Harmonic and Energy Saving Products

Passive vs Active Harmonic Mitigation

MIRUS International Inc.

World class power quality improvement solutions

Passive vs Active Harmonic Mitigation

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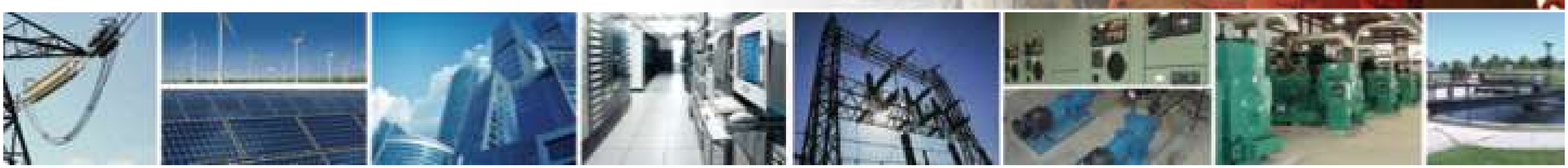
Mirus Is Harmonic Mitigation

MIRUS International Inc. designs and develops world-class power quality improvement products for mission critical operations

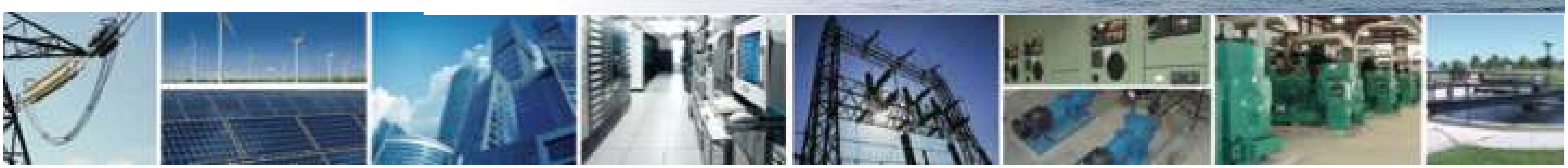
Our solutions:

- Minimize disruption to the power supply
- Improve reliability
- Adhere to the strictest regulatory requirements
- Save energy and reduce operating costs



Harmonics are a Massive Pain for Oil & Gas, Marine, HVAC, Water/Wastewater, Data Centers, Industrial and Commercial Facilities

- Harmonic disturbances damage expensive equipment, cause failure, and add expense via maintenance, replacement, energy consumption, etc.
- They need a solution to mitigate disruptions, high costs and associated risks.
- A proactive approach helps solve harmonic issues and prevent future problems.



What Can Happen When the Wrong Solution is Used?

Detroit Brazil Built Oil Rig Supply Vessels

- 8 Oil Rig Supply Vessels originally equipped with Active Front-end (AFE) VSDs for propulsion that could not get operational
- Replaced by another manufacturer's propulsion package equipped with passive Wide Spectrum Harmonic Filters (WSHF) which have worked flawlessly
  - 3500 HP WSHF with water cooled reactors

OEM Drive Propulsion System

Solution:

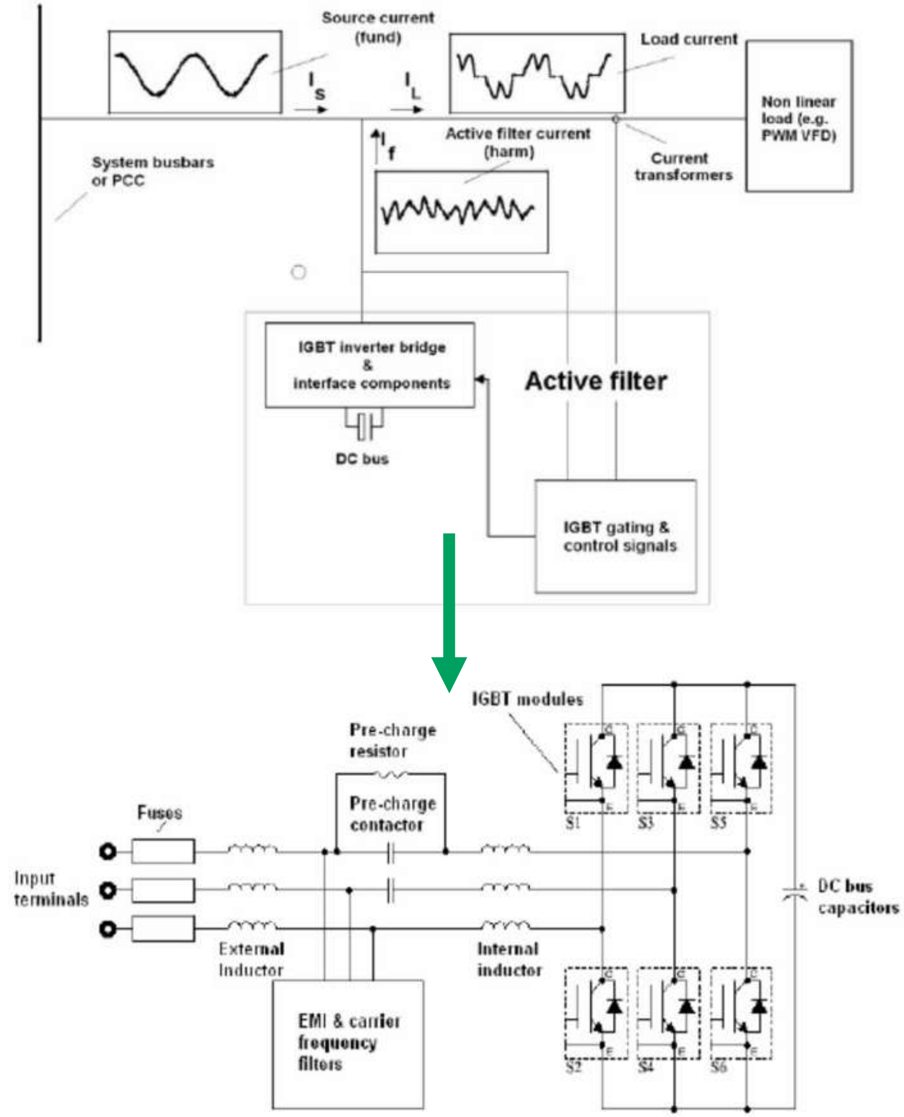
Petrobras removed all the AFE (Active Front End) Drives and replaced with 3500HP Liquid-Cooled WSHF and 6-pulse VSDs.

Outcome:

Power quality met ABS marine standards and IEEE519 recommended practices. The combination of a simple liquid cooled 6-Pulse variable frequency drive and a liquid cooled passive harmonic filter now provides the vessel owner with the most compact and most efficient harmonic free diesel electric propulsion drive available today.

Active Harmonic Filter at 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:

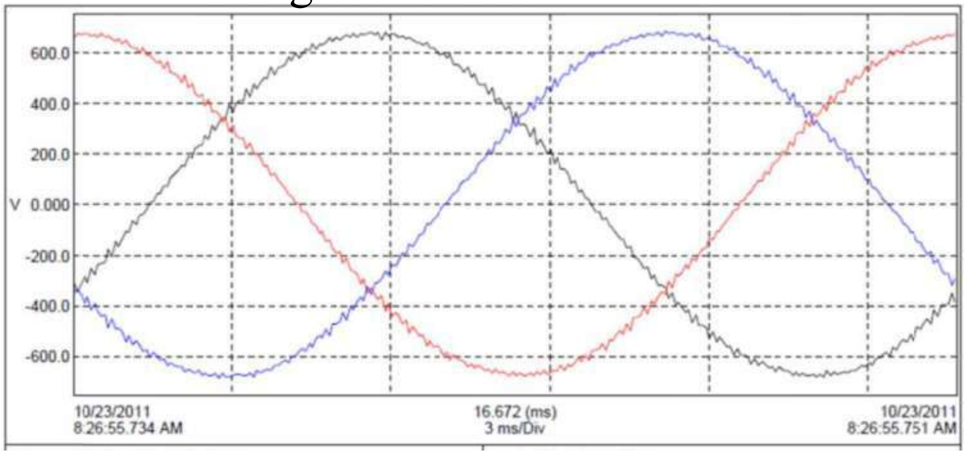
- Solar Equipment Mfr was having 48 Vdc power supply failures in a Photovoltaic Panel Tester
- These failures began to occur after a 450A AHF was installed but they were unaware of this

Active Harmonic Filter at Solar Inverter Manufacturer

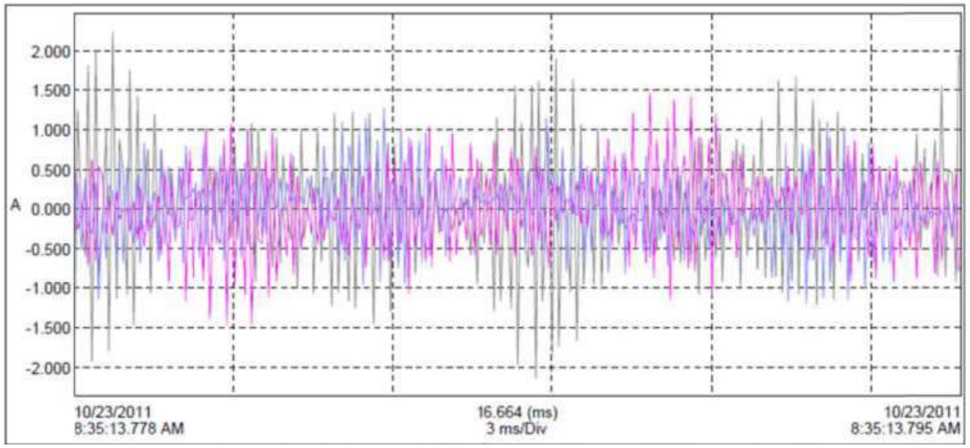
Challenge:

- 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

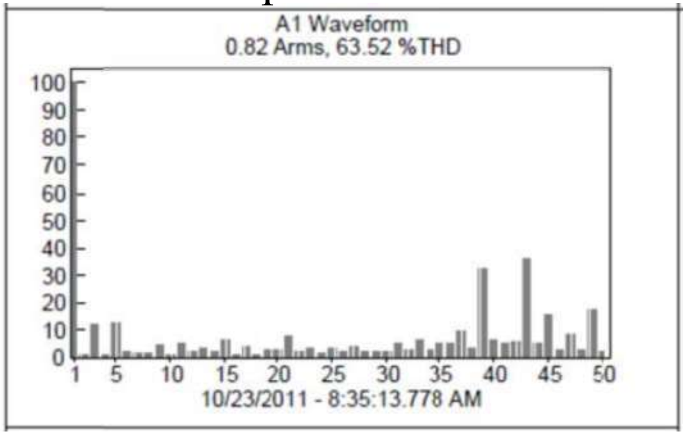
Voltage waveform – VTHD <1%



PS Current waveform at no load



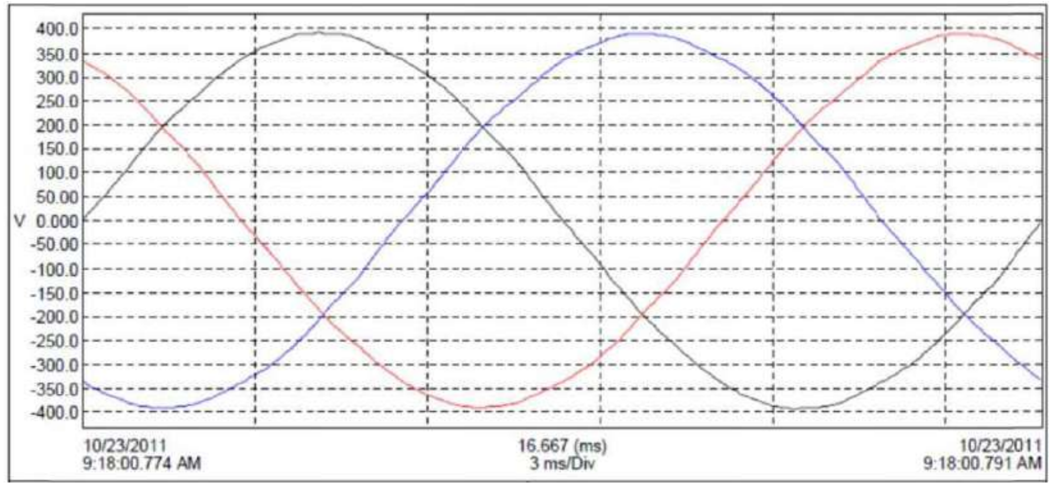
PS Current spectrum at no load

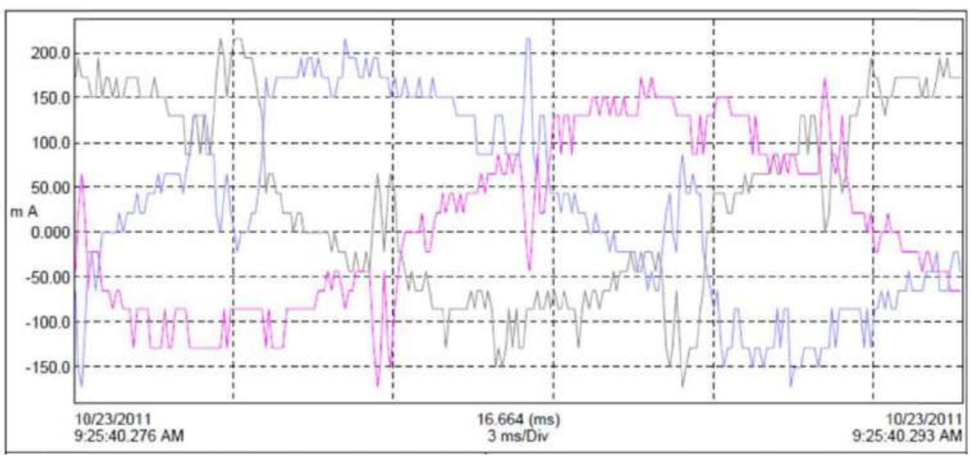


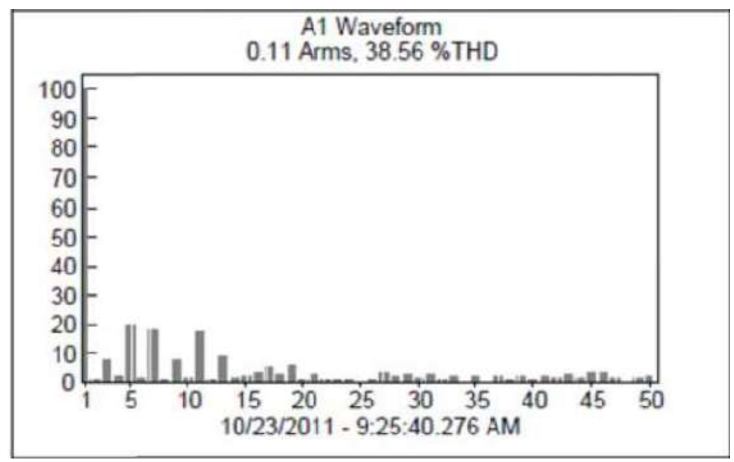
Active Harmonic Filter at Solar Inverter Manufacturer

Solution:

- Permanently turn off AHF







Active Harmonic Filter at iFly Lyon, France Free-fall Simulator

Initial design included two parallel Active Harmonic Filters (AHFs) to cancel harmonic currents generated by the large variable speed drive fan systems

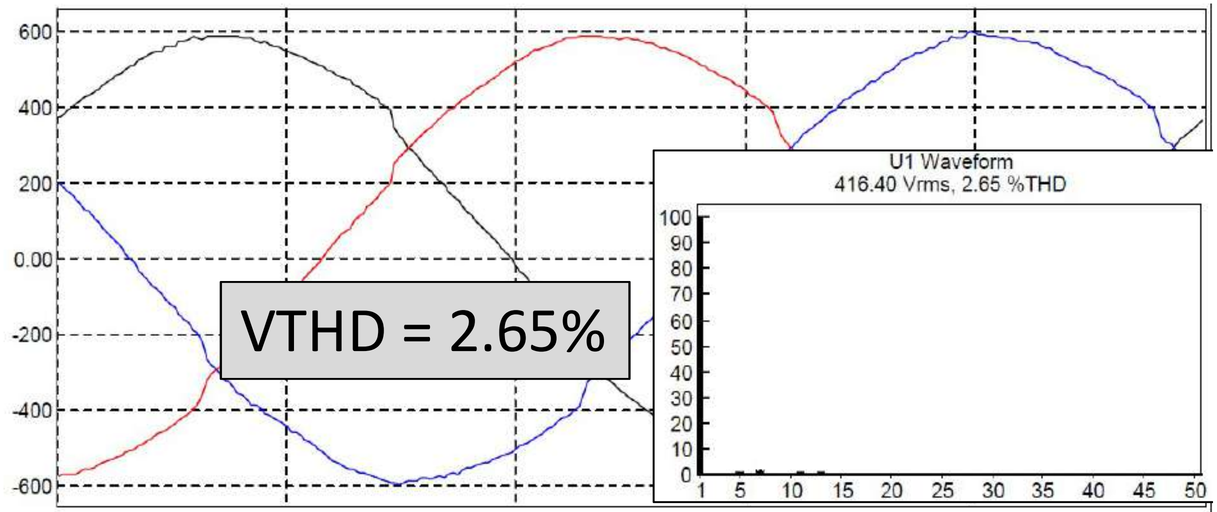
Challenge:

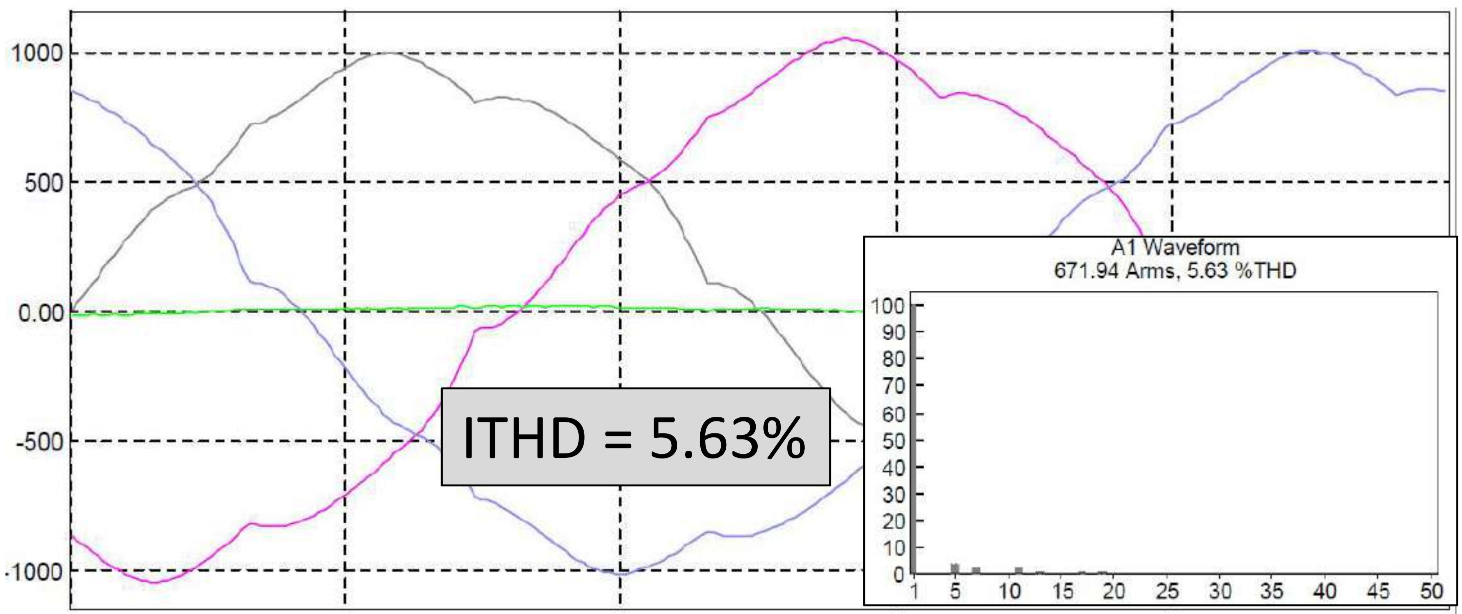
- AHFs had been disconnected because the fan systems would not operate properly with them in the circuit
- Required harmonic limits were not being met

Active Harmonic Filter at iFly Lyon, France Free-fall Simulator

Solution:

- AHFs replaced by two 700HP Wide Spectrum Harmonic Filters
- Harmonic limits were easily met





Offshore Tug/Supply Ship Originally Equipped with Pseudo 12-Pulse System

Challenge:

- Offshore supply ship with SCR type DC drives powering dynamic positioning (DP) propulsion motors
- Equipped with pseudo 12-pulse harmonic mitigation
- Voltage Harmonic distortion up to 24% at full load
- 4x Remote Operated Vehicles (ROVs)
- ROVs inoperable with thrusters engaged
- Failed Sea Trials
- Out of service until able to pass sea trials

Offshore Tug/Supply Ship Originally Equipped with Pseudo 12-Pulse System

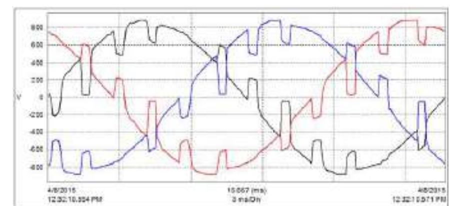
Solution:

- 4x 3000HP (2250kW) and 1x 1500HP (1120kW) Marine and Offshore Specific Lineator (AUHF-MOS) Harmonic Filters installed
- Filters complete with InSight Advanced Monitoring system

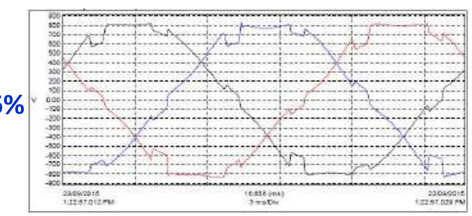
Outcome:

- VTHD reduced to between 5.6% and 7.6% depending on std. operating conditions
- Sea Trials PASSED and ship has been fully operational and in service since Oct 2015

Before
VTHD=20%



After
VTHD=7.6%



6-Pulse VSD and Harmonics

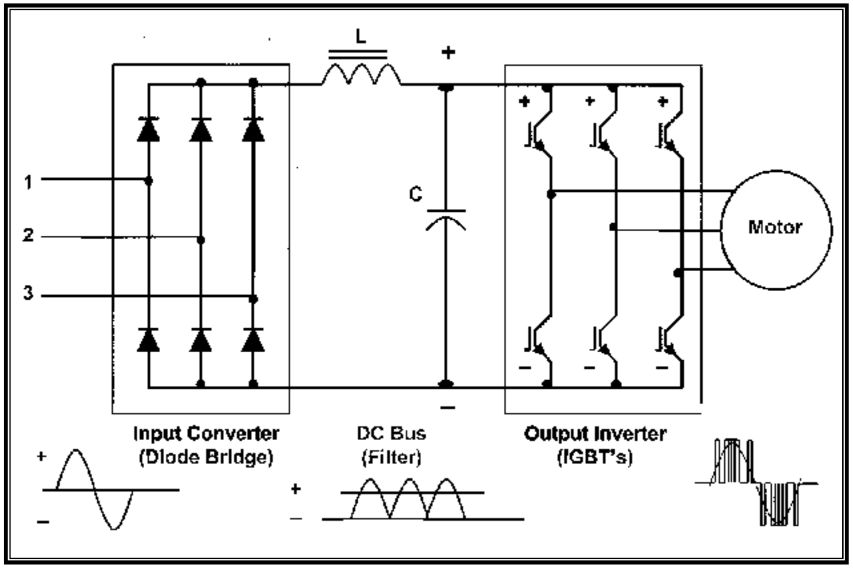
For simple diode bridge rectifiers:

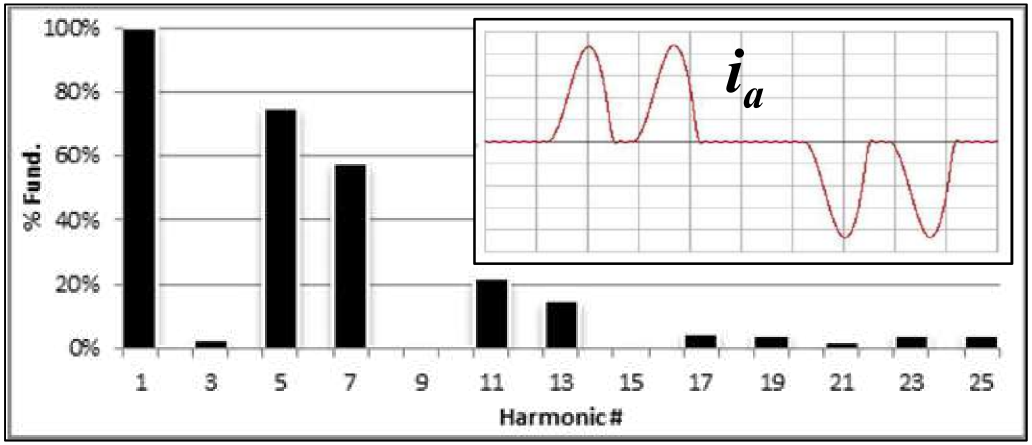
$$h = np \pm 1$$

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

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)

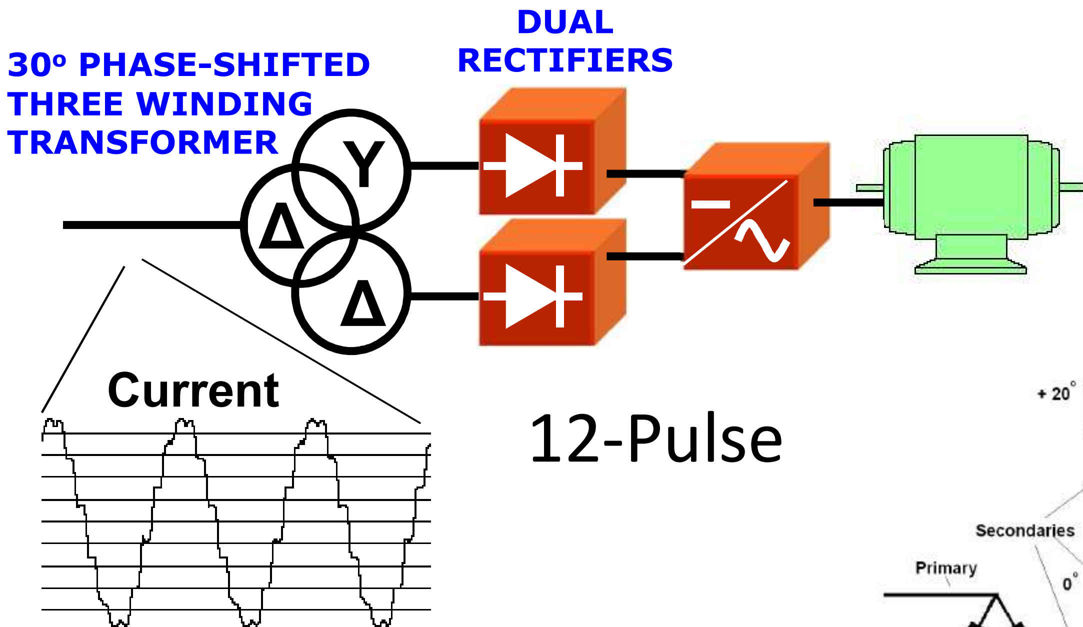
When,
p = 6
h = -- 5,7,--,11,13,--,17,19...



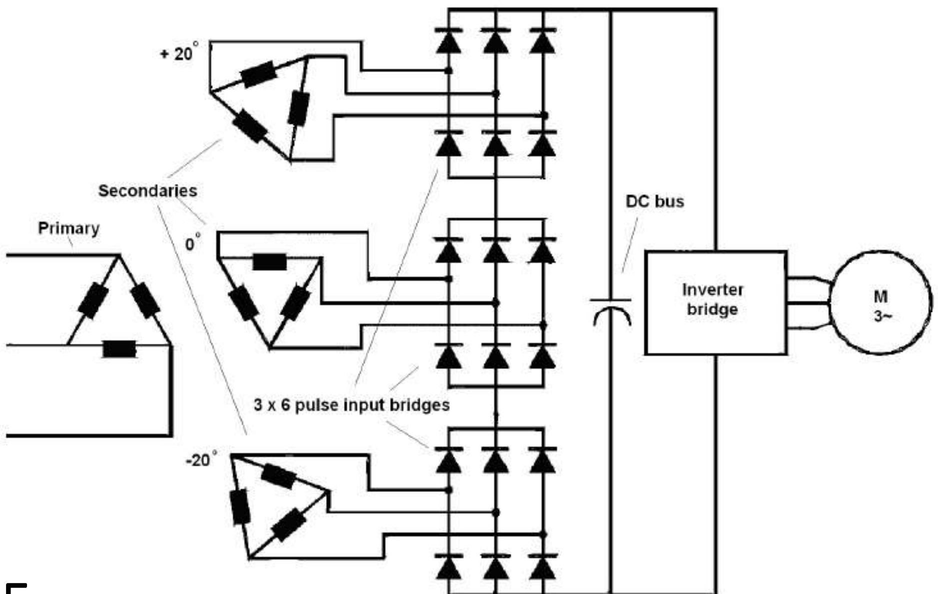


Current Waveform and Spectrum

Multi-Pulse VSD



12-Pulse



18-Pulse

$$h = np \pm 1,$$

When p = 12, h = …11,13,…23,25…

When p = 18, h = …17,19,…35,37…

Active Front-end (AFE) Drives

Operation:

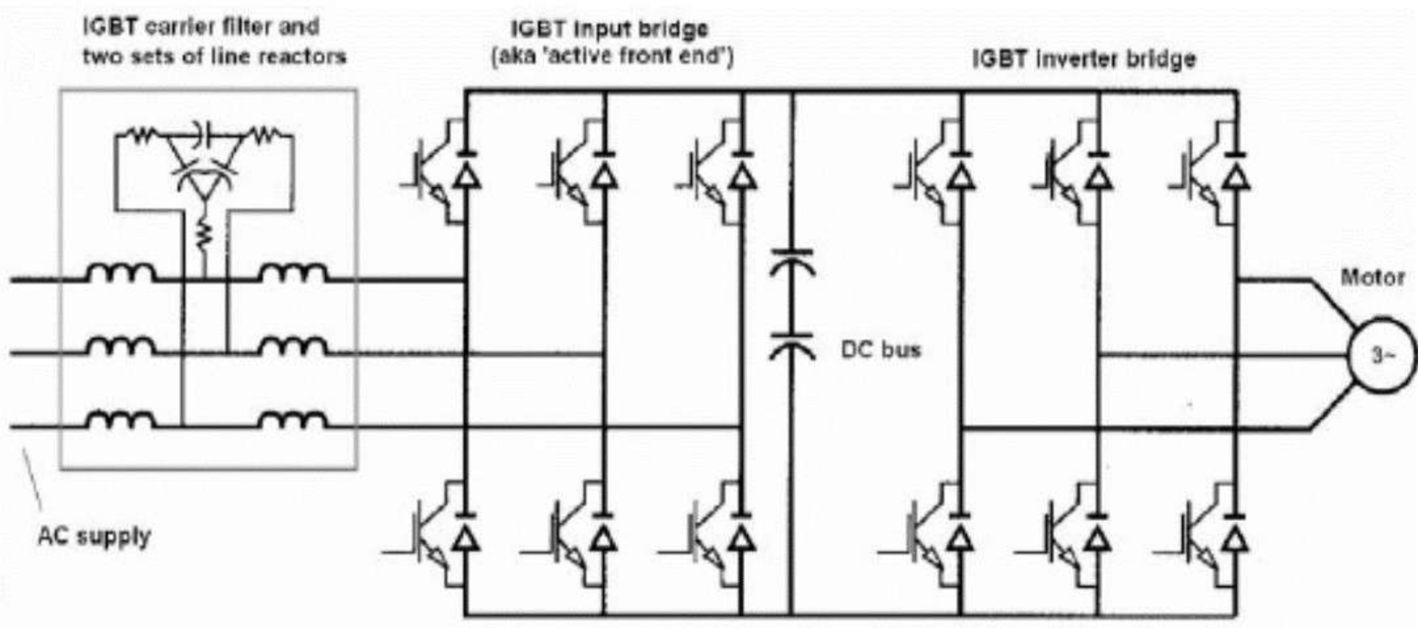
- 6-pulse diode bridge rectifier is replaced by a fully controlled IGBT bridge

Pros:

- Can achieve lowest ITHD but only when measured at harmonics lower than 50^{th}
- Can provide bi-directional power flow

Cons:

- Expensive
- Introduces higher order harmonics and common-mode noise
- Higher EMI radiation
- Much higher losses
- Very complex requiring start-up and service by manufacturer



Parallel Active Harmonic Filter

Operation:

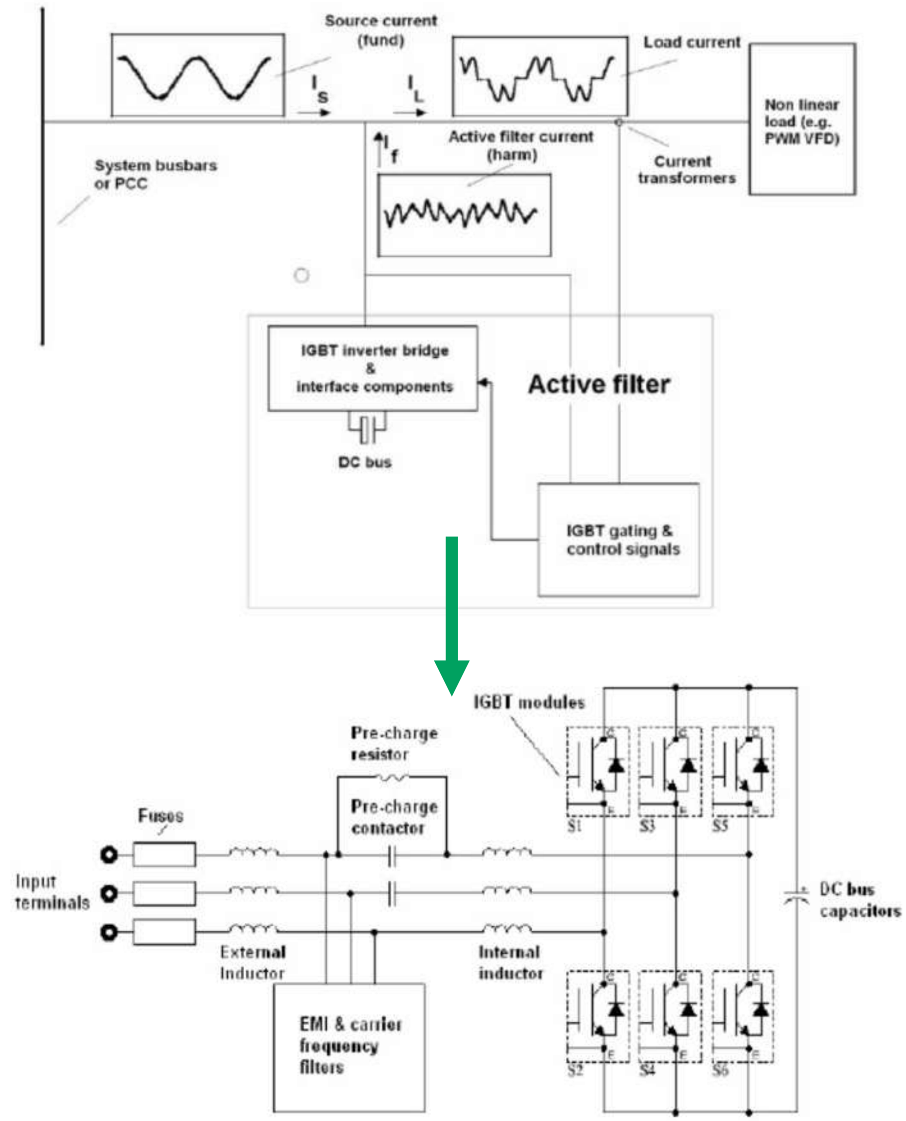
- Distorted current is sampled
- Fast acting IGBT's are used to generate harmonic currents and inject them 180 deg out-of-phase

