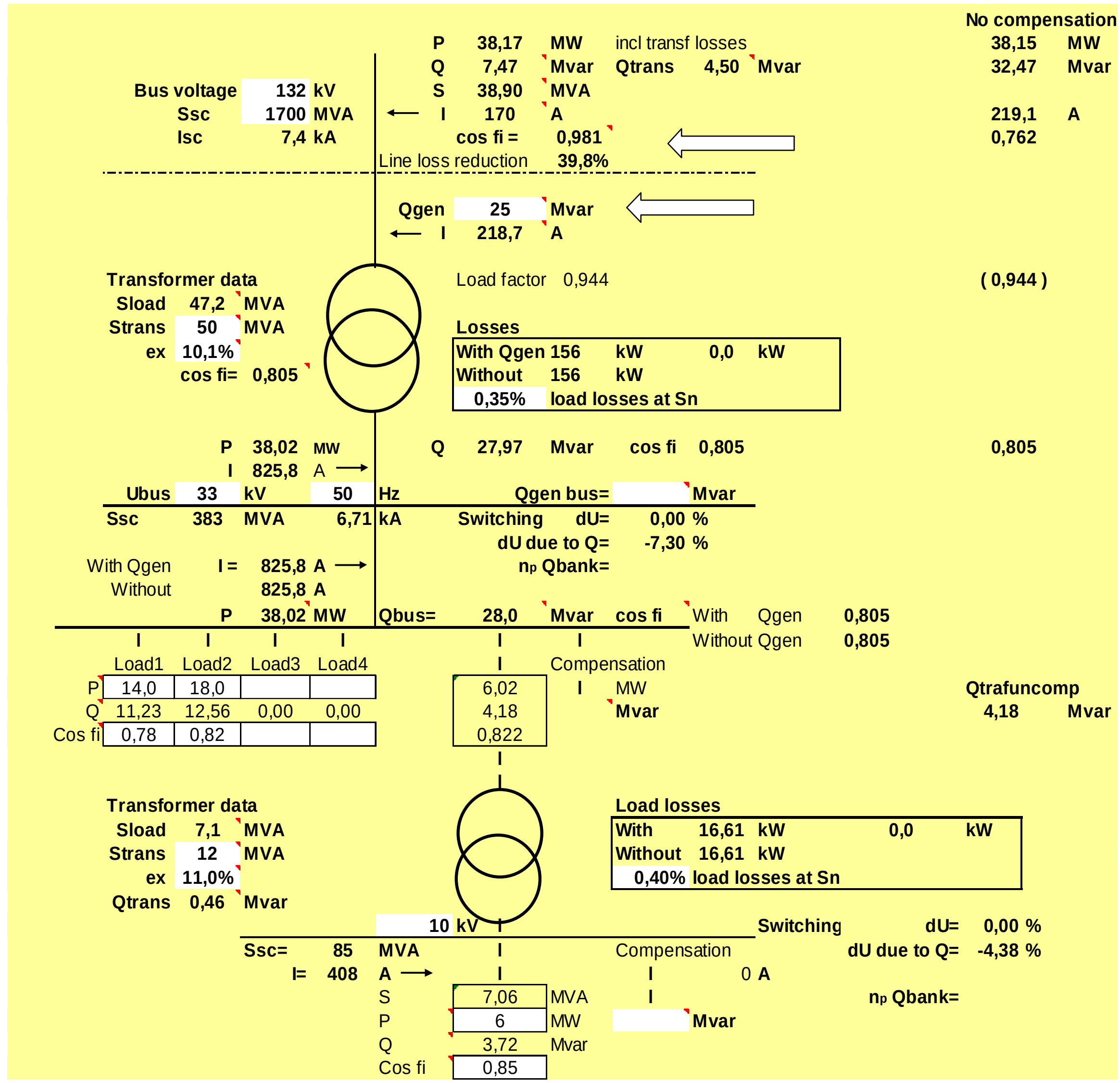
Shunt power capacitors applied to distribution systems are generally located on the distribution lines or in the substations.

