ELECTRICAL POWER QUALITY

What it is, why it's important and how to improve it

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Schneider Electric

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Schneider Electric

Power Quality in Electrical Power Systems

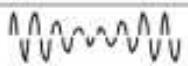
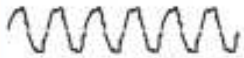
Where do Power Quality problems come from

What is Power Quality

An ideal three-phase Electrical Energy Supply system has the following characterisctics for each phase:

- Nominal magnitude
- Nominal frequency (60Hz)
- Sinusoidal waveform
- Symmetry on all 3 phases

A disturbance of one or may of these parameters constitutes a Power Quality disturbance

Disturbance category	Waveform	Effects	Possible causes
Transients		Equipment malfunction and damage	Lightning or switching of inductive / capacitive loads
Interruption		Downtime, equipment damage, loss of data possible	Utility faults, equipment failure, breaker tripping
Sag		Downtime, system halts, data loss	Utility or facility faults, startup of large motors
Swell		Equipment damage and reduced life	Utility faults, load changes
Undervoltage		Shutdown, malfunction, equipment failure	Load changes, overload, faults
Overvoltage		Equipment damage and reduced life	Load changes, faults, over compensation
Harmonics		Equipment damage and reduced life, nuisance breaker tripping, power losses	Electronic loads (non-linear loads)
Unbalance		Malfunction, motor damage	Unequal distribution of single phase loads
Voltage fluctuations		Light flicker and equipment malfunction	Load exhibiting significant current variations
Power frequency variations		Malfunction or motor degradation	Standby generators or poor power infrastructure
Power Factor *		Increased electricity bill, overload, power losses	Inductive loads (ex. motors, transformers...)

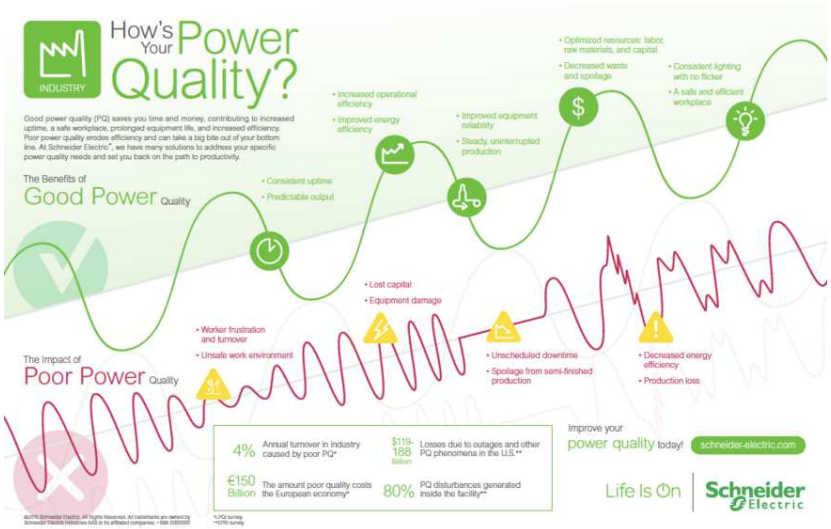
Why do we care about Electrical Power Quality

1. Process reliability
2. Equipment life
3. Maintenance costs
4. Energy efficiency
5. Cost of energy
6. GHG emissions

The primary causes of the increasing prevalence of Power Quality problems are

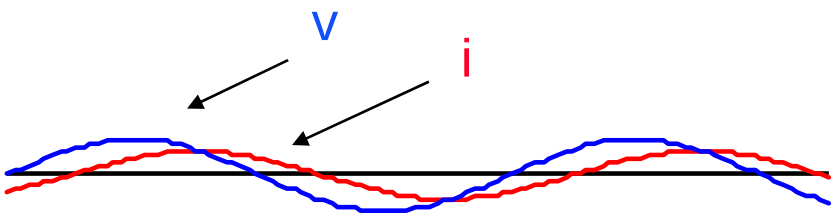
1. A massive increase in the installation and use of non-linear loads

2. An increased reliance on sensitive equipment for the control of production and business processes

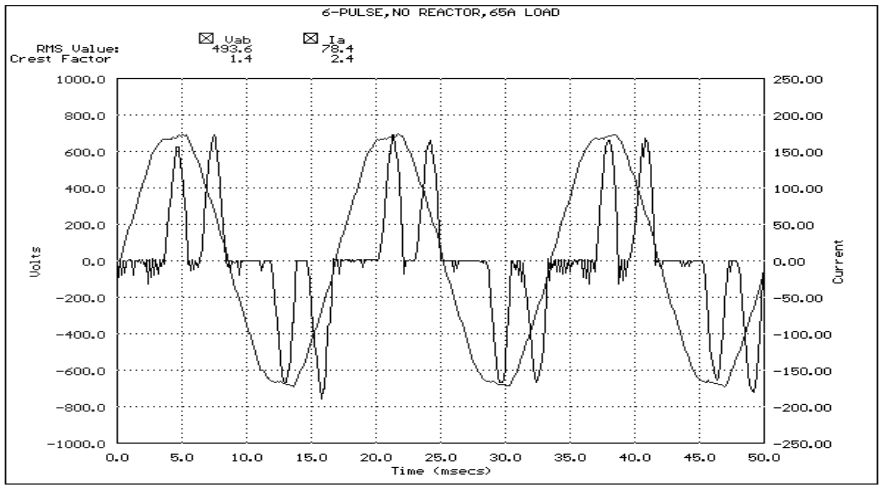


Understanding the root of Power Quality problems

Linear Load



Non-Linear Load



How much does one hour of unplanned downtime cost ?

Industry	Hourly Downtime Costs
Brokerage Operations	$6,450,000
Energy	$2,817,846
Credit Card Sales Authorizations	$2,600,000
Telecommunications	$2,066,245
Manufacturing	$1,610,654
Financial Institutions	$1,495,134
Information Technology	$1,344,461
Insurance	$1,202,444
Retail	$1,107,274
Pharmaceuticals	$1,082,252
Banking	$996,802
Food/Beverage Processing	$804,192
Consumer Products	$785,719
Chemicals	$704,101
Transportation	$668,586
Utilities	$643,250
Healthcare	$636,030
Metals/Natural Resources	$580,588

How much does a Power Quality event cost ?

HOW MUCH ARE POOR POWER QUALITY EVENTS COSTING YOU?

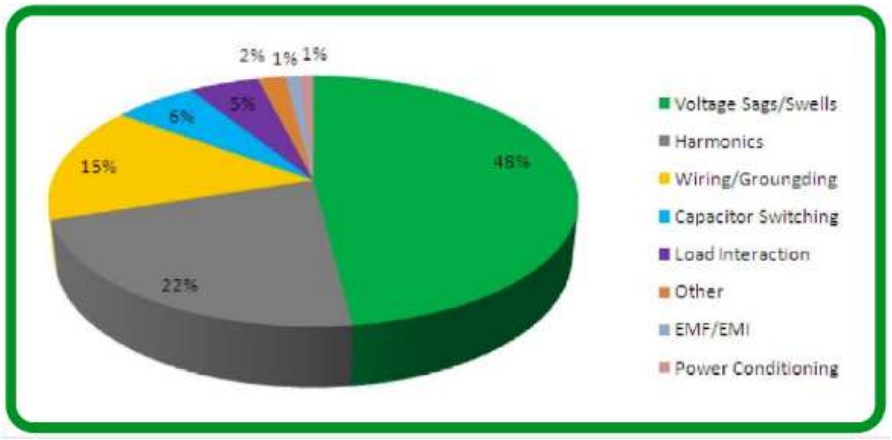
The following average costs by type of poor Power Quality event were calculated from the survey results:

Surge or transient:	€120,000 - 180,000
Long interruption:	€90,000
Short interruption, service sectors:	€18,000 - 36,000
Short interruption, industry:	€7,000 - 14,000
Voltage dip:	€2,000 - 4,000

