Power Quality - Schneider Electric
IEEE/IAS

Presented by:

Mario Teti – Power Services - PQ Business Development Manager

Life Is On | Schneider Electric

Schneider Electric Power Quality Services

Mario Teti

Power Quality Management Lifecycle

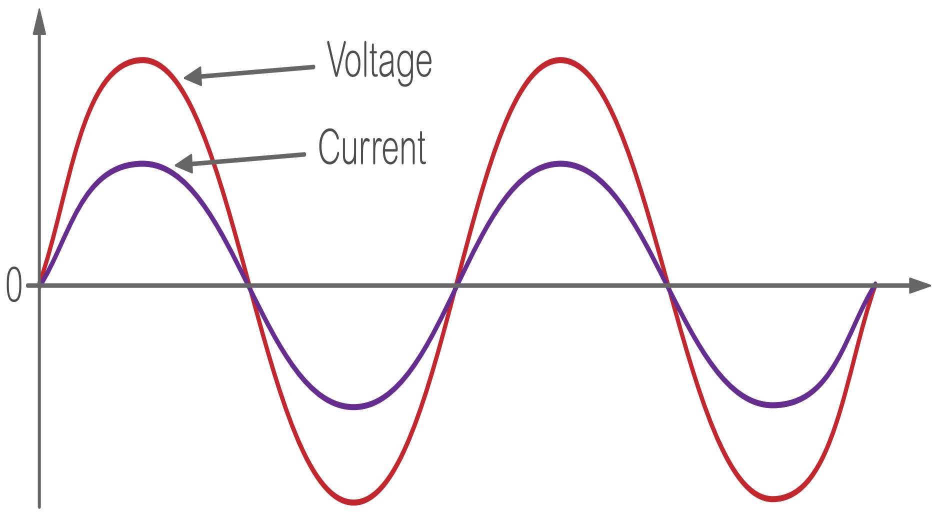
Agenda

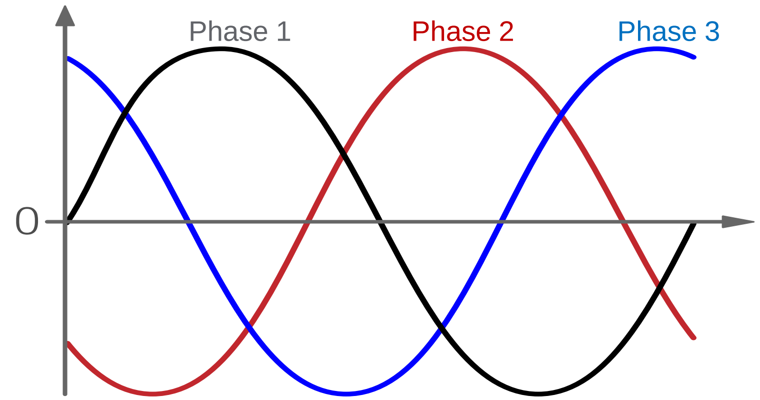
- IMPORTANCE OF POWER QUALITY
- TRENDS IMPACTING POWER QUALITY
- MAXIMIZE POWER QUALITY PERFORMANCE
- QUESTIONS & ANSWERS

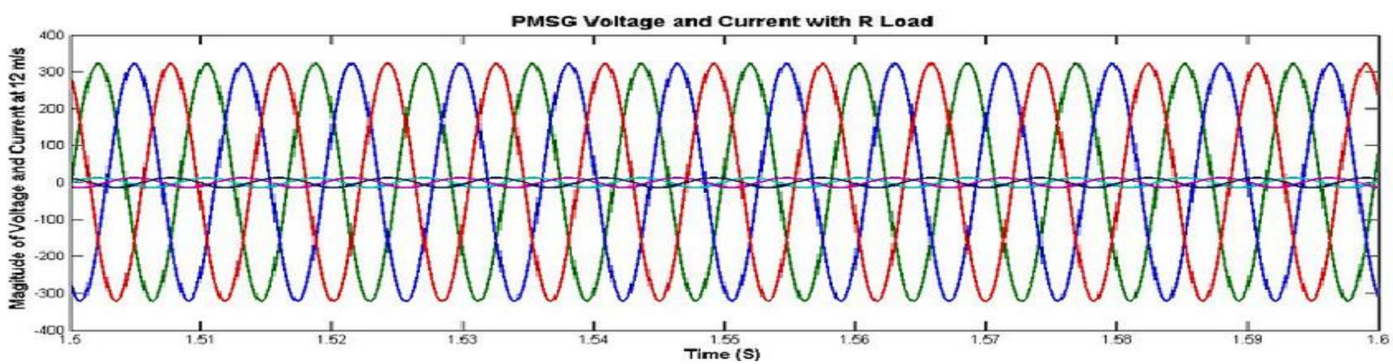

IMPORTANCE OF POWER QUALITY
TRENDS IMPACTING POWER QUALITY
MAXIMIZE POWER QUALITY PERFORMANCE
QUESTIONS & ANSWERS

Power Quality – What is it?

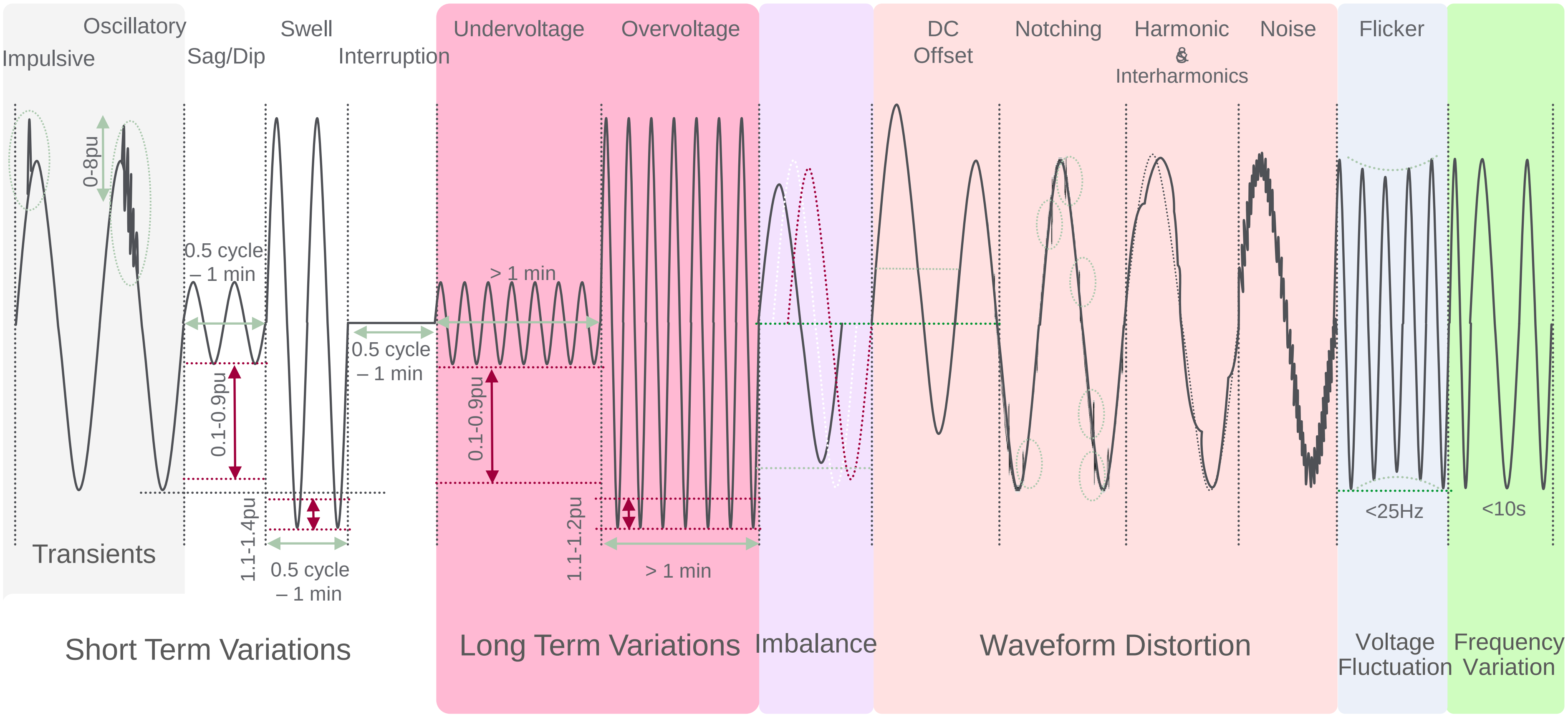
Perfect AC power waveforms







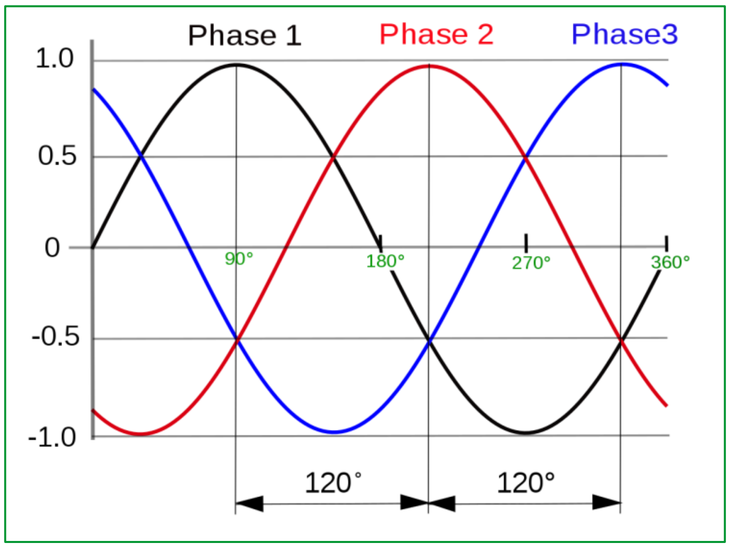
Power Quality Disturbances



Where do most of Power Quality issues originate from?

Ideal utility/source

(3-phase balanced Voltage)



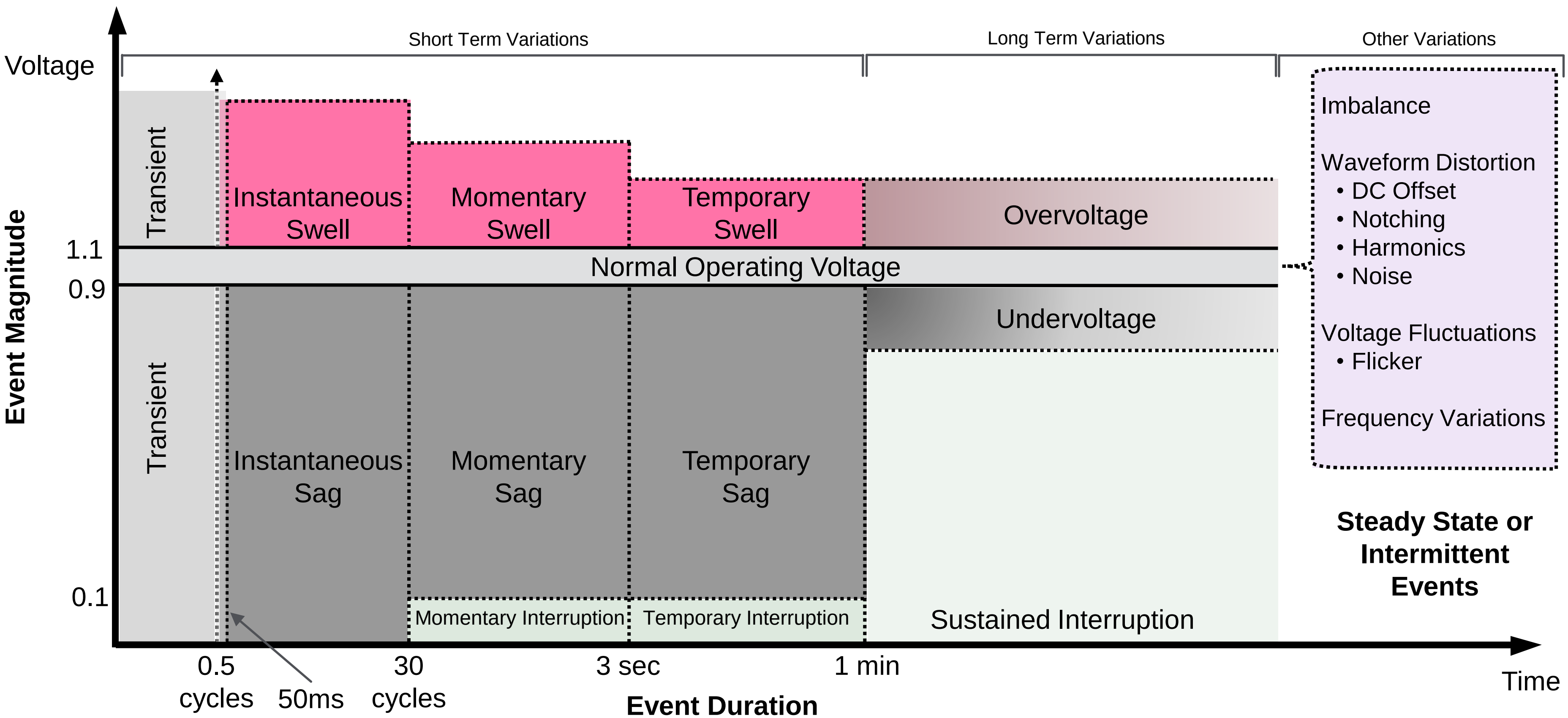
Generally observed within the facility

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...)

