



Peteris Spels, ABB Inc., WMEA, November 18, 2011

HARMONICS

Agenda

- Harmonics:
 - What they are?
 - Where do they come from?
 - Why bother?
- Regulations
- How to detect?
- How to avoid?
- Summary

What are harmonics?

- Some math/ history
 - Every Periodic Function can be represented as a Sum of Infinite number of other periodic functions
 - These other functions are called HARMONICS
 - Joseph Fourie; 1807
- HARMONICS :
Periodic distortions in power supply

What are harmonics?

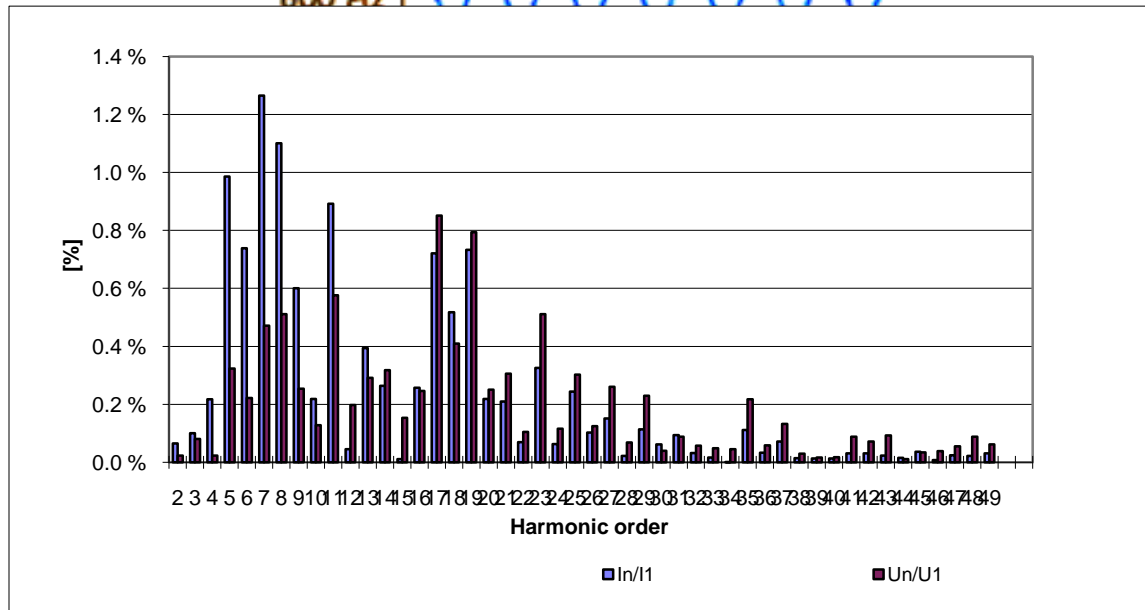
Some Math



$$THD = \sqrt{\sum_{n=2}^{50} \left(\frac{I_n}{I_N} \right)^2}$$

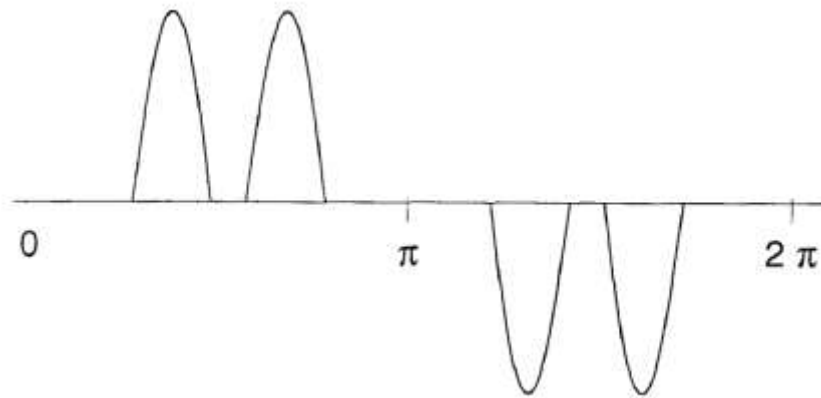
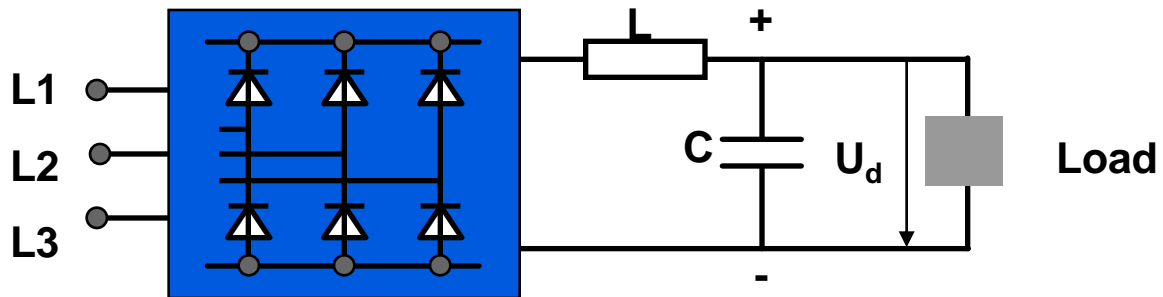
I_n n^{th} harmonic component

