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C H I C A G O

Practical Applications of intelligent data mining in power distribution systems

Evaluation of Harmonic Trends using Statistical Process Control Methods

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Introduction

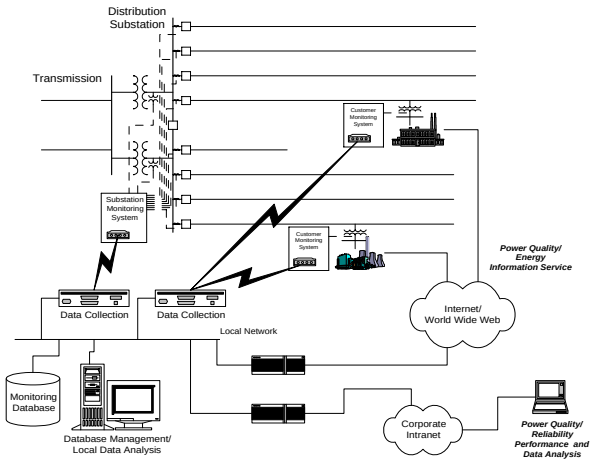
- Power quality data collected are generally voluminous and have to be analyzed in an efficient manner.
- Variations in voltage and current harmonic distortions can be normal or abnormal.
- Paper demonstrates a statistical process control method to determine if the statistical variations in harmonic trend can be considered a normal variation.

Why Monitor Power Quality? (Role of Advanced PQ Monitoring)

- Benchmark system performance levels
  - Understand power quality that can be expected
  - Evaluate performance with respect to standards
  - Provide baseline for premium services
- Reliability reporting
  - (Reliability defined based on customer impacts)
  - Service Quality Index
- ***Improve system operations and reliability***
  - ***e.g. Fault Location***
- ***Identify and solve problems***
  - ***Equipment diagnostics***

Example Power Quality Monitoring System

Example of System Monitoring Concept

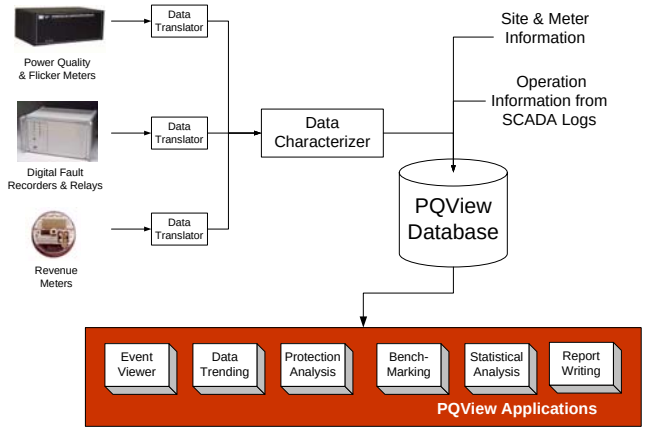


Important Characteristics of a Monitoring System

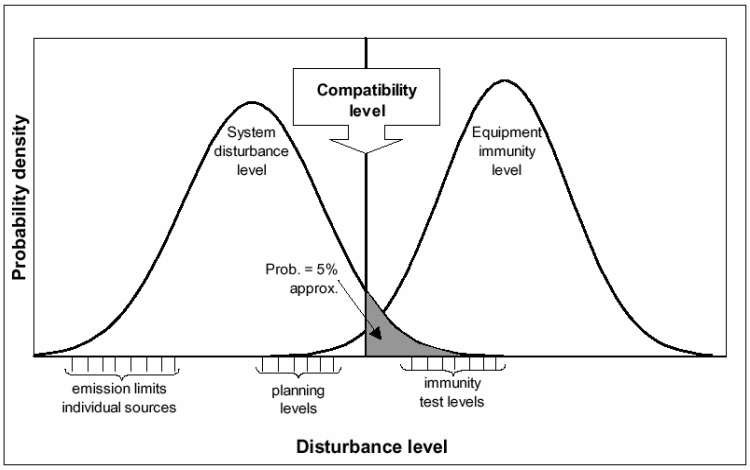
- Open architecture
  - Systems should allow integration of different technologies within utility and customer networks
- Standard Data Formats for exchanging data
  - Power Quality Data Interchange Format (PQDIF)
  - COMTRADE
- Web-based access to the information
- Intelligent applications (timeliness of information becomes important)
- Automated reporting functions

