# ELEC-E8422 Introduction to Electrical Energy Systems

## Power Quality – PQ

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# Power Quality (PQ)

**Power Quality (Standard EN 50160):**

- frequency
- voltage level
- fast voltage fluctuation
- harmonic voltages
- unsymmetry
- signal voltages
- voltage dips
- interharmonic voltages
- operating frequency overvoltages
- transient overvoltages

**Interruptions of supply**

# Frequency

**Std 50160: limits for 10 second values:**

- 95% in the band 50 Hz +/- 1% (49.5 … 50.5 Hz)
- all in the band 50 Hz +4/-6% (47 … 52 Hz)

In Nordic system usually between +/- 0.1 Hz

# Voltage level

Std 50160: limits for 10 minute values

- 95% must be in the band $U_n$ +/- 10%

Measurement for one complete week

In addition, all the 10 min values must be between -15 .. +10 %

In LV-system, according to association of utilities (sener):

- good quality: 10 min values between 220...240 V
- normal quality: 10 min values between 207...244 V
- standard quality: 10 min values between 207...253 V

In MV-system, according to association of utilities (sener):

- good quality: 10 min values between $U_n$ +/- 4%
- normal quality: 10 min values between $U_n$ +/- 10%
- standard quality: 10 min values between $U_n$ +/- 10%

Voltage level is determined by voltage drop due to load current, on-load tap-changer, off-load tap-changer and compensation.

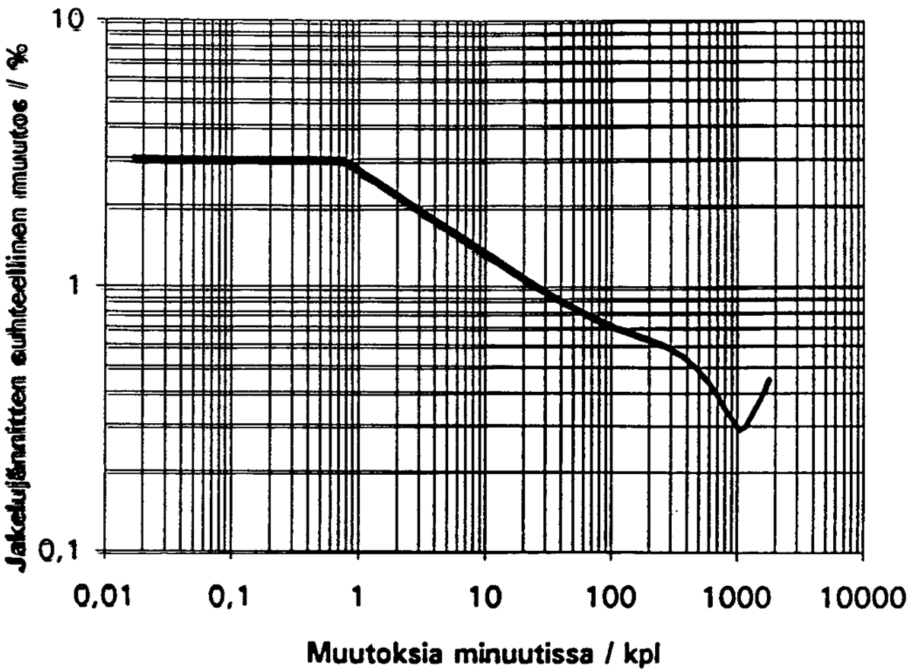
# Fast voltage fluctuation (flicker)

Affects especially lighting and hence vision.
Also electronic equipment may be disturbed.

Fast voltage fluctuation is caused by,

- control of on-load tap-changer
- motor starting
- welding equipment

Limits according to CENELEC:




Voltage %-change / Changes per minute

# Voltage unsymmetry

Std 50160: limits for 10 minute values:

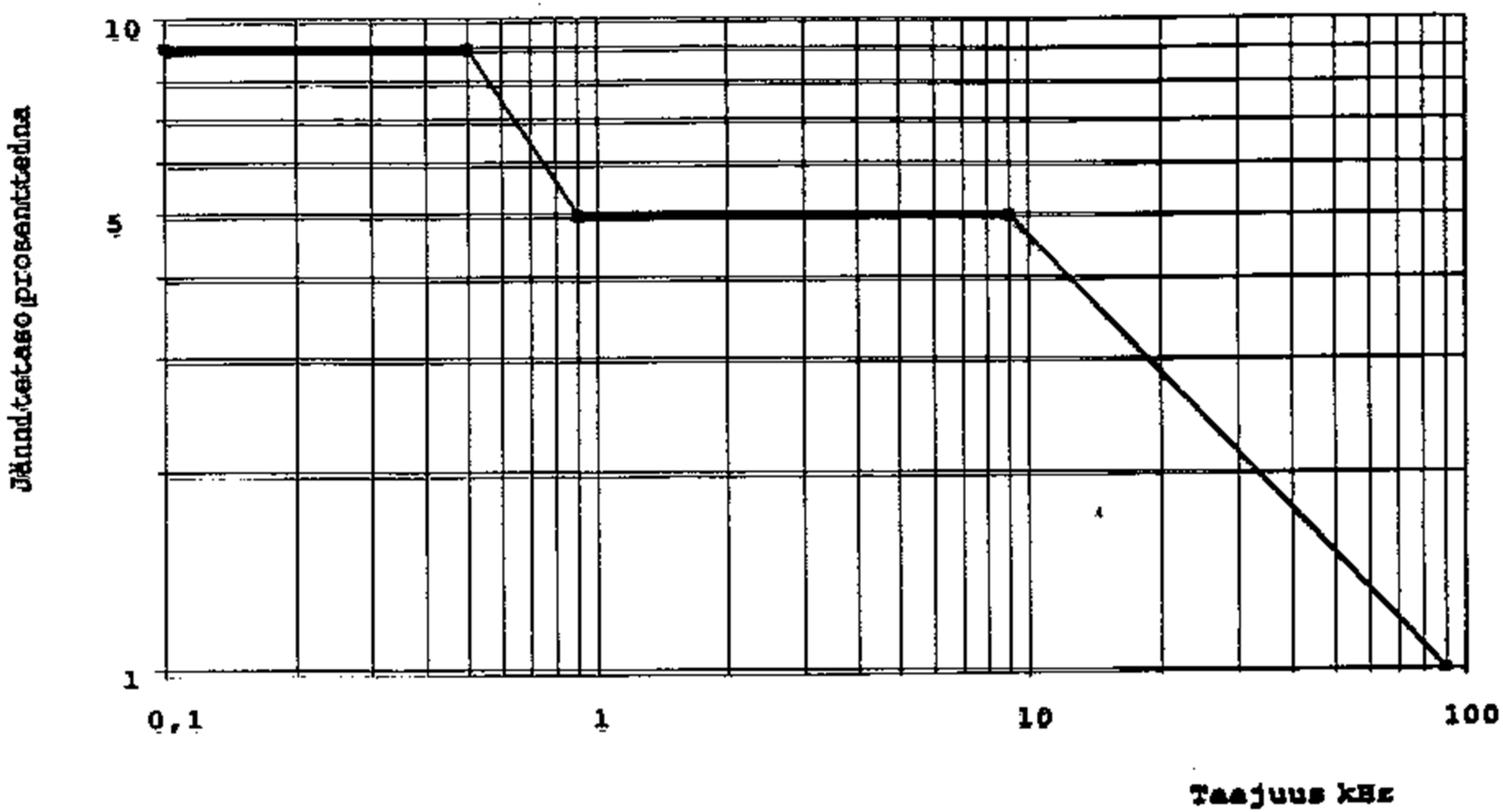
95% of the time the negative sequence component must be less than 2% of the positive sequence component.