2. Examples

No compensation

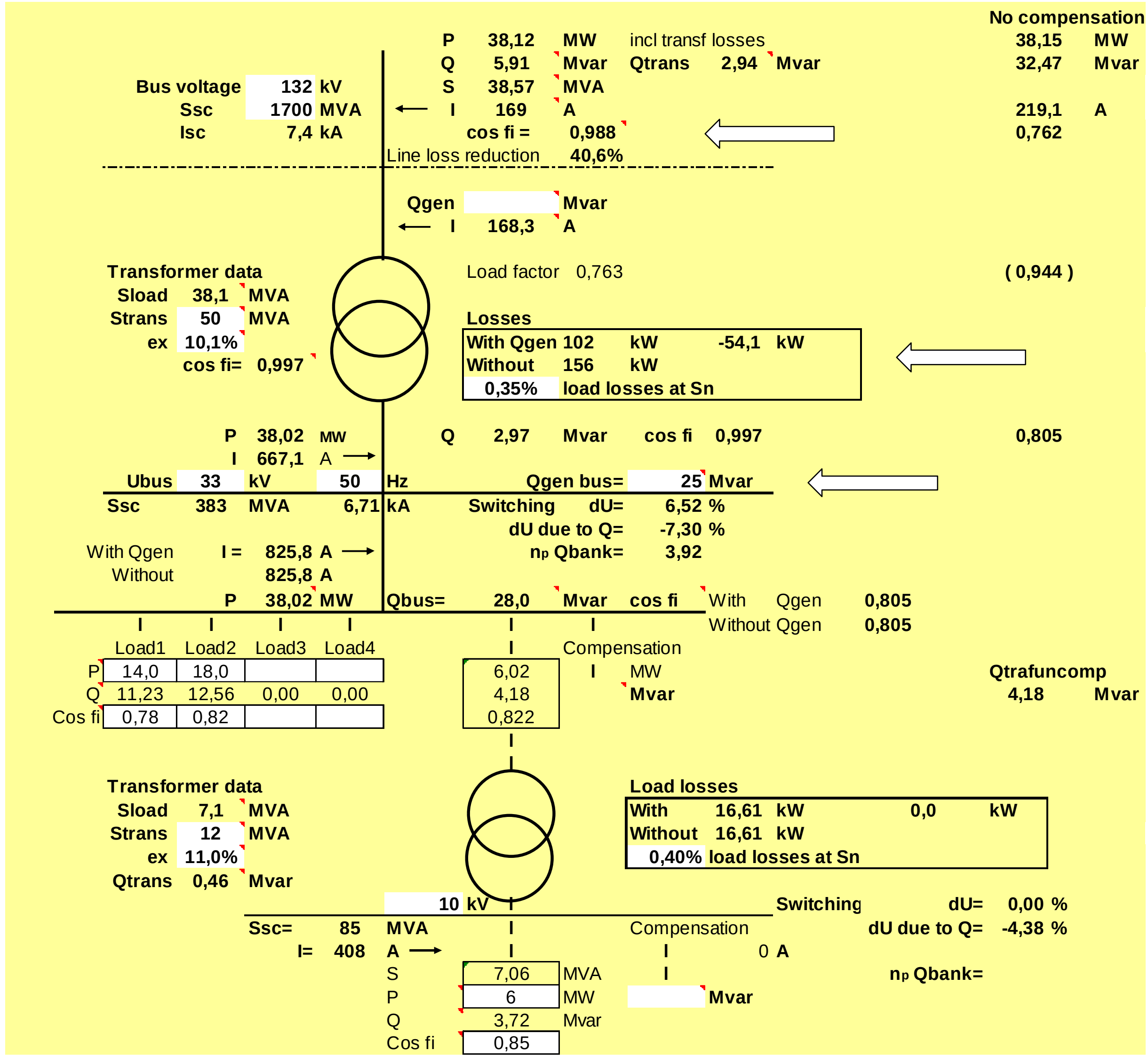


2. Examples
132 kV compensation



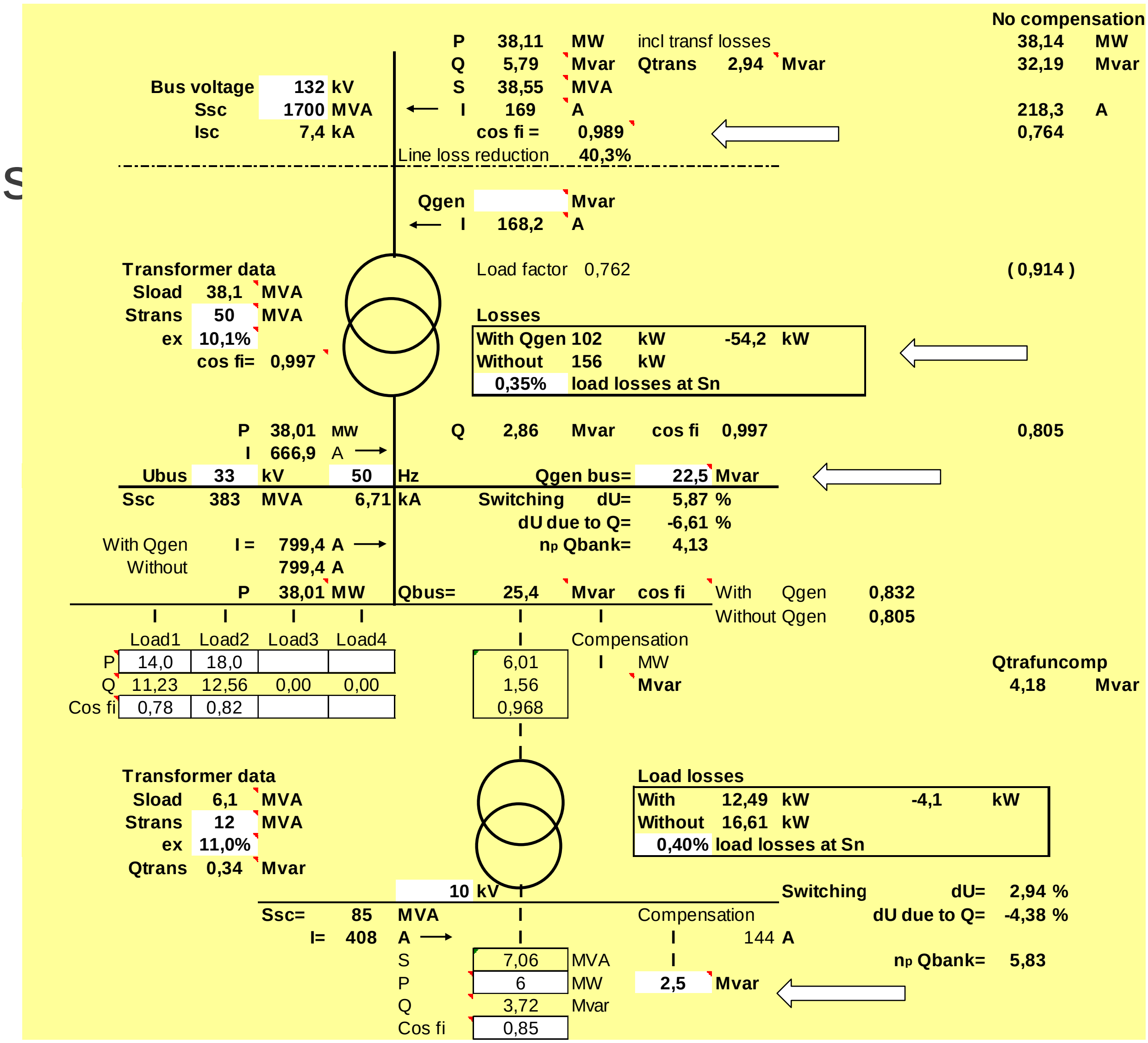
2. Examples

Compensation at 33 kV bus



2. Examples

Compensation at 33 kV and 10 kV bus



3. **Compensation along the power line**

Capacitors located on the distribution lines might be an effective means for minimizing system losses

The capacitor banks should be located where they produce

- the maximum loss reduction
- provide the maximum voltage benefit
- are as close to the load as possible

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3. **Compensation along the power line**

For uniformly distributed loads, the capacitor should be placed two-thirds of the distance from the substation.

For uniformly decreasing distributed loads, the capacitor should be placed one-half of the distance from the substation.

3. **Compensation along the power line**

For maximum voltage rise, the capacitor should be placed near the end of the line.

