Understanding Power Quality & Energy Management

January 2018

Power Quality

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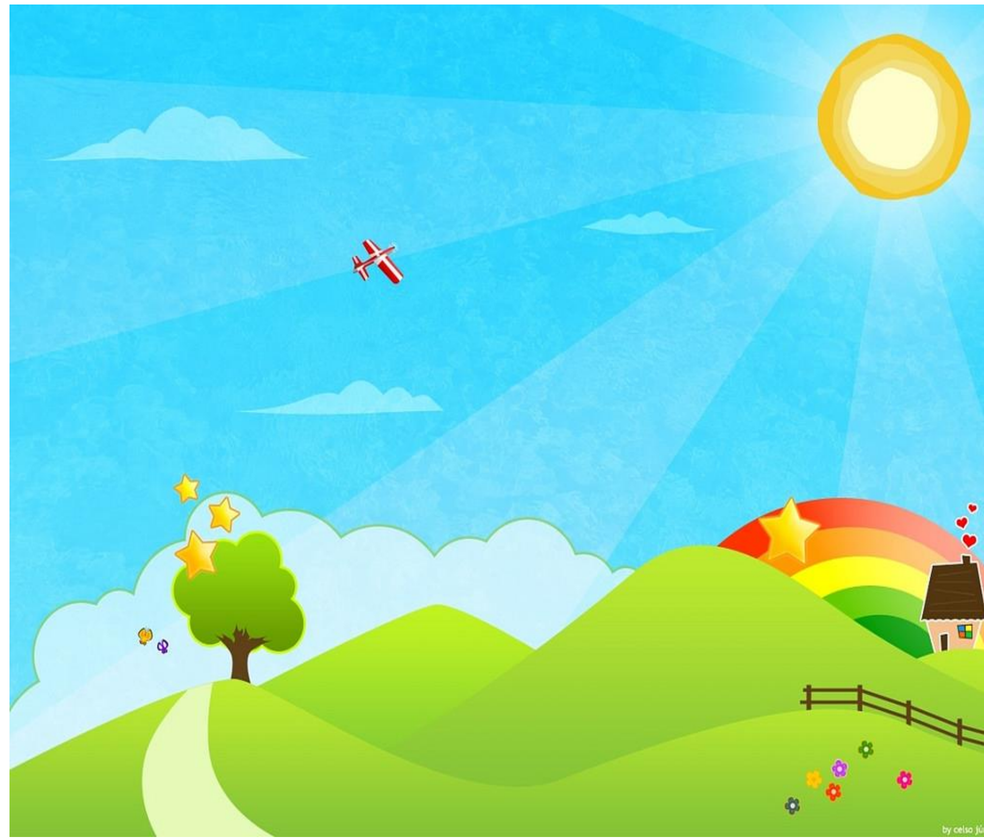
Ideal Power Quality

- Source from an infinite bus
- Purely sinusoidal waveform
- Constant Voltage
- Constant Frequency
- No interruptions



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- The characteristics of the <u>supply voltage</u> and the <u>electrical system</u> that affect the performance of the load.

- The characteristics of the <u>load</u> that affect the electrical supply system and/or other loads

(Terry C 1992)

Reality - Far from ideal

Transient disturbances

- within ½ cycle
  - Voltage Spikes & Surges

Short duration disturbances

- ½ Cycle to 1 minute
  - Sags & Swells, Interrruptions

Long duration disturbances

- > 1 minute
  - Under or Over Voltage
  - Voltage Imbalance
  - RFI / EMI or Noise
  - Harmonics

Cost of Poor Power Quality

- Increase in Maintenance cost due to equipment failures
- Increase in Production cost and time overrun
- Increase in Energy cost due to additional losses

1. RMS voltage variations (voltage regulation)
2. RMS current available to the load (source transformer)
3. Voltage sags and surges (#1 customer complaints)
4. Transient voltage (maximum Vpk) Equipment damage
5. Transient current (Maximum Ipk) from the load (overload)
6. Voltage distortion (Harmonics, Interharmonics) **Rs**
7. Current distortion (Harmonics, Interharmonics) **Rs**
8. Voltage and Current (Imbalance, Unbalance) **Rs**
9. Voltage RMS variation (Flicker)

   The Only Human PQ parameter

Rs = losses to utility

MEASUEMENTS STANDARD

- IEC 61000-4-7 Voltage Flicker
- IEC 61000-4-15 Harmonic Measurement
- IEC 61000-4-30 Measurement Accuracy (“Class A”, “Class S” “Class B”)
- IEC 62052/3-11, 22, 23 Energy Accuracy (“Class 0.2S”, “Class 0.5S”)

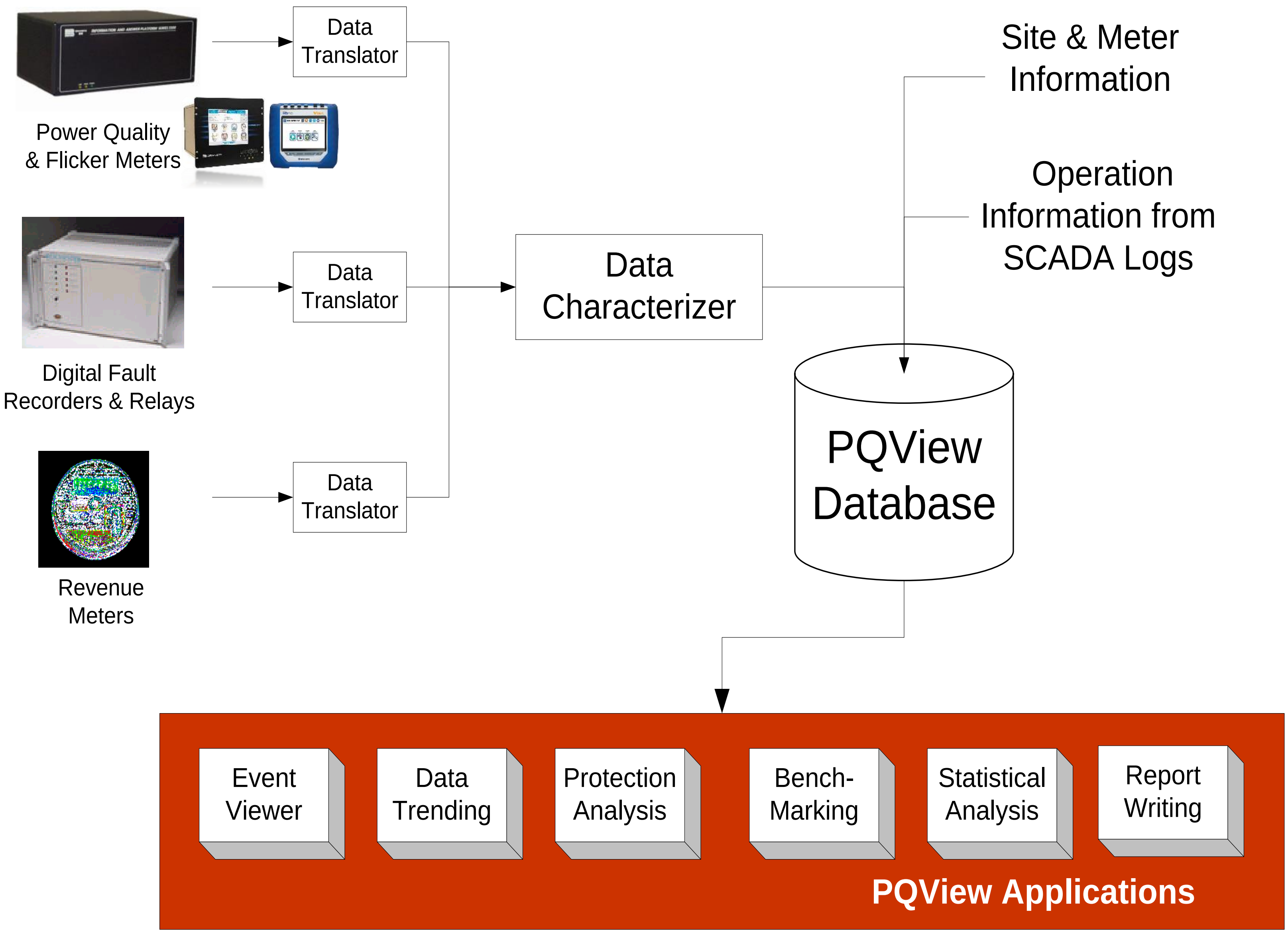
POWER QUALITY STANDARDS

- BS:EN 50160:In use worldwide, in favor of the utilities, voltage only, statistical standard
- IEEE 519 and IEEE 1159: American standards, practical point of view

Instruments and Systems features

- Sag directivity
- Harmonic directivity
- Power Factor Capacitor switching identified
- Distance to fault (utility)
- Automatic setup
- Automatic circuit type selection

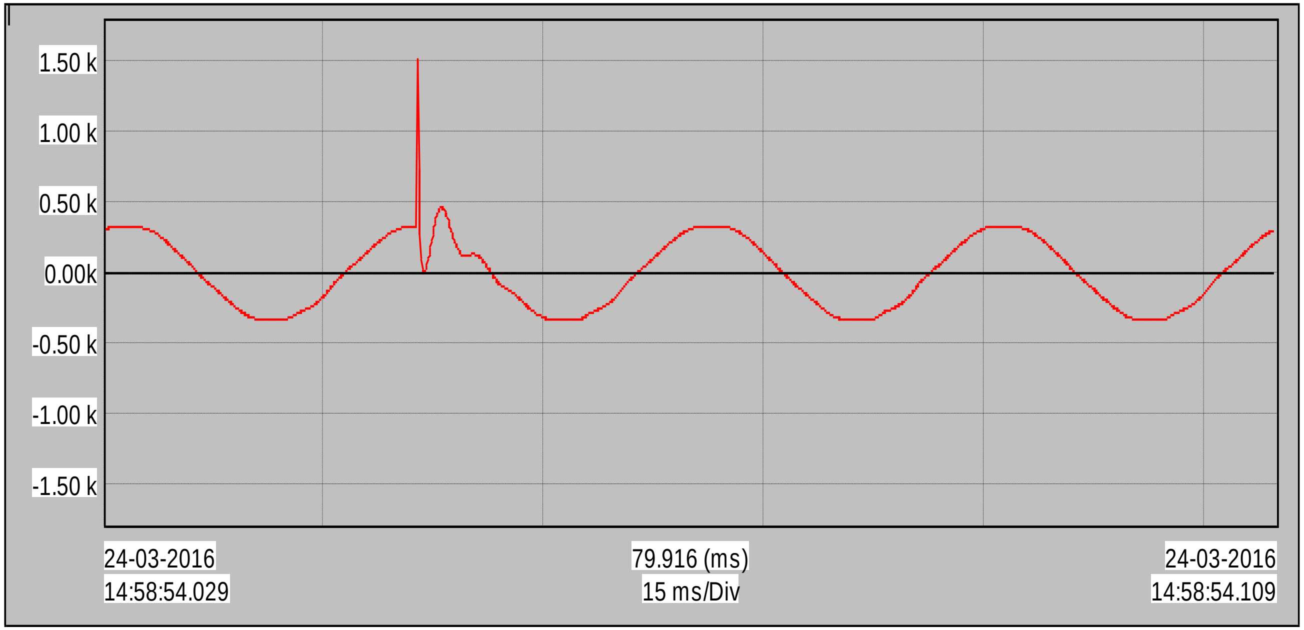
PQ View & Database



Transients

Transient definition

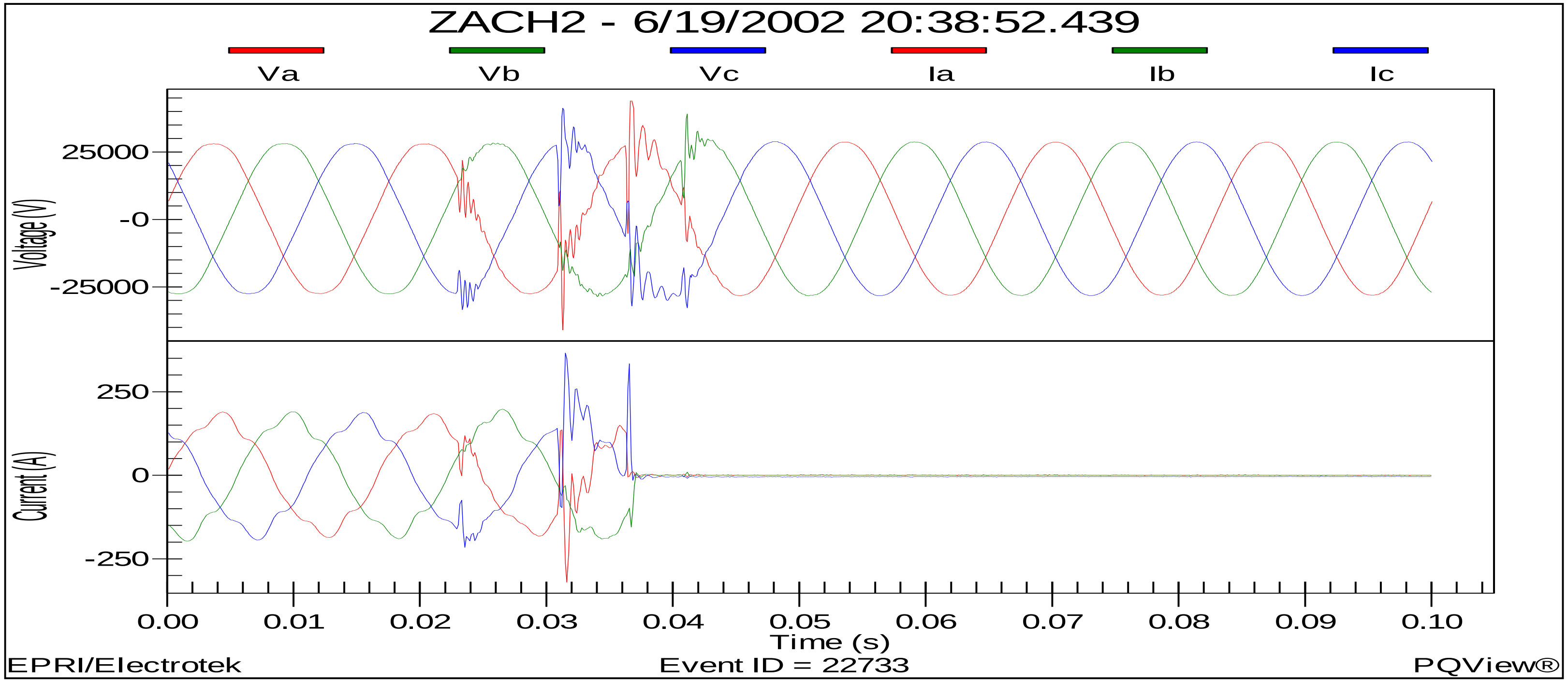
Transients are sudden changes in voltage or current that are momentary in nature.