Pros:

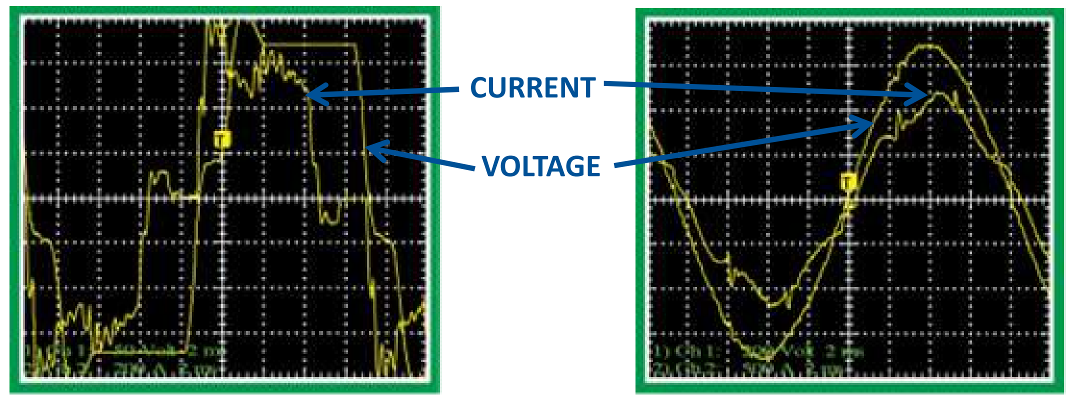
- Sized to harmonic content only
- Relatively easy parallel connection
- Maintains good performance at light loads

Cons:

- Expensive
- Requires AC or DC reactors on all VSDs
- Introduces higher frequency harmonics
- Susceptible to background voltage THD
- Complexity requires start-up and regular service by manufacturer



Passive Wide Spectrum Harmonic Filter



Input Without Filter Installed

Input With Filter Installed

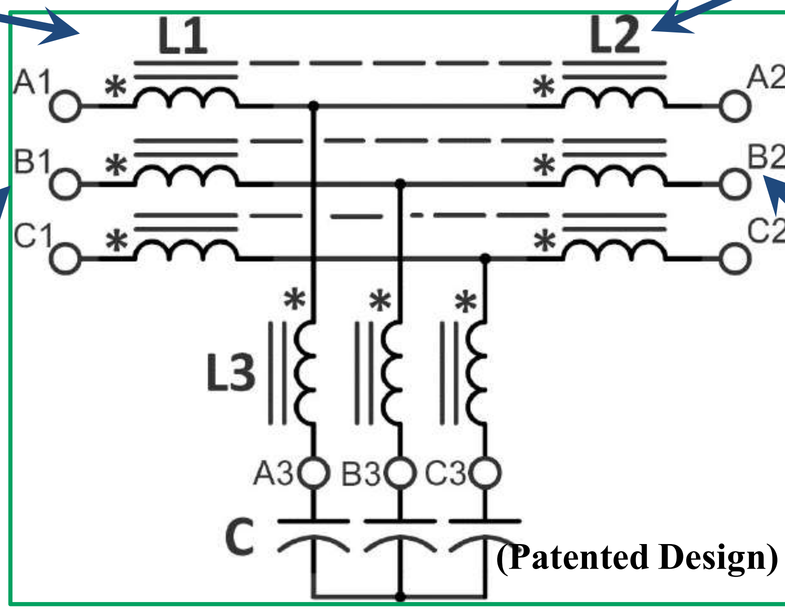
- Input harmonic filter for VSDs
- Better than 18-pulse or AFE performance with 6-pulse VSD
- 'Real-World Guarantee'
- Meets IEEE and IEC harmonic limits
- Near unity power factor
- Generator compatible
- Highest efficiency

Passive Wide Spectrum Harmonic Filter

Multiple windings on a common core

High impedance L1 winding

Compensating winding L2 lowers through impedance reducing voltage drop



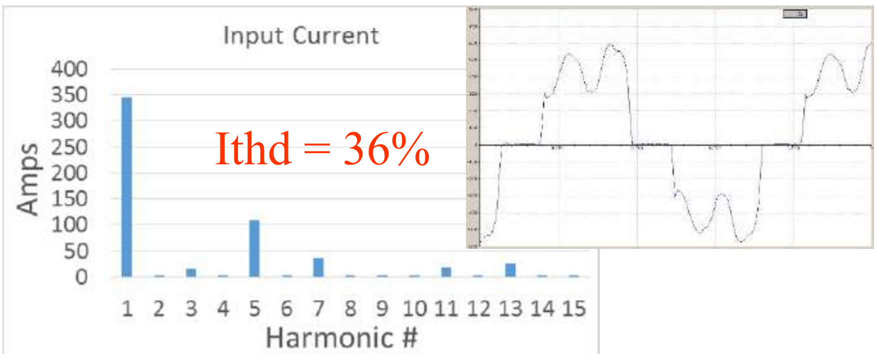
Input tuned below 5th to prevent importation of upstream harmonics

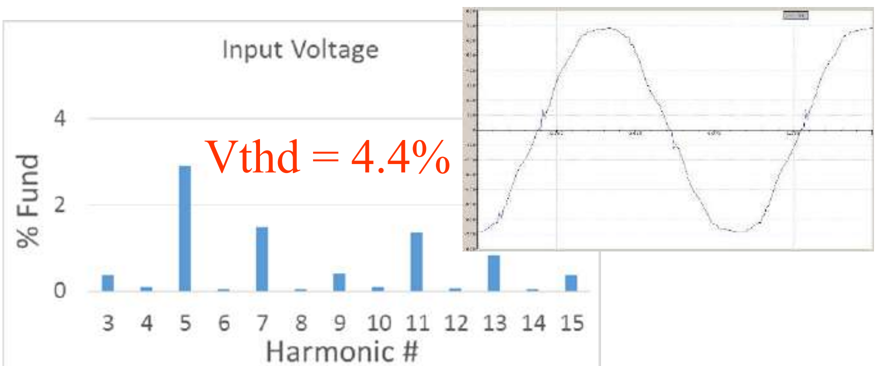
Output tuned near 7th to remove load side harmonics

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

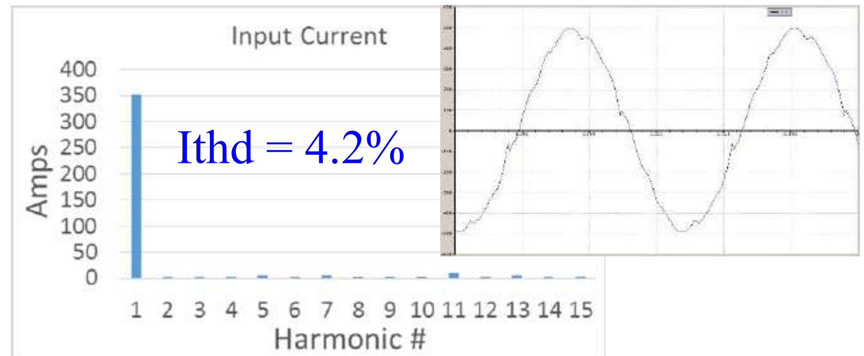
350HP WSHF-HP Performance PWM VSD

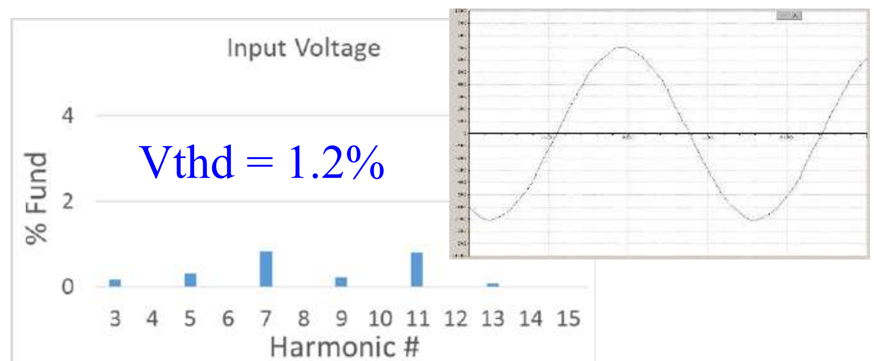
With Reactor





With LINEATOR-HP

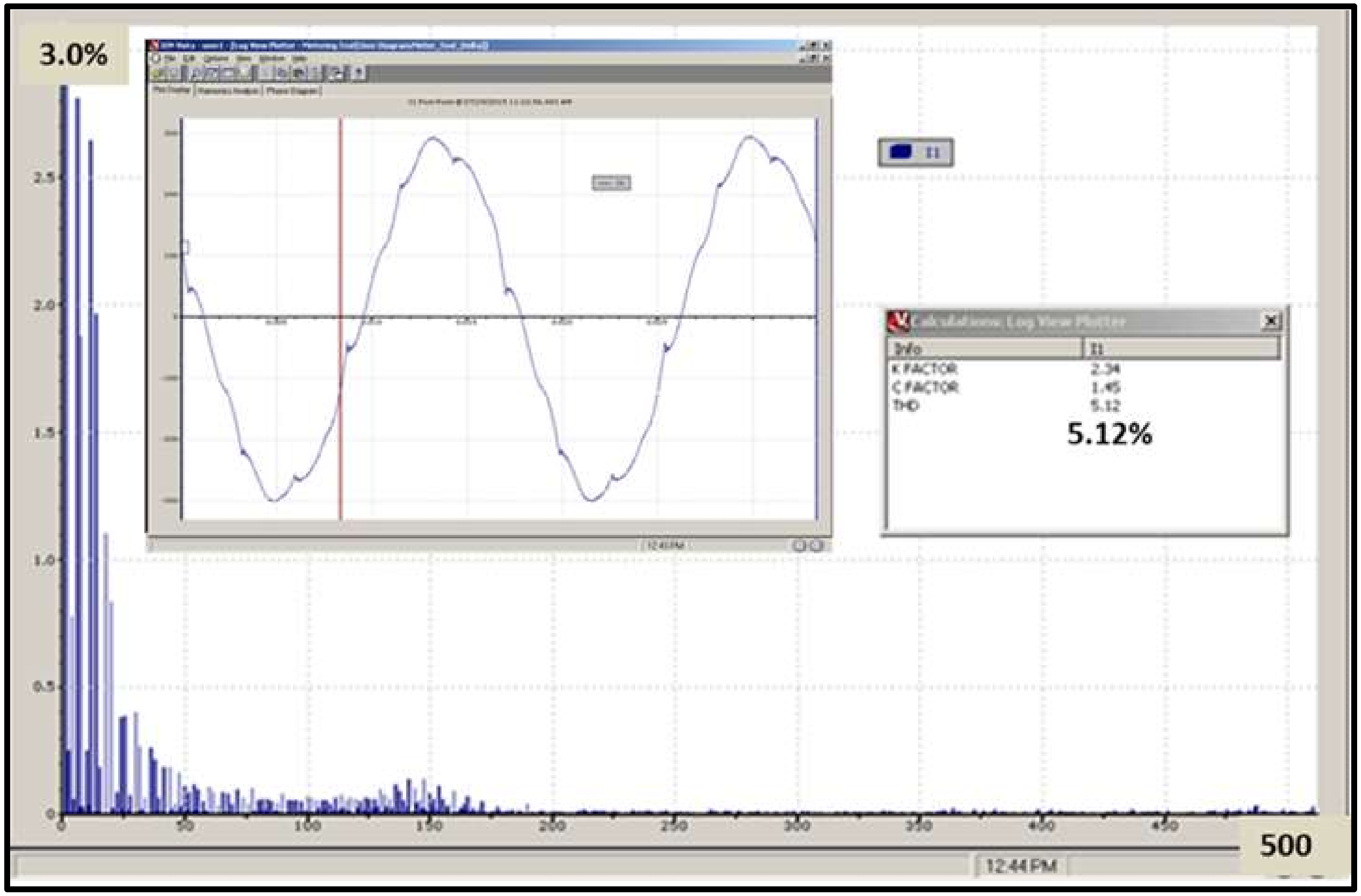




	Current Harmonics (Amps)																	
	RMS		5th		7th		11th		13th		Ithd		Itdd		K-factor		PF	
Load	w/o	With	w/o	With	w/o	With	w/o	With	w/o	With	w/o	With	w/o	With	w/o	With	w/o	With
Full	369	352	110	5.0	37	4.9	19	9.5	25	6.1	36%	4.2%	36%	4.2%	8.9	1.5	0.94	0.98
75%	275	257	83	4.8	35	6.6	16	8.1	17	3.9	37%	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

WSHF Performance – Up to 500th Harmonic

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



IEEE Harmonic Standards

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 50^{th} 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.

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

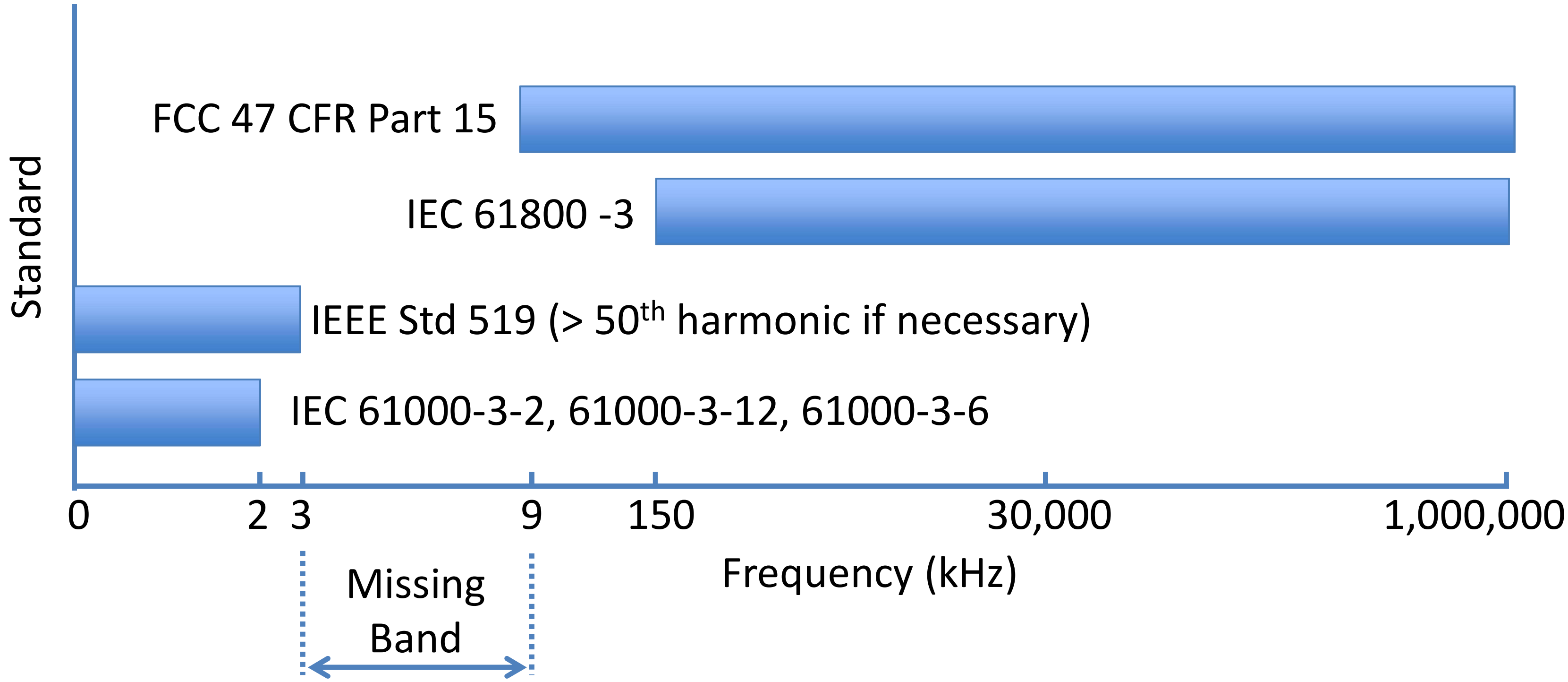
THD
ratio of the r.m.s. value of the harmonics (in this context harmonic currents I_n of the order n) to the r.m.s. value of the fundamental, viz.

