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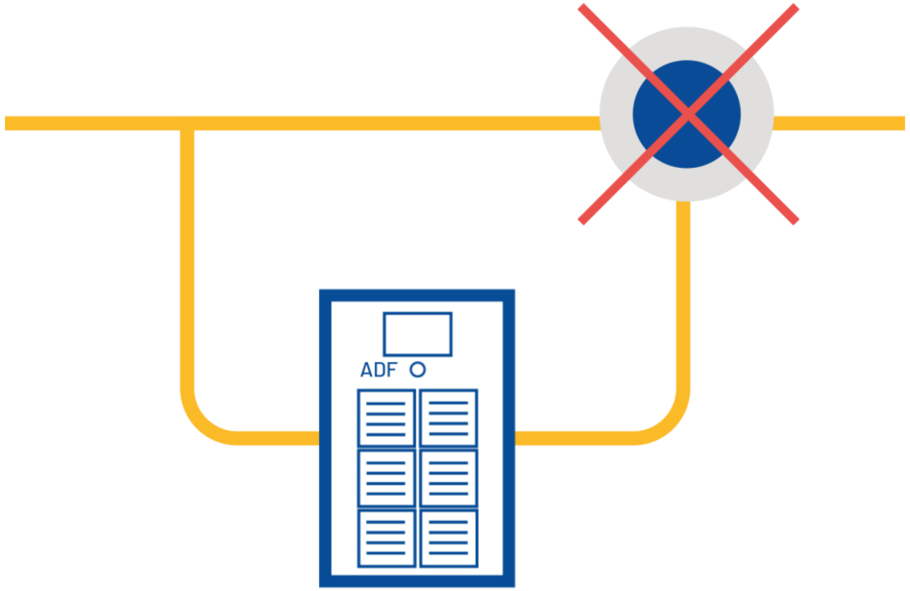
PERFECTING
POWER

ADF Webinar - Sensorless control

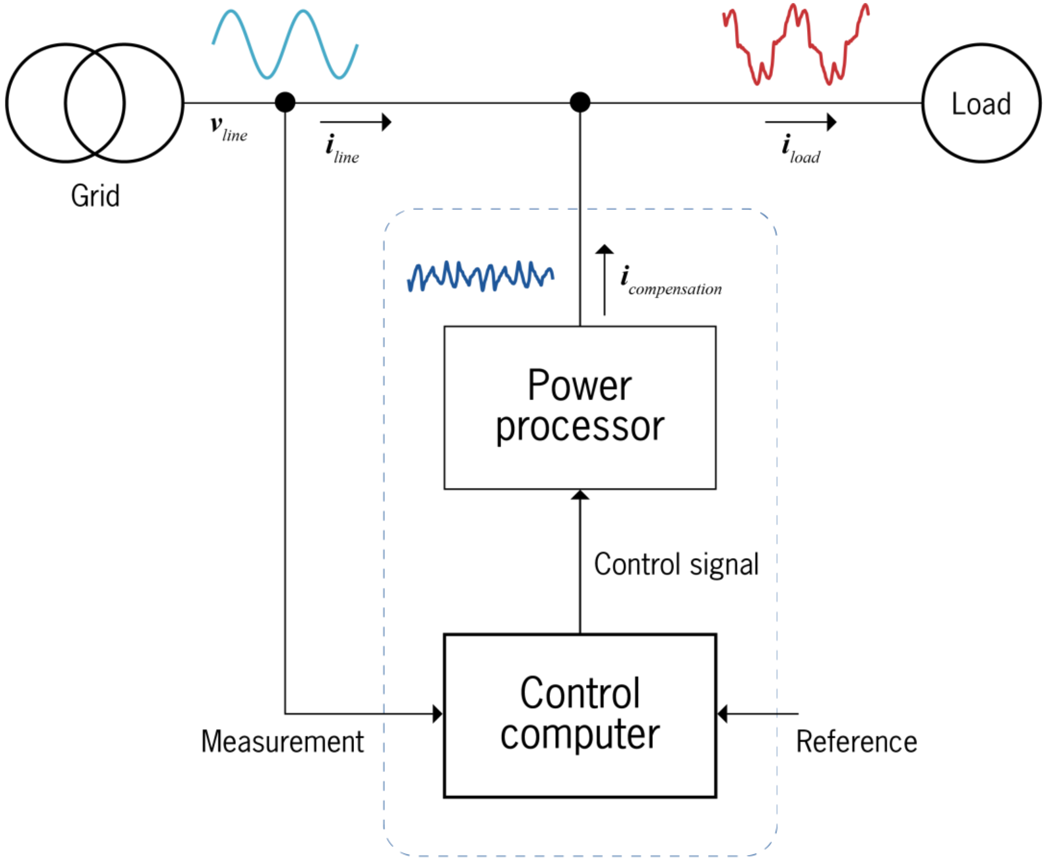
Sensorless control

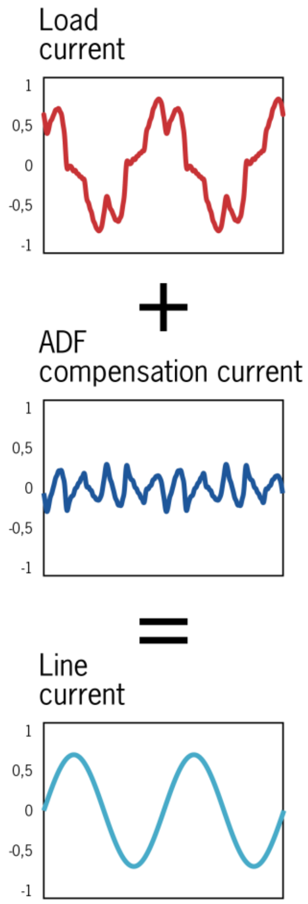
- Sensorless control means compensation without current sensors
- Comsys already uses Sensorless control since a long time
- First introduction was with the ADF P200
- Since 2015 Comsys added Sensorless control to ALL other ADF products



Sensorless Control: Background

- Active Filters inject a counter-current to compensate for a grid/PQ issue
- Typically, active filters are current control
  - Calculates compensation current based on load current





Consequences of high THD_I and THD_U

Harmonic distortion from non-linear loads

Current distortion (THD_I) is created by the load

Transformer losses and heating

Reduced transformer life

Cable losses and heating

Tripping of breaker

Voltage distortion (THD_U) is created by the transformer because of the current distortion