It is estimated that 70-80% of all power quality issues arise within the facility's electrical network.

Emanuel, A. E.; McNeil, J. A. (1997). Electric power quality, Annual Rev. Energy Environ, Worcester Polytechnic Institute, Massachusetts, USA. Ref no. 1997.22:263-303

IEEE 1159 Definitions - IEEE Recommended Practice for Monitoring Electric Power Quality



IEEE 519-2022 Latest IEEE Recommended Practice for Harmonic Standard

IEEE 519-2014

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	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	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.

IEEE 519-2022

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

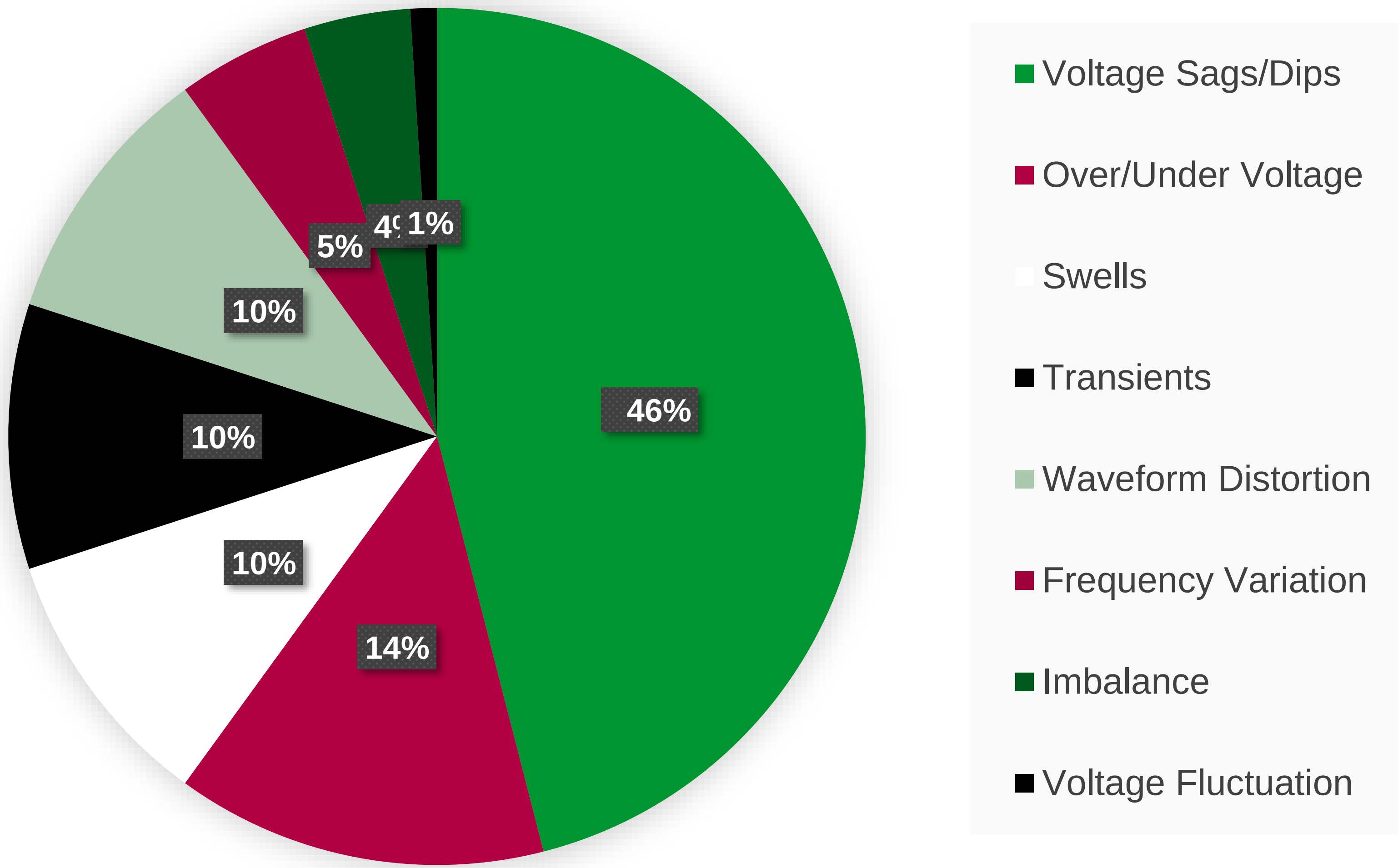
Maximum harmonic current distortion in percent of I_L						
Individual harmonic order[b]						
I_{SC}/I_L	$2 \le h < 11$[a]	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
< 20[c]	4.0	2.0	1.5	0.6	0.3	5.0
$20 < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < 100$	10.0	4.5	4.0	1.5	0.7	12.0
$100 < 1000$	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] For $h \le 6$, even harmonics are limited to 50% of the harmonic limits shown in the table.

[b] Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

[c] Power generation facilities are limited to these values of current distortion, regardless of actual I_{sc}/I_L unless covered by other standards with applicable scope.

Occurrence of Power Quality Disturbances

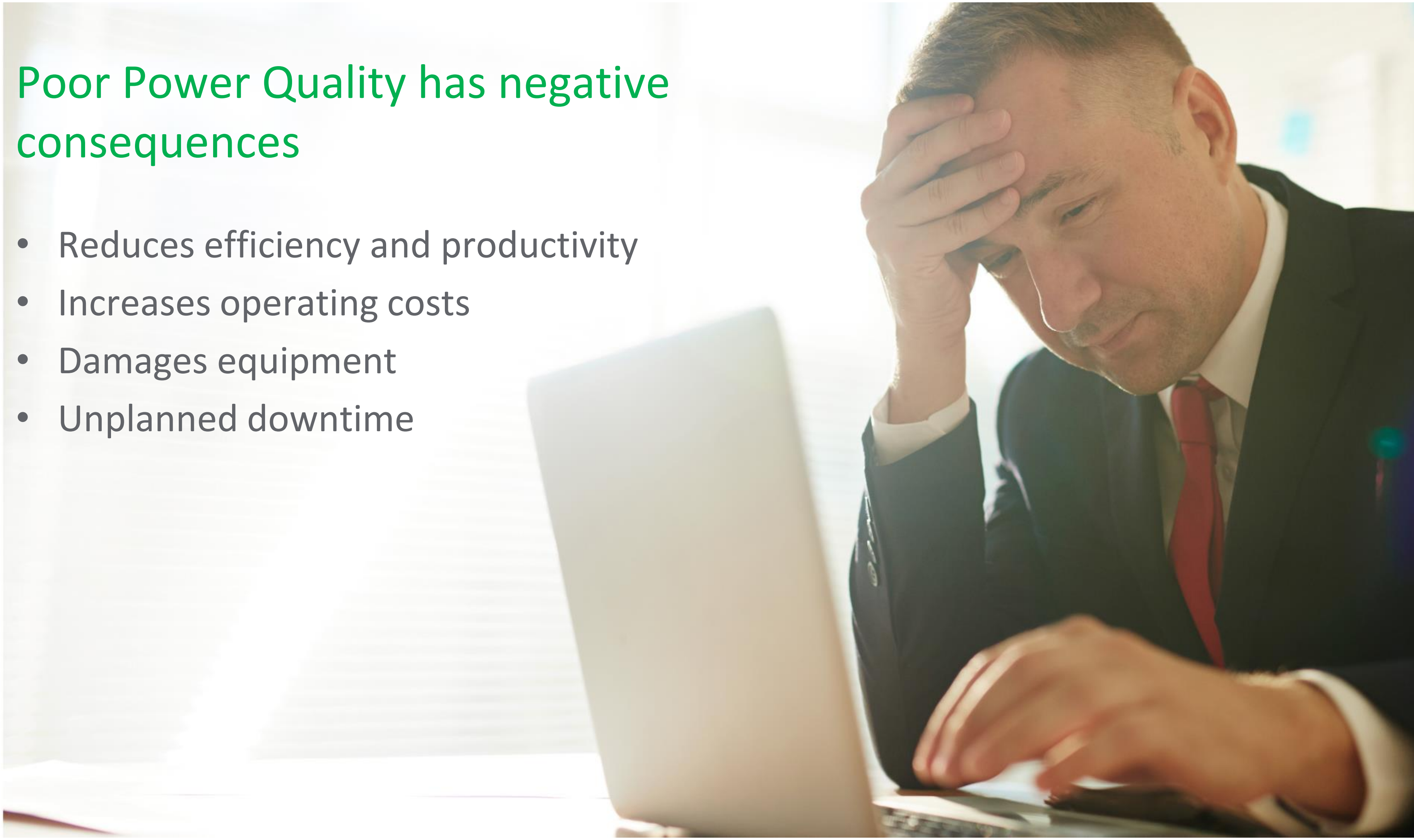


Based on data from Electric Power Research Institute
DPQ-1 Study 2001

Typical Power Quality Symptoms

- Unexpected equipment shutdown
- **Transformers humming**
- Flickering lights
- **Data loss**
- Low system capacity
- **Circuit breakers tripping**

- **Contactors dropping out**
  - Electrical cables running hot
- **Circuit board failures**
  - Malfunction of controllers
- **Premature motor failure**
  - Network communication issues



Poor Power Quality has negative consequences

- Reduces efficiency and productivity
- Increases operating costs
- Damages equipment
- Unplanned downtime

Financial Implications and Downtime Associated with PQ Issues

Cost Associated with Voltage Sag or Outage

Table 1-1
Costs of Voltage Sag and Outage Events. [13]

Industry	Costs in Dollars	Restoration Time
Data Center	$10,000-$40,000 per sag event	3-10 hours
Air Traffic Control – Airport	$15,000 per minute	
Broadcast Facility	$100,000 per 0.5 hours	20-30 minutes
Paper Industry	$10,000-$30,000 per sag event	
Large Semiconductor Manufacturer	$10,000-$50,000 per event	
Plastics Industry	$10,000-$50,000 per sag event	up to 8 hours
Textile Industry	$10,000-$40,000 per event	
Automotive Industry	$15,000 per event	
Office Building	$22,000 per 500 kVA Critical Load	15 - 30 minute for a CPU
Industrial - Manufacturing	$75,000 - $200,000 per event	

Time for a restart.