I_N nominal current



$$x(t) = a_0 + \sum_{n=1}^{\infty} [a_n \cos(n\omega t) + b_n \sin(n\omega t)]$$

Where do they come from? Example



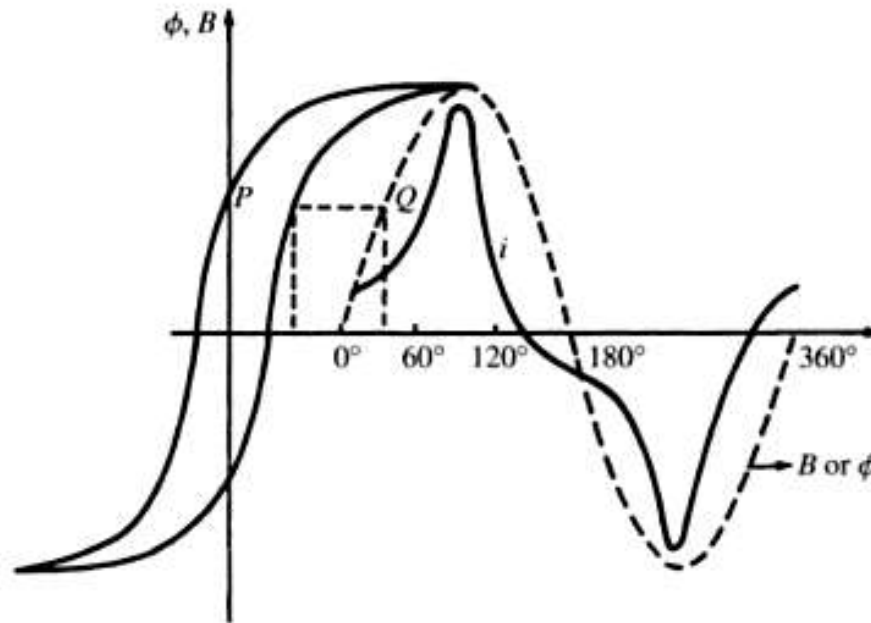
Where do they come from? Propagation



IMPORTANT: X_c and X_L

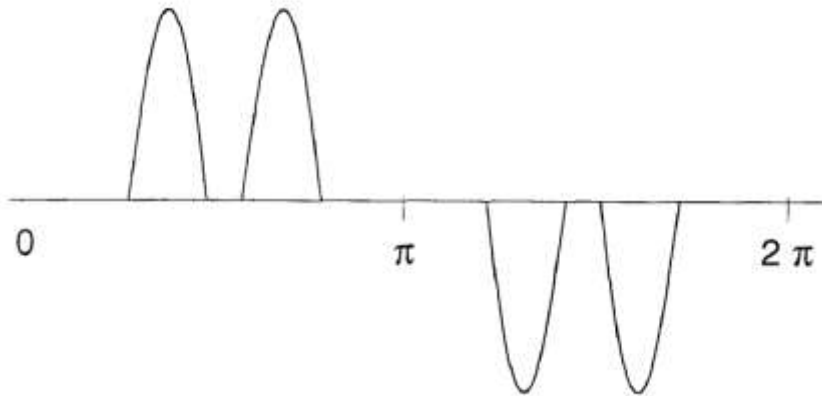
Where do they come from? Sources

- Any load, drawing non-sinusoidal current (non-linear loads)
 - Rectifiers
 - DC drives
 - VFD
 - Welding
 - DC pow
 - Static Var Co
 - Energy Savi
 - Etc. etc.



Why bother?

- An important question – WHY?
- EXAMPLE :
 - Transformer



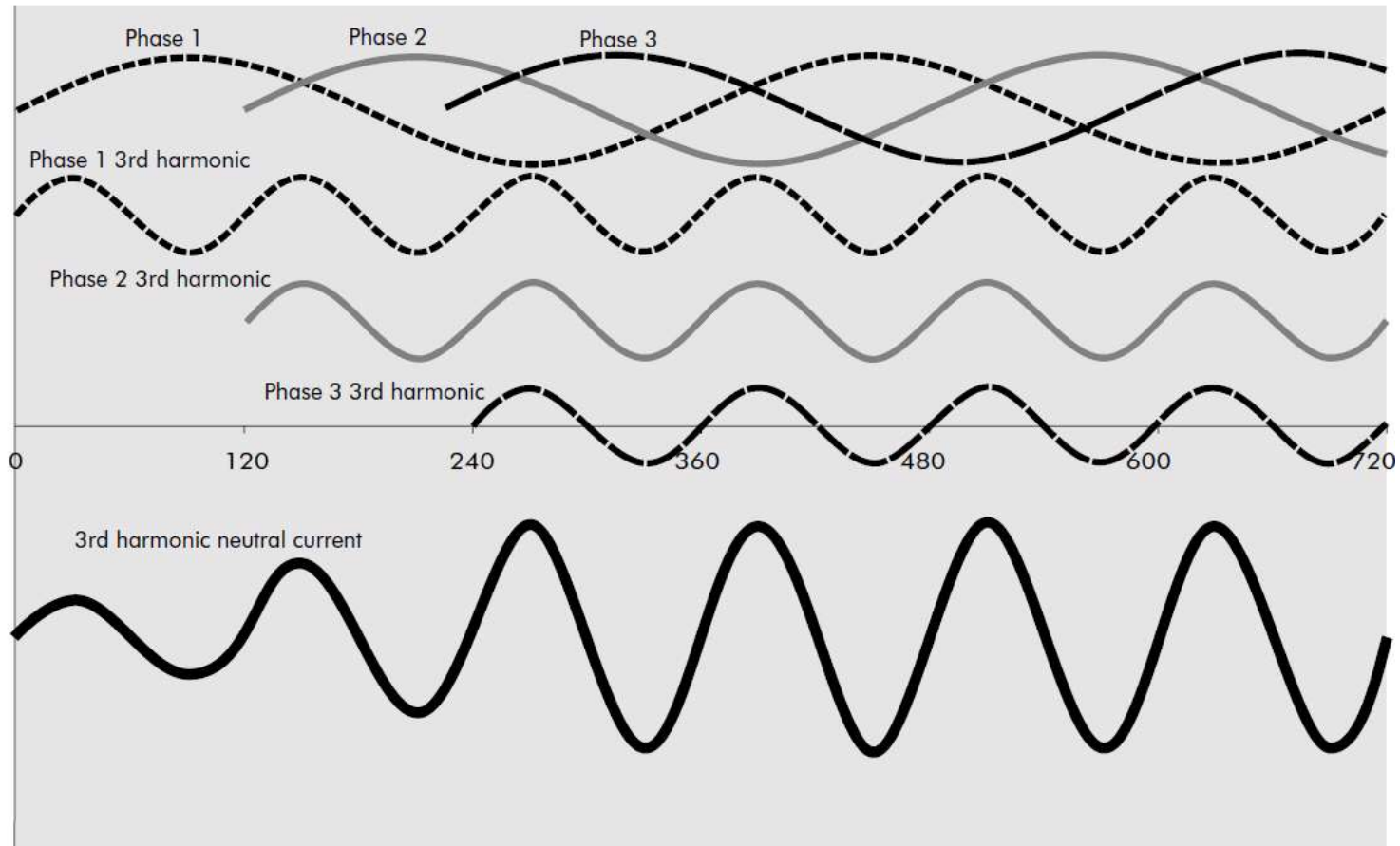
- Weird magnetic flux
- Additional heat (losses)
- Increased temperatures
- Reduced life

- Most important question:
how critical the harmonics are, and at what level problems will start

Why bother?