- **Spikes or Impulsive Transients**
- Sudden unidirectional change in the steady state current or voltage or both.
- Caused mostly by lightning or a tripping of the grid supply.
- Very high in magnitude for a very short duration.
- **Power Conditioning Solution : Metal Oxide Varistors (MOVs) with approriate Voltage & Joule rating**

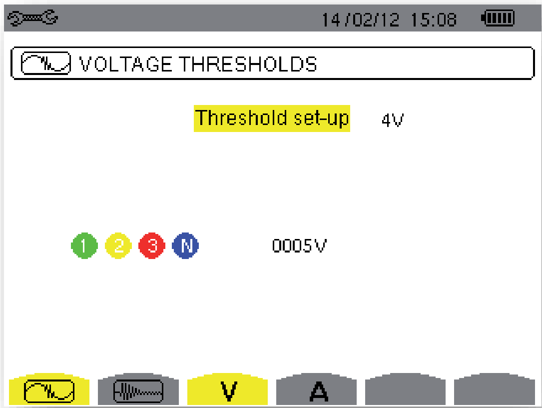
Transient definition

Transients are sudden changes in voltage or current that are momentary in nature.

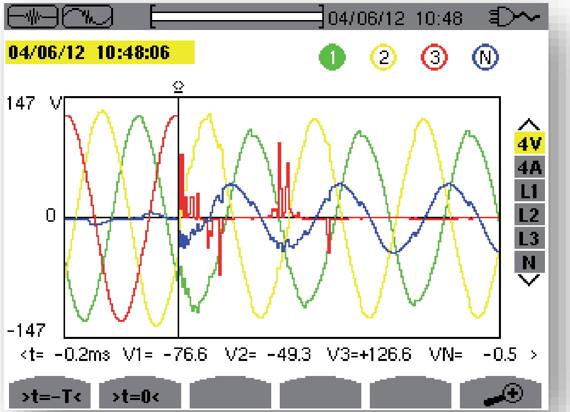


- **Surges or Oscillatory Transients**
- Sudden bi-directional changes in voltage or current or both.
- Caused internally due switching ON of inductive loads or capacitor banks
- Caused externally due to lightning and utility grid switching.
- **Power Conditioning Solution: SPD - Surge Protection Device**

Measuring Transients



Settings

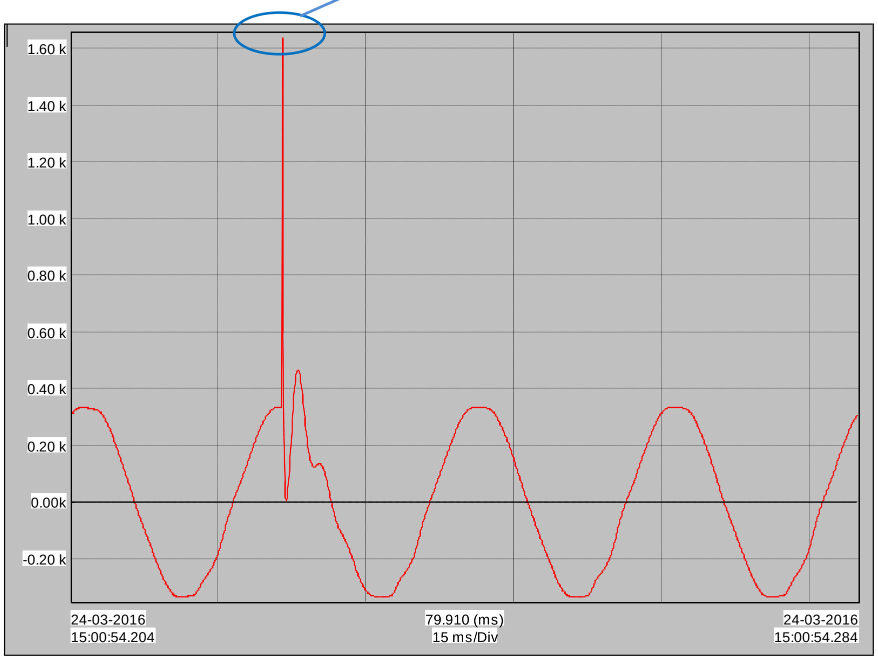


Transient in Instrument

ALM 36 /ALM 33

HDPQ Visa

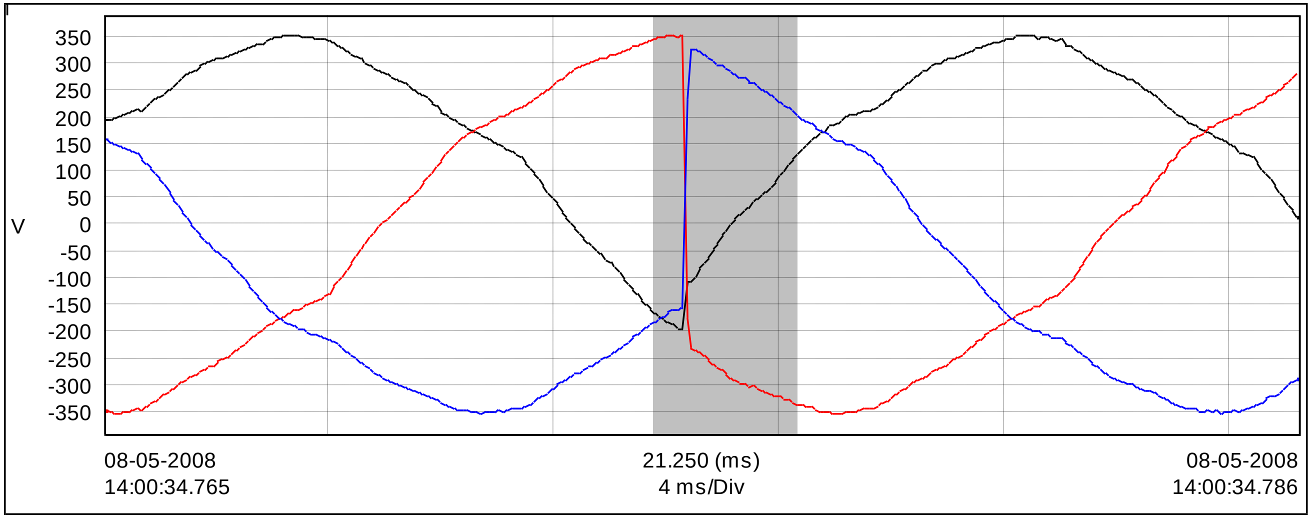
1650 Volts



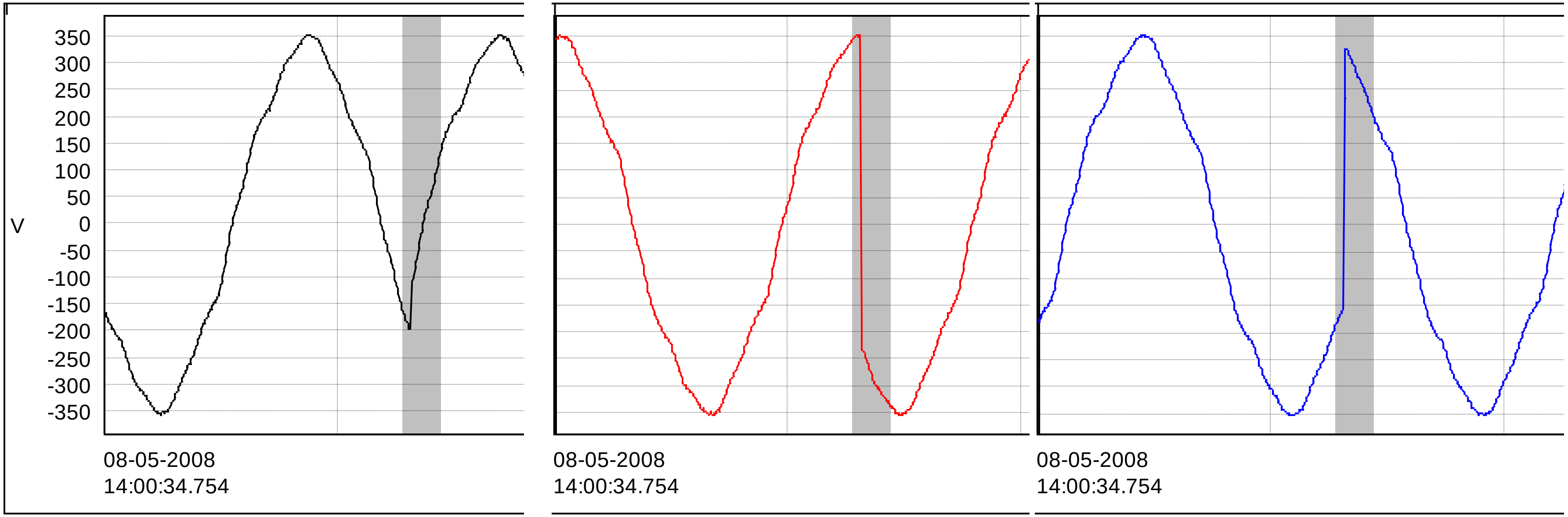
DataView / DranView

Encore Series

Transients During initial loading

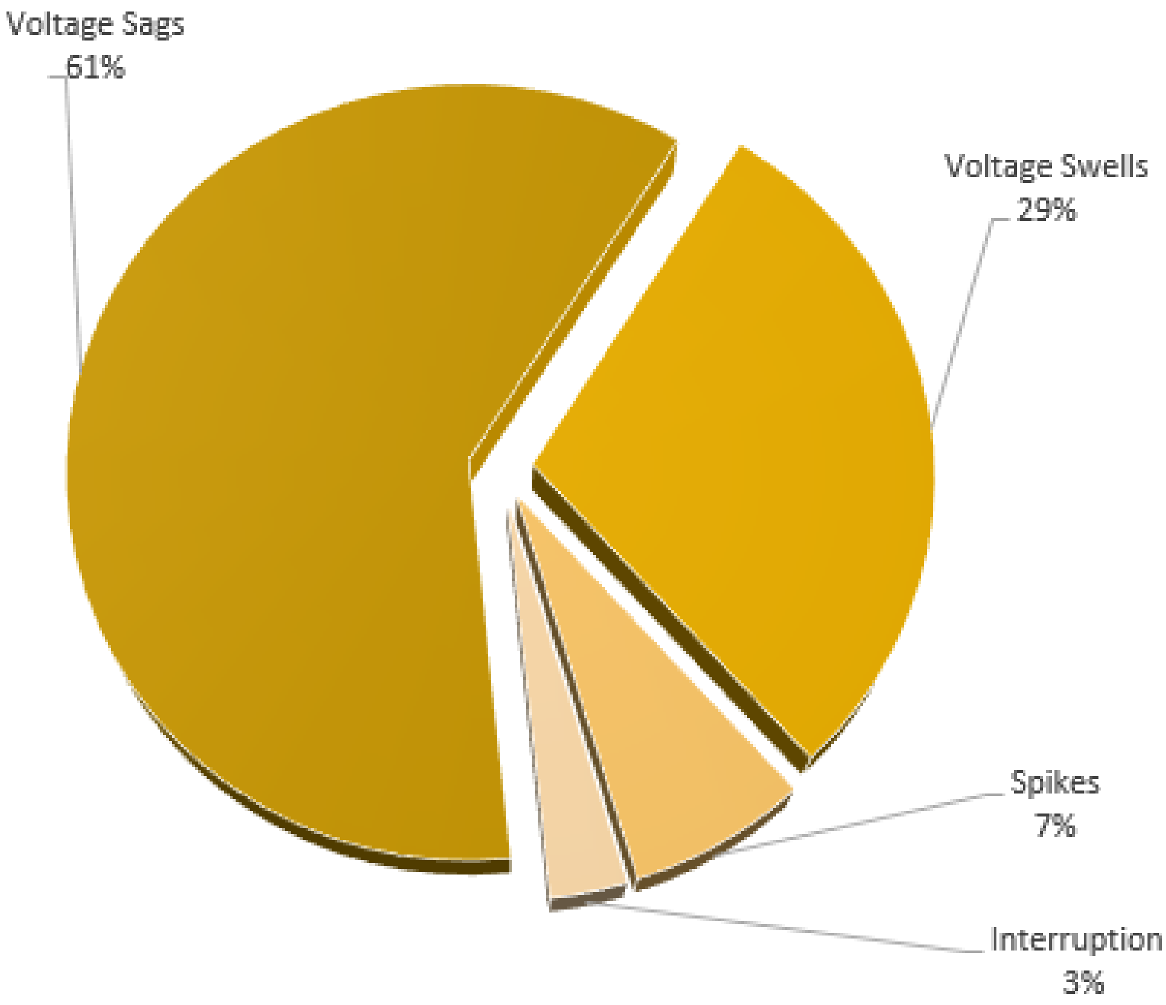


The following transients usually occur in DG & UPS while initial loading or due to poor AVR



