Understanding Harmonics

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Rockwell Automation

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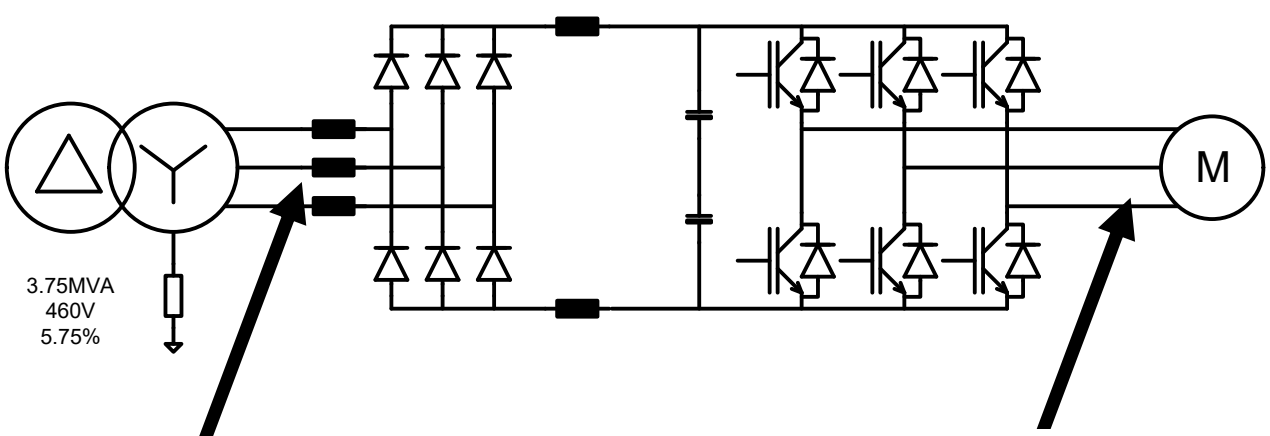
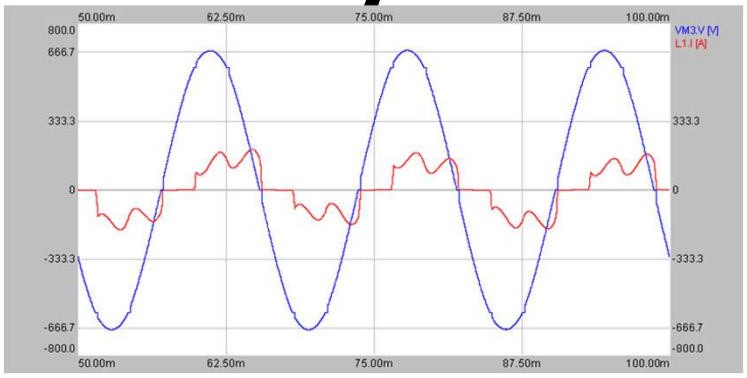
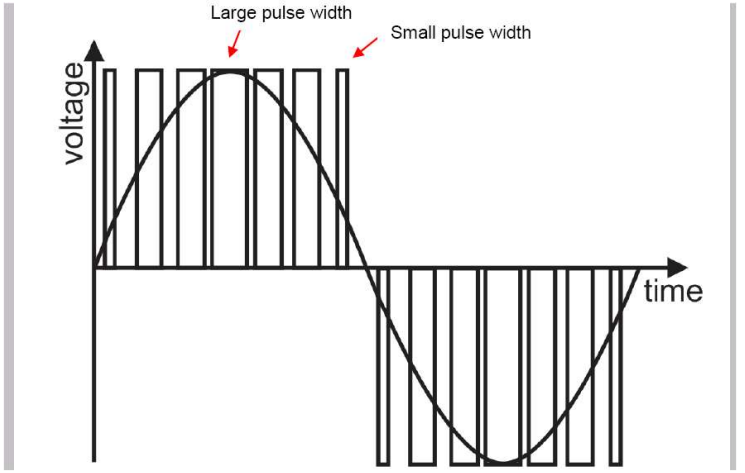
PUBLIC

What a VFD input/output voltage and current looks like

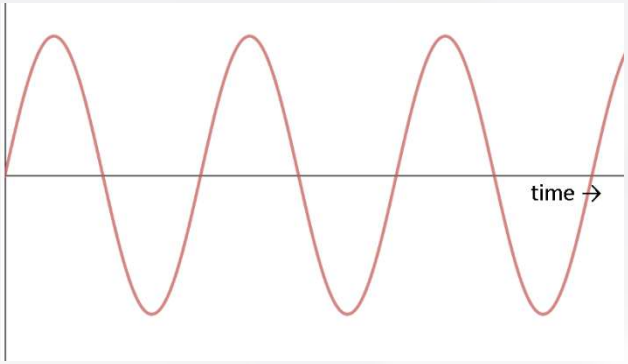




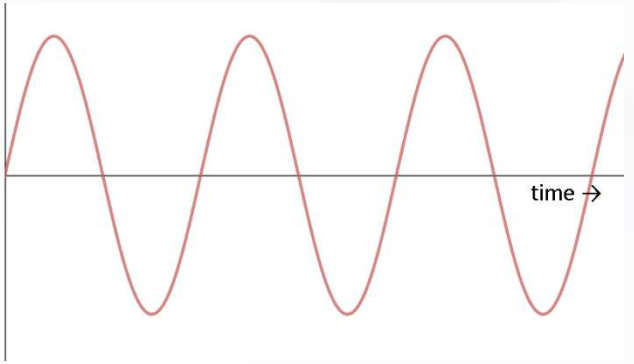


Linear Voltage and Current

Voltage



Current



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Examples of Linear Loads

- Induction motors
- Incandescent lights
- Resistance heaters
- Power Factor Correction Caps
- Electromagnetic devices
  - Transformers
    - non-linear
      - During energization
      - Over-voltage

4

Examples of Non-Linear Loads

Single Phase

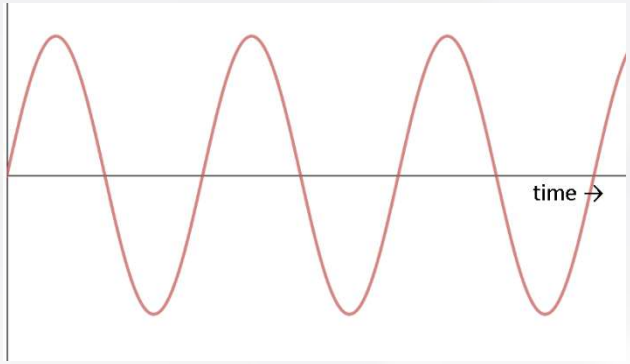
- Fluorescent lights (ballast)
- Incandescent lights with light dimmers
- Anything with an ac-dc power supply
  - Computers (ac-dc PS)
  - Monitors (ac-dc PS)
  - TVs (ac-dc PS)
  - Fax machines (ac-dc PS)

Three Phase

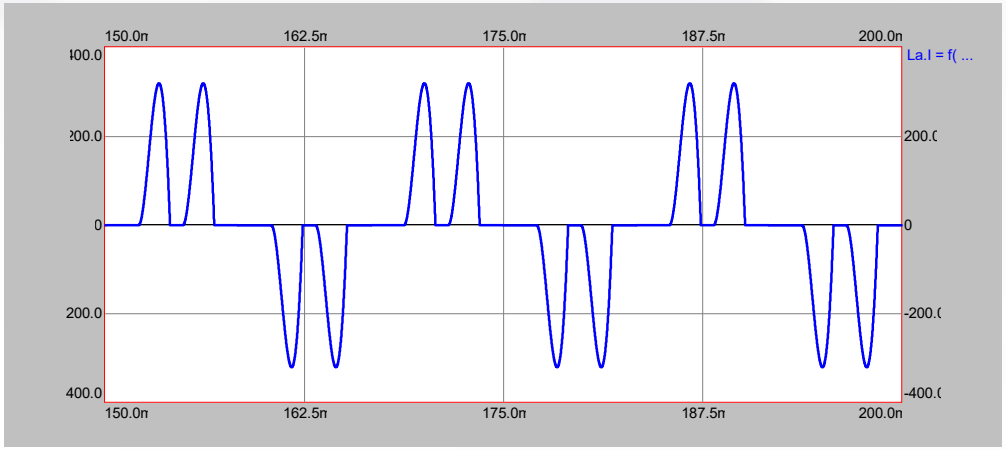
- Welders
- Arc furnaces
- UPS
- DC power supplies
- DC Drives
  - Phase control
  - PWM
- **AC Drives**
  - **6-Step**

Non-Linear Voltage and Current

Voltage

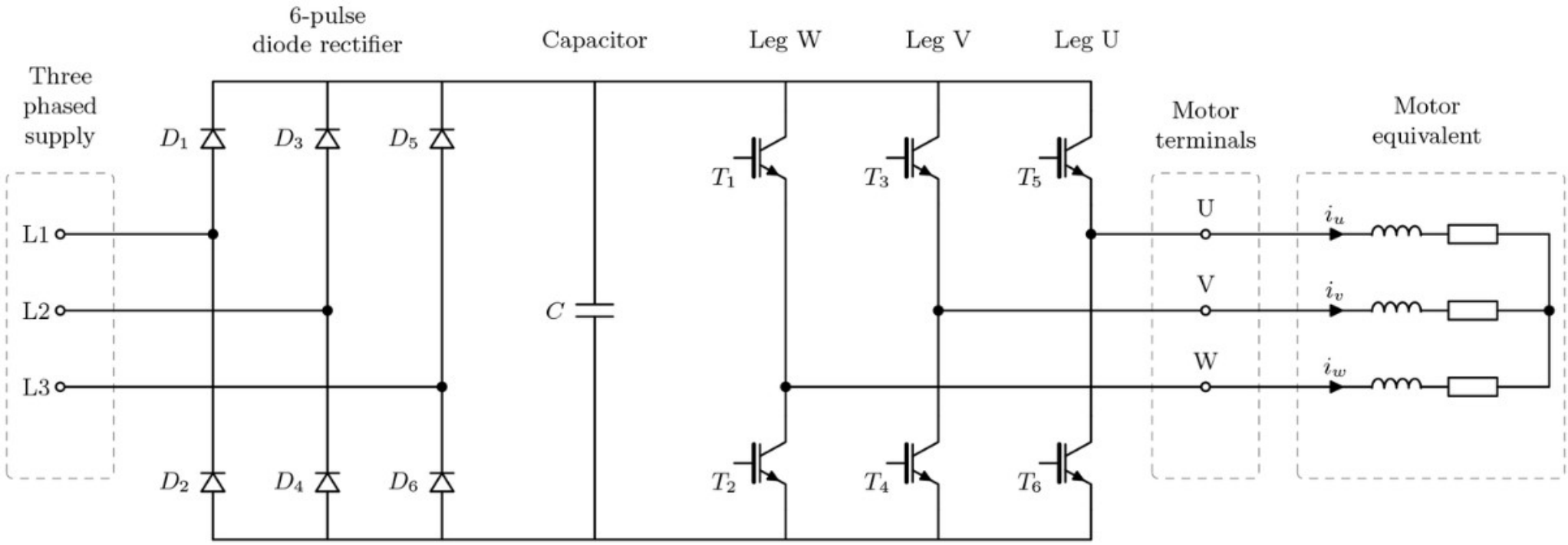


Current

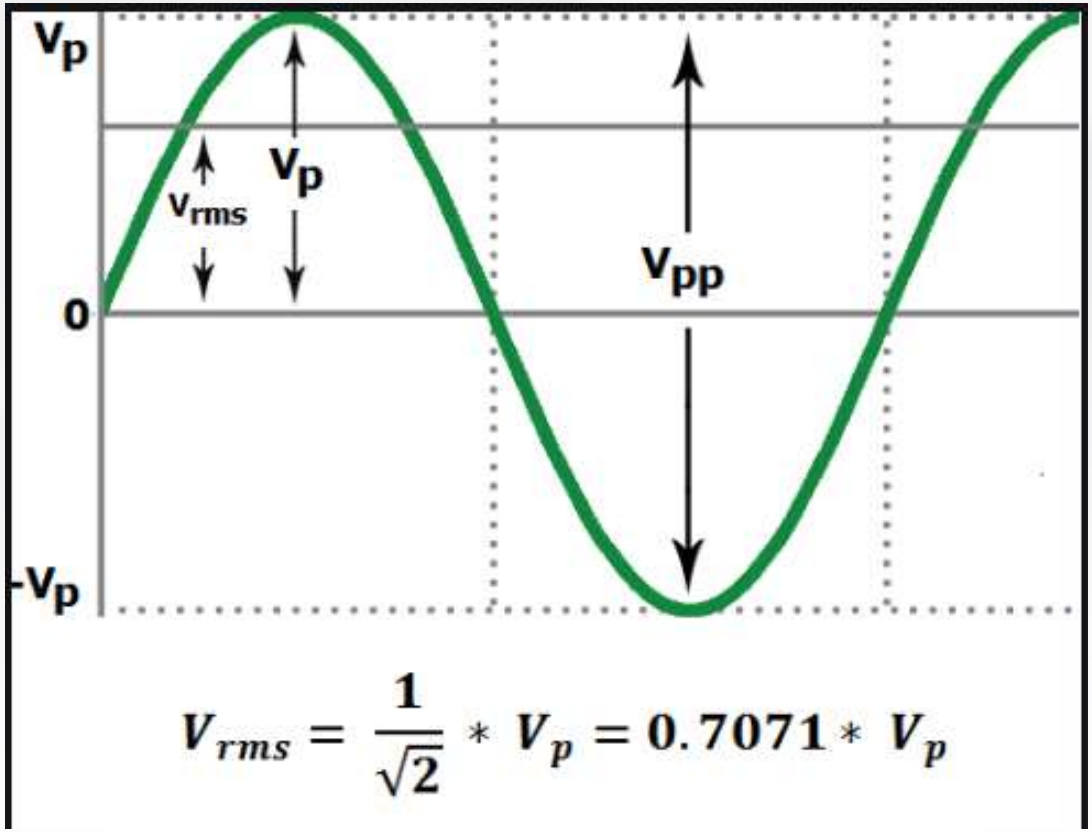


Power Structure of the Component Class Drive

(Most Powerflex 4 and 5 class)