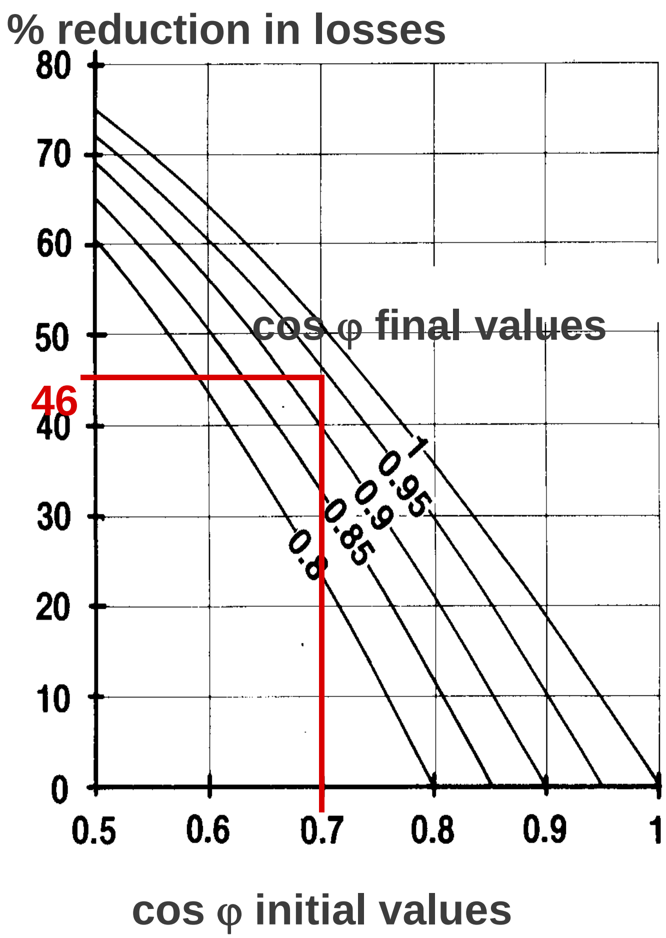
4. **Compensation at the consumer end – LV side**

Significant load is connected on the low voltage side

- Industrial customers
- Commercial buildings
- Residential loads

Compensation close to the load (directly on the LV side) has several advantages

Reduced Joule losses (RI^2)
Cables

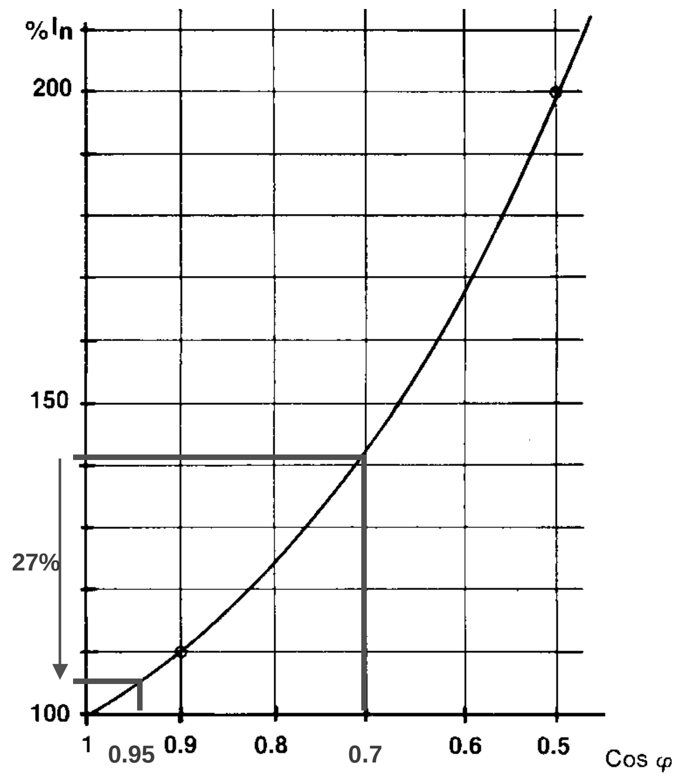


Reduction factor of RI^2 watt (%):

RI^2 watt (%) = $$(1-\frac{\cos\varphi 1}{\cos\varphi 2})^2 * 100$$

For the same load, the losses are reduced by **46%** when PF rises from 0.7 to 0.95

