Power Quality & Harmonic Mitigating Solutions

IEEE CED Seminar, Houston

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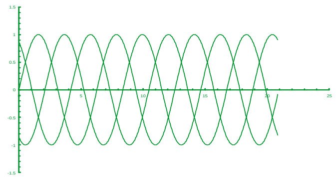
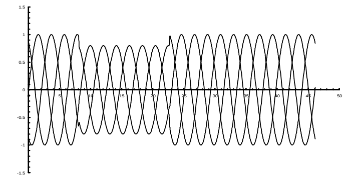
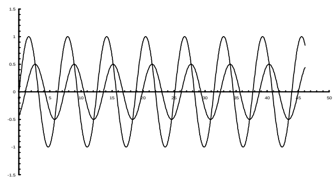
The ideal voltage supply does not exist



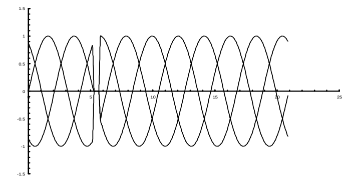
3-phase balanced



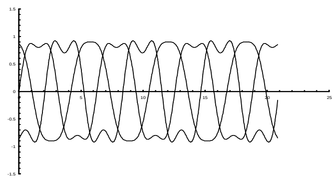
Sags/swells
Overvoltage



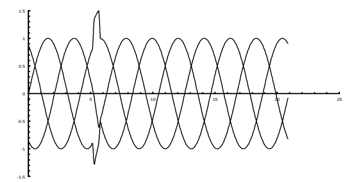
Power Factor



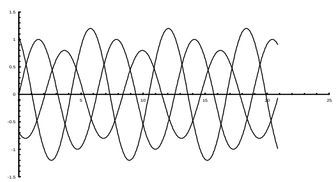
Notches



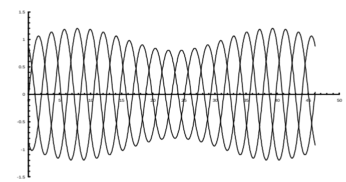
Harmonics



Spikes

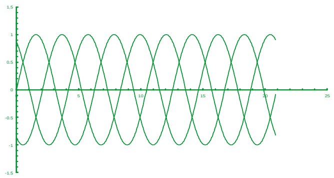


Phase unbalanced

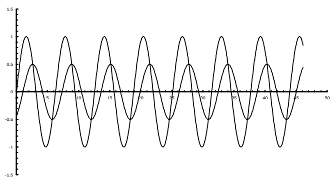


Flicker

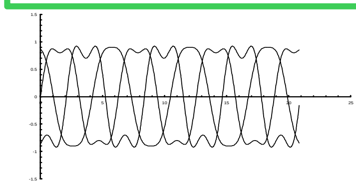
The ideal voltage supply does not exist



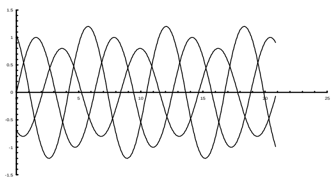
3-phase balanced



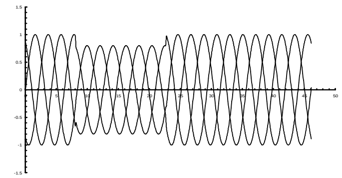
Power Factor



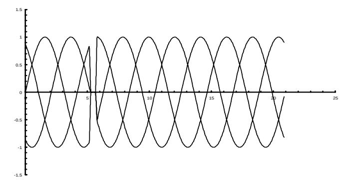
Harmonics



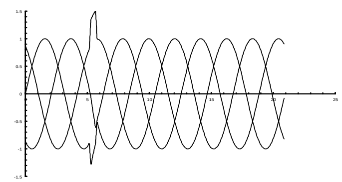
Phase unbalanced



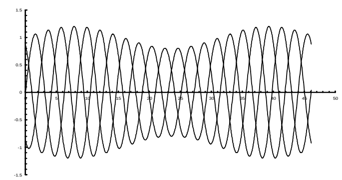
Sags/swells Overvoltage



Notches

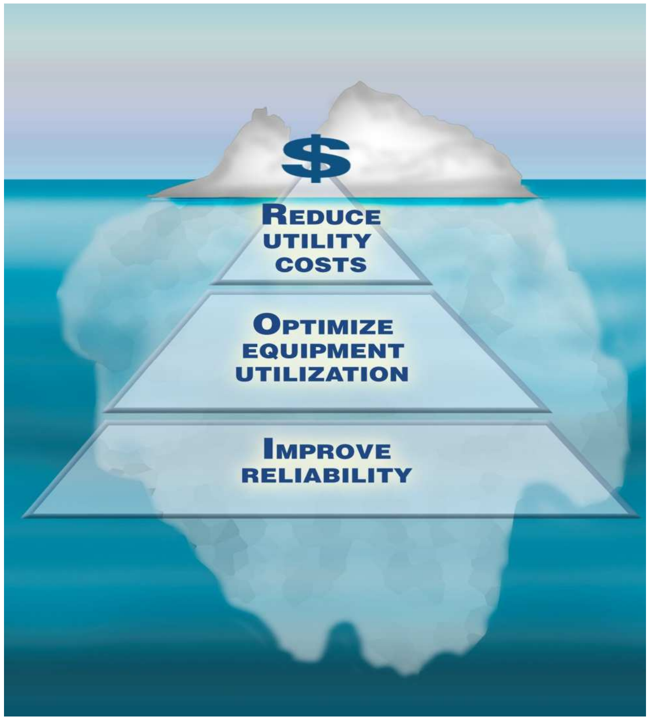


Spikes



Flicker

Energy Efficiency with PFC



Power Factor Correction benefits:

- Reduces Utility Bills
- Reduces loading on transformers
- Reduces I2R losses in Distribution Equipment
- Reduces Carbon Emission
- Reduces voltage drop

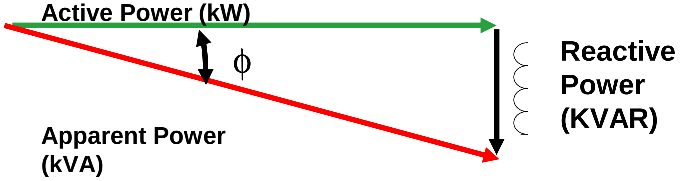
The Power Triangle:

Power Factor is the ratio of Active Power to Total Power:

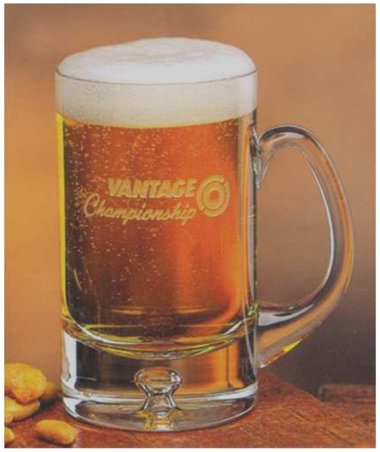
Power Factor = Active (Real) Power / Total Power

= kW / kVA

= Cosine (θ)



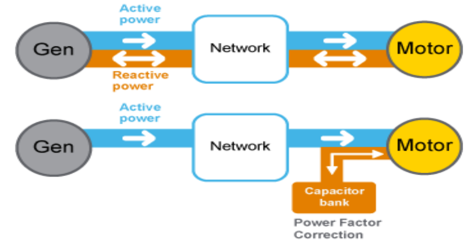
 Power Factor is a measure of efficiency (Output/Input)



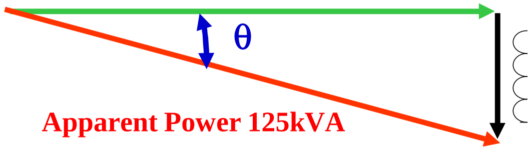
Inductive loads that cause low PF:

- Induction motors
- Welders
- DC drives
- Transformers
- …

How to correct Power Factor?



Active Power 100kW



Apparent Power 125kVA

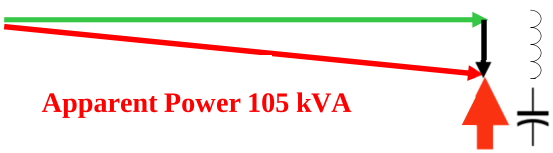
Reactive Power, Inductive

Power Factor = $\frac{\text{Active (Real) Power}}{\text{Apparent Power}}$

= $\frac{100\text{ kW}}{125\text{ kVA}}$

= Cosine (θ) = .80

Active Power 100kW



Apparent Power 105 kVA

.95 pf = $\frac{100\text{ kW}}{kVA}$

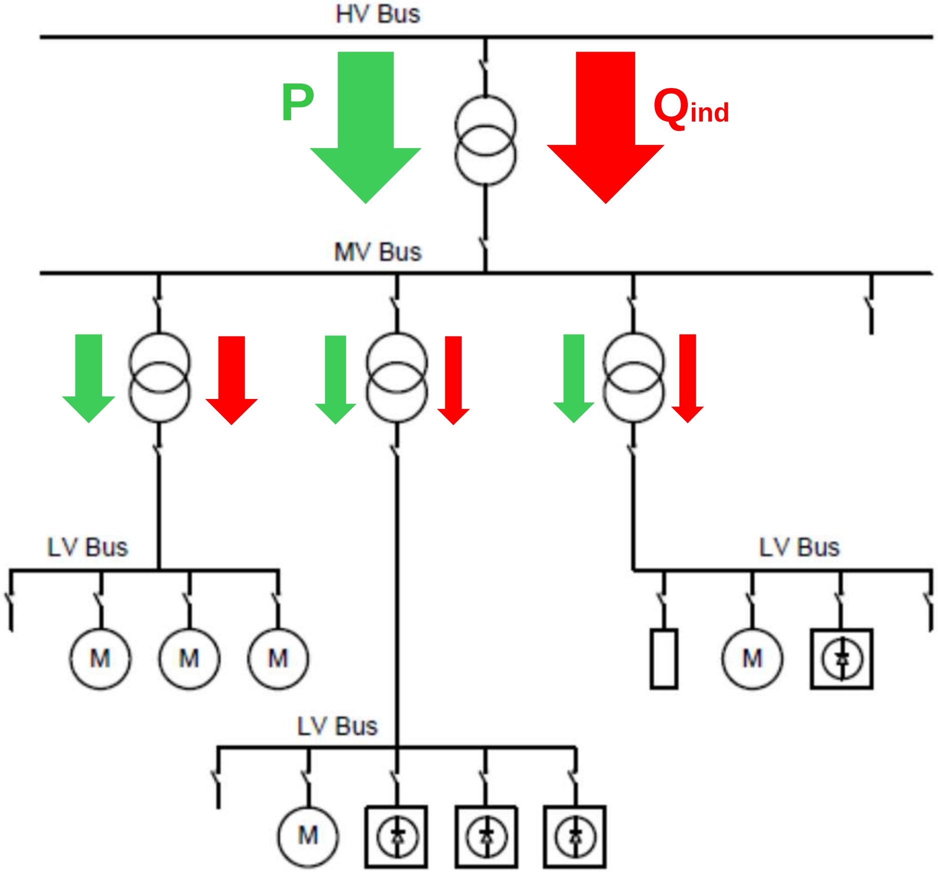
kVA = $\frac{100\text{ kW}}{.95}$

Apparent Power = 105 kVA

Add
42 KVARc
corrects PF
to 95% lag

KVAR = KW x (Tan Cos^{-1}(Present PF) - Tan Cos^{-1}(Desired PF))

Power flow in MV and LV network without compensation



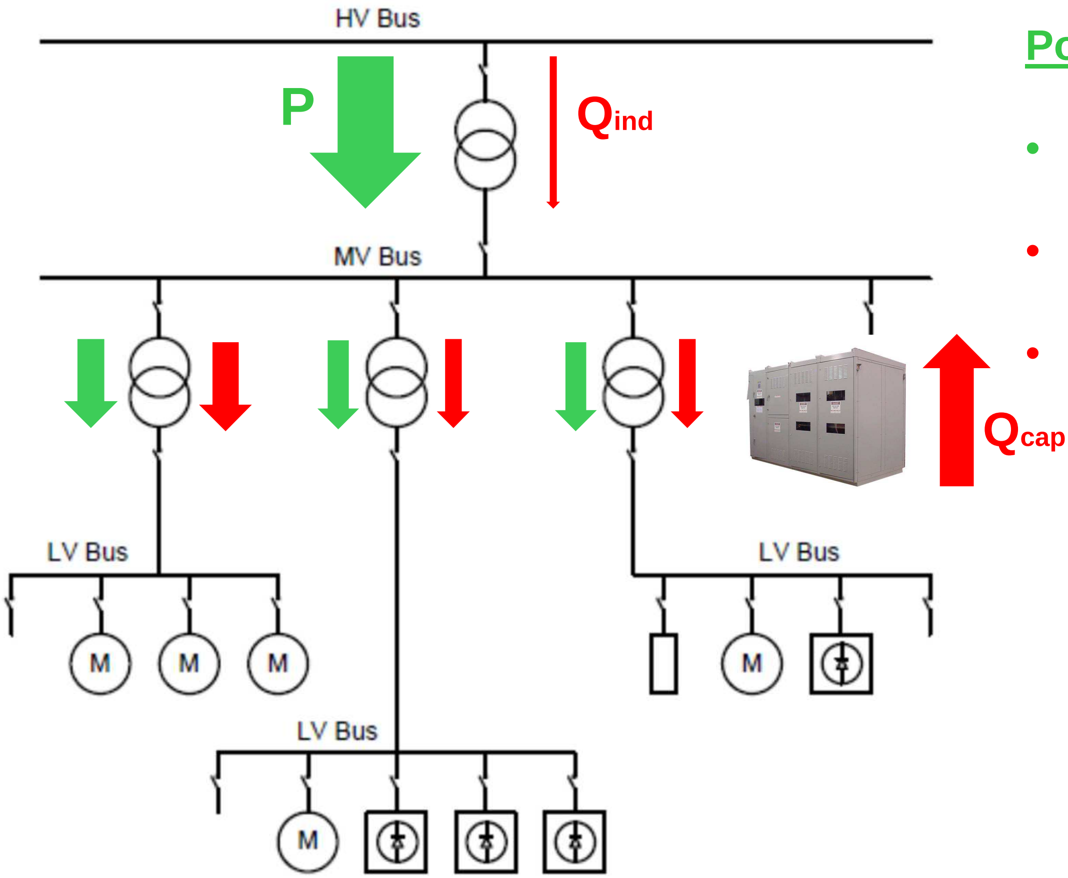
Power Flow:

- Real Power supplied by HV, MV & LV network
- Reactive Power supplied by HV, MV & LV network

Impact:

- PF penalty possible
- No voltage regulation
- No I²R losses or CO² reduction
- No LV or MV network off loading

Power flow in MV and LV network with MV compensation



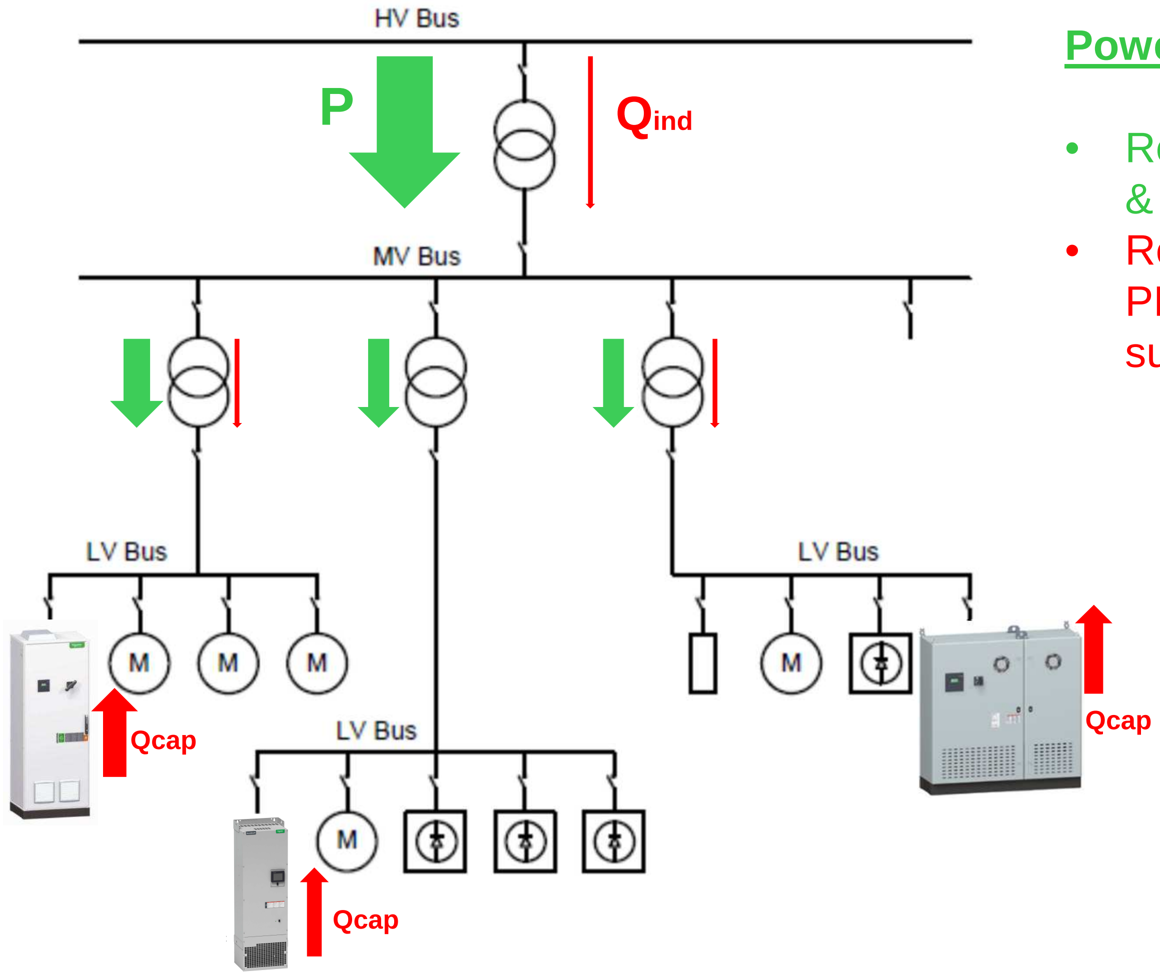
Power Flow:

- Real Power supplied by HV, MV & LV network
- Reactive Power supplied by MV PFC and some by HV network
- Full Reactive Power still flow through the LV network

Impact:

- PF penalty eliminated
- No LV voltage regulation
- Some I^2R & CO^2 reduction
- MV network off loading, no LV network off loading

Power flow in MV and LV network with LV compensation



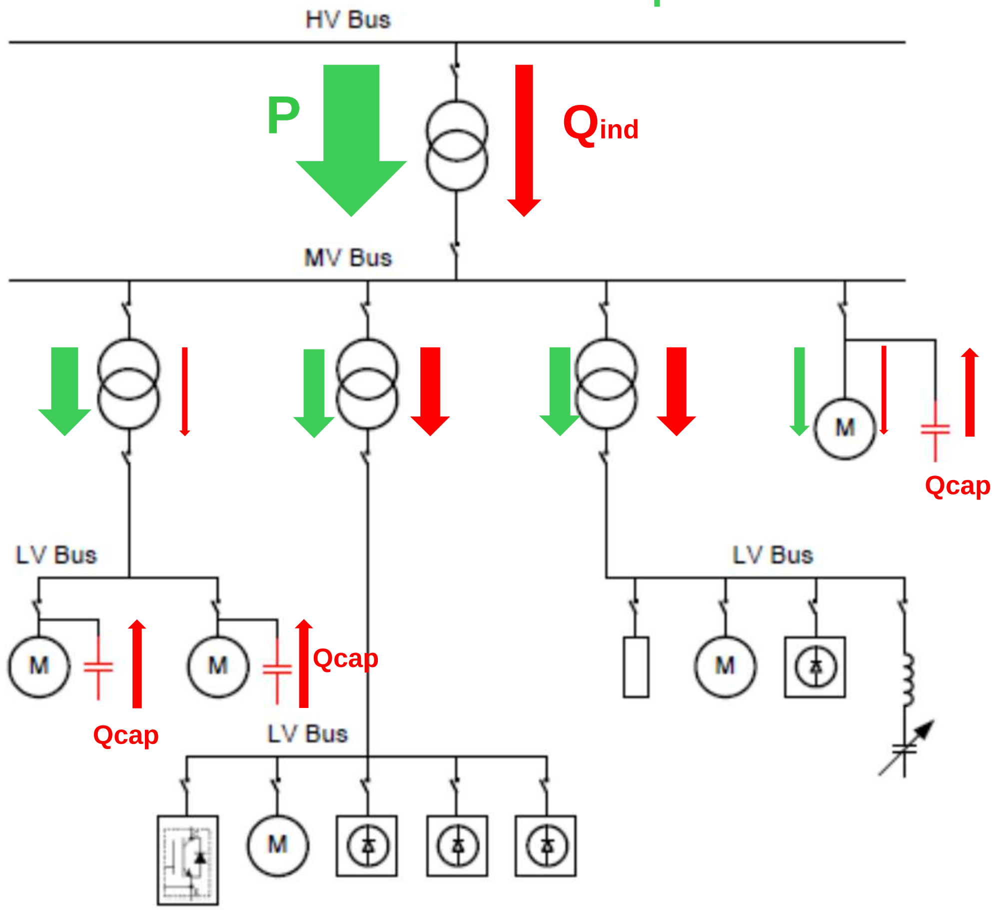
Power Flow:

- Real Power supplied by HV, MV & LV network
- Reactive Power supplied by LV PFC & AccuSine. Small amount supplied by the network

Impact:

- PF penalty eliminated
- Voltage regulation
- Uptimum I²R & CO² reduction
- LV & MV network off loading
- Harmonic reduction by De-Tuned LV PFC and AccuSine PLUS

Fixed Reactive Power Compensation



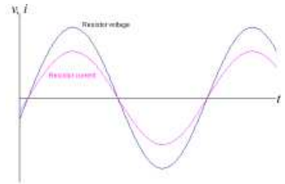
Application :

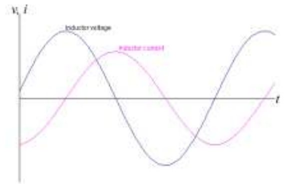
- Fixed capacitor can be used in network with low harmonic distortion level.
- When installed on the main bus, keep fixed capacitor kVAR value below 15% of transformer kVA rating in order to avoid over voltage condition.
- When installed on motors only apply on DOL starter.
- VFD's not allowed on the same bus.
- When reduced voltage starter are present, only energized the Fixed capacitor when motor has reached full speed.
- Back to back capacitor switching issue possible when multiple fixed capacitor are present on the same bus.

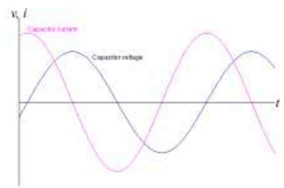
Power Factor Correction for Linear Loads

Linear loads

- The electrical equipment draws current in a "linear" fashion
  - **Current (i) & Voltage (v) are both "Sinusoidal"**





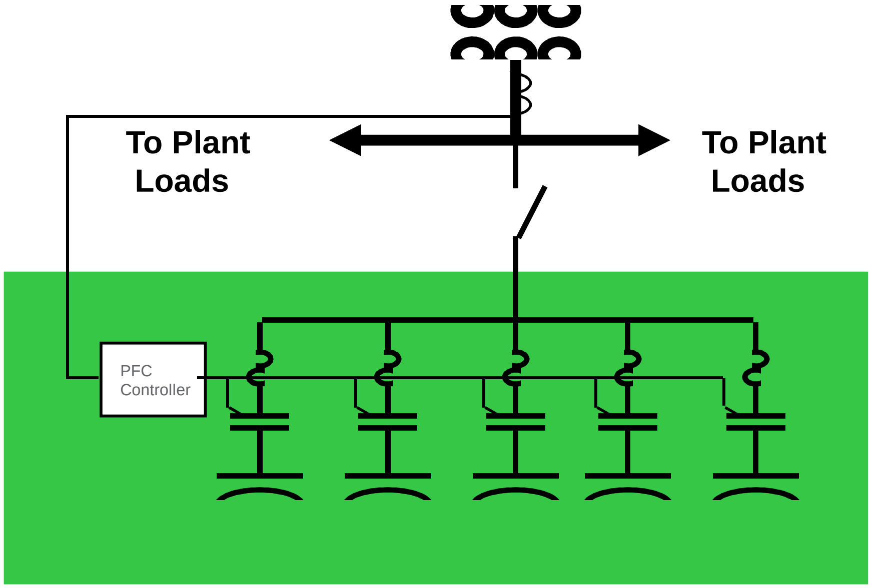
Automatic Capacitor Systems

Automatic Capacitor Systems:

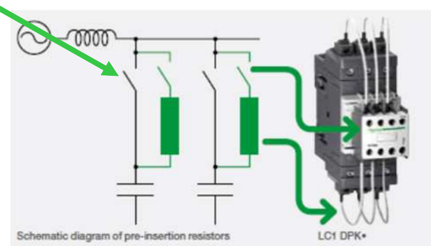
- *Contains:*
  - *PFC Controller*
  - *Stage over current protection, Fuses or Circuit Breaker*
  - *Contactors*
  - *Capacitors*

- *Usually at Main Swith Gear*

- *Controller Measures P.F. & switches banks in & out of service to maintain user defined target P.F.*



LV Automatic Capacitor Bank for Industries



<u>Automatic capacitor bank NEMA 1, Indoor</u>

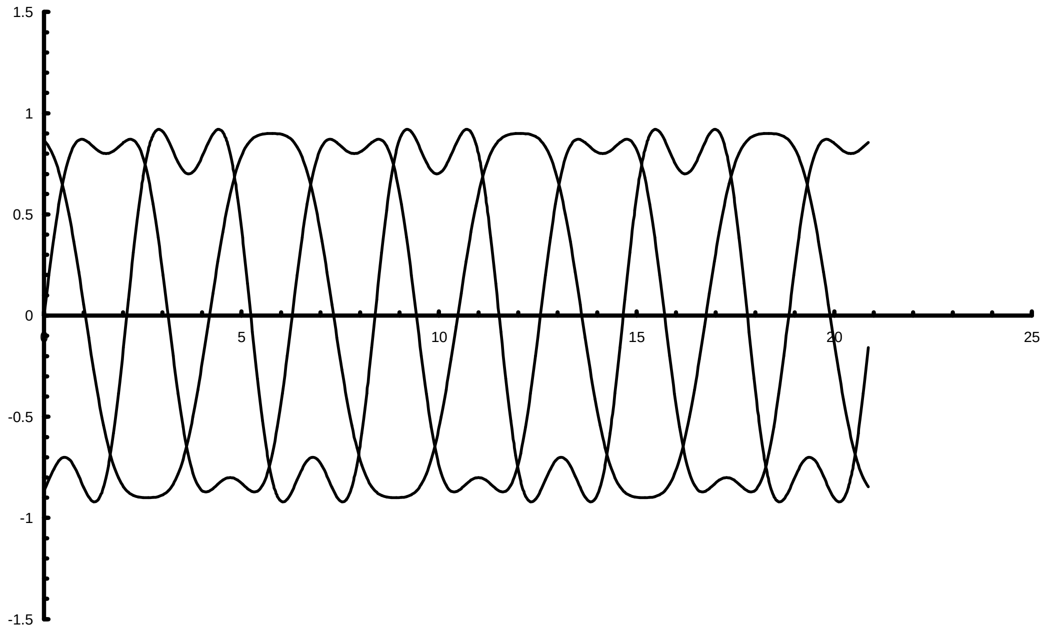
- **Standard Voltage, 208,240, 480 & 600 V, 50-60 Hz**
- **Free Standing, Main Lugs or Main Breaker incoming**
- **Up to 500 KVAR @ 480 or 600 V in each section, 1000 KVAR max in two sections**
- **Section dim: 30" W x 36"D x 90" H**
- **PFC relay, Advanced Microprocessor controller**
- **Stage Circuit Breaker used for overload and over current protection**
- **cCSAul Approved, Optimized air flow & dead front construction**
- **Contactors equipped with soft charge resistors**
- **Heavy Duty LV capacitor, certified as per UL810**

LV Automatic Capacitor Bank for commercial buildings and small industries

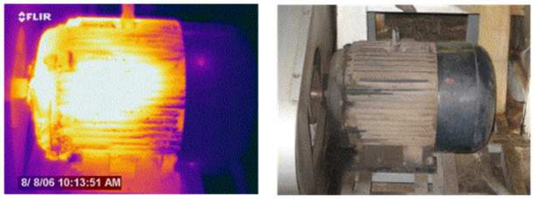
<u>Automatic capacitor bank NEMA 1, Indoor</u>

- **Standard Voltage, 480 & 600 V, 50-60 Hz**
- **Wall Mounted, Main Lugs or Main Breaker incoming**
- **Up to 300 KVAR @ 480 and 250 kVAR at 600 V**
- **Small enclosure: 31.5” W x 16”D x 33.5” H**
- **Large Enclosure: 39.4” W x 16”D x 47” H**
- **PFC relay, Advanced Microprocessor controller**
- **Stage Circuit Breaker used for overload and over current protection**
- **cCSAul Approved, Optimized air flow & dead front construction**
- **Contactors equipped with soft charge resistors**
- **Heavy Duty LV capacitor, certified as per UL810**

Introduction to Harmonics and PF correction in harmonic rich network



Harmonics in electrical systems increase business operating costs…….