Example of Typical Configuration that allows *integration* and *advanced applications*

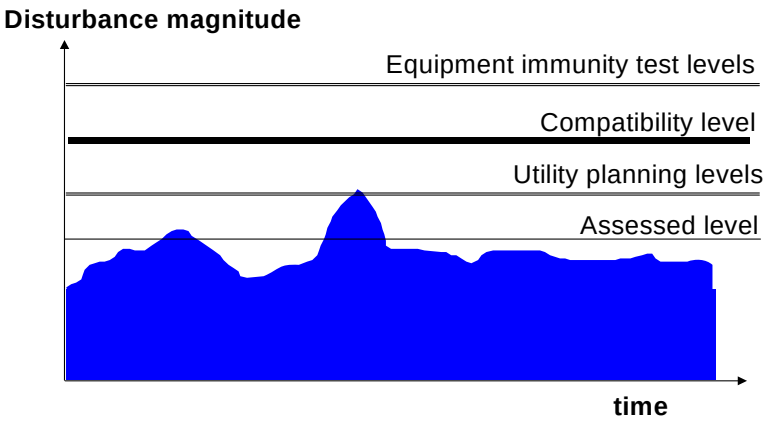
PQView® Architecture



Steady State Concepts

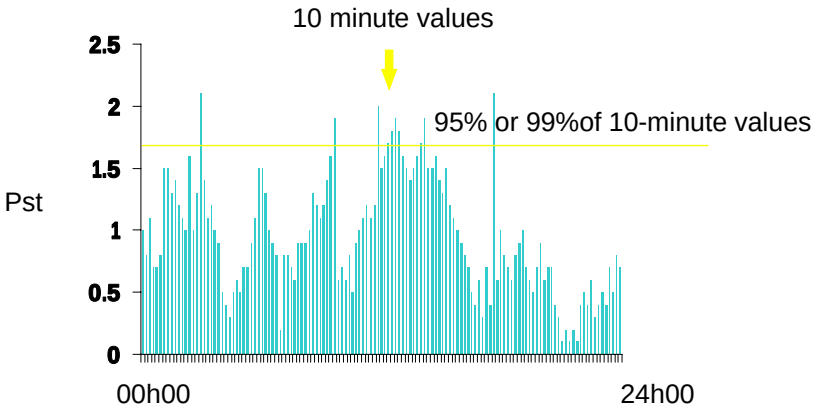


Steady State Concepts

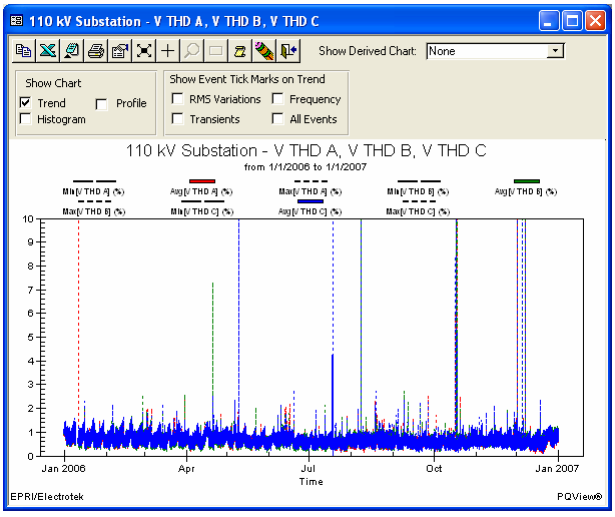


Using monitoring system to assess steady state PQ levels

Measurement period: 7 days



10-Minute Min-Avg-Max V_{THD} Values for One Year



Statistical Process Control

- There are two types of statistics
  - Descriptive statistics
  - Inferential statistics
- Descriptive statistical analysis can be used to detect equipment problems. However failure or changes in the system condition must be known in advance or when the failure has already taken place
- Inferential statistics is the appropriate for analyzing steady state power quality data
- Run-chart and control chart analyses form a part of inferential statistics

