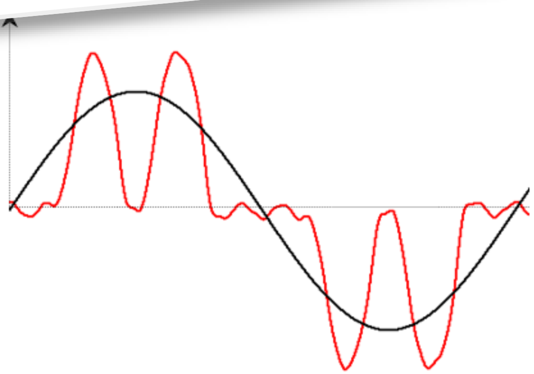
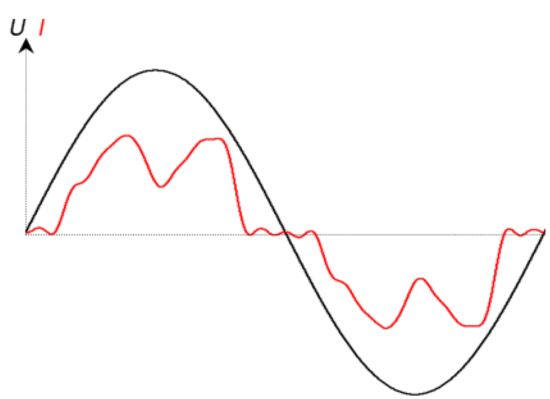
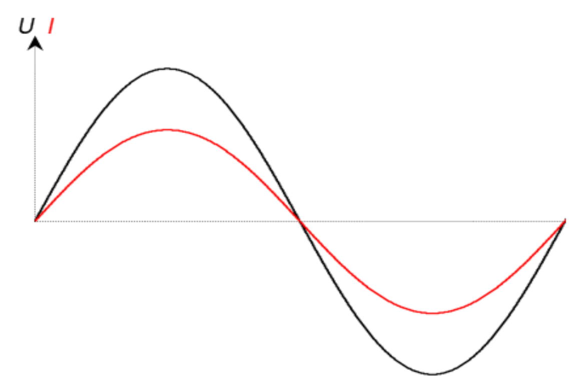
REVCON Optimizing your drive!

Harmonic Distortion of Drives: Issues and Solutions







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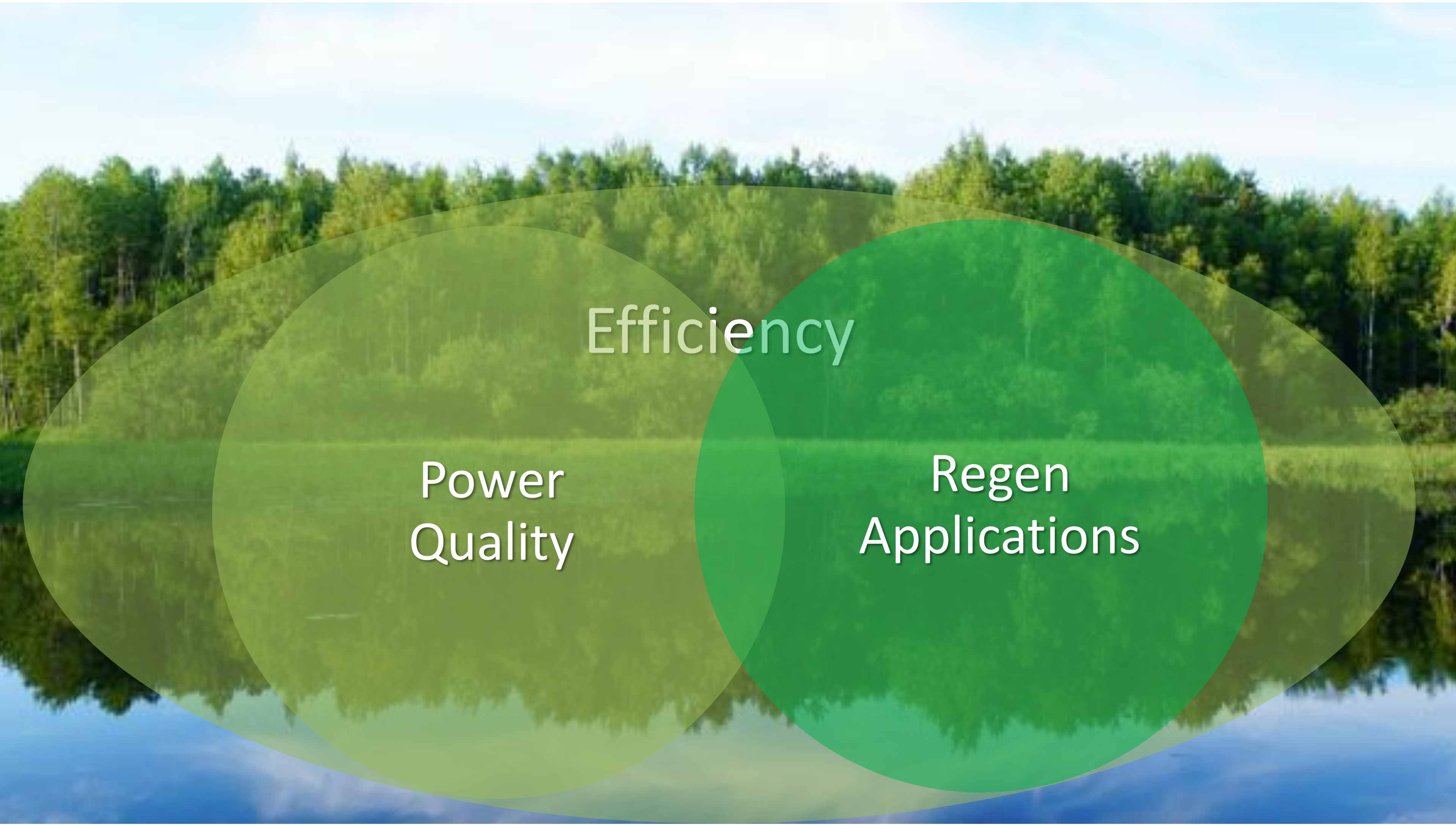
REVCON sales channel

REVCON Focus:



Optimizing your drive!

Harmonic Distortion of Drives: Issues and Solutions

Part 1:

1.1 Training on harmonics: Basics

1.2 Training on harmonics: Problems and issues

1.3 The impact of the short circuit power ratio

Part 2:

2.1 Harmonic solutions available

2.2 Passive Harmonic Filter technologies

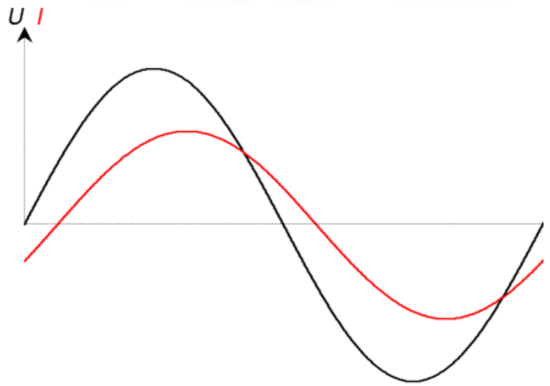
2.3 Hybrid Harmonic Filter

2.4 Open Discussion

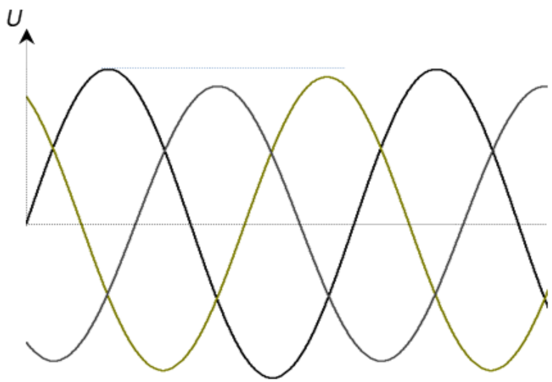
What is a Harmonic?

REVCON Optimizing your drive!

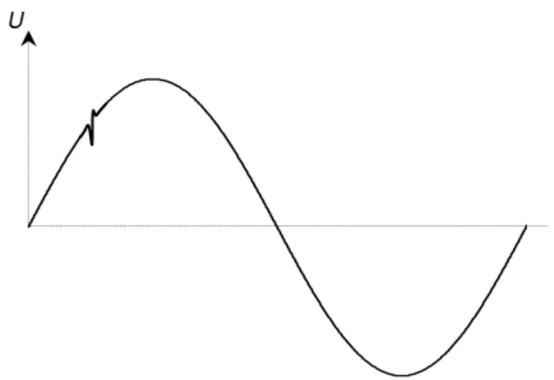
Power Quality - distortion



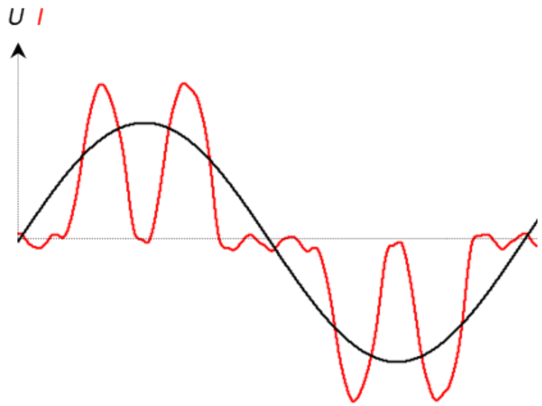
Reactive current on fundamental frequency



Voltage unbalance

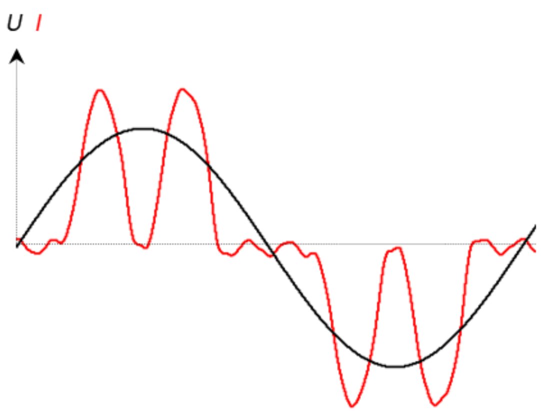


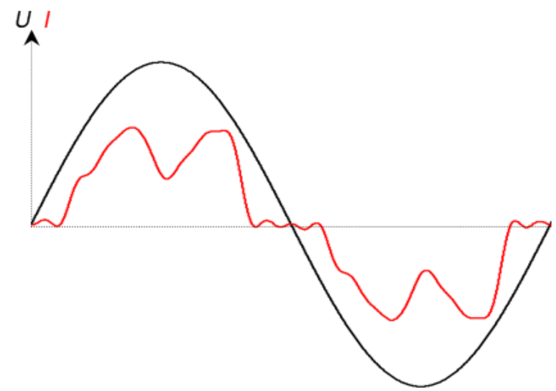
Transients

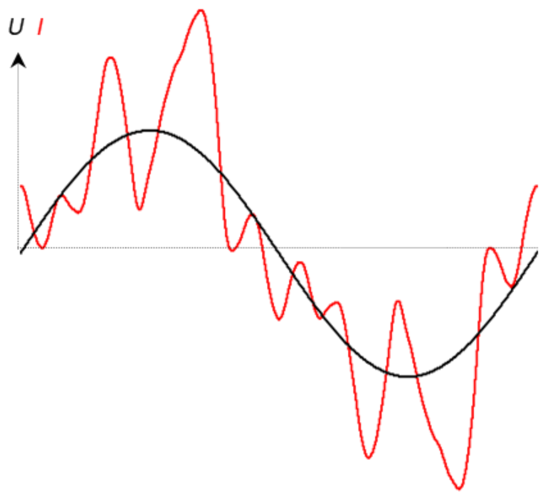


Harmonic distortion

Power Quality - non-linear loads







Rectifier with no/low inductance	Rectifier with ~4% inductance	Mix of non-linear loads
Current shape is significantly different from sinus. Significant distortion.	Current shape is significantly different from sinus, but fundamental part is significantly higher than without choke.	High distortion: The current shape is extremely different from sinus.
Typical equipment: 6-Pulse rectifier without inductance. (e.g.: low power or low quality drives)	Typical equipment: 6-Pulse rectifier with 4% DC-inductance. (e.g.: quality drives)	Typical equipment: mix of single phase and 6-Pulse rectifier without inductance.

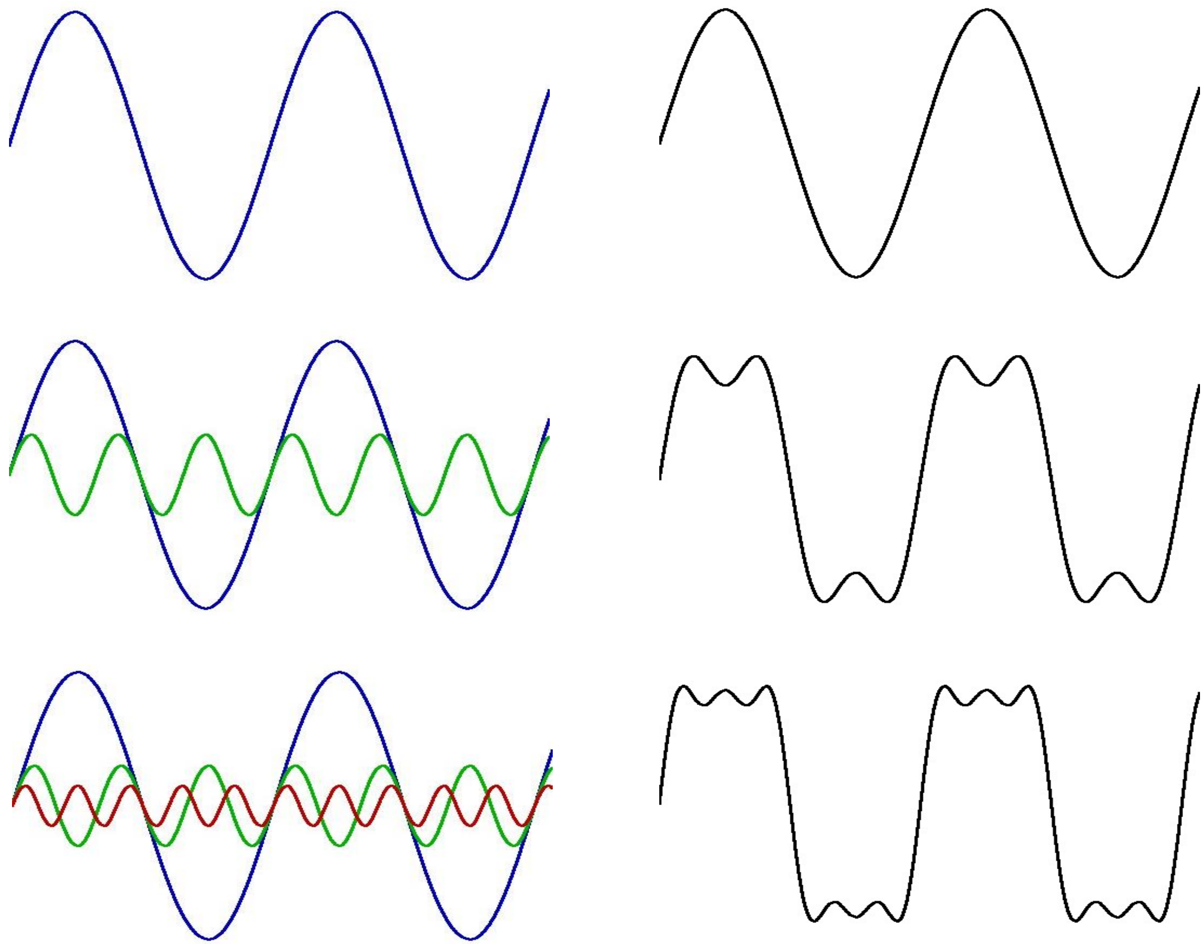
Harmonics - composed frequencies

Spectrum | Individual frequencies | Composed frequencies

Fundamental frequency

Fundamental frequency
+ 3rd Harmonic

Fundamental frequency
+ 3rd Harmonic
+ 5th Harmonic



Harmonic distortion - evaluation of harmonics

The harmonic frequency is defined by:
(n = harmonic number)

$$f_h = n \bullet fundamental\ frequency$$

Example for n = 11 (11th harmonic) in a 50Hz network:

$$f_{h11} = 11 \bullet 50\text{Hz} = 550\text{Hz}$$

The harmonic current is the amplitude value of the corresponding frequency.

I_{h11} = current amplitude of the 550Hz signal

Harmonics - mathematical basic

Fourier transform

- Any signal can be expressed as a sum of its harmonics.
- Harmonics are multiples of the fundamental frequency.

Examples for 50Hz:

- 2nd Harmonic = 100Hz
- 3rd Harmonic = 150Hz

…

- 5th Harmonic = 250Hz

…

- 7th Harmonic = 350Hz

…

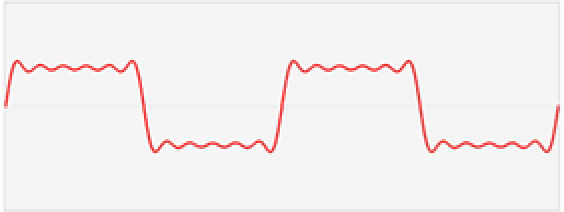
- 11th Harmonic = 550Hz

…

- 13th Harmonic = 650Hz

…

- The **Fourier transform** decomposes a function of time (*a signal*) into its individual frequencies



Reference: www.wikipedia.de

What is a Harmonic?

Harmonics are sinewave signals overlapping the main (fundamental) frequency.

Every Harmonic is defined by:

Harmonic **order** (5th Harmonic = 250Hz, 7th Harmonic = 350Hz …)
Harmonic **amplitude** (how strong is the harmonic)
Harmonic **angle** (harmonics of different angle compensate each other)

Harmonic distortion - evaluation of harmonics

How are Harmonics evaluated?

Harmonic distortion - evaluation of harmonics

***THDi* and *THDv* value**

The harmonic distortion is evaluated by the "Total Harmonic Distortion" (*THD*). This is separated into *THDv* (or *THDu*) for voltage distortion and *THDi* for current distortion. This is typically defined for harmonics up to 40th or 50th.