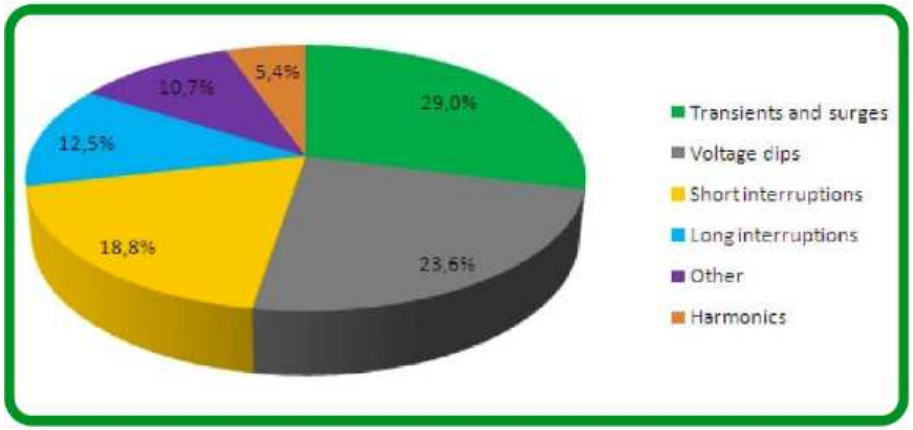
Source: LPQI 2015 (Leonardo Power Quality Initiative)_

Power Quality disturbances are one of the major causes of unplanned outages and equipment failures

30-40% of all unplanned outages are related to poor Power Quality



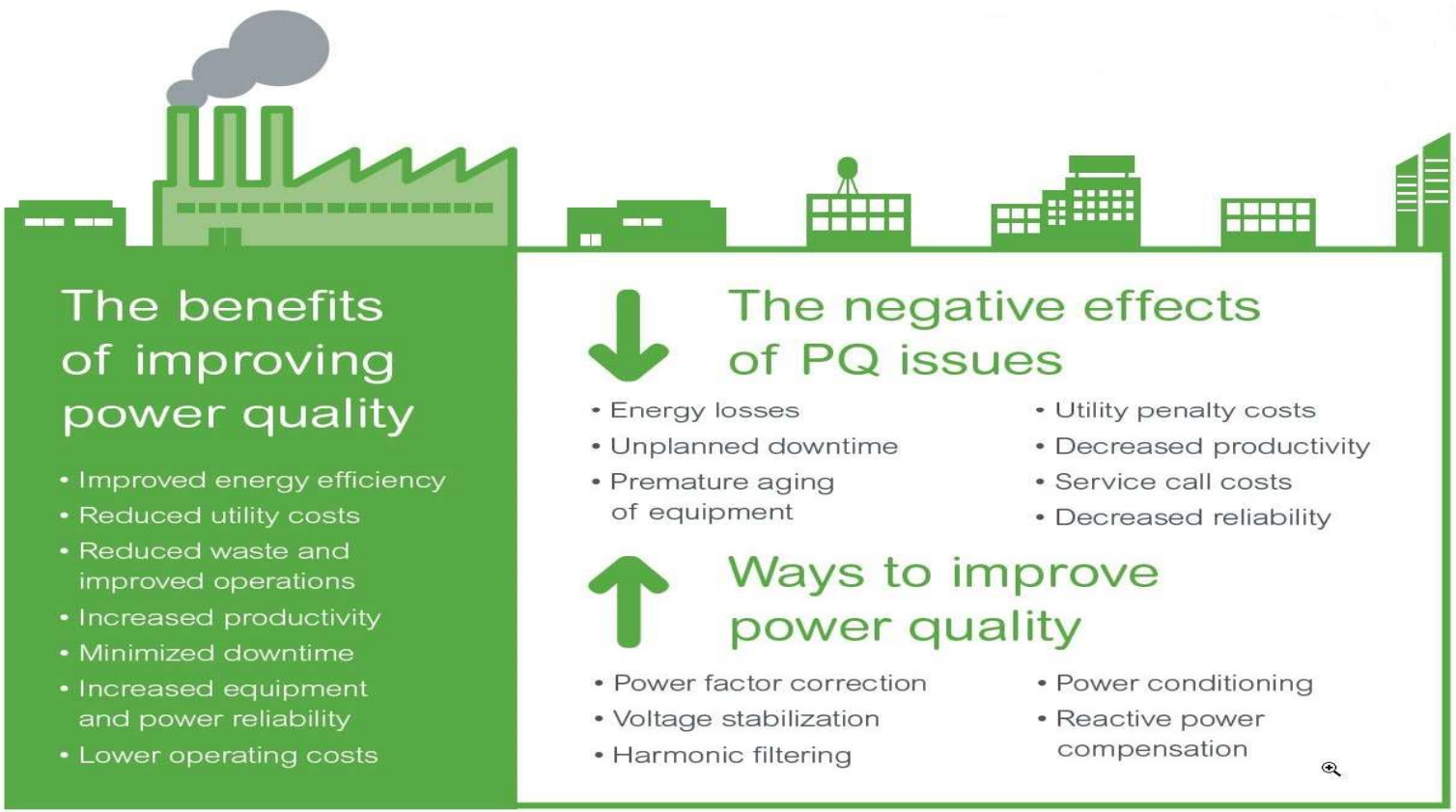
Most common power quality issues (US)



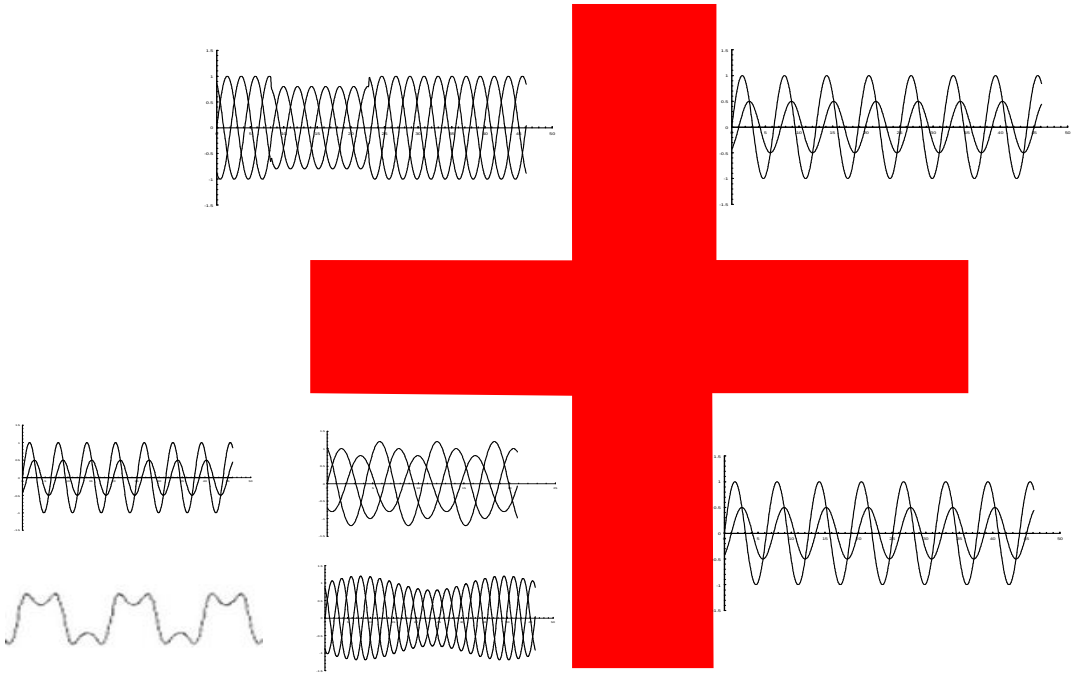
Most common power quality issues (EU)

