Harmonic and Energy Saving Solutions

Supraharmonics – The Next Big PQ Concern

Mirus International, Sept. 2020

What we will discuss

- What are Supraharmonics?
- What Devices Introduce Supraharmonics?
- What can Happen when Supraharmonics are High?
- Power System Resonance and High Frequency Harmonics
- Do Harmonic Standards such as IEEE Std 519-2014 and IEC standards address them?
- Are Supraharmonics a Concern with Passive Rectifiers?
- Summary and Conclusions

What are Supraharmonics?

- Supraharmonics are voltage or current waveform distortions in the range of frequencies between 2 kHz and 150 kHz
- Rapid growth in distributed and embedded inverter technology and active rectifier loads are contributing to the increase in Supraharmonics found on power systems
- Often show wide variability in time making measurement difficult
- Concerns are both with emission and susceptibility
- High impedance or ‘weak’ power systems are most susceptible
- This range typically falls outside of the requirements for harmonic standards so limits are not well defined or enforced

Challenge in Measuring Supraharmonics?

- Most Power Quality Analyzers only measure up to the 50th harmonic
- Due to wide variability at higher frequencies, band aggregate methods are being proposed to measure Supraharmonics
  - IEC 61000-4-7 defines bandwidth of 200 Hz for 2 – 9 kHz range
  - IEC 61000-4-30 defines bandwidth of 2000 Hz for 9 – 150 kHz range

Reference:

1. A Variable Bandwidth Method for Supraharmonic Band Aggregation, Zhe An, Tongxun Wang, Yingxin Wang, et al, State Grid Corporation of China, 2019
2. Evaluating Supraharmonics up to 150 kHz in Electric Vehicles at the University of Applied Sciences Bingen, A-Eberle Power Quality document, 2016

What Devices Introduce Supraharmonics?

- Active Rectifier Loads and Switch-mode Power Supplies
  - Active Frontend (AFE) Drives
  - Electric Vehicle (EV) Charging stations and other Battery Chargers
  - PC's, LED and other lighting, consumer electronics and other household equipment, especially power factor corrected (PFC)
- Inverters used in Alternative Energy Systems
  - Solar Photovoltaic (PV) Systems
  - Wind Turbines
  - Battery Energy Storage Systems (BESS)
  - Uninterruptible Power Supplies (UPS)
- Active Harmonic or Power Filters (AHF or APF)

What Can Happen When Supraharmonics are High?

Effects on Equipment of EMI in Frequency Range 2 – 150 kHz

Street Lighting and Touch Dimmer Lamps (TDL)	Unintentional switching on/off
Traffic Lights & Controls	Malfunction
Solid state meters	Display wrong meter register values
Radio system for railway control	Malfunction
Home telephone	Malfunction of ringing
Heating systems	Incorrect alarms due to sensor faults
Washing machines	Self restart

Electronic lighting ballasts	Audible noise
PCs and Lamps	Audible noise
TV and radio receiver	Audible noise
Keyless entry systems	Malfunction
DC link capacitors in rectifier circuits	Thermal stress, ageing, lifetime reduction
Broadcast standard time-signal systems	Electronic clocks gaining time, malfunction
Amateur radio	Disturbed reception

Reference:

1. Electromagnetic Interference between Electrical Equipment/Systems in the Frequency Range below 150 kHz – Edition 3, CENELEC SC 205A, Oct. 2015

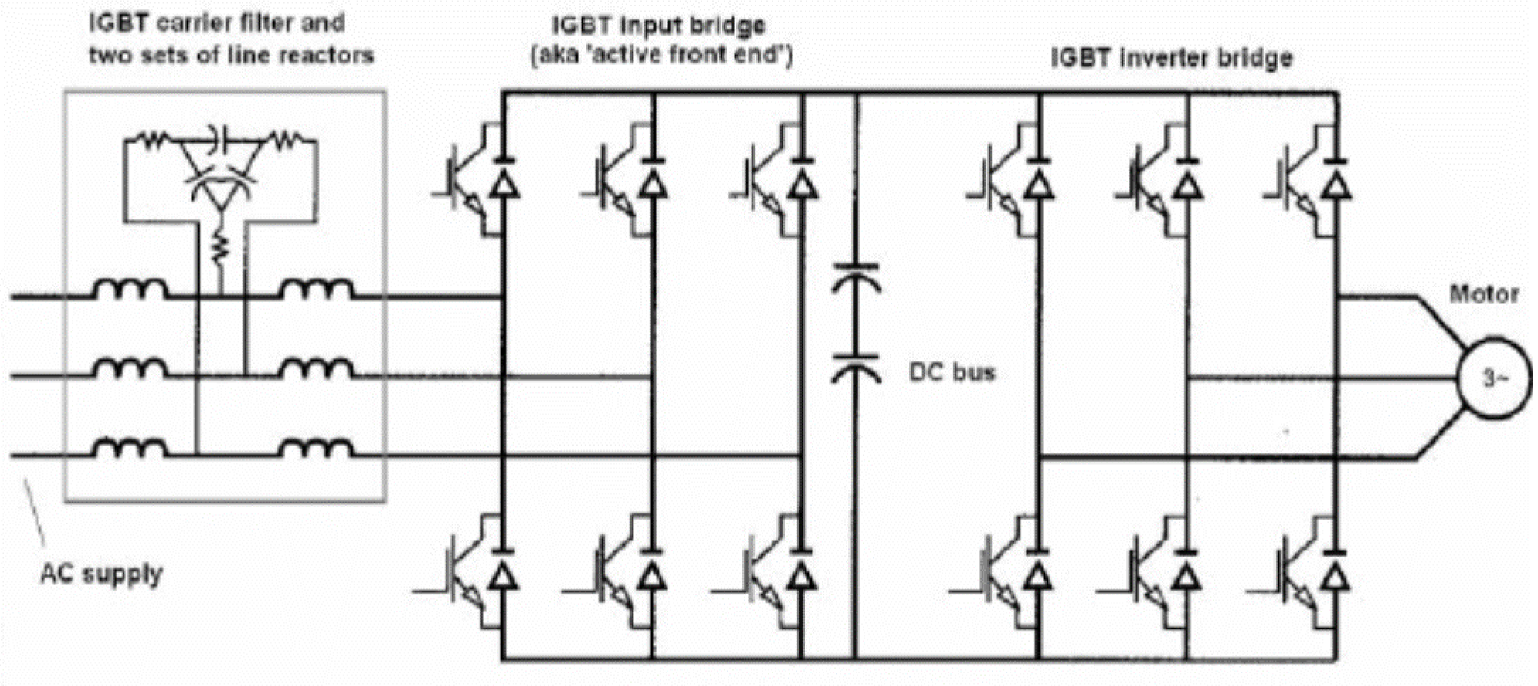
Active Front-end (AFE) Drives and other Active Rectifiers

Operation:

- Front end rectifier is a fully controlled IGBT bridge

Pros:

- Can achieve low ITHD but only when measured at harmonics lower than 50^{th}
- Can provide reverse power flow and regenerative braking



Cons:

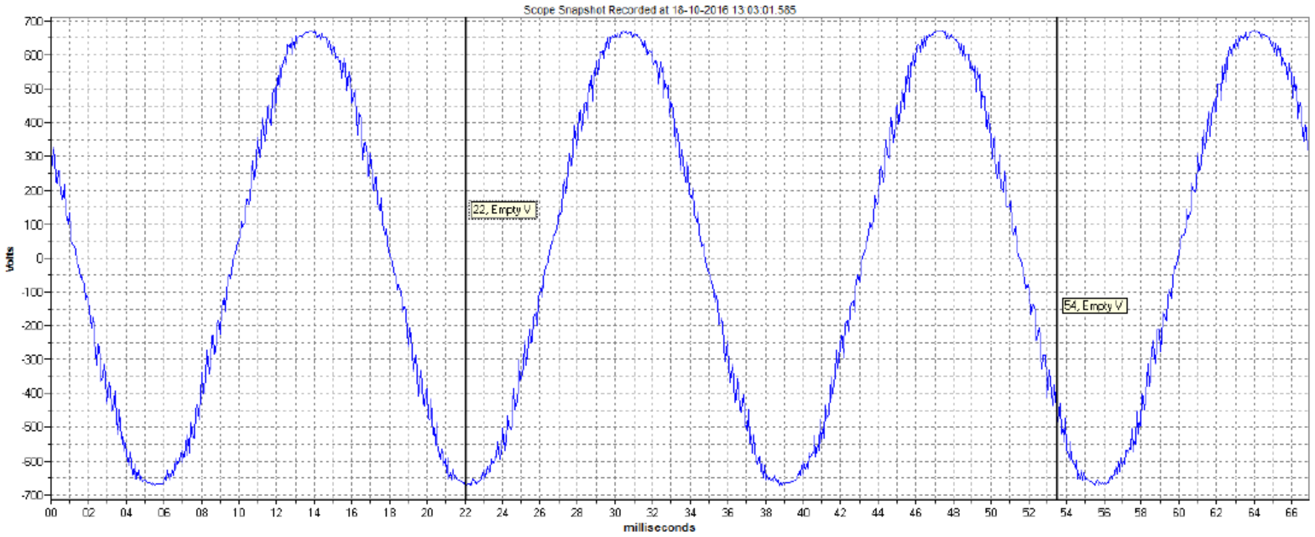
- Expensive
- Introduces higher order harmonics and common-mode noise
- Higher EMI radiation
- Much higher losses

Active Front-end (AFE) Drives on Electrical Submersible Pump

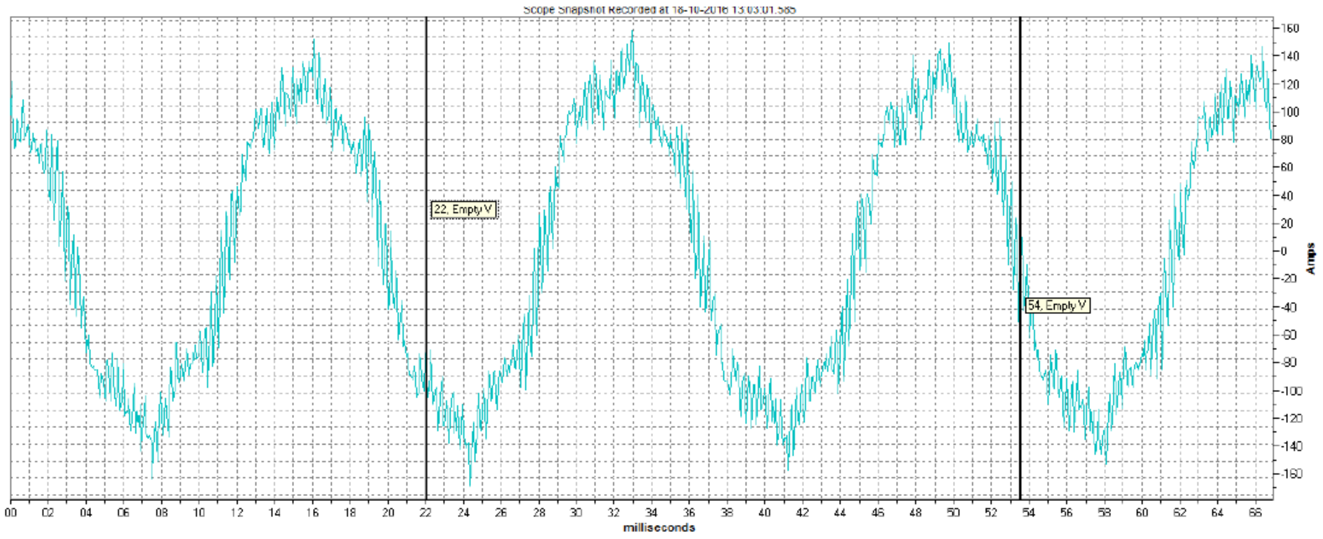
AFE Drive measurements on input to ESP

Switching frequency:
3.6 kHz
(60th harmonic)