Harmonic distortion - evaluation of harmonics

Flashback: what is the I_{RMS}

$$I_{RMS} = \sqrt{\sum_{n=1}^{n=40} I_n^2} = \sqrt{I_{h1}^2 + I_{h2}^2 + I_{h3}^2 + I_{h4}^2 + I_{h5}^2 + I_{h6}^2 + \cdots + I_{h40}^2}$$

Fundamental part ***Harmonic part***

Harmonic distortion - evaluation of harmonics

THDi

The sum of all harmonic currents up to the 40th, are defined as *THC*

$$THC = \sqrt{\sum_{n=2}^{n=40} I_n^2} = \sqrt{I_{h2}^2 + I_{h3}^2 + I_{h4}^2 + I_{h5}^2 + I_{h6}^2 + \cdots + I_{h40}^2}$$

The *THDi* is defined as:

$$THDi = \frac{THC}{I_1} \bullet 100\%$$

Hence:

$$\boldsymbol{THDi} = \frac{\sqrt{\sum_{n=2}^{n=40} I_n^2}}{I_1} \bullet 100\% = \frac{\sqrt{I_{h2}^2+I_{h3}^2+I_{h4}^2+I_{h5}^2+I_{h6}^2+\cdots+I_{h40}^2}}{I_1} \bullet 100\%$$

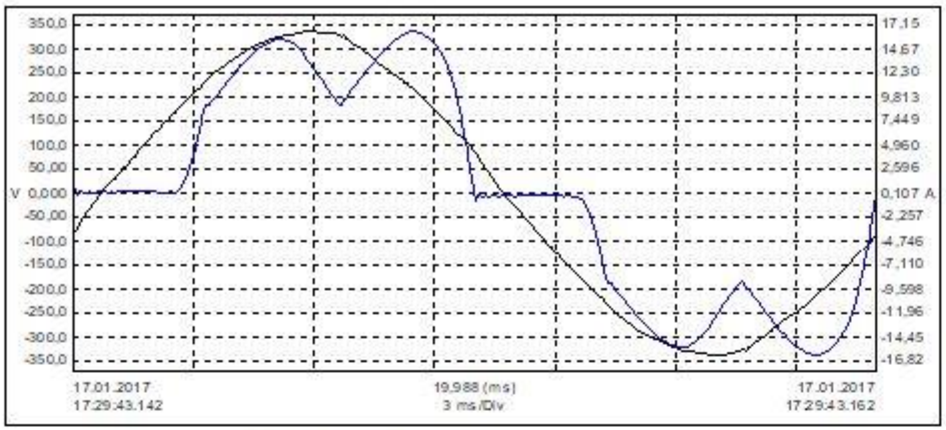
Harmonic distortion - evaluation of harmonics

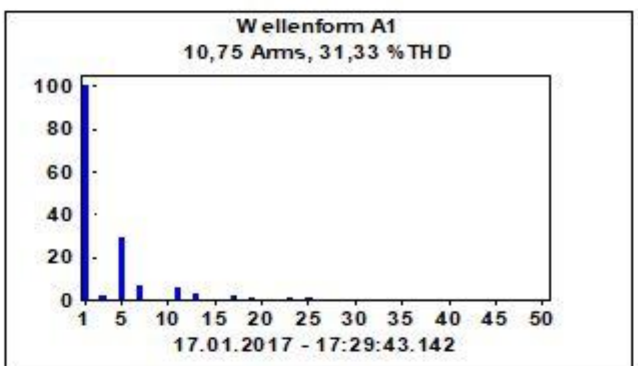
THDv

$$\boldsymbol{THDv} = \frac{\sqrt{\sum_{n=2}^{n=40} v_n^2}}{v_1} \bullet 100\% = \frac{\sqrt{v_{h2}^2 + v_{h3}^2 + v_{h4}^2 + v_{h5}^2 + v_{h6}^2 + \cdots + v_{h40}^2}}{v_1} \bullet 100\%$$

Harmonic distortion - typical measurement

Drive input current





Wellenform A1

	(%)		(%)		(%)
H01	100,0	H19	2,2	H37	0,5
H02	0,3	H20	0,0	H38	0,0
H03	2,4	H21	0,3	H39	0,2
H04	0,1	H22	0,0	H40	0,0
H05	29,2	H23	1,1	H41	0,3
H06	0,1	H24	0,0	H42	0,0
H07	7,1	H25	1,2	H43	0,4
H08	0,1	H26	0,0	H44	0,0
H09	0,6	H27	0,3	H45	0,2
H10	0,1	H28	0,0	H46	0,0
H11	6,5	H29	0,6	H47	0,2
H12	0,0	H30	0,0	H48	0,0
H13	3,4	H31	0,7	H49	0,4
H14	0,0	H32	0,0	H50	0,0
H15	0,5	H33	0,2		
H16	0,0	H34	0,0		
H17	2,4	H35	0,4		
H18	0,0	H36	0,0		

The drive input current shows a significant deviance from the sinusoidal waveform.
The drive input current can be decomposed into its individual frequencies (Harmonics).
For drives these are typically the 5th, 7th, 11th, 13th harmonic.
The fundamental frequency "1st harmonic" is 50Hz, this is the intended frequency.
All other components are considered as "harmonic distortion".

Harmonics

How are Harmonics evaluated?

Harmonic current distortion is evaluated by the ***THDi*** (or *TDD* = Total Demand Distortion)
This is the harmonic content of the I_{RMS} (measured current) divided by the fundamental part

Harmonic voltage distortion is evaluated by the ***THDv***
This is the harmonic content of the v_{RMS} (measured voltage) divided by the fundamental part

Optimizing your drive!

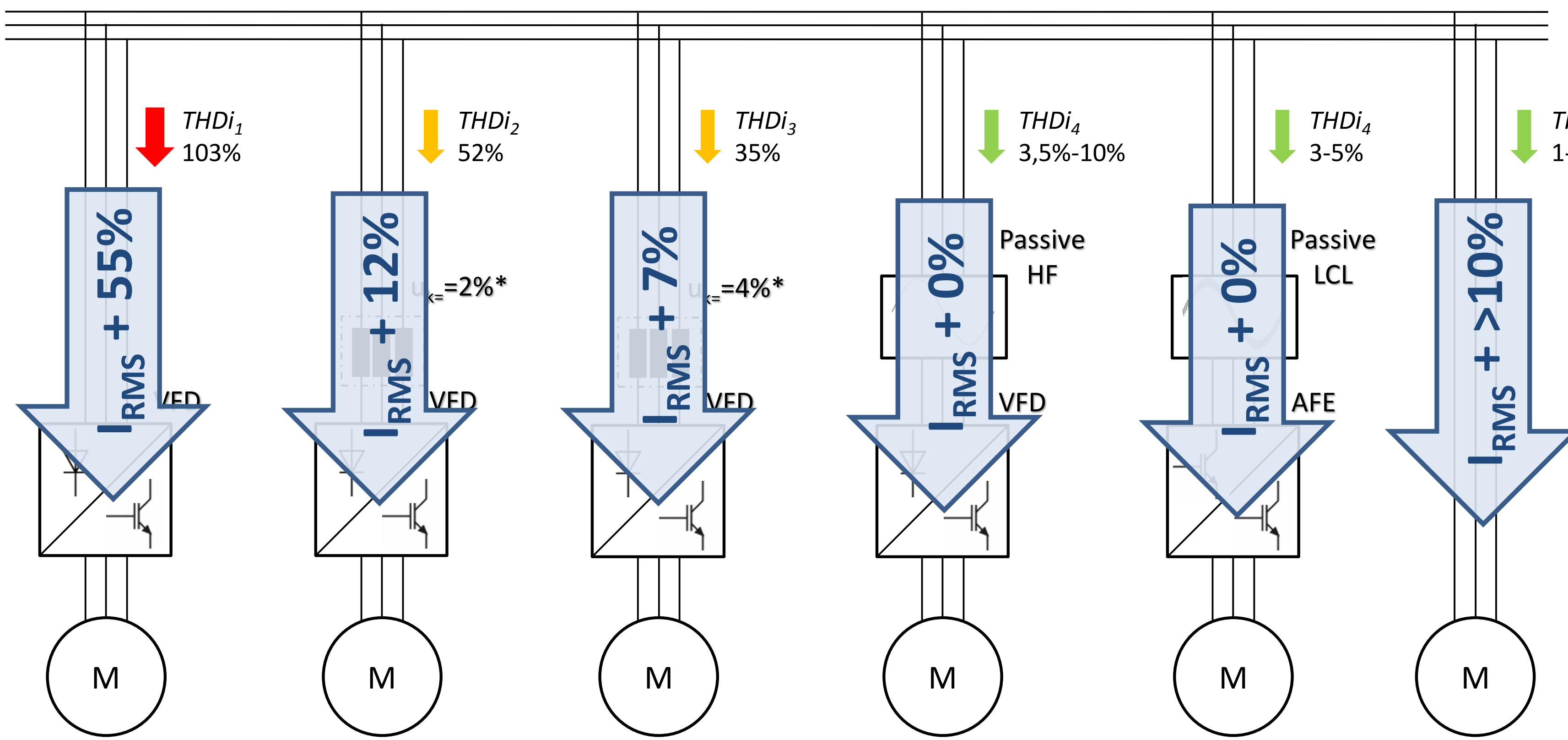
Harmonic Distortion of Drives: Issues and Solutions

Harmonics

Simple! That's it?

Optimizing your drive!

Harmonic distortion of motors / VFD



*choke can be added AC or DC side with similar result. Typically installed DC side.

Simple! That's it?

No!

Using *THDi* as an evaluation for harmonics, gives you quick picture of the harmonic situation.

Looking at the *THDi* equation, all Harmonic orders are equal. They are not!

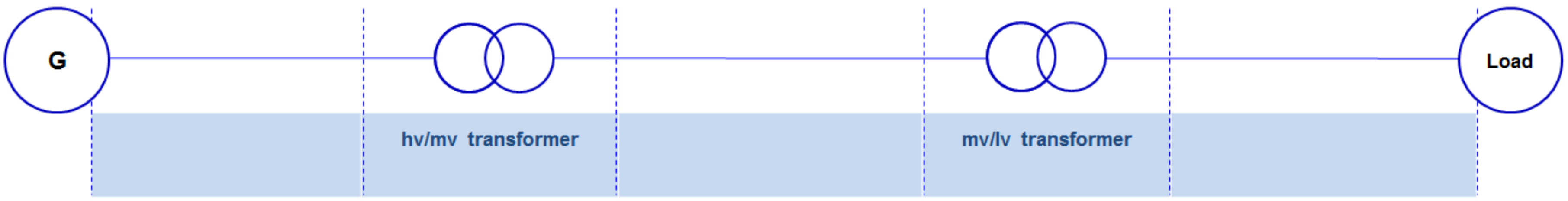
$$\boldsymbol{THDi} = \frac{\sqrt{I_{h2}^2 + I_{h3}^2 + I_{h4}^2 + I_{h5}^2 + I_{h6}^2 + \cdots + I_{h40}^2}}{I_1} \bullet 100\%$$

Harmonics

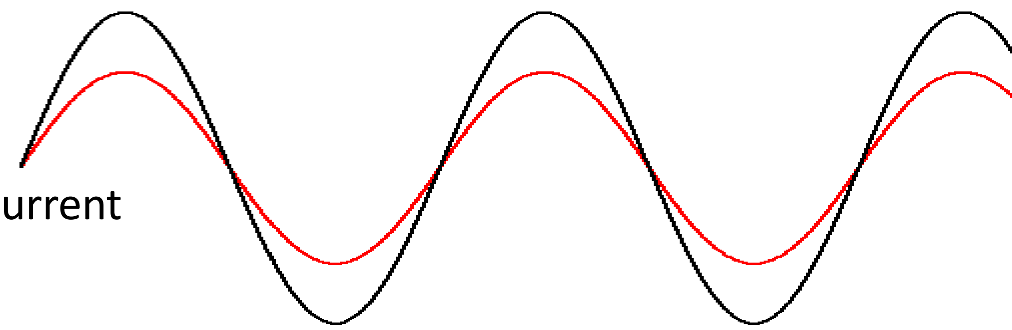
Why do we care about Harmonic currents?

Harmonic distortion - ideal supply

Ideal supply

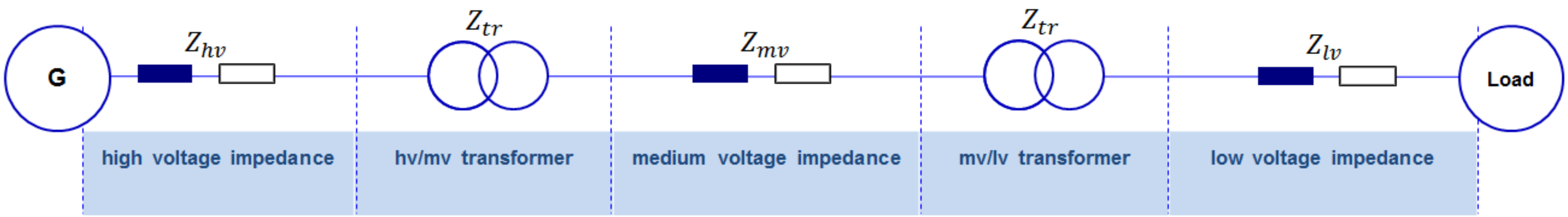


- Generators produce ideal sinusoidal current.
- Transformers and wires don't have
  any impedance
- The Loads are consuming ideal sinus current
- --> No voltage distortion



Harmonic distortion - real supply

Real supply



- Generators produce (almost) ideal sinusoidal current.
- The Loads are consuming non linear current

Ohm´s Law

$$V = I \bullet Z$$

Why do we care about Harmonic currents?

Due to:

$$V = I \bullet Z$$

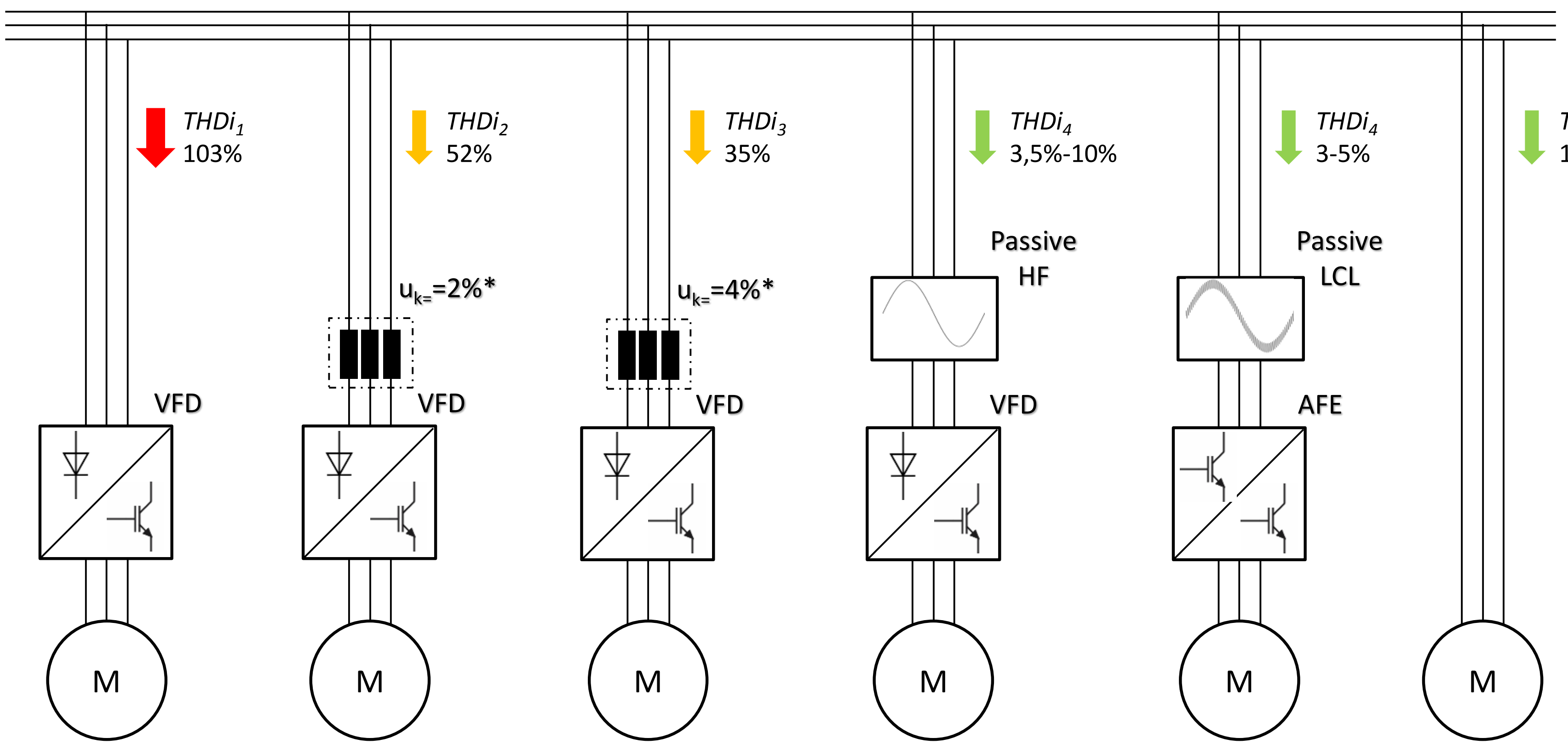
all harmonic currents cause voltage distortion

Voltage Distortion affects all equipment connected

Harmonics

Are all Harmonics equal?

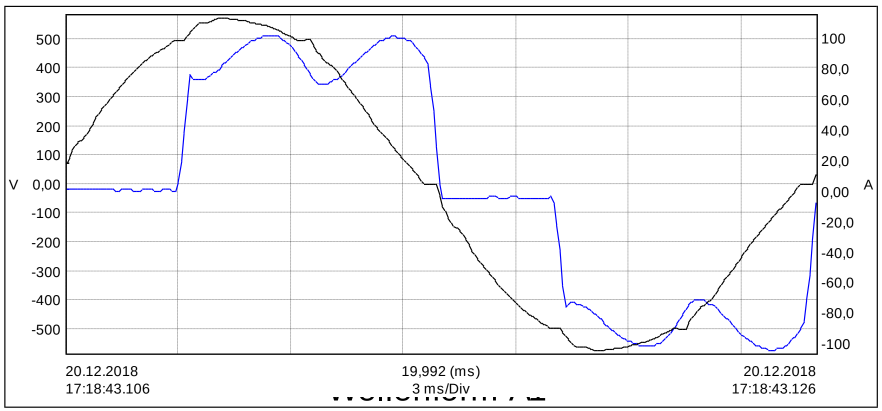
Harmonic distortion of motors / VFD

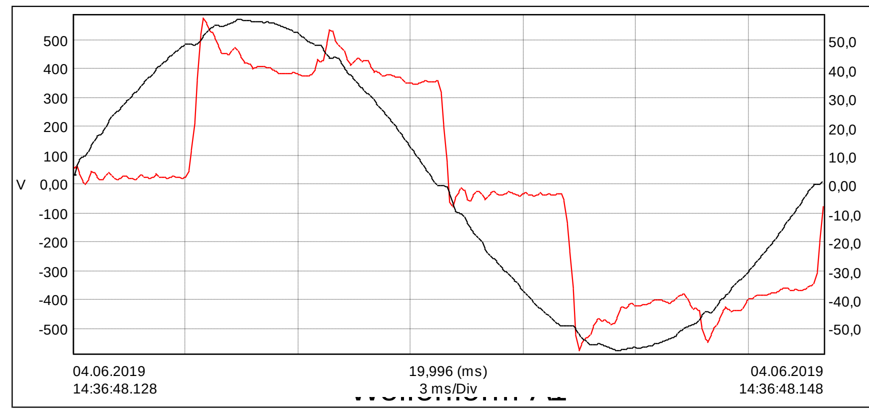


*choke can be added AC or DC side with similar result. Typically installed DC side.