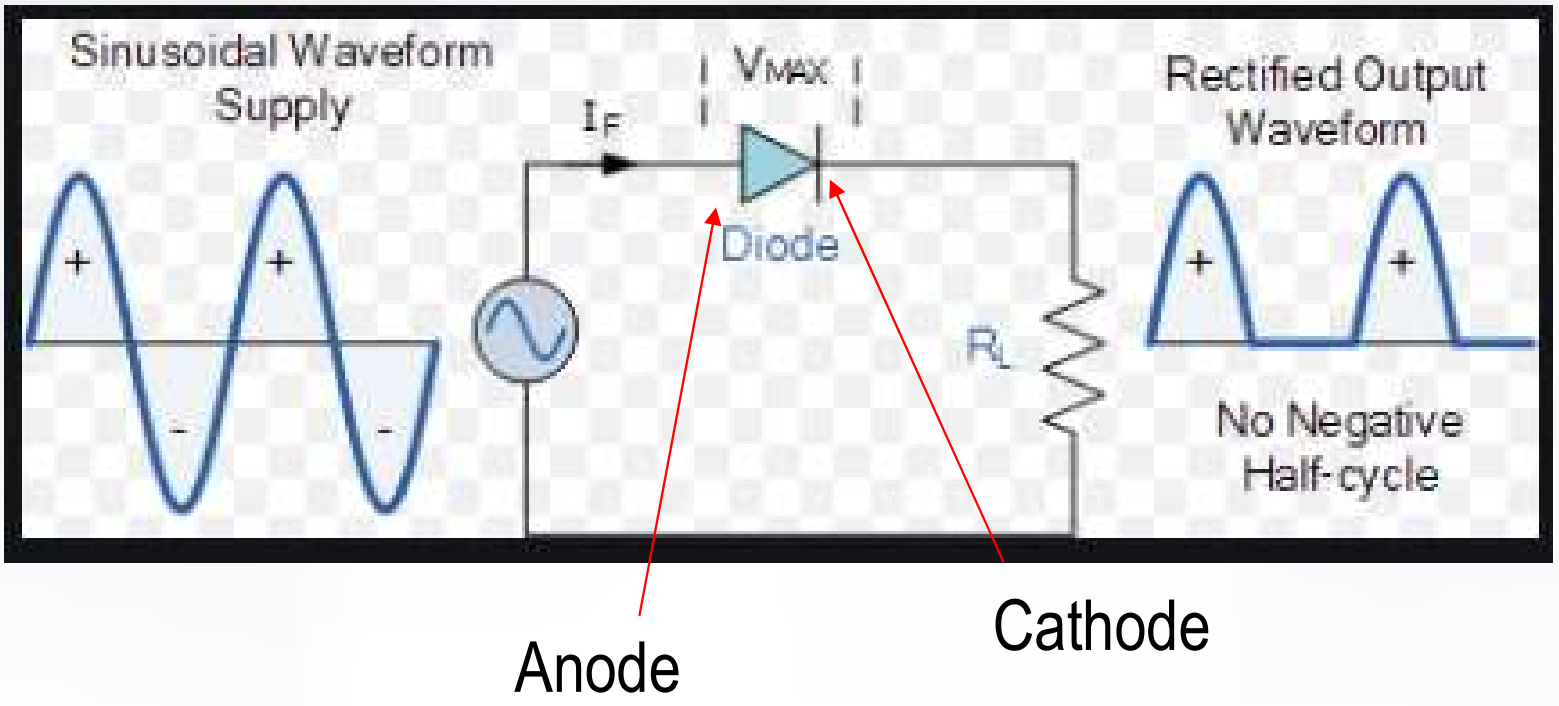


Voltage Applied

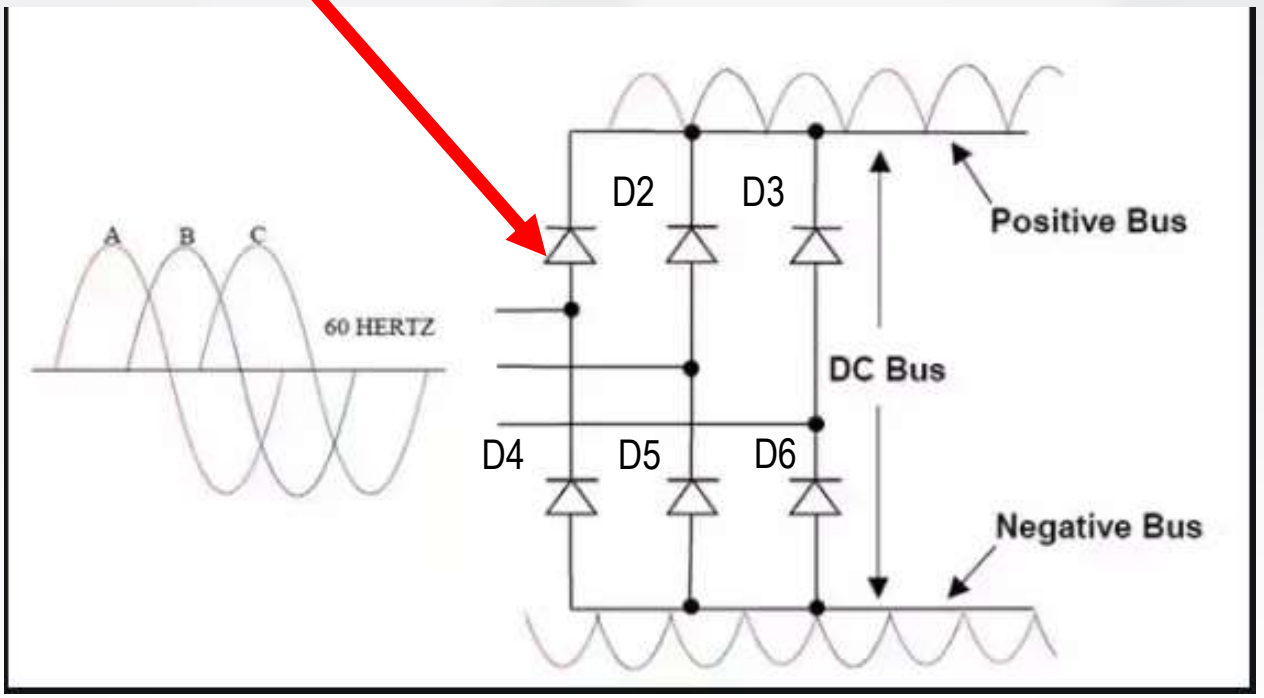


$$V_{rms} = \frac{1}{\sqrt{2}} * V_p = 0.7071 * V_p$$

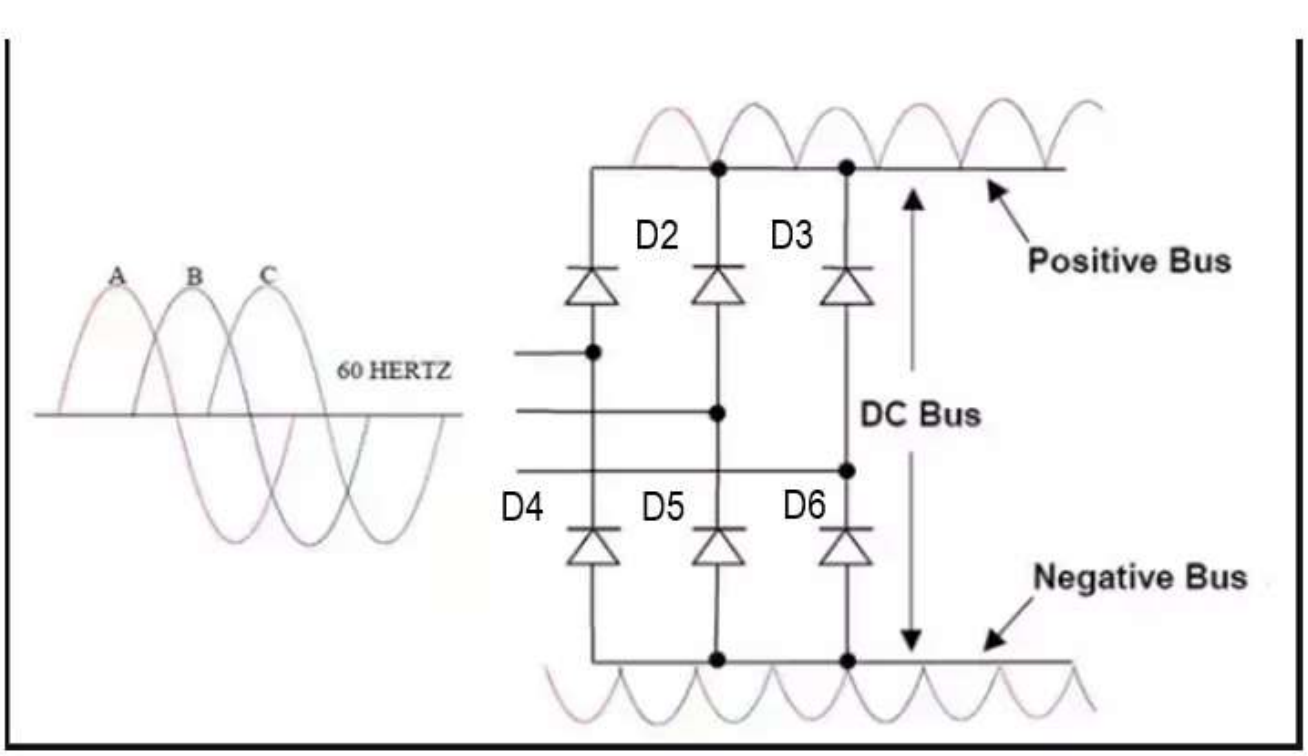
When does a diode conduct?

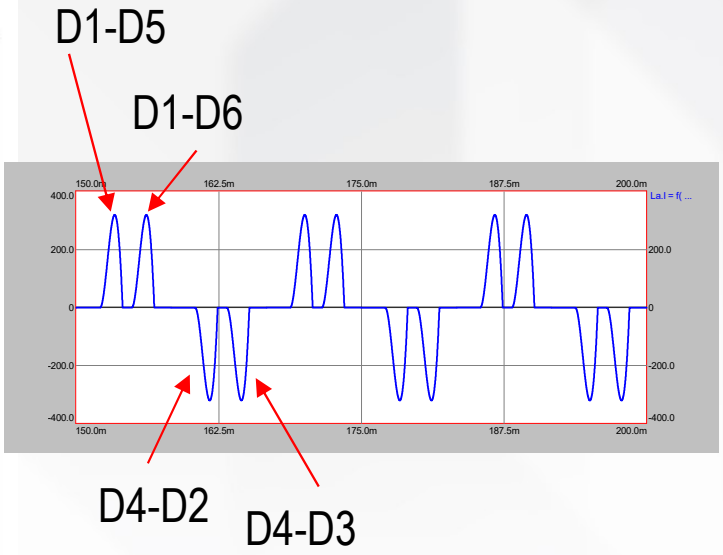


When does D1 Conduct?

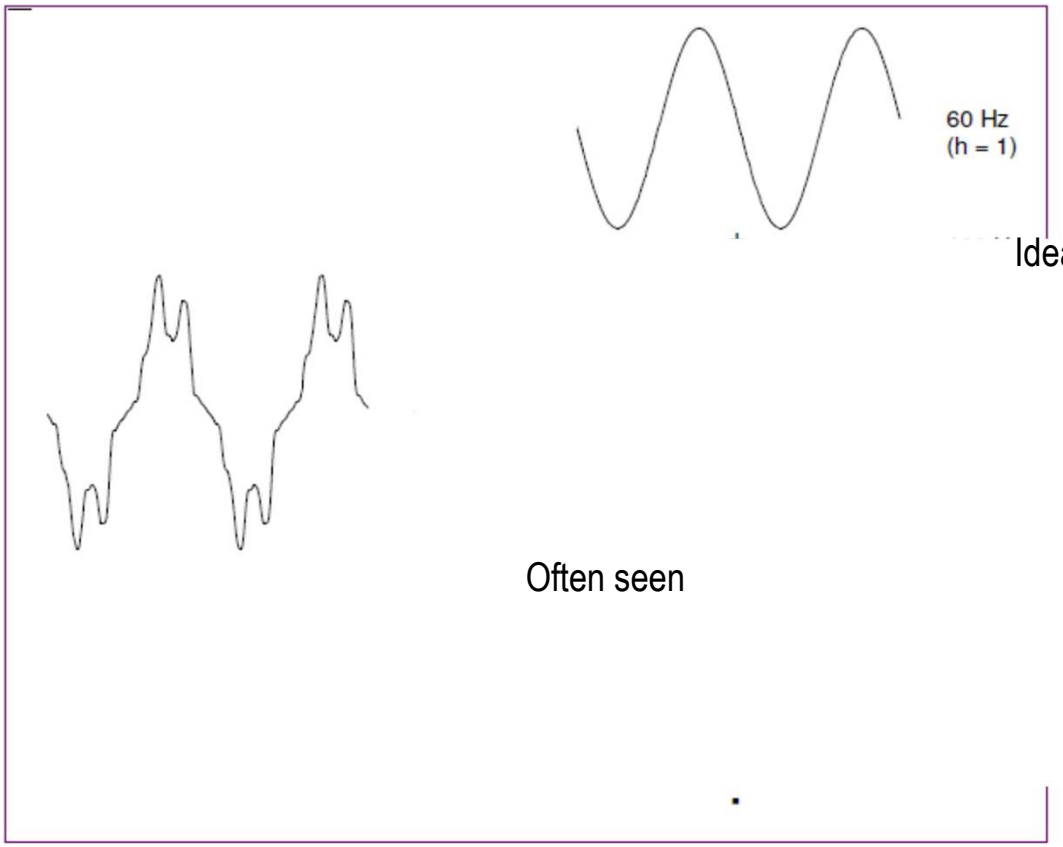


When does D1 Conduct?





What Are Harmonics?



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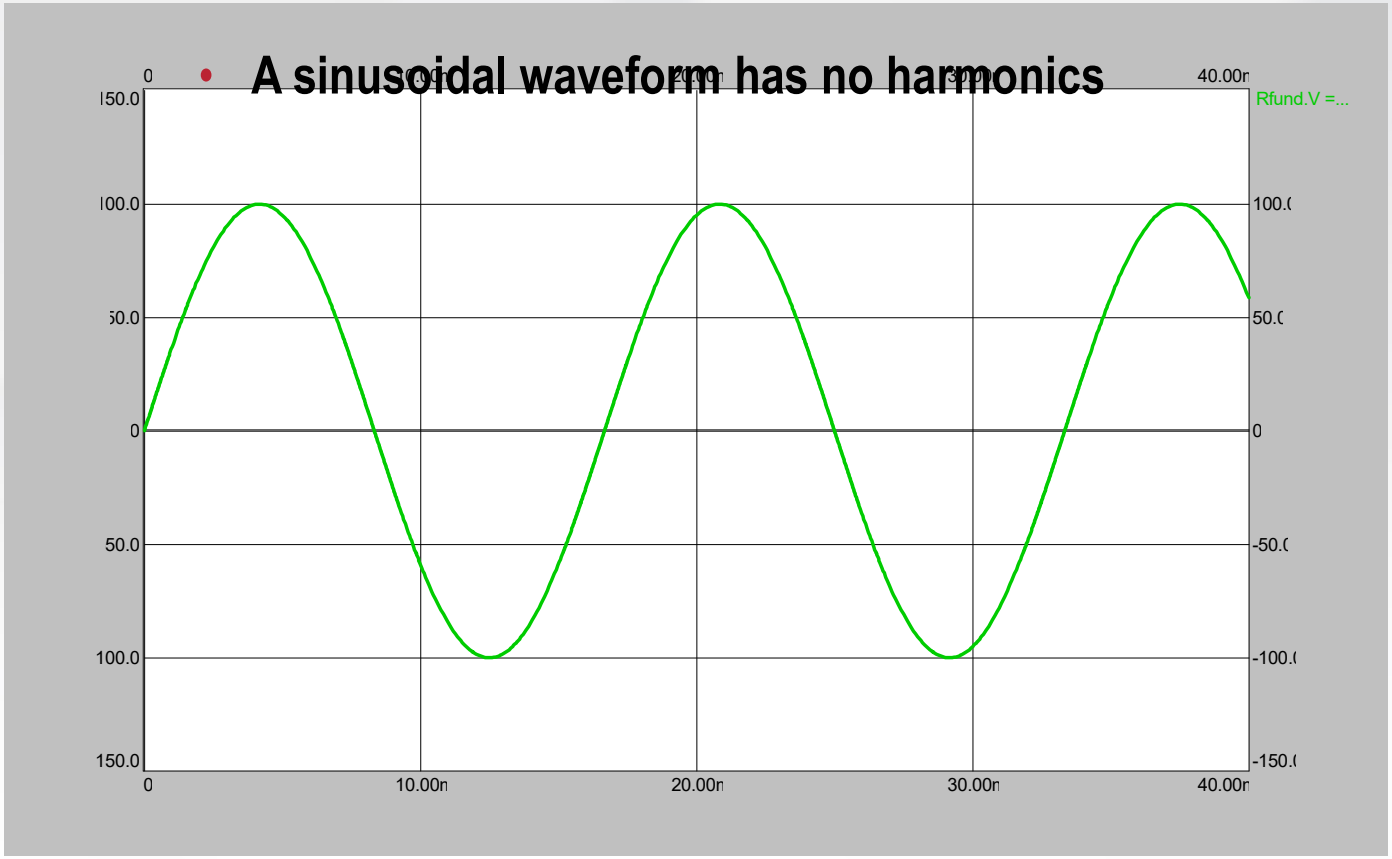
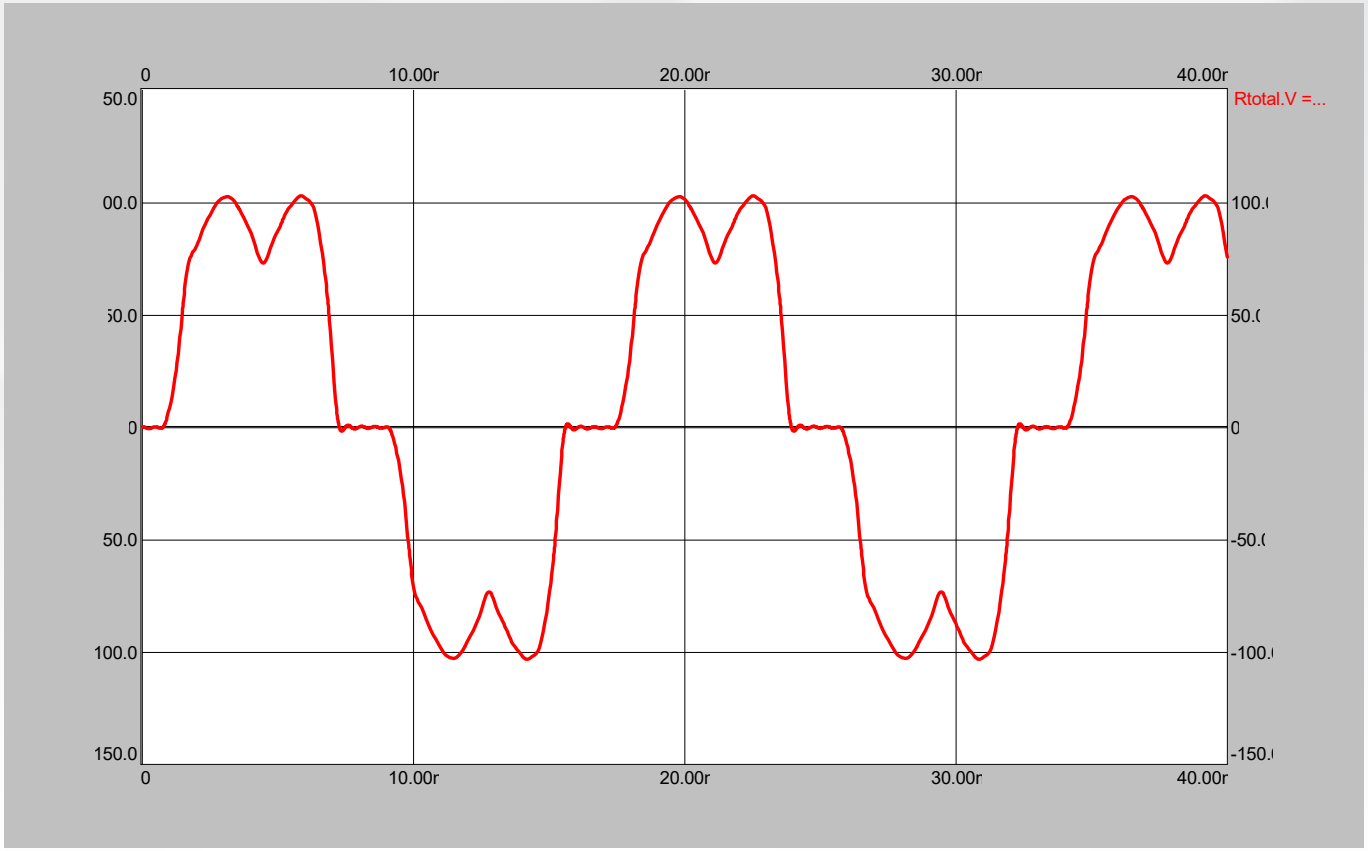
What are Harmonics? What are waveforms?