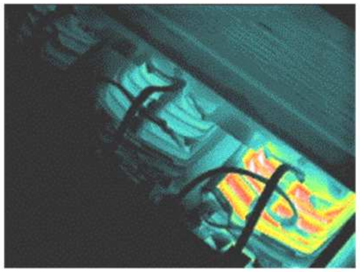
Above thermal and daylight images show a three phase motor which has overheated. Power quality analysis proved condition was caused by negative sequence harmonics.

Increased system downtime

- Nuisance tripping of overloads and circuit breakers
- Bus failures
- Distortion of control signals

Increased maintenance

- Excessive heat places burden on electrical infrastructure from transformers to cables and bussing


Above thermal image shows overheated windings on a step-down transformer, possibly caused by harmonics.

Lower Quality and Efficiency

- Interrupt production causing downtime, rework and scrap

Reduced system capacity

- Requires costly equipment upgrades to support expansion

Harmonics are a circumstance of progress and they effect almost every business in today's environment…

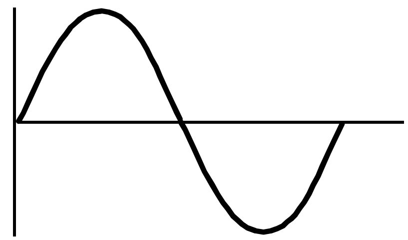
Harmonics: Fundamentals

Definition:

Harmonics are integer multiples of the fundamental frequency that, when added together, result in a distorted waveform

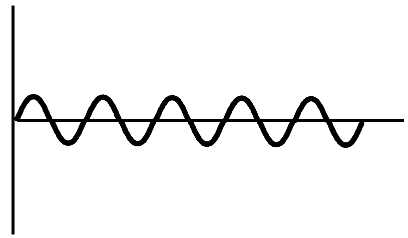
Harmonics: Fundamentals

Sinewave of a specific frequency supplied by the utility (a "clean" sinewave):



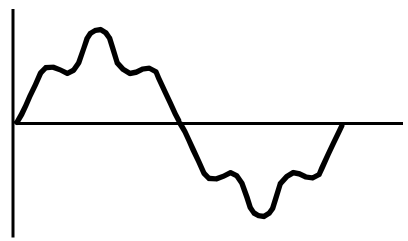
$$f(x) = \sin(x)$$

…plus a "5th" Harmonic Sinewave:



$$f(x) = \frac{\sin(5x)}{5}$$

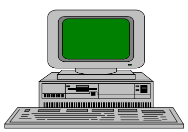
…results in a harmonic rich, non-linear wave shape:



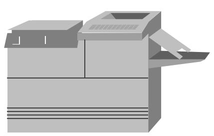
$$f(x) = \sin(x) + \frac{\sin(5x)}{5}$$

Harmonics: Fundamentals

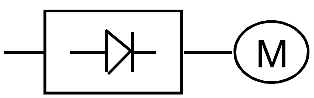
What produces “Non-linear” Current?



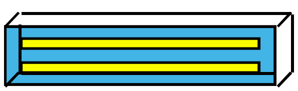
- Computers



- Copiers

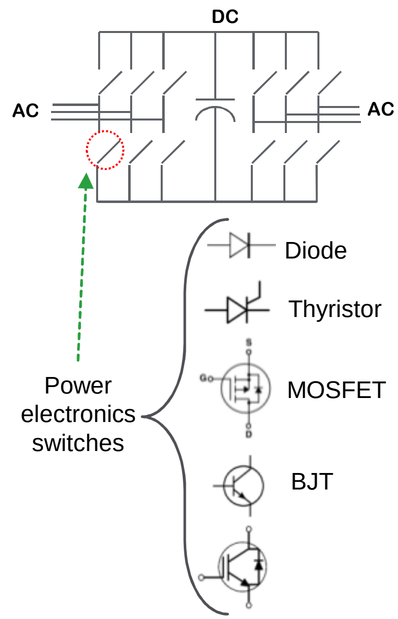


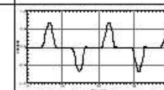
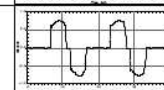
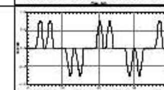
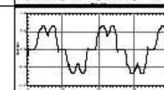
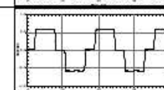
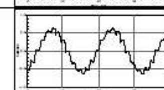
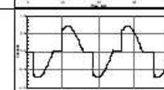
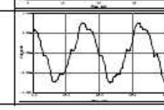
- AC or DC drives



- Electronic Ballasts

Nonlinear loads:



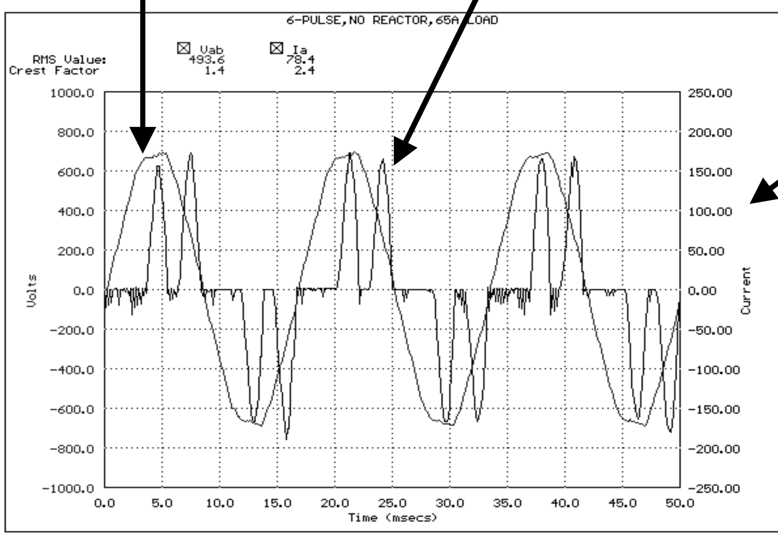
Type of Load	Typical Waveform	Current Distortion
Single Phase Power Supply		80% (high 3rd)
Semiconverter		high 2nd,3rd, 4th at partial loads
6 Pulse Converter, capacitive smoothing, no series inductance		80%
6 Pulse Converter, capacitive smoothing with series inductance > 3%, or dc drive		40%
6 Pulse Converter with large inductor for current smoothing		28%
12 Pulse Converter		15%
ac Voltage Regulator		varies with firing angle
Fluorescent Lighting		20%

Harmonics: Fundamentals

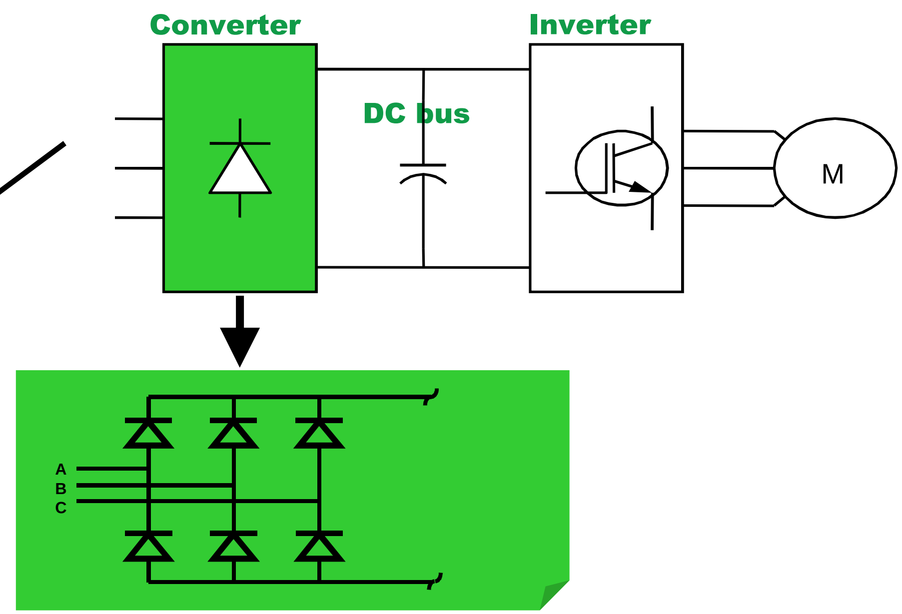
- **Nonlinear loads draw harmonic current from source**
  - Does no work

Voltage: flat topping of waveform

Current: high TDD between 90-100%

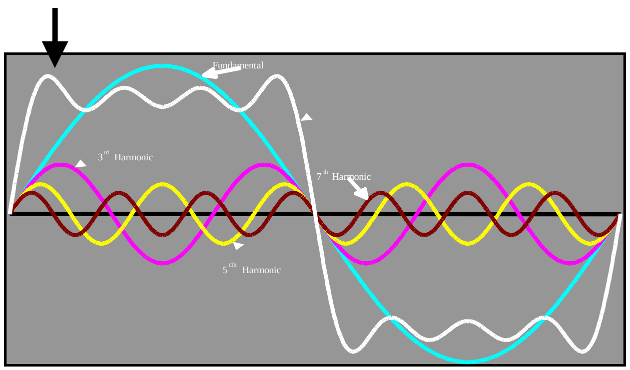


Basic PWM VSD



Harmonics: Fundamentals

Waveform seen with oscilloscope



Harmonic	Frequency	Sequence
1	60Hz	+
2	120Hz	-
3	180Hz	0
4	240Hz	+
5	300Hz	-
6	360Hz	0
7	420Hz	+
:	:	
19	1140Hz	+

- Characteristic harmonics are the predominate harmonics seen by the power distribution system
  - Predicted by the following equation:

$$H_c = np \pm 1$$

  - H_C = characteristic harmonics to be expected
  - n = an integer from 1,2,3,4,5, etc.
  - p = number of pulses or rectifiers in circuit

- Amplitude is inverse of harmonic order (perfect world)

Multi-pulse converter

Harmonic signature

Harmonics present by rectifier design					
	Type of rectifier				
Hn	1 phase 4-pulse	2 phase 4-pulse	3 phase 6-pulse	3 phase 12-pulse	3 phase 18-pulse
3	×	×			
5	×	×	×		
7	×	×	×		
9	×	×			
11	×	×	×	×	
13	×	×	×	×	
15	×	×			
17	×	×	×		×
19	×	×	×		×
21	×	×			
23	×	×	×	×	
25	×	×	×	×	
27	×	×			
29	×	×	×		
31	×	×	×		
33	×	×			
35	×	×	×	×	×
37	×	×	×	×	×
39	×	×			
41	×	×	×		
43	×	×	×		
45	×	×			
47	×	×	×	×	
49	×	×	×	×	

$H_c = np +/- 1$

H_c = characteristic harmonic order present

n = an integer

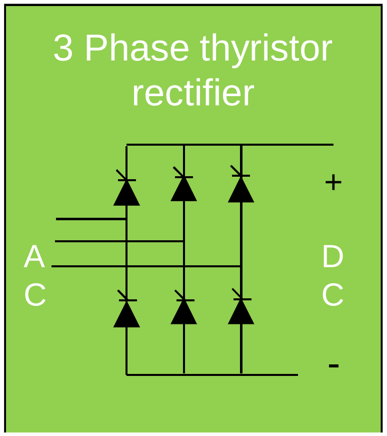
p = number of pulses

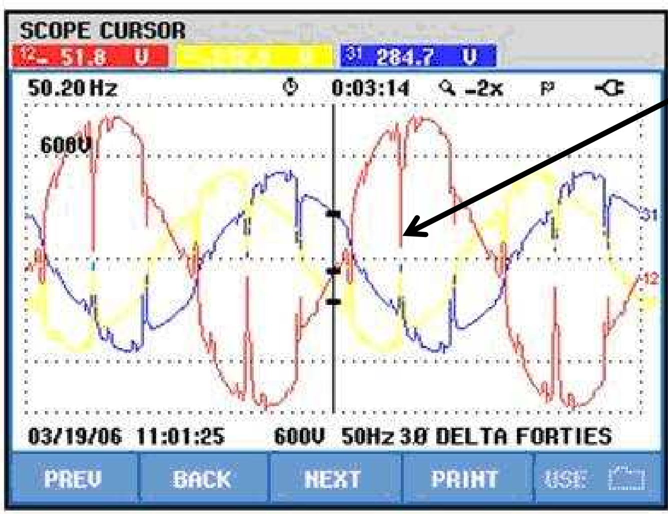
Multi-pulsing (ie: 12 & 18 pulses):

Elimination of lower order harmonic

removes largest amplitude harmonics

Harmonics: Fundamentals





3 Phase thyristor rectifier (parallel, phase to phase)

Converts **AC** to controlled **DC**

Max harmonics at full load

Best PF at full load

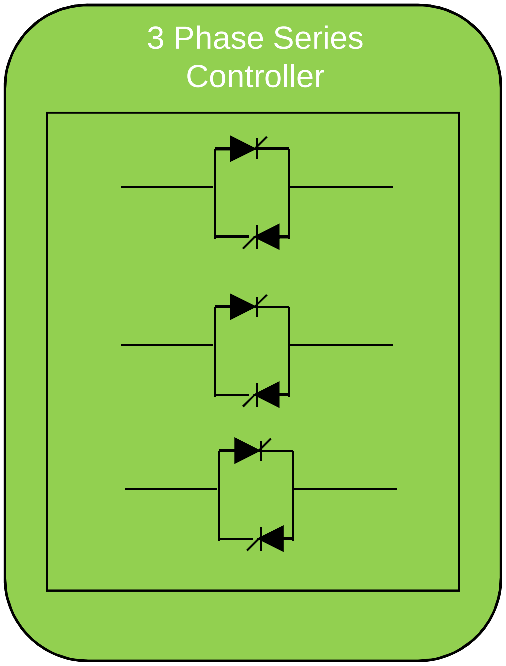
Harmful characteristic

Causes voltage notching (THDv)

> Requires input line reactors (inductance) to reduce notch depth

Notch created by a momentary short circuit when SCR commute from one phase to the other

Harmonics: Fundamentals



Transitions are short duration (2-3 seconds)
PF according to AC motor design

3 Phase controller (series)
Opposing (anti-parallel) thyristors per phase (not a rectifier)

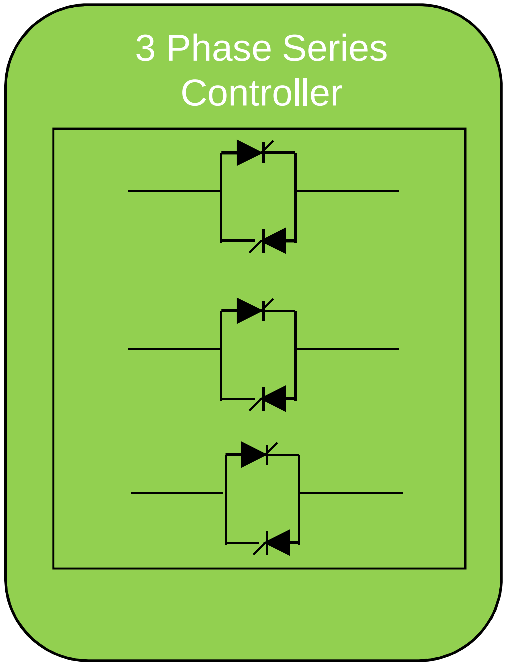
AC to **AC (variable volts)**
No harmonics at full output
PF is load dependent
i.e. AC Motor

Solid State Starters (SSS)
Transition harmonics only
During acceleration and deceleration

- Transition lagging PF
  - At full voltage – AC motor characteristics apply
  - Thyristors are full ON or Bypass contactor used to bypass

No snubbers (R-C) on thyristors

Harmonics: Fundamentals



Harmonics and PF increase and decrease together

Resistive & Inductive Heaters

Same thyristor configuration as SSS
Different use as compared to SSS

- Designed to control current through resistor banks or inductive coils to control heating
- ***High*** harmonics - except at full load
- ***Poor*** PF – except at full load

Harmonic Standards

IEEE 519-2014

Harmonic Standards

IEEE 519-2014

IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems

Harmonic voltage distortion limits are provided to reduce the potential negative effects on user and system equipment. Maintaining harmonic voltages below these levels necessitates that

- All users limit their harmonic current emissions to reasonable values determined in an equitable manner based on the inherent ownership stake each user has in the supply system and
- Each system owner or operator takes action to decrease voltage distortion levels by modifying the supply system impedance characteristics as necessary.

%TDD limits on users

%THDv limits on suppliers

Harmonic Standards

IEEE 519-2014

Note: THDi is not used in IEEE 519-2014

Harmonic distortion terms used

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.

total harmonic distortion (THD): 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 fundamental. Harmonic components of order greater than 50 may be included when necessary.

The recommended limits in this clause apply only at the point of common coupling and should not be applied to either individual pieces of equipment or at locations within a user's facility. In most cases, harmonic voltages and currents at these locations could be found to be significantly greater than the limits recommended at the PCC due to the lack of diversity, cancellation, and other phenomena that tend to reduce the combined effects of multiple harmonic sources to levels below their algebraic summation.

Harmonic Standards

IEEE 519-2014

Supplier standard for THDv

New category for <1.0 kV (applies at 480 & 600 VAC)

New voltage class

Table 1—Voltage distortion limits

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

Harmonic Standards

Limited to 50th order

IEEE 519-2014

USER standard for

TDD limits

Same as 519-1992

Table 2—Current distortion limits for systems rated 120 V through 69 kV

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., half-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 load current (fundamental frequency component) at the PCC under normal load operating conditions

TDD versus THD(I)

•TDD and THD(I) are not the same except at 100% load

Example: with AccuSine PCS+ operating

	Measured				
	Total I, rms	Fund I, rms	Harm I, rms	THD(I)	TDD
Full load →	936.68	936.00	35.57	3.8%	3.8%
	836.70	836.00	34.28	4.1%	3.7%
	767.68	767.00	32.21	4.2%	3.4%
	592.63	592.00	27.23	4.6%	2.9%
	424.53	424.00	21.20	5.0%	2.3%
	246.58	246.00	16.97	6.9%	1.8%
	111.80	111.00	13.32	12.0%	1.4%

As load decreases, TDD decreases while THD(I) increases.

How Harmonics Affect Capacitors:

Capacitors are naturally a <u>low impedance</u> to high frequencies:

- **Caps absorb harmonic in current**

As capacitor absorbs harmonic in current, the capacitor heats up

- **Reduced life expectancy**

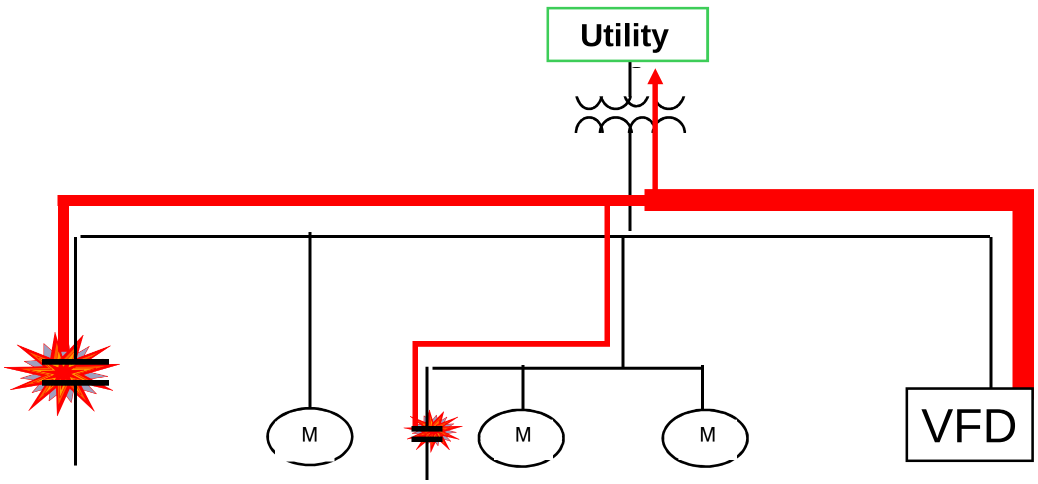
Voltage harmonics stress the capacitor dielectric

- **Reduced life expectancy**

Parallel combination of capacitors with motor or transformer can cause resonance.......

Capacitors Absorb Harmonic in current

The capacitor has lower impedance than the utility,
therefore it absorbs the harmonics

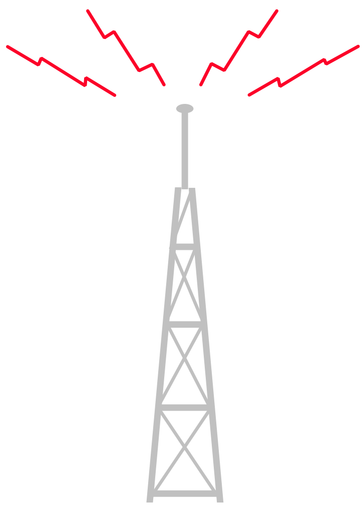


- capacitor diverts flow of harmonics
- Harmonic current increases
- capacitor absorbes harmonic current
- capacitor overheats & can fail over time

or worse......

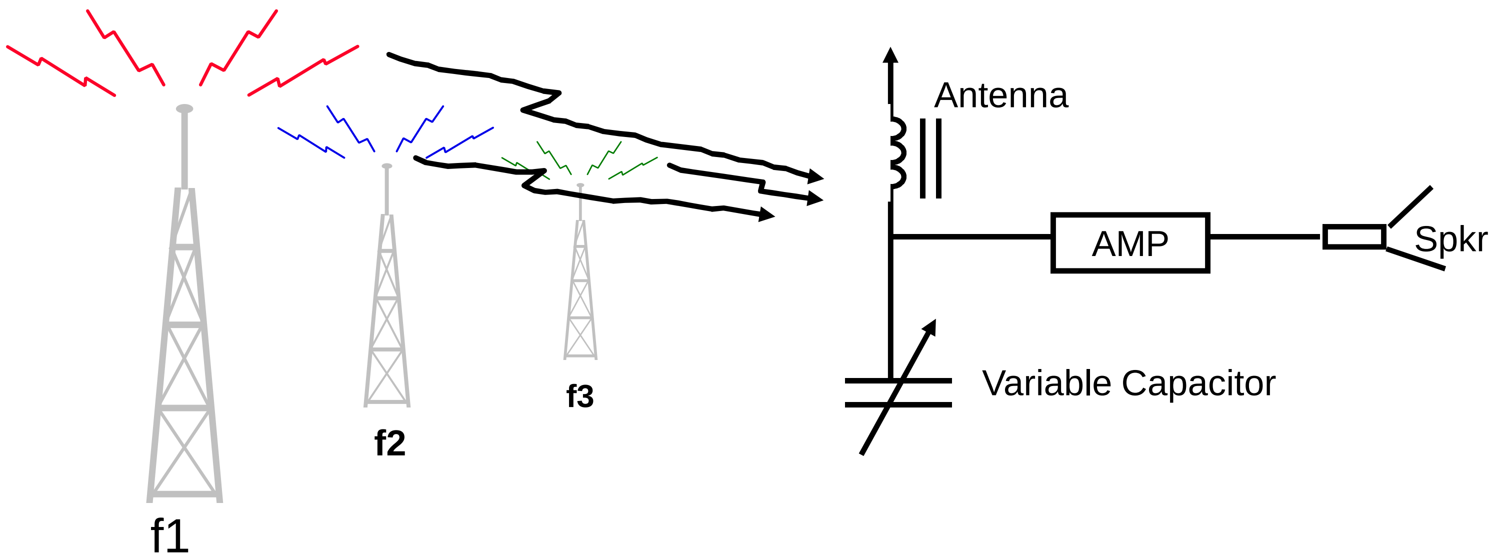
How Harmonics Affect Capacitors:

You use the principle of resonance every day!