Most Common PQ Complaints

❖ Voltage sag/dip or short outage



Power Quality –

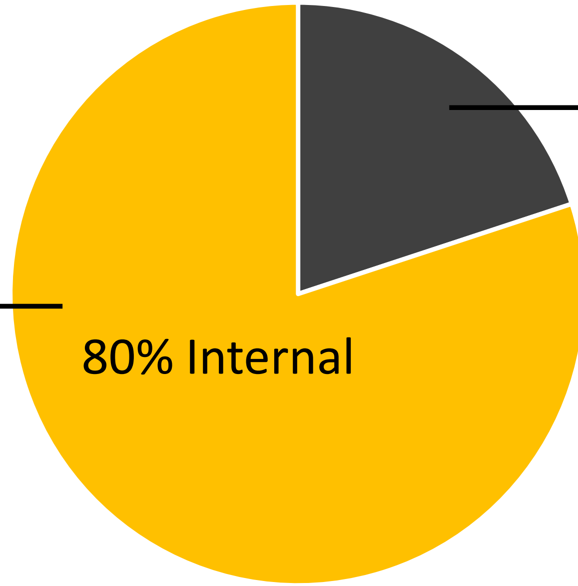
Recoverable failures short duration voltage swells, spikes, sags & momentary interruptions

Power Reliability –

Caused by irrecoverable failures, long duration interruptions

PQ Sources and Losses

- Elevators
- Pumps
- Motors
- Air Conditioners
- Compressors
- Blower Motors
- Office Copiers
- Switching Cap Banks



20% External

- Lightning
- Utility Grid switching

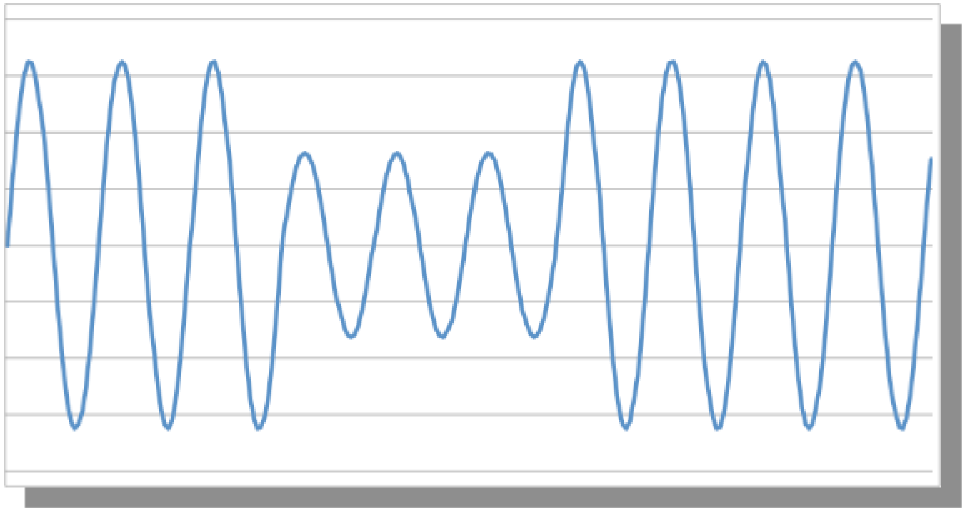
- In PQI's 19 years of experience and data shows
  - **80%** of the PQ problems are on the customer side of the meter and losses caused **20%** of the Rs. losses .
  - **20%** of the problems **from the utility** side of the meter causes **80%** of the **Rs** losses
  - Majority of the problems from utility are **Voltage Sags or Short Outages**.

Short Duration Disturbances

Voltage Sags

Voltage Sags or Dips

RMS voltage < Nominal voltage by 10 - 80% for ½ cycle to less than a minute.



Causes

- Large loads Inrush current
- Accidents and Short Circuits.
- Cable under-rating
- Loose Contacts

Effects

- Sensitive equipment such as Computers or CNC Controllers may unexpectedly reboot
- Relays and contactors may suffer Drop Out resulting in machine trip
- Quality of production output in voltage sensitive processes may suffer

Power Conditioning Solution : Uninterrupted Power Supply (UPS)

SAG in Engineering Industry

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Frame Zoom Instrument Tools Window Help

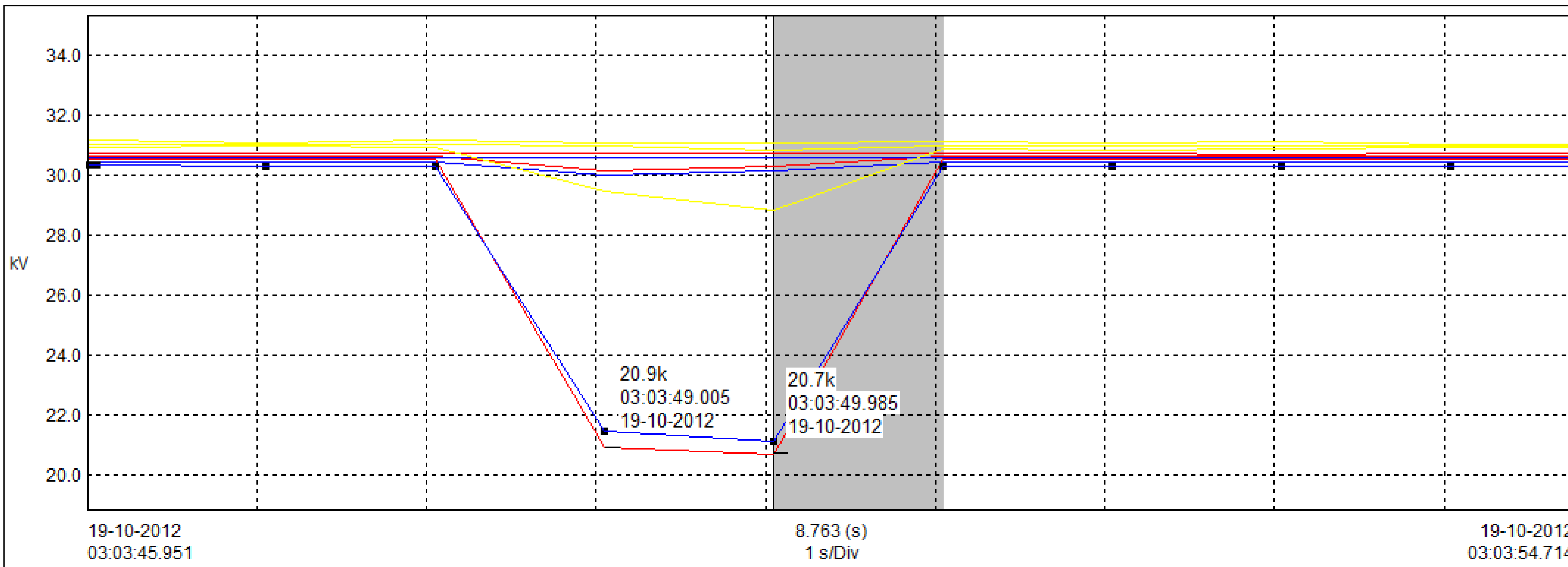
Name	Date	Time	Avg	Min	Max	Units	Duration	Units
U1 RMS	19-10-2012	02:30:00.000	30.970	29.100	31.560	k V	1:30:00	(h:min:s)
U2 RMS	19-10-2012	02:30:00.000	31.361	30.000	31.950	k V	1:30:00	(h:min:s)
U3 RMS	19-10-2012	02:30:00.000	30.803	29.730	31.410	k V	1:30:00	(h:min:s)
U1 RMS MAX	19-10-2012	02:30:00.000	31.054	29.700	31.620	k V	1:30:00	(h:min:s)
U2 RMS MAX	19-10-2012	02:30:00.000	31.438	30.570	32.100	k V	1:30:00	(h:min:s)
U3 RMS MAX	19-10-2012	02:30:00.000	30.916	30.090	31.500	k V	1:30:00	(h:min:s)
U1 RMS MIN	19-10-2012	02:30:00.000	30.851	20.700	31.440	k V	1:30:00	(h:min:s)
U2 RMS MIN	19-10-2012	02:30:00.000	31.275	28.800	31.920	k V	1:30:00	(h:min:s)
U3 RMS MIN	19-10-2012	02:30:00.000	30.655	21.120	31.290	k V	1:30:00	(h:min:s)

19-10-2012 - 03:03:50.000

Value	
30.30k	U1 RMS
30.84k	U2 RMS
30.15k	U3 RMS
30.72k	U1 RMS MAX
31.08k	U2 RMS MAX
30.57k	U3 RMS MAX
20.70k	U1 RMS MIN
28.80k	U2 RMS MIN
21.12k	U3 RMS MIN

U1 RMS MIN (V)

Date	Time	Val	Units
19-10-2012	03:03:46.000	30.510	k V
19-10-2012	03:03:47.000	30.540	k V
19-10-2012	03:03:48.000	30.510	k V
19-10-2012	03:03:49.000	20.940	k V
19-10-2012	03:03:50.000	20.700	k V
19-10-2012	03:03:51.000	30.510	k V
19-10-2012	03:03:52.000	30.510	k V
19-10-2012	03:03:53.000	30.510	k V
19-10-2012	03:03:54.000	30.510	k V
19-10-2012	03:03:55.000	30.510	k V

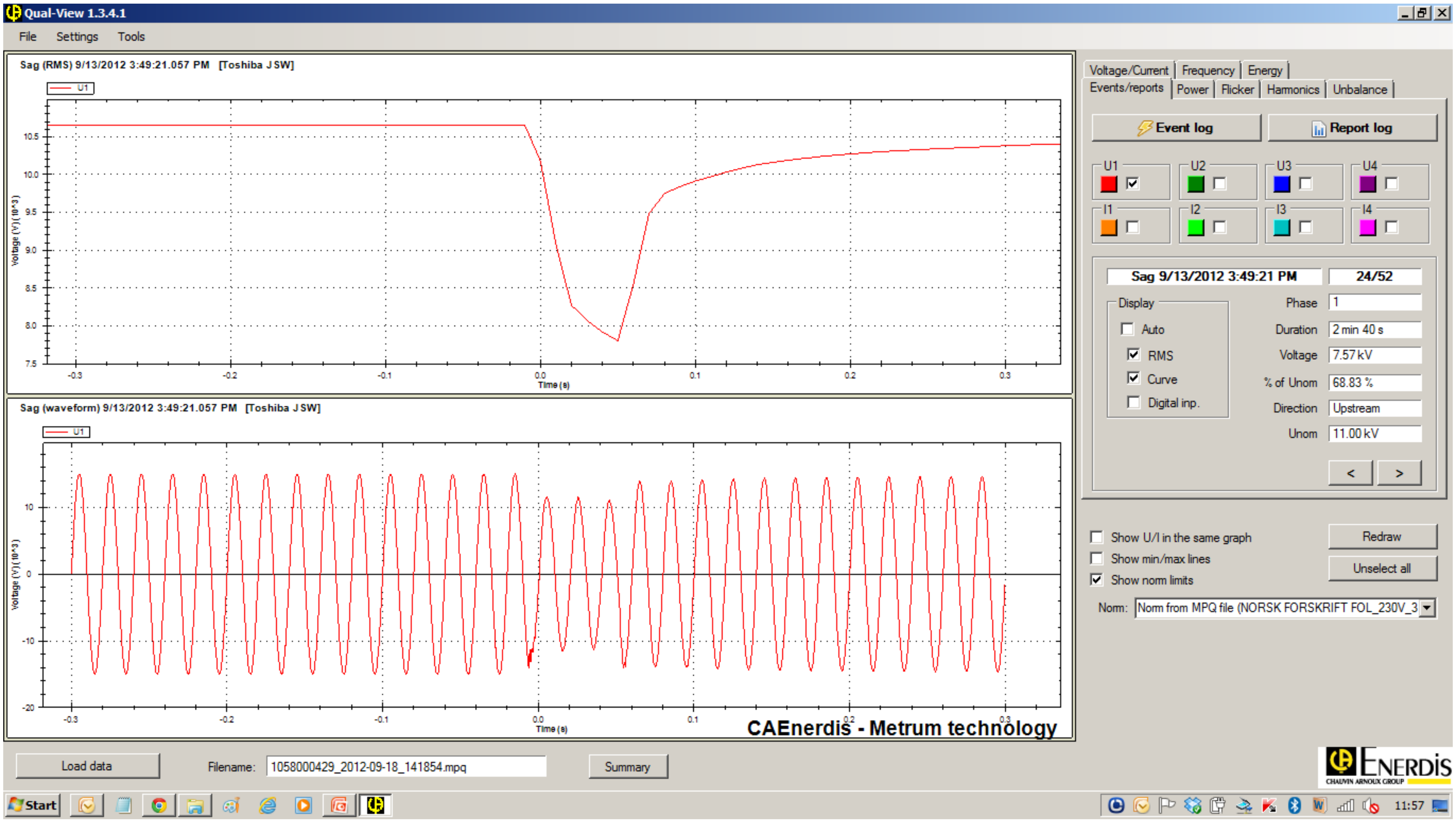


Summary of Pic-2

- In picture-2 two events are displayed for U1 & U3 RMS which are consecutive 1sec samples
- In both events 1 sec average voltage for U1 & U3 are above 30K
- U1 & U3 RMS min within the 1 sec duration for a short period there was a dip in voltage, the lowest value of this dip is below 21 kV as captured in the below alarm. The dip duration was about 80 - 90milliseconds which is beyond the control of Stabiliser function.
- In the above picture the trend has also captured other phase voltages, which are slightly affected compare to U1 & U3 voltage.