What are Harmonics and Waveforms

- This non-sinusoidal waveform contains harmonics



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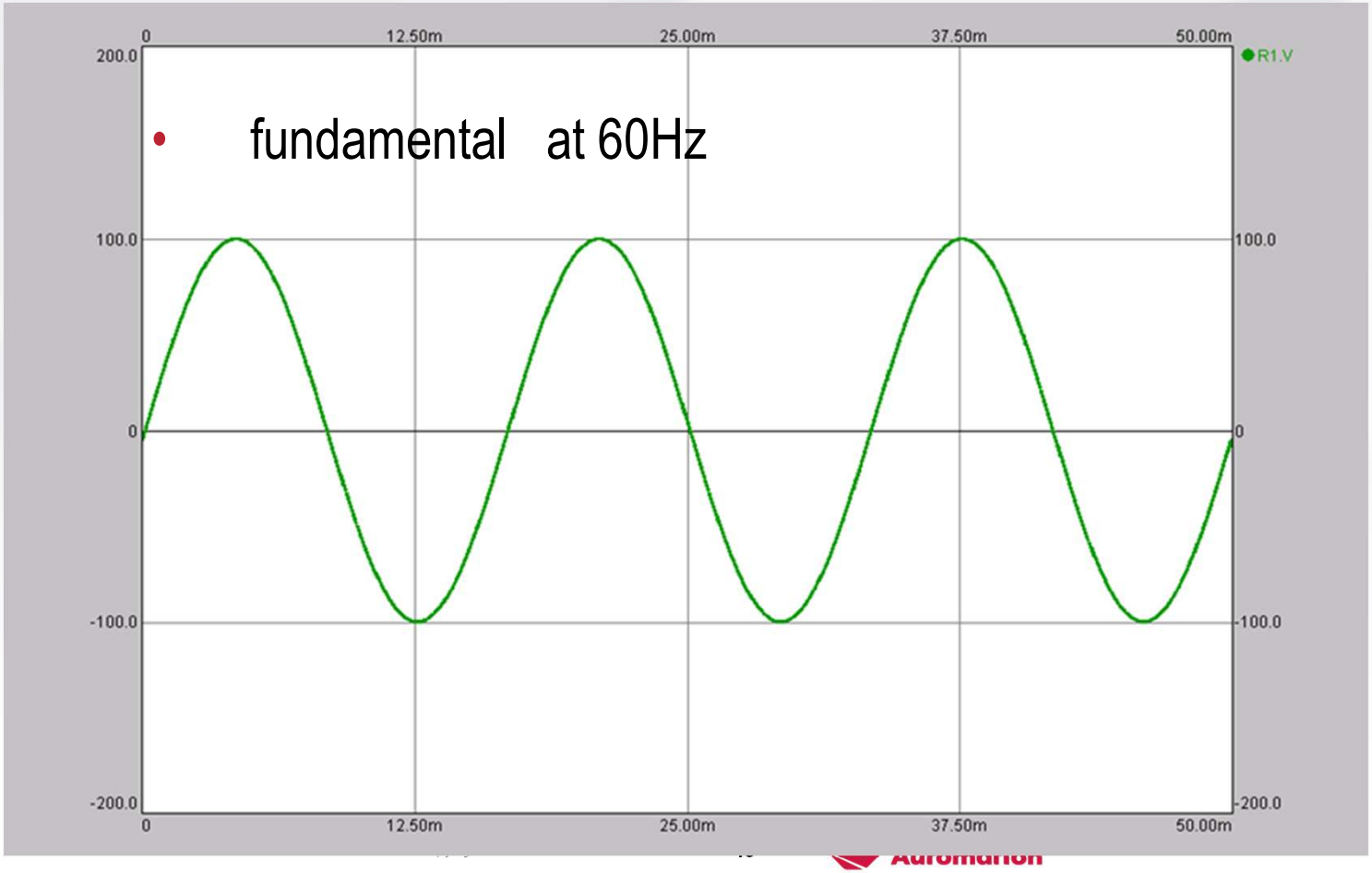
Let’s create a distorted waveform