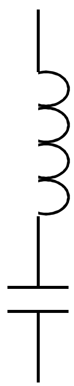
How Harmonics Affect Capacitors:

A Radio uses Resonance to Capture a Radio Station:



How Harmonics Affect Capacitors (Resonance)

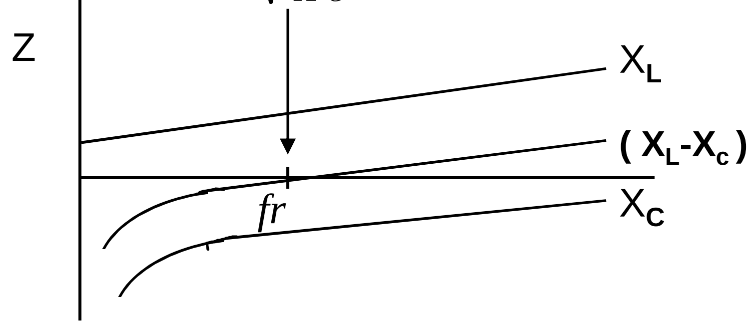
Resonance:



$$X_L = 2\pi fl$$

$$X_C = \frac{1}{2\pi fc}$$

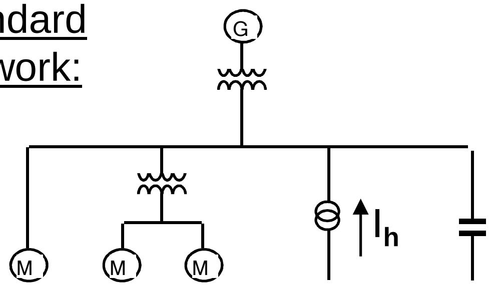
$$fr = f_1\sqrt{\frac{X_L}{X_C}}$$ ➡ Resonance



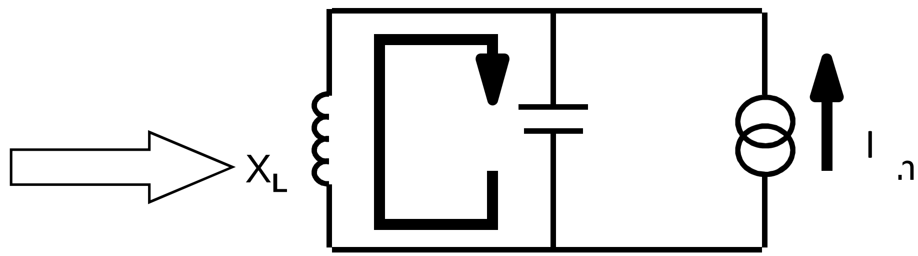
How Harmonics Affect Capacitors:

How Capacitors “Tune” a circuit:

Standard Network:



Equivalent circuit:



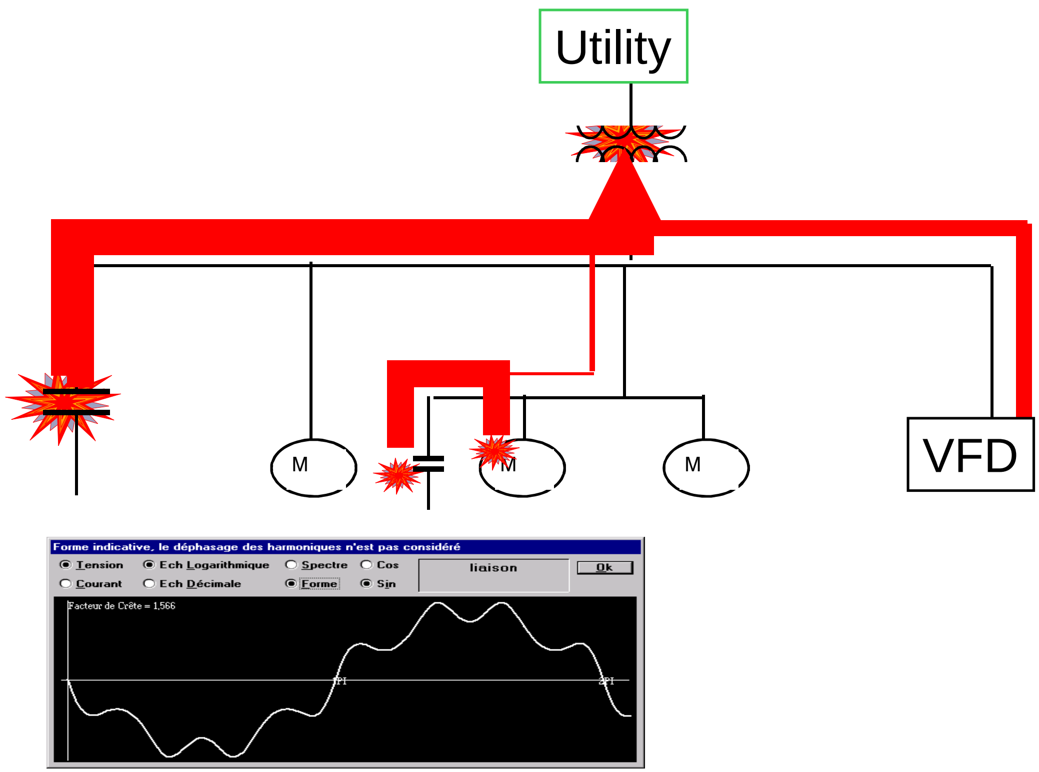
$$fr = 60 \times \sqrt{\frac{kVA \times 100}{kVAR \times Iz}}$$

e.g... 1500 kVA
225 kVAR
5.5% Iz

$$\therefore \; fr = 60 \times \sqrt{\frac{1500 \times 100}{225 \times 5.5}} = 660 \; hz = h_{11}$$

Parallel Resonance and harmonic magnification

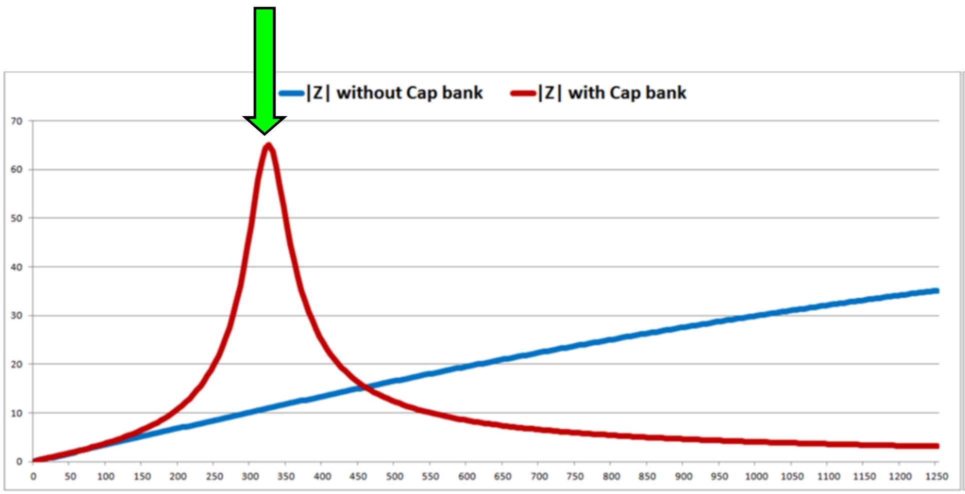
- **Resonance:**

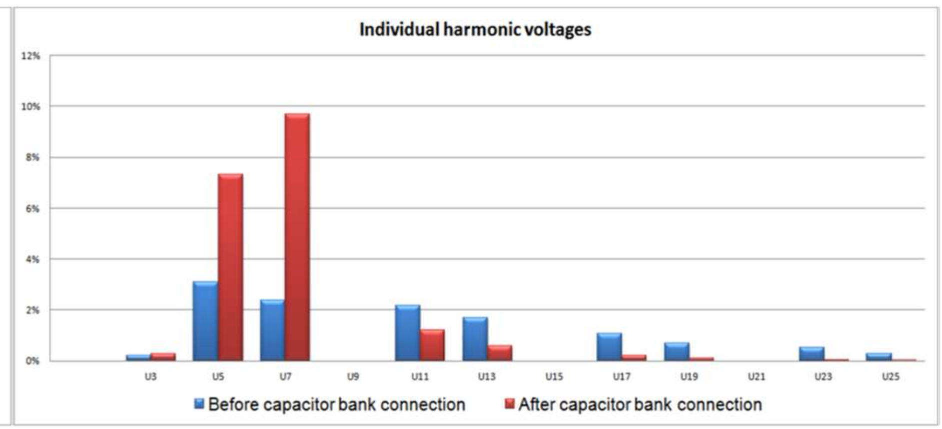


- **Amplification of current between capacitor and transformer**
- **Current distortion rises**
- **Voltage distortion rises**
- **Main transformer &/or capacitor fuses blow**
- **Equipment damage**

Parallel Resonance

Resonant Point likely to amplify dominant harmonic (typically 5th, 7th and 11th)

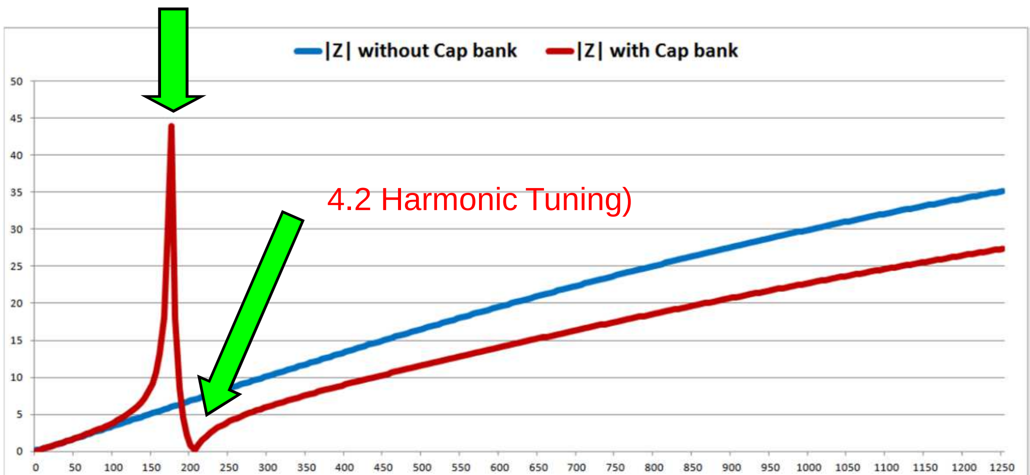


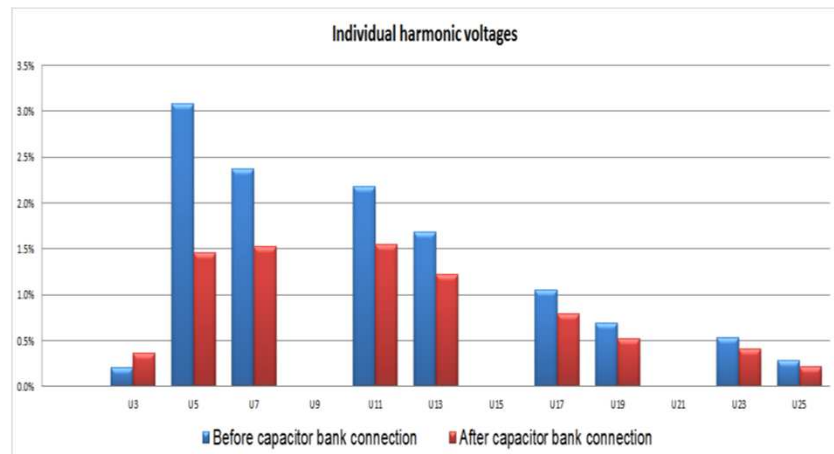


Magnification of Harmonic Current and Voltage when Standard Capacitor are Added to the Network

De-Tune to Avoid Resonance

Resonant Point where no Harmonic
Content present (3.7th typical)



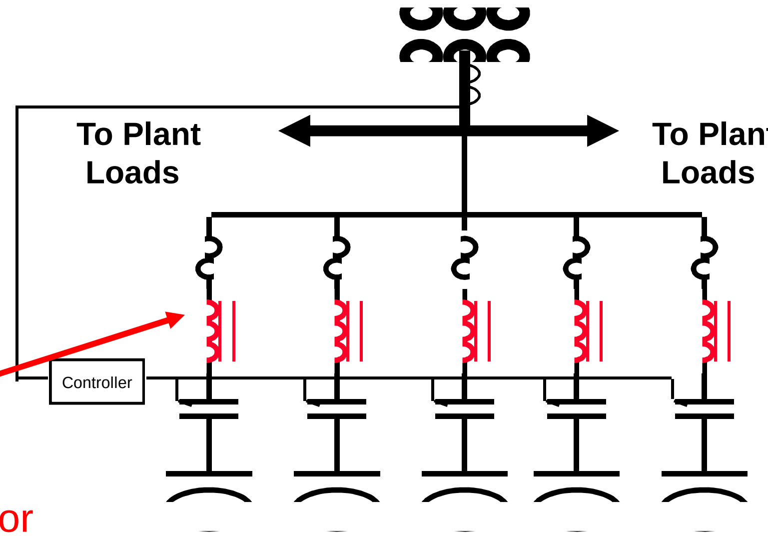


Effect on Harmonic Current and Voltage when De-Tuned Capacitor Bank
is Applied (AV6000 & AT6000)

Low Voltage Automatic Capacitor Bank with De-tuning reactors

De-Tuned (DR) automatic capacitor bank :

- Same as automatic capacitor bank with c/w De-Tuning reactors.
- Works like a standard automatic capacitor bank
- Avoid resonance between the capacitors and the supply transformer.

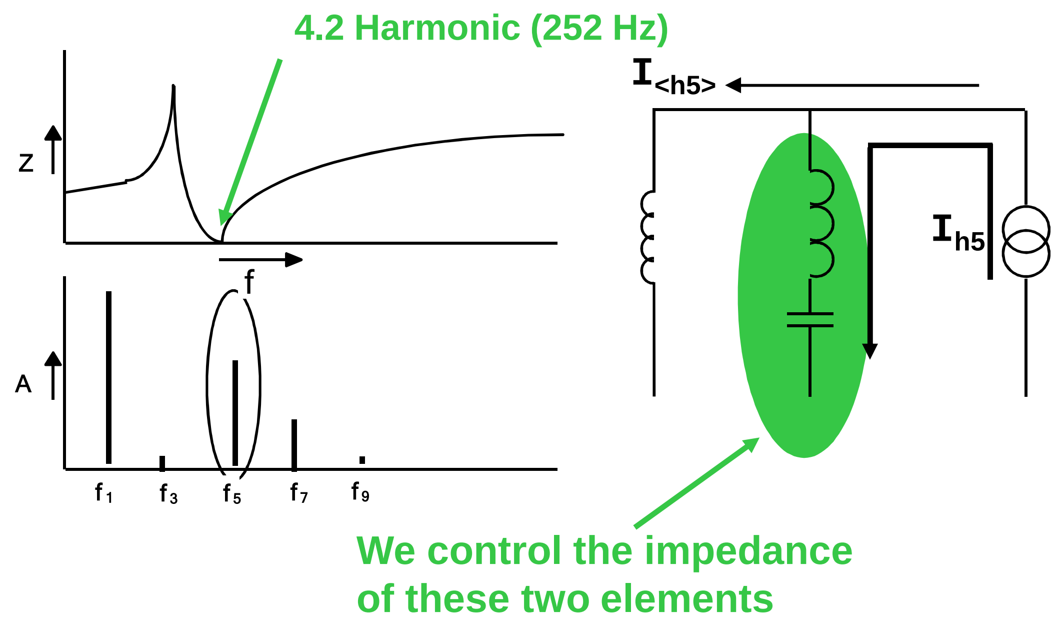


De-Tuning Reactor

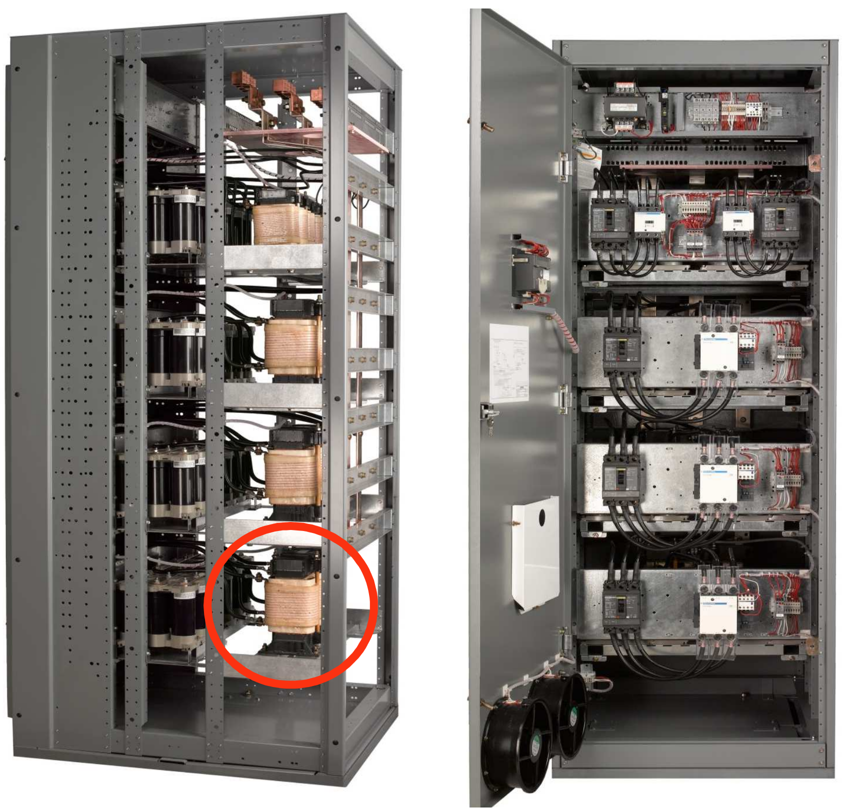
Power Factor Correction With Harmonics:

De-tuning a network:

- "Force" the resonant point away from naturally occurring harmonics



Low Voltage De-Tuned Automatic Capacitor Bank for Industries



Automatic capacitor bank NEMA 1, Indoor

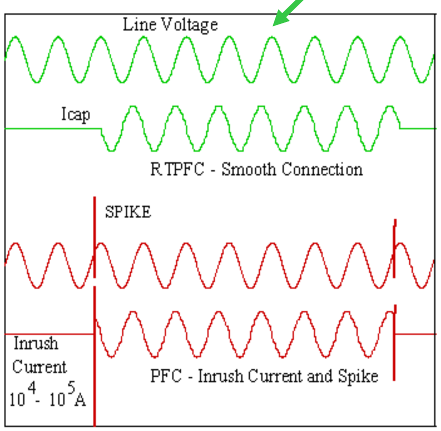
- **Standard Voltage, 208,240, 480 & 600 V, 50-60 Hz**
- **Free Standing, Main Lugs or Main Breaker incoming**
- **Up to 400 KVAR @ 480 or 600 V in each section, 1200 KVAR max in three sections**
- **Section dim: 30" W x 36"D x 90" H**
- **PFC relay, Advanced Microprocessor controller**
- **Stage Circuit Breaker used for overload and over current protection**
- **cCSAul Approved, Optimized air flow & dead front construction**
- **Contactors rated for capacitor switching**
- **Heavy Duty LV capacitor,certified as per UL810**
- **De-Tuning Reactors tuned to 252 Hz**

LV De-Tuned Automatic Capacitor Bank for commercial buildings and small industries

Automatic capacitor bank NEMA 1, Indoor

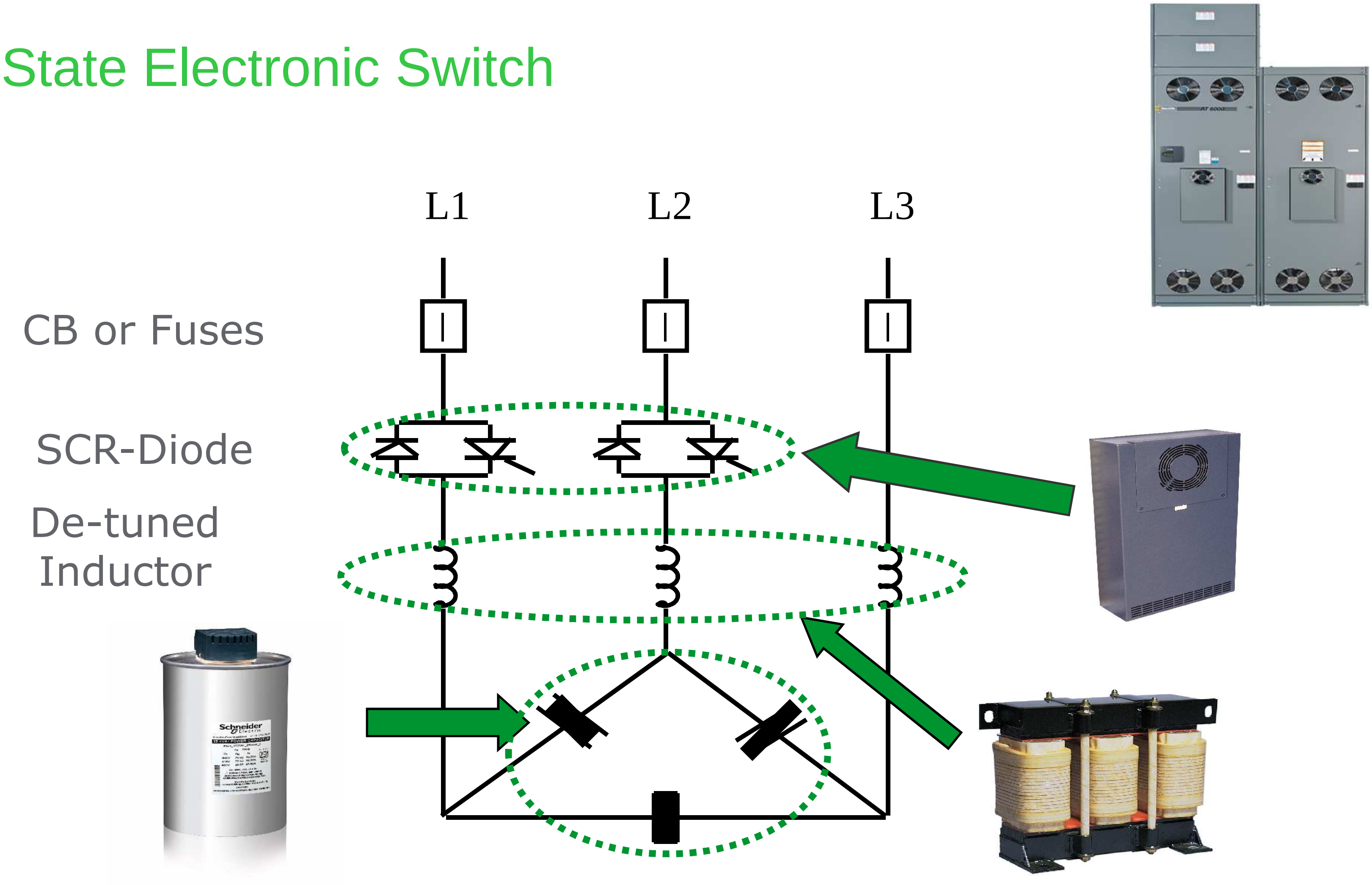
- **Standard Voltage, 480 & 600 V, 50-60 Hz**
- **Floor or Wall Mount, Main Lugs or Main Breaker incoming**
- **Up to 200 KVAR @ 480 or 600 V**
- **Enclosure size: 31.5” W x 16”D x 33.5” H**
- **PFC relay, Advanced Microprocessor controller**
- **Stage Circuit Breaker used for overload and over current protection**
- **cCSAul Approved, Optimized air flow & dead front construction**
- **Contactors rated for capacitor switching**
- **VarPLus Can Heavy Duty LV capacitor, certified as per UL810**
- **De-Tuning Reactors tuned to 252 Hz**

Transient Free Automatic Capacitor Banks

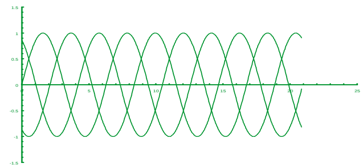


- **For sensitive networks**
- Similar to De-Tuned Capacitor Bank except it's equipped with solid state switching
- Transient Free switching
- Reactor tuned to 4.2 to 4.7
- Response time of less than 5 sec
- Up to 450kVAR per section
- Expandable up to 1350kVAR without split incoming
- Larger systems available with split incoming
- Additional cubicles can be field installed if required
- cCSAul Approved

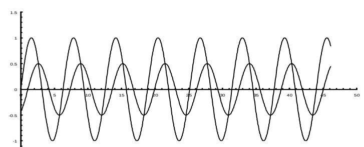
Solid State Electronic Switch



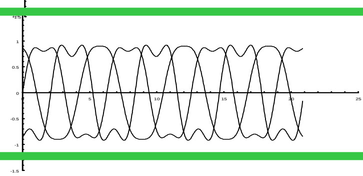
The ideal voltage supply does not exist, Active Harmonic Filters can correct 3 PQ problems



