Hubbell Industrial Controls

Basics of Power Quality

Basic concepts – Voltage and Current

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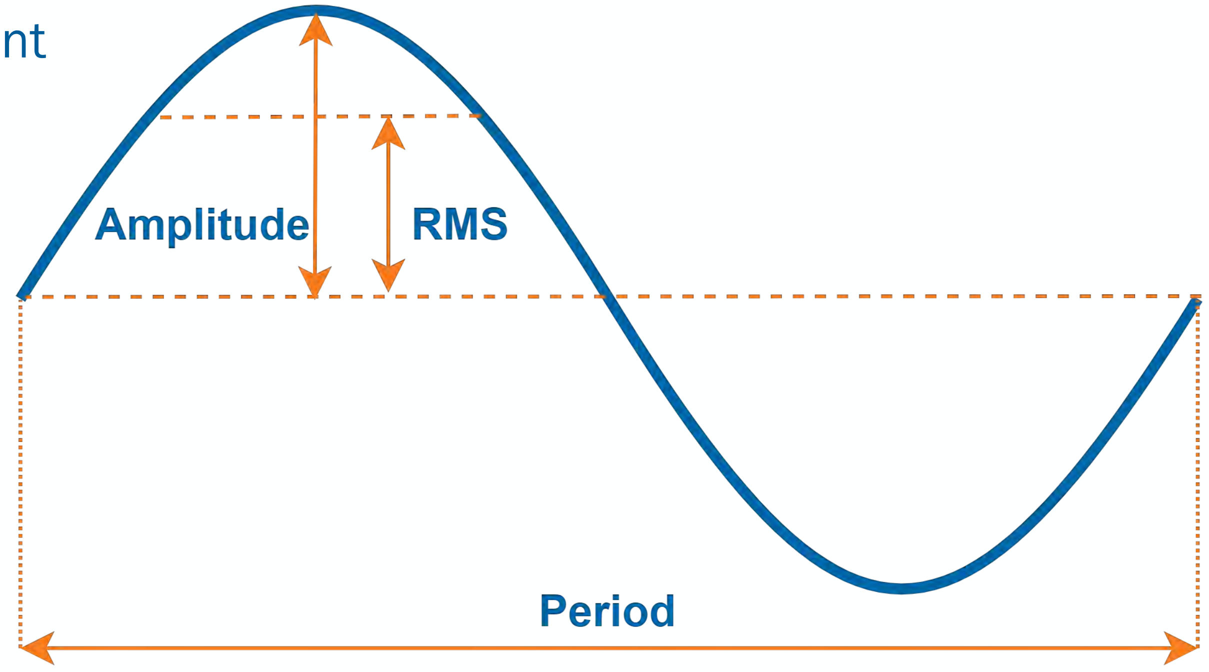
- In AC system voltage and current alternate between positive and negative maximum
- Maximum value is called amplitude
- RMS value is the effective value of voltage or current
- Period is the duration of one cycle
  - 20 ms in 50 Hz system
  - 16.67 ms in 60 Hz system



