Harmonics and Design of Filters – case study

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Power Quality (PQ) Drivers

1. **Penalties** by utilities drive harmonic filter sales
2. Transition to **PC-based controls** in manufacturing plants
3. **IEEE standards** foster the use of harmonic filters
4. **Rising energy costs** promote harmonic filter market
5. **Reduced equipment life** drives harmonic filter market
6. **Losses in production** due to tripping and shutdowns incite sales
7. Shift from **Electric to Electronic** loads spurs market growth
8. **Environmental considerations** instigate harmonic filter market
9. Increase in **Nonlinear Loads** ignites harmonic filter demand

Nonlinear, Harmonic Causing Loads

1. Electronic equipment such as PC
2. Battery chargers
3. Lighting dimmer controls
4. Fluorescent lights
5. Welders
6. Electronic ballasts
7. Printers
8. Photocopiers
9. Fax machines
10. Variable Frequency Drives (VFD)

All Above PQ damagers are mandatory for today's developed World.

Hence the PQ products are getting popular

Harmonic Filter Market

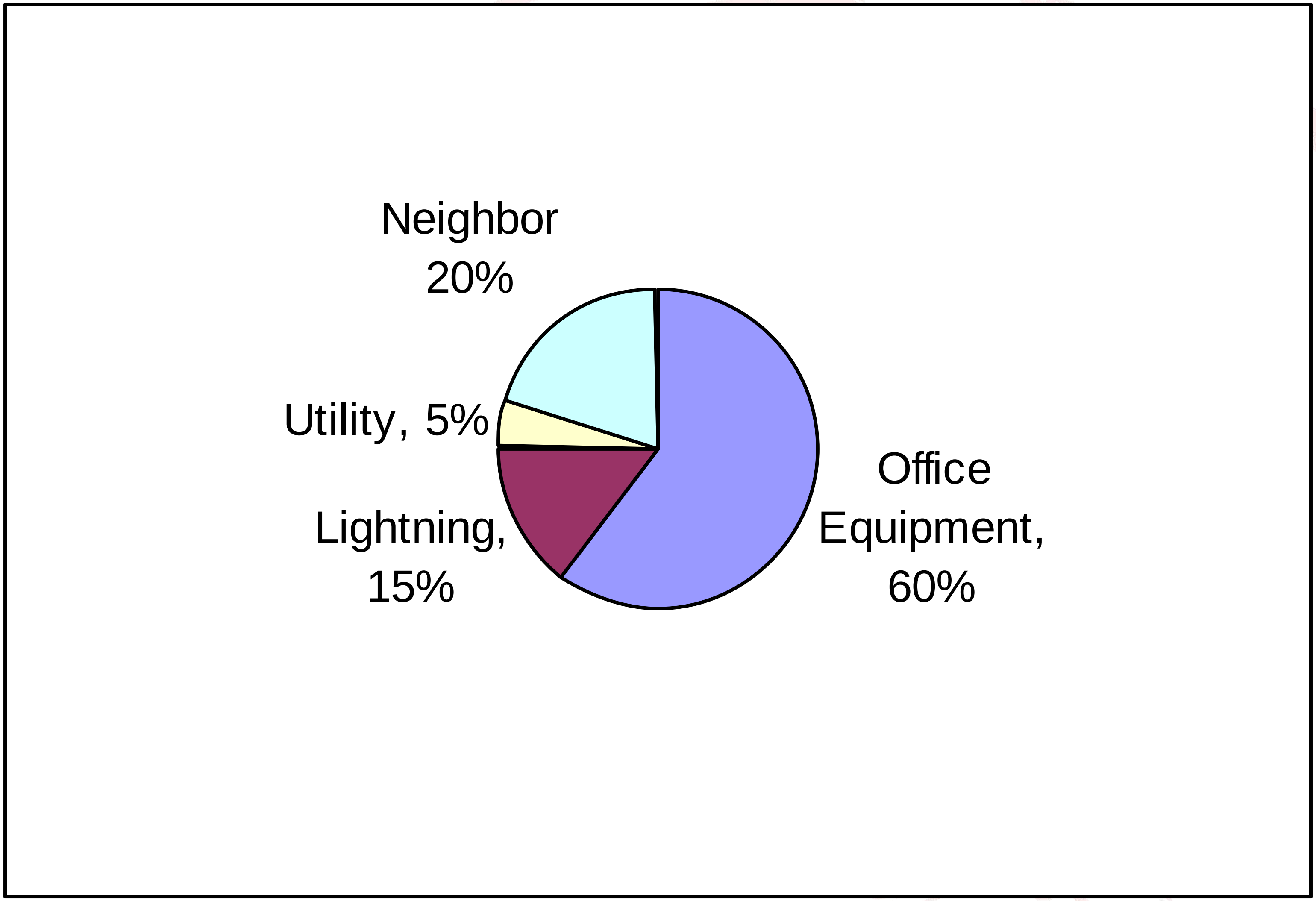
Low Voltage	:- 449.2mUSD	:- 71.9%
Medium Voltage	:- 105.8mUSD	:- 16.9%
High Voltage	:- 69.2mUSD	:- 11.2%

	Active	Passive
Overall Harmonic Filter Market	**23.8%**	**76.2%**
Low Voltage Harmonic Filter	31.6%	68.4%
Medium Voltage Harmonic Filter	04.6%	95.4%
High Voltage Harmonic Filter	Low	100%

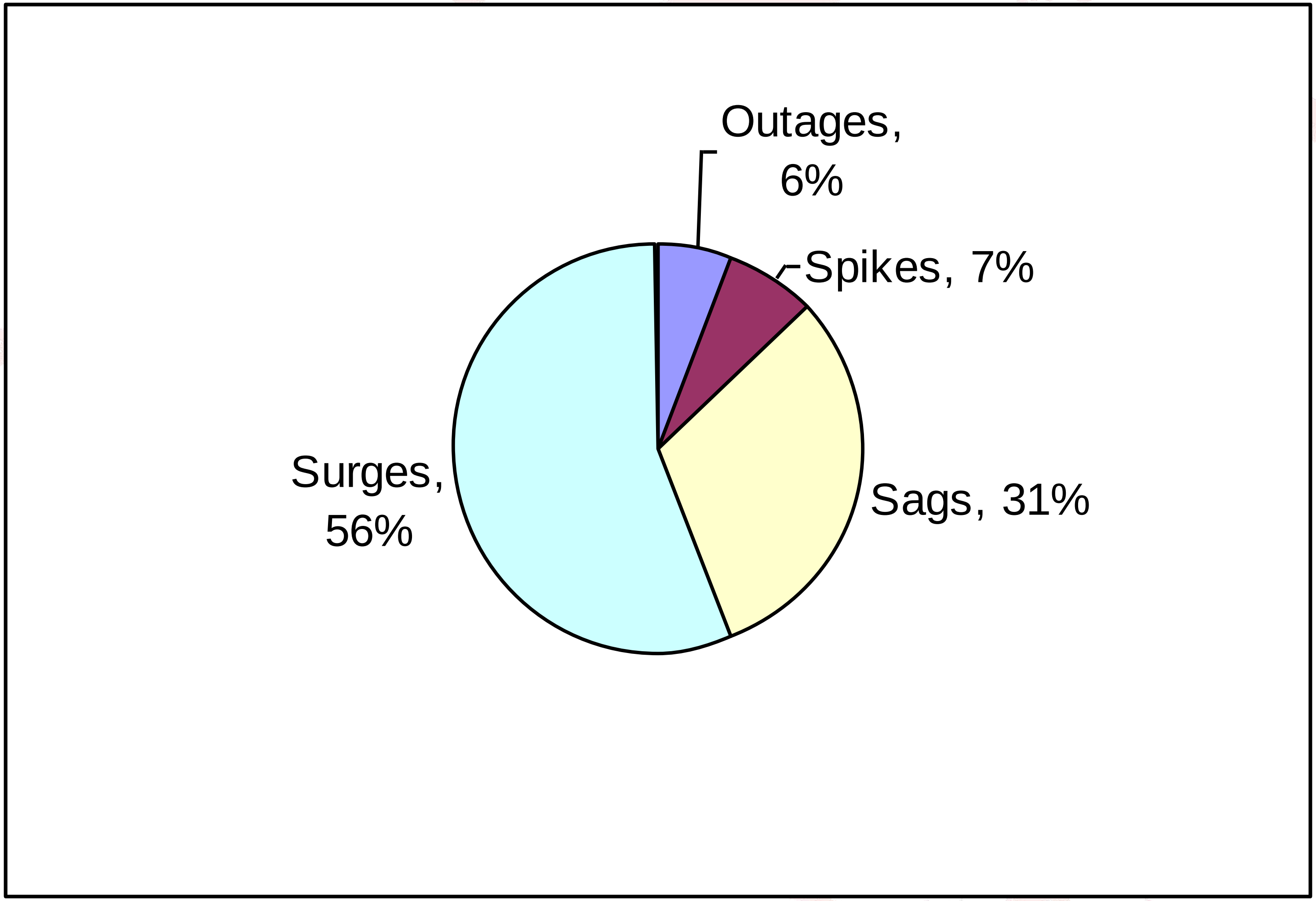
Passive Vs Active Filter

Passive Filter:--	Active Filter:--
• Source impedance dependent	• Independent of source independent
• Tuned only for Characteristic harmonics	• Can compensate even for Non- characteristic harmonics
• Individual passive filters are needed for each harmonic.	• Independent of system frequency.
• Performance depends on system frequency.	• One AHF can take care of all the harmonics