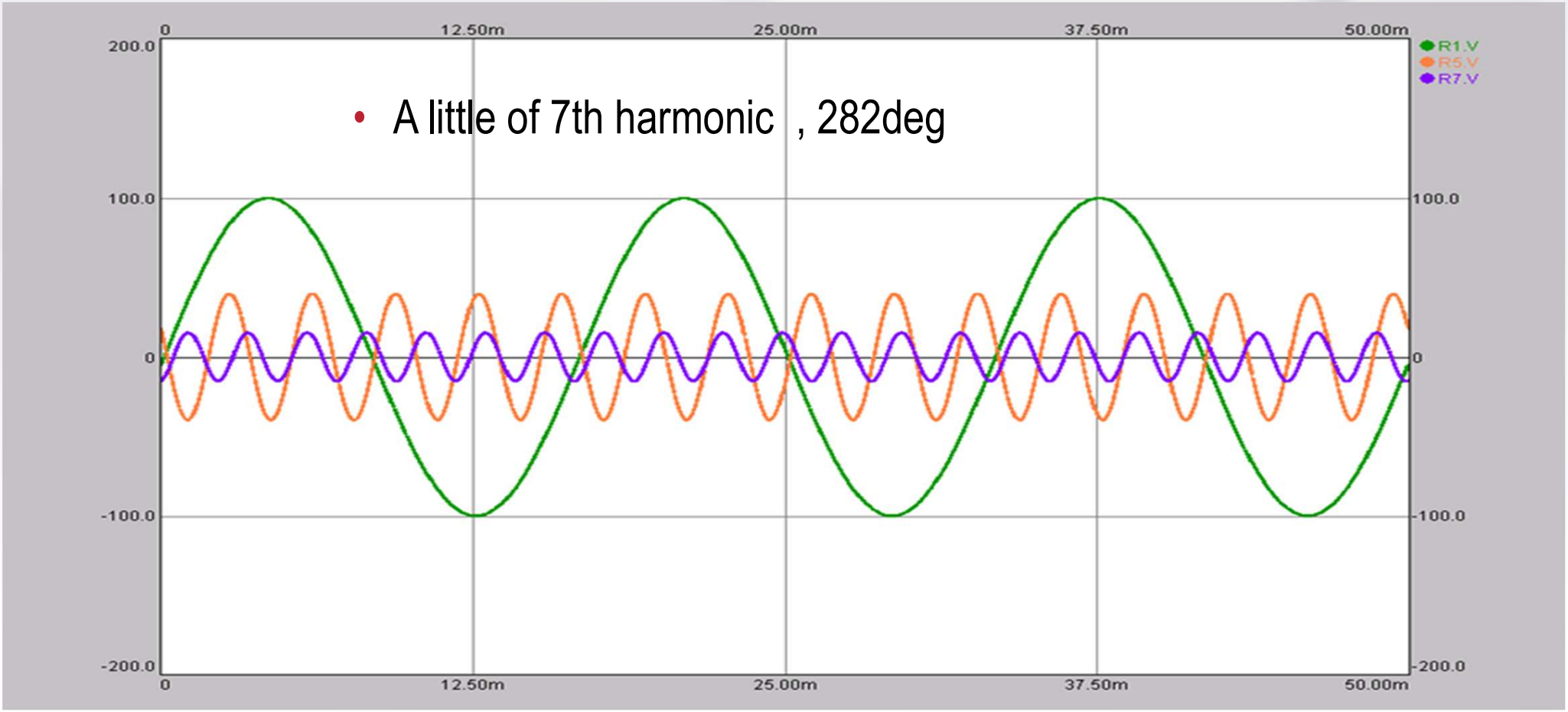
Fundamental (1st harmonic) Only



Fundamental and 5th Harmonic

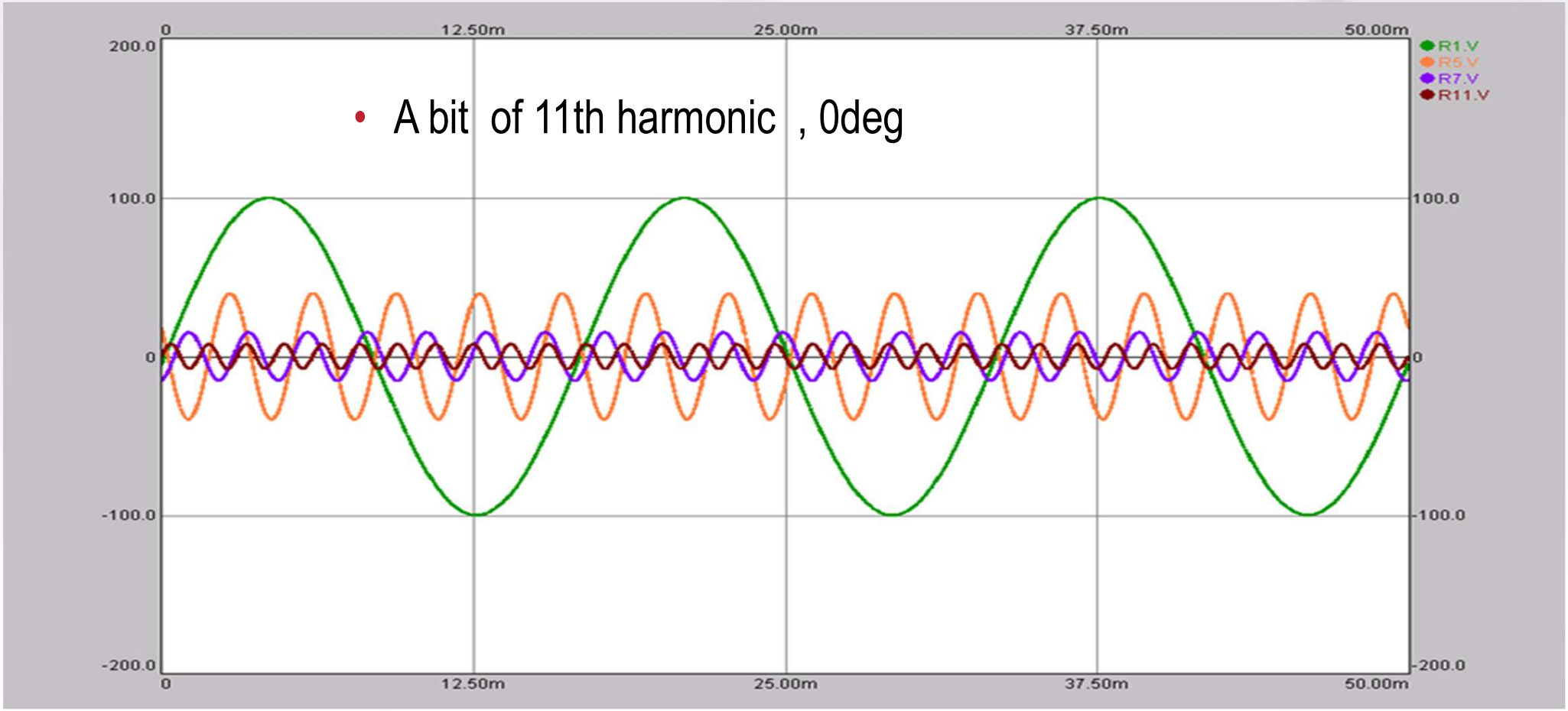
- Some 5th harmonic , 153deg

1st, 5th and 7th Harmonics

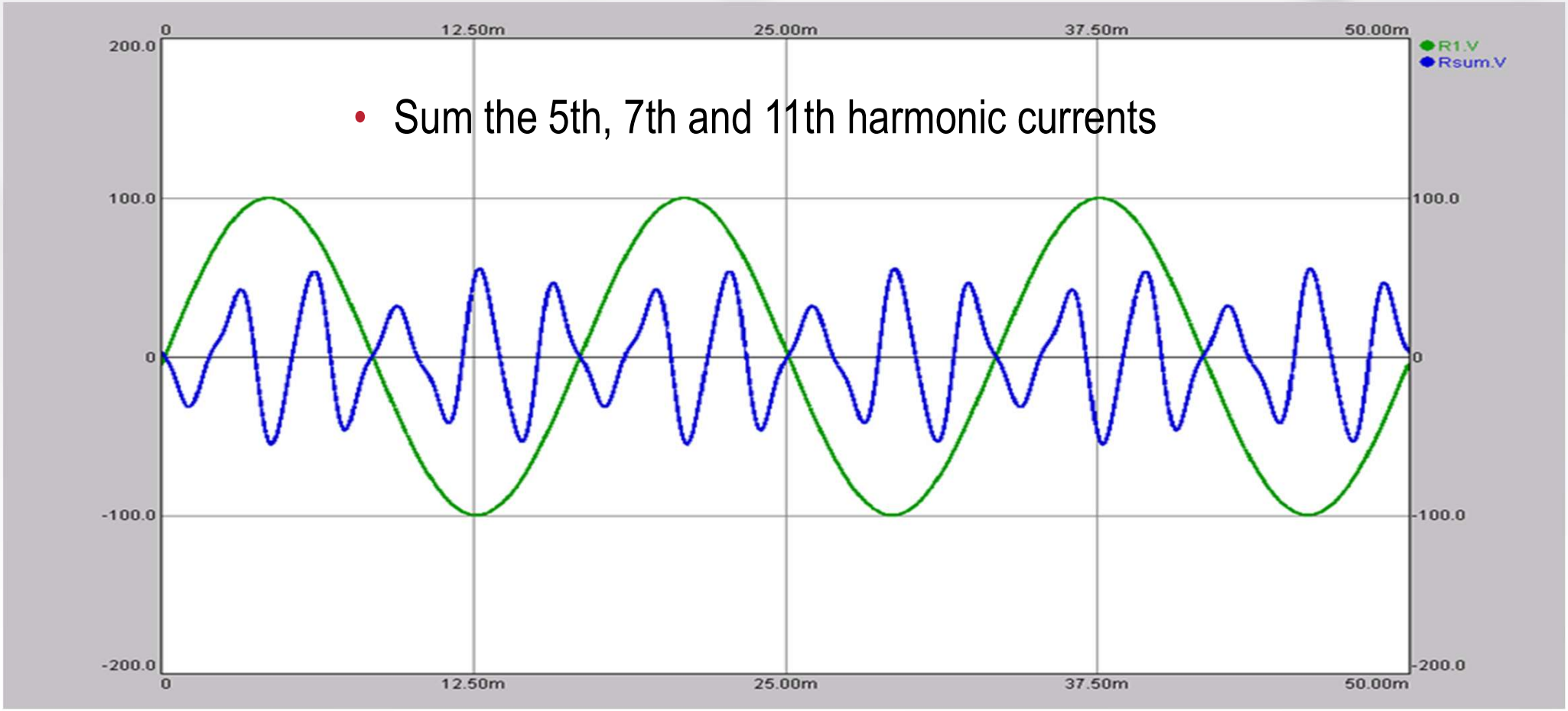


- A little of 7th harmonic , 282deg

1st, 5th, 7th and 11th Harmonics



1st and Sum of the 5th, 7th and 11th

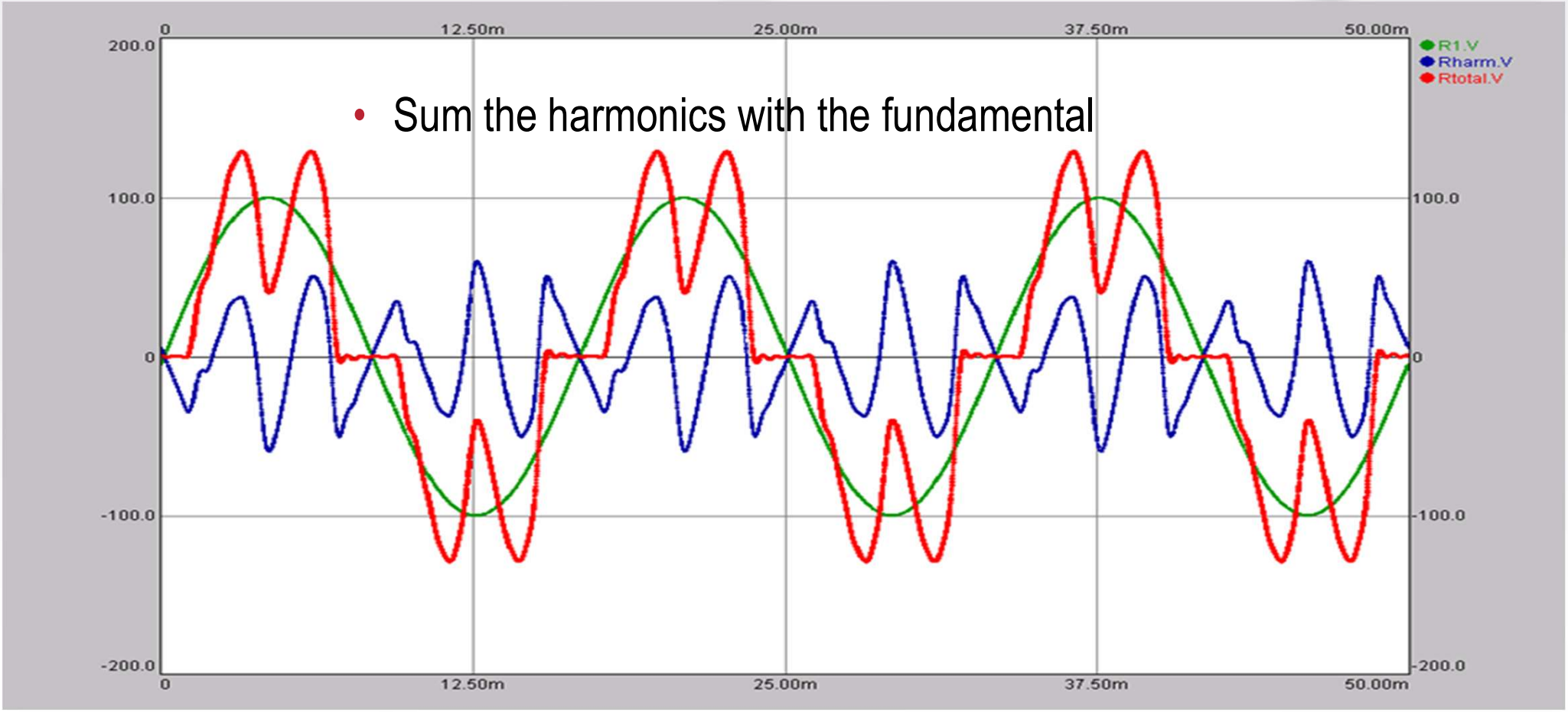


- Sum the 5th, 7th and 11th harmonic currents

Why are you talking about the 5th, 7th and 11th harmonic? Seems arbitrary.

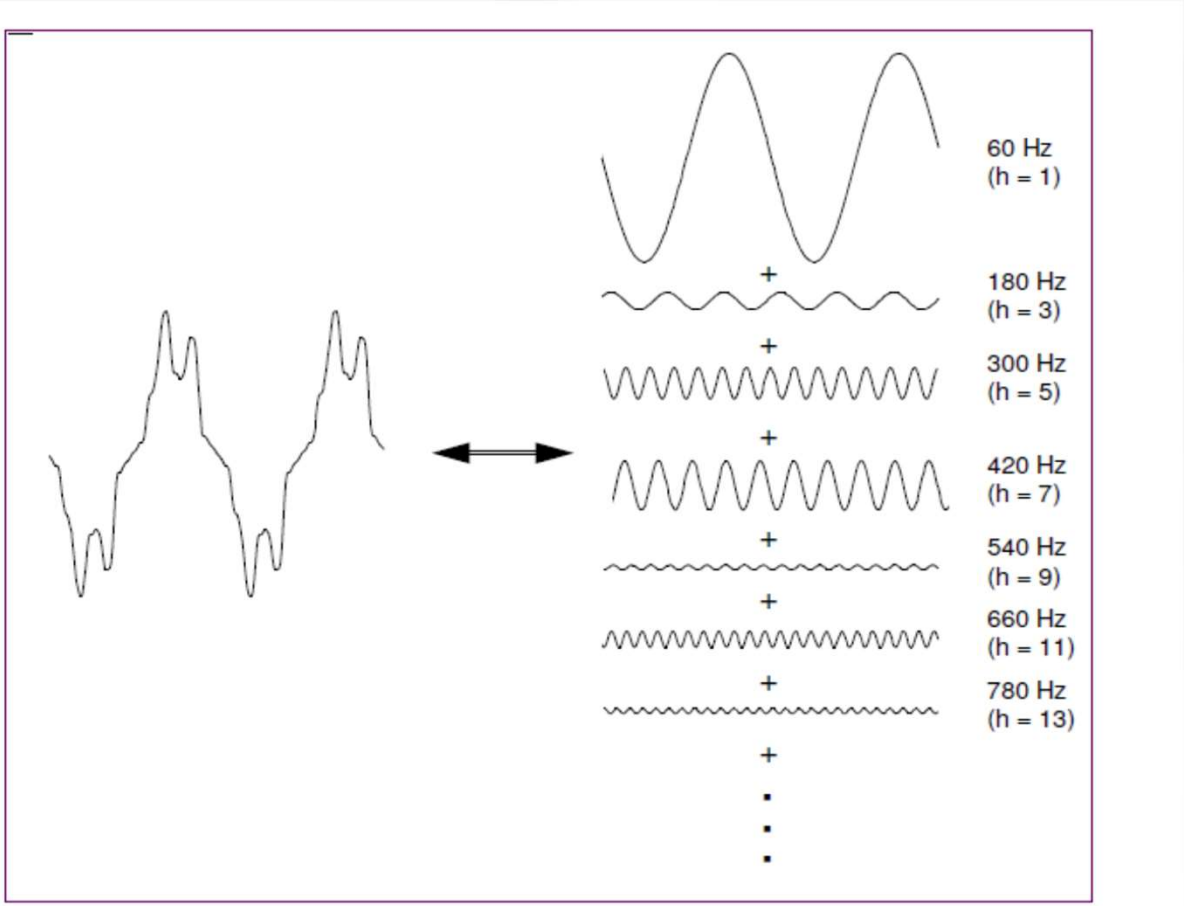
- Rules for which Harmonics matter:
  - Only odd harmonics (even harmonics cancel out
  - Harmonics that are not divisible 3. Meaning no 3rd, 6th, 9th etc.
  - P*n+/-1 Where P is the number of pulse of the bridge
    n is a whole number and constant

Fundamental, Harmonics, Total

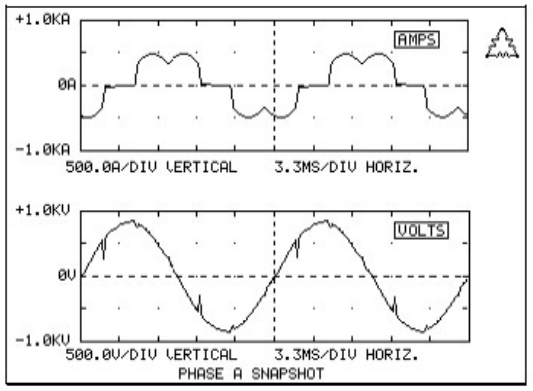


- Sum the harmonics with the fundamental

What Are Harmonics?

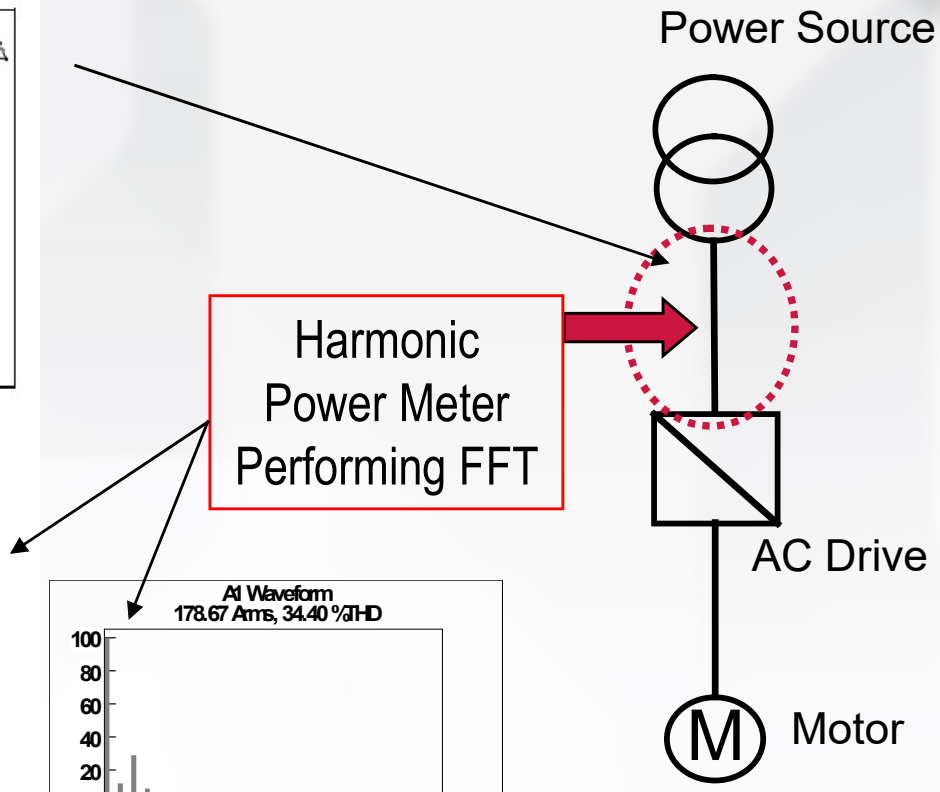


FFT (Fast Fourier Transform) and how are Harmonics measured?



PHASE A CURRENT SPECTRUM 2:51:53 PM
Fundamental amps: 346.2 A rms
Fundamental freq: 60.0 Hz

HARM	PCT	SINE PHASE	HARM	PCT	SINE PHASE
FUND	100.0%	-43°	2nd	0.3%	68°
3rd	0.4%	-126°	4th	0.2%	30°
5th	25.3%	-30°	6th	0.1%	61°
7th	5.5%	-122°	8th	0.2%	10°
9th	0.6%	37°	10th	0.2%	-45°
11th	8.2%	-102°	12th	0.1%	-37°
13th	3.9%	170°	14th	0.2%	-65°
15th	0.3%	-40°	16th	0.2%	-119°
17th	5.0%	-179°	18th	0.1%	-126°
19th	2.9%	93°	20th	0.2%	-136°
21st	0.3%	-44°	22nd	0.2%	167°
23rd	3.4%	109°	24th	0.1%	162°
25th	2.1%	14°	26th	0.2%	150°
27th	0.2%	-144°	28th	0.2%	100°
29th	2.7%	39°	30th	0.1%	86°
31st	1.9%	-59°	32nd	0.2%	74°
33rd	0.2%	99°	34th	0.2%	29°
35th	2.1%	-35°	36th	0.1%	6°
37th	1.7%	-135°	38th	0.2%	3°
39th	0.3%	41°	40th	0.2%	-42°
41st	1.8%	-110°	42nd	0.2%	-72°
43rd	1.5%	150°	44th	0.2%	-70°
45th	0.5%	-30°	46th	0.3%	-113°
47th	1.7%	177°	48th	0.2%	-146°
49th	1.4%	70°	50th	0.2%	-142°
ODD	28.9%		EVEN	1.0%	
THD:	28.9%				



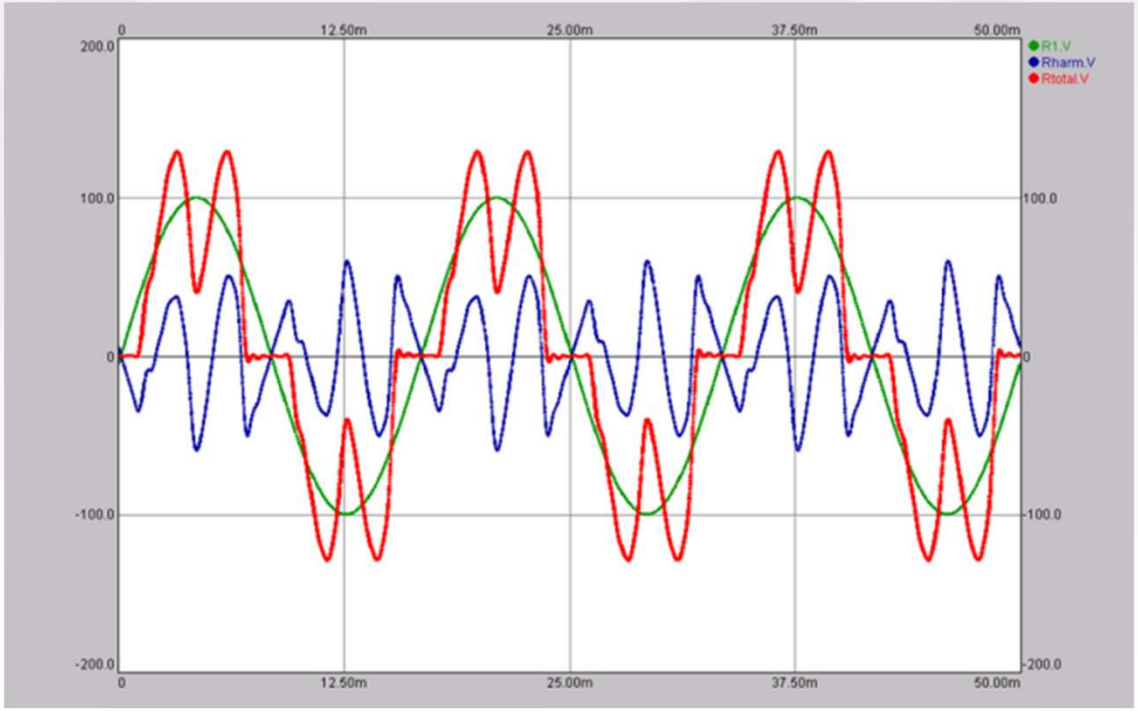
THD (Quantifying Harmonics)