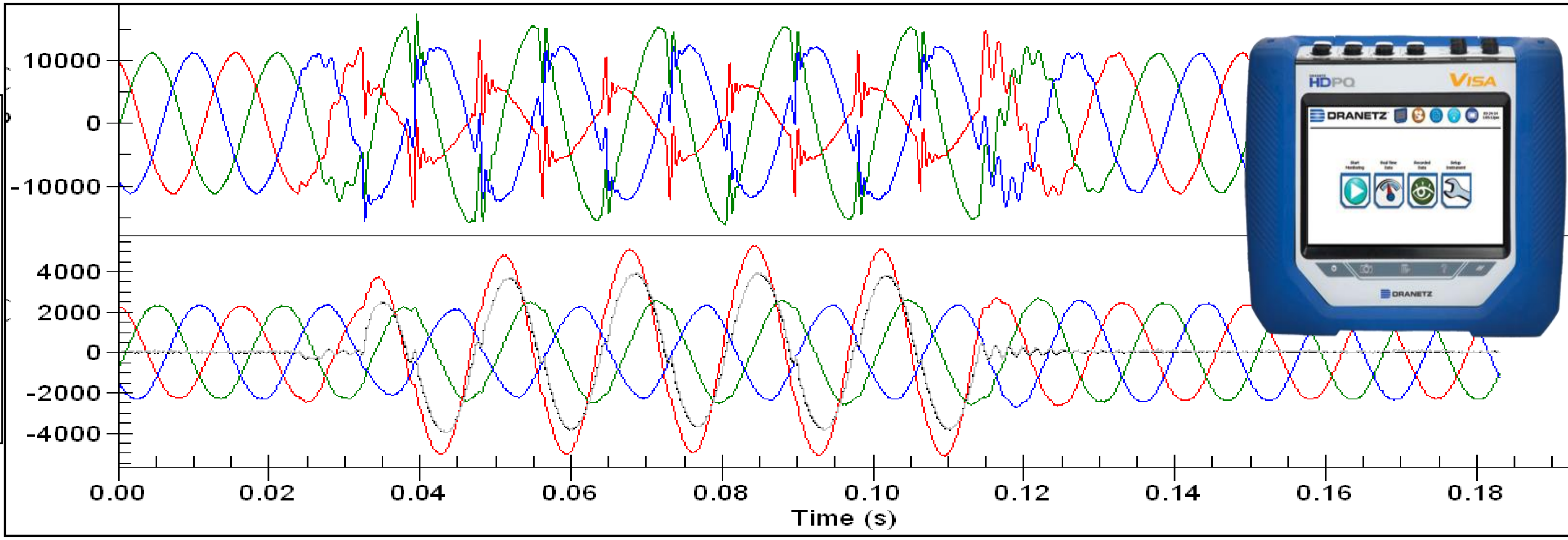
Measurement	Extreme Value	Duration (s)	Extreme Value		Date Started	Time Started
			Date	Time		
Urms L3	21 kV	0.08	19-10-2012	03:03:50.02	19-10-2012	03:03:49.95
Urms L3	21 kV	0.09	19-10-2012	03:03:50.02	19-10-2012	03:03:49.95
Urms L1	20 kV	0.08	19-10-2012	03:03:50.02	19-10-2012	03:03:49.96

Sag analysed with RMS trend & Waveform

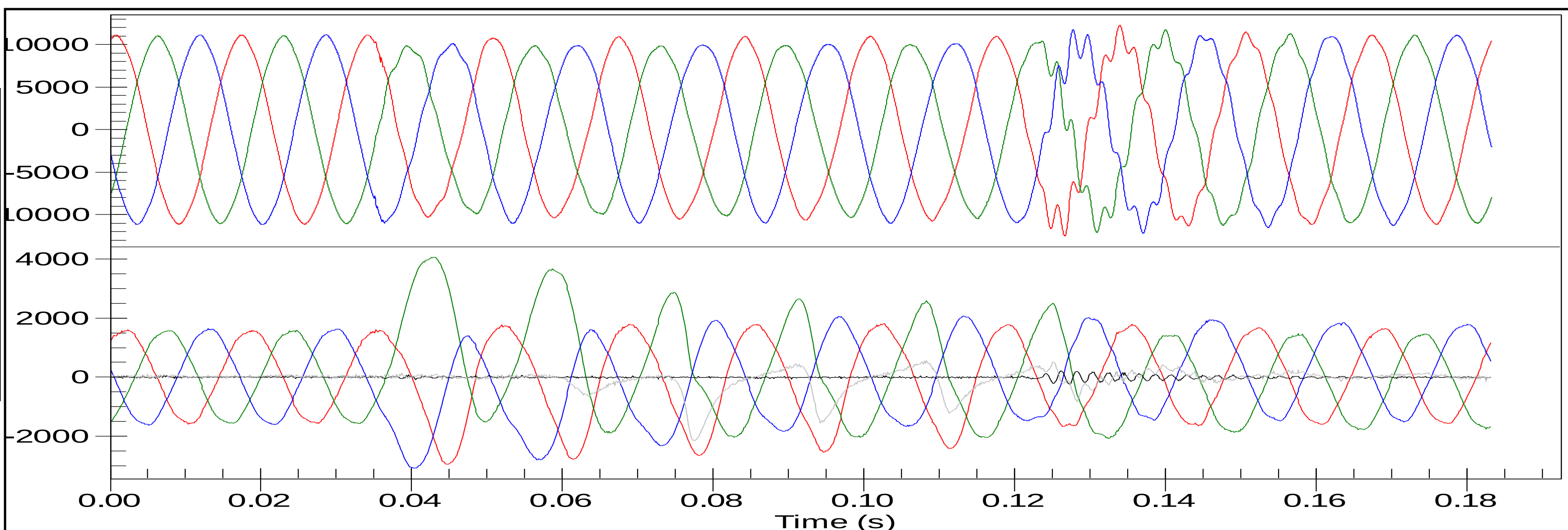


Voltage sag captured by Krykard MAP Compact

Fault Current versus Inrush Current

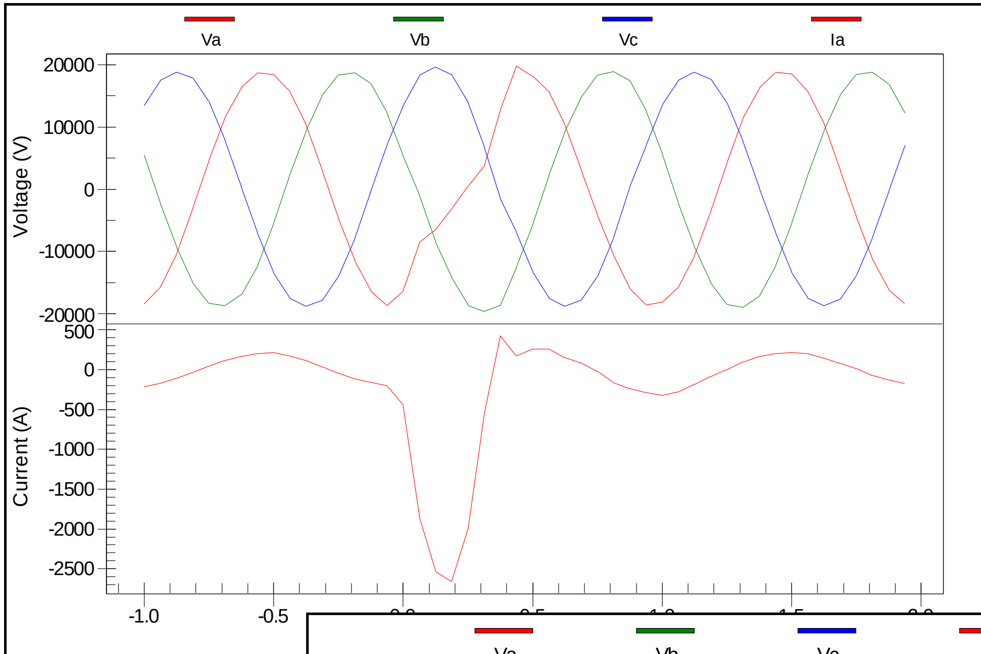


Real Fault

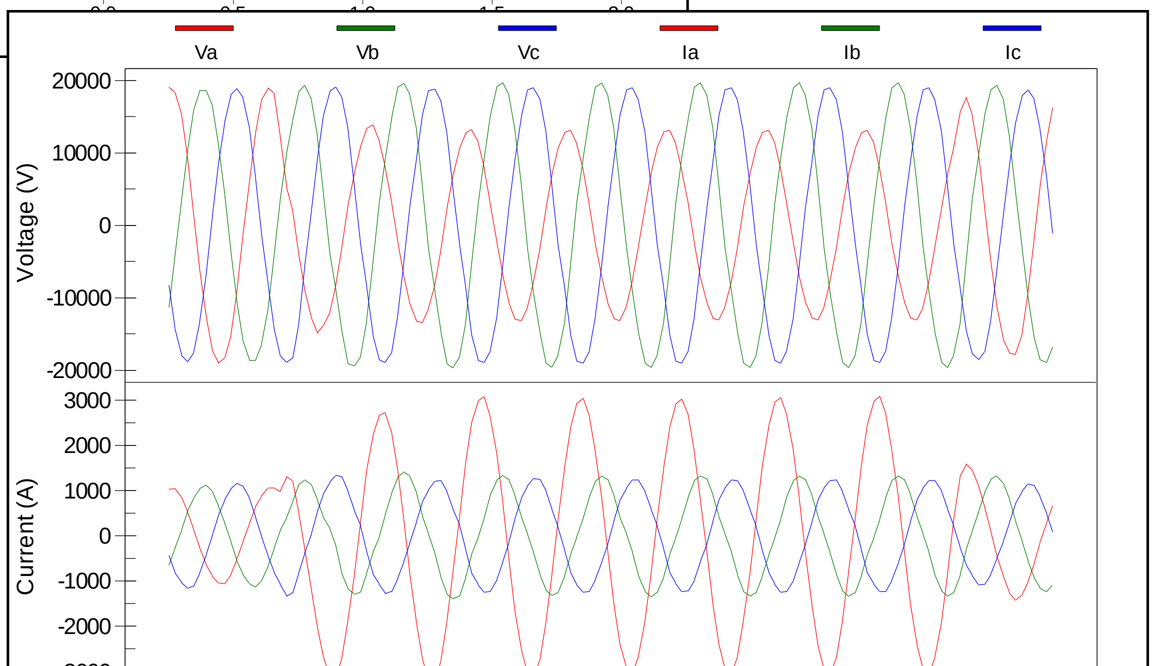


Inrush Event

Incipient Fault Location Functionality



Reactance-to-Fault: 2.6 ohms



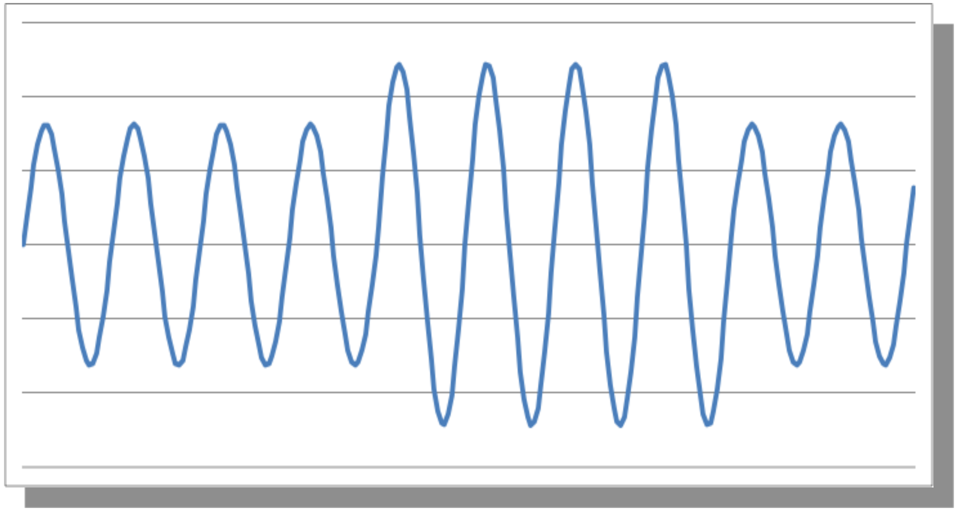
Voltage Swells

Voltage Swells

RMS voltage > Nominal voltage by 10 - 80% for ½ cycle to less than a minute.