Sources of Power Quality Disturbance



Types of Power Quality Disturbance

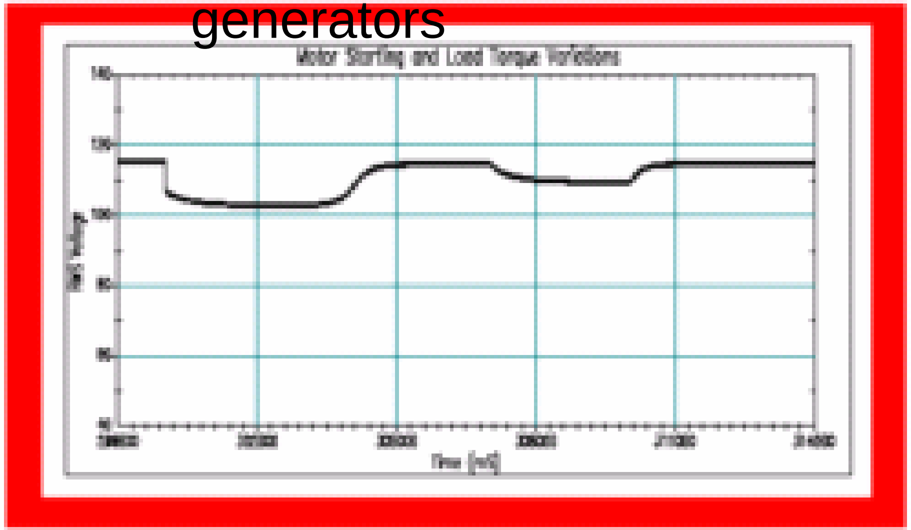


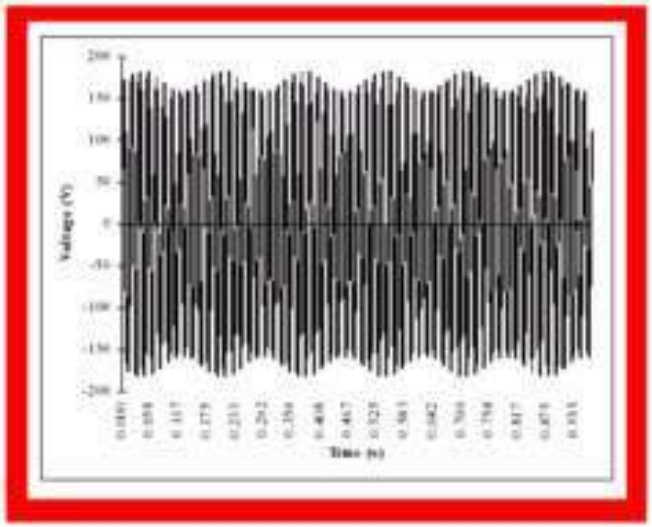
Different Power Quality Disturbance

1. Flicker
2. Interruption
3. Power Oscillation
4. Sag and Swells
5. Voltage Instability
6. **Harmonics**
7. **Unbalance Load**

1. Flicker

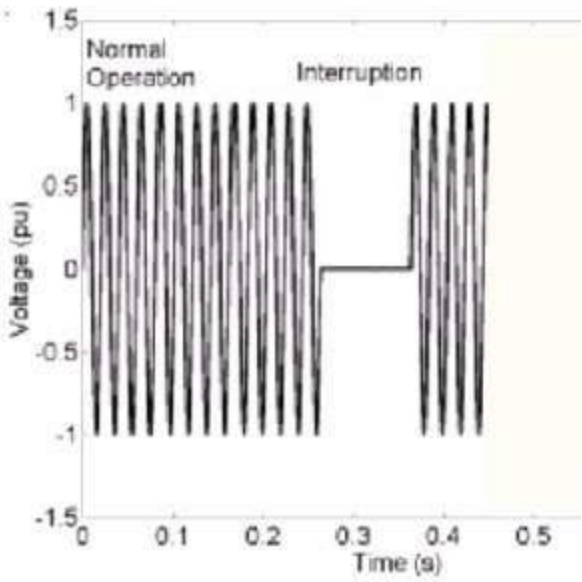
1. A **fluctuation** in system voltage that can lead to noticeable changes in light output.
2. It can either be a **periodic or aperiodic** fluctuation in voltage magnitude
3. Slowly fluctuating periodic flickers, in the **0.5 – 30.0Hz range**, are considered to be **noticeable by humans**.
4. The main **sources** of flicker are electric arc **furnaces, welding** machines, large **induction motors**, and **wind power** generators





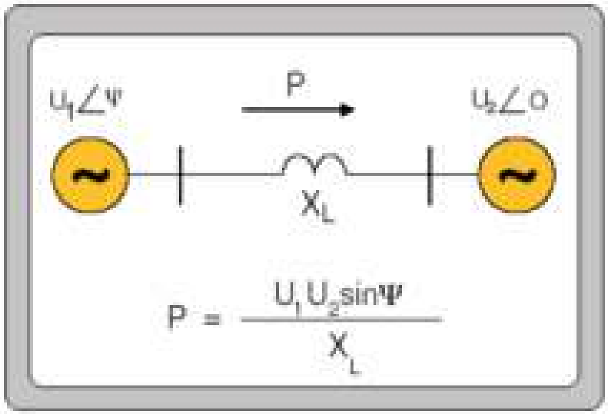
2. Interruption

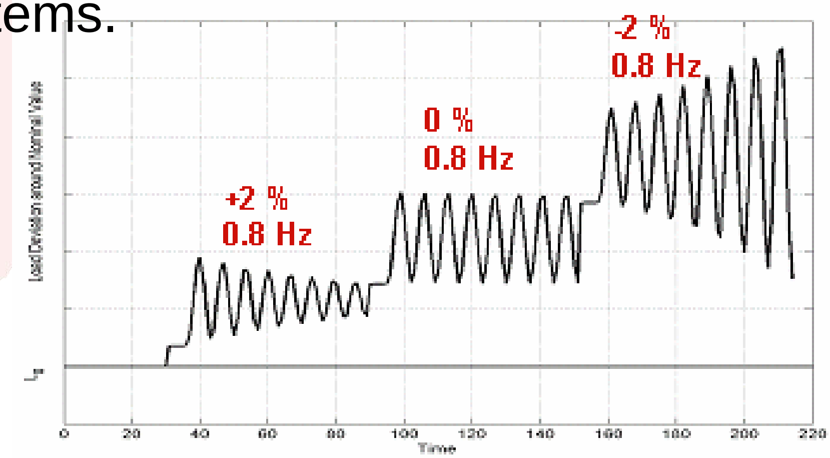
1. Occur when the supply **voltage drops below 10%** of the nominal value
2. The term sag covers voltage drops down to 10% of nominal voltage whereas an interruption occurs at lower than 10%.
3. A Sustained Interruption occurs when this voltage decrease **remains for more than 01 minute**.
4. An interruption is usually caused by downstream faults that are cleared by **breakers or fuses**



3. Power Oscillation

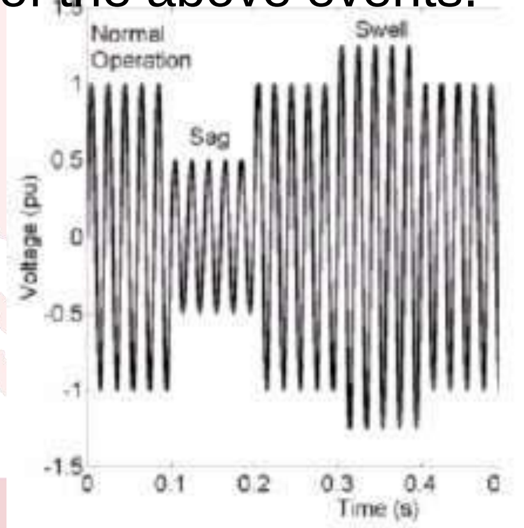
1. Periodic variations in generator angle or line angle due to transmission system disturbances
2. The oscillations may **last for 3 -20 seconds** after a severe fault.
3. During angular oscillation period significant cycle **variations in voltages, currents, transmission line flows** will take place.
4. The active power oscillations on a transmission line tend to limit the amount of power that may be transferred, thus may result in stability concerns or utilization restrictions on the corridors between control areas or utility systems.





