Appendix C

Training materials for Association of Energy Engineers Workshops

5022-3220

ASEAM3 WORKSHOP

A Simplified Energy Analysis Method
Version 3.0

Sofia

June 10, 1996

Sponsored by: **US AID**

Organized by: **Electrotek Concepts, Inc.**
Eneffect, The Bulgarian Foundation for Energy Efficiency
TYSAK Engineering Co.

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WORKSHOP OBJECTIVES

- Expand the capability of AEE members to perform modeling tasks efficiently
- Introduce A Simplified Energy Analysis Method of building heat loss/gain modeling
- Provide a basic understanding of the computer modeling process using the ASEAM3 program
- Assisting the gaining of necessary hands-on skills

SCHEDULE

June 10, 1996

10:00-12:00	Introduction Workshop Schedule Building Heat Loss/Gain Modeling
12:00-13:00	Lunch break
13:00-15:00	About the ASEAM3 Program ASEAM5 Model Preview
15:00-15:30	Coffee break
15:30-17:00	Modeling Steps Thermal Zone Selection

June 11, 1996

8:00-10:00	Load Inputs System Inputs
10:00-10:20	Coffee break
10:20-12:00	Plant Inputs Run Files
12:00-13:00	Lunch break
13:00-15:00	Weather Files
15:00-15:30	Coffee break
15:30-17:00	Quick Inputs ECO Inputs

June 12, 1996

8:00-10:00	Program Calibration Principles
10:00-10:30	Coffee break
10:30-12:00	Output Reports Building Life Cycle Cost Program (BLCC)
12:00-13:00	Lunch break
13:00-15:00	Modeling Skills workshop Workshop Review
15:00-15:30	Coffee break
15:30-17:00	Questions and Answers Workshop Conclusion

ORGANIZATION AND SPIRIT

We all want this Workshop to be interesting, productive and useful. We will do the following to ensure the workshop is:

Interesting:

- Maintain flexibility of, and responsiveness to, our agenda
- All topics will be explained by using examples.
- Each topic (e.g. creating a new file) will be "tested" on computer

Productive:

- We must utilize time as usefully as possible
- We will avoid reading the manual (you can do it later)
- Questions should be asked and answered as needed
- We will focus on the practical side of the modeling work with ASEAM3
- One-on-one assistance will be provided, as needed and as practical

Useful:

- At the "end of the day," you should be able to use this program, after investing a reasonable amount of time and effort.
- ASEAM3 should help you get reasonably accurate results
- You will be able to assess Energy Conservation Opportunities quickly

THEREFORE, DO NOT HESITATE TO:

- Ask questions anytime you need to
- Ask for the repetition of any topics
- Suggest spending more time on any topic of greater interest
- Tell me when I present any subjects you already know (to prevent wasting our time)
- Discuss any specific issues/examples

BUILDING HEAT LOSS/GAIN MODELING

The most frequent reasons for the modeling effort:

- Determine Energy Requirements for new, old, or upgraded buildings
- Determine the impact of Energy Conservation Opportunities on consumption
- Support economically-based decisions whether or not to implement Energy Conservation

Modeling Methods/Tools:

- Estimates and empirical methods
- Manual Calculations using known algorithms, tables, and graphs
- Simplified PC based Computer Models using known algorithms and "low effort" inputs
- Elaborate on precise programs, such as DOE2, for either PC or mainframe computers

What parameters can be modeled:

- Heat loss through the building envelope (Walls, Windows, Roofs, Doors, Miscellaneous)
- Ventilation/Infiltration (Natural and forced ventilation, window and door air leakage)
- Building Systems (Heat balancing, radiator temperature, pipe loses)
- Plant (Water/steam boilers, combustion efficiency, fuels)
- Controls (Occupied/Setback zone temperatures, economizer mode)
- Domestic Water Heating (flow restricting, supply temperature, insulation, demand management)

ABOUT THE ASEAM3 PROGRAM

General:

- It is a public domain program developed by the US DOE Office of Federal Energy Management.
- It is a PC-computer program requiring only 256K RAM, keyboard only (no mouse required)
- It has a calculation algorithm based on ASHRAE , IES, DOE2, and NBS standards
- It is menu driven, simple and easy to use
- It uses weather data in bin form
- Up to 15 zones can be modeled
- Many reports to chose from

Best suited for:

- New and old building load calculations for preliminary system sizing
- Heating/cooling cost calculations
- Evaluation of energy consumption efficiency
- Analysis of energy conservation opportunities
- Energy analysis of large areas/multiple buildings

Not Suited for:

- Detail design purposes
- High accuracy modeling

Why the simplified method is used:

- Very easy to use
- Reasonably accurate
- Saves time and money, increases productivity of engineers

Features:

- Full screen input/editing
- Quick input routines
- Single/Batch Modes
- Parametric Processor Mode
- ECO Mode
- Variety of Output Reports

ASEAM5 MODEL PREVIEW

- ASEAM5 is the newest release of the program (December 1995)
- Written in C-language, with a Window-like user interface
- It uses the same algorithms (the calculation process has not change at all)
- ASEAM3 users will "convert" very easily. It is beneficial to be familiar with ASEAM3
- Utilizes On-line help (a manual is not available)
- Can model an unlimited number of zones, schedules, walls, windows, etc.

Why ASEAM5 is not being used:

- The public domain release has not yet been completed ???
- Using the manual for ASEAM3 seems to be better suited for learning
- ASEAM5 will not work properly with the Windows background (especially with Windows 95)
- ASEAM5 does not have the Weather File Editor (You will need to use ASEAM3 anyway in order to create weather files for a new location)
- ASEAM3 will give you a better understanding of how the program works. You can use ASEAM5 later, when it is available and "clean"

MODELING STEPS

Get Building information:

- Existing Building -from architectural, HVAC and electrical drawings, management, accounting, etc.
- Energy bills for at least one year (a greater number of years is preferable)

Site survey:

- Visit the building. Walk-through, get familiar with the structure, occupancy, the building's purpose, and its operation
- Detail data collection in the building (walls, windows, lights, occupants, miscellaneous loads, etc.)
- Obtain information on ventilation/infiltration
- Heating system inspection, general information
- Boiler room inspection
- If possible, perform at least "snapshot" measurements of zone conditions
- Maximize the utilization of information from management/operating personnel
- Assign thermal zones
- Prepare the information for input into ASEAM3

THERMAL ZONE SELECTION

- Make a drawing/sketch of the modeled building
- Selecting the zones is critically important, yet strongly subjective
- Select thermal zones based on:
    - Building characteristics
    - Indoor temperature characteristics (such as chronically lower room temperature in a corner room)
    - Similar wall, window, and door orientations
    - Similar use
    - Relation to the systems
- Use your best judgment. Although this step is critical, it is a strongly subjective decision and requires expertise and experience.
- Several sketches - examples of thermal zone selections follow:

LOADS INPUT SCREEN MAP

Attached table

SYSTEM INPUTS

The system input file is necessary for running ASEAM3

Energy demands are calculated and then passed to the plant segments in order to determine energy consumption

The following systems are included with ASEAM:

Heating and Cooling

1. Double duct or Multi-zone, Air (DDMZ)
2. Constant Volume Reheat, Air (CVRH)
3. Variable Air Volume Reheat, Air (VAVR)
4. Ceiling Bypass Variable Air Volume (CBVAV)
5. Single Zone Reheat, Air (SZRH)
6. Fan Coil Unit, Air (FCU)
7. Water Source Heat Pump (WSHP)
8. Air-to-Air Heat Pump (AAHP

Heating Only

9. Baseboards (BB), hot water radiators
10. Furnace (FURN)
11. Unitary Heaters (UH)
12. Heating and Ventilation Units (HV)

Cooling Only Systems

13. Window Air Conditioners

PLANT INPUTS

Plants:

1. Centrifugal Chiller
2. Absorption Chiller
3. Double Bundle Chiller
4. Reciprocating Chiller
5. Cooling Tower
6. Domestic Hot Water Heater
7. Boiler

Fuels:

1. Natural Gas
2. Oil (#2, #4, #6)
3. Electricity
4. District Heating
5. District Cooling

Tip:

If you do not know the boiler parameters (efficiency), perform the calculations by selecting District Heat.

RUN FILES

ASEAM3 Performs calculations in :

Single Run Mode

- Loads Only, System Only, and Plant Only
- Loads, System, and Plants

Batch Run Mode

- Several single runs together

Parametric Run Mode

- Run with variable parameters (% of original, or replacement value)
- No need to create new input file
- A changed variable applies to all zones

Single ECO Run Mode

- A single run for ECO does not require the creation of a new file
- Creates BEPS and LCC reports only

Multiple ECO Run Mode

- Used for cumulative effects of more than one ECO (mutually non-exclusive)
- More than one ECO is used to modify the base file
- All ECO files must be in the data sub-directory

WEATHER AND SOLAR DATA FILES

Sources of Weather and Solar Data:

- National Climatic Centers
- Major Airports
- Power Plants, Heating Plants, Utilities
- Scientific Centers (Universities, Laboratories, etc.)

Note: Data for Sofia included: ASEAM3\ Weather\SofiaBL.

Typical Raw Data Format:

- Hourly readings in ASCII, DATASAV2, XLS , and 8760 records per year

ASEAM3 Weather Data Format:

ASHRAE - six four-hour blocks (file extension .AWD)
Composite of typical monthly weather data from different years

BATTELLE - eight three-hour blocks (file extension .BWD)
Test reference year - year selected as statistically typical

DOD - three eight-hour blocks (file extension .DWD)
Several years' average data

Solar Data :

- Calculated for the 15th day of each month (ASHRAE calculates for the 21st day)
- Uses local time (instead of solar time)
- Require Wind Speed (MPH) and Fraction Percent Sunshine (%, not a decimal)

Tips:

It is not possible to get weather data for every location.
For locations without such data, do the following:

- Assess the differences in mean annual extremes, elevation, etc.
- Modify the known city data accordingly
- Compare the location with other cities for which you have data
- (save the file under a new name prior to any changes)
- Use the comparable city file and adjust the results

QUICK INPUTS

- Simplified routine that allows very fast generation of all files
- Assumes many parameters such as occupation, U-values, etc.
- Several building shapes, zone layouts, and operation types to chose from
- Several systems and plants are on file
- Useful for general observations, comparisons of energy saving improvements
- Saves time and resources if accurate results are not required

ECO INPUTS

ECO's selected for analysis are usually determined by the building audit

Conventional ECO Modeling:

- Define the base case input files, calibrate, and perform calculations
- Change input variables (save as new file) and perform calculations
- Manually determine the resultant energy savings by comparing the results
- Perform a Life Cycle Cost analysis if desired

ASEAM3 Modeling:

Simple ECO

- Minimal changes to base case input files
- Easy to follow input screens for each type of ECO
- No need to create new sets of input files

Complex ECO's

- Some complex ECO's can not be modeled in the ECO mode.
- New Input files should be created by copying and modifying the base file
- This case includes:
    - Wall replacement with windows
    - Partial replacement of a System
    - Use of different plants, etc.

PROGRAM CALIBRATION PRINCIPLES

Note that building heat loss/gain modeling is not a precise science

Many variables are difficult to measure or otherwise obtain. The list will definitely include:

- Infiltration rate
- Window leakage coefficients
- Schedules related to occupants

Therefore, the base case inputs must be calibrated. The process is as follow:

- Base case inputs are generated with the best available data and professional estimates.
- The baseline energy consumption is determined for a specific year (the best option) based on billing records and that year's weather data.
- The ASEAM results, adjusted for energy losses (combustion, distribution), are compared on a monthly basis with billing records.
- Adjustments are made to the inputs which are most likely the cause of the difference (e.g. infiltration) until the calculated values match the billing records.

OUTPUT REPORTS

1. Loads

For each zone(the 24 hourly values for reports LB through LW are written to file by month

LC - Diversified Total Load (the sum of all time-dependent diversified load components excluding temperature-dependent loads such as conduction and infiltration)

LD - Peak Opaque CLTD Load (sum of wall and roof CLTD)

LE - Peak Glass Solar Load

LF - Peak Lighting Load

LG - Diversified Lighting Load

LH - Peak Plenum Load

LI - Diversified Plenum Load

LJ - Peak People Load

LK - Diversified People Load

LL - Peak Equipment Load

LM - Diversified Equipment Load

LN - Daylighting Footcandles on Work plane, Function 1, Overcast Sky

LO - Daylighting Footcandles on Work plane, Function 2, Overcast Sky

LP - Daylighting Footcandles on Work plane, Function 3, Overcast Sky

LQ - Daylighting Footcandles on Work plane, Function 1, Clear Sky

LR - Daylighting Footcandles on Work plane, Function 2, Clear Sky

LS - Daylighting Footcandles on Work plane, Function 3, Clear Sky

LT - Wall CLTD Load

LU - Roof CLTD Load

LV - Direct Solar on Glass (only considers the effect of external shading, *not* orientation)

LW - Shaded Solar on Glass (only considers the effect of external shading, *not* orientation)

OUTPUT REPORTS

2. Systems Reports

For each system (the values are written to file by cycle, by month, and by bin)

SA - System Loads (Zone Diversified Loads on System)

SB - System Energy Requirements (System Loads on Plant)

SC - System Psychrometrics (Central Systems)

SD - System Psychrometrics (Unitary Systems)

3. PLANT REPORTS

For each plant component (values are written to file by cycle, by month, and by bin)

SLDS - Plant Loads (Composite System Loads on Plant)

PDHW - Domestic Hot Water

PCEN - Centrifugal Chiller

PABS - Absorption Chiller

PDBC - Double Bundle Chiller

PREC - Reciprocating Chiller

PDBH - Double Bundle Heating

PBLR - Boiler

PTOW - Cooling Tower

BEPS report - building end-use summary (this report is *not* LOTUS-compatible)

MCON - Monthly energy consumption by fuel type.

Note: All reports *except* the Peak Loads Summary (LA) and the Building Energy End-Use Summary (BEPS) are suitable for importing into LOTUS.

The files from these reports are also saved in the data sub-directory.

BUILDING LIFE CYCLE COST PROGRAM (BLCC)

BLCC program is not included in the program and must be obtained from NTIS

Input files for the BLCC program must be run separately from ASEAM3. You must exit ASEAM and access the BLCC program in order to create the "New Input Data File" or "Edit Existing Data File."

Principles of the BLCC program are not part of this seminar. The documentation is not available.

Make sure the Input file is in the \ASEAM\DATA sub-directory , even if you have your project files in a different sub-directory (this is a bug)

Once you create the Input Data Files, ASEAM3 will perform BLCC calculations and generate an output report

DEVELOPMENT OF MODELING SKILS

- **Development of the Model for the Gabrovo Municipal Hospital Building**

- **Collecting Available Data on the Building:**

    ◊ Building Structure
    ◊ Heating System
    ◊ Boiler House
    ◊ Occupancy
    ◊ Electric Equipment (Lighting and Plug-in equipment)
    ◊ Domestic Hot Water Heating
    ◊ Energy bills for a period of at least one year

- **Zoning the building structures**

- **Create and input all files for the high-rise building**

- **Run the calculation**

- **Calibrate the model**

- **Review Output files**

- **Model selected Energy Conservation Opportunities (ECO)**

WORKSHOP REVIEW

The workshop was designed to provide you with:

- working knowledge of the ASEAM3 computer program and enable you to model building heat loss/gain more efficiently
- the capability to assess the Energy Conservation Potential of Building Energy Efficiency Improvements
- Eliminate the need for extensive manual calculations, raw estimates (which are sources of error), and elaborate computer modeling with sophisticated programs (such as DOE2)

??? Did we accomplish our goals ???

Questions and Answers

Time for your comments on quality and usefulness of this workshop

Conclusion

ELECTROTEK
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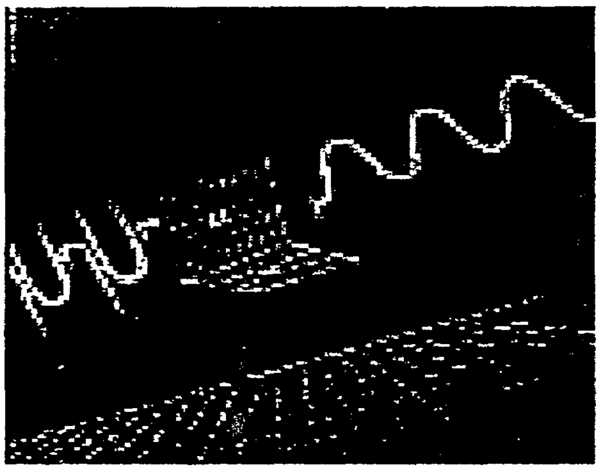
High Efficiency Motors & Adjustable Speed Drives and Power Quality Seminar



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Association of Energy Engineers - Bulgaria
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June 23 - 24, 2997

Sofia, Bulgaria

Finding, Solving, and Learning from Power Quality Problems

David Mueller
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Electrotek Concepts, Inc.
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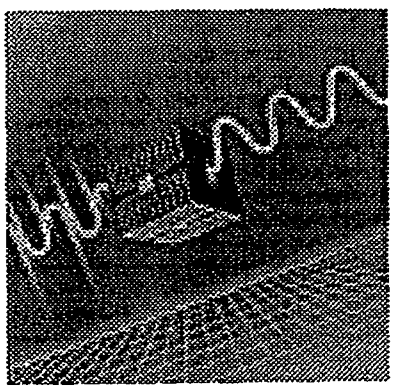
June 1997



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Finding, Solving, and Learning from Power Quality Problems

AGENDA

- Introduction to Power Quality and Types of Disturbances
- Finding the Source of Power Quality Problems
- Solving Power Quality Problems
- Electric Utility Power Quality Efforts
- New Technologies and Trends

Finding, Solving, and Learning from Power Quality Problems

David Mueller
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www.electrotek.com

Who is Electrotek?

- Leader in Power Quality Consulting / Support
- Approximately 40 Engineers (Knoxville, Syracuse, Washington DC, Palo Alto, Pittsburgh)
- Seminars, Training
- System Monitoring Projects / Software
- Analytical Studies/Software (EMTP, Harmonics Users Groups)
- Industrial/Commercial Studies (PQ surveys, harmonics, transients, voltage sag concerns)
- Utility Power Quality Program Development Support

Importance of Power Quality

- Electricity as a PRODUCT - What are the quality requirements?
- Customer equipment is more sensitive
- Networks (interconnections)
- Increasing penetration of nonlinear loads (harmonics)
- Efficiency concerns and power factor correction considerations
- Competition in the utility industry

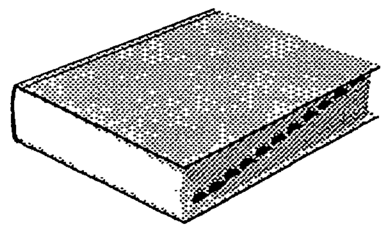
What is "Power Quality" ?

- Power Quality is an issue driven by end users
- Power Quality is a collection of various subjects which utilities have traditionally dealt with individually:
  - Interruptions
  - Sags
  - Flicker
  - Voltage Regulation
  - Harmonics
  - Capacitor Switching
  - Lightning Surges
  - Reliability
- Power Quality requires looking at the whole picture

What is a Power Quality Problem?

A power quality problem is:

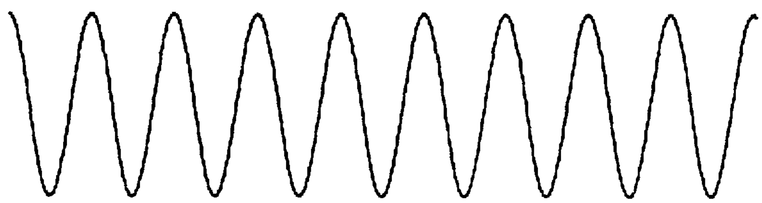
"Any occurrence manifested in voltage, current, or frequency deviations which results in failure or misoperation of end-use equipment"



Quality of Supply

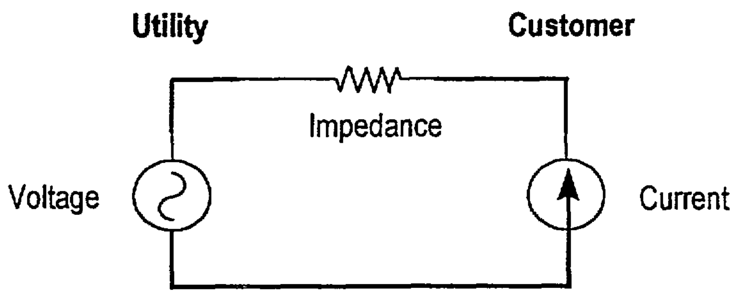
Power Quality = Voltage Quality

A voltage waveform with proper magnitude, frequency, free from harmonic distortion or transient disturbances that would affect end use equipment.



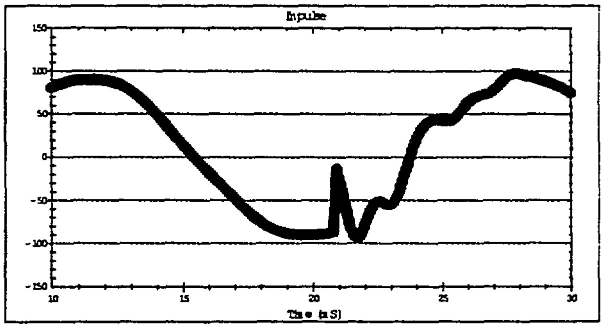
Power Quality = Voltage Quality

- "Power" Quality actually refers to the quality of the voltage supplied by the utility
- Because the system has impedance, currents outside the direct control of the utility can adversely affect power quality

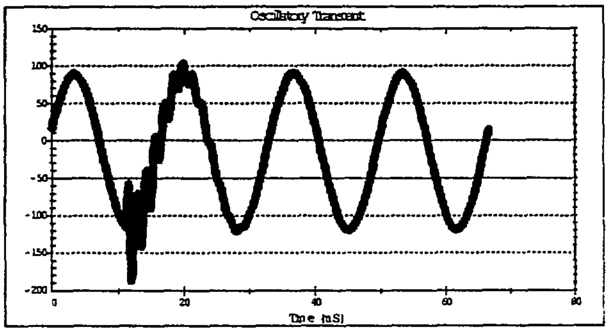


Transients

Impulsive

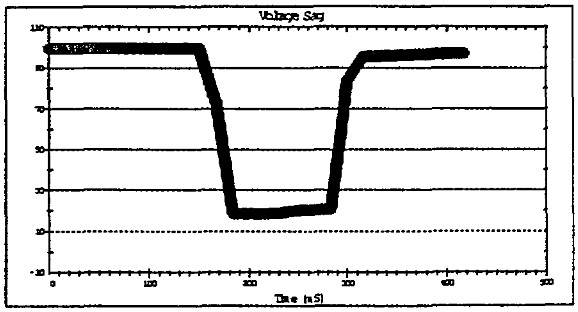


Oscillatory

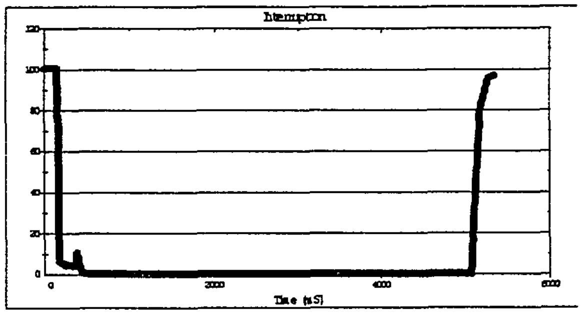


Sags/Swells and Momentary Interruptions

Voltage Sag
(0.1-0.9 pu)



Interruption
(less than 0.1 pu)



Categories for Short Duration Variations

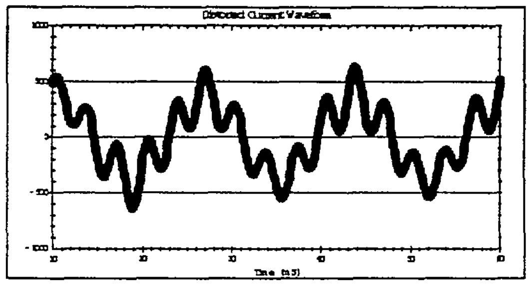
- Instantaneous
  - 0.5-30 cycles
- Momentary
  - 30 cycles-3 seconds
- Temporary
  - 3 seconds-1 minute
- Longer variations are called "long duration variations"

Steady State Power Quality Variations

- Waveform Distortion (Harmonics)
- Voltage Regulation (Long Duration Variations)
- Flicker

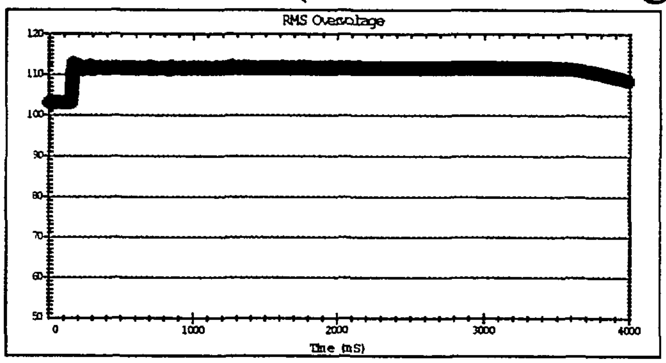
Waveform Distortion

- DC Offset
- Harmonics (IEEE 519)
- Interharmonics (and subharmonics)
- Notching
- Noise



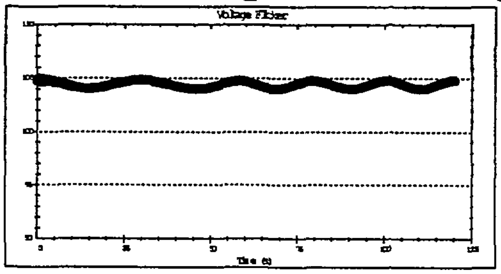
Long Duration Voltage Variations

- Overvoltages
- Undervoltages
- Acceptable range +7% to -13%
- Imbalance (<3% according to C84.1)



Voltage Fluctuations (Flicker)

- Modulation of the fundamental frequency component
- 0-30 Hz
- Standards include weighting for effect of human response to light variations



Reliability

- The first level of power quality is reliability, which is a measure of whether or not the power is on.
- Most measures of reliability, reliability indexes, only consider events which are of five (5) minutes duration or longer.
- These reliability indexes measure the ability to prevent or restore outages.

SAIFI

- System Average Interruption Frequency Index (Sustained Interruptions >5 minutes)

$$\text{SAIFI} = \frac{\text{Total Number of Customer Interruptions}}{\text{Total Number of Customers Served}}$$

SAIFI - (interruptions/year)

USA	0.5 - 1.5 - 3.3
Great Britain	0.72
Italy	2.5 - 5.0
France	0.8 - 5.0
Norway	2.0
Columbia	132

Sources: IEEE, UNIPEDE, UNIANDES

SAIDI

- **System Average Interruption Duration Index**

$$\text{SAIDI} = \frac{\text{Total Sum of Customer Interruption Durations}}{\text{Total Number of Customers Served}}$$

SAIDI - (minutes/year)

USA	40 - 100 - 250
Great Britain	67
Italy	120
France	33 - 390
Norway	300
Korea (KEPCO)	39
Columbia	158 hours

Sources: IEEE, UNIPEDE, UNIANDES, KEPCO

CAIDI

- **Customer Average Interruption Duration Index**

$$\text{CAIDI} = \frac{\text{Total Sum of Customer Interruption Durations}}{\text{Total Number of Customer Interruptions}}$$

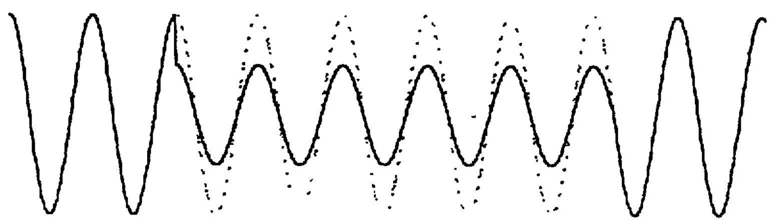
CAIDI - (minutes/interruption)

USA	30 - 80 - 180
Great Britain	92
Italy	45 - 48
France	41 - 78
Norway	150
Columbia	183

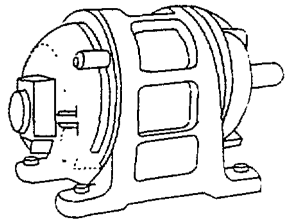
Sources: IEEE, UNIPEDE, UNIANDES

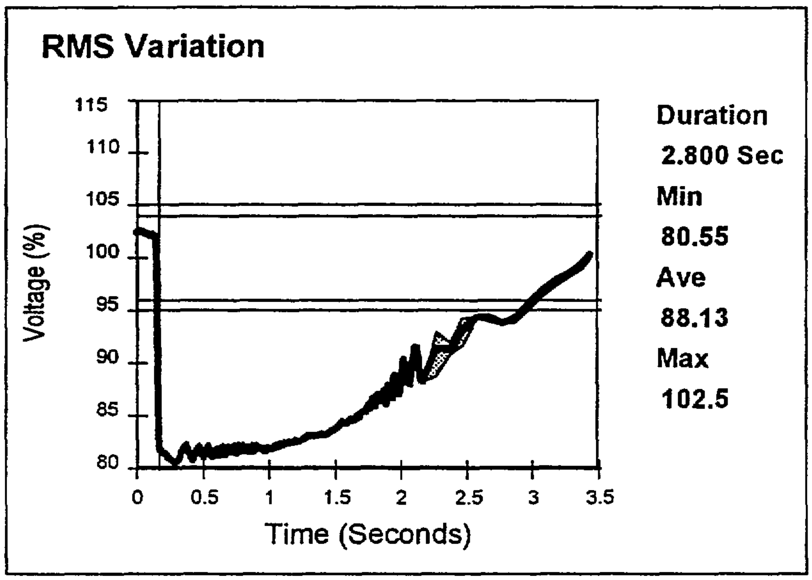
Voltage Dip (Sag)

- A voltage dip is a momentary undervoltage condition caused by motor starting, or by a power system fault.