Companies get sued & people get fired when this stuff happens

Benefits of improving your Power Quality



Our Technology



Mini-EVR
SureVolt
SagFighter

Volt. Regulation

Sags
Swells

VarSet
AV6000
AT6000

LV Cap Banks

LV PFC

Harmonics
Load imbalance
Ficker
PPC

Active Harmonic Filtering and VAR Compensation

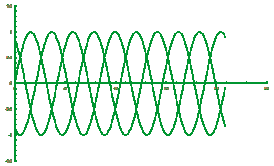
AccuSine PCS+
AccuSine PFV+
AccuSine SWP

MV Equipment

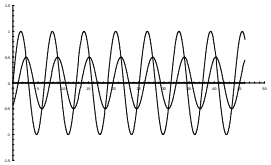
MV PFC

Capacitors (Propivar NG)
Metal Enclosed Banks

Power Quality problems

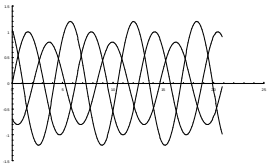


3-phase balanced

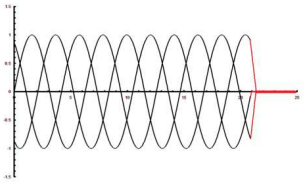


Power Factor

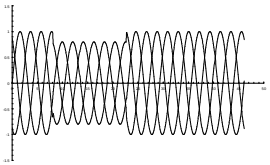
Harmonics



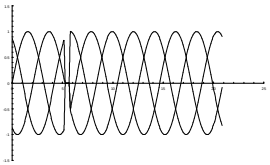
Phase unbalance



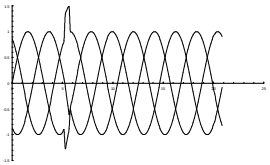
Blackout



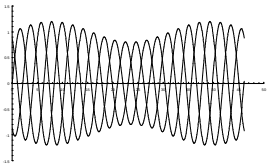
Sags/swells
Overvoltage



notches



Transient (Spike)



Flicker

Noise

Power Management Offer Portfolio

Measure

Gather accurate power and energy data from key distribution points, monitor power quality, log events

Interoperability
Standard Industry protocols and form factors
Customization: scalability in size and performance

Understand

Turn data into meaningful, actionable information for you and your stakeholders

Robust, flexible software platform architectures
Real-time energy consumption monitoring
Dynamic control interfaces
Real-time and historical power quality analysis

Act

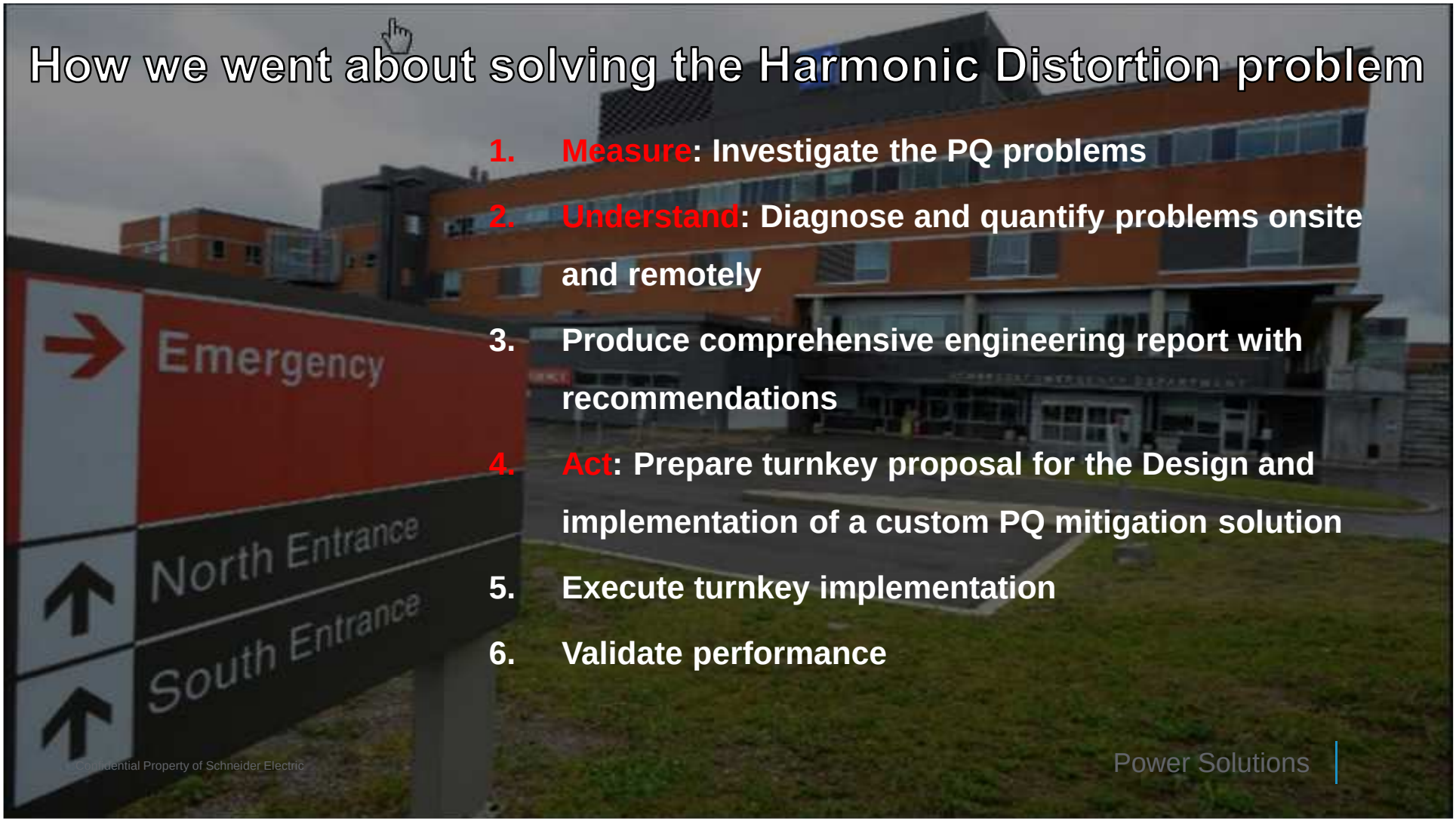
Make timelier, intelligent decisions based on valid, actionable information

Increased energy efficiency and cost savings
Maximize electrical network reliability and availability
Optimize electrical asset performance

Turnkey Project case study

Active Harmonic Filter installation in existing hospital

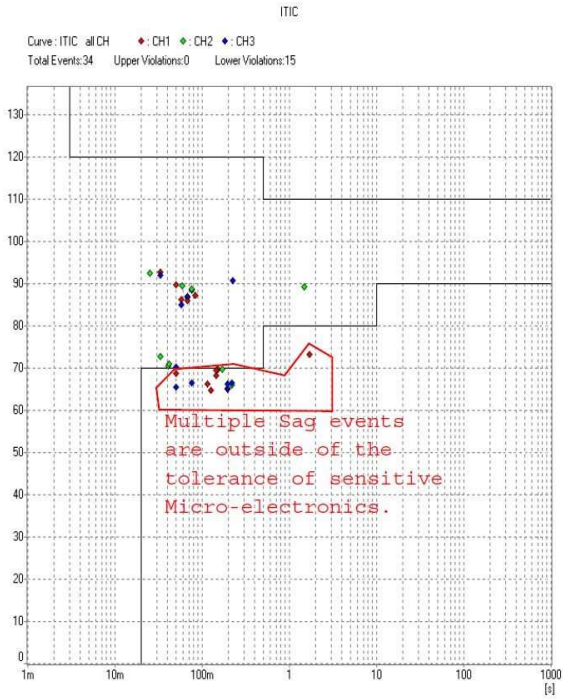
How we went about solving the Harmonic Distortion problem