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

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



- 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 9 kHz

No standards exist from 50th harmonic to 9 kHz

Is this a concern?

Absolutely, since typical IGBT switching frequencies are between 2 kHz and 8 kHz which falls precisely within this band

Next we need to ask ourselves

Why are we applying harmonic mitigation?

Is it to truly resolve problems or simply comply with standards?

AFE and AHF solutions may comply with standards but they often introduce bigger problems than they resolve

Active Front-end (AFE) Drive and Parallel Active Harmonic Filters

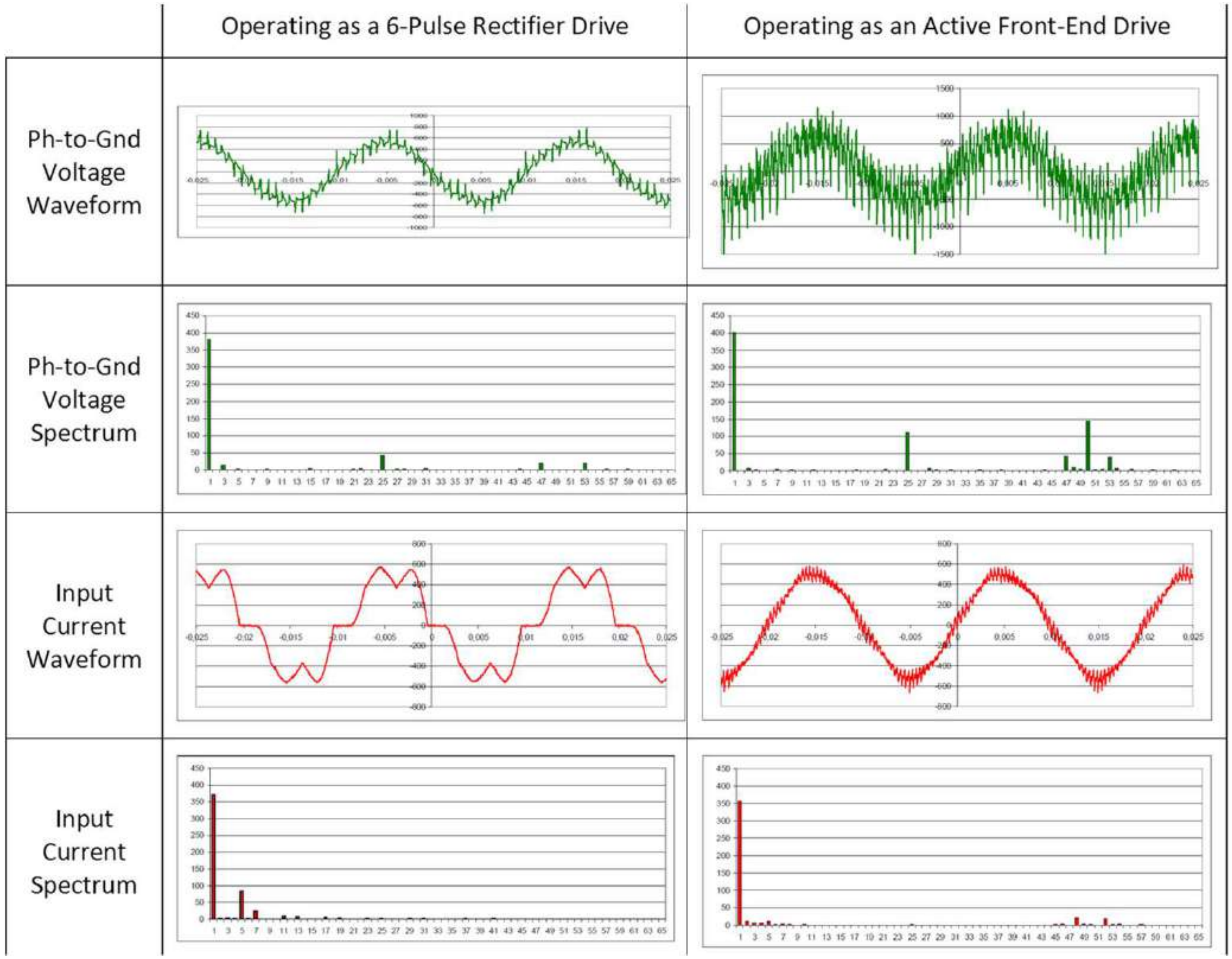
AFE and AHF manufacturers will claim that their technology provides the best solution for treatment of VSD harmonics, but the reality is:

- AFE’s and AHF’s generate high frequency harmonics which can have more serious consequences than low frequency harmonics.
- AFE’s and AHF’s generate significant levels of ground leakage current which can cause inadvertent ground fault trips and failure of sensitive equipment.
- When 6-Pulse VSDs and AFE Drives are on the same switchboard, voltage ripple from the AFE Drive can raise the DC bus voltage in the 6-Pulse VSDs creating overvoltage conditions.

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

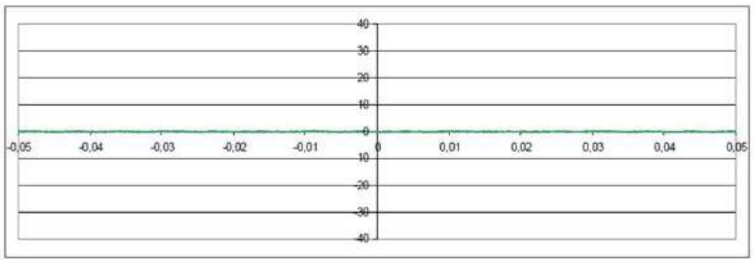
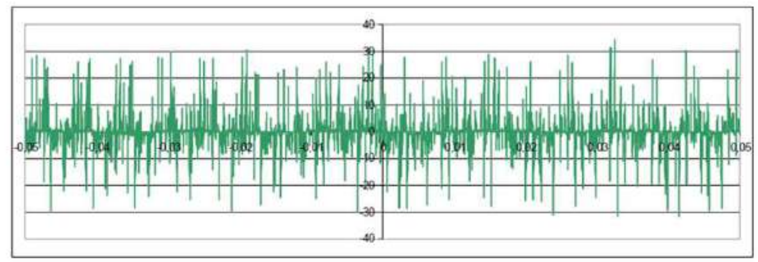
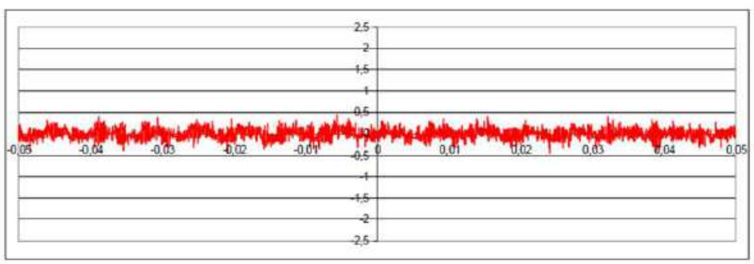
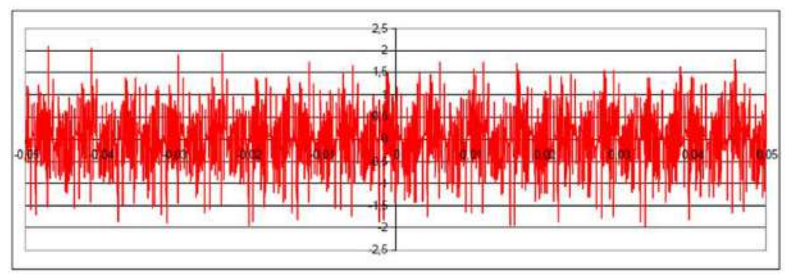


Reference:

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

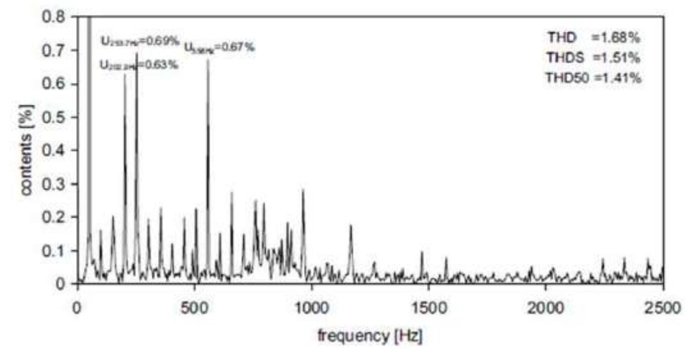
Reference:

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

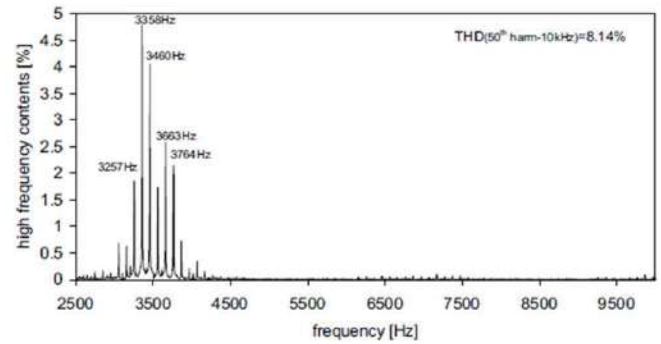
Active Front-end (AFE) Drives High Frequency Harmonics

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

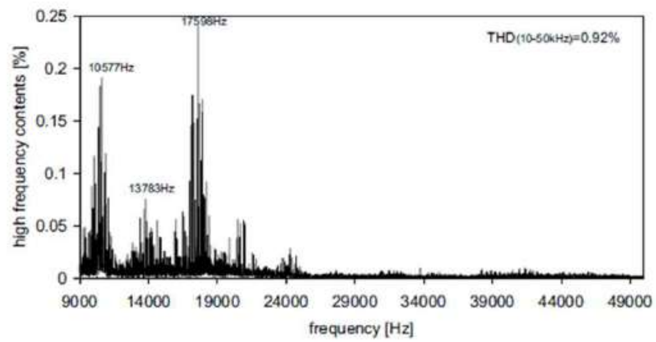
AFE voltage harmonic spectrums at various frequency ranges



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

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

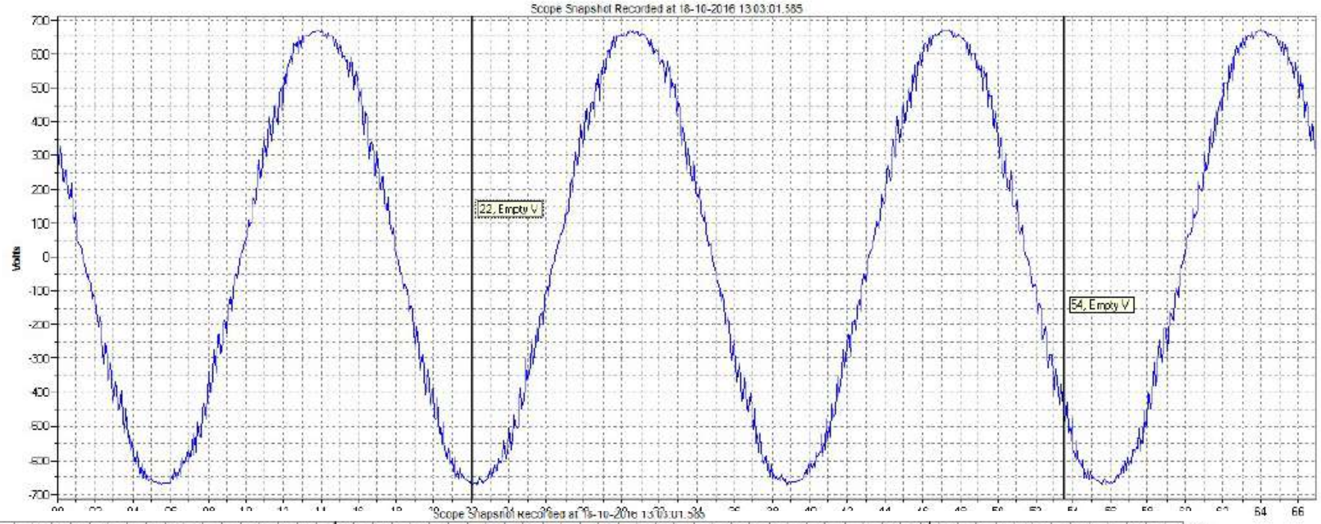
Reference:
1. An assessment of distortions of supply voltage waveform in All-Electric Ship Power Network, Marius Szweda, Tomasz Tarasiuk, Oct. 2007

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

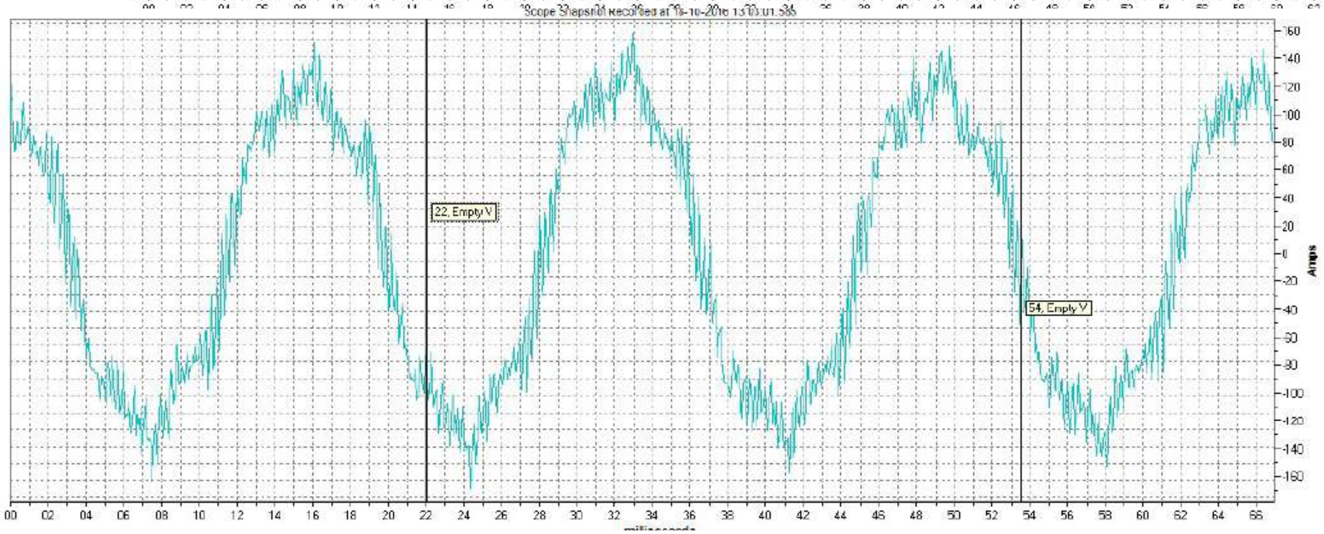
AFE Drive measurements on input to ESP

Switching frequency = 3.6 kHz (60th harmonic)

Voltage Waveform



Current Waveform



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

AFE Drive measurements on input to ESP

Voltage	AN	BN	CN	NG
V RMS	273.8	270.6	275.6	7.5
V PK	419.0	425.0	422.5	24.9
V CF				3.3
% THD				488.7
Freq				
Current				N
A RMS	96.6	86.0	91.6	0.0
A PK	188.9	165.6	165.0	0.0
A CF	2.0	1.9	1.8	1.4

%VTHD	3.7	3.6	3.3
% ITHD	13.8	14.7	14.1

VTHD and ITHD do not include 60th harmonic switching frequency since meter only measured to the 50th

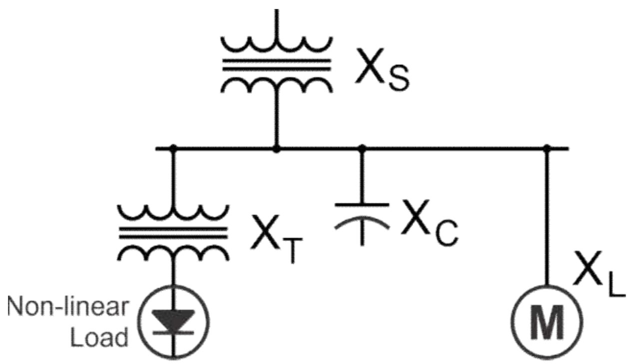
Power	A	B	C	Total
kW	25.484	22.081	24.534	72.100
kVA	26.456	23.269	25.249	75.029
kvar	7.104	7.339	5.967	20.759
PF	0.963	0.949	0.972	0.961
DPF	0.991	0.975	0.996	0.989
	Lag	Lag	Lag	

Active Front-end (AFE) Drive and Parallel Active Harmonic Filter

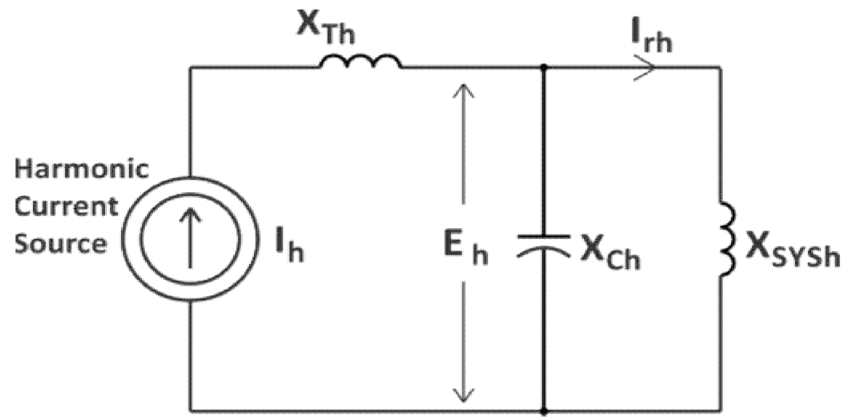
AFE and AHF manufacturers will claim that their technology provides the best solution for treatment of VSD harmonics, but the reality is:

- Although an active solution, AFE's and AHF's still require input passive filters (LCL and EMI/RFI filters) to control switching frequency harmonics and to attenuate ripple in the mains side voltage and current.
- LCL and EMI/RFI filters are more likely to resonate with the power system at the higher rectifier harmonic frequencies (ie. 11^{th}, 13^{th}, 17^{th}, 19^{th}, etc.) than are passive WSHF's tuned below the 5^{th}.