Motor Starting Voltage Dip





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RMS Voltage Disturbances

IEEE Std. 1159 Definitions

Short Duration Variations	**Duration**	**Voltage Magnitude**
Instantaneous		
Sag	0.5 to 30 cycles	0.1 to 0.9 pu
Swell	0.5 to 30 cycles	1.1 to 1.8 pu
Momentary		
Interruption	0.5 cycles to 3 s	< 0.1 pu
Sag	30 cycles to 3 s	0.1 to 0.9 pu
Swell	30 cycles to 3 s	1.1 to 1.8 pu
Temporary		
Interruption	3 s to 1 min	< 0.1 pu
Sag	3 s to 1 min	0.1 to 0.9 pu
Swell	3 s to 1 min	1.1 to 1.8 pu
Long Duration Variations		
Sustained Interruption	> 1 min	0.0 pu
Undervoltage	> 1 min	0.8 to 0.9 per unit
Overvoltage	> 1 min	1.1 to 1.2 per unit

New Reliability Indices (Proposed)

- Assess rms variations, harmonics, transients, unbalance, regulation
- Assess various service quality levels
  - Voltage drops: 90%, 80%, 70%, 50%, and 10%
  - Voltage rises: 110%, 120% and 140%
- Assess systems of varying size
  - Entire system, distribution substation, single feeder

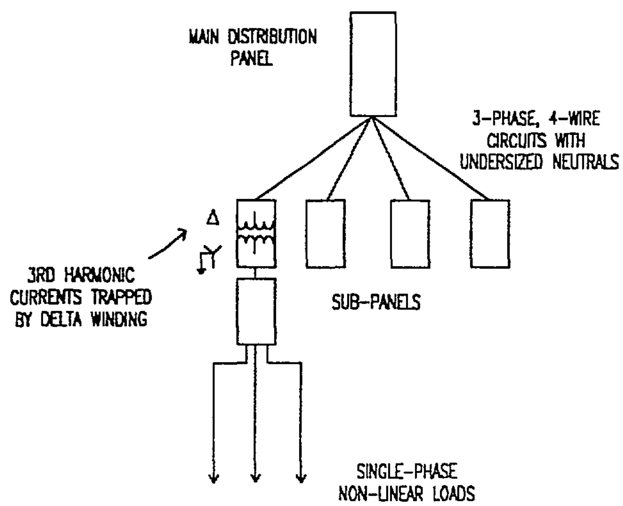
System Average RMS (Variation) Frequency Index $_{\text{Threshold}}$ -- $\text{SARFI}_{\%V}$

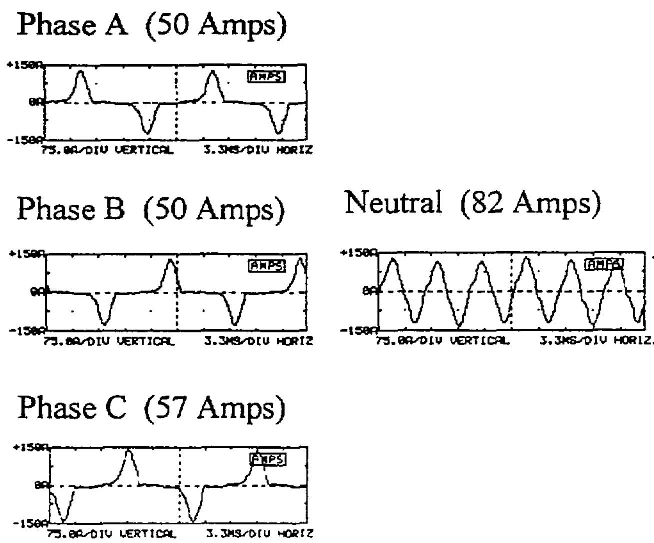
$$SARFI_{\%V} = \frac{\sum N_i}{N_T}$$

$\%V \equiv$ rms voltage threshold
140, 120, 110, 90, 80, 70, 50, 10
$N_i \equiv$ number of customers experiencing
rms < $\%V$ for variation i
(rms > $\%V$ for $\%V > 100$)
$N_T \equiv$ total # system customers

Finding the Source of Power Quality Problems

Harmonics Cause Neutral Conductor Overheating





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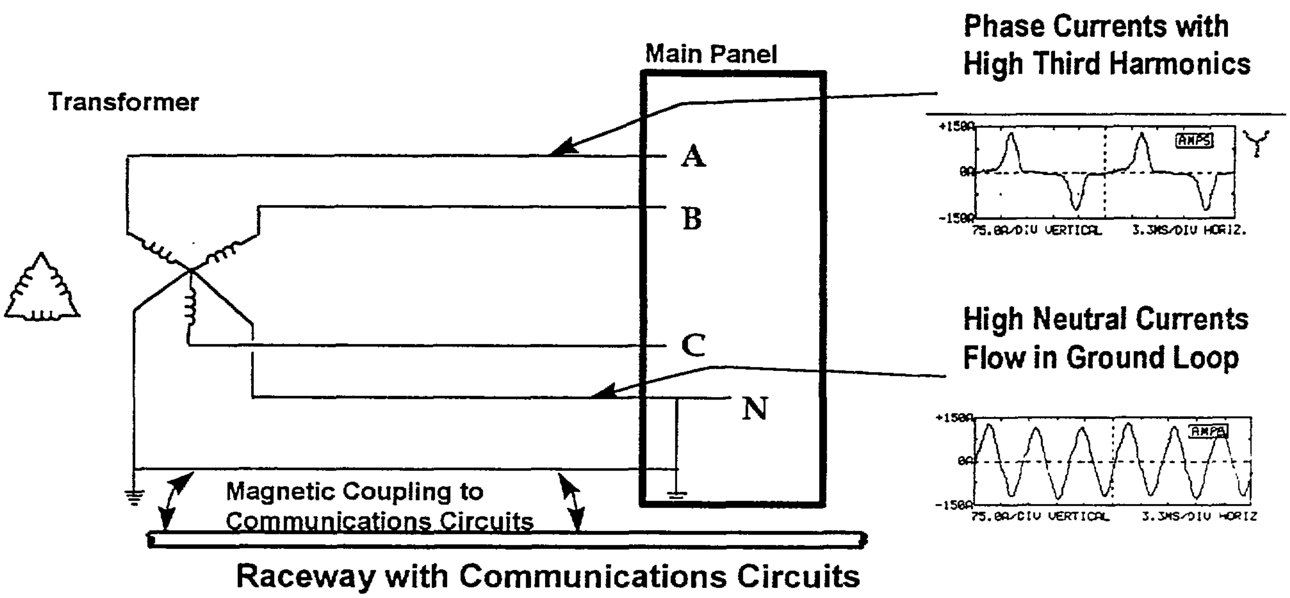
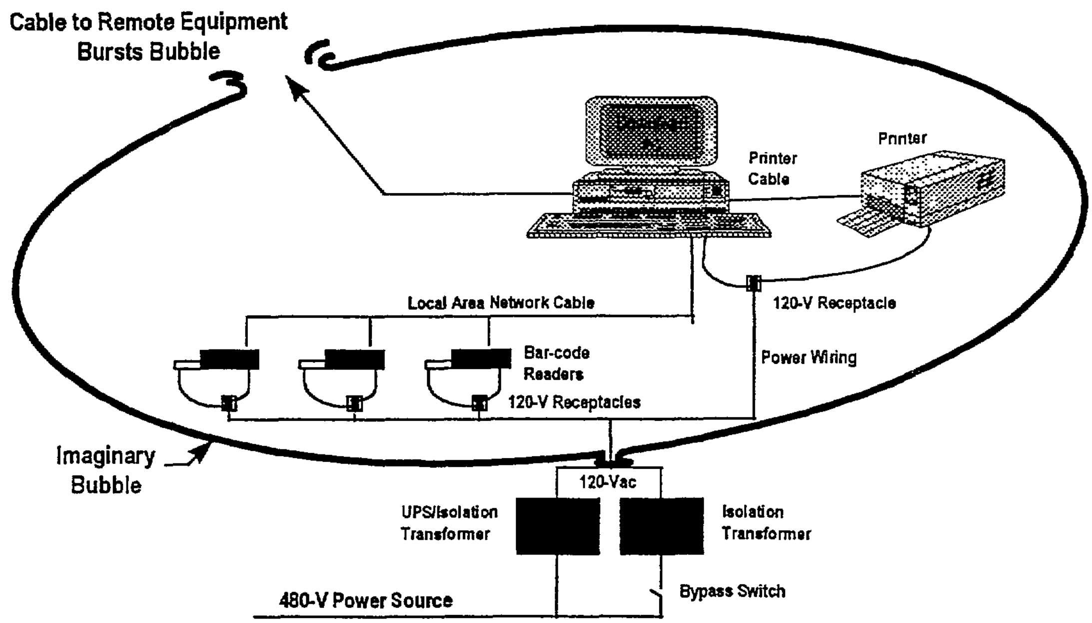
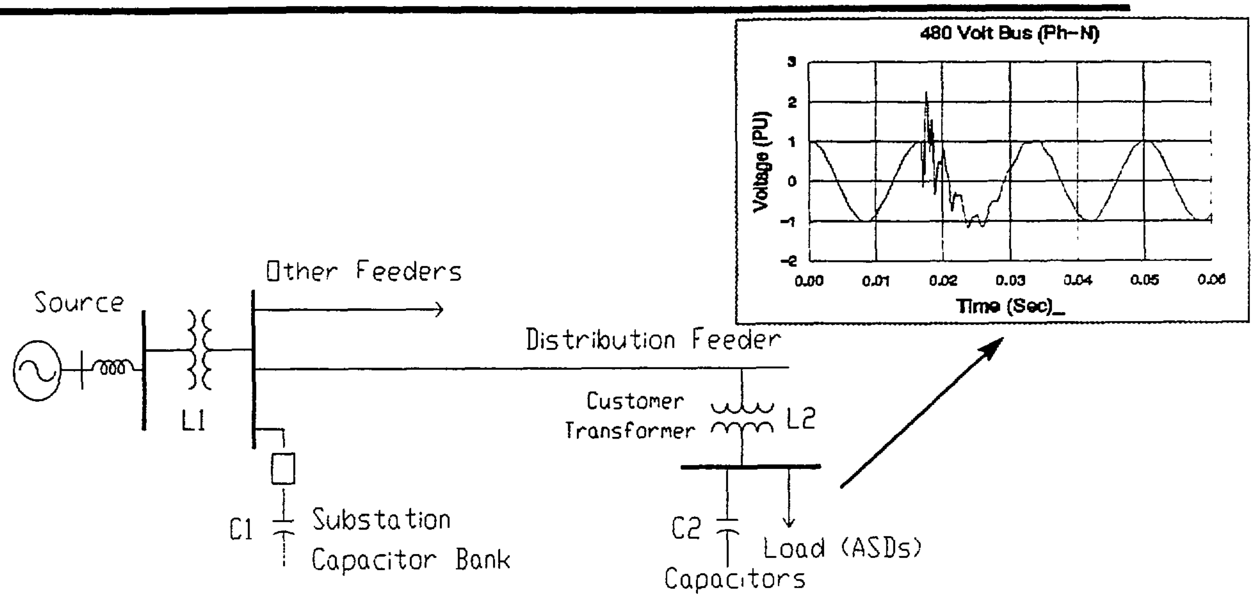
Interference from Neutral Currents



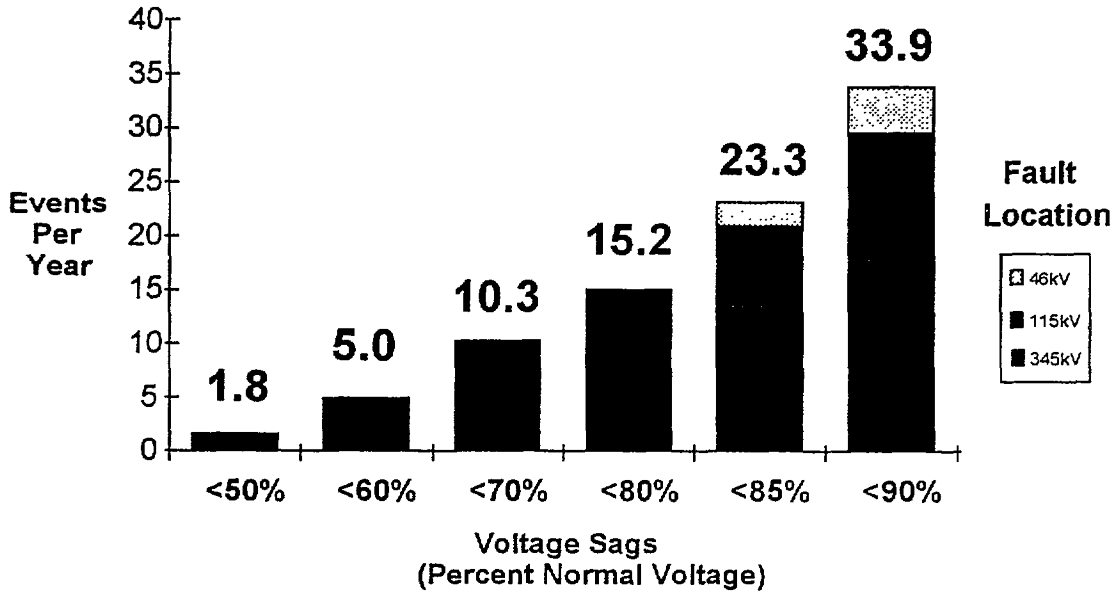
Ground Loops



Transients - Capacitor Switching Transients



Voltage Sags - System Performance



Initial Site Survey

- Before performing extensive monitoring, some information should be gathered:
  - » Nature of the problem
  - » Characteristics of the sensitive equipment
  - » When the problems occur
  - » Coincident problems or known operations
  - » Existing power conditioning equipment being used
  - » Electrical system data

Trouble Logs

Operator Name: ____________________
Location: ____________________
Equipment Description: ____________________

Date	Time	Description of Problem	Damage	Site Condition	Weather/Temp/ Humidity	Downtime	Observed Electrical Problems

Monitor Installation

- Environmental Concerns
- Transient Protection
  - » Phone line is most susceptible
- Transducer Connections
  - » Verify phase order, pairing and polarity
- Instrument Setup
  - » Set and verify scale factors (transducer ratios)
  - » Set and verify triggers
- Sanity Check
  - » Ensure steady state data is correct (V, I, Q, S, PF)
  - » Ensure that instrument is not triggering continuously

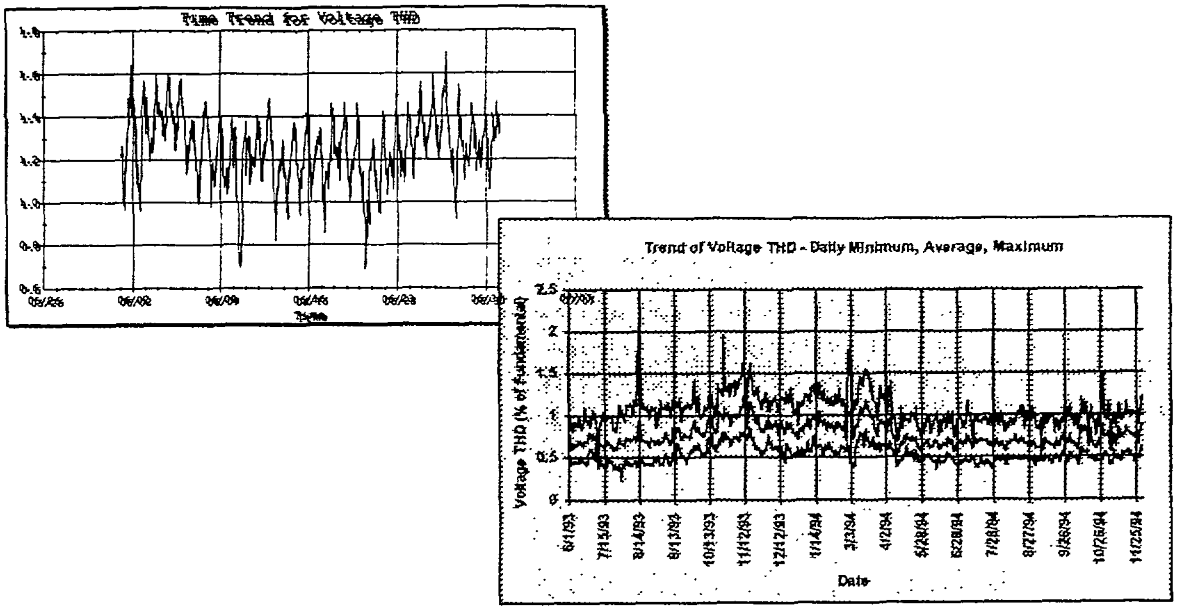
Where To Monitor

- Service entrance
- Load experiencing problems
- Transformers, distribution panels, receptacle sockets

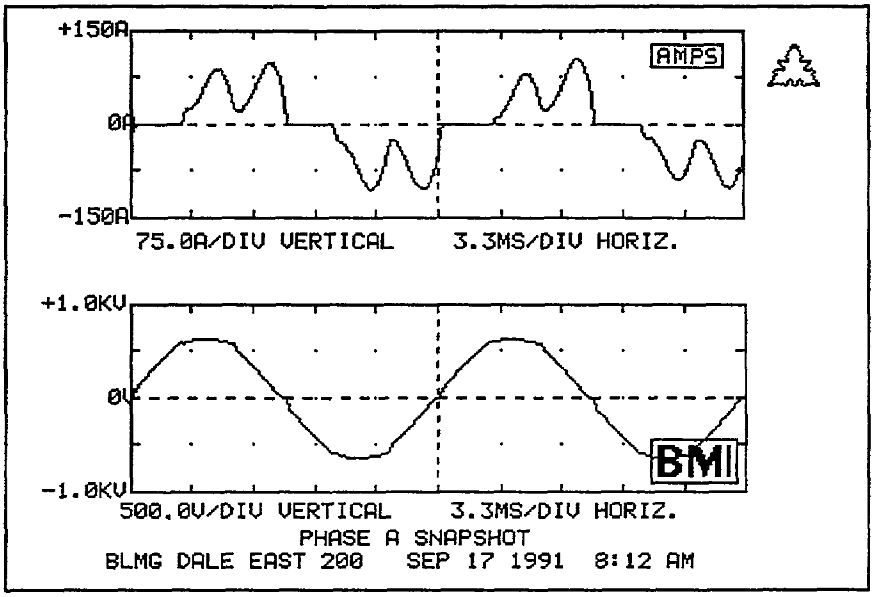
How Long to Measure

- Disturbances
  - Minimum one month
  - Must be able to accurately characterize events
- Steady-State Variations
  - Depends on load characteristics
  - Usually one week

Steady State Voltage Trends



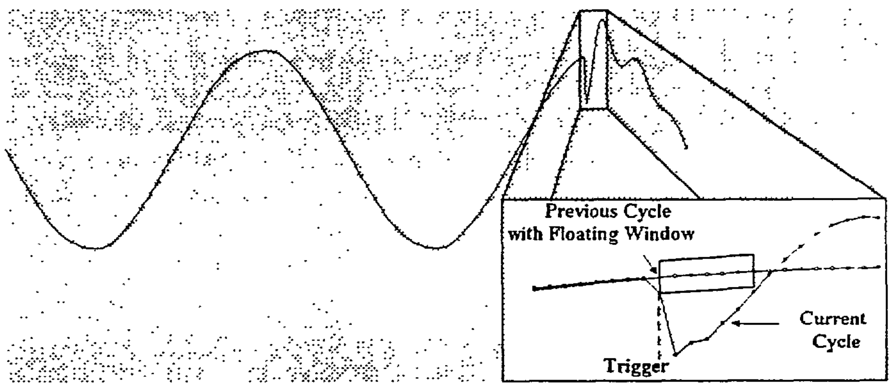
Snapshots



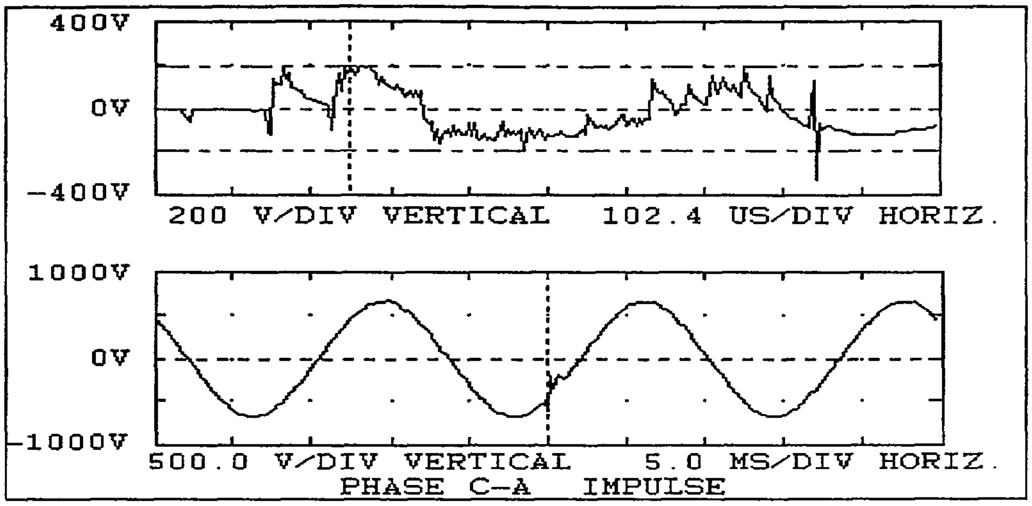
AMPS
+150A
0A
-150A
75.0A/DIV VERTICAL
3.3MS/DIV HORIZ.
+1.0KV
0V
-1.0KV
BMI
500.0V/DIV VERTICAL
3.3MS/DIV HORIZ.
PHASE A SNAPSHOT
BLMG DALE EAST 200 SEP 17 1991 8:12 AM

Transient Voltages

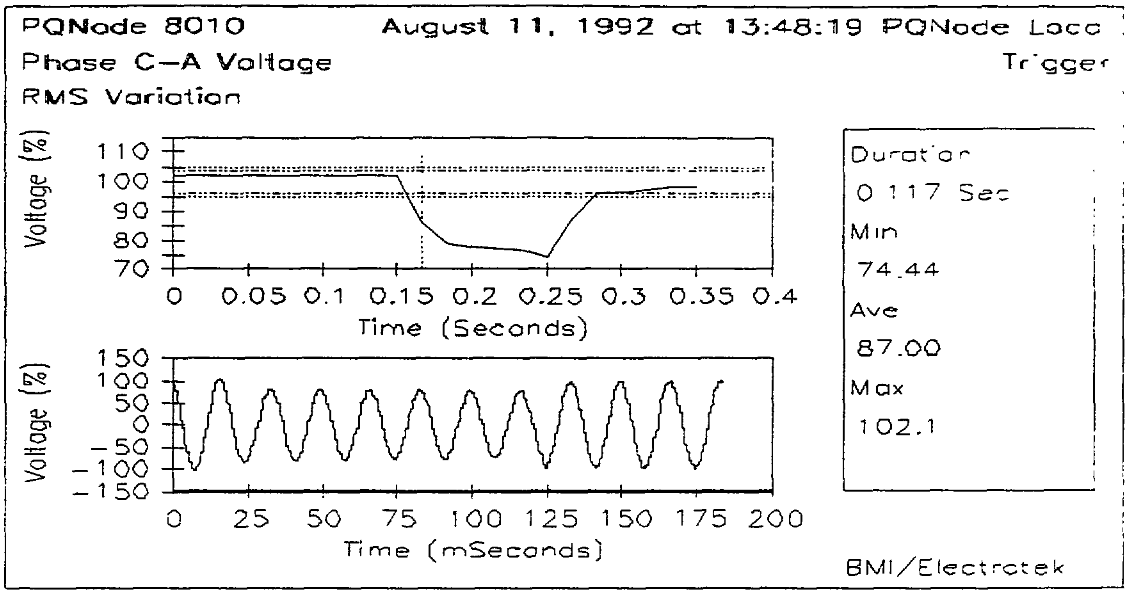
- Sampling Rate
- Triggering on all phases simultaneously
- Voltage and Current



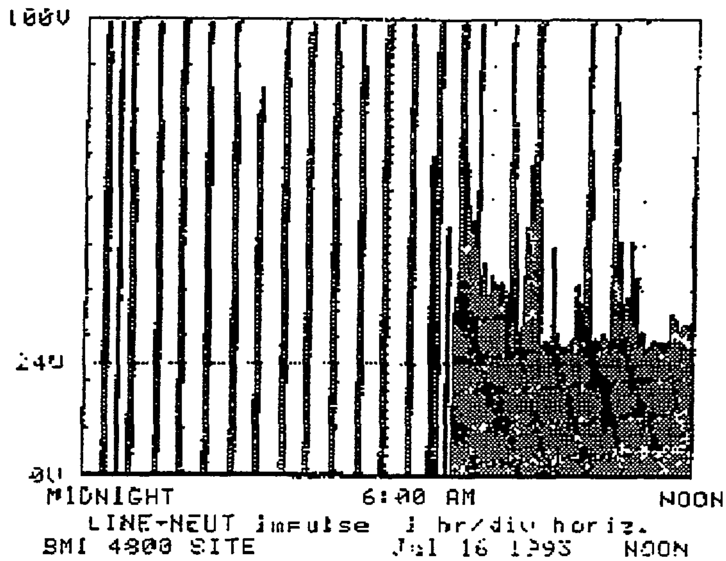
Impulses


400V
0V
-400V
200 V/DIV VERTICAL 102.4 US/DIV HORIZ.
1000V
0V
-1000V
500.0 V/DIV VERTICAL 5.0 MS/DIV HORIZ.
PHASE C-A IMPULSE