Iharm = 30.83A

Ifund = 70.71A

Itotal = 77.14A

I(THD) = 43.6%
= Iharm / Ifund



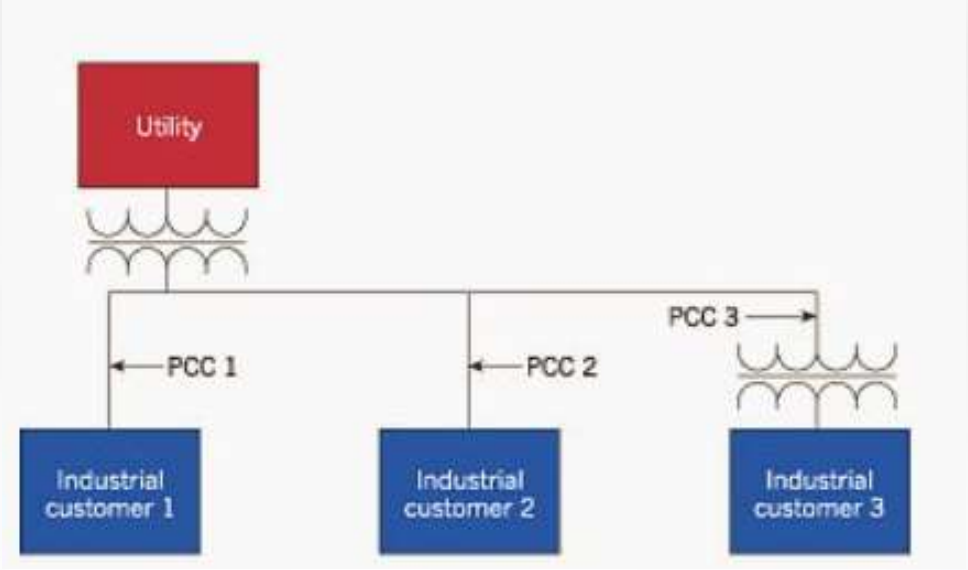
What Is I(THD)?

- I(THD) = Iharm / Ifund
- So, Iharm = I(THD) * Ifund
- I(THD) is a ratio between two numbers, it does not stand alone!

We can **decrease** I(THD)
by either **decreasing** Iharm or **increasing** Ifund

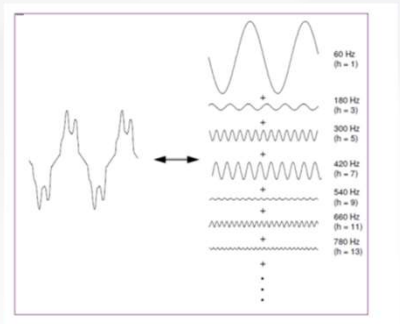
Where you measure Harmonics...

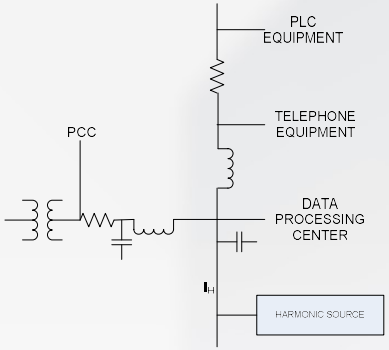
Point of Common Coupling (PCC)



What do Harmonics do anyway?
Why do we care?

Current Harmonics





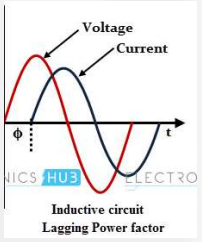
create

Voltage Distortion

Heat

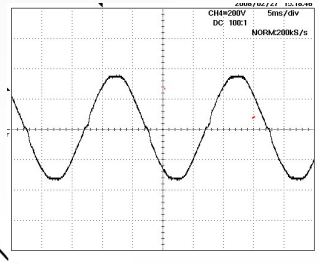
What other problems do they cause?

- Increased Utility current

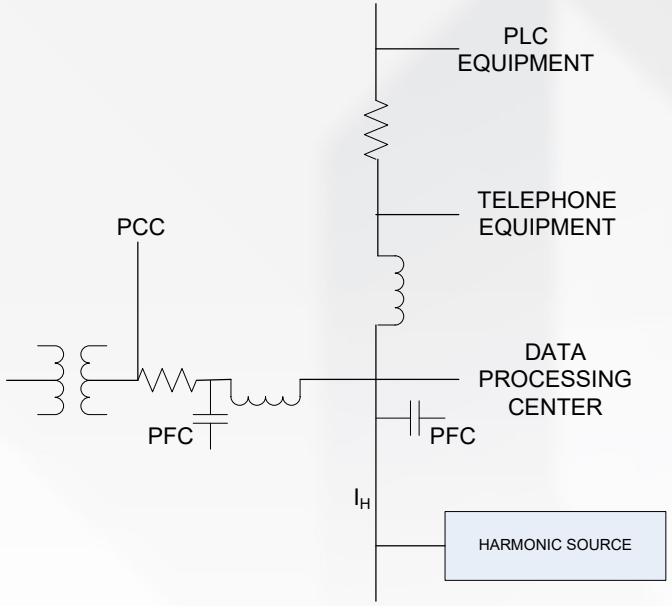


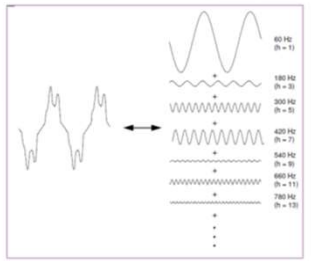
- Component overheating

- Equipment malfunction

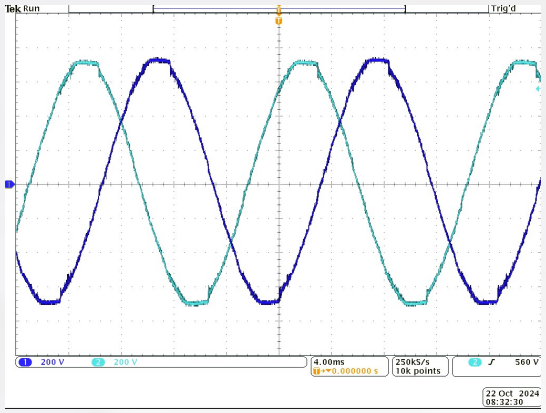


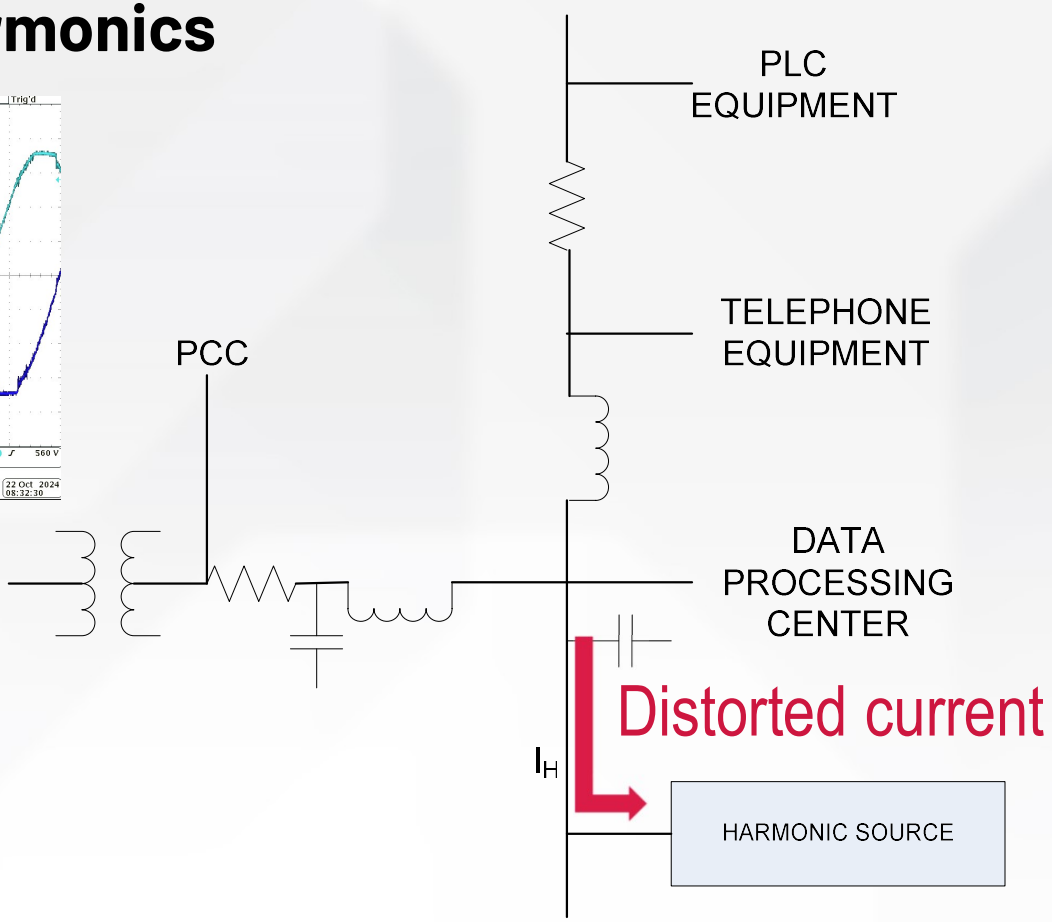
- Excitation of Power System Resonance's creating over-voltage's
  - **If PFCC in system**



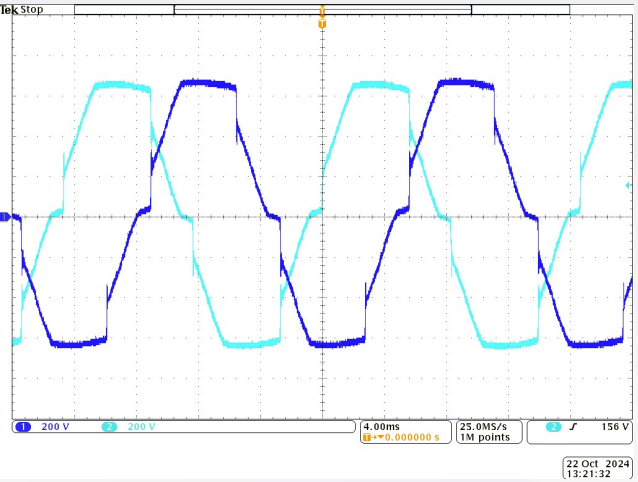


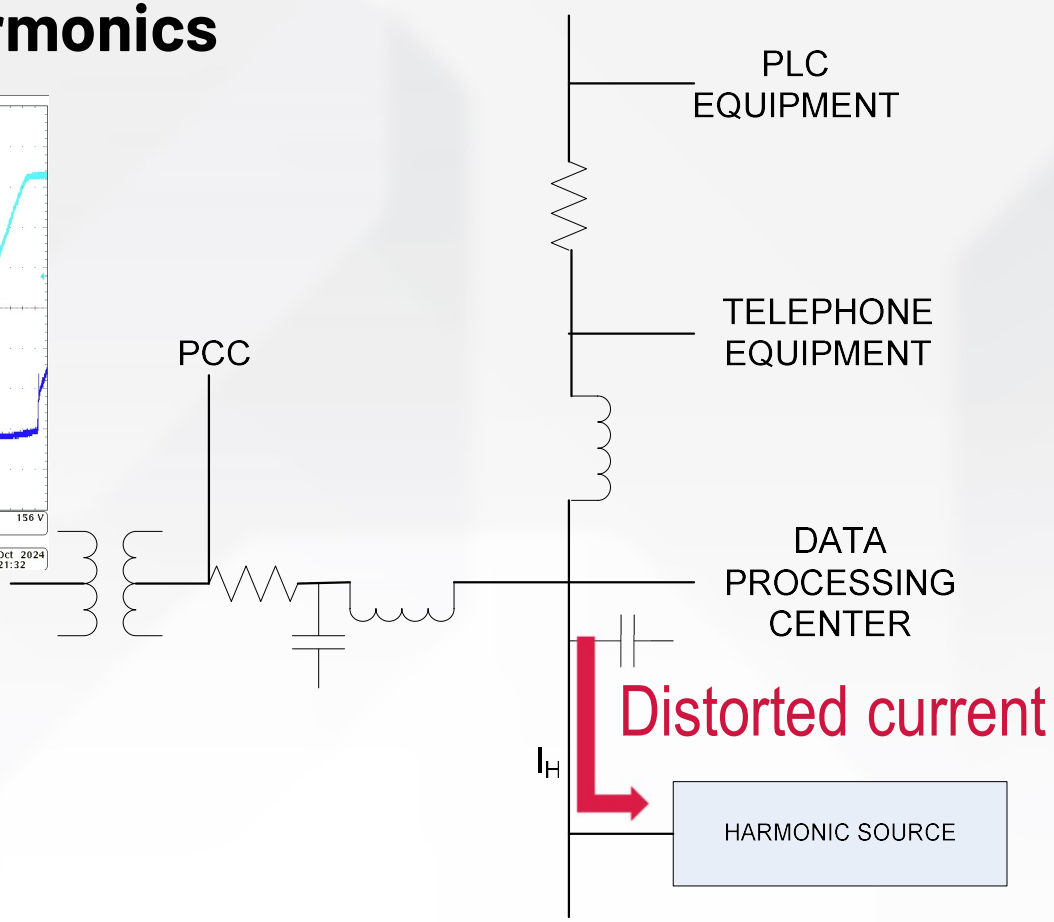
Main Point on Harmonics





Main Point on Harmonics

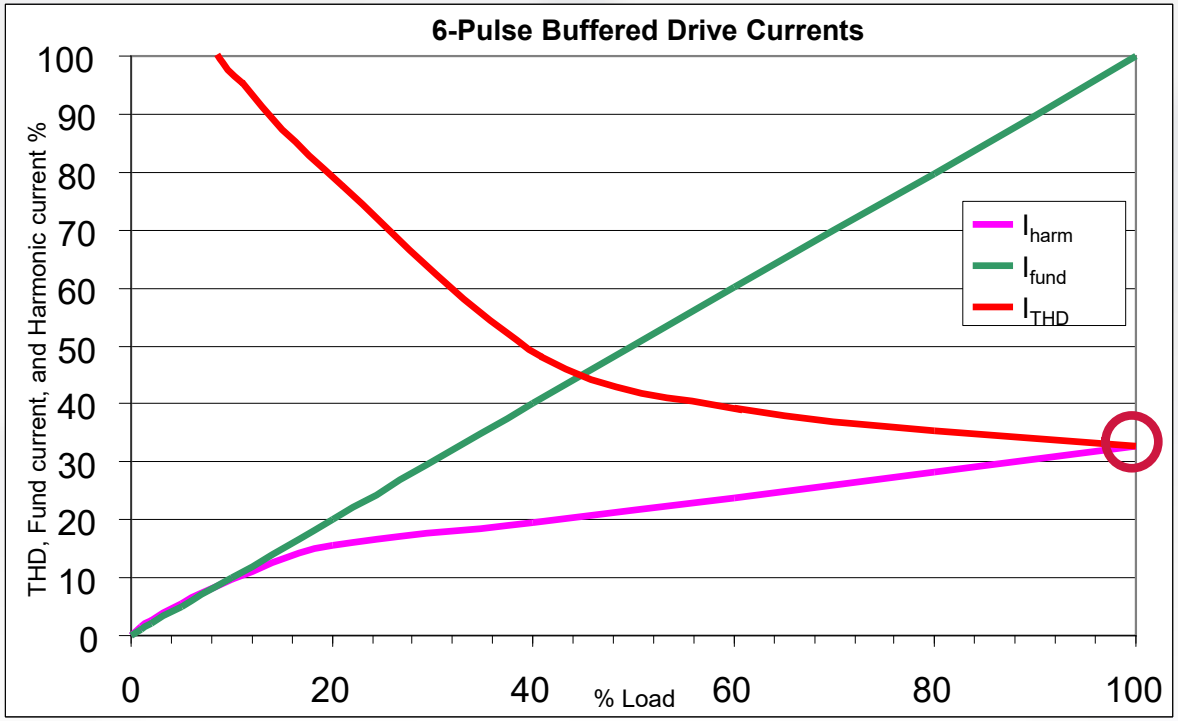




When should you be concerned about Harmonics?