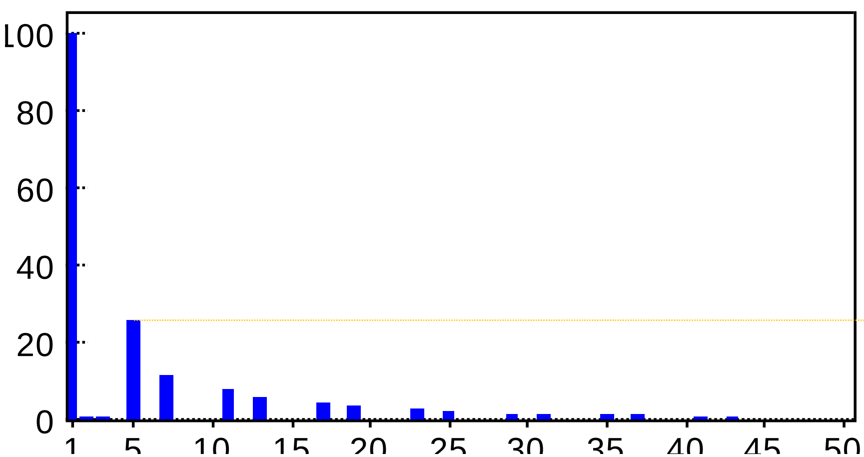
Harmonic distortion - comparison

Standard Drive vs. Slim DC Bus Drive

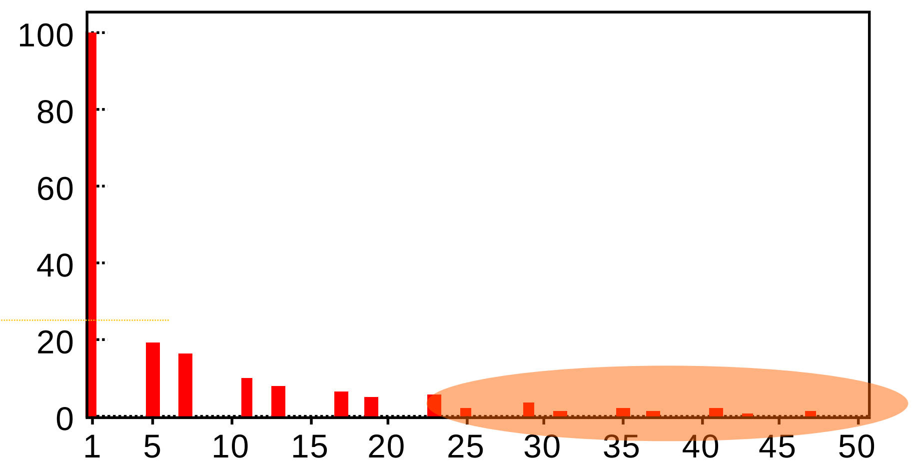




72,17 Arms, 31,10 %THD



34,63 Arms, 31,17 %THD



Harmonic distortion - evaluation of harmonics

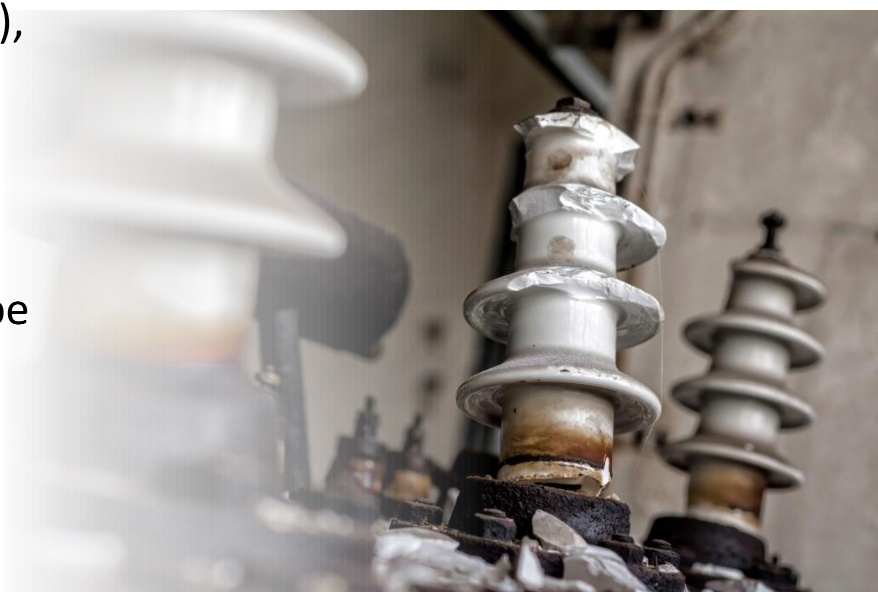
The ***THD*** is a good evaluation for Harmonic Distortion but it **is not sufficient to give a full evaluation of the problems that may be caused by harmonics**.

Example:
100A distortion on the 5th Harmonic (I_5=100A)
will cause the same *THDi* as:
100A distortion on the 37th Harmonic (I_{37}=100A),

Power loss inside a transformer caused by I_{37} would be significantly higher.

Power loss inside a motor caused by I_{37} would be significantly higher.

And so on…



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Harmonic distortion - evaluation of harmonics

IEC define PWHD

The **Partial Weighted Harmonic Distortion** is a value to evaluate the higher harmonics between the 14^{th} and 40^{th}. This evaluation is available for current (*PWHD,i*) and voltage (*PWHD,v*) and is used in several standards.

$$\boldsymbol{PWHD,i} = \frac{\sqrt{\sum_{n=14}^{n=40} I_n^2}}{I_1} \bullet 100\% = \frac{\sqrt{I_{h14}^2 + I_{h15}^2 + I_{h16}^2 + I_{h17}^2 + \cdots + I_{h40}^2}}{I_1} \bullet 100\%$$

$$\boldsymbol{PWHD,v} = \frac{\sqrt{\sum_{n=14}^{n=40} U_n^2}}{U_1} \bullet 100\% = \frac{\sqrt{U_{h14}^2 + U_{h15}^2 + U_{h16}^2 + U_{h17}^2 + \cdots + U_{h40}^2}}{U_1} \bullet 100\%$$

Standards - IEEE

IEEE 519-2014

Current distortion level of for systems 120V – 69kV

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{SC}/I_L	<11	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0
Even harmonics are limited to 25% of the odd harmonic limits above.						
Current distortions that result in a dc offset, e.g. half-wave converters, are not allowed.						
* All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.						

Where

- I_{sc} = maximum short-circuit current at PCC.
- I_L = maximum demand load current (fundamental frequency component) at PCC.
- TDD = Total demand distortion (RSS), harmonic current distortion in % of maximum demand load current (15 or 30 min demand).
- PCC = Point of common coupling.

Harmonics

Are all Harmonics equal?

No. Higher Order Harmonics will typically cause more harm than lower order harmonics.

Evaluation of Harmonic distortion based on *THDi* or *TDD* is only possible, if the harmonic spectrum is known.
(e.g. Drive load with high performance / high quality drive)

Harmonics

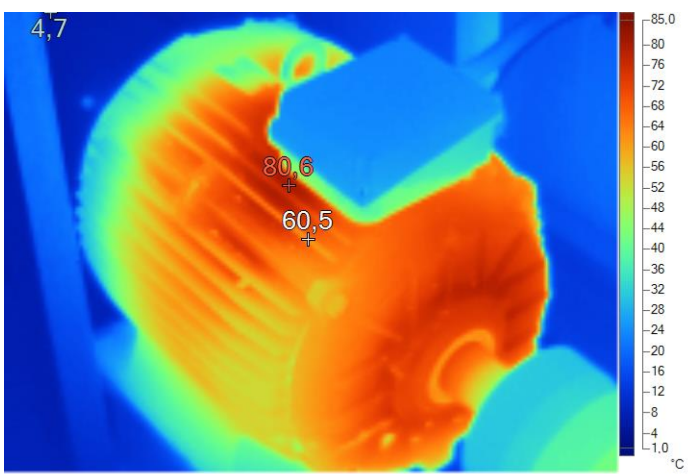
Which damage is caused by harmonics?

Harmonic voltage distortion

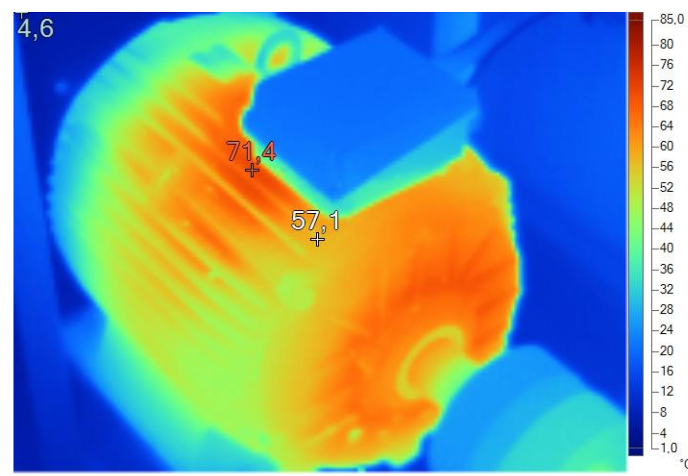
Voltage distortion cause power loss!

Comparison of Motors DOL @ equal load but different voltage distortion

18.5kW
THDv = 6,8%



18.5kW
THDv = 1,8%



@ 8% *THDv*, a motor DOL can run max. 85% load

Harmonic distortion - Problems

Transformers and PFC

Increased losses!

Reduced power! Expected lifetime lower!

Transformers and capacitor banks must be oversized or might overheat at nominal load.

Electronical equipment

Increased losses, and reduced lifetime expectation.

Equipment failures → Lost data, Production stop, Equipment costs

Wrong evaluation of signals → troubleshooting costs and production loss

Harmonic distortion - Problems

Motors and Generators (uncontrolled)
Increased losses, and reduced lifetime expectation. Reduced torque and unsteady torque (even vibrations) on shaft output. Lower lifetime expectations of Bearings, gearboxes and further connected equipment

System Efficiency
Equipment efficiency may be affected by the harmonic distortion of the mains voltage. In addition connection wires will produce higher losses. This leads to higher costs for user.

Which damage is caused by harmonics?

Every non resistive equipment will suffer from Harmonics.

Lower lifetime
Electrical and mechanical damage
Less efficiency

Harmonic Distortion of Drives: Issues and Solutions

Part 1:

1.1 Training on harmonics: Basics

1.2 Training on harmonics: Problems and issues

1.3 The IEEE 519 and the impact of the short circuit power ratio

Part 2:

2.1 Harmonic solutions available

2.2 Passive Harmonic Filter technologies

2.3 Hybrid Harmonic Filter

2.4 Open Discussion

Harmonics

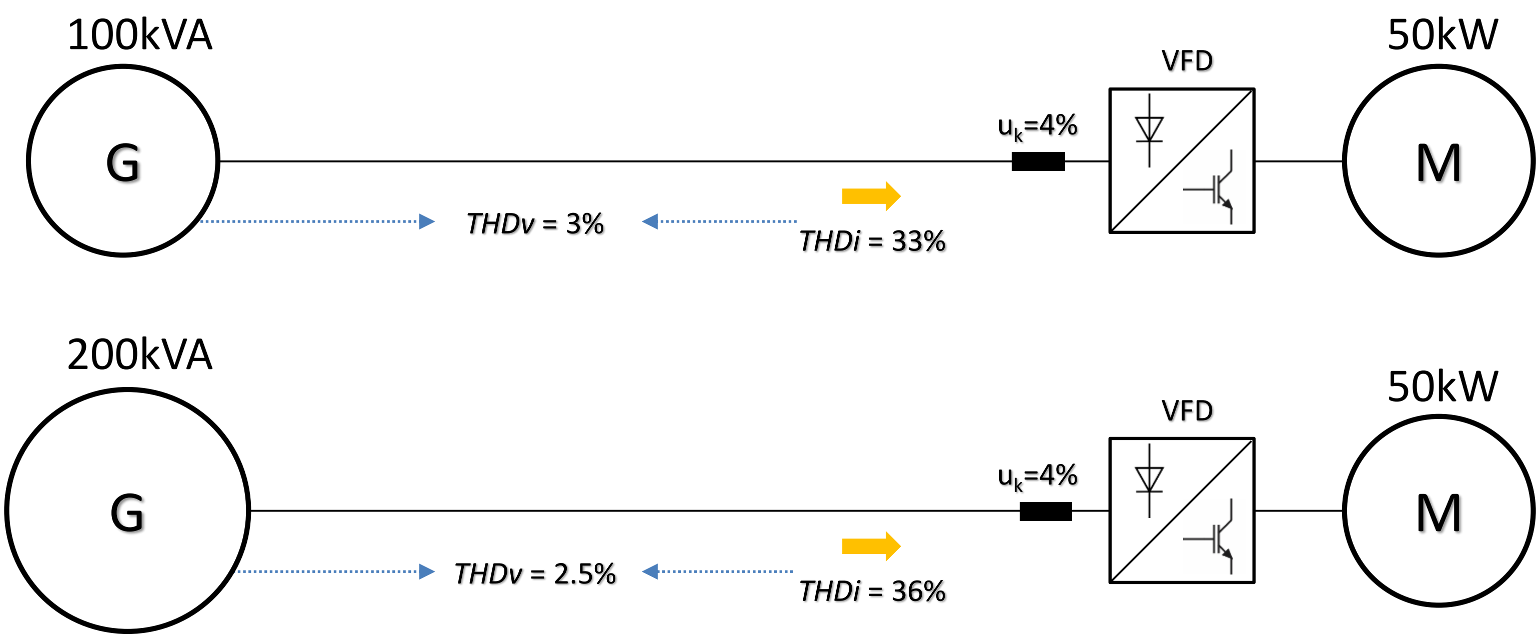
Do I need Harmonic mitigation?

Optimizing your drive!

Standards - Network conditions

The harmonic currents of equipment cause harmonic distortion on the mains voltage.
The impact of the voltage depend on the strength of the mains supply.

Simplified diagrams:



Harmonics – Standards and Recommendation

Standard	Class	*THDv* limit
EN 50160	-	8%
IEC 61000-2-4	1	5%
IEC 61000-2-4	2	8%
IEC 61000-2-4	3	10%
IEEE 519-2014	<1000V	8%
G5/4	400V	5%

Practice	-	*THDv* limit
Good Practive	-	5%
IEEE 519-2014 Target	-	5%

Standards - IEEE

IEEE 519-2014

Current distortion level of for systems 120V – 69kV

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{SC}/I_L	<11	11≤h<17	17≤h<23	23≤h<35	35≤h	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
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Where

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- PCC = Point of common coupling.

Harmonic distortion - evaluation of harmonics

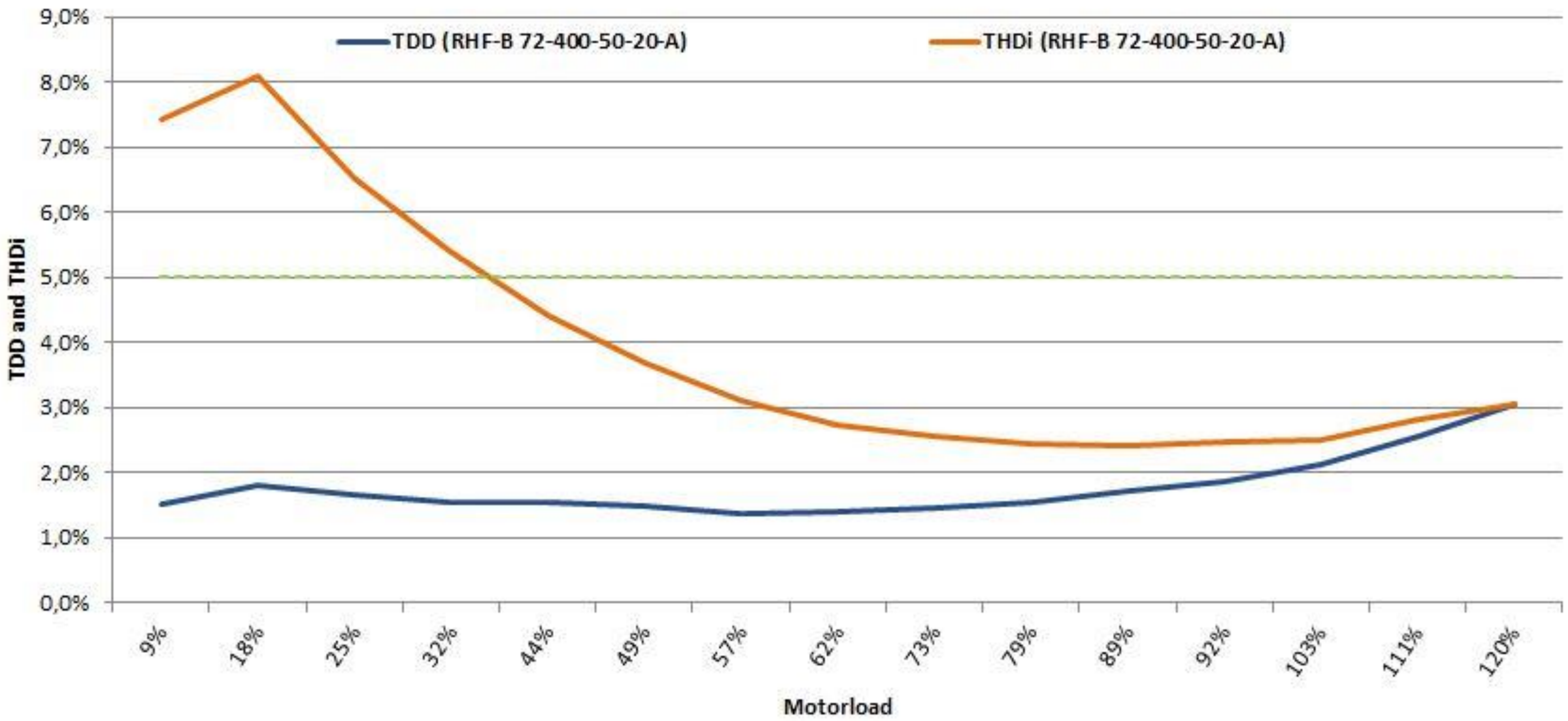
TDD

Total Demand Distortion of the current (used in e.g. IEEE-519:2014)
Equal to THDi the TDD express the distortion of harmonics from 2nd - 40th. But the THC is divided through I_L instead of I_1.
I_L is also the fundamental frequency amplitude, but defined as the maximum demand current. IEEE-519: “This current value can be established at the PCC and should be taken as the sum of the currents corresponding to the maximum demand during each of the twelve previous months divided by 12.“

$$TDD = \frac{\sqrt{\sum_{n=2}^{n=40} I_n^2}}{I_L} = \frac{\sqrt{I_{h2}^2 + I_{h3}^2 + I_{h4}^2 + I_{h5}^2 + I_{h6}^2 + \cdots + I_{h40}^2}}{I_L} \bullet 100\%$$

At full load: ***TDD = THDi***

Harmonic distortion - TDD vs. THDi



Looking at THDi only, an Inexperienced user, might think that 18% load is worst case harmonic distortion.

***TDD* is user friendly** as always taking reference to the maximum current and showing worst case harmonic distortion (here 120% load).

Optimizing your drive!

Standards - Network conditions

$$R_{SCE} = \frac{S_{SC}}{S_{equ}} \approx \frac{I_{SC}}{I_L}$$

$$S_{SC} = \frac{U_{nom}^2}{Z_{sc}}$$

$$Z_{sc} = \sqrt{R_{sc}^2 + X_{sc}^2}$$

R_{SCE}: *Short circuit power ratio*

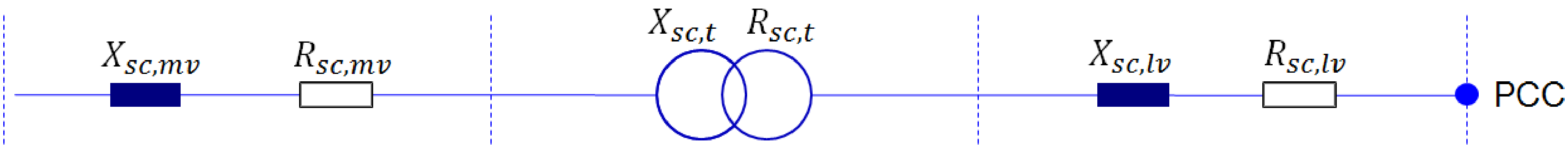
S_{SC}: *Short circut power*
I_{SC}: *Short circut current*

S_{equ}: *Eqipment power*
I_L: *Load current*

Z_{sc}: *Short circuit impedance (50Hz)*

Standards - short circuit power calculation

Z_{sc}: **Short circuit impedance (50Hz)**



medium voltage impedance	transformer	low voltage impedance
$R_{sc,mv} \approx 0 \rightarrow X_{sc,mv} \approx Z_{sc,mv}$	$X_{sc,t} = \frac{U_{lv}^2}{S_t} \bullet \frac{u_x}{100\%}$	$X_{sc,lv} = \omega \bullet L_{wire}$ *(L_{wire} based on spez. inductance and length)*
$X_{sc,mv} = \frac{U_{lv}^2}{S_{mv}}$ *	$R_{sc,t} = \frac{U_{lv}^2}{S_t} \bullet \frac{u_r}{100\%}$	$R_{sc,lv}$ *($R_{sc,lv}$ based on spez. resistance and length)*

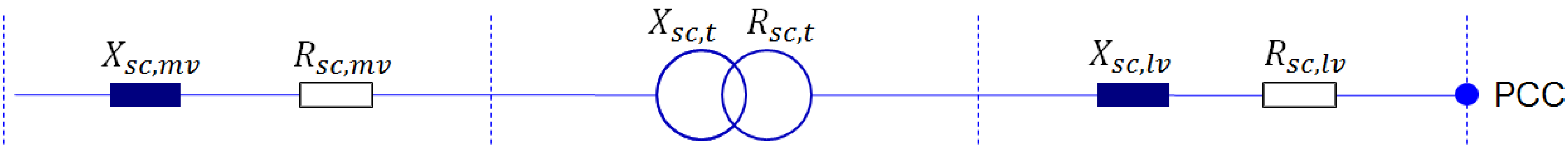
$$Z_{sc} = \sqrt{R_{sc}^2 + X_{sc}^2} = \sqrt{\left(R_{sc,t} + R_{sc,lv}\right)^2 + \left(X_{sc,mv} + X_{sc,t} + X_{sc,lv}\right)^2}$$

*low voltage value must be used in order to add up the Impedance values!