Voltage Waveform



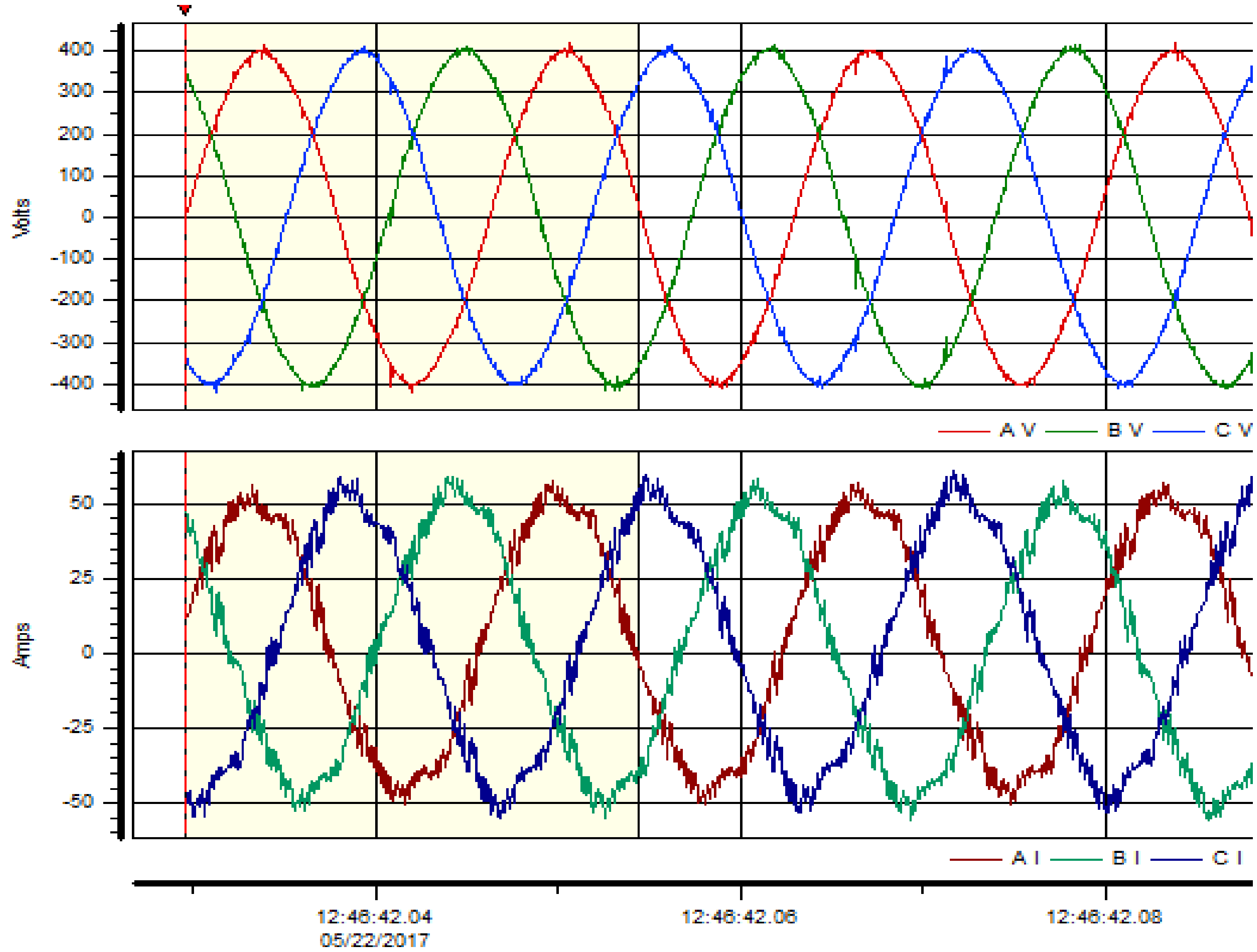
Current Waveform



New Matrix Topology AFE Drive

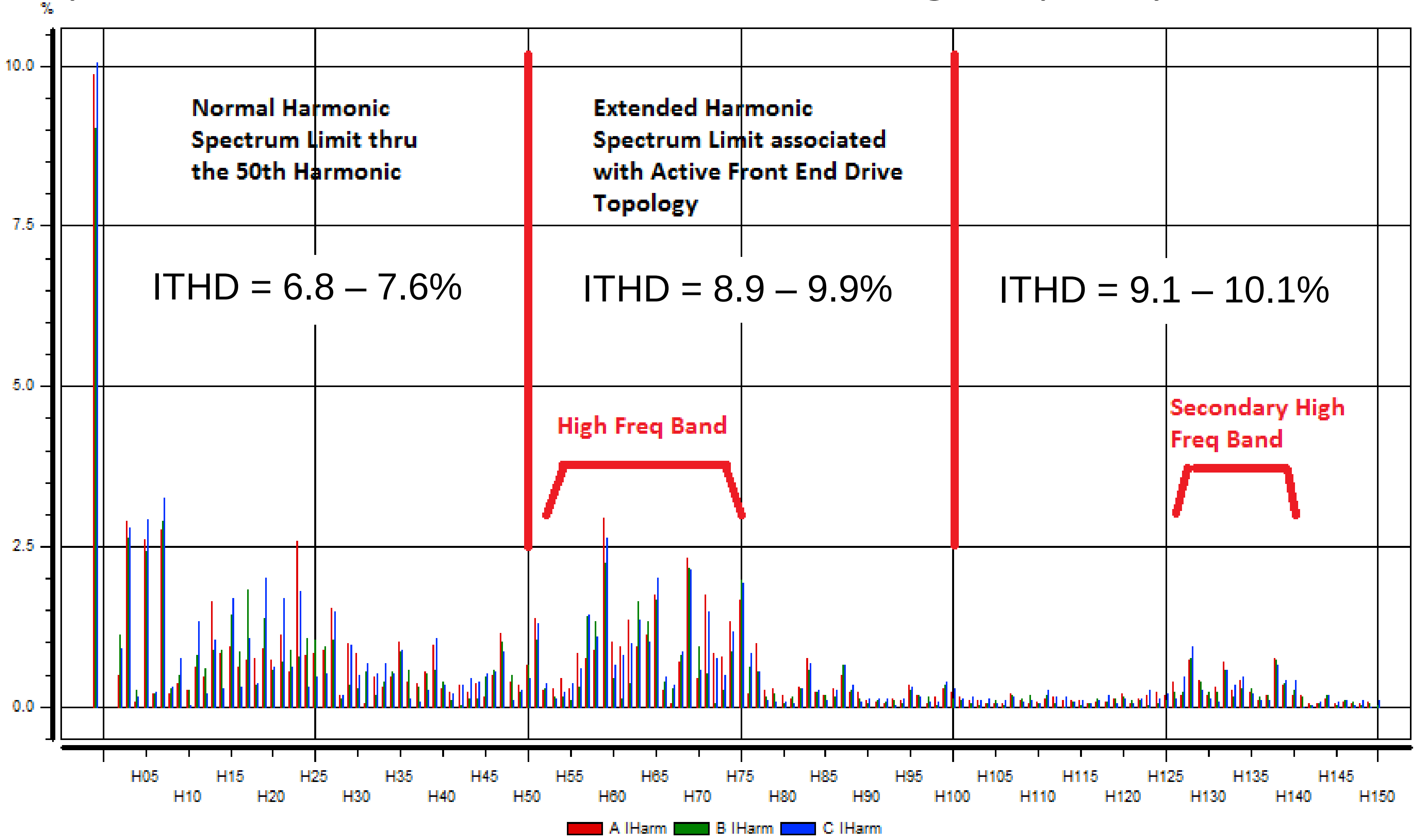
Voltage Waveform

Current Waveform



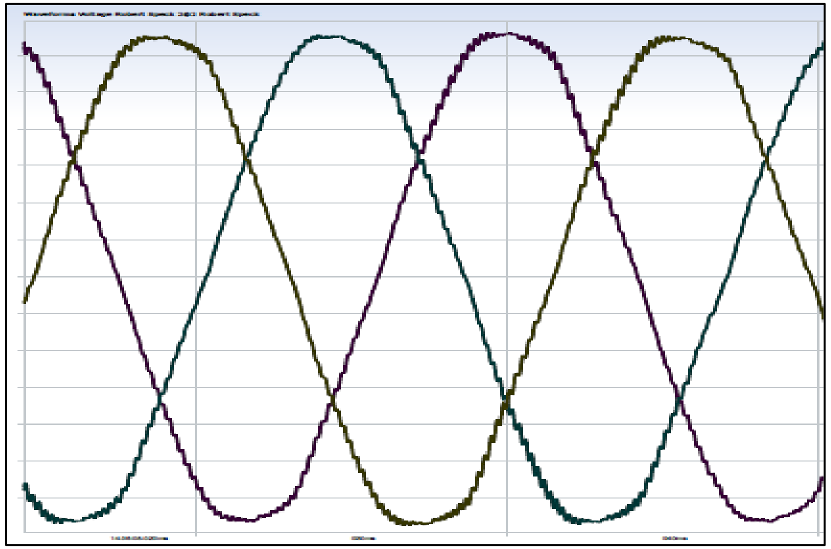
New Matrix Topology AFE Drive

Input Current Harmonics with IGBT Switching Frequency Contribution

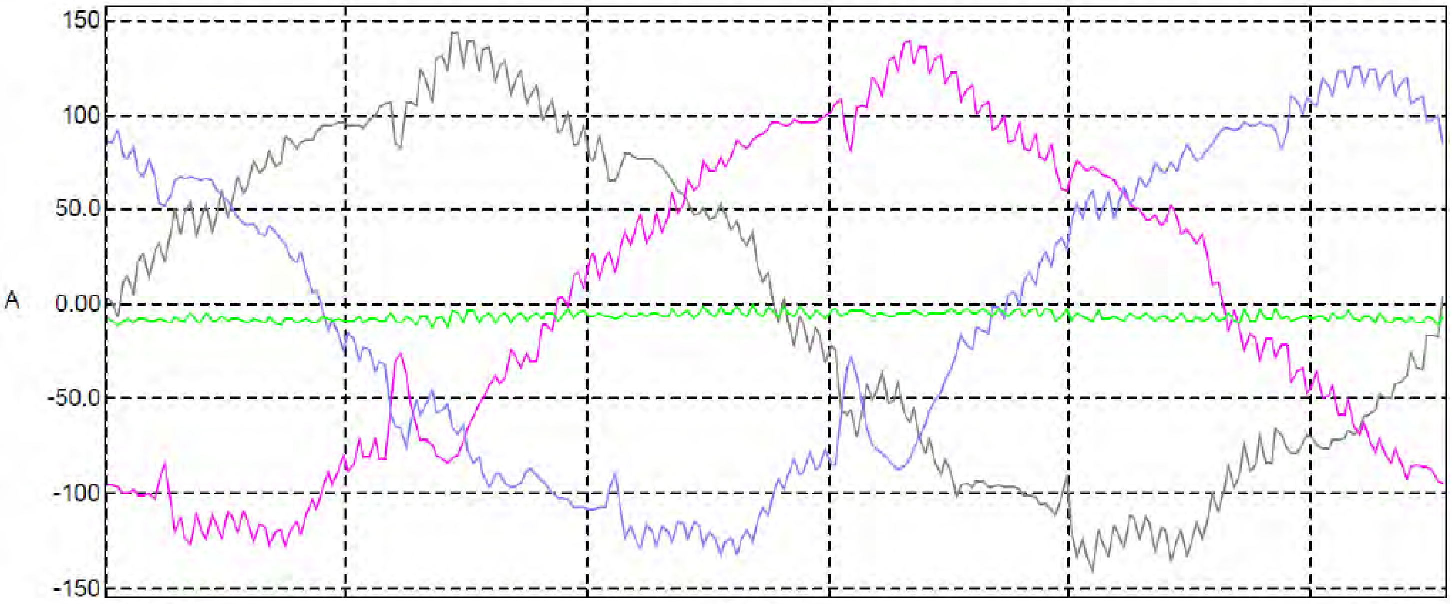


Magnetic Centrifugal Chiller equipped with Active Front-end (AFE) Drive

Voltage Waveform

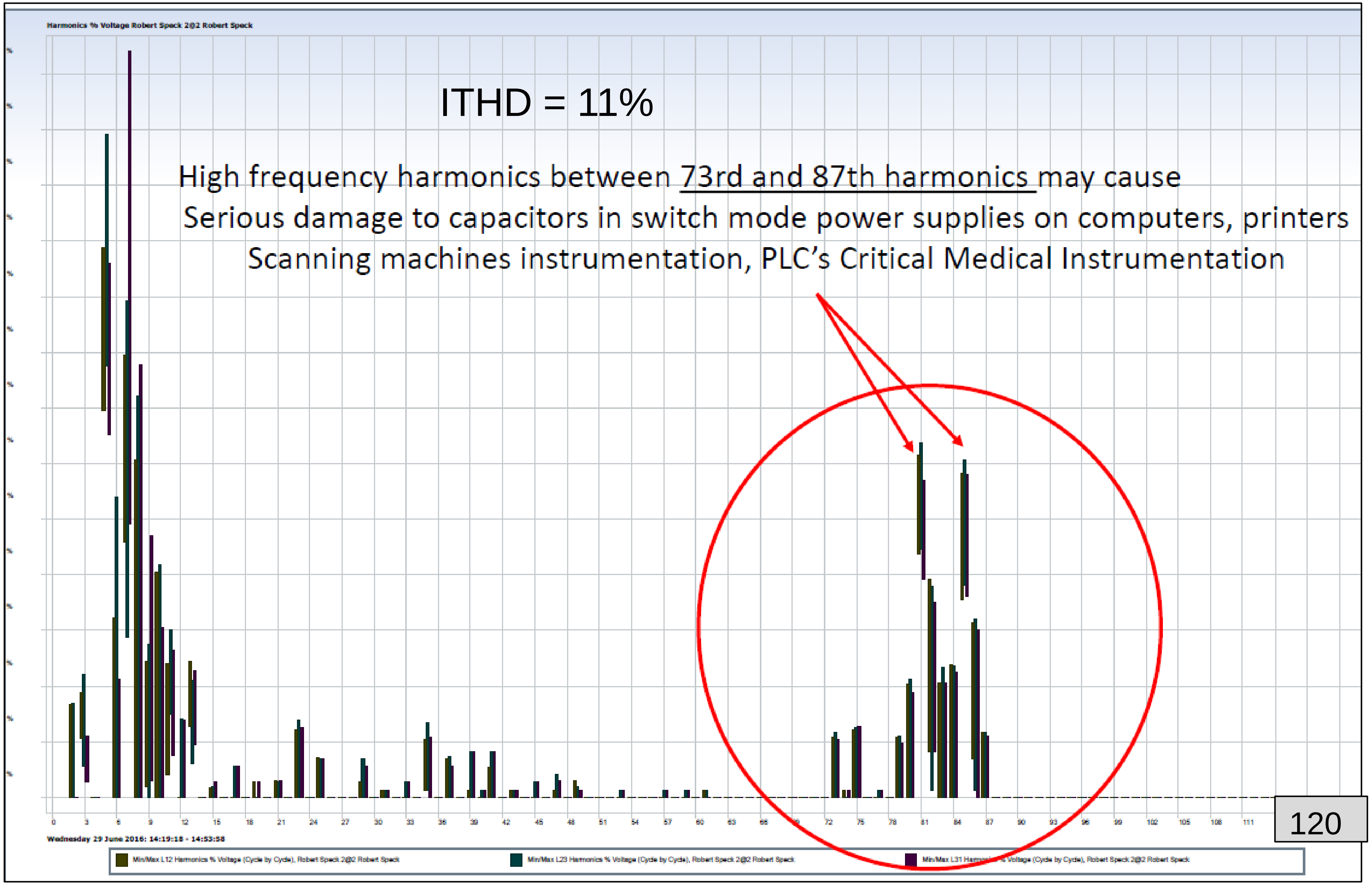


Current Waveform



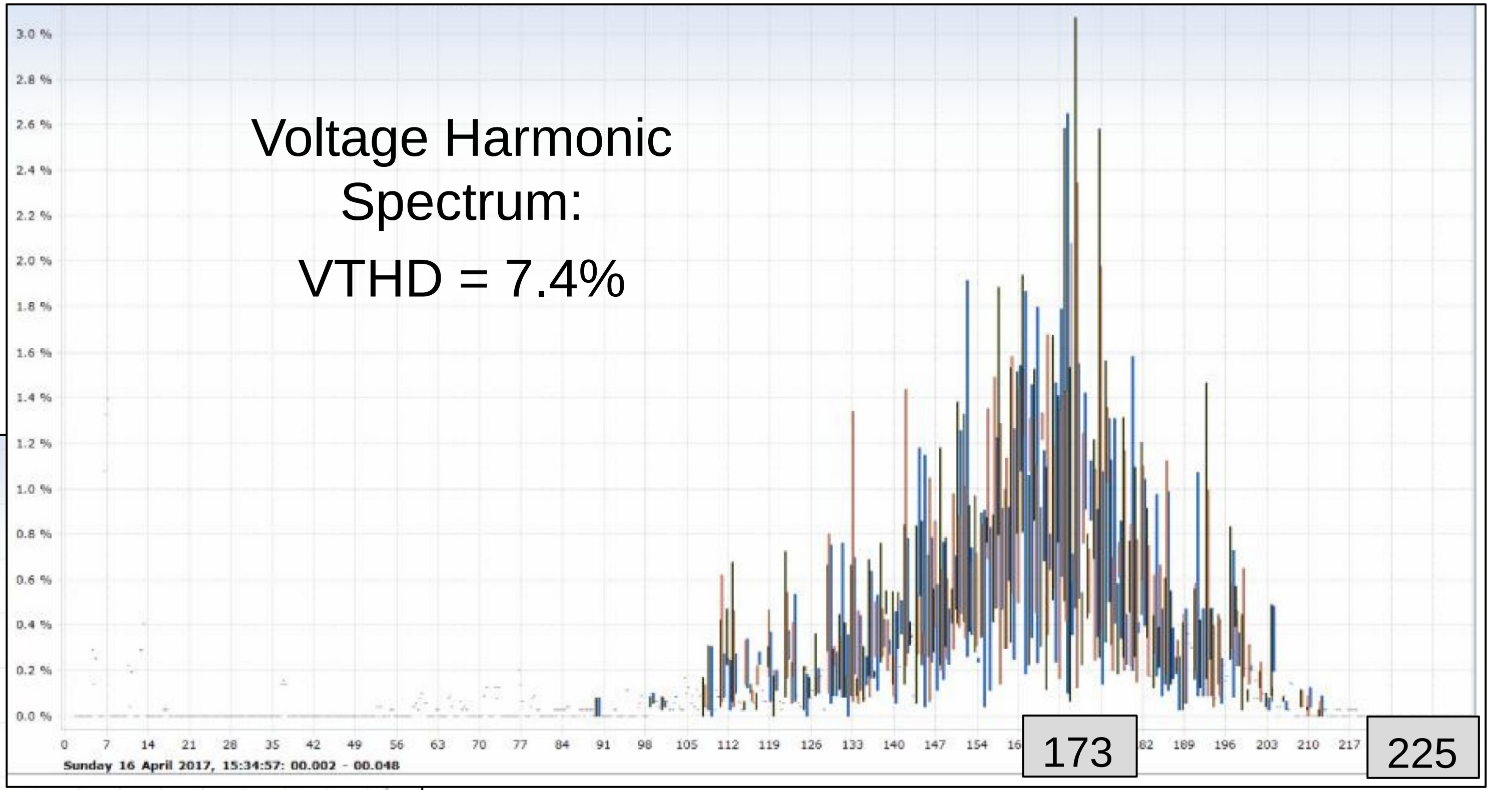
Magnetic Centrifugal Chiller equipped with Active Front-end (AFE) Drives

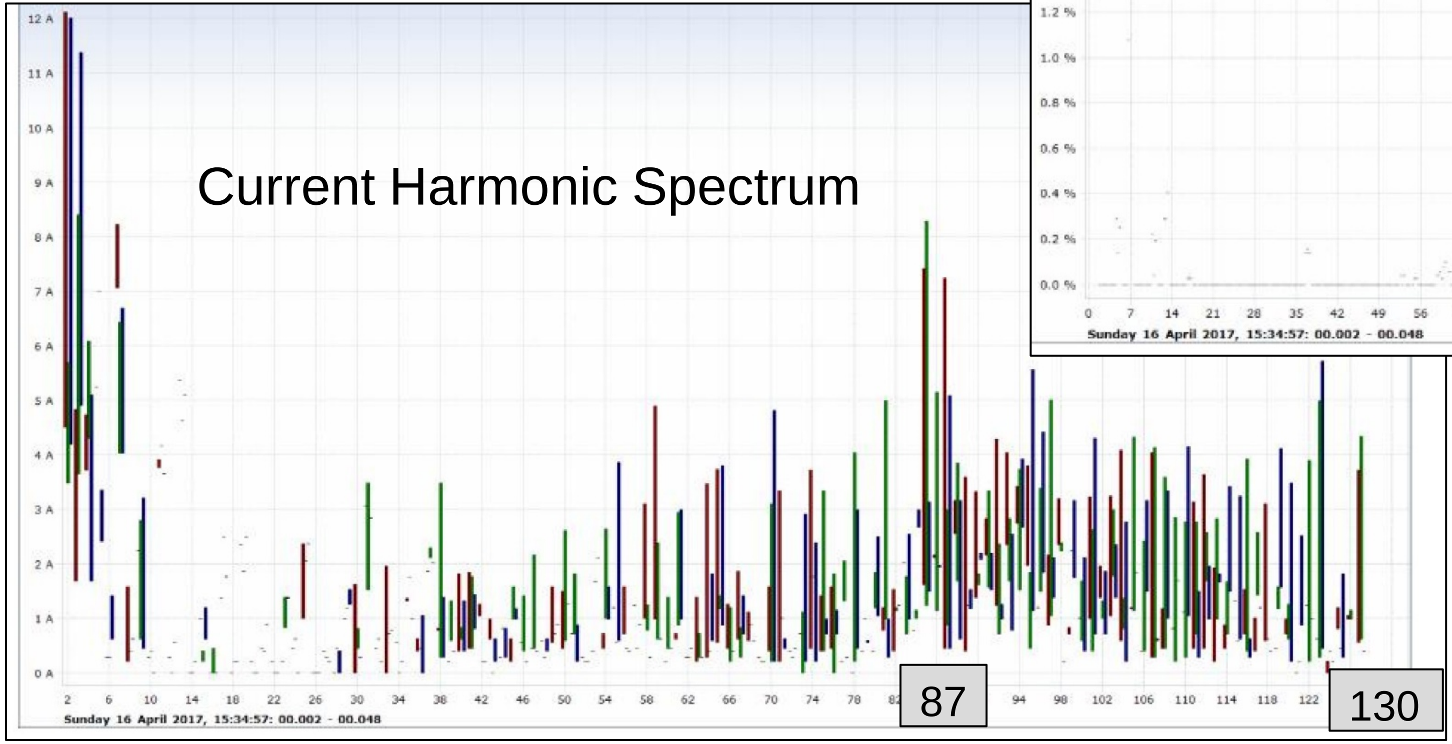
Current Spectrum



Magnetic Centrifugal Chiller equipped with AFE Drive – Hospital, Abu Dhabi UAE

High frequency harmonics believed to have caused failure of 2000 kVA transformer

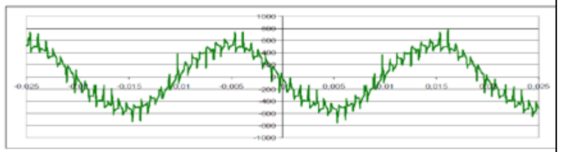
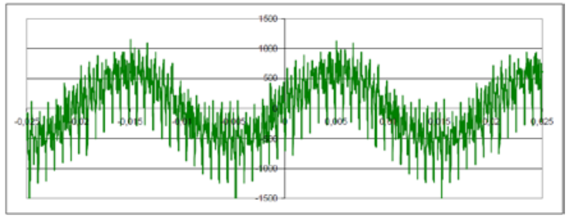
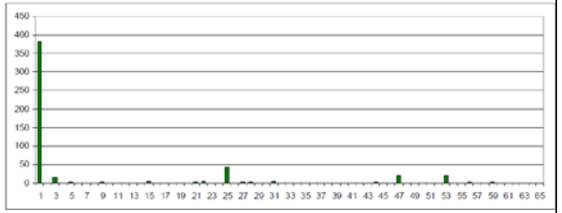
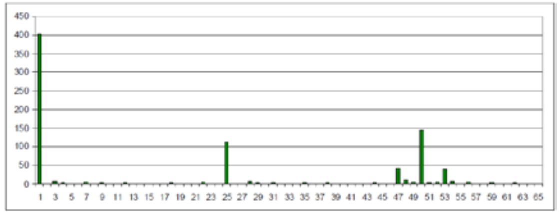
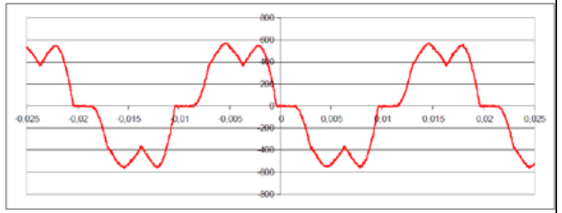
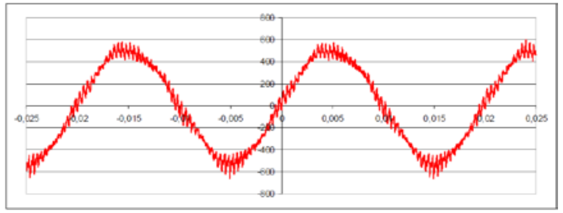
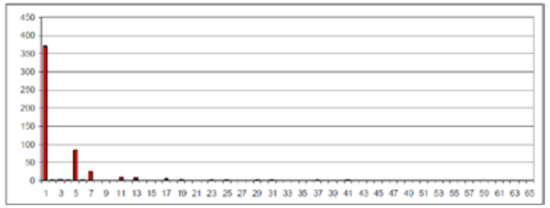
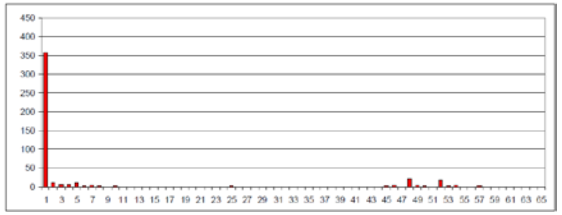




Active Front-end (AFE) Drives High Frequency Harmonics

AFE's generate high frequency harmonics which can have more serious consequences than low frequency harmonics

Example of an
AFE Drive
operating in both
6-Pulse mode and
AFE mode

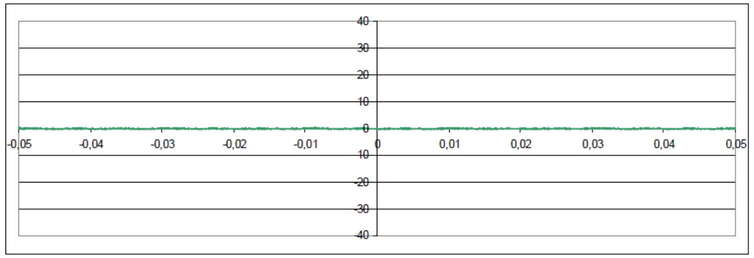
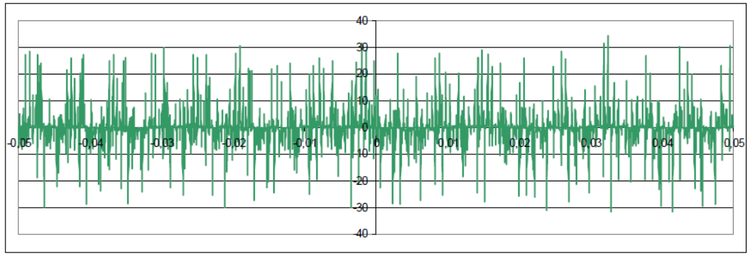
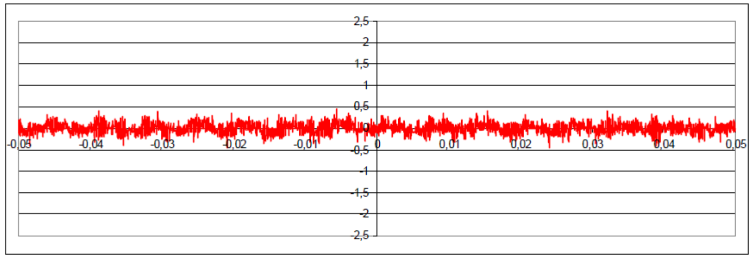
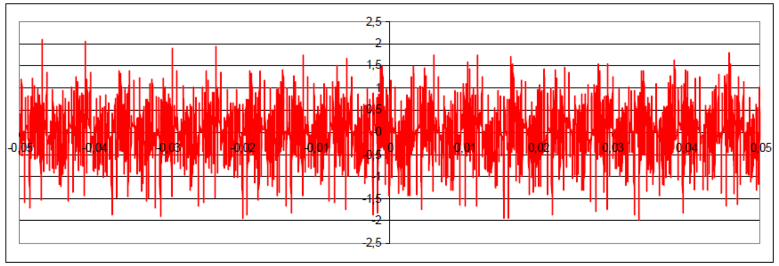
	Operating as a 6-Pulse Rectifier Drive	Operating as an Active Front-End Drive
Ph-to-Gnd Voltage Waveform		
Ph-to-Gnd Voltage Spectrum		
Input Current Waveform		
Input Current Spectrum		