- When Voltage Distortion exceeds 8%
- If service Transformer is Loaded near rating 60%
- 20 % of total Transformer rated current is Non-Linear electronic load
- When PF correction capacitors Used or Planned

How Does Motor Load Affect I_{THD}?



I_{TDD}

NOTES:

$I_{THD} = I_{harm} / I_{fund}$

I_{THD} **increases** as load decreases

I_{fund} **decreases** as load decreases

I_{harm} **decreases** as load decreases

(drive is at full speed)

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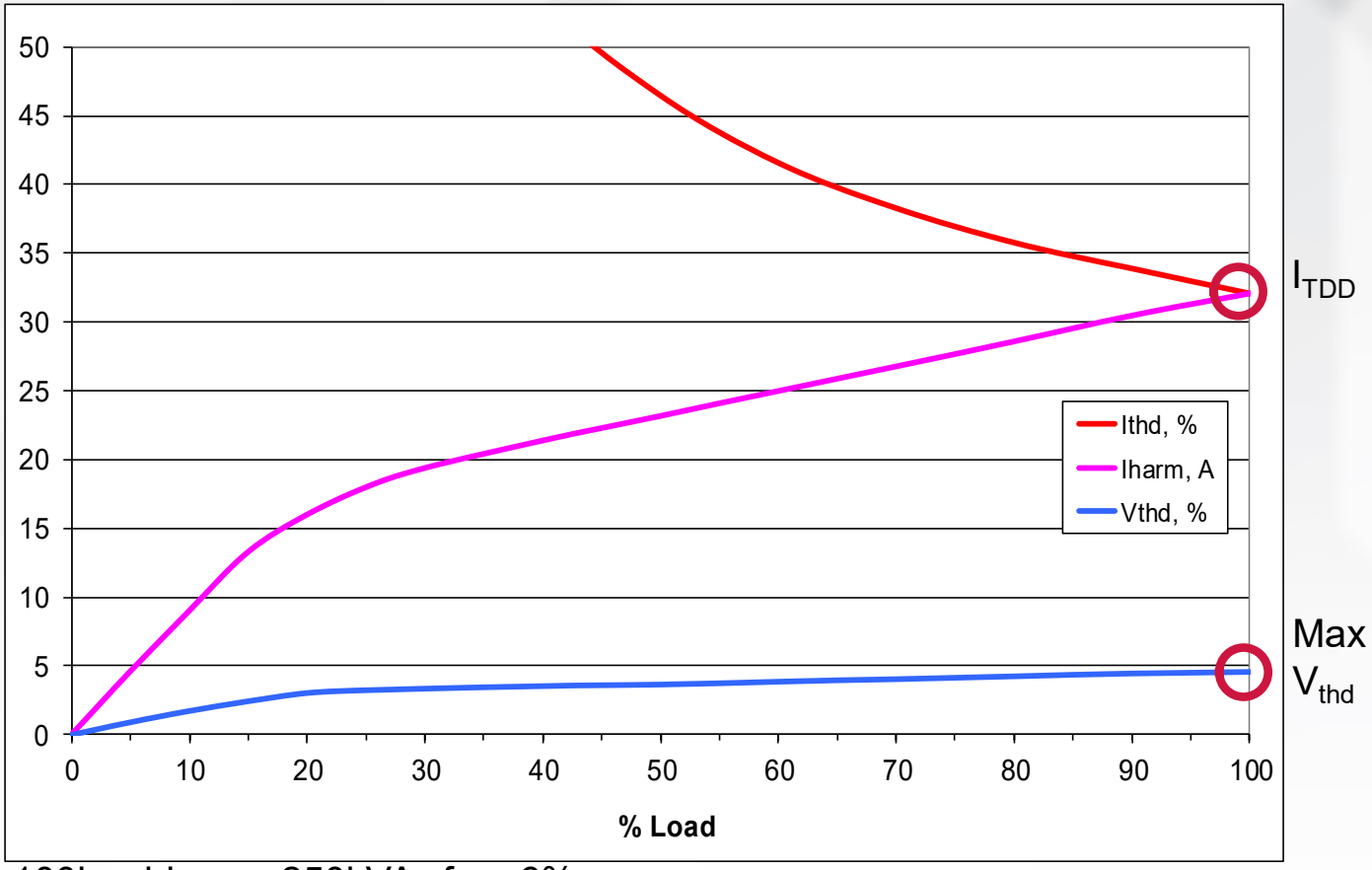
Vthd vs Load



100hp drive on 250kVA xfmr, 6%

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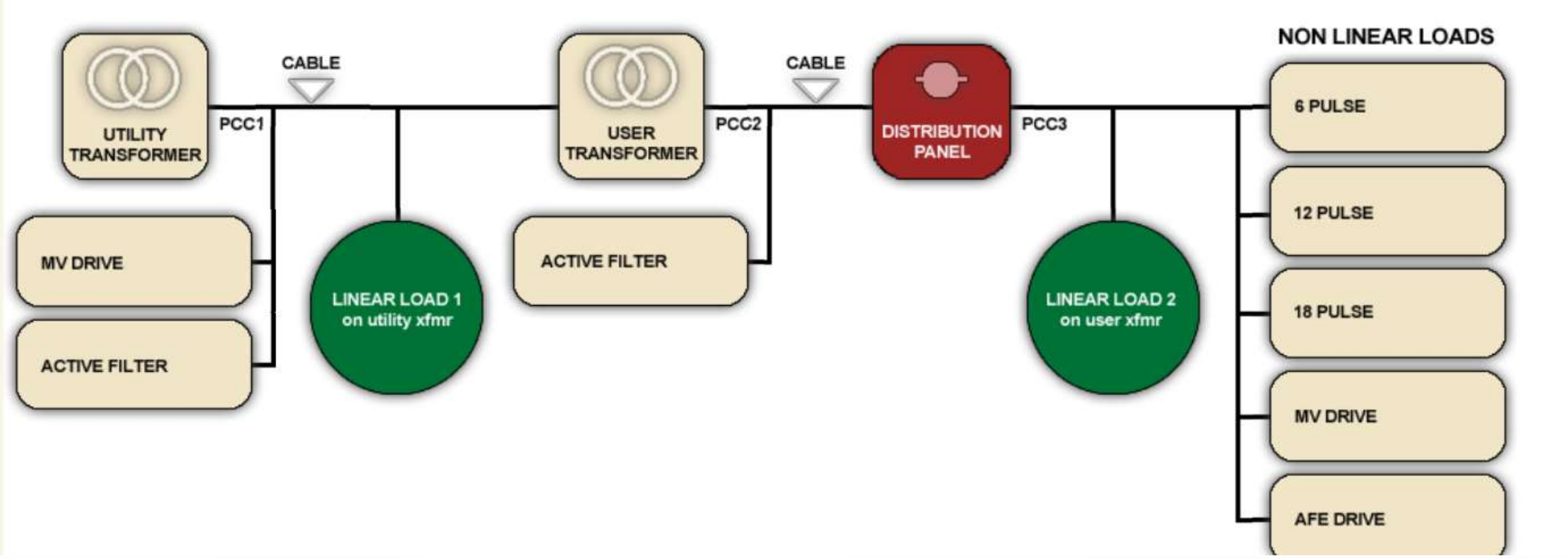
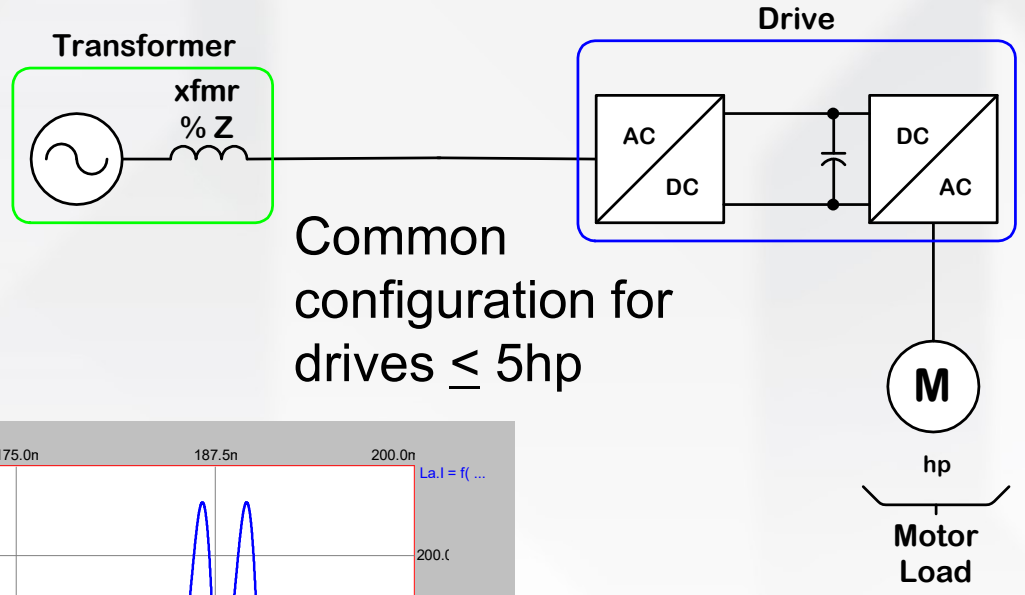
Customers who ask about harmonics are also concerned about their effect in their plant

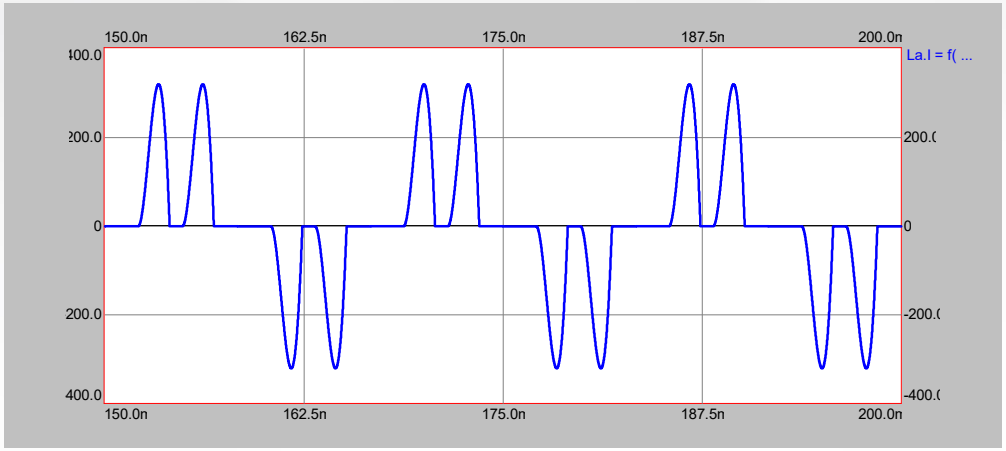


Drive Without DC Link Choke

- Typical I_{THD} of 80 to 120%
- Sensitive to line voltage transients
- High peak line currents