Power System Harmonic Resonance



Single Line Diagram



Equivalent Diagram

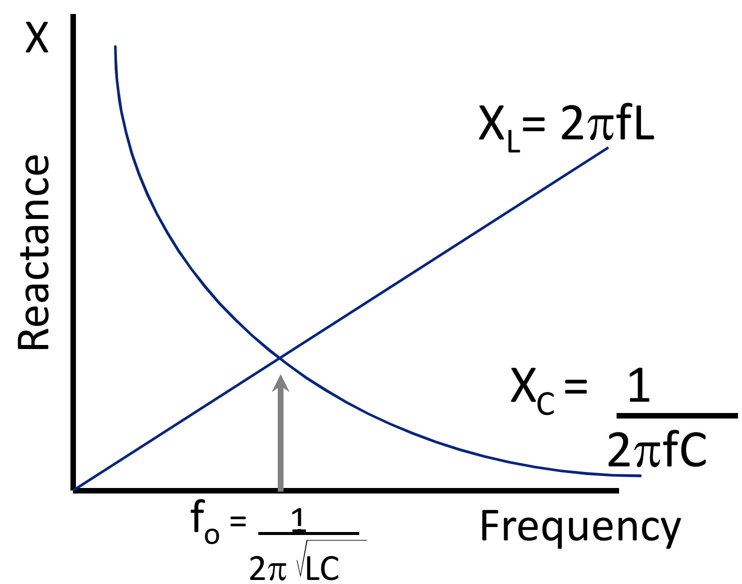
Resonance will occur when:

$$X_{Ch} = X_{SYSh} \qquad (X_{SYSh} = X_S \,||\, X_L)$$

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 Passive Filter on Power System Resonance

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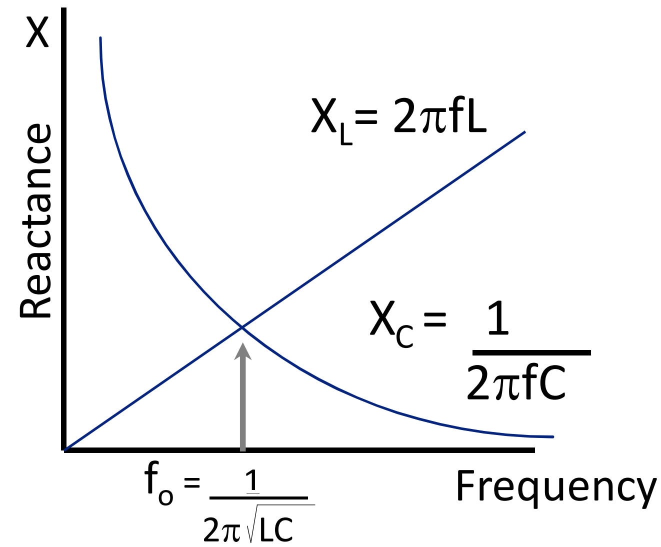
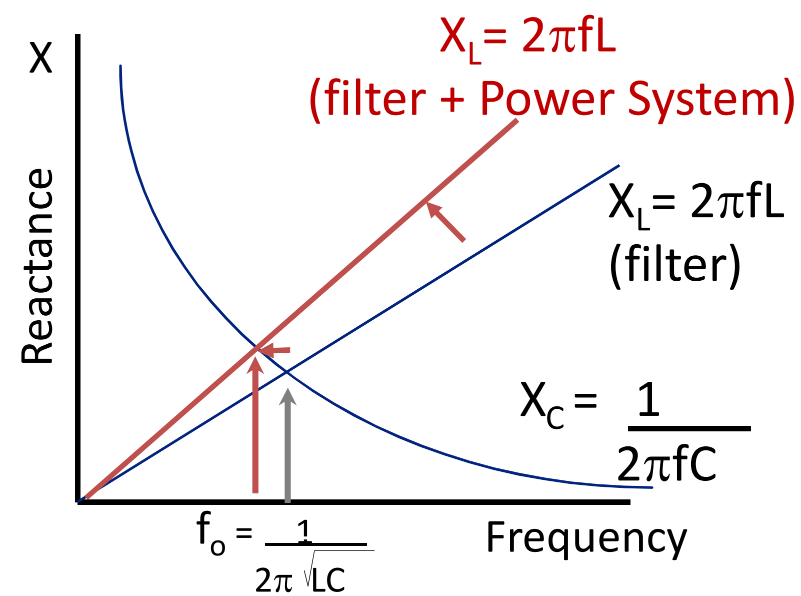
- Power systems are inductive in nature
  - Only capacitive if overcompensated by PFC capacitors which must be avoided
- Power system will tend to move the resonant frequency of a passive filter lower as inductance increases moving curve upwards
- WSHF is tuned below the 5th harmonic, ensuring that power system resonance with predominant harmonics is avoided
- LCL filters are tuned at higher frequencies so adding power system inductance can shift resonance to a predominant harmonic





Example of AFE LCL Failure – Australian Lithium Mine

AFE failure risks lithium mine expansion plans

The soaring demand for lithium for electric vehicle batteries has prompted an Australian mine to double its output. But its expansion plans risked being delayed when the filter in an AFE (active front-end) system, used in a drive for an on-site mill, failed.

Active Front-end (AFE) Drive and Parallel Active Harmonic Filter

AFE and AHF manufacturers will claim that their technology provides the best solution for treatment of VSD harmonics, but the reality is:

- AFE losses are significantly higher and efficiencies much lower than a 6-Pulse VSD with Lineator AUHF.

Efficiency Comparison: 6-Pulse with WSHF vs Active Front-end (AFE) Drives

AFE has much higher losses than 6-P with passive WSHF

Type	VSD Rating (kW)	VSD Losses (kW)	AUHF Losses (kW)	Total Losses (kW)	Efficiency	Difference
AFE Drive	75	4.1		4.1	94.8%	
6-P with Lineator		1.9	0.8	2.7	96.5%	1.7%
AFE Drive	400	20		20	95.2%	
6-P with Lineator		9.1	3.6	12.7	96.9%	1.7%

- AFE input bridge has higher losses than WSHF
- 1.7% higher overall efficiency with passive solution

Efficiency Comparison: 6-Pulse with WSHF vs Active Front-end (AFE) Drives

Energy Savings Analysis

Application: 400 kW VSD, Diesel-Electric Thruster on an Offshore Support Vessel (OSV)

Assumptions:

$L = 400\ kW$	VSD load (motor rating)
$t = 2935\ h/yr$	Operating time (average load of 33.5% based on Figure 3-1)[1]
$G = 0.017$	Efficiency %Gain (1.7% from previous slide)
$f = 0.4\ L/kWh$	Diesel generator consumption[2]
$\mathrm{c} = 0.80\ \$/L$	Fuel Cost

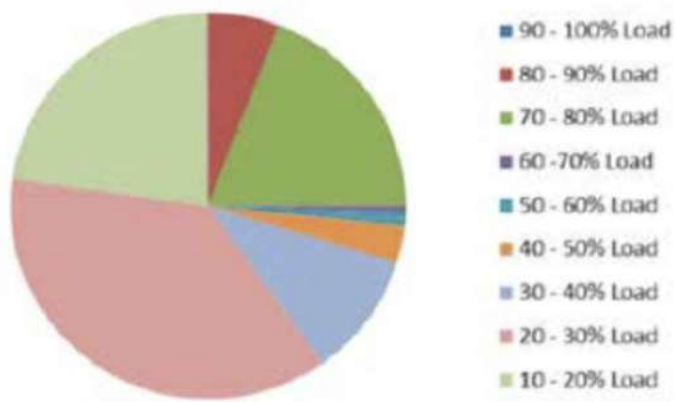


Figure 3-1 Example of Engine Operating Profile for typical OSV (14)

References:

1. Factors Influencing Machinery System Selection for Complex Operational Profiles, Mats Johan Heian, June 2014.
2. http://energyeducation.ca/encyclopedia/Diesel_generator

Efficiency Comparison: 6-Pulse with WSHF vs Active Front-end (AFE) Drives

Energy Savings Analysis

Application: 400 kW VSD, Diesel-Electric Thruster on an Offshore Support Vessel (OSV)

Calculations:

$$EnergySavings/year = L \times t \times G$$

$$= 400kW \times 2935\frac{h}{yr} \times 0.017$$

$$= 19955\ ^{kWh}/_{yr}$$

$$FuelSavings/year = 19955\ ^{kWh}/_{yr} \times 0.4\frac{L}{kWh} = 7982\frac{L}{yr}$$

$$\boldsymbol{CostSavings/year} = 7982\ ^{L}/_{yr} \times 0.80\frac{\$USD}{L} = \boldsymbol{6386\ ^{\$USD}/_{yr}}$$

Typical payback on harmonic mitigation equipment of 1-2 years based on Energy Savings alone.

Compared with AFE, initial capital costs are also lower.

Efficiency Comparison: 6-Pulse with WSHF vs Active Front-end (AFE) Drives

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Energy Savings Analysis

Application: 400 kW VSD, Diesel-Electric Thruster on an Offshore Support Vessel (OSV)

$$FuelSavings/year = 7982\frac{L}{yr}$$

	Units	CO_2	CH_4	N_2O	CO_2e
Marine Diesel	kg/L	2.556	0.00015	0.0011	2.888
Emissions/yr	**kg/yr**	**20402**	**1.2**	**8.8**	**23052**

GHG Equivalent Savings for 10 yrs

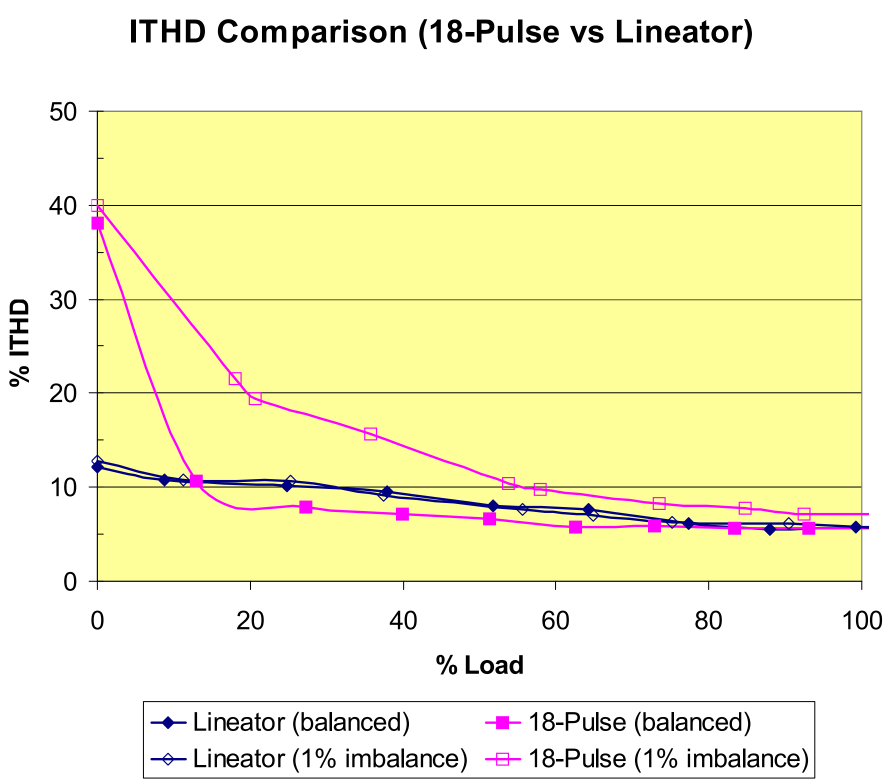
References:
1. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

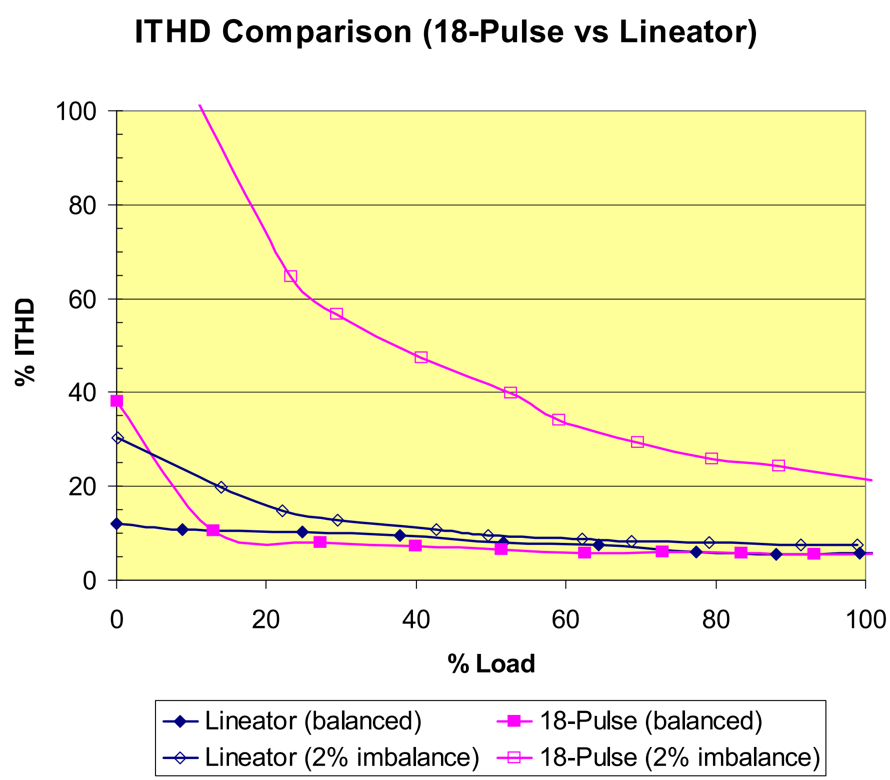
WSHF vs Multi-pulse VSD

WSHF outperforms Multi-pulse Drives:

- Performance of multi-pulse Drive drops off dramatically with any level of voltage imbalance or background voltage distortion
  - WSHF maintains high performance even with voltage imbalance and background voltage distortion
- WSHF/6-P VSD combination is at least 2% – 3% more efficient than Multi-pulse Drive
- WSHF/6-P VSD combination is a smaller package than Multi-pulse VSD
- WSHF/6-P VSD combination is less expensive than Multi-pulse
- WSHF/6-P VSD combination has lower operating costs than Multi-pulse

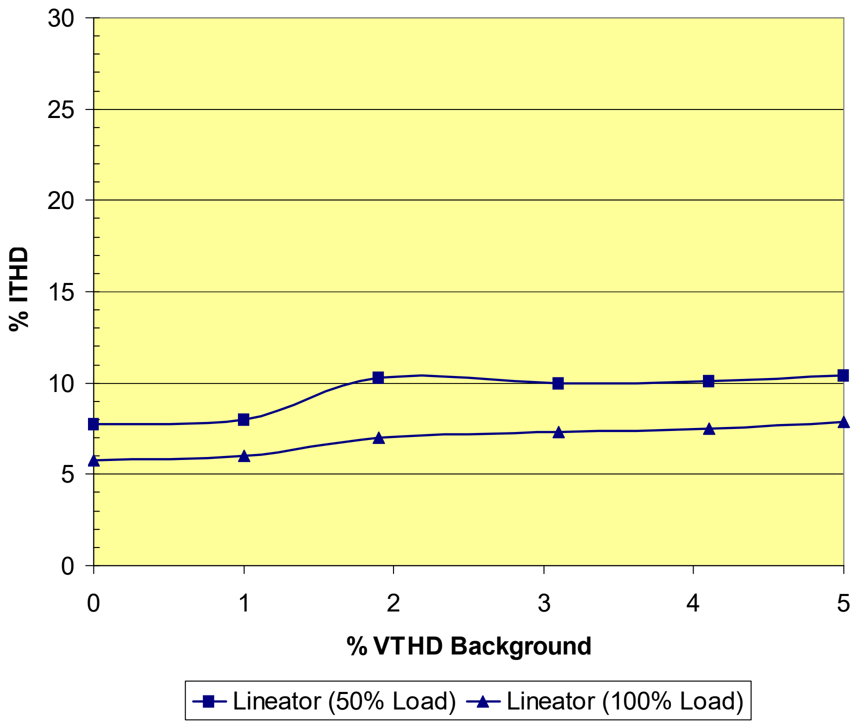
WSHF vs Multi-pulse VSD with Voltage Imbalance