Transformers and distribution cables lightened



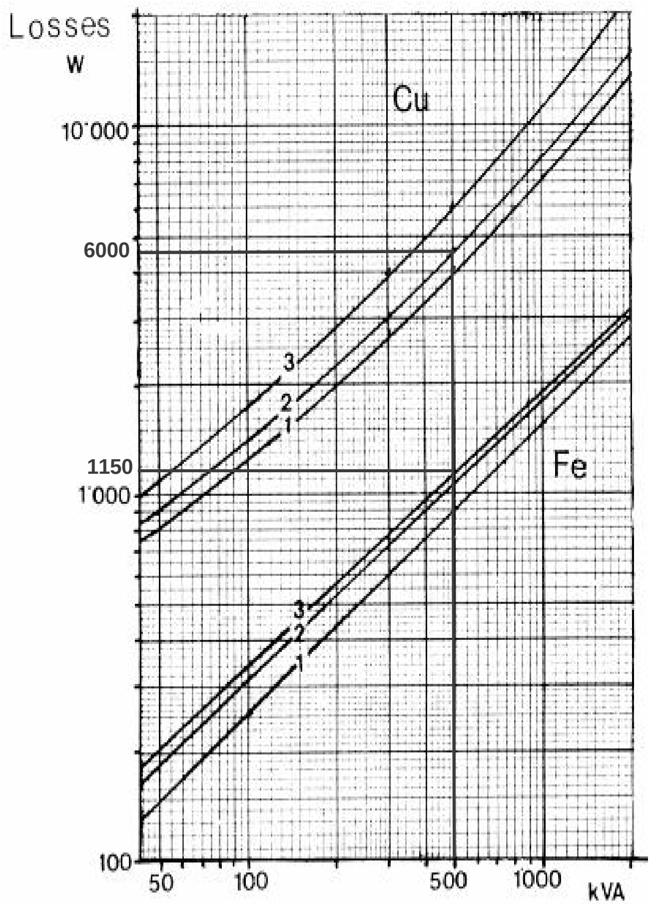
Current drawn from the network reduced

Reduction in factor of:

$$(1 - \frac{\cos \varphi 1}{\cos \varphi 2}) * 100$$

Ex: For the same kW, In is reduced by 27% when PF rises from 0.7 to 0.95

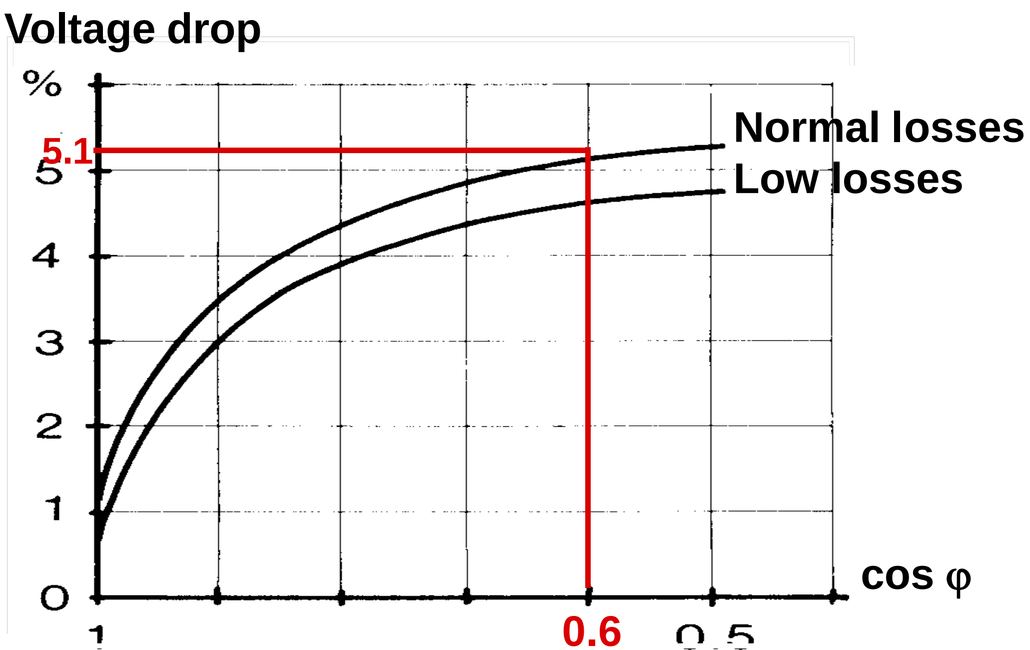
Reduced Joule losses (RI²)
Transformer



3 = transformer with normal losses
2 = transformer with reduced losses
1 = transformer with low losses
Two types of losses
- **Iron** (or core losses)
  - power dissipated in the transformer under no load conditions
- **Copper** (or winding losses) ⌫ f(I)²