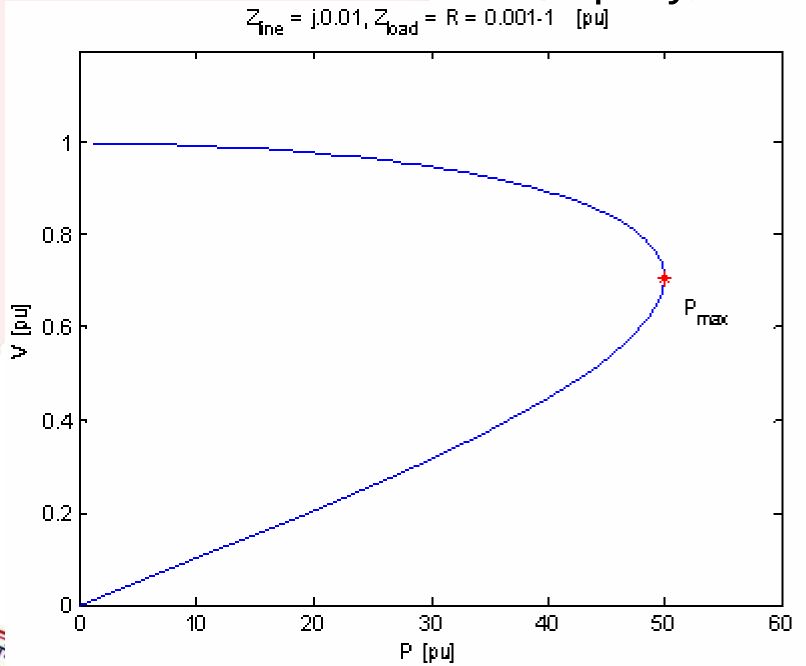
4. Sags and Swelles

1. Short duration **decrease/increase** (sag/swell) in **supply voltage**
2. A Voltage **Sag** or Voltage Dig is a **decrease in supply voltage of 10% to 90%** that lasts in duration from **1/2 cycle to 01 minute**.
3. A Voltage **Swell** is an **increase in supply voltage of 10% to 80%** for the same duration.
4. Sags can be created by sudden but brief changes in load such as transformer and motor inrush and short circuit-type faults. Also by a step change in load followed
5. A voltage *swell* may occur by the reverse of the above events.



5. Voltage Installability

1. Post-disturbance excursions of voltages at some buses in the power system out of the steady operation region
2. Voltage instability is basically caused by an **unavailability of reactive power support** in an area of the network, where the voltage drops uncontrollably.
3. Beyond peak of “nose curve” no additional power can be transmitted to the load as the voltage becomes uncontrollable and decreases rapidly



6. Harmonics

- **Harmonics Order**

  3n-3 (Zero sequence)

  3n +/- 1(Positive & Negative sequence)

- **Effects of Harmonics:-**

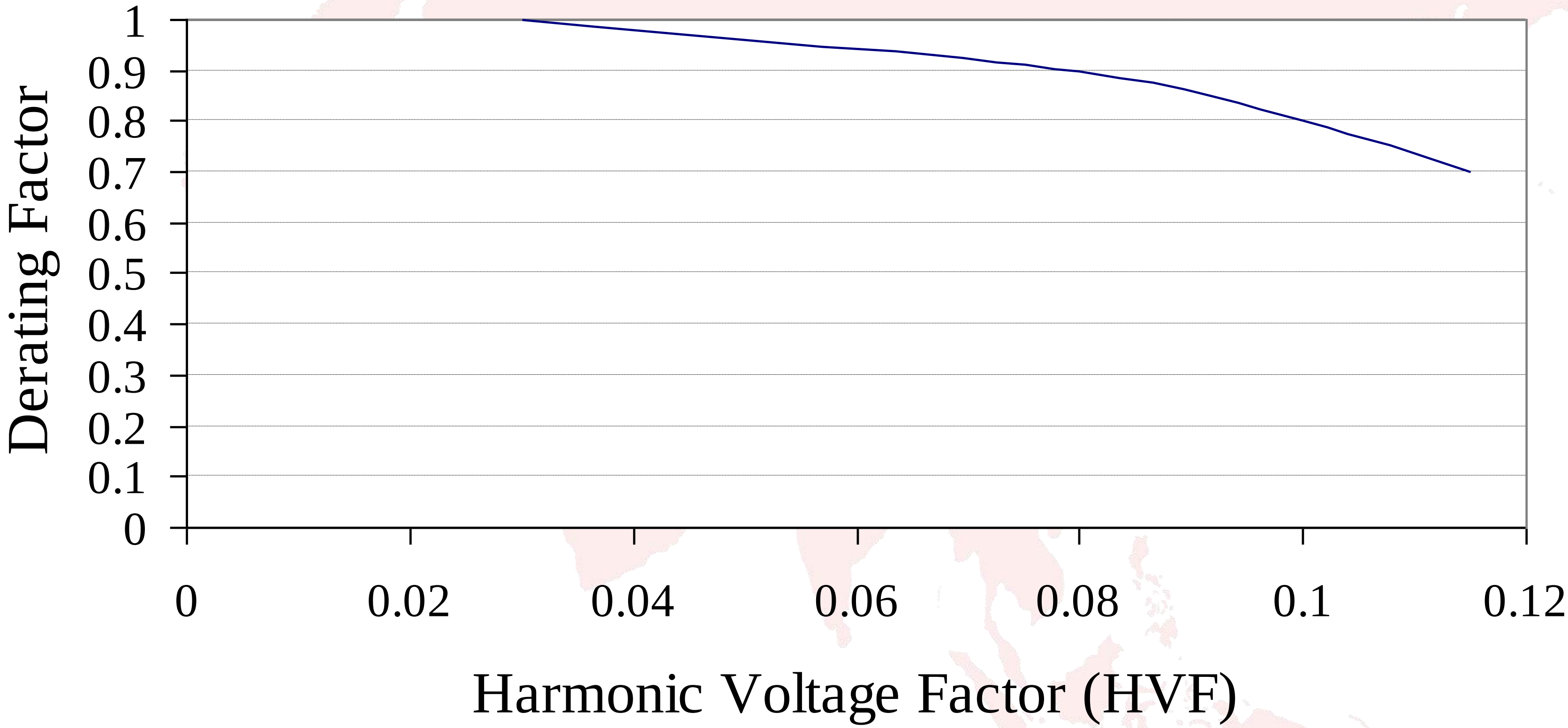
  1. Heating Effects
  2. Steady Harmonic Torque

  (Developed by the interaction of harmonic stator mmf with harmonic rotor mmf/current of the same order)

  3 Pulsating Harmonic Torque

  (Developed by the interaction of harmonic stator mmf with harmonic rotor mmf/current of the different order)

De-rating due to HVF (NEMA MG1 Part 30, 30.1.2.1)



7. Unbalance Load

1. A load which does not draw balanced current from a balanced three-phases supply
2. Typical unbalanced loads are loads which are connected phase-to-neutral and also loads which are connected phase-to-phase.
3. Unbalanced voltage may also arise from impedance imbalances
4. The percent current imbalance drawn by a motor may be 6 to 10 times the voltage imbalance, creating an increase in losses and in turn an increase in motor temperature.