1. **Measure: Investigate the PQ problems**
2. **Understand: Diagnose and quantify problems onsite and remotely**
3. **Produce comprehensive engineering report with recommendations**
4. **Act: Prepare turnkey proposal for the Design and implementation of a custom PQ mitigation solution**
5. **Execute turnkey implementation**
6. **Validate performance**

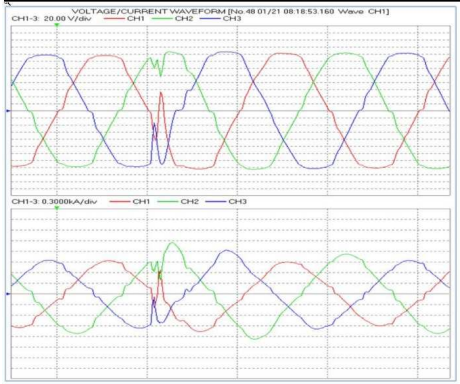
Power Quality disturbances

- 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 %



Possible solutions

Solution	Pros	Cons	Mitigates Voltage Distortion on Dialysis Machine	Mitigates Voltage Sag on Dialysis Machine	Mitigates Multiple Zero Crossings on Dialysis Machine	Estimate	Recommended
1. **Active Harmonic Filter**	Will solve Vthd problem in the entire distribution system	Requires further analysis to size correctly	✓	✗	✗	TBD	✓
2. **SagFighter**	Protects the Dialysis Machines	No effect on PQ problems	✗	✓	✓	64,000$ + installation	✓
3. **UPS**	Protects the Dialysis Machines	No effect on PQ problems	✓	✓	✓	120,000$ + installation	✗

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Substation measurements

Unit Substation B (600V)

Bus A: THDv = 3.6 %,
THDi = 14.8 % at 1,113 A

Bus B: THDv = 4.2 %
THDi = 13.8 % at 1,368 A

Switchboard ED (600V)

Bus A: THDv = 3.7%
THDi = 8.0% at 594 A

Bus B: THDv = 4.6%
THDi = 19.3% at 723 A

Unit Substation C (208V)

Bus A: THDv = 3.6%
THDi = 6.2 % at 200 A

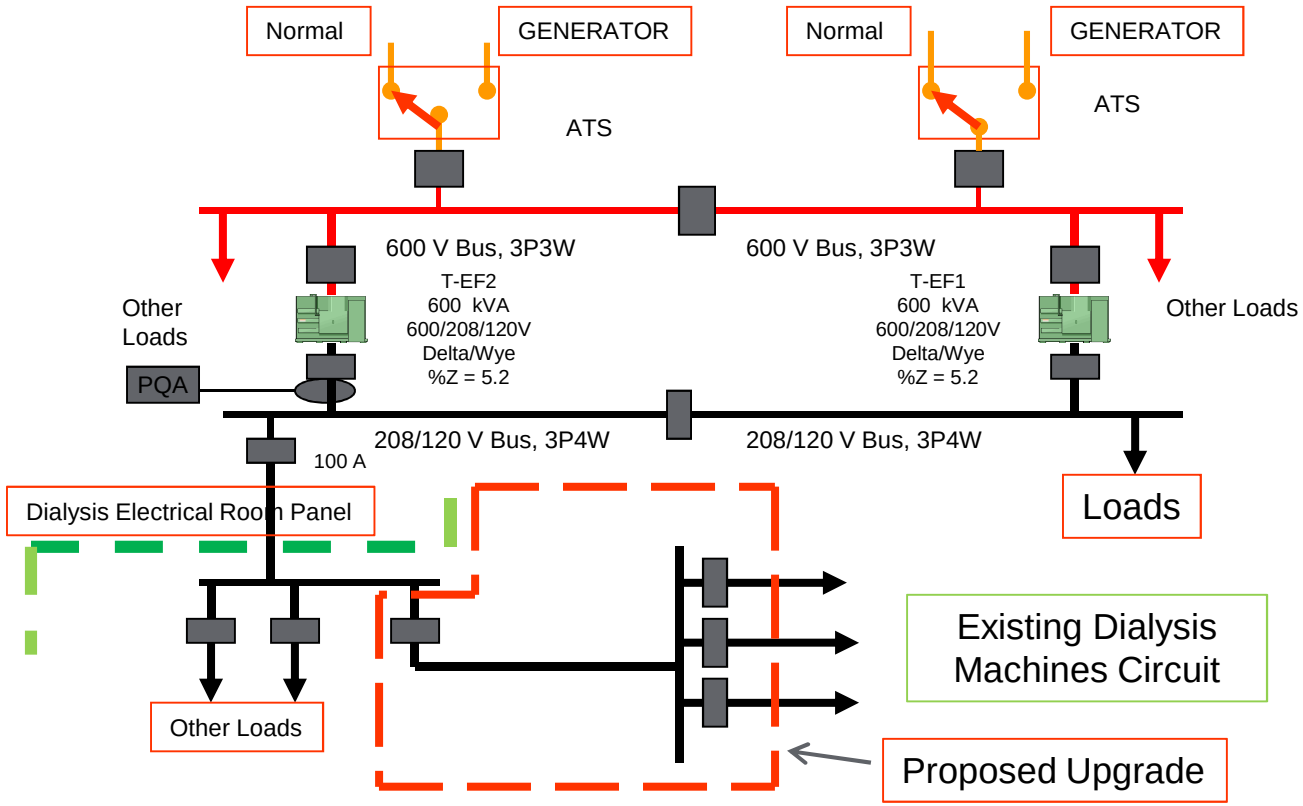
Bus B: THDv = 4.2%
THDi = 3.4% at 295 A

Unit Substation EF (208V)