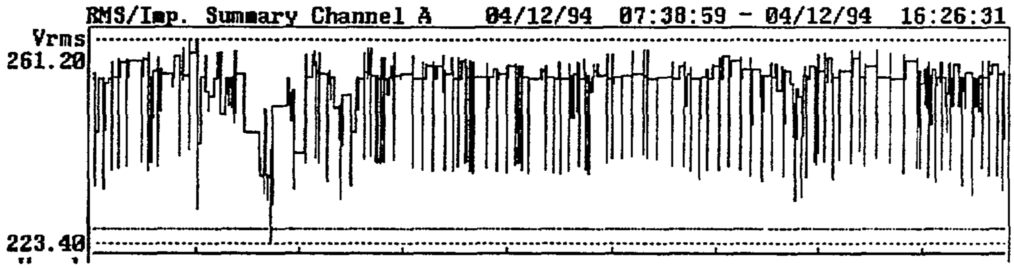
RMS Disturbances



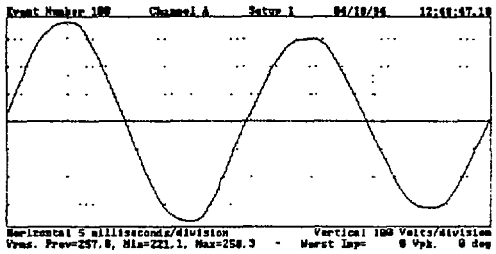
Signal Pulses

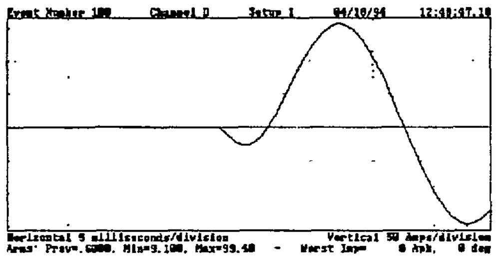


Repetitive Voltage Dips

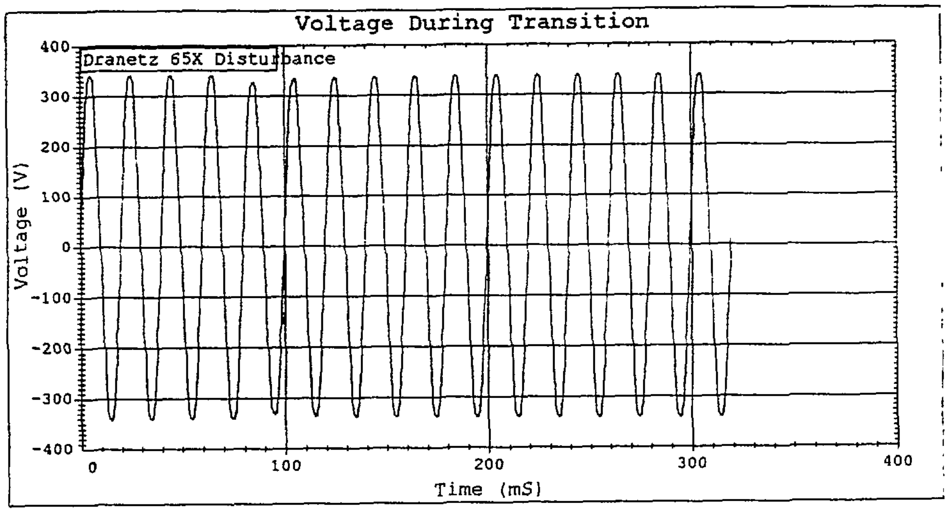


Air Compressor Voltage and Current

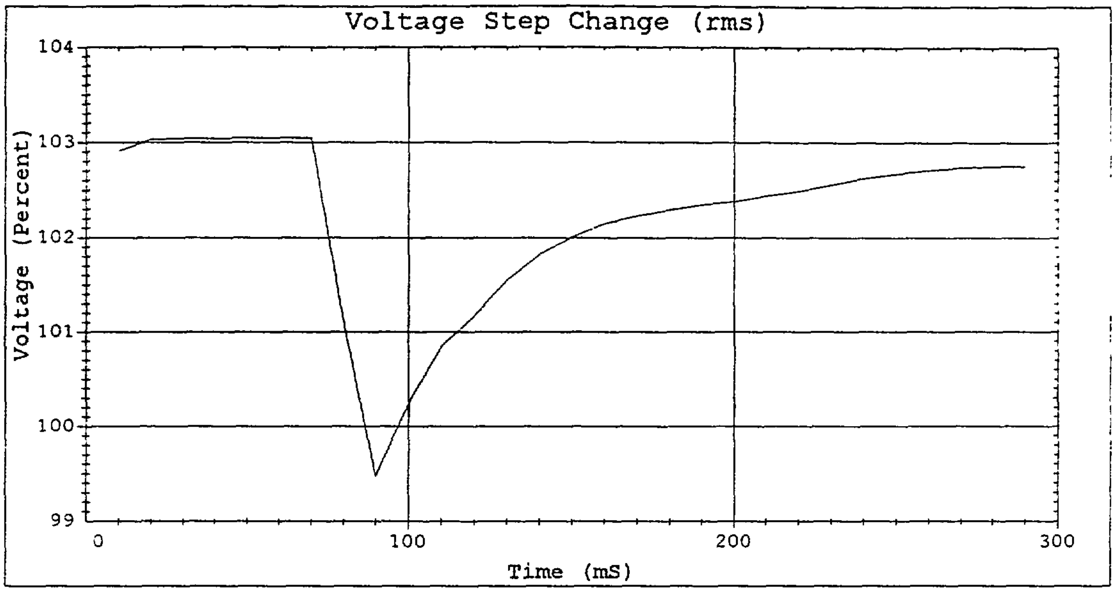




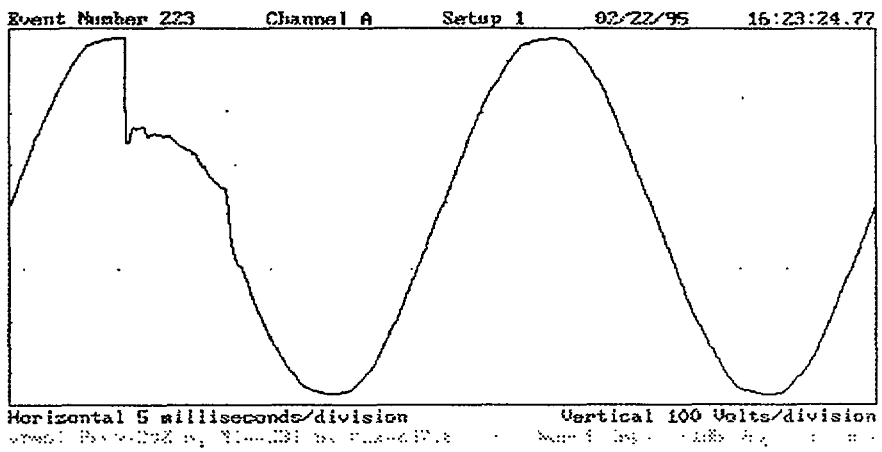
Motor Starting Voltage



RMS Plot During Motor Starting

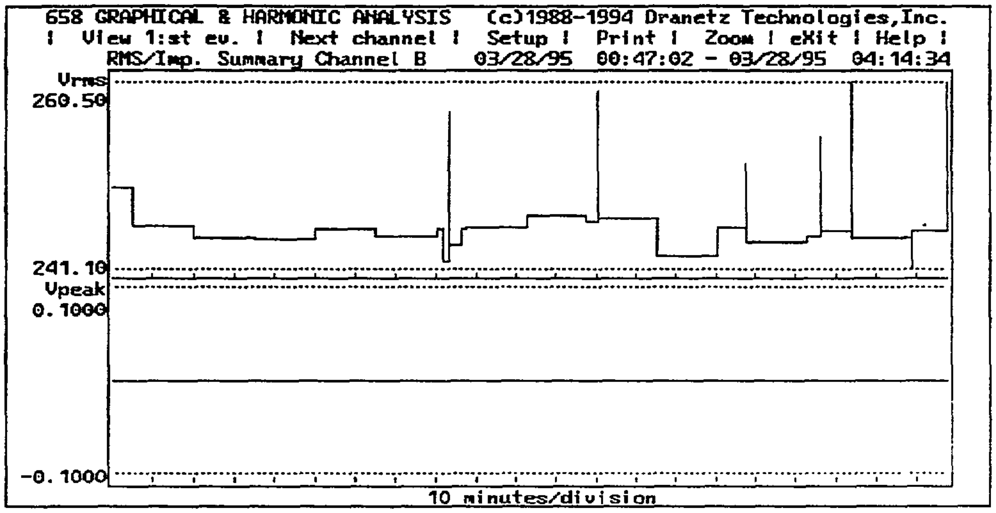


Voltage with Insulation Failure

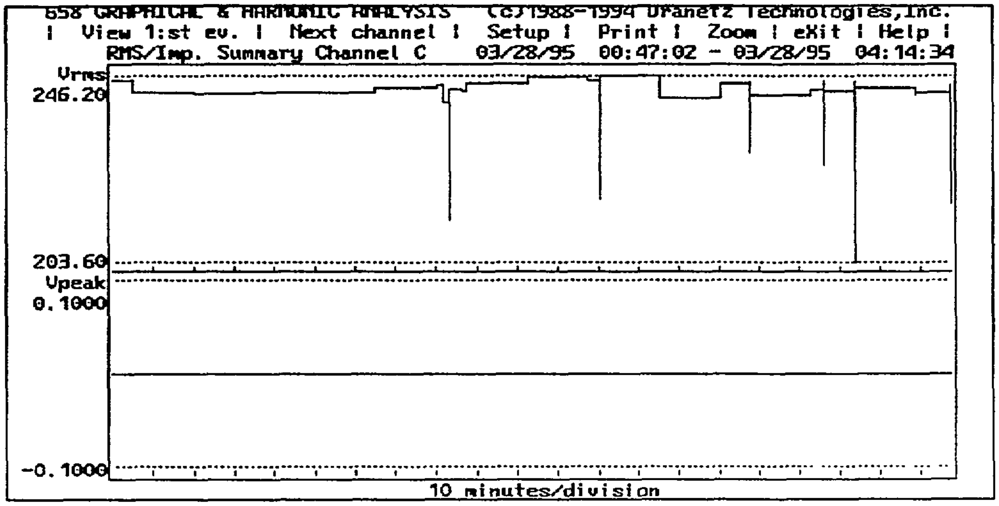


74

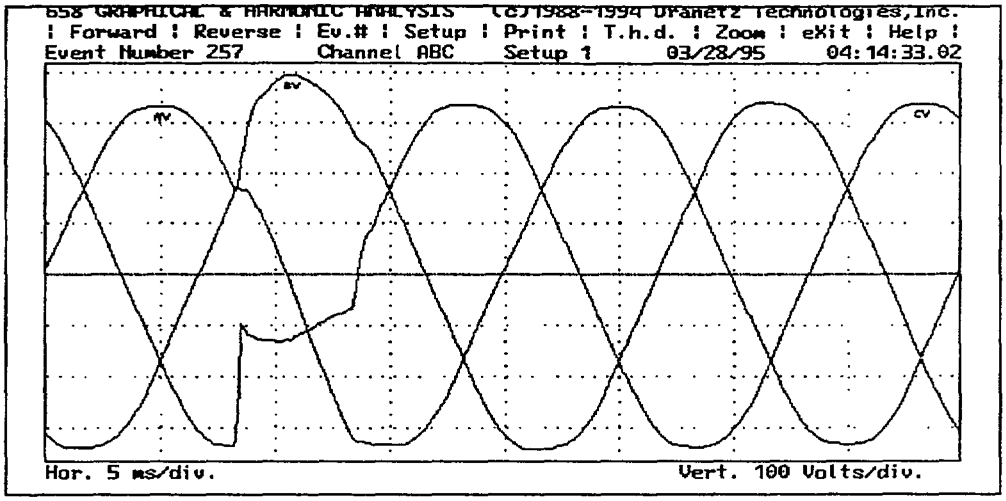
Repetitive Swell



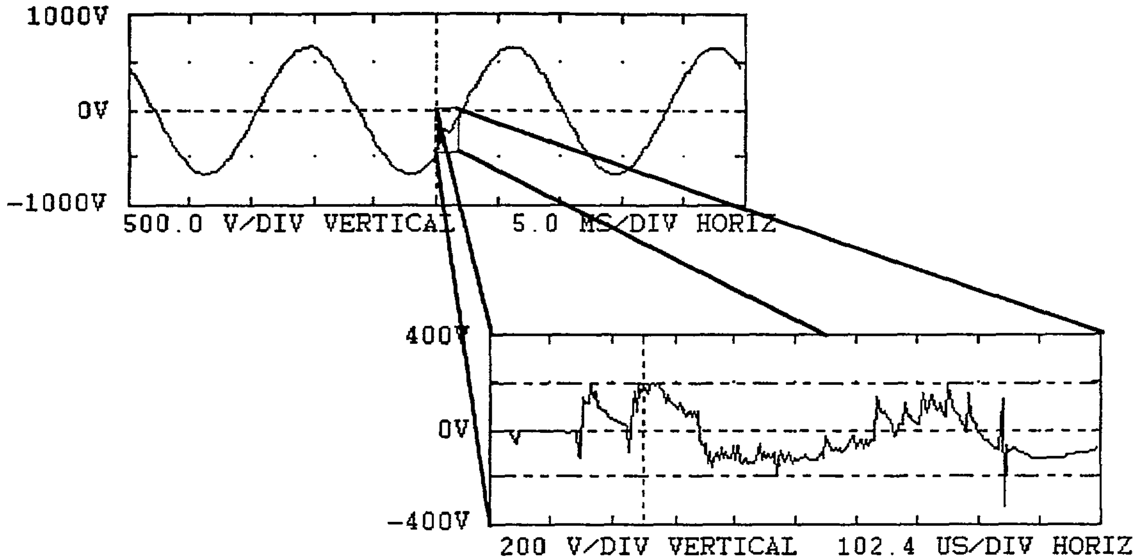
Repetitive Sag



Voltage Waveform

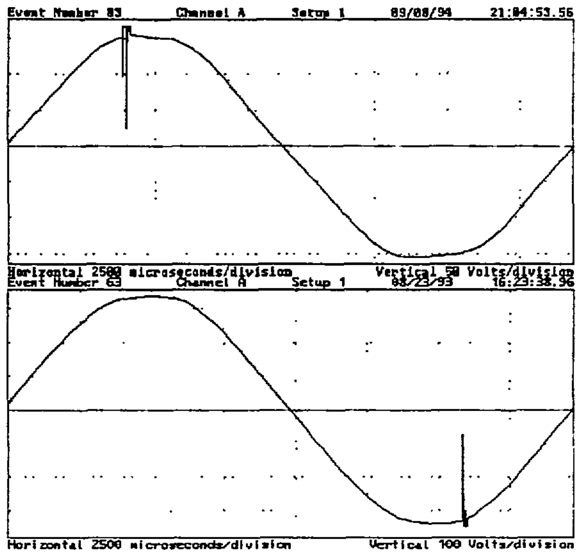


Switch Contact Arcing

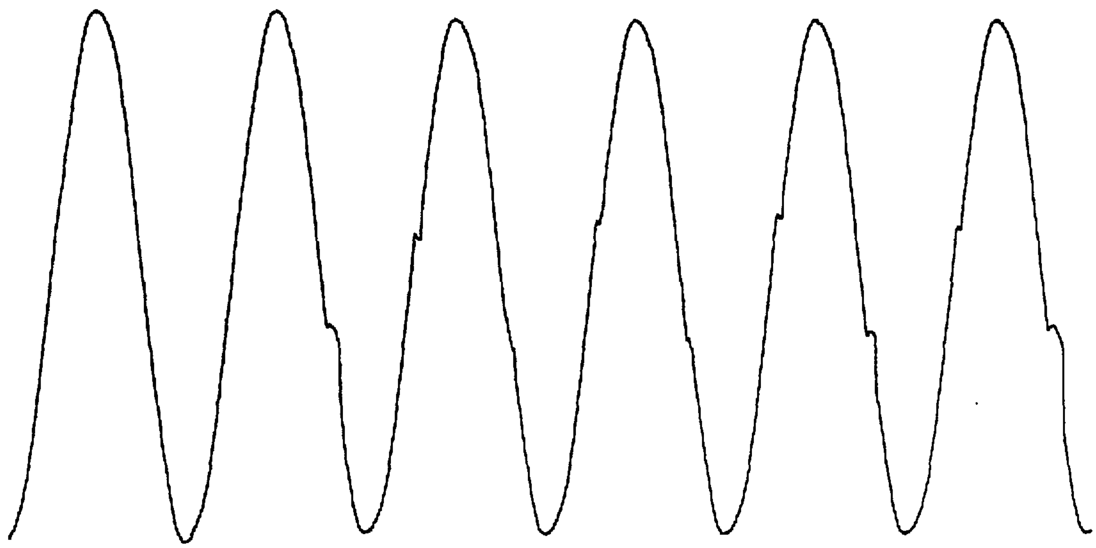


Electrotek Concepts, Inc.

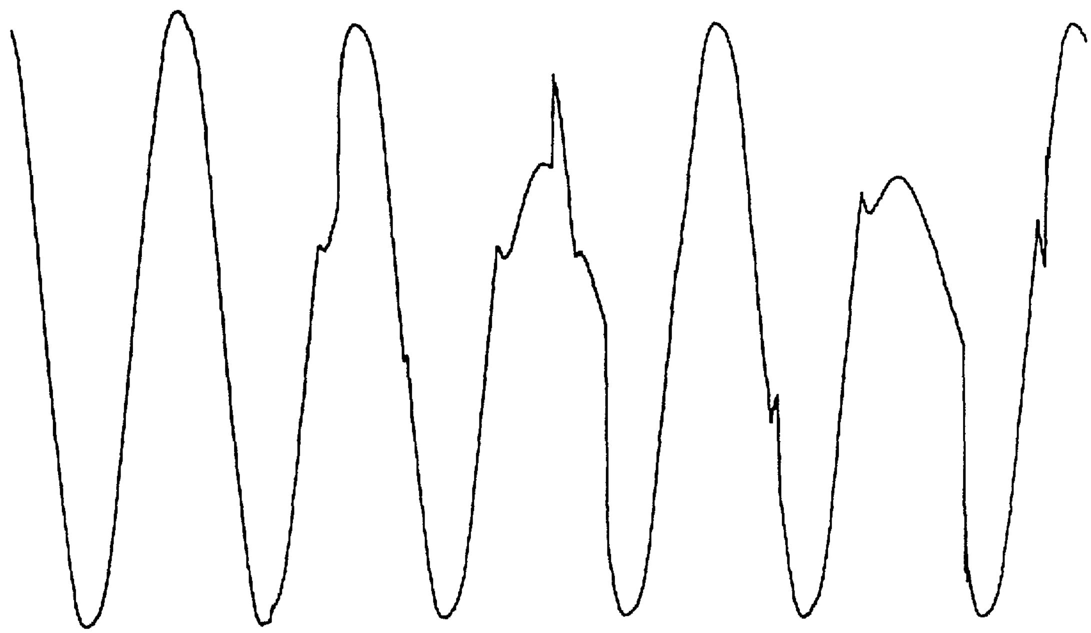
Other Load Switching Transients



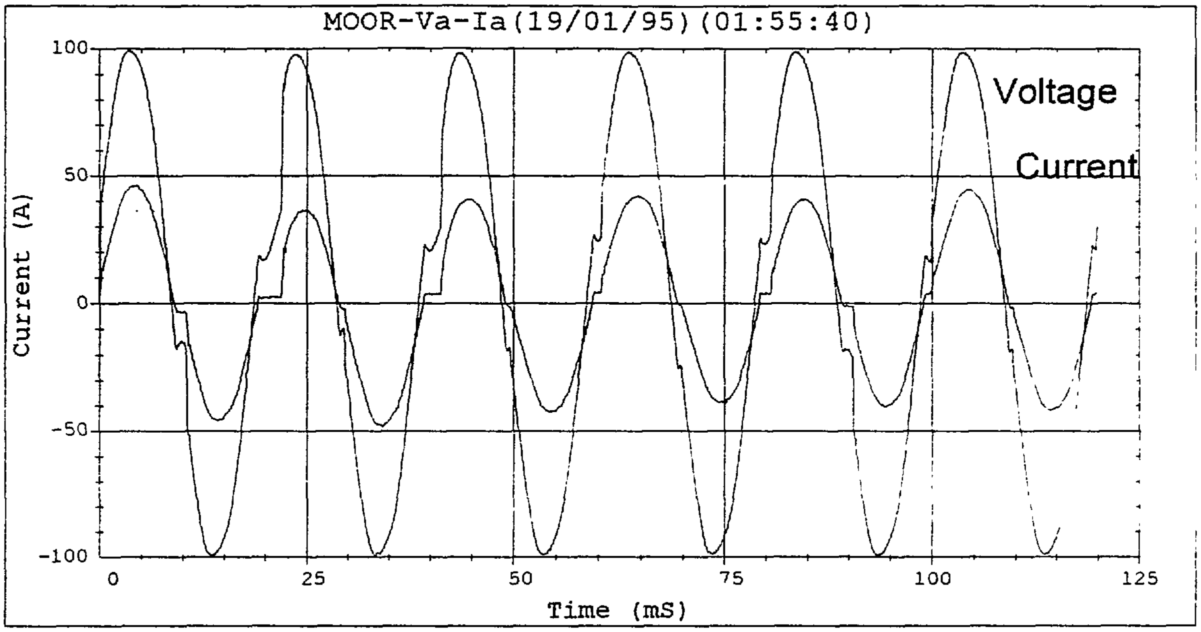
Voltage with a Loose Connection



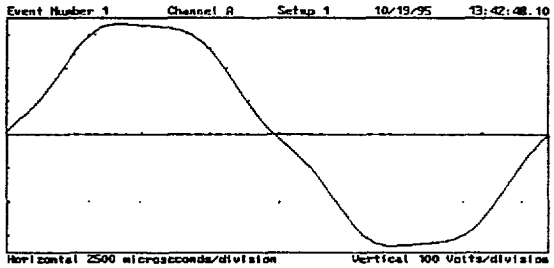
Loose Connection Progressing



Voltage and Current Waveforms



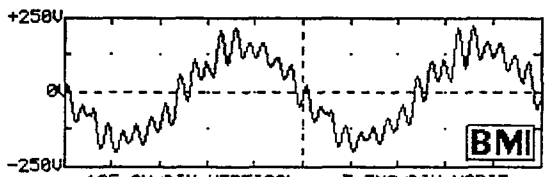
"Flat-topped" voltage



Fnd:	239.15V	89 deg	18th:	0.0%	97 deg
2nd:	0.0%	274 deg	19th:	0.0%	64 deg
3rd:	1.2%	279 deg	20th:	0.0%	122 deg
4th:	0.0%	68 deg	21st:	0.0%	260 deg
5th:	5.4%	288 deg	22nd:	0.0%	56 deg
6th:	0.0%	229 deg	23rd:	0.0%	10 deg
7th:	0.3%	344 deg	24th:	0.0%	300 deg
8th:	0.0%	106 deg	25th:	0.0%	112 deg
9th:	0.1%	82 deg	26th:	0.0%	236 deg
10th:	0.0%	50 deg	27th:	0.0%	292 deg
11th:	0.1%	5 deg	28th:	0.0%	91 deg
12th:	0.0%	146 deg	29th:	0.0%	309 deg
13th:	0.1%	149 deg	30th:	0.0%	260 deg
14th:	0.0%	296 deg	31st:	0.0%	131 deg
15th:	0.0%	201 deg	32nd:	0.0%	227 deg
16th:	0.0%	275 deg	33rd:	0.0%	237 deg
17th:	0.0%	67 deg	34th:	0.0%	226 deg

T.H.D.: 5.5% ODD CONTRIB.: 5.5%

Severe Harmonic Distortion



125.0V/DIV VERTICAL 3.3MS/DIV HORIZ.
PHASE A SNAPSHOT

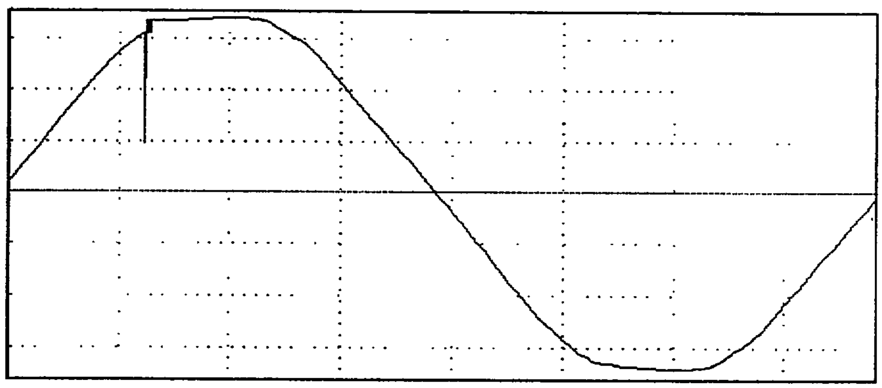
TE COPIER Sep 16 1991 (Mon)
PHASE A VOLTAGE SPECTRUM 9:58:25 AM
Fundamental volts: 113.6 Vrms
Fundamental freq: 60.0 Hz

HARM	PCT	SINE PHASE	HARM	PCT	SINE PHASE
FUND	100.0%	0	2nd	0.4%	105
3rd	0.5%	-168	4th	0.2%	54
5th	6.9%	73	6th	0.1%	-43
7th	5.1%	0	8th	0.2%	117
9th	0.8%	16	10th	0.2%	179
11th	8.9%	-156	12th	0.2%	-147
13th	10.4%	121	14th	0.4%	-59
15th	3.4%	135	16th	2.0%	-140
17th	24.1%	-176	18th		
19th	4.1%	98	20th	0.2%	-114
21st	0.6%	77	22nd	0.2%	-135
23rd	0.9%	-56	24th	0.2%	146
25th			26th		
27th	0.1%	-39	28th	0.2%	-109
29th	0.4%	-106	30th	0.1%	48
31st	0.6%	147	32nd	0.1%	21
33rd	0.4%	159	34th	0.1%	-59
35th	0.5%	11	36th		
37th	0.6%	-78	38th	0.2%	-20
39th	0.4%	-89	40th		
41st	1.0%	150	42nd	0.1%	100
43rd	0.7%	68	44th	0.2%	-29
45th	0.4%	31	46th		
47th	0.9%	-84	48th		
49th	0.7%	-167	50th	0.1%	86
ODD	29.6%		EVEN	2.2%	

THD: 29.7%

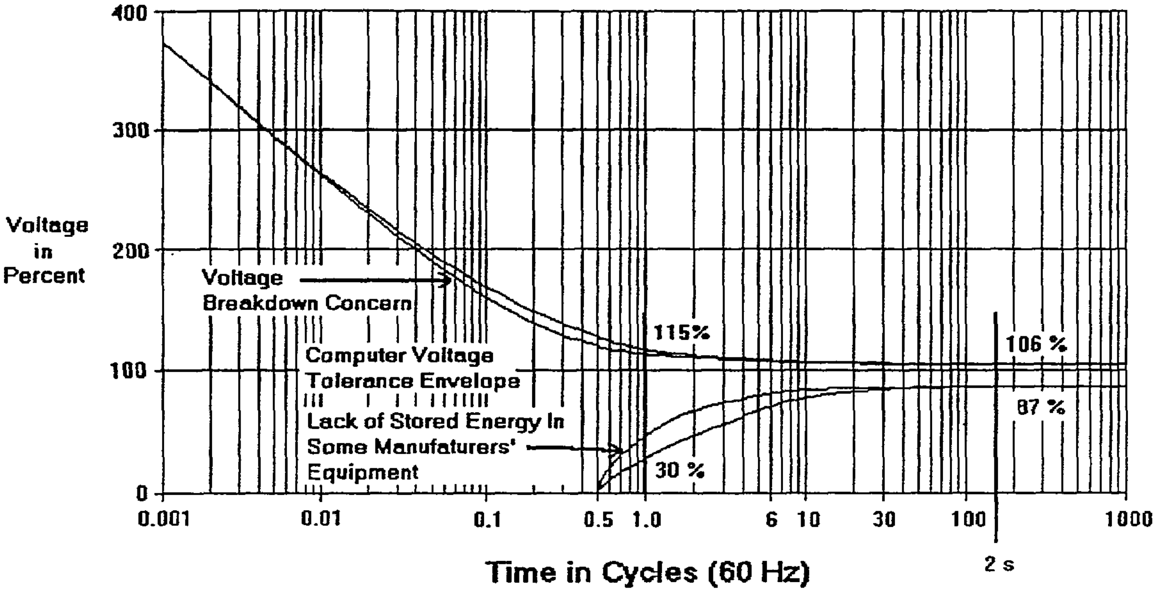
Impulses from Street Lighting

- Repetitive impulses, caused by faulty street lighting components, caused time clocks to run fast.