Basic concepts – 3-phase system

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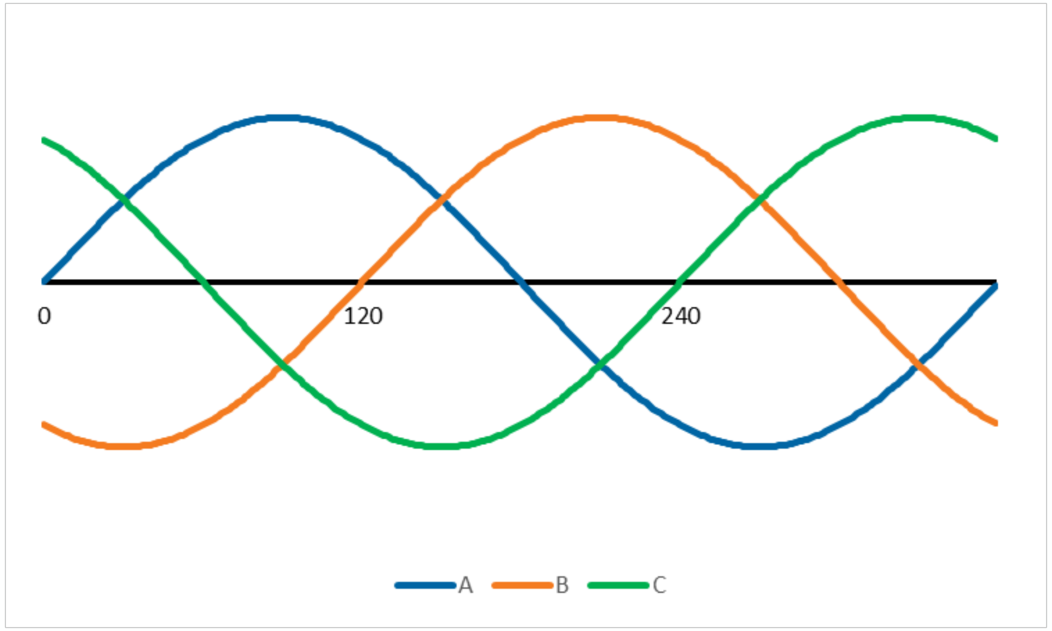
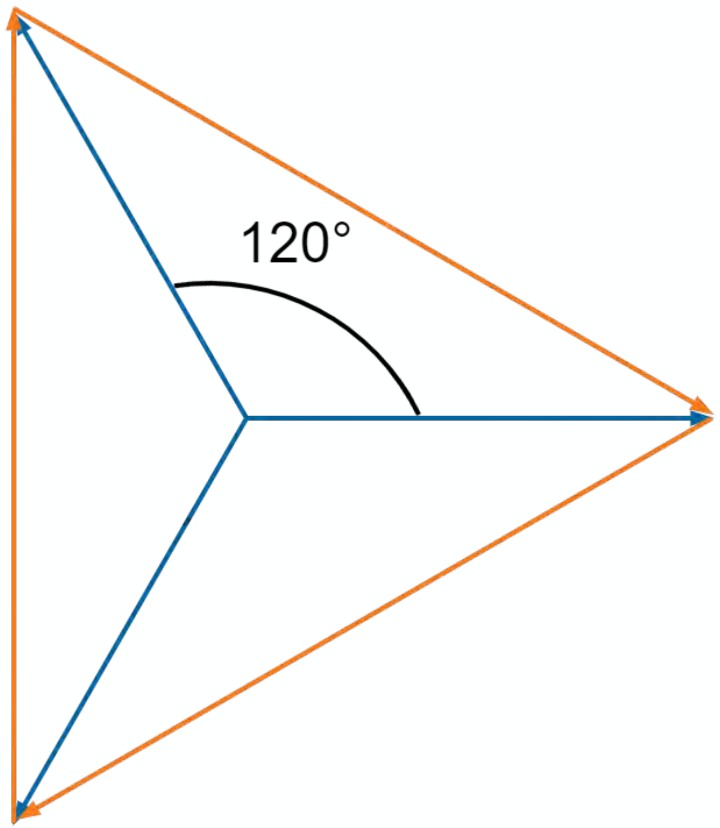
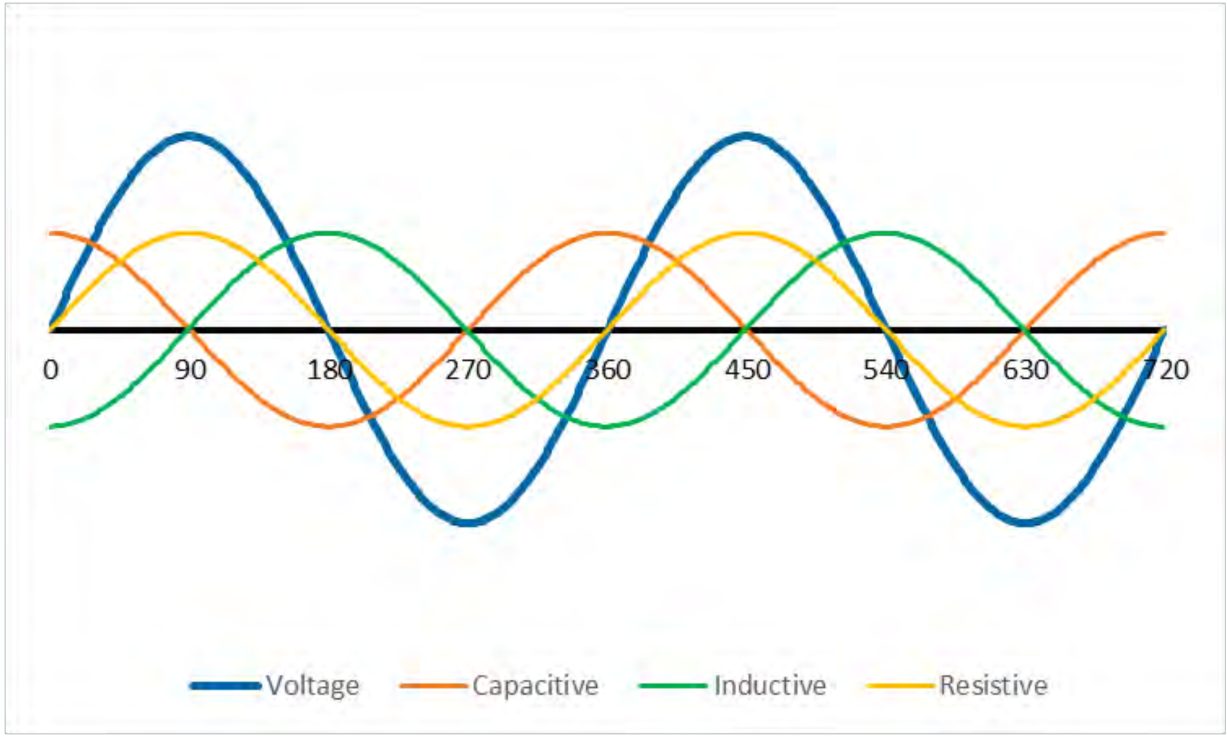
- There are three phases in power system
- Each phase has 120 degree phase shift relative to other two phases
- In ideal situation all amplitudes are equal
- Two different voltage components
  - Line to Neutral (ground)
  - Line to Line





Basic concepts – Reactive current

- There are three basic linear load elements in AC-system
  - Resistive
  - Inductive
  - Capacitive
- Resistive current is in phase with the voltage
- Inductive current lags the voltage 90 degrees
- Capacitive current leads the voltage 90 degrees
- Inductive and capacitive current have 180 degree phase shift



Basic concepts – Harmonics

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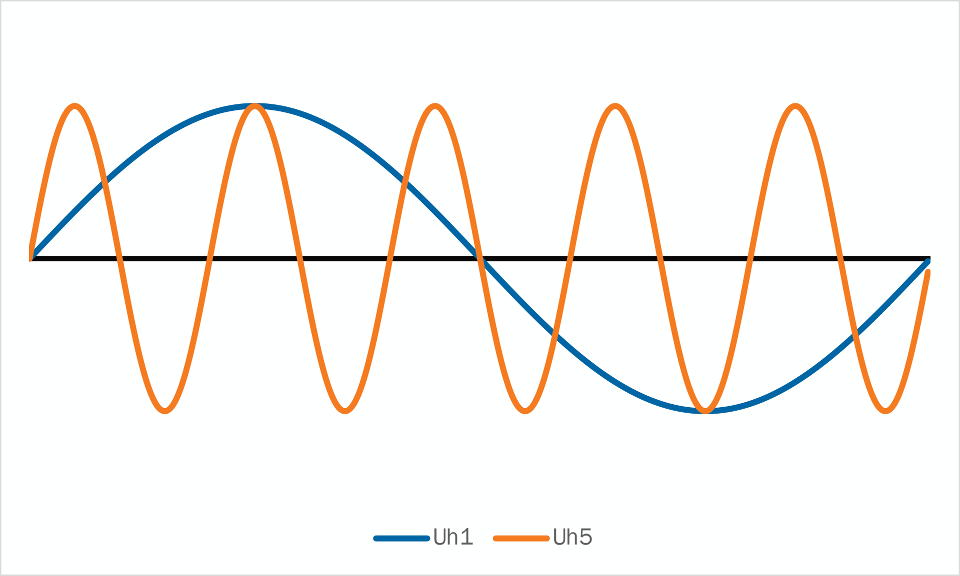
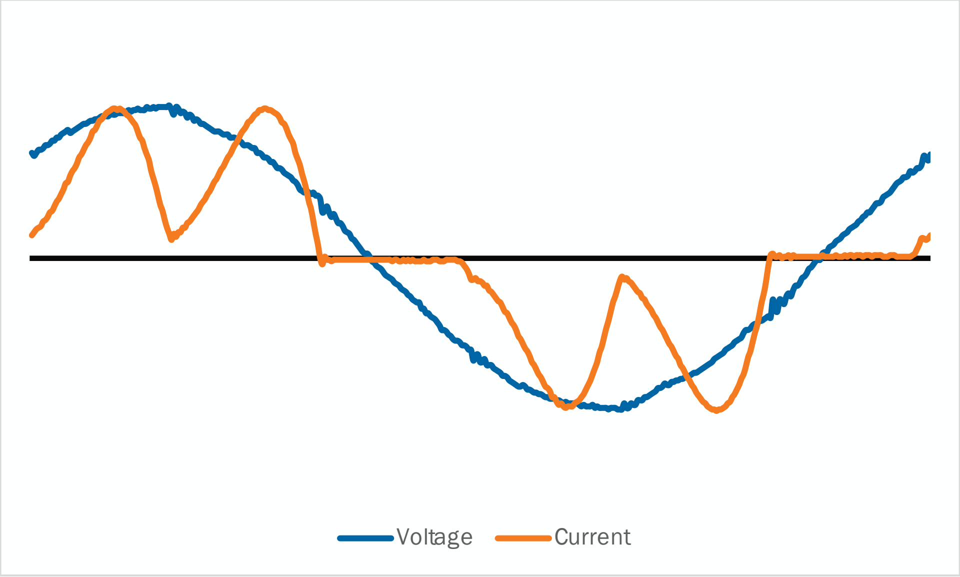
- Harmonic voltages and currents are integer multiples of the fundamental frequency
- Fourier analysis can be used to determine the amplitude of individual harmonic components in any waveform
- The amplitude of harmonics is typically compared to either amplitude of the fundamental waveform or RMS wave form