Standards - short circuit power estimation

Z_{sc}: Short circuit impedance (50Hz)

(simplified calculation based on transformer impedance)



medium voltage impedance	transformer	low voltage impedance
$X_{sc,mv} = 0$	$X_{sc,t} = \frac{U_{lv}^2}{S_t} \bullet \frac{u_x}{100\%}$	$X_{sc,lv} = 0$
$R_{sc,mv} = 0$	$R_{sc,t} = \frac{U_{lv}^2}{S_t} \bullet \frac{u_r}{100\%}$	$R_{sc,lv} = 0$

$$S_{sc,t} = \frac{S_T}{u_k} \bullet 100\% =$$

REVCON Optimizing your drive!

Harmonics

Do I need Harmonic mitigation?

Good Practice

Transformer Load	% Non-linear Load	Harmonic Mitigation
<30%	0-100%	Not required
>30% <90%	<10%	Not required
>30% <90%	10-100%	Required*
>90%	<10%	Required*
>90%	10-100%	Target 5% TDD

*Harmonic mitigation in accordance to IEEE 519-2014: Table 2

Part 1 completed, Thanks!

10min. Break

Harmonic Distortion of Drives: Issues and Solutions

Part 1:

1.1 Training on harmonics: Basics

1.2 Training on harmonics: Problems and issues

1.3 The IEEE 519 and the impact of the short circuit power ratio

Part 2:

2.1 Harmonic solutions available

2.2 Passive Harmonic Filter technologies

2.3 Hybrid Harmonic Filter

2.4 Open Discussion

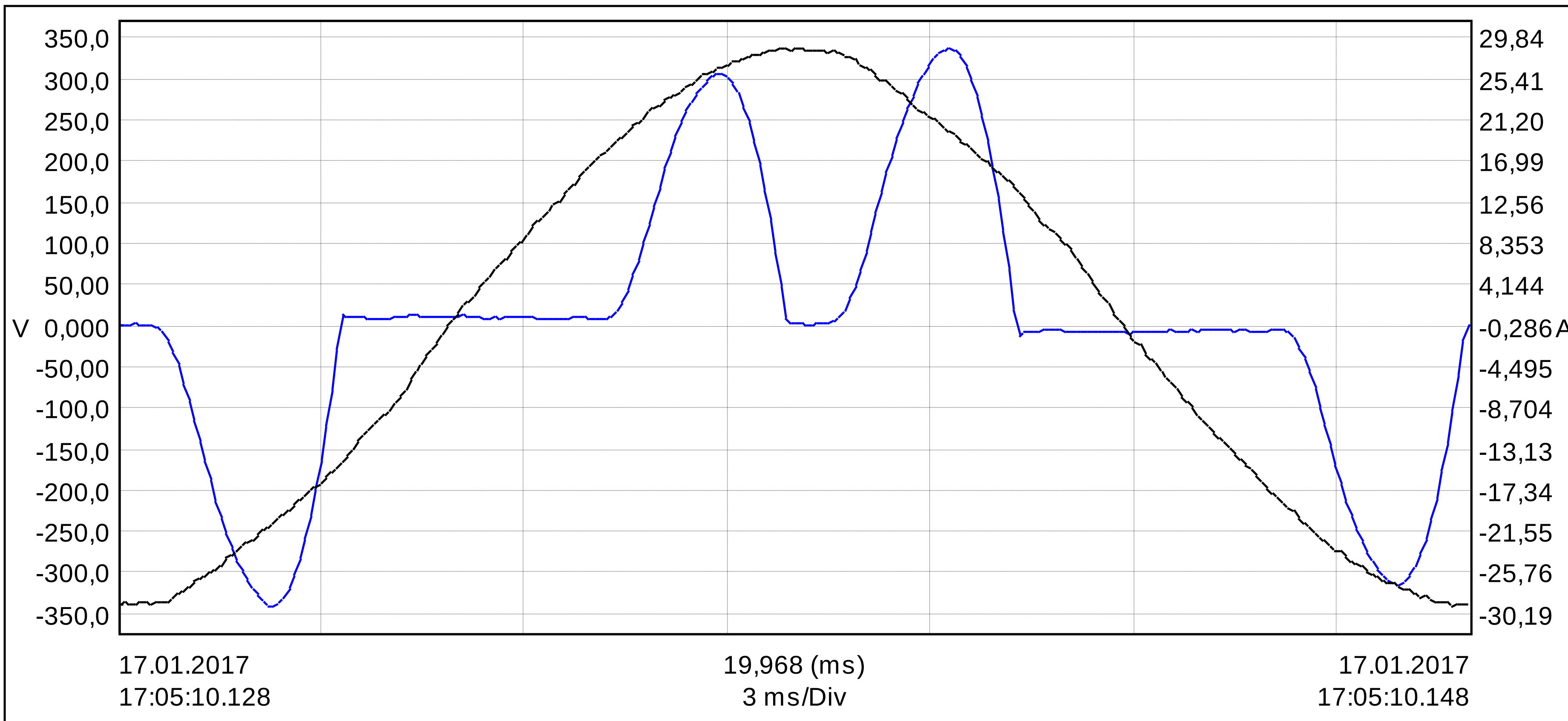
Harmonics

What does a Harmonic current look like?

Optimizing your drive!

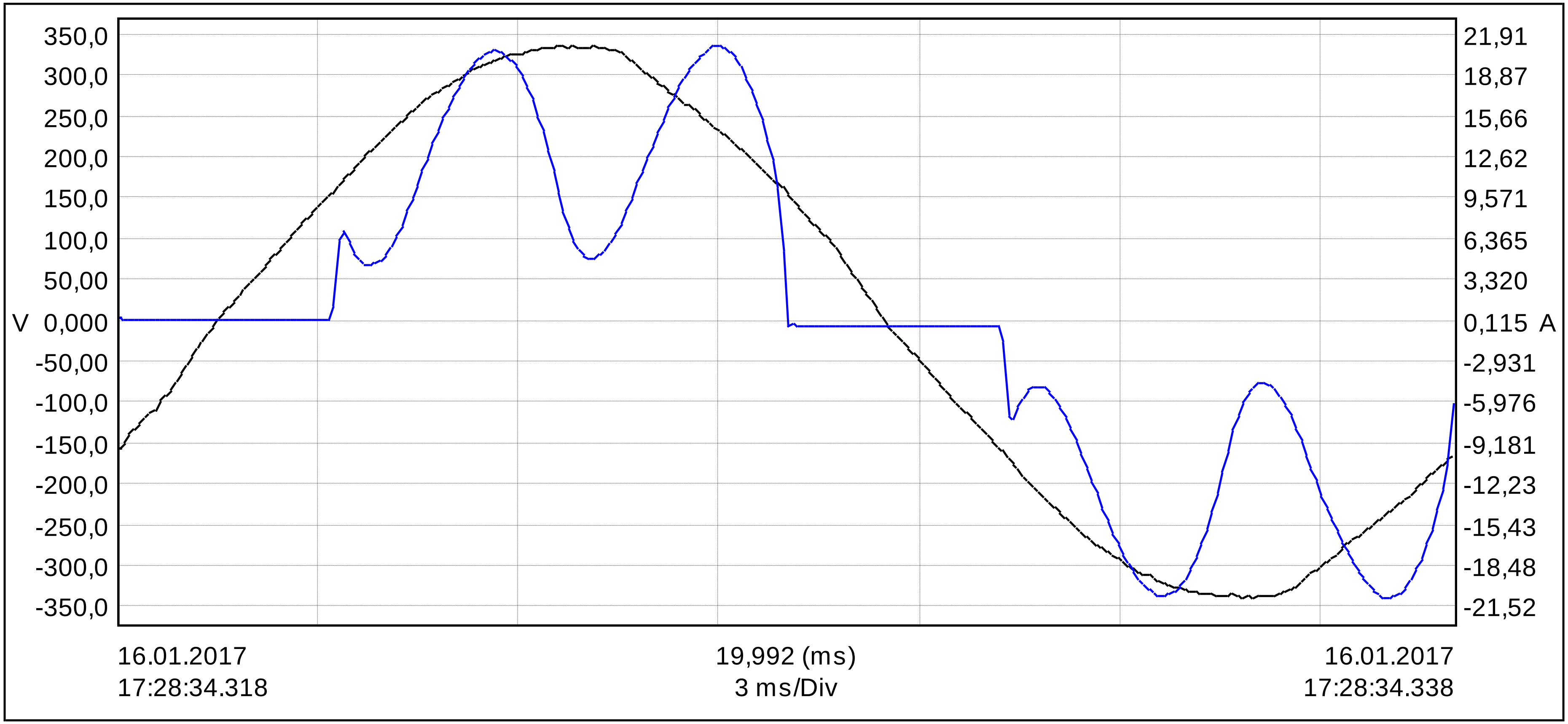
Harmonic Solutions for VSD - input current

Input current of a drive with 0,6% choke at 7kW load, 89%THDI



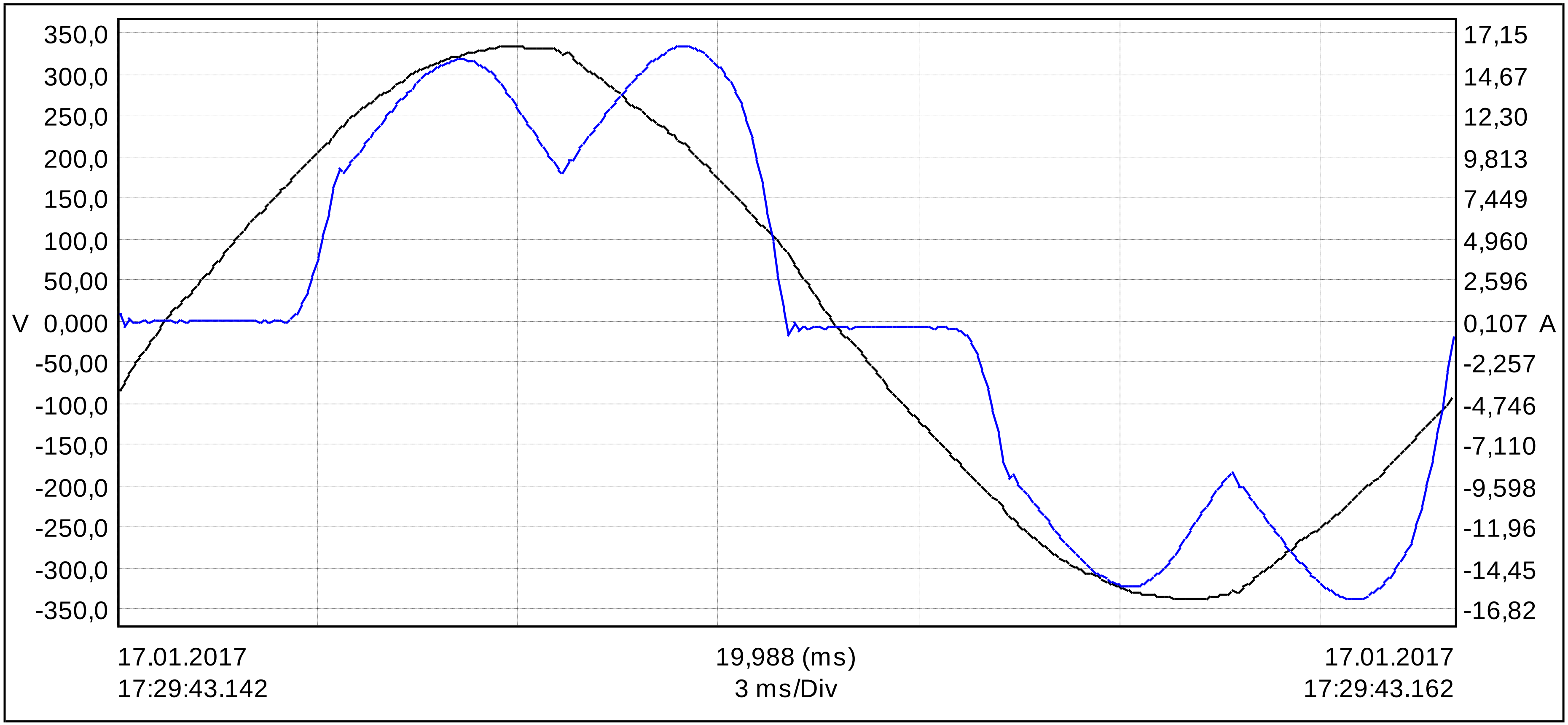
Harmonic Solutions for VSD - input current

Input current of a drive with 1,8% choke at 7kW load, 51%THDI



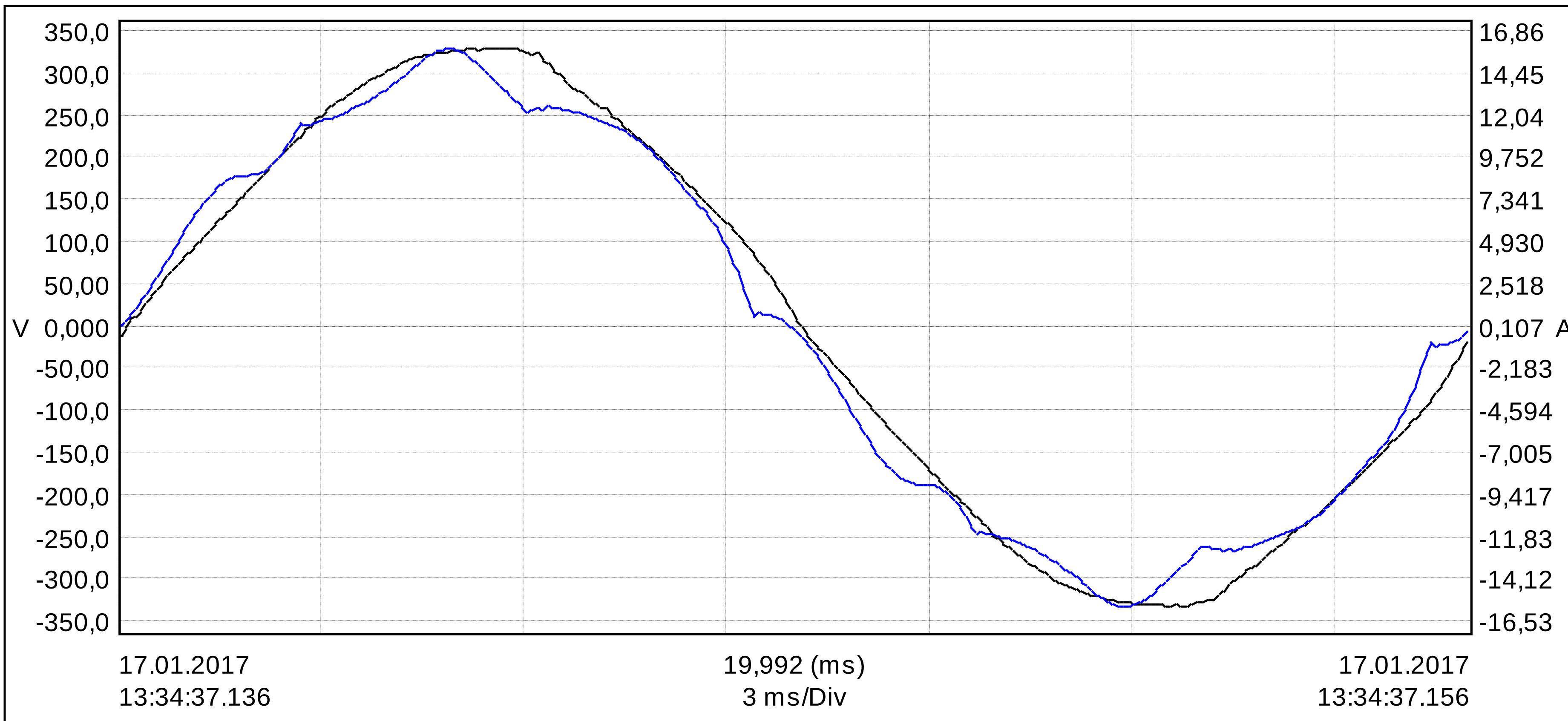
Harmonic Solutions for VSD - input current

Input current of a drive with 5,4% (AC + DC) choke at 7kW load, 32%THDI



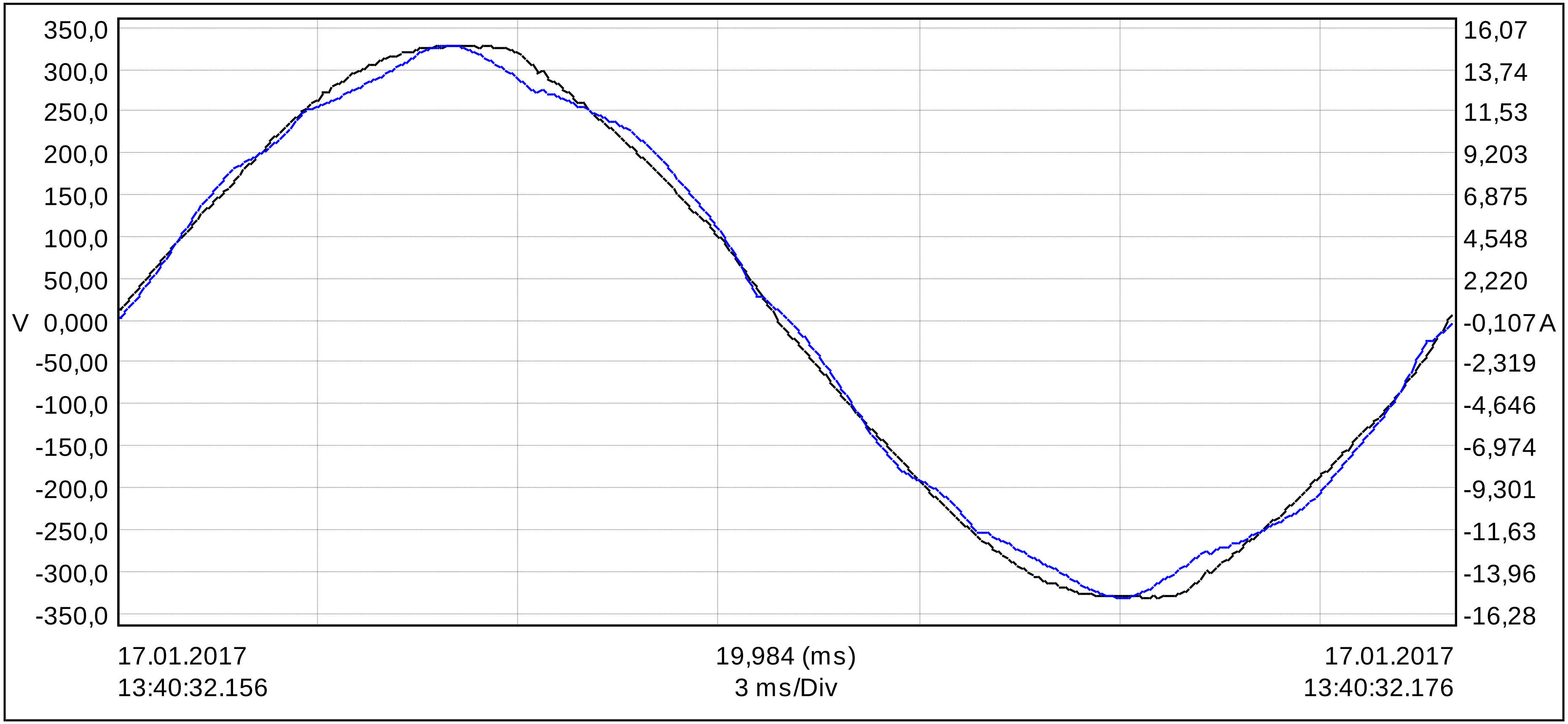
Harmonic Solutions for VSD - input current

