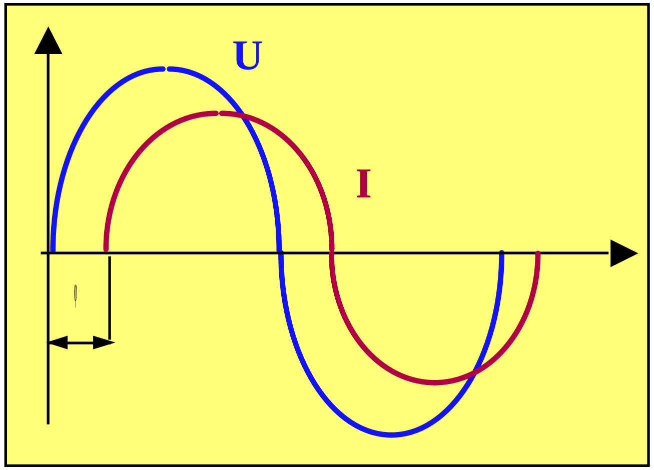
Harmonic Solutions in Electrical Systems

Raed Odeh – Application Specialist - Power Quality & Electrical Distribution

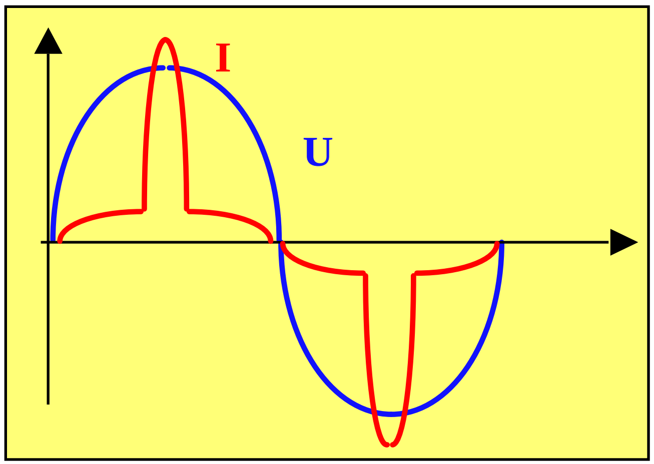
Agenda

- I. Harmonic Basics
- II.Harmonic Mitigation Solutions
- III.Case Study

Harmonic Basics

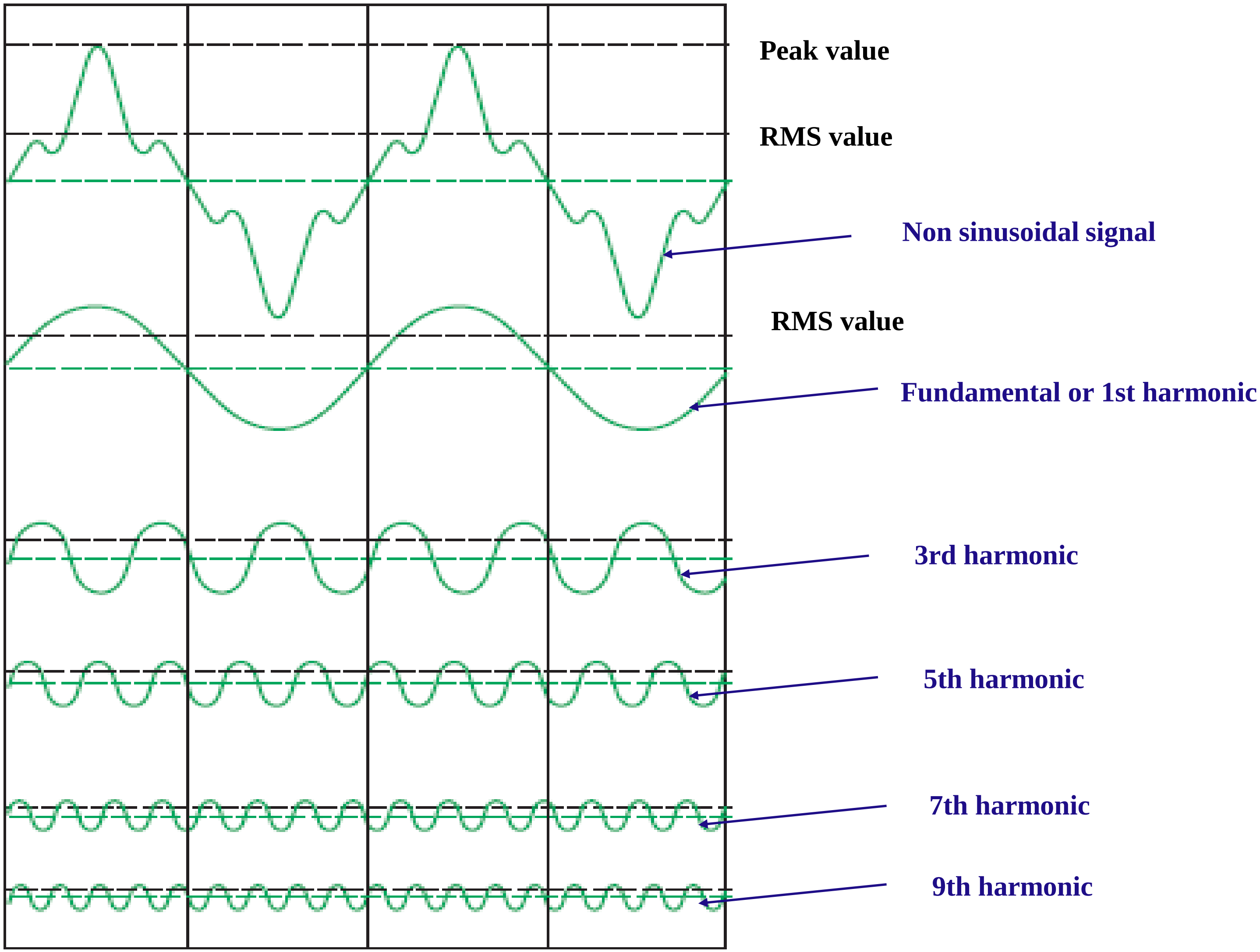


- *Linear Loads*
  - *Resistive heaters*
  - *Lights*
  - *Induction motors*



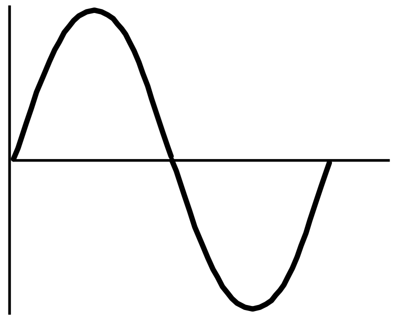
- *Non-linear Loads*
  - *House hold appliances (TVs, Microwave, etc.)*
  - *Induction heaters & welders*
  - *Lighting equipment with ballasts*
  - *Variable Speed Drives*
  - *Office equipment (PCs, Photocopiers, fax,etc.)*

Harmonic Basics



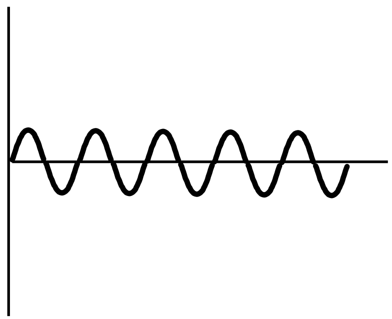
Harmonic Basics

Sinewave of a specific frequency supplied by the utility (a "clean" sinewave):



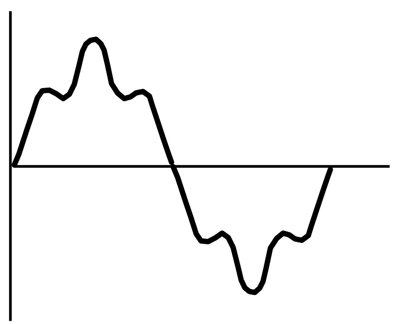
$$f(x) = \sin(x)$$

…plus a "5th" Harmonic Sinewave:



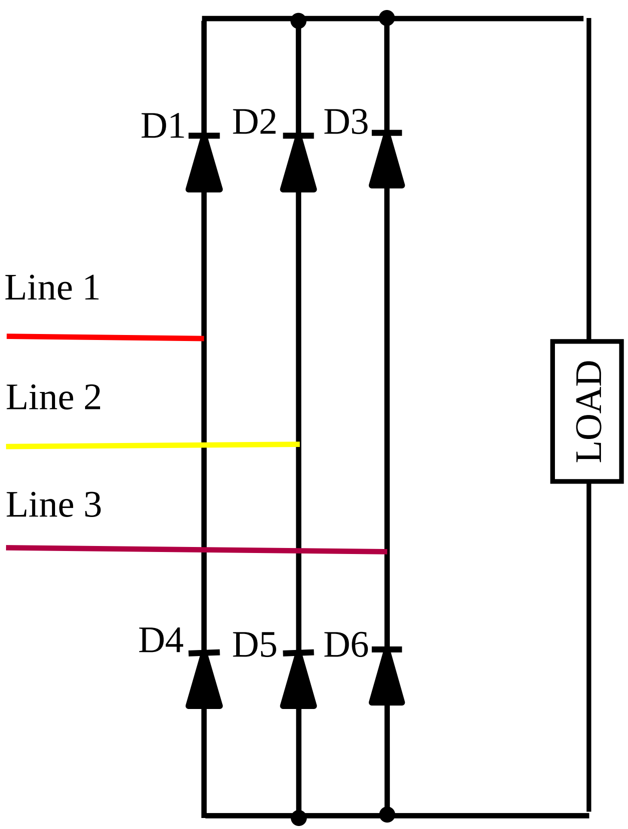
$$f(x) = \frac{\sin(5x)}{5}$$

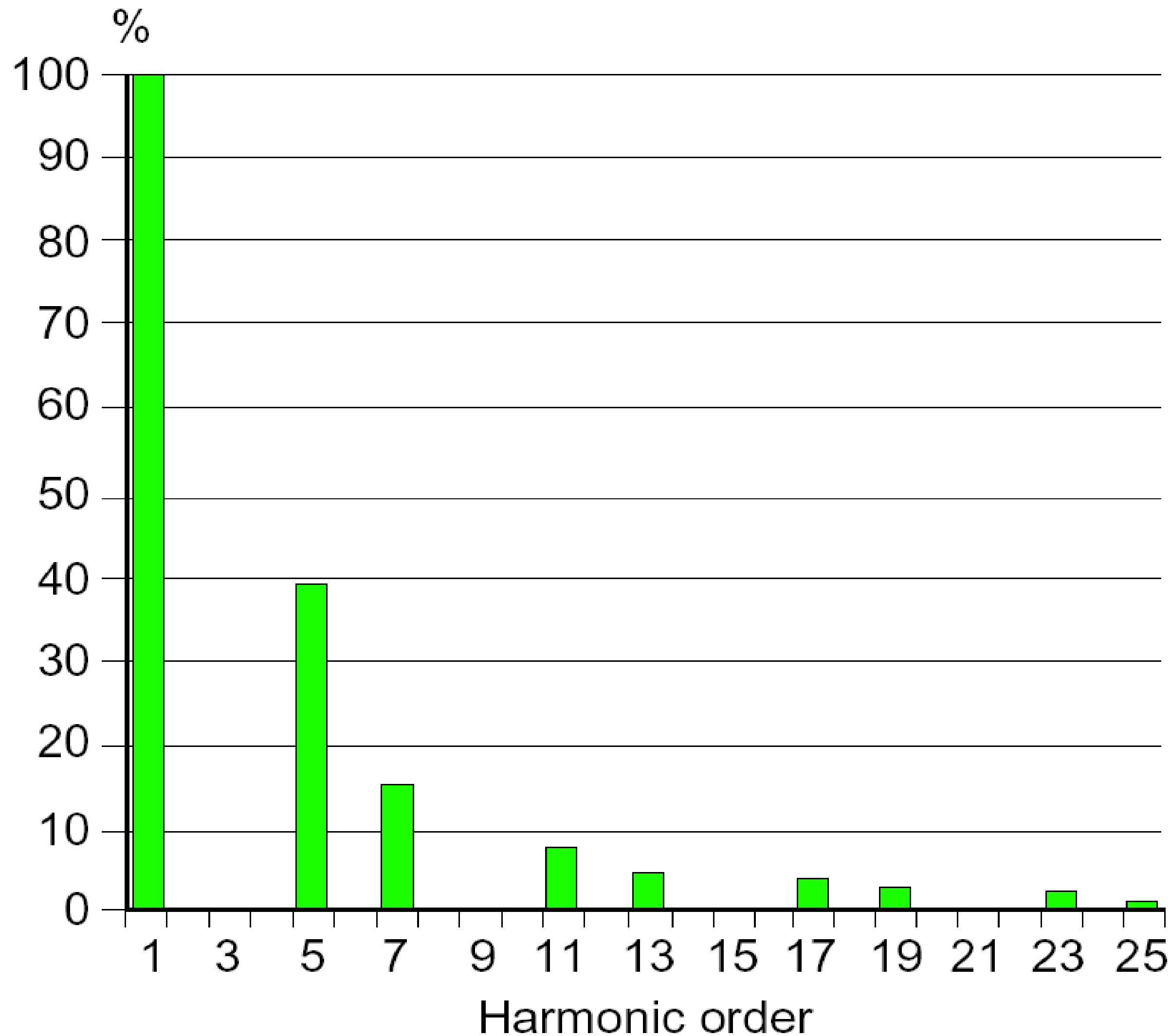
…results in a harmonic rich, non-linear wave shape:



$$f(x) = \sin(x) + \frac{\sin(5x)}{5}$$

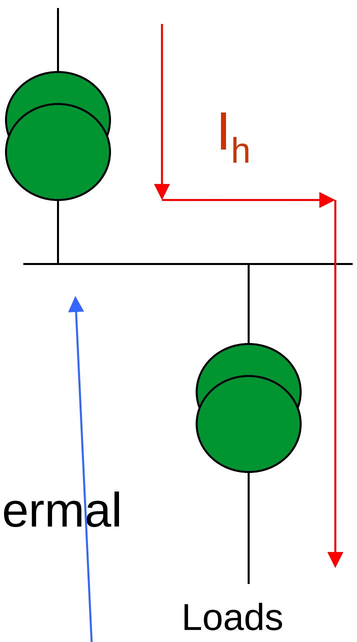
Harmonic Basics





Harmonic Basics

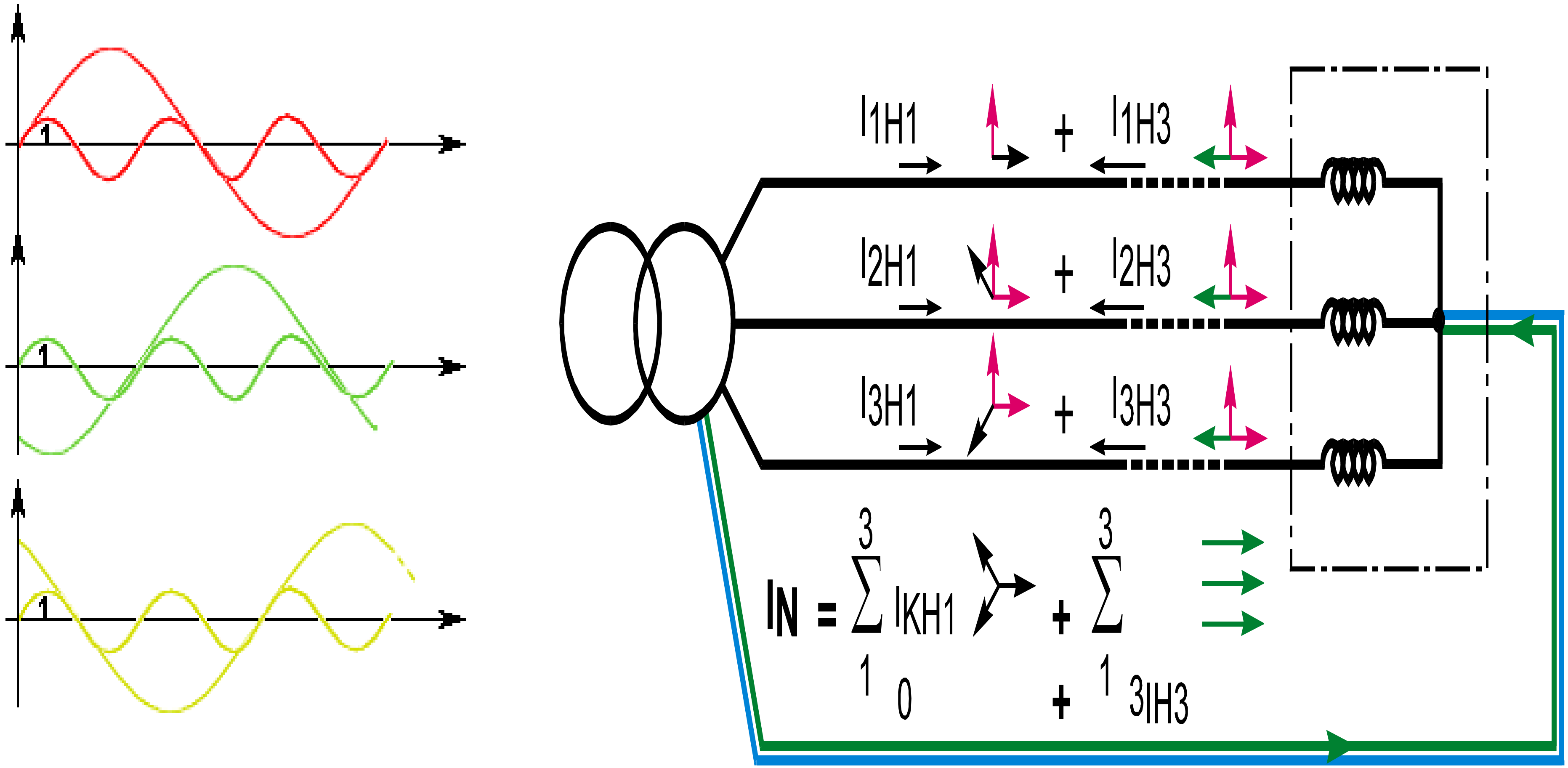
- Why the concern?
  - Current distortion
    - Added heating = reduced capacity
    - Equipment failures
      - Transformers
      - Conductors and cables
      - Nuisance tripping of electronic circuit breakers (thermal overload)