Reference:

1. Practical Problems Associated with the Operation of ASDs Based on Active Front End Converters in Power Distribution Systems, Luis Moran, Jose Espinoza, et al, IEEE Transactions on Industrial Applications, 2004

Active Front-end (AFE) Drives High Frequency Harmonics

AFE's generate significant levels of ground leakage current which can cause inadvertent ground fault trips and sensitive equipment failure

	Operating as a 6-Pulse Rectifier Drive	Operating as an Active Front-End Drive
N-to-Gnd Voltage		
N-to-Gnd Current		

Example of an AFE Drive operating in both 6-Pulse mode and AFE mode

- Much higher neutral-to-ground harmonics (common-mode) in AFE mode

Reference:

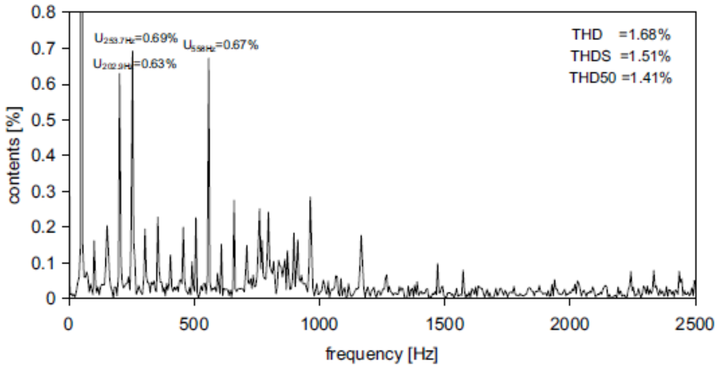
1. Practical Problems Associated with the Operation of ASDs Based on Active Front End Converters in Power Distribution Systems, Luis Moran, Jose Espinoza, et al, IEEE Transactions on Industrial Applications, 2004

Active Front-end (AFE) Drives High Frequency Harmonics

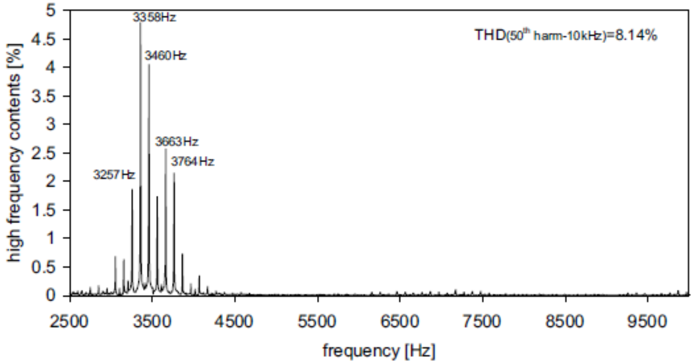
An AFE Drive will generate higher levels of harmonics at its IGBT switching frequency

AFE voltage harmonic spectrums at various frequency ranges

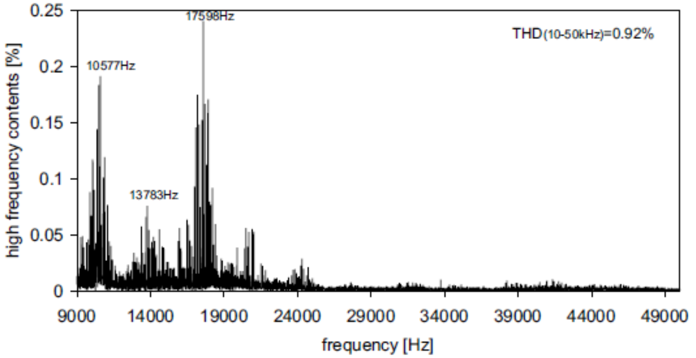
VTHD = 8.38% when harmonics up to 100th are considered



a) Up to 50th harmonic (VTHD = 1.68%)



b) 50th harmonic to 10 kHz (VTHD = 8.14%)



c) 10 kHz to 50 kHz (VTHD = 0.92%)

Frequency bands	THD [%]
0-50kHz	8.38
0-50th harmonic	1.68
50th harmonic-10kHz	8.14
10-50kHz	0.92

d) Summary of VTHD at various frequency bands

Reference:
1. An assessment of distortions of supply voltage waveform in All-Electric Ship Power Network, Marius Szweda, Tomasz Tarasiuk, Oct. 2007

Parallel Active Harmonic Filter

Operation:

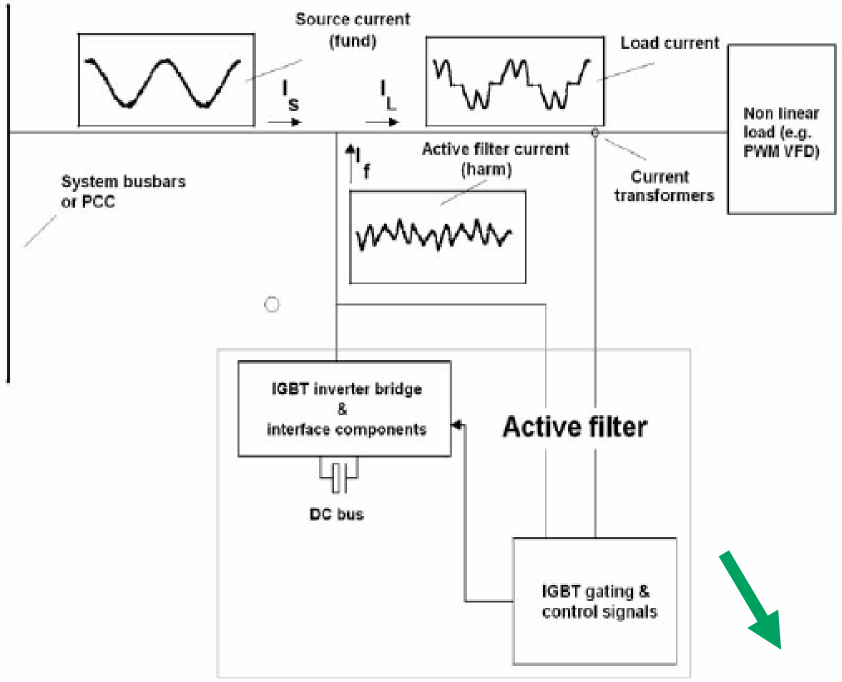
- Distorted current is sampled
- Fast acting IGBT's are used to generate harmonic currents and inject them to supply load requirement

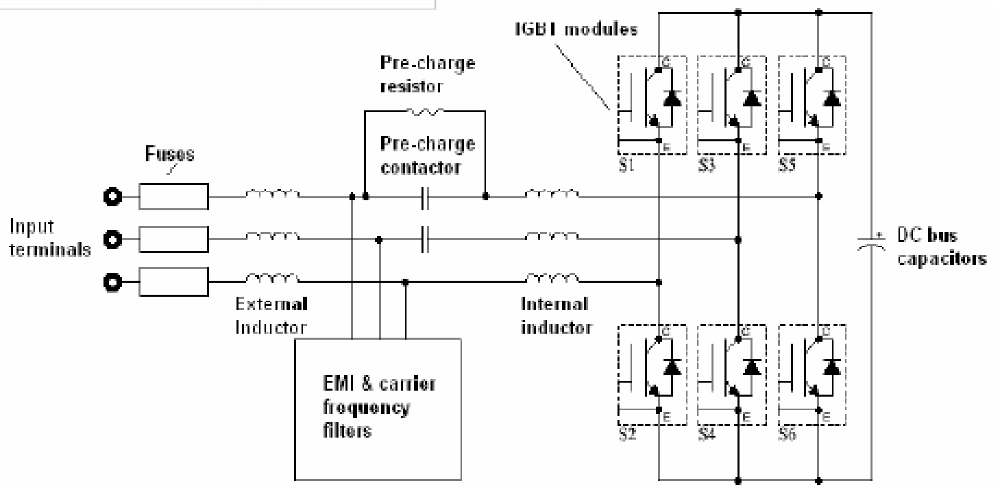
Pros:

- Sized to harmonic content only
- Maintains good performance at light load

Cons:

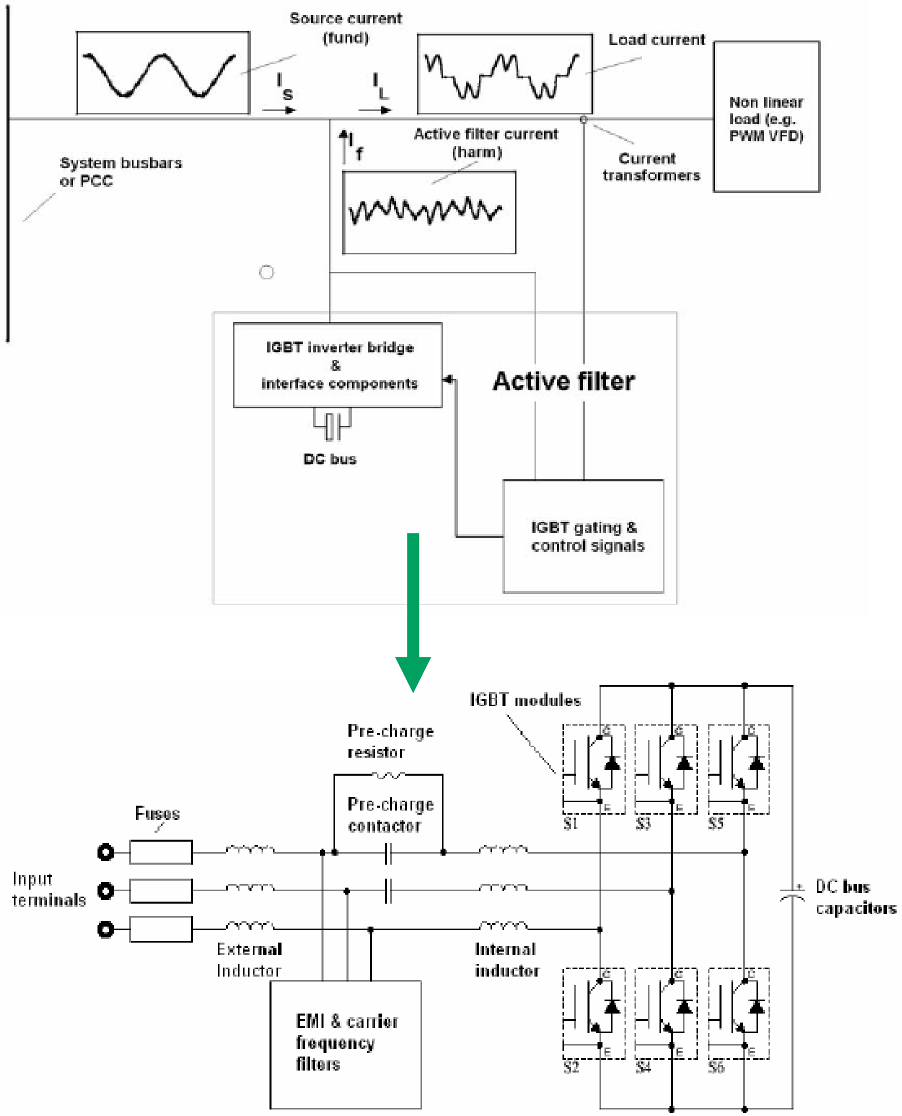
- Expensive
- Introduces higher frequency harmonics
- Susceptible to background voltage THD
- Complexity requires start-up and regular service by manufacturer





Active Harmonic Filter Resonance Problem - Solar Inverter Manufacturer

Parallel Active Harmonic Filter (AHF) was used to cancel harmonic currents generated by the rectifiers on a Solar Inverter Test line



Challenge:

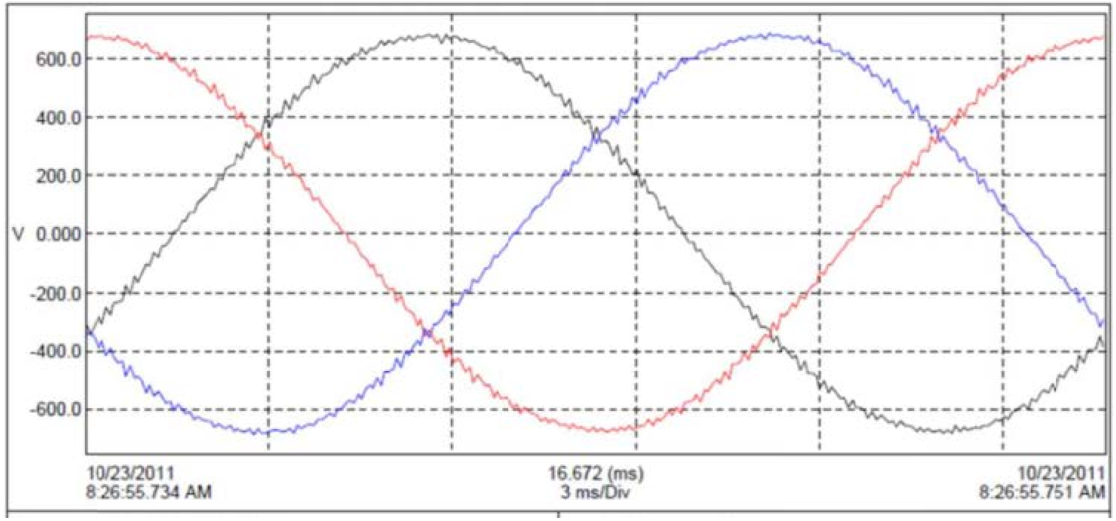
- Solar Equipment Mfr was having 48 Vdc power supply failures in a Photovoltaic Panel Tester
- These failures began to occur after a 450A AHF was installed on a Solar Inverter Test line

Active Harmonic Filter Resonance Problem - Solar Inverter Manufacturer

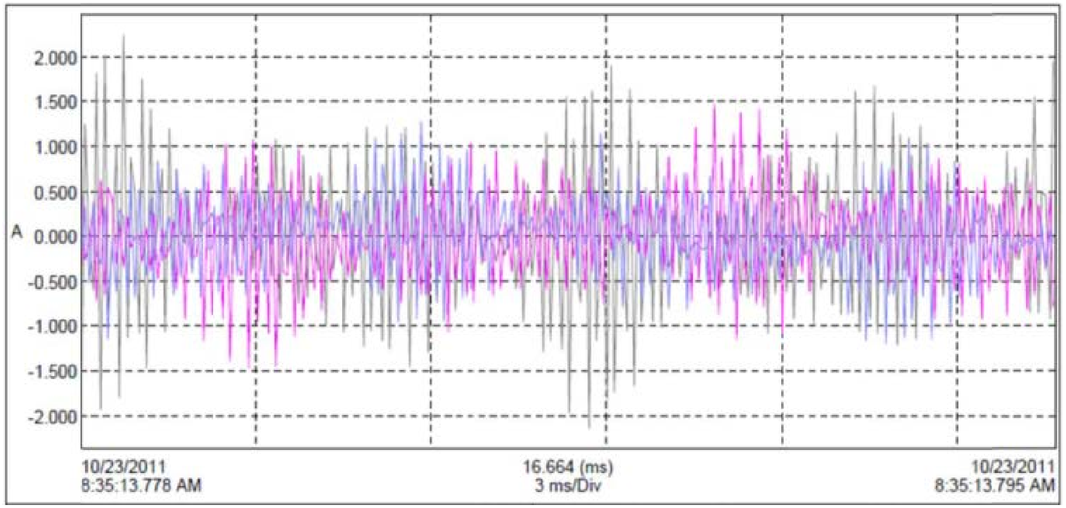
Challenge:

- AHF IGBT harmonics were creating a high frequency ripple on the supply voltage
- 48 Vdc power supply resonated near the 41st harmonic causing it to overheat and fail upon startup

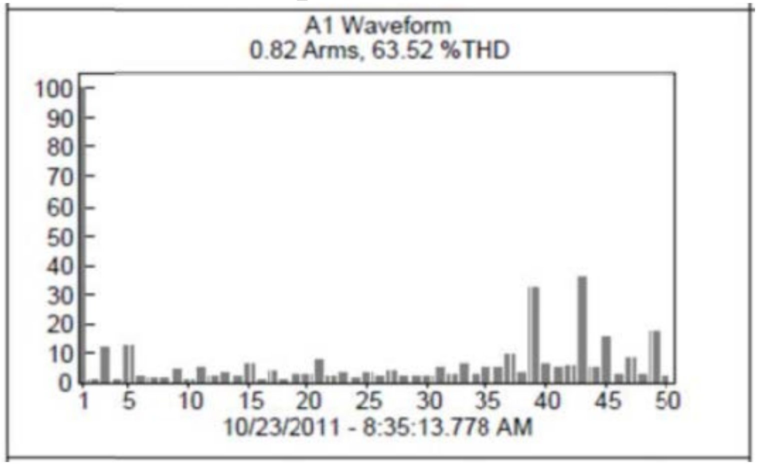
Voltage waveform – VTHD <1%



PS Current waveform at no load



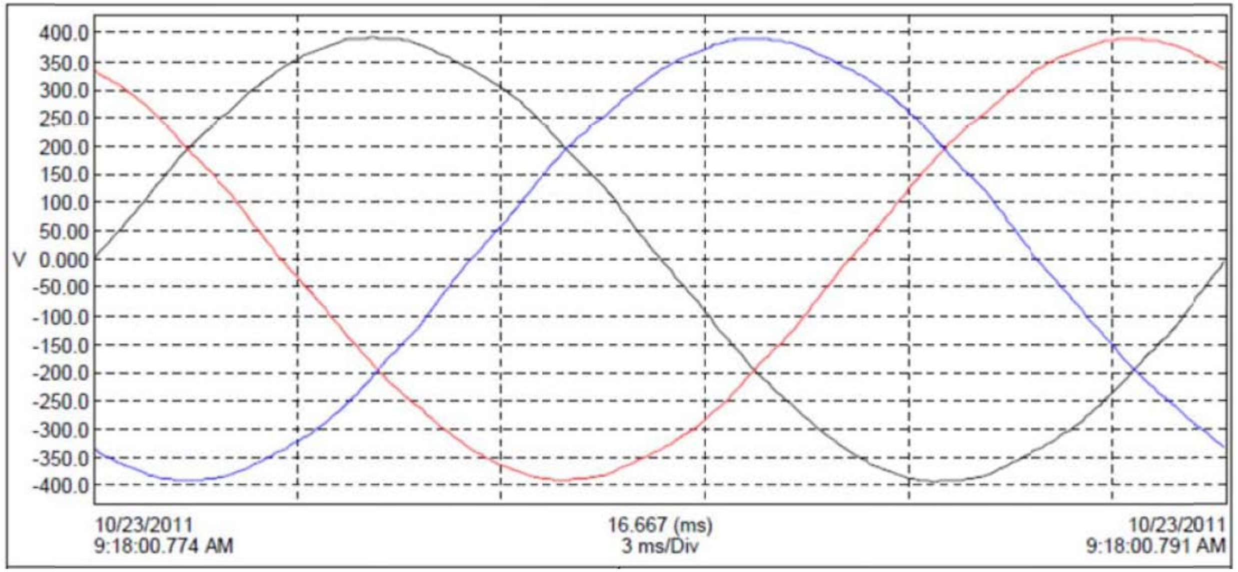
PS Current spectrum at no load



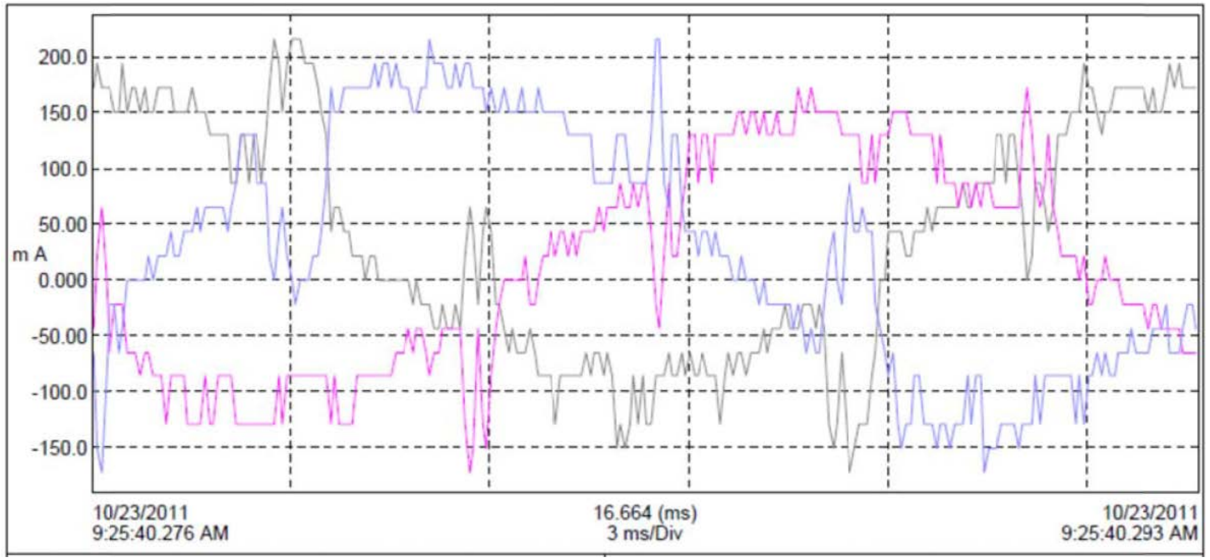
Active Harmonic Filter Resonance Problem
Solar Inverter Manufacturer