$$U_{h\%-f} = \frac{U_h}{U_1} \quad U_{h\%-r} = \frac{U_h}{U_{RMS}}$$

- Total harmonic distortion (THD) represents the total harmonic content of voltage or current

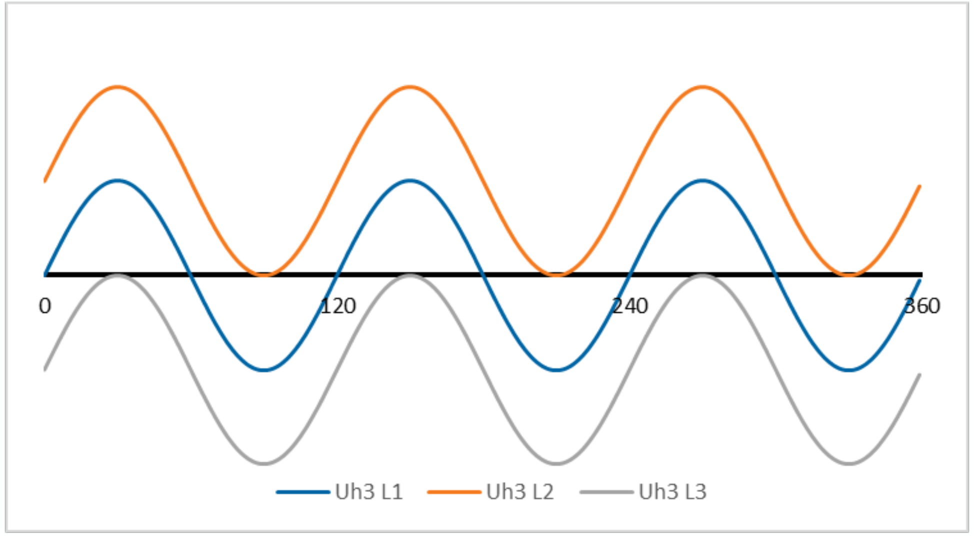
$$THD_f = \frac{U_{htot}}{U_1}\frac{\sqrt{\sum_{h=2}^{n} U_h^2}}{U_1} \quad THD_r = \frac{U_{htot}}{U_{RMS}} = \frac{\sqrt{\sum_{h=2}^{n} U_h^2}}{U_{RMS}} = \frac{\sqrt{\sum_{h=2}^{n} U_h^2}}{\sqrt{U_1^2+U_{htot}^2}}$$





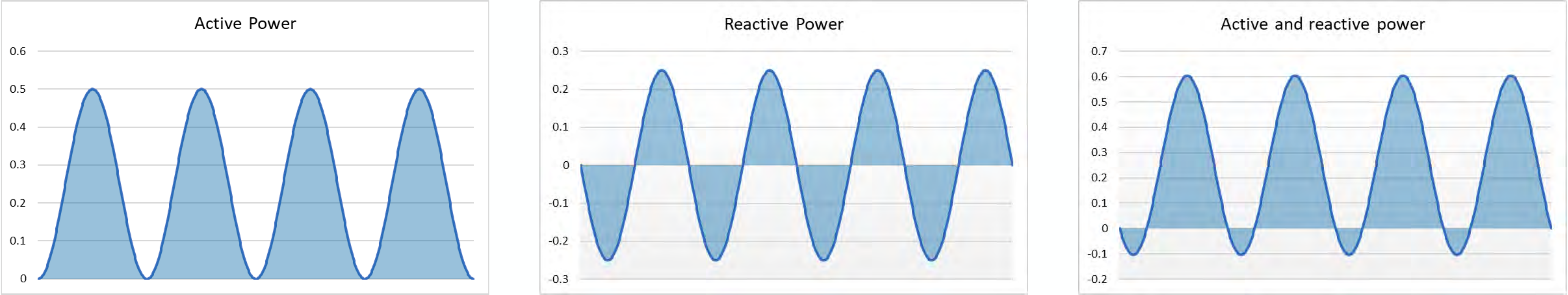
Basic concepts – Triplen Harmonics

- Triplen harmonics are harmonics which are divisible by three
  3^{rd}, 9^{th}, 15^{th}, ...
- They do not have phase shift relative to each other
  - Instead of cancelling out each other in the neutral wire they sum up
  - 100 A third harmonic in each phase equals 300 A in neutral