Causes

- Switching Off of heavy loads
- Ground Faults on the Electrical power system



Effects

- Power Supplies of equipment get damaged in severe cases
- In most cases the damage is gradual and accumulative to the insulation of Motors and Transformers

Power Conditioning Solution : Uninterrupted Power Supply (UPS)

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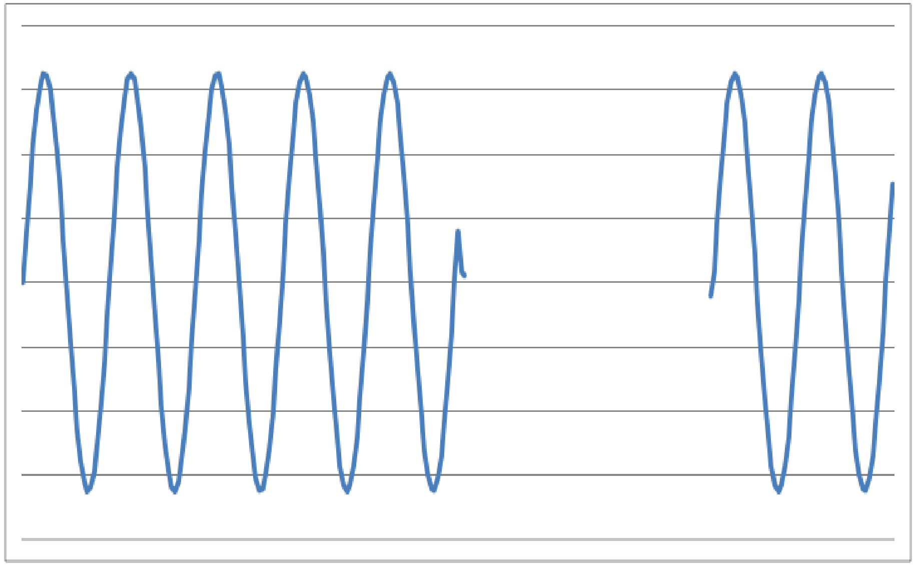
Power Interruptions

Brief but complete loss of supply voltage



Causes

- Malfunction of Switching devices
- Chattering of Contactors
- Loose Contacts in system

Effects

- Machine trip or System Reboot

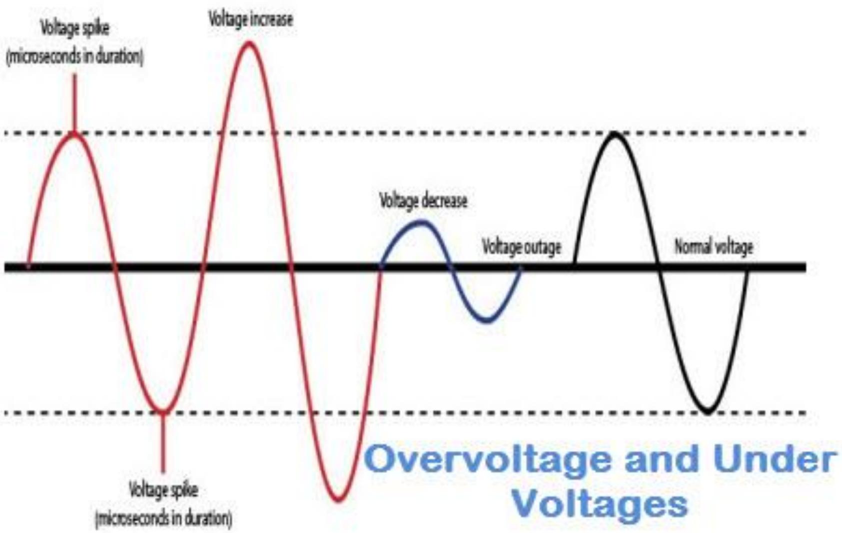
Power Conditioning Solution:

Uninterrupted Power Supply (UPS)

Long Duration Disturbances

Under-Voltage / Over-Voltage

Voltage being less than or more than the "Nominal" voltage for a period of time.



Causes

- Electrical power system loading
- Switching On or Off of Heavy loads

Effects

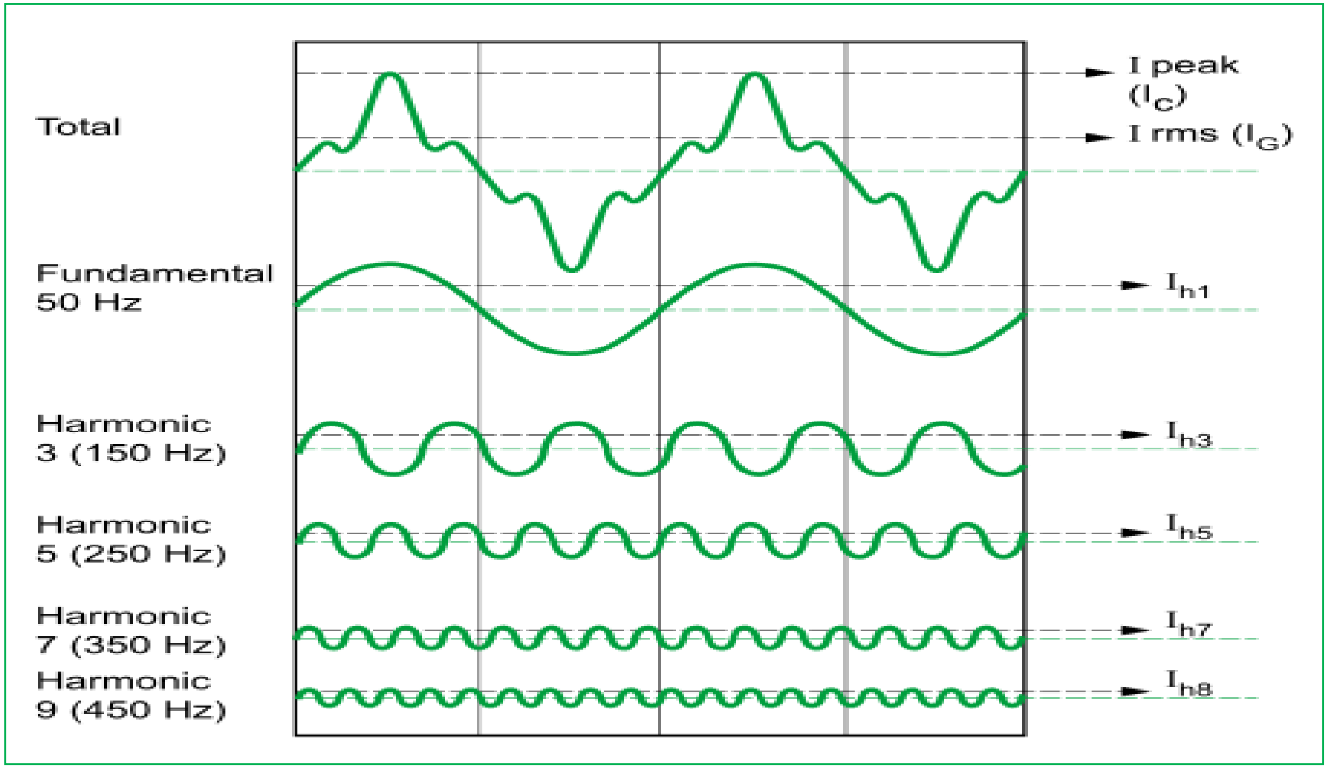
- Under-Voltage causes drop in torque and heating in motors
- Over-Voltage causes higher iron losses and gradual degradation of Insulation
- Higher energy losses

Power Conditioning Solution: Servo Controlled Voltage Stabiliser

An Harmonic is a waveform whose frequency is an integral multiple of the fundamental frequency. These harmonics can be classified as even and odd harmonics.

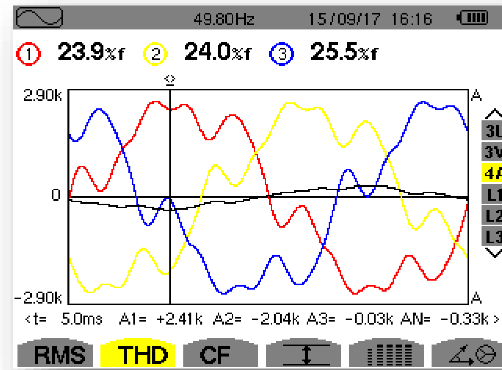
EVEN HARMONICS: 2 , 4 , 6 , 8 .... etc. orders.

ODD HARMONICS: 3 , 5 , 7 , 9 .... etc. orders.



Total Harmonic Distortion

THD stands for **T**otal **H**armonic **D**istortion, It is the ratio of the equivalent root mean square (RMS) voltage/current of all the harmonic frequencies (from the 2nd harmonic on) over the RMS voltage/current of the fundamental frequency.

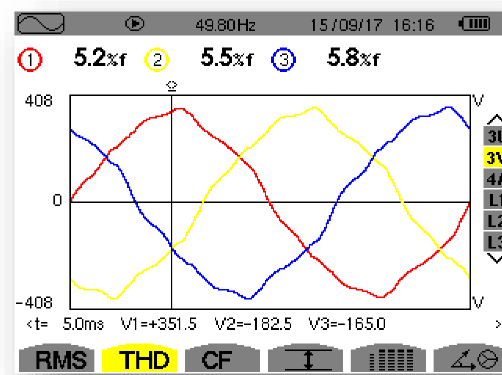


I - THD

THD Types :

I - THD : Total Harmonic Distortion present in the Current signal.

$$\%THD = \frac{\sqrt{I_2^2 + I_3^2 + \ldots + I_N^2}}{\sqrt{I_1^2}} \times 100$$



V - THD

V - THD : Total Harmonic Distortion present in the Voltage signal.

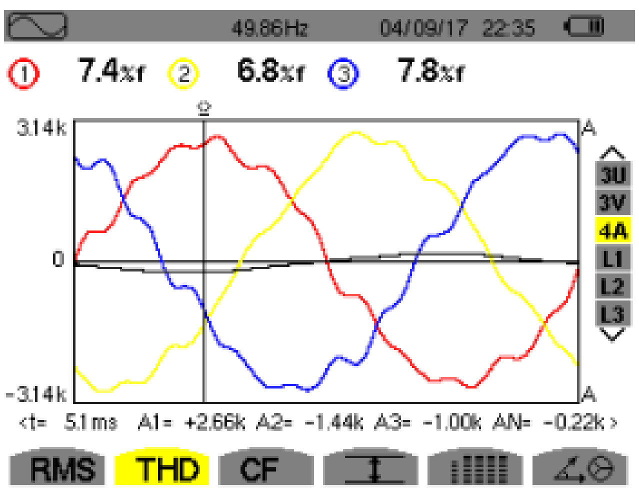
$$\%THD = \frac{\sqrt{V_2^2 + V_3^2 + \ldots + V_N^2}}{\sqrt{V_1^2}} \times 100$$

THD Limits & Standards as per (CEA)

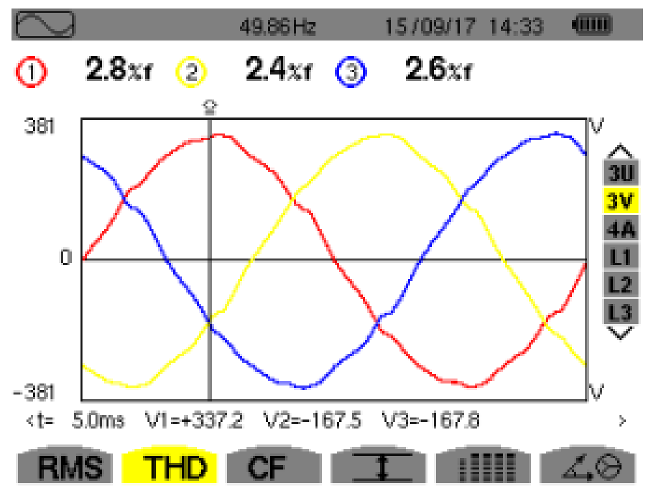
IEEE recommended , practices and requirements for harmonic control in electric power systems as per IEEE 519. The recommended limits for current and voltage total harmonic distortions in an electrical distribution system are as follows:

The Voltage THD must be maintained below 5 % .

The Current THD must be maintained below 8 % .



I - THD

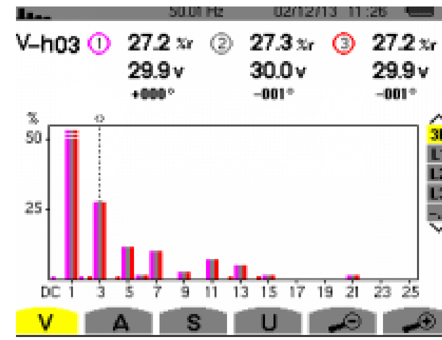


V - THD

Individual Harmonics

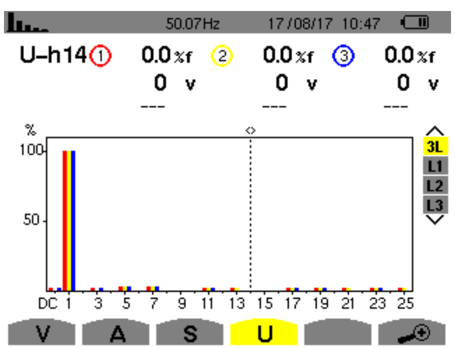
Measure the individual harmonics up to 50th order

- V – Ph-N
- U – Ph-Ph
- A – Current Harmonics
- S – VA harmonics export & Import.