Strongly increased losses and heating in all linear and non-linear loads

Equipment malfunction

Reduced lifetime of Equipment

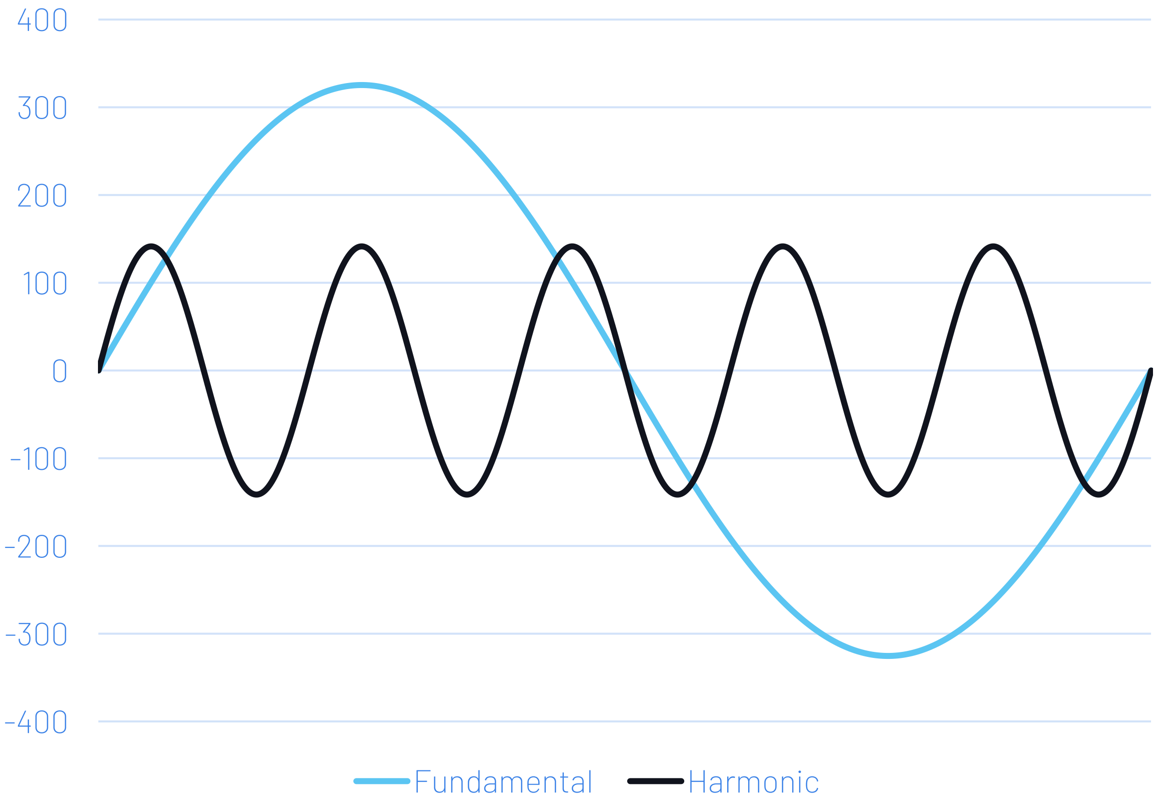
Reduced manufacturing productivity

Sensorless Control: Background

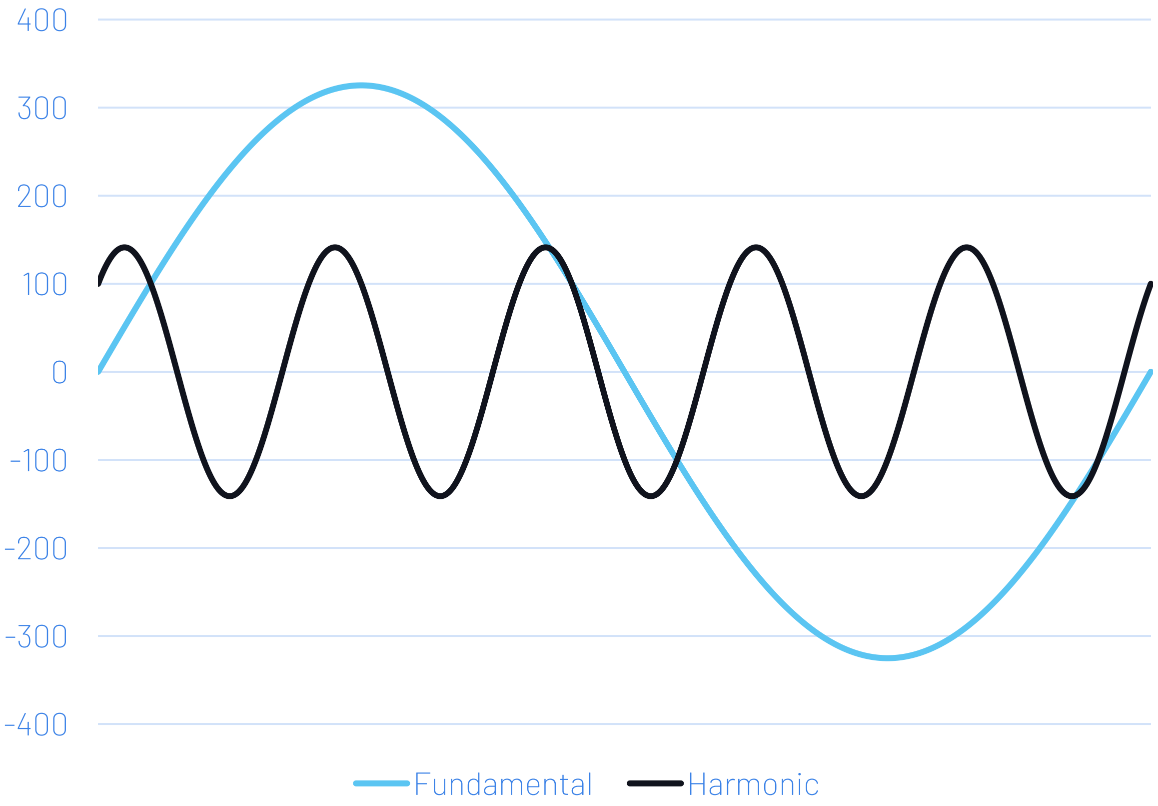
- Most common goal of an active filter:
  To lower the VOLTAGE harmonics!
- So, we measure current to remove current harmonics, and “hope” that the voltage improves
- This works in most cases, but the idea is flawed
  - The filter “assumes” all harmonic current is bad
  - The filter does not take the background voltage distortion into account
- Sensorless control
  Looks only on the voltage. Current sensors are removed
  - Connect the phases and you are ready to go!