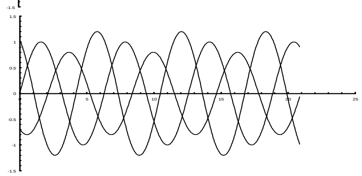
3-phase balanced



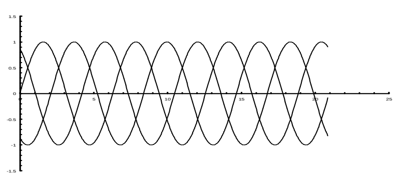
Power Factor



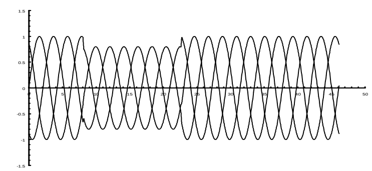
Harmonics



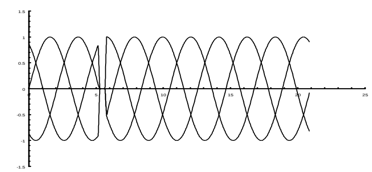
Phase unbalanced



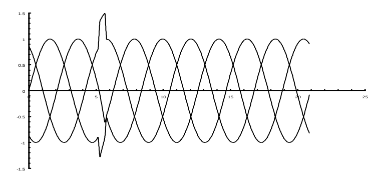
Blackout



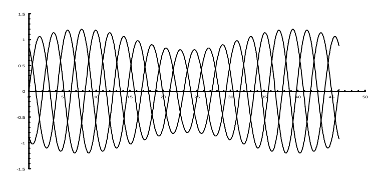
Sags/swells
Overvoltage



notches



Spikes

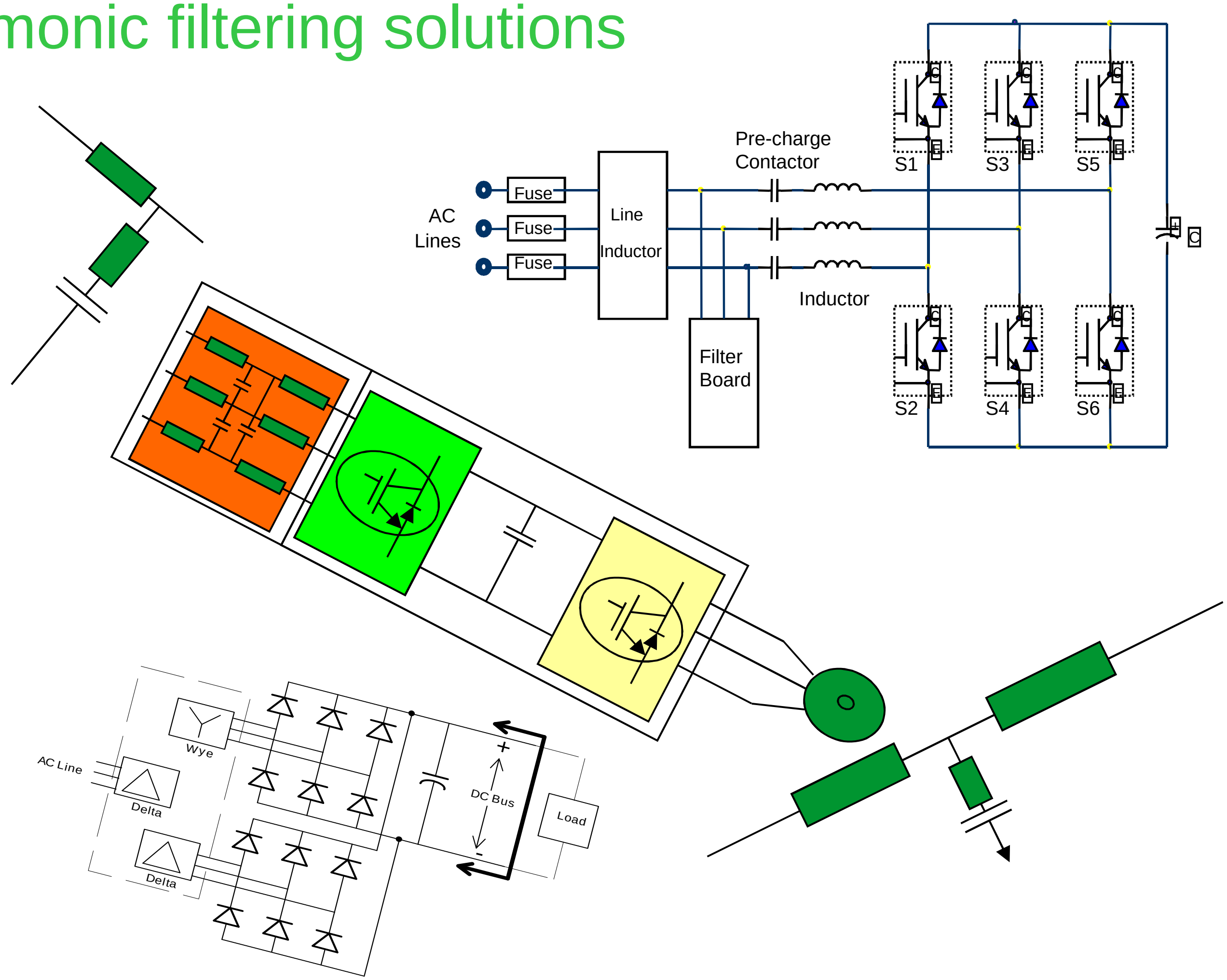


Flicker

Various type of harmonic filtering solutions

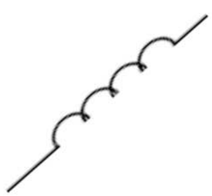
Applied per device

- Inductance
- 5th harmonic trap filters
- Broadband filters
- Multi-pulsing
- Active Front End converter

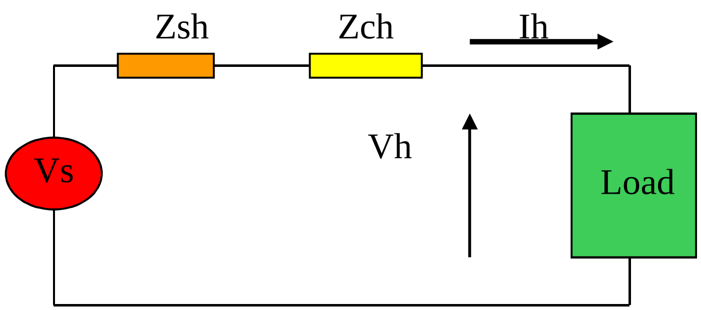


Applied per system

- Active harmonic filter(AHF)



Harmonics: Fundamentals



Vh = Harmonic voltage

Ih = Harmonic current

Zsh = Source impedance for harmonic current

Zch = Cable impedance for harmonic current

Vh = Ih * (Zsh + Zch)

Harmonic voltages (Vn):

- Develop as the harmonic current traverses the electrical system.
- Each harmonic order has its own system impedance (Zn) and thus develops its own harmonic voltage.
- The root-mean-square (rms) of all harmonic orders equals the total amplitude of harmonic current or voltage.
- Ohm's Law applies: Vn = In * Zn
- To reduce Vh: Reduce system impedance (Zsh & Zch) or reduce current (Ih)

Inductors/Transformers/DC Bus Chokes

Description:

Converter-applied inductors or isolation transformers.

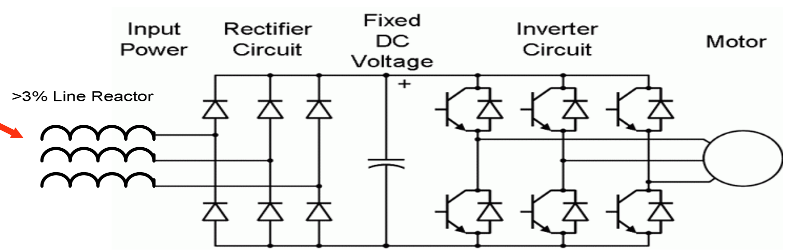
Pros:

- Inexpensive & reliable
- Transient protection for loads
- 1st Z yields big TDD reduction (90% to 35% with 3% Z)
- Complimentary to active harmonic control

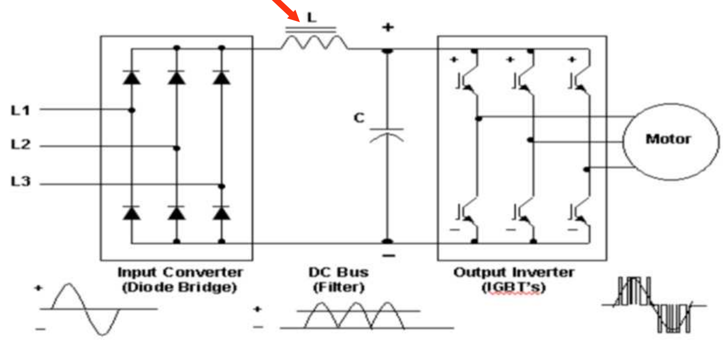
Cons:

- Limited reduction of TDD at equipment terminals after 1st Z
- Reduction dependent on source Z

3% line reactor

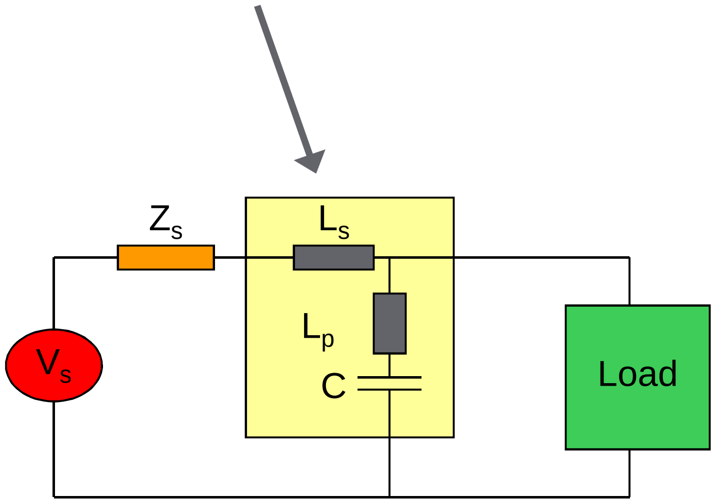


5% DC bus choke



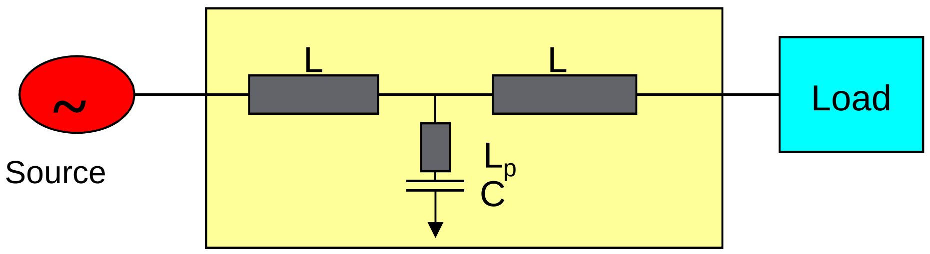
5th Harmonic Filter (Trap Filter)

- Inductor (L_p) and Capacitor (C) provide low impedance source for a single frequency (5^{th})
  - Must add more tuned filters to filter more frequencies
- Inductor L_s required to detune filter from electrical system and other filters
  - If L_s not present, filter is sink for all 5^{th} harmonics in system, that can result in overlaod.
  - If L_s not present, resonance with other tuned filters possible
- Injects leading reactive current **(KVAR) at all times** – may create leading PF and/or issues with back up generator



Broadband Filters

- Mitigates up to 13th order or higher
- Each inductor (L) > 8% impedance
    - V drops ~ 16% at load
    - Trapezoidal voltage to load
        - Can only be used on diode converters
    - Prevents fast current changes (only good for centrifugal loads)
    - When generators are present, re-tuning may be required
- Capacitor (C) designed to boost V at load to proper level (injects leading VARs)
- Physically large
- High heat losses (>5%)
- Series device



Multi-Pulse Drives

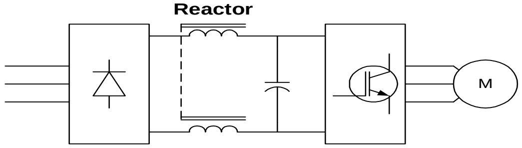
Description: Drives/UPS with two (12 pulse) or three (18 pulse) input bridges fed by a transformer with two or three phase shifted output windings.

- Pros:
  - Reduces TDD to **10% (12 pulse)** & **5% (18 pulse)** at loads
  - Reliable
- Cons:
  - High installation cost with external transformer
  - Large footprint (even w/autotransformer)
  - Series solution with reduction in efficiency
  - One required for each product
  - Cannot retrofit

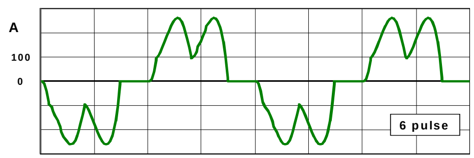
Harmonic mitigation methods

VFD mitigation topologies

6-Pulse converter

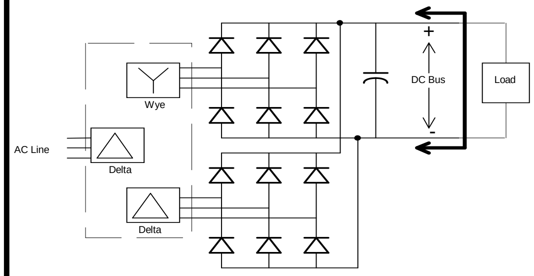


"C-less" or 3% reactance min (if included); small footprint, simplified cabling



Current waveform distorted
TDD 30% to 40% with 3% reactor (depending on network impedance)

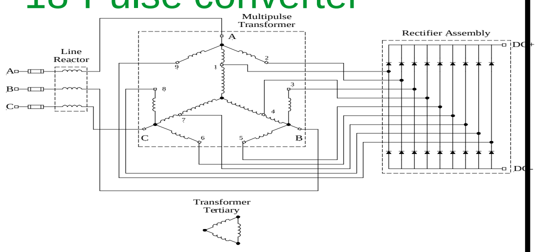
12-Pulse converter



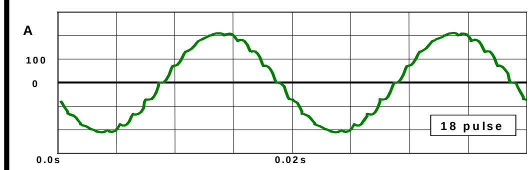
Externally mounted 3 winding transformer; more wire and cabling; complicated

Current slightly distorted
TDD 8% to 15% (depending on network impedance)

18-Pulse converter



Large footprint, more steel & copper (losses)



Current wave form good
TDD 5% to 7% (depending on network impedance)

Active Front End (AFE) Converters

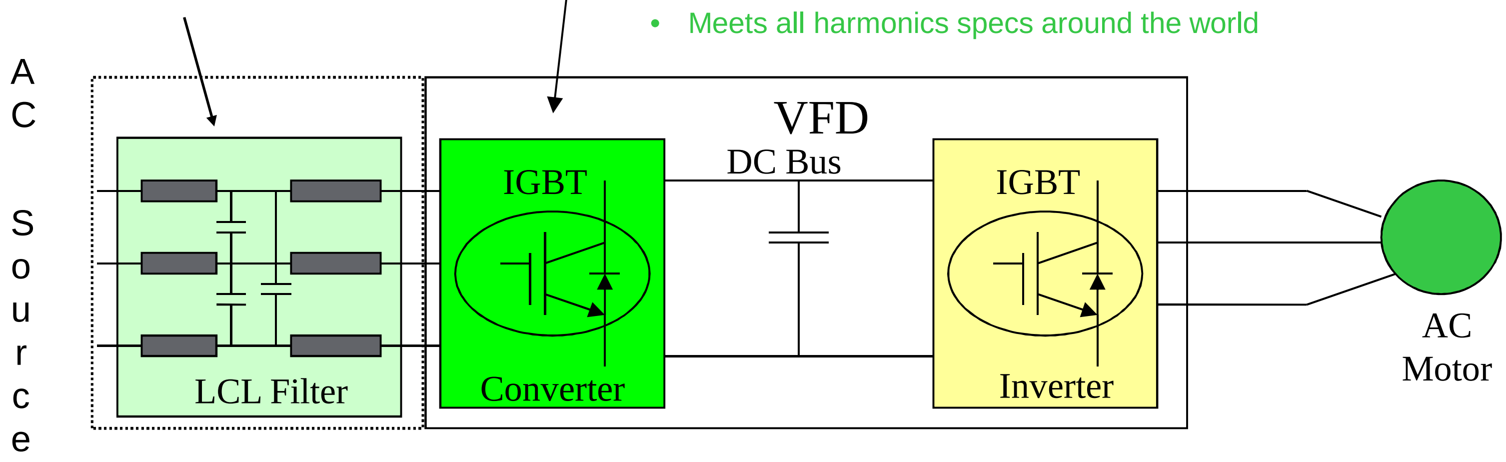
Used in UPS and VFD

Replaces diode converter with IGBT converter

Pros

- Permits current smoothing on **AC lines (< 5% TDD)**
- Permits 4-quadrant operation of VFD
- Maintains unity TOTAL PF
- Meets all harmonics specs around the world

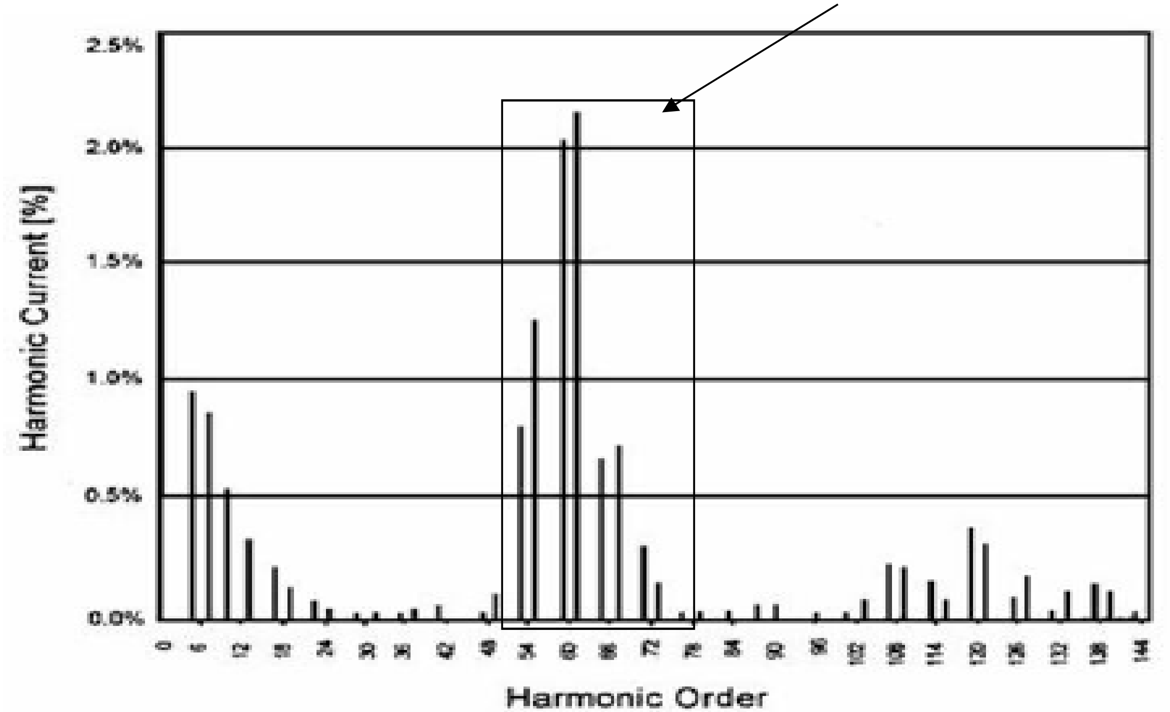
Input Filter
Required to limit
THDv to <5%



AFE Converters

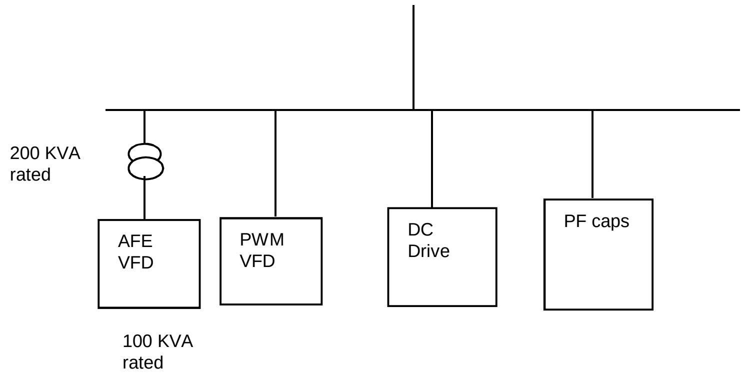
American Bureau of Shipping (ABS) requires examination to 100th order when AFE applied

Significant harmonics above 50th order



Higher frequencies yield higher heating of current path & potential resonance with capacitors

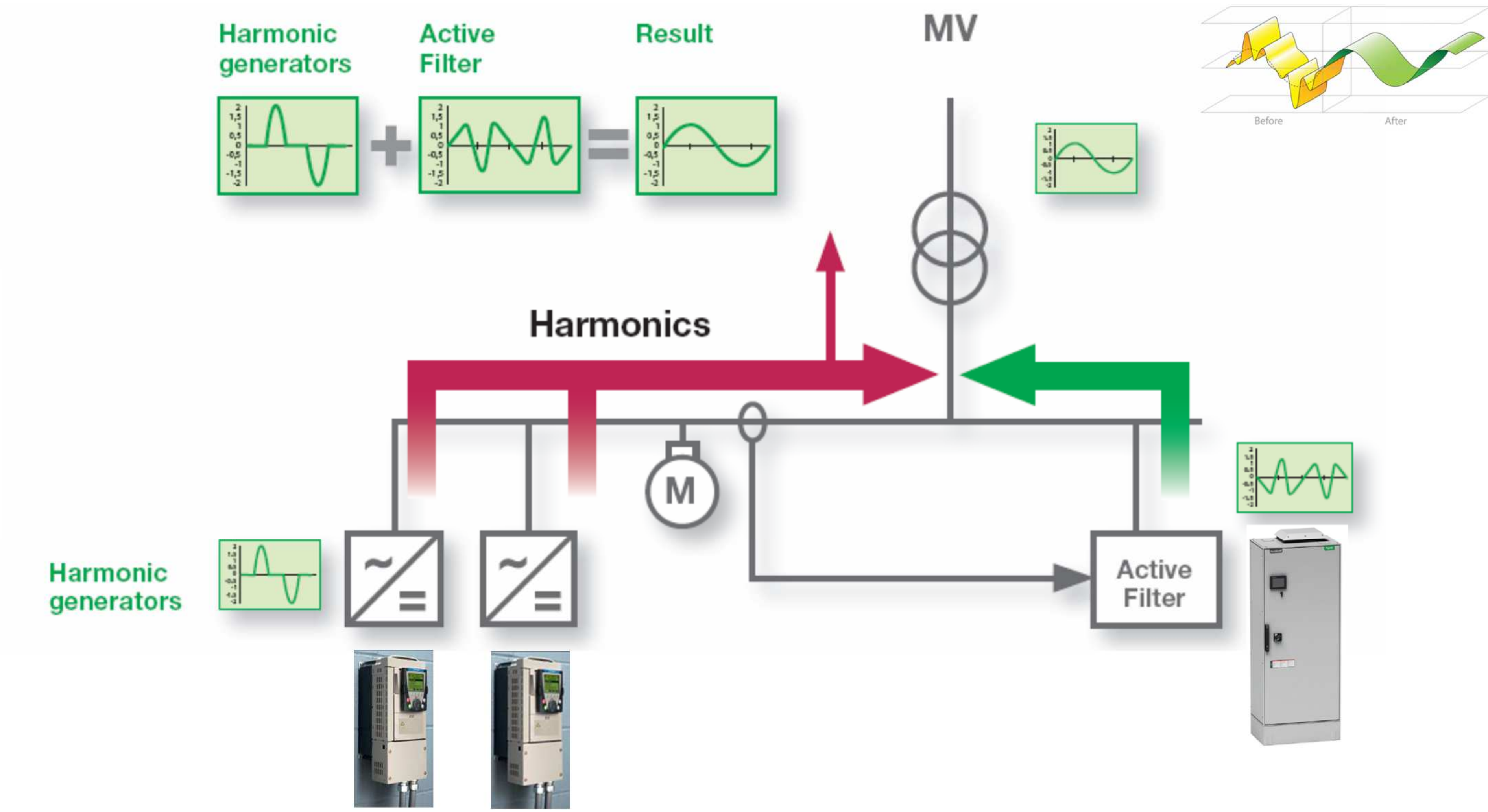
AFE Converters



Cons

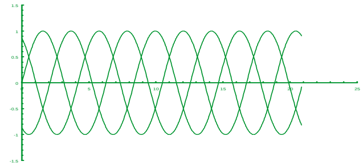
- Larger and more expensive than 6 pulse drives
  - Approximately twice the size & price
- Mains voltage must be free of imbalance and voltage harmonics
  - Generates more harmonics
- Without mains filter THD(V) can reach 40%
- Requires short circuit ratio ≥ 40 at PCC
- Switched mode power supplies prohibited
- Capacitors prohibited on mains
- IGBT & SCR rectifiers prohibited on same mains
  - No other nonlinear loads permitted

Active Harmonic Filter

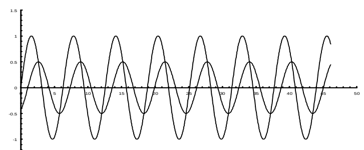


Harmonic generators
Active Filter
Result
MV
Before
After
Harmonics
M
Harmonic generators
Active Filter

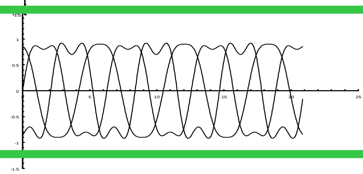
The ideal voltage supply does not exist, some AHF can correct 3 PQ problems



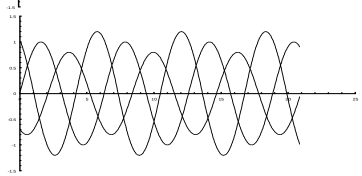
3-phase balanced



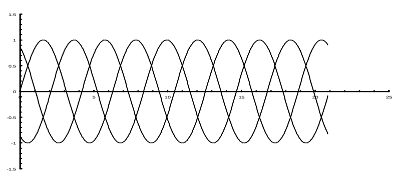
Power Factor



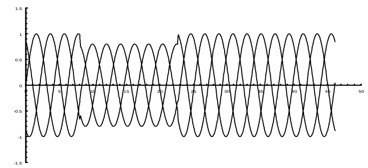
Harmonics



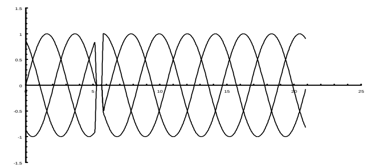
Phase unbalanced



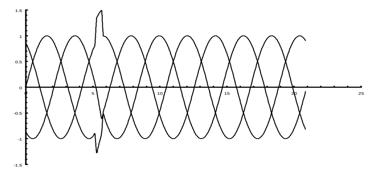
Blackout



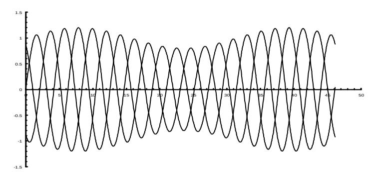
Sags/swells
Overvoltage



notches



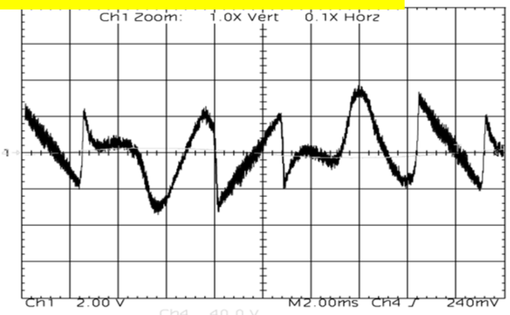
Spikes



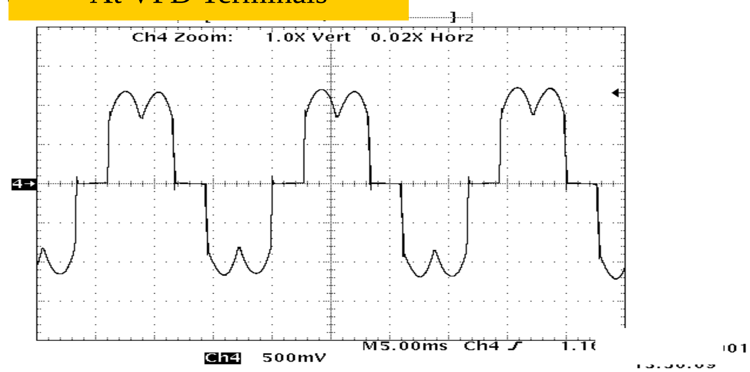
Flicker

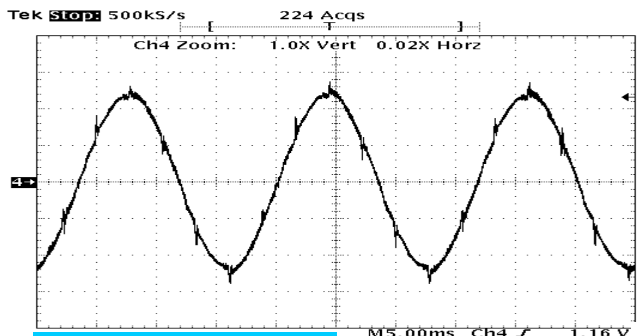
Harmonic Mitigation with AHF

AccuSine injection



At VFD Terminals

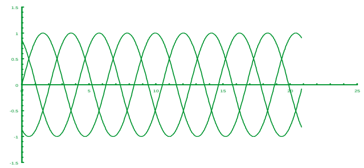




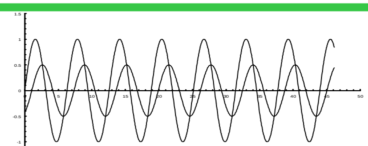
Source current

	OFF	ON
Order	% I fund	% I fund
Fund	100.000%	100.000%
3	0.038%	0.478%
5	31.660%	0.674%
7	11.480%	0.679%
9	0.435%	0.297%
11	7.068%	0.710%
13	4.267%	0.521%
15	0.367%	0.052%
17	3.438%	0.464%
19	2.904%	0.639%
21	0.284%	0.263%
23	2.042%	0.409%
25	2.177%	0.489%
27	0.293%	0.170%
29	1.238%	0.397%
31	1.740%	0.243%
33	0.261%	0.325%
35	0.800%	0.279%
37	1.420%	0.815%
39	0.282%	0.240%
41	0.588%	0.120%
43	1.281%	0.337%
45	0.259%	0.347%
47	0.427%	0.769%
49	1.348%	0.590%
% THD(I)	35.28%	2.67%