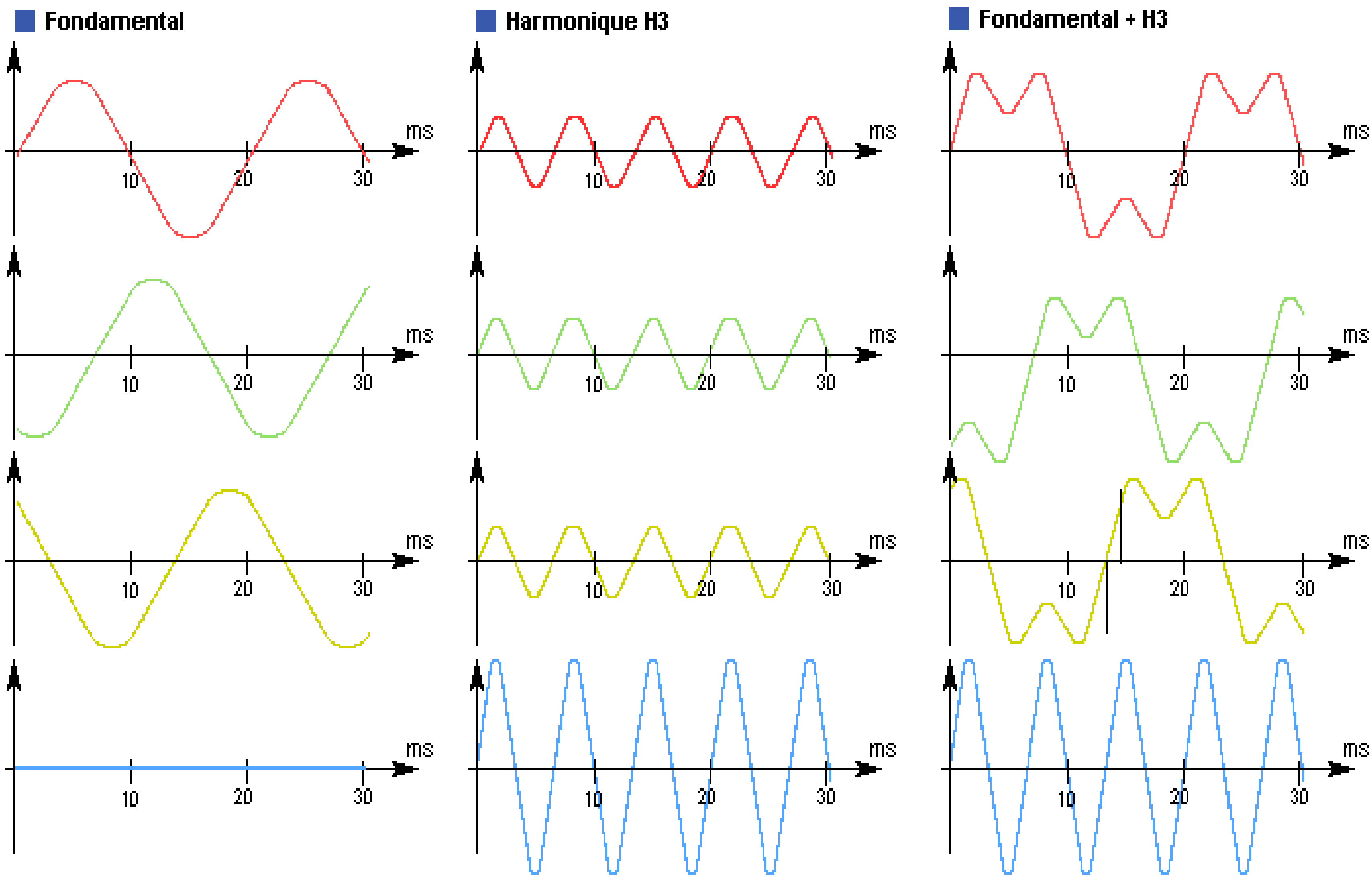
$$V_h = I_h \times Z_h$$

- Heating proportional to harmonic order in cables
  - Squared effect on transformers & motors

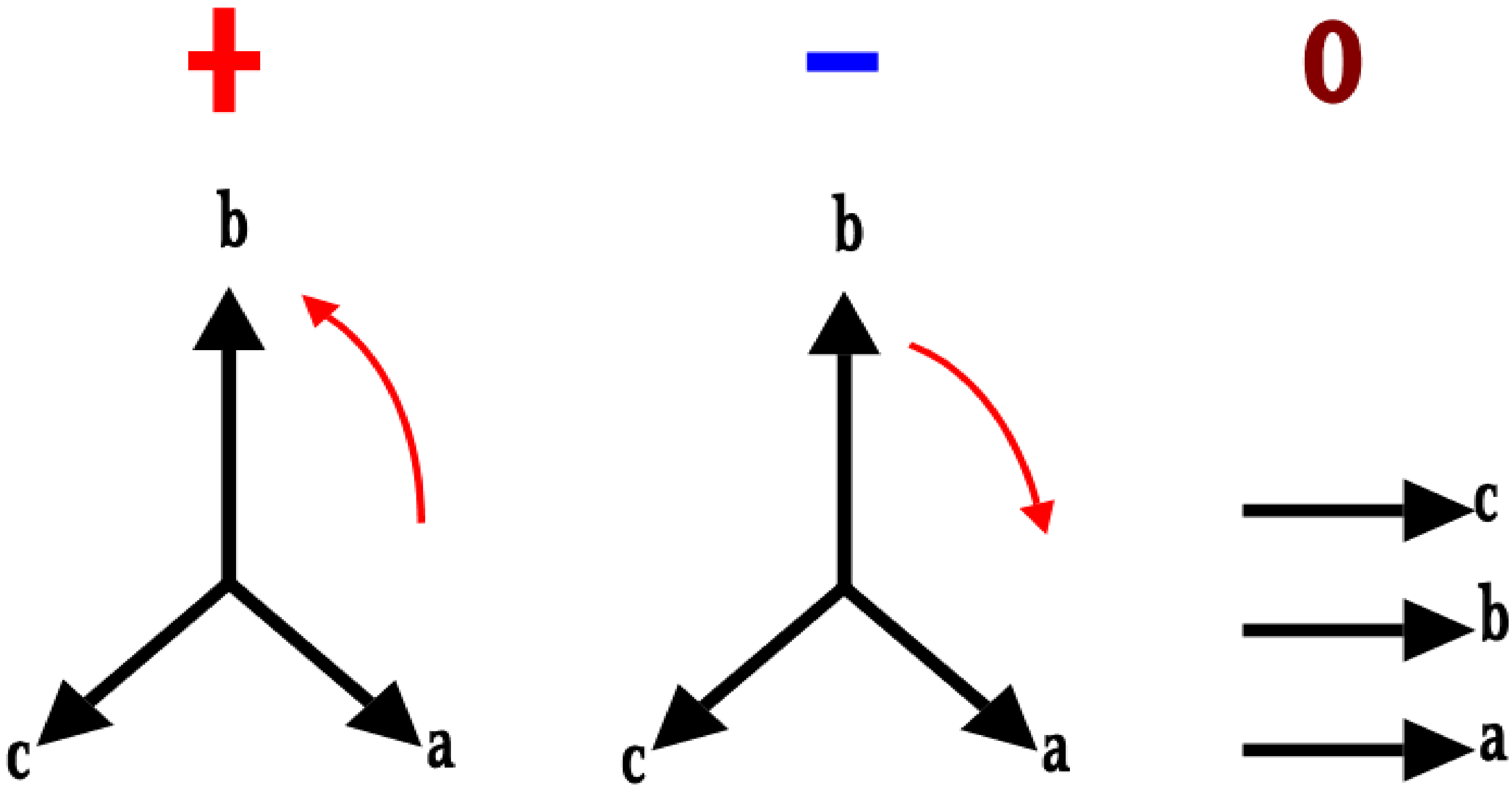
Harmonic Basics



Harmonic Basics

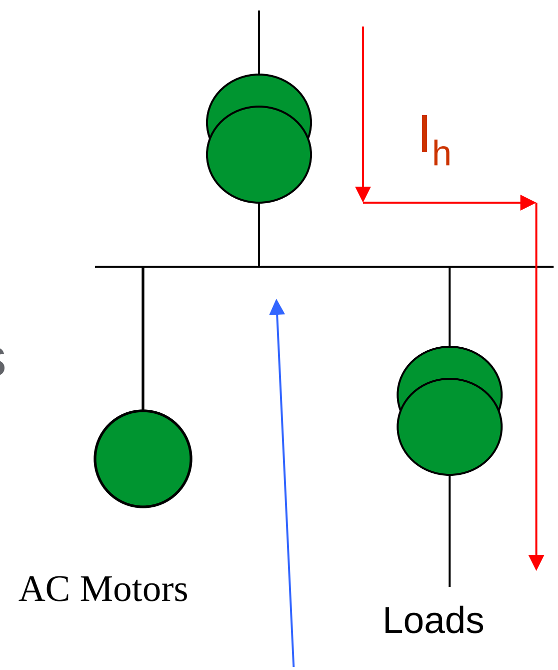


Harmonic Basics



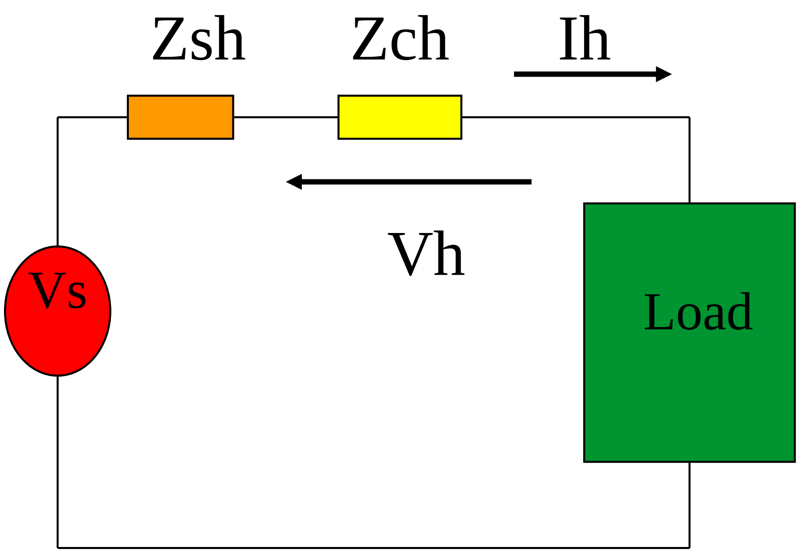
Harmonic Basics

- Why the concern?
  - Voltage distortion
    - Interference with other electronic loads
      - – Malfunctions to failure
    - Induces harmonic currents in linear loads
      - – i.e. AC motor winding over heating & bearing failures



$$V_h = I_h \times Z_h$$

Harmonic Basics



Vh = Harmonic voltage

Ih = Harmonic current

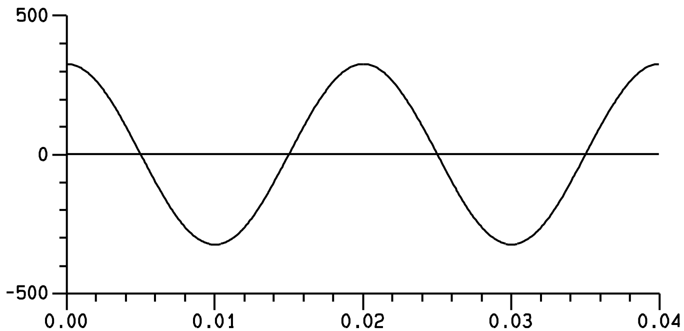
Zsh = Source impedance for harmonic current