Effects of harmonics

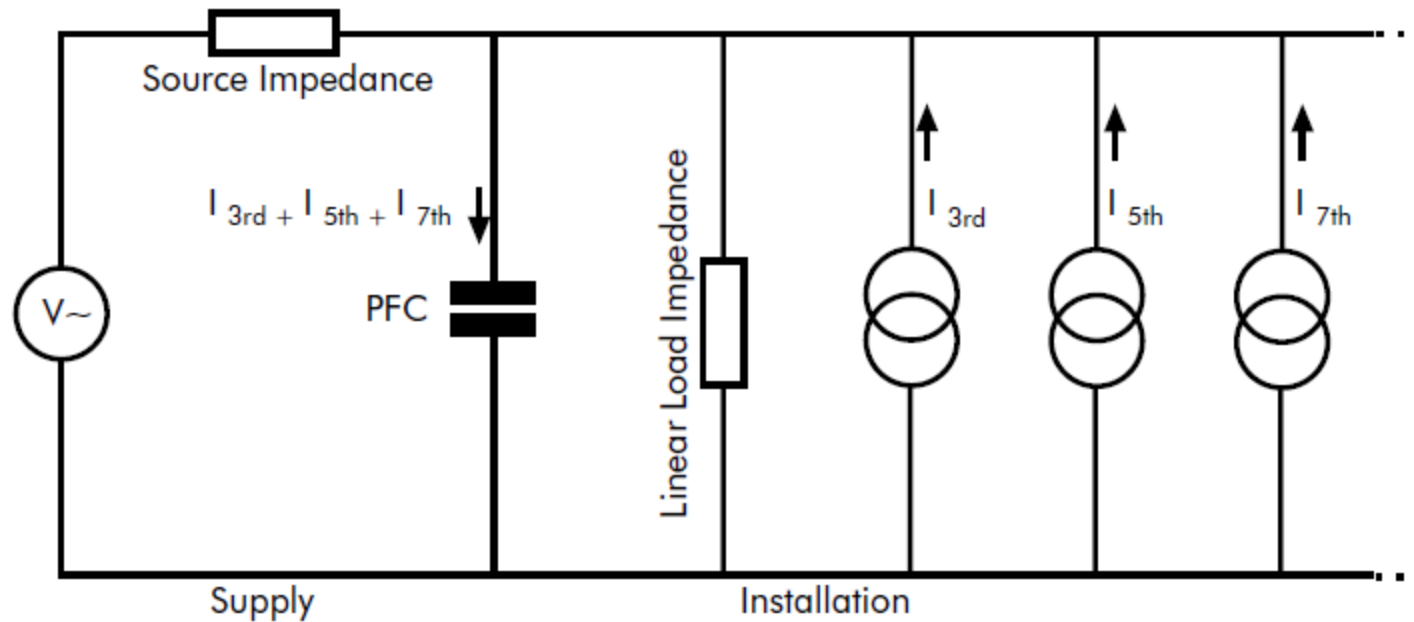
- Neutral conductor overheating



Why bother?

Effects of harmonics

- PFC capacitor overload



Why bother?

Effects of harmonics

- Resonance conditions

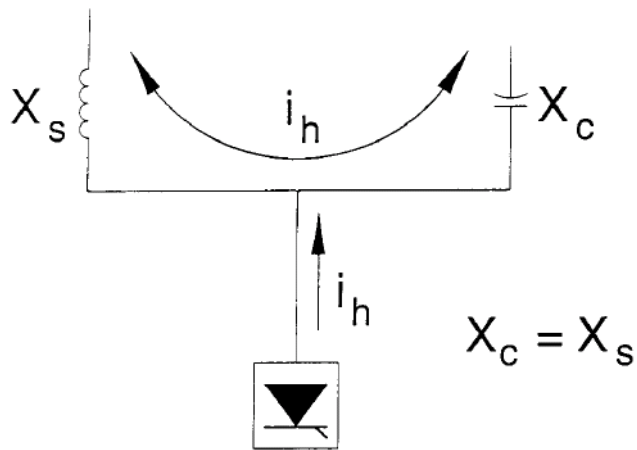


Fig 5.2
Parallel Resonance Condition

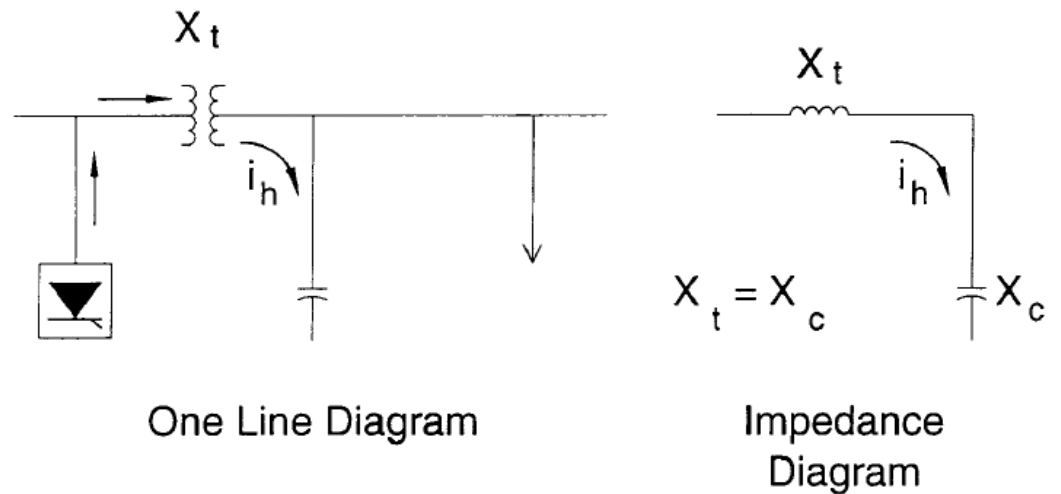


Fig 5.3
Capacitor Bank Resulting in Series Resonance

Why bother?

Effects of harmonics

- Rotating Machines
 - Additional heating (losses)
 - Reduced life
 - Power loss
 - Torque oscillations / pulsations
- Benefit: motors dampen harmonics

Why bother?

Effects of harmonics

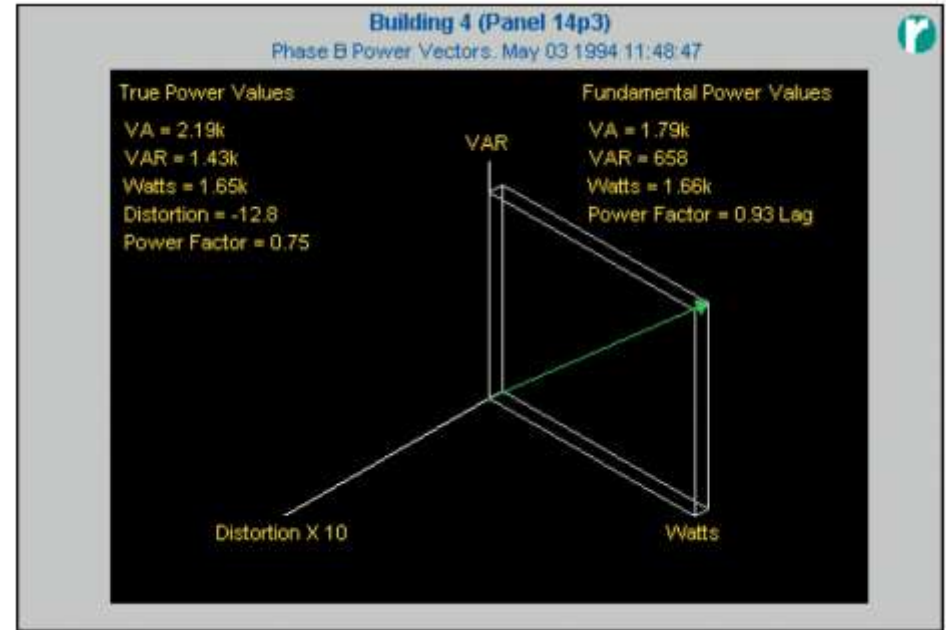
- PFC capacitor overload
- Additional losses (costs, heat)
- Increased transformer temperatures (reduced life)
- Nuisance tripping of breakers etc
- Malfunction of electronics, sensors
- Impact on rotating machinery

Regulations

- IEEE 519 – 1992
 - Technical document – good source of information
 - Voluntary, not a “standard” or “code”
 - Recommendations of mitigation and limits
- IEC 61000 series
 - Code – a “must comply” for overseas manufacturers, utilities and users
 - Electro-Magnetic Compatibility (EMC) – covers all electromagnetic phenomena,
 - ...*including nuclear bomb explosion effects (HEMP)*
 - Compatibility, rather than limits – equipment must be able to withstand disturbances, power supply must comply to quality standards

How to detect?