Table 1-2
Average and Median Number of Hours Required to Restart after a Complete Shutdown. [14]

Industry	Average Value – Hours	Median Value – Hours
Chemical	20.7	20.0
Petroleum	37.3	24.0
Pulp and Paper	10.0	10.0
Rubber and Plastics	2.3	2.0
Textile	58.3	72.0
Manufacturing	2.2	2.0

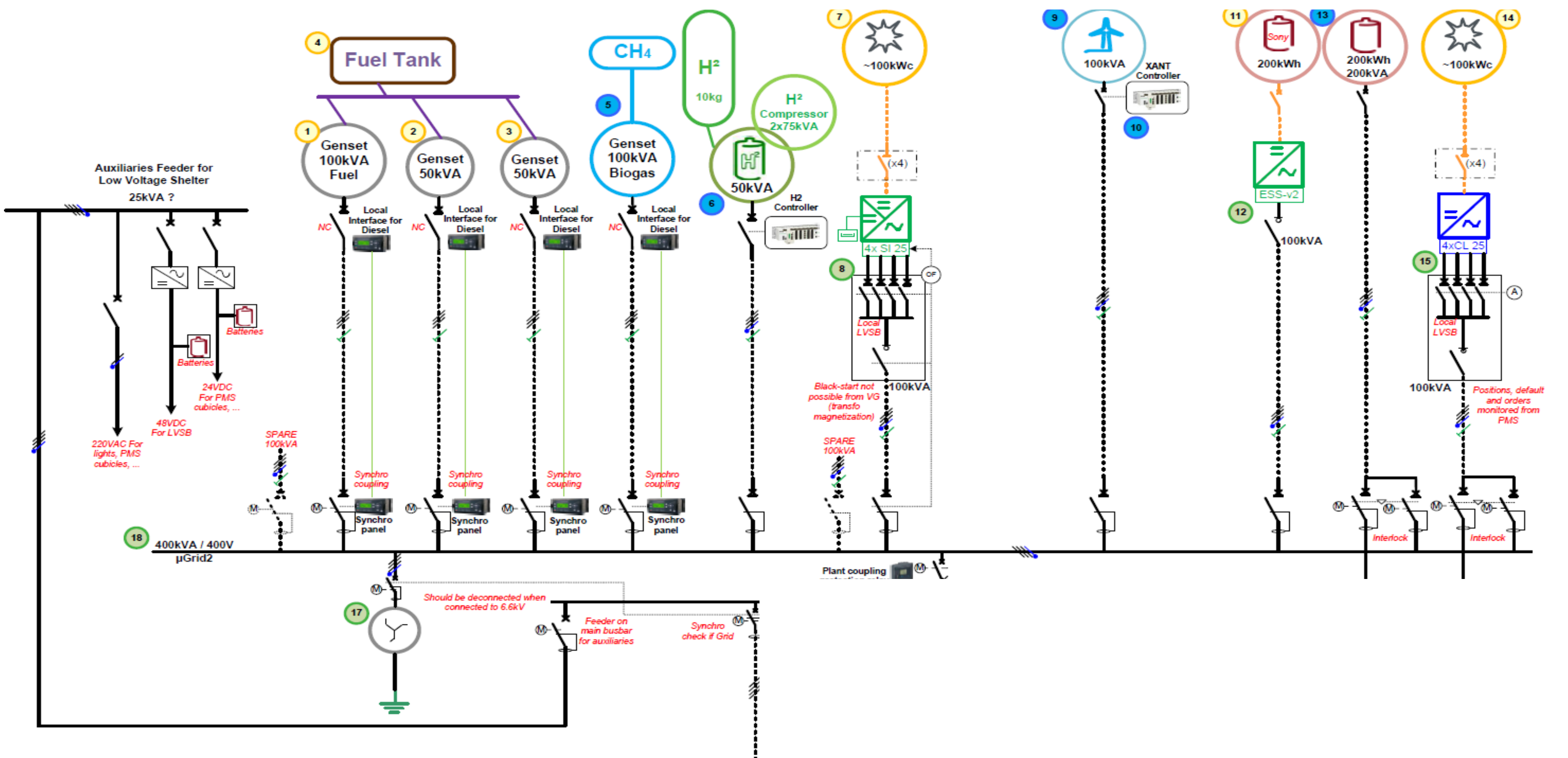
Source: EPRI 113874 Power Quality Applications Guide for Architects and Engineers


IMPORTANCE
OF
POWER QUALITY
TRENDS
IMPACTING
POWER QUALITY
MAXIMIZE
POWER QUALITY
PERFORMANCE
QUESTIONS
&
ANSWERS

Power Quality is more important than ever!

Electrical Networks will be more complex

TRENDS

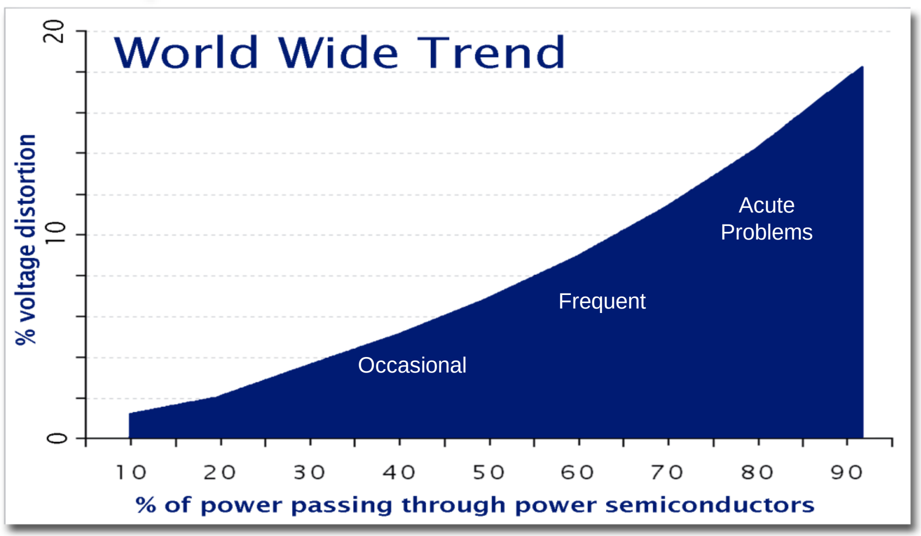


Internal

Digitization will bring more harmonics

TRENDS

“Presently, 30% of all electric power generated uses power electronics somewhere between the point of generation and end use. **By 2030, 80% of all electric power will flow through power electronics.**” - *US Department of Energy*



Study from EPRI

Effects of Voltage & Current Harmonics

Where do harmonics come from?

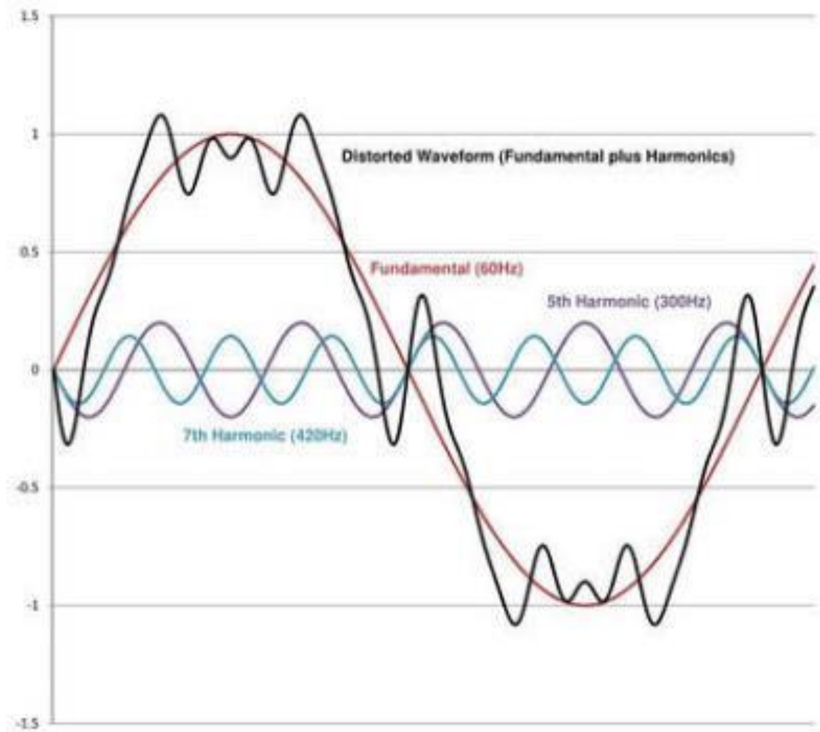
Motor speed controls
(VFD’s

UPS

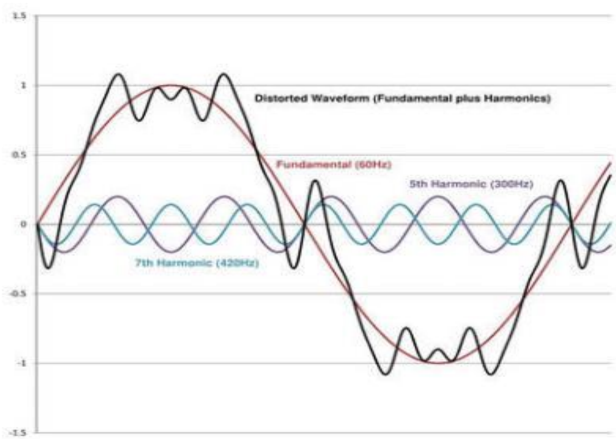
Servos

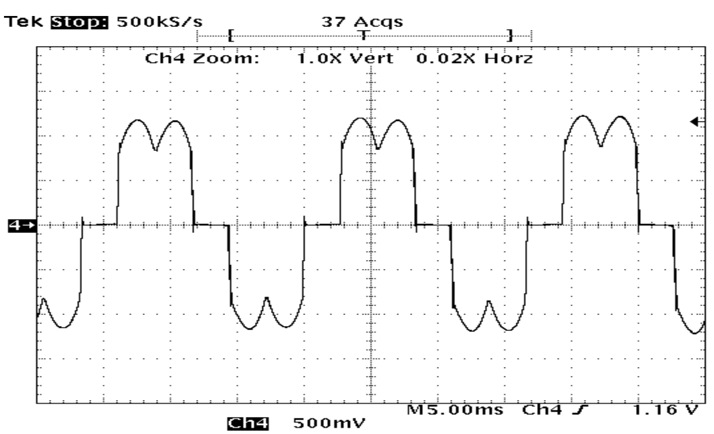
+ many more

LEDs



Multipulse converters





At VFD terminals

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	x	x			
5	x	x	x		
7	x	x	x		
9	x	x			
11	x	x	x	x	
13	x	x	x	x	
15	x	x			
17	x	x	x		x
19	x	x	x		x
21	x	x			
23	x	x	x	x	
25	x	x	x	x	
27	x	x			
29	x	x	x		
31	x	x	x		
33	x	x			
35	x	x	x	x	x
37	x	x	x	x	x
39	x	x			
41	x	x	x		
43	x	x	x		
45	x	x			
47	x	x	x	x	
49	x	x	x	x	

H_c = np +/- 1

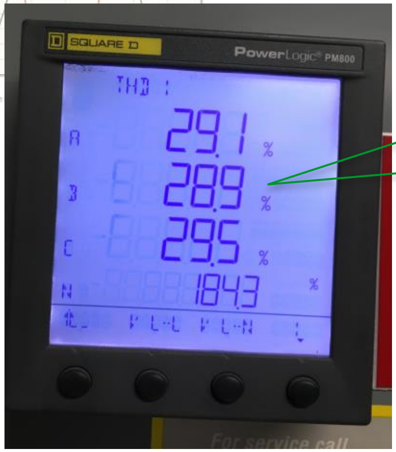
H_c = characteristic harmonic order present

n = an integer

p = number of pulses

Distortion and Harmonics

Harmonics



Only PM8000 series meters or higher can show wave shape. If the client has PME, look for waveforms like these.

Rating of Harmonic Filter? If ITHD is 30%, with Load Current of 1000A , then AHF rating = 300A.
Important : You need to figure out the max load.
AccuSine is that simple to recommended !!!