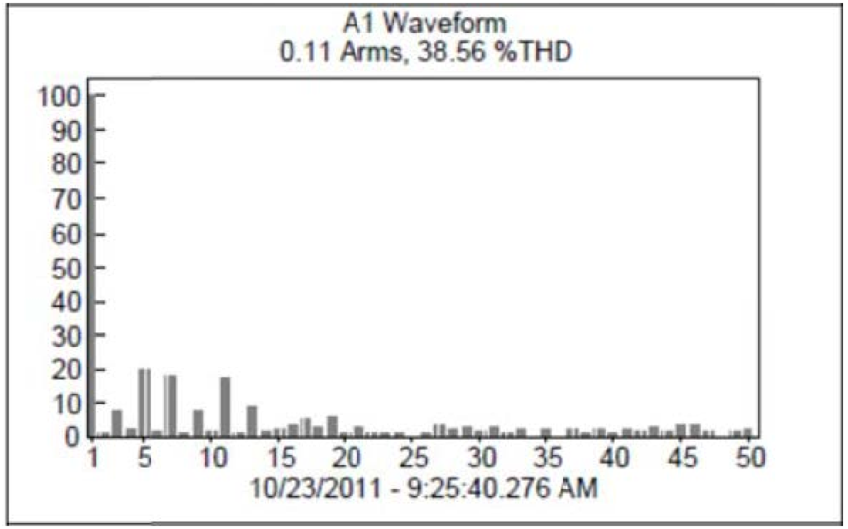
Solution:

- Permanently turn off AHF



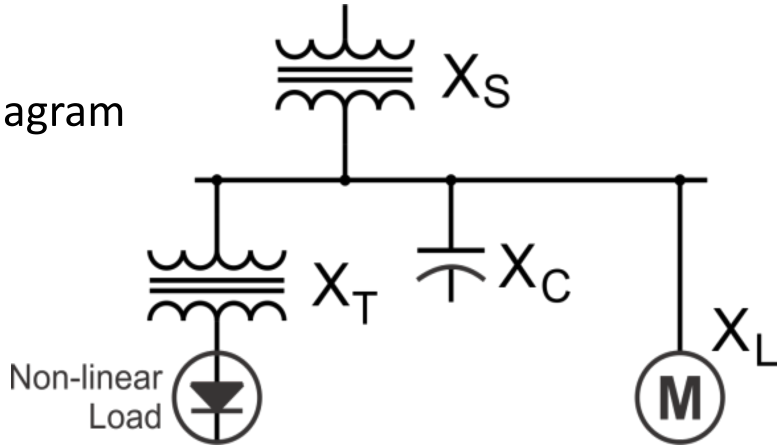
Note: This frequency was actually just below the supraharmonic range but demonstrates what problems can develop at the higher frequencies.

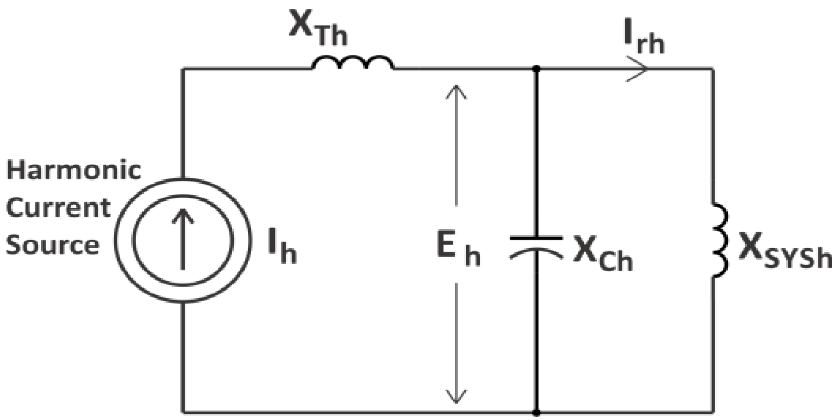




Power System Harmonic Resonance

Single Line Diagram





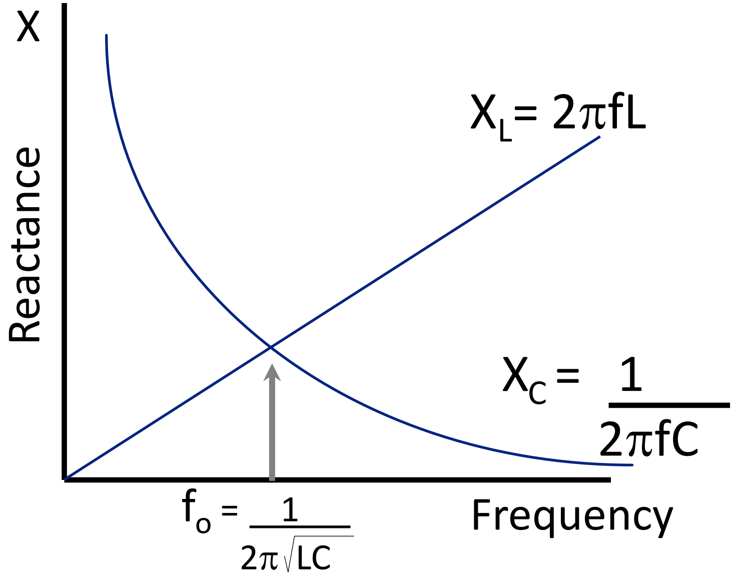
Equivalent Diagram

Resonance will occur when: $X_{Ch} = X_{SYSh}$ $(X_{SYSh} = X_S \,||\, X_L)$

At resonance, the circulating current is limited only by the resistance in the circuit.

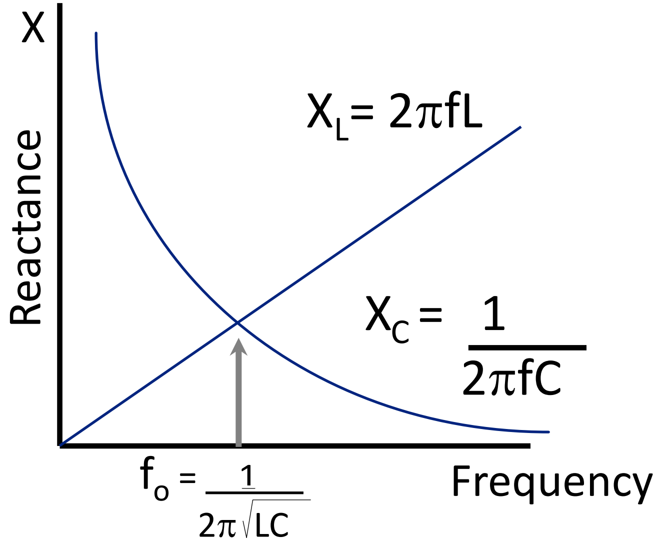
Problems that can result include:

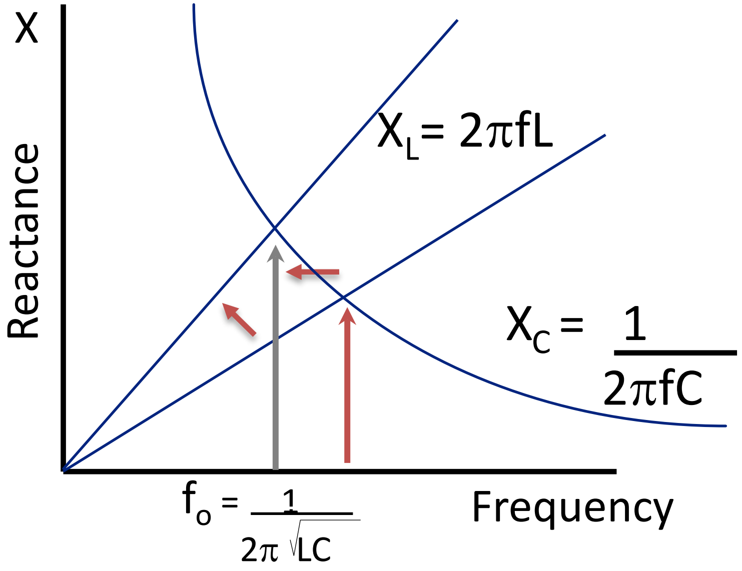
- High current and voltage distortion
- Destroyed capacitors and their fuses
- Damaged surge suppressors
- Failure of connected equipment
- System shutdowns



Effect of Power System Impedance on Resonance

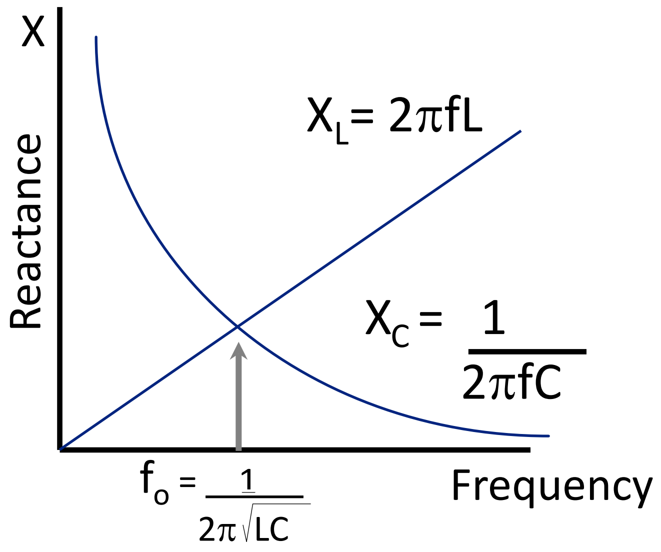
- Power Systems are inductive in nature
  - Will be capacitive only when over compensated by PFC capacitors which always should be avoided
- Adding power system inductance will shift this resonance frequency lower
- With a 'stiff', low impedance source, this shift will be minor
- Shift will be greater on a 'weak', high impedance source



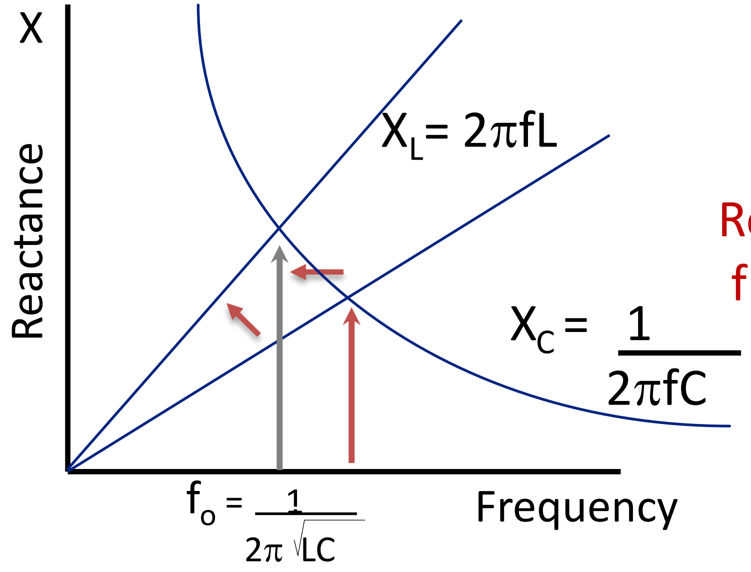


LCL Filter Resonance with Power System

- Active Rectifier LCL filters and Grid Tie Inverter sinewave filters are designed to reduce IGBT switching frequency harmonics so are tuned below these frequencies
- Adding power system inductance will shift this resonance frequency lower



- Especially on ‘weak’ power systems, this can result in resonance near a predominant harmonic
  - Below switching frequency but above 5th
- Harmonics can be amplified to levels that cause failures



Resonance can occur at frequencies above 5th

Evaluating Supraharmonics in Electric Vehicle Charging: University of Applied Sciences - Bingen, Germany

5 kW, 1-Ph Inverter for EV Charging

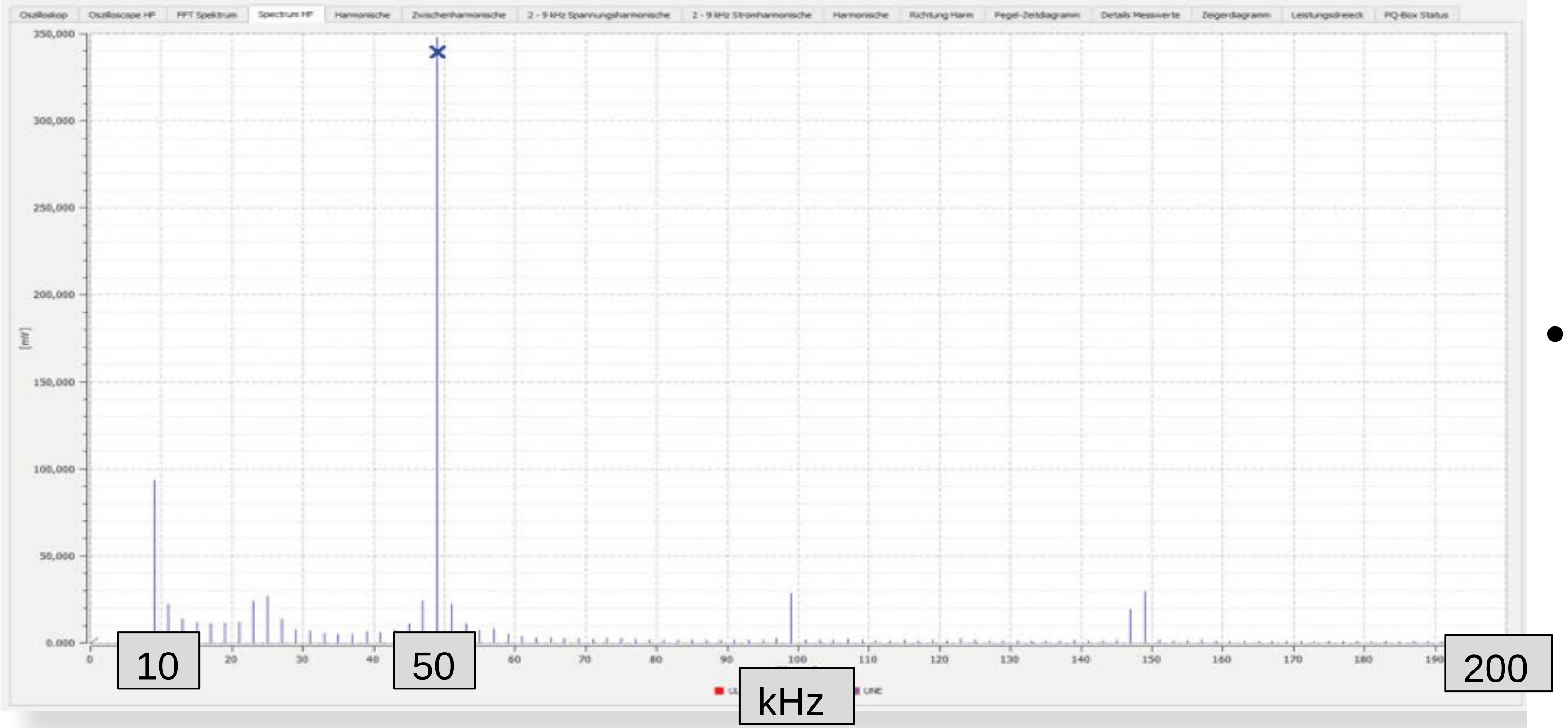


Fig. 1: Electric vehicle with a 50 kHz chopper frequency; shown with 2 kHz frequency bands

Current Spectrum of EV Charger with 50 kHz Chopper Frequency

- Various Electric Vehicles were studied
  - Chopper frequencies varied between 8 kHz and 50 kHz
  - Chart shows EV charger with 50 kHz chopper frequency
  - Clear evidence of current harmonics at 50 kHz and smaller bands at 2x and 3x

Reference:

1. Evaluating Supraharmonics up to 150 kHz in Electric Vehicles at the University of Applied Sciences Bingen, A-Eberle Power Quality document, 2016

Evaluating Supraharmonics in Electric Vehicle Charging: University of Applied Sciences - Bingen, Germany

5 kW Inverter with 50 kHz Chopper Freq

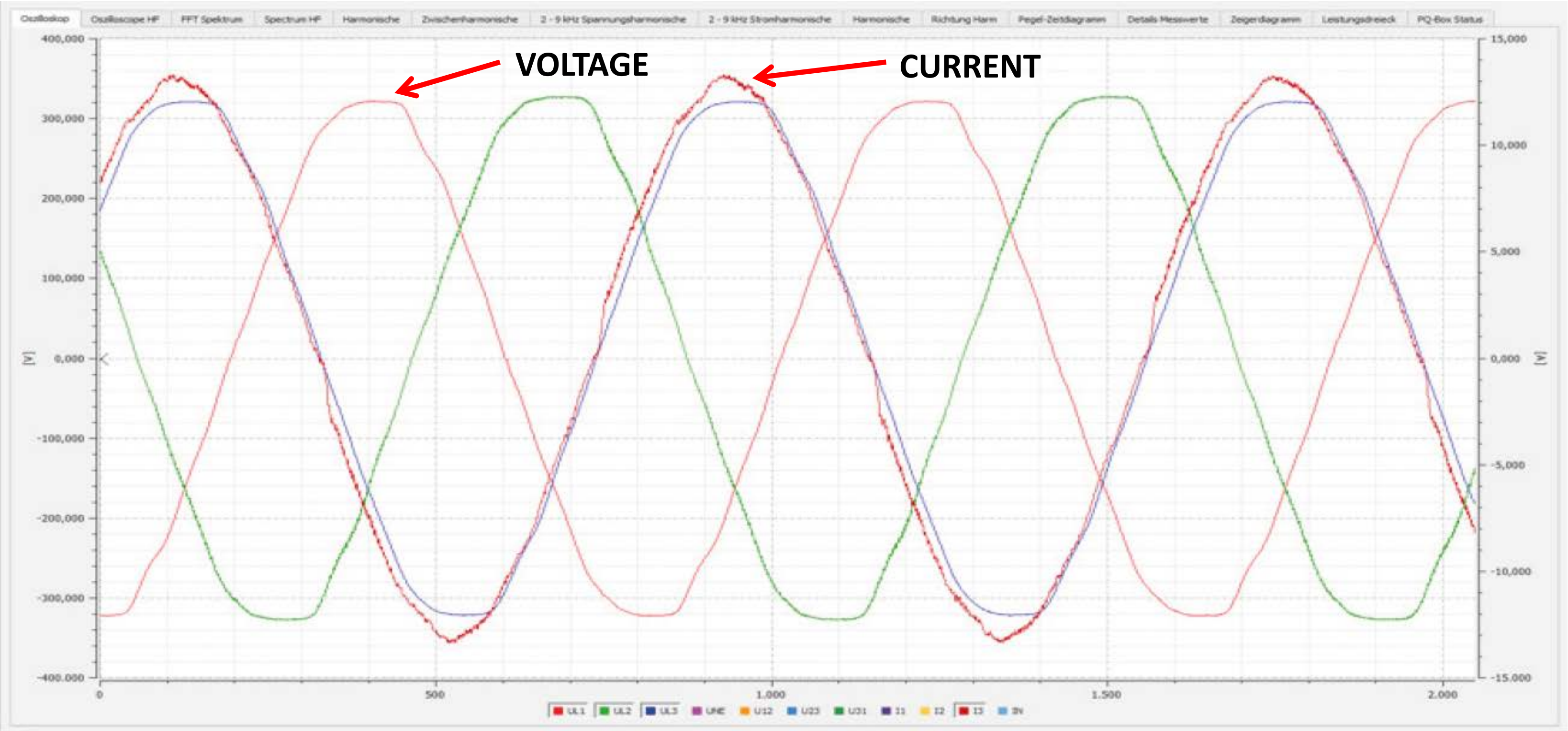


Fig. 3: Electric vehicle No. I connected to the outlet alone

- High frequency ripple on current drawn by charger

Voltage and Current Waveforms of EV Charger with 50 kHz Chopper Frequency

Reference:
1. Evaluating Supraharmonics up to 150 kHz in Electric Vehicles at the University of Applied Sciences Bingen, A-Eberle Power Quality document, 2016