Zch = Cable impedance for harmonic current

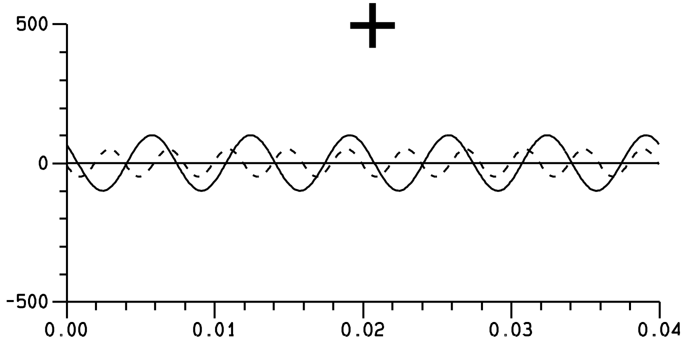
$$Vh = Ih * (Zsh + Zch)$$

Harmonic Basics

Fundamental Signal

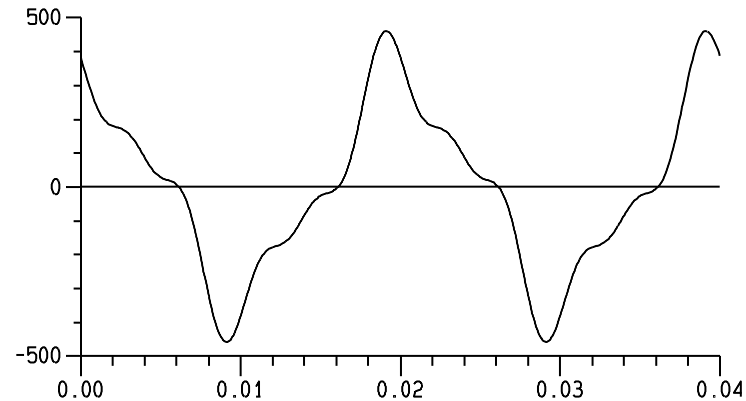


+



Harmonic Signal

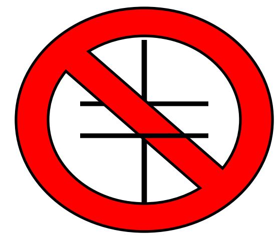
=



Total RMS Signal

Harmonic Basics

- Interaction with PF caps
  - PF caps interact with all frequencies
  - Overheating of PFC capacitors
    - Tripping of PF protection equipment
    - Capacitor failures
  - Cause resonance
    - Shutdown to damage to electronic equipment



Harmonic Mitigation Solutions

- Every method has its place
- Every method adds complexity
  - Added costs
  - Added heat losses
    - Additional cooling requirements
    - Larger footprint – needs more space
  - Adds installation complexity
    - Additional power cabling
    - Current transformers
  - Application performance may be impacted
    - Too much impedance limits load performance
      - di/dt ($\Delta i/\Delta t$) defines speed of change of current over time
    - Generator interaction difficulties

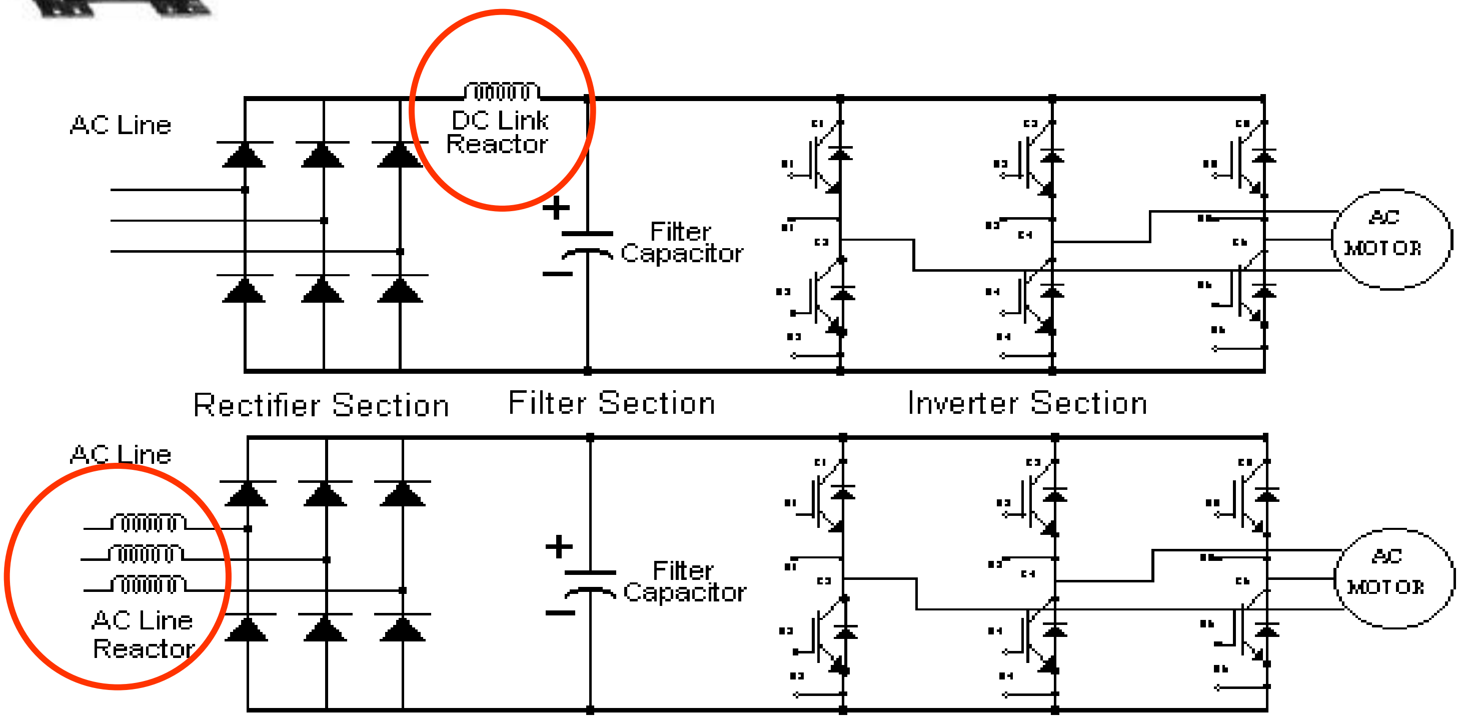
Harmonic Mitigation Solutions

- Applied per device (VFD based discussion)
  - Reduced harmonic designs
  - Passive
    - Line reactors/DC bus chokes/isolation transformers
    - 5th harmonic filters
    - Broadband filters
    - Multi-pulse transformers/converters
  - Active front end (AFE) converter

- System solution
  - Active harmonic filter (AHF)

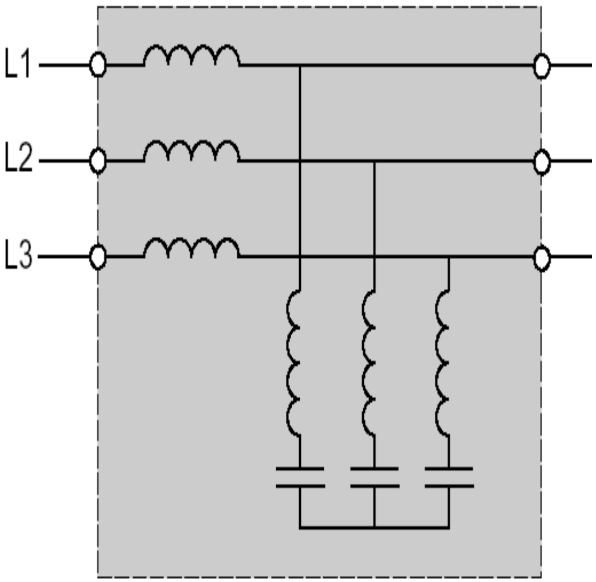
Harmonic Mitigation Solutions

- Reactors/chokes **smooth the current shape**
- Reduces **the** harmonic distortion