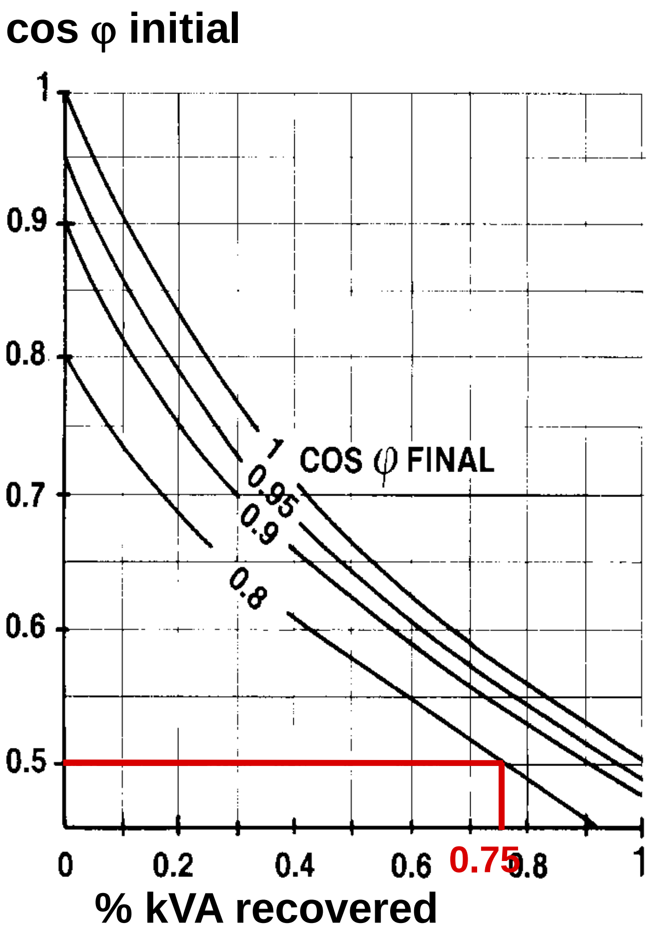
Tlosses = Fe + Cu (actual load / rated load) ²

Voltage drop in transformer



Cos φ = 0.6 gives about 5.1% drop in voltage

kVA output reduced



kVA = kW (1/cos φ 1 – 1/cos φ 2)
Example:
  Load of 200kW
  kVA recovered = 200*0.75 = 150 kVA
Transformer load
    With cosφ =0.5 ⌫ 200/0.5=400kVA
    With cosφ =0.8 ⌫ 200/0.8=250kVA
    kVA recovered = 150

Typical PF encountered in industry

Industry	*Power factor*
Textile	0.65/0.75
Chemical	0.75/0.85
Machine shops	0.4/0.65
Arc welding	0.35/0.4
Arc furnaces	0.7/0.9
Coreless induction furnaces and heaters	0.15/0.4
Cement works	0.78/0.8
Clothing factories	0.35/0.6
Breweries	0.75/0.8
Steel works	0.6/0.85
Collieries	0.65/0.8
Brick works	0.6/0.75
Cold stores	0.7/0.8
Foundries	0.5/0.7
Plastics moulding	0.6/0.75
Printing	0.55/0.7
Quarries	0.5/0.7
Rolling mills (thyristor drives)	0.3/0.75

Motor compensation – for fixed compensation at motor terminal

- Induction motors are one of the most common load in an industrial sector
- Operates at low PF, around 0.80
- Always choose the capacitor such that the capacitor current is smaller than 90% of the no-load current of the motor

5. **Summary**

- Why compensation
- Location is important
- Examples of different locations
- Compensation along the distribution line
- Compensation at the consumer’s premises – LV customer

5. **Summary/Conclusion**

- The location of compensation system is important and has impact on the system
- Be observant on
  - Voltage increase at connection
  - Resonance / amplification
- Incorrect network information due to lack of knowledge may result in unexpected results

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