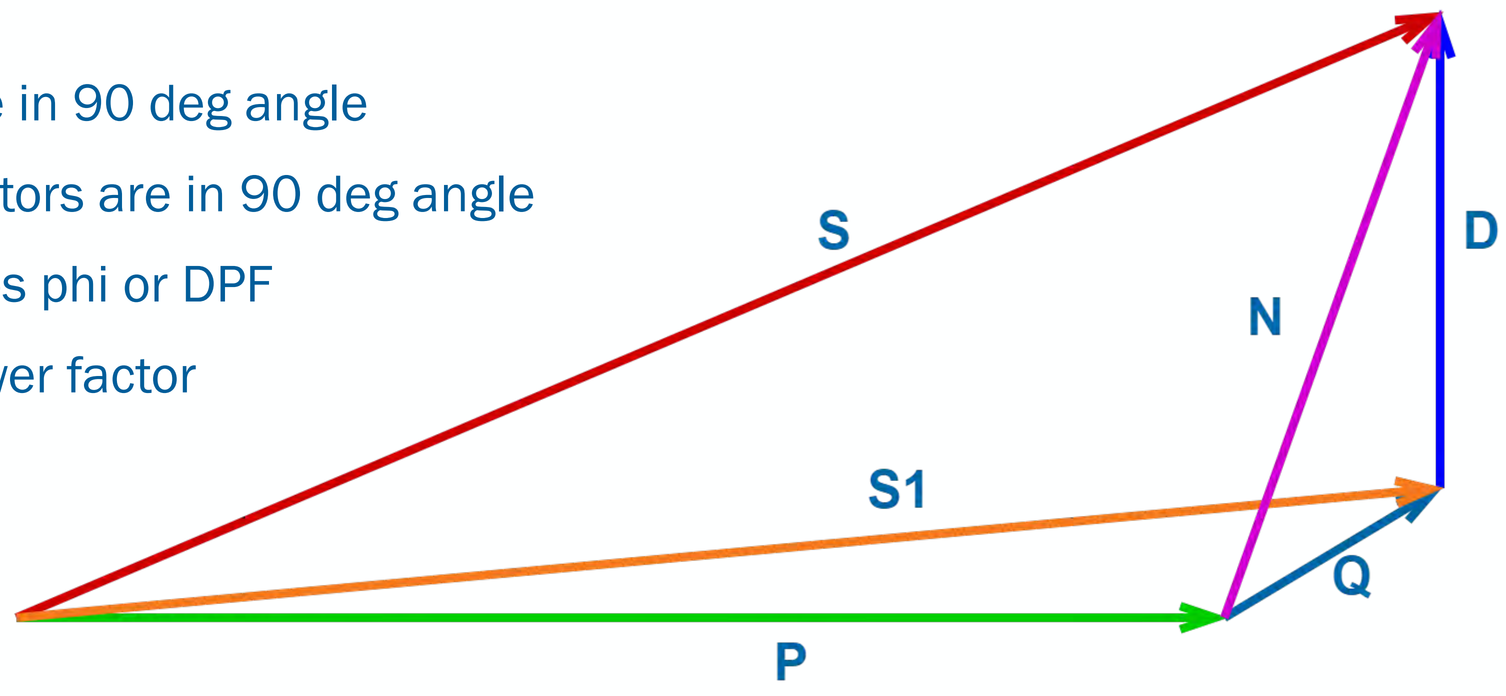
Basic concepts – AC-Power

- AC-power constantly fluctuates with 2 x system frequency
- With active current power fluctuation between 0 and max value
- With reactive current average = 0 → no net energy transfer
- When both resistive and reactive load present minimum power fluctuates between positive and negative and average ≠ 0
- Only active power needs to be produced with a generator unit
- Reactive power can be produced locally with a compensator unit



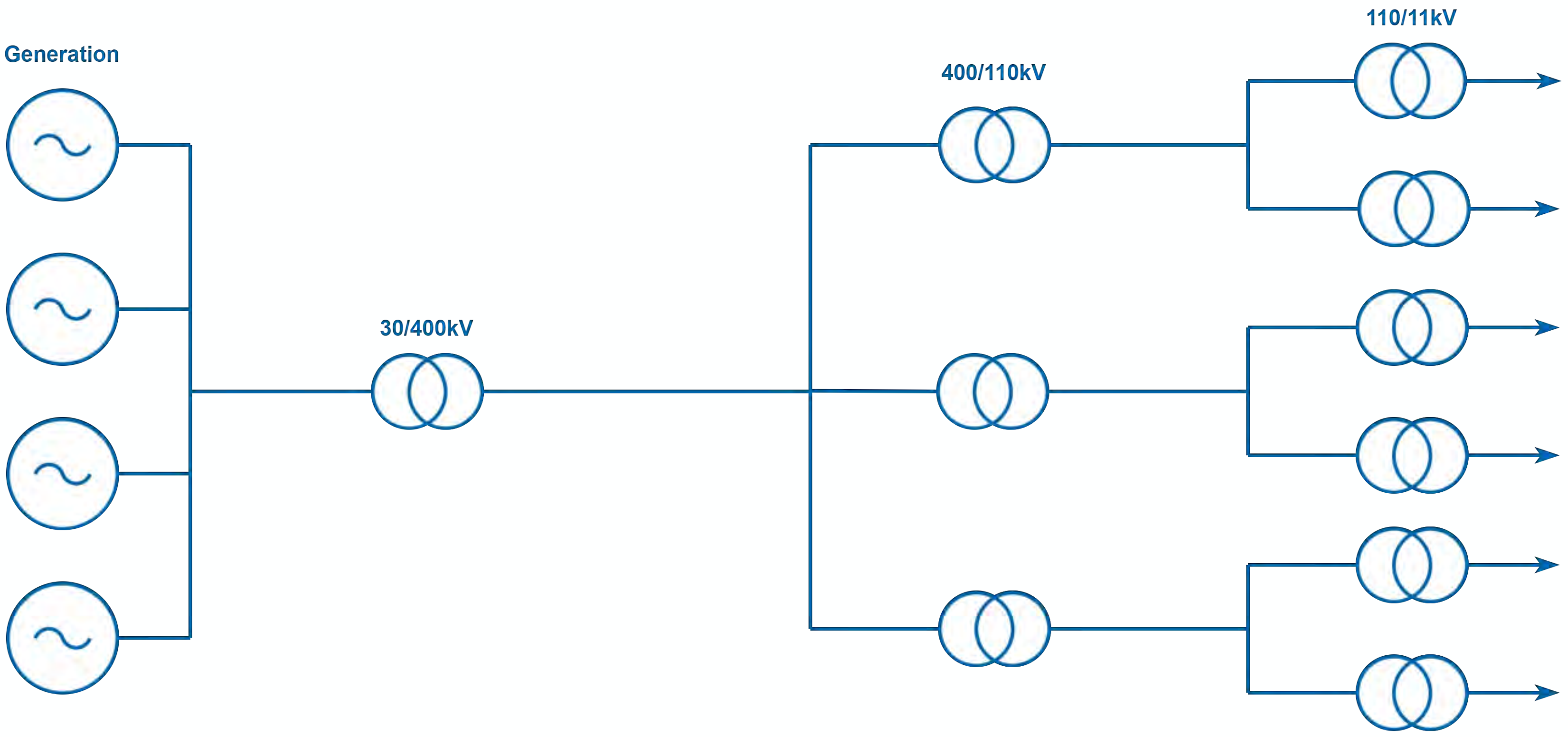
Basic concepts – Power triangle

- Typically different power components classified to
  - Active power P
  - Reactive power Q
  - Distortion power D
  - Non-active powers N
  - Fundamental apparent power S1
  - Apparent S
- Active and reactive power vectors are in 90 deg angle
  - Reactive and distortion power vectors are in 90 deg angle
  - Angle between P and S1 called cos phi or DPF
  - Angle between P and S called power factor