Harmonic Mitigation Solutions

Passive Filters



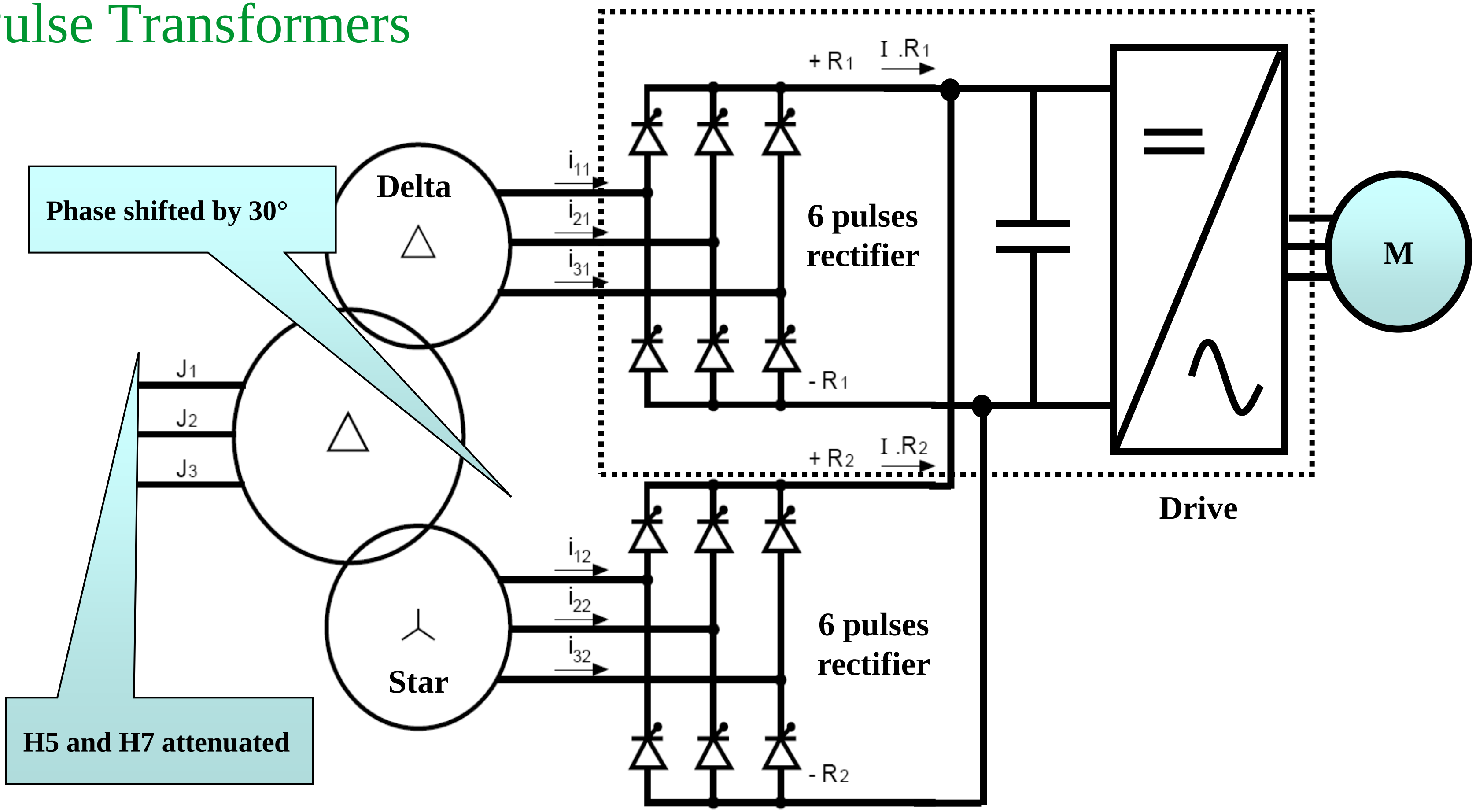
- Consist of a large series reactor and shunt harmonics traps
  - The series reactor reduces the thdi and isolates the harmonics traps from the network harmonics.
- The passive filter offer allows the THDI level to be reduced from 16% to 10%, and down to 5% in combination with inductance
- Can be used on single or multiple drives

Harmonic Mitigation Solutions

- 12-Pulse Transformers
  - 11th, 13th, 17th, 19th.
  - Current distortion: 10-12% THDI.
  - Only available at design stage.
  - Requires special transformers.
  - Cancellation at primary side.
- 18-Pulse Transformers
  - 17th, 19th.
  - Current distortion: 5-7% THDI.
  - Only available at design stage.
  - Requires special transformers.
  - Cancellation at primary side.