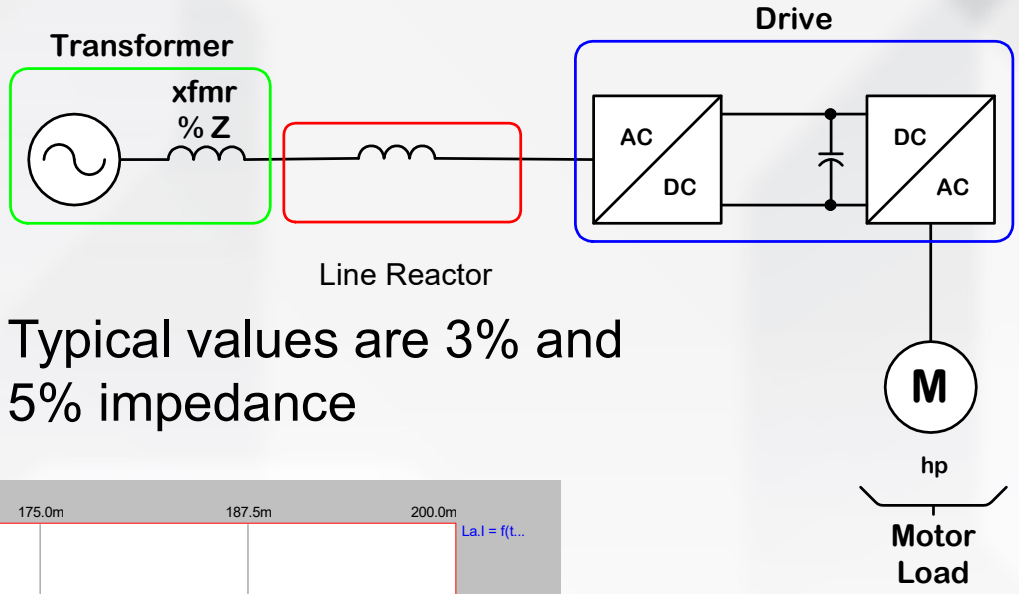
Common configuration for drives ≤ 5hp



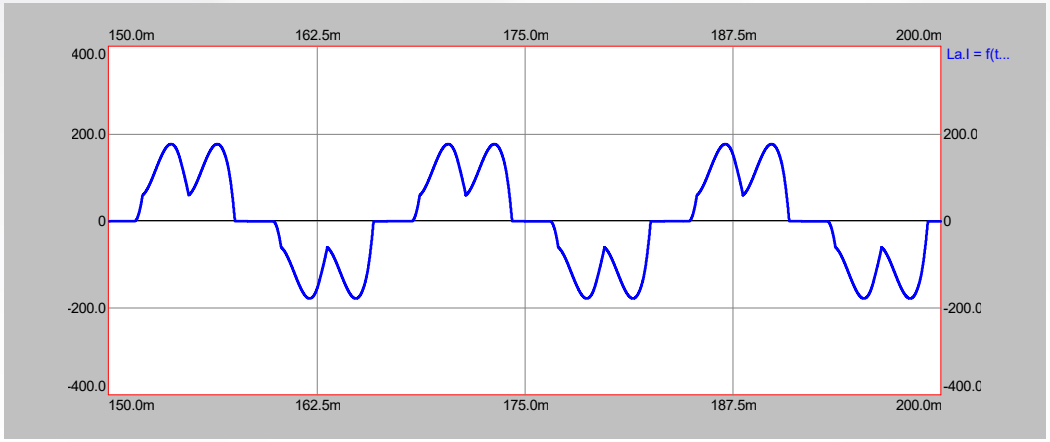
NOTE: Ipk about 3x Irms

Line Reactor, Drive w/o DC Link Choke

- Typical I_{THD} of 30 to 45%
- Big help for drives without DC link choke



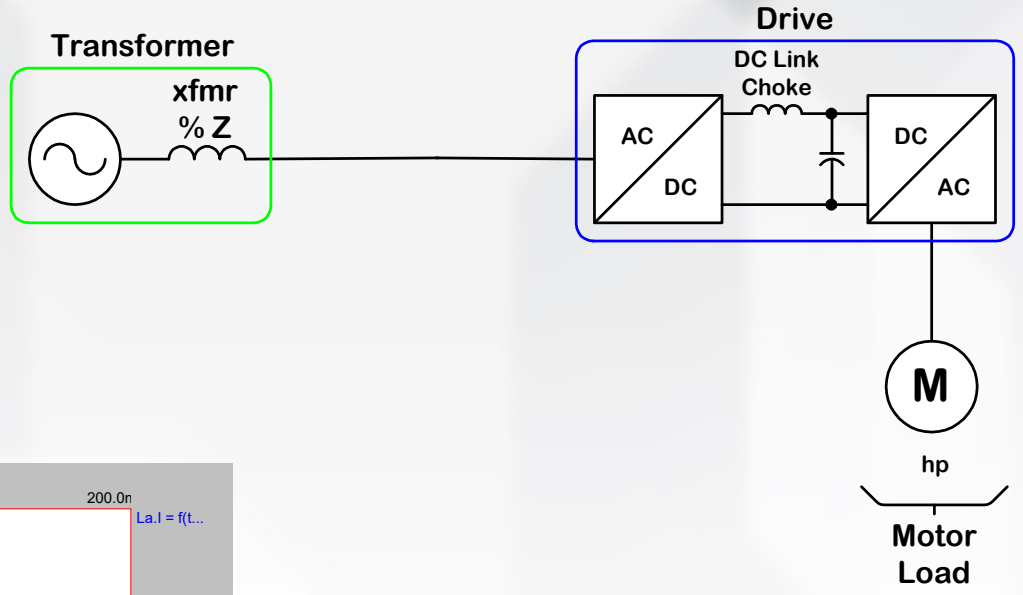
Typical values are 3% and 5% impedance

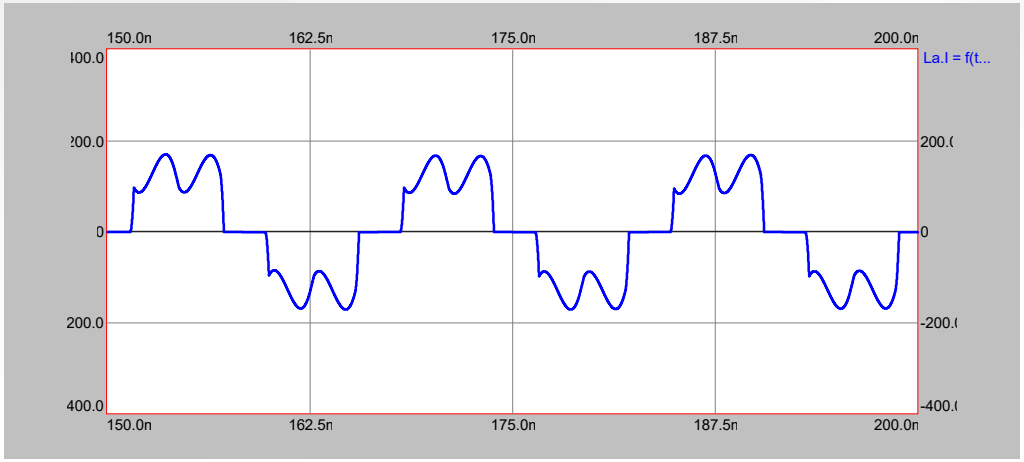


NOTE: shown is 3% LR

Drive With DC Link Choke

- Typical I_{THD} of 30 to 40%
- Less sensitive to line transients

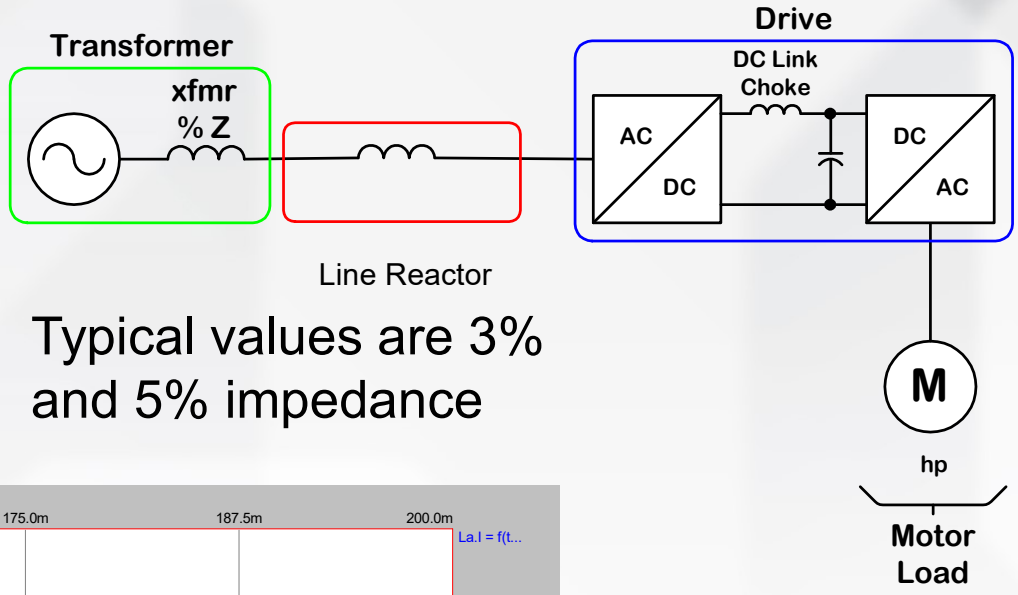




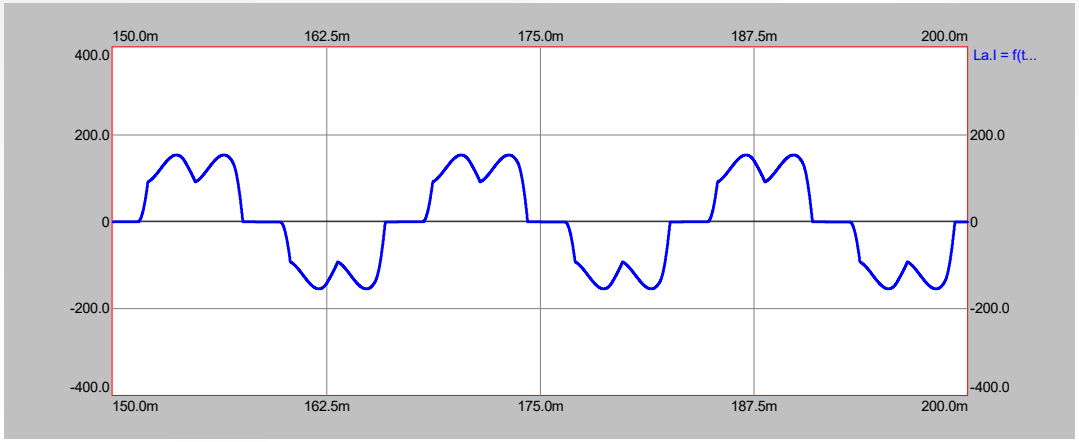
NOTE: Ipk about 1.5x Irms

Line Reactor in Addition to a DC Link Choke

- Typical I_{THD} of 20 to 35%
- Big help for drives w/o DC link choke
- 0.75 - 0.95 PF



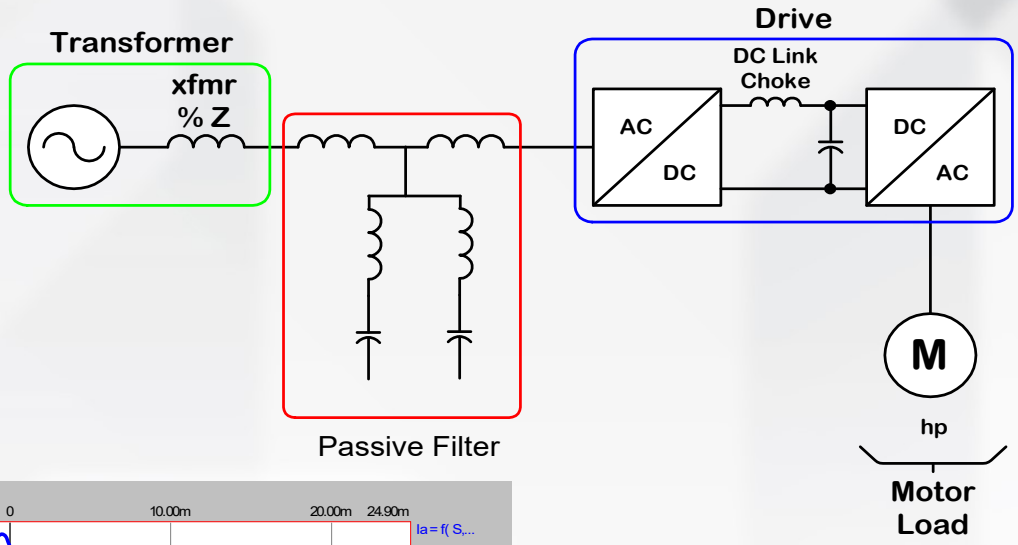
Typical values are 3% and 5% impedance

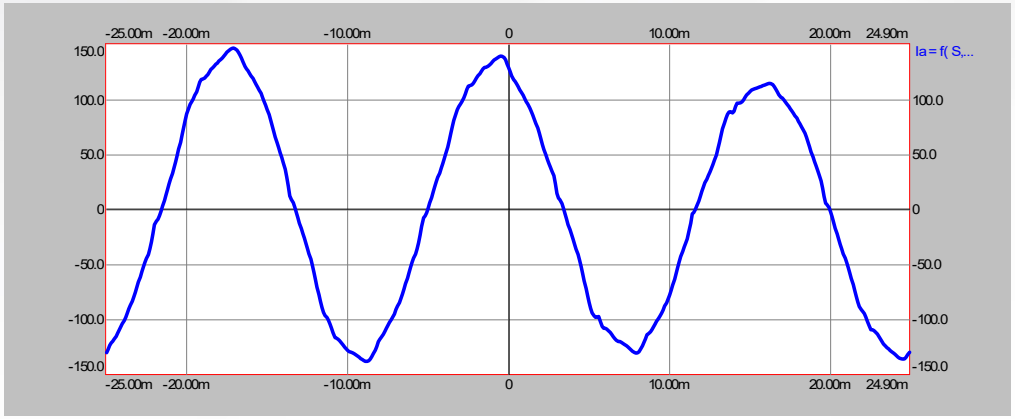


NOTE: shown is 3% LR

Passive Harmonic Filter

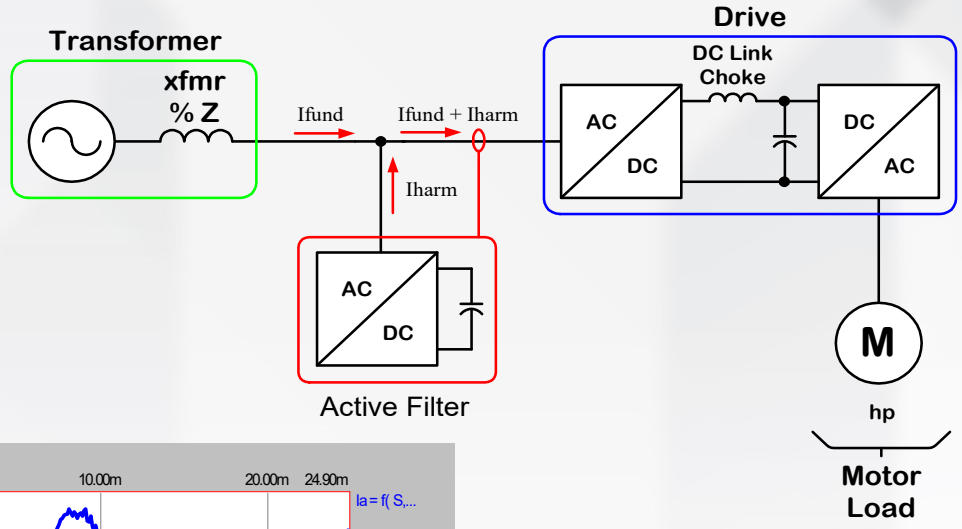
- Typical I_{THD} of 4 to 7%
- 0.3 to 1.0 PF