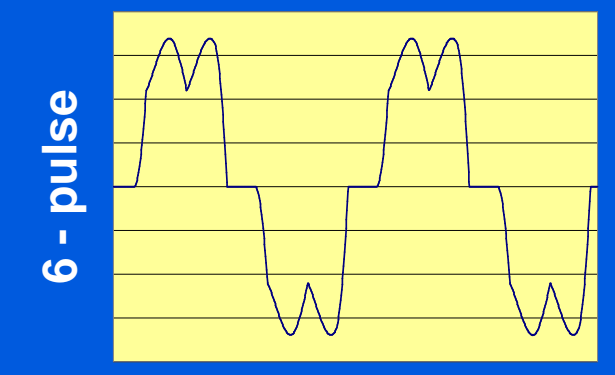
- Measure!
- Keywords:
 - Power quality analyzer,
 - Power quality recorder
 - Power meter/ analyzer / recorder



How to avoid?

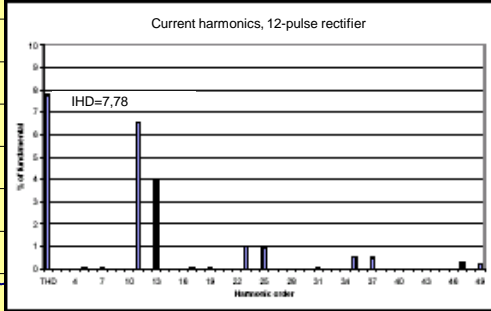
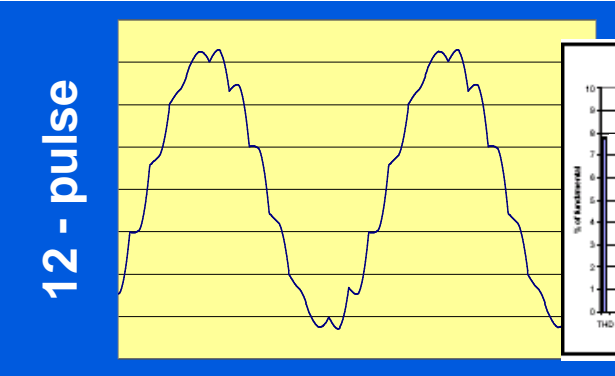
- Engineer them out!
 - Design studies (power flow)
 - Selection of right equipment
 - Transformers
 - Drive technology
 - Filtering measures
 - Short Circuit Capacity
 - Power factor control
- If already there:
 - Filtering
 - Defeat at the source
 - Smart measures – case specific

Comparison of Technologies



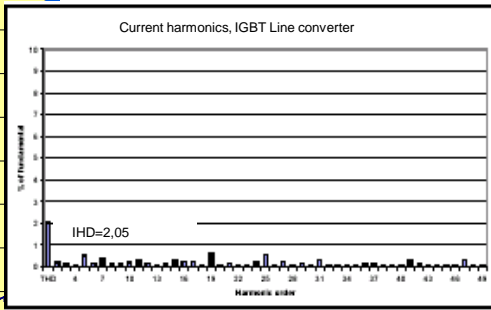
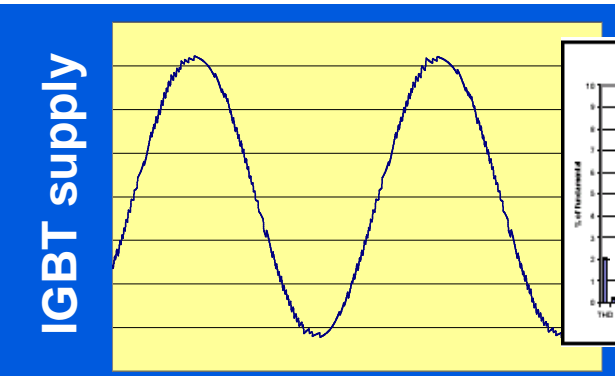
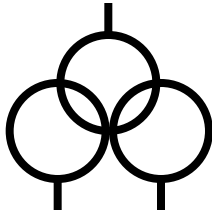
6 - pulse

$I_{THD} = 30 \%$
 $U_{THD RSC=20} = 10 \%$
 $U_{THD RSC=100} = 2 \%$
 $COS \varphi_{total} = 0,93...0,95$



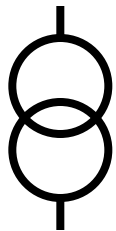
12 - pulse

$I_{THD} = 12 \%$
 $U_{THD RSC=20} = 7 \%$
 $U_{THD RSC=100} = 1,4 \%$
 $COS \varphi_{total} = 0,93...0,95$



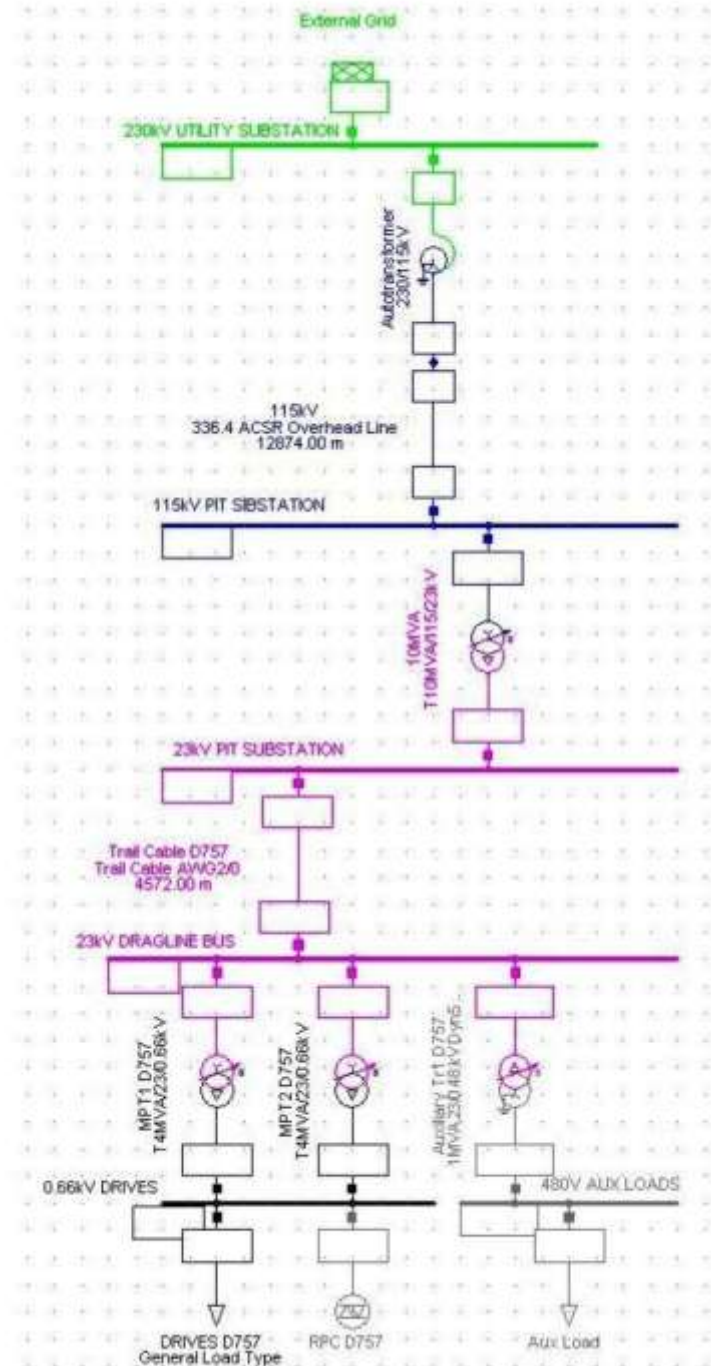
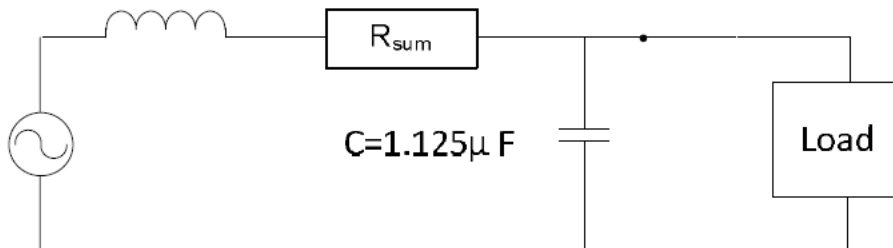
IGBT - Supply unit