Basic concepts – Power System

- Different components in power system
  - Voltage sources (generation)
  - Impedances (lines, transformers, linear loads)
  - Current sources (non-linear loads)



Basic concepts – Reactive power

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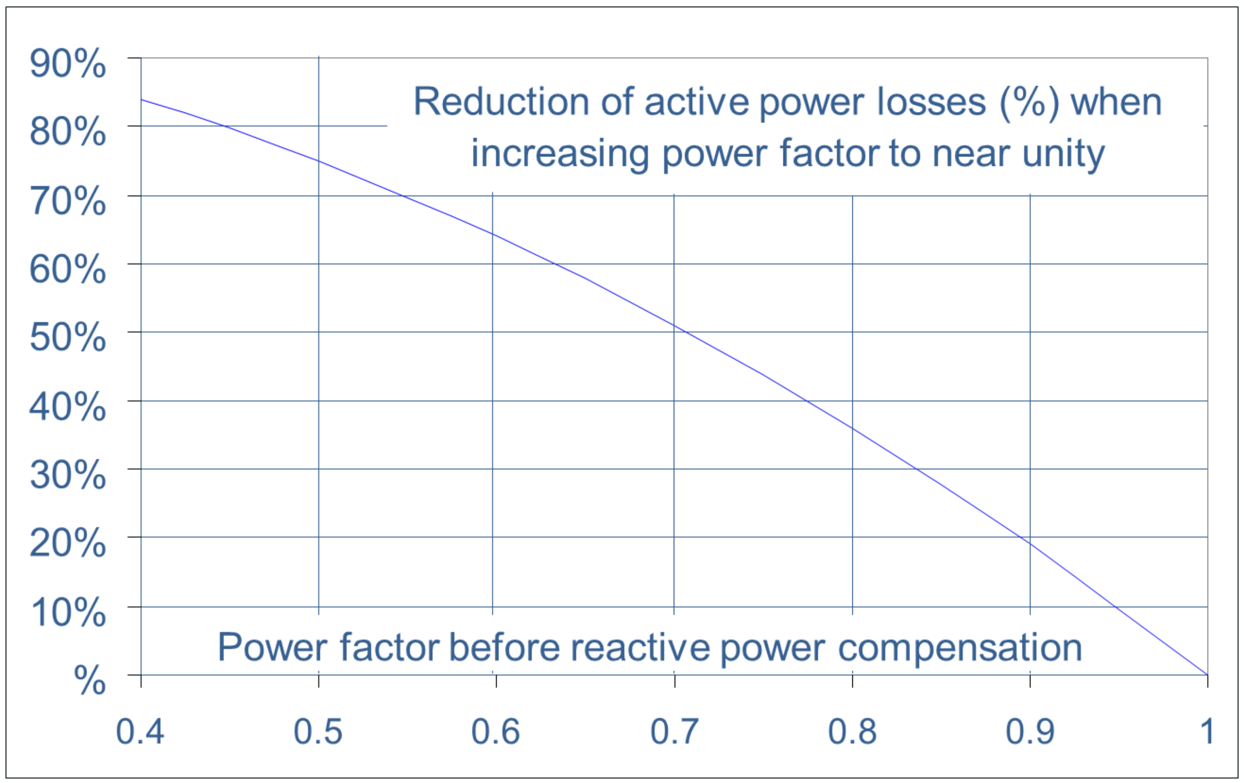
- Active power losses are caused by current flow through the power system's resistances
- Reactive power losses are caused by current flow through the power system's reactances
- Reactive power can be produced locally with compensator devices
  - No need to transfer it through the power system

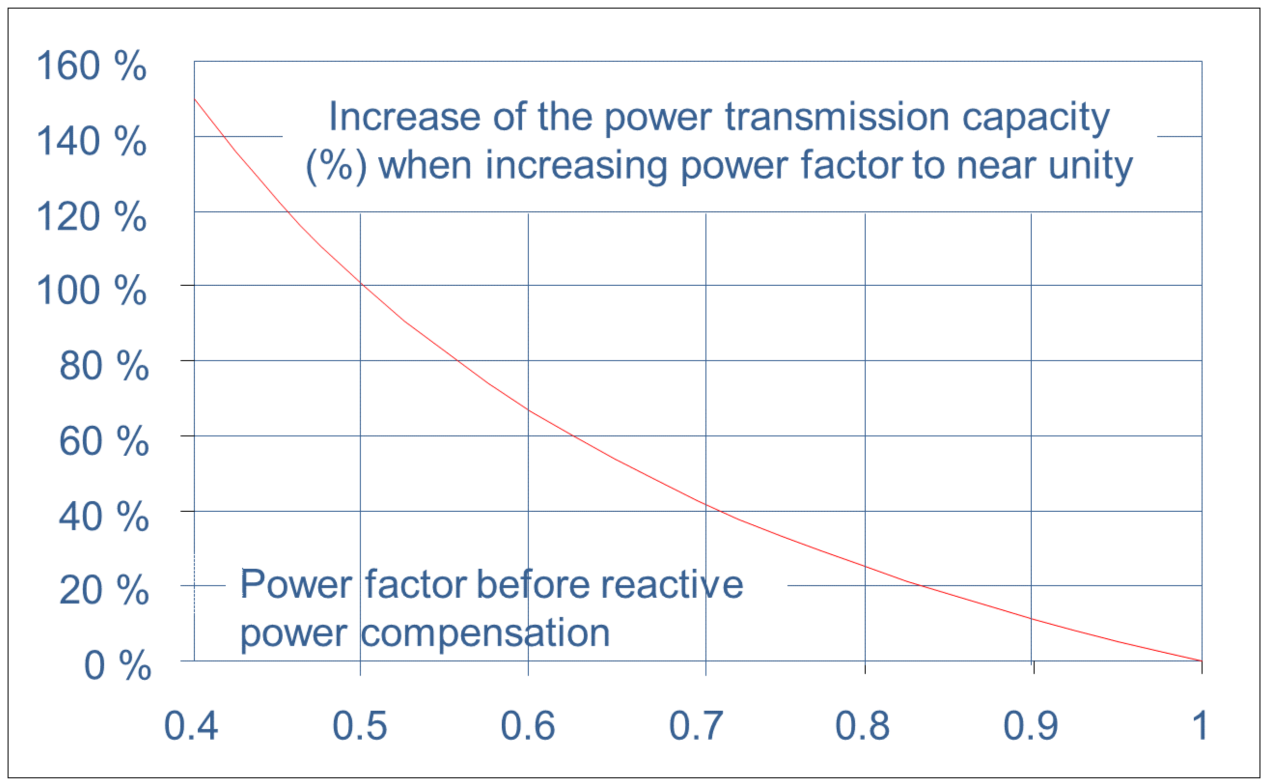
$$P_{Losses} = 3 \times I^2_q \times R$$