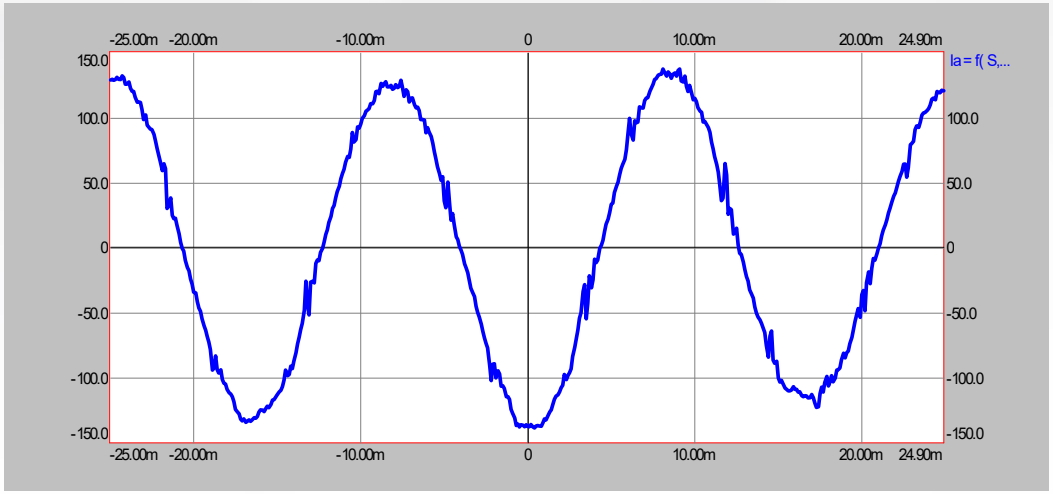


Active Harmonic Filter

- Typical I_{THD} of 3 to 6%
- 0.9 - 0.99 PF



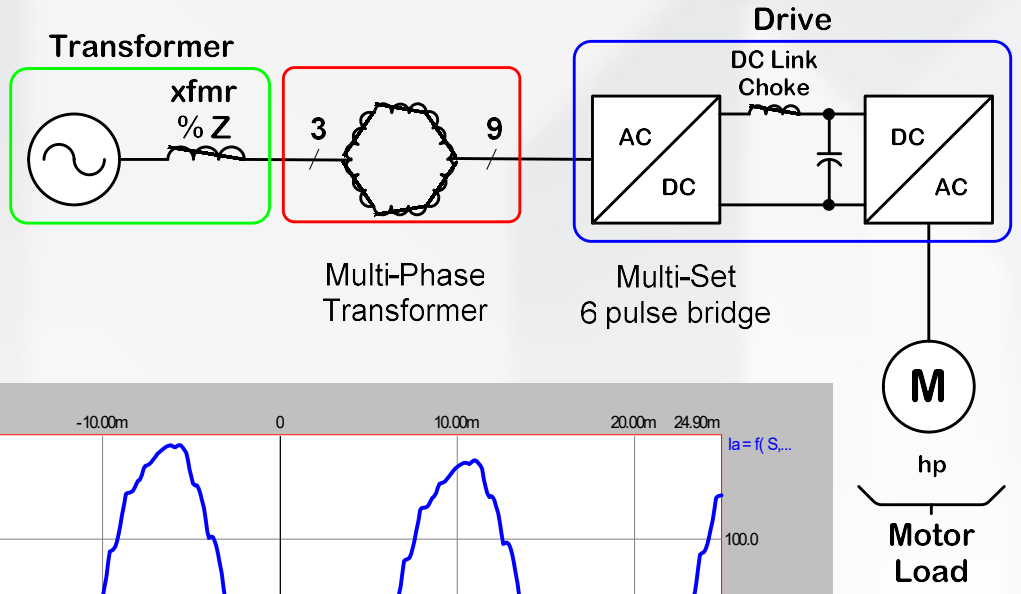
Current from Transformer

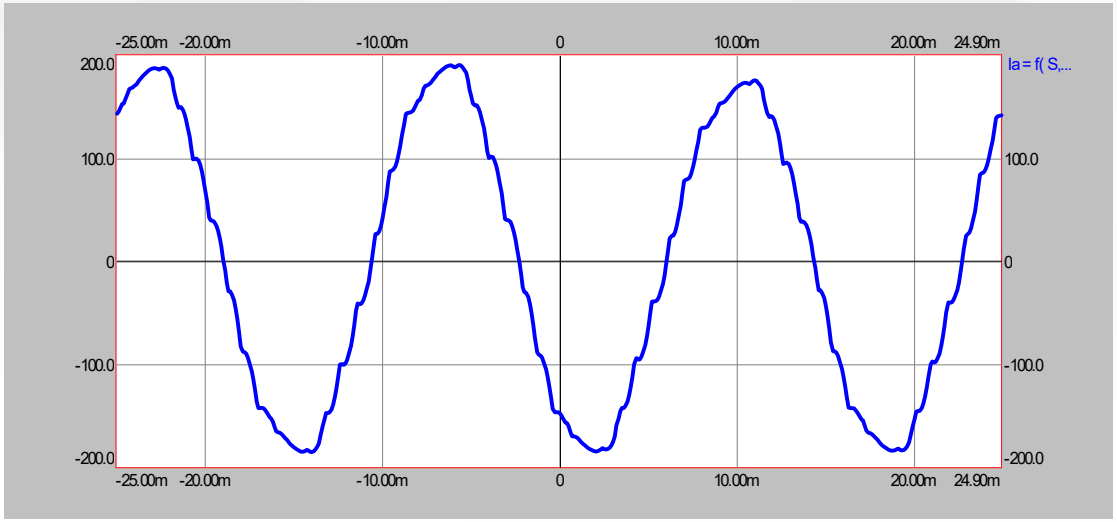


Rockwell Automation

Multi-Pulse

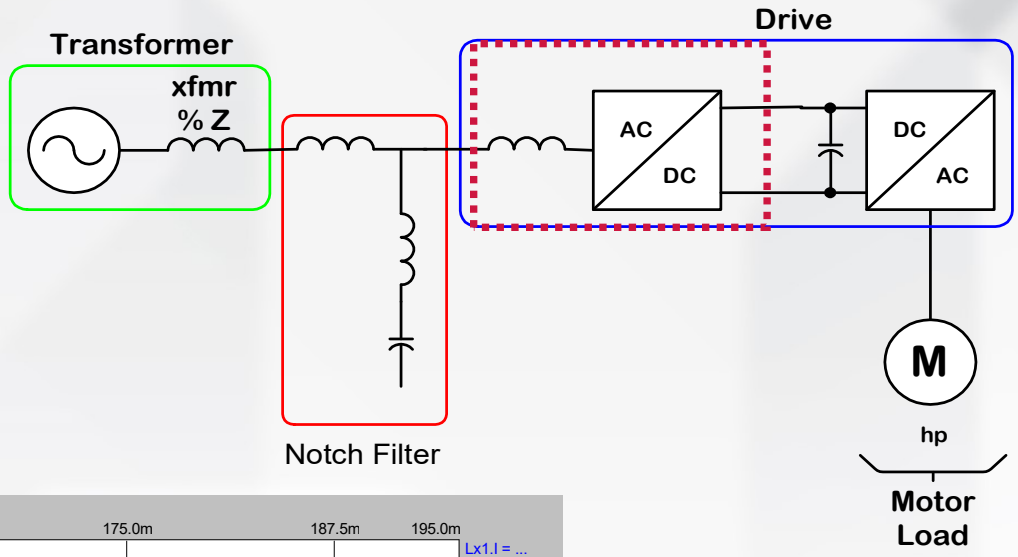
- 12-Pulse Typical I_{THD} of 9 to 12%
- 18-Pulse Typical I_{THD} of 4 to 5%
- 0.90 - 0.99 PF

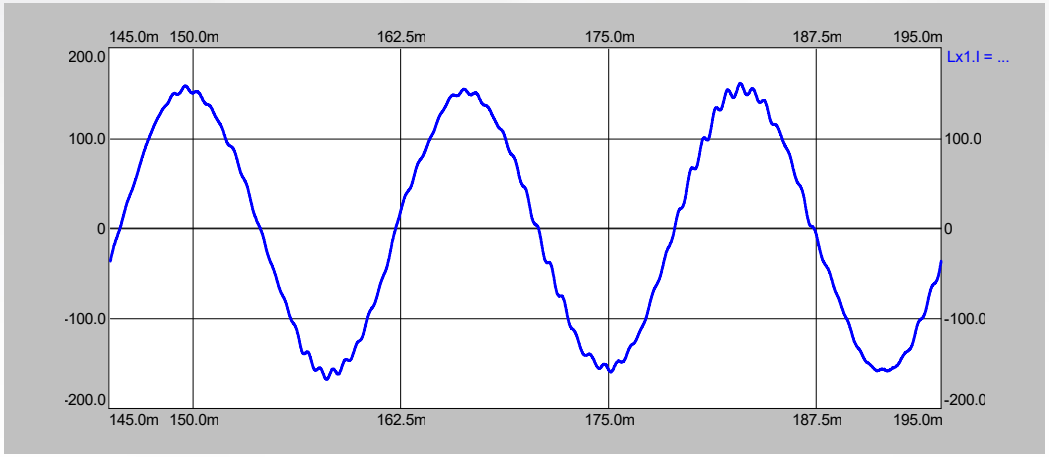




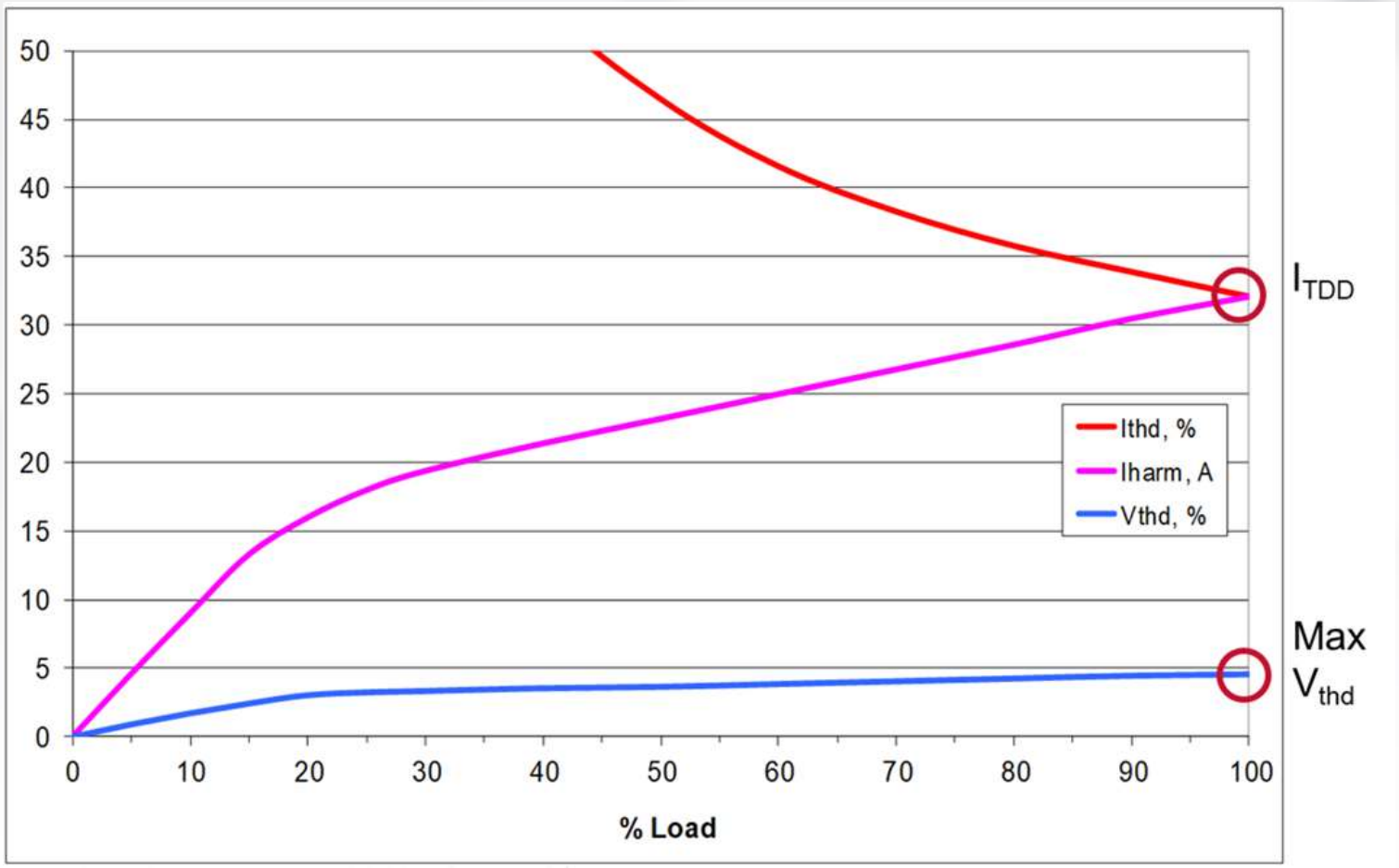
Active Front-End

- Typical I_{THD} of 3 to 5%
- Regen
- 0.8 – 1.0 PF

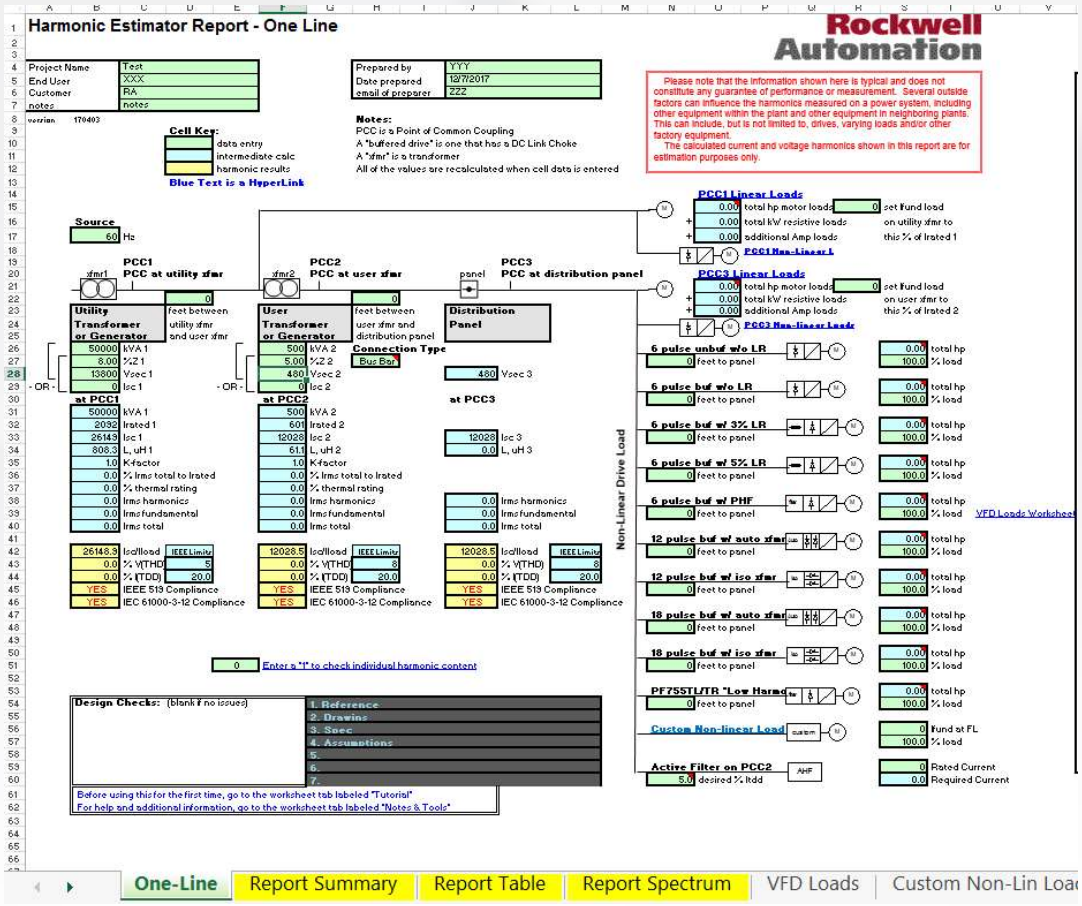




Important point on Active Front Ends

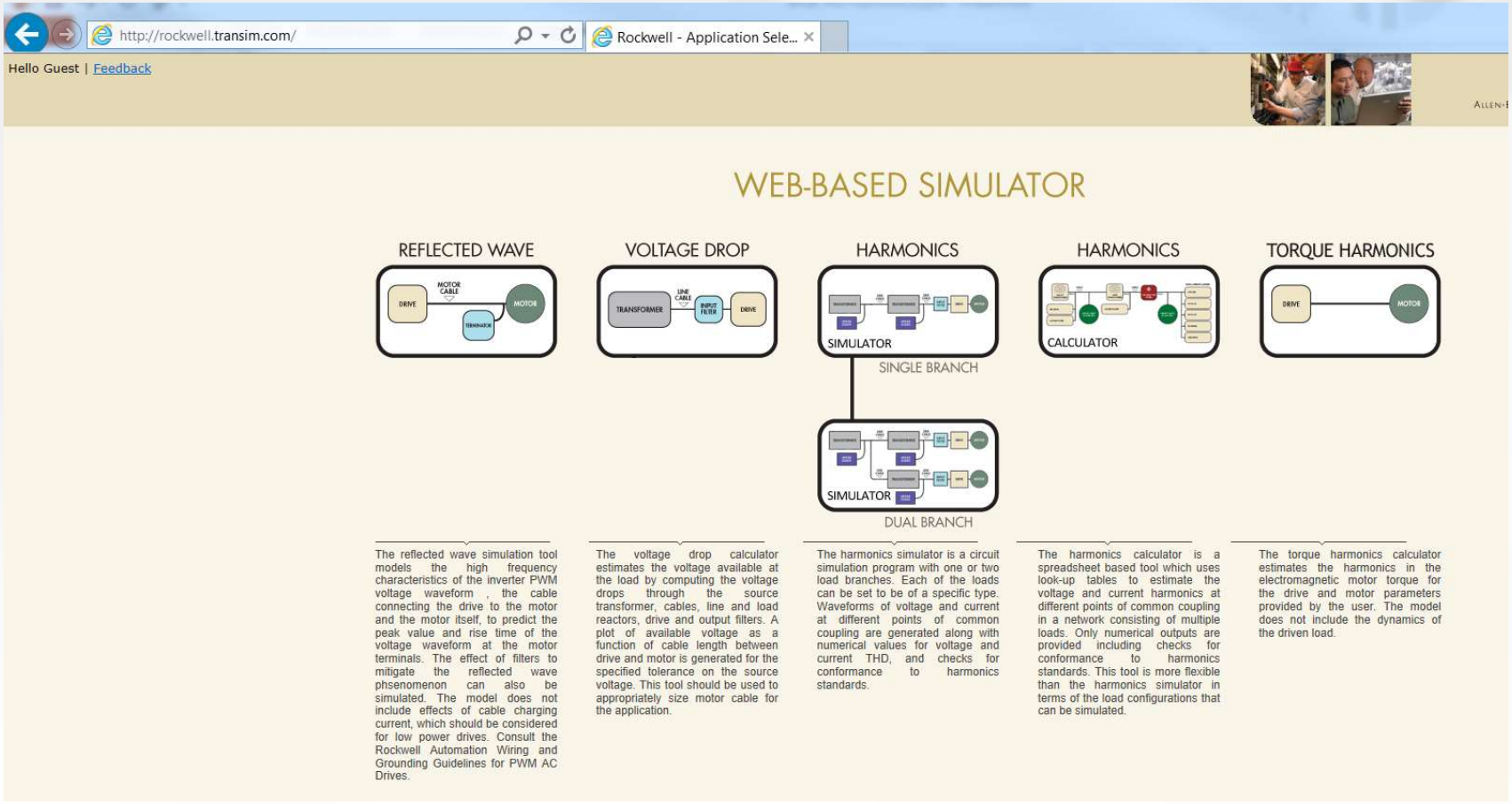


Harmonic Estimation Tools



Rockwell Automation

Harmonic Estimation Tools - http://rockwell.transim.com/



Questions?

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