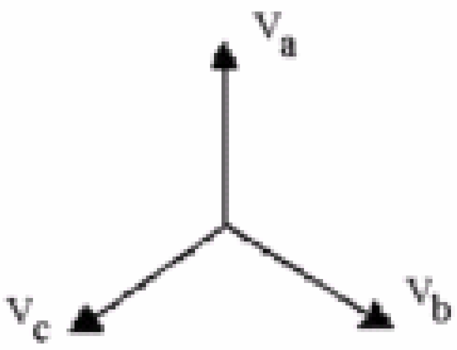


Fig 1 Balanced Voltages

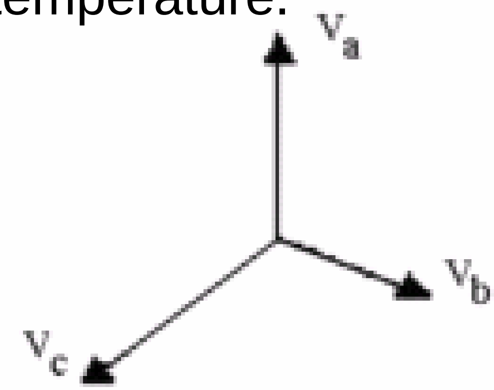
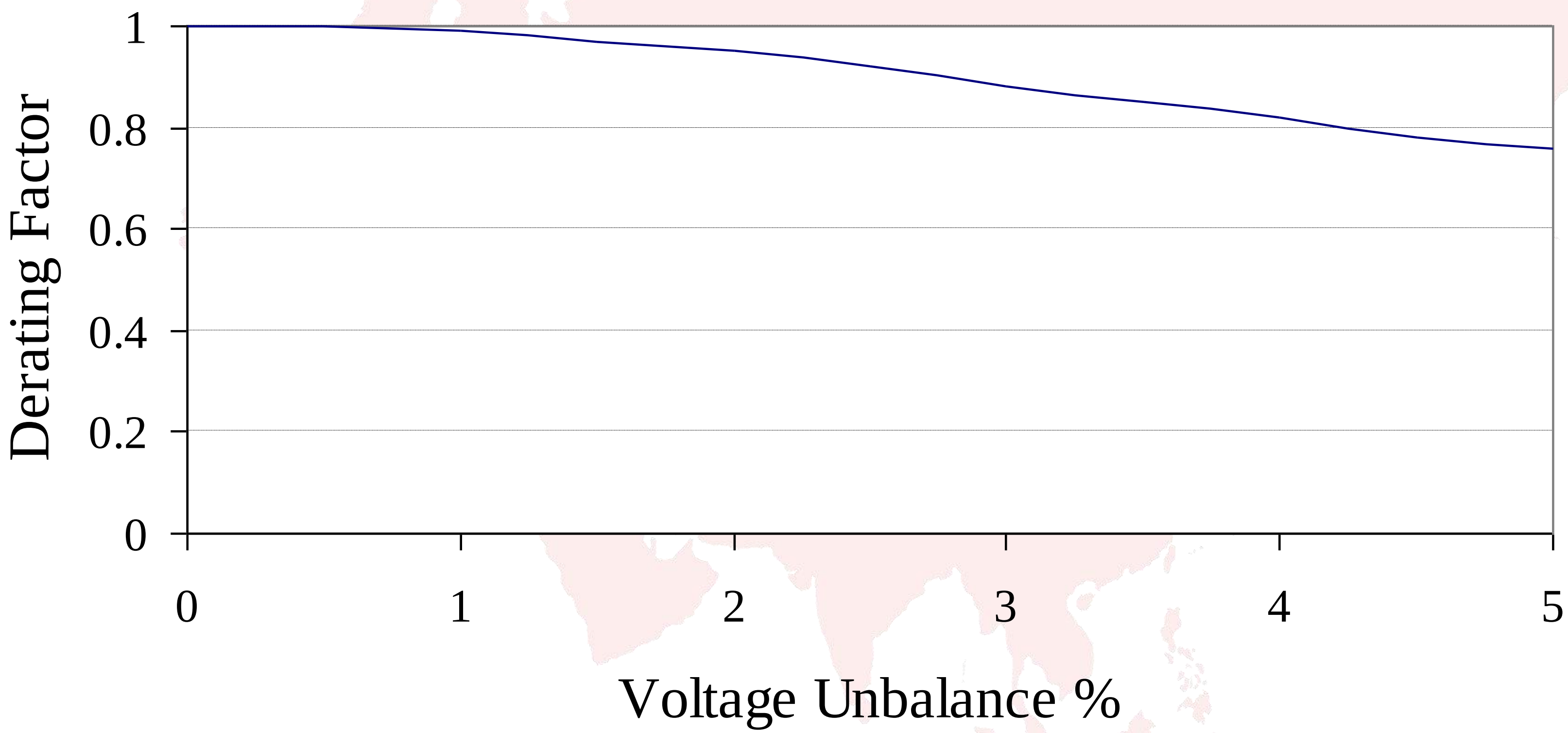


Fig 2 Unbalanced Voltages

De-rating (NEMA MG1 Part 20, 20.24.2)



Power Quality (PQ) Application

PQ Problem	LV	MV	HV
Flicker	**Q support & THD**	Q & THD	
Interruption	UPS		
Power Oscillations	Generator excitation Problem		
Sag & Swell	DVR or TSC+TCR **or Q Support**		
Voltage Instability	Not a PQ problem. Only reactive support @MV&HV		
Harmonics	**AHF** or passive filter		
Unbalance load	**Negative sequence compensation using VSC**		
Reactive power support	**STATCOM**	SVC (TSC+TCR)	SVC (TSC+TCR)

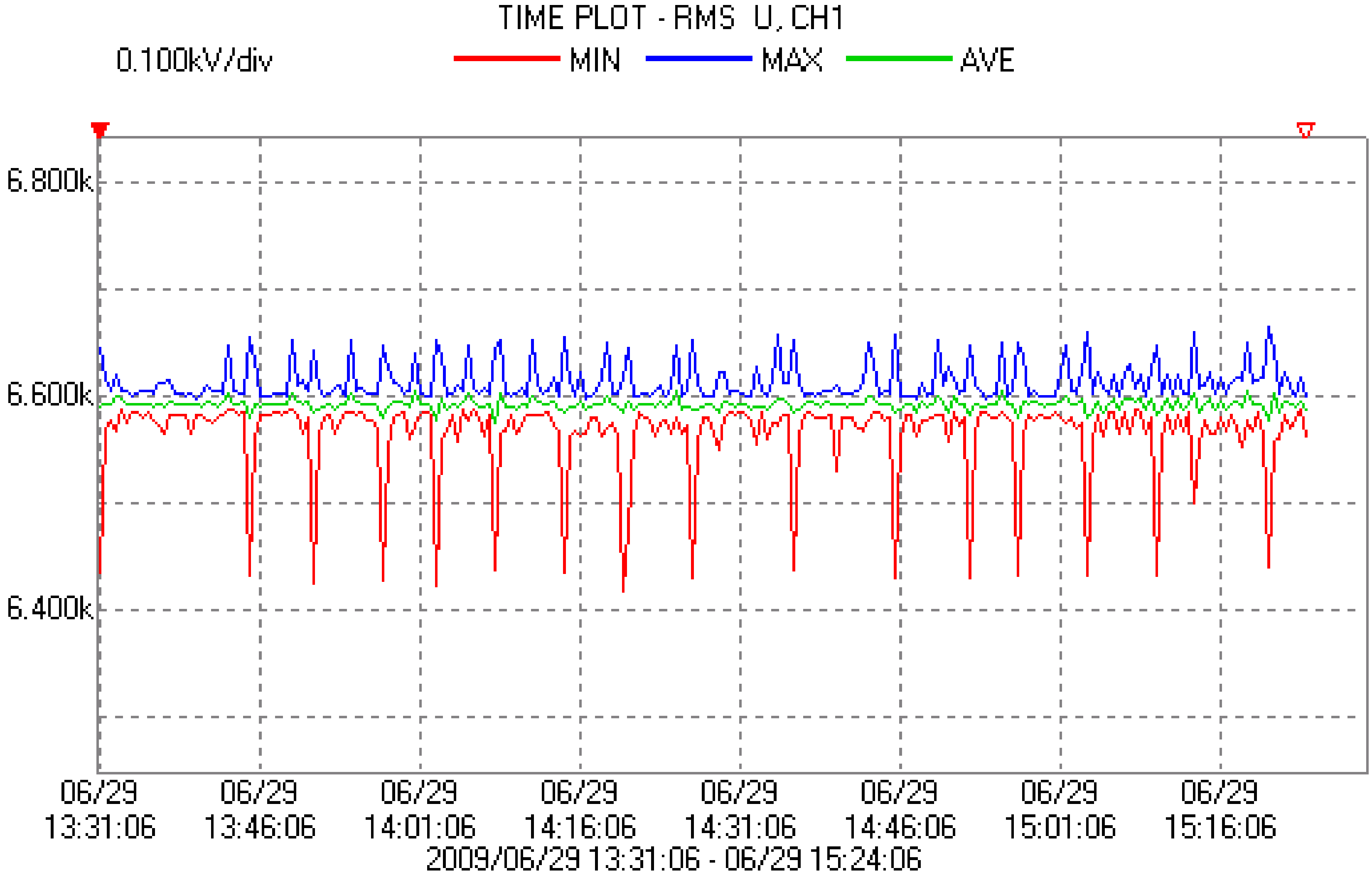
Effects of Bad Harmonics

1. Voltage distortions
2. Excessive currents on neutral wires
3. Overheating of motors
4. Microprocessor control problems
5. Unexplained computer crashes
6. Shortened transformer life
7. Unexplained equipment trips or shutdowns
8. Occasional equipment damage or component failure
9. Erratic control of process performance
10. Random lockups and data errors
11. Power system component overheating