$$Q_{Losses} = 3 \times I^2_q \times X$$

Basic concepts – Reactive power

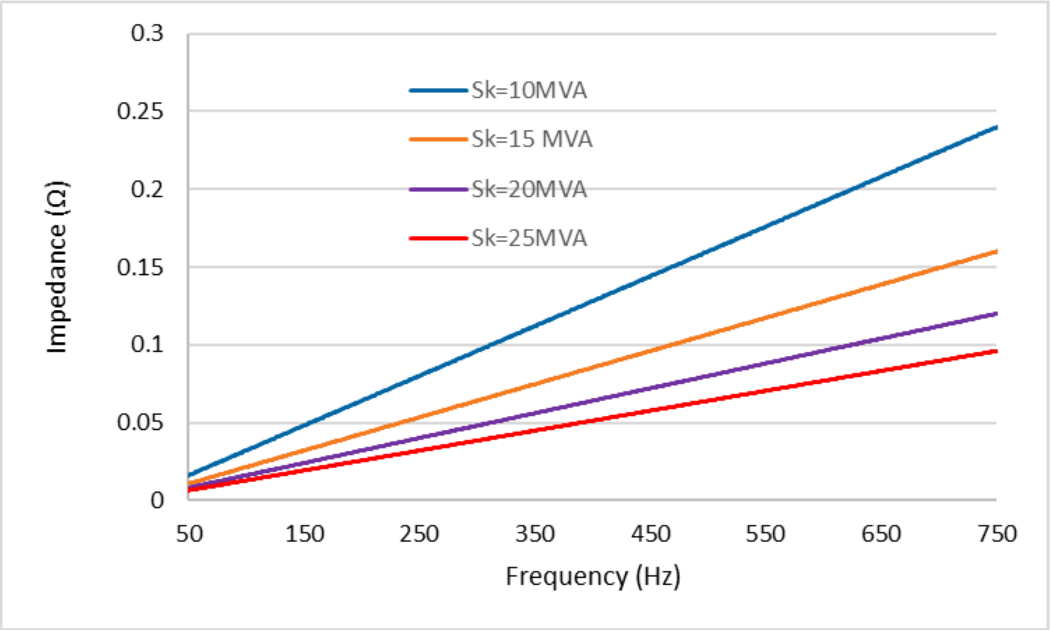
- Compensation reactive power at source has a significant impact on the power system's losses and capacity → system operators enforce strict power factor limits

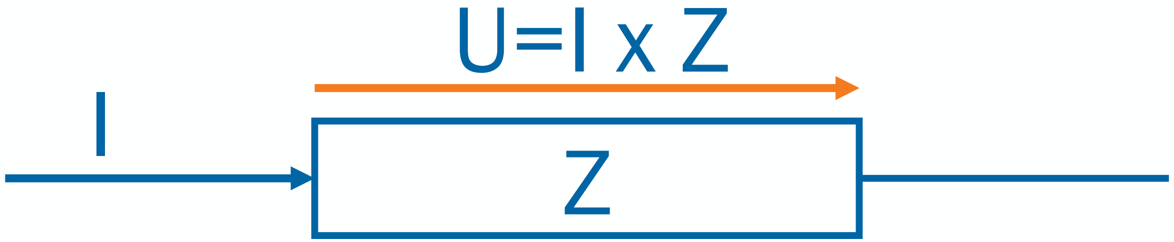




Basic concepts – Fault level

- Fault level (short circuit current) is a figure used to indicate how “stiff” the power grid is
  - High fault level means low impedance
- Power system impedance has two components
  - Resistive
  - Inductive
- Inductive component dominant on HV and MV lines
- Almost linear impedance vs frequency behaviour
- Voltage drop proportional to the impedance
  - High fault level → lower voltage drop





Basic concepts – Power quality standards

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- EN 50160
  - European standard
  - Defines power quality at the supply point
  - Defines only voltage quality
- IEEE 519
  - Globally used standard
  - Defines limits for voltage and current
  - Covers only harmonics and related phenomena
- IEC 610003-6
  - International standard
  - Gives limits for harmonic emissions
- G5/4
  - British standard
  - Limits for harmonic voltages and related phenomena
  - Also gives current limits during the planning stage

Basic concepts – Power quality indices

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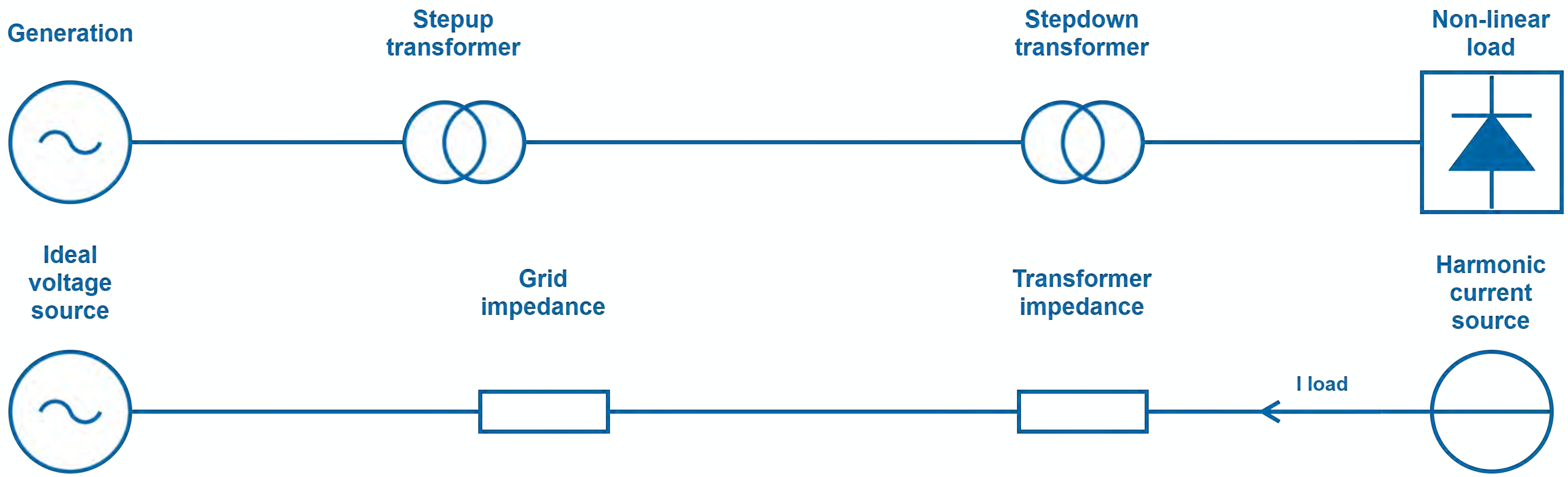
- Total harmonic distortion (THD)
  - Compares total harmonic content either to fundamental (THD-f) or RMS (THD-r) value of the voltage or current
  - IEEE 519 limits compared to the nominal value e.g. 230 V
- Total demand distortion (TDD)
  - Compares current harmonics to maximum demand current
  - Used in IEEE 519 current limits
  - Always smaller that the THD
- Unbalance
  - Different calculation methods give significantly different results in certain conditions
  - Describes how symmetrical 3-phase voltage/current are
- Flicker
  - Short-term indices (Pst) calculated over 10 minute period
  - Long-term indices (Plt) calculated from 12 short term indices
  - Describes how much voltage variation affects to luminosity of lighting