Control Chart Analysis

- Control chart analysis method uses control limits namely the upper control limit (UCL) and lower control limit (LCL).
- Control limits act as boundary to distinguish between common causes and special causes for variation in trend.
- The control limits are generally 0.001 probability limits.

Harmonic Trend Analysis

What is normal variation?

- To use the control chart method, one must specify “normal trend” or “normal variation” of the data
- Question: How does a normal variation be defined?
- Users to provide “reference data.” Based on this reference data, statistical characteristics or limits are derived. Users can simply give dates (e.g., 1/1/06 – 2/15/06) to indicate the reference data. All other data behavior will be compared to this reference data using the control chart method.

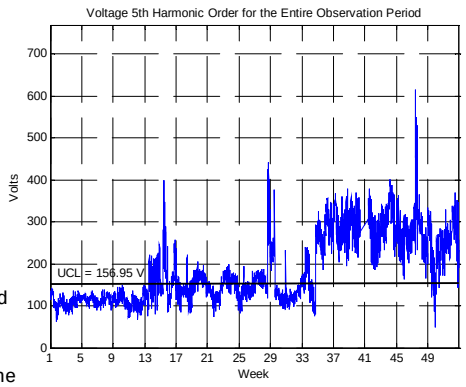
Harmonic Trend Analysis

General Procedures – Users to specify reference data and compute UCL

- Example: the first 4½ weeks of data as reference data.
- Control analysis method is performed to determine upper control limits (UCL):

$$UCL = \mu_x + 3 \cdot \sigma_x$$

- μ_x and σ_x are the mean and standard deviation of the variations, respectively
- Control limits are generally based on 0.001 probability limits.
- If random causes alone were responsible for the variation in the trend, the probability of a point falling beyond the control limits would be one out of a thousand.



Harmonic Trend Analysis

- A trend is normal if 95% of the times the data points in the harmonic distortion time-series are below the UCL
- Segment violation is triggered if less than 95% of the data points are below the reference UCL
- For example shown, variation is stable between the 5th and the 12th week
- From week 13 and forward, many data points are above UCL and hence trend could be abnormal

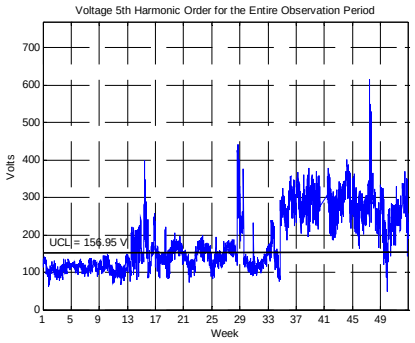


Fig. 3. The overall fifth order harmonic voltage distortion data with a UCL computed based on the first 4 ½ weeks of reference data

Harmonic Trend Analysis

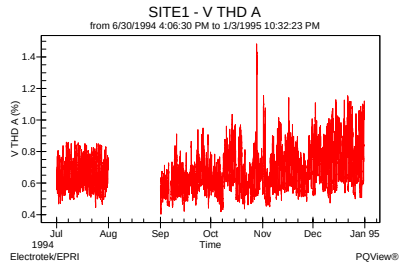
- Parameters used to analyze the trend are
  - Time Interval
  - Acceptable Probability
  - Permissible Consecutive Segment Variations
  - Upper Control Limit (UCL)