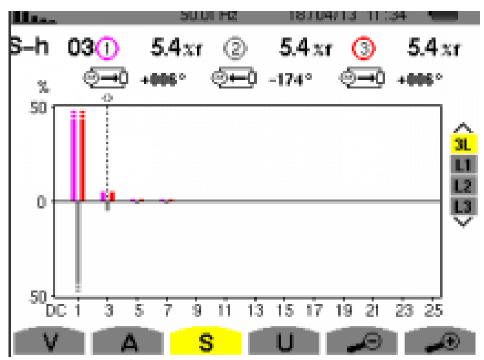


V-h

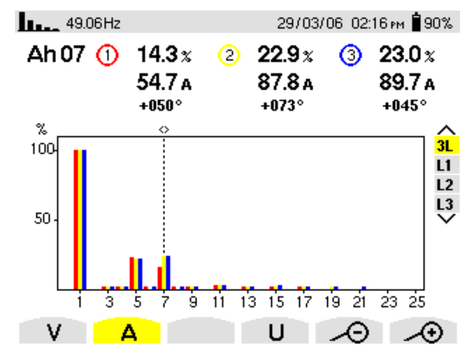
With help of this we can find out which order of the harmonic orders is contributing for the THD and mitigate those orders to reduce the THD to its limits.



U-h



S-h



A - h

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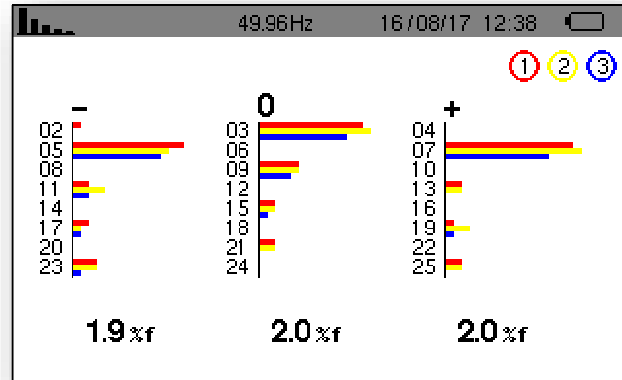
Entire harmonics can be classified into three harmonic sequences based on their orders like positive , negative and zero sequences.

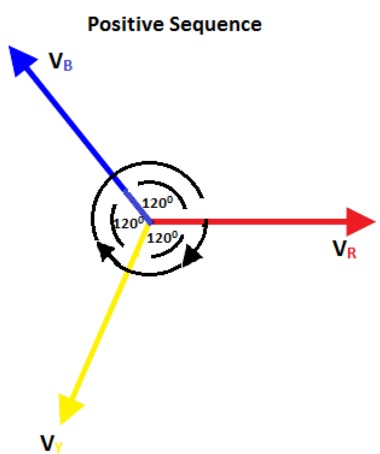
Presence of positive and negative sequences of harmonics make the machines like motors to vibrate and there by reduce the life span of the machines.

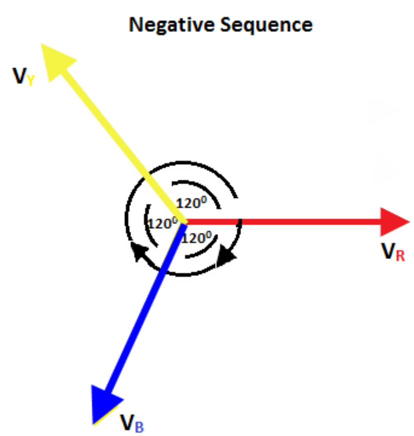


Positive sequence : 4^{th} , 7^{th} , 10^{th}, 13^{th} etc.

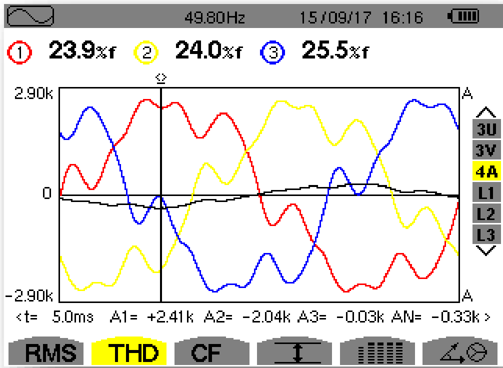
Negative sequence : 2^{nd} , 5^{th} , 8^{th}, 11^{th} etc.

Zero sequence : 3rd order , 6th order , 9th order etc.

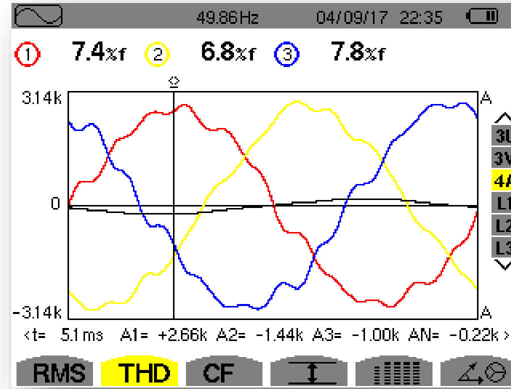




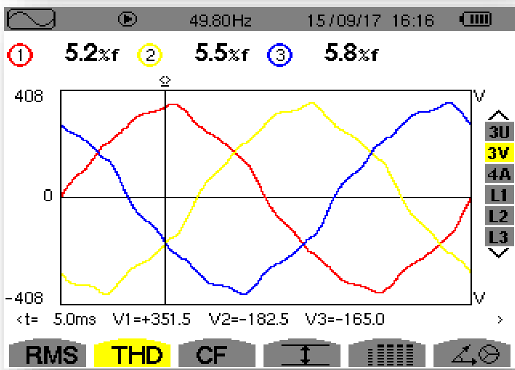
Harmonic Mitigation and Facts



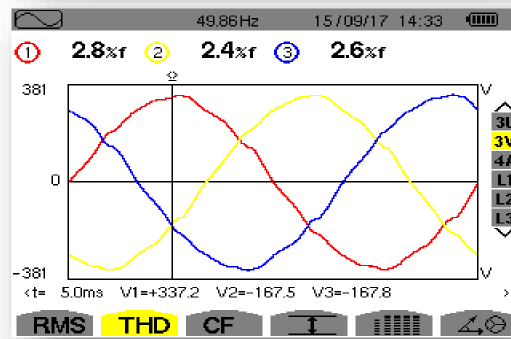
I THD before Installing AHF



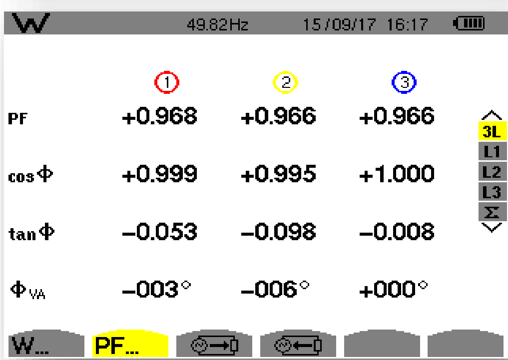
I THD After Installing AHF



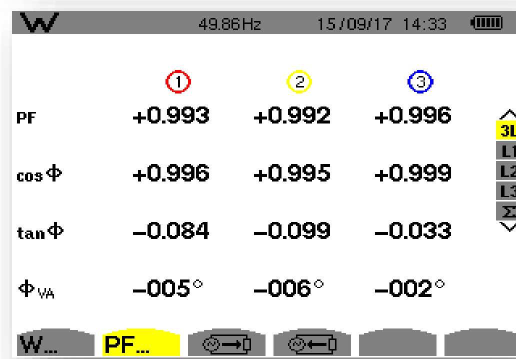
V THD before Installing AHF



V THD After Installing AHF



PF before Installing AHF



PF After Installing AHF

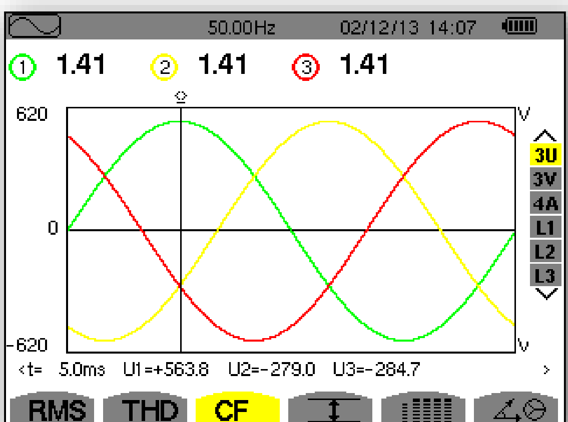
Voltage & Current Crest Factor

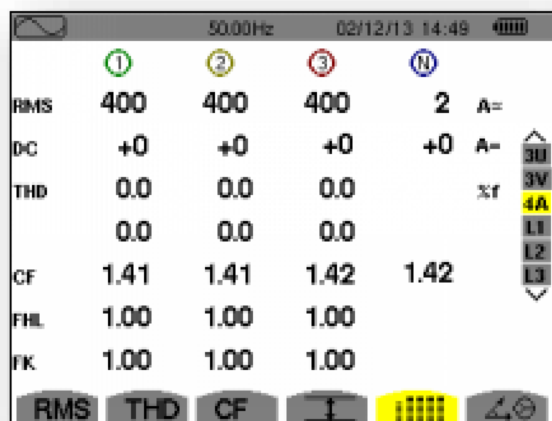
Crest factor is defined as the ratio of Peak Vs RMS value of a Voltage or Current waveform.

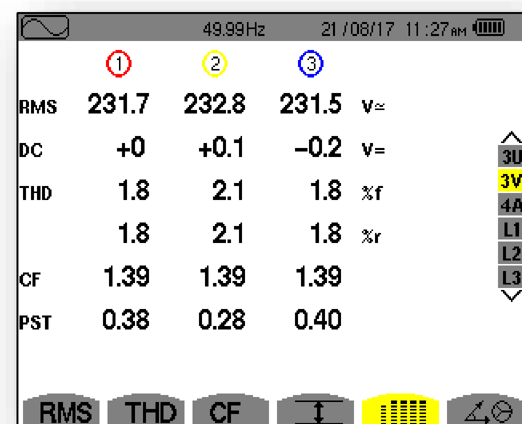
The Voltage & Current Crest Factor of a pure sinusoidal wave is **1.414**

High Current Crest Factors indicate high peak currents which is a notification for us to increase the cable size ,MCCB ratings and relay settings if they are not as per the required ratings.

Low Voltage Crest Factors indicate high peak currents which is a notification for us to Minimise the harmonics / increase the cable size,







Case study 1:

A Textile mill in Haridwar

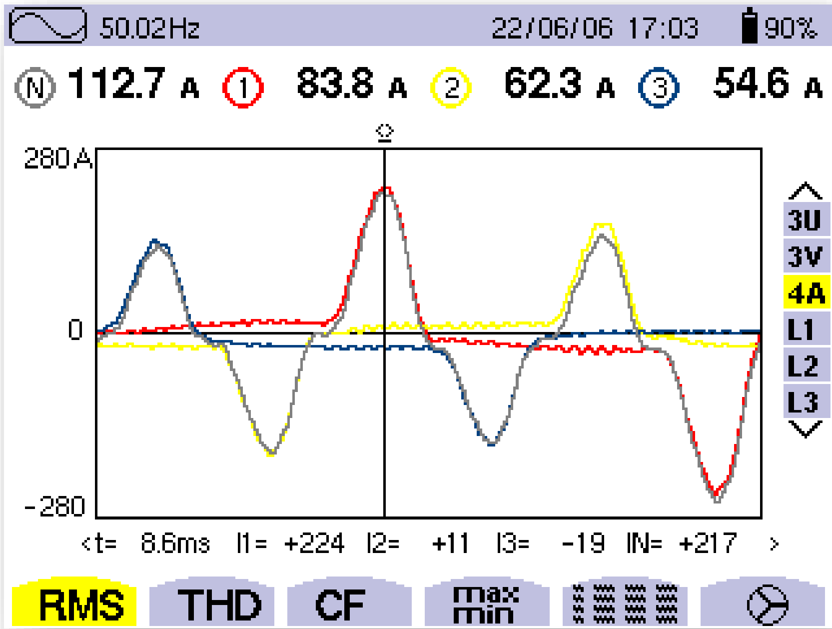
Problem

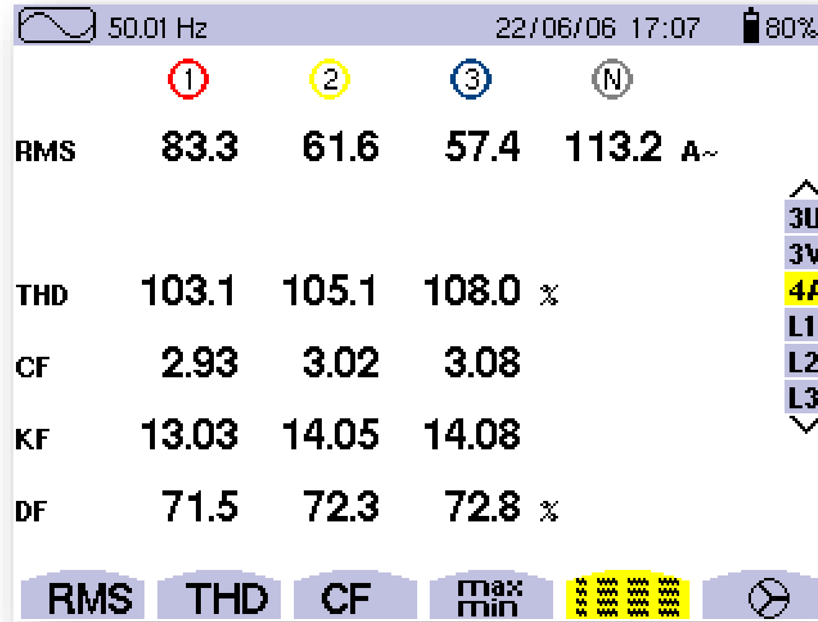
- A Generator connected to work stations was tripping erratically

Steps attempted to identify and correct the fault

1. A generator engineer measured average RMS current and reduced MCCB rating at to avoid generator tripping
2. After the modification, the MCCB started tripping and the UPS engineer insisted that MCCB should not be increased beyond the standard rating
3. Insulation tests were carried out, but no solution was found
4. The problem was then handed-over to an Energy auditor

Solution





1. After conducting the power quality study, it was noticed that the peak currents observed were much higher than the expected values.
2. This was also verified by the high value of the CF
3. Load-by-load analysis was carried out for all connected loads in the generator circuit.
4. It was found that a rectifier load connected in the circuit was drawing these large peak currents.
5. Once this load was isolated from the circuit, the currents returned to normal values.