$I_{THD} = 4 \%$
 $U_{THD RSC=20} = 3 \%$
 $U_{THD RSC=100} = 0,8 \%$
 $COS \varphi_1 = 1$
 $COS \varphi_{total} = 0,99$



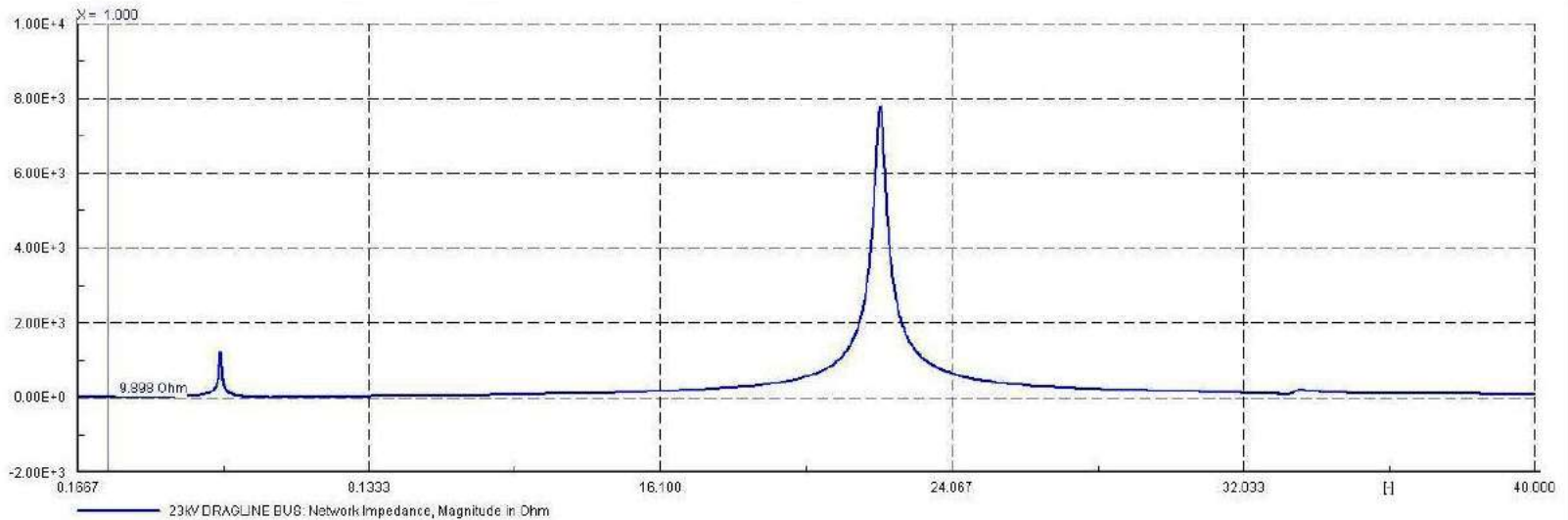
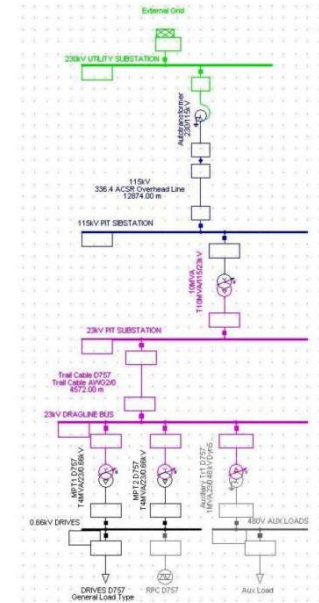
How to avoid? Example – design study

- Power study
 - Goal: IEE519 compliance at 115kV
- Greenfield site
- AC dragline proposed