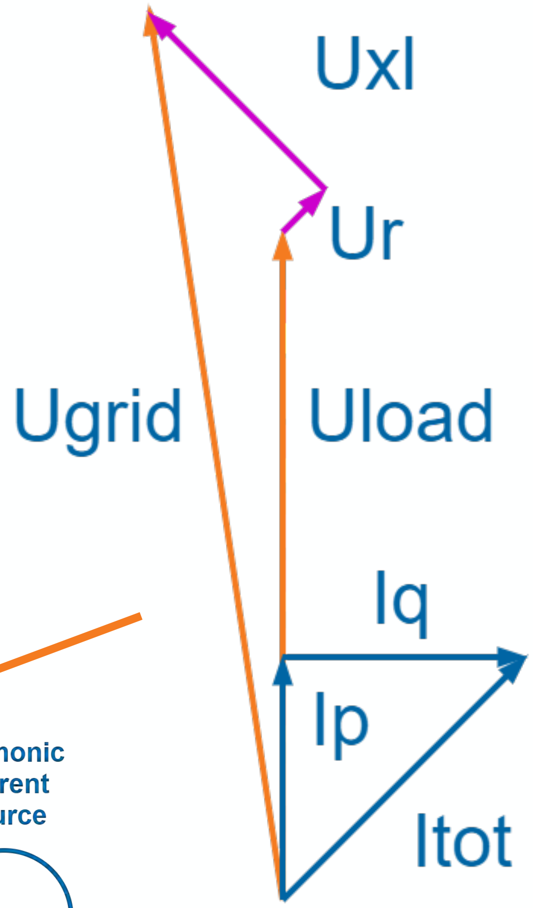
Reactive power compensation – Example load

- Typical large scale industrial load
- One section of HV line considered
  - Grid impedance represents total impedance before stepdown transformer



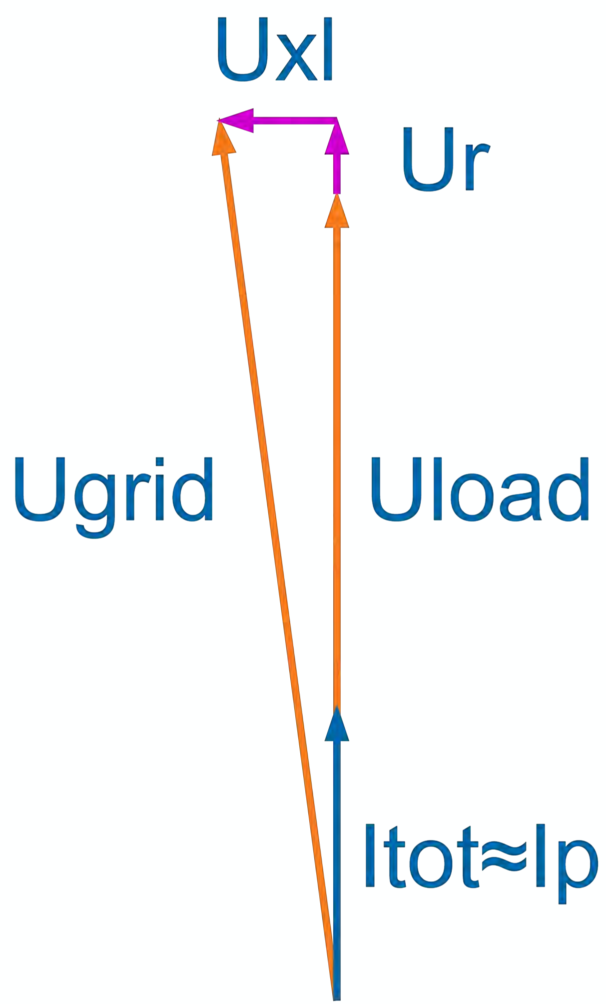
Reactive power compensation – Voltage drop

- Typical large scale industrial load
  - Active power 50MW
  - Reactive power 44.1MVAR
  - Cos phi 0.75
- Voltage at the sending end 132kV
- Voltage at the receiving end 110.6kV
- Voltage drop over the line 21.4 kV
  - Mainly from the inductive component
  - **16.2 %**
- Load active current 261A
- Load reactive current 230 A
- Total (apparent) load current 348A