Understanding the waves

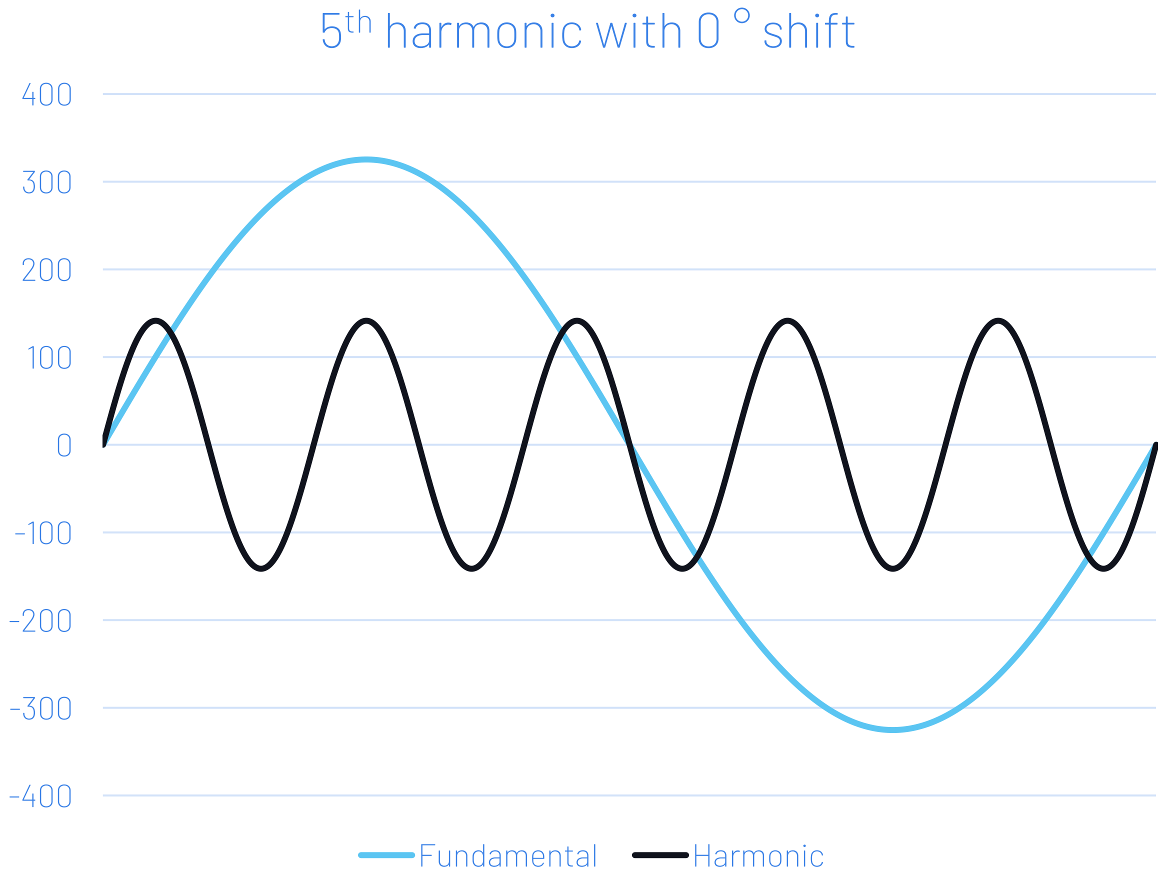
5th harmonic with 0 ° shift

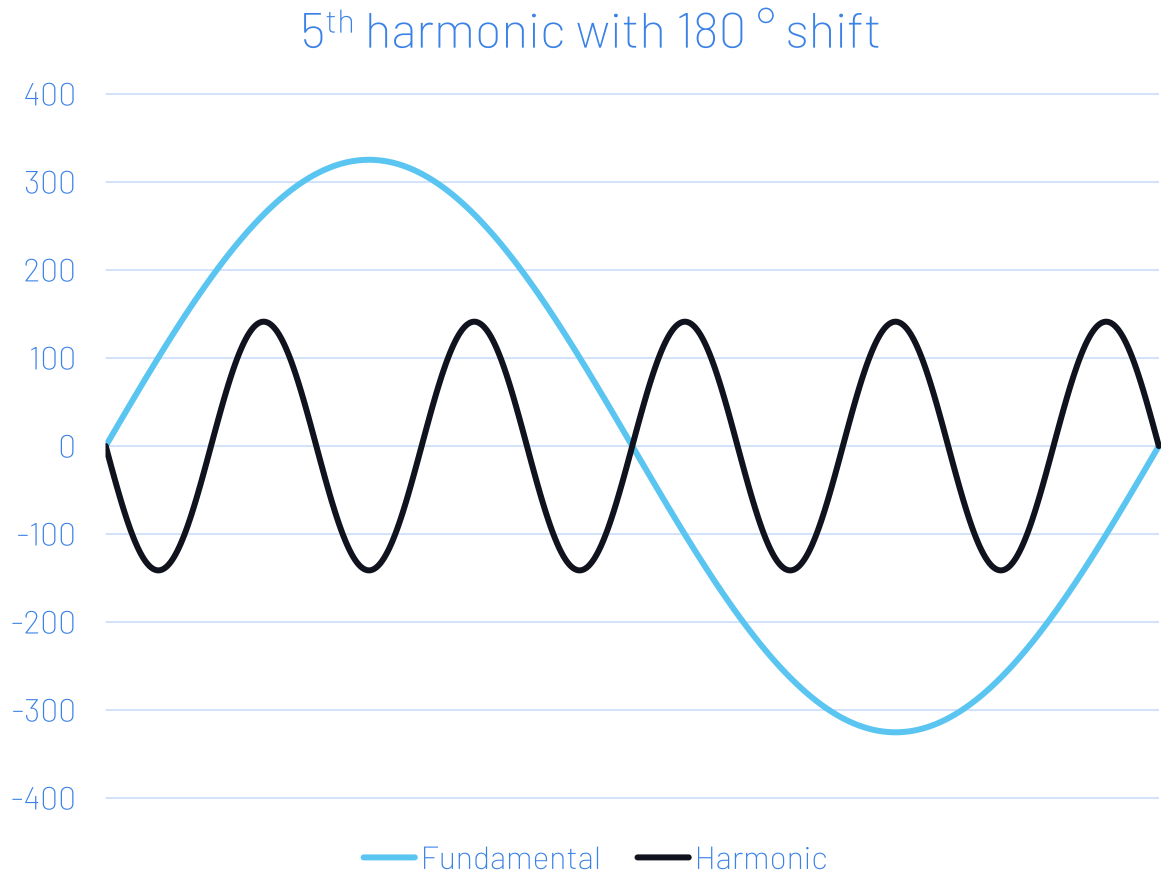


5th harmonic with 45 ° shift

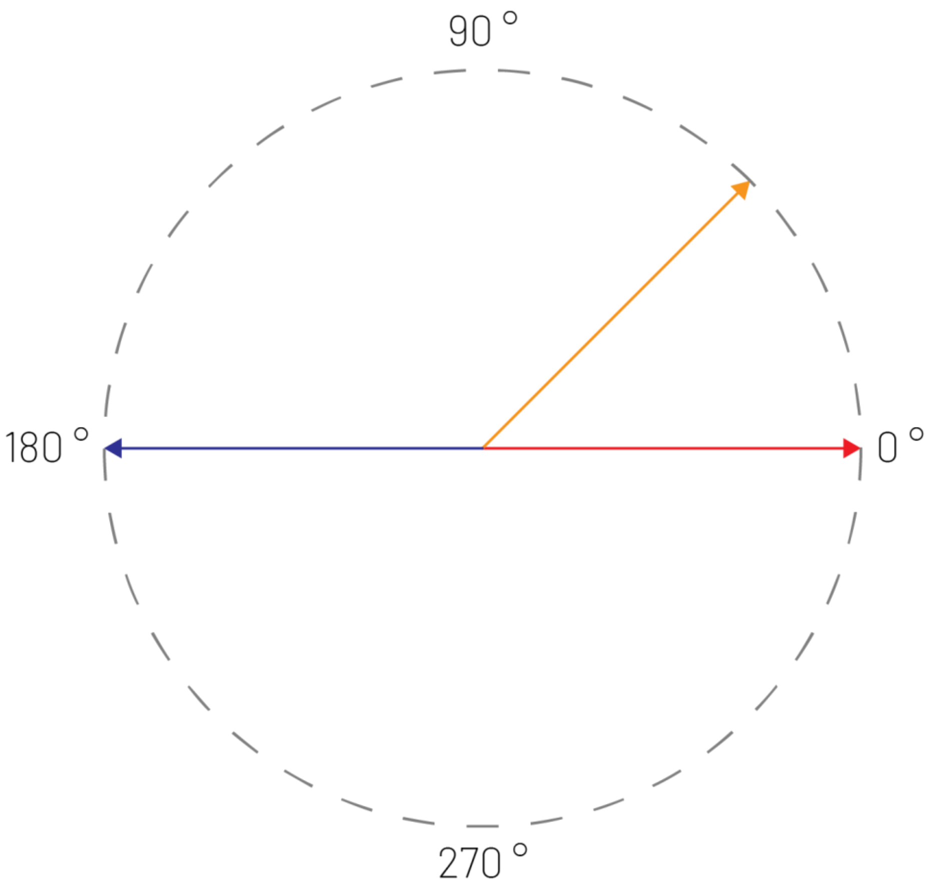


Understanding the waves





Waveforms are the same as vectors

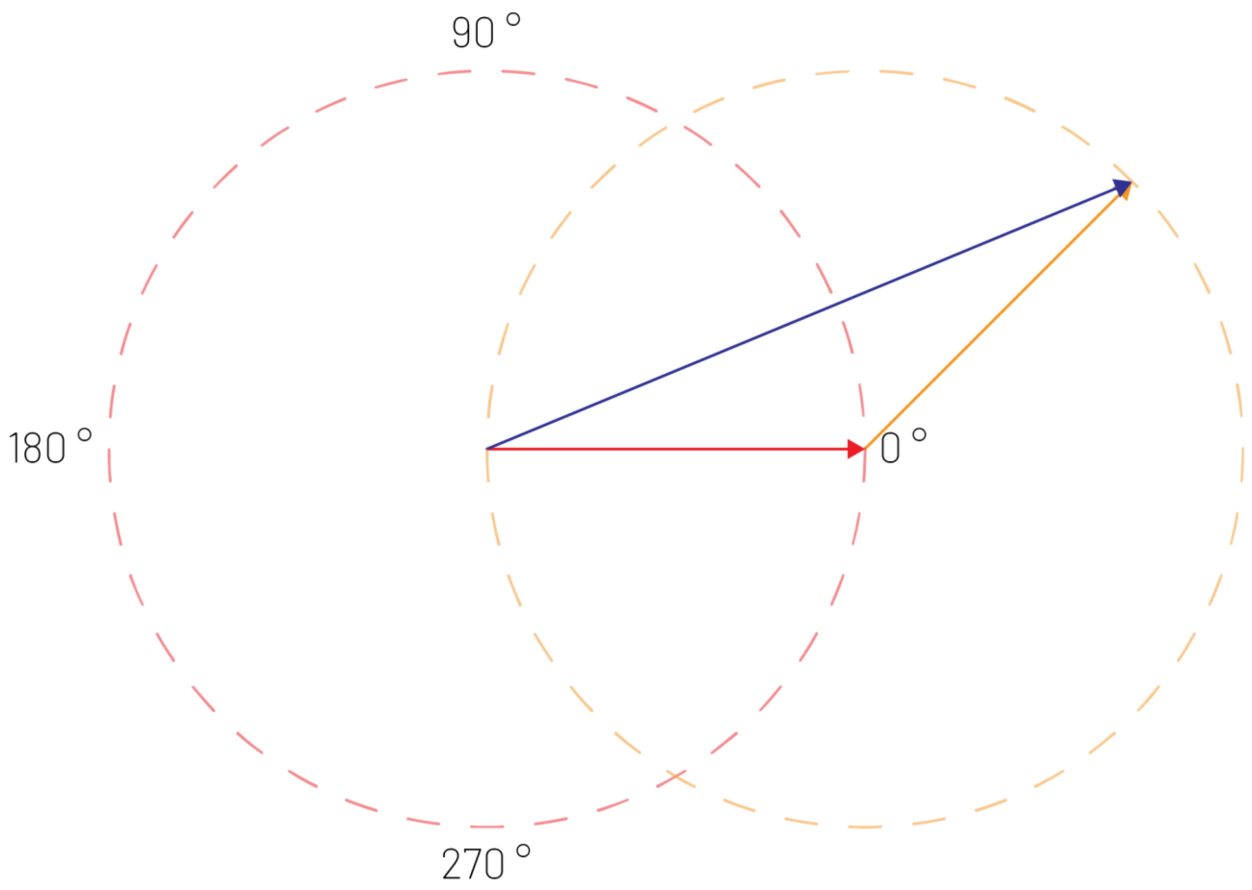


- A vector shows nothing else than a waveform. Beside the amplitude (length of the vector) it also shows the phase shift
- Red is in phase
- Yellow is 45 ° shifted