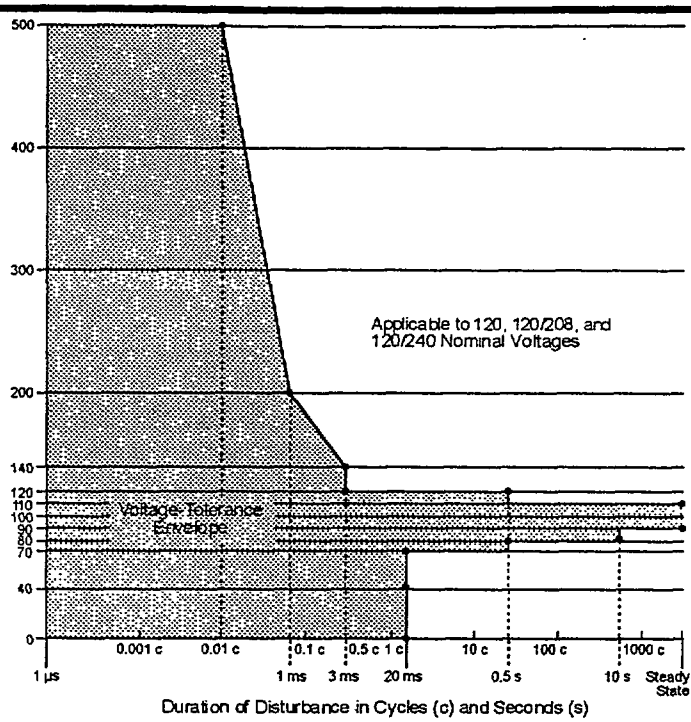


IEEE 446 - 1987 Limits

CBEMA

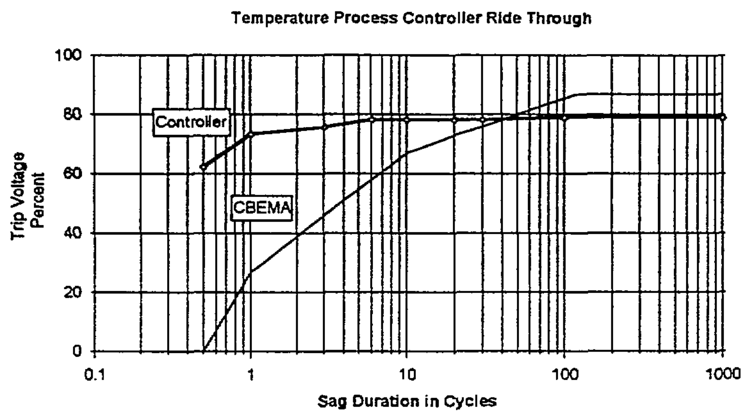


Revised (1996) IT Industry Tolerance Curves

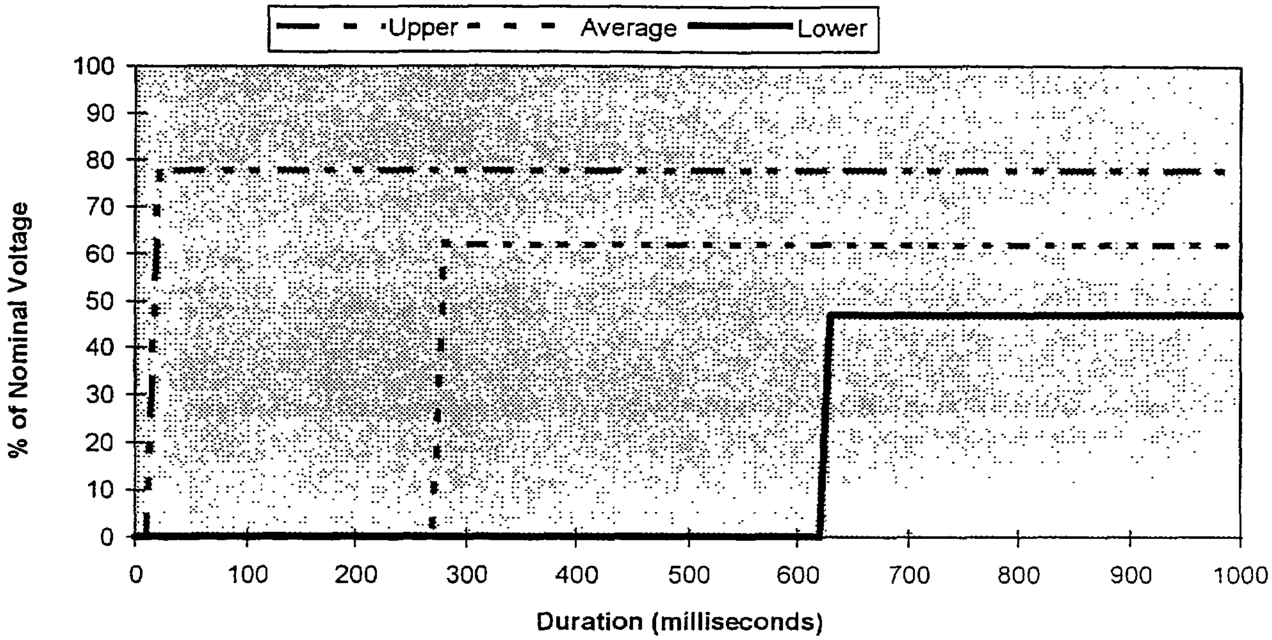


Equipment Sensitivity - Reality

- CBEMA curve does not apply to most equipment.

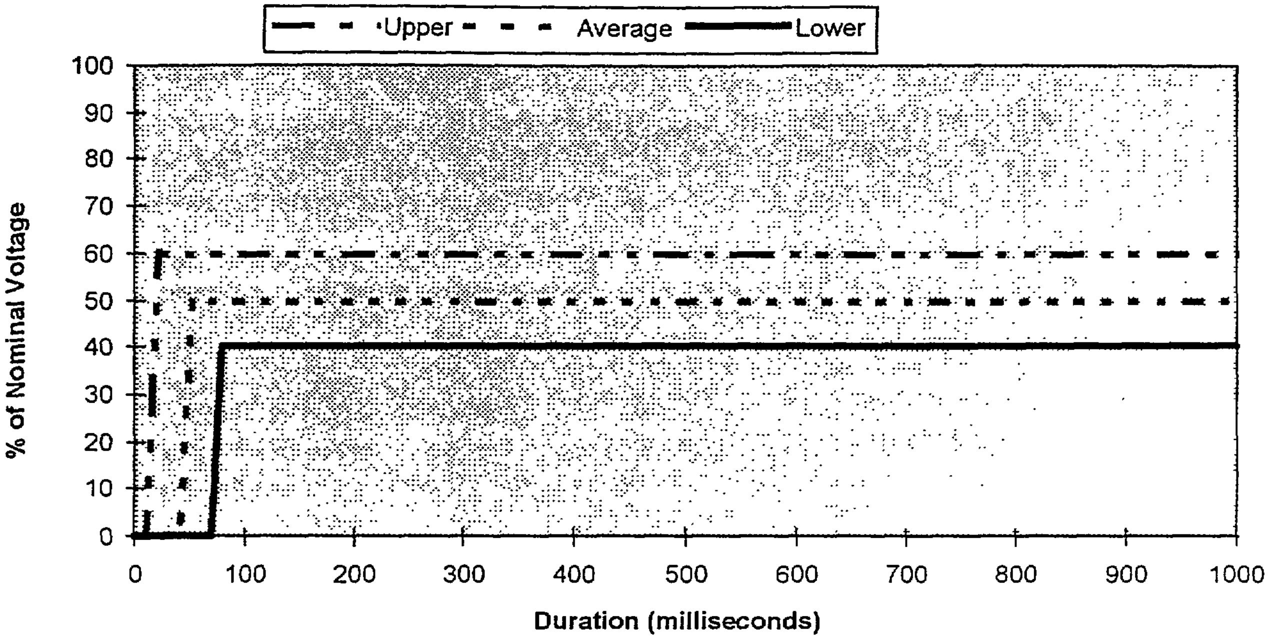


Programmable Logic Controller Voltage Sag Tolerance Curves

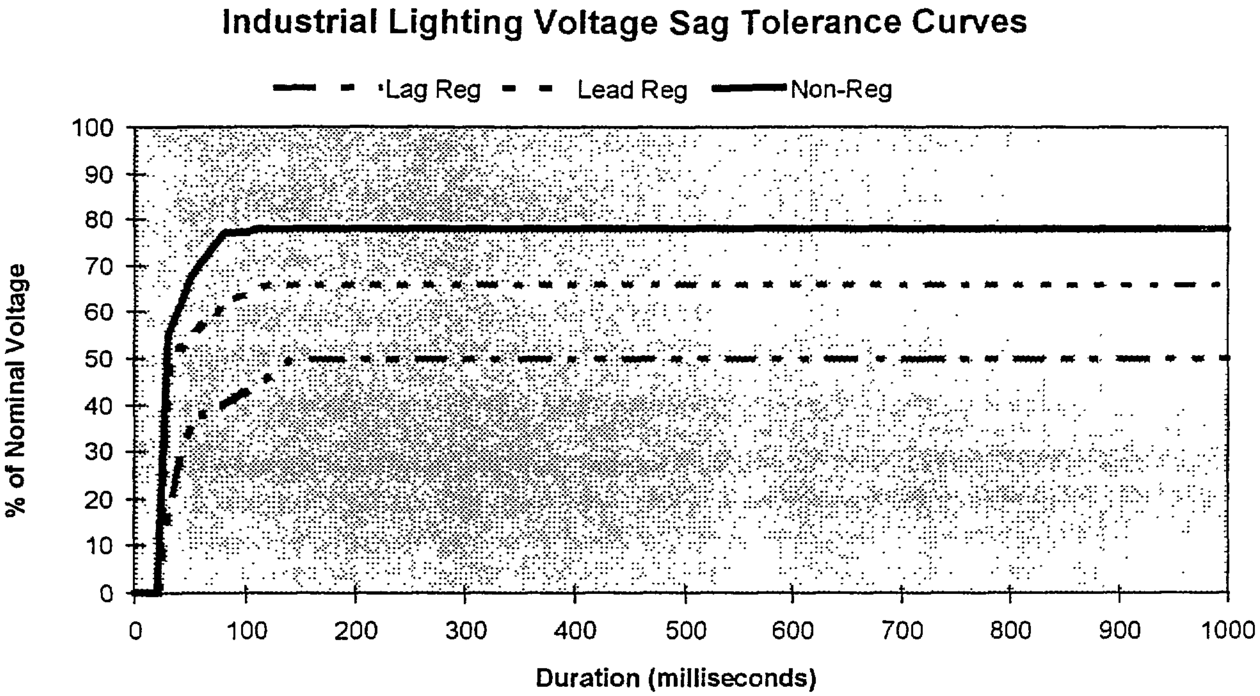


Source: IEEE P1346 Draft 4.0

Motor Starter Coil Voltage Sag Tolerance Curves

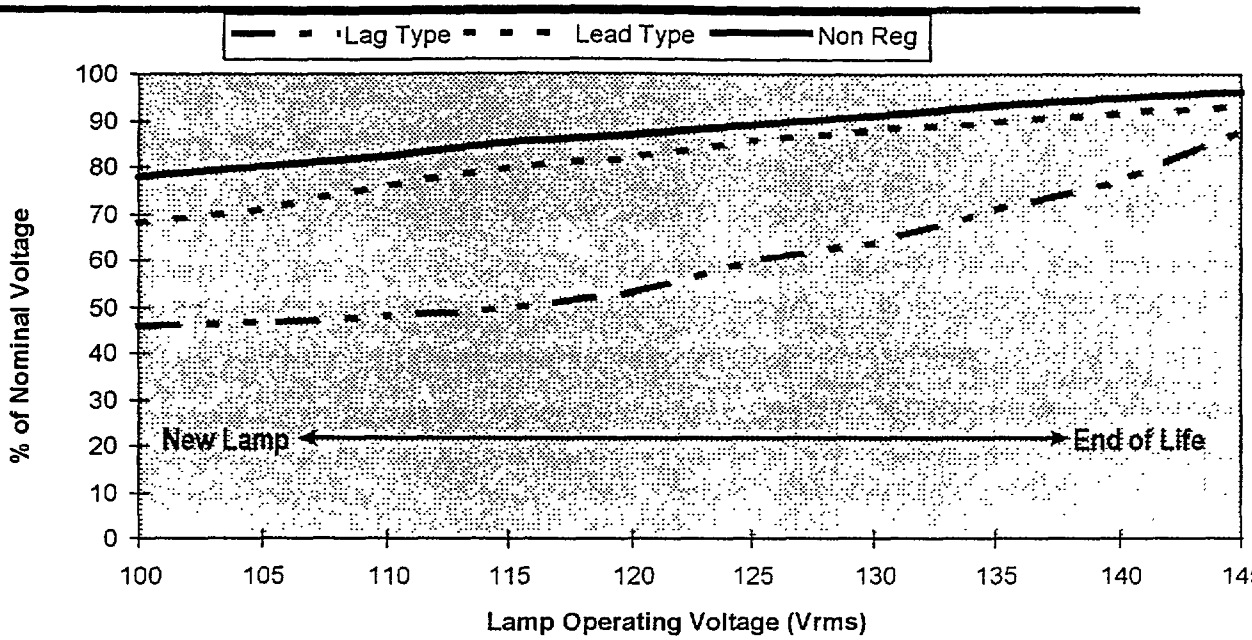


Source: IEEE P1346 Draft 4.0

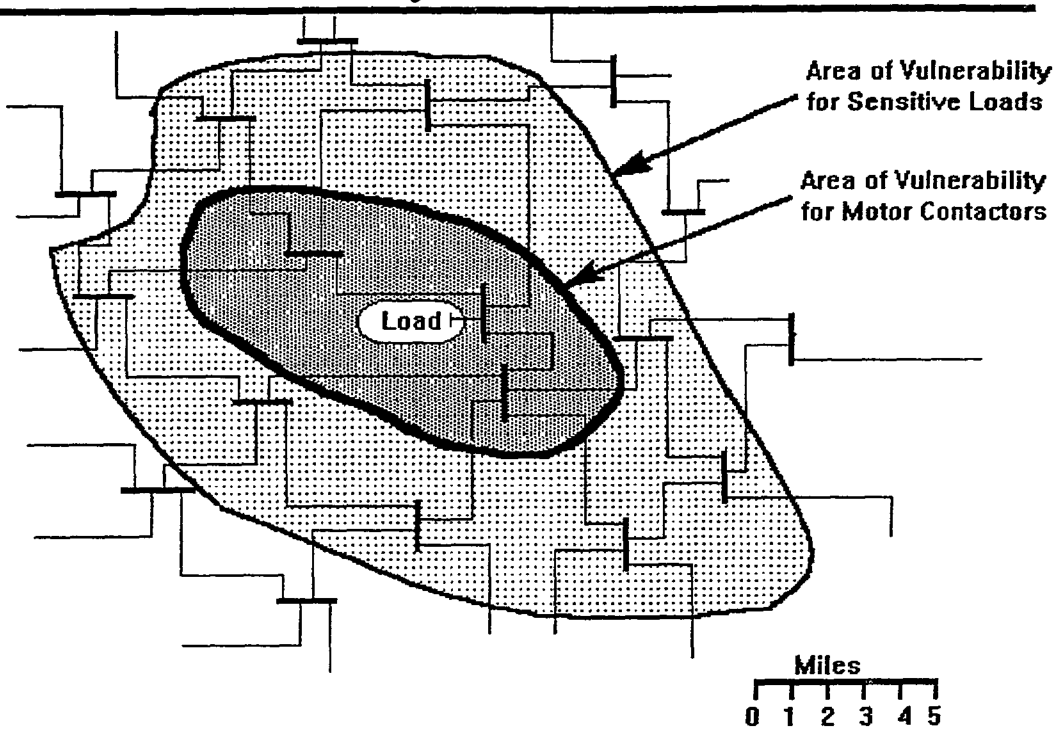


Source: A. Morinec, Centerior Energy

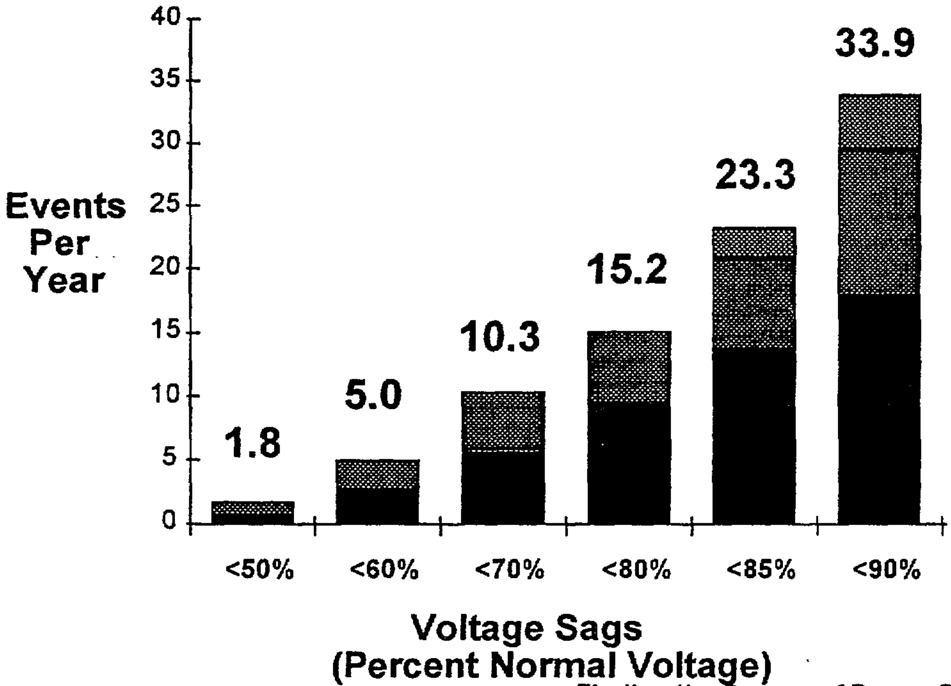
HPS Lamp Voltage Sag Tolerance Curves



Area of Vulnerability



Performance vs. Sensitivity Level



Solving Power Quality Problems

Solutions to Voltage Sag Problems

- Equipment Solutions
  - Modification of Electronic Controls
  - Equipment Procurement Specifications
- Customer Solutions
  - Power Conditioning
- Utility Solutions
  - Prevent Faults
  - Modify Fault Clearing Practices

Equipment Solutions

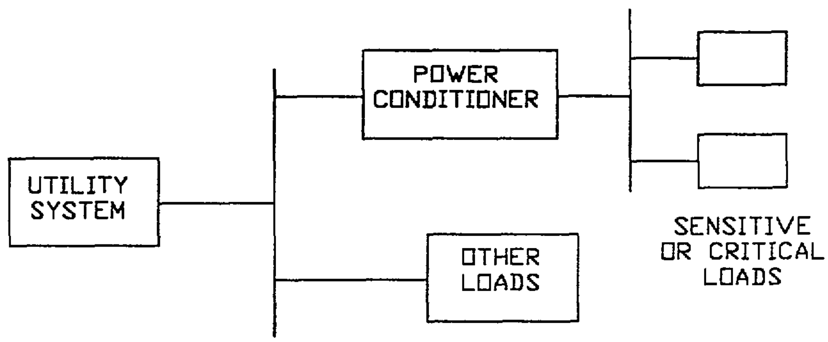
- Modification of sensitive electronic controls
  - Double layer capacitors can sometimes be used for protection of dc powered controls
  - More than twenty times the capacitance density of conventional capacitors
  - 4 Farads at 24 Volts can be packaged in a 6 x 4 x 1.5 inch box

Equipment Specifications

- The best solution is to to keep problem equipment out of the plant through equipment procurement specifications.
- Equipment manufacturers should have ride through capability curves available.
- A ride through capability limit should be chosen for at least the 70% level.

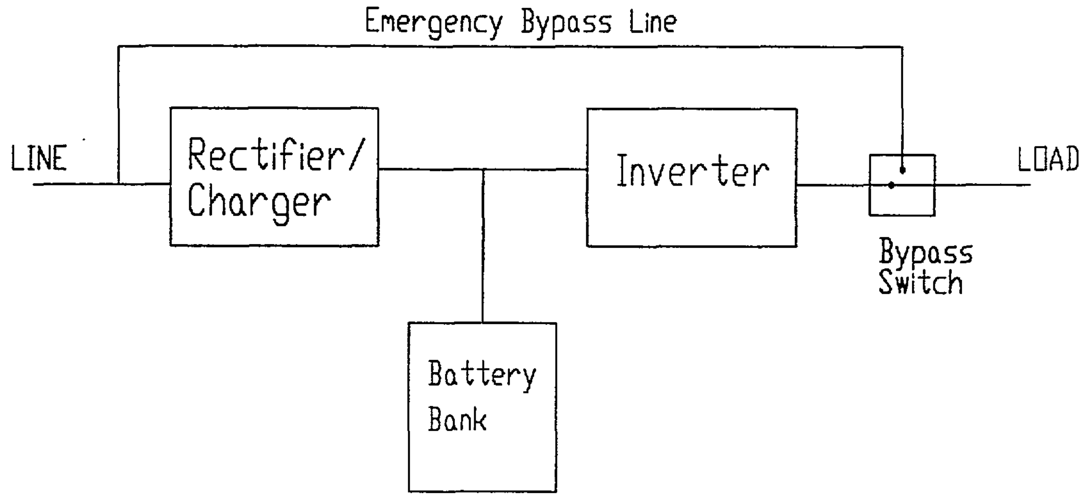
Power Conditioning Solutions

- Customer solutions often involve power conditioning for sensitive loads (although equipment specifications and modifications should be considered first)



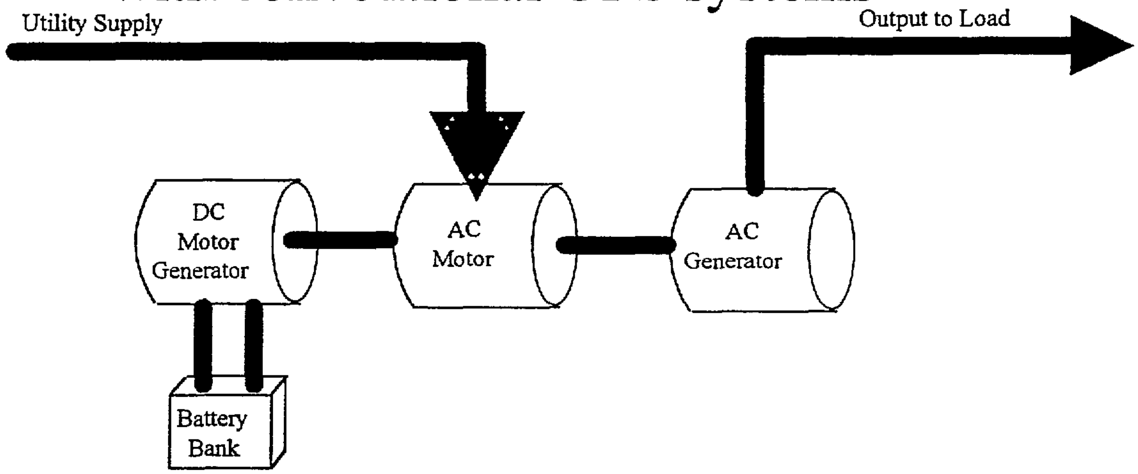
Uninterruptible Power Supplies (UPS)

On-line Power Supply:



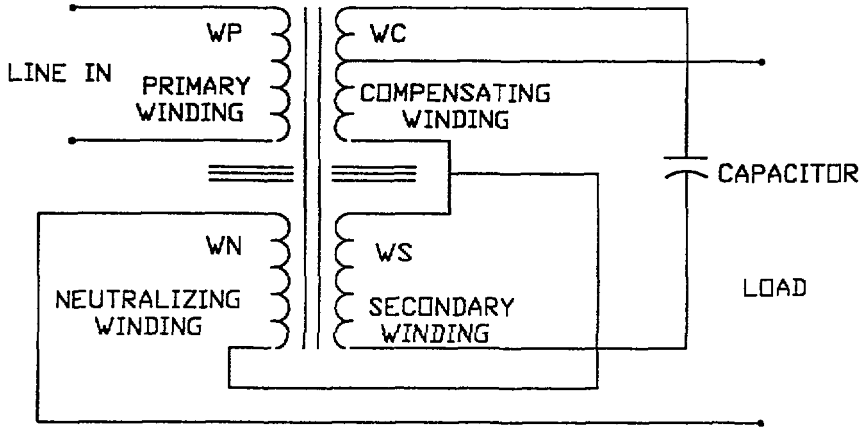
Rotary UPS Systems

- This design eliminates the rectifier/charger, inverter and static bypass switch associated with conventional UPS systems

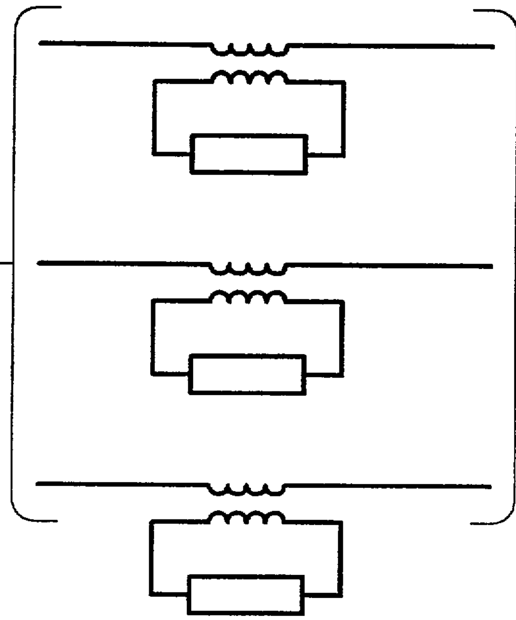


Constant Voltage Transformers

- Constant voltage transformers provide a constant output voltage for an input voltage that varies.