Case Study Sites

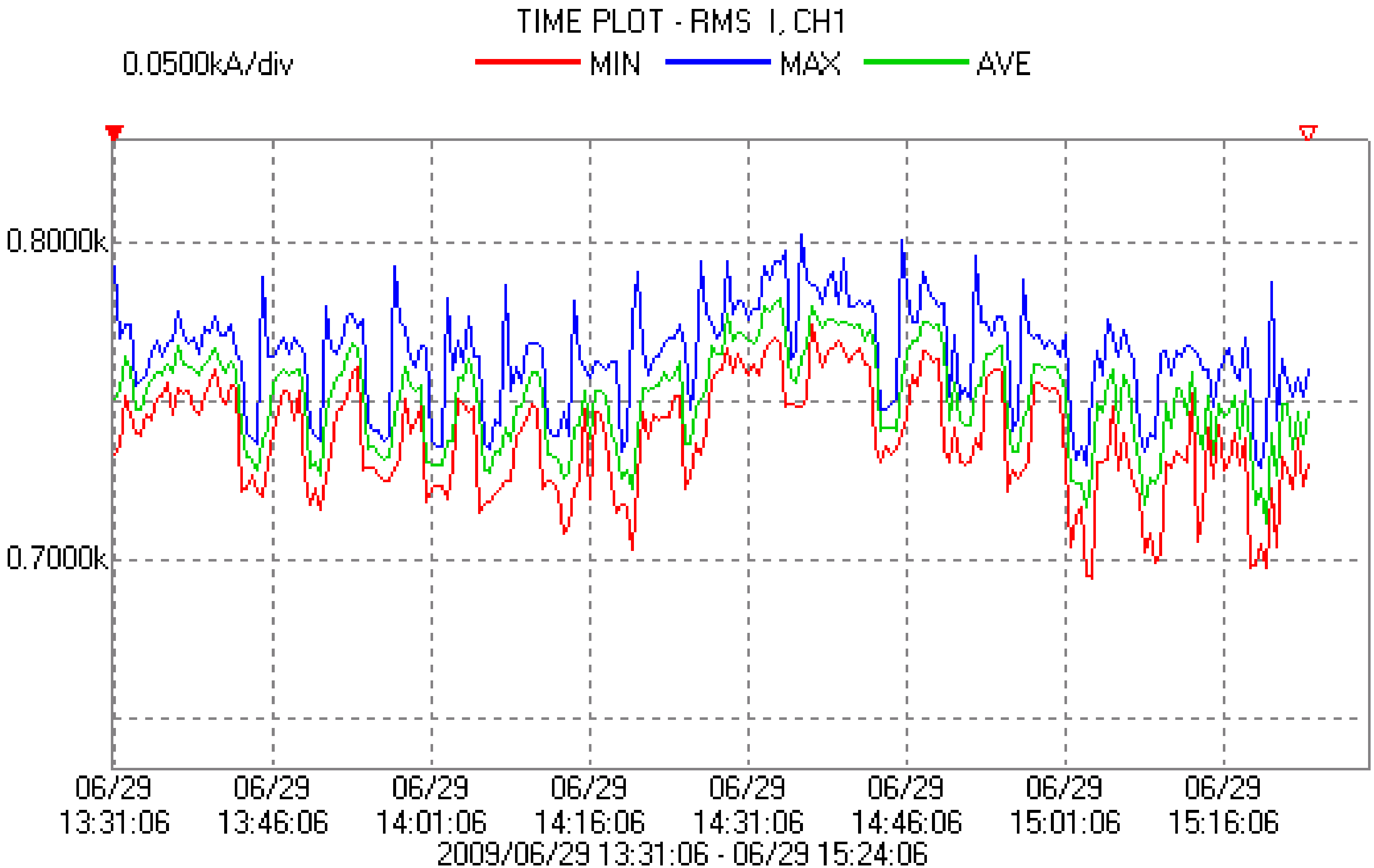
1. Godawari Power Ltd, Raipur
2. Malanpur Captive Power Ltd, Malanpur
3. Sarda Minerals and Power Ltd, Raipur
4. Ambuja Cements, Raipur
5. Heera Power, Raipur
6. CGL Kanjur Complex, Mumbai
7. CGL Fractional HP Machine Factory, Goa
8. Kalika Steel Plant, Jalna

Site A



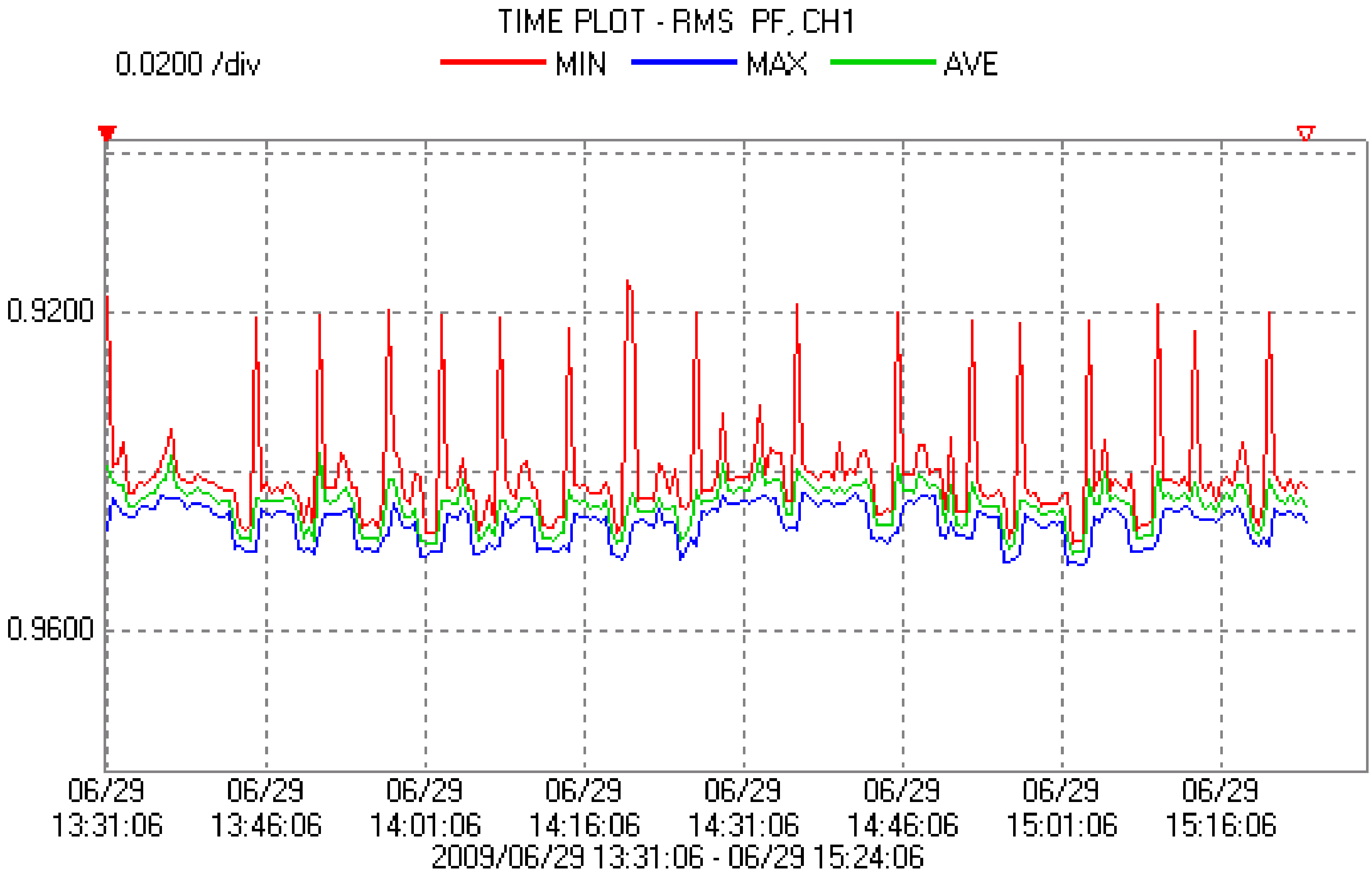
TIME PLOT - RMS U, CH1
0.100kV/div
MIN
MAX
AVE
6.800k
6.600k
6.400k
06/29 13:31:06
06/29 13:46:06
06/29 14:01:06
06/29 14:16:06
06/29 14:31:06
06/29 14:46:06
06/29 15:01:06
06/29 15:16:06
2009/06/29 13:31:06 - 06/29 15:24:06