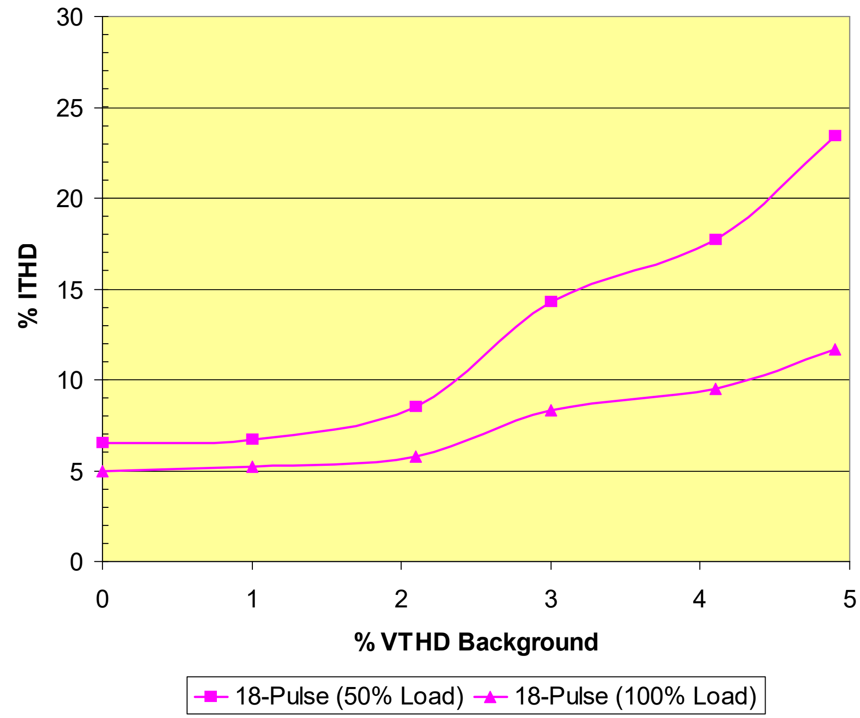


WSHF vs Multi-pulse VSD with Background Voltage Distortion

Lineator Performance with Background Voltage Distortion



18-Pulse Performance with Background Voltage Distortion



WSHF vs Multi-pulse VSD Efficiency Comparison

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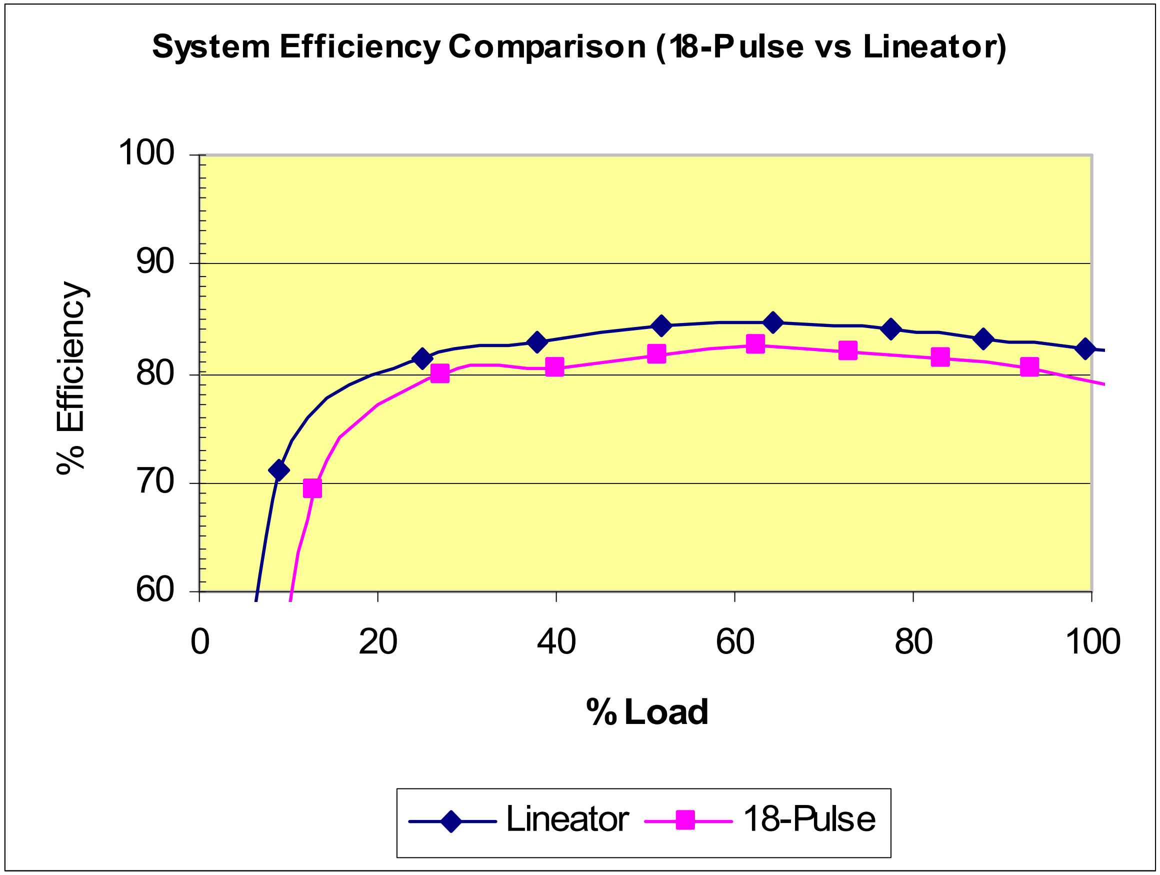
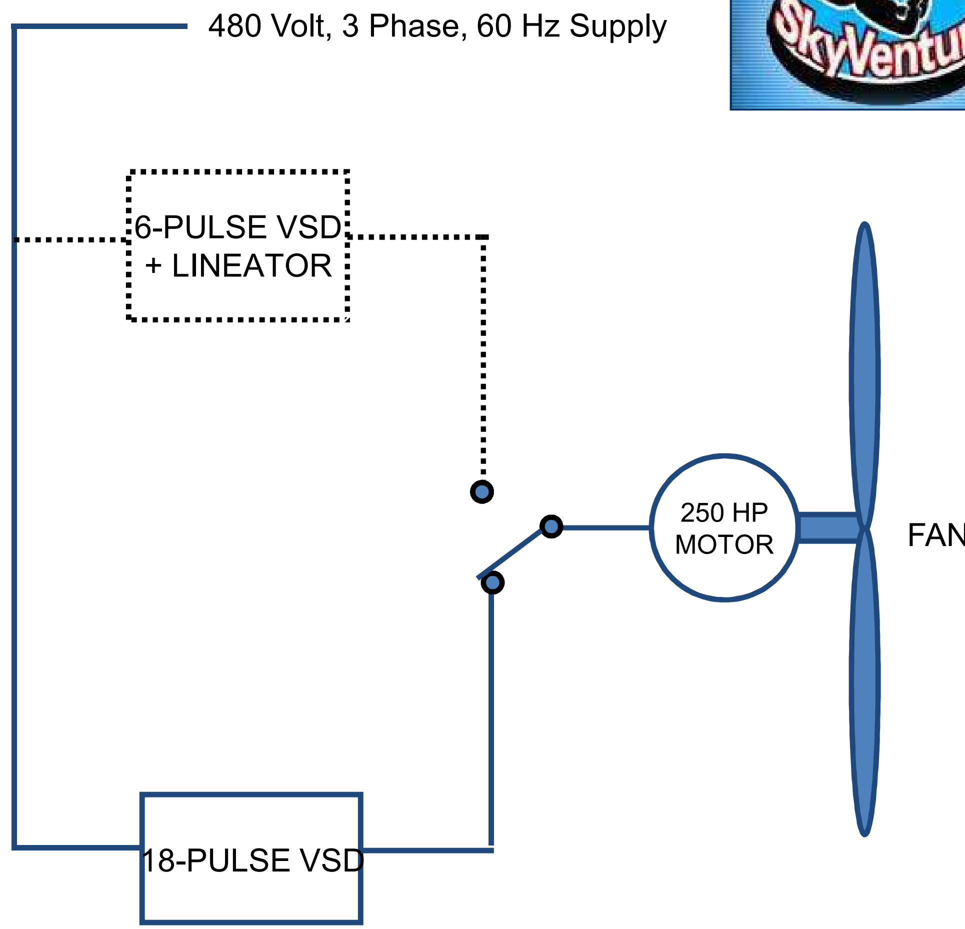
Efficiency using
Lineator is
2% to 3% better



When compared to an 18-P VSD, a 400HP Lineator/6-P system will save more than $3,000 in annual operating costs when averaging 75% loading at $0.07 / kwhr.

Case Study: SkyVenture Free-fall Simulator Orlando, FL

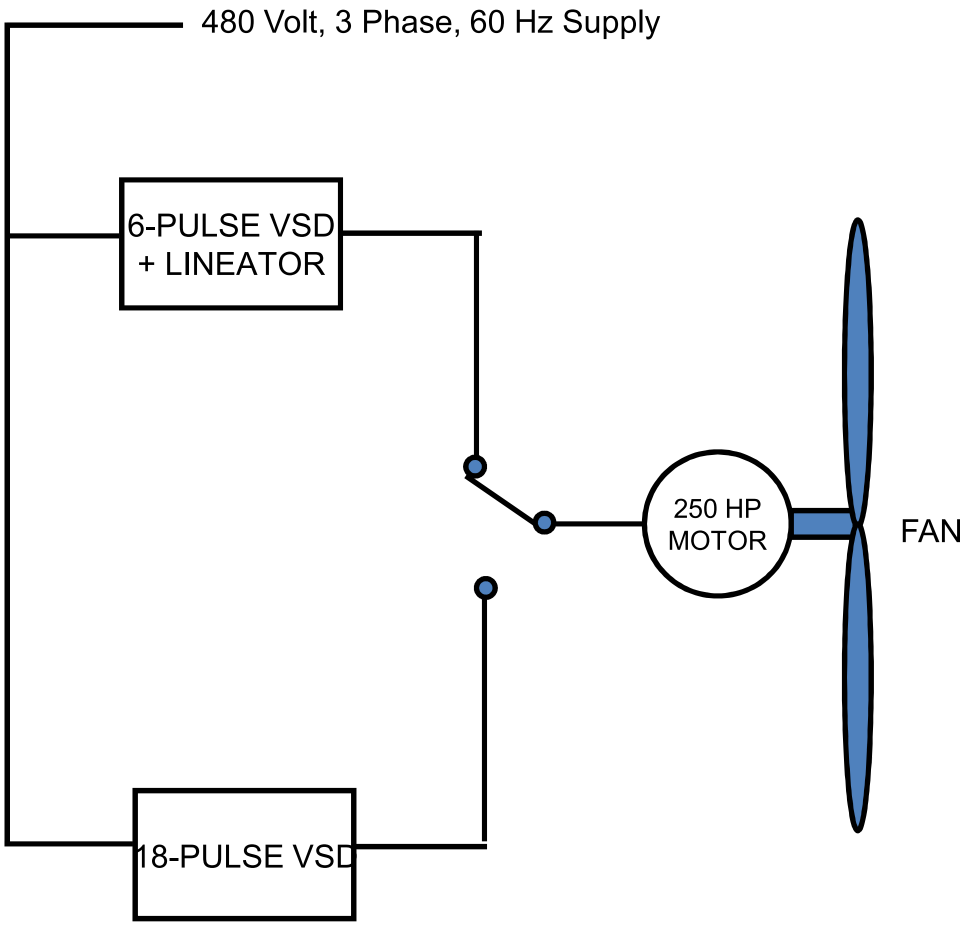
Fan (RPM)	Drive (Hz)	18-Pulse (kW)
818	55.92	152.47
889	60	190.03



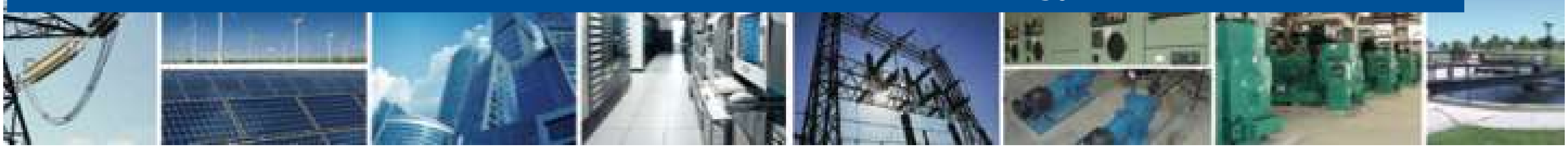
Case Study: SkyVenture Free-fall Simulator Orlando, FL

KW SAVED WITH 6-PULSE VSD + WSHF
at 889 RPM : 6.89kW
at 818 RPM: 9.2kW

Fan (RPM)	18-Pulse VSD		6-Pulse VSD + Lineator	
	Drive (Hz)	kW	Drive (Hz)	kW
818	55.92	152.47	55	143.27
889	60	190.03	60	183.14

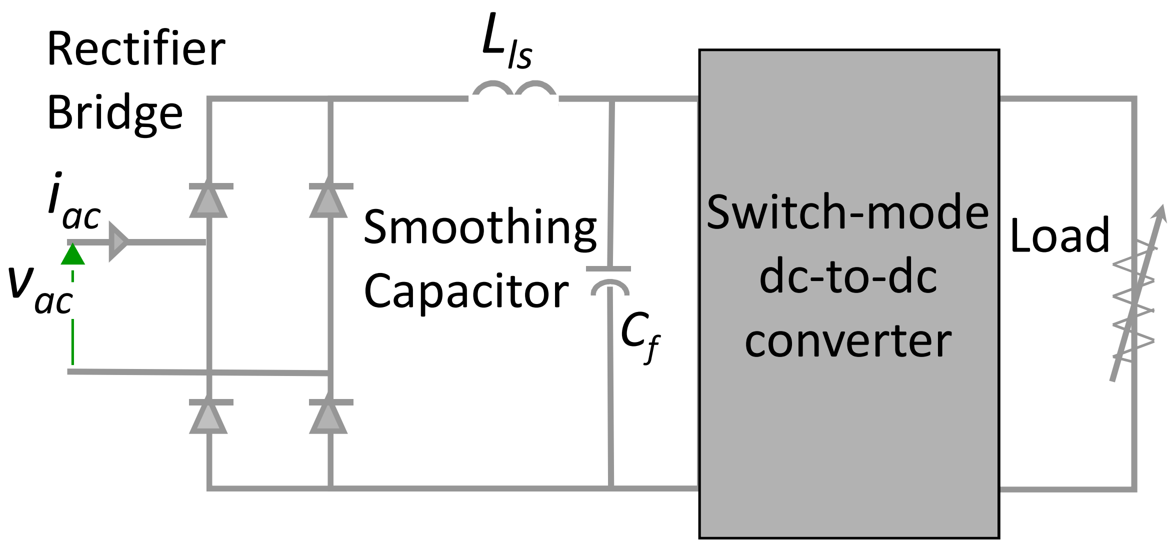


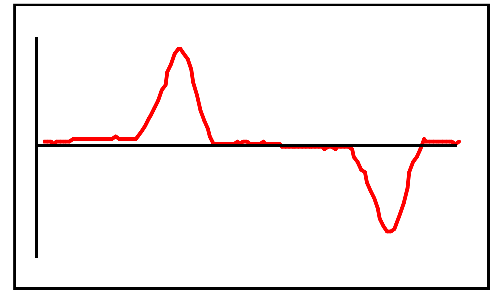
6-PULSE DRIVE + WSHF saved 3.5% to 6% of energy needed to run fan

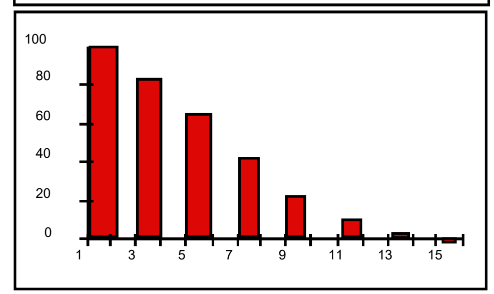


Harmonics and 1-Phase Non-linear Loads

Typical Circuit Diagram of Switch-mode Power Supply







For simple diode bridge rectifiers,

$$h = np \pm 1,$$

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

When, p = 2

h = 3, 5, 7, 9, 11,13, 15, 17, 19...