Unsymmetry is caused by:

- uneven load between the three phases
- one-phase LV-faults (blown fuse)

# Signal voltages

Std: Defined as 3 s values, measured in LV-connection point;
99% of the time the values must be equal or less than:




Signal voltages as % of nominal / Frequency kHz

Frequencies 95 kHz … 148.5 kHz may be used in customer installations

## Voltage sags

Mostly caused by network faults, no standard limits

## Interharmonic voltages

The levels of these are increasing due to inverter connected
Generation – no limits given

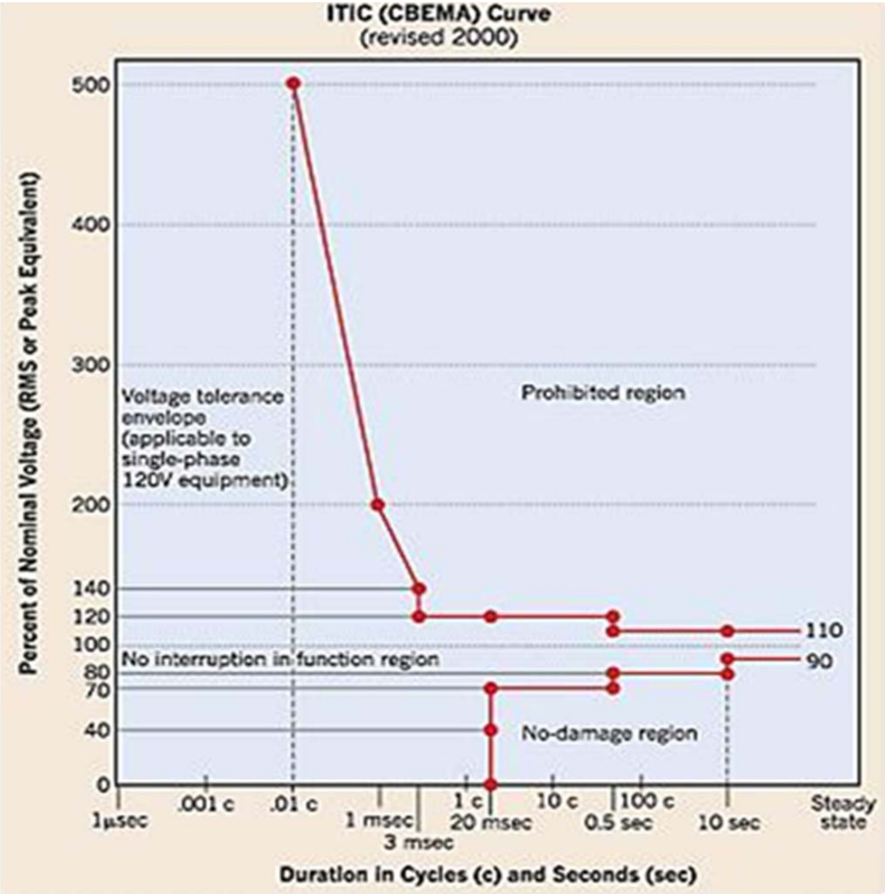
## Power frequency overvoltages

Caused by power system faults. Limits of voltage levels apply.

## Transient overvoltages

Caused by lightnings, faults and switching actions

# Immunity of electronic loads to voltage




CBMA)Computer Business Manufactures Association

(ITIC) International Committee for Information Technology Standards ...

# Harmonic voltages

Std 50160: limits for 10 minute mean values.
total harmonic distortion THD 8% at maximum

$$THD = \sqrt{\sum_{h=2}^{40} (U_h)^2}$$

Other harmonics:

Maximum allowed harmonics as % of the nominal voltage in LV-connection point. Limits given up to the order 25.

| odd harmonics | | | | even harmonics | |
|---|---|---|---|---|---|
| not multiple of 3 | | multiple of 3 | | | |
| order n | voltage %/Un | order n | voltage %/Un | order n | voltage %/UN |
| 5 | 6 % | 3 | 5 % | 2 | 2 % |
| 7 | 5 % | 9 | 1,5 % | 4 | 1 % |
| 11 | 3,5 % | 15 | 0,5 % | 6…24 | 0,5 % |
| 13 | 3 % | 21 | 0,5 % | | |
| 17 | 2 % | | | | |
| 19 | 1,5 % | | | | |
| 23 | 1,5 % | | | | |
| 25 | 1,5 % | | | | |

# Harmonic currents by diode rectifiers

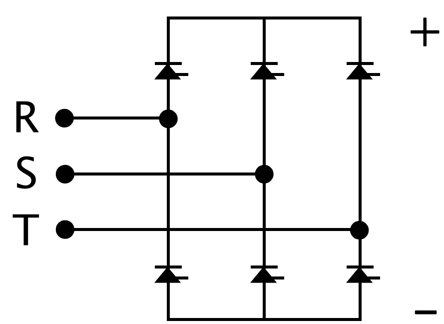
In an ideal case (a) the harmonics of the current are:

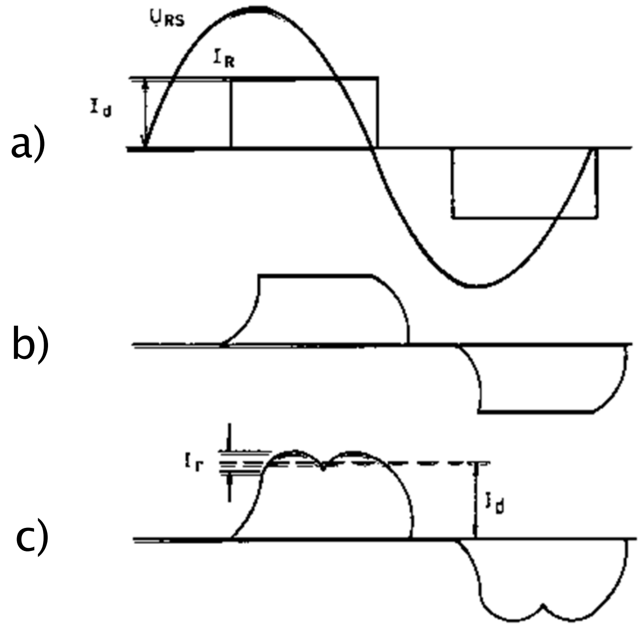
$I_n = I_1 / n$

n is the harmonic number

n = kp +/– 1 (k = 1,2,3,...), p is the pulse number

commutation (b) and ripple in DC-current (c) smooth the pulse edges, which makes the lower frequencies to increase and higher to decrease.



# Maximum values for diode rectifiers

| Harmonic order | $I_n/I_1$ |
|---|---|
| 5. | 30% |
| 7. | 12% |
| 11. | 6% |
| 13. | 5% |

Other sources of harmonics:

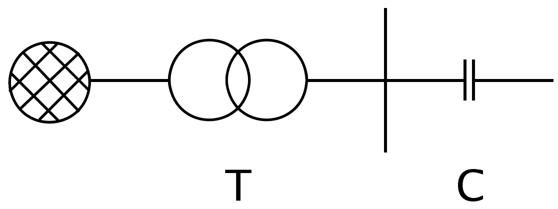
- discharge lamps
- power units of electronics

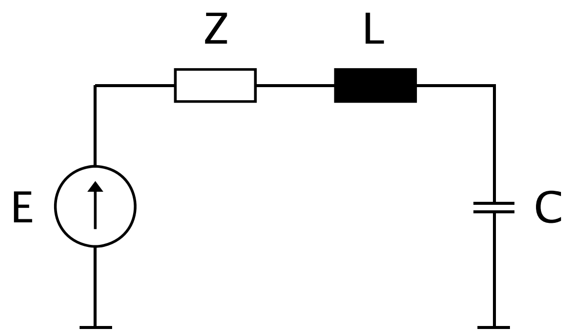
*In pulse width modulated (PWM) rectifiers the switching frequency $f > 2$ kHz ⇔ lower harmonics are very small*

# Harmonic series resonance

- Power system as a voltage source
- Transformer inductance and capacitor in series
- Low voltage distortion strongly amplified