IMPORTANCE OF POWER QUALITY
TRENDS IMPACTING POWER QUALITY
MAXIMIZE POWER QUALITY PERFORMANCE
QUESTIONS & ANSWERS

#1: Management of Power Quality - Measurements

Power Quality Audits and Temporary PQ Monitoring

Flexible, strategic, can investigate specific problems on particular equipment or locations.

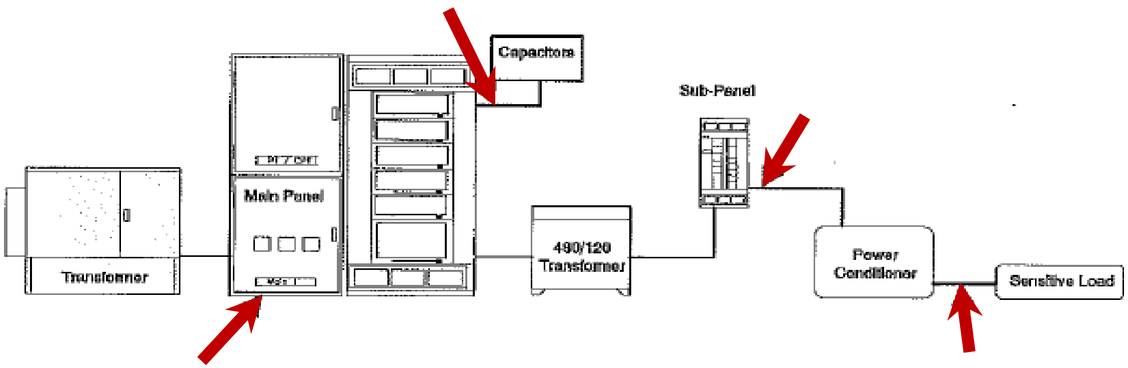
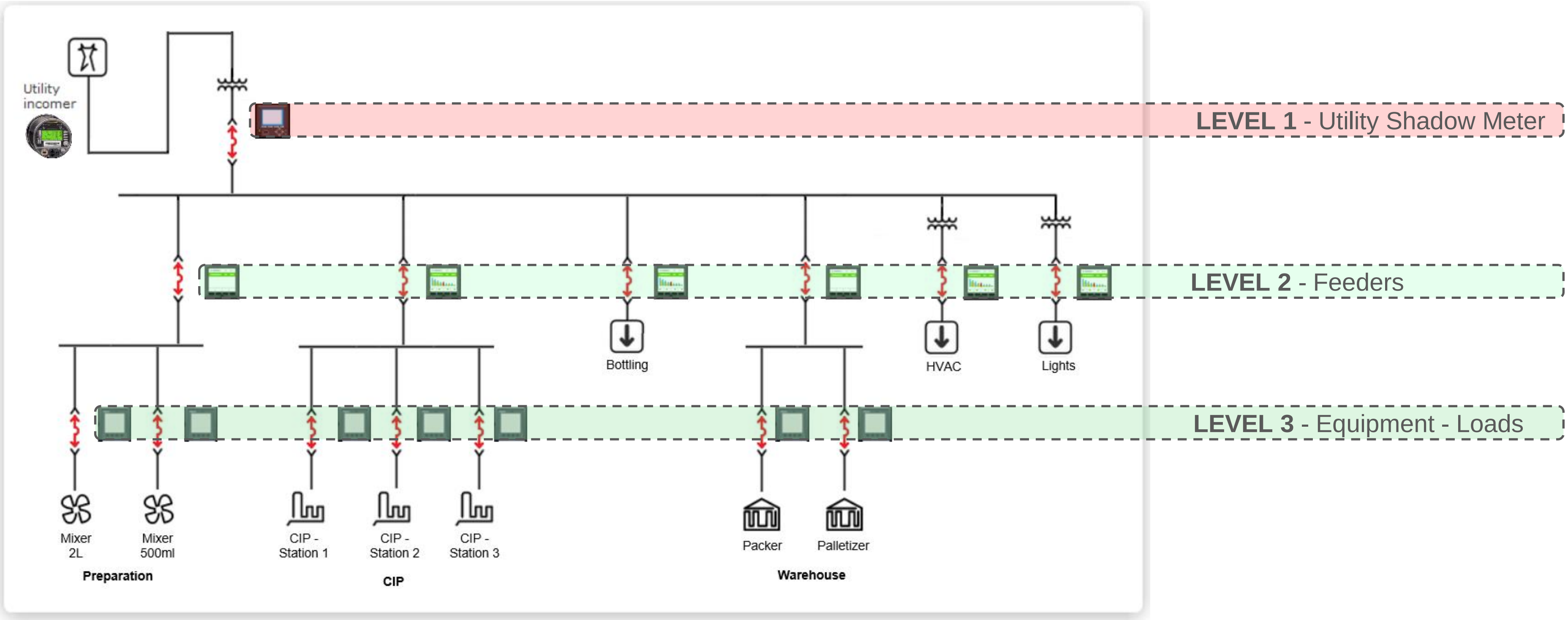


Figure 21—Suggested monitoring locations on typical low-voltage system (Arrows point to suggested location of probes.)

Permanent Power Quality Monitoring

Continuous real-time monitoring for fast detection and response.
Never miss anything.



What to Measure

PQ events & disturbances	Level 1	Level 2	Level 3
Transient events with waveforms	✓	✗	✗
Flicker	✓	✗	✗
Disturbance Direction Detection	✓	✓	✗
Interruption with waveforms	✓	✓	✗
Voltage sag/swell with waveforms	✓	✓	✗
Over/under voltage with waveforms	✓	✓	✗
Frequency variation	✓	✓	✗
Unbalance (Voltage & Current)	✓	✓	✓
Harmonics (Voltage & Current)	✓	✓	✓

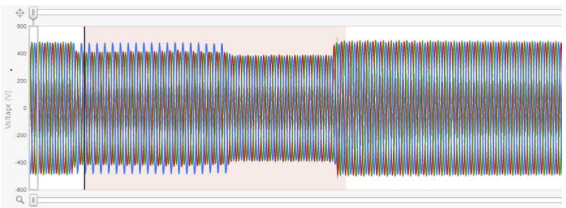
Key PQ Standards for Metering

- **IEC 61000–4–30 Class A**
- **C12.20–2015**
  with 0.1% Accuracy Class definition
- **IEC 62053–2 2nd Edition**
  with 0.1% Accuracy Class definition

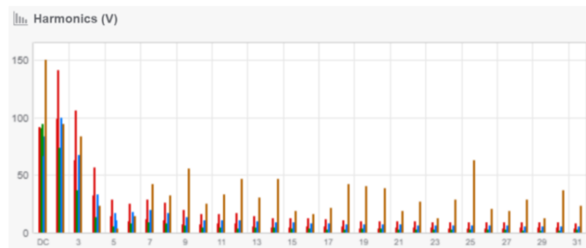
#2: Management of Power Quality - Diagnose