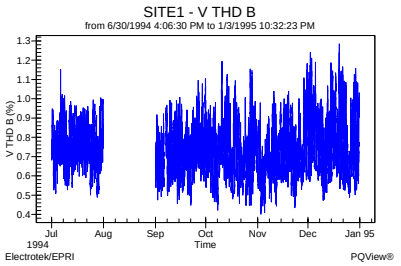
TABLE I
PERFORMANCE EVALUATION OF 5TH ORDER HARMONIC VOLTAGE DISTORTION IN WEEKLY INTERVALS

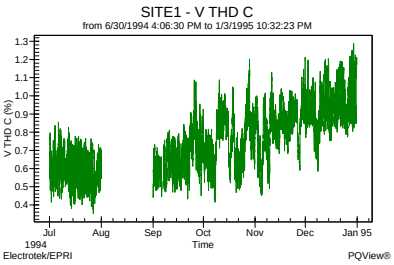
Date range of reference normal data: 1/1/2005 to 1/7/2005
Upper Control Limit : 156.95V
Acceptable Probability : 95.000%
Permissible violation : 3
Time Interval/Segment: Weekly

Week	% of times the variation is below UCL	Within Acceptable Limit
6	100.00	ok
7	100.00	ok
8	100.00	ok
9	99.83	ok
...	...	...
13	68.89	NO
14	28.60	NO
15	43.49	NO
16	56.35	NO
...	...	...

Example #1: using V_{THD} Data







Selected time span:
From: 01-Jul-1994, 00:13:00
To: 31-Dec-1994 , 18:40:00

Example Procedure (1)
Control Chart Analysis of Reference V_{THD} Data

- There are 4 week of data points in the reference.
  Each point corresponds to VTHD taken every 30 minutes. Total number of data points for the reference amounts to

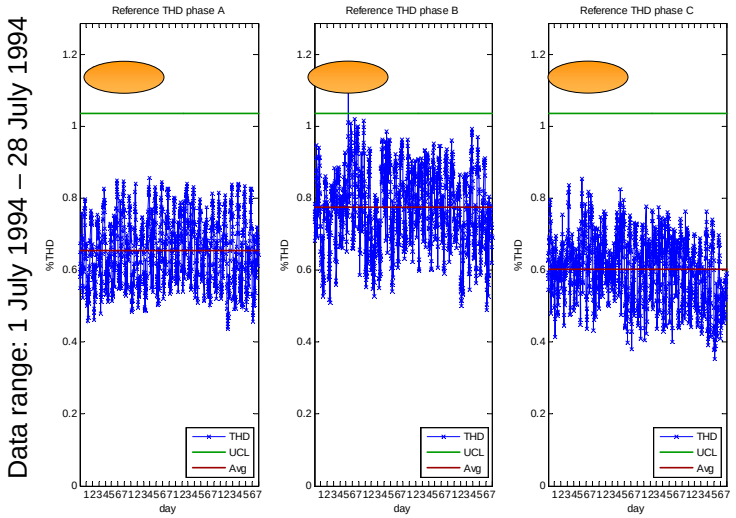
  (4 * 7 * 24 * 60) / 30 = 1344 data points

Phase	Average of %VTHD	UCL $\mu_x + 3(\sigma_x)$	Data points above UCL
A	0.65%	0.93%	0
B	0.78%	1.09%	1
C	0.60%	0.87%	0
Concatenated (all phases linked together)	0.68%	1.04%	1