- Blue is 180 ° shifted

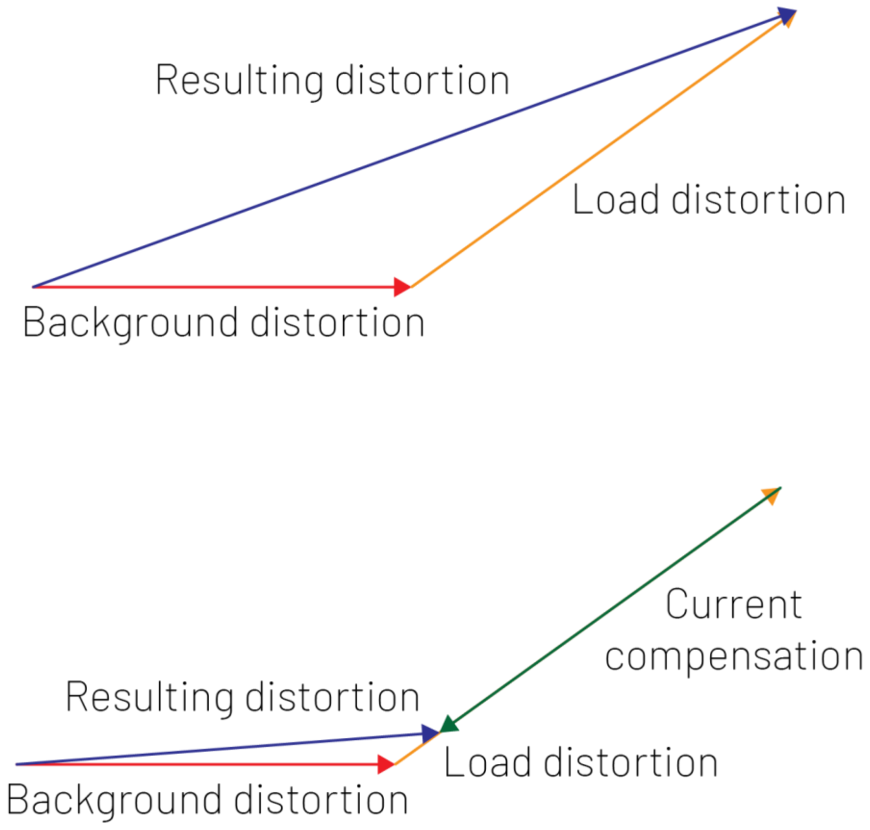
- Every harmonic has not only an amplitude, but also a direction
- Two harmonics, of the same order, do not add only with the amplitude, but also with the vector

Adding two harmonics

- Here we have three different harmonic vectors
- Red is the background voltage distortion
- Yellow is the harmonic created by the load
- Blue is the sum of red and yellow. This is what we actually measure