Specialized Software designed for Power Quality Analysis

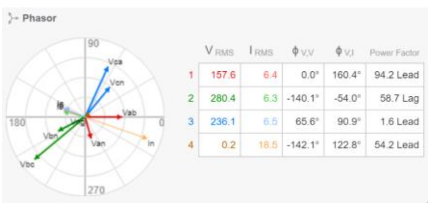
Waveform analysis tools

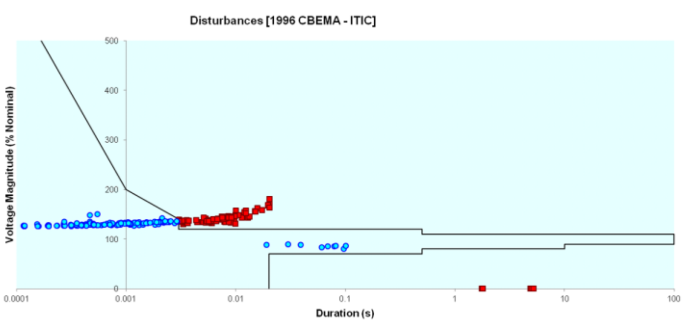


Harmonic histograms

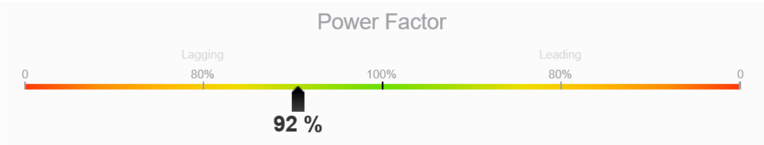


Phasor diagrams



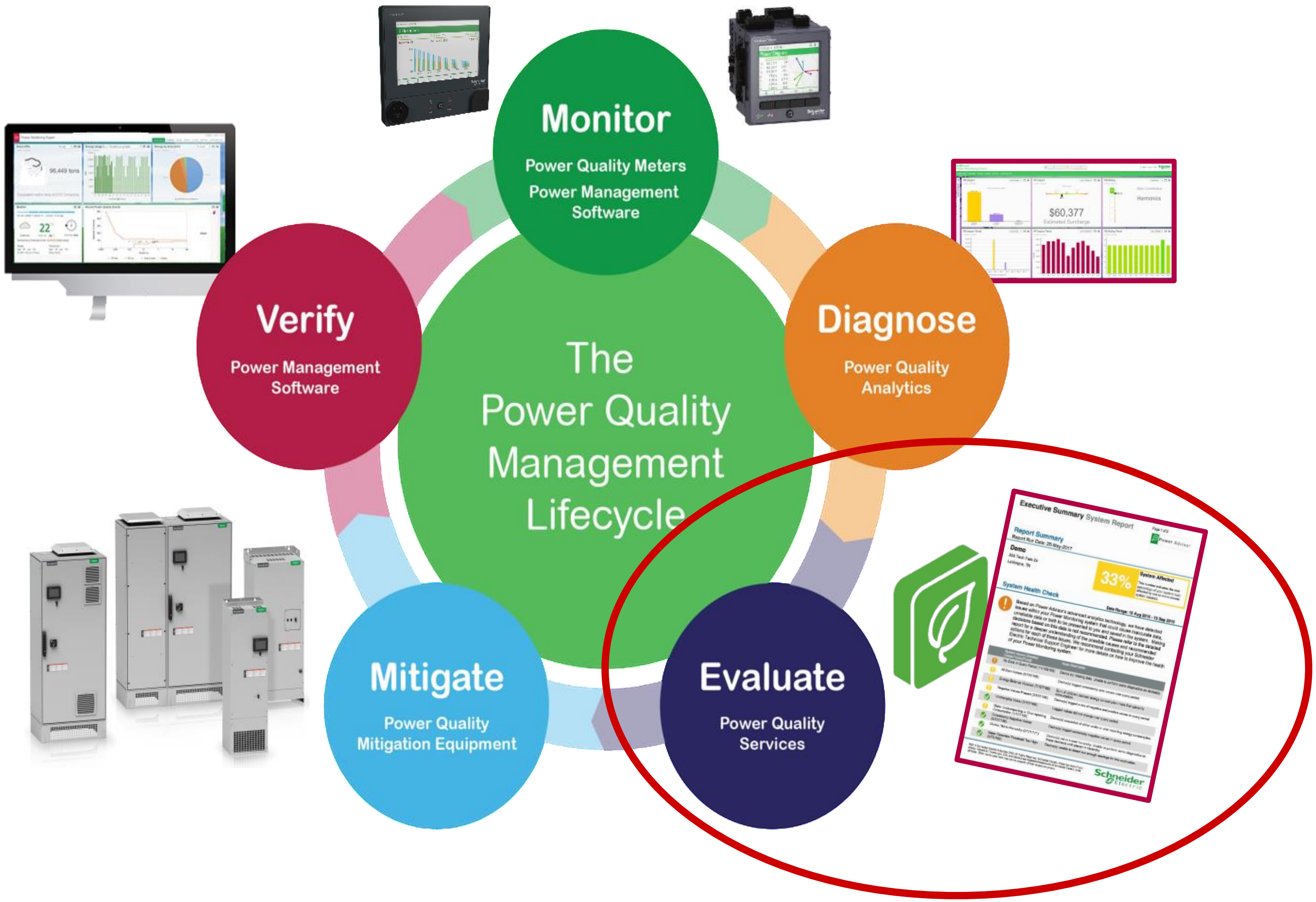


CBEMA – ITIC plots



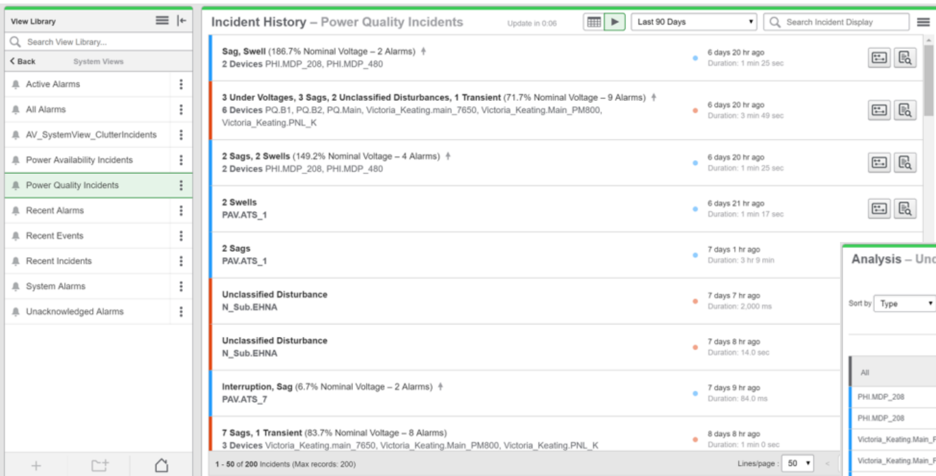
Lagging and Leading Power Factor

#3: Management of Power Quality - Evaluate

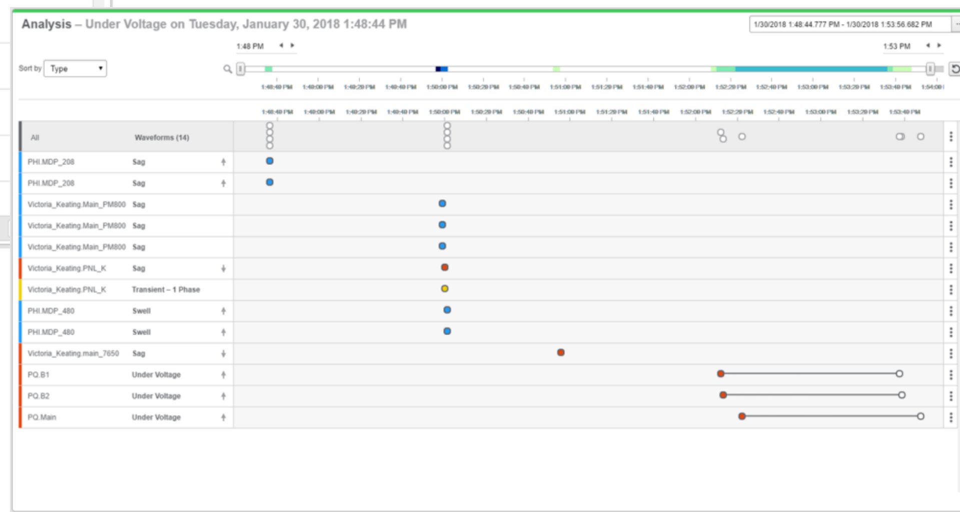


Power Events Analysis

PQ Incident Management



Timeline Analysis



Automated Power Quality Compliance Reporting

EN50160-2010

EN50160v2010 Report

1/1/2016 12:00:00 AM - 5/12/2016 12:00:00 AM (Server Local)

Measurement and Observation Period Compliance Table

Complete Compliance in this Summary? **No**

OOO.PM8000_1		Power Frequency	Supply Voltage Magnitude	Flicker	Supply Voltage Dips	Short And Long Interruptions	Supply Voltage Swells	Supply Voltage Unbalance	Harmonic Voltage	Interharmonic Voltage
Observation 1	2/20/2016	Yes	Yes	N/A	No	No	No	No	Yes	N/A
Observation 2	2/27/2016	Yes	Yes	N/A	No	Yes	No	No	Yes	N/A
Observation 3	3/5/2016	Yes	Yes	N/A	No	Yes	Yes	No	Yes	N/A
Observation 4	3/12/2016	Yes	Yes	N/A	No	Yes	No	No	Yes	N/A
Observation 5	3/19/2016	Yes	Yes	N/A	Yes	Yes	Yes	No	Yes	N/A
Observation 6	3/26/2016	Yes	Yes	N/A	No	Yes	Yes	No	Yes	N/A
Observation 7	4/2/2016	Yes	Yes	N/A	No	Yes	Yes	No	Yes	N/A
Observation 8	4/9/2016	Yes	Yes	N/A	Yes	Yes	Yes	No	Yes	N/A
Observation 9	4/16/2016	Yes	Yes	N/A	Yes	Yes	Yes	No	Yes	N/A
Observation 10	4/23/2016	Yes	Yes	N/A	No	Yes	Yes	No	Yes	N/A
Observation 11	4/30/2016	Yes	Yes	N/A	No	Yes	Yes	No	Yes	N/A
Observation 12	5/7/2016	Yes	Yes	N/A	No	Yes	Yes	No	Yes	N/A

IEEE519-2014/2022

Short Term Current Distortion Compliance - 99th Percentile						
Isc/IL=40	Individual Harmonic Order (Odd)					TDD (%)
Ratio Window Limit (20-50)	<11	11<=h<17	17<=h<23	23<=h<35	35<=h<=50	
IEEE 519 Limit (%)	10.5	5.3	3.8	1.5	0.8	12.0
Non-compliant 10-minute Weeks	2					1
Total Days	20					
%Days out of Compliance	10.00%					5.00%
Recommendation	WARNING					PASS

Short Term Current Distortion Non Compliant Weeks - 99th Percentile		
Date	Individual Harmonic	TDD - Limit 12.0%
Jan 15 2018	98.99%	99.90%
Feb 5 2018	99.30%	94.50%
Mar 28 2018	96.37%	93.40%

Short Term Current Distortion Compliance - 95th Percentile						
Isc/IL=40	Individual Harmonic Order (Odd)					TDD (%)
Ratio Window Limit (20-50)	<11	11<=h<17	17<=h<23	23<=h<35	35<=h<=50	
IEEE 519 Limit (%)	7.0	3.5	2.5	1.0	0.5	8.0
Non-compliant 10-minute Weeks	1					1
Total Days	20					
%Days out of Compliance	5.00%					5.00%
Recommendation	PASS					PASS

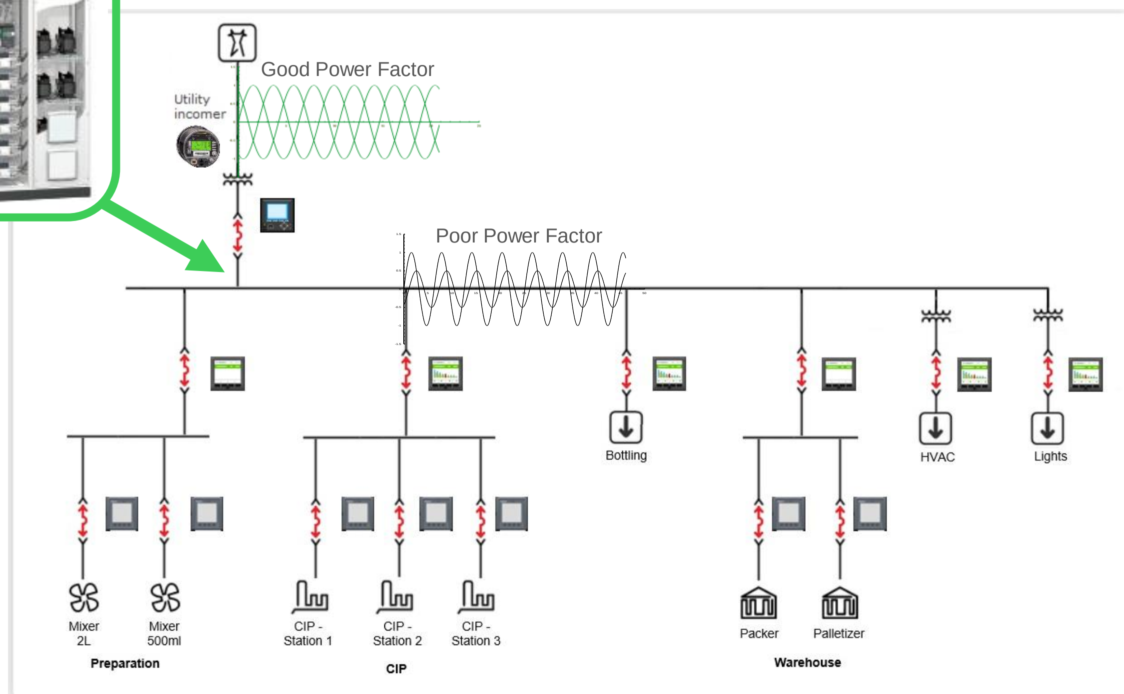
Short Term Current Distortion Non Compliant Weeks - 95th Percentile		
Date	Individual Harmonic	TDD - Limit 8.0%
Mar 28 2018	91.20%	90.10%

#4: Management of Power Quality - Mitigate

Power Factor Correction

Avoid Power Factor penalties or kVAr charges on utility bills and improve energy efficiency.

Power Factor Correction Equipment



PECO and Power Factor Correction

Effective July 1, 2020

ISSUED BY: CEO PECO Energy Distribution Company 2301 MARKET STREET PHILADELPHIA, PA. 19103

Tariff Electric Pa. P.U.C. No. 6

PECO Energy Company **Original Page No. 25**

RULES AND REGULATIONS (continued)

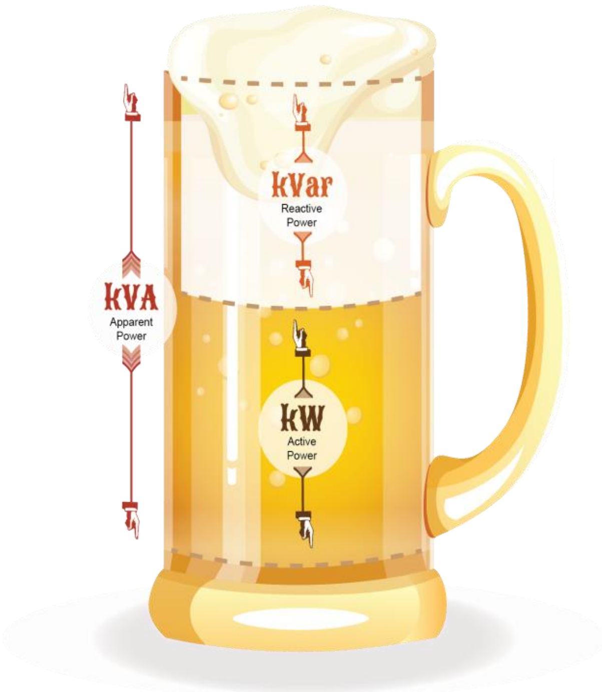
15.3 POWER FACTOR ADJUSTMENT.

A. Standard Power Factor Values (based on measured demands)

Measured Demands (Kw)	Standard Power Factor
0 -185	80%
186 - 2,500	90%
Over 2,500	95%

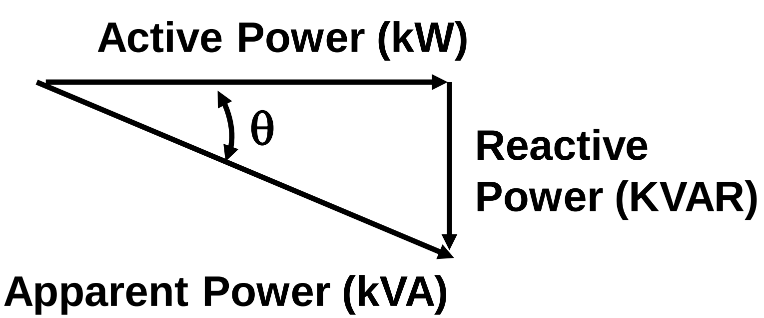
B. Adjustment to Measured Demand. When a customer's measured power factor is less than the standard power factor values above, the Company shall increase the customer's measured demand by the ratio of the standard power factor to the measured power factor. The Company will then use this adjusted demand as a basis for calculating the customer's billing demand in accordance with the applicable rate schedule.