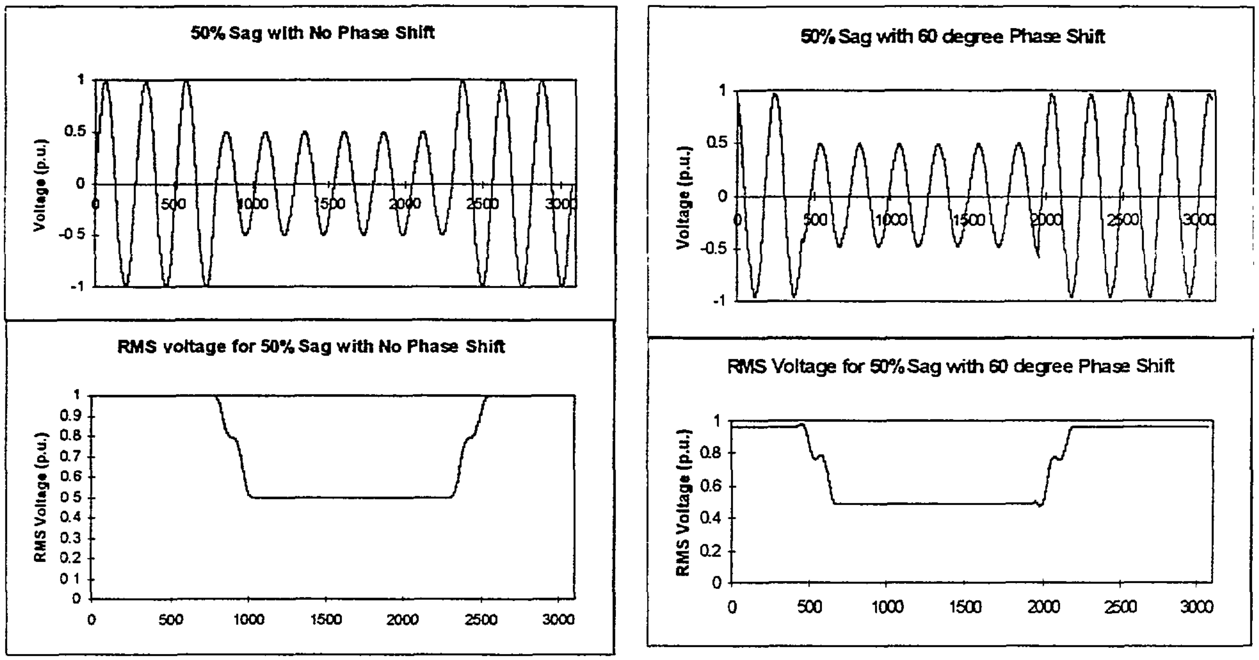
Static Series Compensator



Application Considerations

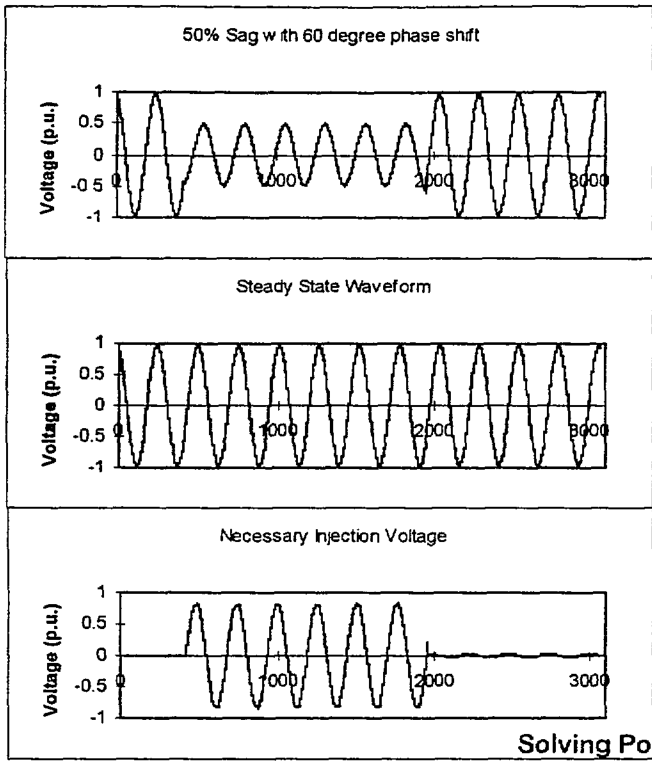
- Series Static Compensation
- Response time
- Waveshape to be corrected
- Phase angle jump
- Affect on upstream loads
- Coordination with reclosers and other protective devices

Phase Angle Jump



Source: IEEE P1409

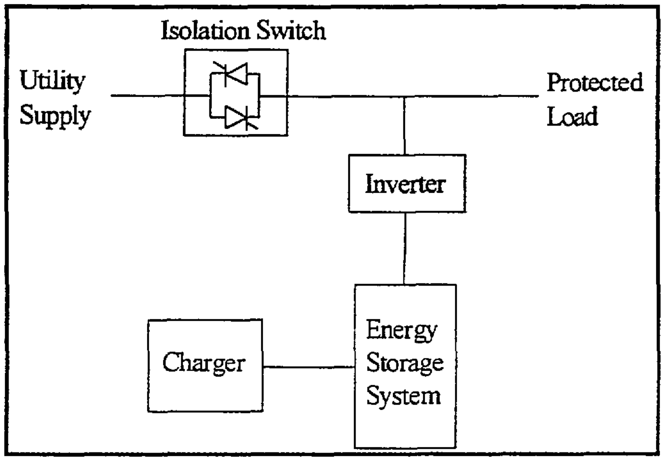
Missing Voltage



Source: IEEE P1409

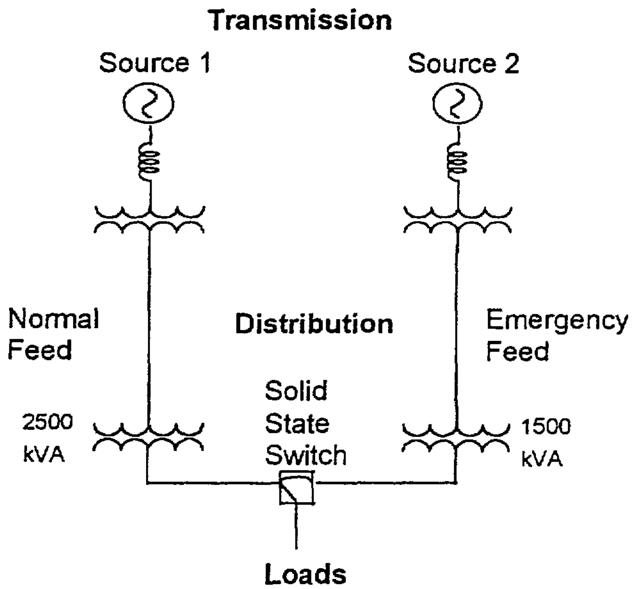
General Energy Storage System

- Isolation Switch
- Inverter
- Energy Storage System
  - » Capacitors
  - » Batteries
  - » Superconducting Coils
  - » Flywheels
- Charger



Solid-State Switches with Dual Feeders

- Solid-state switches can be used to switch load from one feeder (normal) to the emergency backup feeder in less than a quarter-cycle which is fast enough to prevent load interruptions.
- Available for primary or secondary application.

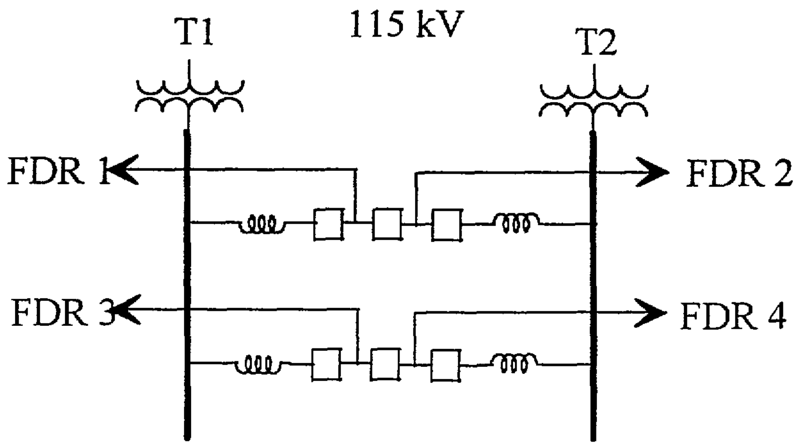


Utility Side Solutions

- Transmission
  - Tower Footing Resistance
  - Counterpoise
  - Line Arresters
  - Insulator Washing
- Distribution
  - Tree Trimming
  - Animal Guards
  - Arresters
  - Loop Schemes
  - Modified Feeder Design
  - Modify Protective Coordination

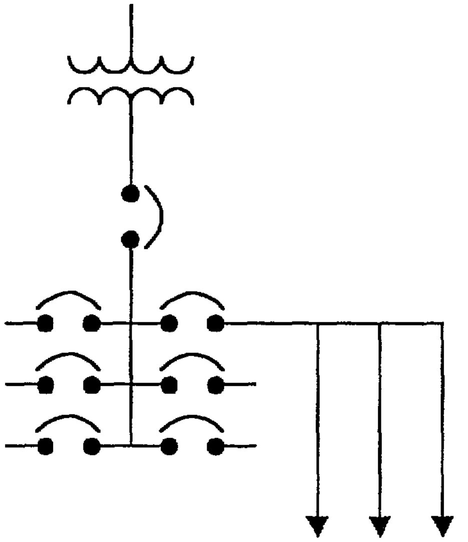
Feeder Reactors can Limit Voltage Sags

- Feeder reactors and low impedance substation transformers can be used to limit voltage sags to 80% for faults on parallel feeders



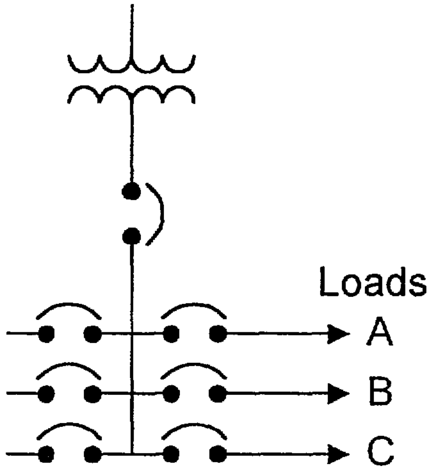
Common System Design

- What problems does this design cause?

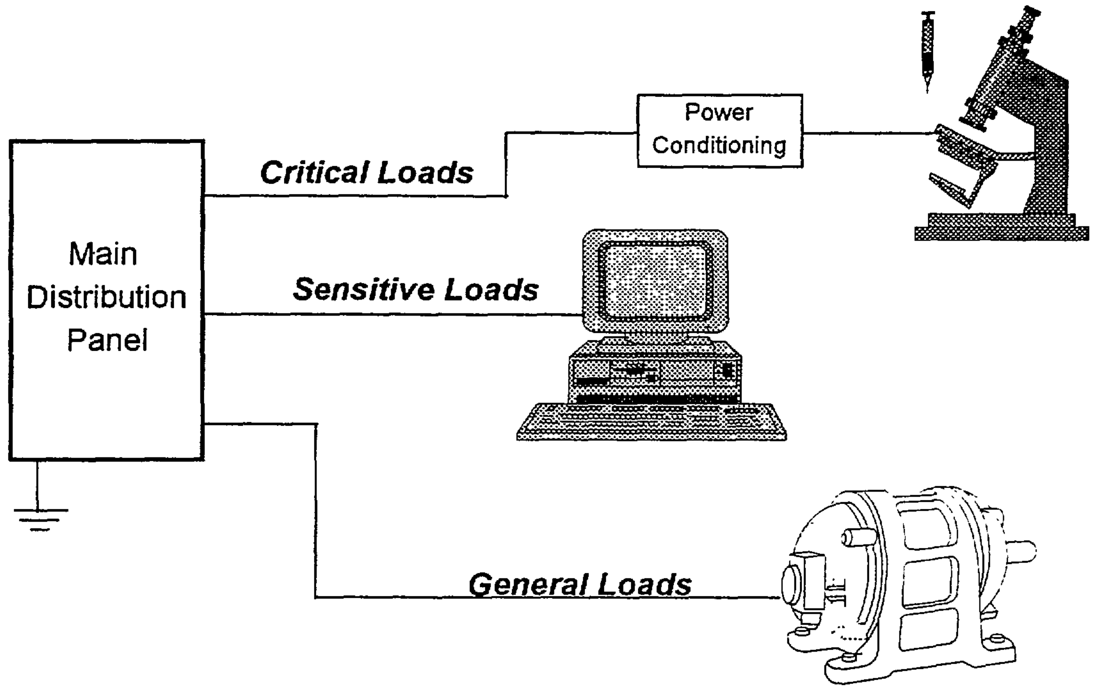


Improved System Design

- Separate Branch Circuits (with separate grounds) solve what problems?



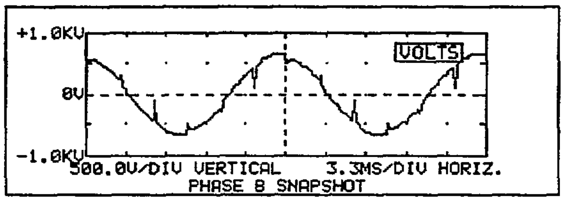
Load Grouping



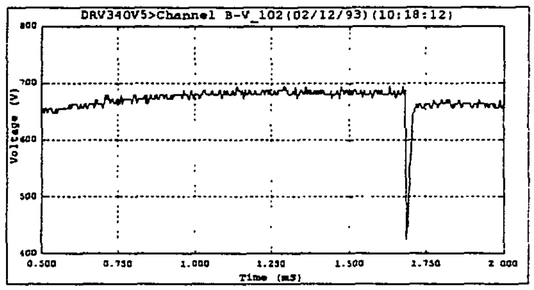
Voltage Notching

- Natural result of commutation in power electronic devices
- High frequency components
- Additional zero crossings cause timing problems

Voltage Notching Snapshot

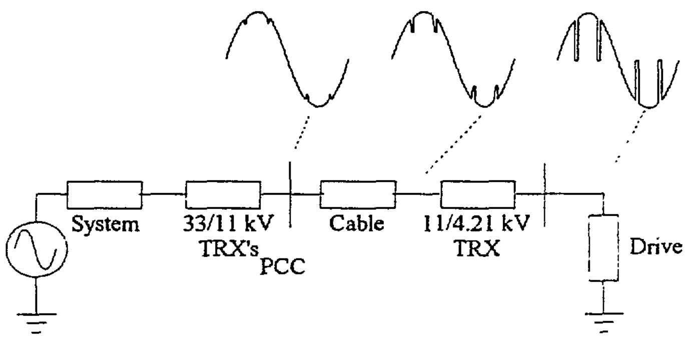


Expanded Waveform



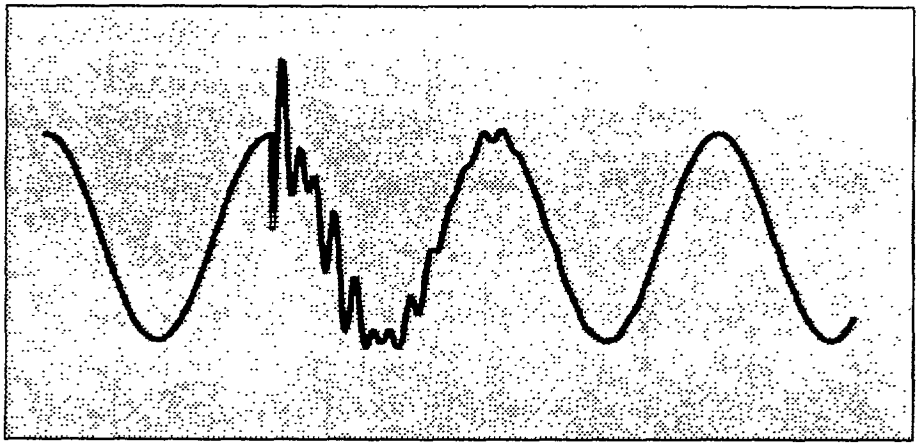
Line Notching

- The simplest solution to notching problems is the addition of a choke or isolation transformer on the input to the drive.

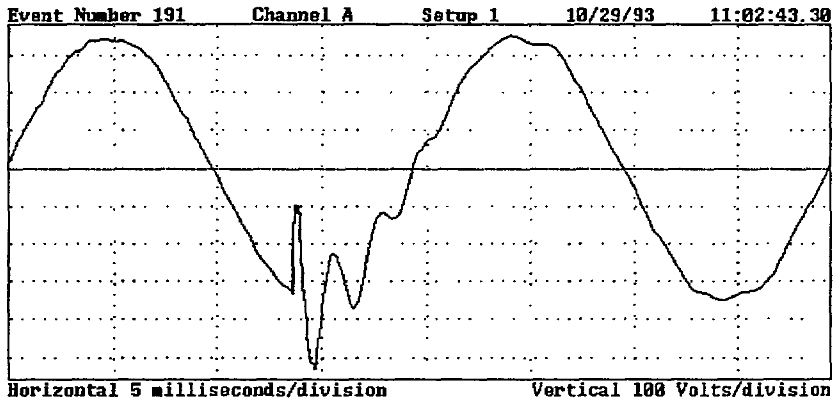


The Capacitor Switching Transient

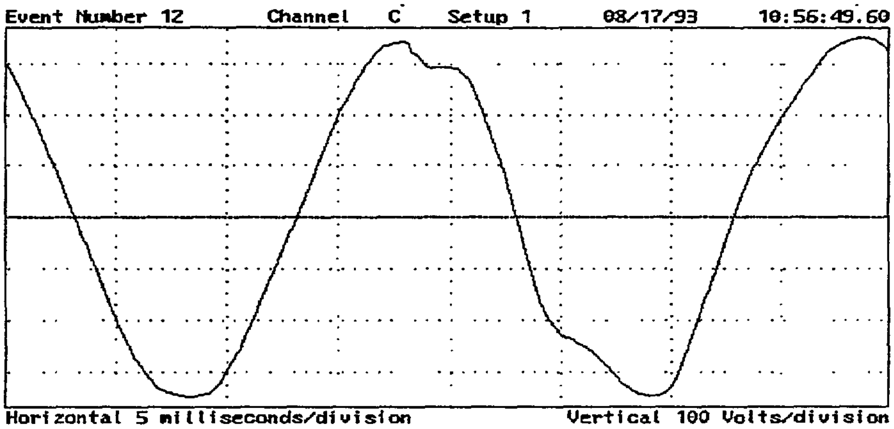
- Peak Magnitude
- Oscillation Frequency



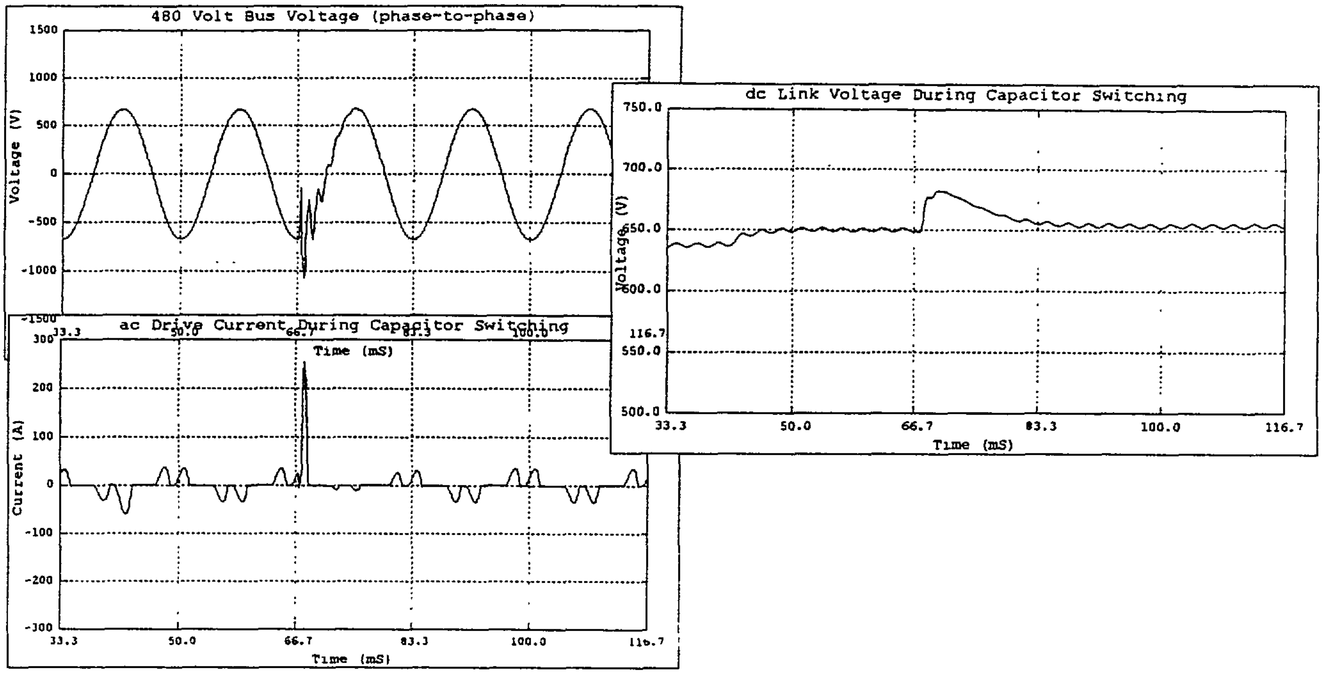
Nearby Capacitor Switching



Remote Capacitor Switching

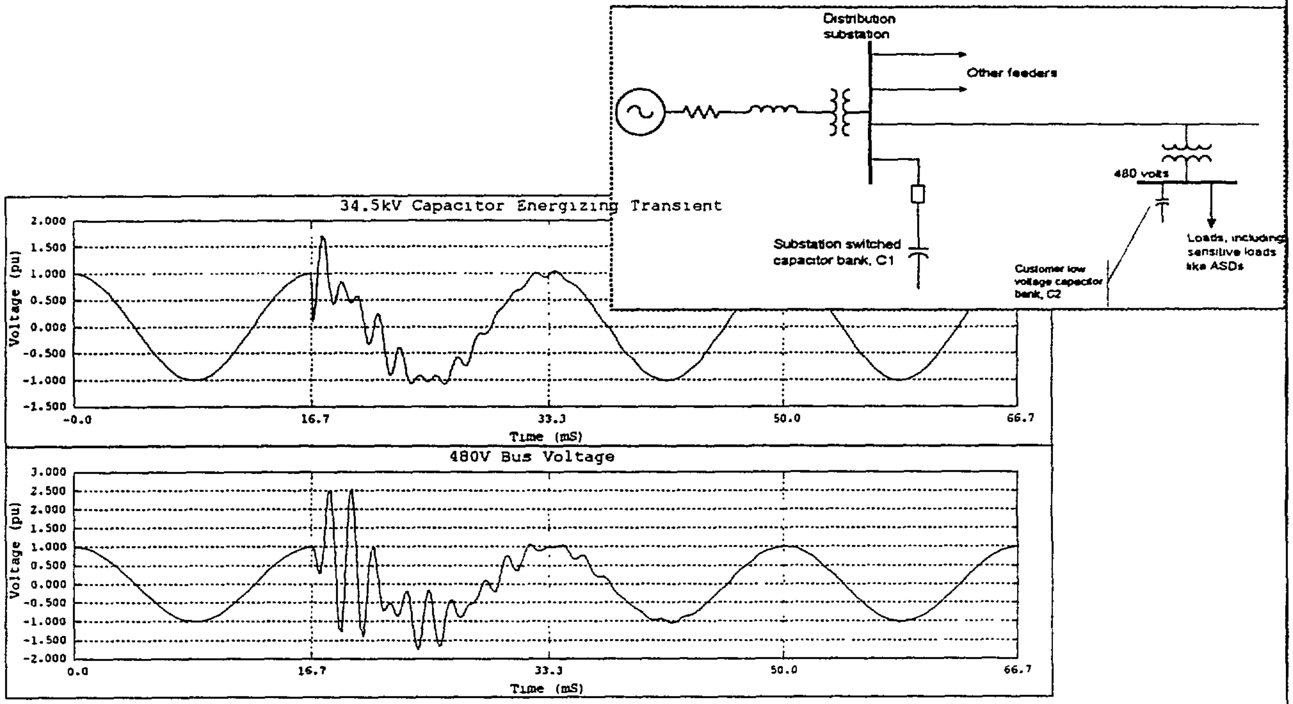


ASD Nuisance Tripping

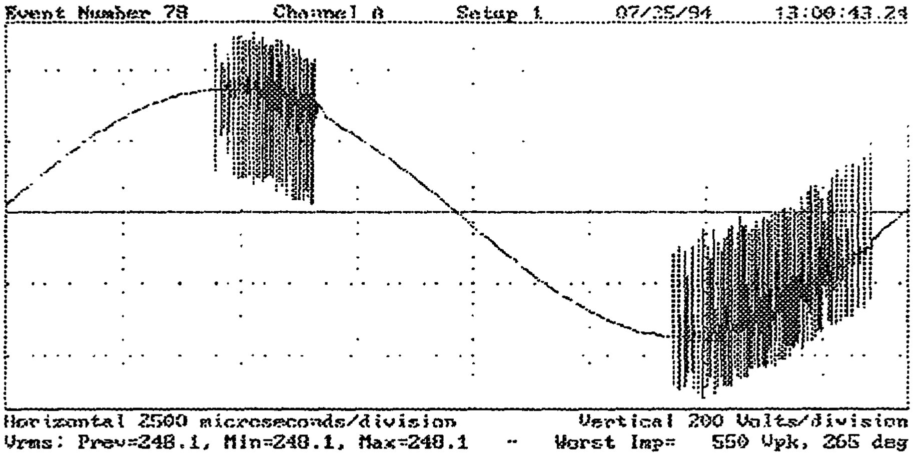


Electrotek Concepts, Inc.

Magnification at Lower Voltage Capacitors



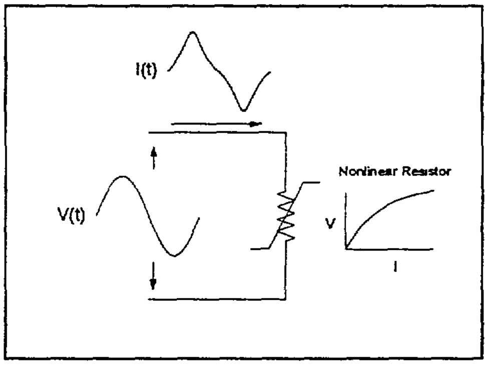
Transient Causing Failure in a Satellite TV Receiver



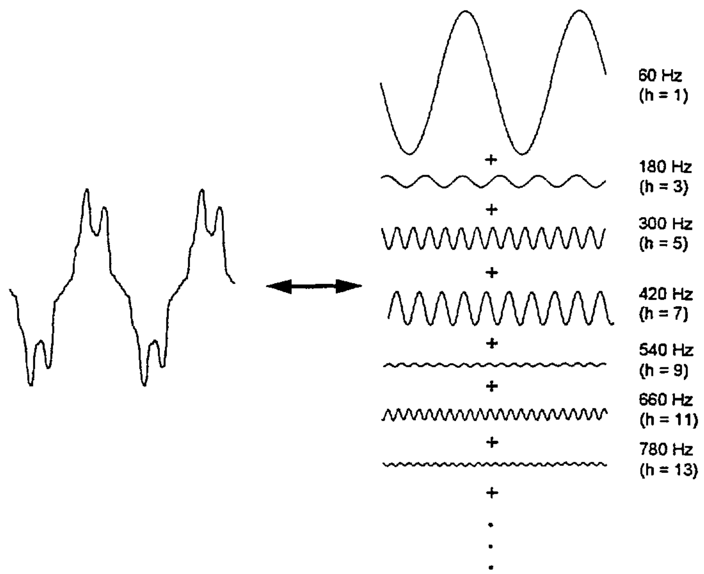
Harmonics

What Are Harmonics

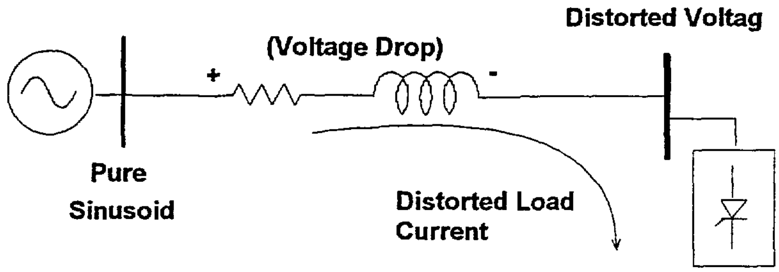
- Harmonics are due to *periodic* distortion of the voltage or current waveform
- The distortion comes from *nonlinear* devices, principally loads



Decomposition into Harmonic Components



Current vs. Voltage Harmonics

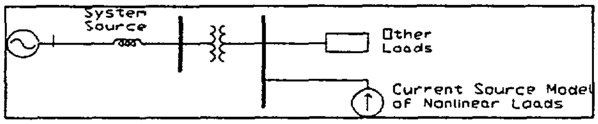


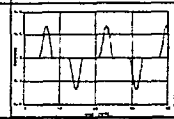
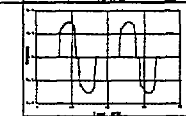
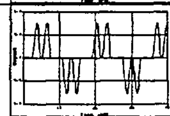
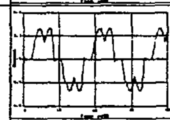
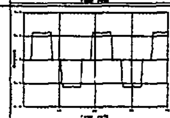
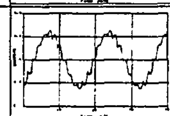
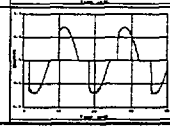
Harmonic currents flowing through the system impedance results in harmonic voltages at the load

Harmonics Vs. Transients

- Harmonics are Steady-State and persistent
  - Frequency components are multiples of a base frequency
- Transients are due to changes in state
  - Frequency components are natural frequencies of the system

Sources of Harmonics



Type of Load	Typical Waveform	Current Distortion	Weighting Factor (W_i)
Single Phase Power Supply		80% (high 3rd)	2.5
Semiconverter		high 2nd,3rd, 4th at partial loads	2.5
6 Pulse Converter, capacitive smoothing, no series inductance		80%	2.0
6 Pulse Converter, capacitive smoothing with series inductance > 3%, or dc drive		40%	1.0
6 Pulse Converter with large inductor for current smoothing		28%	0.8
12 Pulse Converter		15%	0.5
ac Voltage Regulator		varies with firing angle	0.7

Impact on Capacitors

- Higher harmonics: overcurrent
- High peak voltage
- Frequently first element to fail
- First place to look for harmonics problems

Note !