Input current of a drive with RHF-8P filter at 7kW load, 7%THDI



Harmonic Solutions for VSD - input current

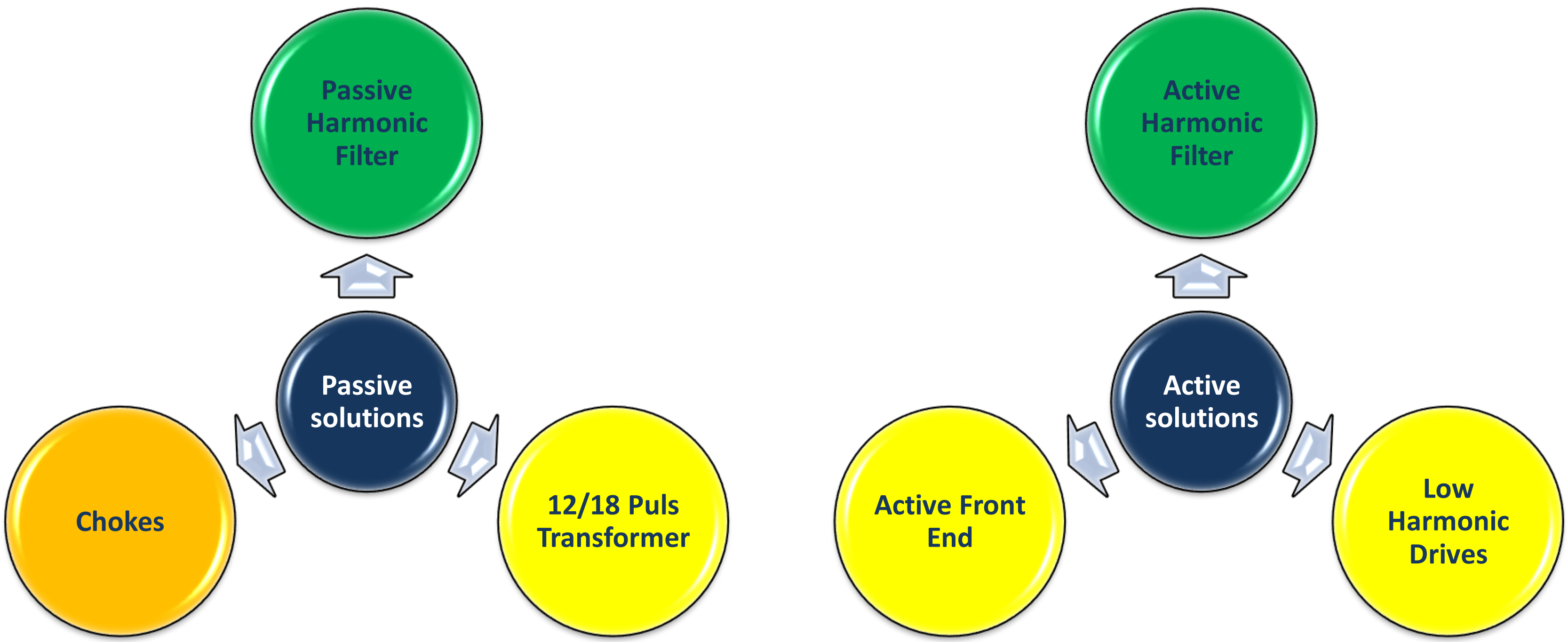
Input current of a drive with RHF-5P filter at 7kW load, 3.9%THDI



Harmonics

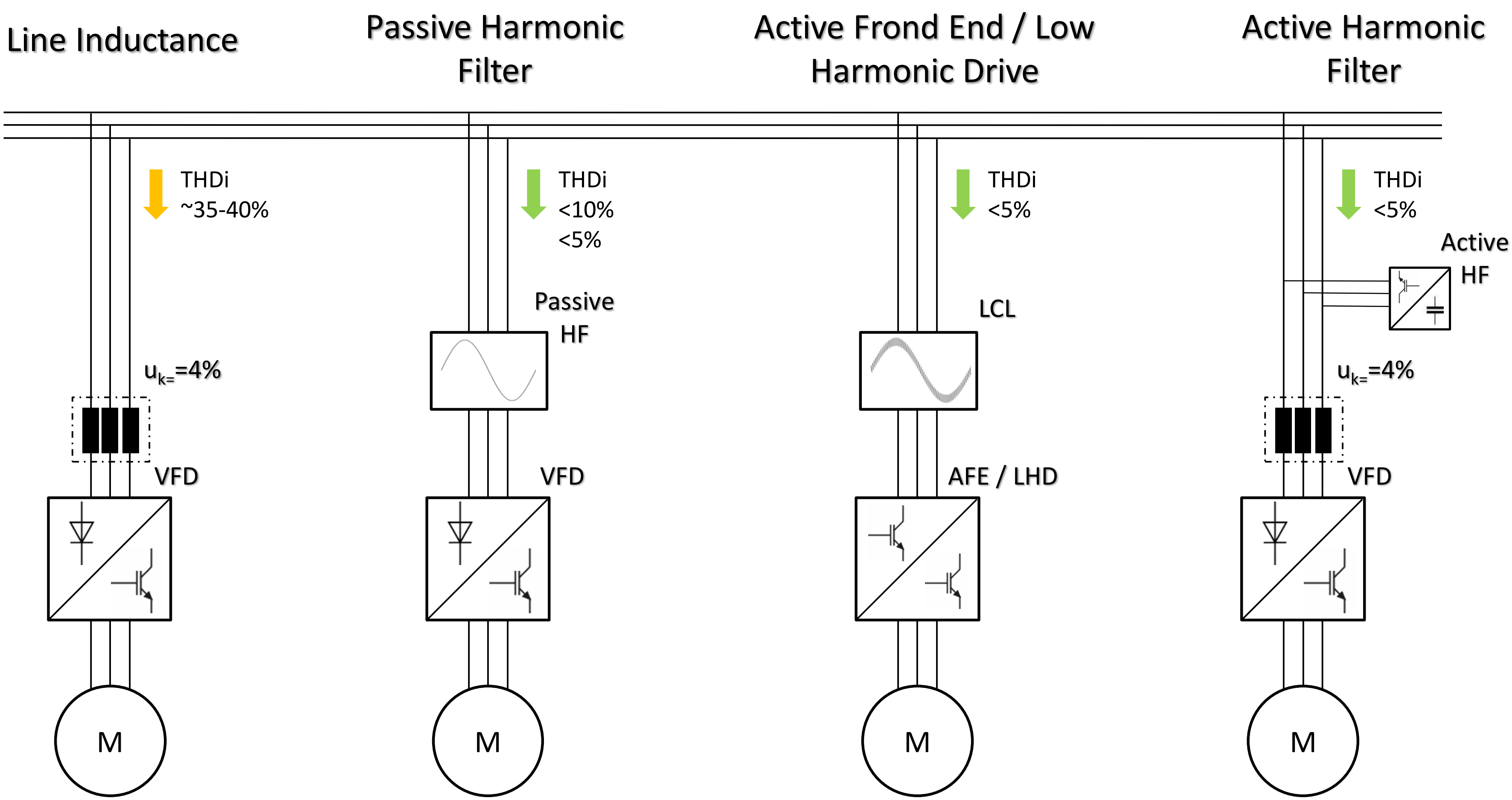
What kind of Harmonic Solutions are useful?

Harmonic Solutions for VSD - overview



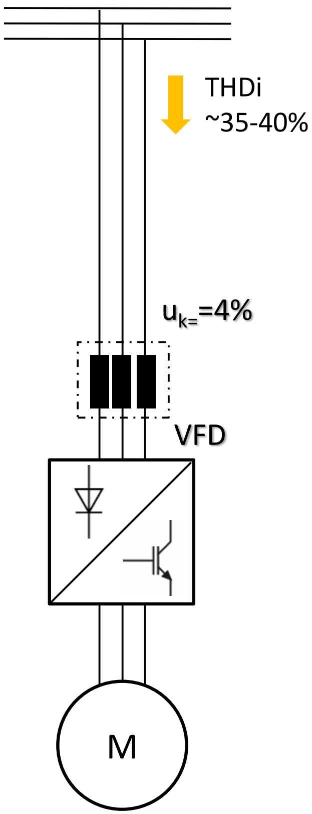
REVCON Optimizing your drive!

Harmonic Solutions for VSD - overview



Optimizing your drive!

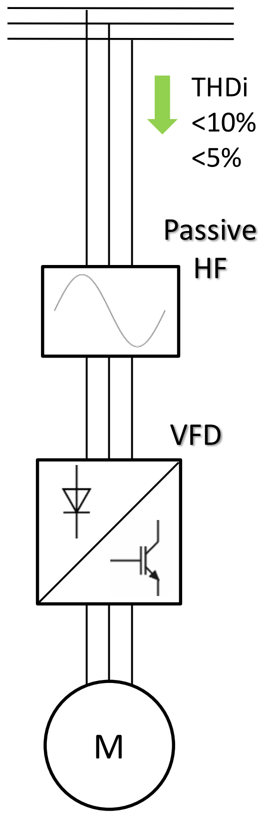
Harmonic Solutions for VSD - Choke



Solution	DC or AC choke
Value	4% impedance
Typical performance	35-50% *THDi*
Advantage	Low costs
Disadvantage	Low performance
Recommended	Yes, for small drives and networks with much linear loads

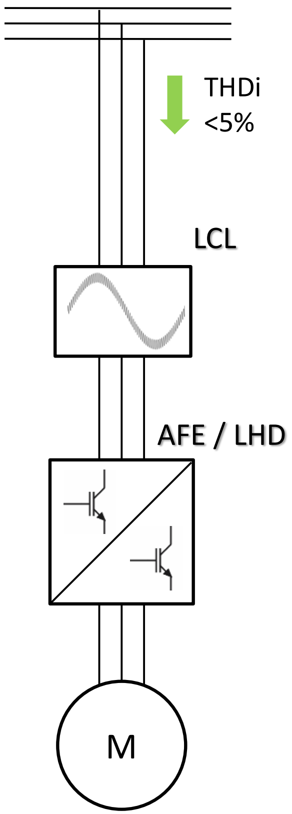
This solution is very basic and usually inbuilt by factory inside the VSD. Therefore this is not considered as a harmonic solution in the following presentation.

Harmonic Solutions for VSD - Passive HF



Solution	Passive Harmonic Filter
Typical value	n.a.
Typical performance	<5% or <10%
Advantage	Good cost/performace ratio
Disadvantage	Significant different circuits and products available.
Recommended	Yes, if taking brand specific specification such as performance and efficiency into account.

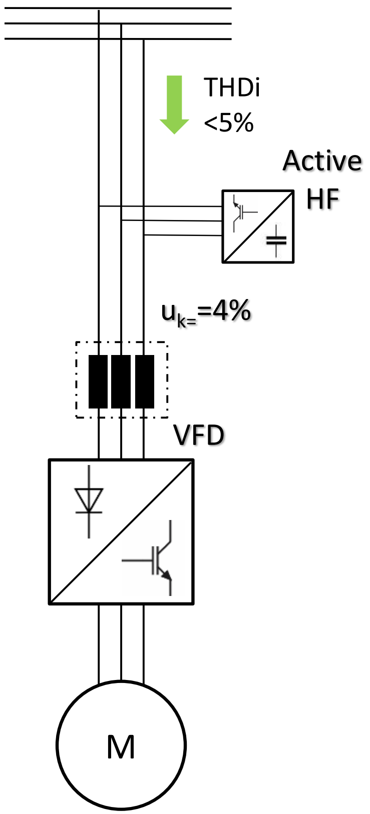
Harmonic Solutions for VSD - AFE and LHD



Solution	Active Front End Technology / (ultra) Low Harmonic Drives*
Typical performance	<5%
Advantage	Low *THDi* (<40th Harmonic)
Disadvantage	Bad cost/performance ratio Low efficiency (high switching) High distortion (>100th Harmonic) Expensive Low Lifetime expectance No performance scaling
Recommended	No

*Some manufacturer have recognized the disadvantage of IGBT active infeed for harmonic mitigation. Still the drive is considered as "low harmonic drive" but it use internal passive filter or active filter. These solutions are recommended.

Harmonic Solutions for VSD - Active HF

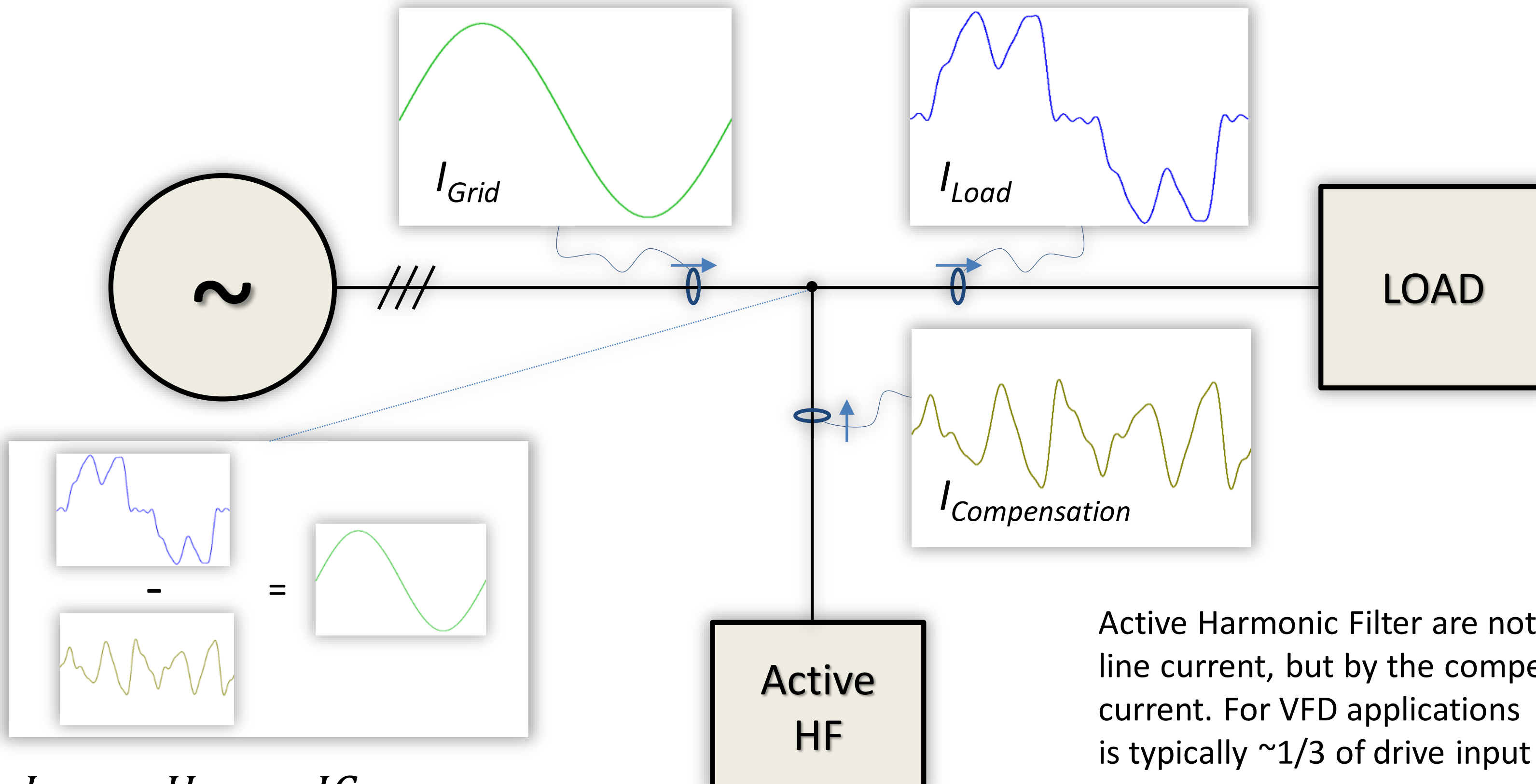


Solution	Active Harmonic Filter
Typical performance	<5%*
Advantage	High performance Easy to retrofit in systems Can be used for universal load Scalable for any performance High Efficiency
Disadvantage	Medium price/performance ratio Some brand require expensive commissioning
Recommended	Yes, especially in combination with passive harmonic filter

*depend on filter size.

Harmonic Solutions for VSD - Active HF

Working principle Active Harmonic Filter



Active Harmonic Filter are not sized by line current, but by the compensation current. For VFD applications $I_{compensation}$ is typically ~1/3 of drive input current.

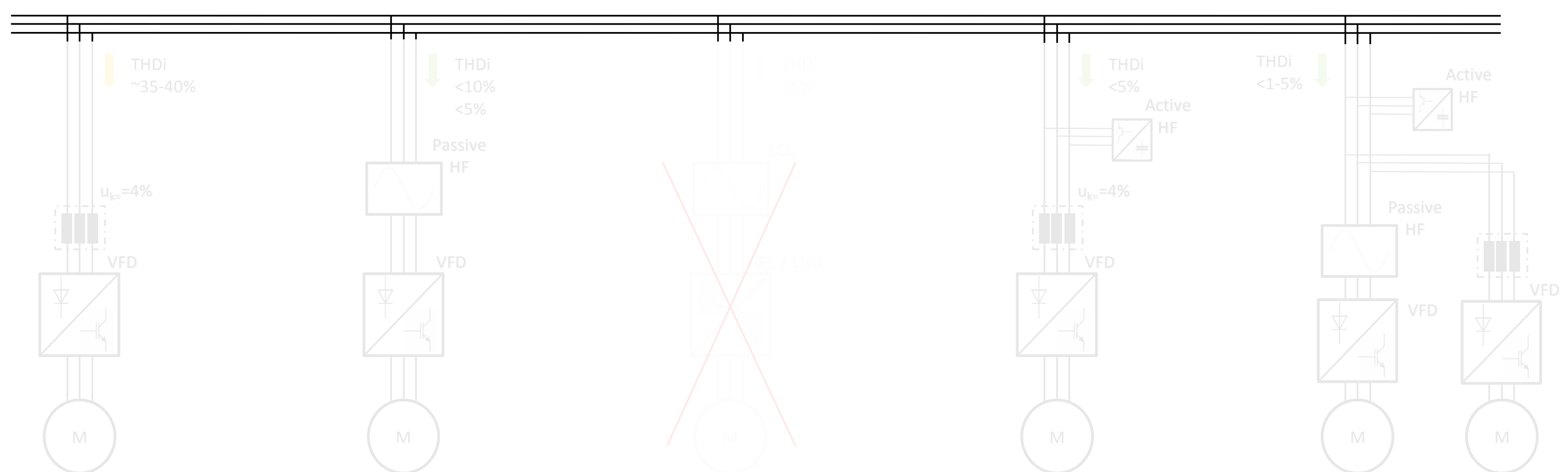
$$I_{Grid} = IL_{oad} - IC_{ompensation}$$

REVCON Optimizing your drive!

Harmonic Solutions for VSD - conclusion

What kind of Harmonic Solutions are useful?

Inductane	Passive HF	AFE or LHD	Active HF	Active and Passive HF
Low performance. Therefore not considered as solution	Good performance to a reasonable price but filter efficiency should be considered	Not recommend due to high installation costs and low efficiency.	Recommend especially for retrofit and systems with many small drives	Often best technical and commercial solution. Efficiency of the harmonic solutions should be considered.