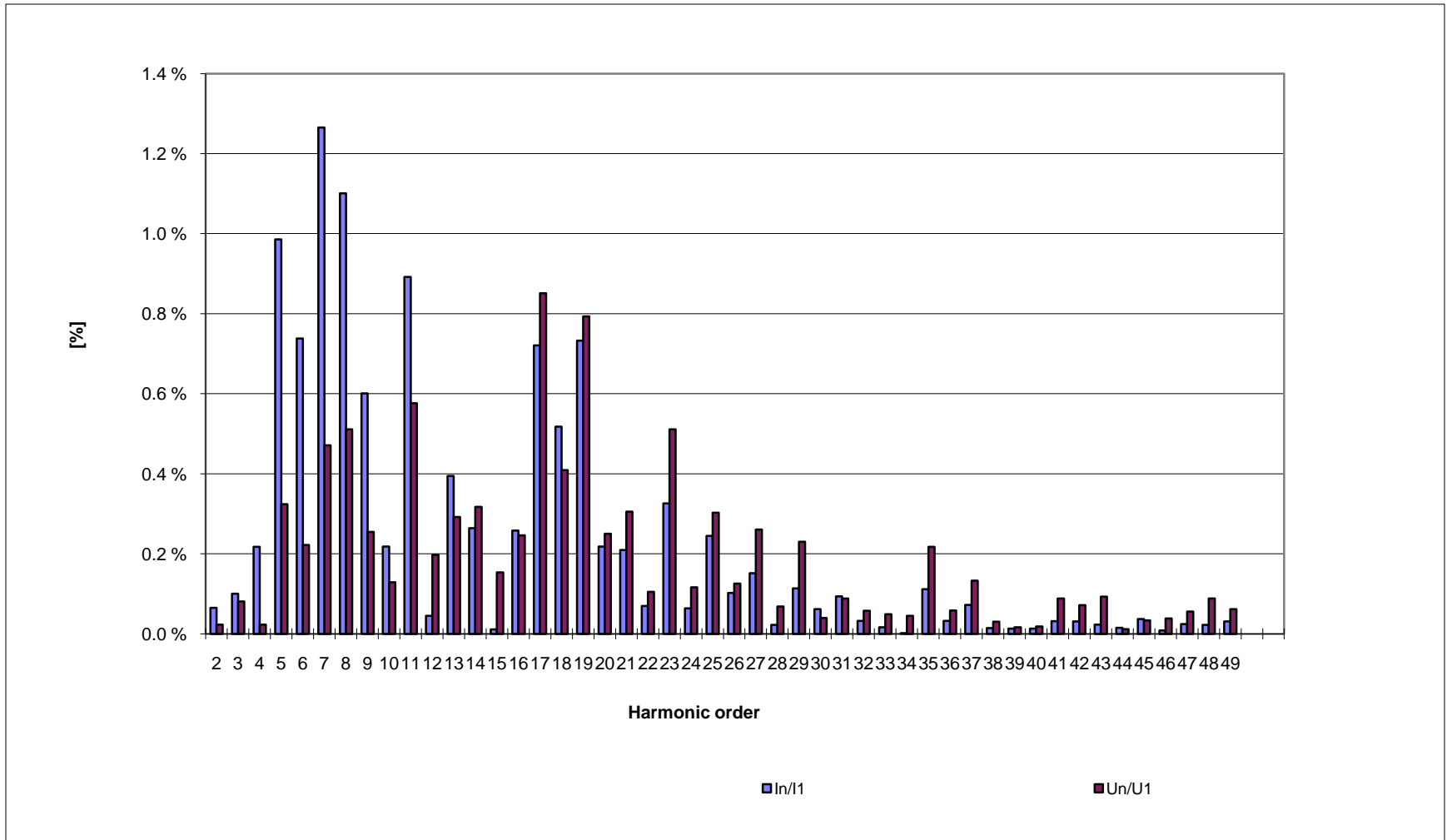
How to avoid? Example – design study

- Grid modeling
- Impedance sweep (frequencies)
- Recommendations – what to do
- **Every grid has a resonant frequency!**



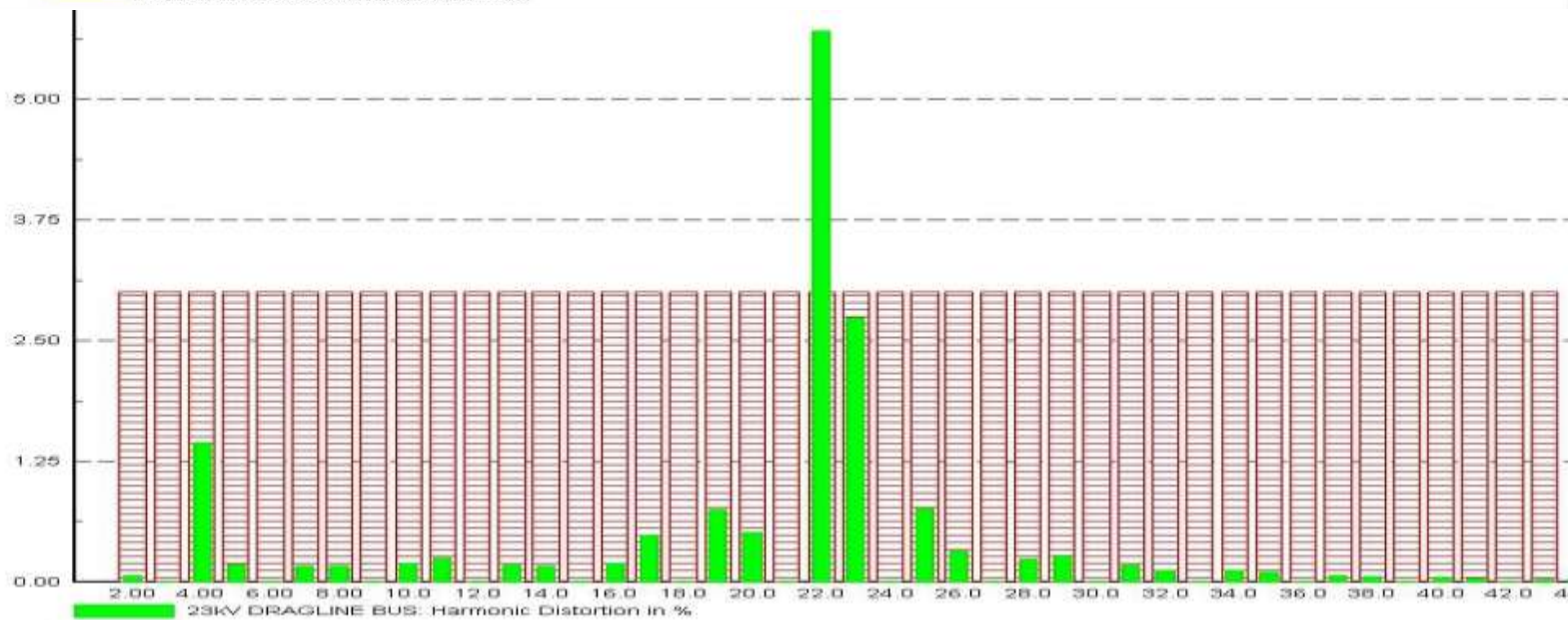
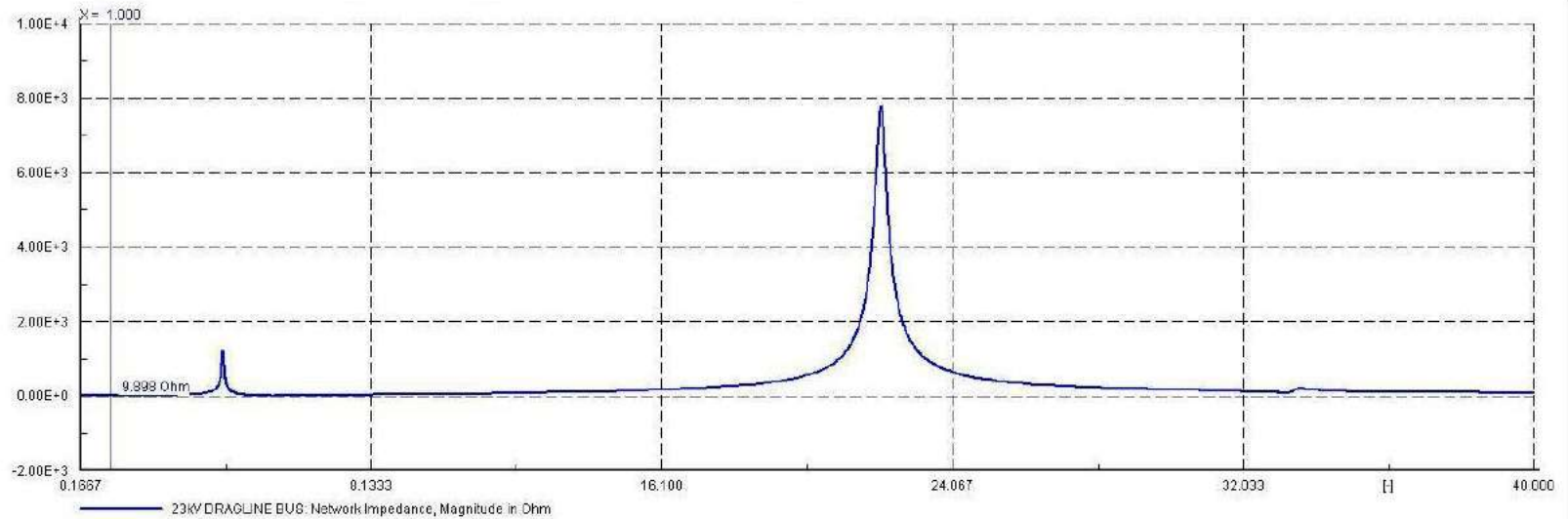
How to avoid?