Evaluating Supraharmonics in Electric Vehicle Charging: University of Applied Sciences - Bingen, Germany

5 kW Inverter with 50 kHz Chopper Freq

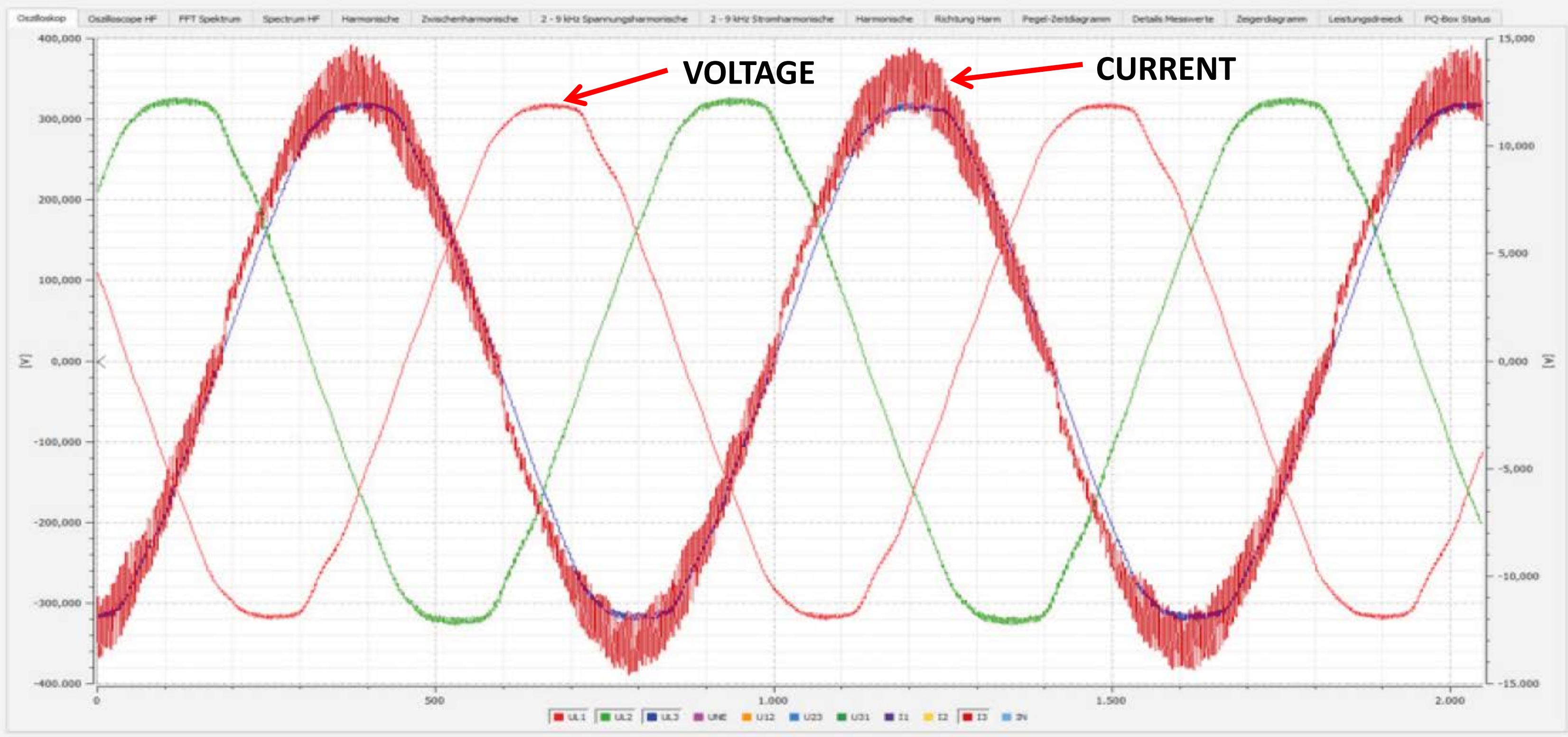


Fig. 4: Electric vehicles No. 1 and No. 2 connected in parallel to the charging station and the outlet

Voltage and Current Waveforms of EV Charger with 50 kHz Chopper Frequency

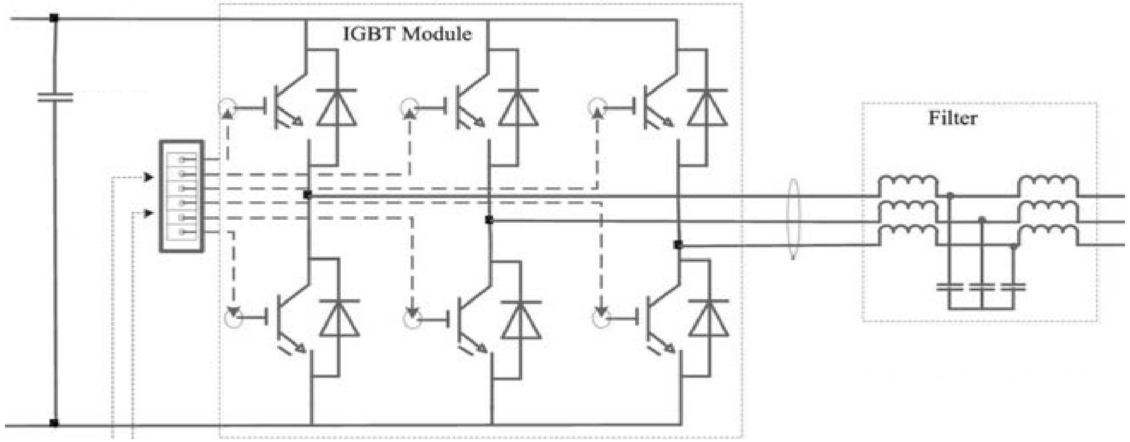
- A second EV was connected in parallel with a 10 kHz chopper frequency
- High frequency ripple in current of first EV charger substantially increased
- More noticable in voltage

Reference:

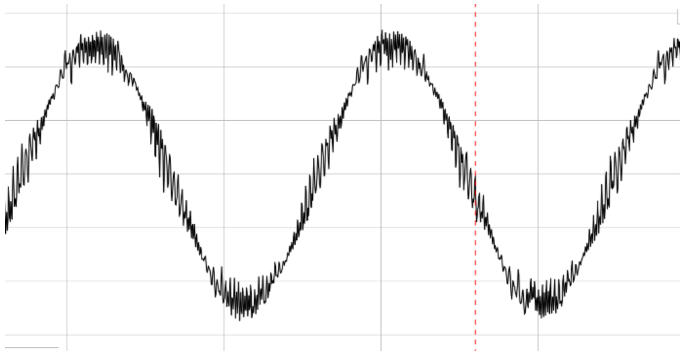
1. Evaluating Supraharmonics up to 150 kHz in Electric Vehicles at the University of Applied Sciences Bingen, A-Eberle Power Quality document, 2016

PWM Inverter Sinewave Filter

- Low pass filters designed to reduce PWM IGBT inverter switching frequency
  - Typically 2 to 16 kHz
- For near sinusoidal voltage, the filter's tuned frequency must be well below the inverter's switching frequency and comfortably above its output fundamental frequency
  - Conventional design uses a minimum cutoff frequency of 10x fundamental and, at least, 2 to 2.5x below the switching frequency



PWM Inverter with Sinewave Filter



Resultant Output Voltage Waveform with residual switching frequency ripple

Evaluating Supraharmonics in Electric Vehicle Charging: University of Applied Sciences - Bingen, Germany

EV Chargers and Solar Inverter Systems Operating Simultaneously

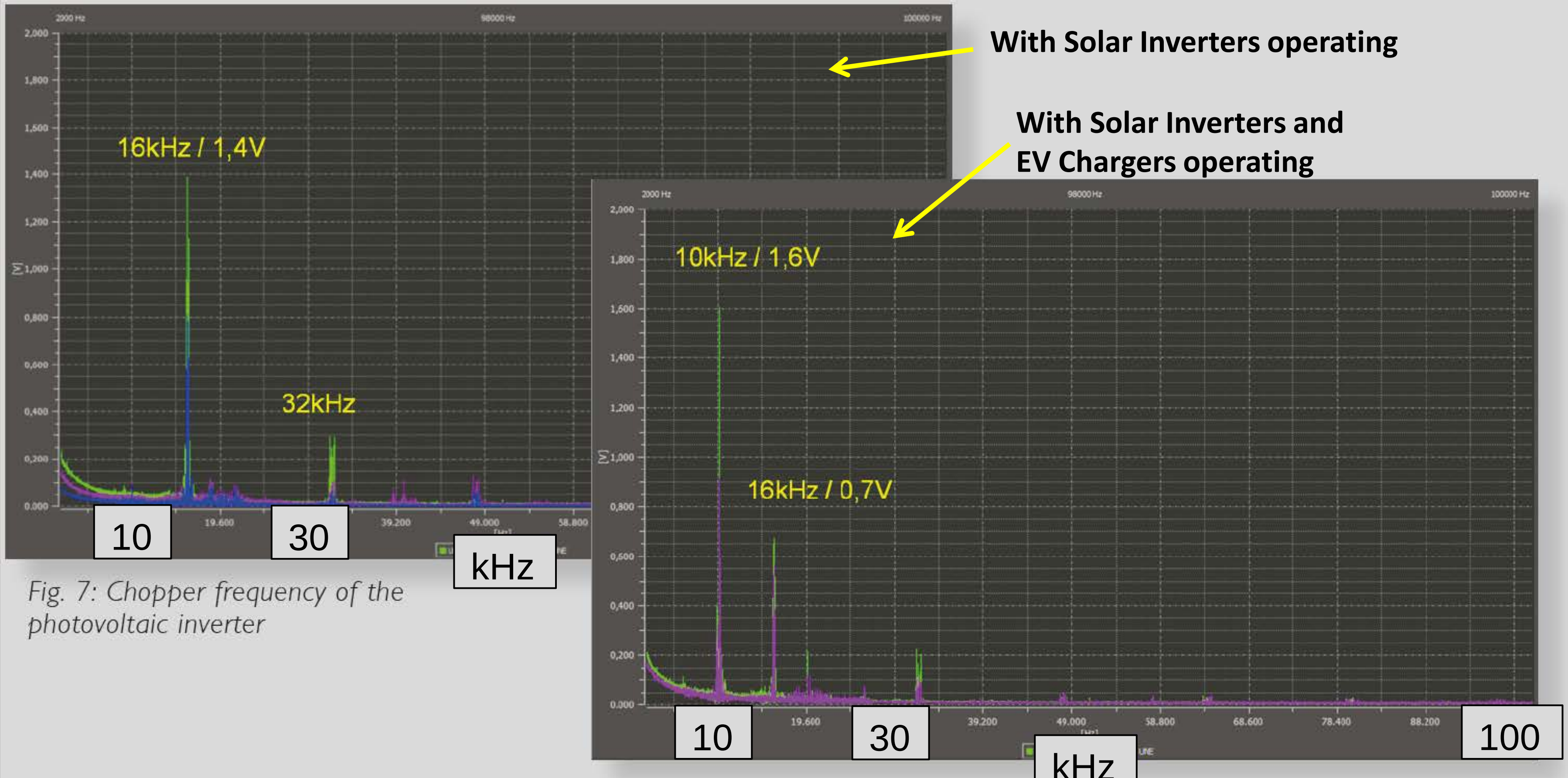


Fig. 7: Chopper frequency of the photovoltaic inverter

Fig. 8: Chopper frequency of the photovoltaic inverter and one electric vehicle

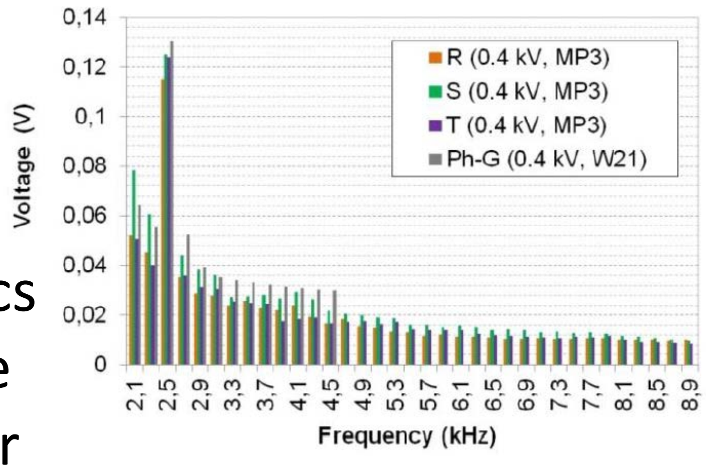
- Solar Inverter switching at 16 kHz
- 10 kHz EV Chargers added
- Both switching freqs are evident
- 16 kHz distortion from Solar dropped when EV's added (1.4V to 0.7V)
- Likely being sinked into EV Chargers

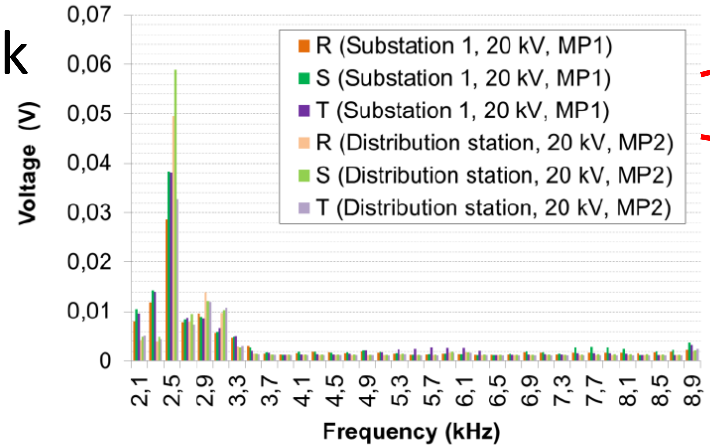
Reference:

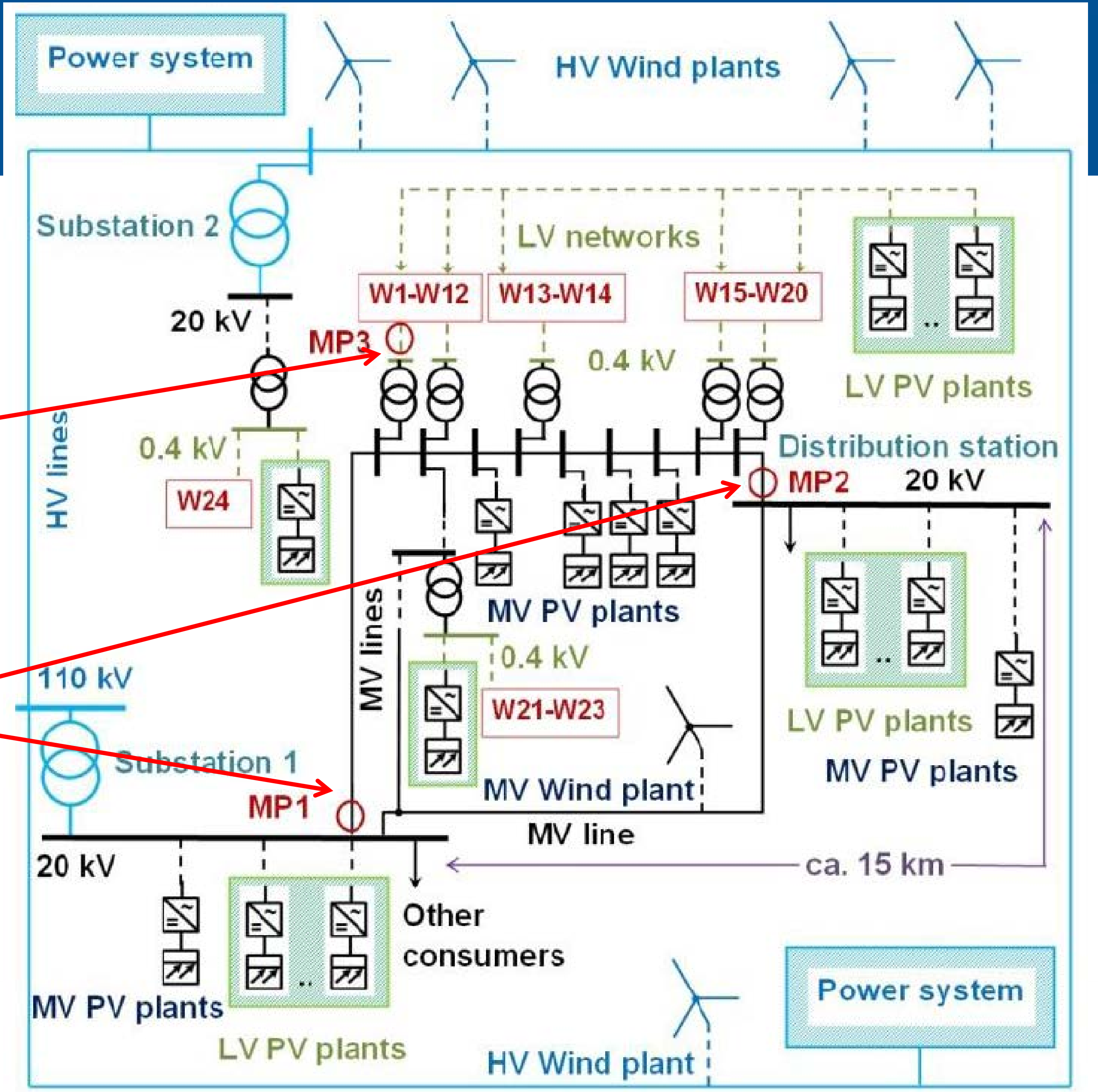
1. Evaluating Supraharmonics up to 150 kHz in Electric Vehicles at the University of Applied Sciences Bingen, A-Eberle Power Quality document, 2016

Supraharmonics in Power Grid with Renewable Energy

Supraharmonics can propagate through Power System network







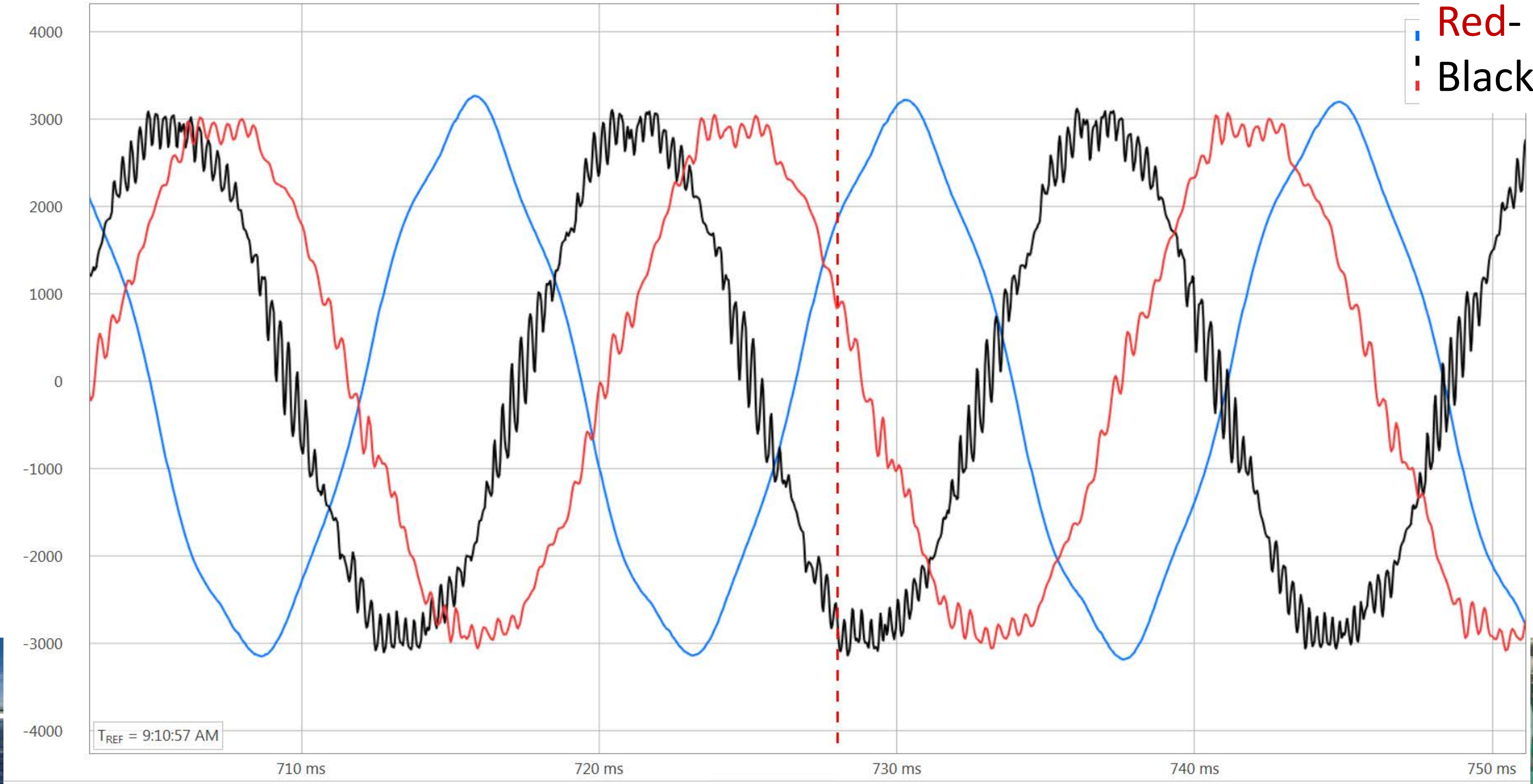
Reference:

1. Measurements and Analysis of Supraharmonic Influences in a MV/LV Network Containing Renewable Energy Sources, Alexander Novitskiy et all, Dept of Power Systems, Technische Universitat, Ilmenau, Germany, 2019

Comparison of Sinewave Filters on Various Electrical Submersible Pumps

Voltage Waveform comparison of Mirus Inversine Sinewave Filter vs two other competitive sinewave filters in similar ESP applications

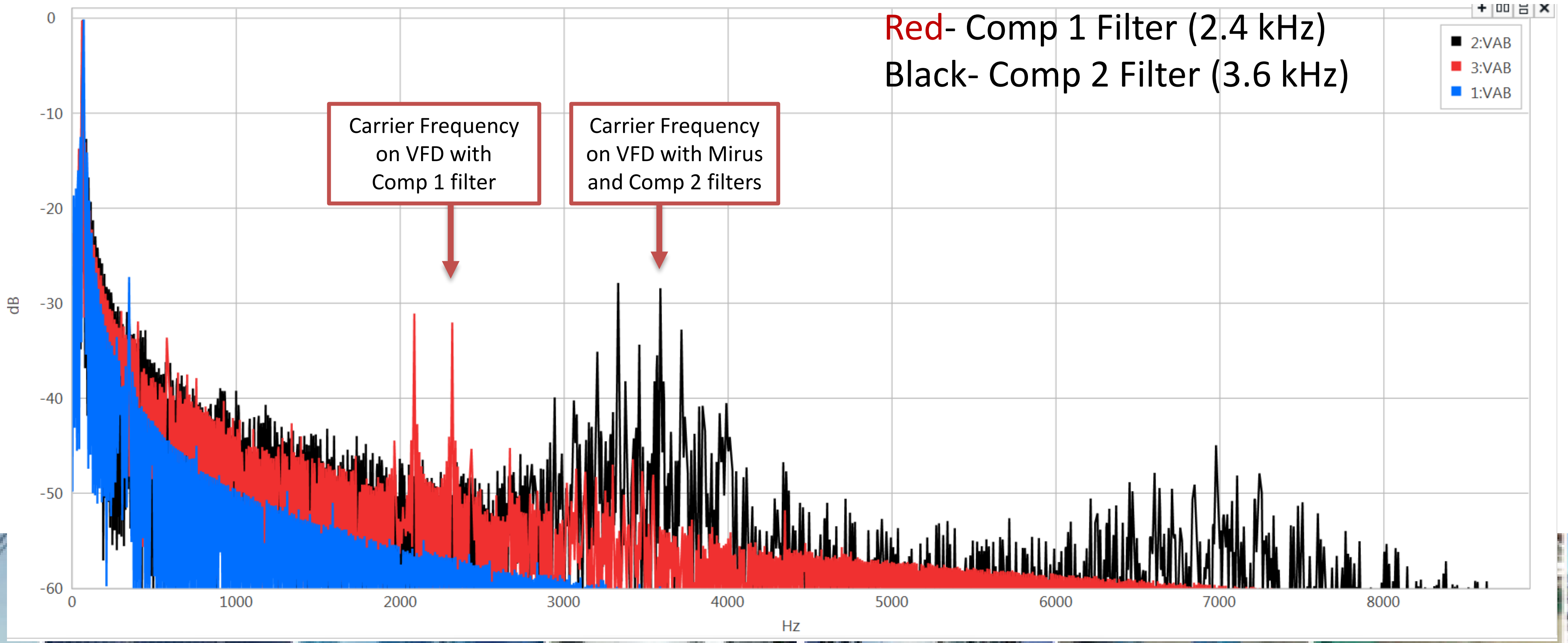
Blue- Mirus Inversine
Red- Comp 1 Filter
Black- Comp 2 Filter



Comparison of Sinewave Filters on Various Electrical Submersible Pumps

Voltage Spectrum comparison of Mirus Inversine vs two other competitive sinewave filters in similar ESP applications

Blue- Mirus Inversine (3.6 kHz)
Red- Comp 1 Filter (2.4 kHz)
Black- Comp 2 Filter (3.6 kHz)



Harmonic Standard: IEEE Std 519 – 2014

IEEE Std 519, Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems

- Defines voltage and current distortion limits at PCC
- Intended to be used as a system standard
- Recognizes responsibility of both User and Utility
- Considers both linear and non-linear loading
- Definitions for Total Demand Distortion (current) and Total Harmonic Distortion (voltage) apply to harmonics up to 50th but allow for inclusion of > 50 when necessary

total demand distortion (TDD): The ratio of the root mean square of the harmonic content, considering harmonic components up to the 50th order and specifically excluding interharmonics, expressed as a percent of the maximum demand current. Harmonic components of order greater than 50 may be included when necessary.

IEEE Std 519 – 2014 Definitions

Point of Common Coupling (PCC)

Point on a public power supply system, electrically nearest to a particular load, at which other loads are, or could be, connected. The PCC is a point located upstream of the considered installation.

Total Harmonic Distortion (THD)

The ratio of the root mean square of the harmonic current, considering harmonic components up to the 50th order and specifically excluding interharmonics, expressed as a percentage of the fundamental. Harmonic components of order greater than 50 may be included when necessary.

Total Demand Distortion (TDD)

The ratio of the root mean square of the harmonic current, considering harmonic components up to the 50th order and specifically excluding interharmonics, expressed as a percentage of the maximum demand current. Harmonic components of order greater than 50 may be included when necessary.

Maximum Demand Current (I_L)

The current value at the PCC taken as the sum of the currents corresponding to the maximum demand during each of the 12 previous months divided by 12.

$$iTDD = iTHD \times \frac{I_{(meas)}}{I_L}$$

IEEE Std 519 – 2014 Voltage Distortion Limits (Table 1)

MIRUS International Inc.

Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \le 1.0$ kV	5.0	8.0
1 kV $< V \le$ 69 kV	3.0	5.0
69 kV $< V \le$ 161 kV	1.5	2.5
161 kV $< V$	1.0	1.5[a]

[a]High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal whose effects will have attenuation at points in the network where future users may be connected.

- Major change is that for systems < 1.0 kV, vTHD is allowed to be as high as 8.0%
- Also, lower voltage distortion limits for Special Applications and higher limits for Dedicated Systems have been removed

IEEE Std 519 – 2014 Current Distortion Limits for Systems Rated 120V through 69kV (Table 2)

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)[a,b]						
I_{SC}/I_L	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	TDD
< 20[c]	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

[a]Even harmonics are limited to 25% of the odd harmonic limits above
[b]Current distortions that result in a dc offset, e.g., have-wave converters, are not allowed
[c]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 current (fundamental frequency component) at the PCC under normal load operating conditions

- Essentially no change from previous edition

IEC Harmonic Standards – Low Frequency

- IEC 61000-3-2, Limits for harmonic current emissions (equipment input current < 16A/ph single & 3 phase)
- IEC 61000-3-12, Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16A and < 75A
- IEC 61000-3-6, Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems
- Only applied to harmonics up to the 40th

THD

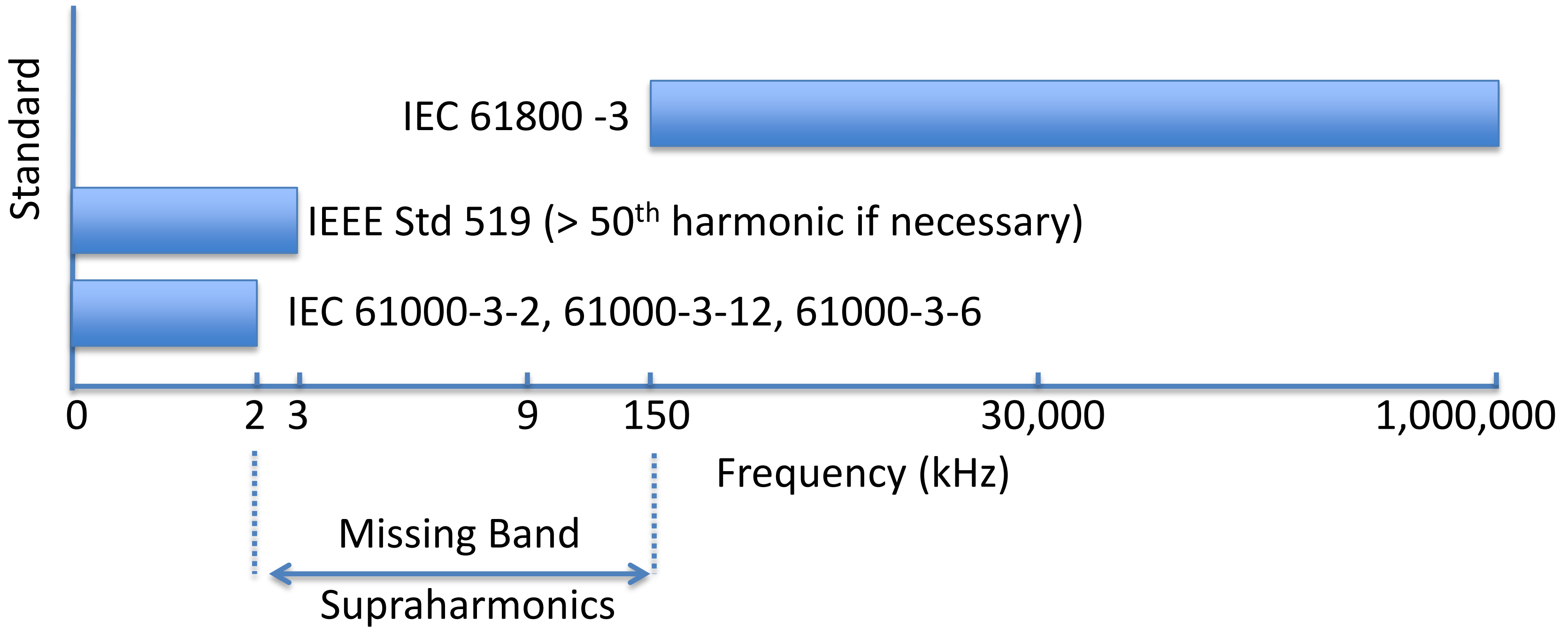
ratio of the r.m.s. value of the harmonics (in this context harmonic currents I_n of the order n) to the r.m.s. value of the fundamental, viz.

$$THD = \sqrt{\sum_{n=2}^{40} \left(\frac{I_n}{I_1} \right)^2}$$

High Frequency Standards

- IEC 61800-3, EMC Product Standard for Power Drive Systems
  - The source of high frequency emission from frequency converters is the fast switching of power components such as IGBTs
  - Covers frequency range from 150 kHz to 30 MHz conducted and 30 MHz to 1000 MHz radiated
- FCC 47 CFR Part 15
  - Regulates emissions in the radio frequency spectrum from 9 kHz and higher

Harmonic Standards and the Missing Band - Supraharmonics



- Low frequency regulations end at 40th or 50th harmonic unless IEEE 519 allowance of including harmonics above 50 is applied
- High frequency standards begin at 150 kHz

No standards exist from 50th harmonic to 150 kHz

Missing Frequency Band in Standards

Is this a concern?

Absolutely, since typical IGBT switching frequencies are between 2 kHz and 16 kHz which falls precisely within this band

Missing Frequency Band in Harmonic Standards

Active rectifiers and active harmonic solutions may comply with standards but they often introduce bigger problems than they resolve

Can Harmonics be Treated without Introducing Supraharmonics?

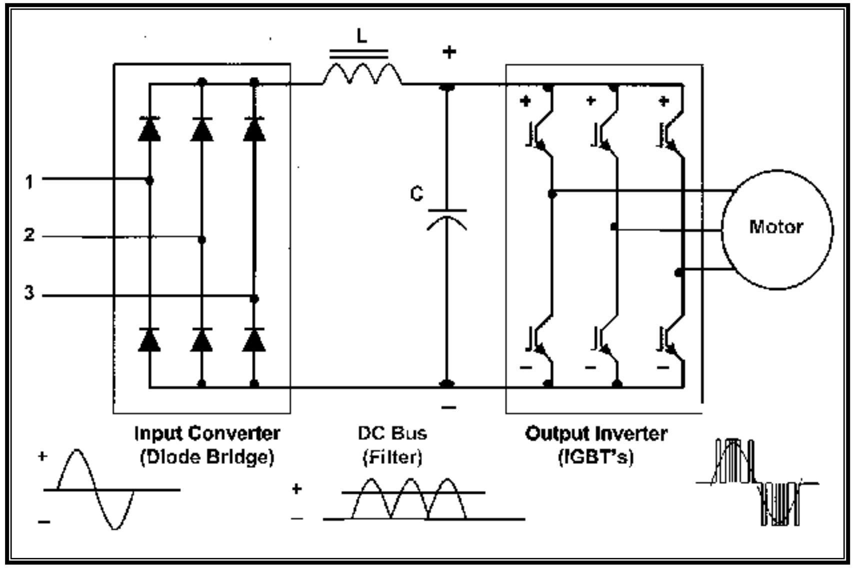
For simple diode bridge rectifiers:

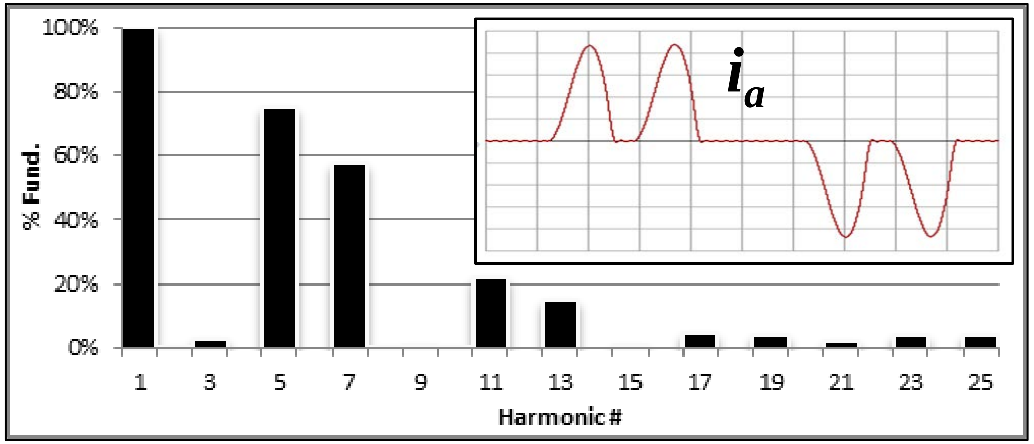
$$h = np \pm 1$$

$$I_h \sim \frac{I}{h}$$

h = harmonic number
p = # of pulses in rectification scheme
n = any integer (1, 2, 3, etc.)
I_h = magnitude of harmonic current
(addition of DC bus cap increases I_h)

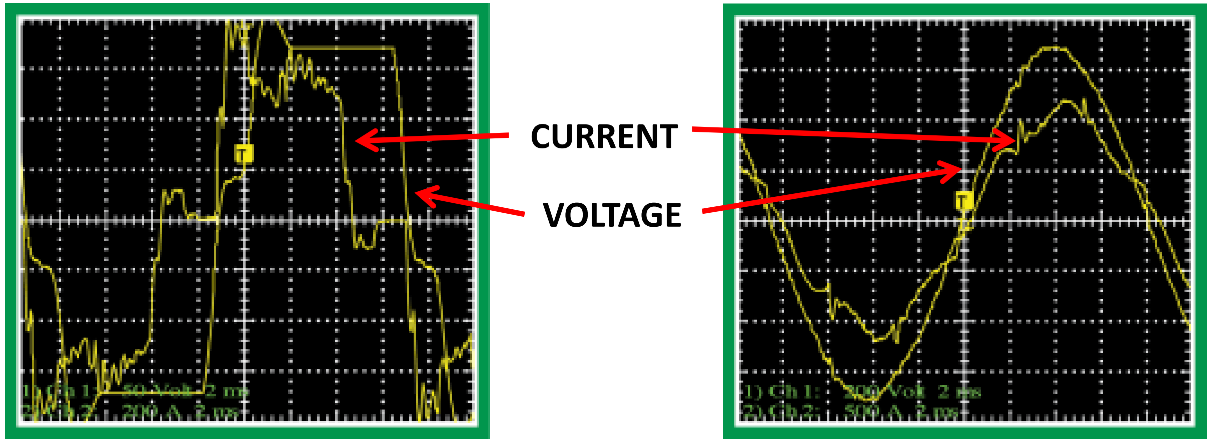
When,
p = 6
h = -- 5,7,--,11,13,--,17,19...