h = harmonic number

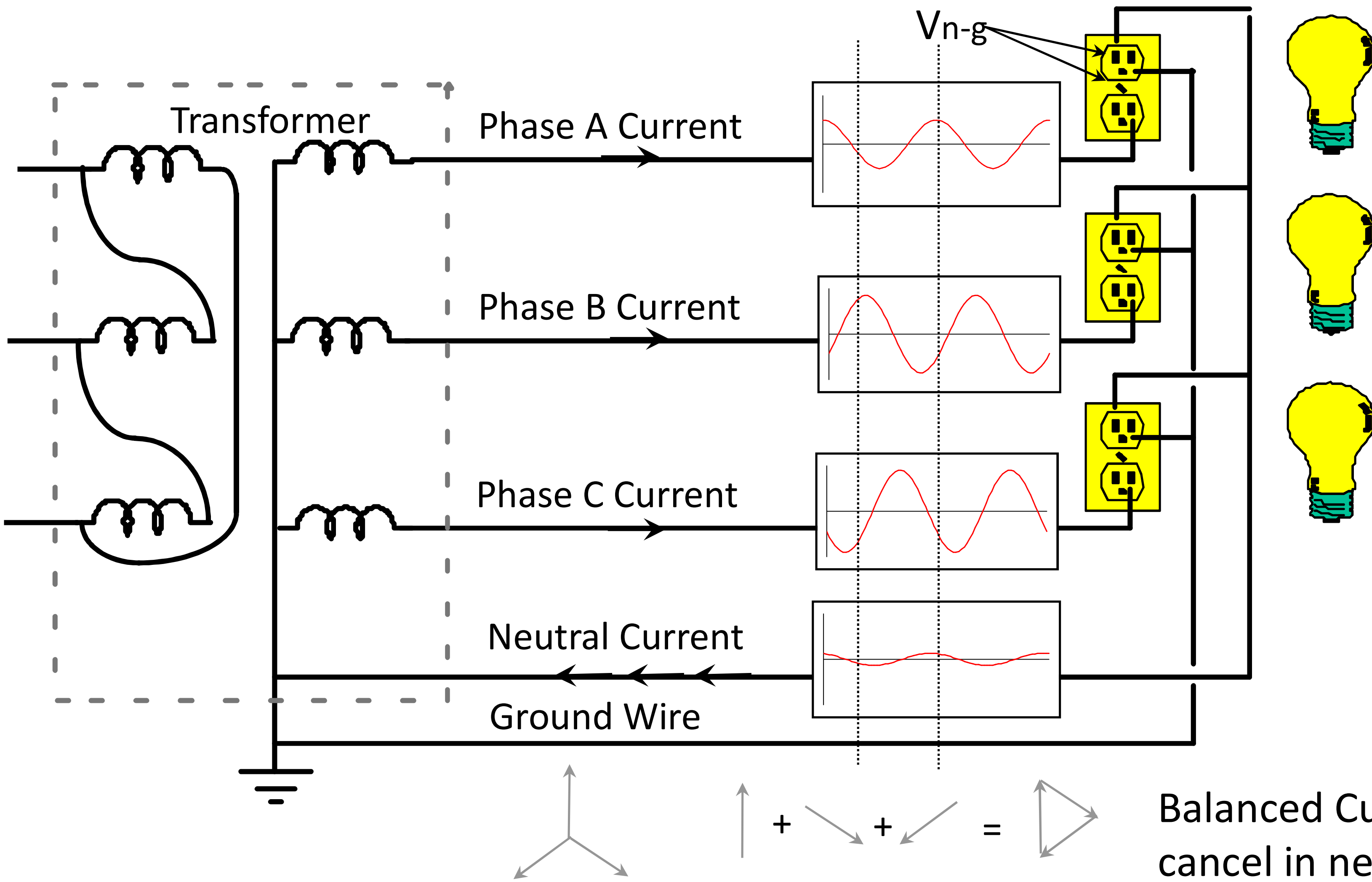
p = # of pulses in rectification scheme

n = any integer (1, 2, 3, etc.)

I_h = magnitude of harmonic current

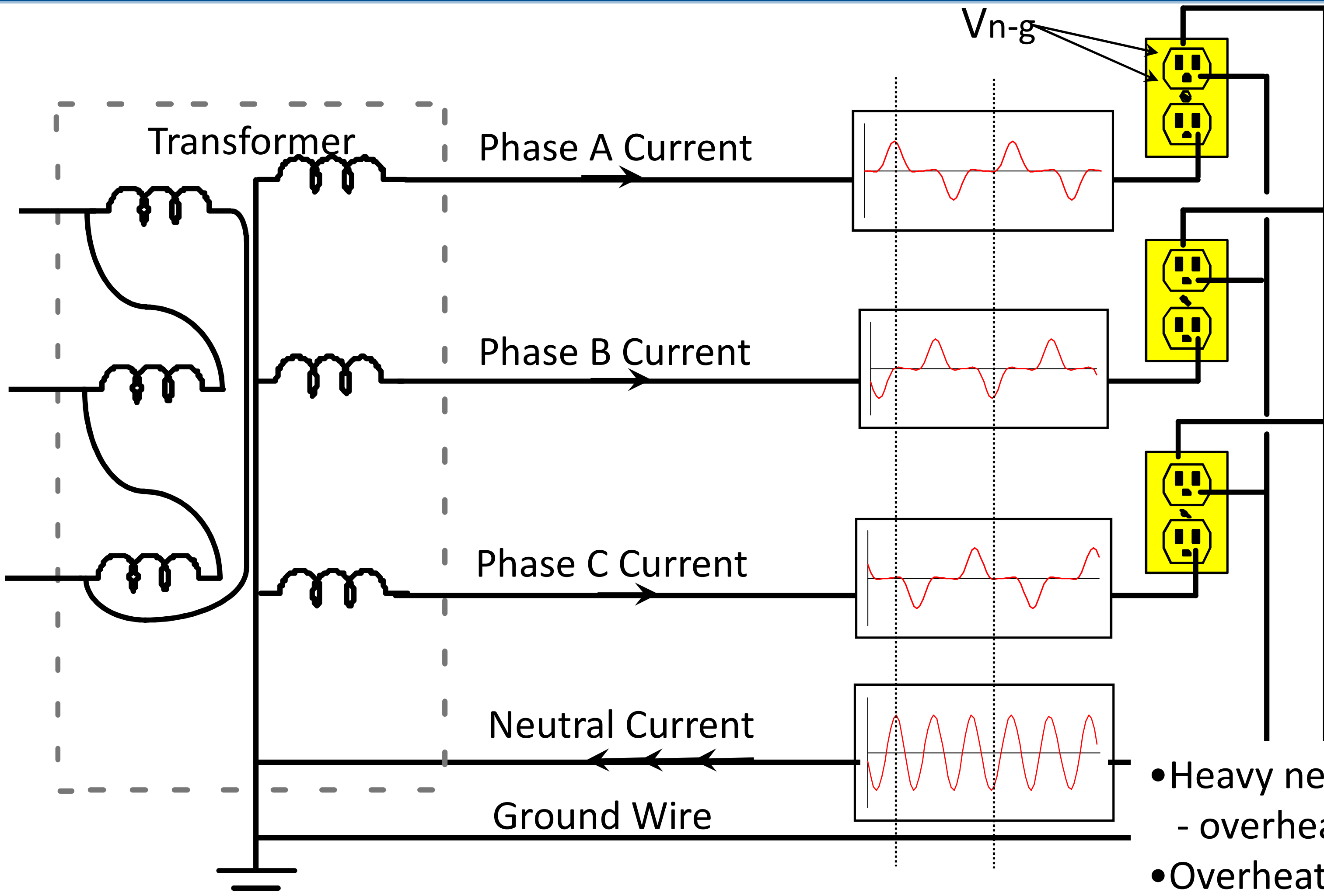
(addition of DC bus cap increases I_h)

Electrical Distribution with 1-Phase Linear Loads



Balanced Currents cancel in neutral

Electrical Distribution with 1-Phase Non-linear Loads



- Heavy neutral currents
  - overheating neutrals
- Overheating transformers
- High neutral-gnd voltage
- High Voltage distortion

Harmonic Mitigating Autotransformers

Neutral Current Eliminator (NCE™)

Combined Neutral Current Eliminator (CNCE™)

- Reduces neutral current and neutral-to-ground voltage
  - Diverts harmonic currents away from neutral conductor and upstream transformer
  - Eliminates need to double ampacity of neutral conductor
- Improves power quality by lowering voltage distortion
  - Prevents voltage flat-topping caused by non-linear loads, such as computers, broadcasting equipment, lighting
  - Prevents premature equipment failure
  - Meet IEEE Std 519 harmonic limits
- Reduces current distortion at UPS, generator or Utility service
- Eliminates transformer overheating

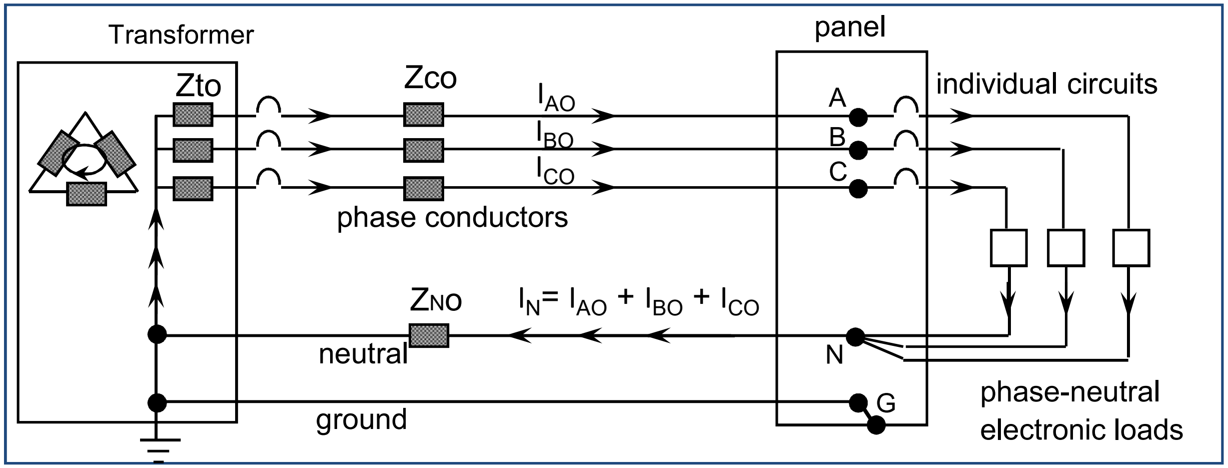
Harmonic Mitigating Transformers

Harmony™ Series

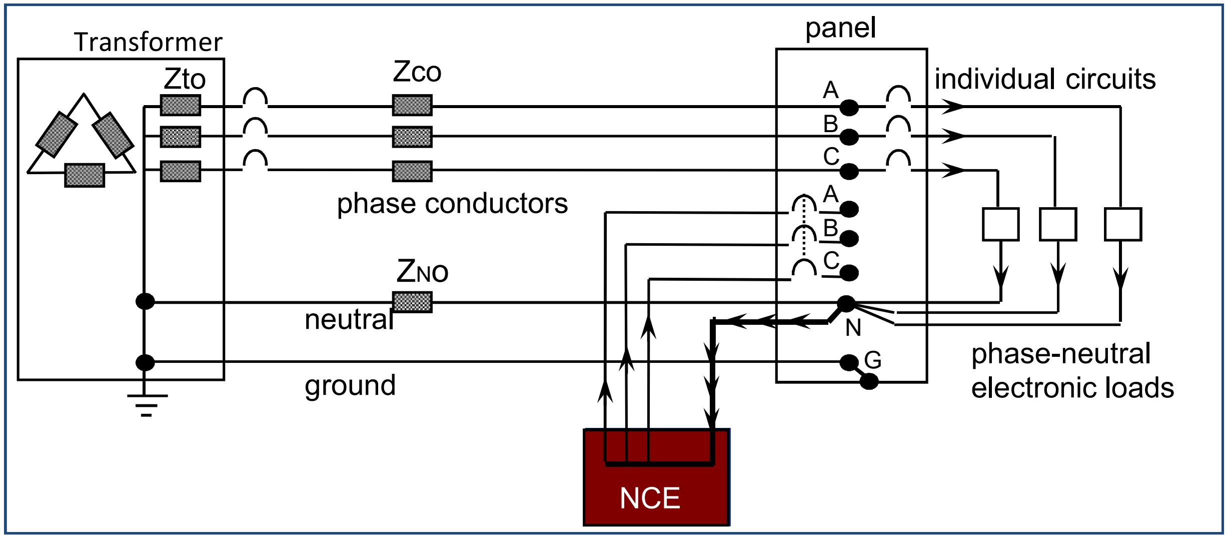
ULLTRA™ Series

- High efficiency transformers even under heavy non-linear loading
  - NEMA TP-1 or DOE2016 compliant
  - Save energy by reducing harmonic losses
- Improve power quality by lowering voltage distortion
  - Prevent voltage flat-topping caused by non-linear loads, such as computers, broadcasting equipment, lighting, etc.
  - Prevent premature equipment failure
  - Meet IEEE Std519 harmonic limits
- Reduce current distortion at UPS, generator or Utility service
- Eliminate transformer overheating and high operating temperatures

Treating Triplen Harmonics through Low Zero Sequence Impedance



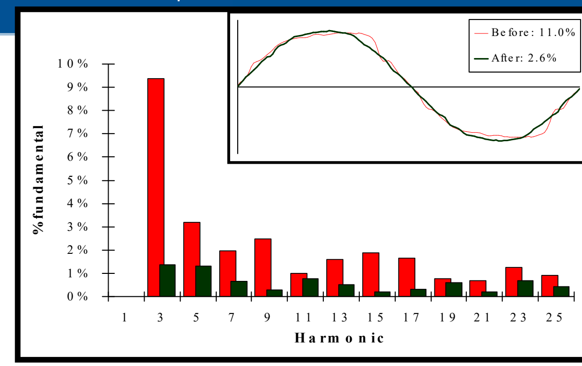
- Additive in Neutral
- Circulate in trans. primary winding
- High V_{NG}
- High V_{THD}



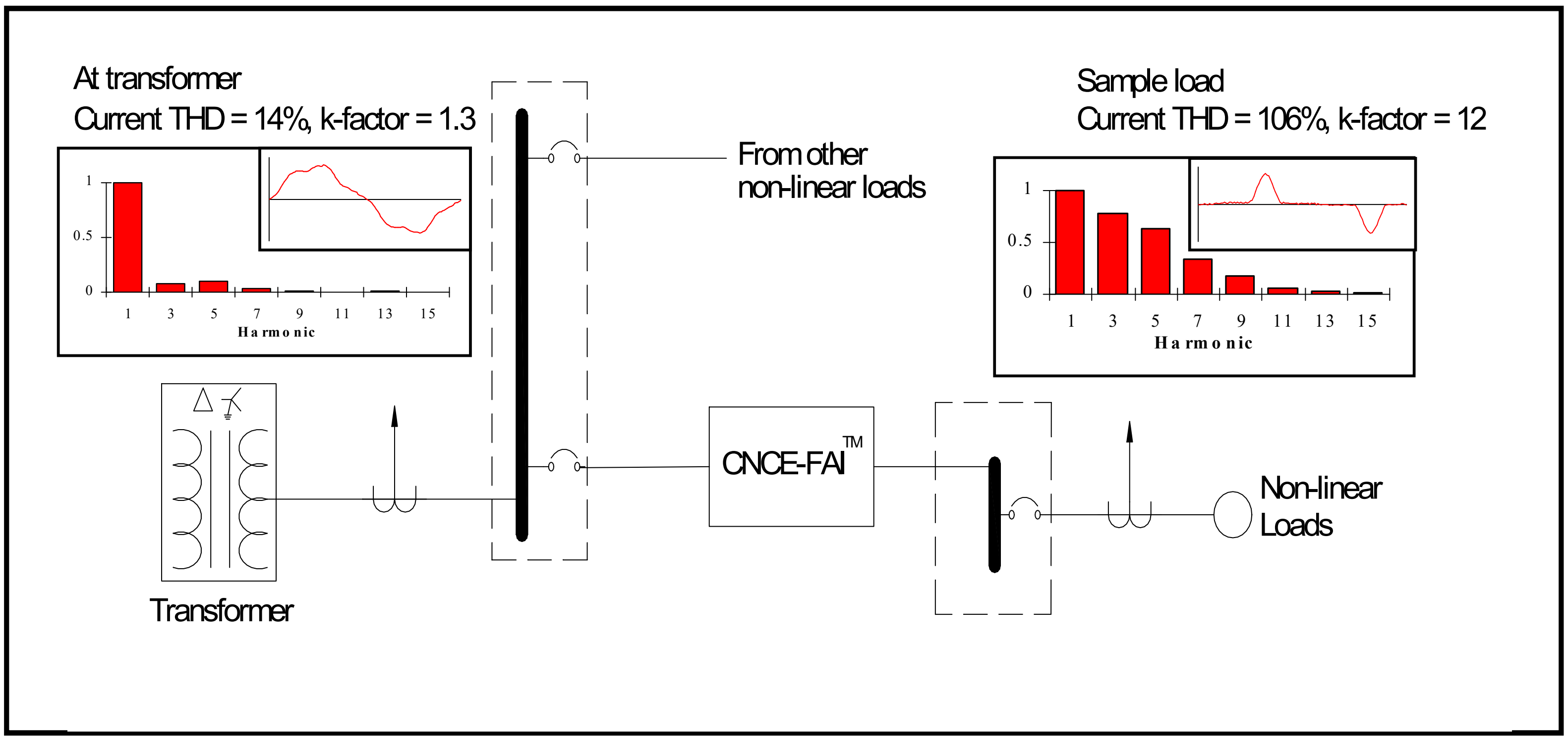
- Lowers neutral current
- Reduces current in trans.
- Lowers V_{NG}
- Lowers V_{THD}

CNCE-FAI Typical Performance

Parameter	Before	After	Performance
Voltage Distortion	11.05%	2.60%	76% reduction
Feeder Neutral Current (A)	111	18	84% reduction
Neutral-Ground Voltage (V)	6.04	1.6	74% reduction
Current Distortion	64%	14%	78% reduction
Current Imbalance	22.60%	5.00%	78% reduction
Current Crest Factor	2.1	1.7	19% reduction
Power Factor	0.76	0.95	25% improvement



Voltage Distortion at Panelboard



New England Studios Sound Stage

Features:

- (4) 18,000 SF NC25 Rated Sound Stages near Boston
- Drive on Stages
- Dedicated Dimmer Rooms
- (6) Six 1,200 Amp Power Services per Stage
- Fully Integrated Fiber Optic Communications
- 120 Tons of Silent Heat and Cooling per Stage
- 40,000 Square Feet of Onsite Grip & Electric Rentals and Mill Buildings

Challenge:

- Electrical distribution could not handle heavy neutral current from non-linear lighting loads
- Faced with $250k in wiring upgrades to increase neutral ampacity and was significantly limiting transformer capacity

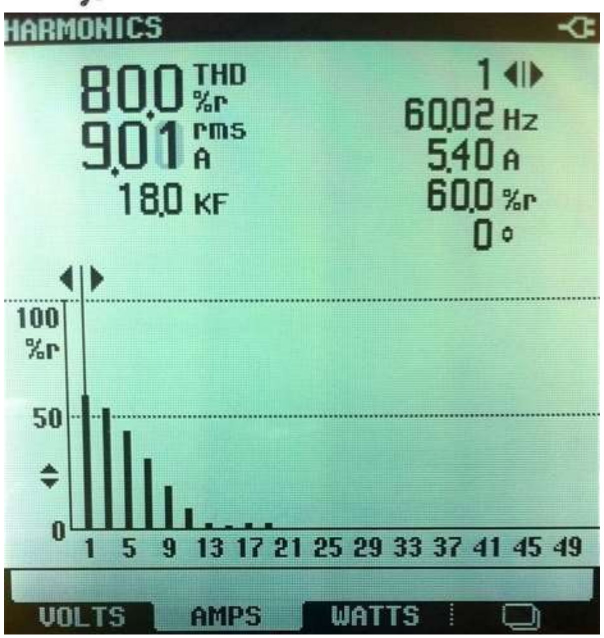
New England Studios Sound Stage: Harmonics in the Neutral Conductor

FAQ Kino Flo Lighting

FAQ | Rigging Information | Conversion Chart

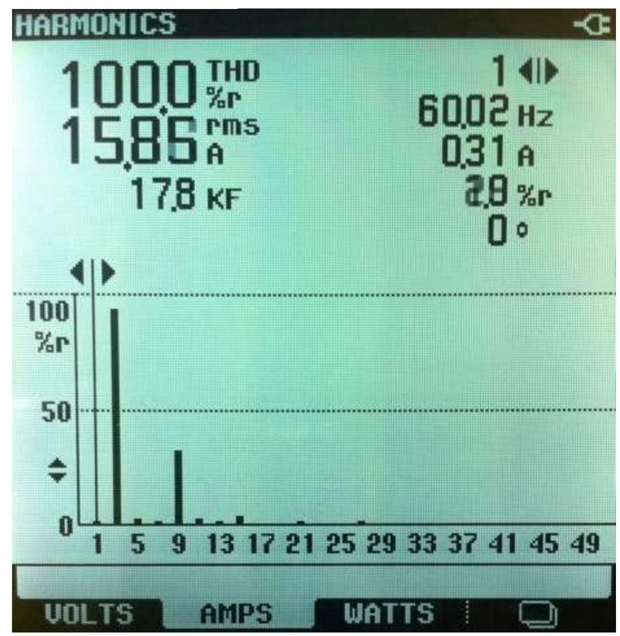
Why is the neutral drawing more than the hot leg?

Kino Flo ballasts are generally not power factor corrected. They will draw double the current on the neutral from what is being drawn on the two hot legs. On large installations it may be necessary to double your neutral run so as not to exceed your cable capacity. The Diva-Lite, ParaBeam, BarFly Dimming, ParaZip and Imara series of fixtures are power factor corrected and do not need additional capacity on the neutral.



1-phase load on

2-phases loads on



3-phases loads on

New England Studios Sound Stage: Harmonics in the Neutral Conductor

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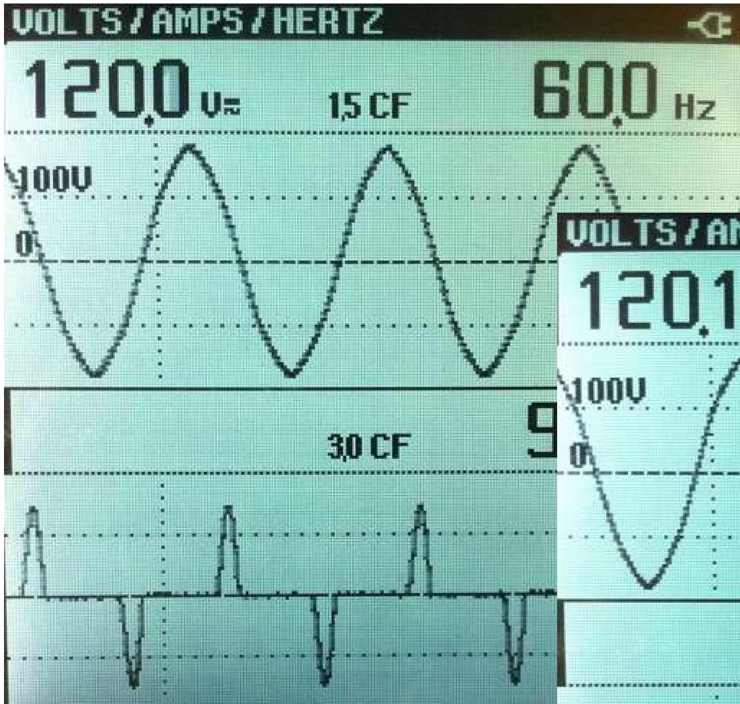
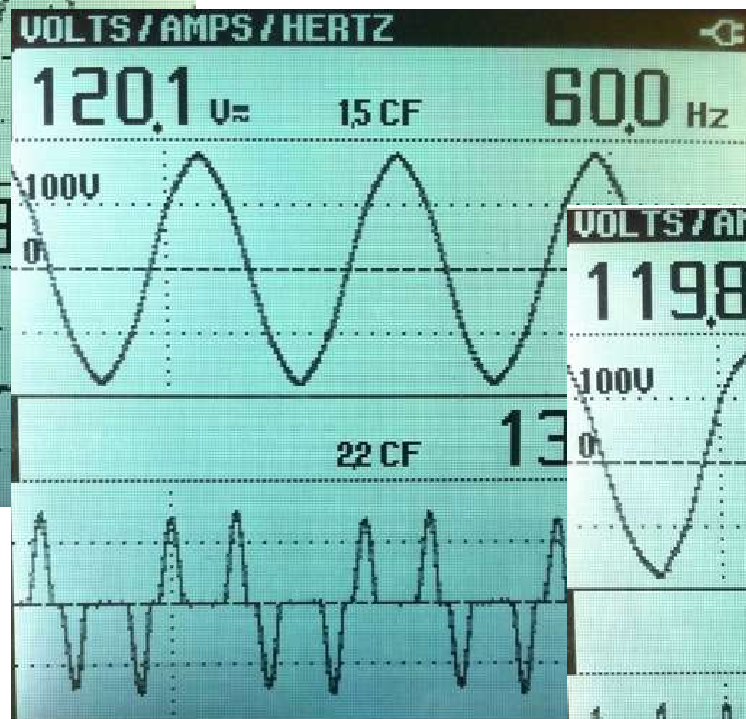
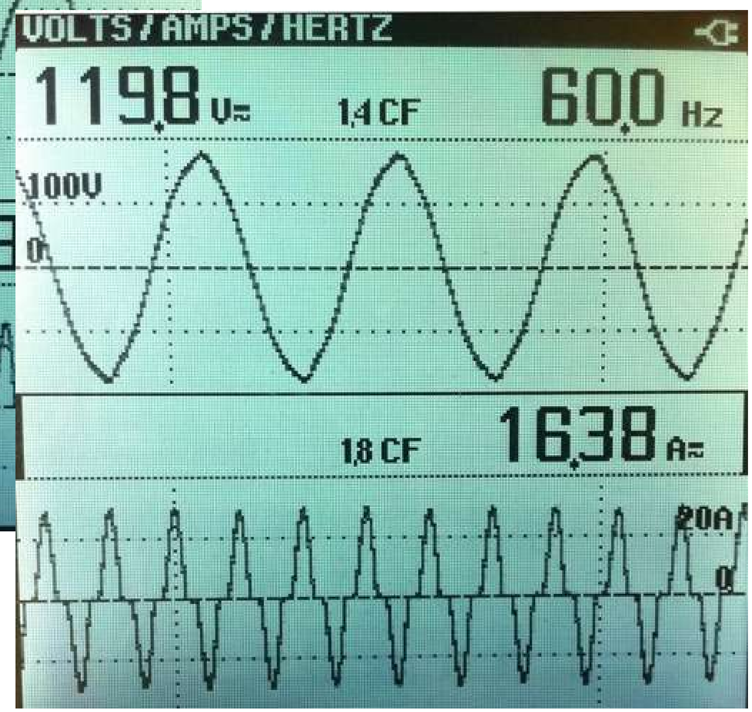


1-phase load on



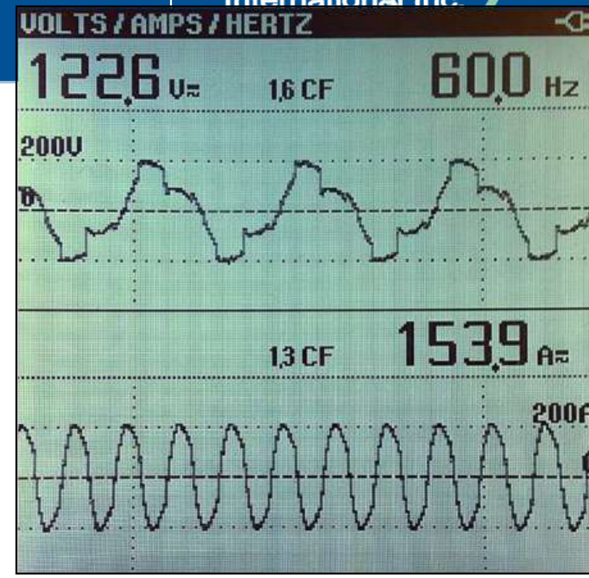
2-phases loads on



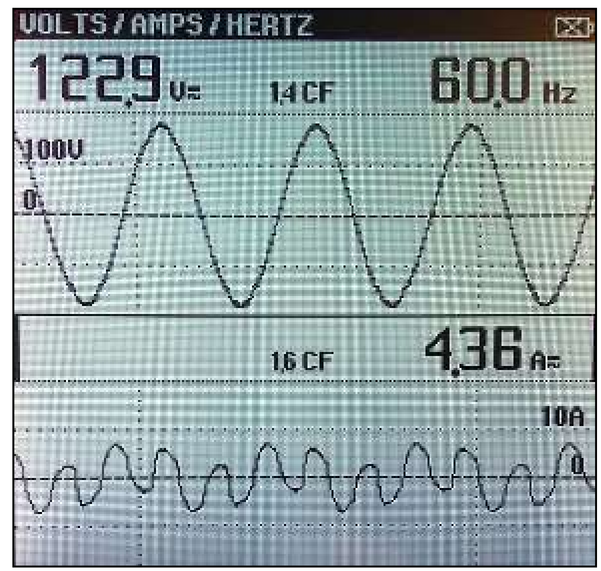
3-phases loads on

New England Studios Sound Stage: Deployment of HMT Autotransformer

- Modified existing harmonic mitigating technology to include dual outputs, industry standard cam connectors and lifting frame
- HMT removed 3rd harmonic neutral current while phase shifting to cancel 5th & 7th harmonics
  - Without HMT: In = 154A
  - With HMT: In = 4.4A
- Portable for use only where needed
- Facility now has state of the art electrical distribution for lighting allowing it to handle high-tech special effects production
- A potentially serious and limiting problem was converted to a positive selling feature for the studio



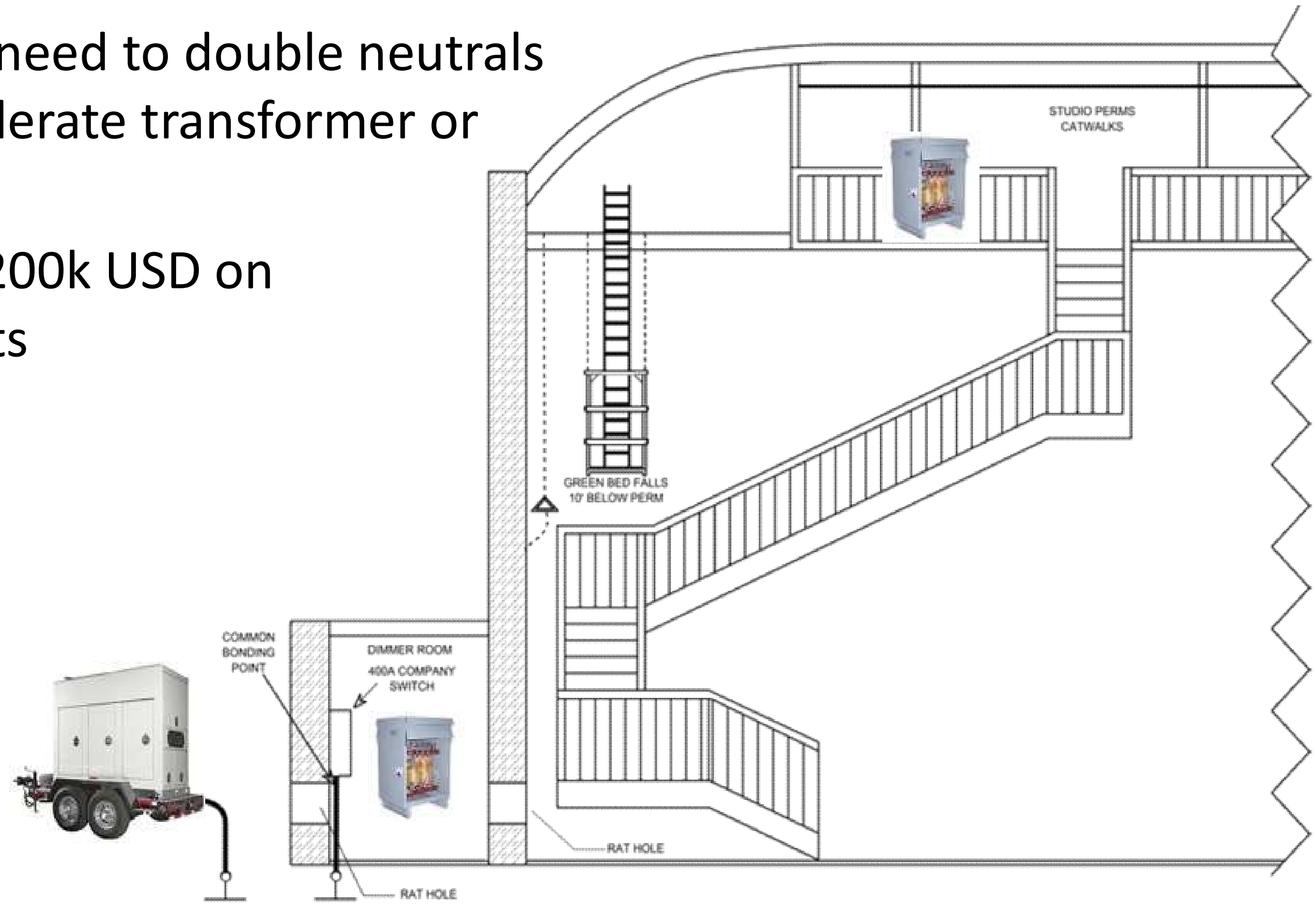
Without HMT



With HMT

New England Studios Sound Stage: Deployment of HMT Autotransformer

- Dual output HMT autotransformer with cam connectors and lifting frame
- Applied downstream of 400A Company Switches
  - As close to the non-linear loads as possible
- Eliminated the need to double neutrals upstream and derate transformer or generator
- Saved nearly $200k USD on installation costs



Summary

- Harmonics generated by non-linear loads require treatment by an effective means of harmonic mitigation
- Both passive and active methods of harmonic mitigation are available
- Serious problems can arise when the wrong form of harmonic mitigation is used
  - Active solutions generate high levels of high frequency harmonics which can cause worse problems than they resolve
  - Multipulse Drives do not perform well in environments with background THD(V) or voltage imbalance
  - Most passive filters void their performance guarantees in environments of even low levels of background THD(V) and must be significantly derated
- The right passive solution can meet all of the challenges in a very cost effective manner

How to Decide on the Best Harmonic Mitigation Solution for a VFD Application

- Run computer simulation to determine if harmonic mitigation is necessary to meet standards and prevent problems
- Consider pros and cons of various harmonic mitigation options
  - Line reactors or dc chokes
  - Multipulse VFD
  - Active Frontend Drive
  - Parallel Active Harmonic Filter
  - Passive Wide Spectrum Harmonic Filter
- Consider truly important criteria for addressing harmonics
  - Prevent overheating and failure of electrical distribution equipment
  - Prevent misoperation and failure of connected equipment due to high voltage distortion
  - Do not introduce unintentional negative side effects
  - Optimize VFD energy saving benefits by not introducing excessive losses
  - Provide a proven and reliable solution
- Run computer simulation to determine if passive harmonic solution will meet requirements

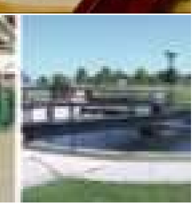
Discussion

Questions and feedback







Thank You

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