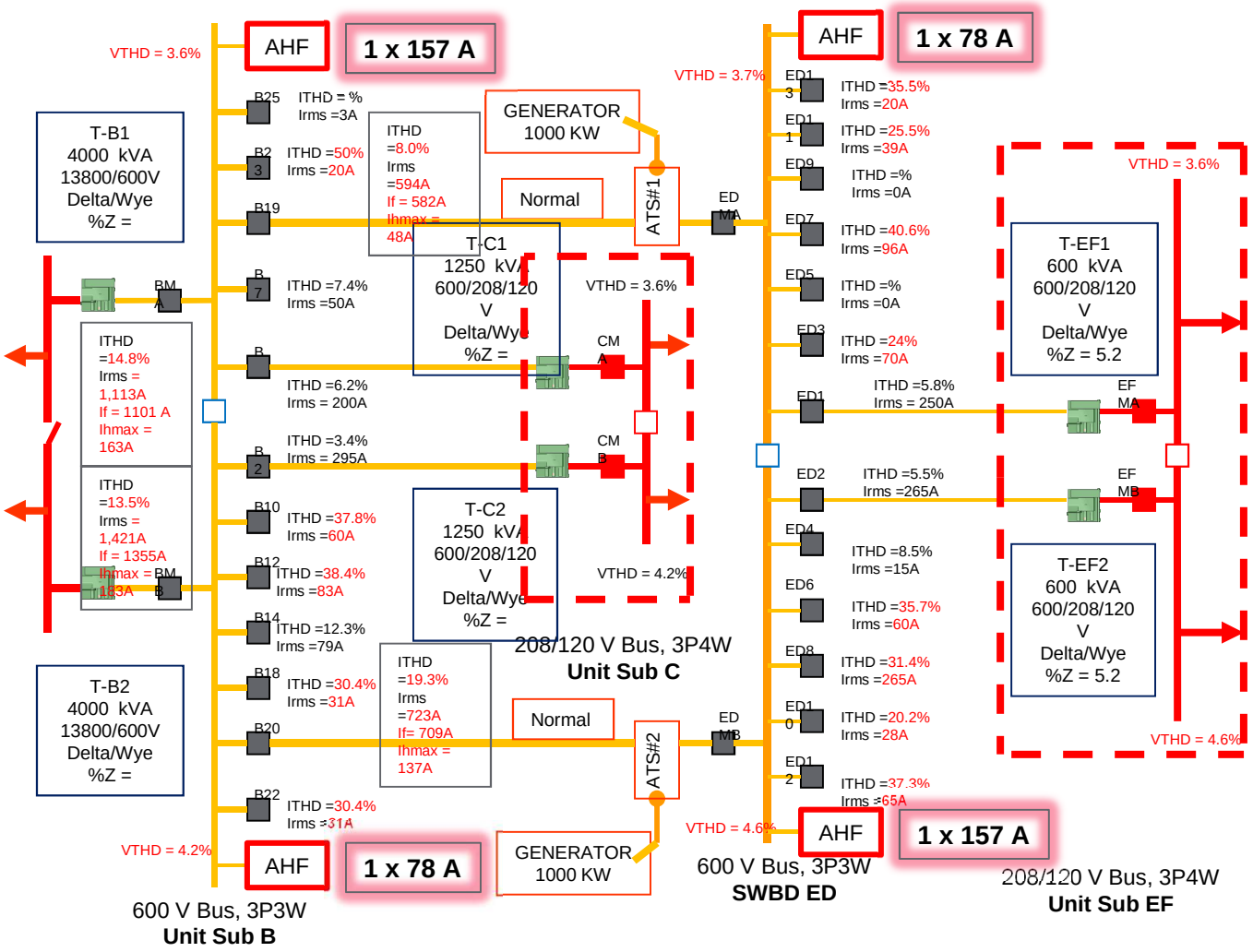
Bus A: THDv = 3.6%
THDi = 5.8% at 250 A

Bus B: THDv = 4.6%
THDi = 5.5% at 265 A

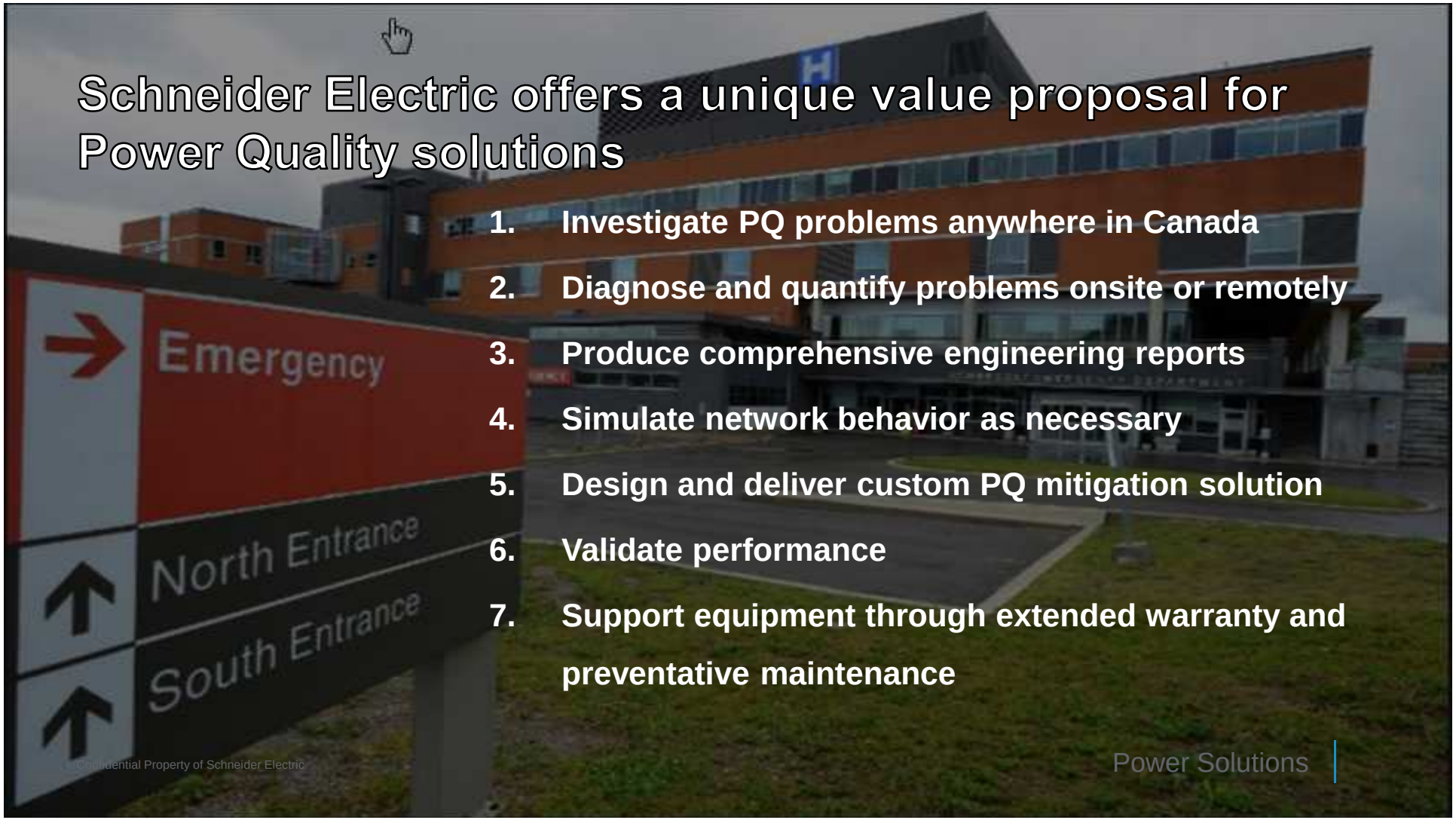
Simplified hospital electrical system



T-EF2/ T-EF1 Electrical System


VTHD = 3.6%
AHF
1 x 157 A
T-B1
4000 kVA
13800/600V
Delta/Wye
%Z =
B25
ITHD = %
Irms =3A
B2 3
ITHD =50%
Irms =20A
B19
ITHD =8.0%
Irms =594A
If = 582A
Ihmax = 48A
GENERATOR
1000 KW
Normal
ATS#1
ED MA
T-C1
1250 kVA
600/208/120 V
Delta/Wye
%Z =
VTHD = 3.6%
CM A
B 7
ITHD =7.4%
Irms =50A
BM A
ITHD =14.8%
Irms = 1,113A
If = 1101 A
Ihmax = 163A
B 6
ITHD =6.2%
Irms = 200A
ITHD =3.4%
Irms = 295A
CM B
B 2
B10
ITHD =37.8%
Irms =60A
T-C2
1250 kVA
600/208/120 V
Delta/Wye
%Z =
VTHD = 4.2%
B12
ITHD =38.4%
Irms =83A
ITHD =13.5%
Irms = 1,421A
If = 1355A
Ihmax = 183A
BM B
B14
ITHD =12.3%
Irms =79A
208/120 V Bus, 3P4W
Unit Sub C
B18
ITHD =30.4%
Irms =31A
ITHD =19.3%
Irms =723A
If= 709A
Ihmax = 137A
T-B2
4000 kVA
13800/600V
Delta/Wye
%Z =
B20
Normal
ATS#2
ED MB
B22
ITHD =30.4%
Irms =31A
VTHD = 4.2%
AHF
1 x 78 A
GENERATOR
1000 KW
600 V Bus, 3P3W
Unit Sub B
VTHD = 3.7%
AHF
1 x 78 A
ED1 3
ITHD =35.5%
Irms =20A
ED1 1
ITHD =25.5%
Irms =39A
ED9
ITHD =%
Irms =0A
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
ED1 0
ITHD =20.2%
Irms =28A
ED1 2
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

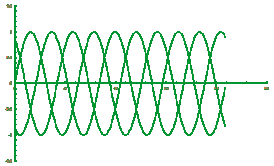
Our Value Proposal



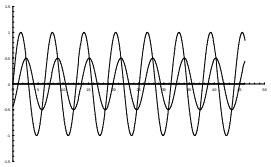
Schneider Electric offers a unique value proposal for Power Quality solutions