Current Waveform and Spectrum

Passive Wide Spectrum Harmonic Filter



Input Without Filter Installed

Input With Filter Installed

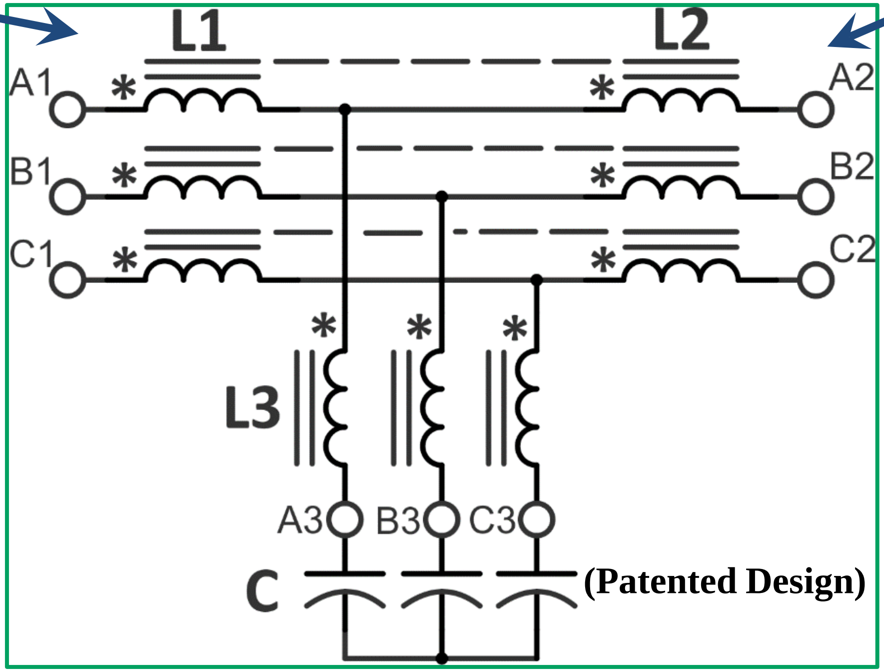
- Input harmonic filter for VSDs
- Better than 18-pulse or AFE performance with 6-pulse VSD
- ‘Real-World Guarantee’
- Meets IEEE and IEC harmonic limits
- Near unity power factor
- Generator compatible
- Highest efficiency

Passive Wide Spectrum Harmonic Filter

Multiple windings on a common core

High impedance L1 winding

Compensating winding L2 improves performance without increasing voltage drop



Input tuned below 5^{th} to prevent importation of upstream harmonics

Output tuned near 7^{th} to remove load side harmonics

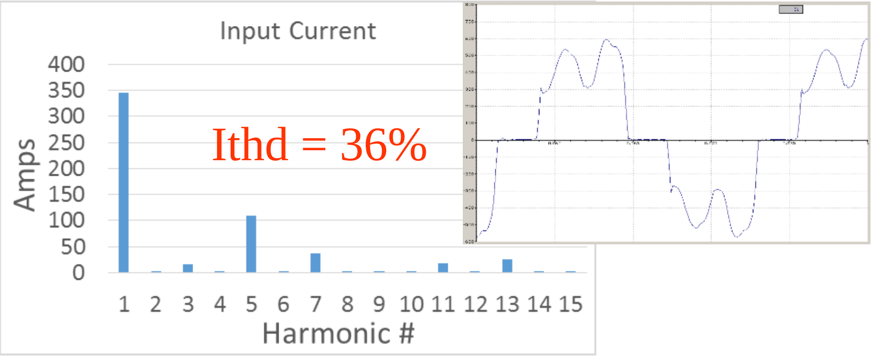
Unique reactor design allows for smaller cap bank to reduce voltage boost and reactive power at no load

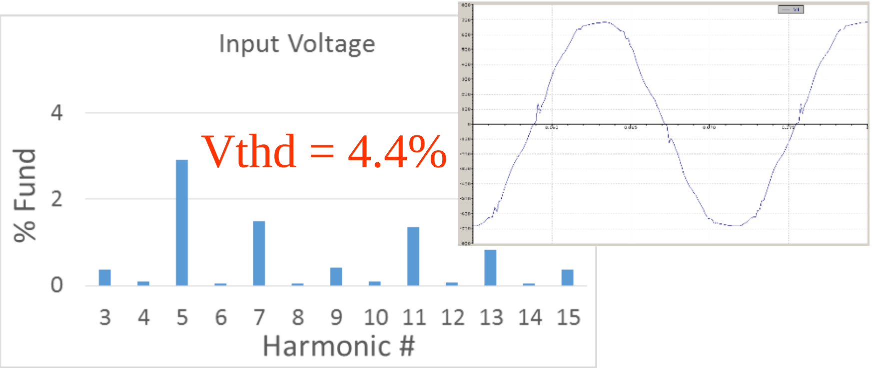
LINEATOR™

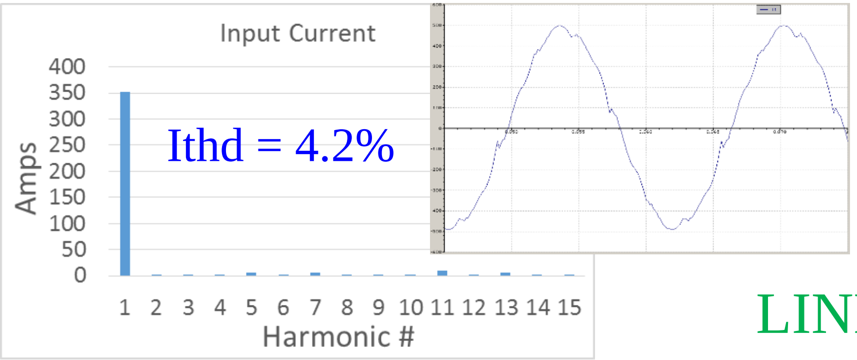
With continuous innovation since its introduction in 1999, the Mirus Lineator™ remains the best harmonic mitigation solution for AC and DC Drives.

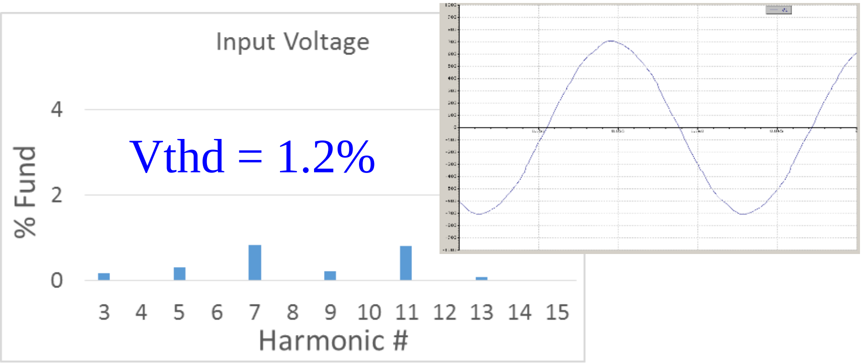
350HP WSHF-HP Performance PWM VSD

With Reactor







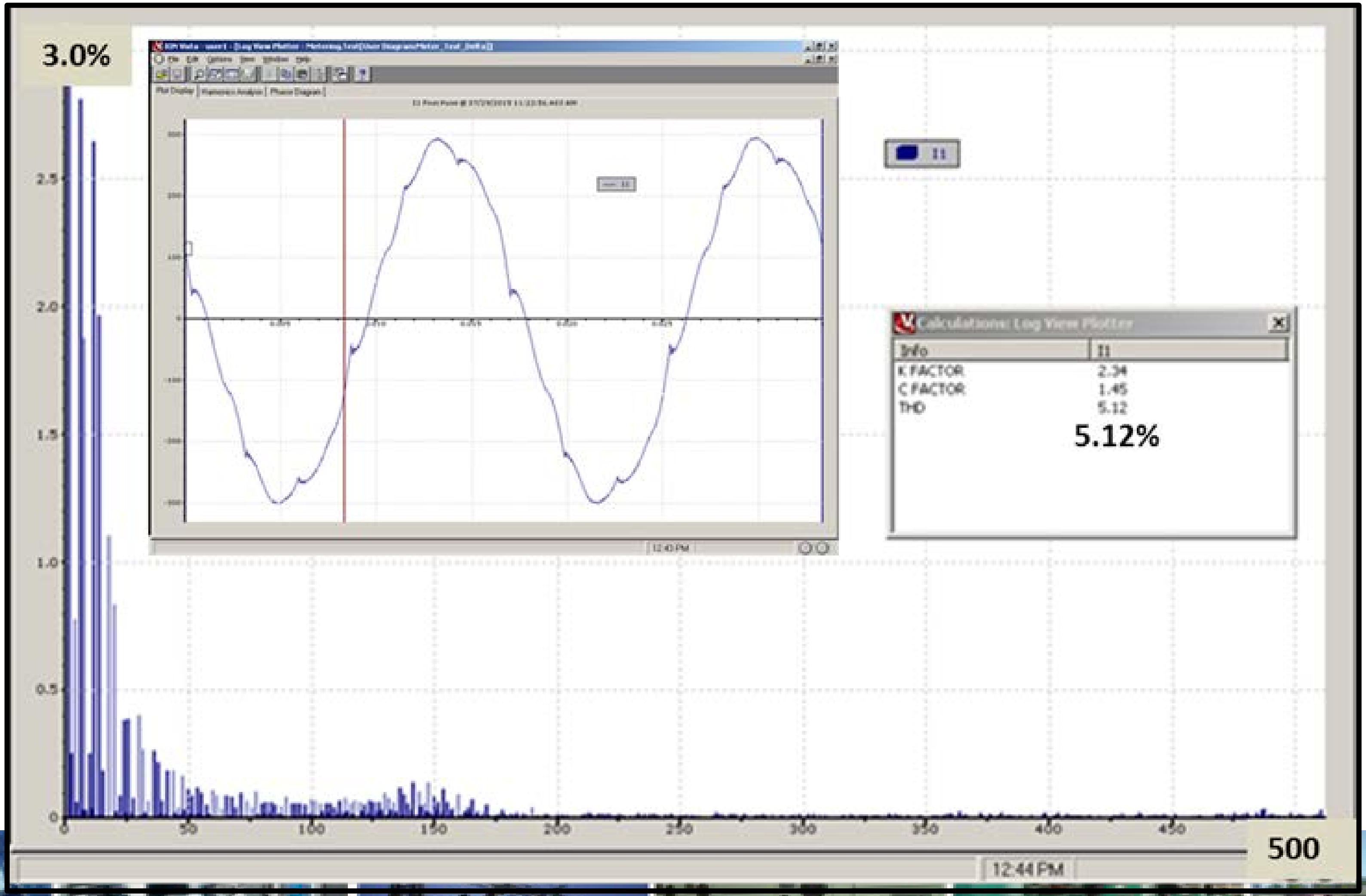


With LINEATOR-HP

	Current Harmonics (Amps)																	
	RMS		5th		7th		11th		13th		Ithd		Itdd		K-factor		PF	
Load	w/o	With	w/o	With	w/o	With	w/o	With	w/o	With	w/o	With	w/o	With	w/o	With	w/o	With
Full	369	352	110	5.0	37	4.9	19	9.5	25	6.1	36%	4.2%	36%	4.2%	8.9	1.5	0.94	0.98
75%	275	257	83	4.8	35	6.6	16	8.1	17	3.9	37%	5.2%	28%	3.9%	9.3	1.7	0.94	1.00
50%	188	171	67	3.5	27	5.7	5.6	5.6	14	3.9	44%	6.1%	22%	3.0%	10	2.2	0.92	1.00
30%	123	108	48	2.8	27	5.9	4.1	3.3	9.2	1.8	55%	7.8%	16%	2.4%	17	2.4	0.88	0.96
25%	109	92	55	2.4	34	5.8	5.3	2.7	7.3	1.8	77%	8.7%	19%	2.2%	17	2.6	0.79	0.93

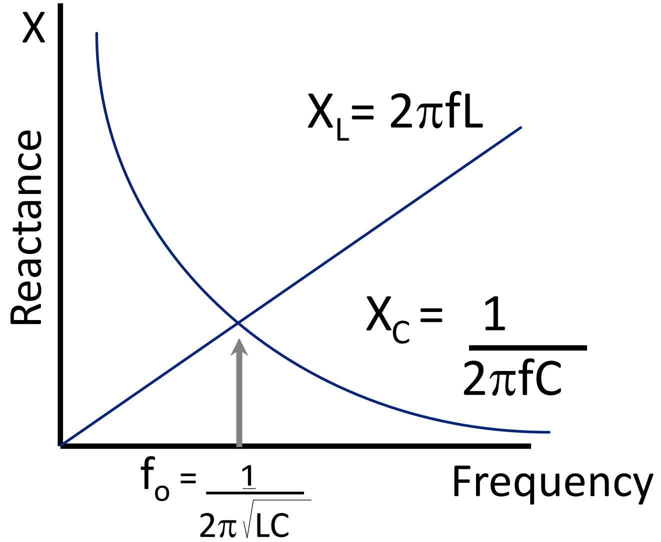
Lineator AUHF Performance – Current Harmonics up to 500th

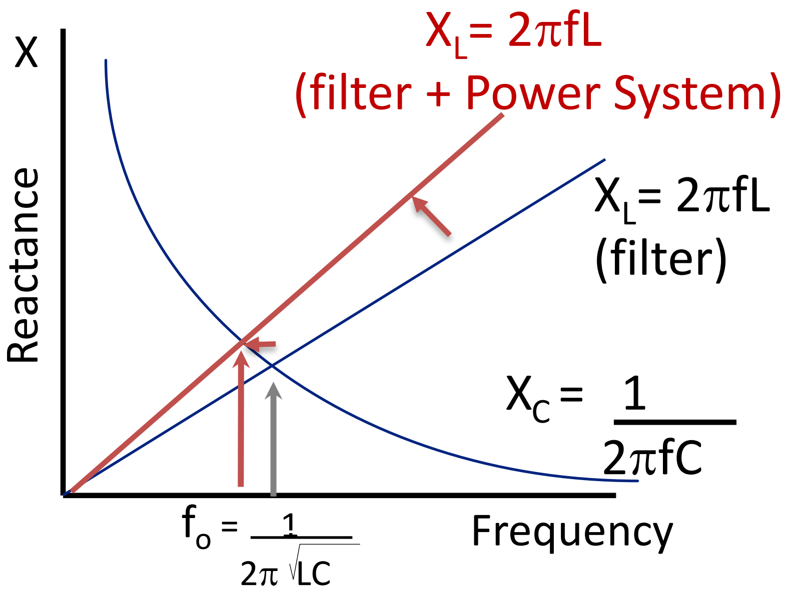
- Treats entire spectrum of harmonics
- No introduction of high frequency harmonics unlike Active Front End drives and Parallel Active Filters



Wide Spectrum Passive Filter and Power System Resonance

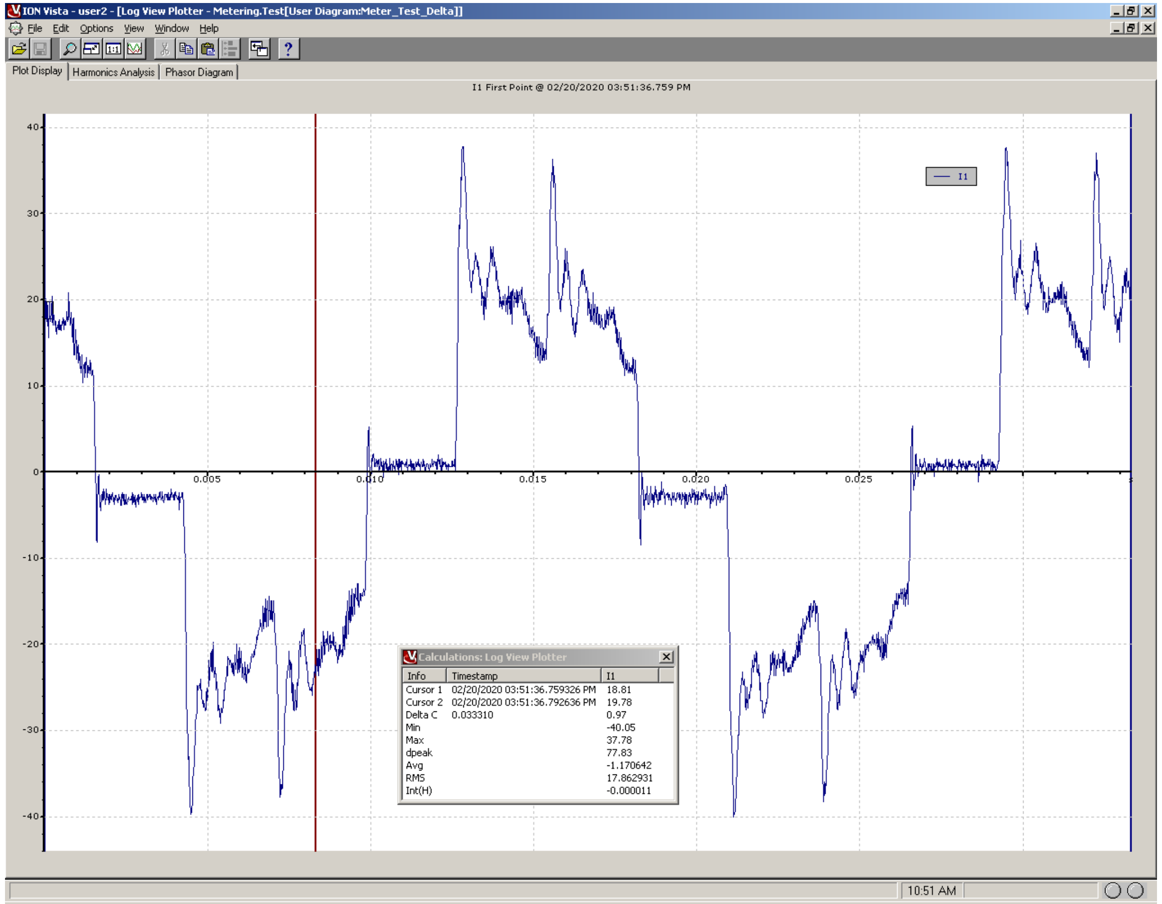
- Power systems are inductive in nature
  - Only capacitive if overcompensated by PFC capacitors which should be avoided
- Inductance of power system will tend to move the resonant frequency lower
- Tuned input frequency of the filter shifts further away from the 5th and other predominant power system harmonics
- Therefore, filter can be applied to both ‘stiff’ and ‘weak’ systems without concern for power system resonance

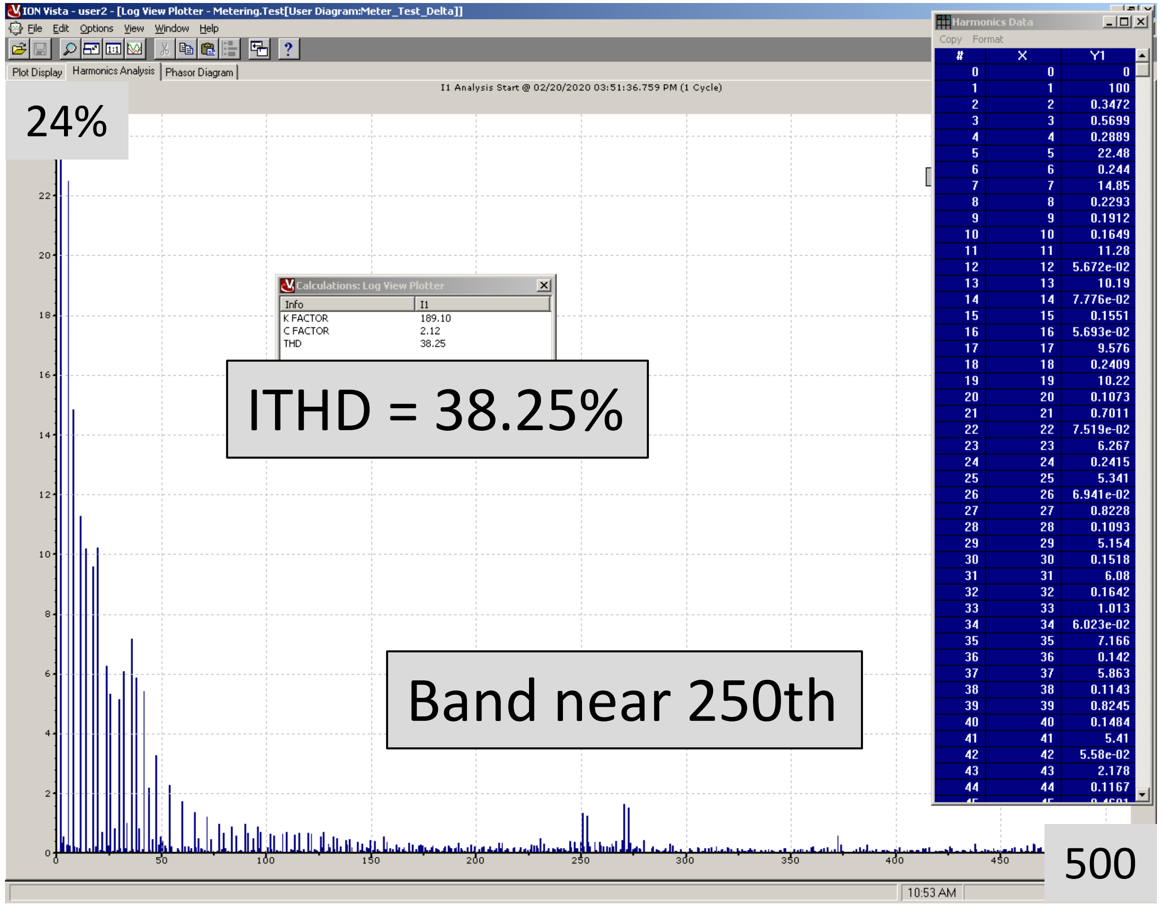




6-Pulse Rectifier/Inverter with Low DC Bus Capacitance

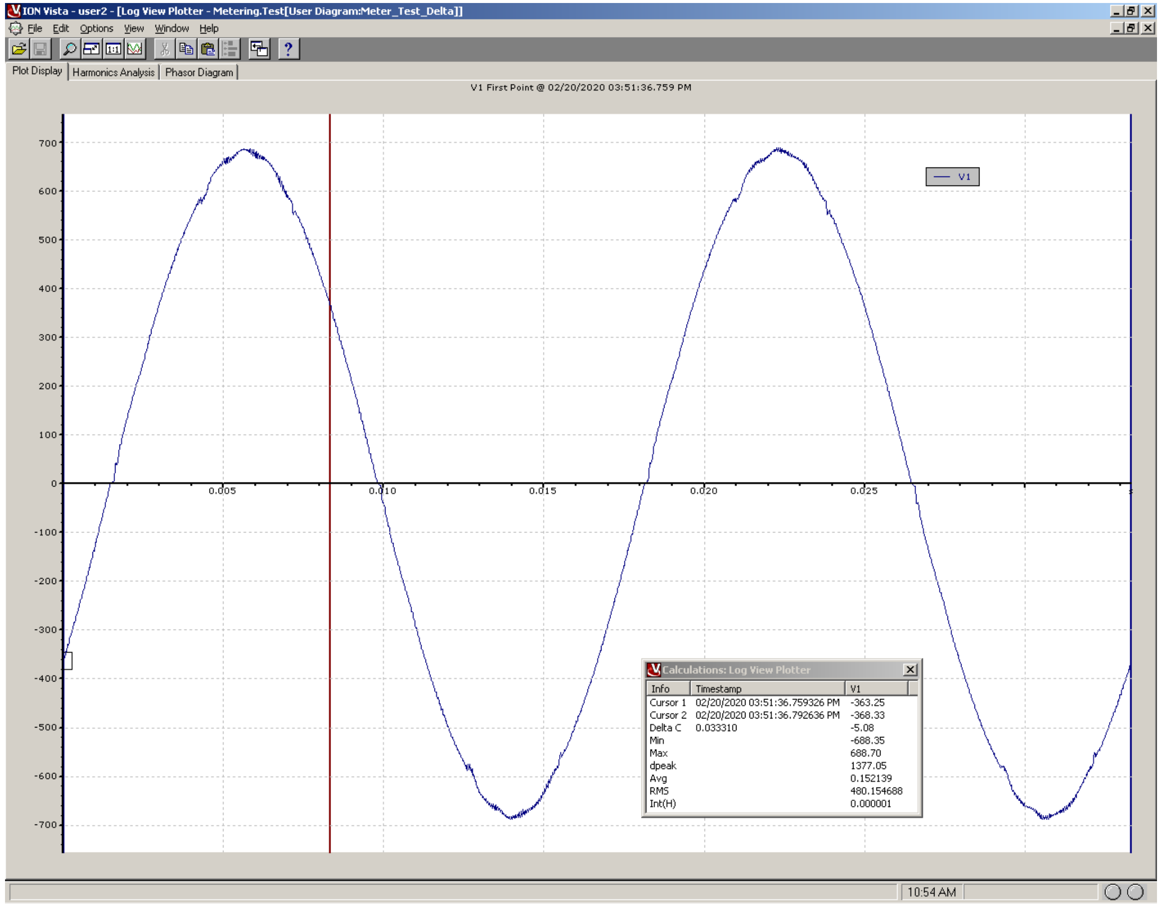
PQ meter capable of measuring up to the 500th harmonic