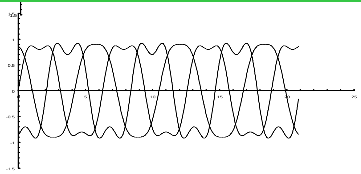
The ideal voltage supply does not exist, Active Harmonic Filters can correct 3 PQ problems



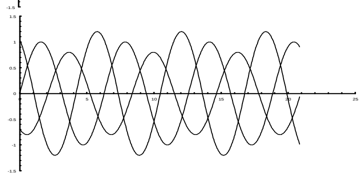
3-phase balanced



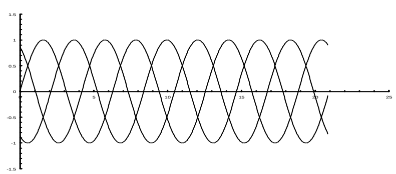
Power Factor



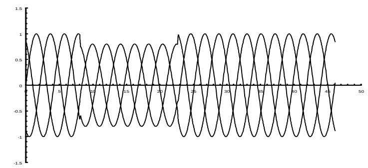
Harmonics



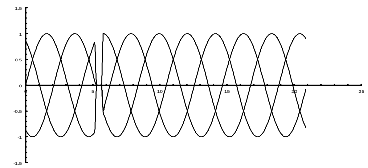
Phase unbalanced



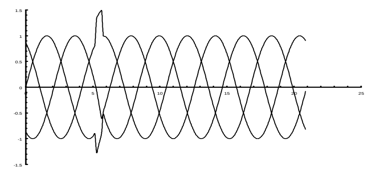
Blackout



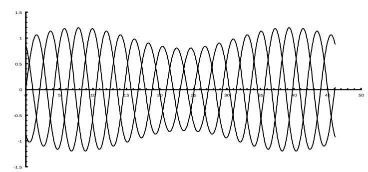
Sags/swells
Overvoltage



notches



Spikes

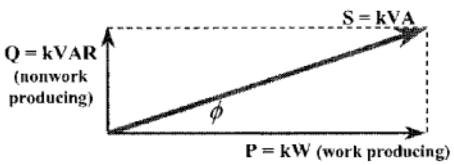


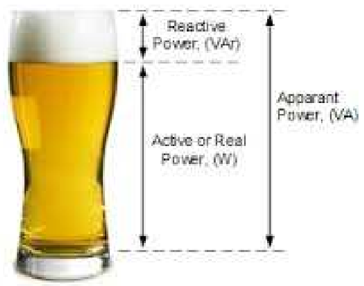
Flicker

"Evolution" of Power Factors

With linear vs. nonlinear loads

Electrical system with ONLY linear loads

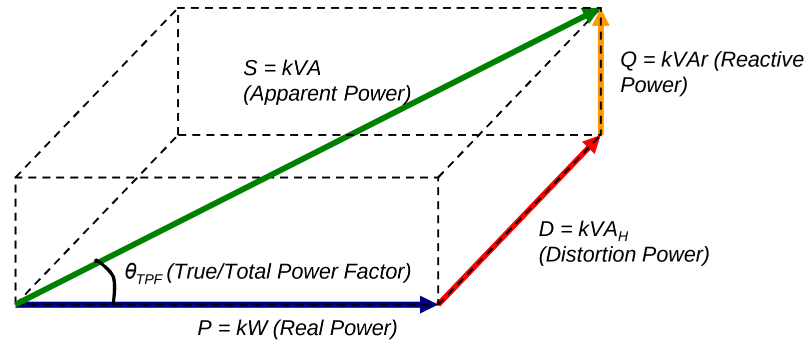




$$S(kVA) = \sqrt{P^2 + Q^2} = \sqrt{kW^2 + kVAr^2}$$

$$\text{power factor, } \cos\phi = \frac{P}{S} = \frac{kW}{kVA}$$

Electrical system with Nonlinear loads



$$S(kVA) = V_{rms} I_{rms} = \sqrt{P^2 + Q^2 + D^2}$$

True/Total Power Factor : $\cos\theta_{TPF} = \cos\theta_{dispPF} \cdot \cos\theta_{distPF}$

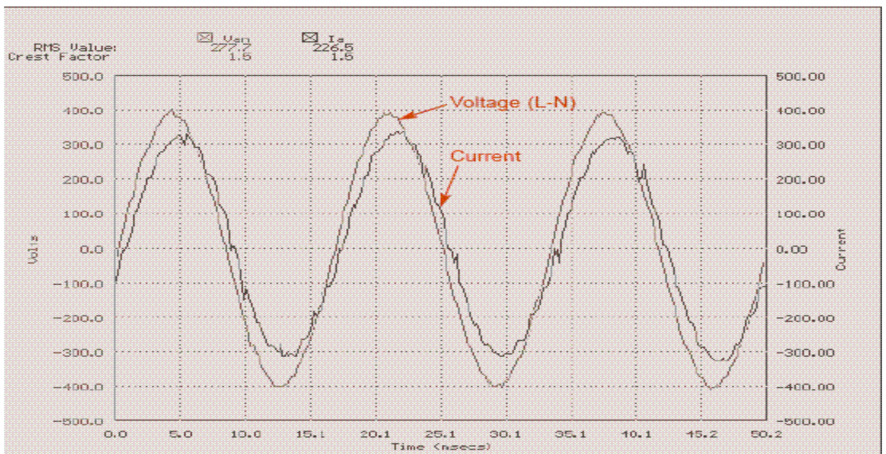
Displacement Power Factor (Fundamental Components): $\cos\theta_{dispPF} = \frac{kW}{kVA(fundamental)}$

Distortion Power Factor (Harmonic Components): $\cos\theta_{distPF} = \frac{1}{\sqrt{1+THD_v^2}\sqrt{1+THD_i^2}}$

Active Harmonic Filter
PF correction

When PF mode is activated

- Assign priority to Harmonic or **PF (fundamental) modes.**
- **AccuSine injects fundamental current (60 Hz) to correct the Power Factor.**



$$I_{as} = \sqrt{I_h^{\ 2} + I_f^{\ 2}}$$

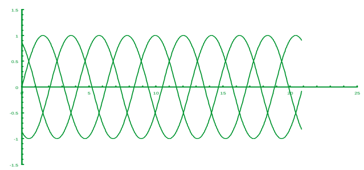
I_{as} = rms output current of AccuSine PCS

I_h = rms harmonic current

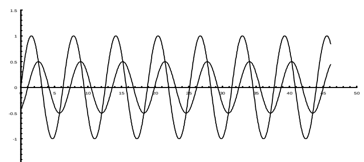
I_f = rms fundamental current

Examples		
I_{as}	**I_h**	**I_f**
100.0	10.0	99.5
100.0	20.0	98.0
100.0	30.0	95.4
100.0	40.0	91.7
100.0	50.0	86.6
100.0	60.0	80.0
100.0	70.0	71.4
100.0	80.0	60.0
100.0	90.0	43.6
100.0	95.0	31.2

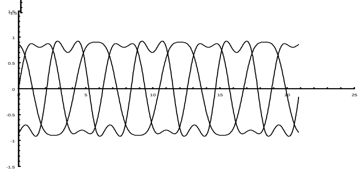
The ideal voltage supply does not exist, some AHF can correct 3 PQ problems



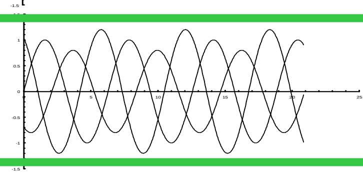
3-phase balanced



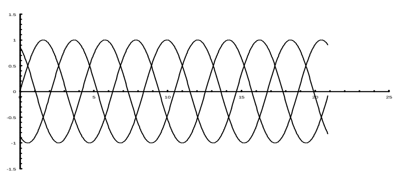
Power Factor



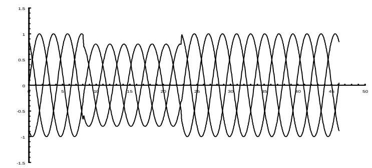
Harmonics



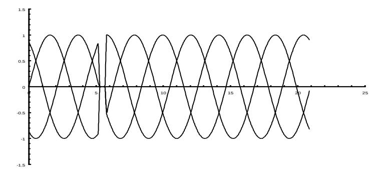
Phase unbalanced



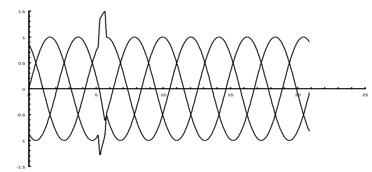
Blackout



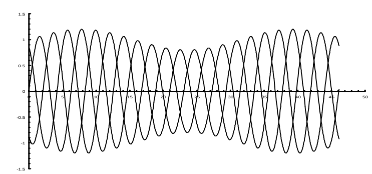
Sags/swells
Overvoltage



notches



Spikes

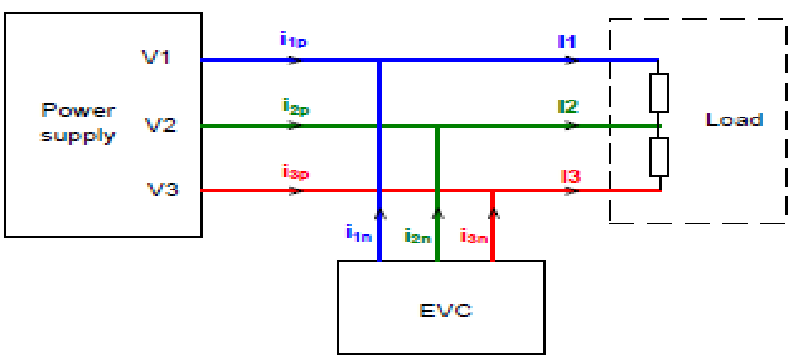


Flicker

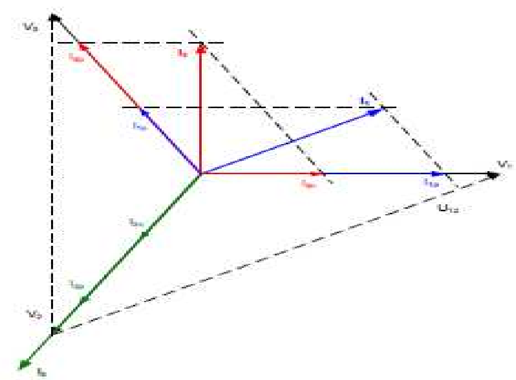
Load Balancing with some Active Harmonic Filter

Principle of load balancing

The principle of load current balancing is to inject a system of negative sequence current into the circuit (i_{1n}, i_{2n}, i_{3n}), so that only the system of positive sequence current (i_{1p}, i_{2p}, i_{3p}) has to be generated by the power supply.



Vector construction of positive and negative sequence systems:

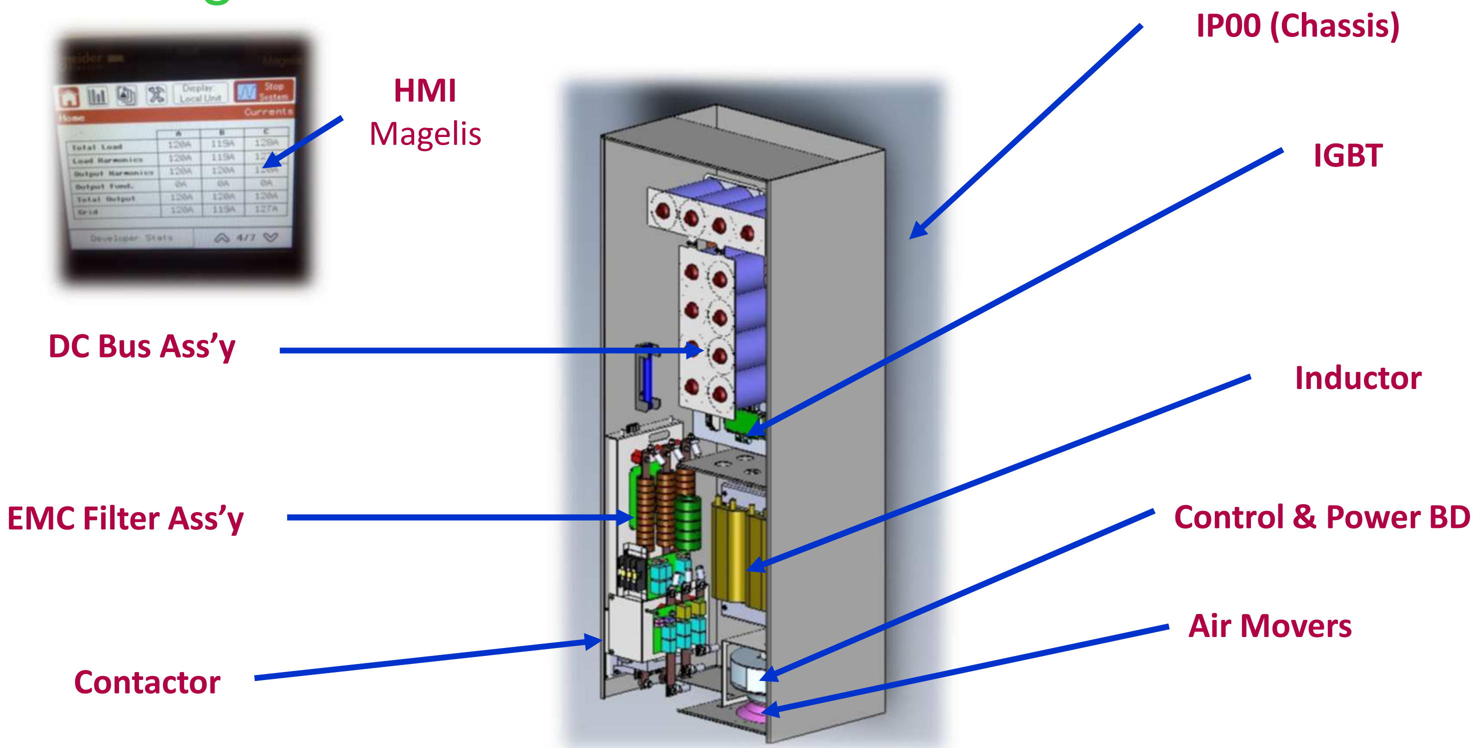


Example of Active Harmonic Filter ratings & performance

AHF ratings:

- Dynamic Harmonic mitigation form the 2nd to the 51st harmonic order
- Can meet a THD(I) of 3%, THD(V) and THD(I) target set point
- Standard Voltage, 208,240, 480, 600 and 690 V, 50-60 Hz
- Wall Mount or Free Standing, Main Lugs or Main Breaker incoming
- 60, 120, 200 and 300 A @ 480 V or 47, 94, 157 and 235 A @ 600 V per cubicle
- Enclosure type: NEMA 1, NEMA 2 and NEMA 12
- 3 levels IGBT design with optimized losses
- Closed loop c/w FFT digital logic
- 2 cycle response time for harmonic correction and ¼ of a cycle for reactive power injection
- cULus and CE certified
- And much more…

Technical Structure of Active Harmonic Filter, based on Schneider design



Technical Structure of Active Harmonic Filter, based on Schneider design

Customer Connections

Modbus RTU Port*

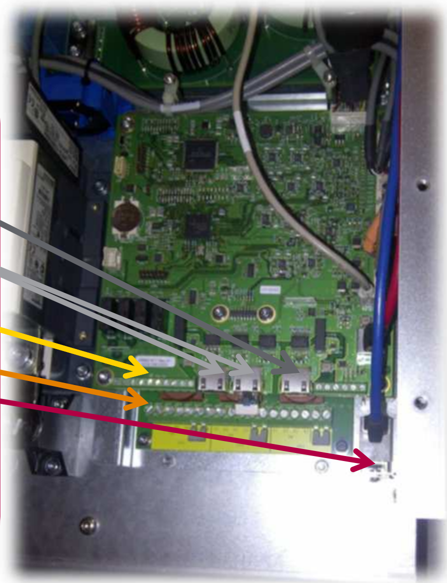
Parallel COM Ports*

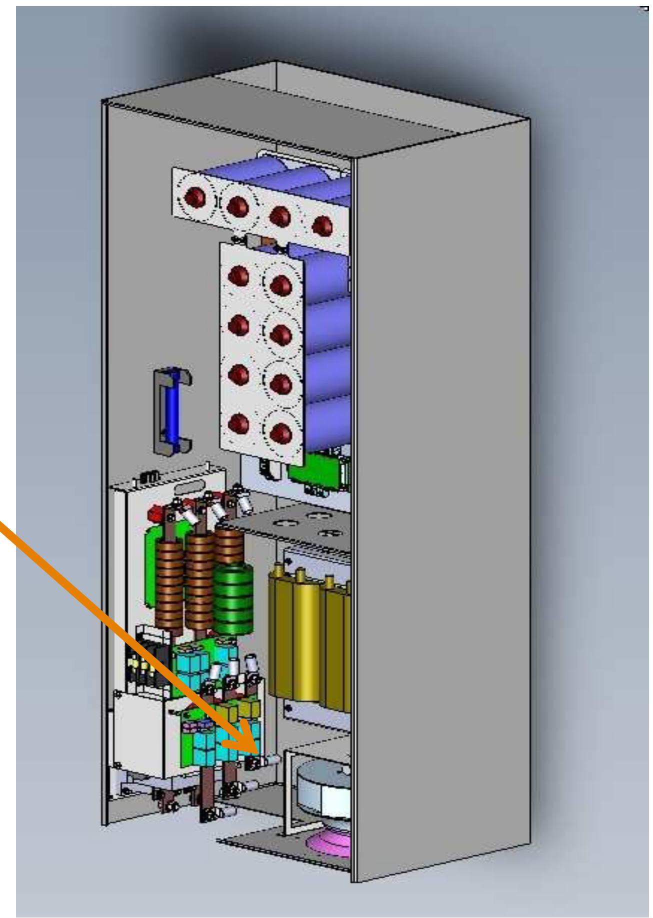
I/O dry terminals

CT connections

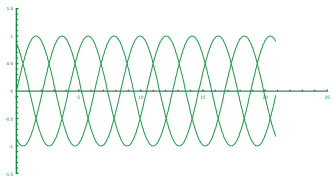
Modbus TCP/IP Port*

*Ports are RJ45 type

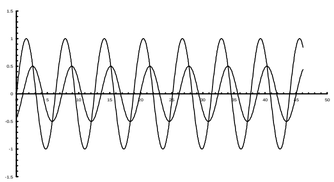




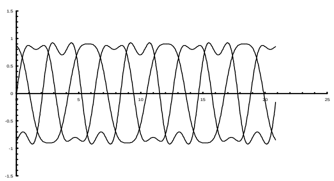
The ideal voltage supply does not exist



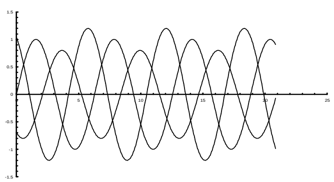
3-phase balanced



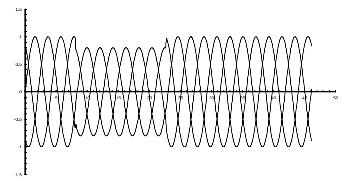
Power Factor



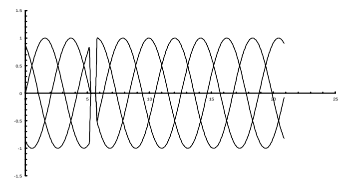
Harmonics



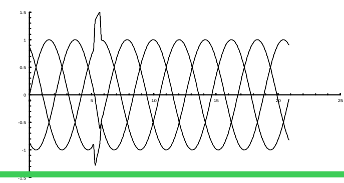
Phase unbalanced



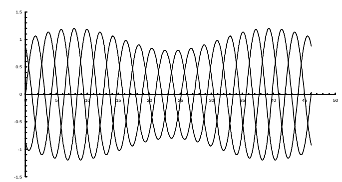
Sags/swells Overvoltage



Notches



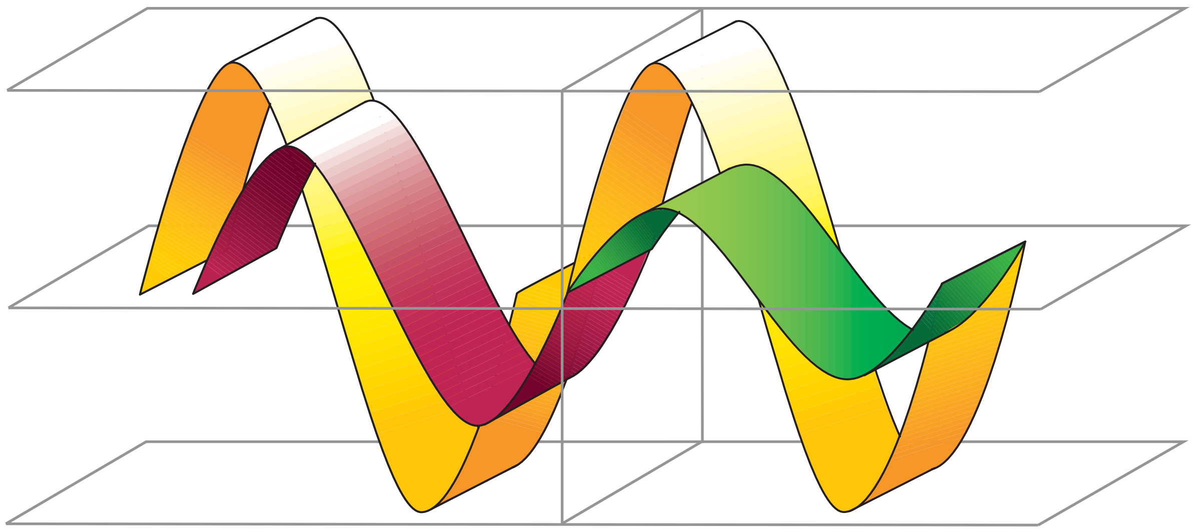
Spikes



Flicker

Introduction to Hybrid Var Compensator (HVC)

HVC is a solution for flicker compensation



Flicker Producing Loads

Ball Mill
(Rock Crushers)

Spot welder

Steel Shredder

- Large motors starting
- Hoist
- Rubber batch mixer
- Linear Induction Motor
- …

Results in equipment faulting
Results in flicker (medical issues)

Hybrid Var Compensator (HVC)

Real Time VAR injection for voltage regulation and flicker control.