1. Investigate PQ problems anywhere in Canada
2. Diagnose and quantify problems onsite or remotely
3. Produce comprehensive engineering reports
4. Simulate network behavior as necessary
5. Design and deliver custom PQ mitigation solution
6. Validate performance
7. Support equipment through extended warranty and preventative maintenance

Power Factor Correction Capacitor Banks

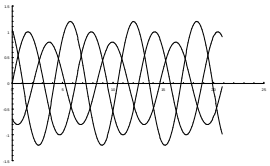


3-phase balanced

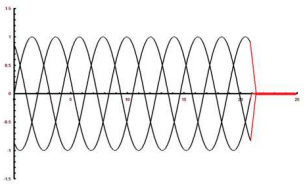


Power Factor

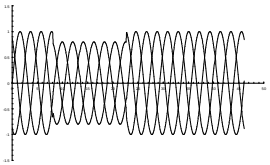
Harmonics



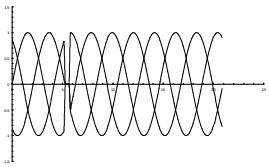
Phase unbalance



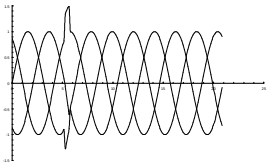
Blackout



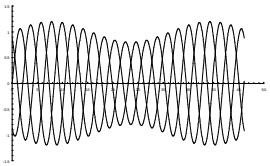
Sags/swells
Overvoltage



notches



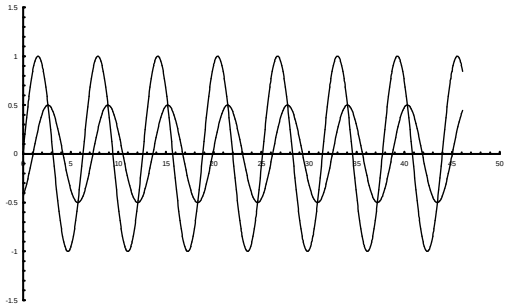
Transient (Spike)



Flicker

Noise

Power Factor Problem



Causes

- Large motors, Lightly loaded transformers

Signs/Symptoms

- Power Factor penalty on utility bills

Business Impact

- $$$ Penalty
- Wasted electrical capacity

Solution

- Capacitor Bank
- Inverter-based PFC system

Poor Power Factor is an opportunity for savings

- Power Factor (PF) is a measure of how efficiently one draws power from the grid
- It is expressed as a percentage
  - 77% or 0.77
- Below 90% (or 95%), a billing penalty is applied by the utility
- If the current is “in phase” with the voltage, the PF=100%
- PF can be improved with AC capacitors

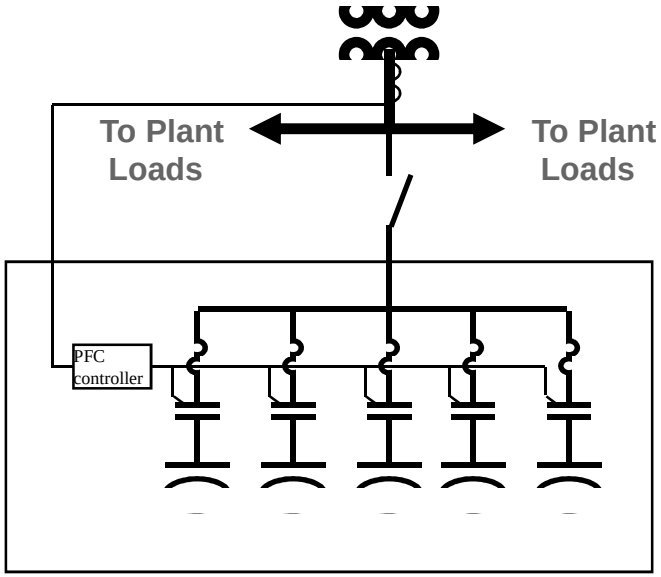
Be careful !!!

- By applying the wrong capacitor system, you can create other PQ problems: Resonance, Voltage Distortion, Voltage Transients

Standard Automatic Capacitor Bank

Standard automatic capacitor bank:

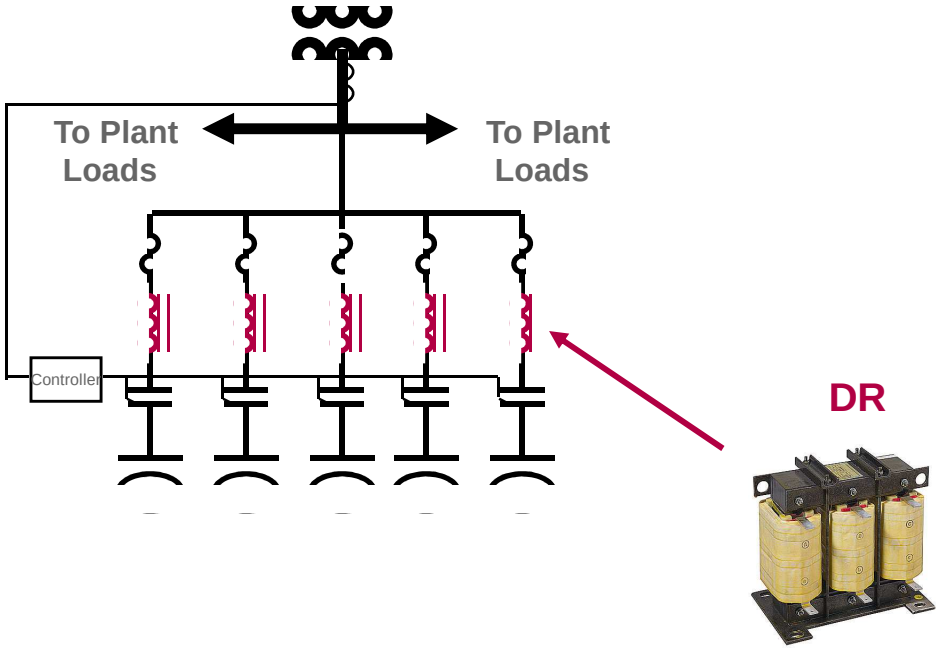
- Contains stages (or steps)
- Each stage contains:
  - Mold Case Circuit Breakers
  - Contactors for switching capacitor
  - Capacitors
- Usually installed at the main substation
- The PFC Controller measures the PF & switched capacitor stages as required to maintain a PF above the desired value



Anti-Resonant Low Voltage Automatic Capacitor Bank with Detuning Rector (DR)

De-Tuned automatic capacitor bank :

- Same as automatic capacitor bank with **De-Tuning Reactor (DR)** :
- Works like a standard automatic capacitor bank
- **Stops the resonance** between the capacitors and the supply transformer.
- (aka **Filtered** or **Anti-Resonant**)

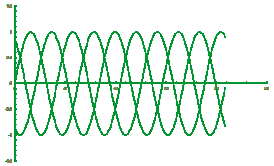


VarSet LV Capacitor Bank

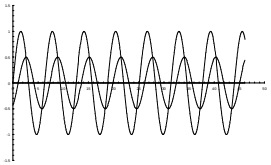
- Available at 208V, 480V and 600V
- Available with Main Lugs and Main Breaker
- Available in Standard Automatic and Detuned Automatic