Benefits of Power Factor Correction



- Reduce Power Bills
- Reduce loading on transformers - Increase capacity utilization
- Reduce I^2R losses in conductors
- Improve voltage drop
- Increase Service life
- CO_2 reduction

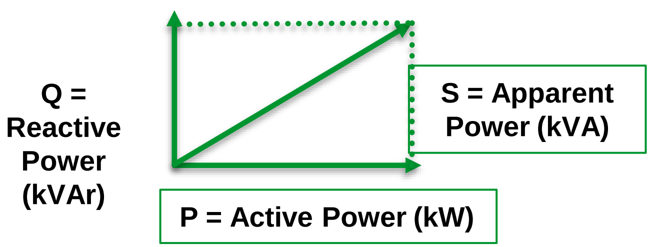
Power Triangle



$$\text{Power Factor} = \frac{\text{Active (Real) Power}}{\text{Apparent Power}} = \frac{\text{kW}}{\text{kVA}} = \text{Cosine } (\theta)$$

True Power Factor

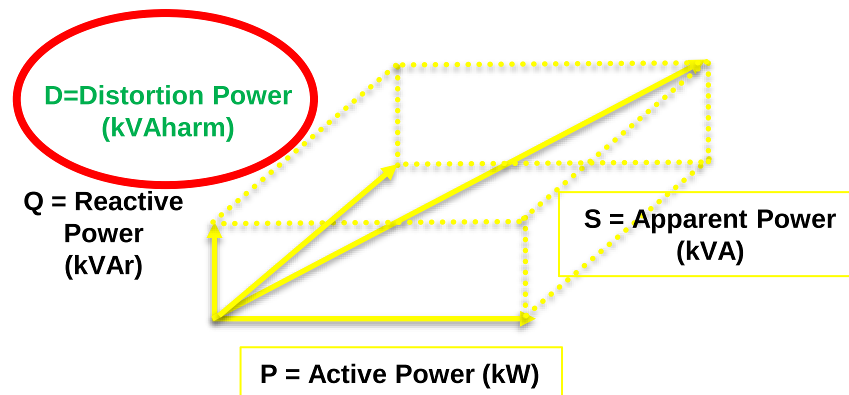
Linear Loads (60Hz only)



Displacement PF

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

Linear + Non-Linear Loads (all frequencies)



True (Total) PF

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

Resonance (adding pfc in a harmonic rich network)

- Every capacitance value added to a system causes a new parallel tuning point
- Fixed capacitors only create one tuning point

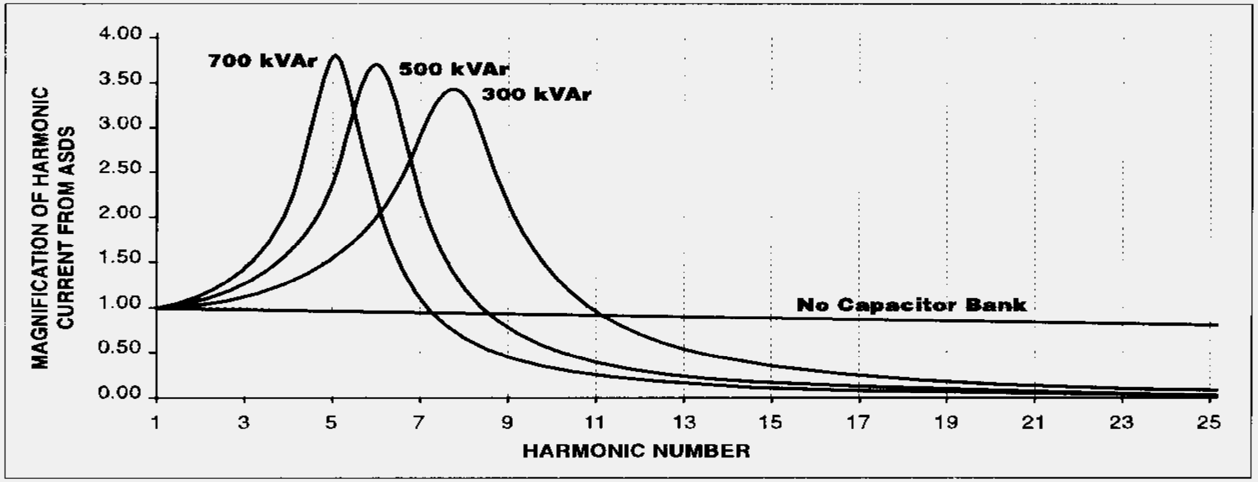
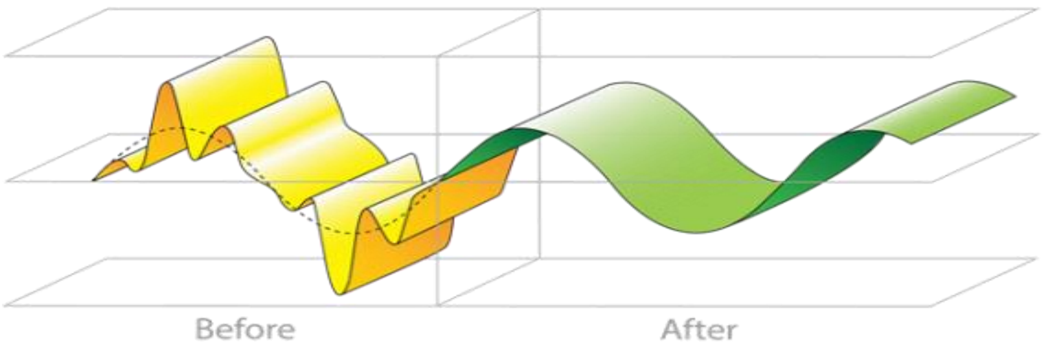


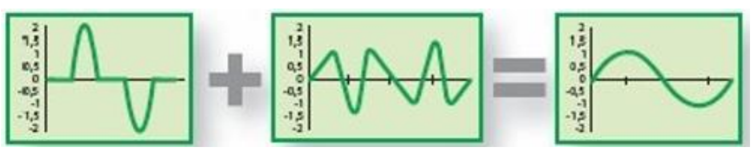
Fig. 3: Magnification of Harmonic Current When Standard Capacitors are Added to the Network

PowerLogic PFC Smart Capacitor Bank

Built in reactors to prevent harmonic resonance

If harmonics levels are very high and power factor correction is required - active harmonic filtering (AHF) can be used.



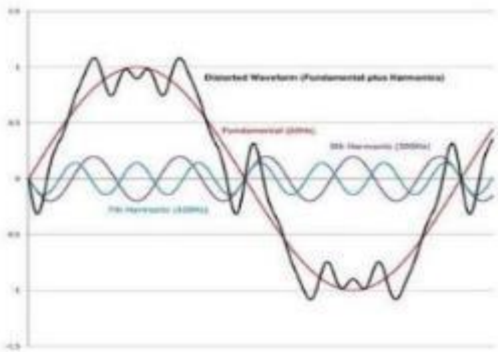


Harmonic Generators

Harmonic Filter

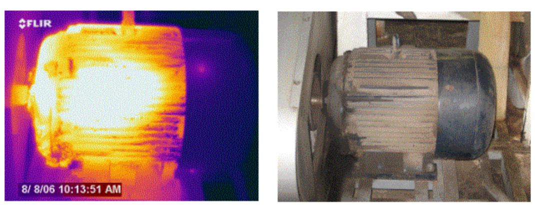
Clean Power

When to apply AHF for specifically Harmonic filtering?



1. High harmonics
2. Not meeting IEEE519 standards.
3. Increased maintenance - electronic loads fail more frequently
4. Major lighting retrofit ie LED installation
5. Increased downtime. Breaker tripping and fuses blowing more frequently
5. Excessive heat. Transformer/cables running hot and/or making loud noises.
6. Premature Motor failure. Motor winding repair/Motor replacement often.

Motor speed controls (VFD's)



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

Active Harmonic Filtering (AHF) - AccuSine Lineup

AccuSine EVC+

- Very **<u>fast</u>** stepless PF correction
- Includes <u>some</u> harmonic mitigation
- PF market disruptor and <u>competitive pricing</u>

¼ cycle PF correction

Some phase harmonic cancellation 5, 7, 11, 13^{th}

Phase unbalance correction

Currently available in 75 kVA and 100 kVA (can be combined)

AccuSine PCS+

- Feature-rich
- Multi standard
- Scalable, integrate-able
- Award-winning platform

Active harmonic filter

Phase harmonic cancellation from the 2^{nd} to the 51^{st} harmonic level

Reactive power compensation

Mains load balancing

AccuSine PCSn

- Built on AccuSine+ platform
- New rack module offe

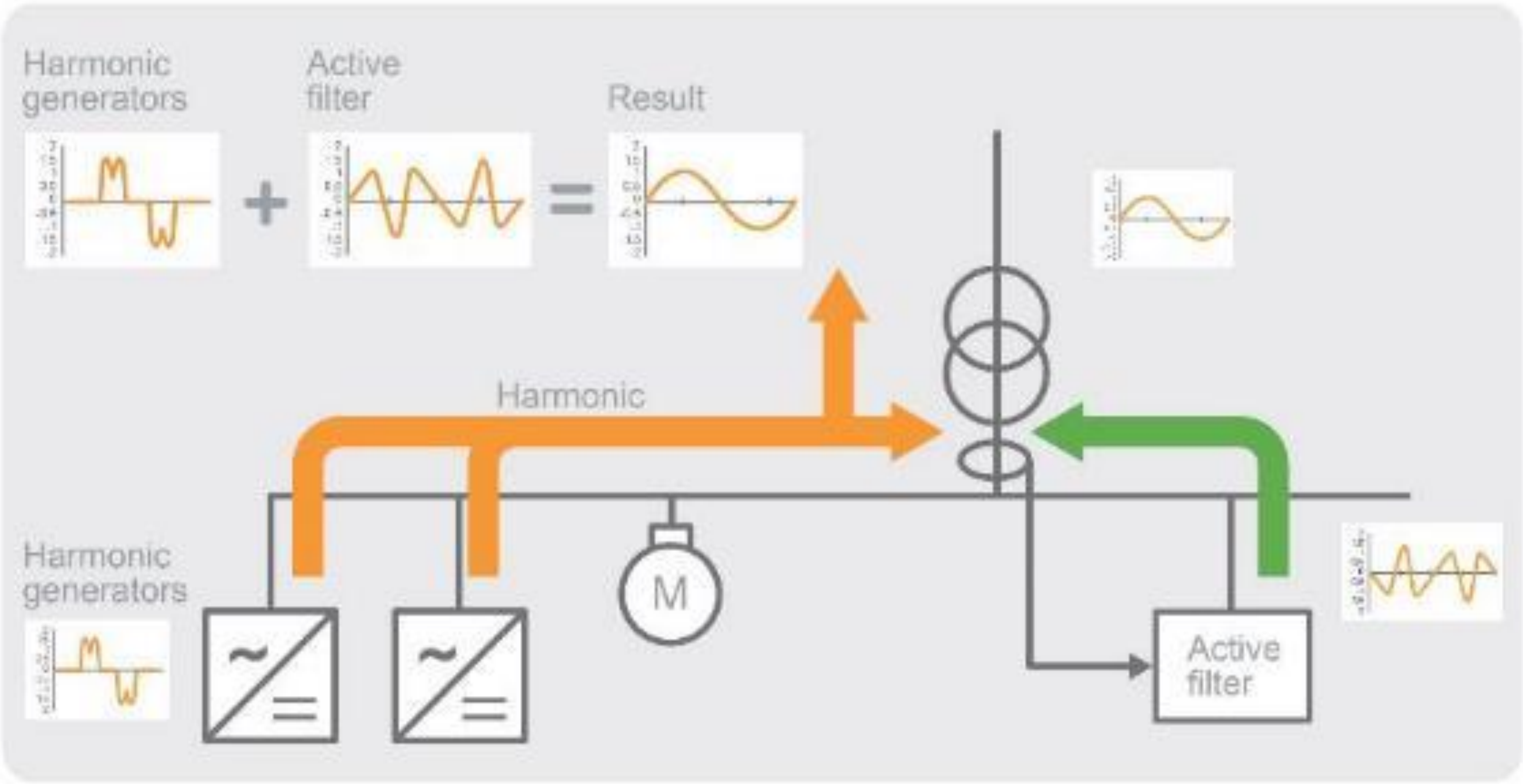
Active harmonic filter

Phase & Neutral harmonic cancellation

Reactive power compensation

Mains load balancing

Where to install active harmonic filtering?