Example – design study



How to avoid?

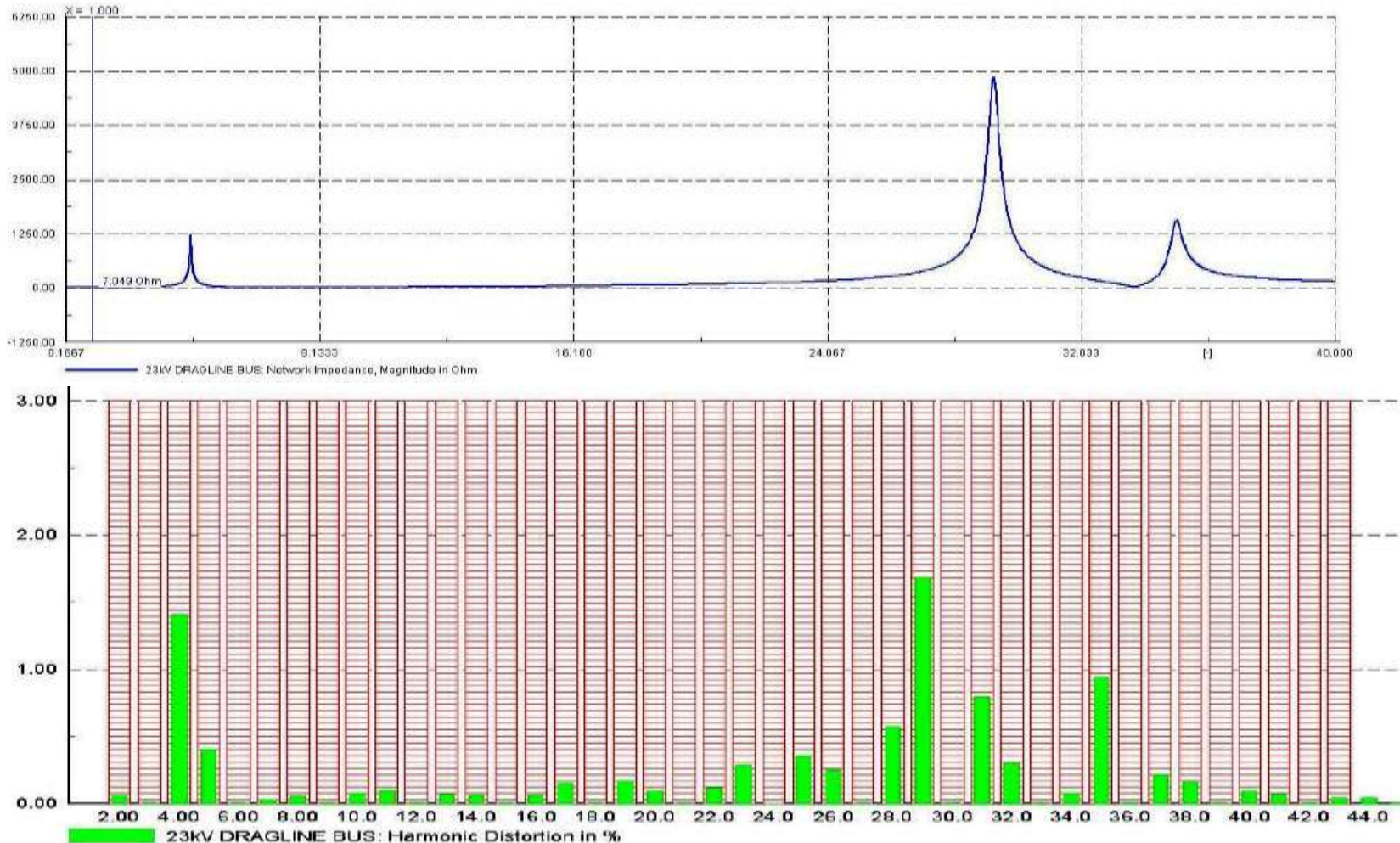
Example – design study



How to avoid?

Example – design study

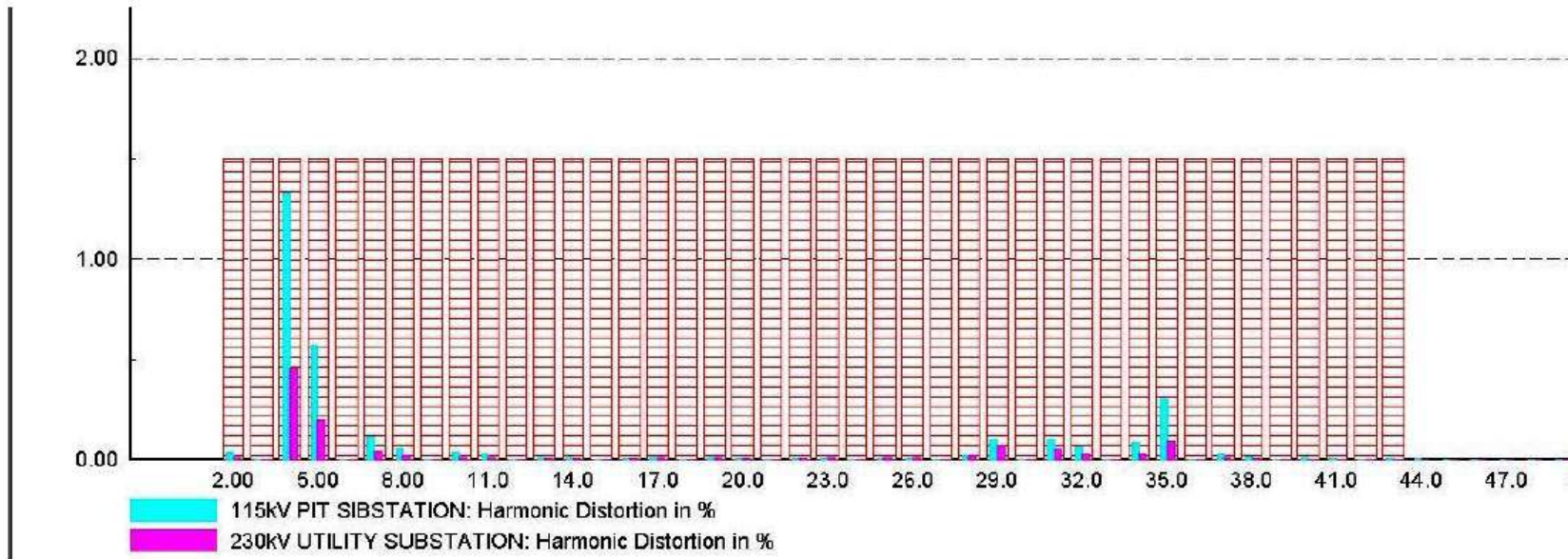
- Solution – pick a different cable!



How to avoid?