Condition : $$2\pi f = \frac{1}{\sqrt{LC}}$$

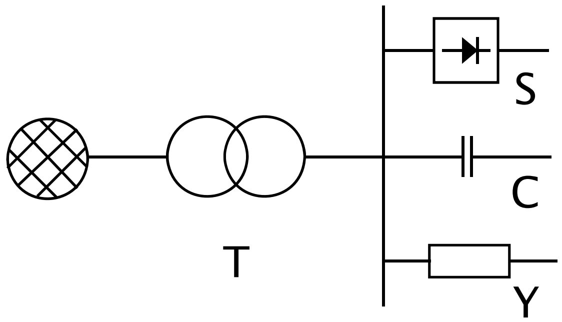


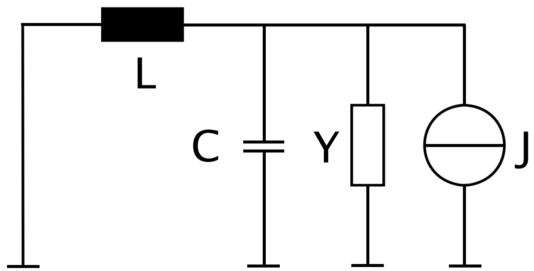



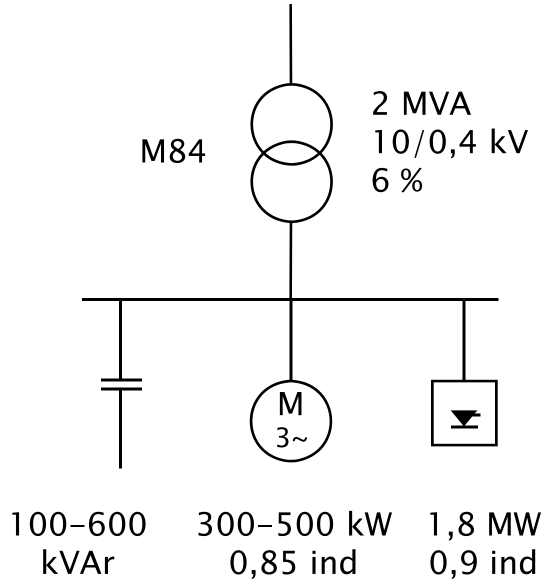
# Harmonic parallel resonance

- More dangerous than series resonance
- Transformer load as harmonic current source
- Transformer inductance and capacitor in parallel
- Resistive load causes attenuation
- High risk of damage to the capacitor

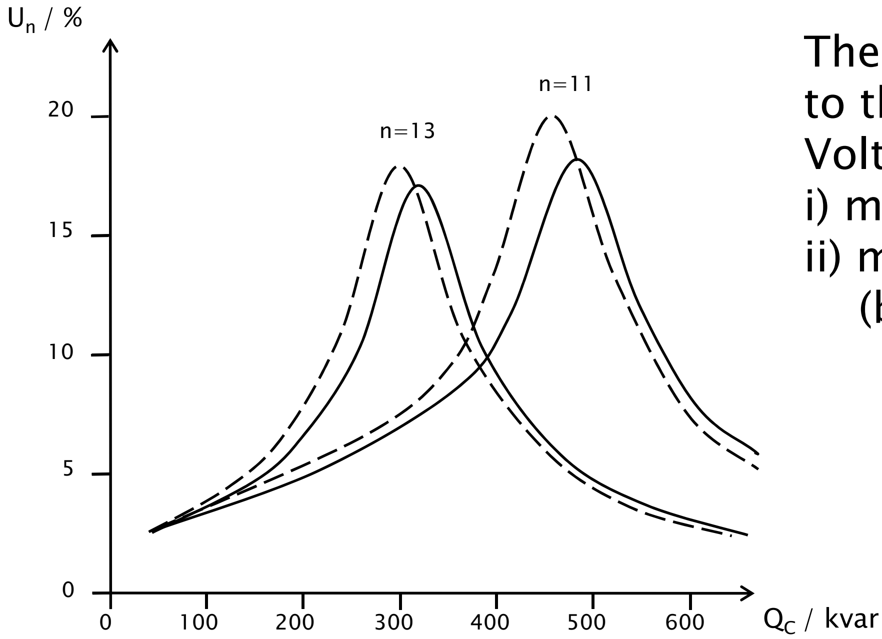
Condition : $$2\pi f = \frac{1}{\sqrt{LC}}$$






An example case: 0,4 kV
Motor control centre

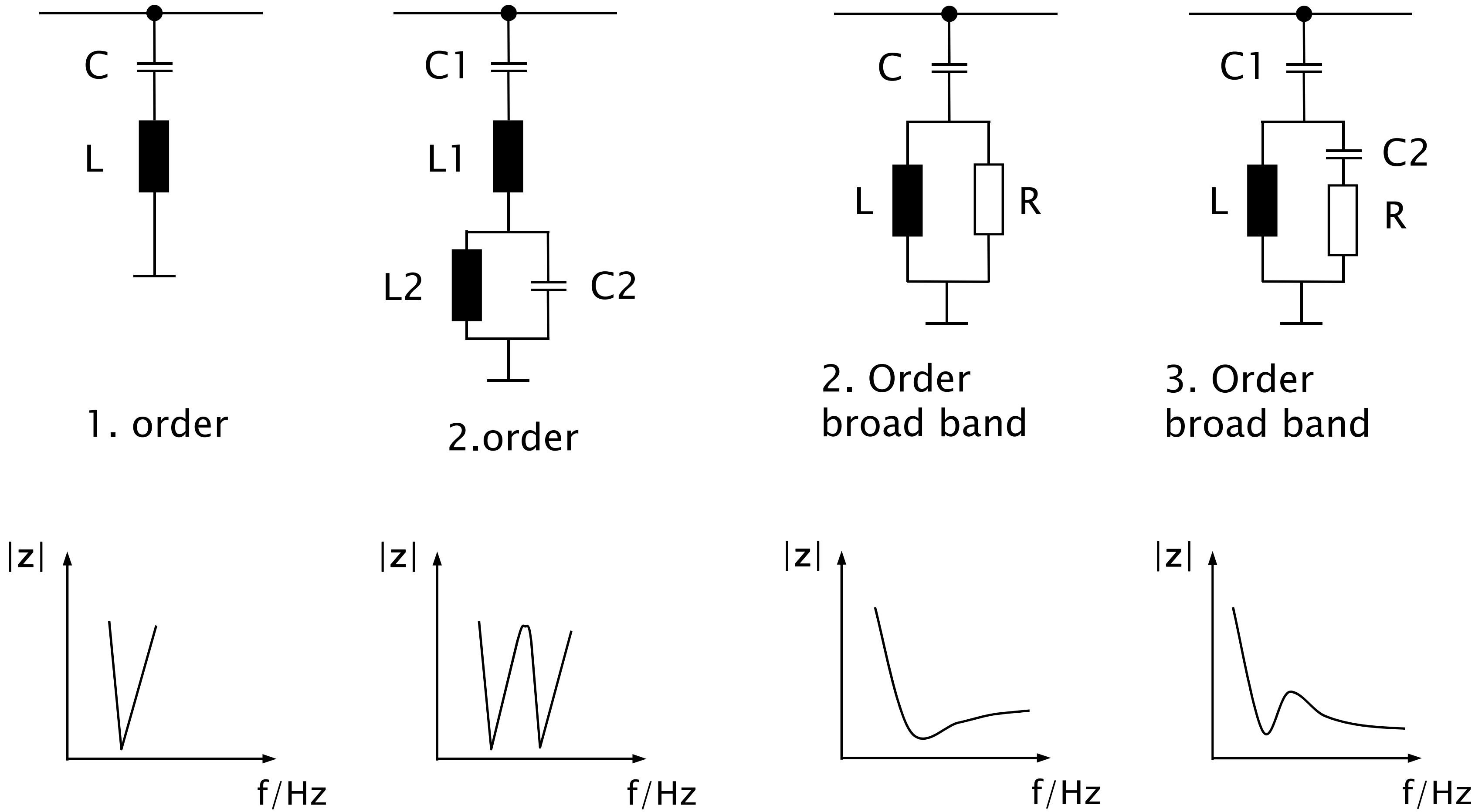



The effect of induction machine load to the 11. And 13. harmonic voltage. Voltages % of the rated voltage.

i) machine load 500 kW

ii) machine load 300 kW (broken line)

# Different types of passive harmonic filters



# Interruptions

- Planned interruptions vs. interruptions by faults
- Unexpected interruptions mostly by faults in MV-network
- In transmission, single fault causes no outage (n-1 criteria)
- Customers outage costs are a substantial factor