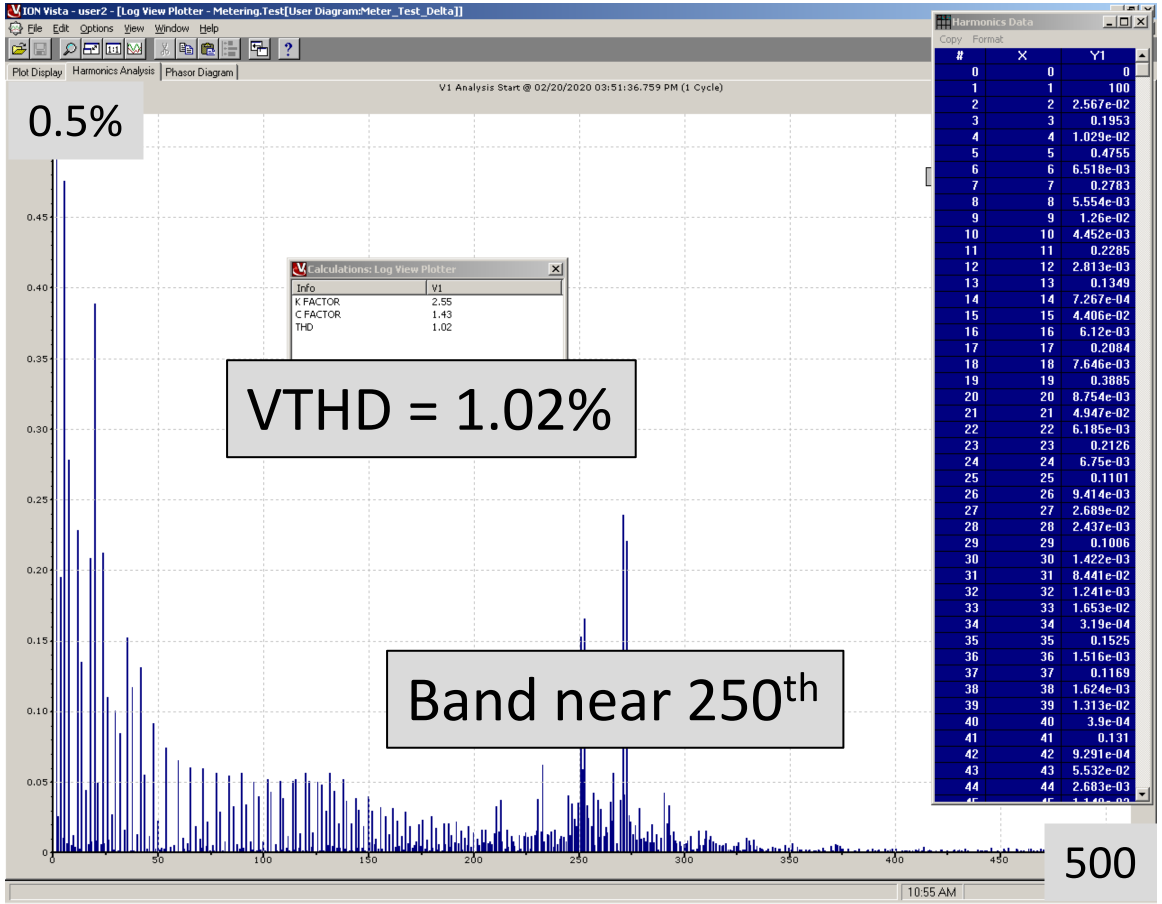




- Input current measurements on 4 x 3.75 HP, 480V EC fans with low DC bus capacitance
- Inverter switching frequency band appears around 250th harmonic (15 kHz)

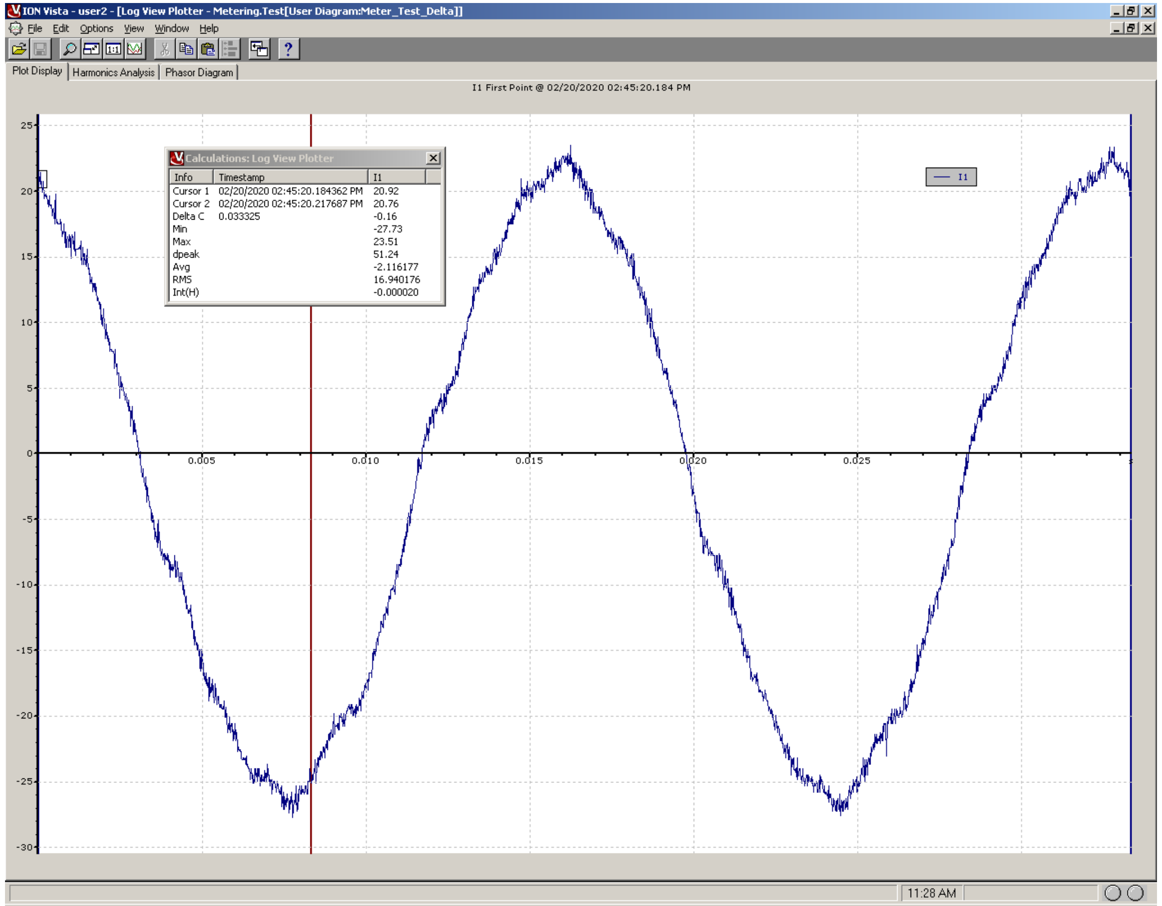
6-Pulse Rectifier/Inverter with Low DC Bus Capacitance

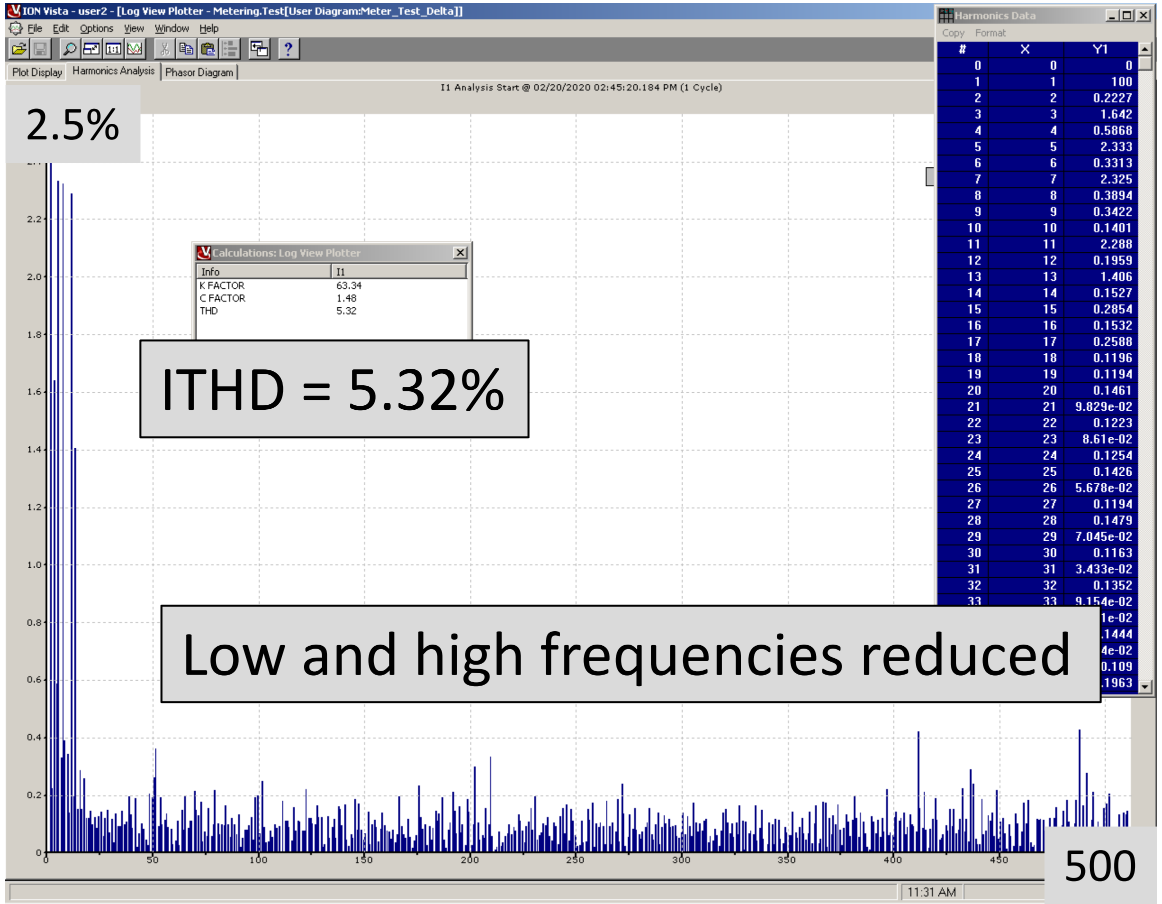




- Voltage measurements on 4 x 3.75 HP, 480V EC fans with low DC bus capacitance
- Relatively high harmonics near 250th caused by inverter switching frequency

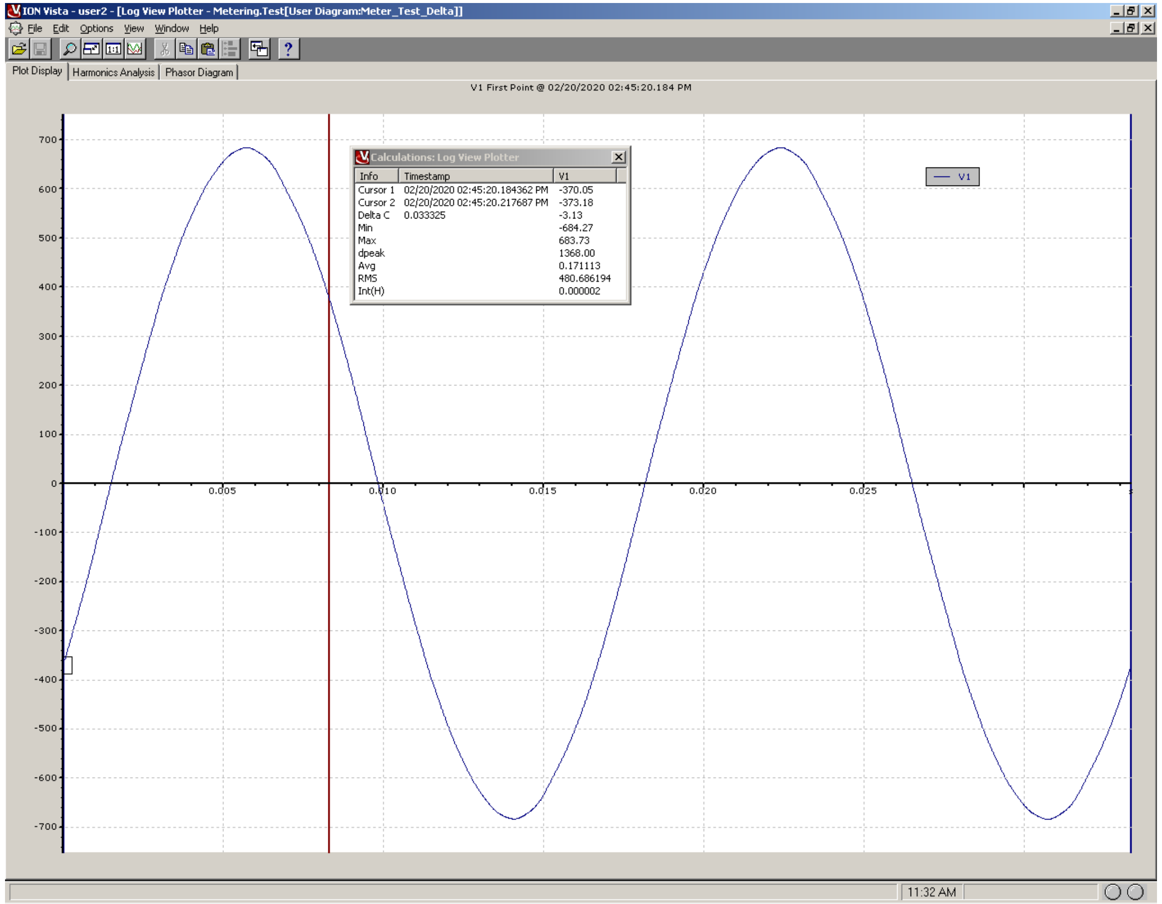
6-Pulse Rectifier/Inverter with Low DC Bus Capacitance and Wide Spectrum Harmonic Filter

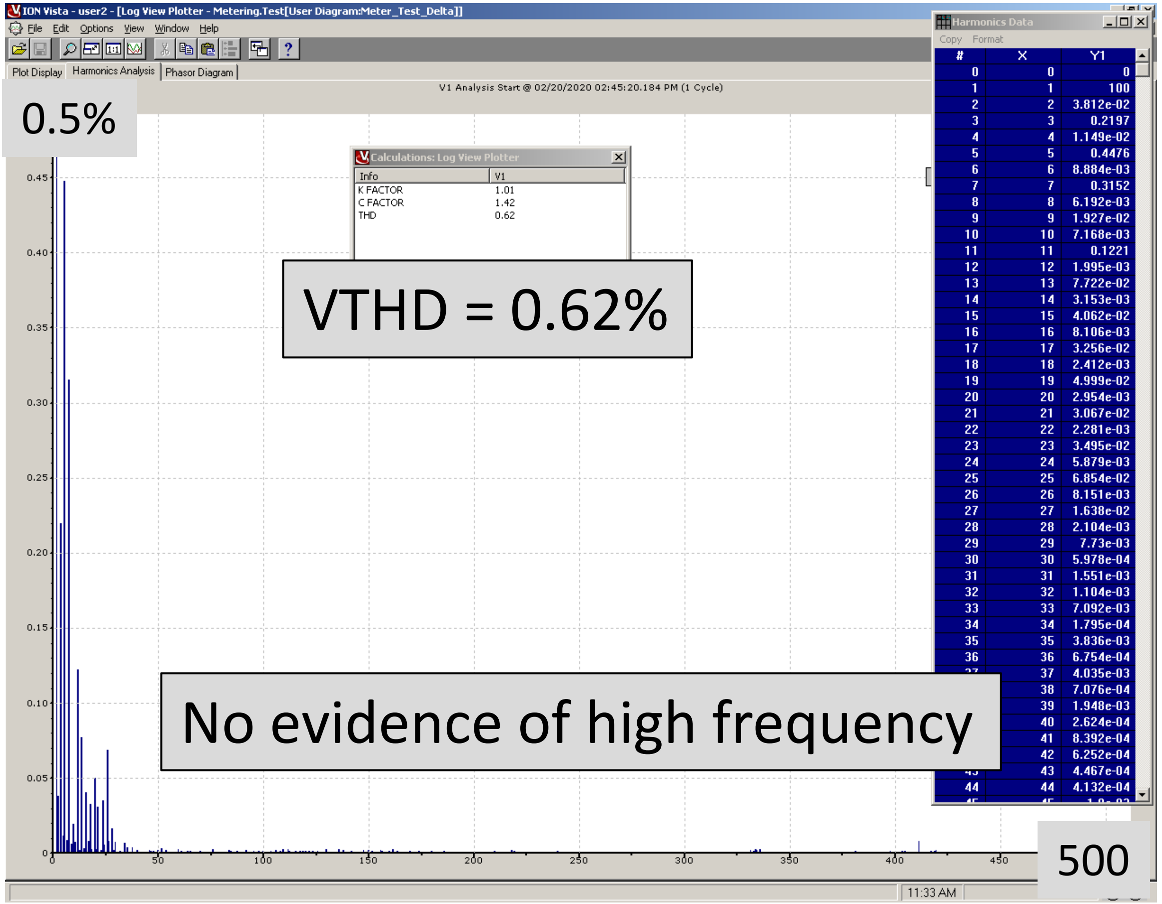




- Input current measurements on 4 x 3.75 HP, 480V EC fans with low DC bus capacitance
- Some inverter switching frequency remains but is substantially reduced

6-Pulse Rectifier/Inverter with Low DC Bus Capacitance and Wide Spectrum Harmonic Filter





- Voltage measurements on 4 x 3.75 HP, 480V EC fans with low DC bus capacitance
- No evidence of switching frequency harmonics remains

Summary and Conclusions

- Supraharmonics are becoming the next big power quality concern
- Defined as the frequency range from 2 kHz to 150 kHz, they are generated by active rectifiers and inverters
- This range falls outside the requirements of most existing harmonic standards
- Resonance with the power system can make matters worse
  - ‘Weak’ or high impedance sources are particularly susceptible
- Supraharmonics are not a concern when passive rectifiers are used
  - Low frequency harmonics can be very effectively reduced using Wide Spectrum Harmonic Filters
- Rectifier/inverters with low DC bus capacitance can pass inverter switching frequency harmonics to the line side
  - A Wide Spectrum Harmonic Filter can be used to reduce both low frequency and high frequency harmonics

Discussion

QUESTIONS AND FEEDBACK

Thank You

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