Harmonic Distortion

AccuSine PQ Inverter

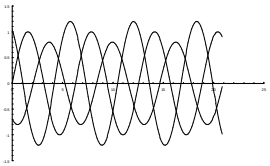


3-phase balanced

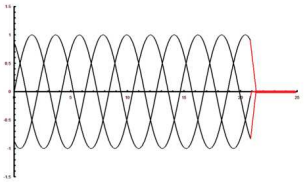


Power Factor

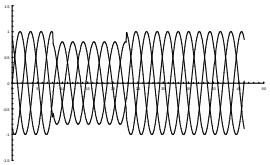
Harmonics



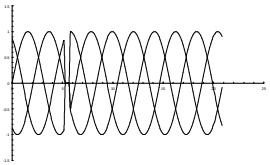
Phase unbalance



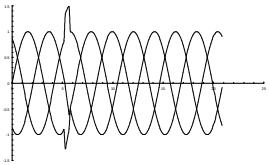
Blackout



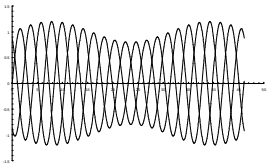
Sags/swells
Overvoltage



notches



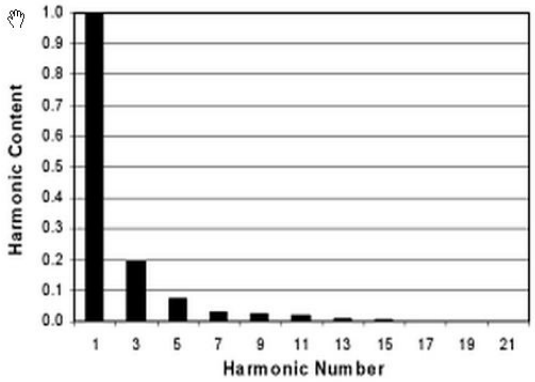
Transient (Spike)



Flicker

Noise

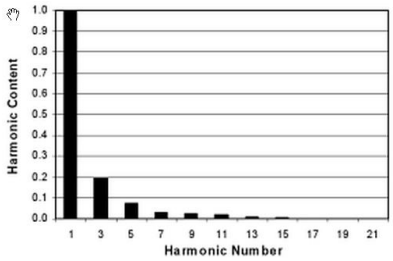
Harmonic Distortion Problem



Harmonic Distortion can affect current and voltage

- Harmonic Distortion exists because the waveform contains higher order frequencies (multiples of the 60Hz fundamental or “harmonics”)
- Harmonic Distortion is the most common Power Quality problem today, excluding poor PF
- In the context of Electrical Power Systems, Harmonic Distortion is usually separated into:
  1. Current Distortion
  2. Voltage Distortion

Harmonic Distortion – Current



Harmonic Current Distortion is the most common form of electrical pollution in today's industrial, institutional and commercial facilities

Causes

- "Non-linear" loads: VFDs, electronic power supplies, Arc Furnaces, anything electronic, Most things energy efficient

Signs/Symptoms

- Transformers/cables overheating
- Nuisance tripping of circuit breakers
- Fuses blowing
- Voltage Distortion
- Capacitors overheating

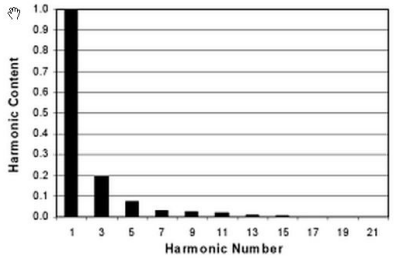
Business Impact

- Low energy efficiency
- High repair costs

Solution

- Active Harmonic Filter
- Line inductances in front of "non-linear" loads
- Passive Harmonic Filter
- Distortion free devices

Harmonic Distortion - Voltage



Harmonic Voltage Distortion is the most pernicious Power Quality problem encountered in today's industrial, institutional and commercial facilities

Causes

- Usually, Current Distortion flowing through standard transformers
- Rarely, Distorted Voltage from Utility

Signs/Symptoms

- Sensitive equipment "crashing" intermittently: Computers, PLCs, VFDs, Medical equipment, Communication systems
- Motors overheating
- Capacitors failing prematurely
- High replacement rate for sensitive electronics

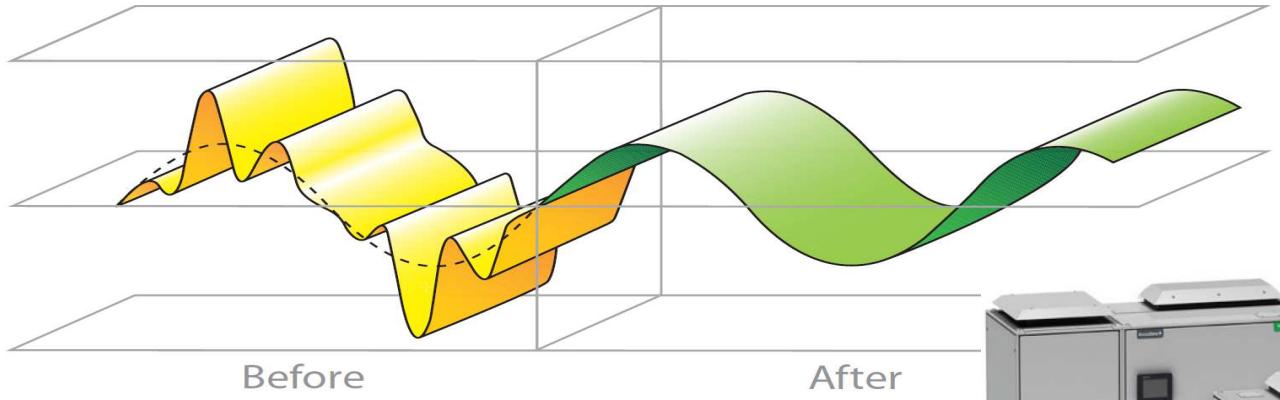
Business Impact

- Unreliable electrical system: Downtime
- Intermittently unavailable IT and financial transaction systems
- High repair costs
- Low energy efficiency