- **Available in Low and Medium Voltage**
- **High Speed Response, 5 milli seconds response time**
- **Infinite Variability**
- **Full Duration**
- **Can maintain Unity Power Factor**

HVC Approach

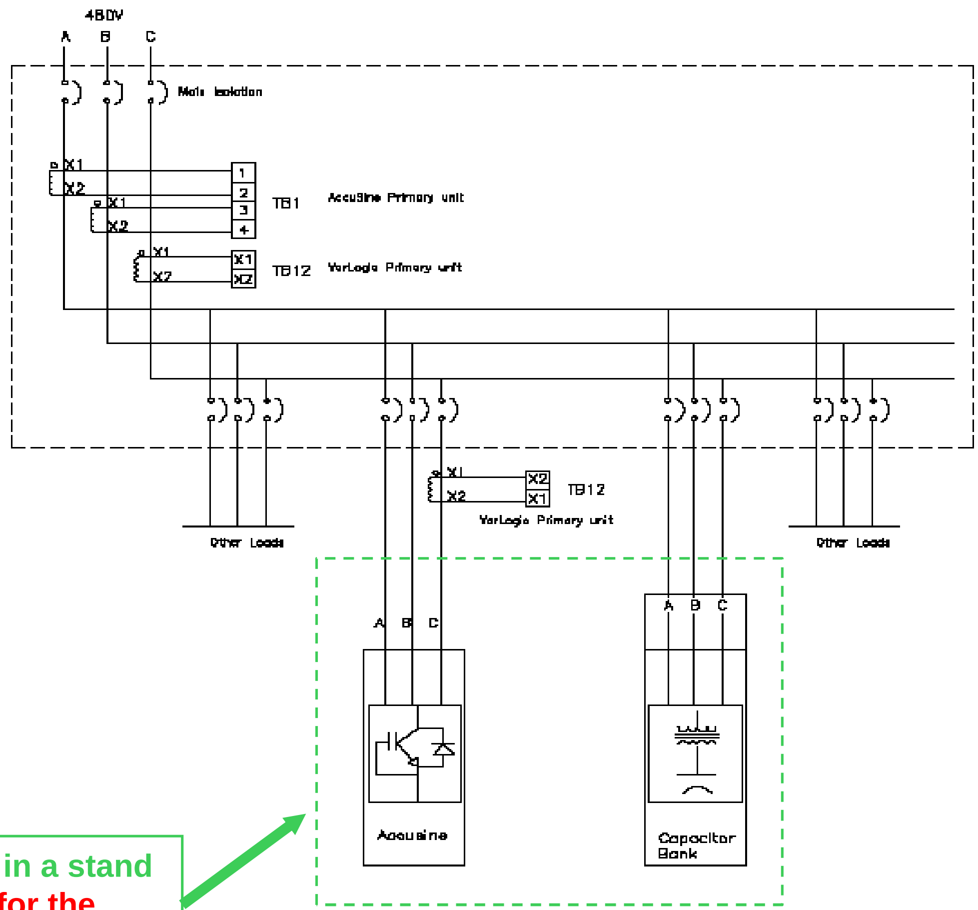
Use fix or automatic capacitor bank

for inrush support

- **Always on line**
- **Instant response**

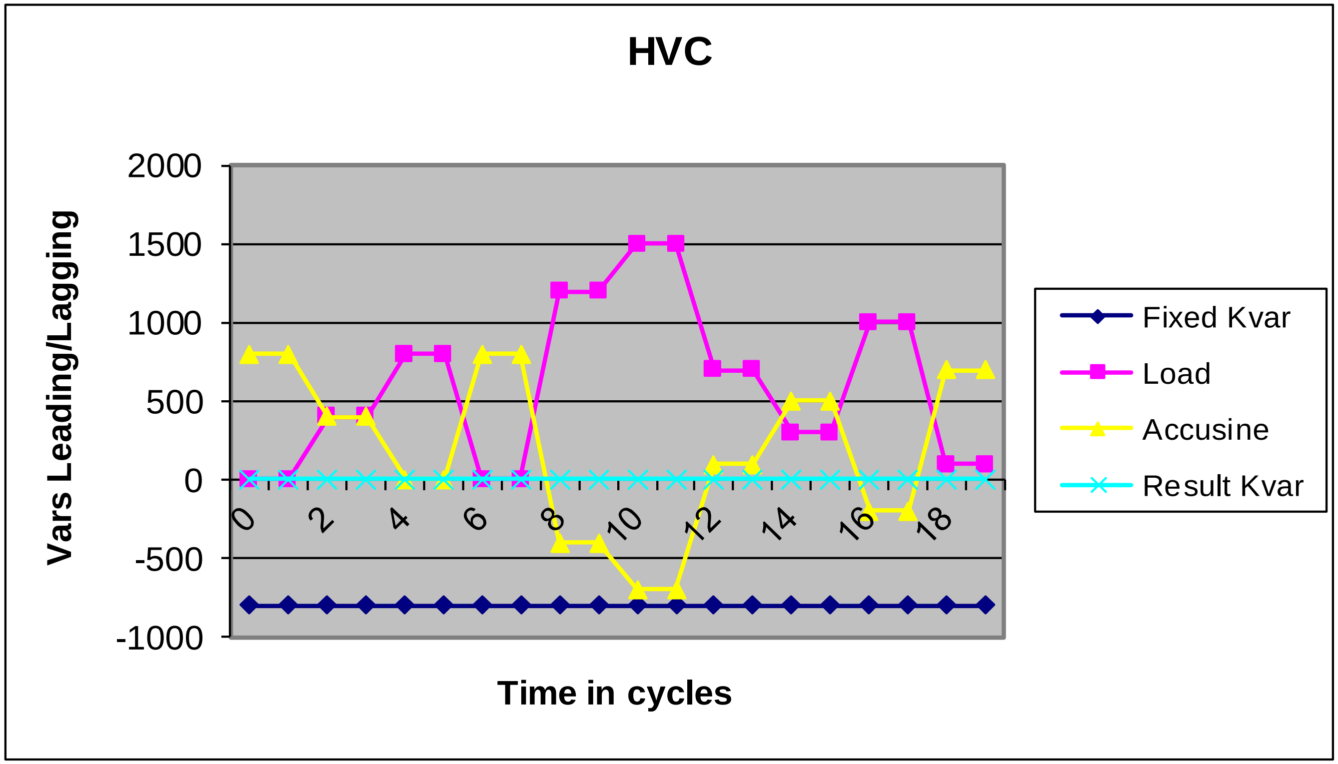
Use AccuSine PFV+ for fine tuning

- **Injects leading or lagging VARs**
- **Cancels fix caps leading VARs at no load**
- **Adds leading VARs as loads increase**
- **5 ms response time**



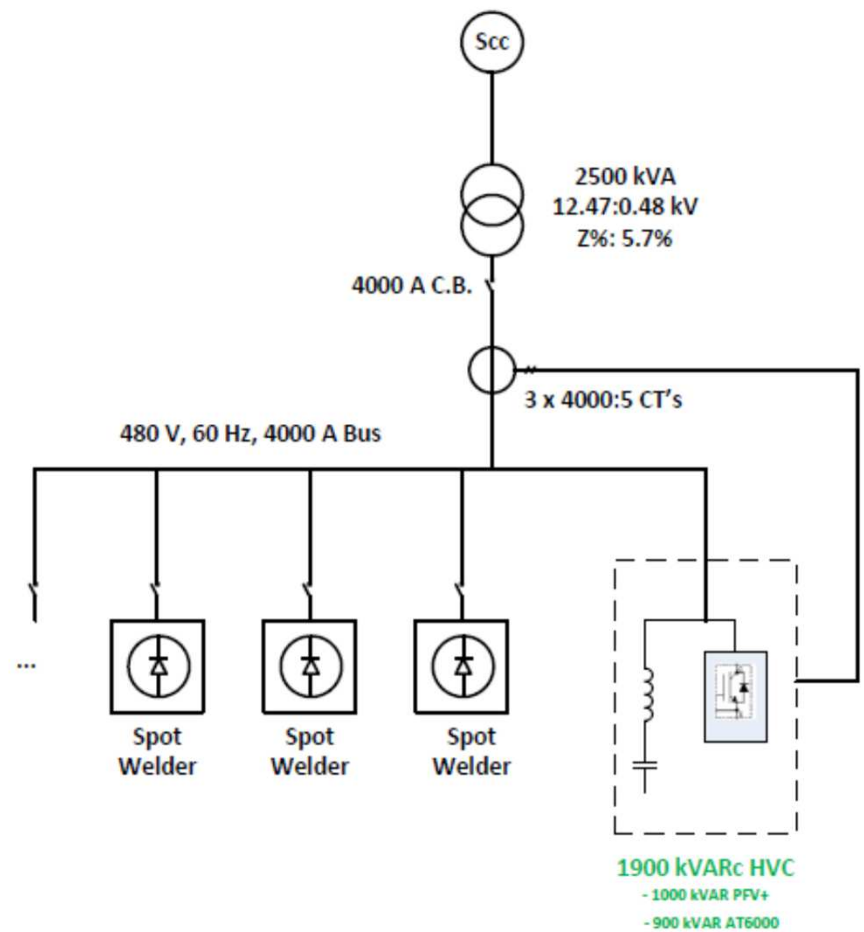
HVC in one enclosure or in a stand alone cubicle. Designed for the customer's site requirement.

HVC Concept

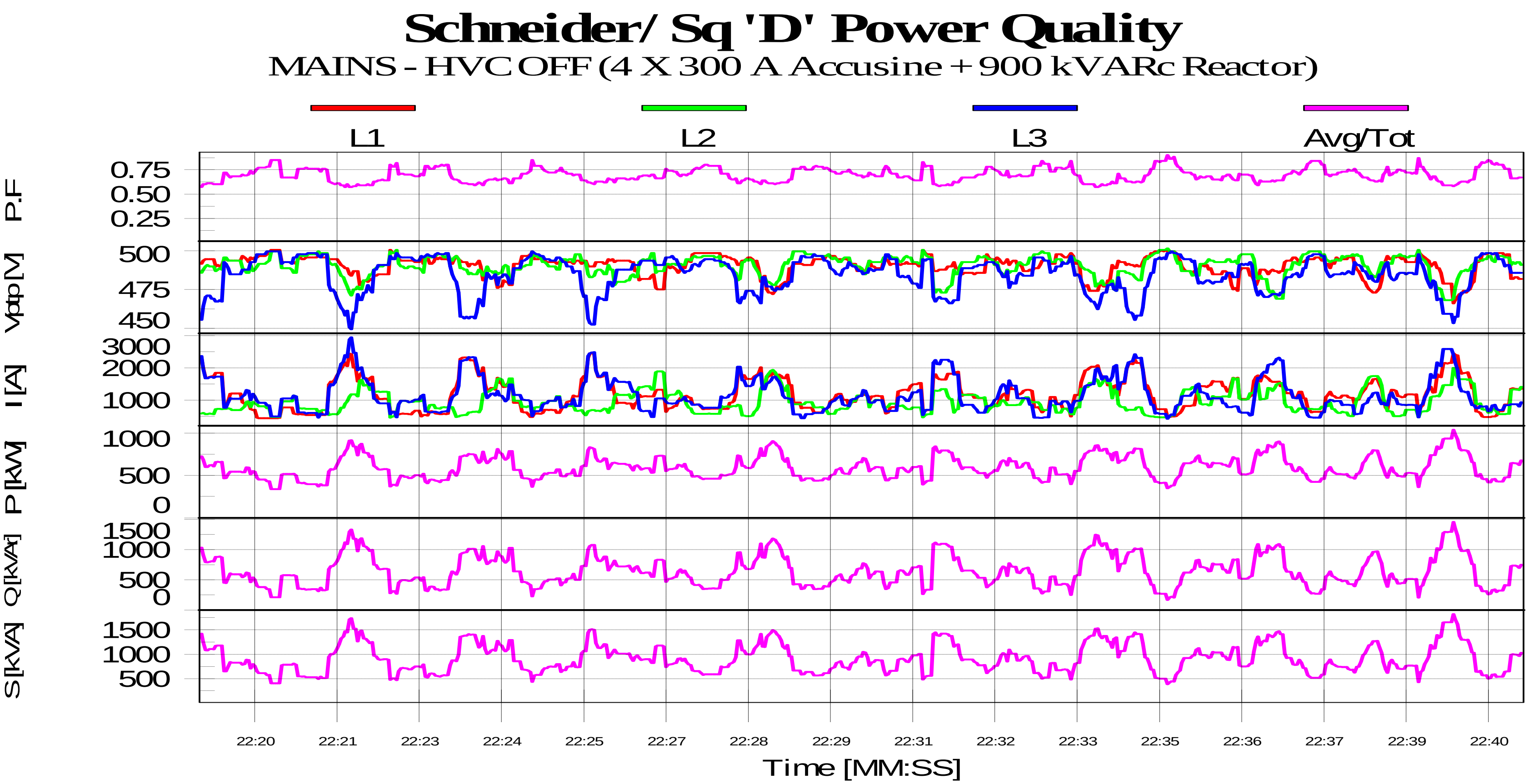

HVC
Vars Leading/Lagging
2000
1500
1000
500
0
-500
-1000
0
2
4
6
8
10
12
14
16
18
Time in cycles
Fixed Kvar
Load
Accusine
Result Kvar

LV HVC case study
spot welding sub station

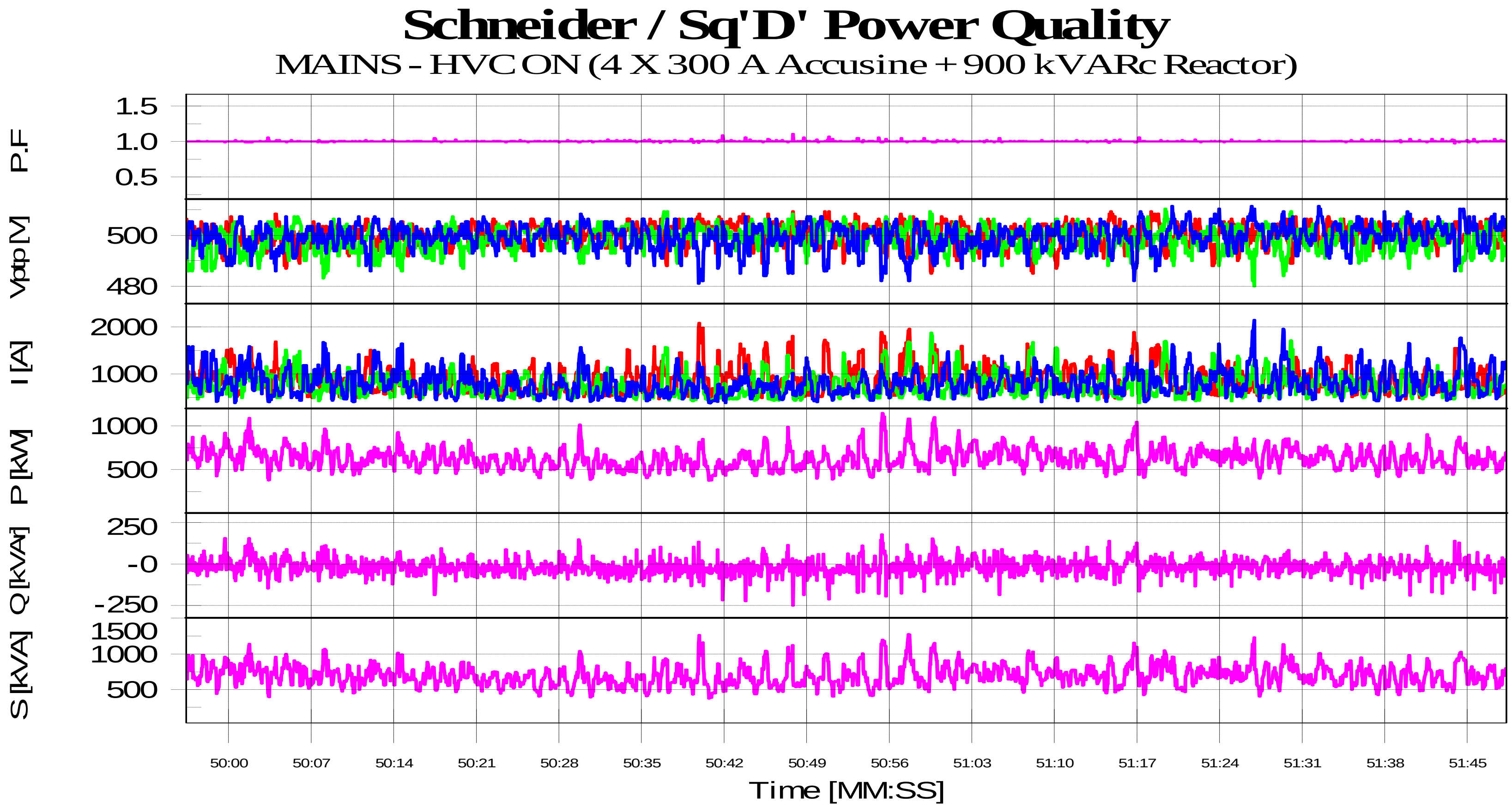
Futaba welding sub, HVC SLD



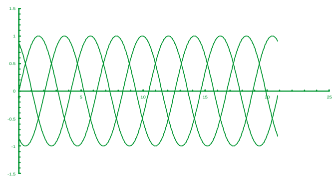
Futaba welding sub, HVC OFF



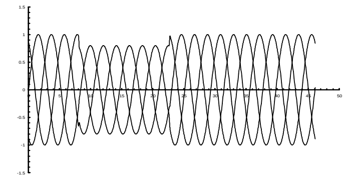
Futaba welding sub HVC ON



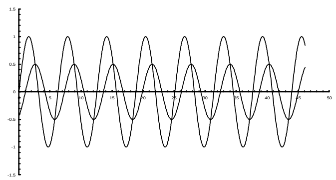
The ideal voltage supply does not exist



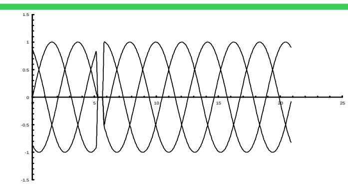
3-phase balanced



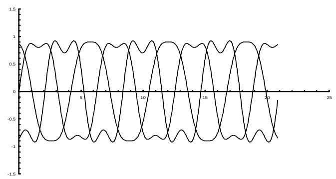
Sags/swells
Overvoltage



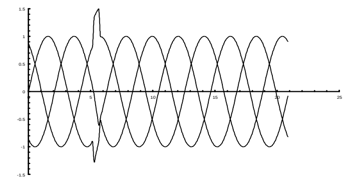
Power Factor



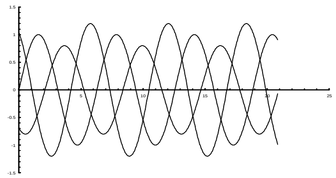
Notches



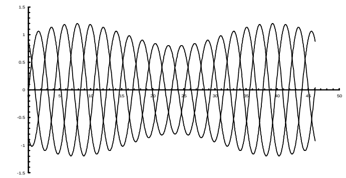
Harmonics



Spikes



Phase unbalanced

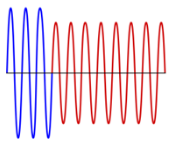


Flicker

Voltage Problems – Basics

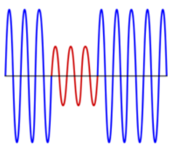
Chronic Voltage Regulation issues

Voltage outside ±10% for > 60 seconds



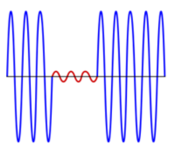
Voltage Sag

Voltage < 90% for ½ cycle to 1 minute



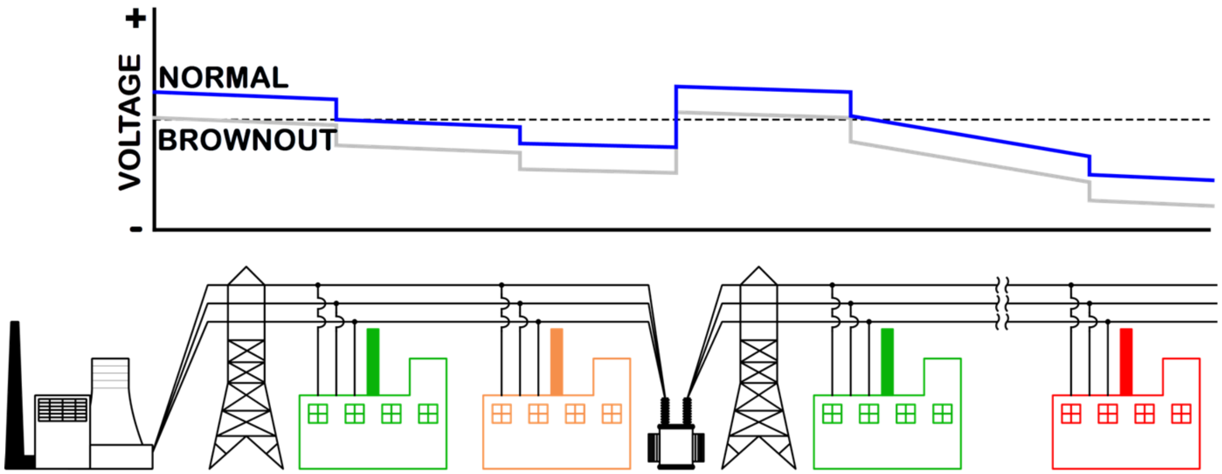
Interruption

Voltage < 10% for >3 cycles



95% of Voltage Quality Problems

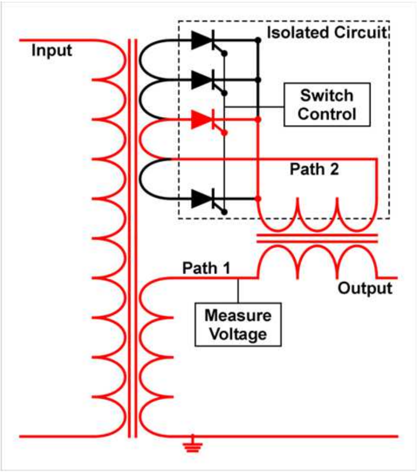
Chronic Voltage Problems

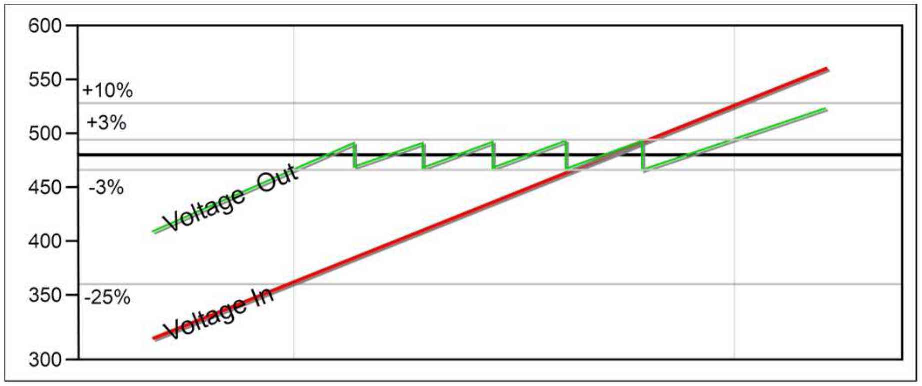


Brownout – intentional reduction in grid voltage

External: Line Drops & Brownouts

Solid State tap switching voltage regulator



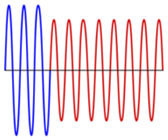


- Microprocessor controlled tap-switching
- Input voltage range: **+10 to -25%**
- Output regulation: **±3%**
- Response time: 1 cycle typical
- Overload capacity: 1000% for 1 second
- No load or power factor limitations
- Independently regulated, shielded, isolated output
- Fan-free and maintenance-free
- Single or three phase
- 5 to 2,000 kVA
- 50 or 60 Hz
- Any input or output voltages up to 600v

Voltage Problems – Basics

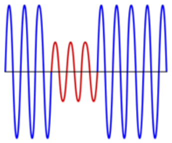
Chronic Voltage Problems

Voltage outside ±10% for > 60 seconds



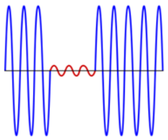
Voltage Sag

Voltage < 90% for ½ cycle to 1 minute



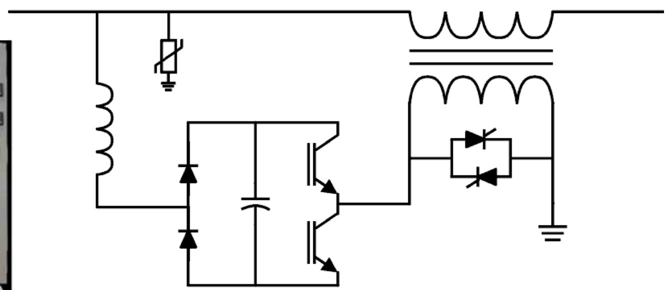
Interruption

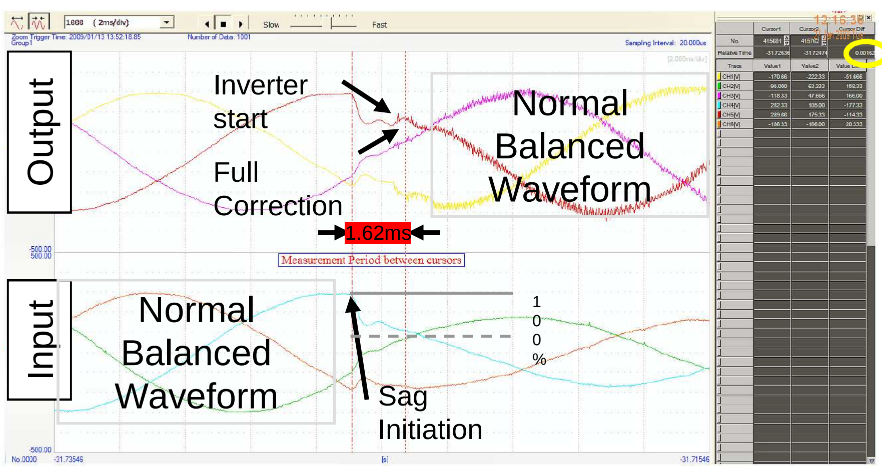
Voltage < 10% for >3 cycles



95% of Voltage Quality Problems

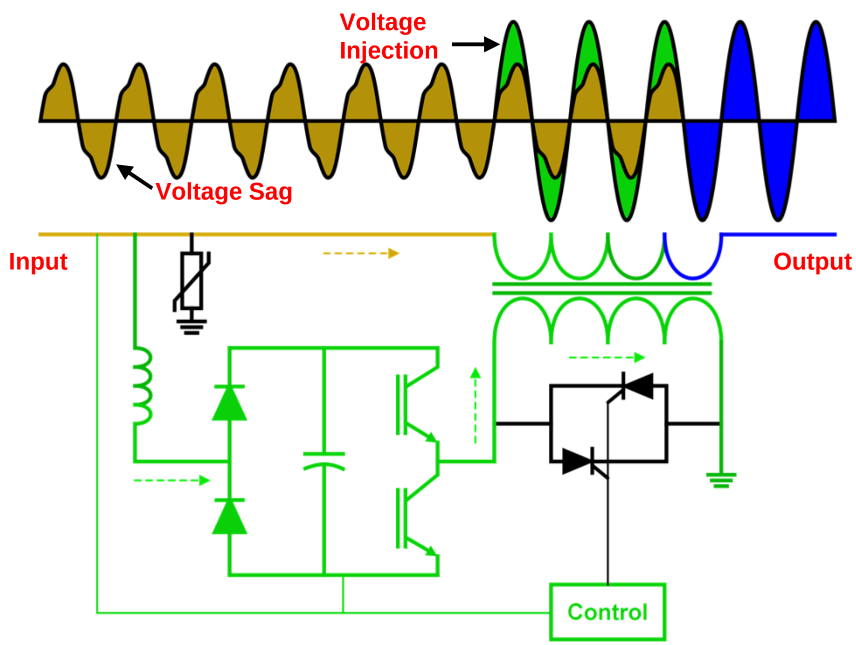
Sag Mitigation Device





- Inverter-based, voltage injection design
- Corrects voltage sags back to >95% nominal voltage
- For sags down to **30% remaining voltage for 1 or 2 phase sags**
- For sags down to **60% remaining voltage for 3 phase sags**
- 2ms response time
- Provides SEMI-F47 compliant protection
- Correction independent of load or load pf, sag depth or duration
- Corrects phase shifting during sag event
- 3 phases, 20 to 2500 kVA, 50 or 60 Hz, up to 600 V.