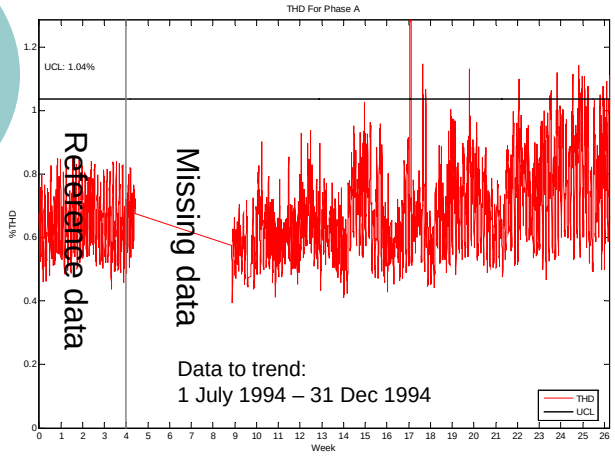
Use this number as the upper control limit for V_{THD} for all phases

Example Procedure (2)
4-Week Reference V_{THD} Data and Control Chart Analysis

Data range: 1 July 1994 – 28 July 1994



Example Procedure (3)
Trend analysis of V_{THD} A (for entire data record)



UCL = 1.04% (computed based on the reference data)

RESULTS:
Number of data points above the UCL is 1.30%

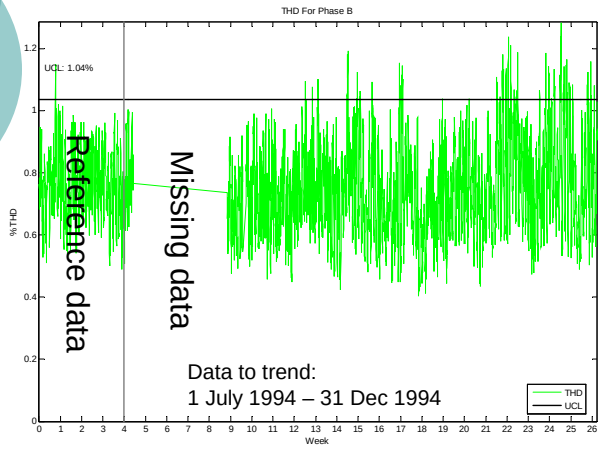
Conclusion for VTHD A:

"98.70% of the time, VTHD A is below 1.04%."

NORMAL TREND

Note: Missing data are not included in the trend analysis

Example Procedure (4)
Trend analysis of V_{THD} B: (for entire data record)



UCL = 1.04% (computed based on the reference data)

RESULTS:
Number of data points above the UCL is 3.93%

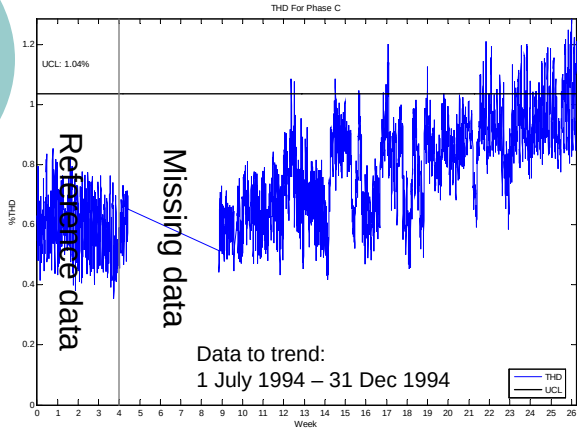
Conclusion 1 for V_{THD} B:

"96.07% of the time, V_{THD} B is below 1.04%."

NORMAL TREND

Note: Missing data are not included in the trend analysis

Example Procedure (5)
Trend analysis of VTHD C: (for entire data record)



UCL = 1.04% (computed based on the reference data)

RESULTS:
Number of data points above the UCL is 5.27%

Conclusion #1 for V_{THD} C:

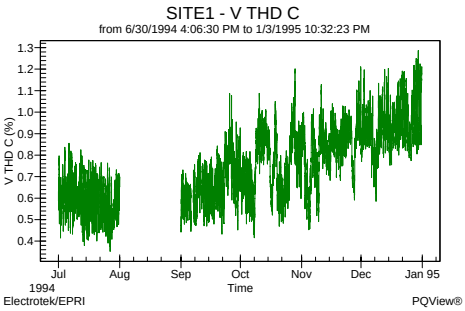
"94.73% of the time, V_{THD} C is below 1.04%."