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Harmonic Distortion of Drives: Issues and Solutions

Part 1:

1.1 Training on harmonics: Basics

1.2 Training on harmonics: Problems and issues

1.3 The IEEE 519 and the impact of the short circuit power ratio

Part 2:

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2.2 Passive Harmonic Filter technologies

2.3 Hybrid Harmonic Filter / Hybrid Solution

2.4 Open Discussion

RHF - 5P and RHF-8P

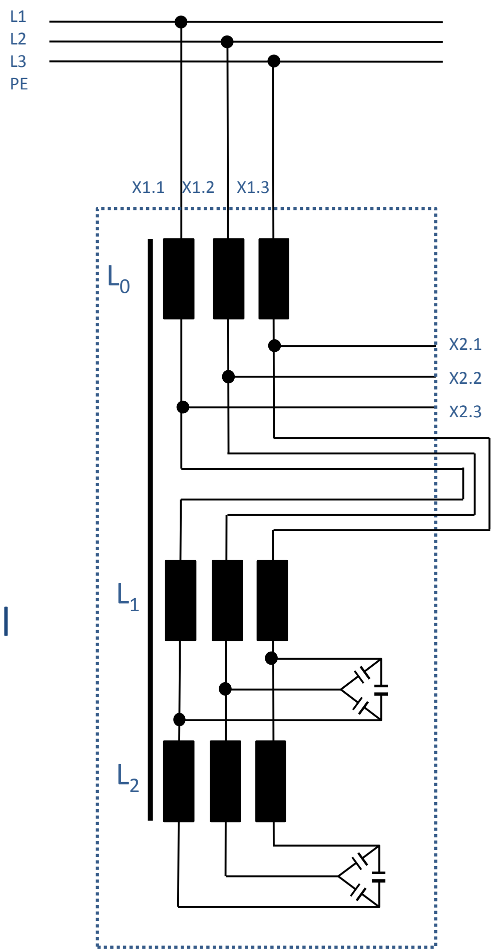
RHF – 3rd Generation

Standard Compact Size

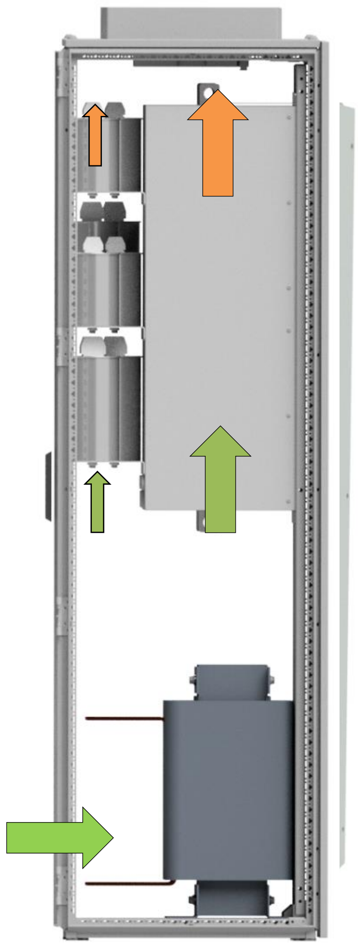
- Available from 1.1 – 280kW (400V)
- Two different performance levels [THDi]

  RHF-8P <8% (typ. test result 6,7%)

  RHF-5P <5% (typ. test result 2,7%)
- High efficiency typically >99-99.5%
- Most efficient harmonic solution available
- Core temperature supervision and fan control
- Improves (true) power factor (*pf* or λ)
- Available for all common networks
- High lifetime expectation (typ. >15 Years)



RHF - high power range 2nd generation



RHF – 3rd Generation

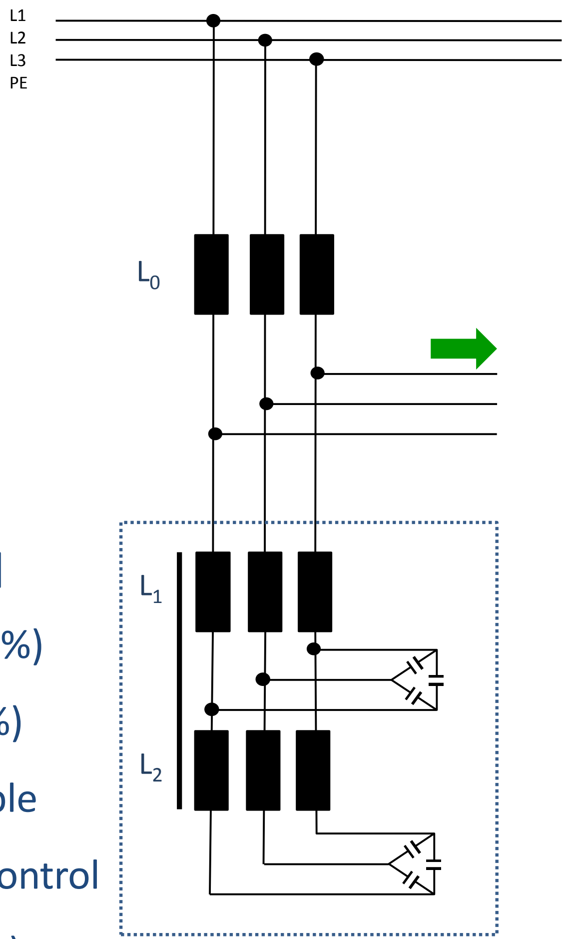
High Power Split or Enclosed design

- Available up to 710kW (400V nom.)
- Available up to 1MW (690V nom.)

  Mains inductance separated
- High efficiency typically 99,5%
- Two different performance levels [THDi]

  RHF-5P <8% (typ. test result 6,7%)

  RHF-B <5% (typ. test result 2,7%)
- Most efficient harmonic solution available
- Core temperature supervision and fan control
- High lifetime expectation (typ. >15 Years)



Harmonics

A passive filter, is a passive filter. Right?

Benefits of the RHF

Benefit 1:

Performance

Benefit 2:

Efficiency

Benefit 3:

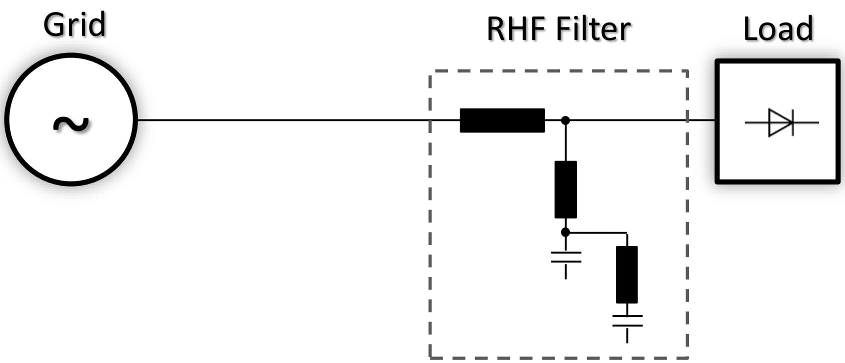
DC-Bus Level

Benefit 4:

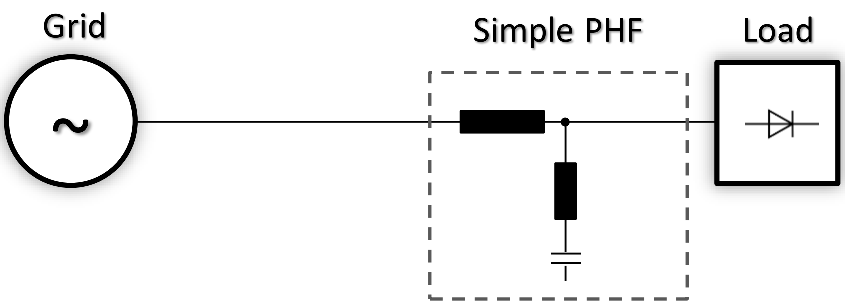
Quality

Optimizing your drive!

Harmonic Solutions for VSD - Passive HF

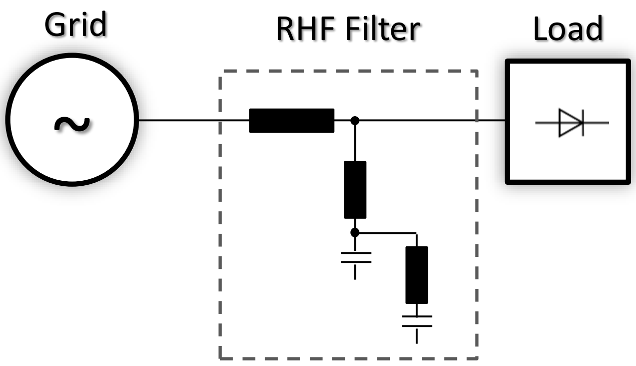


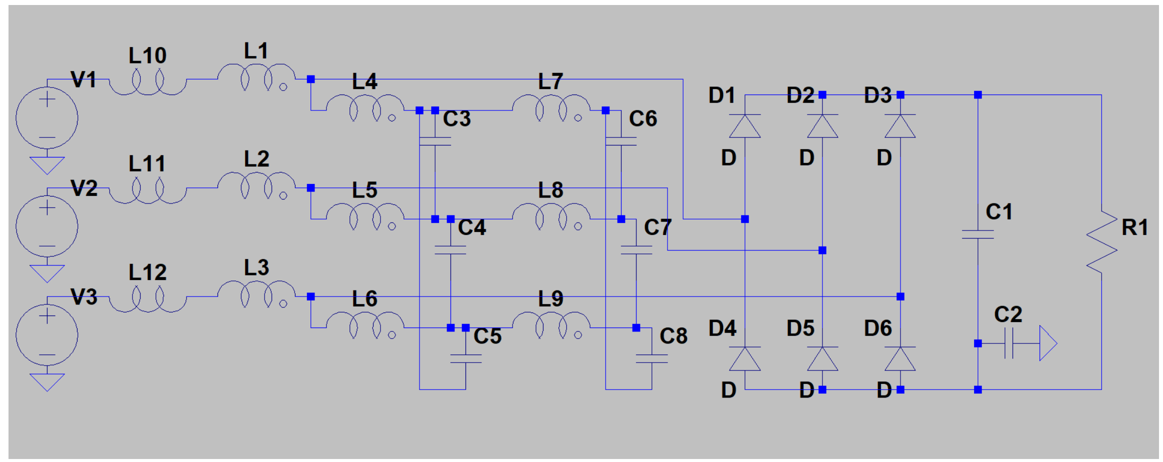
Setup	RHF-8P: High Efficient Harmonic Filter
Typical THDi	6-8%
Circuit	2 – Stage Filter
Advantage	Harmonic mitigation for all Harmonics
Disadvantage	Higher production costs

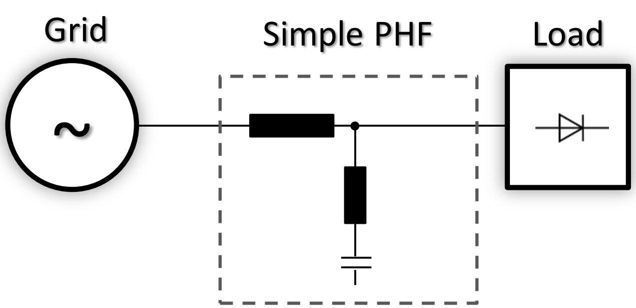


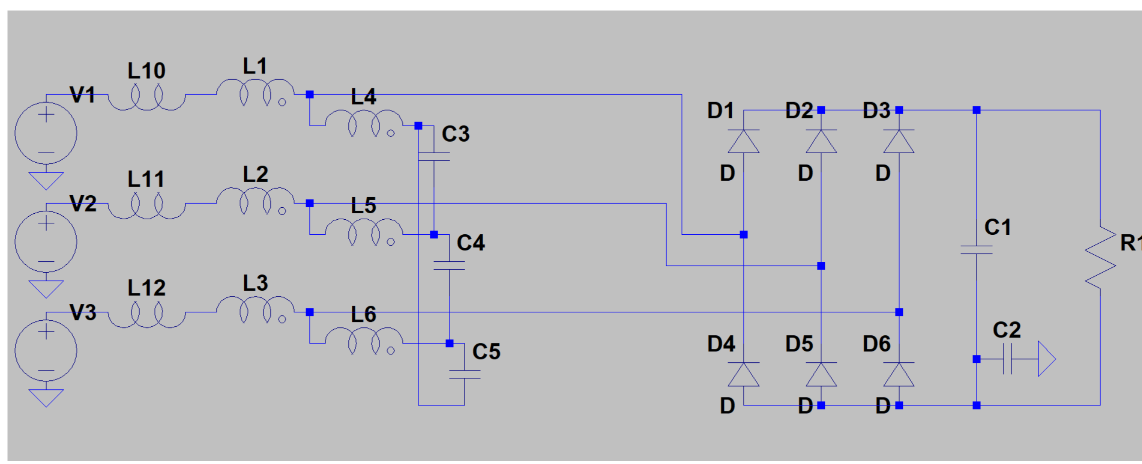
Setup	Simple Passive Harmonic Filter
Typical THDi	10-12%
Circuit	1 – Stage Filter
Advantage	Cheap
Disadvantage	Strong absorption only for 5th and 7th Harmonic. Low absorption of 11th and 13th harmonic. Very low absorption of high harmonics (>13th)

Simulation RHF (10%) vs. Simple-PHF (10%)



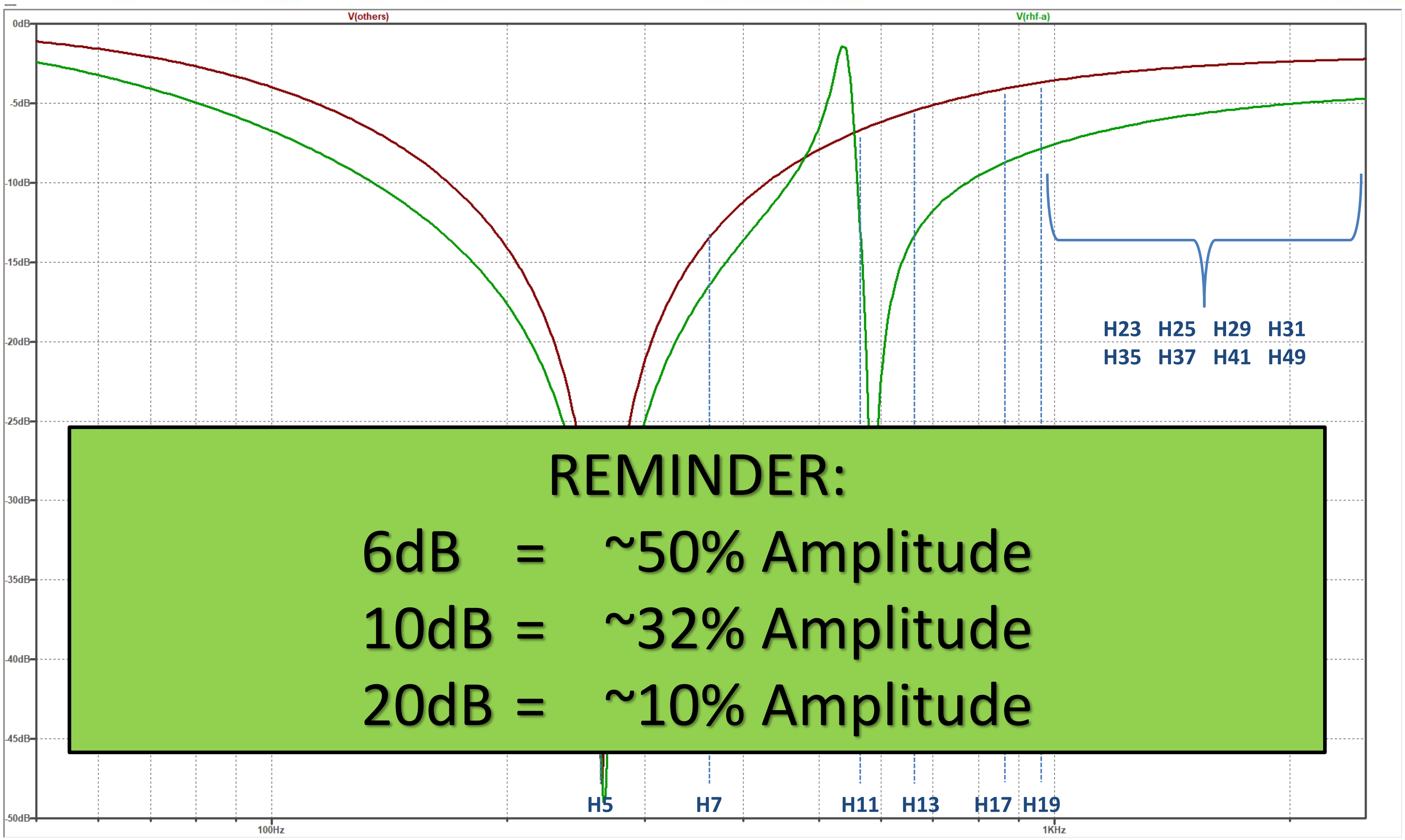






REVCON Optimizing your drive!

Simulation RHF (10%) vs. Simple-PHF (10%)



REMINDER:

6dB = ~50% Amplitude

10dB = ~32% Amplitude

20dB = ~10% Amplitude

Benefits of RHF

Harmonic Spectrum * (frequency band based on 50Hz fund.)	*THD* with RHF-A/B	*THD* with Simple HF	*THD* with AFE
2nd – 7th Harmonic (100Hz - 350Hz)	Very Low	Very Low	Very Low
2nd – 50th Harmonic (0,1kHz - 2,5kHz)	Very Low	Medium	Very Low
50th – 200th Harmonic (2,5kHz – 10kHz)	Very Low	Medium	High

*most common standards are only referring to harmonics up to 40 or 50.

Optimizing your drive!

Performance Guarantee Competitor

[redacted] Performance Guarantee

Select and install the [redacted] Harmonic Filter in a variable torque AC variable frequency drive application, within our published system limits and we guarantee that the input

MINIMUM SYSTEM REQUIREMENTS

The guaranteed performance levels of this filter will be achieved when the following system conditions are met:

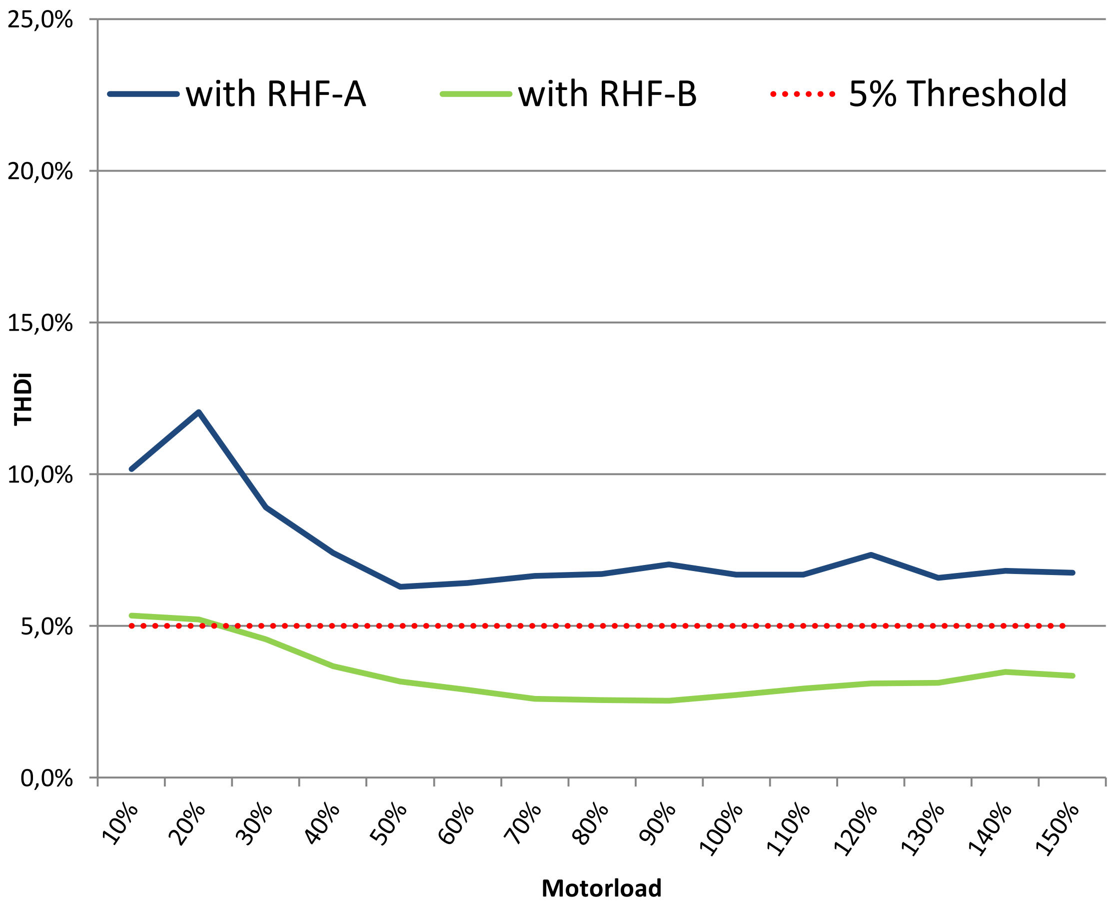
Frequency:	Nominal Frequency ± 0.75Hz
System Voltage:	Nominal System Voltage (line to line) ±10%
Balanced Line Voltage:	Within 1%
Background Voltage Distortion:	0% THVD

NOTE: The presence of background voltage distortion will cause motors and other linear loads to draw harmonic currents. Additional harmonic currents may flow into the [redacted] filter if there is harmonic voltage distortion already on the system.

harmonic voltage distortion already on the system.