Site A



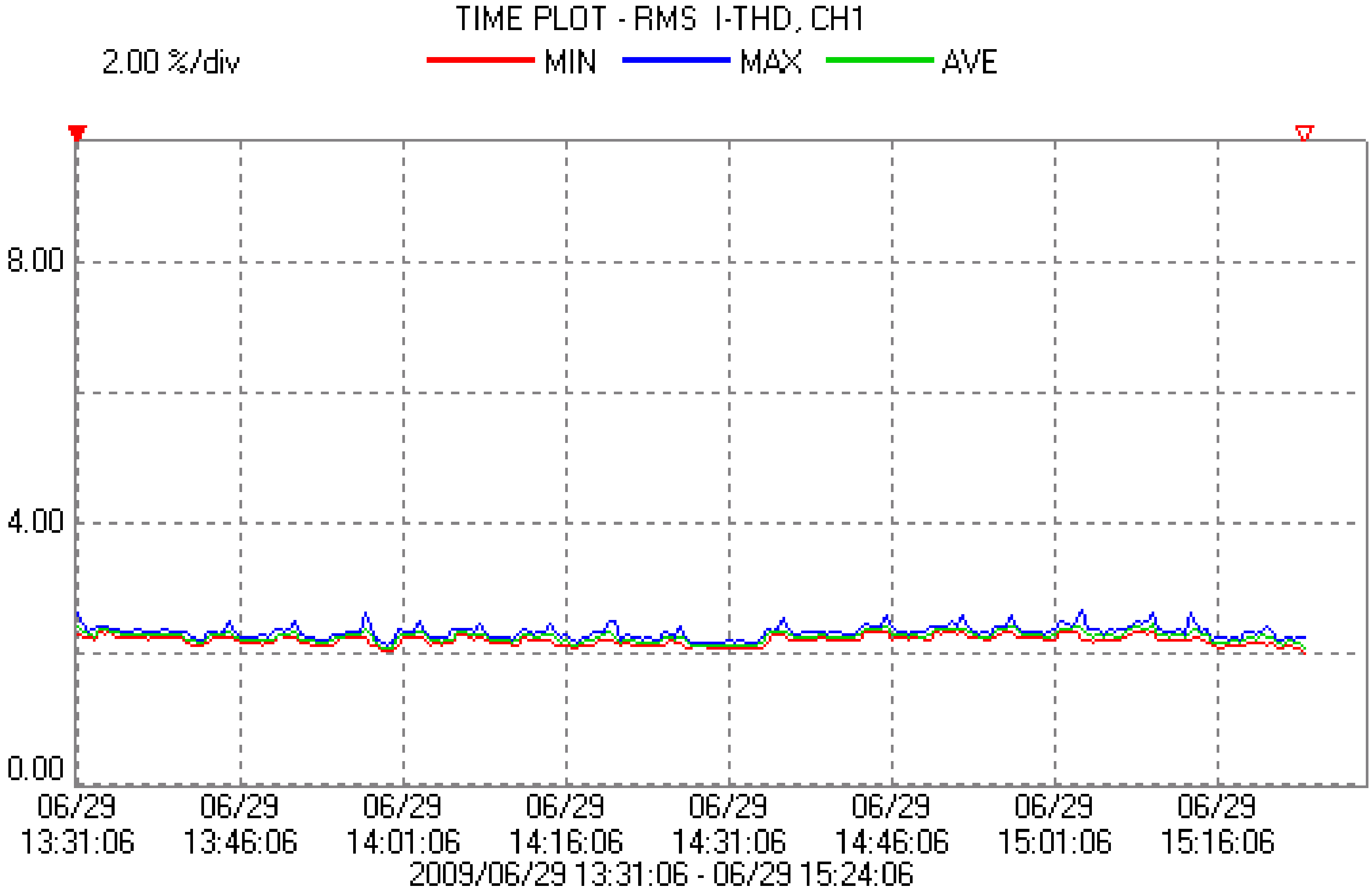
TIME PLOT - RMS I, CH1
0.0500kA/div
MIN
MAX
AVE
0.8000k
0.7000k
06/29 13:31:06
06/29 13:46:06
06/29 14:01:06
06/29 14:16:06
06/29 14:31:06
06/29 14:46:06
06/29 15:01:06
06/29 15:16:06
2009/06/29 13:31:06 - 06/29 15:24:06