## Typical Fault frequencies in Finnish transmission system

| | Amount of faults (pcs / 100km,a) | Faults divided by cause (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Lightning | Other natural | External influence | Operation & maintenance | Technical equipment | Other | Unknown | 1-phase faults | Permanent faults |
| 400 kV lines | 0.11 | 77.5 | 7.8 | 0.9 | 2.9 | 1.0 | 3.9 | 5.8 | 54.0 | 4.0 |
| 220 kV " | 0.71 | 46.4 | 3.3 | 3.3 | 0.5 | 0.6 | 1.1 | 44.8 | 67.0 | 3.0 |
| 110 kV " | 1.29 | 44.2 | 3.9 | 2.1 | 1.3 | 0.5 | 0.9 | 47.1 | 75.0 | 2.0 |

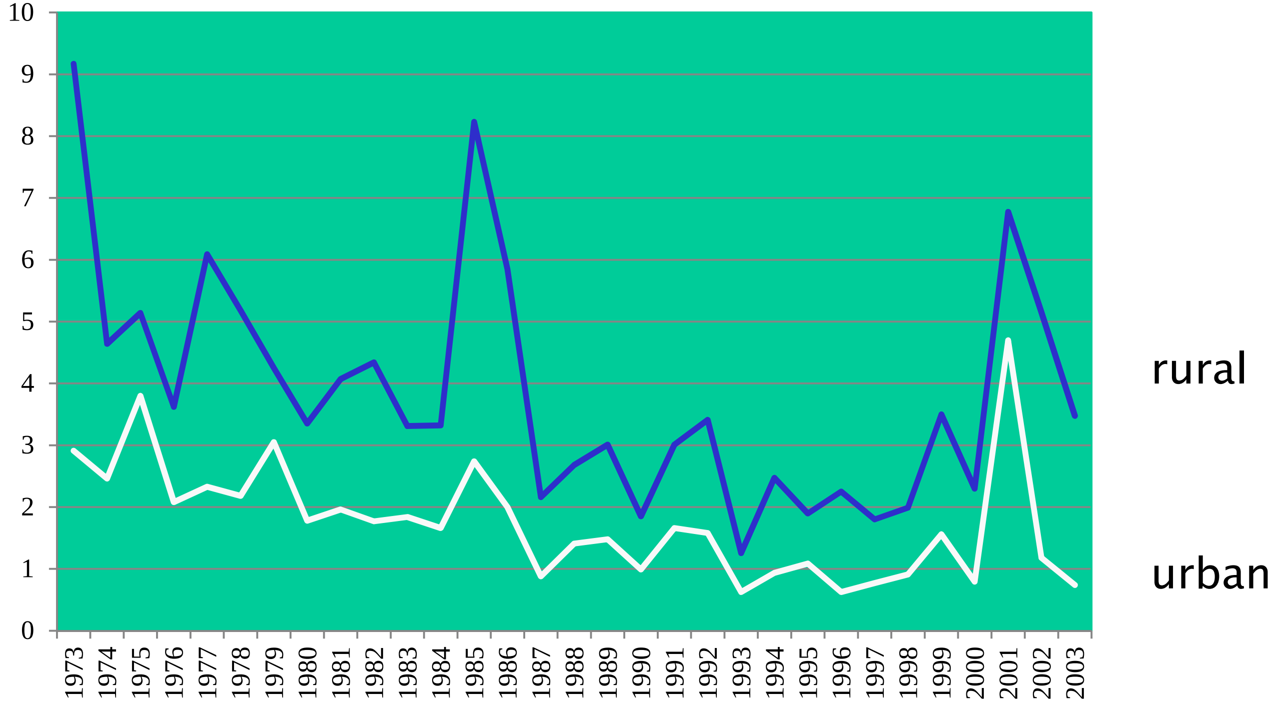
## Reclosings

| Fast reclosing | 400 kV | | 220 kV | | 110 kV | | sum | |
|---|---|---|---|---|---|---|---|---|
| | pcs | % | pcs | % | pcs | % | pcs | % |
| Succesful | 13 | 87 | 5 | 83 | 177 | 82 | 195 | 81 |
| Succesful in one end only | 0 | 0 | 0 | 0 | 5 | 2 | 5 | 2 |
| Failed due to a permanent fault | 0 | 0 | 0 | 0 | 9 | 4 | 9 | 4 |
| Failed due other reasons | 2 | 13 | 1 | 17 | 27 | 12 | 30 | 13 |
| Sum | 15 | 100 | 6 | 100 | 218 | 100 | 239 | 100 |

Annual average outages if MV-distribution networks classified by fault reasons. Faults / 100 km of line

| FAULT CAUSE | BARE CONDUCTOR OVERHEAD LINES | COVERED CONDUCTOR OVERHEAD LINES | AERIAL CABLES | GROUND CABLES |
|---|---|---|---|---|
| NATURE | 3,39 | 0,24 | 0,07 | 0,10 |
| - Wind and storm | 2,38 | 0,19 | 0,07 | 0,01 |
| - Snow and ice | 0,53 | 0,05 | 0,05 | 0,00 |
| - Lightnings | 0,29 | 0,03 | 0,08 | 0,05 |
| - Other weather | 0,20 | 0,01 | 0,01 | 0,20 |
| - animals | 0,18 | 0,07 | 0,00 | 0,03 |
| Technical cause | 0,54 | 0,04 | 0,11 | 0,33 |
| - Mechanical cause | 0,39 | 0,03 | 0,12 | 0,24 |
| - misoperation | 0,19 | 0,03 | 0,02 | 0,15 |
| others | 0,84 | 0,04 | 0,02 | 0,38 |
| - Public misbehavior | 0,30 | 0,02 | 0,01 | 0,29 |
| - unknown | 0,51 | 0,02 | 0,04 | 0,13 |
| SUM | 4,77 | 0,32 | 0,36 | 0,81 |

Outage times in urban & rural network hrs/a in years1973...2003

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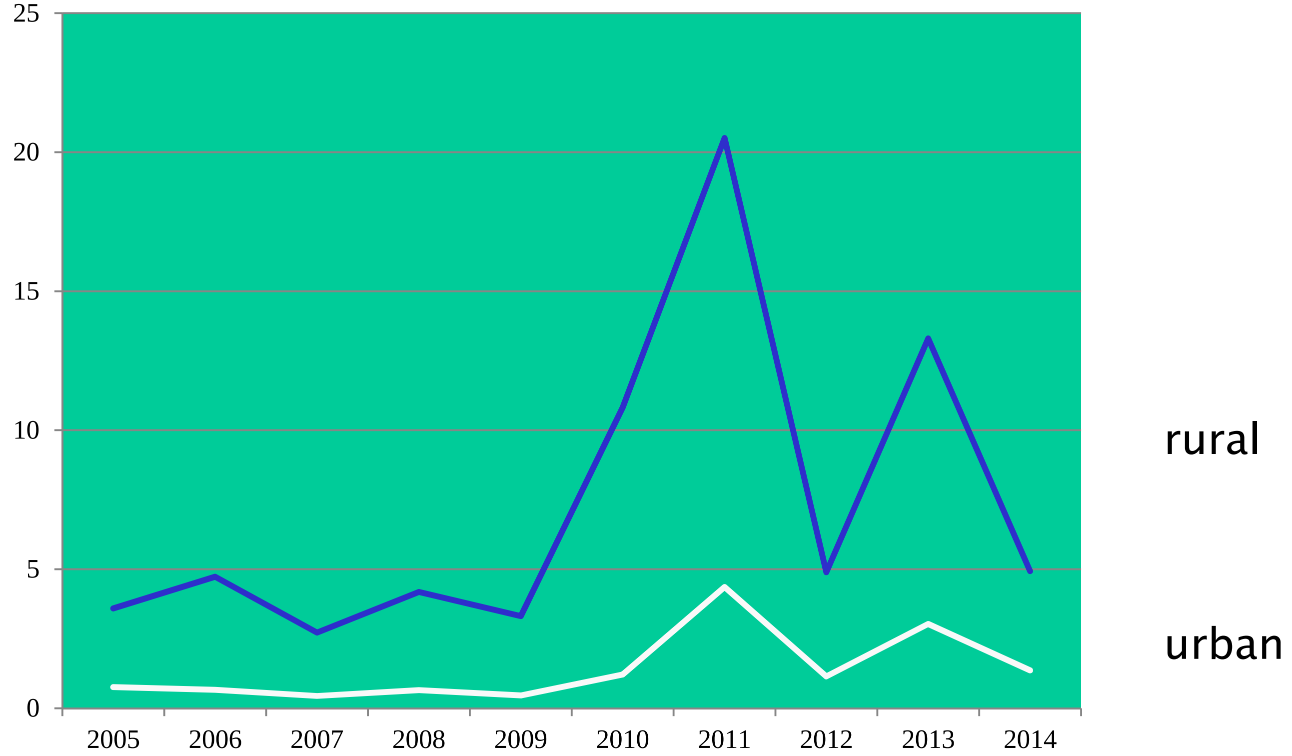
# Outage times in urban & rural network hrs/a in years1973…2003
2005…2014