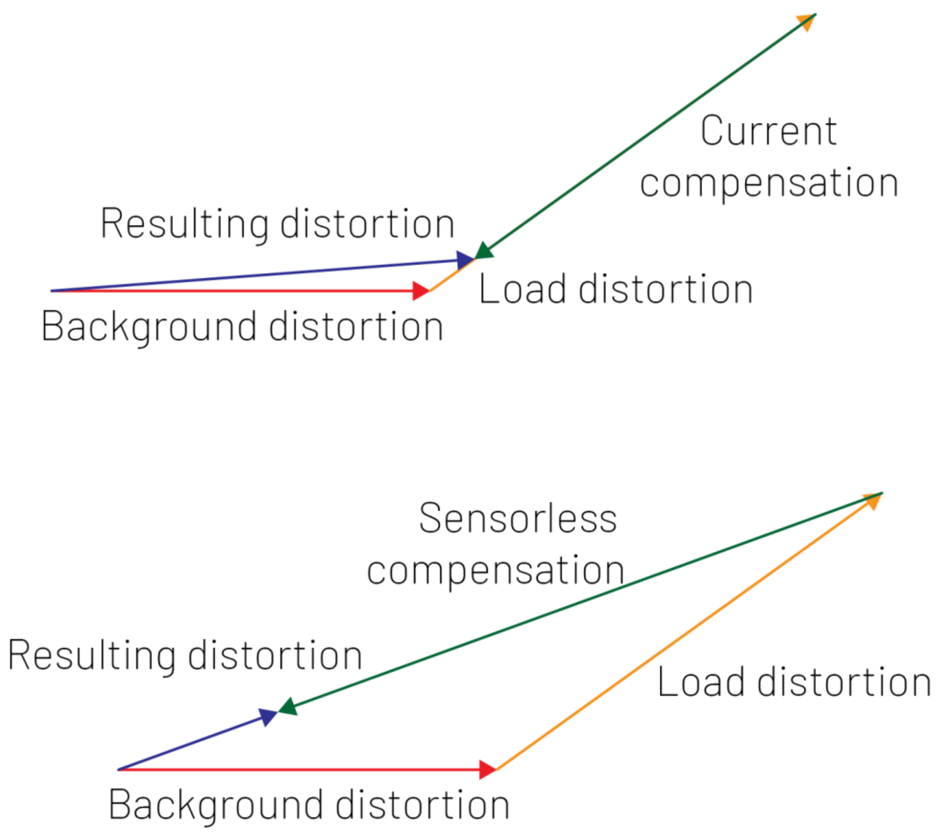


Sensorless Control: How it works



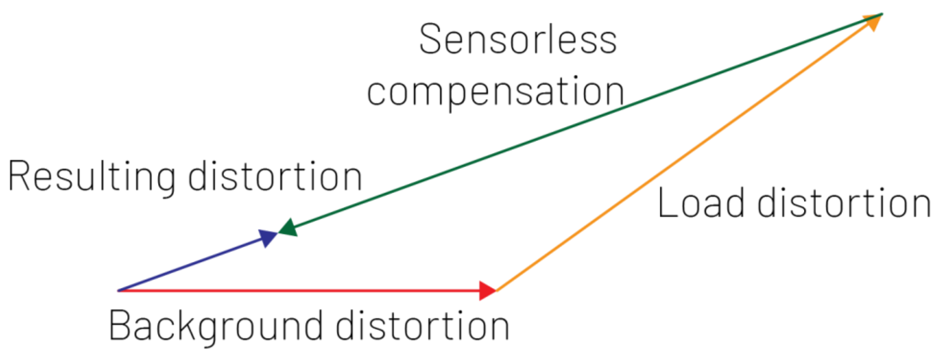
- Sensorless control is more efficient when the goal is to achieve a certain voltage distortion level
- Due to mixing of background distortion and load distortion, current control never works in correct phase angle
- In current control, ADF is bound to follow load current only
- This limits ultimate results, and may be a waste of power (depending on phase angles)

Sensorless Control: How it works



- Sensorless control enables filter to work in exactly correct phase angle, optimizing current used
- The compensation current “follows the resultant” in Sensorless control
- This results in more being done with less current, or a bigger reduction with the same amount of current!
- Background distortion between 1 - 2 % is very common. Sometimes even higher. This can be compensated with Sensorless control

Sensorless Control: How it works



- How can we compensate the voltage distortion with an Active Harmonic Filter? It only can create a current output.

- Our old friend from the 1800s Georg Ohm can help us
- U = R * I
- Every current across a resistance is creating a voltage.
- Our resistance is in AC so we call it impedance (Z) instead
- U = Z * I
- The impedance is the grid impedance. The harmonic current running through the transformer is creating a voltage harmonics
- If the current is compensation current, the voltage will be compensation voltage

Sensorless Control: Converting current in voltage

- If you are interested in detail, we suggest to read through the British Engineering Recommendation G5 in issue 4 or 5
- https://www.energynetworks.org/assets/files/ENA_EREC_G5_Issue_5_(2020).pdf
  - Section 8.4.4 on page 69 has reasonable impedance calculations for harmonics
- $V_h(\%) = \frac{I_h * V_{nom} * \sqrt{3} * h}{S_{sc}} * 100(\%)$
- Example, a 400 V grid with 20 MVA short circuit power has 300 A on the 5th harmonic
  - $V_5(\%) = \frac{300\ A * 400\ V * \sqrt{3} * 5}{20\ MVA} * 100(\%)$
  - $V_5(\%) = 0.05196 * 100(\%)$
  - $V_5(\%) = 5.196\ \%$
- In this example the ADF can create 5.2% voltage distortion with 300 A of output current. As long as this output current is in the correct angle, the voltage distortion will act as compensation

Sensorless Control: Sizing

- Important:
  - ADF sizing does not depend on load
  - ADF sizing depends on grid impedance
  - Regular ADF sizing can be done, in that case the background distortion is assumed to be zero
    ➔ Regular sizing only calculates the contribution to the THD_U
- Calculation helper is in the handout
- Some factors could be important to add to the sizing
  - 20% safety margin

Sensorless compensation calculation (ADF derating not included)

S_{SC}	20,83	MVA				
Vnom	440,00	V				
				ADF Current		
				Full compensation	Target compensation	Result with Target Comp.
h	Voltage dist	Target				
5	10,1%	1,7%		552,20 A	459,26 A	1,7%
7	4,9%	1,7%		191,36 A	124,97 A	1,7%
11	2,5%	1,7%		62,13 A	19,88 A	1,7%
13	2,6%	1,7%		54,67 A	18,93 A	1,7%
17	2,0%	1,7%		32,16 A	4,82 A	1,7%
19	1,5%	3,0%		21,58 A	0,00 A	1,5%
23	1,3%	3,0%		15,45 A	0,00 A	1,3%
25	1,3%	3,0%		14,22 A	0,00 A	1,3%
29	1,1%	3,0%		10,37 A	0,00 A	1,1%
31	0,9%	3,0%		7,94 A	0,00 A	0,9%
35	0,8%	3,0%		6,25 A	0,00 A	0,8%
37	0,8%	3,0%		5,91 A	0,00 A	0,8%
41	0,7%	3,0%		4,67 A	0,00 A	0,7%
43	0,5%	3,0%		3,18 A	0,00 A	0,5%
47	0,6%	3,0%		3,49 A	0,00 A	0,6%
49	0,5%	3,0%		2,79 A	0,00 A	0,5%
	12,4%		Total:	592,14 A	476,77 A	5,0%

Pros vs Cons
Open Loop / Closed Loop / Sensorless

<table>
<tr><th></th><th>Open Loop</th><th>Closed Loop</th><th>Sensorless</th></tr>
<tr><td rowspan="2">Pros:</td><td colspan="2">+ Able to compensate on a load level
+ Prevent interference by CT-placement
+ Fine-tuning of compensation easy
+ Pre-distortion level can be calculated when system is on
+ Clever use of summation CTs give interesting application opportunities</td><td rowspan="2">+ Optimal use of ADF current
+ Combat background voltage distortion
+ Use in sub-grid isolation
+ Stability
+ Quick and easy installation</td></tr>
<tr><td>+ Ideal for central compensation</td><td>+ Can not stimulate a resonance
+ More stable on higher order harmonics</td></tr>
<tr><td rowspan="2">Cons:</td><td colspan="2">- Inefficient in applications with high background voltage distortion and/or special phase angles
- Requires CTs</td><td rowspan="2">- Cannot isolate load
- Cannot easily fine-tune degree of compensation
- Voltage reference (pre-distortion) is lost
- THD_U may increase on feeding grid
- Multi-Master is not possible (plan for 2.2 software)
- No control of THD_I</td></tr>
<tr><td>- Can stimulate a resonance</td><td>- Calibration of CTs might be needed</td></tr>
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CT position/Sensorless selection

	Open Loop	Closed Loop	Sensorless
Use if:	• Flicker compensation • MV compensation • Very dynamic load • Passive filter in close proximity • High order compensation • Only compensate select sub-grid	• Regular application (harmonics, reactive) • Load balancing • Central compensation	• Background distortion needs to be removed • CT-installation too complex • Central compensation
Don't use if:	• Results need to be visible in ADF • Central compensation	• Flicker • MV compensation	• THD_I is target level • Reactive power or load balancing is required • Multiple ADFs are required (until software 2.2)