Impact on Motors

- Increased Heating due to distorted bus voltage
- Harmonic fluxes rotate at other than synchronous speed and induce extraneous currents while contributing little torque

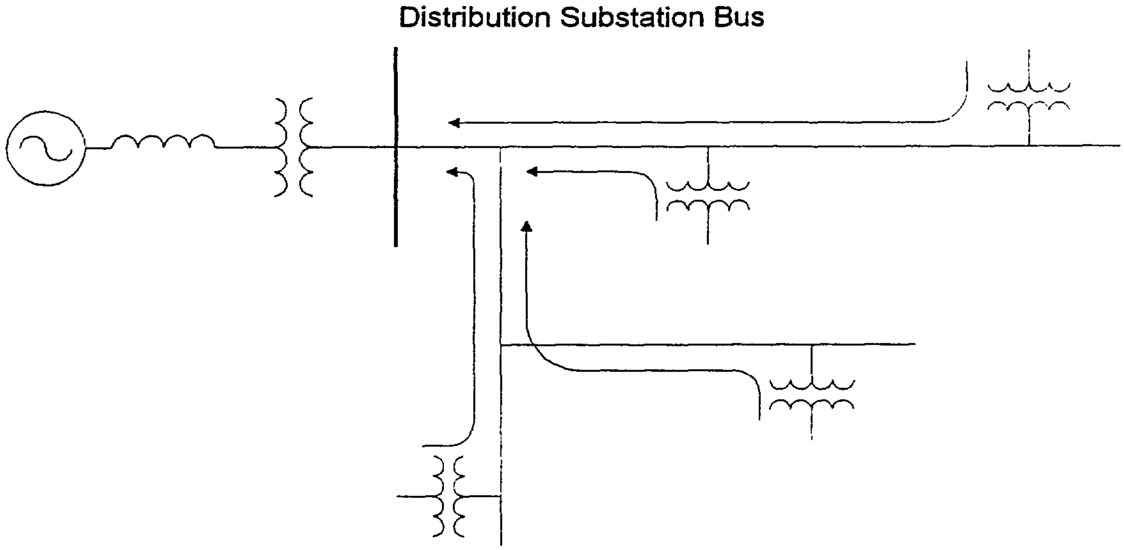
Impact on Transformers

- Distorted Voltage Increases Core Losses
- Load Current Increases Stray Eddy Losses
  - K-Factor designed to address this
- Zero-Sequence Fluxes

System Response to Harmonics

- As important as the size of harmonic sources
- Dictates the voltage distortion
- Resonance of system is a key problem

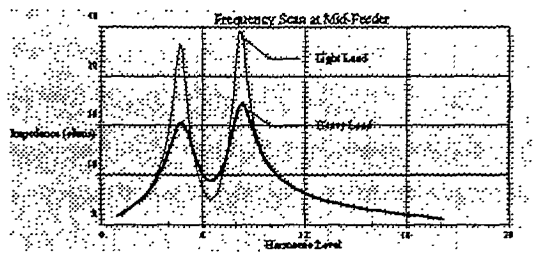
Where do harmonics go?



Electrotek Concepts, Inc.

What are the Problems?

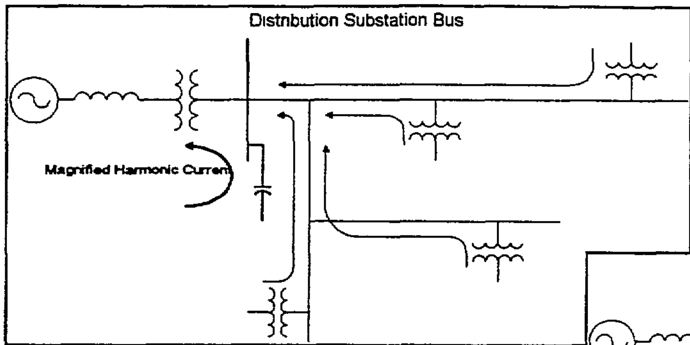
- Almost all harmonic problems relate to resonance conditions where harmonic levels are magnified by capacitor applications.
  - capacitor failures
  - fuse blowing
  - transformer overheating
  - electronic equipment malfunction
  - clocks running fast
  - motor heating



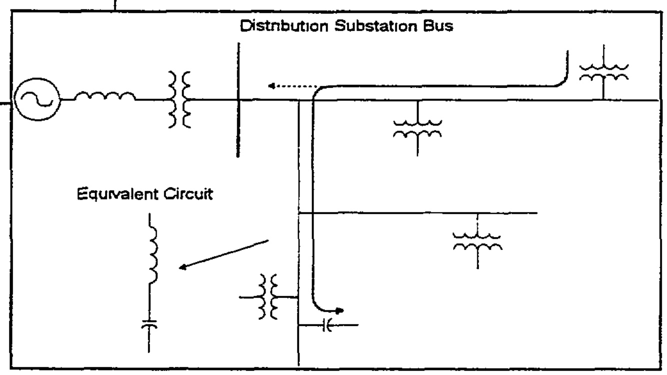
- There are also concerns for the penetration of single phase nonlinear loads causing harmonic losses and unacceptable voltage distortion.

Resonance Concerns

Parallel Resonance



Series Resonance



Principles for Controlling Harmonics

- Reduce harmonic distortion in load currents
- Filter the harmonics
- Modify the system frequency response

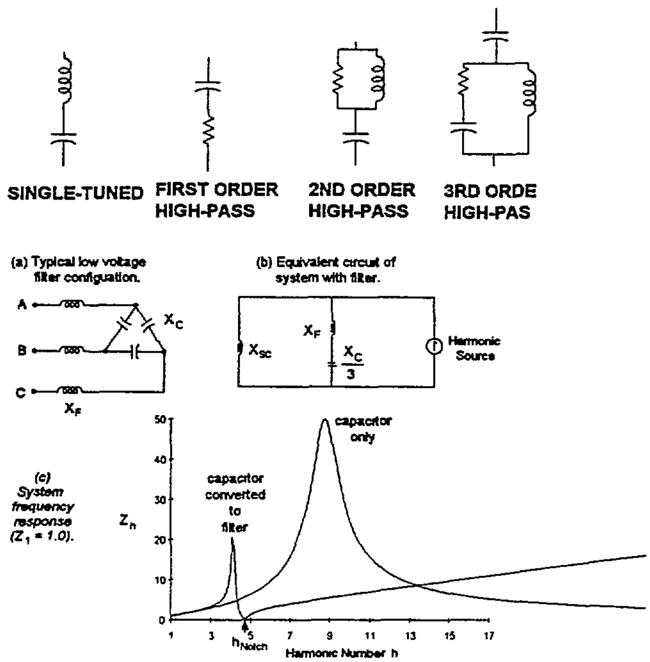
Reducing Currents in Loads

- Line Reactors
- Transformer connections
  - Mixed Y-Y, Y-Delta
  - Approximate 12-pulse loads
  - Zig-zag for triplens
- Purchasing specifications

Filtering

- Shunt Filter is most common
  - Corrects voltage as well as siphoning off current
- Blocking filter (Parallel)
  - Not commonly used
- Neutral Filters
- Active Filters

Shunt Filter Styles



Electric Utility Power Quality

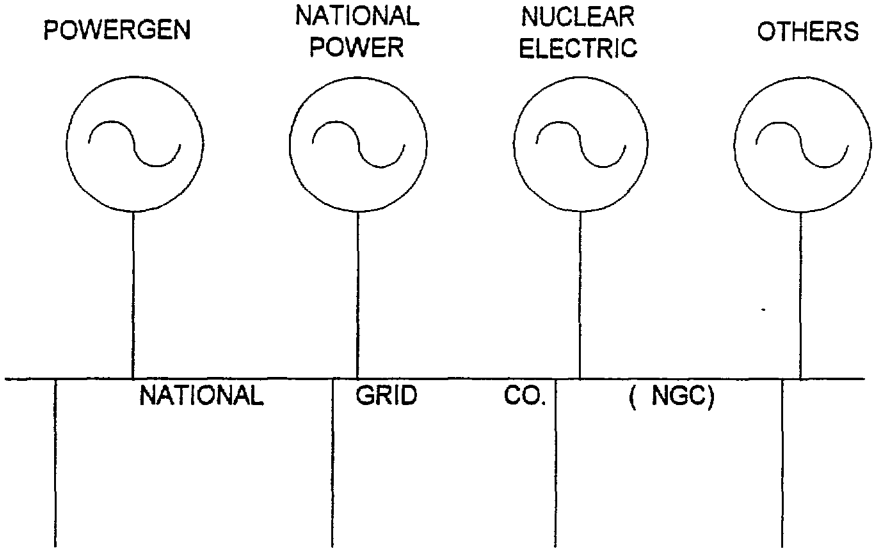
Trends in the Industry

- Industry Trends
- Deregulation
- Re-engineering
- Increasing End User Concerns
- Communications Technologies

United Kingdom (U.K.)

- Nationalised 1948
- Privatised 1990
- Merger activity

Structure of the UK privitisation



Twelve (12) Regional Electricity Companies

Competition Levels in the UK

FIRST TIER	1MW & ABOVE
SECOND TIER	200kW & ABOVE
THIRD TIER	ANY CUSTOMER

PQ in the UK

- Scottish Power - Some activity to help high-technology customers.
- East Midlands Electricity, plc. - Established "Power Quality Services" to market power quality
- Research that was done by the Electricity Association has been slowly devolved.

European Power Quality Efforts

- Leadership in Standardisation
- EDF - France largest utility with leadership in technical issues on power quality
- UK - Privatisation
- Monitoring projects in Spain, Norway, France, UK

Industry Trends - Europe

Electricity as a Product

Directive 85/374/EEC - July 25, 1985

- Article 1

  The producer shall be liable for damage caused by the defect in his product.

- Article 2

  The term "product" also refers to electricity.

Standardization of Electrical Voltage EN 50160

"Voltage Characteristics of Electricity Supplied by Public Distribution Systems"

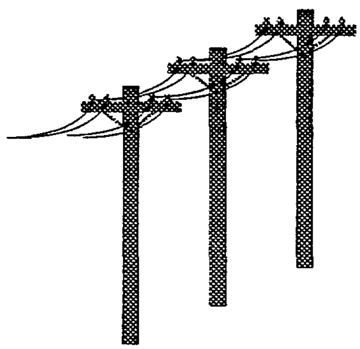
- Gives the main characteristics of the voltage that the customer's supply terminals in public low voltage and medium voltage electricity distribution systems under normal operating conditions.
- Describes the characteristics of
  - frequency (50Hz +/- 1% for 95% of the measurements)
  - magnitude (+/-10% of 10min average rms values for 95% of the measurements over one week)
  - waveform (Thd<8% of 10min mean rms values for one week)
  - symmetry of the three phase voltages (V2/V1<2%, but allows for up to 3% in some areas)
  - flicker (Plt=1 for 95% of the measurements, rapid changes less than 4% change)
- Allows for voltage dips and overvoltages

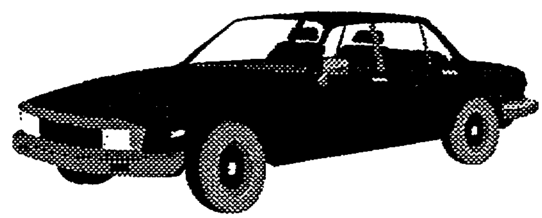
Premium Power

- In the U.S., "premium power" contracts are often sold.
- Premium power normally means "enhanced services."
- Some "power quality" parks are being considered, where special construction and energy storage techniques are be explore to supply power with a high reliability.

Service Guarantees

- Detroit Edison and General Motors Corporation



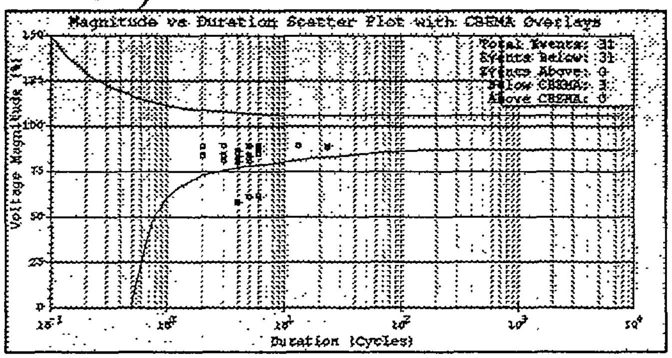


Definitions

- Utility
  - Voltage Sag
    - » Not defined
  - Outage
    - » Complete loss of ac power (voltage less than 10% of nominal) for 1 minute or more.
    - » Used past five years of outage data to obtain an average

"Customer" Outage

- Customer definition of an outage
  - Any rms variation outside of the computer business and equipment manufacturers association (CBEMA) curve (ANSI/IEEE Std. 446-1987).



Utility Payments to Customer

- Every outage over the Target Outage
  - Target: ½ an outage every year
  - after four years, one outage every four years
  - rolling twelve month period
- Payments will vary by facility
  - $2,000 - $326,000 per outage

Customer Concessions

- Customer will enter into a 10 year contract with utility
- Customer will shut down all co-generation
- Customer agrees that Detroit Edison will be sole supplier of electric service

EDF Emeraude Contract

- Concerns HV customers
- Explicit recognition of the joint responsibility of the supplier and user for the quality of electric power
- Sets disturbance limits that EDF undertakes not to exceed
- Interesting is that they use the second lowest voltage on unbalanced voltage sags!

Features of the Emeraude Contract

- Definition of operating conditions: the distributor cannot be held responsible for product quality because of circumstances that are unpredictable and beyond the distributor's control.
- Product definition: magnitude, frequency, harmonics, voltage flicker.
- Stipulation on good relations between the parties on the contract: the distributor must inform the customer about circumstances with the network; the customer must inform the distributor about new disturbing loads.
- Shared responsibilities: responsibilities are shared when a disturbance affecting the customer's installations causes loss. The extent to which the customer has exercised due care and attention can limit the liability of the distributor.
- Flexible contract: in the basic version of the contract, the distributor will meet the conditions specified in 90% of the cases already. Some customers will require special considerations.

Technical Details of the Emeraude Contract

- MV customer standard contract
  - 8 long (greater than 1 minute)
  - 30 short (from 1 second to 1 minute)
- MV customer personalized contracts
  - based on the previous history
- HV customer contracts
  - 3 long
  - 10 short

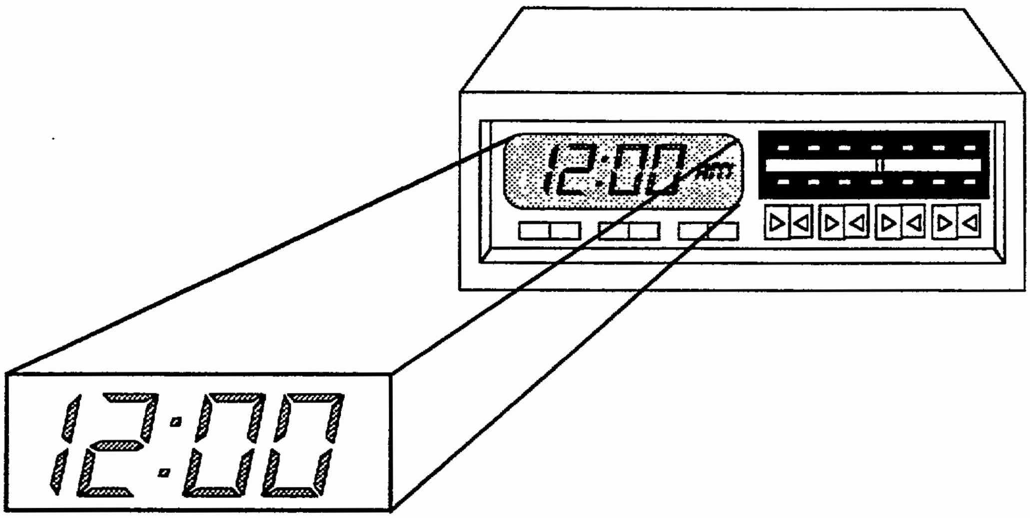
Implementation of the Emeraude Contract

- Test period with 10% of the customers
- Sales staff had trouble explaining voltage disturbances other than power cuts (harmonics, unbalance, etc.)
- 1 of 5 customers were installed with a quality of supply indicator developed by Landis & Gyr for EDF

Results of the Emeraude Contract

- A total compensation of 1 MF ($150,000) was awarded, all of it was to MV customers during the trial period (2 years).
- 2/3 customers were satisfied with the new arrangements.
- Some customers were satisfied with the existing quality, and were not interested in the new arrangements.
- Some customers wanted the company to assume more risk, and were disappointed that the proposed guarantees were higher than the existing number of power cuts.
- Customers wanted guarantees on voltage sags.

The Blinking Clock Problem



When Faults Occur

- Timely communications. In the U.S. we do not know of any instances where information given from the utility to the customer has resulted in legal problems, etc.
- Information regarding fault locating or other actions that could cause further disturbances.
- Assurance that the utility is meeting local standards for maintenance and reliability of supply.

Communications with Large Customers

- Key customer account manager
- Special telephone number for large customers to call
- Notification when special maintenance events are undertaken

Allocating System Capacity for Disturbing Loads

- "First come, first served" approach (G5/3)
- Absolute limits (IEEE-519)
- Billing for short circuit power

Billing for Short Circuit Power

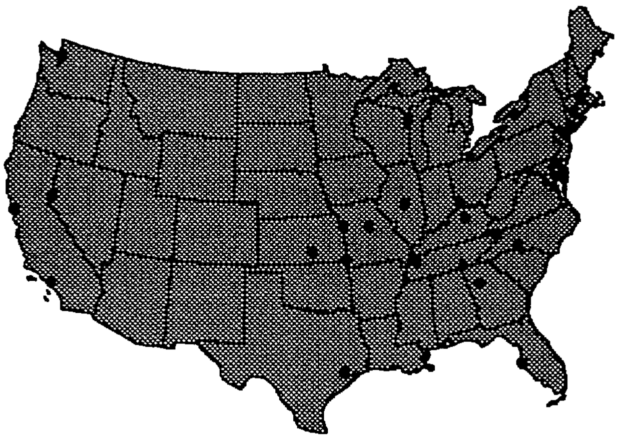
- NESA in Denmark (500,000 customers).
- Earlier methods were for the customer to pay for a particular fuse size, i.e. the highest expected demand current. But the customer also had to pay for system reinforcements if their emmissions led to poor power quality.
- Now customer pays for his emission of electrical noise into the distribution network by subscribing to a short circuit power.
- Analyze emmissions based upon a "reference network" which depends partly on the size of the service to the customer, and also on established limits.

Why Characterize Utility Power Quality?

- To compare against national averages
- To provide data to customers
- To monitor system protection performance
- To identify trends

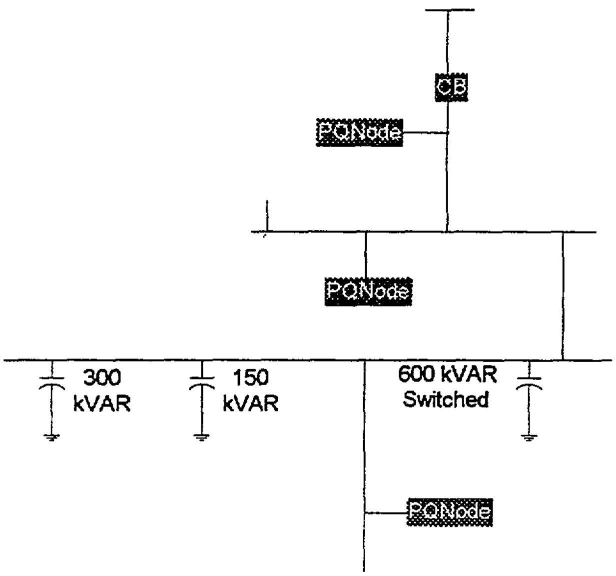
Utility Participants

Multi-phase, multi-year project involving 24 EPRI member utilities.



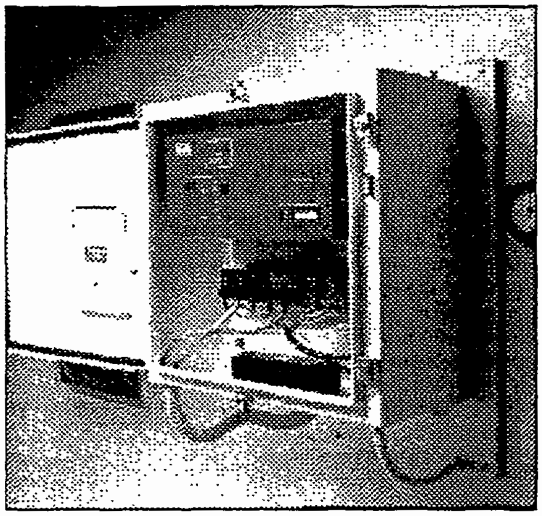
- Boone Electric Cooperative
- Chattanooga Power Board
- Cincinnati Gas & Electric Company
- Delmarva Power & Light Company
- Duke Power Company
- East Kentucky Power Cooperative
- Elizabethan Electric System
- Empire District Electric Company
- Florida Power Corporation
- Georgia Power Company
- Gibson County Electric Membership
- Houston Lighting & Power
- Illinois Power Company
- Kansas City Power & Light Company
- Long Island Lighting Company
- Los Angeles Department Of Water & Power
- Massachusetts Electric Company
- Northeast Utilities Service
- Pacific Gas & Electric Company
- Public Service Electric & Gas Company
- Rochester Gas & Electric Corporation
- Sierra Pacific Company
- Snohomish Public Utility District #1
- Western Resources

Power Quality Monitoring Instrument Locations



- 100 hundred feeders were selected for monitoring.
- Each of the 24 utilities has PQNodes installed on one to three feeders.
- Three monitors are installed on each feeder. One is at the substation and two others are randomly placed along the feeder.

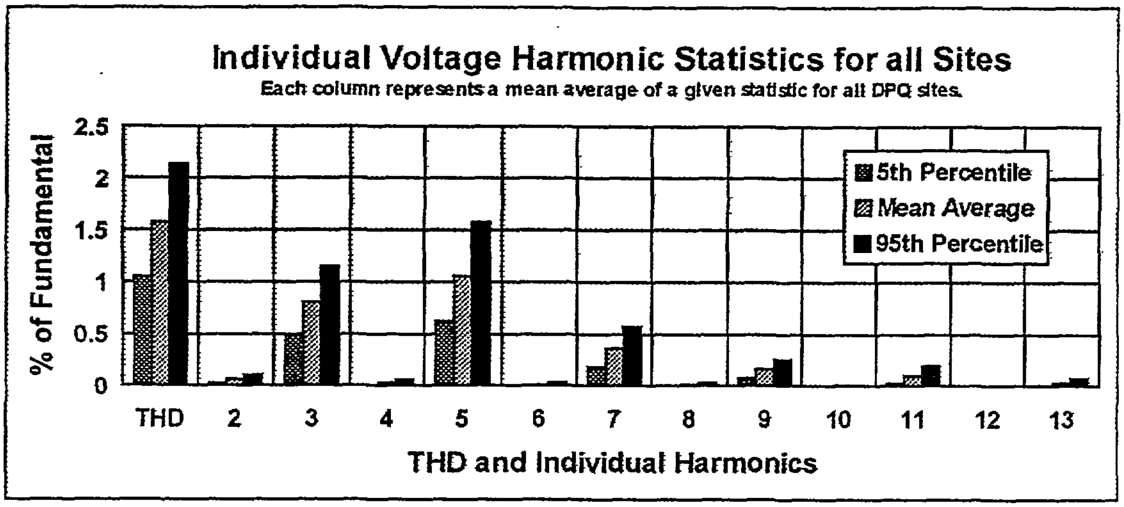
BMI PQNode 8010 Specifications



- Designed to meet the project's power quality measurement demands:
- Eight channel device
- Triggered by any phase voltage deviation
- 14 bit ADC, 256 points per cycle on voltage channels, 128 points per cycle on current channels, phase-locking
- 100th harmonic voltage, 50th harmonic current
- One to eight megabyte memory capacity
- Data retrieved via telephone
- PQNode functionality determined by modem-upgradeable firmware
- User defines thresholds and collects data via modem or serial cable

Individual Voltage Harmonic Statistics

- All EPRI DPQ Sites, 6/1/93 to 6/1/94
- 2,045,994 measurements from 222 sites



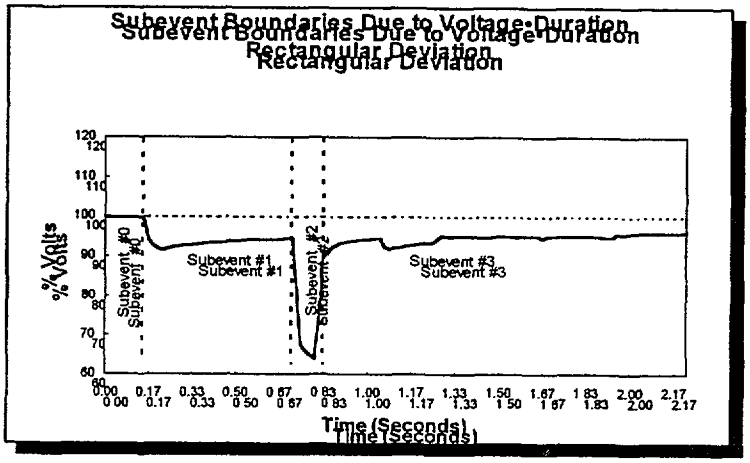
RMS Voltage Disturbances

IEEE Std. 1159 Definitions

Short Duration Variations	**Duration**	**Voltage Magnitude**
Instantaneous		
Sag	0.5 to 30 cycles	0.1 to 0.9 pu
Swell	0.5 to 30 cycles	1.1 to 1.8 pu
Momentary		
Interruption	0.5 cycles to 3 s	< 0.1 pu
Sag	30 cycles to 3 s	0.1 to 0.9 pu
Swell	30 cycles to 3 s	1.1 to 1.8 pu
Temporary		
Interruption	3 s to 1 min	< 0.1 pu
Sag	3 s to 1 min	0.1 to 0.9 pu
Swell	3 s to 1 min	1.1 to 1.8 pu
Long Duration Variations		
Sustained Interruption	> 1 min	0.0 pu
Undervoltage	> 1 min	0.8 to 0.9 per unit
Overvoltage	> 1 min	1.1 to 1.2 per unit

Measurement Subevents Based upon Rectangular Deviation

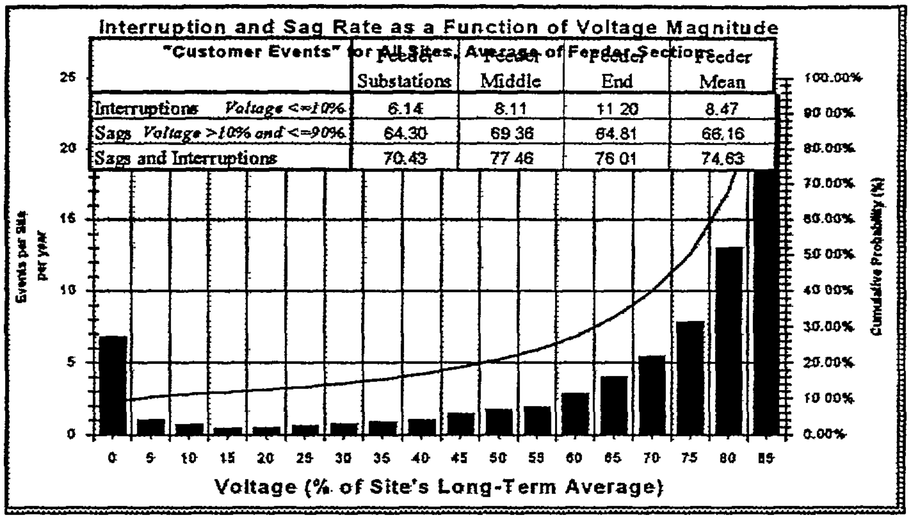
- The disturbance is broken into a series of rectangular components which each can be approximated by a single magnitude and duration pair reasonably well.