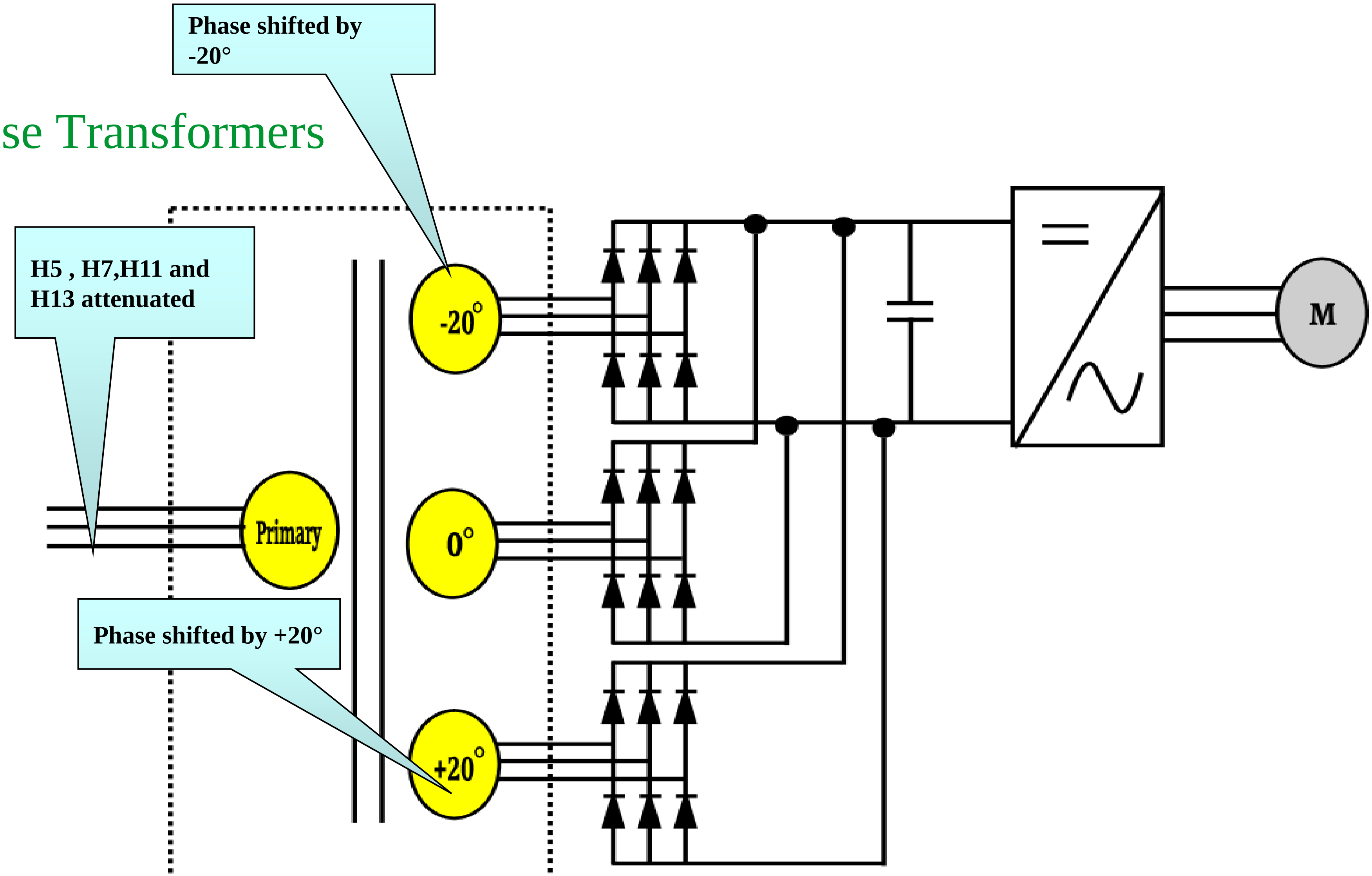
Harmonic Mitigation Solutions

12-Pulse Transformers



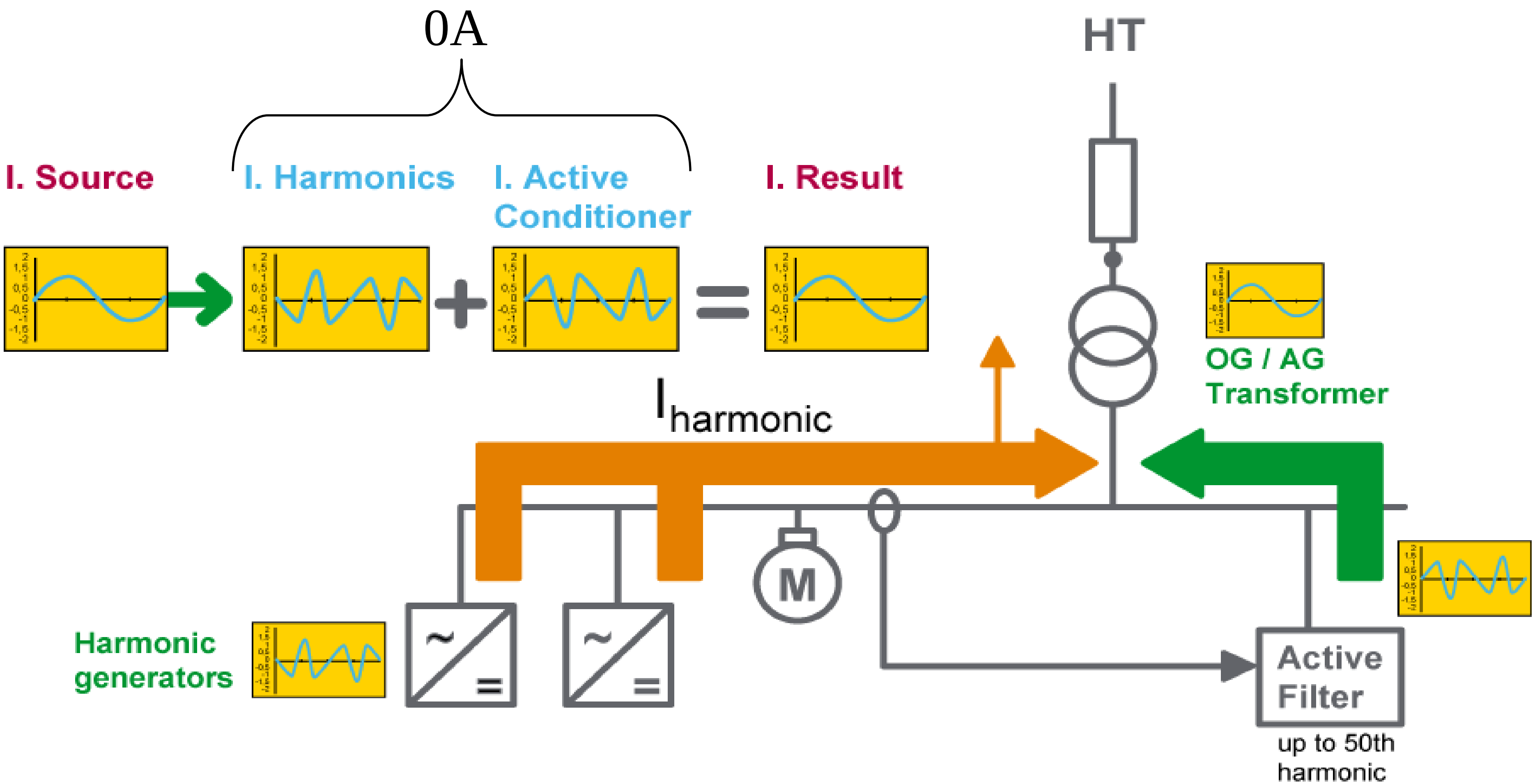
Harmonic Mitigation Solutions

18-Pulse Transformers



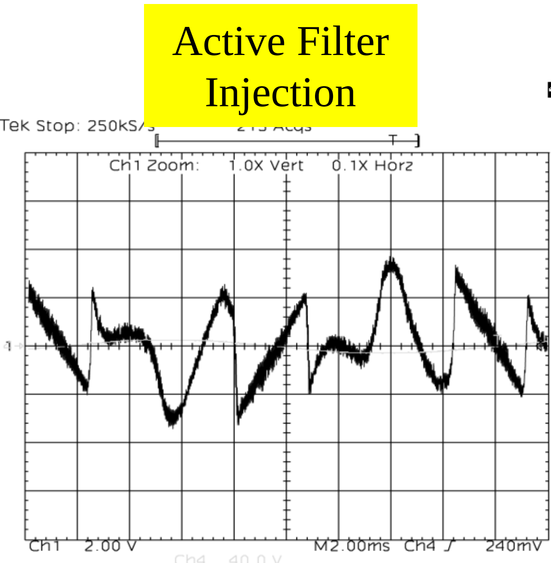
Harmonic Mitigation Solutions

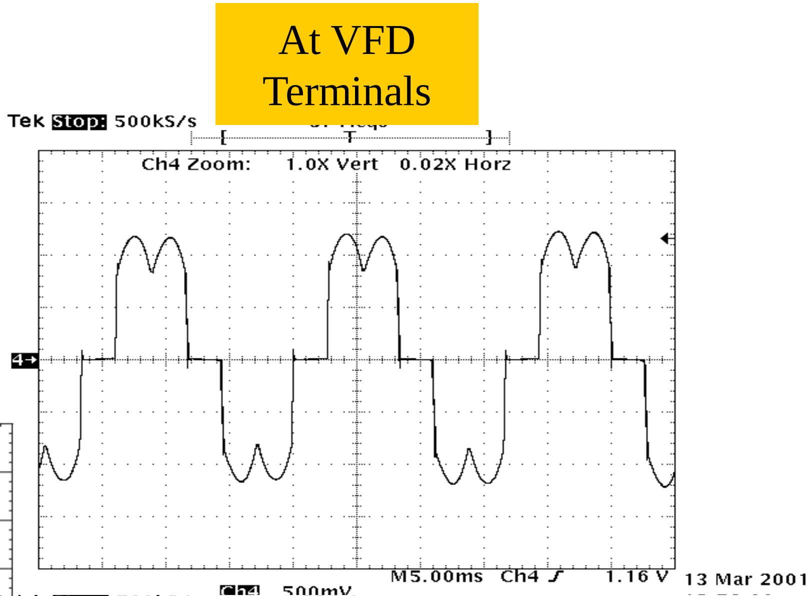
- Active filters
  - Cancellation of harmonic currents by currents generated in opposition

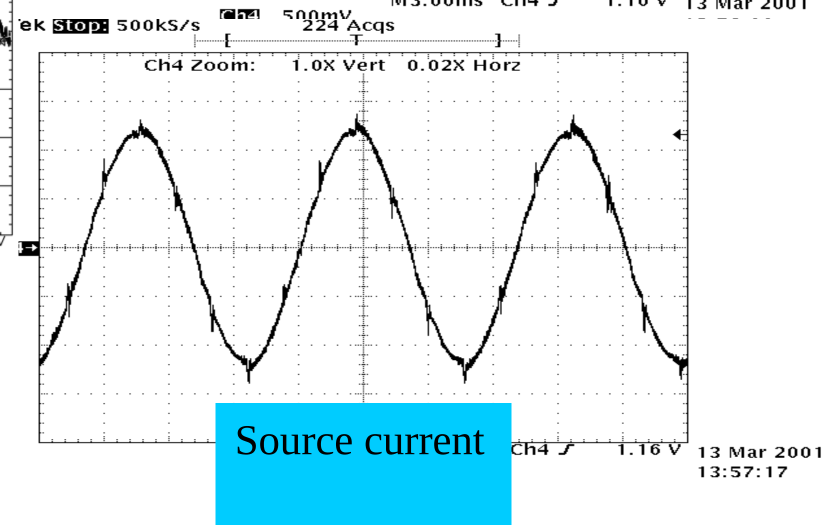


Harmonic Mitigation Solutions

- Active filters

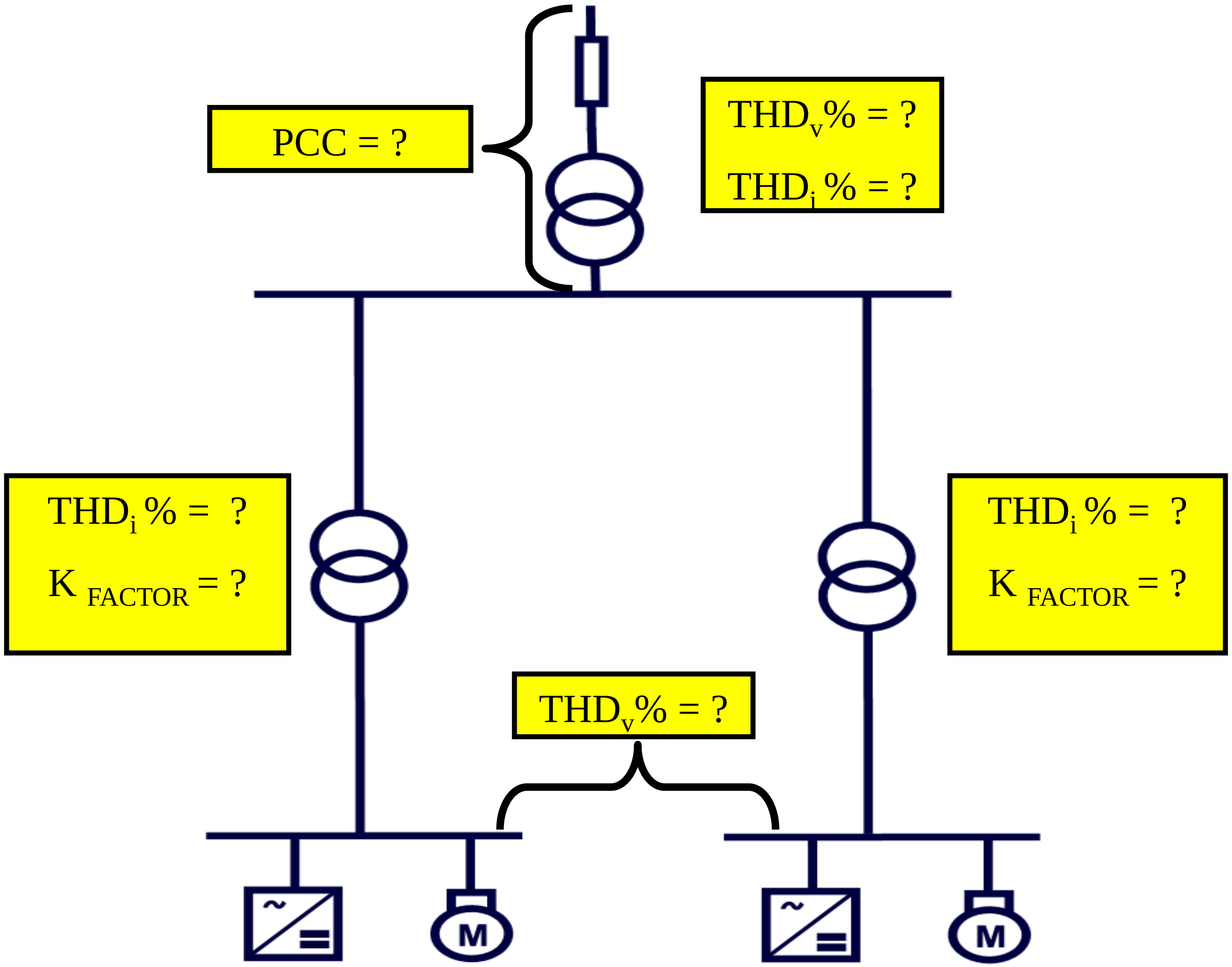






Order	AS off % I fund	AS on % I fund
Fund	100.000%	100.000%
3	0.038%	0.478%
5	31.660%	0.674%
7	11.480%	0.679%
9	0.435%	0.297%
11	7.068%	0.710%
13	4.267%	0.521%
15	0.367%	0.052%
17	3.438%	0.464%
19	2.904%	0.639%
21	0.284%	0.263%
23	2.042%	0.409%
25	2.177%	0.489%
27	0.293%	0.170%
29	1.238%	0.397%
31	1.740%	0.243%
33	0.261%	0.325%
35	0.800%	0.279%
37	1.420%	0.815%
39	0.282%	0.240%
41	0.588%	0.120%
43	1.281%	0.337%
45	0.259%	0.347%
47	0.427%	0.769%
49	1.348%	0.590%
% THD(I)	35.28%	2.67%