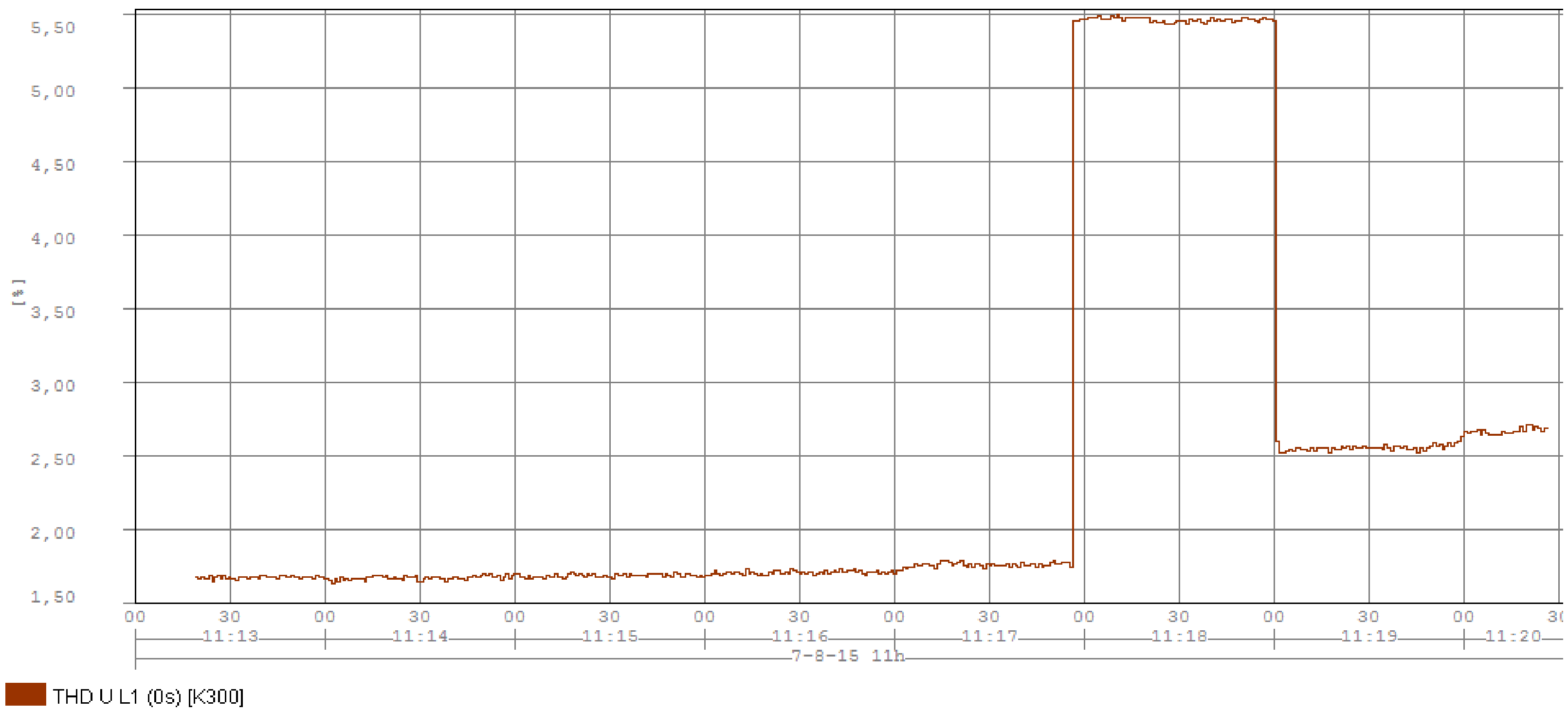
Video

- Check out our videos on https://adf.academy
- Sensorless control: https://www.youtube.com/watch?v=KzMzB2wrCsU
  - Still with the older ADF software

- Enjoy the demo!

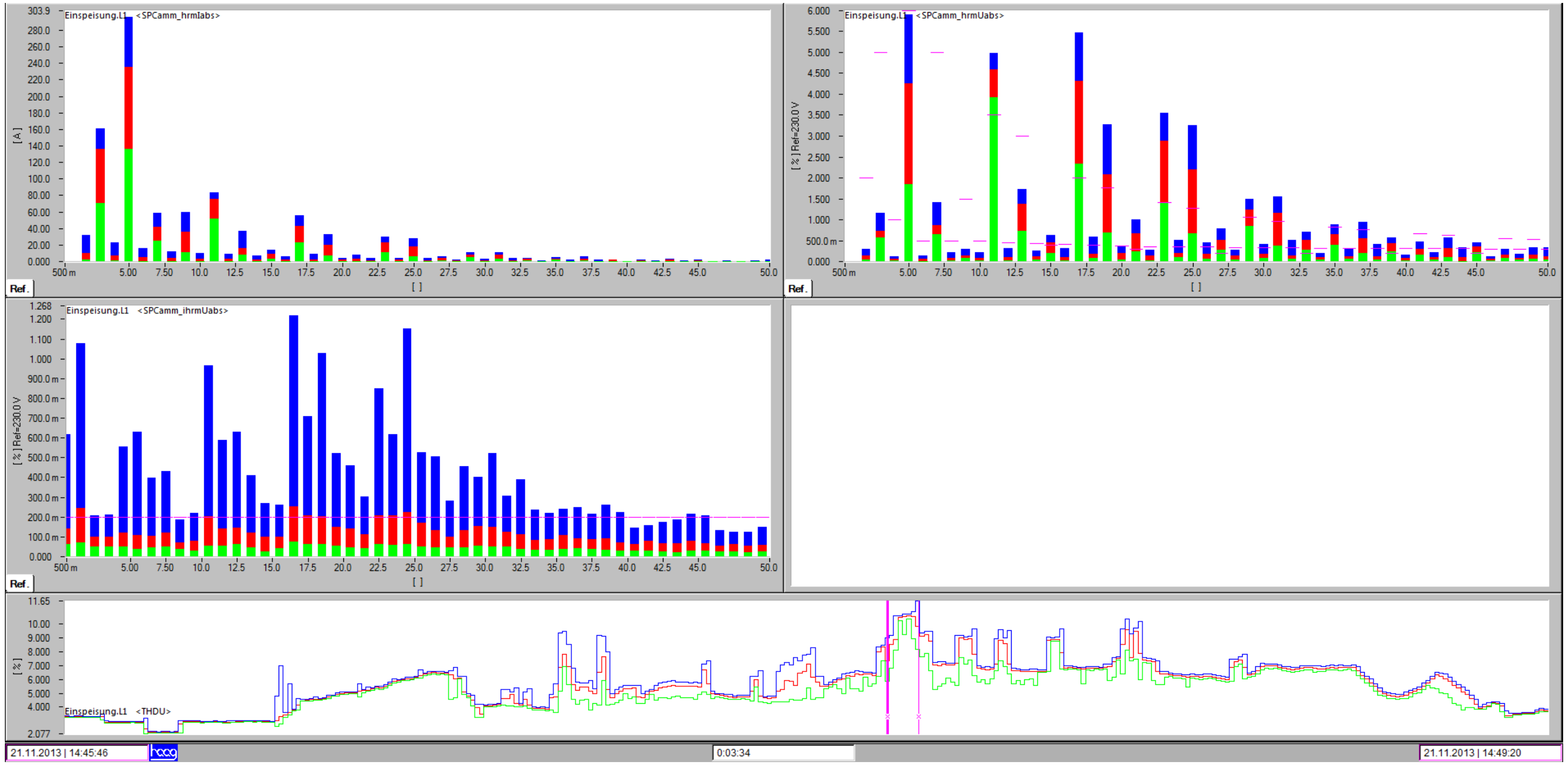
Case Story: HHNK (Hollands Noorderkwartier)

- Application is a wastewater facility
- All the loads are 6-pulse VFDs
- Installation was running is current control for 2-3 years
- Sensorless control was installed by the partner to see the effects of Sensorless for themselves
- Results:
  - Left: Sensorless control (THD_U = 1.75 %)
  - Middle: ADF tuned off (THD_U = 5.5 %)
  - Right: Current control (THD_U = 2.5 %)