RMS Voltage Data
Interruption and Sag Rate

- Histogram uses the Aggregate Event data reduction method

All EPRI DPQ Sites, 6/1/93 to 6/1/94



Measurement Subevents Based upon Rectangular Deviation

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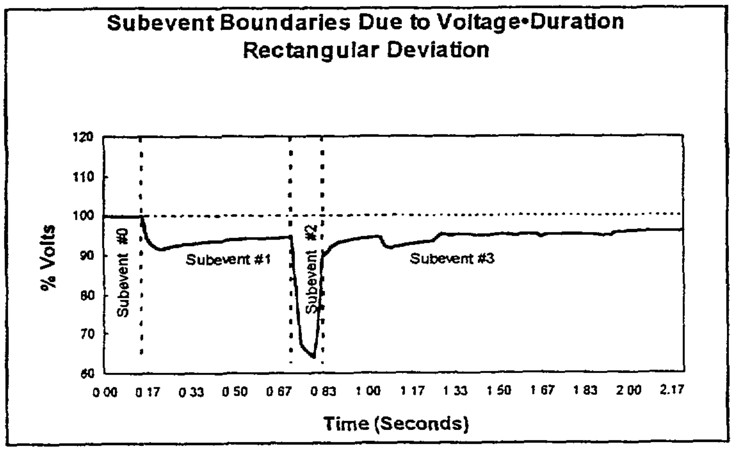
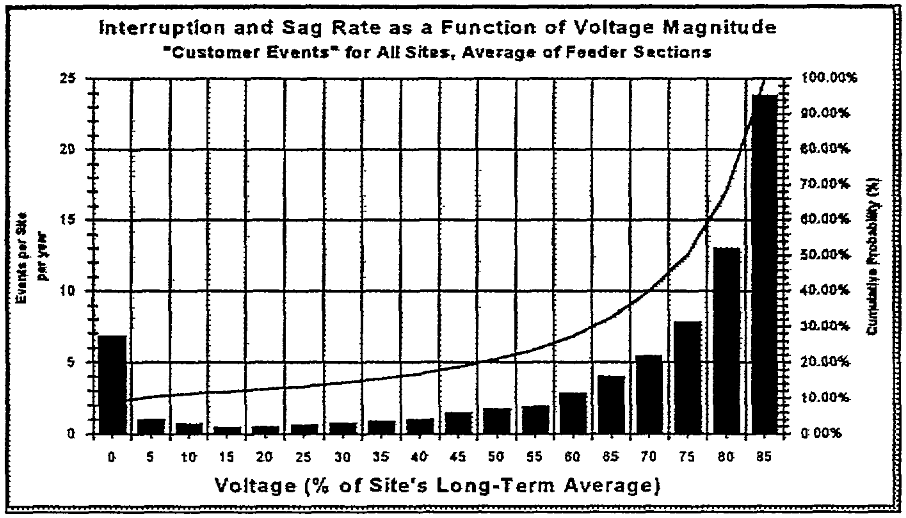


RMS Voltage Data
Interruption and Sag Rate

	Feeder Substations	Feeder Middle	Feeder End	Feeder Mean
Interruptions *Voltage <=10%*	6.14	8.11	11.20	8.47
Sags *Voltage >10% and <=90%*	64.30	69.36	64.81	66.16
Sags and Interruptions	70.43	77.46	76.01	74.63



All EPRI DPQ Sites, 6/1/93 to 6/1/94

Using the Internet to Provide Information to Customers

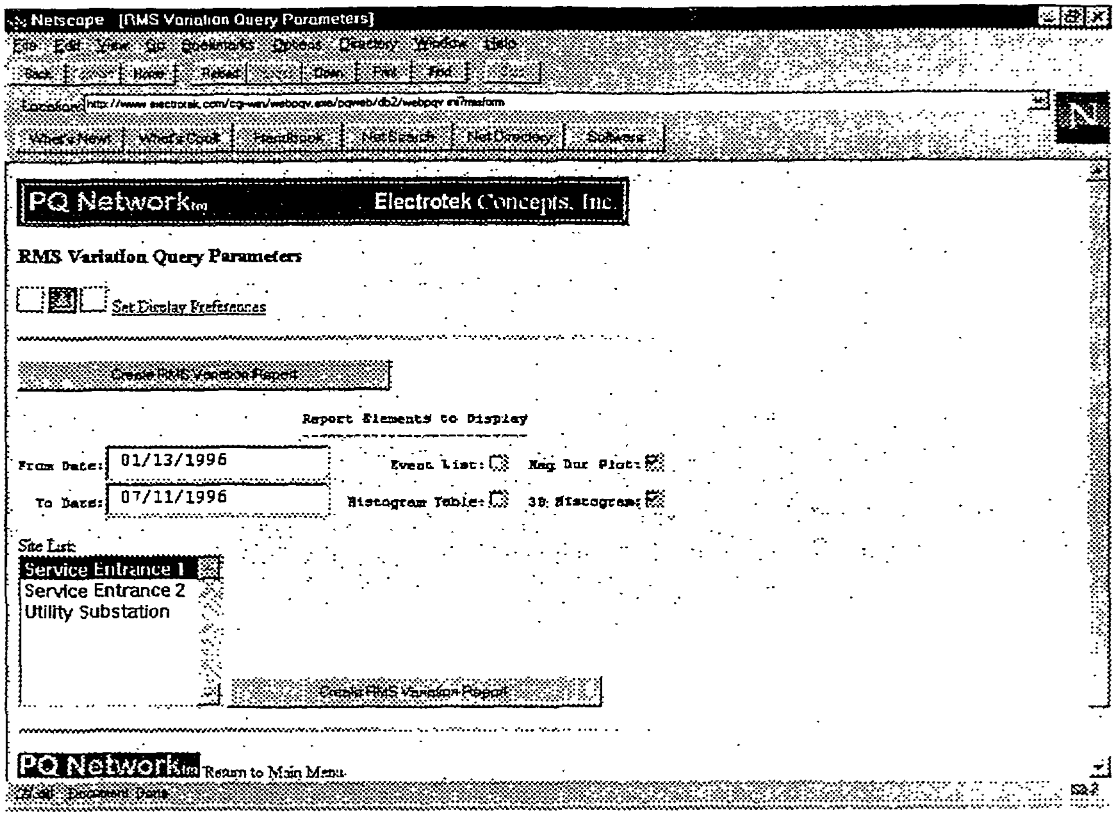
Monitoring at Specific Customer Sites

- "See what the customer sees" in terms of power quality
- Provide data to the customer so they can understand the sensitivity of their load equipment
- Use the Internet to provide information to the customer

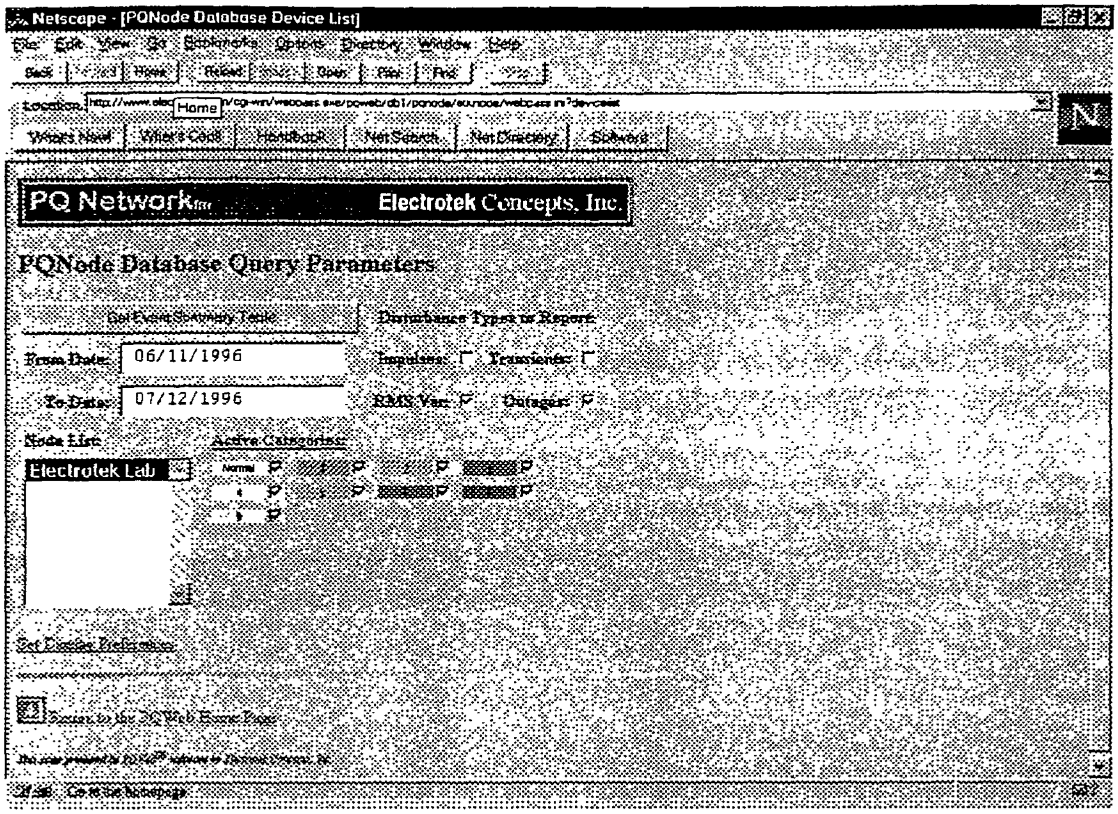
Why the World Wide Web?

- Does not require special software at the customer site.
- Password-protected access possible.
- Allows hyper-text linking to other sites, giving exposure of other activities to the customer

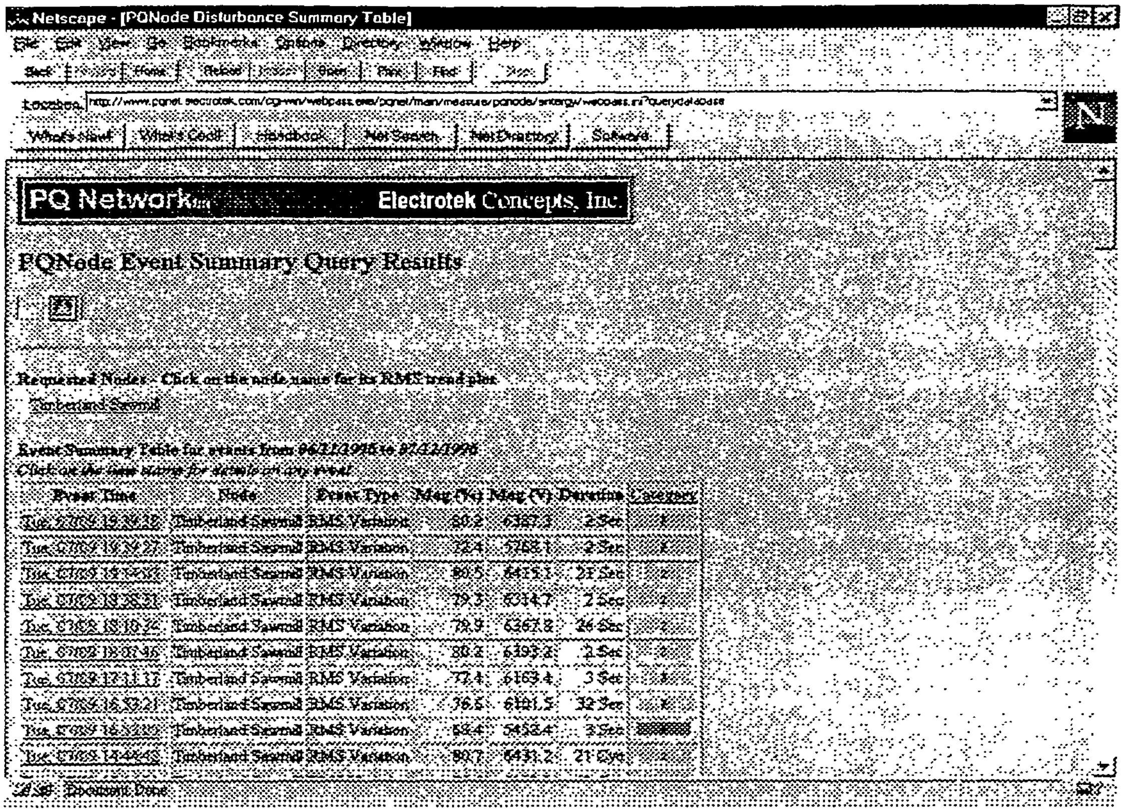
Select Site and Dates of Interest



Select Disturbances to View



View Disturbance List



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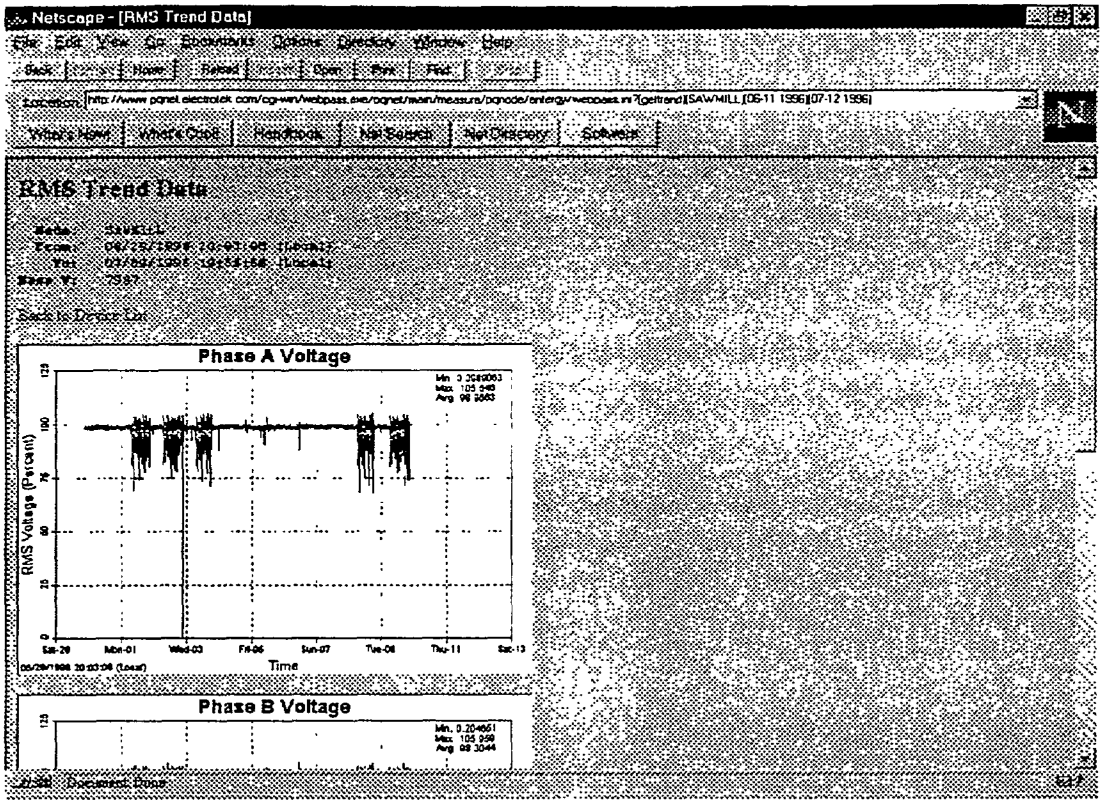
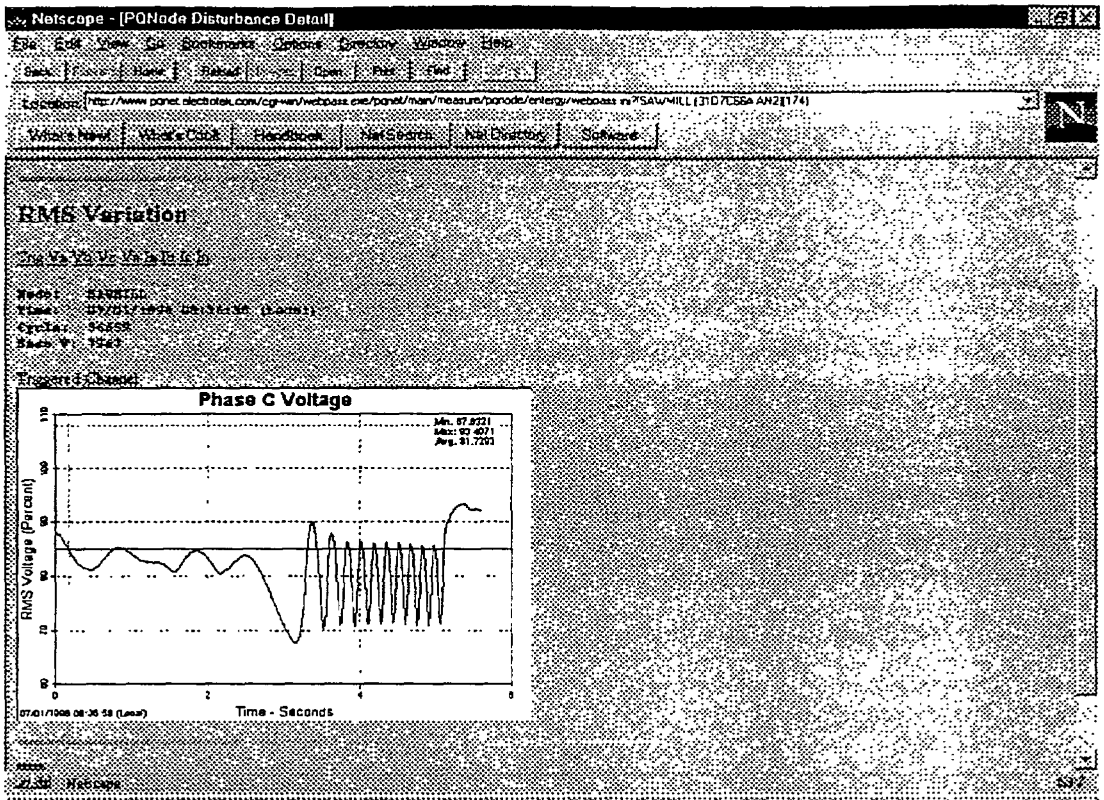
View Weekly Summary



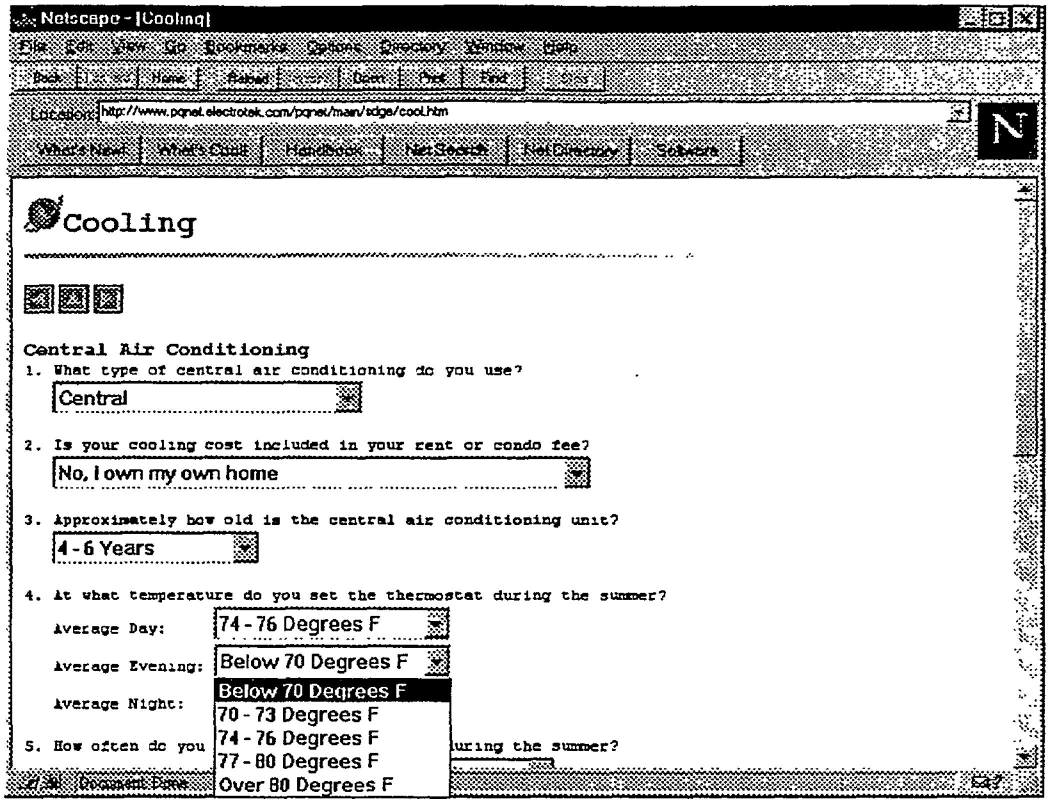
View Individual Event Details



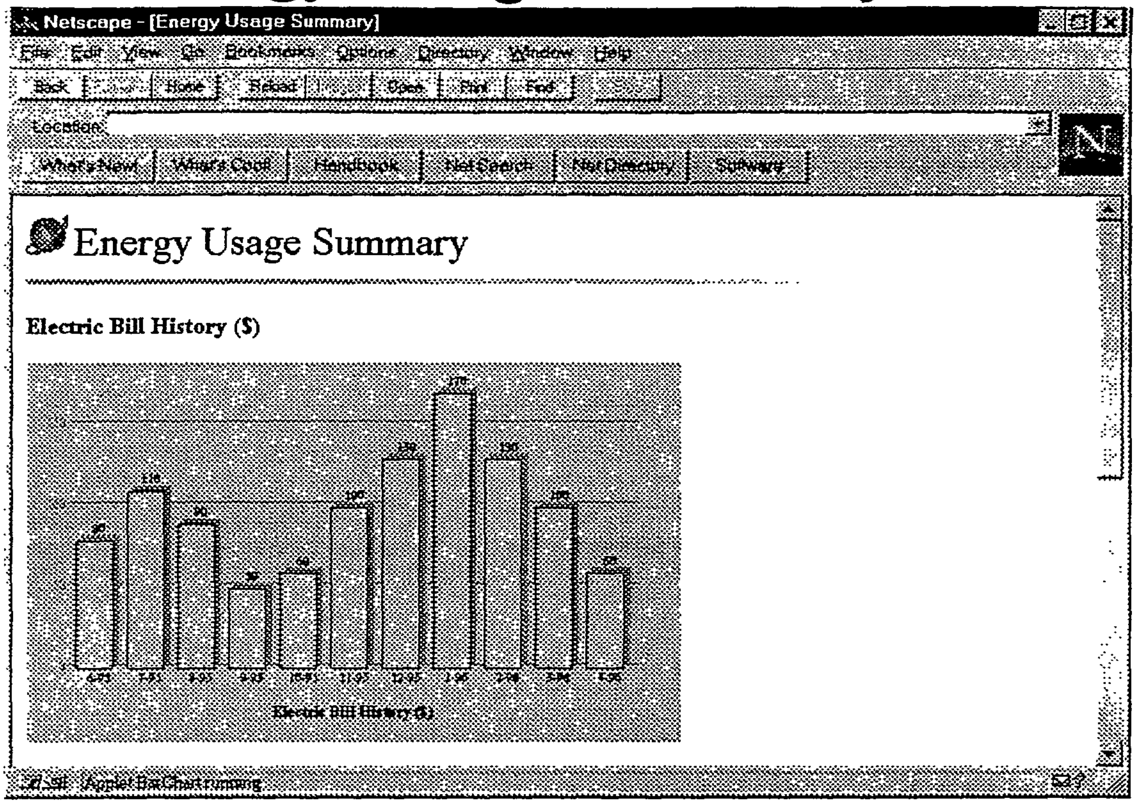
What About Energy?

- Energy usage, energy cost, and other load patterns are also of interest to customers
- The Internet also provides a convenient method for exchanging information with customers
- REBA^{tm} - residential energy bill analyzer - helps customers understand their energy use patterns.

Energy Survey Input Form



Energy Usage Summary Plot



Energy Audit Results

Netscape - [http://www.pqnet.electr...t/main/sdge/results.htm]

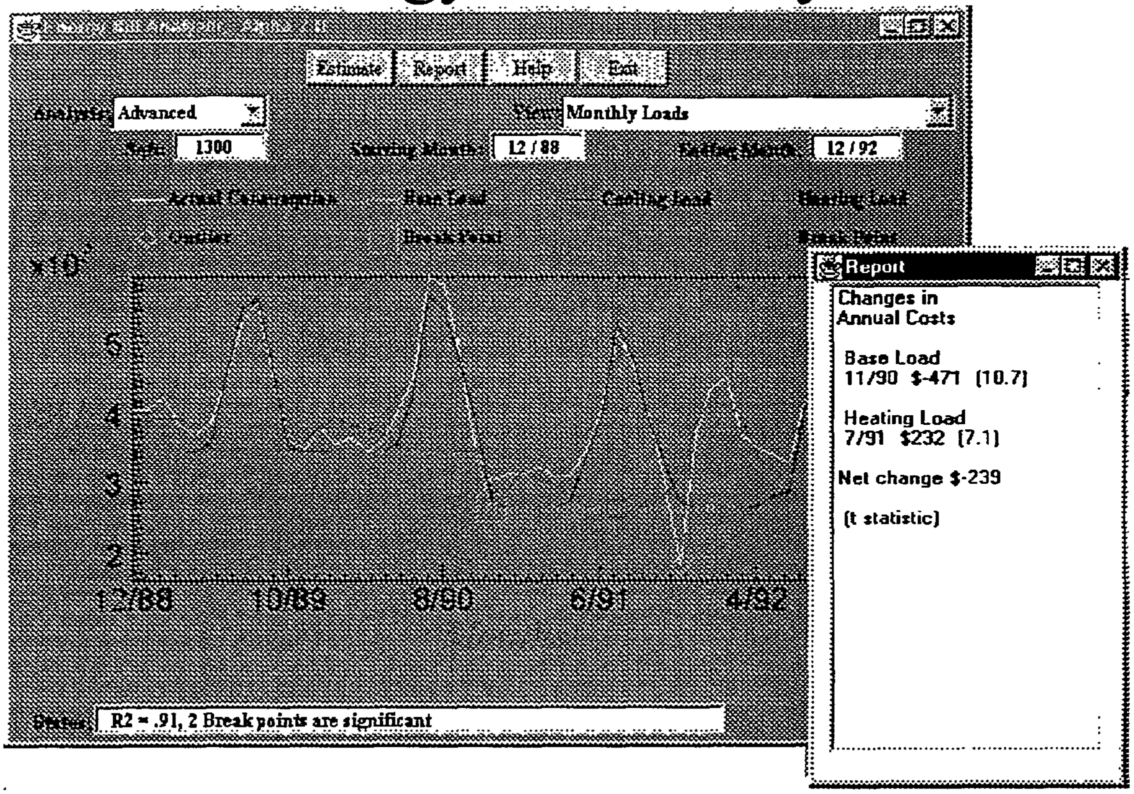
Energy Audit Results

Your Energy Cost Profile

For January 27, 1993 - January 26, 1994

Appliance	Electric	Natural Gas	Cost
Heating Fans/Pumps	0.20%	0.00%	$5.24
Supplemental Heating	0.20%	0.00%	$5.24
Microwave Oven	0.60%	0.00%	$15.73
Stereos	0.60%	0.00%	$15.73
Dishwashers	1.20%	0.00%	$31.47
Televisions	2.40%	0.00%	$62.94
Cooking	1.20%	1.20%	$62.94
Aquarium	2.60%	0.00%	$68.18
Laundry	1.00%	1.70%	$70.80
Freezers	3.70%	0.00%	$97.03
All Other Uses	5.80%	0.00%	$152.09
Spa or Hot Tub	1.00%	5.90%	$180.94
Air Conditioning	7.10%	0.00%	$186.18
Refrigerators	9.10%	0.00%	$238.63
Water Heating	1.00%	8.20%	$241.25
Lights	10.40%	0.00%	$272.72
Central Heating	0.00%	11.20%	$293.70
Swimming Pool Pumps	11.90%	0.00%	$312.06
Waterbed Heaters	12.00%	0.00%	$314.68

Energy Bill Analyzer



Conclusions

- New industry trends are increasing the need toward better relationships with customers.
- Utilities are providing improved reporting on energy use and power quality to customers.
- The World Wide Web (Internet) technologies allow new information to be exchanged with customers.

Visit the PQ Network!