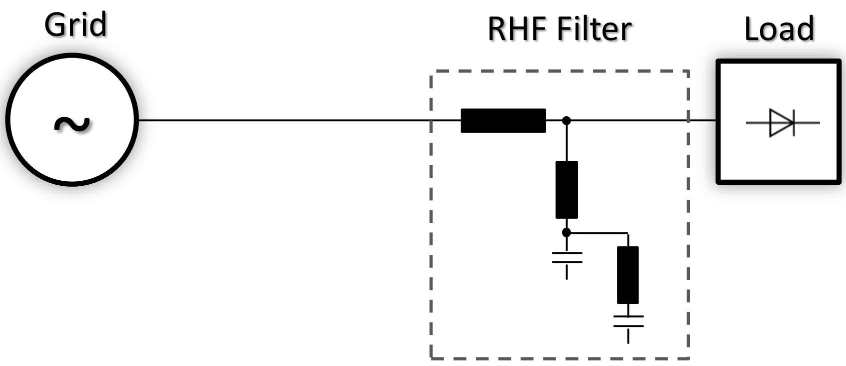
Optimizing your drive!

REVCON test conditions

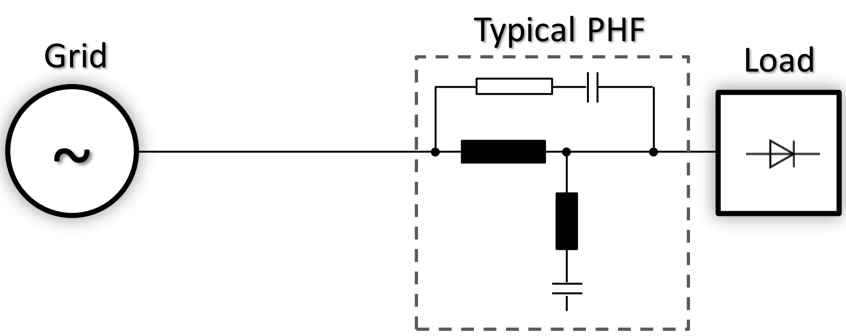


Condition during test	
Mains voltage	**+2-4%**
V Unbalance	**0.7 – 1.1%**
Frequency	**+0.13Hz**
Background THvD distortion	**1.5-2%**

Harmonic Solutions for 5% THDi



Setup	High Efficient Harmonic Filter
Possible THDi	2-5%
Circuit	2 – Stage Filter
Advantage	Harmonic mitigation for all Harmonics
Disadvantage	Higher production costs

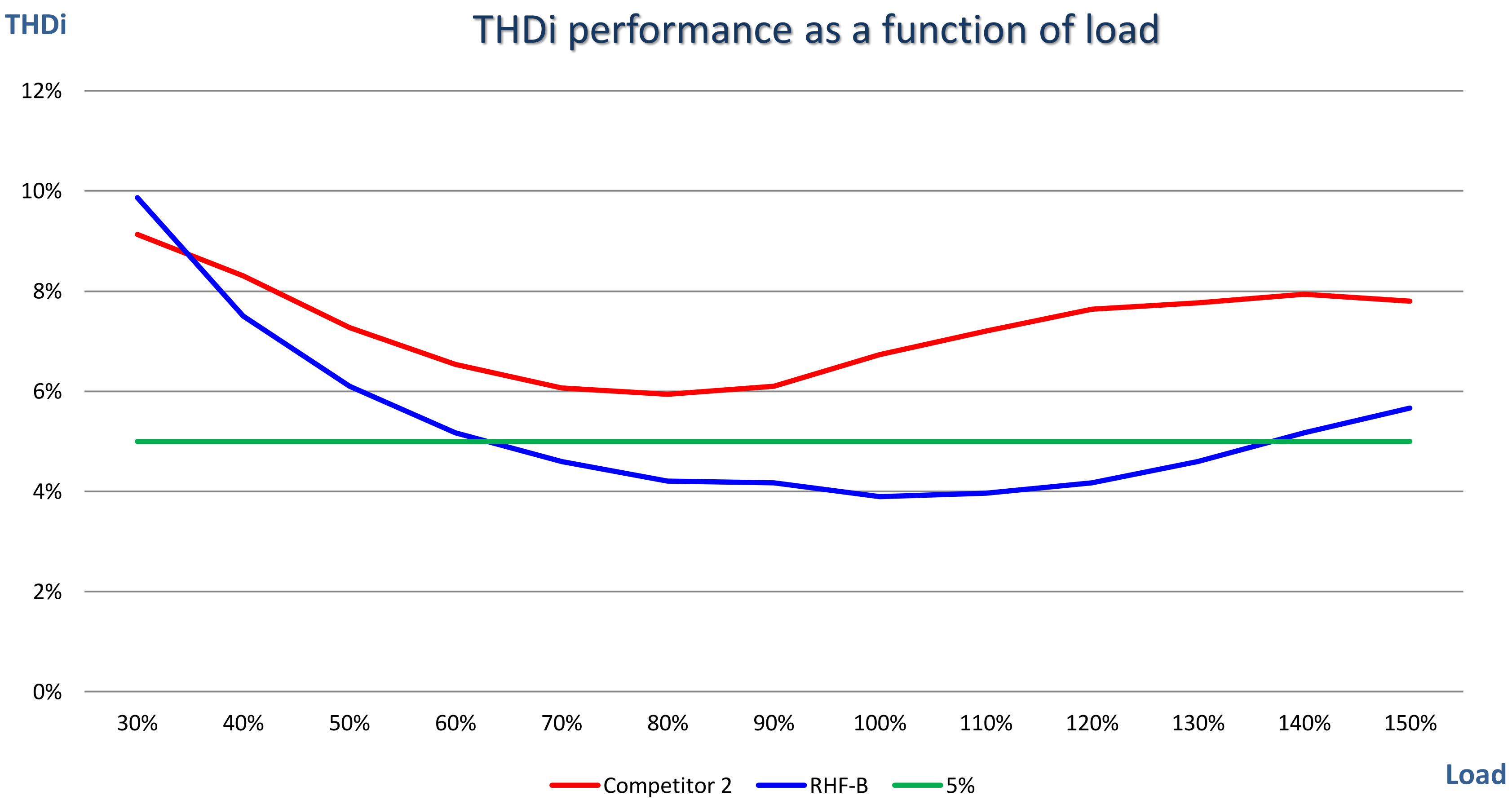


Setup	Simple Passive Harmonic Filter "S-PHF"
Possible THDi	4-6%
Circuit	1 – Stage Filter with RC Circuit.
Advantage	Lower Weight compared to 2-Stage
Disadvantage	High Power Loss

Misleading Statements (from competitor)

	Recommended requirement
Hardware	**“Note: Performance specification in this brochure refer to six pulse diode rectifier with 8% DC-link choke. “ Comment: There are no drives with 8% DC-link choke on the market. DC Bus decrease would be significant and reduce drive performance**
Performance	**„THiD ~5%“ Comment: ~ 5% = About 5%. This means can be 6-7%. Correct: <5%**
Power Quality	**Background THvD distortion 0% Comment: this is not possible. Do not accept these kind of statements**
Standards	**“Helps/Supports to reach the IEEE519-2014” Normally means you need further equipment to reach the standard.**

Benefits of the RHF



✓ competitor products reach the required / stated values only under ideal conditions

Benefits of the RHF

Benefit 1:

Performance

Benefit 2:

Efficiency

Benefit 3:

DC-Bus Level

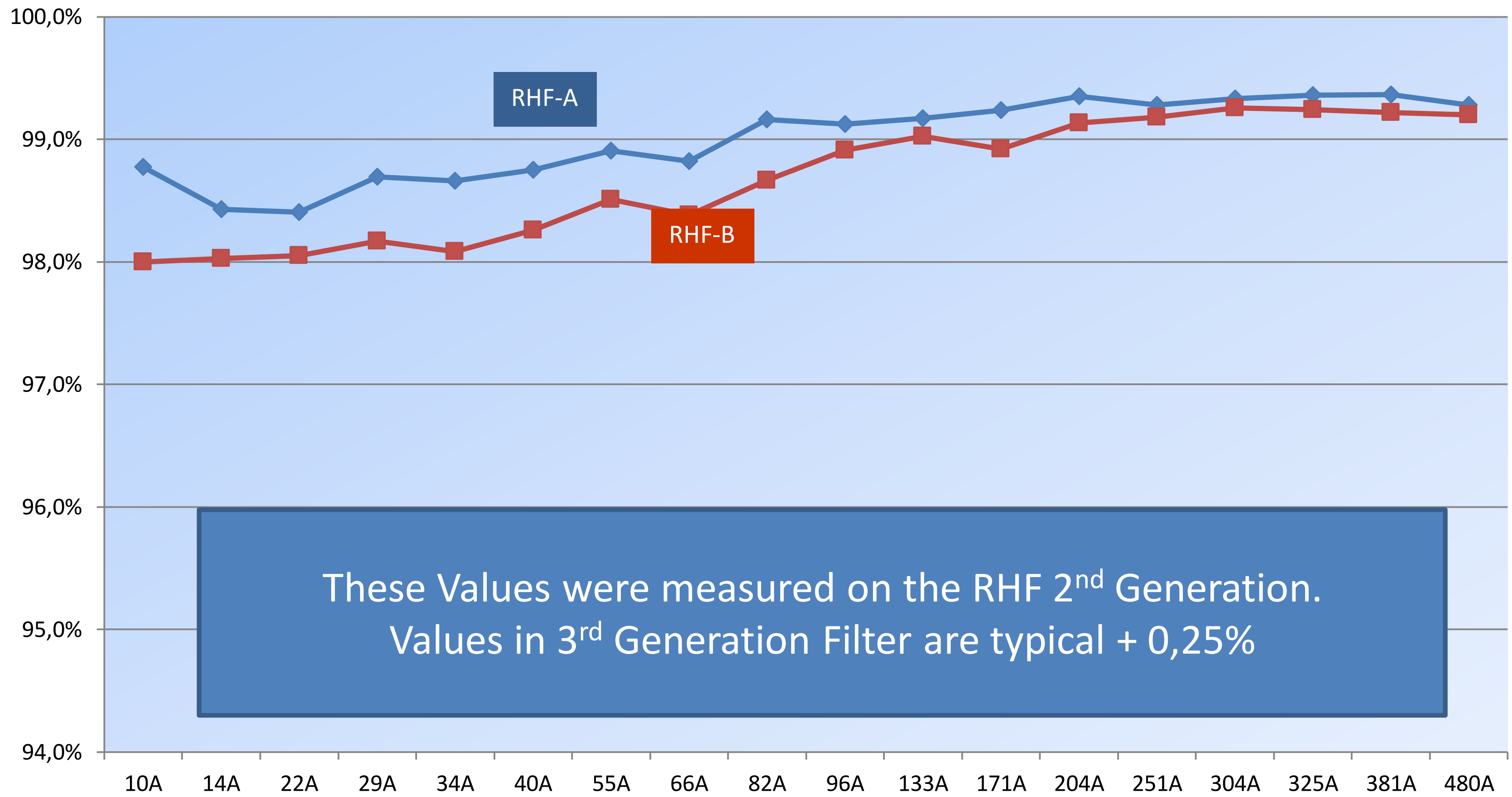
Benefit 4:

Quality

Optimizing your drive!

η of Harmonic Solutions - RHF

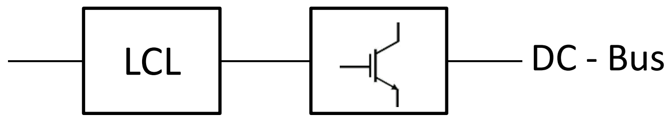
The efficiency of the Filter were measured with a Yokogawa high precision power meter WT 1800



η of Harmonic Solutions - 200A example

Active Front End / Low Harmonic Drive

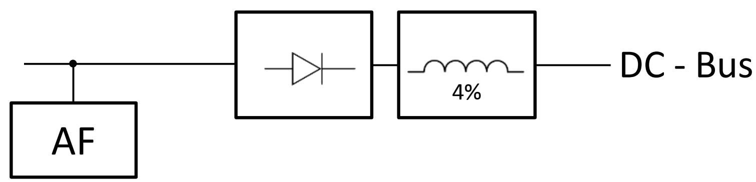
P_{LOSS} = 3%



97% efficiency

Active Filter
+ B6 rectifier and DC- choke

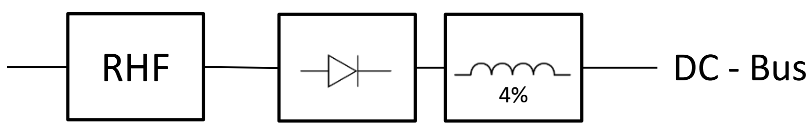
P_{LOSS} = 0.9% + 0.8% = 1.7%



98,3% efficiency

High efficient Passive Harmonic Filter
+ B6 rectifier and DC- choke

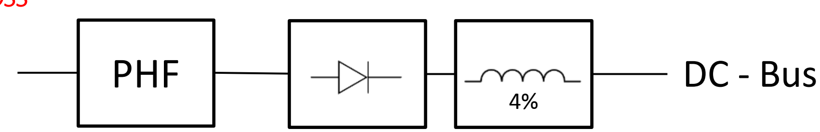
P_{LOSS} = 0.75% + 0.8% = 1.55%



98.45% efficiency

Simple Passive Harmonic Filter
+ B6 rectifier and DC- choke

P_{LOSS} = 1.8-2.3% + 0.8% ≈ 2.85%



97.15% efficiency

* Assuming active filter sized for 30% of load current, filter efficiency of 97%.

REVCON Optimizing your drive!

η of Harmonic Solutions - 200kW example

Calculation example for: 200kW Drive $\left(\frac{\mathbf{24h}}{\mathbf{d}}\ ;\ \frac{\mathbf{365d}}{\mathbf{a}}\ ;\ \frac{\mathbf{0{,}15\$}}{\mathbf{kWh}}\right)$

Efficiency RHF topology: $\eta = 98.45\%$

Efficiency AFE topology: $\eta = 97\%$

➡ $\Delta\eta = 98.45\% - 97\% = -1.45\%$

Annual energy savings:

$$E_{save} = P_{Input} \bullet \Delta\eta \bullet \frac{24\text{h}}{\text{d}} \bullet \frac{365\text{d}}{\text{a}} = 220\text{kW} \bullet 0.0145 \bullet \frac{24\text{h}}{\text{d}} \bullet \frac{365\text{d}}{\text{a}} = 27\ 944\ \frac{\text{kWh}}{\text{a}}$$

Annual cost savings:

$$C_{save} = E_{save} \bullet energy\ cost = 27\ 944\ \frac{\text{kWh}}{\text{a}} \bullet 0.15\ \frac{\$}{\text{kWh}} = 4\ 192\ \frac{\$}{\text{a}}$$

Benefits of the RHF

Benefit 1:

Performance

Benefit 2:

Efficiency

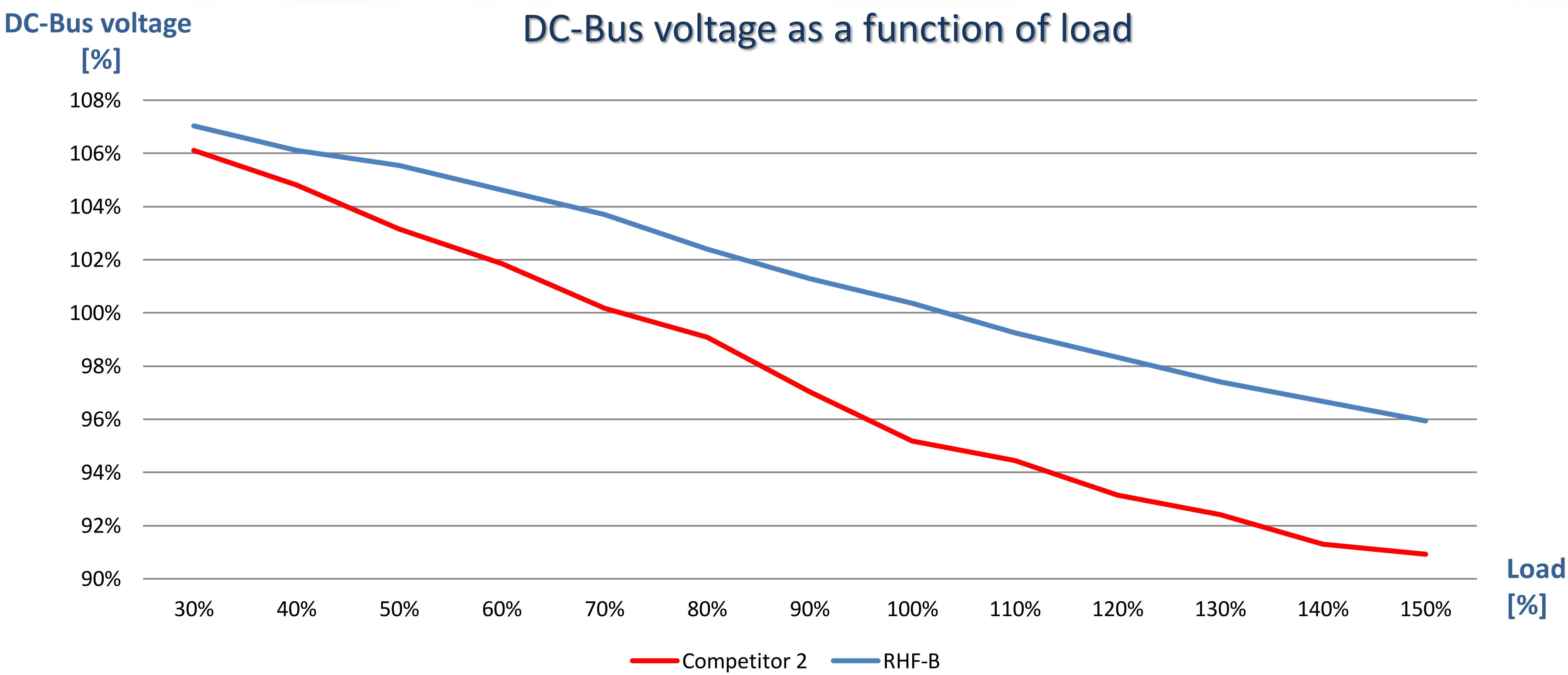
Benefit 3:

DC-Bus Level

Benefit 4:

Quality

Benefits of RHF



✓ Higher DC bus voltage leads to better motor performance (full motor torque), less IGBT losses and higher lifetime expectance.

Benefits of the RHF

Benefit 1:

Performance

Benefit 2:

Efficiency

Benefit 3:

DC-Bus Level

Benefit 4:

Quality

Optimizing your drive!

reasons to use the REVCON RHF

- ✓ Individual full load testing for each harmonic filter!
- ✓ Reliable PELV thermal protection
- ✓ High quality terminals with defined connection torque
- ✓ Follows sustainable development goals of UN
- ✓ True ISO 9001 : 2015 certification
- ✓ Corporate Social Responsibility – our quality management personnel are ambassador of CSR
- ✓ Production in accordance to European quality standards

✓ ∑ RHF product failure = 0%

Harmonics

A passive filter, is a passive filter. Right?

Passive Harmonic Filter show some significant difference in internal setup.
This leads to difference in:

***THDi* Performance (higher order harmonics)**
Efficiency (for 5% *THDi* Filters)
Drive Performance (DC-Bus level)
Quality (Terminals! Thermal Protection!)