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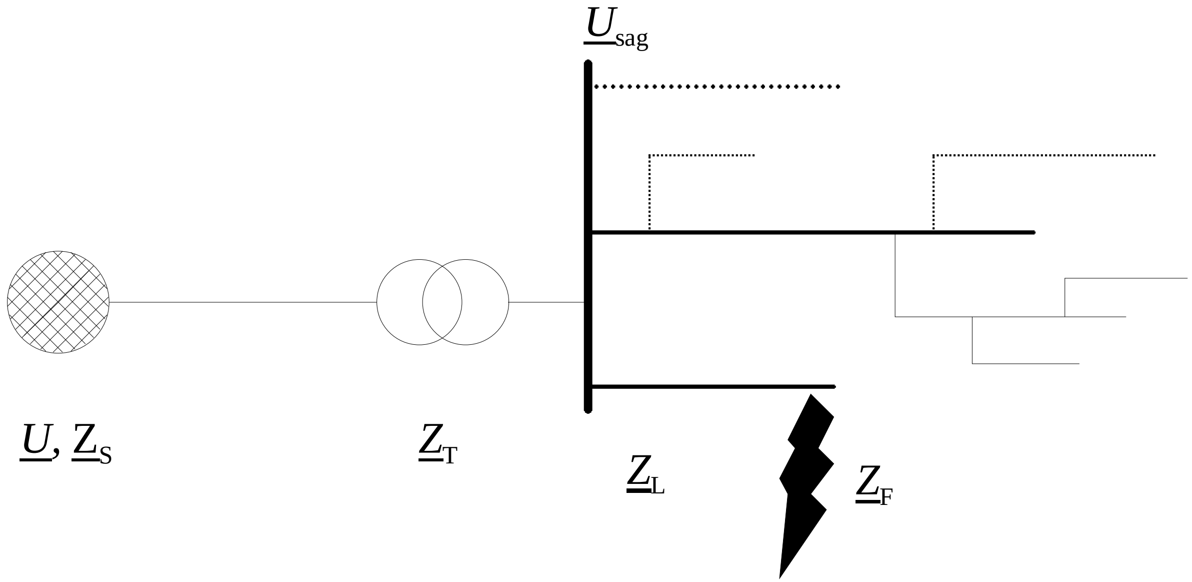
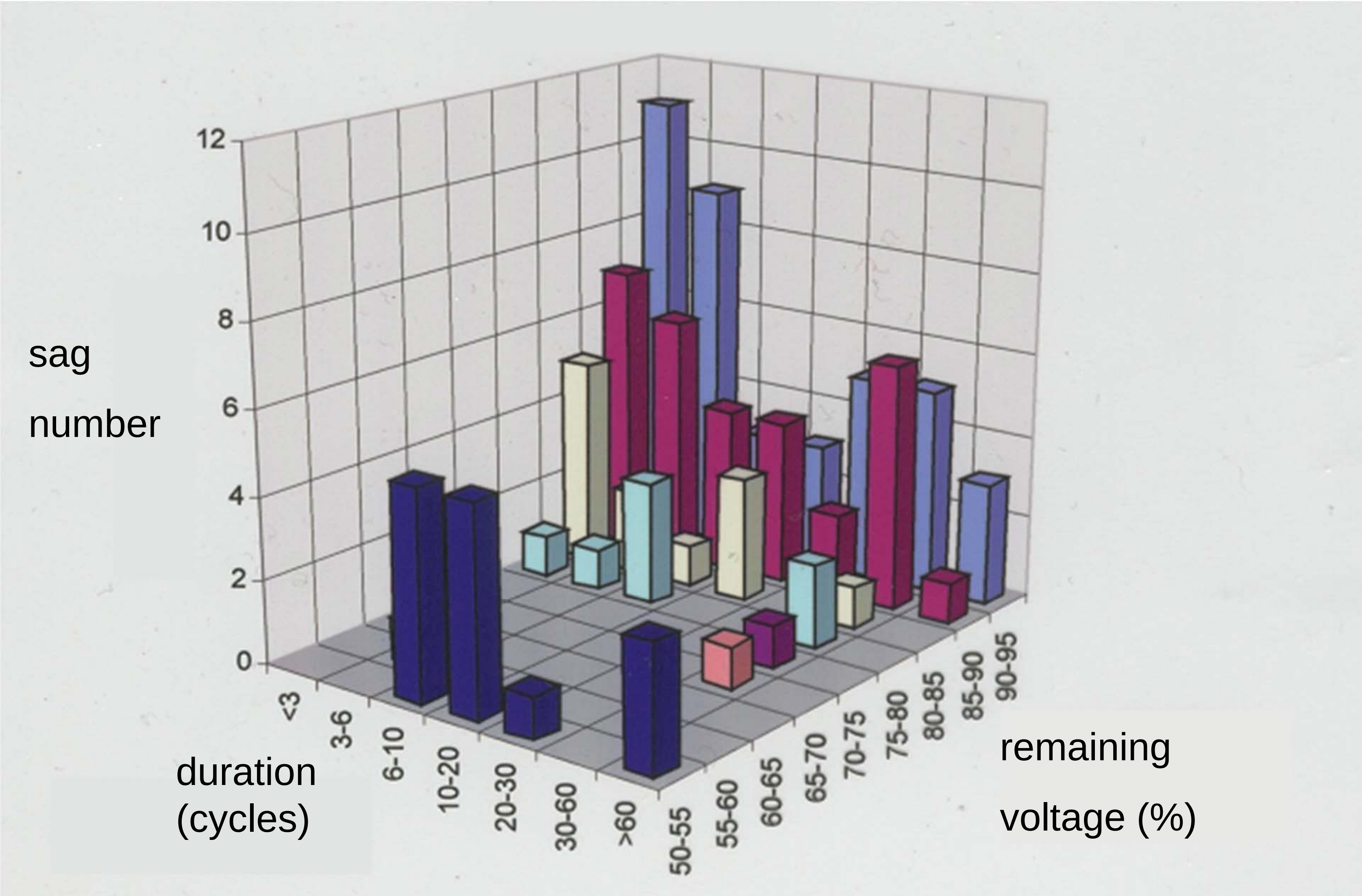
- **Voltage sags**

- Sag caused by a short circuit fault:
- Outage in the faulty feeder – sag in all the parallel lones
- Time of sag is determined by relay protection tripping time




$$\underline{U}_{sag} = \frac{\underline{Z}_L + \underline{Z}_F}{\underline{Z}_S + \underline{Z}_T + \underline{Z}_L + \underline{Z}_F} \cdot \underline{U}$$