Nitriding furnace

- Poor power quality
- THD_U up to 11.65 %
- Top left: Harmonic current (A)
- Top right: Harmonic voltage (%)
- Middle left: Interharmonics voltage (V)
- Bottom: THD_U as a trend. Measurements above are taken between the pink lines

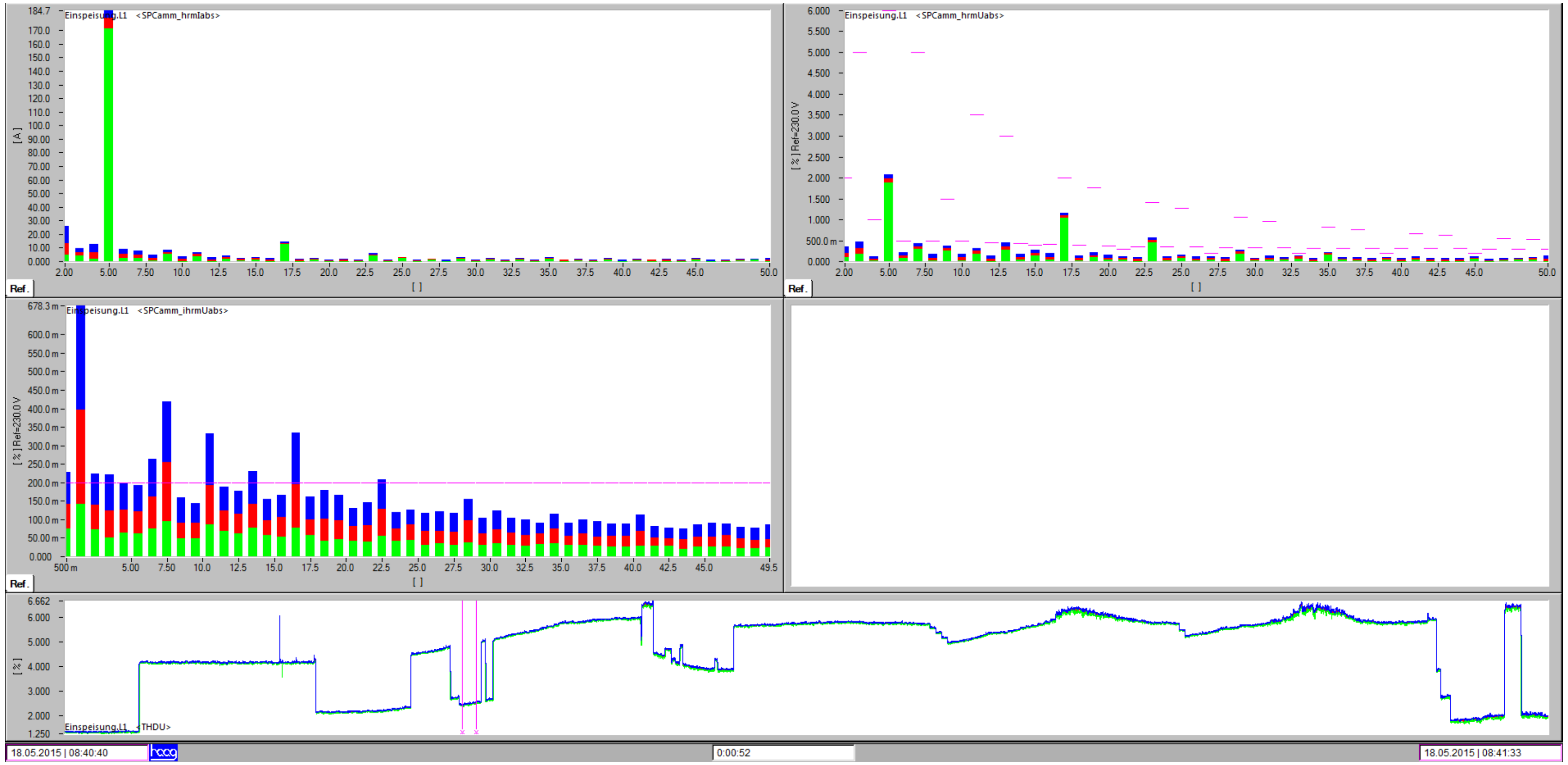


Nitriding furnace

- Installation of two ADFs
- ADF P300 for the lower frequency harmonics
- ADF P200 for the higher frequencies and interharmonics

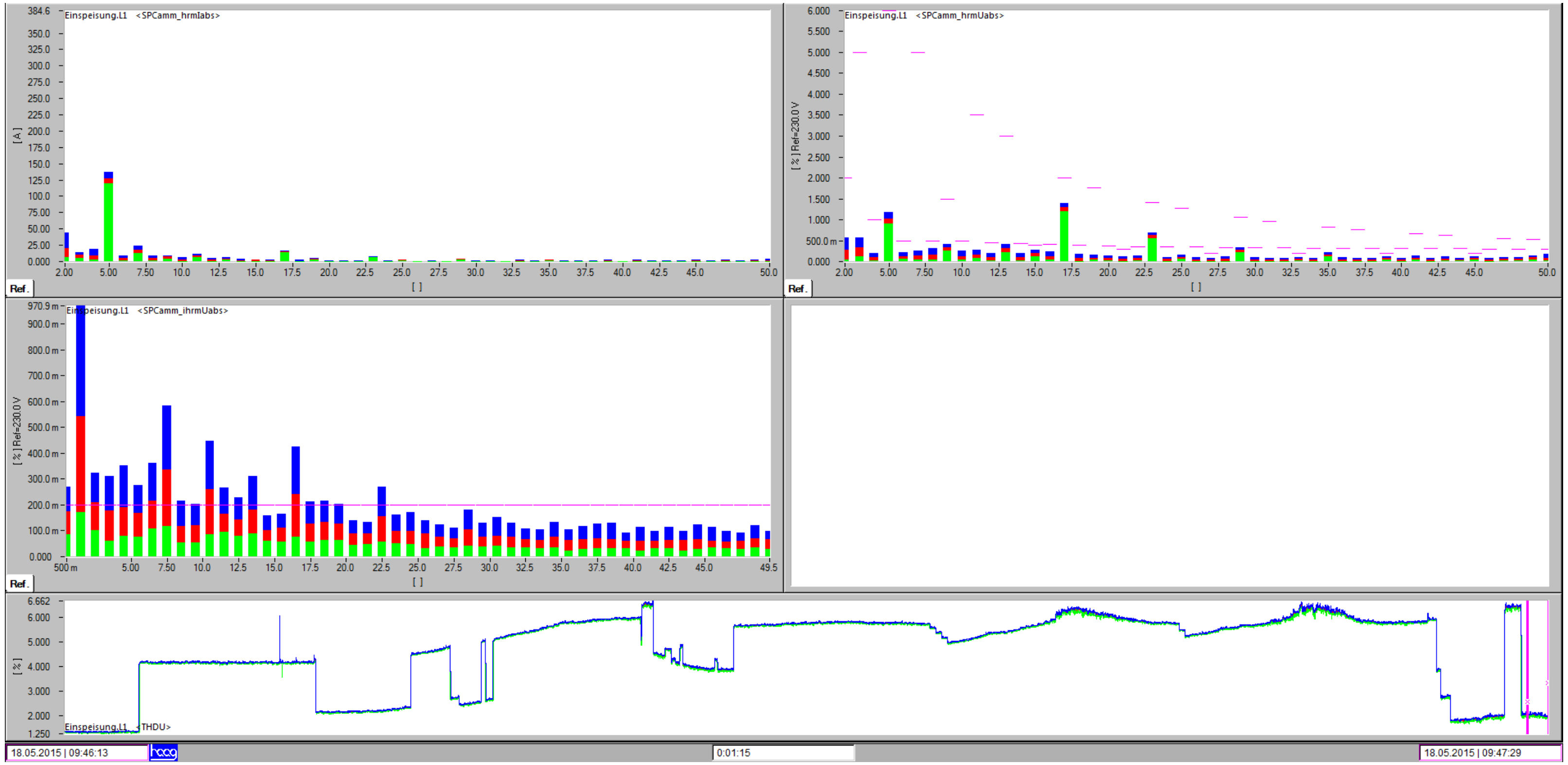
Nitriding furnace

- ADF P200 is running in Sensorless operation
- ADF P300 is running in current control
  - ADF is fully utilized
  - 185 A are left on the 5th harmonic
  - There is still 2 % voltage distortion on the 5th harmonic