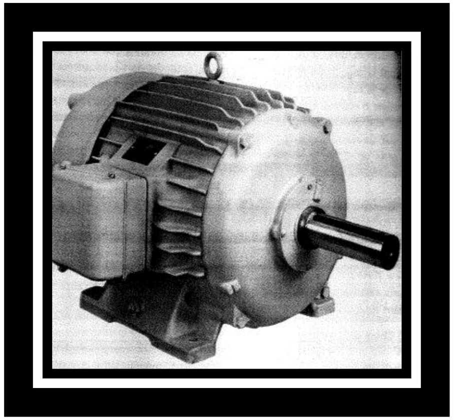


When should AHF's be implemented specifically for Flicker?

High Inrush Loads

Rock Crushers

Arc welder

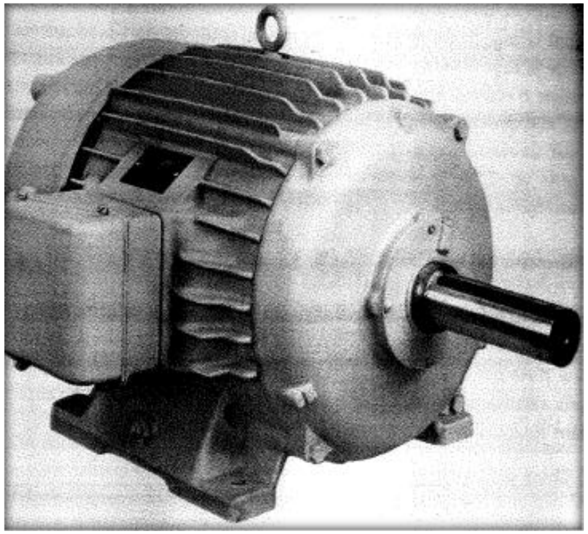


Large motor start

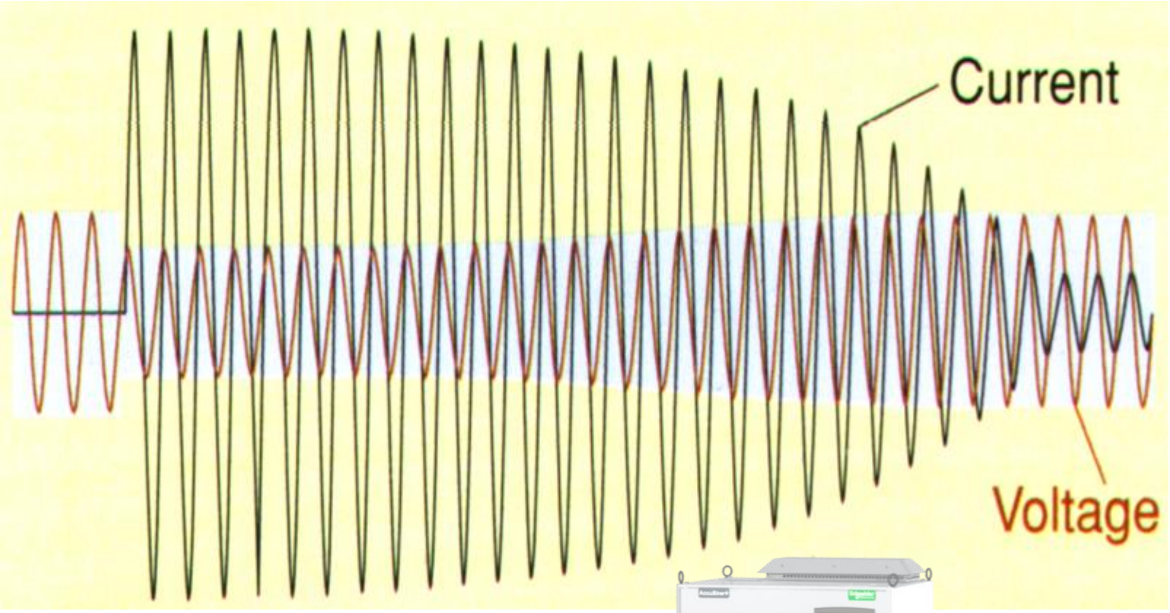
Automobile Shredder

Motor Start Waveforms

5.3



Large motor start



¼ cycle response time

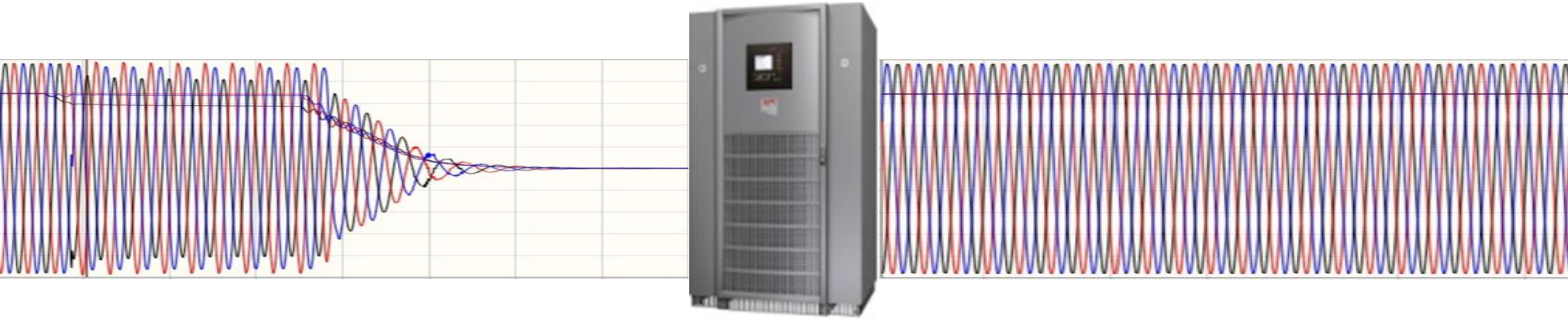
They will make you pay… Harmonics and Flicker!

Power Quality (Transmission, Generation and End-User) 7.1 Harmonics and Flicker Certain electrical equipment located at a Connecting Party facility (arc furnaces, cycloconverters, etc.) may generate flicker and harmonics that can negatively impact the FE Transmission System and other facilities connected to such system. The Connecting Party shall cause its connected facility to comply with harmonic voltage and current limits specified in IEEE Standard 519-1992, "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems". Flicker shall be measured as described in IEEE Std 1453-2004, "IEEE Recommended Practice for Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems". Pst is a measure of short-term perception of flicker obtained for a ten-minute interval. Plt is a measure of long-term perception of flicker obtained for a two-hour period calculated from 12 consecutive Pst values. The connected facility shall be designed and operated such that Pst does not exceed 0.8 and Plt does not exceed 0.6 for more than 1% of the time (99% probability level) using a minimum assessment period of one week. These flicker and harmonics limits must be met during normal (N-0) system configurations including a generating unit outage. The Interconnection or Operating Agreement for the connected facility must recognize that for scheduled outages of

Jersey Central® Power & Light
A FirstEnergy Company

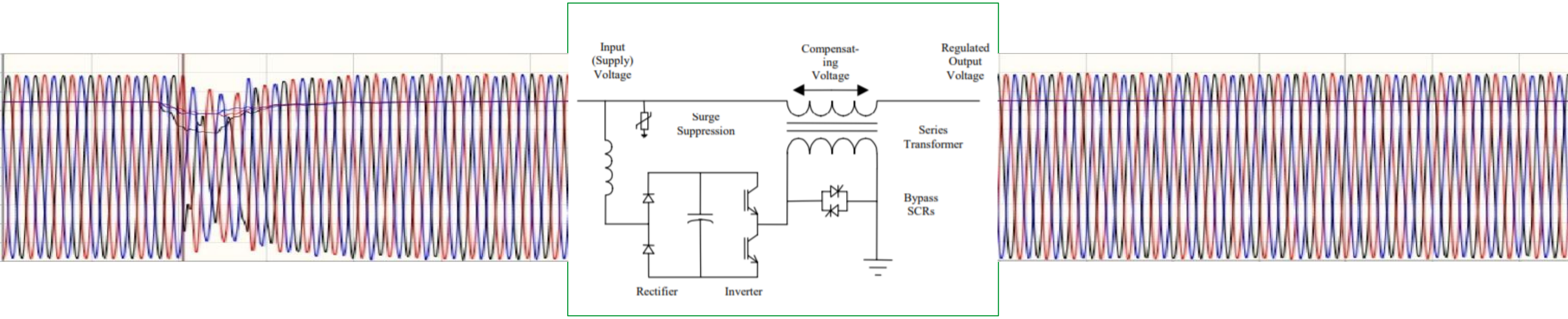
a flicker (or harmonics) producing connected facility must curtail operation as necessary so that these flicker and harmonics levels do not result in PQ complaints. It is recognized that excursions of flicker and harmonics levels beyond these required limits might occur during unscheduled forced outages resulting in PQ complaints. Voltage flicker for infrequent events such as large motor starting will be evaluated based upon the resulting percent voltage dip per event (see Annex A of IEEE Std. 1453-2004). In no case shall the resulting percent voltage dip per motor starting event exceed 3% on the FE Transmission System. FE may initially, or in the future, require the installation of a harmonic and/or flicker monitoring system in order to permit ongoing assessment of compliance.

Power Conditioning for Reliability

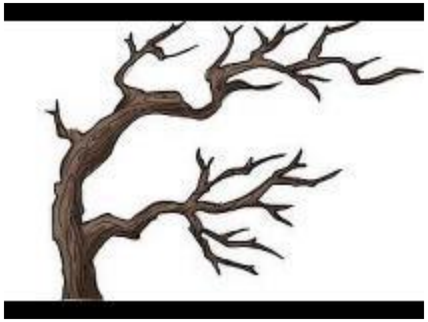


UPS

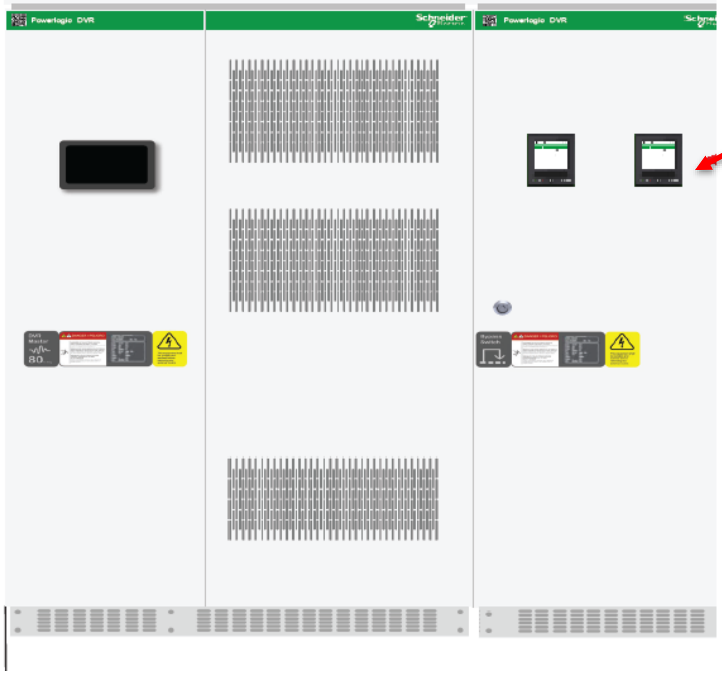
Voltage Conditioner



PQ Issues: Voltage Sags… where do they come from?