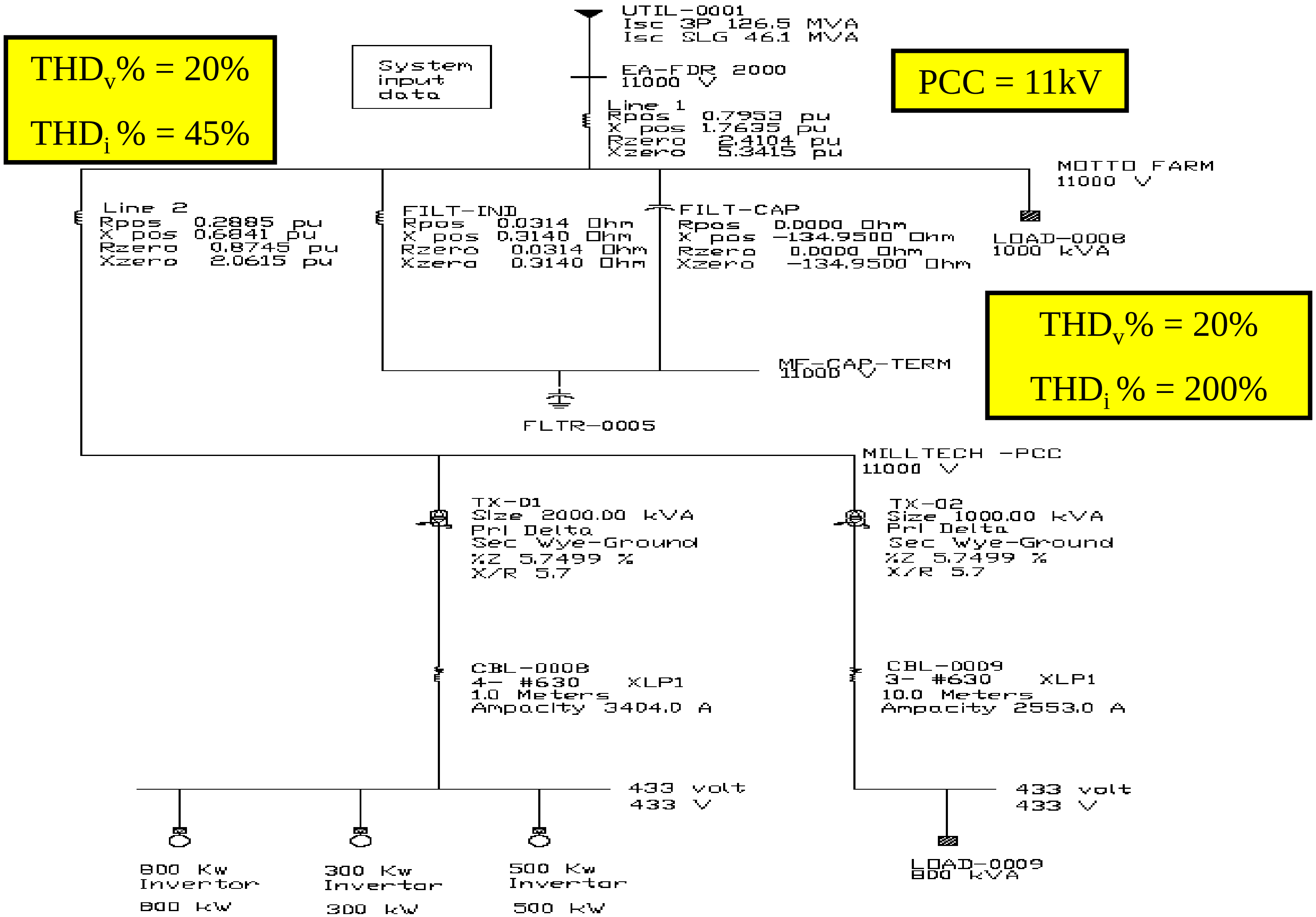
Harmonic Mitigation Solutions



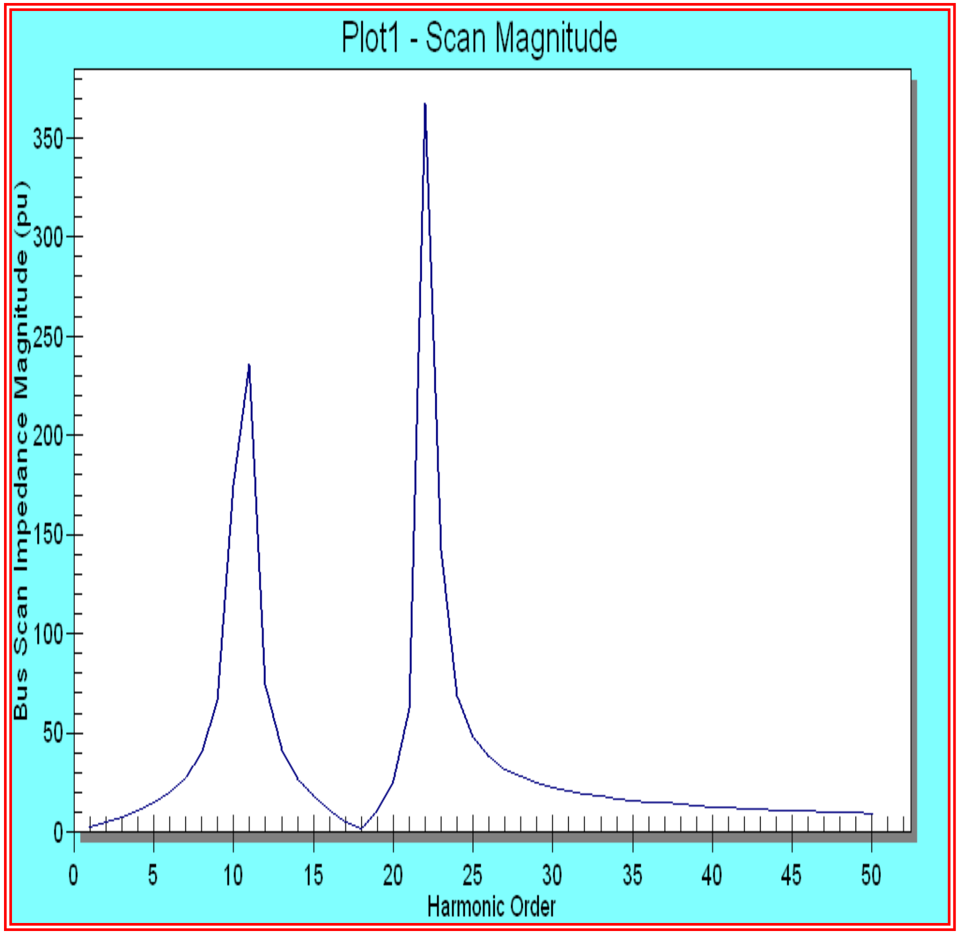
Harmonic Mitigation Case Study

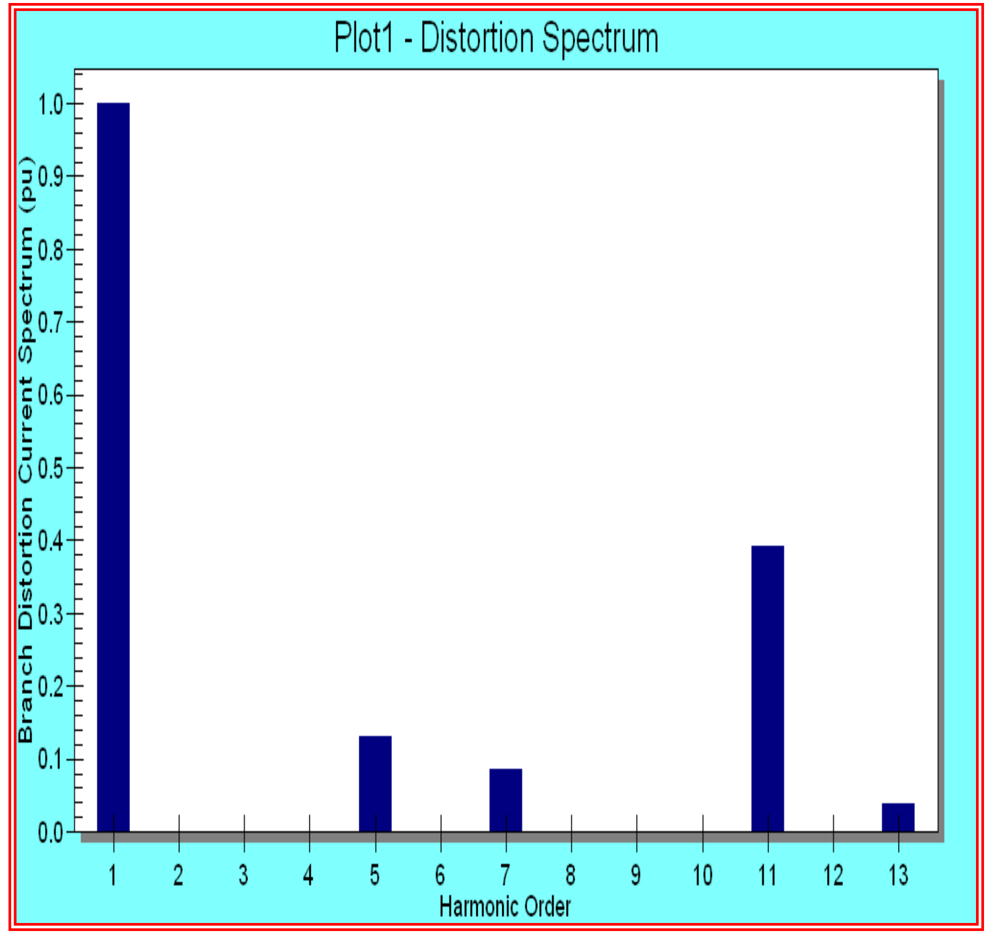
- Background
  - Induction heaters: 300 kW, 500kW, 800kW
  - SCR control
  - Limited supply
  - 1MVAR Capacitor @11kV
- Issues
  - High THD_v% & THD_i%
  - Voltage Notching
  - Low PF
  - Limited supply
  - Resonance @11kV