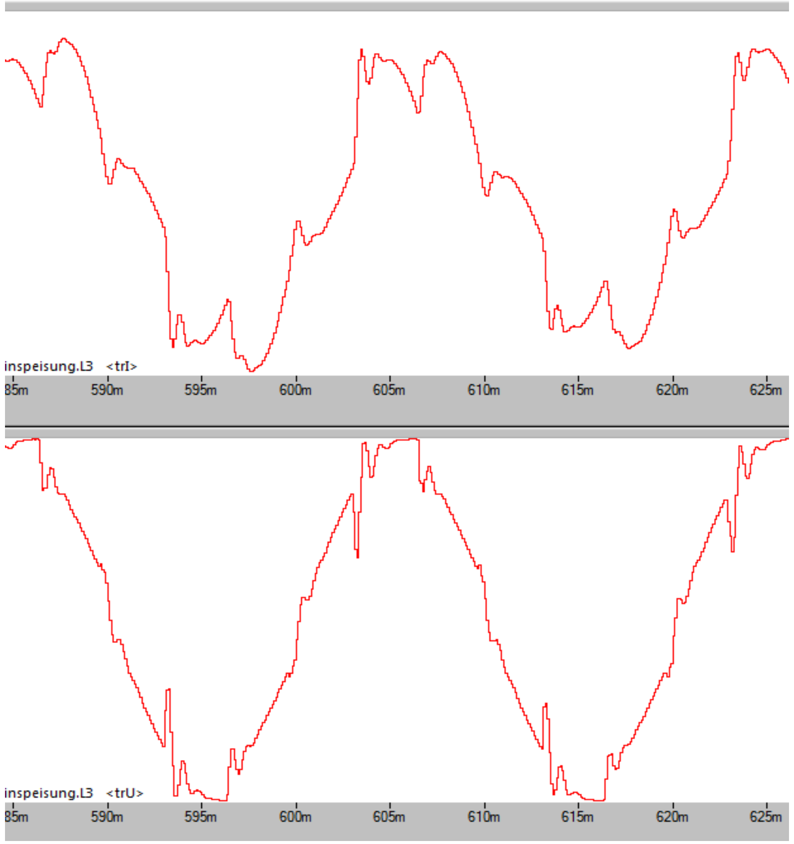
Nitriding furnace

- Both systems are running is Sensorless control
- 5^{th} harmonic voltage distortion is down to only 1 %
- Current distortion on the 5^{th} is reduced to 150 A

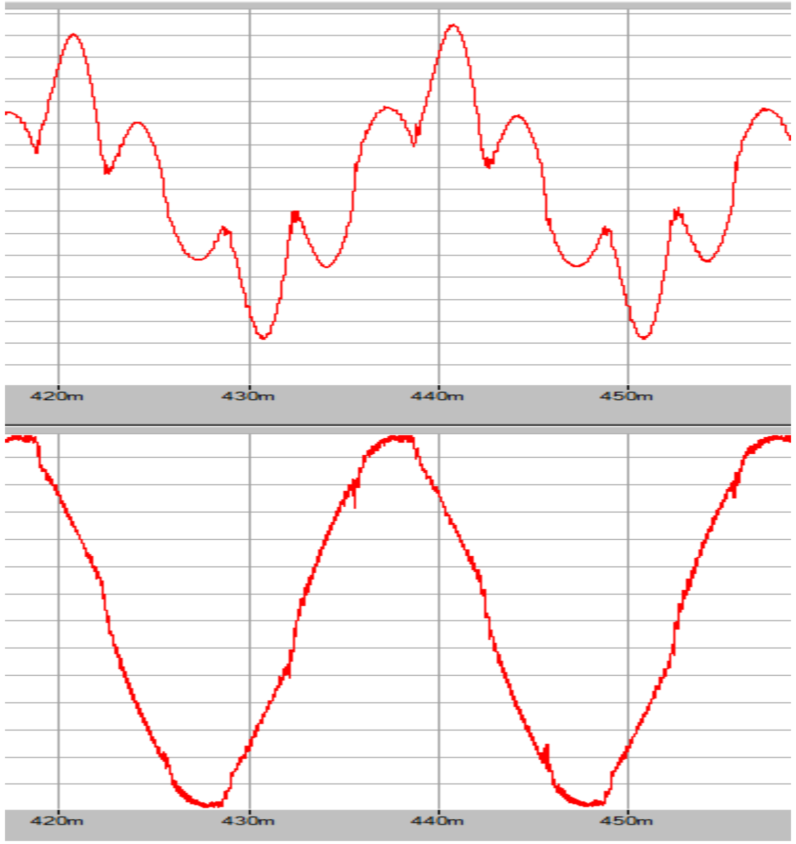


Nitriding furnace

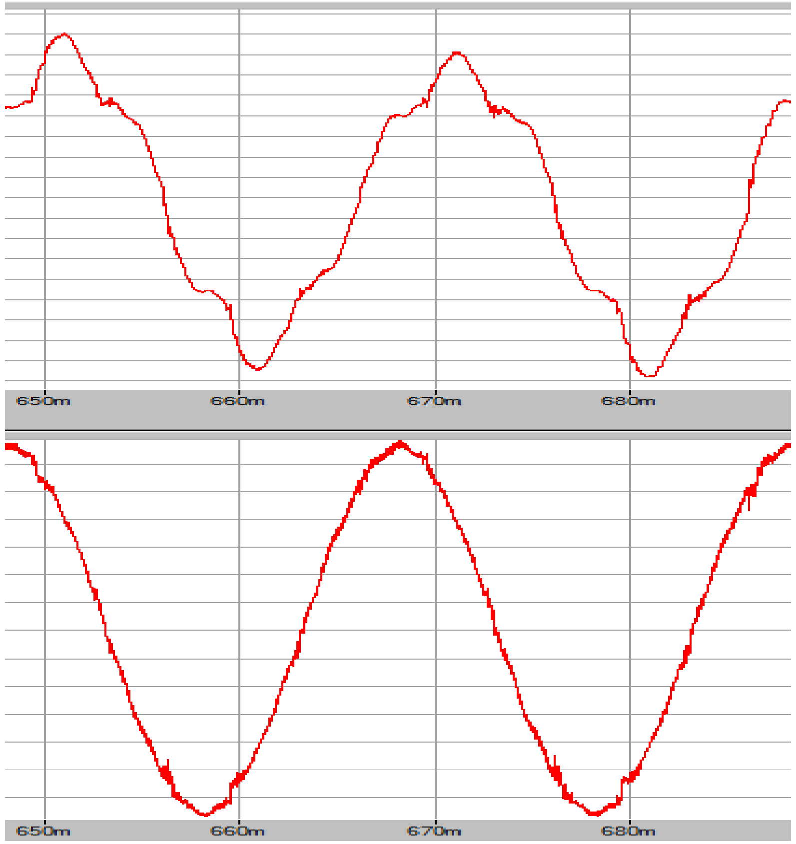
ADF's off



ADF's in current control



ADF's in Sensorless control

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