Solution

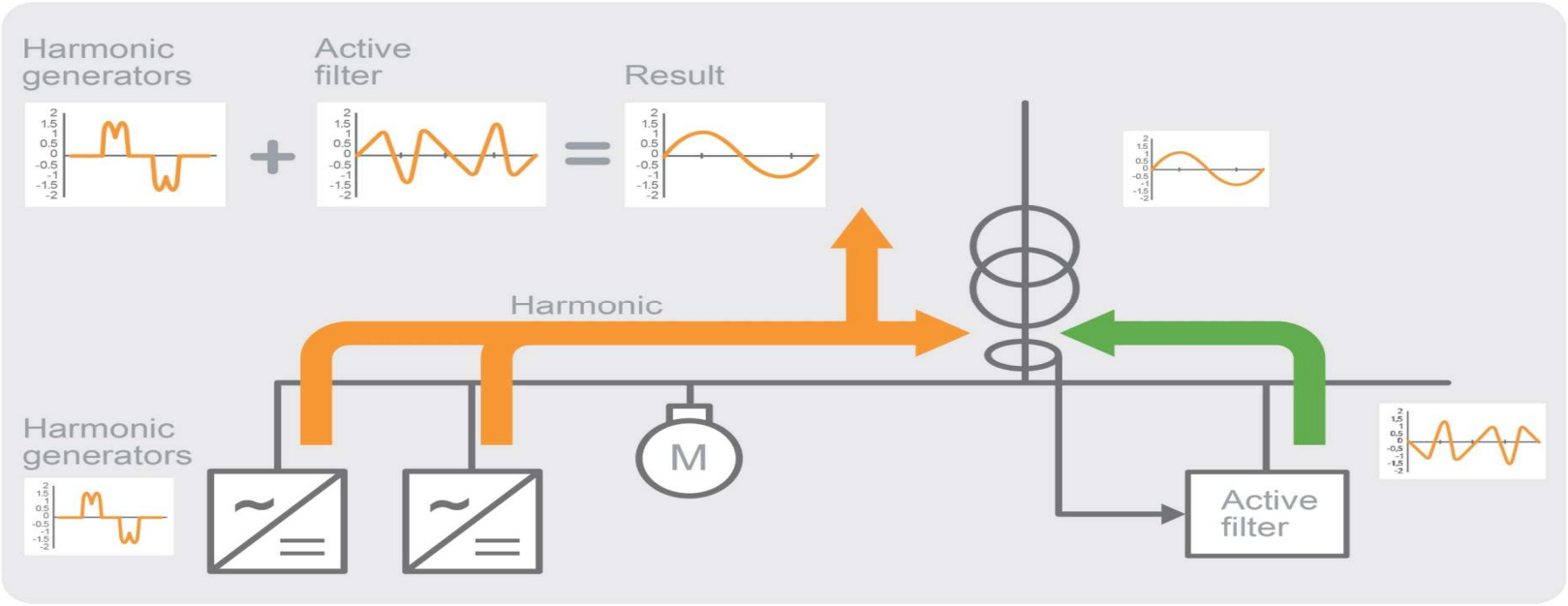
- Eliminate Current Distortion

AccuSine PCS+

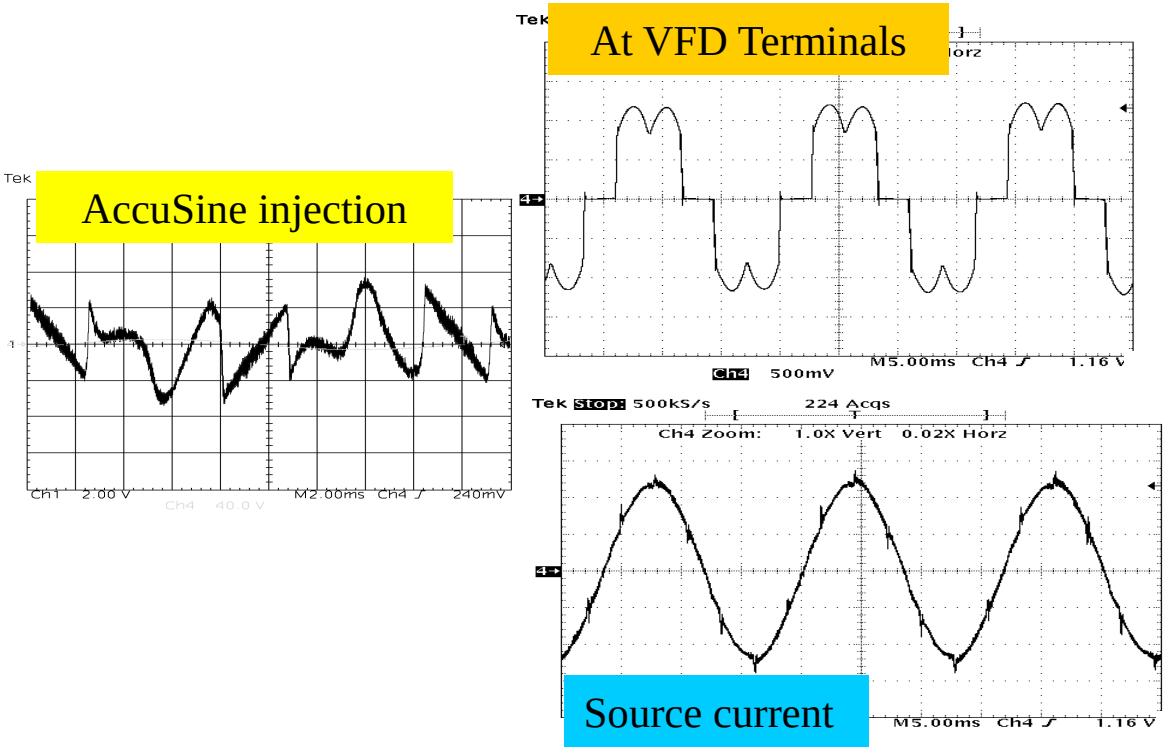


AccuSine PLUS theory of operation

AccuSine PLUS is a power electronic converter utilizing digital logic to inject corrective currents into a 3-phase power-source. These injected currents will compensate for existing harmonic currents from the 2nd to the 50th harmonic order drawn by non-linear loads connected to that grid.

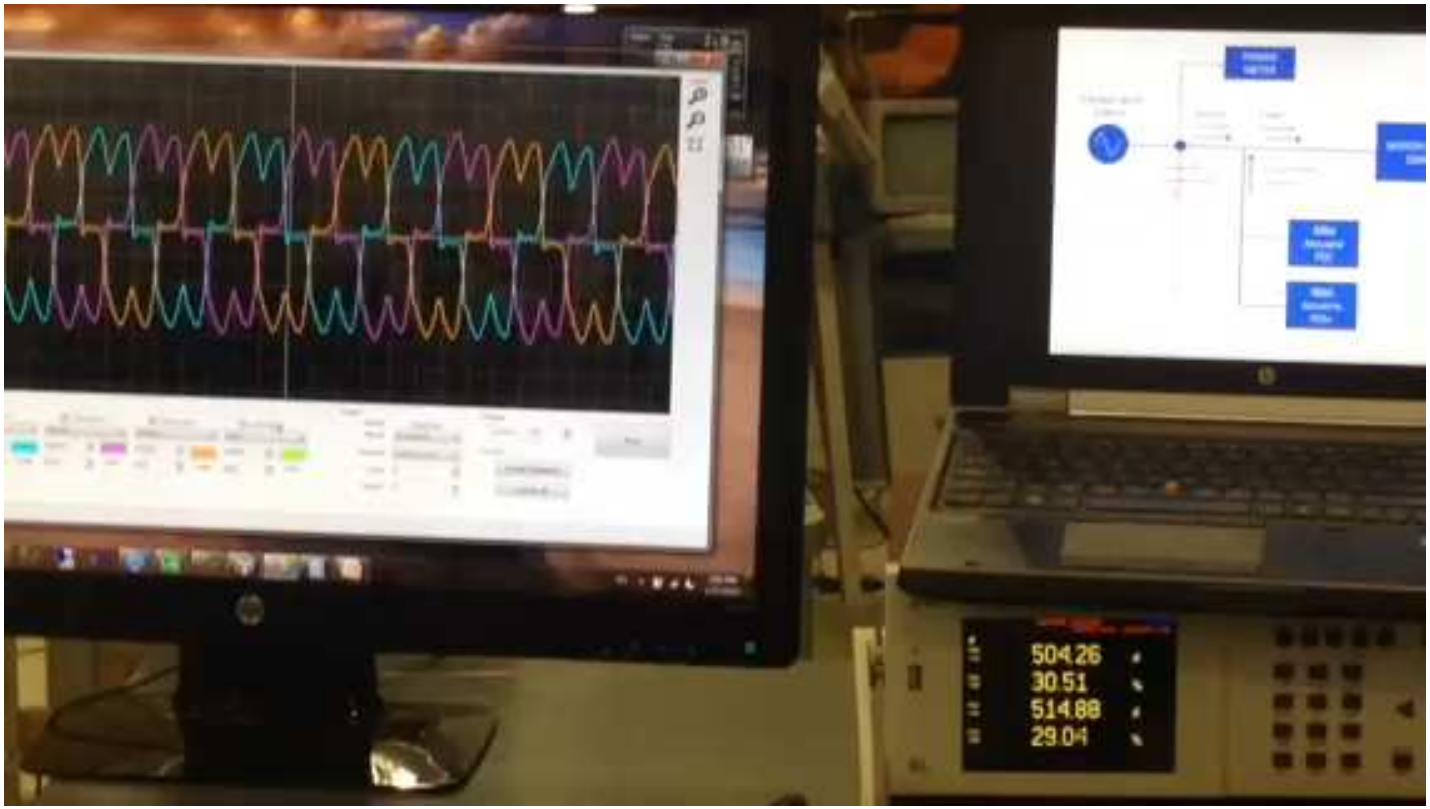


Harmonic Mitigation with AccuSine® PCS



Order	AS off % I fund	AS on % 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%

AccuSine PCS+ Performance




Life Is On