Voltage Regulation - PowerLogic DVR

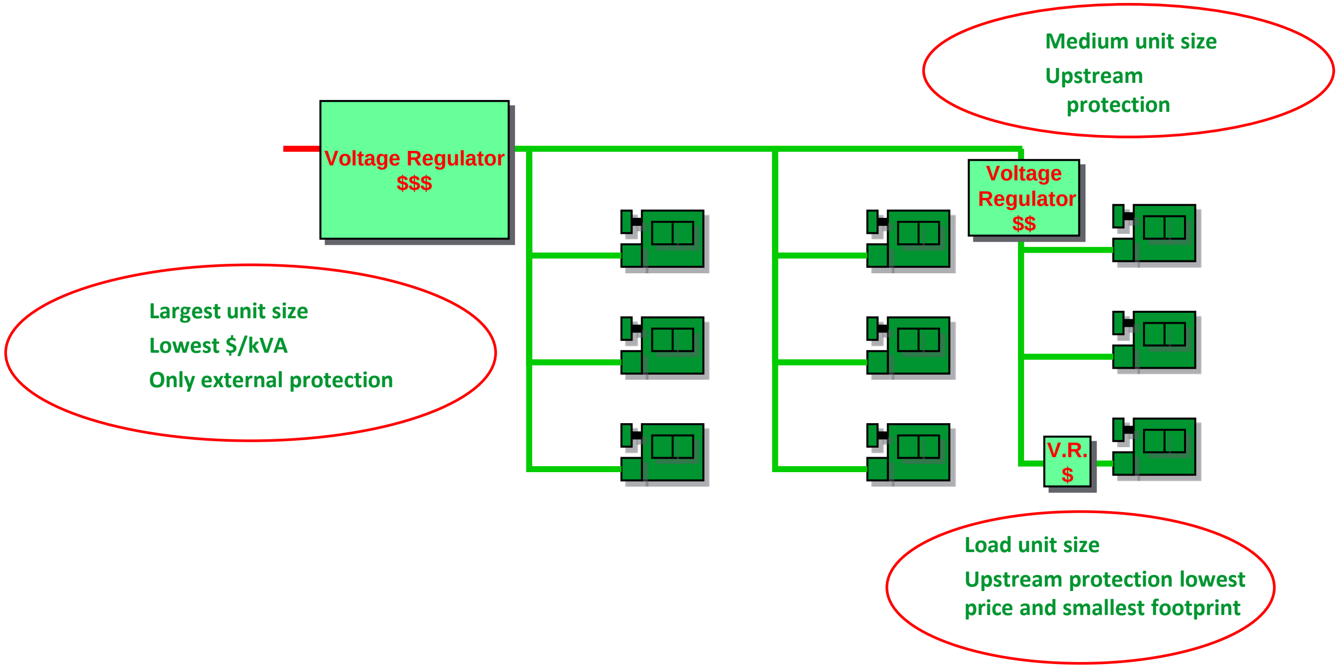


Power Quality meters (shows the before and after measurements)

Deep protection for critical power

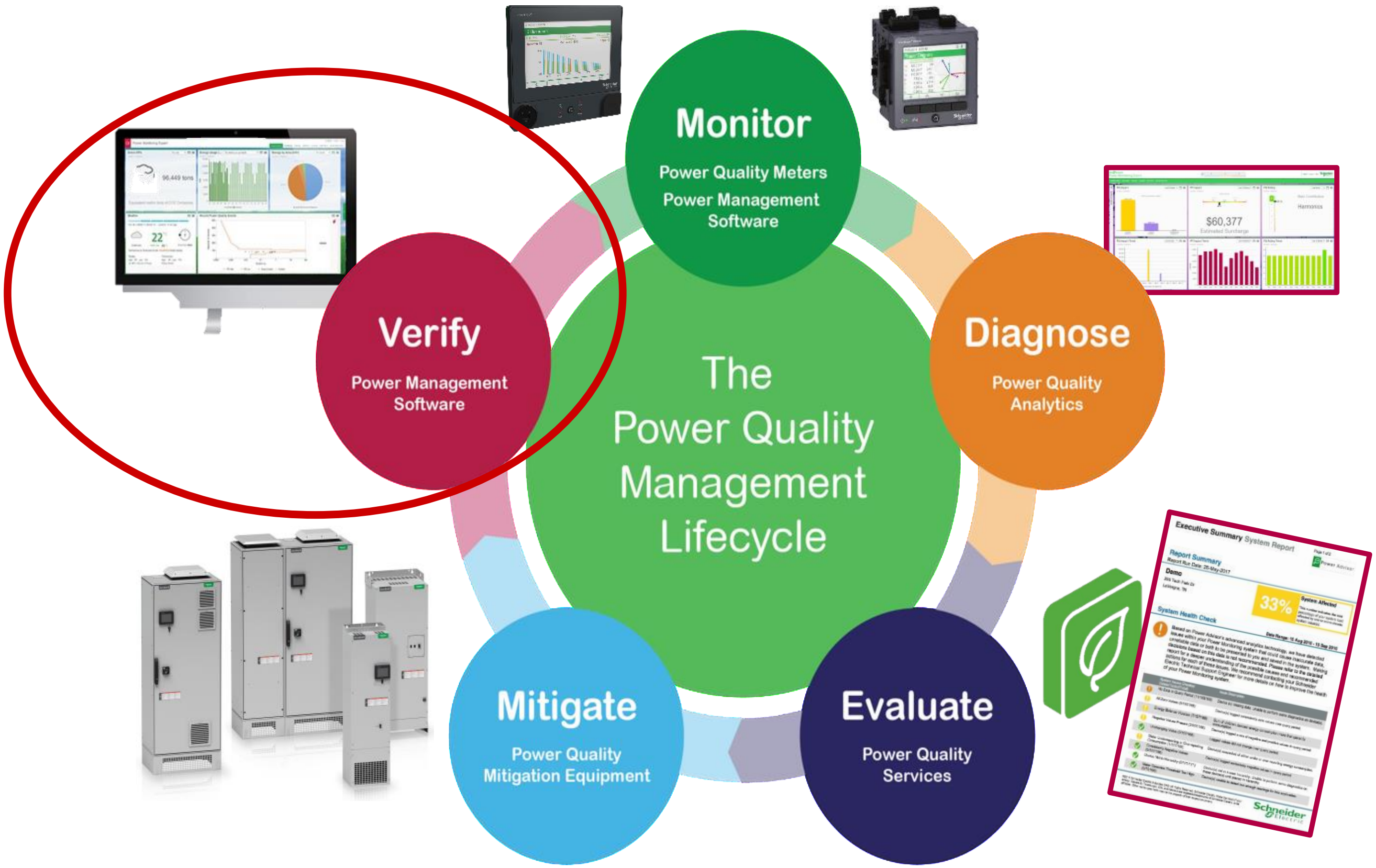
System parameters	PowerLogic DVR
Input Nominal Voltage	200 to 690 Vac **(Medium voltage ratings on request)**
Range	150 - 900 KVA **(larger KVA rating on request)**
Continuous Voltage Regulation	+20% -20%
Frequency	50/60 Hz ±10%
Global Efficiency	> 98%
Overload	110% -30 sec, 150% -1 sec (normal mode)
Maximum sag depth (3-phase)	-40% **(larger sag rating on request)**
Maximum 1.2 ph Sag Correction	-70%
Static regulation	±1%
Response time	< 3 ms
Transference Time to Bypass	< 0.5 ms

Application Optimization



Protection from Utility and or internal problems

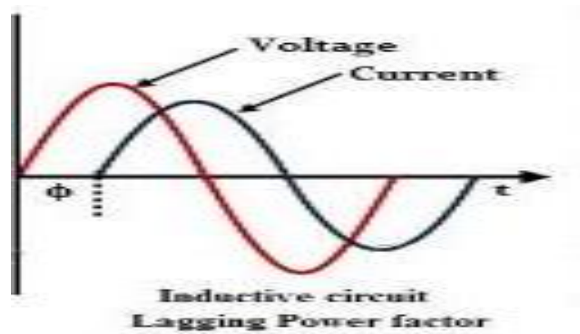
Power Quality Management Lifecycle

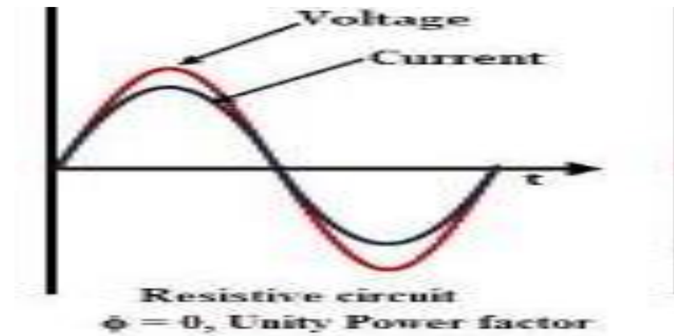


Verification:

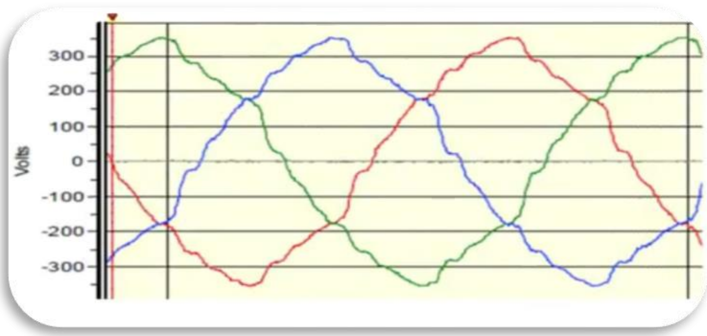
Before: | **After:**

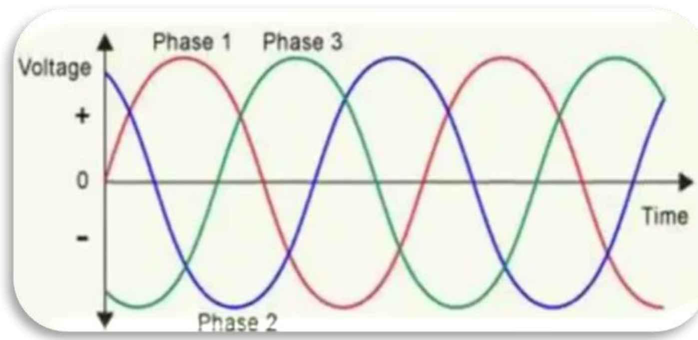
Power Factor



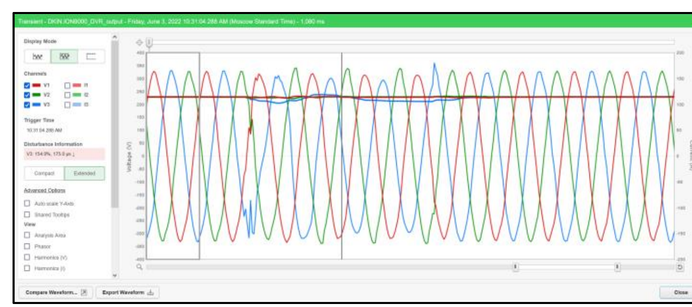


Harmonics





Voltage



In closing:
Feel free to visit the Schneider Electric table for more information on:

Schneider Electric's PowerLogic Power Quality Offer


IMPORTANCE
OF
POWER QUALITY
TRENDS
IMPACTING
POWER QUALITY
THE
POWER QUALITY
JOURNEY
QUESTIONS
&
ANSWERS


Q&A

THANK YOU !