Harmonic Mitigation Case Study



Harmonic Mitigation Case Study



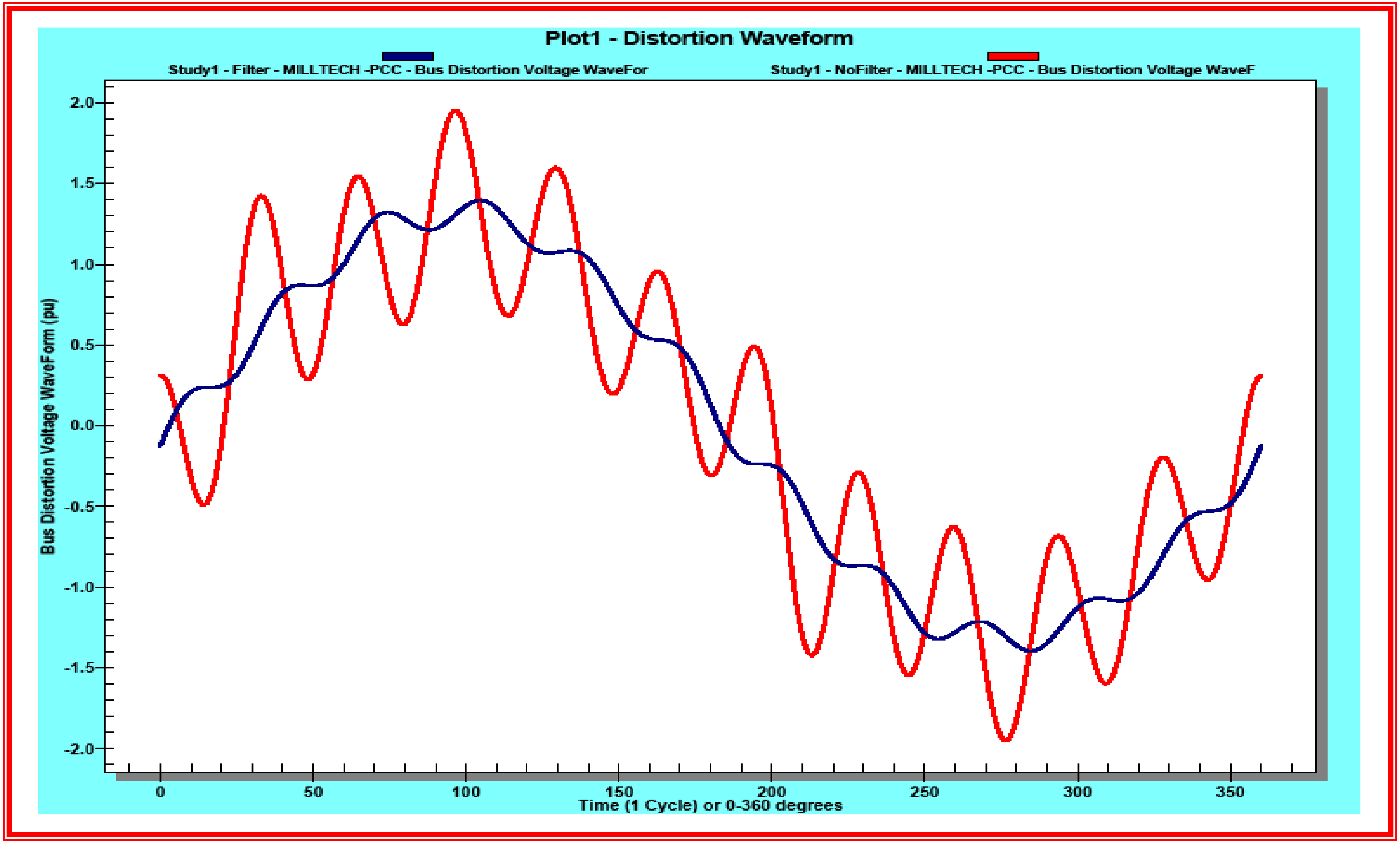


Harmonic Mitigation Case Study

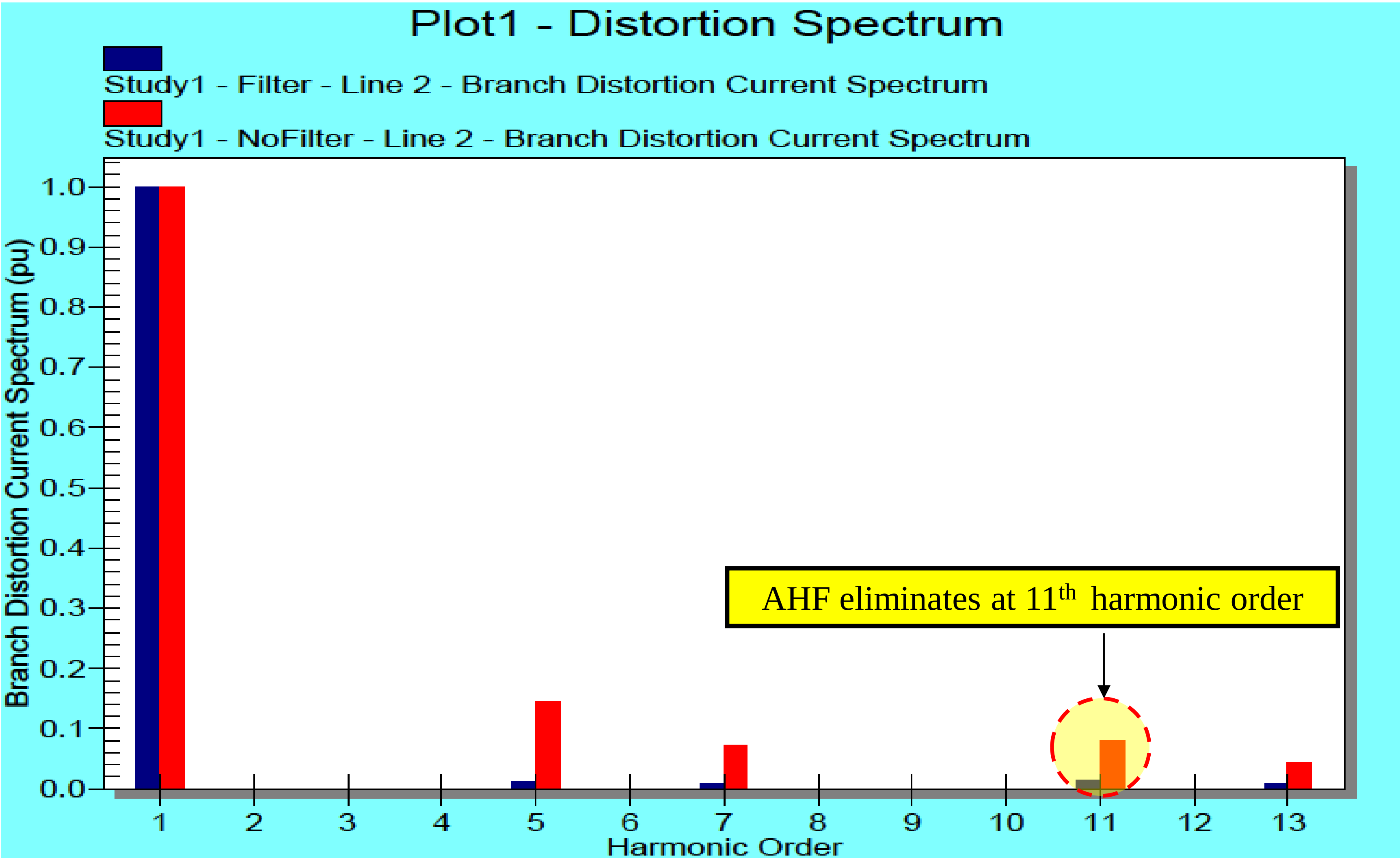
- Solution
  - Line reactors (3-5)%
  - Active Harmonic Filter “900A”

- Result
  - THD_v %< 8%
  - THD_i%<7%
  - Voltage Notching: eliminated
  - PF =0.98 Lagging
  - Resonance @11kV: eliminated

Harmonic Mitigation Case Study



Harmonic Mitigation Case Study



Questions?

Thank you!