Site A

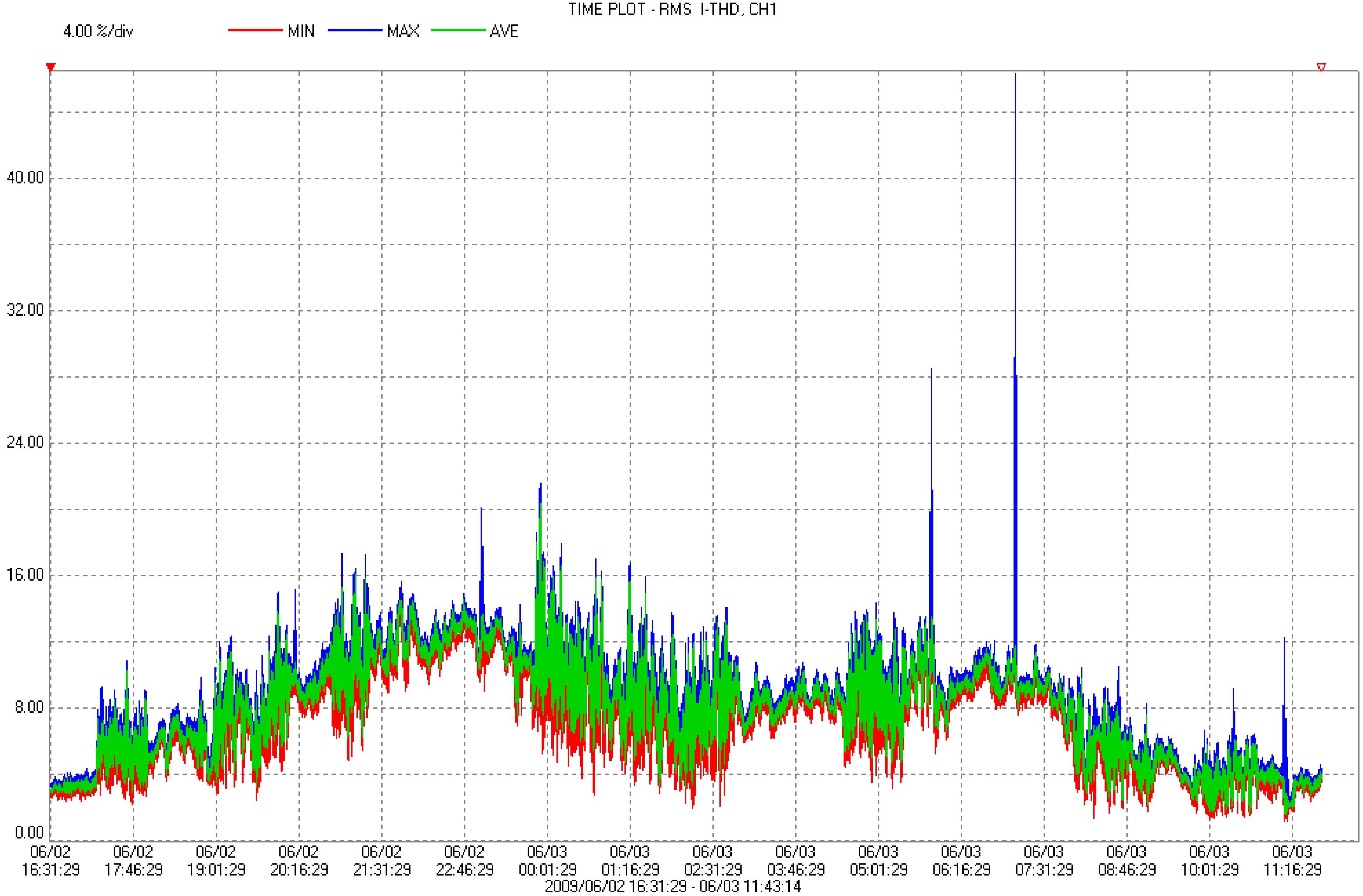


TIME PLOT - RMS PF, CH1
0.0200 /div
MIN
MAX
AVE
0.9200
0.9600
06/29 13:31:06
06/29 13:46:06
06/29 14:01:06
06/29 14:16:06
06/29 14:31:06
06/29 14:46:06
06/29 15:01:06
06/29 15:16:06
2009/06/29 13:31:06 - 06/29 15:24:06

Site A

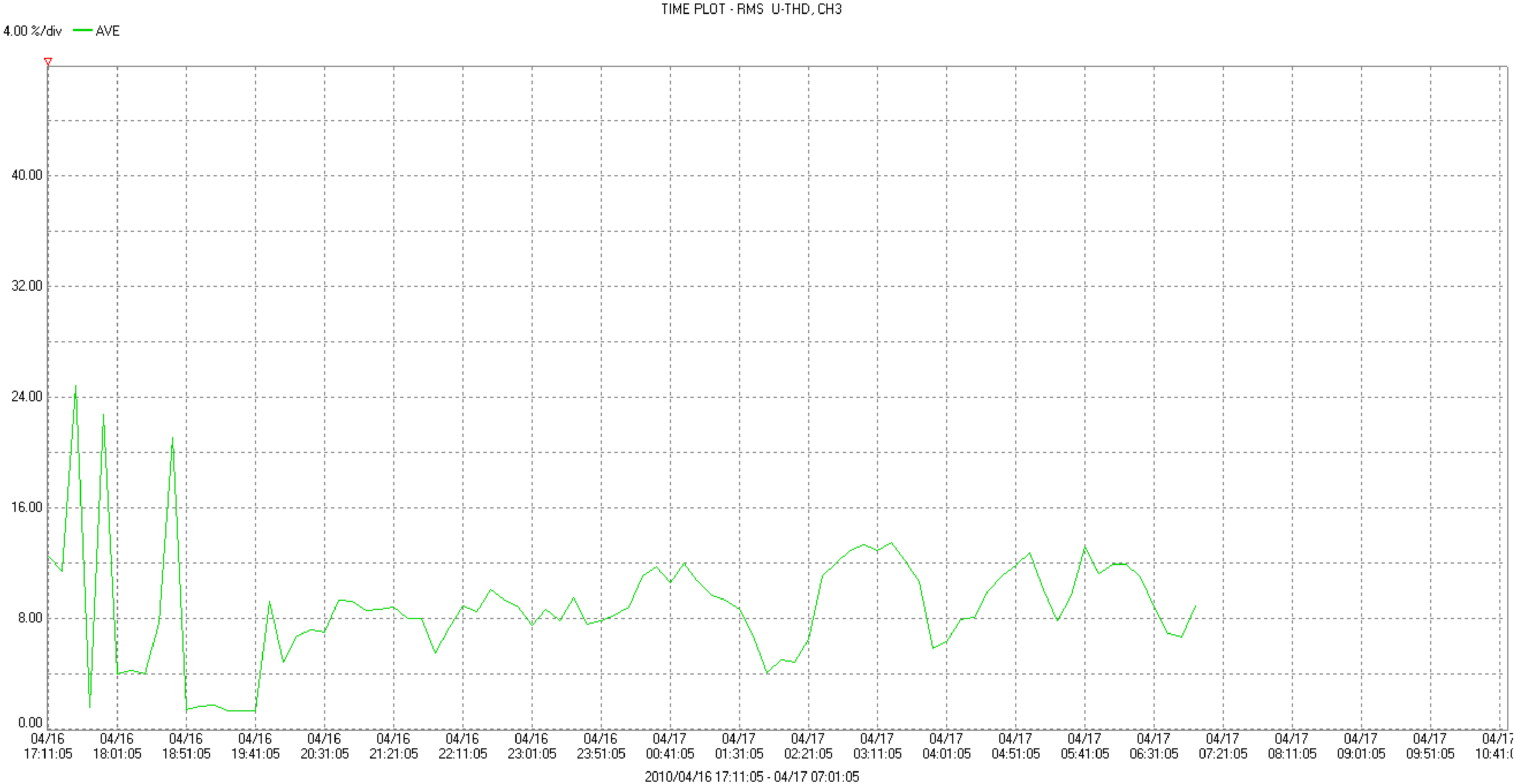

TIME PLOT - RMS I-THD, CH1
2.00 %/div
MIN
MAX
AVE
8.00
4.00
0.00
06/29 13:31:06
06/29 13:46:06
06/29 14:01:06
06/29 14:16:06
06/29 14:31:06
06/29 14:46:06
06/29 15:01:06
06/29 15:16:06
2009/06/29 13:31:06 - 06/29 15:24:06