Sag Mitigation Device operation



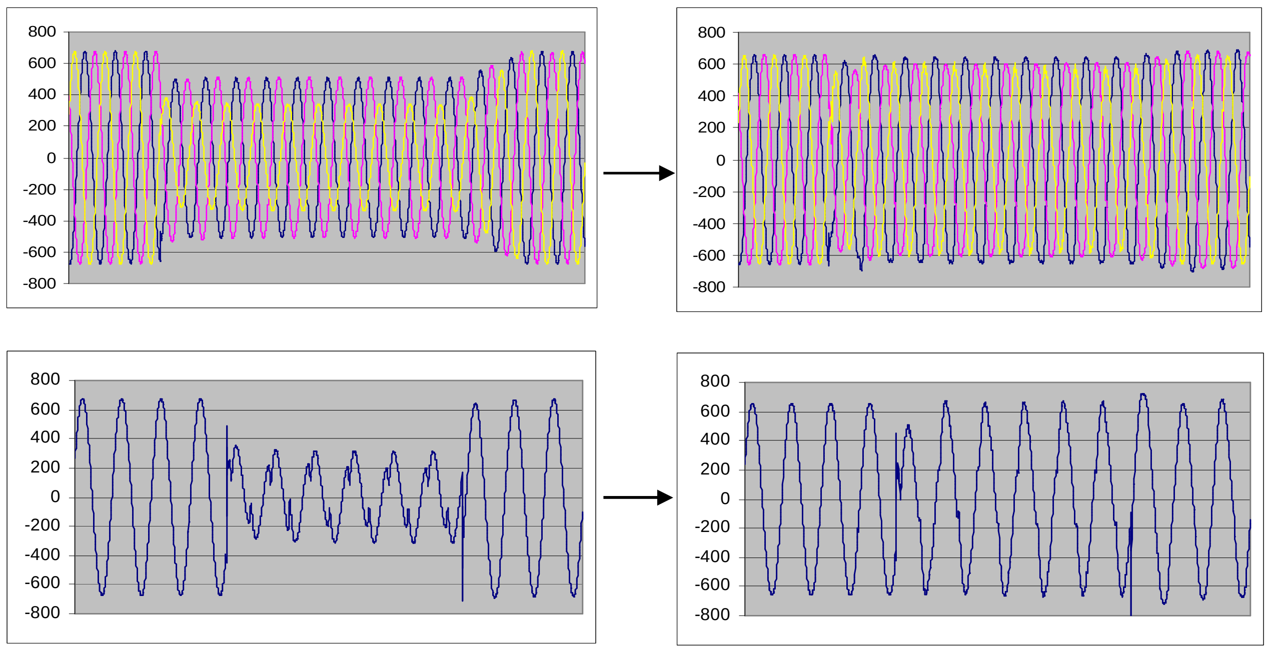
- •Transformer “un-shorted”
- •DC bus powered - inverters are ON
- •Energy transfer phase-to-phase
- •Non-sagging → sagging phases
- •All in 2 ms

Input Voltage Sag – Correction Mode

Electronic Sag Fighter Performance

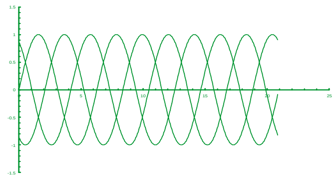
Input

Output

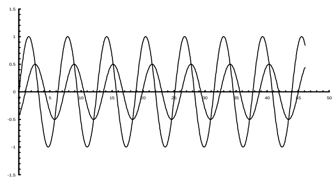


Surge Suppression Device
aka SPD or TVSS

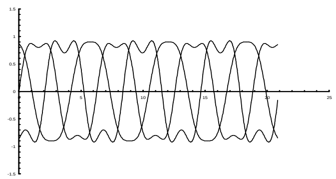
The ideal voltage supply does not exist



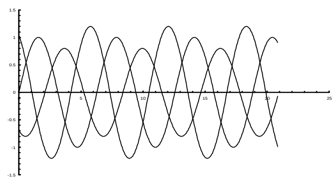
3-phase balanced



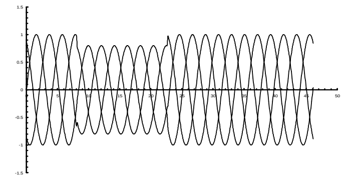
Power Factor



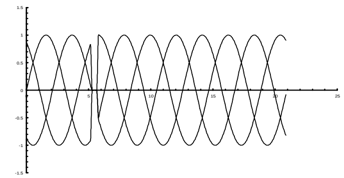
Harmonics



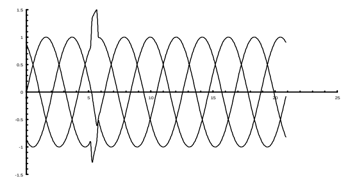
Phase unbalanced



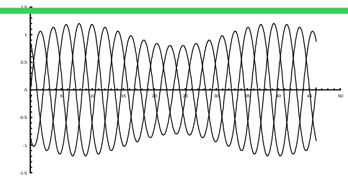
Sags/swells
Overvoltage



Notches



Spikes

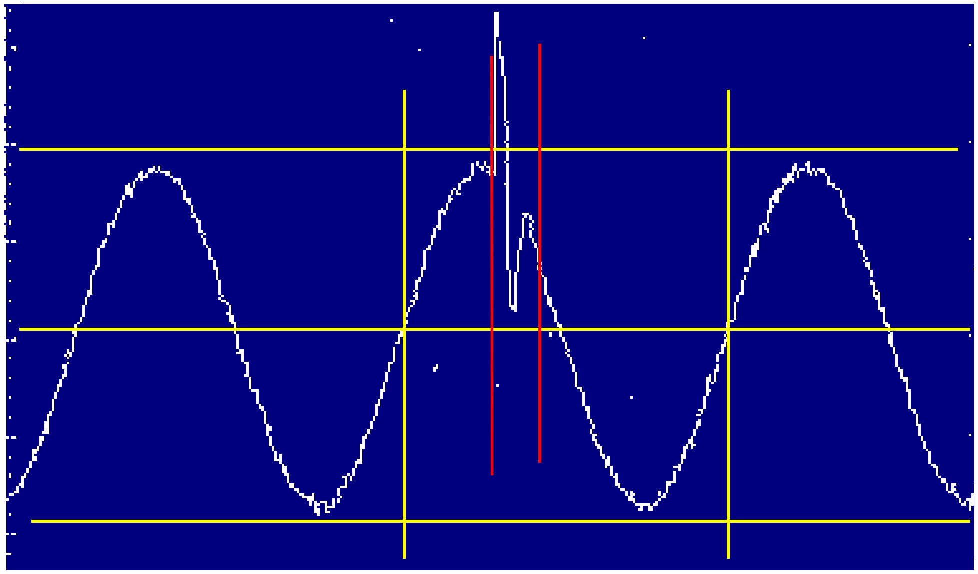


Flicker

What is a Transient Surge?

> A surge or transient is a voltage spike that only lasts a few millionths of a second (the "blink of an eye" is thousands of times longer than the typical surge).

> A surge can contain thousands of volts and thousands of amps.



1 cycle at 60 Hz = 16.6 milliseconds

Transient event (between red lines) approximately 500 **microseconds**

Where do Transient Surges Come From?

Elevators

Pump Motors

Air conditioners

80% inside

Air compressors

Blower Motors

Office Copiers

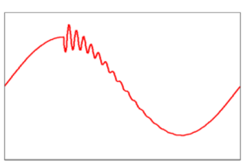
Lightning

Electrical Accidents

20% outside

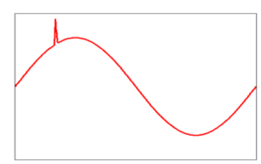
Switching Cap Banks

Utility Grid Switching



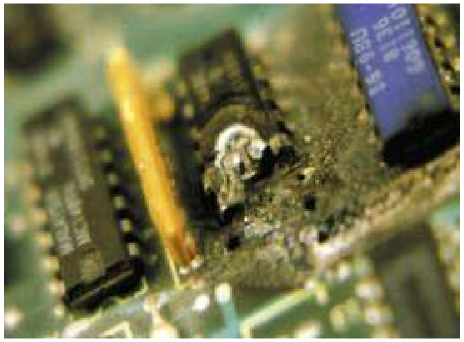
Oscillatory transients
Typical of Internal events
(Smaller, lower energy)

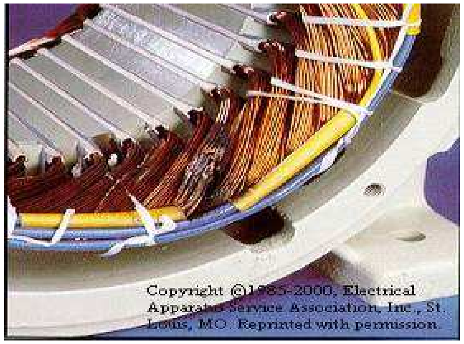
Impulse transients
Typical of External events
(Larger, higher energy)



The Effects of Transients on Business

$80B





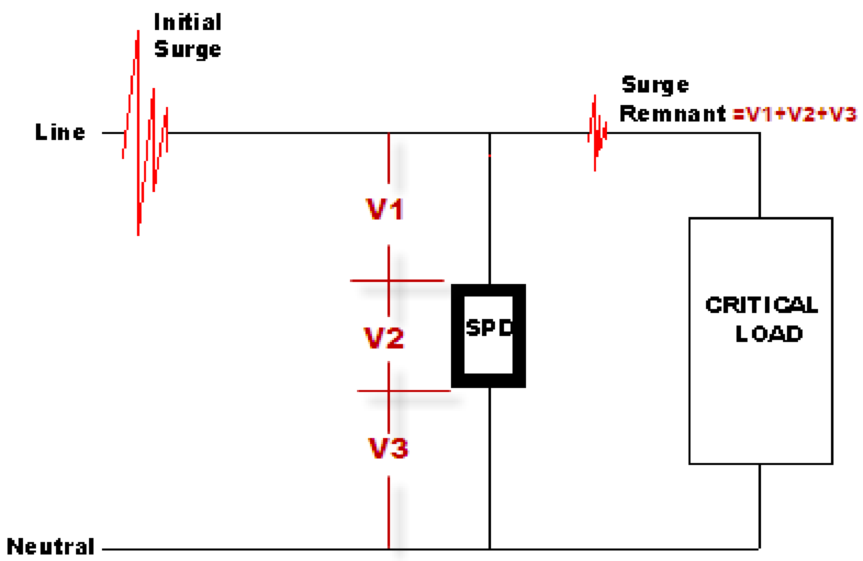
"Power related problems cost companies over $80 billion a year"
(Source: Lawrence Berkeley National Laboratory)

"Industry experts estimate that power surges cost businesses $26 billion annually in lost time and equipment repairs and replacements"
(Source: Insurance Institute for Business & Home Safety)

- High Facility Maintenance Costs
- Equipment Failure
- Long-term System Degradation
- Process disruptions
- Data Loss or Corruption
- Costly Downtime
- Safety to drinking water

How does an SPD work?

The purpose behind installing any SPD is to divert damaging voltage and currents away from down stream equipment.



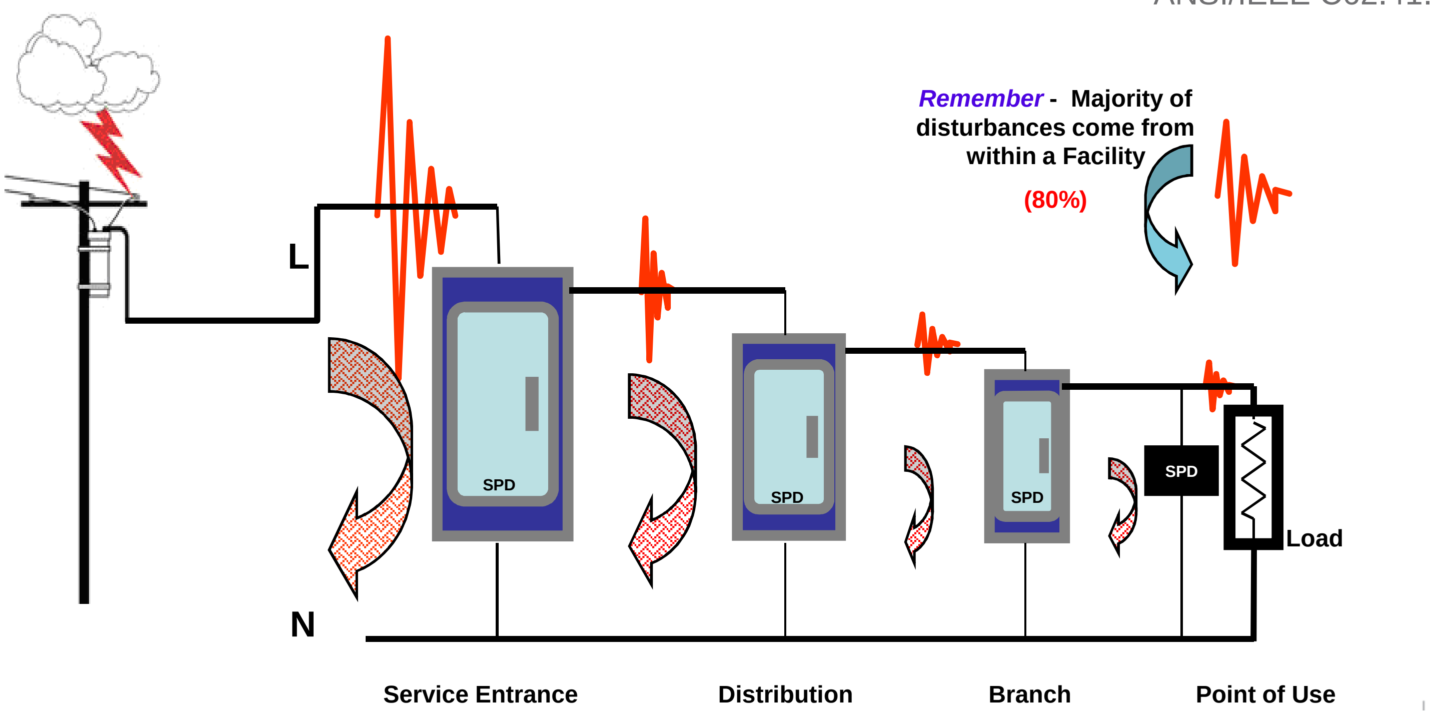
SPD Method of Operation

1. The SPD is installed in a parallel path with respect to the load.
2. When a surge voltage does come down the line, the SPD will respond in nanoseconds creating a low impedance path through the components within the SPD.
3. Current will flow through the path of least resistance.
4. The SPD becomes the path of least resistance and shunts the damaging energy before it is forced through the down stream protected equipment.
5. NO SPD will shunt 100% of the initial surge energy away from the load.
6. There is always some voltage/current that will be pushed through the load.
7. But if the SPDs are installed correctly and in the proper location, this Surge Remnant is well below the damaging level of the protected equipment.

Cascading - *Location*

Cascading (layering) **your protection throughout your facility insures proper protection for your equipment.**

ANSI/IEEE C62.41.1



Recommended Protection Levels

kA ratings may be modified to correspond with the intensity and frequency of transients.

High lightning areas or areas with a high frequency of Utility grid switching surges, etc. may require an increased kA rating.

The higher the frequency of surges, the higher the kA rating should be.

The dollar value of sensitive electronic equipment which receives power from the Branch Panel needs to be considered.

Service Entrance **240 kA**

Distribution **120-160 kA**

Branch **100-120 kA**

Rule of Thumb: The higher the kA rating on the product, the better its withstand capability and overall robustness. For each level of protection (cascading) cut the kA rating by half.

Modes of Suppression: L1-N, L2-N, L3-N, L1-G, L2-G, L3-G, L1-L2, L1-L3, L2-L3, N-G.

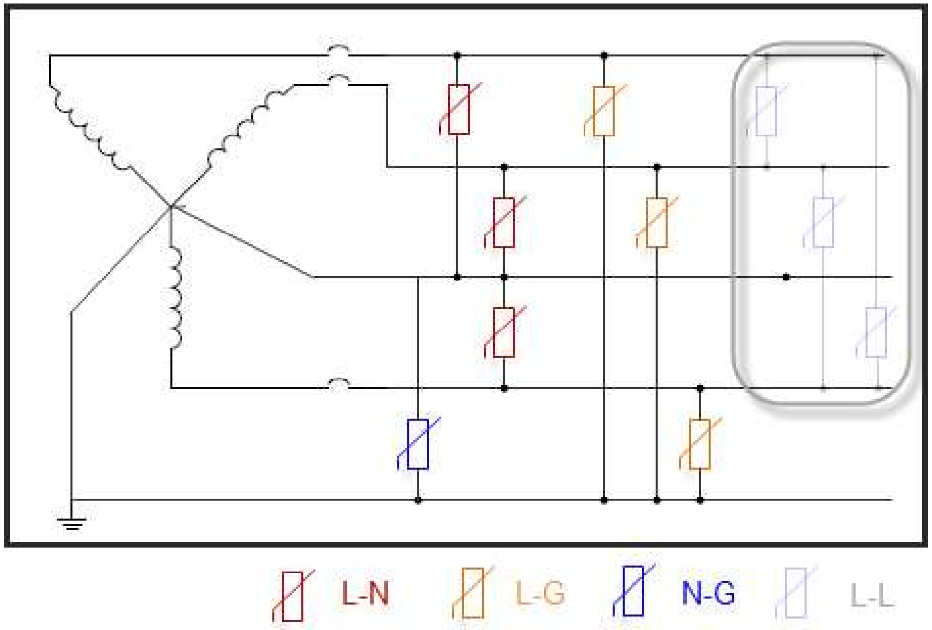
4 Mode: 4 Mode will provide protection to all ten modes via the L-N and N-G MOV's.

- This configuration is not used often because of the poor levels of protection but is sometimes used because of the costs.

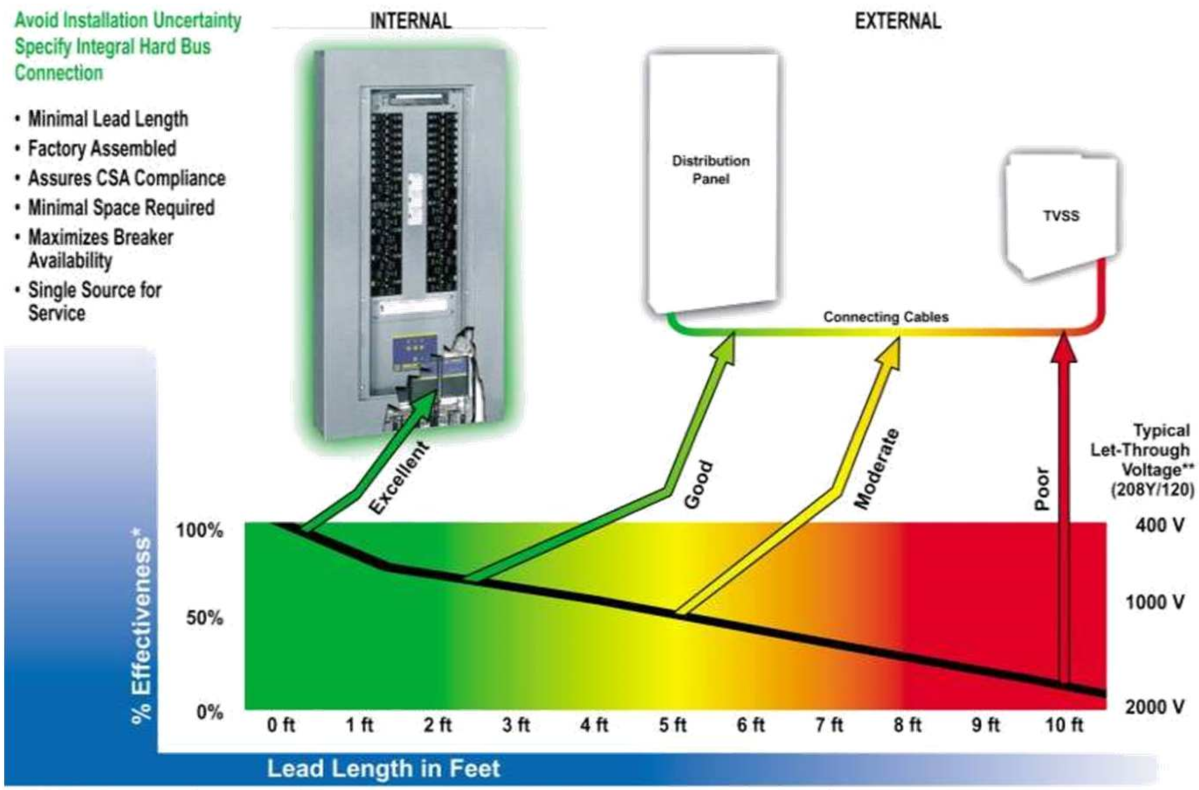
7 Mode: The 7 Mode will provide protection to all ten modes via the L-N, L-G and N-G MOVs.

- This is the most popular configuration as it allows the components to properly be sized for the voltage levels they are intended to protect. Most Manufactures, provide this type of surge protection, it is proven and works well.

10 Mode: 10 mode, All Mode and Discrete, are more Marketing driven via a Specification than performance driven.



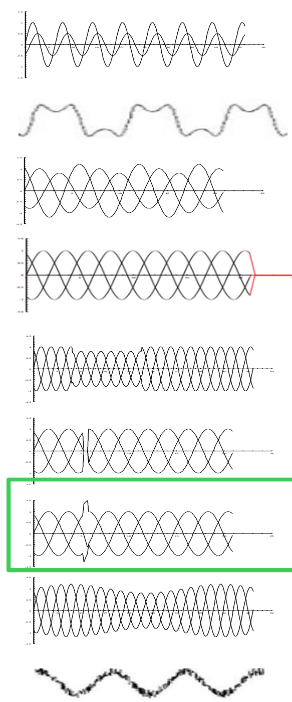
Lead Lengths - *Installation*



* % Effectiveness refers to the ability to keep the let-through voltage at minimal levels for typical transients

** Approx 160V / ft

Transient Voltage Surge Suppressors



Power Factor

Harmonics

Phase unbalance

Blackout

Sags/swells
Overvoltage

Notches

Transient (Spike)

Flicker

Noise

Case Studies

Active Harmonic Filter, turnkey project

Problem:

In late 2013 the hospital reported the malfunction of several dialysis machines which were significantly impacting the quality of patient care.

Audit:

Audit **PME 7.2** (Power Monitoring Expert) was utilized, in conjunction with a fleet of PM800 Meters to gather the Power Quality Data.

The existing situation

The hospital's air conditioning system had recently **been modernized with a fleet of Variable Speed Drives (VSDs).** These VSDs were polluting the hospital's electrical network and **were regularly causing the new dialysis machines to malfunction**. Diabetic patients were regularly sent home and asked to reschedule their treatment.

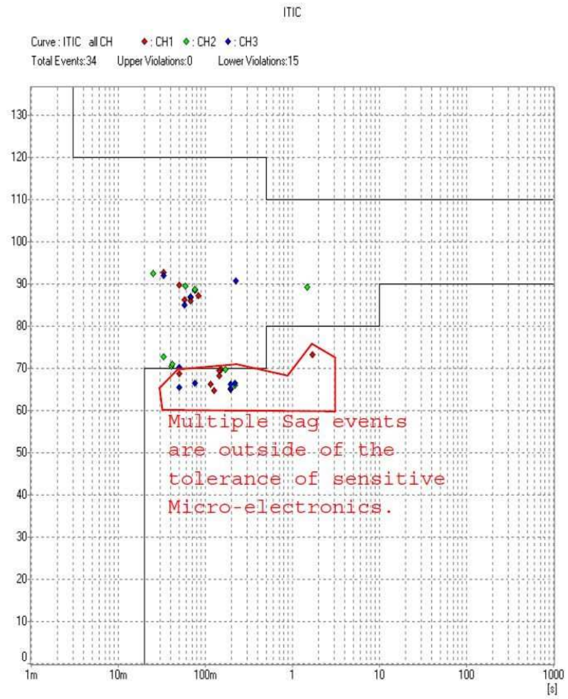
- The VSD caused high THD(V) and THD(I)

Other PQ issues:

- Switching from Utility to generator mode caused short duration voltage sags
- Utility Capacitor bank switching caused ringing transient and multiple Zero Crossing

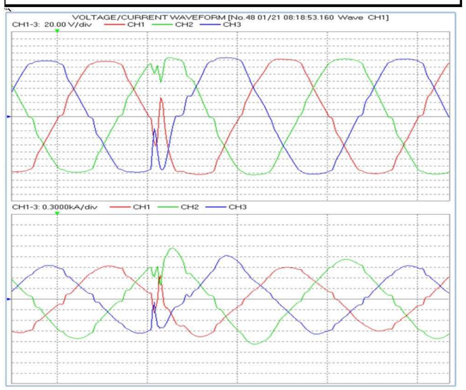
Power Quality disturbances

- 1. Voltage Distortion (aka THDv or Vthd)
- 2. Voltage Sag
- 3. Multiple Zero crossings



POWER		VOLTAGE		CURRENT	
Freq	57.813 Hz				
P1	0.0473MW	U1	116.48 V	I1	0.4268kA
P2	0.0611MW	U2	115.84 V	I2	0.5341kA
P3	0.0521MW	U3	115.70 V	I3	0.4640kA
Psum	0.1606MW	THD-U1	3.25 %	THD-I1	10.12 %
S1	0.0497MVA	THD-U2	6.79 %	THD-I2	10.71 %
S2	0.0619MVA	THD-U3	7.41 %	THD-I3	12.48 %
S3	0.0537MVA	Upk+1	157.57 V	Ipk+1	0.616kA
Ssum	0.1653MVA	Upk+2	163.26 V	Ipk+2	0.884kA
Q1	0.0152Mvar	Upk+3	165.17 V	Ipk+3	0.792kA
Q2	0.0097Mvar	Upk-1	-164.25 V	Ipk-1	- 0.715kA
Q3	0.0128Mvar	Upk-2	-160.14 V	Ipk-2	- 0.841kA
Qsum	0.0377Mvar	Upk-3	-159.81 V	Ipk-3	- 0.736kA
PF1	0.9523	Uave	116.01 V	KF1	1.17
PF2	0.9877	Uunb	0.65 %	KF2	1.24
PF3	0.9711			KF3	1.30
PFsum	0.9716			Iave	0.4750kA
				Iunb	7.63 %

POWER		VOLTAGE		CURRENT	
Freq	59.968 Hz				
P1	0.0728MW	U1	119.09 V	I1	0.6225kA
P2	0.0872MW	U2	120.17 V	I2	0.7303kA
P3	0.0717MW	U3	120.51 V	I3	0.6059kA
Psum	0.2317MW	THD-U1	4.78 %	THD-I1	7.94 %
S1	0.0741MVA	THD-U2	4.72 %	THD-I2	8.86 %
S2	0.0878MVA	THD-U3	4.70 %	THD-I3	8.51 %
S3	0.0730MVA	Upk+1	163.45 V	Ipk+1	0.931kA
Ssum	0.2349MVA	Upk+2	163.81 V	Ipk+2	1.112kA
Q1	0.0139Mvar	Upk+3	164.07 V	Ipk+3	0.939kA
Q2	0.0103Mvar	Upk-1	-162.38 V	Ipk-1	- 0.944kA
Q3	0.0137Mvar	Upk-2	-162.93 V	Ipk-2	- 1.120kA
Qsum	0.0379Mvar	Upk-3	-163.74 V	Ipk-3	- 0.940kA
PF1	0.9824	Uave	119.92 V	KF1	1.53
PF2	0.9930	Uunb	0.30 %	KF2	1.47
PF3	0.9822			KF3	1.59
PFsum	0.9863			Iave	0.6529kA
				Iunb	6.18 %