ABNORMAL TREND

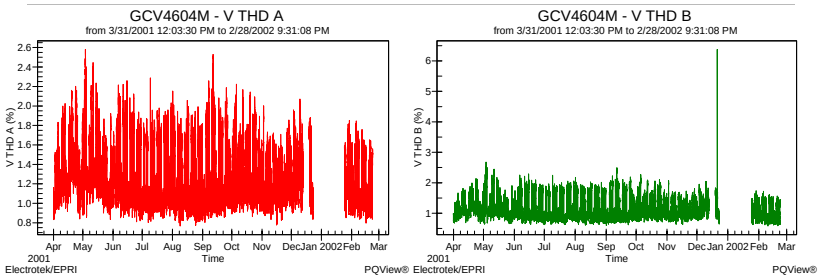
Note: Missing data are not included in the trend analysis

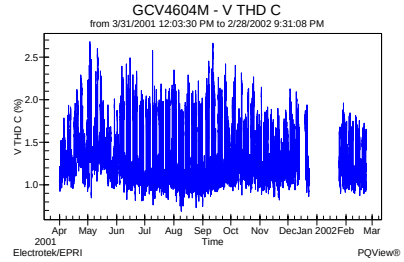
Conclusion for Example #1

- Based on the analysis, THD variation in Example #1 is considered abnormal. This is due to the persistence increase in V THD C .



Example 2: Database (V_{THD})





Selected time span:
From: 31-Mar-2001, 19:25:15
To: 22-Feb-2002, 14:02:07

Example 2 Database. (2)
Control Chart Analysis of Reference V_{THD} Data

- There are 4 week of data points in the reference. Each point corresponds to VTHD taken every 30 minutes. Total number of data points for the reference should amount to

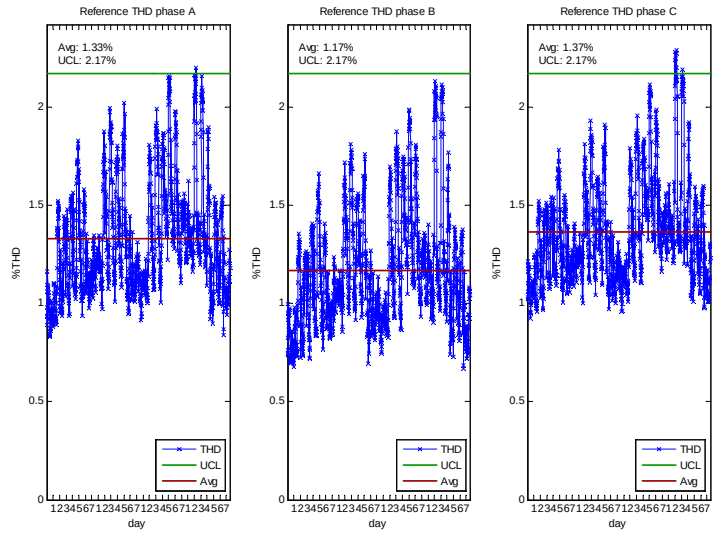
  (4 * 7 * 24 * 60) / 30 = 1344 data points

but there are **2 missing data** between **1 Apr 2001 01:55:28 and 1 Apr 2001 03:25:20**