•**Voltage sag distribution**

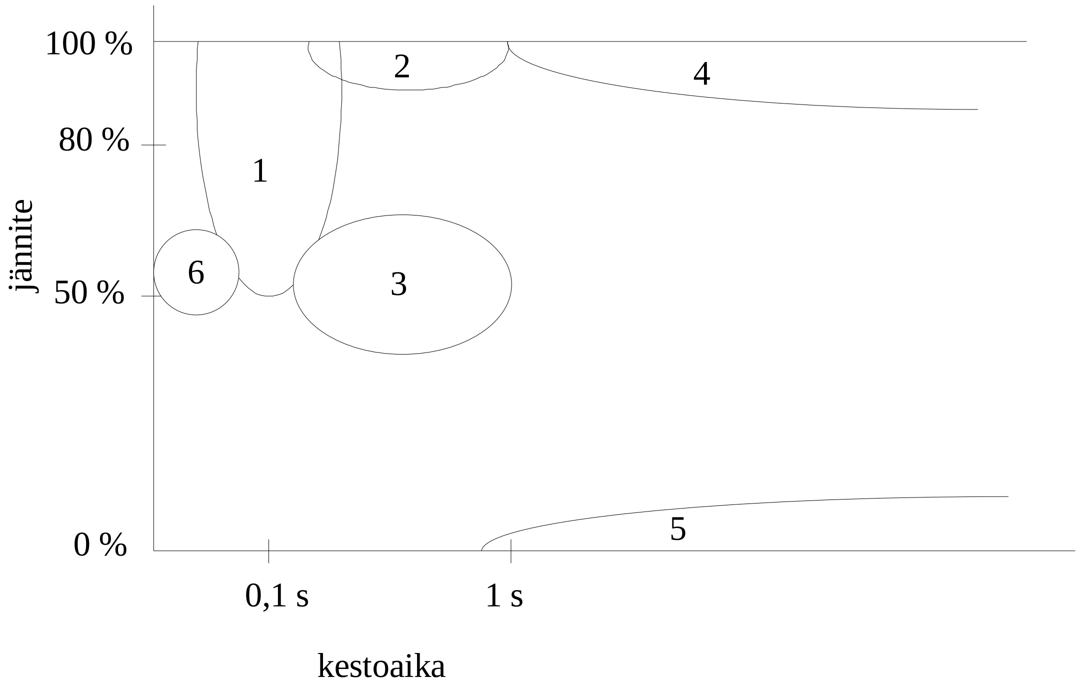


# Power Quality

•**Voltage Sags**

•Causes:

- Transmission faults (1)
- Fault in adjacent MV (2)
- Fault in local MV (3)
- Motor starting (4)
- Short outages (5)
- Fuse blows (6)

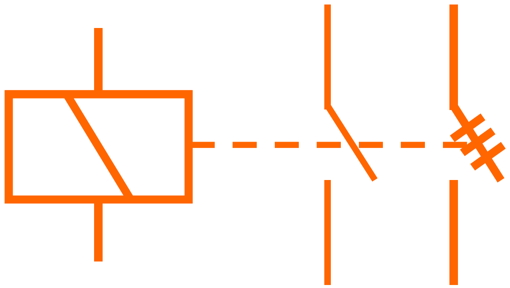


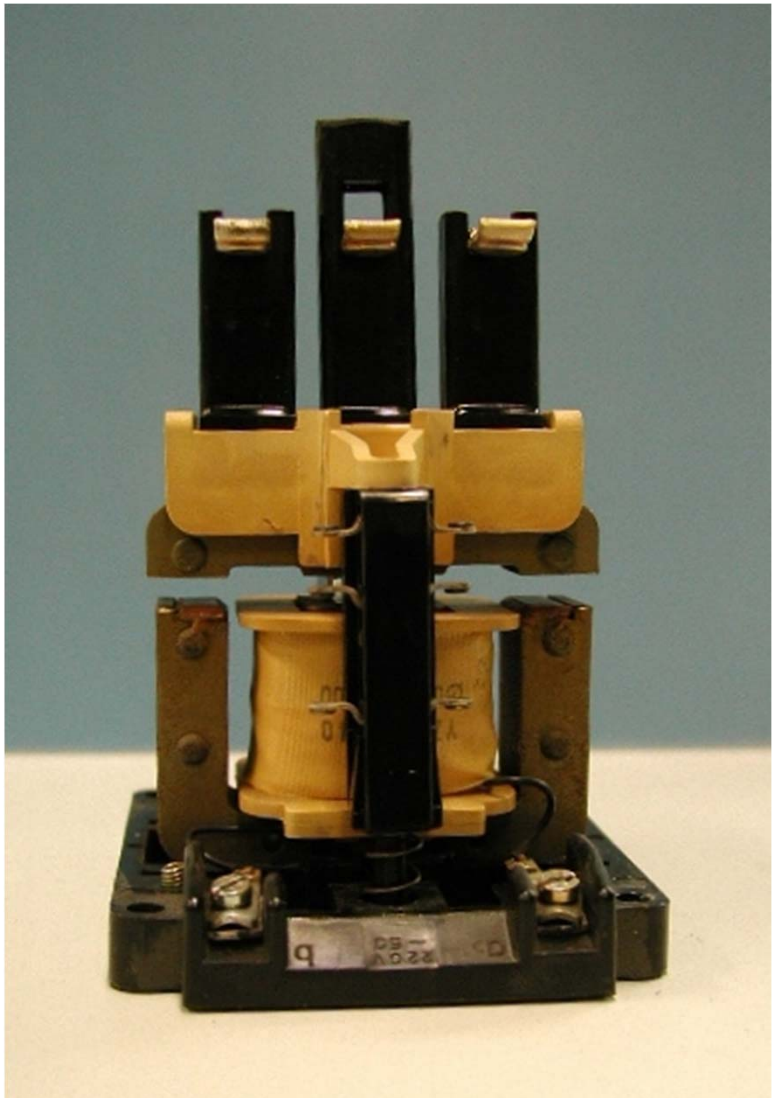

The time and depth of the sag depends on the cause. In above Figure some main causes are listed (horizontal: Time - vertical - Voltage)

# Devices and sags – contactors

Simple construction, controls critical loads in sag sensitive industrial processes in paper, metal, chemical industry

Remais closed as long as auxiliary power connected ⇔ if voltage lost, opens and remains open