Turnkey Solutions: Engineer, Supply, Install & Start up

High THD(V) & THD(I)

Supply:

- 2 x 94 Ampere AccuSine PLUS at 600 V
- 2 x 157 Ampere AccuSine PLUS at 600 V
- 24 x Current Transformer
- 78 x 3% linear reactors for the VSD’s

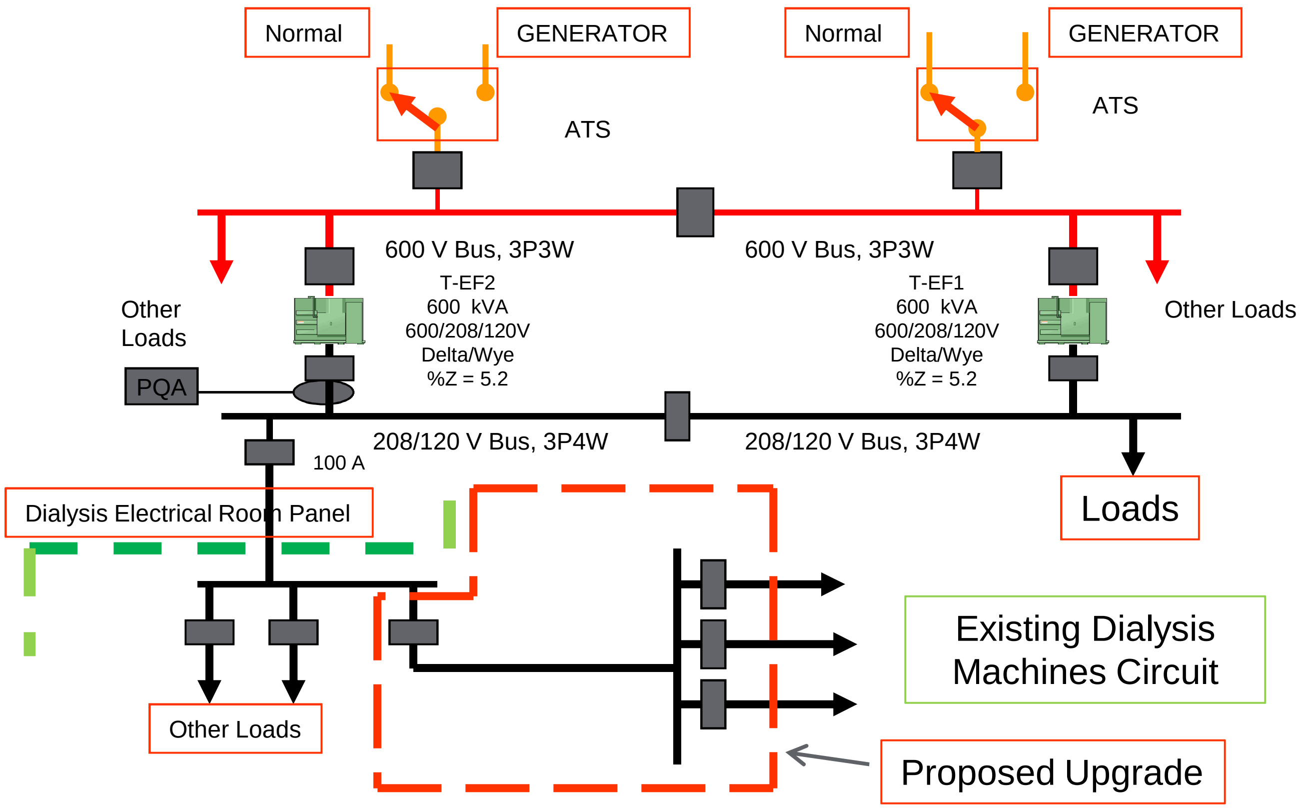
Voltage Sags

- Not coincidental with dialysis machines shut down, not considered to be a problem by the end user.

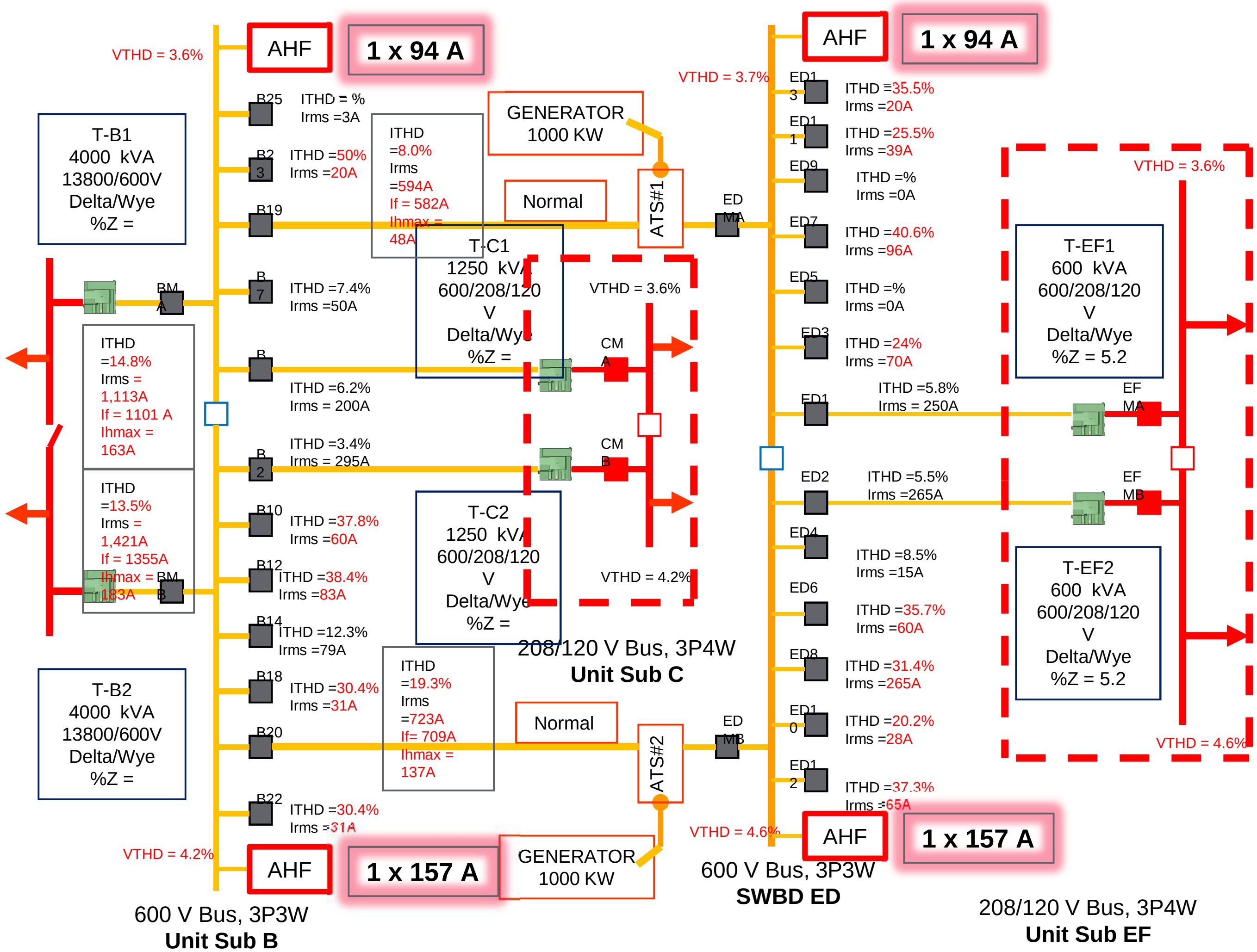
Ringing Transient and Multiple Zero Crossing

- Installation of 3 isolation transformers on branch circuits that are feeding sensitive equipment

Simplified hospital electrical system

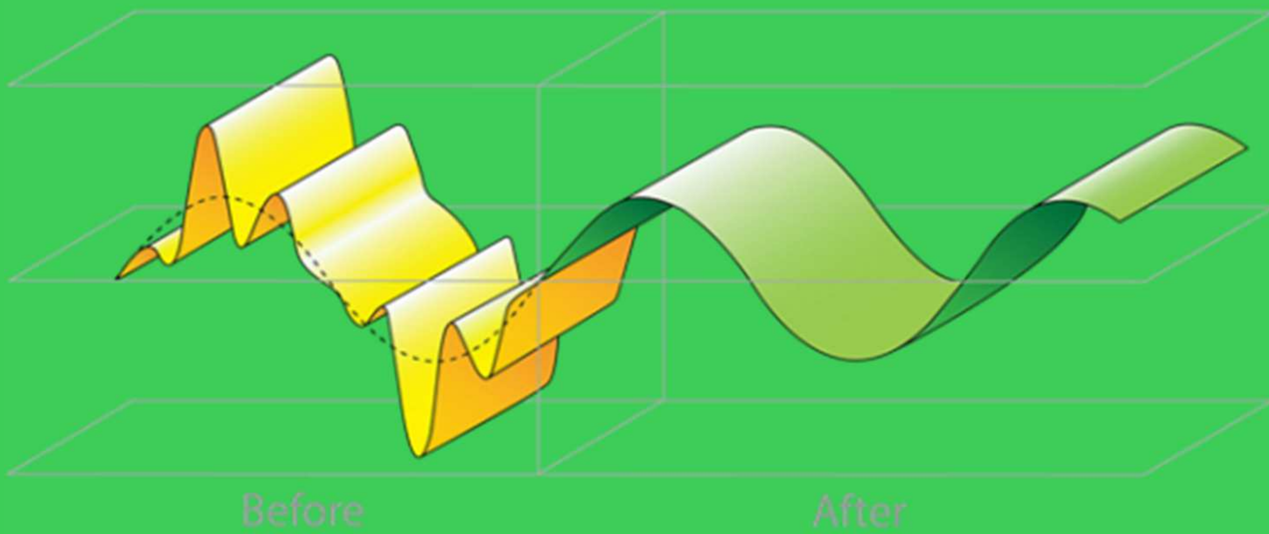


T-EF2/ T-EF1 Electrical System



VTHD = 3.6%
AHF
1 x 94 A
T-B1
4000 kVA
13800/600V
Delta/Wye
%Z =
B25 ITHD = % Irms =3A
B23 ITHD =50% Irms =20A
B19
ITHD =8.0% Irms =594A If = 582A Ihmax = 48A
GENERATOR 1000 KW
Normal
ATS#1
B7 ITHD =7.4% Irms =50A
BMA
ITHD =14.8% Irms = 1,113A If = 1101 A Ihmax = 163A
T-C1 1250 kVA 600/208/120 V Delta/Wye %Z =
VTHD = 3.6%
CMA
B ITHD =6.2% Irms = 200A
B2 ITHD =3.4% Irms = 295A
CMB
ITHD =13.5% Irms = 1,421A If = 1355A Ihmax = 183A
BMB
B10 ITHD =37.8% Irms =60A
B12 ITHD =38.4% Irms =83A
T-C2 1250 kVA 600/208/120 V Delta/Wye %Z =
VTHD = 4.2%
B14 ITHD =12.3% Irms =79A
208/120 V Bus, 3P4W
Unit Sub C
T-B2
4000 kVA
13800/600V
Delta/Wye
%Z =
B18 ITHD =30.4% Irms =31A
ITHD =19.3% Irms =723A If= 709A Ihmax = 137A
B20
Normal
ATS#2
B22 ITHD =30.4% Irms =31A
VTHD = 4.2%
AHF
1 x 157 A
GENERATOR 1000 KW
600 V Bus, 3P3W
Unit Sub B
VTHD = 3.7%
AHF
1 x 94 A
ED13 ITHD =35.5% Irms =20A
ED11 ITHD =25.5% Irms =39A
ED9 ITHD =% Irms =0A
ED MA
ED7 ITHD =40.6% Irms =96A
ED5 ITHD =% Irms =0A
ED3 ITHD =24% Irms =70A
ED1 ITHD =5.8% Irms = 250A
ED2 ITHD =5.5% Irms =265A
ED4 ITHD =8.5% Irms =15A
ED6 ITHD =35.7% Irms =60A
ED8 ITHD =31.4% Irms =265A
ED MB
ED10 ITHD =20.2% Irms =28A
ED12 ITHD =37.3% Irms =65A
VTHD = 4.6%
AHF
1 x 157 A
600 V Bus, 3P3W
SWBD ED
VTHD = 3.6%
T-EF1 600 kVA 600/208/120 V Delta/Wye %Z = 5.2
EF MA
EF MB
T-EF2 600 kVA 600/208/120 V Delta/Wye %Z = 5.2
VTHD = 4.6%
208/120 V Bus, 3P4W
Unit Sub EF

Low Harmonic Emission Solution



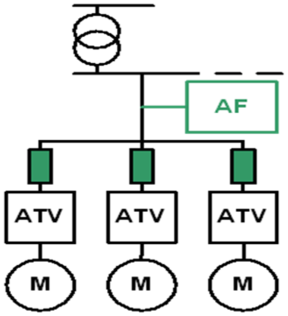
2 ways to achieve 'Low Harmonic' system

End-User
< 5% THDi

- Main Goal
  - **Comply with harmonic standards and reach a THDi level below 5%**
- 2 solutions

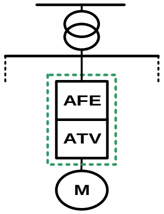
❶ Active Harmonic Filters for multiple standard VSD

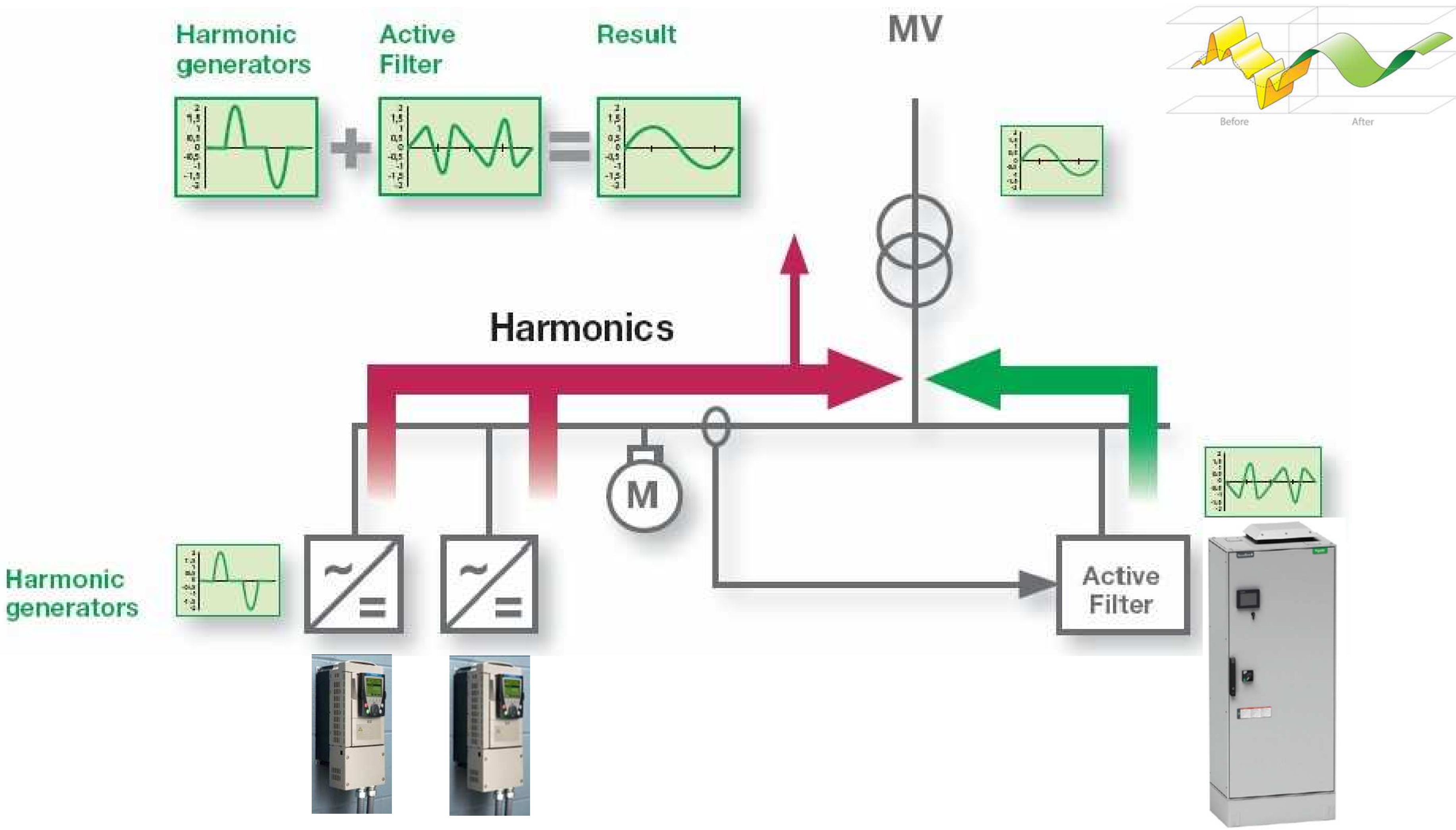
- Active Harmonic Filter (AccuSine PCS+ 60,120,200 or 300A) :
  - For groups of multiple ATV600 & ATV900, up to 630kw each
  - Achieve a THDi below 5%
  - AC or DC chokes are needed at VSDs level (3-5% Z) to meet 5% THDi
  - Can also be used to compensate for harmonics from non-VSD loads on the same bus as well as to provide PFC for line connected motors



2 'Low Harmonic' drives up to 630kW "ATV680 & ATV980"

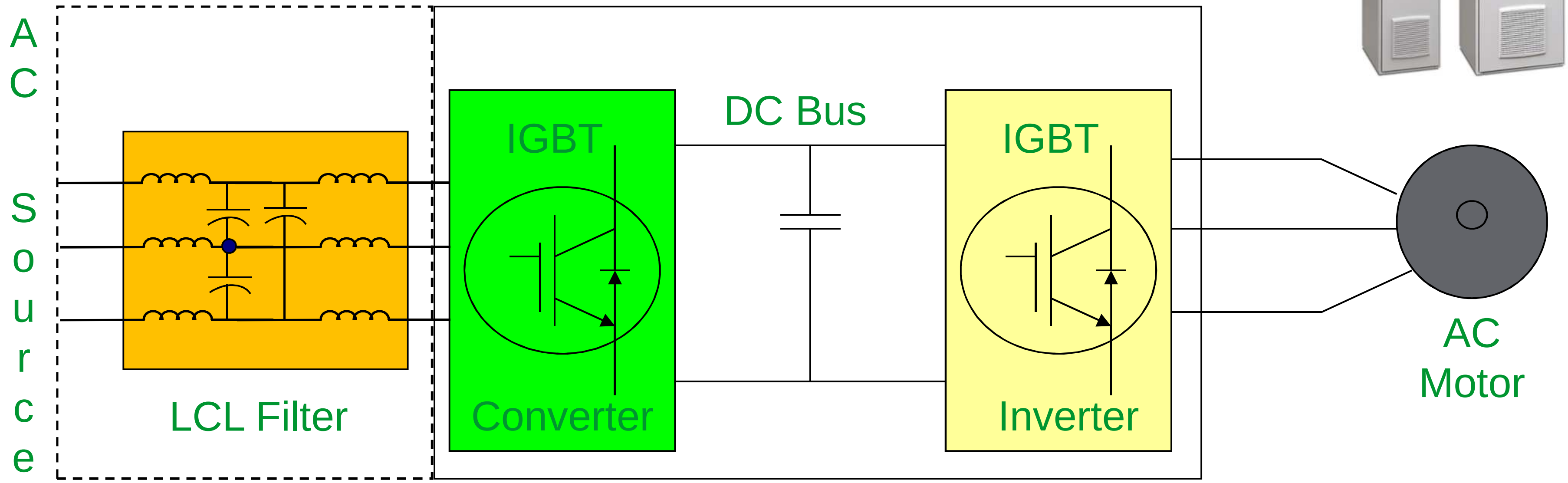
- One enclosure with ATV680 & ATV980, complete with AFE module
- 380 to 480 V, 50/60Hz, IP23 & IP54, THDi < 5%
- Can achieve a PF of 100%




Harmonic generators
Active Filter
Result
MV
Before
After
Harmonics
M
Harmonic generators
Active Filter

AFE VSD Harmonic Solution

AFE VSD main building blocks



AFE Drive advantages

1. It's normally more cost effective for application with one large drive in comparison to AHF.
2. It has a foot print advantage over the AHF for installation of one or two drives.
3. It will be compliant to IEEE 519 when operating as Low Harmonic Drive when transmitting full load power.
4. It has a high power factor, going as high as 99% lagging, for most application it will have a lower kVA demand than AHF combined with 6-pulse VSD.
5. It's capable of re-injecting power into the grid during dynamic breaking, therefore yielding some operation expenses saving during these instances.

AHF PCS+ advantages when Combined with standard 6-pulse VSD

1. When the AHF is sized appropriately, compliance to IEEE 519-2014 is attained regardless of the VSD loading.
2. One AHF can correct for multiple 6-pulse VSD unlike an AFE VSD where you need one for each drive product, making AHF more cost effective for multiple drive application, especially when redundant pumps are present.
3. AHF have less losses compared to AFE Drive, therefore it reduces the installation operating cost over time.
4. AHF introduces less switching ripple than AFE because it uses a higher commuting frequency, therefore reducing the risk of interaction with other loads present in the network.
5. AHF can simultaneously correct PF and do load balancing while mitigating harmonic, therefore improving the overall power quality of the installation.

AHF PCS+ advantages when Combined with standard 6-pulse VSD

6. The AHF parallel installation makes it easy to retrofit an installation and it also increases the continuity of service, basically the drive can still operate even though the AHF is off line.
7. The AHF can easily be integrated in MCC or in switch gear which can optimize the installation footprint and reduce construction costs.
8. Generally speaking, 6-pulse VSD are more robust and less complex than AFE VSD, therefore reducing maintenance frequency and complexity when they are combined with AHF.
9. AFE VSD offer begins at 110 KW and increases with KW rating. AHF advantage is that it be applied to all KW ratings (from 0.75 KW to 900 KW).

ATV680 Versus ATV630/ATV660 combined with PCS PLUS 1 to 5 identical VSD ranging from 110 to 500 kW

Base of comparison:

- **the cost of ownership,**
- **the lineup footprint,**
- **the lineup weight,**
- **the apparent power**
- **and the losses of each solution.**

Green color: advantage to the Altivar 680

Blue color: advantage ATV630/ATV660 + AccuSine PCS+

Quantity of 1 VFD on the same bus					
Advantage ATV680	Advantage ATV630/ATV660 with PCS+				
VFD size in KW	Cost of ownership	Line up length	Weight	Adj. KVA	Losses (kw)
110	Green	Green	Green	Green	Blue
132	Green	Green	Green	Green	Blue
160	Green	Green	Green	Green	Blue
200	Green	Green	Blue	Green	Blue
250	Green	Green	Blue	Green	Blue
315	Blue	Green	Blue	Green	Blue
355	Blue	Green	Blue	Green	Blue
400	Blue	Green	Blue	Green	Blue
450	Blue	Green	Blue	Green	Blue
500	Blue	Green	Blue	Green	Blue

Quantity of 2 VFD's on the same bus					
Advantage ATV680	Advantage ATV630/ATV660 with PCS+				
VFD size in KW	Cost of ownership	Line up length	Weight	Adj. KVA	Losses (kw)
110	Green	Green	Green	Green	Blue
132	Blue	Green	Green	Green	Blue
160	Blue	Green	Green	Green	Blue
200	Blue	Green	Blue	Green	Blue
250	Blue	Green	Blue	Green	Blue
315	Blue	Green	Blue	Green	Blue
355	Blue	Blue	Blue	Green	Blue
400	Blue	Green	Blue	Green	Blue
450	Blue	Green	Blue	Green	Blue
500	Blue	Blue	Blue	Green	Blue

Quantity of 3 VFD's on the same bus					
Advantage ATV680	Advantage ATV630/ATV660 with PCS PLUS				
VFD size in KW	Cost of ownership	Line up length	Weight	Adj. KVA	Losses (kw)
110	Blue	Green	Green	Green	Blue
132	Blue	Blue	Green	Green	Blue
160	Blue	Blue	Green	Green	Blue
200	Blue	Blue	Green	Green	Blue
250	Blue	Green	Green	Green	Blue
315	Blue	Green	Blue	Green	Blue
355	Blue	Blue	Blue	Green	Blue
400	Blue	Blue	Blue	Green	Blue
450	Blue	Blue	Blue	Green	Blue
500	Blue	Green	Blue	Green	Blue

Quantity of 4 VFD's on the same bus					
Advantage ATV680	Advantage ATV630/ATV660 with PCS PLUS				
VFD size in KW	Cost of ownership	Line up length	Weight	Adj. KVA	Losses (kw)
110	Blue	Green	Blue	Green	Blue
132	Blue	Green	Green	Green	Blue
160	Blue	Green	Green	Green	Blue
200	Blue	Green	Blue	Green	Blue
250	Blue	Green	Blue	Green	Blue
315	Blue	Green	Blue	Green	Blue
355	Blue	Blue	Blue	Green	Blue
400	Blue	Blue	Blue	Green	Blue
450	Blue	Blue	Blue	Green	Blue
500	Blue	Blue	Blue	Green	Blue

Quantity of 5 VFD's on the same bus					
Advantage ATV680	Advantage ATV630/ATV660 with PCS PLUS				
VFD size in KW	Cost of ownership	Line up length	Weight	Adj. KVA	Losses (kw)
110	Blue	Blue	Blue	Green	Blue
132	Blue	Blue	Blue	Green	Blue
160	Blue	Green	Green	Green	Blue
200	Blue	Blue	Green	Green	Blue
250	Blue	Green	Blue	Green	Blue
315	Blue	Green	Blue	Green	Blue
355	Blue	Blue	Blue	Green	Blue
400	Blue	Blue	Blue	Green	Blue
450	Blue	Blue	Blue	Green	Blue
500	Blue	Blue	Blue	Green	Blue

Conclusion

Both types of systems are effective at mitigating harmonic distortion and meeting the most stringent harmonic standard around the world.

An advantage can be given to AFE VSD when only one drive is involved in the project, especially when dynamic braking is required.

However, a definitive advantage can be given to AHF with standard 6-pulse VSD when multiple drives are operating on the same bus. The greatest benefits of a system solution are reflected in the cost of ownership and the operating cost reduction due to the efficiency optimization of a system approach .

Questions?