Flickering Pst & Lst

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The flicker (as defined by the IEC/EN standard) characterizes voltage variations which cause lighting fluctuations.

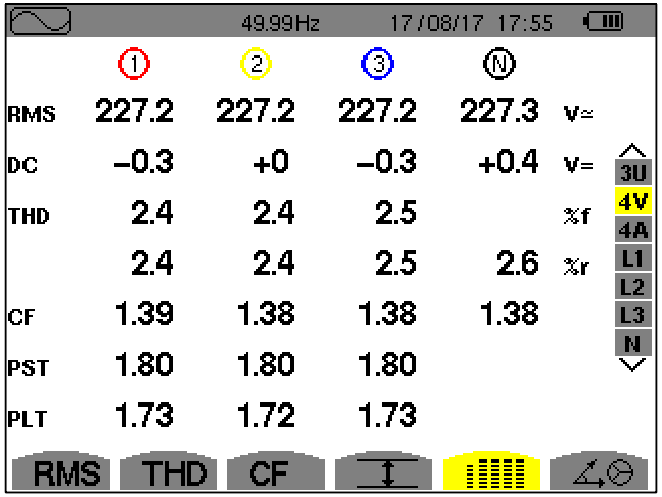
According to the applicable standards, the level of Flicker is expressed by 2 measurement methods:

- The **Pst** short-term flicker: Calculation of the Pst parameter, which is used to assess the level of flicker, is based on statistical processing of the voltage signal sampled. It is measured over a period of 10 minutes.

- The **Plt** long-term flicker: This is a multiple of the Pst. It is measured over a period of 2 hours.

In the standard **IEC 61000-3-3** the observation intervals and the limiting values for Pst and Plt are specified:

Value	Interval	Limits
Pst	10min	1.0
Plt	2Hrs	0.65



Typical Voltage waveform with Flicker

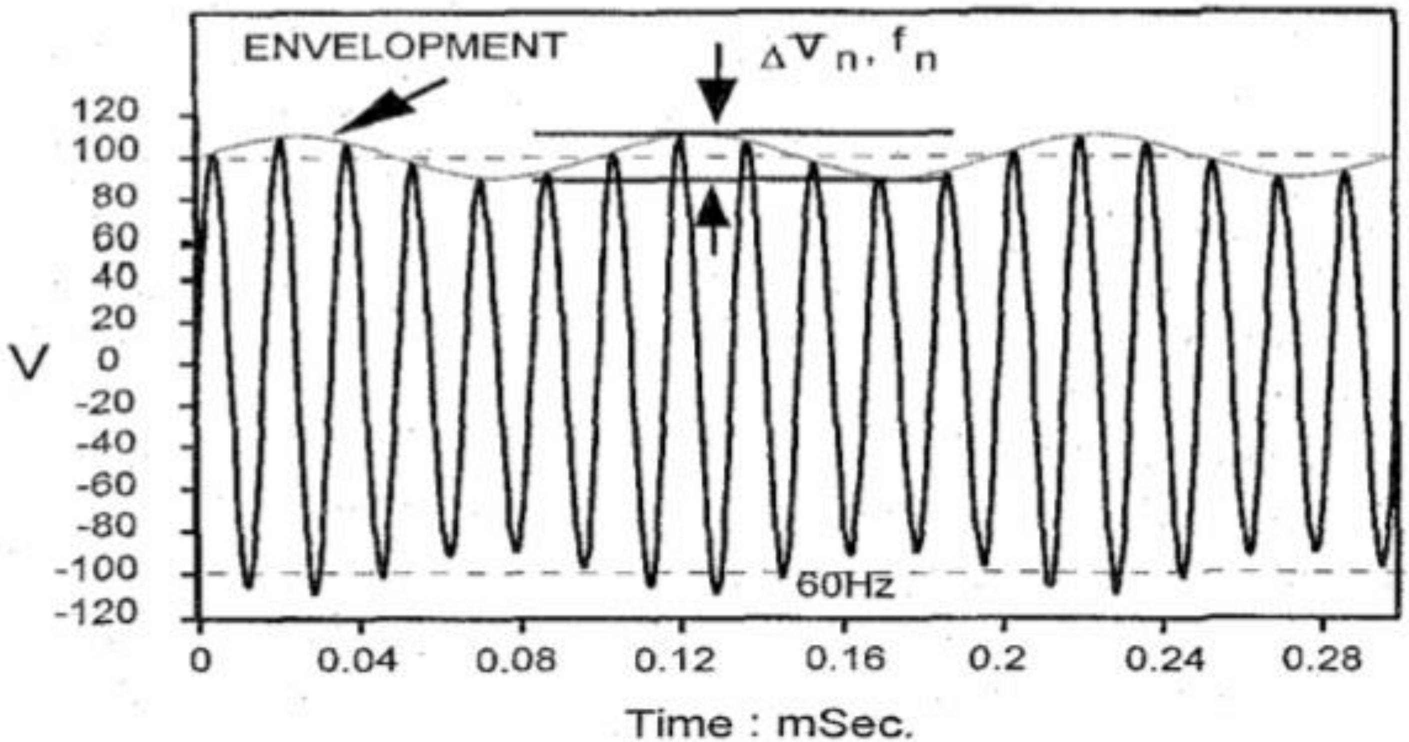
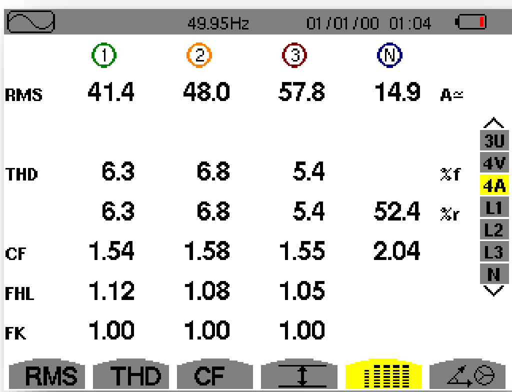


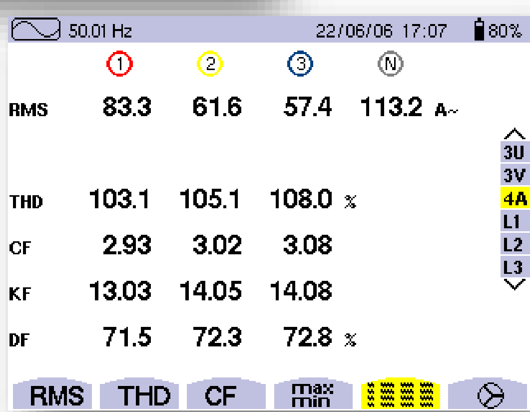
Figure . A voltage flicker waveform, f_1=10 Hz, $\Delta\bar{V}_1$=20 V.

10

K-factor is weighting of the harmonic load currents according to their effects on transformer heating. The higher the K-factor, the greater the harmonic heating effects.

FHL is Harmonic Loss Factor. It indicates the de-rating factor of the connected transformer.



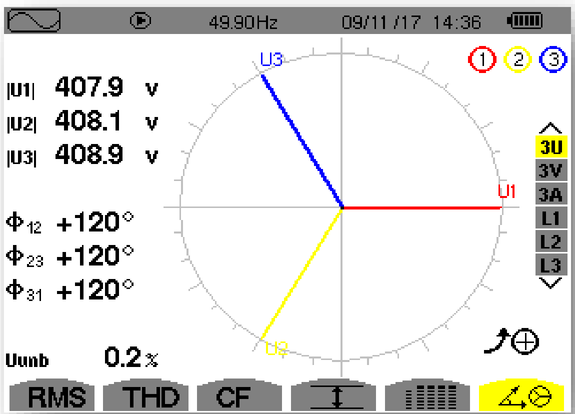


Typical Load K-Factors	
Load	**K-Factor**
Electric discharge lighting	K-4
UPS with optional input filter	K-4
Welders	K-4
Induction heating equipment	K-4
PLCs and solid state controls	K-4
Telecommunications equipment (e.g.. PBX)	K-13
UPS without input filtering	K-13
Multiwire receptacle circuits in general care areas of health care facilities and classrooms of schools, etc.	K-13
Multi-wire receptacle circuits supply-ing inspection or testing equipment on an assembly or production line	K-13
Mainframe computer loads	K-20
Solid state motor drives (variable speed drives)	K-20

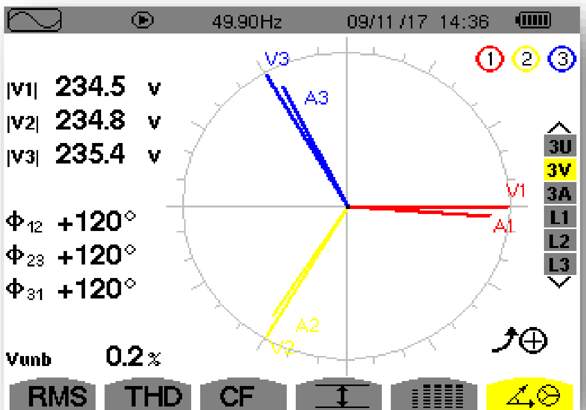
Voltage & Current Unbalance

Any deviation in voltage and current waveform from perfect sinusoidal, in terms of magnitude or phase shift is termed as unbalance.

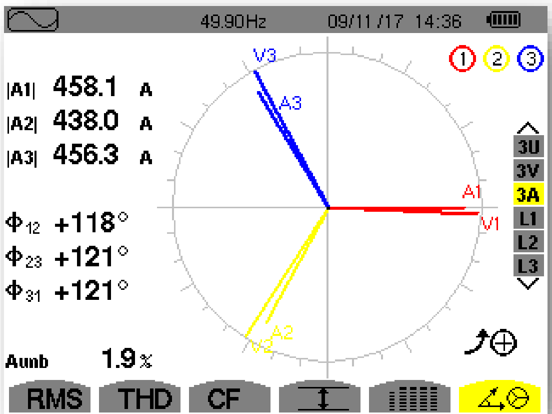
The supply voltage unbalance percentage should not be more than 2%.