Site B

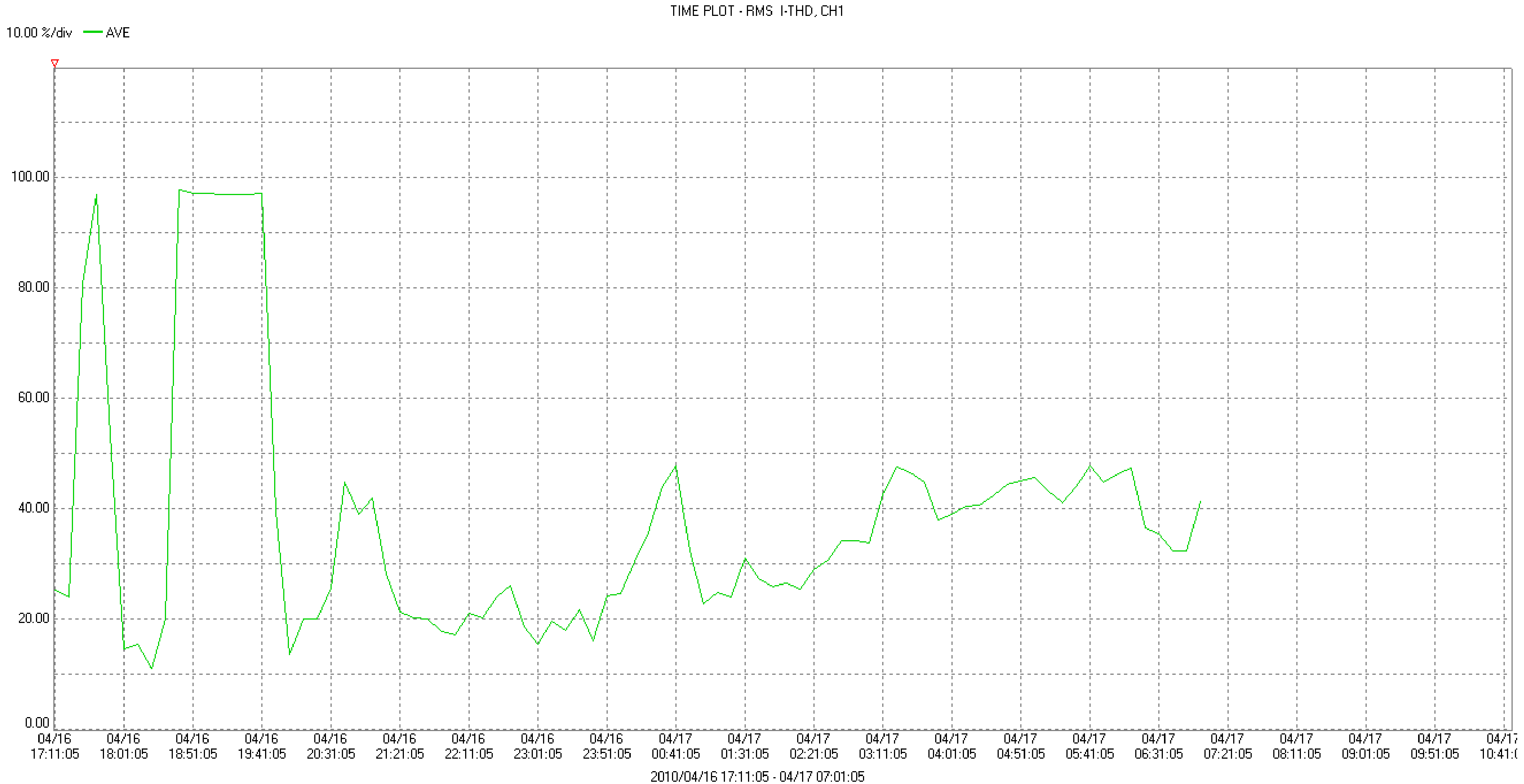


TIME PLOT - RMS I-THD, CH1
4.00 %/div
MIN
MAX
AVE
40.00
32.00
24.00
16.00
8.00
0.00
06/02 16:31:29
06/02 17:46:29
06/02 19:01:29
06/02 20:16:29
06/02 21:31:29
06/02 22:46:29
06/03 00:01:29
06/03 01:16:29
06/03 02:31:29
06/03 03:46:29
06/03 05:01:29
06/03 06:16:29
06/03 07:31:29
06/03 08:46:29
06/03 10:01:29
06/03 11:16:29
2009/06/02 16:31:29 - 06/03 11:43:14

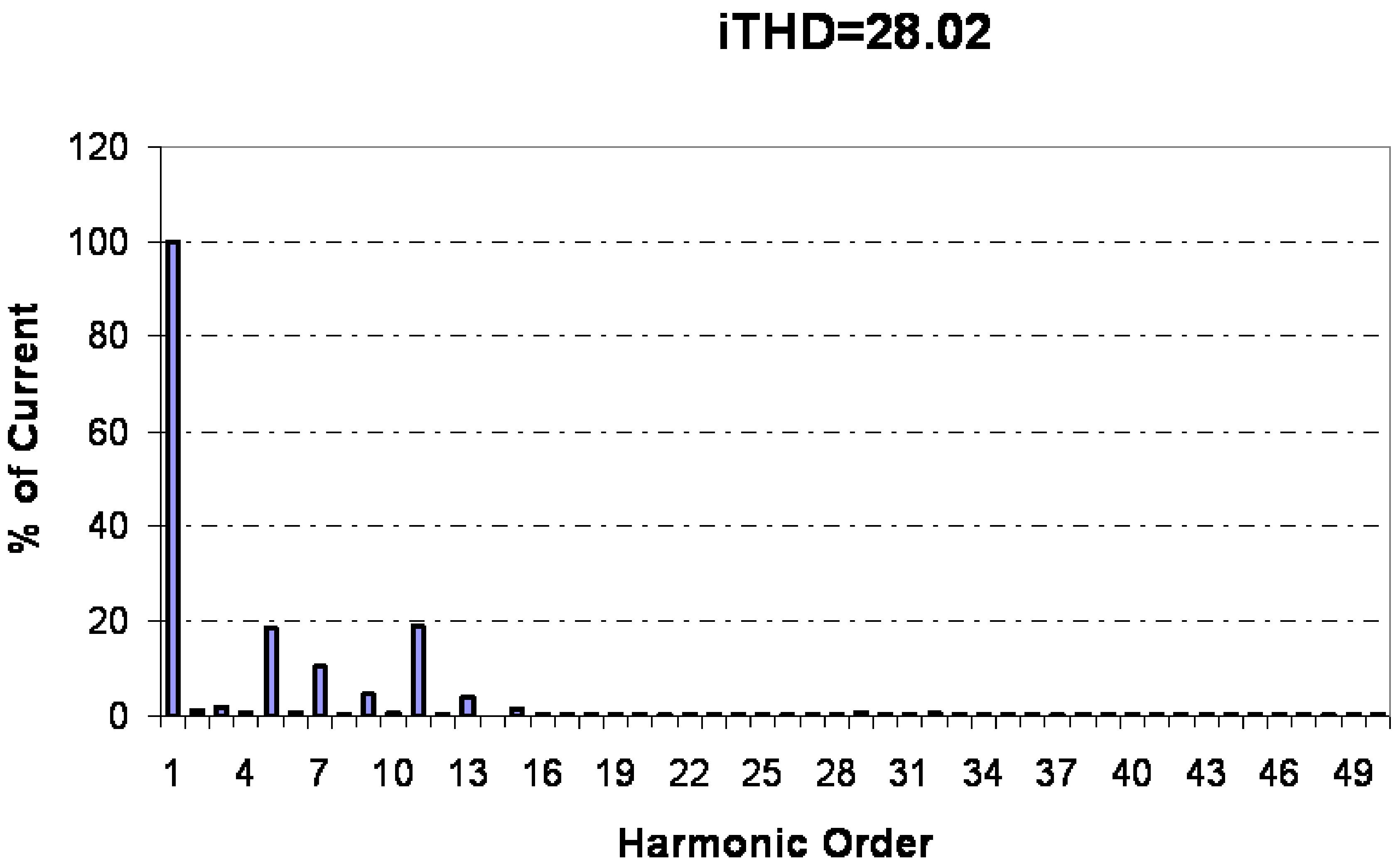
Site C


TIME PLOT - RMS U-THD, CH3
4.00 %/div
AVE
40.00
32.00
24.00
16.00
8.00
0.00
04/16 17:11:05
04/16 18:01:05
04/16 18:51:05
04/16 19:41:05
04/16 20:31:05
04/16 21:21:05
04/16 22:11:05
04/16 23:01:05
04/16 23:51:05
04/17 00:41:05
04/17 01:31:05
04/17 02:21:05
04/17 03:11:05
04/17 04:01:05
04/17 04:51:05
04/17 05:41:05
04/17 06:31:05
04/17 07:21:05
04/17 08:11:05
04/17 09:01:05
04/17 09:51:05
2010/04/16 17:11:05 - 04/17 07:01:05

Site C


TIME PLOT - RMS I-THD, CH1
10.00 %/div
AVE
100.00
80.00
60.00
40.00
20.00
0.00
04/16 17:11:05
04/16 18:01:05
04/16 18:51:05
04/16 19:41:05
04/16 20:31:05
04/16 21:21:05
04/16 22:11:05
04/16 23:01:05
04/16 23:51:05
04/17 00:41:05
04/17 01:31:05
04/17 02:21:05
04/17 03:11:05
04/17 04:01:05
04/17 04:51:05
04/17 05:41:05
04/17 06:31:05
04/17 07:21:05
04/17 08:11:05
04/17 09:01:05
04/17 09:51:05
2010/04/16 17:11:05 - 04/17 07:01:05

Site C


iTHD=28.02
120
100
80
60
40
20
0
% of Current
1
4
7
10
13
16
19
22
25
28
31
34
37
40
43
46
49
Harmonic Order

Information for SVC/SVG Selection

1. Response time
2. Voltage flickers
3. Reactive power profile
4. Size
5. Cost
6. Losses
7. Reliability
8. Harmonics
9. Resonance
10. Tariff
11. Load profile
12. Load forecast
13. System parameters (SLD, SC limit, type of load-linear load & non linear load, % of voltage regulation, system Reactances)
14. Standard as per application
15. Mandatory requirement
16. Voltage-Current profile
17. Features (interlocks, alarms, distance of the control room, data logger, indicators, communication)

CGL Power Quality Products


Automatic Capacitor Switch
11kV, 600 kVAr


Thyristor Switched Capacitor (TSC)
440V,1000 kVAr , 12 Steps

STATCOM – 3Ph 3Wire
440V,180 kVAr

STATCOM – Load Balancer / 1Ph Statcom
440V,100kVA

Issues in Power Quality Business

- **Slow development of awareness towards PQ**
  - Stringent implementations of regulations is missing
- **Customer prefer conventional passive solutions**
  - High end solutions exists in the form of SVC (imported)
  - Customer hesitate to pay more for high end solutions
- **PQ business is driven by capacitor manufacturers** (capacitors form more than 40% of material cost)

References

1. Florida Power Society, 1993
2. EPRI 1994
3. World Harmonic Filter Market, Frost & Sullivan, May 2004

Thank You