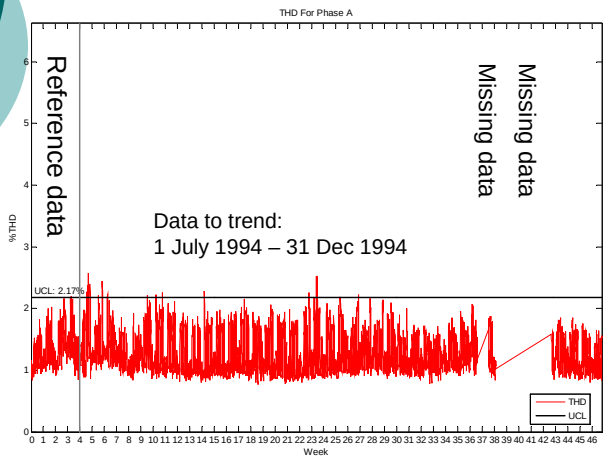
Phase	Average of %VTHD	UCL $\mu_x + 3(\sigma_x)$	Data points above UCL
A	1.33%	2.18%	1
B	1.17%	2.07%	12
C	1.37%	2.15%	13
Concatenated	1.29%	2.17%	9

Example 2 Database (3)
4-Week Reference V_{THD} Data and Control Chart Analysis

Data range: 31 Mar 2001 – 22 Feb 2002



Example 2 Database (4)
Trend analysis of VTHD A: (for entire data record)



UCL = 2.17% (computed based on the reference data)

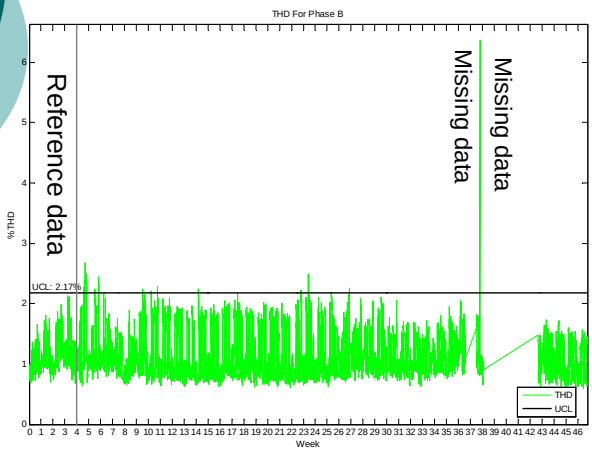
RESULTS:
Number of data points above the UCL 0.60%

Conclusion for VTHD A:

"99.40% of the time, VTHD A is below 2.17%."

NORMAL TREND

Example 2 Database (5)
Trend analysis of VTHD B: (for entire data record)



UCL = 2.17% (computed based on the reference data)

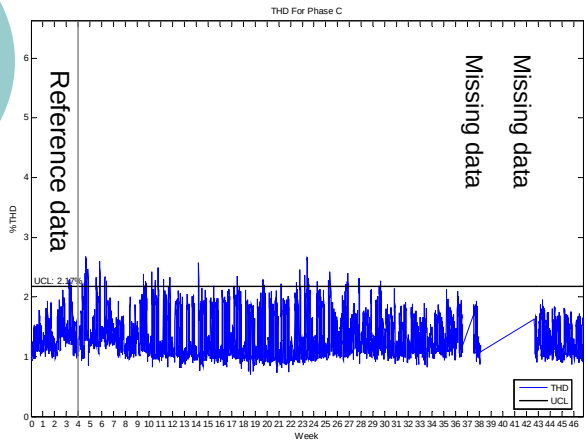
RESULTS:
Number of data points above the UCL is 0.58%

Conclusion #1 for VTHD B:

"99.42% of the time, VTHD B is below 2.17%."

NORMAL TREND

Example 2 Database (6)
Trend analysis of VTHD C: (for entire data record)



UCL = 2.17% (computed based on the reference data)

RESULTS:
Number of data points above the UCL is 1.32%

Conclusion #1 for VTHD C:

"98.68% of the time, VTHD C is below 2.17%."

NORMAL TREND

Conclusion for Example #2

- Based on the analysis above, THD variation in Example #2 is considered **normal.**

Conclusion

- Control chart analysis can be used to analyze the statistical behavior of steady-state power quality data
- This method can be used to determine if the harmonic trend is caused by normal variation or abnormal variation