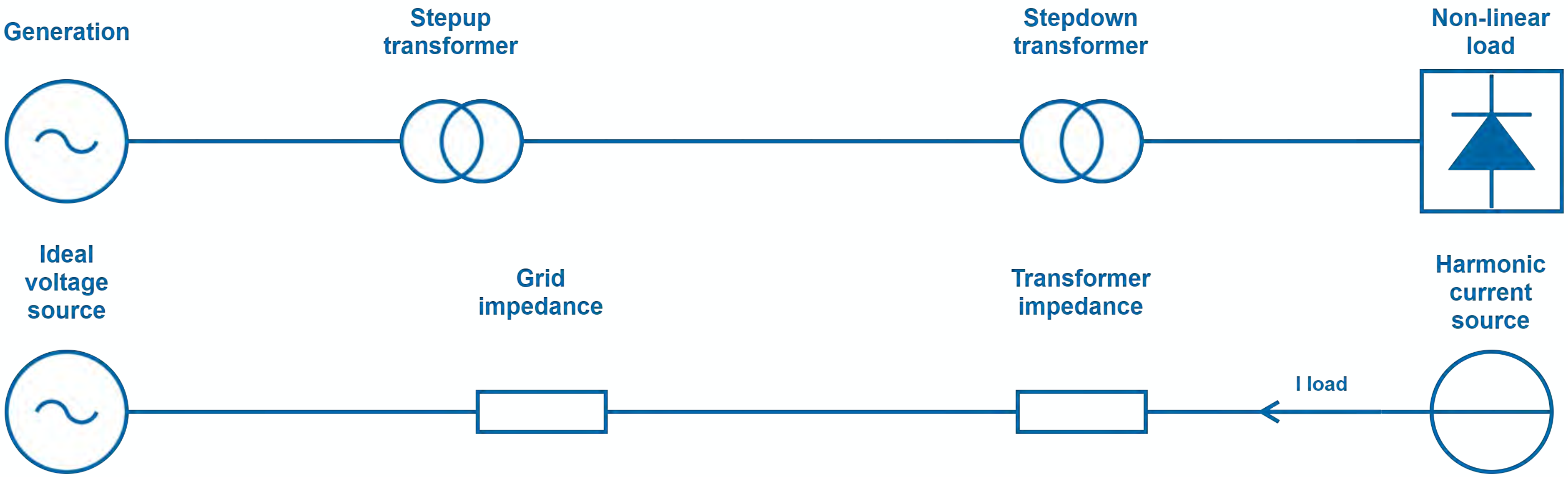


Reactive power compensation – Voltage drop

- Typical large scale industrial load
  - Active power 50MW
  - Reactive power 4.1MVAR
  - Cos phi 0.99
- Voltage at the sending end 132kV
- Voltage at the receiving end 125.8kV
- Voltage drop over the line 21.4 kV
  - Mainly from the inductive component
  - **4.7 %**
- Load active current 229A
- Load reactive current 20 A
- Total (apparent) load current 230A



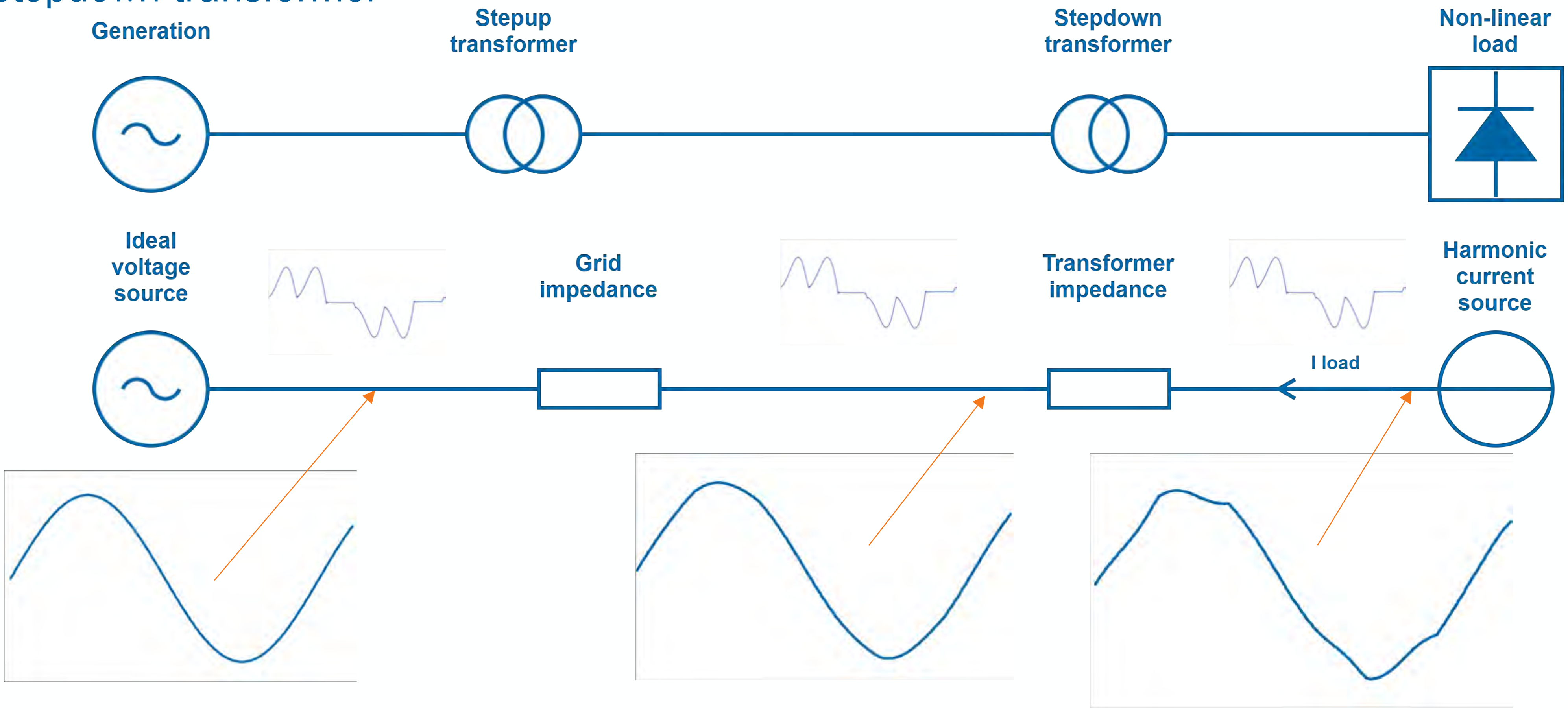
Reactive power compensation – Power losses



Scenario	1	2	3	4	5
Load					
Active power (MW)	50	50	50	50	50
Power factor	0.8	0.85	0.9	0.95	1
Reactive power (MVAR)	37.5	31	24.2	16.4	0
Apparent power (MVA)	62.5	58.8	55.6	52.6	50
Generator					
Active power (MW)	53.6	53	52.6	52.4	52.1
Power factor	0.552	0.634	0.709	0.791	0.939
Reactive power (MVAR)	80.9	64.6	52.3	40.5	19.1
Apparent power (MVA)	97	83.5	74.2	66.2	55.5

Harmonic compensation – Example load

- Typical industrial load
- One section of HV line considered
  - Grid impedance represents total impedance before stepdown transformer

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