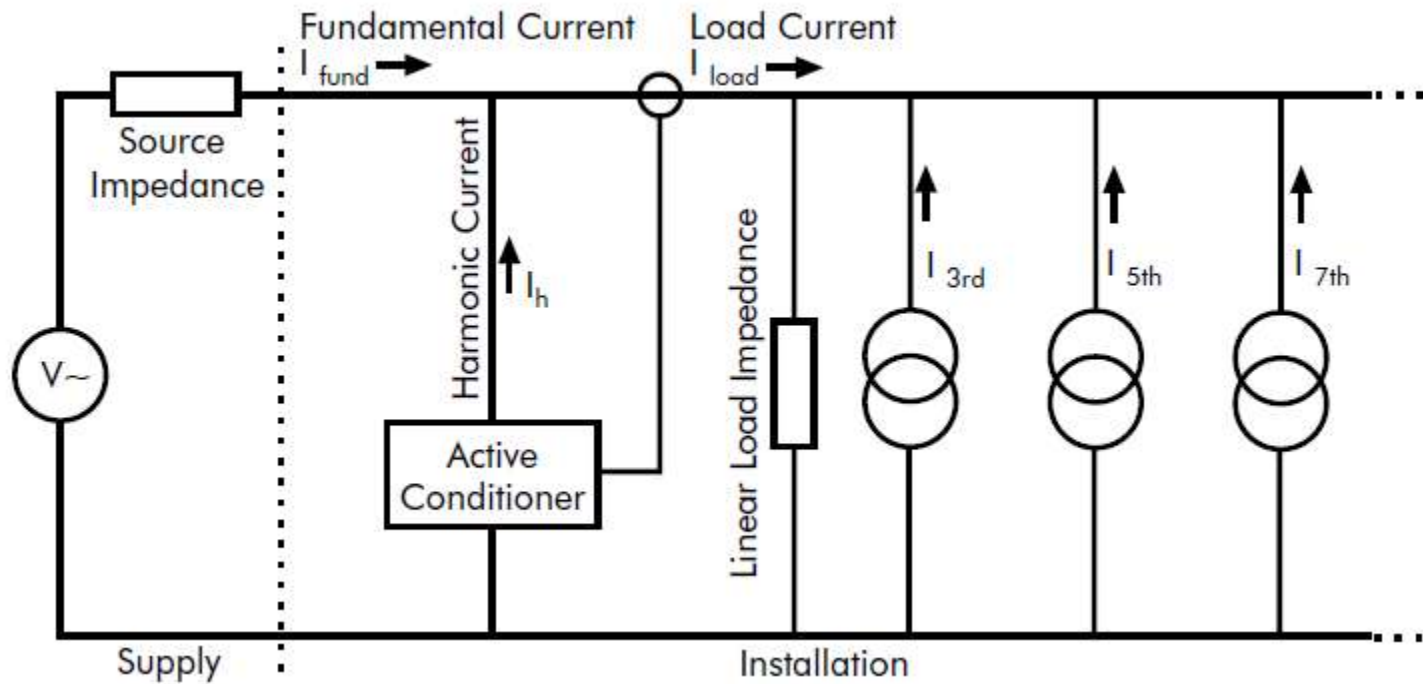
Example – design study

- In both cases – levels at 115kV BUS – negligible
- The single – frequency overshoot present only in the trail cable and at the secondary of dragline substation transformer at 22kV.
- Potentially – if other equipment connected to that bus would have seen some minute voltage distortions.



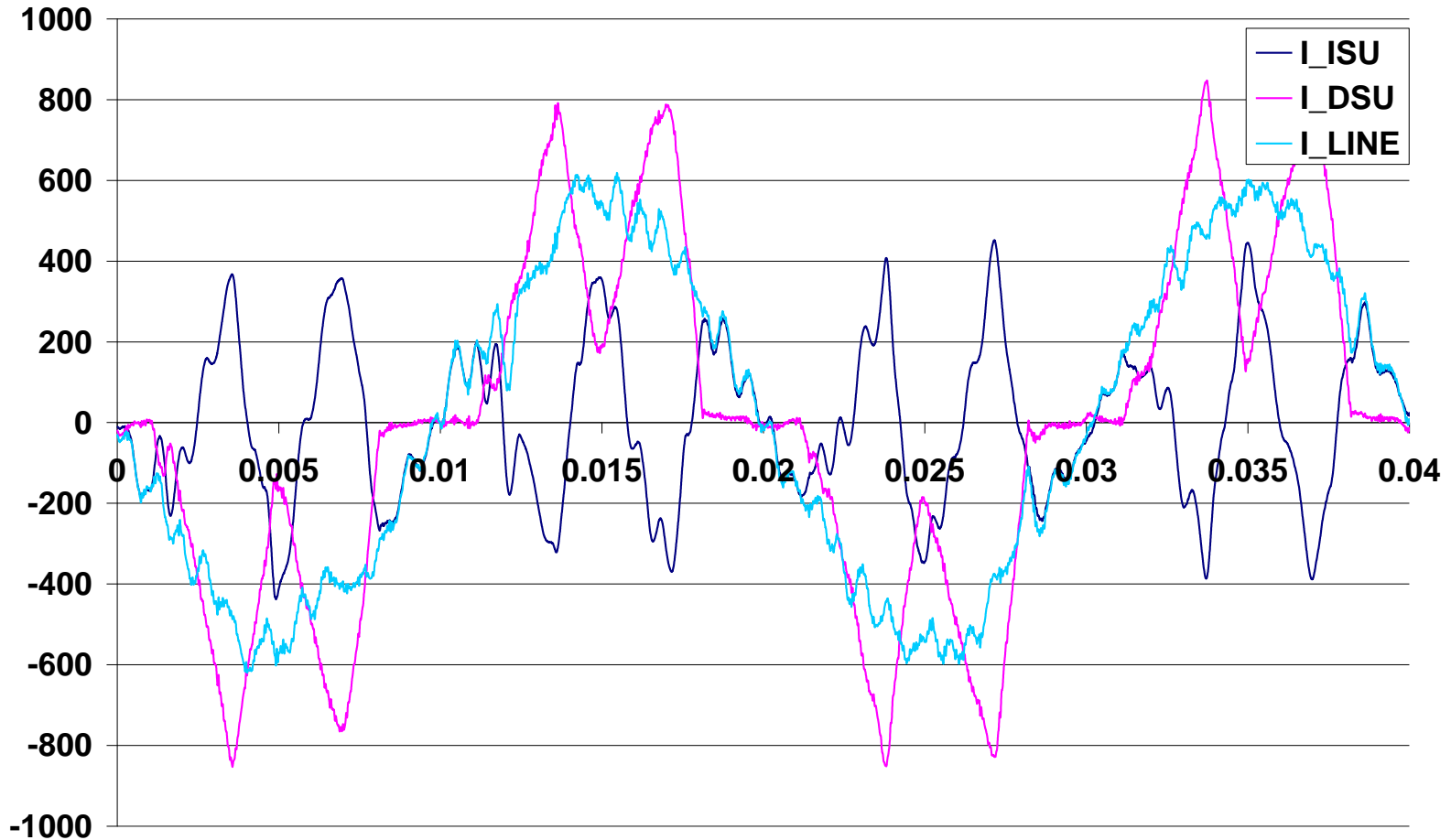
How to avoid? Filtering

- Two types of filters
 - Passive
 - Active



How to avoid? Filtering

- Active filter example – shovel



SUMMARY

- Harmonics – distortions in power supply represented in frequency domain (other harmonic, periodic functions)
- Harmonics are created by nonlinear loads (rectifiers, etc.)
- They are always there
- Problems: heating/losses, reduced life, nuisance trips, capacitor overloading, rare cases – torque oscillations
- Solutions:
 - Engineer them out
 - Proper technology
 - Filtering

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