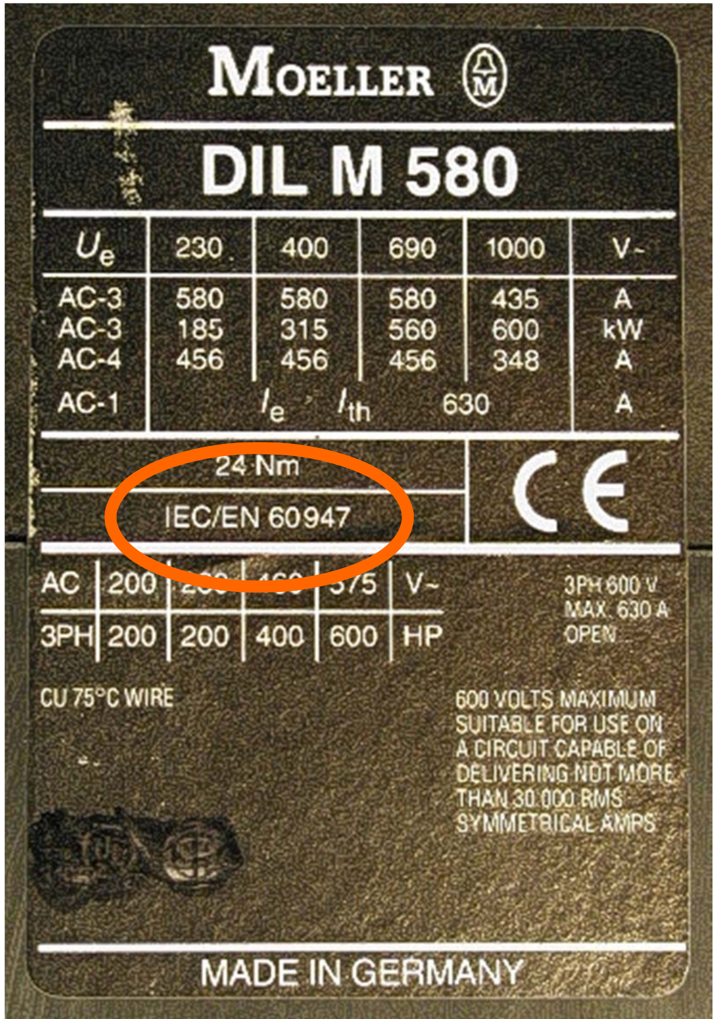
# CONTACTORS AND STANDARDS

IEC 60947-4-1:
Must be able to close for U= 85% …110%

Must open when U= 20% … 75%

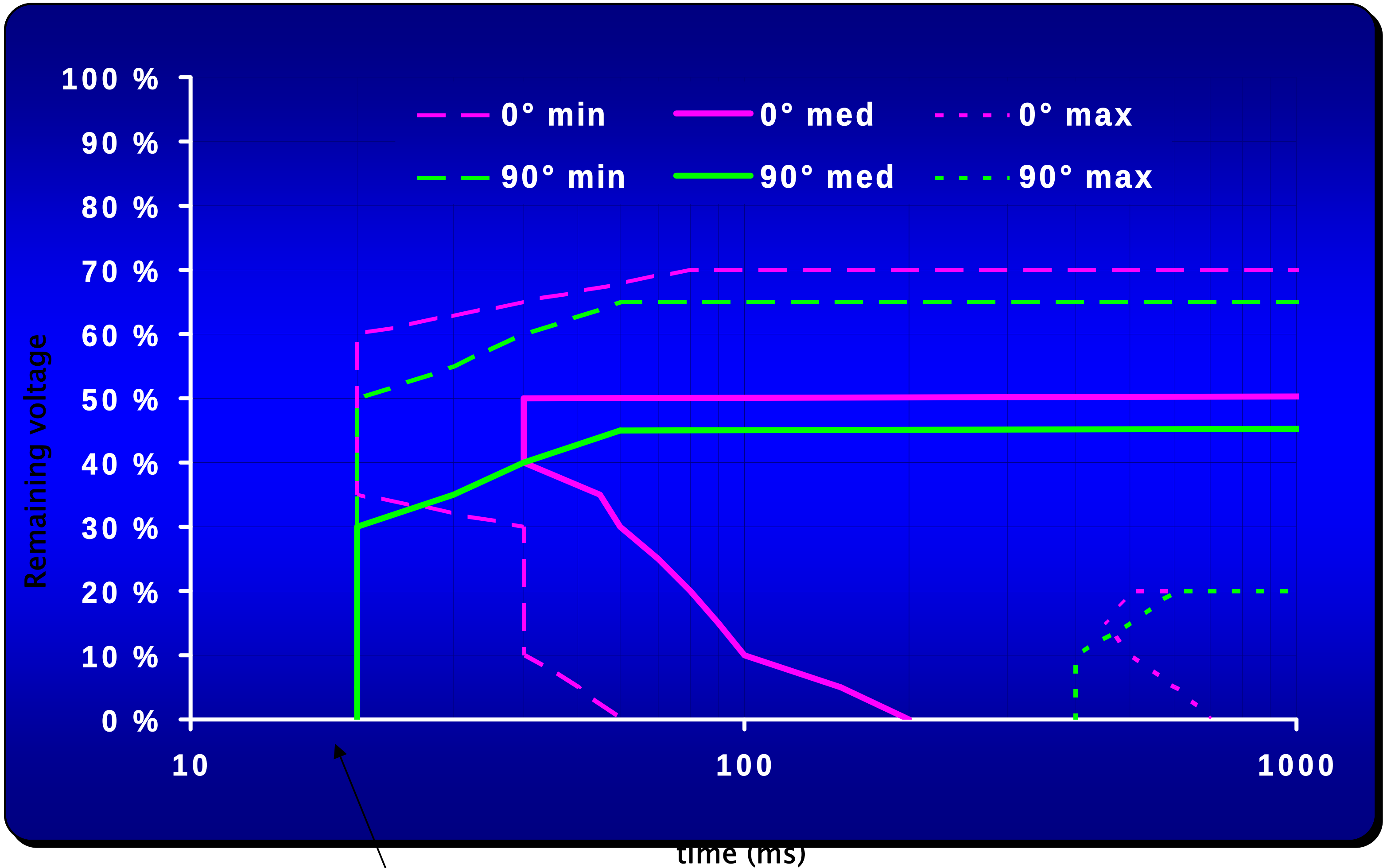
If opened, closes only on command

Voltage sags not really considered while
Writing the standard



# Sag sensitivity of contactors

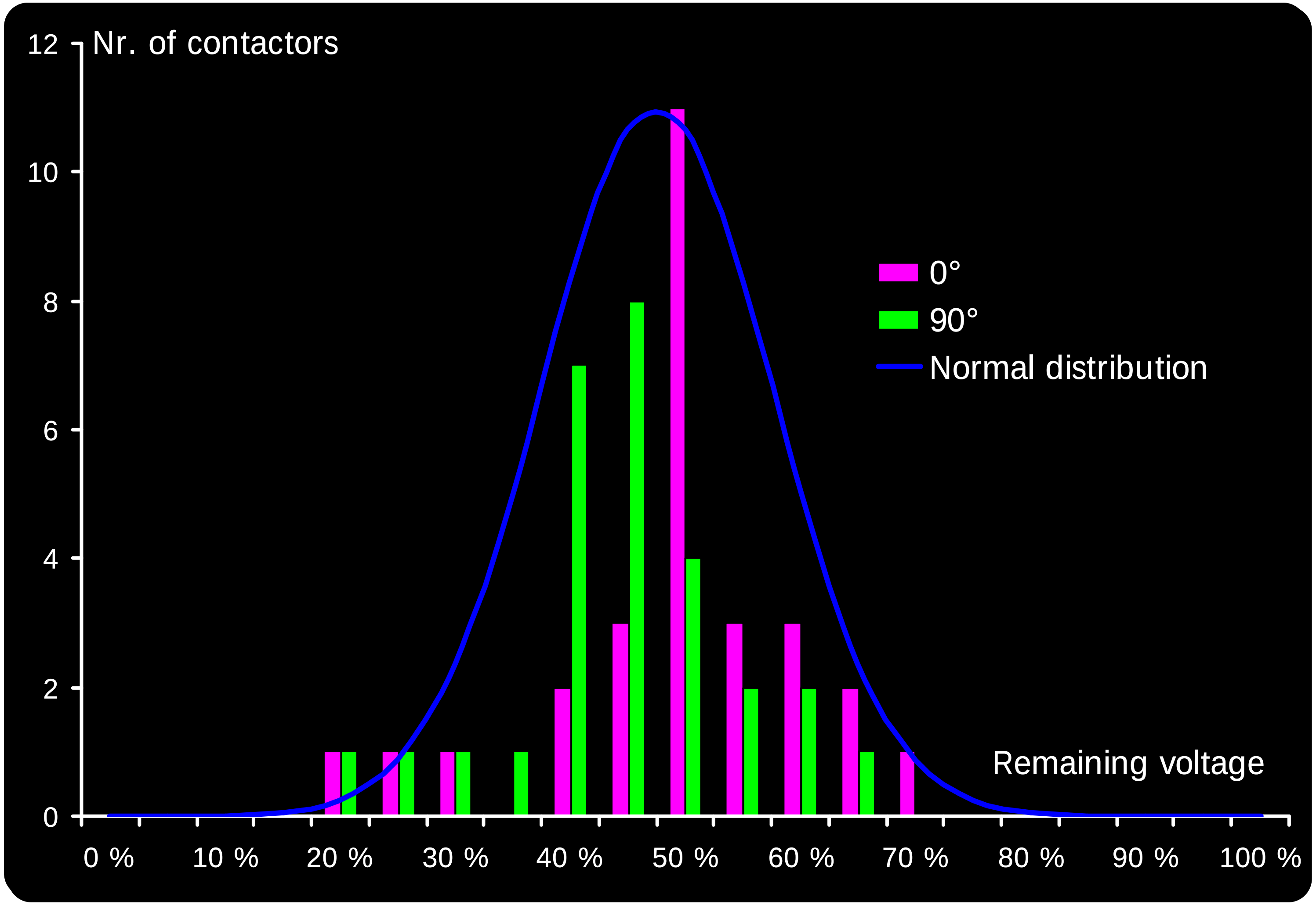
Tolerance levels (min, max, median)