Harmonic Distortion of Drives: Issues and Solutions

Part 1:

1.1 Training on harmonics: Basics
1.2 Training on harmonics: Problems and issues
1.3 The IEEE 519 and the impact of the short circuit power ratio

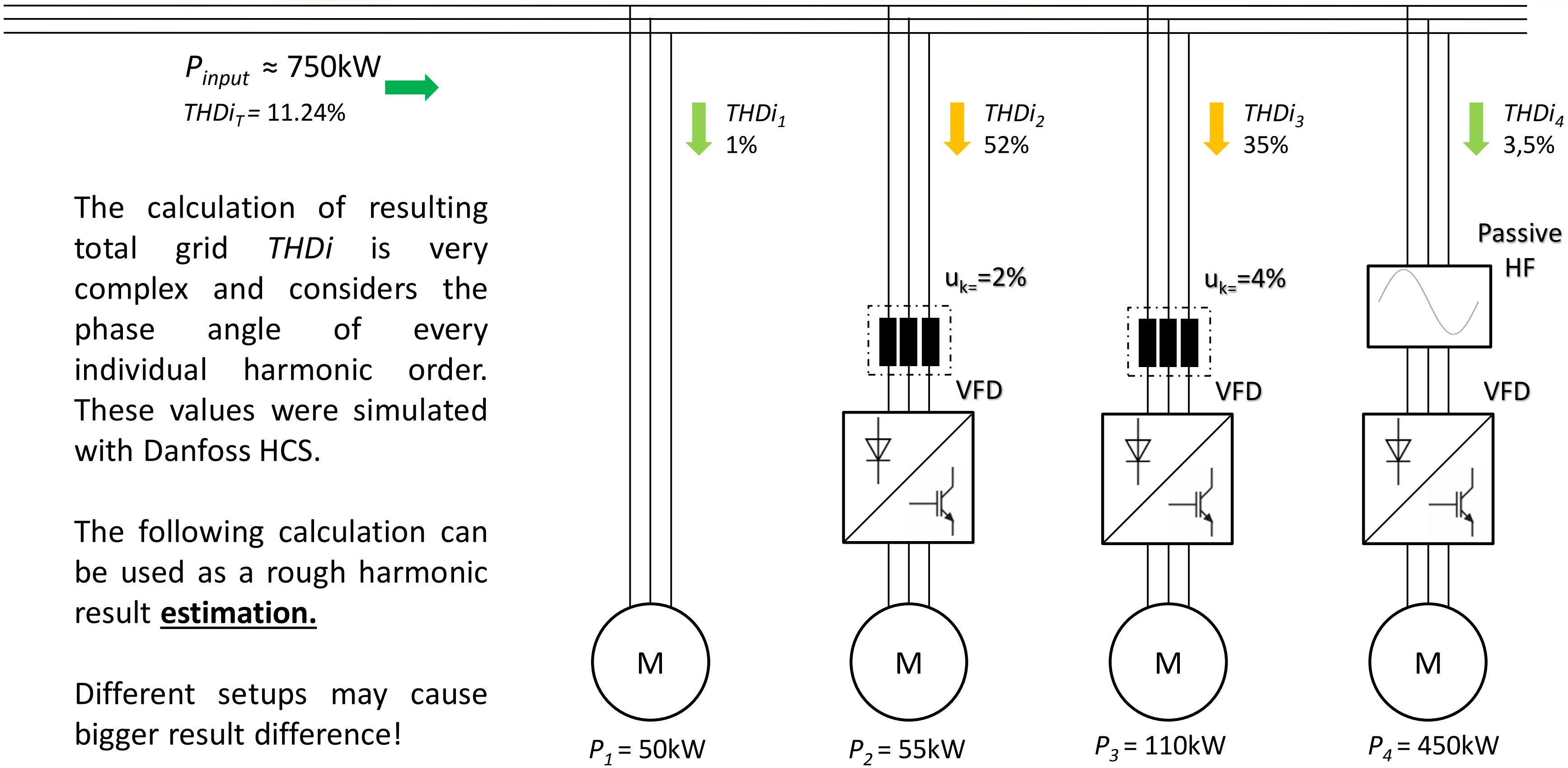
Part 2:

2.1 Harmonic solutions available
2.2 Passive Harmonic Filter technologies
➡ **2.3 Hybrid Harmonic Filter / Hybrid Solution**
2.4 Open Discussion

Harmonics

What is the best Harmonic Solution?

Harmonic Solutions for VSD - System distortion



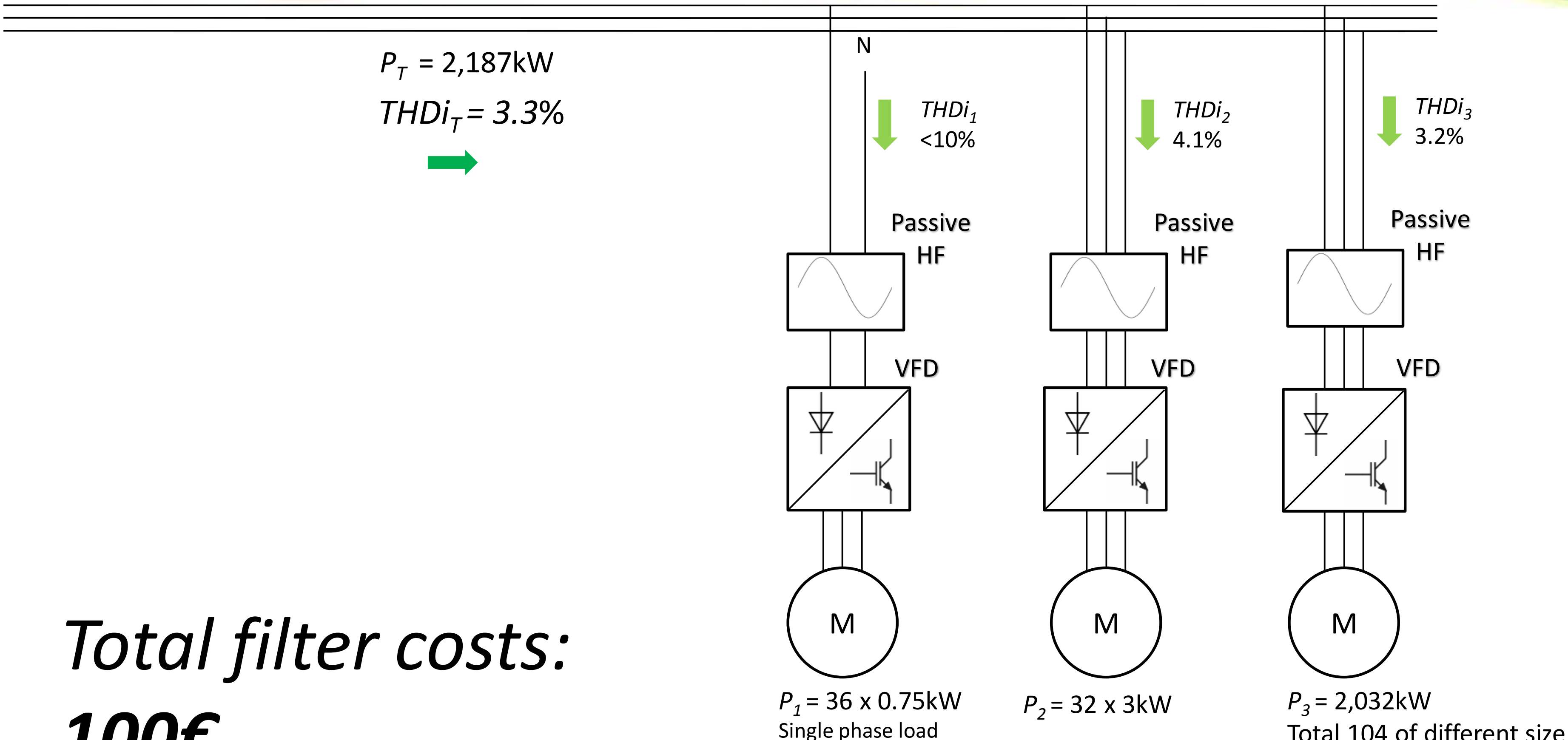
The calculation of resulting total grid *THDi* is very complex and considers the phase angle of every individual harmonic order. These values were simulated with Danfoss HCS.

The following calculation can be used as a rough harmonic result **estimation.**

Different setups may cause bigger result difference!

$$THDi_{input} \approx \frac{P_1 * THDi_1 + P_2 * THDi_2 + P_3 * THDi_3 + P_4 * THDi_4}{P_{1+2+3+4}} = 12{,}8\%$$

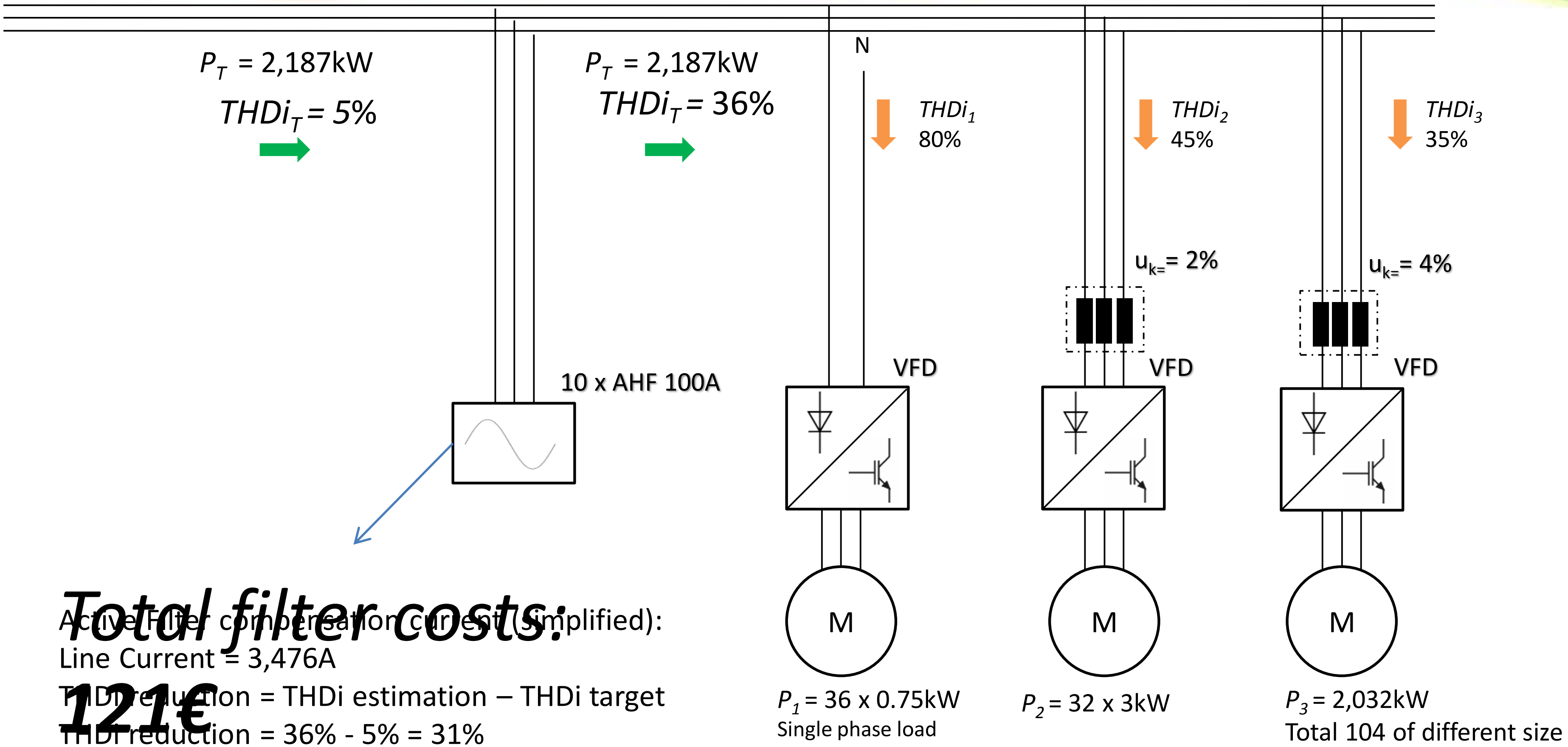
Project HK SST



Total filter costs:

100€

Project HK SST



Active Filter compensation current (simplified):

Line Current = 3,476A

THDi reduction = THDi estimation – THDi target

THDi reduction = 36% - 5% = 31%

Compenastion current = **1029A**

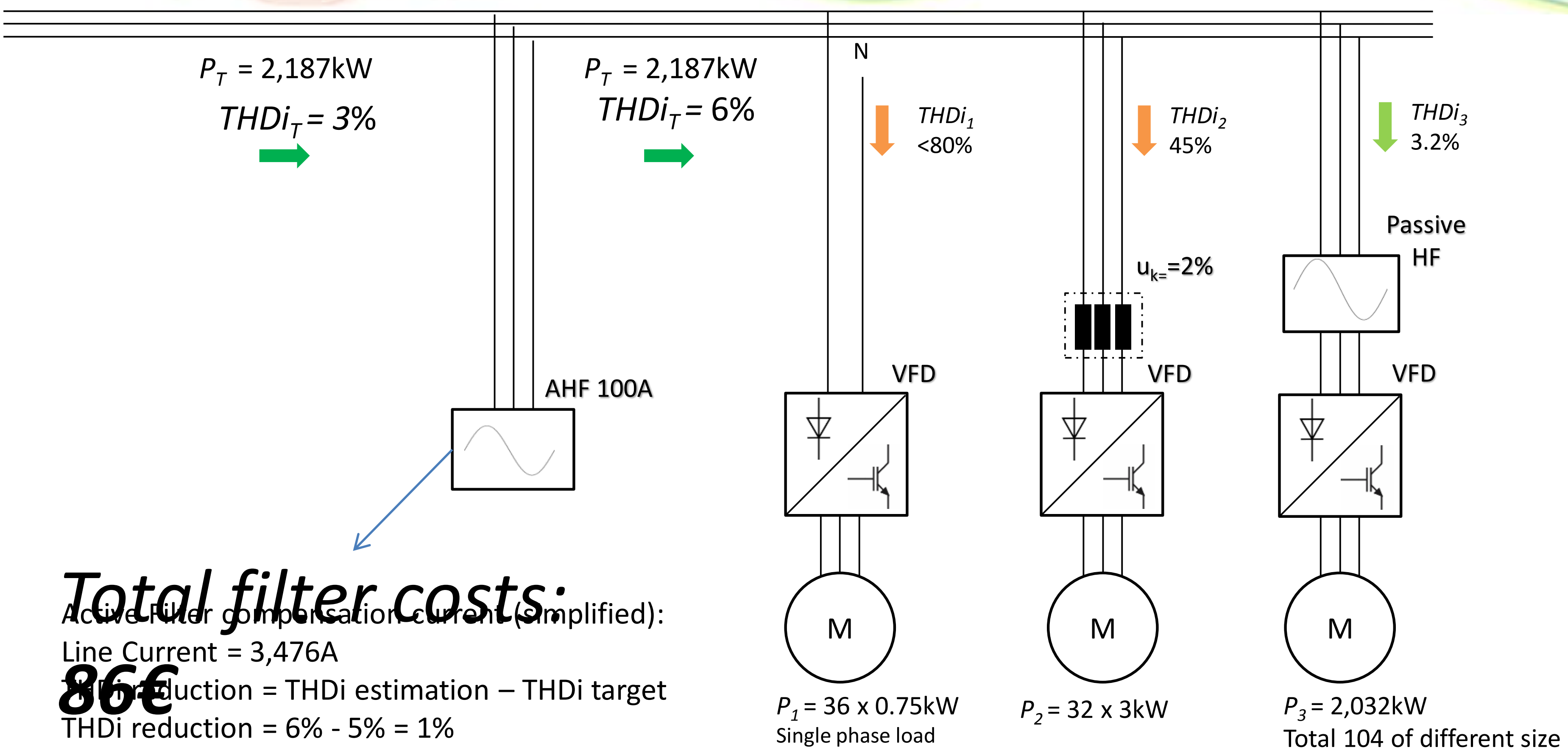
Total filter costs:

121€

(21% higher costs)

Optimizing your drive!

Project HK SST



Total filter costs:

86€

(savings 14%)

Active Filter compensation current (simplified):

Line Current = 3,476A

THDi reduction = THDi estimation – THDi target

THDi reduction = 6% - 5% = 1%

Compenasation current = 34,76A

Harmonics

What is the best Harmonic Solution?

All Harmonic Solutions have their advantages and disadvantages

Pure Passive Solution (good when many **big loads**)

Pure Active Solution (good for many **small drives**)

Hybrid (good for **mix of big and small drives**)

Active Front End (good for applications with **regenerative power)**

Harmonic Distortion of Drives: Issues and Solutions

Part 1:

1.1 Training on harmonics: Basics

1.2 Training on harmonics: Problems and issues

1.3 The IEEE 519 and the impact of the short circuit power ratio

Part 2:

2.1 Harmonic solutions available

2.2 Passive Harmonic Filter technologies

2.3 Hybrid Harmonic Filter

→ **2.4 Open Discussion**

RHF - Active

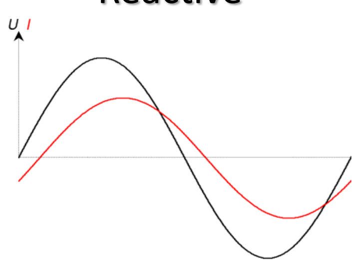
RHF-Active 100-400-50/60-20-A

- Advanced IGBT 3-Level topology
- Low losses = Compact size
- Power Loss 2078W max.
- Switching frequency 10-20kHz
- Unlimited parallel setup
- Efficient Harmonic elimination up to 50th
- 99% system efficiency

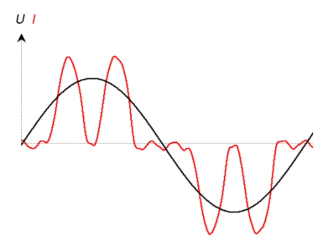
44kg

50dm³

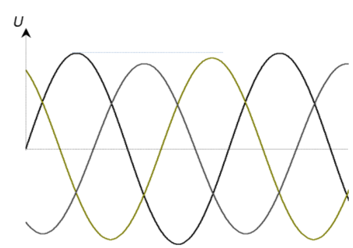
Reactive



Harmonics



Unbalance



Optimizing your drive!

RHF - Active

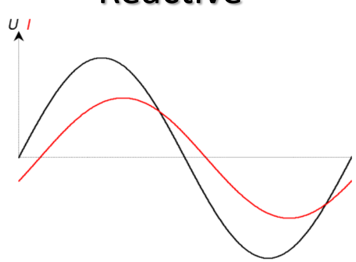
RHF-Active 15-400-50/60-20-A

7kg

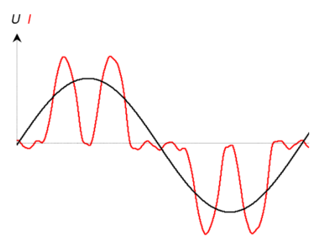
8dm³

- SiC-Power MOSFET´s and Schottky
- Low losses = Compact size
- System Efficiency 99,4% (based on 30% THDi Reduction)
- Unit Efficiency 98% @60kHz!
- High performance on strongly distorted load (e.g. 90% to 7%)
- High Performance on high order harmonics
- Noiseless!

Reactive



Harmonics



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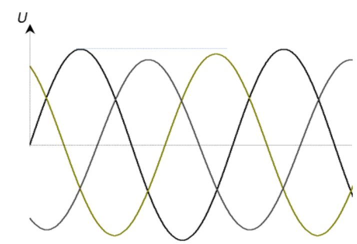

Revcon references

Danfoss

Schneider Electric

MITSUBISHI ELECTRIC

ABB Power and productivity for a better world™

Rockwell Automation

SEW EURODRIVE

ZIEHL-ABEGG

ThyssenKrupp

Lenze

DEMATIC

emotron

EMERSON. Industrial Automation

CONTROL TECHNIQUES


THANK YOU
for your attention!