U Ph-Ph Unbalance %



V Ph-N Unbalance %



I Unbalance %

Causes

- Utility can be the source of unbalanced Voltages
- Load imbalance due to uneven mix of single and 3 Phase loads
- Malfunctioning equipment
- Floating Neutral

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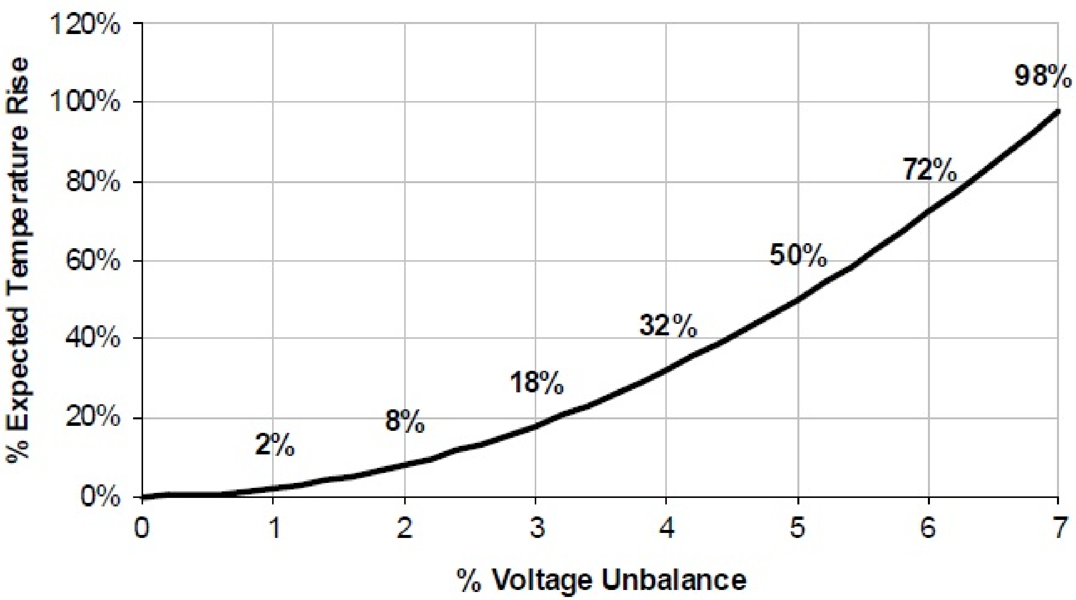
Effects

- The main effect of voltage unbalance is motor damage from excessive heat
- Generally accepted norm <2% unbalance. More is a cause for concern
- **% Temp. Rise increases by twice the square of % voltage unbalance.**



Power Conditioning Solution: Galvanic D / Y Isolation Transformer + Servo Stabiliser

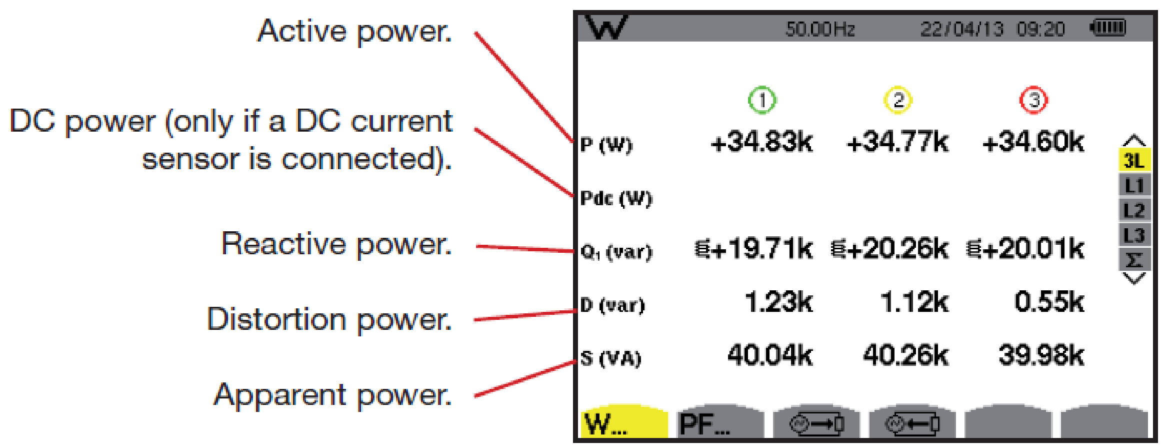
Mitigation

- Load balancing
- Replacing the disturbing equipment's i.e. with unbalanced three phase reactance
- Motors with unbalanced phase reactance should be replaced and re-wound.
- Reducing the harmonics also reduces the unbalance, which can be done by installing active filters.

Distorted kVAr Measurement

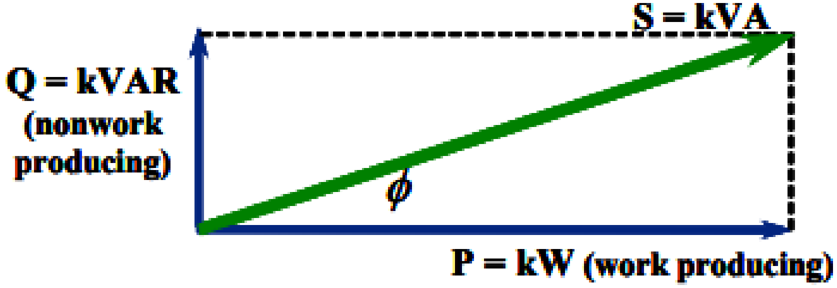
Now it's possible to quantify the power generated by the harmonics. This power value is better known as Distorting Power (D) and it is linked to the distorting amperes. The unit is distorting Volt-Ampere (VAd); This **distortion** power has an immediate effect on the waveform and on the THD of the current.

Power factor correction equipment will not be of any use because it acts only on the displacement power factor. Correcting reactive power generated by the harmonics will become more dangerous for power factor correction equipment. To reduce the current harmonics (and therefore the distorting amperes), you must install filtering equipment.



Distorted kVAr Measurement

With Linear Loads

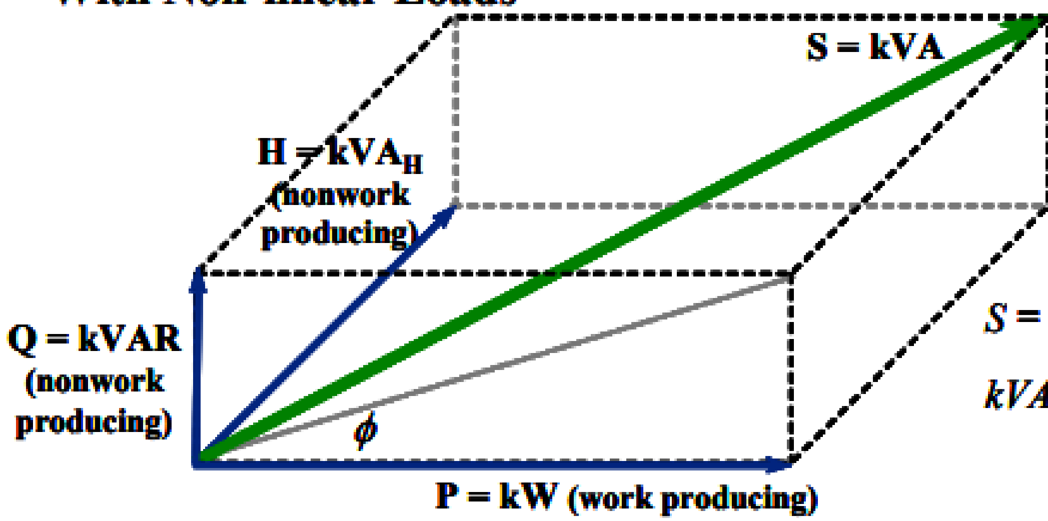


$$pf = \frac{P}{S} = \frac{kW}{kVA} = \cos\phi$$

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

$$kVA = \sqrt{kW^2 + kVAR^2}$$

With Non-linear Loads



$$pf = \frac{P}{S} = \frac{kW}{kVA} \neq \cos\phi$$

$$S = \sqrt{P^2 + Q^2 + H^2}$$

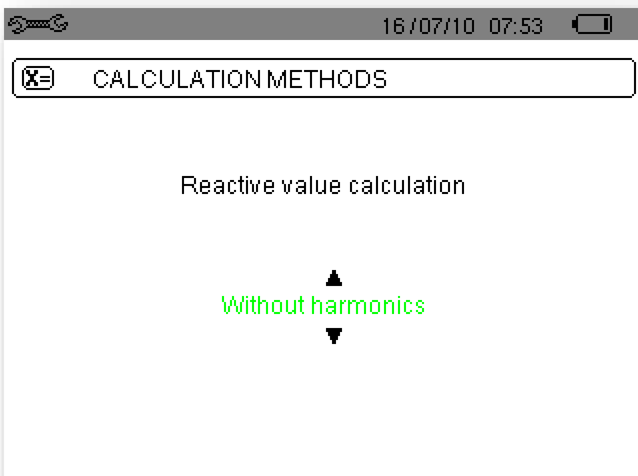
$$kVA = \sqrt{kW^2 + kVAR^2 + kVAR_H^2}$$

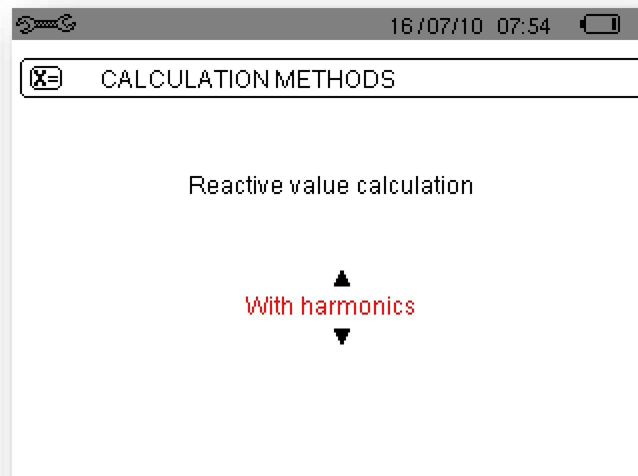
True Power Factor = (Displacement Power Factor) x (Distortion Power Factor)

Figure 3- 1: Power factor relationship for Linear and Non-linear loads

Case study 2: Problem in APFC panel due to DRIVES

- In a starch manufacturing unit in Delhi, it was noticed that after connecting drives, APFC panel started working erratically
- Customer has used a true RMS instrument which has included the harmonics power, found PF to be low and connected kVAr to improve the PF
- However, this led to excess kVAr in the circuit, leading to the malfunctioning of the APFC panel
- To correctly assess the problem, measurements were carried out with and without the effect of harmonics on the PF.

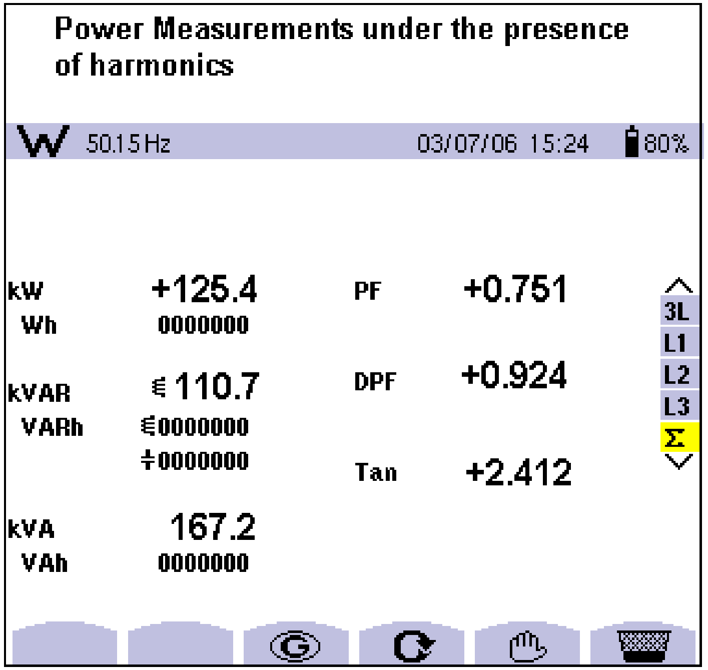


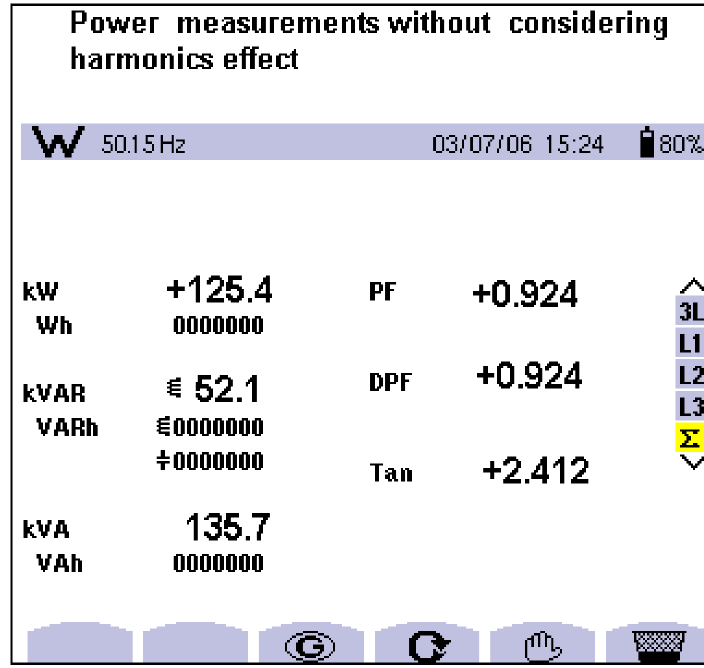


Option available in KRYKARD ALM 30 , ALM 32, ALM 35 & ALM 10

Solution:

kVAr measurement with harmonics & without harmonics





1. The excess kVAr connected was reduced
2. Filters were added to reduce the I THD content
3. Therefore, the effect of harmonics on the PF was reduced to bring it to the expected level

RFI / EMI Noise

Presence of unwanted higher Radio Frequency or Electro Magnetic Frequecies on the Power Line

Causes

- EMI is generated by electronic switching devices such as solid state rectifiers and SMPS
- RFI is generated by Radio Transmitters or other high frequency communication equipment

Effects

- Noise can cause mis-operation of some sensitive equipment
- Hum on telephone circuits and distortion on VDUs
- Data corruption

Solutions:

- EMI/RFI Filter for Transverse Mode Noise
- Isolation transformer for Common Mode Noise

KRYKARD PQ Analysers, EMS and T&M

- Widest range in the market
- Easiest to use
- Comprehensive measurements
- Boosts Productivity
- Built Tough
- Well Supported

ALENSOFT

KRYKARD PQ Analysers - CT Range




NEW NEW

Mini Ampflex	Ampflex	Ampflex	J93
70 mm Ø	140 mm Ø	250 mm Ø	72 mm Ø
10000A AC	10000A AC	10000A AC	3500A AC / 50 - 5000A DC





E3N	MN 93	MN 93A	C 193	PAC 93
11.8 mm Ø	20 mm Ø	20 mm Ø	52 mm Ø	39 mm Ø
100A AC/DC	200A AC	5A & 100A AC	1000A AC / 1300A DC	1000A AC / 1300A DC

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