sag < 20 ms not testes

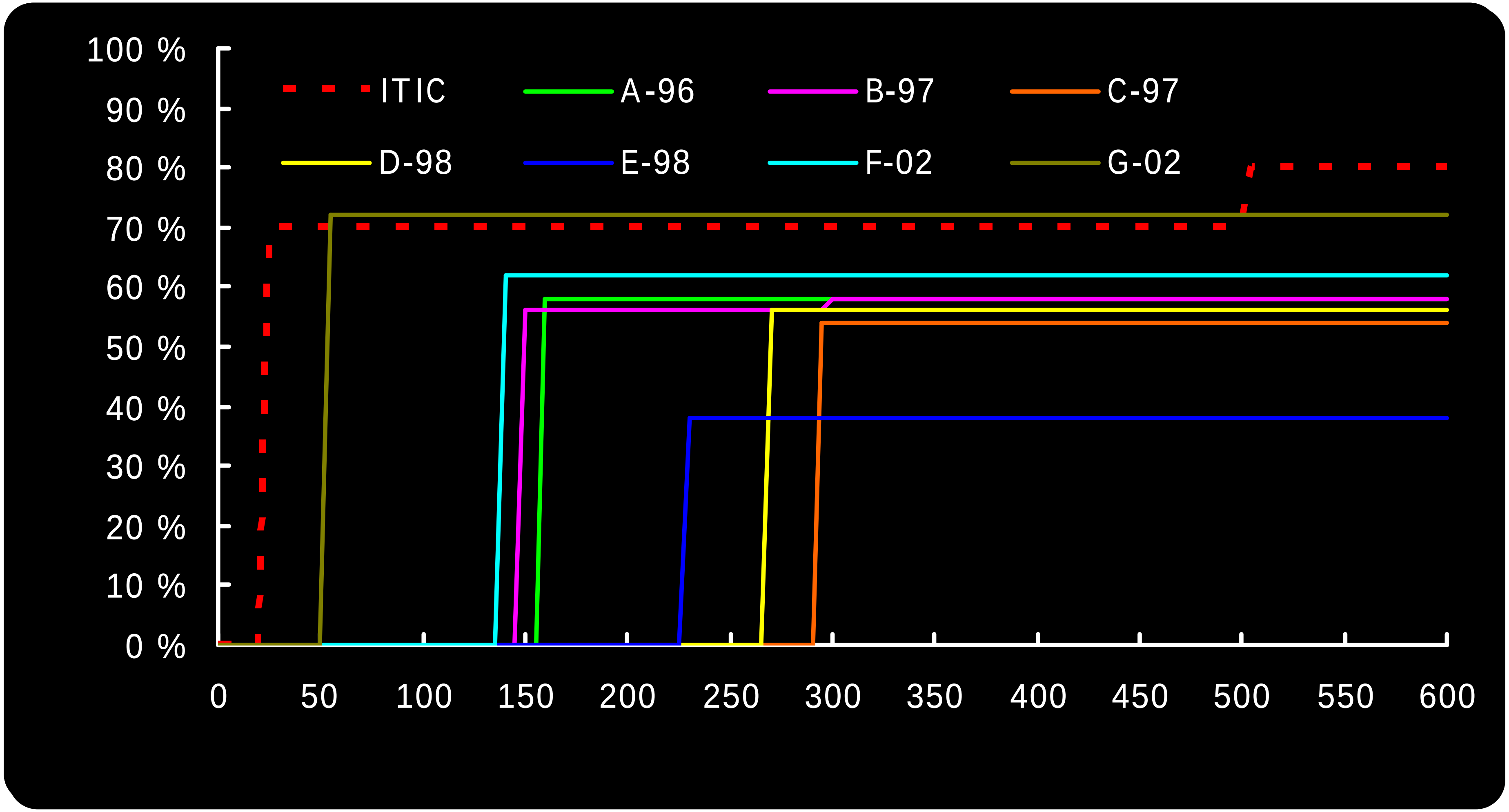
# Contactors and voltage sags

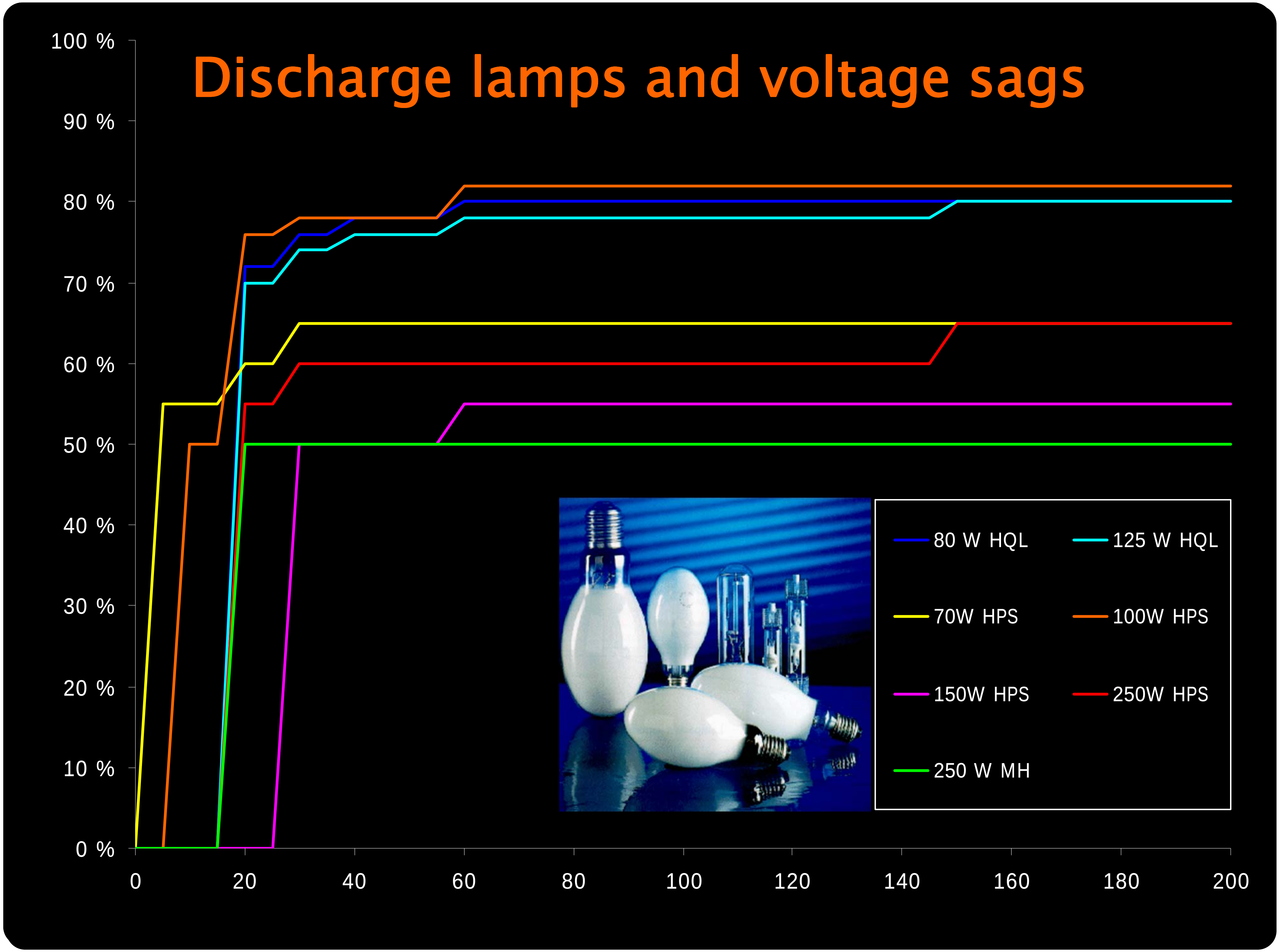
Distribution of sag sensitivity limits (long lasting sags)



# Computers and voltage sags

- 7 Laptop PCs:





Discharge lamps and voltage sags
100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
0
20
40
60
80
100
120
140
160
180
200
80 W HQL
125 W HQL
70W HPS
100W HPS
150W HPS
250W HPS
250 W MH