Visit the PQ Network at

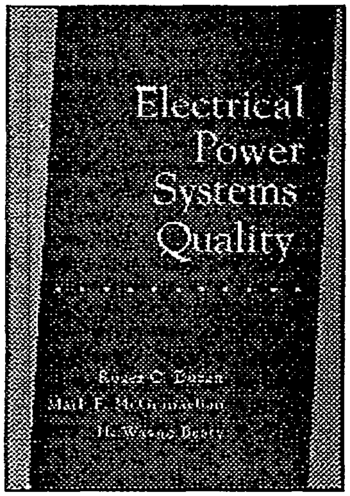
www.electrotek.com

References

Some Important References

- *Electrical Power Systems Quality*
  - Dugan, McGranaghan, Beaty
  - McGraw-Hill, 1996
- *Power Quality Workbook for Utility and Industrial Applications*
  - Electric Power Research Institute, BPA
  - Available through BPA (Barry Kennedy)
- *IEEE Gold Book* (New Chapter 9 for Voltage Sag Analysis)
- *IEEE Emerald Book* (Wiring and Grounding Issues)
- *IEEE Standard 519-1992* (Harmonics)

Electrical Power Systems Quality



Electrical Power Systems Quality
by Dugan, McGranaghan, Beaty

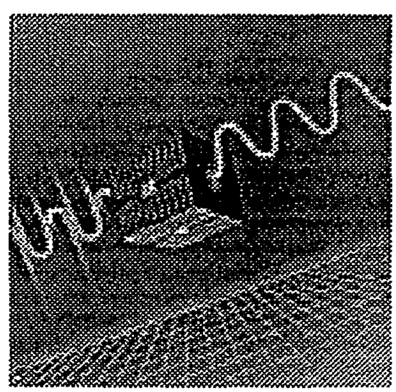
Hard ISBN 0-07-018031-8 1996
265p. 145 Illus. 6 x 9
$55.00

McGraw Hill Publishers
New York

High Efficiency Motors and Adjustable Speed Drives

David Mueller
Bill Roettger
Electrotek Concepts, Inc.
www.electrotek.com

June 1997



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US Agency for
International Development

High Efficiency Motors and Adjustable Speed Drives

AGENDA

- High Efficiency Motors
- Adjustable Speed Drive (ASD) Motor Applications
- Saving Money with ASD Motor Applications
- Types and Characteristics of ASD Motor Systems
- Installing Reliable ASD Motor Systems
- Power System Interfacing Considerations with Large ASD Motor Systems

High Efficiency Motors and Adjustable Speed Drives

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Energy Efficient Motors and Drive Systems

- High Efficiency Motors
- Adjustable Speed Drives

High Efficiency Motors

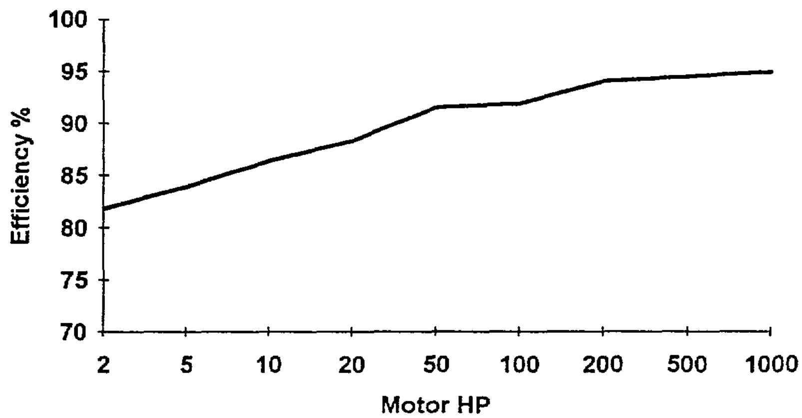
- Definitions and Typical Values
- Economics
- Motor Master Software
- Application Considerations
- Summary

Defining Motor Efficiency

$$\text{Efficiency} = \frac{\text{Power In} - \text{Losses}}{\text{Power In}} * 100\%$$

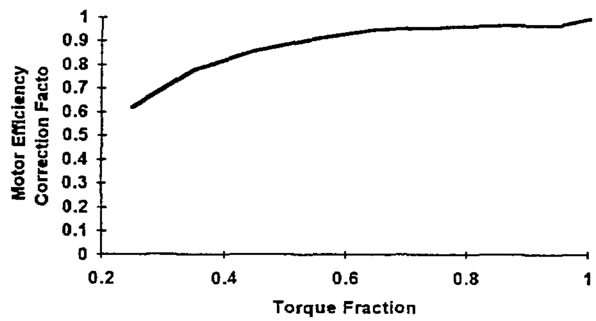
Typical Standard Motor Efficiencies

Efficiency at rated load and voltage

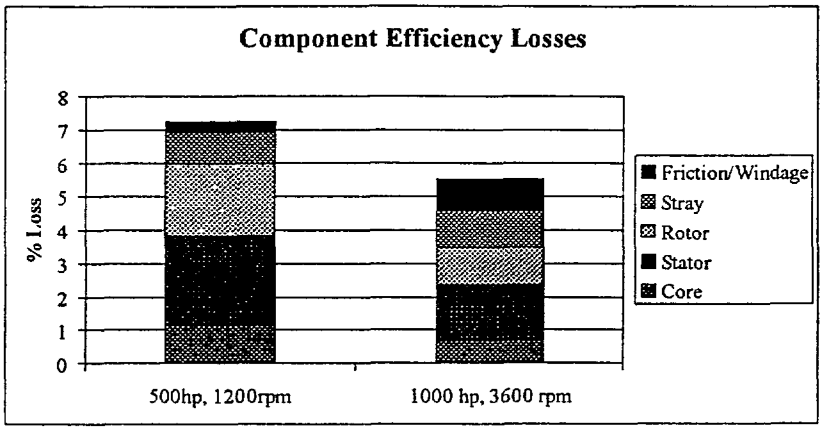


Factors that Affect Efficiency

- Mechanical Load
- Terminal Voltage (Magnitude and Balance)



Five Losses for Induction Motor



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Energy Efficient Motors - 7

Electrical Losses (I^2R)

Losses due to I^2R result in heat produced by the current flowing in the stator and rotor windings. These losses typically represent 40 - 60% of the total loss.

Stator Copper Losses
Typically 25 - 40% of the total loss
These may be reduced by modifying the slot design or reducing insulation thickness to allow for more copper

Rotor Copper Losses
Typically 15 - 25% of the total loss
These may be reduced by increasing the size of conducting bars and end rings

Magnetic Losses (Core)

This loss is due to the energy required to magnetize the core material. Typically 15 - 25% of the total loss.

By using silicon sheet steel and lengthening the core, the magnetic flux densities will be reduced.

Thin laminations provide magnetizing short circuits that reduce eddy current loss.

Mechanical Losses (Windage and Friction)

This loss results from bearing friction and air resistance from the cooling fan. Typically 5- 15% of the loss and independent of motor loading.

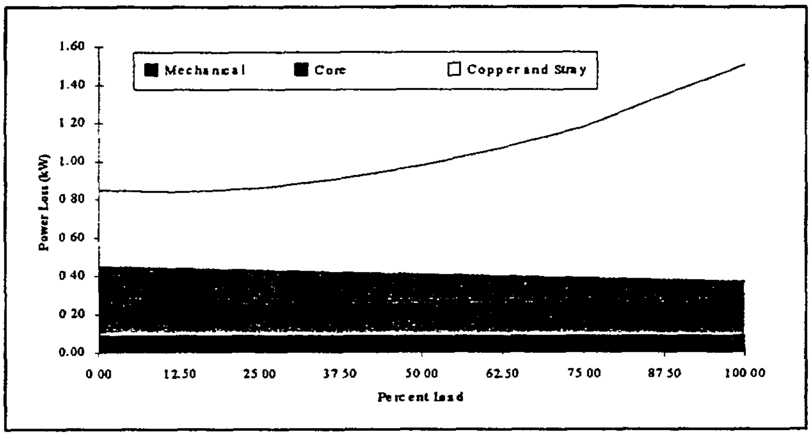
Proper lubrication practices can reduce bearing friction.

With improved insulation, cooling requirements may be reduced and a smaller fan may be employed.

Stray Losses (Leakage Flux)

The manufactures design impacts the magnitude of leakage flux. Typically 10 - 20% of the total loss and will increase with the size of the motor.

Variation of losses with load for a 10-hp motor:



Motor Efficiency Testing

Standard	Full-Load Efficiency (%) 7.5 hp	20 hp
Canadian (CSA C390)	80.30	86.90
United States (IEEE - 112, Test Method B)	80.30	86.90
International (IEC - 34.2)	82.30	89.40
British (BS - 269)	82.30	89.40
Japanese (JEC - 37)	85.00	90.40

Differences between standard and premium efficiency motors

- Higher quality and thinner steel laminations
- More copper in the windings
- Smaller air gap between rotor and stator
- Reduced fan losses
- Close machining tolerances

High Efficiency Motor Statistics

- 15% of induction motor sales are high efficiency (HE) motors.
- Price premium for HE motors = 15-20%
- Efficiency improvements about 2 - 3%

High Efficiency Motors

- Definitions and Typical Values
- **Economics**
- Motor Master Software
- Application Considerations
- Summary

Utility Rate Structure

- Basic Hookup Charge
  - Single Phase, Three Phase, Combination
- Energy Charges
  - Primary Metering Discount
- Demand Charges
  - On Peak, Off Peak
- Power Factor Penalty

Sample Rate Structure

- Basic Charge $4.55 for 1Phase, $19.00 for 3 phase
- Demand $5.35 per kW over 50kW
- Energy Charge

October - March	April - September	
5.2156	4.9672	cents per kWh for the first 20,000 kWh
4.1820	3.9829	cents per kWh for the next 155,000 kWh
2.9695	2.8281	cents per kWh for all over 175,000 kWh

Load Factor Calculation

- Average percentage of motor full load

$$P_{Ave\ 3\Phi} = \sqrt{3}V * I * DPF$$

$$\text{Load Factor} = \frac{P_{Ave}}{P_{Full\text{-}Load}} * 100\%$$

kW and kWh Savings

$$kW_{saved} = HP * \text{Load Factor} * 0.746 \left(\frac{100}{E_{std}} - \frac{100}{E_{HE}} \right)$$

$$kWh_{savings} = kW_{saved} * \text{Annual Operating Hours}$$

Annual Energy Savings

$$\text{Total Savings} = \left(kW_{Saved} \bullet 12 \bullet \text{Monthly Demand Charge}\right) + \left(kWh_{Savings} \bullet \text{Energy Charge}\right)$$

Economic Feasibility

- Simple Payback
- Life Cycle Costing Methodologies
  - Net Present Value
  - Benefit to Cost Ratio
  - Internal Rate of Return

Simple Payback

$$Payback_{New} = \frac{\text{Price Premium} - \text{Utility Rebate}}{\text{Total Annual Cost Savings}}$$

$$Payback_{Exchange} = \frac{\text{New Motor Cost} + \text{Installation} - \text{Utility Rebate}}{\text{Total Annual Cost Savings}}$$

Purchase and Running Costs I

- Market Price Comparison for Horizontal Motors (1800 RPM and 460 Volt)

	Open Dripproof			TEFC		
HP	STD EFF	PREM EFF	DIFFERENCE	STD EFF	PREM EFF	DIFFERENCE
10	$175	$221	$46	$239	$337	$98
50	$574	$702	$128	$948	$1,248	$300
100	$1,184	$1,437	$253	$2,211	$2,804	$593

Purchase and Running Costs II

10-HP Open Frame Motor:

- \$46 Premium for purchasing High Efficiency
- C = \$0.08/kWh
- N = 4000 hours (two shifts, five days per week)
- $E_a = 86.5$
- $E_b = 91.0$
- S = \$136/year

$$\text{PAYBACK} = \frac{\$46}{\$136 / \text{YR}} = 0.33 \text{ YEARS}$$

High Efficiency Motors

- Definitions and Typical Values
- Economics
- **Motor Master Software**
- Application Considerations
- Summary

Motor Master + Software - Overview

- An Energy Efficient Motor Selection and Energy Management Tool
  - Rewind or Replace
  - Calculates Energy Savings & Payback Period
  - 13,800 motors in database (IEC motors to be added).
  - Almost free (US Department of Energy)
  - http://www.motor.doe.gov

Electrotek Concepts Inc — Energy Efficient Motors - 23

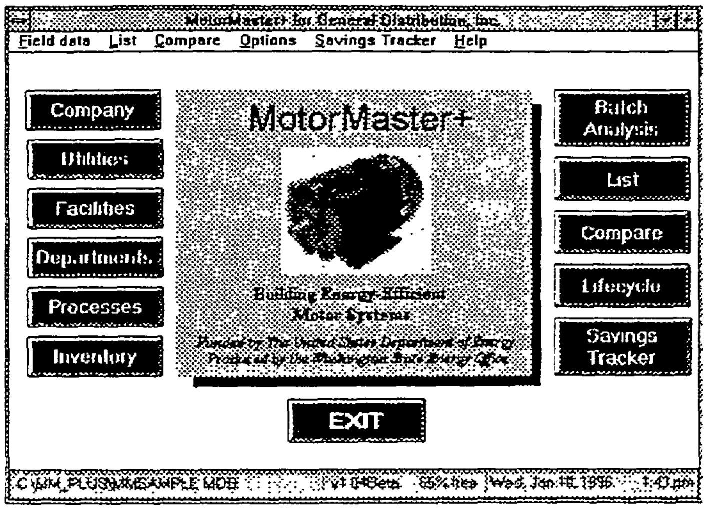
Database 1 - 600 hp, 900- 3600 rpm, 200 V - 4160 V

To guarantee consistency, efficiency measurements are taken in accordance with the Institute of Electronic and Electrical Engineers (IEEE) 112 Test Method B protocol

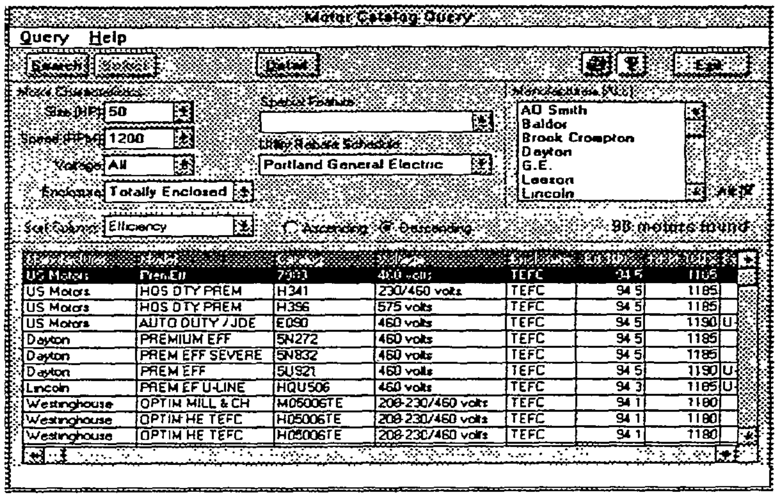
With MotorMaster, motor efficiencies, purchase prices, and other performance characteristics can readily be compared. The software also contains analysis features that determine annual energy demand and dollar savings, and the simple payback on investment from using a particular energy efficient motor in a new purchase or retrofit application. Load factor, motor efficiency under load, purchase price, energy cost, hours of operation, and utility rebates are taken into account. In this way, MotorMaster simplifies the selection of the best available energy-efficient motor for a given application.

MotorMaster+ not only facilitates the selection of energy-efficient motors, but also can assist Energy Coordinators at medium-sized and large industrial facilities to implement an effective energy management program

Motor Master + Software - Main Screen

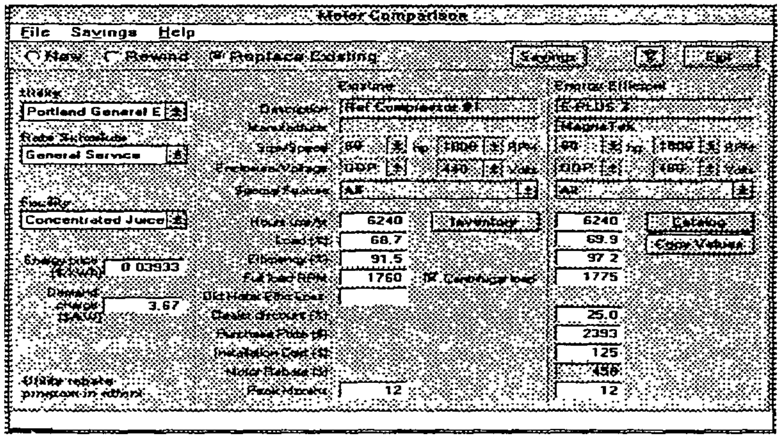


Motor Master + Software List



This feature displays a list of all motors meeting the specifications input by the user. Type of enclosure, horsepower, motor speed, voltage, and any special features are provided, and performance and purchase data, including the manufacturer and model, list price, and full-load efficiency rating and operating speed, are displayed (see Screen 2). The user can scroll up and down the list of motors, and can view supplemental information such as part-load efficiency and power factor for any motor by "double-clicking" on it. Included in the resulting list are utility rebate qualification criteria, and entries reading "NEMA 12-10" and "NEMA 12-11" (see Screen 3). Motors listed above those lines are eligible for a utility rebate or meet that standard for energy efficiency.

Motor Master + Software Compare



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Energy Efficient Motors - 26

It is used to compare two motors for a particular application in terms of annual energy consumption and energy costs. It indicates the costs of acquiring and operating an energy-efficient motor with those of a standard model. It also predicts potential energy and cost savings for energy-efficient models, and calculates the simple payback period from energy-cost savings assuming that the energy-efficient motor is more expensive to purchase.

There are three options within the Compare module:

- Replace Working Motors: The costs of operating an existing motor can be compared to the full cost of purchasing and installing a new motor. This evaluation can be used to decide whether an older rewound, low-efficiency, or oversized and under-loaded motor should be replaced.

- New Motor Purchase: The costs of acquiring and operating a new standard motor can be compared with those of an energy-efficient model, taking into account potential energy and cost savings. The incremental cost or price premium associated with the energy efficient product and any available utility rebate are taken into account when determining the simple payback period.

- Rewind versus New: The cost-effectiveness of rewinding a failed motor can be compared to the cost of purchasing a new standard or energy-efficient motor. This comparison considers the efficiency reduction of the rewound motor due to age and rewind losses.

Motor Master + Software
Life Cycle Analysis

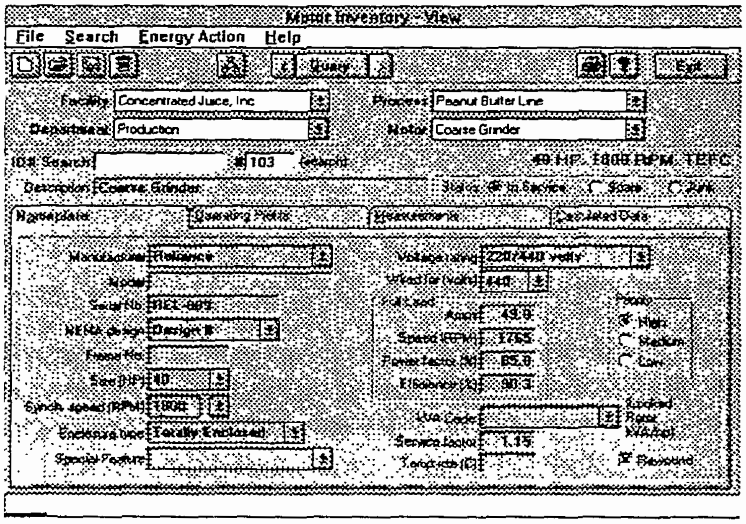
- Considers all costs of owning and operating
  - Time value of money
  - Cash Flows (Before and After Taxes)
  - Rate of Return on Investment
  - Net Present Value
  - Benefit / Cost Ratio

Electrotek Concepts Inc — Energy Efficient Motors - 27

MotorMaster+ also contains Life cycle Cost Analysis (LCCA) capability. LCCA is an economic decision making tool for selecting between alternative motors or motor driven systems which are intended to serve the same purpose. The LCCA considers all costs related to the owning and operation of a motor driven system and adjusts for the time value of money over the designated study horizon.

The LCCA outputs include before and after-tax cash flows, after tax rate of return on investment, net present value, benefit-to-cost ratio, and levelized cost of the energy conserved.

Motor Master + Software
Field Data Module



Electrotek Concepts Inc Energy Efficient Motors - 28

In order to help develop a motor improvement plan or establish an energy management program, *MotorMaster+* provides a motor nameplate and field data storage repository. This module may be used to store and manage important information, as well as to locate motors that are overloaded or operate under suboptimal power supply conditions, such as over- or under-voltage or voltage unbalance. Inputs to the inventory include motor nameplate information, identification, process and location codes; load type, operating hours and working environment descriptions; and measured data such as voltage, amperage, power factor, and speed at the load point.

Motor Master + Software
Batch mode operation

- Analyze all motors at the same time
  - Identify any motors that beat a specified payback period.
  - Energy and dollar savings summarized for all motors that meet criteria.

This feature makes it possible to analyze all the motors at an industrial plant at the same time. Energy, demand, dollar savings, and rebate entitlements can be summarized for all motors which beat a specified simple payback period. This option allows plant personnel to examine the cost-effectiveness of a group change-out to energy-efficient motors, or to determine which motors should be replaced by energy-efficient models when they fail.

High Efficiency Motors

- Definitions and Typical Values
- Economics
- Motor Master Software
- **Application Considerations**
- Summary

U-Frame and T-Frame motors

- Can an energy efficient motor replace my present U or T frame motor
  - YES
  - T - T straight replacement
  - Adapter for U - T
  - Some manufacturers are making Energy Efficient U frame motors

T frame EE motors generally use the same frame castings as a standard motor so T - T should be a straight replacement. An adapter or transition base is required for U - T. Some manufacturers are now making EE U frame motors.

NEMA Design E motors

- 1994 - MG1 Specification issued
  - Minimum efficiency Table 12-11 (Efficiency Requirements > Table 12-101)
  - Meets IEC standards
  - Allowed to have higher locked rotor current and "inrush current" (first 10 milliseconds)
  - Final slip is likely to be lower

460 Vs 230 volt operation

- I^2 R loss represent about 50% of all motor losses
  - I^2 are reduced to 25%
  - Higher voltage is better for both motor and distribution losses
- Relationship doesn't hold at higher voltages (2160 or 4000) since more insulation thickness is required.

Rewind and Efficiency - I

- Oven stripping can cause an increase in motor iron and core loss.
  - Lamination damage for type C3 and C5 coreplate- increased eddy current
  - Iron oxide lamination insulation not damaged
  - Water jet stripping does not damage core

Rewind and Efficiency - II

- Core Loss as a Percentage of all Motors Rewound

% Increase in Core Loss	5 - 20 hp	25 -60 hp	75 - 200 hp
0 - 9	36	39	21
10 - 50	47	48	58
51 - 100	9	4	11
101 - 400	8	9	10

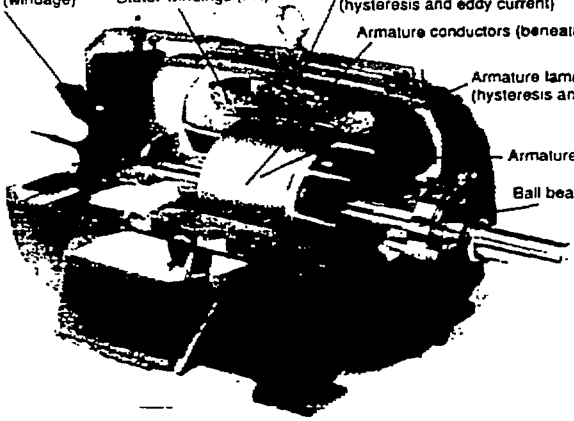
Rewind and Efficiency - III

- High efficiency rewinds where motor efficiency is actually improved are possible
  - Where larger diameter wire can be fitted into the winding slots.
  - Efficiency may improve by 0.5 - 1.0 %

Dirt and Grime Effects

- Efficiency drops due to reduced cooling
  - A 0.5 % drop for 50hp motor (Trise = 20degC)
  - decreased insulation life (Contamination and Thermal)

Summary and Questions



Adjustable Speed Drives

Adjustable Speed Drives (ASD)

- ASD Applications
- Saving Money with ASD
- Types and Characteristics of ASDs
- Installing Reliable ASD Systems
- Power System Interfacing Considerations

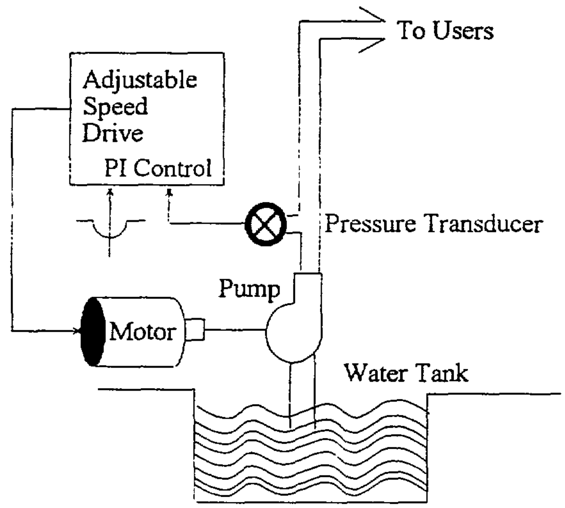
Reasons Why ASDs are used

- Energy Efficiency
- Process Optimization (Improve Productivity)
- Improved End User Comfort
- Environmental Benefits
- Soft Start Features (decrease electrical stresses, motor starting voltage sags)

Applications Where ASDs are Used

- Primary Applications
  - Fans
  - Blowers
  - Pumps
  - Conveyors
- Other Applications
  - Compressors
  - Extruders
  - Hoists
  - Machine Tools

Example - Pumping Application



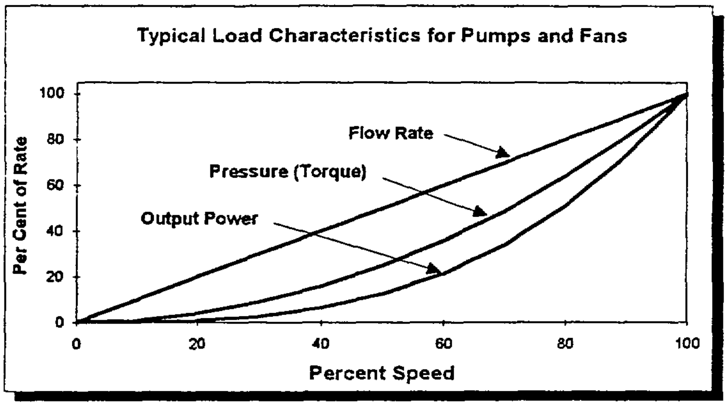
Adjustable Speed Drives (ASD)

- ASD Applications
- **Saving Money with ASD**
- Types and Characteristics of ASDs
- Installing Reliable ASD Systems
- Power System Interfacing Considerations

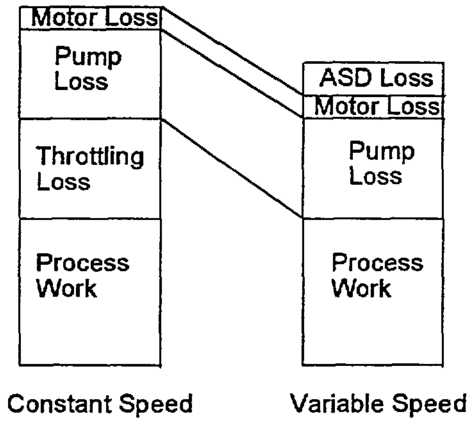
Affinity Laws - I

- Pumps, Fans, and Blowers
  - Flow rate varies proportionally with the driven equipment speed
  - Pressure and torque vary proportionally with the square of the flow rate
  - The motor shaft output (neglecting motor and ASD losses) varies proportionally with the cube of the flow rate

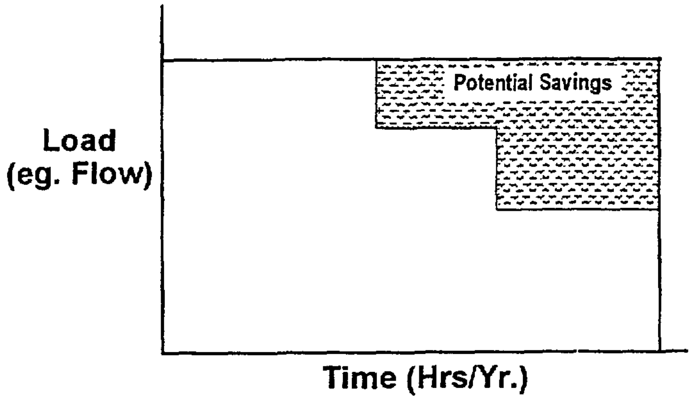
Affinity Laws - II



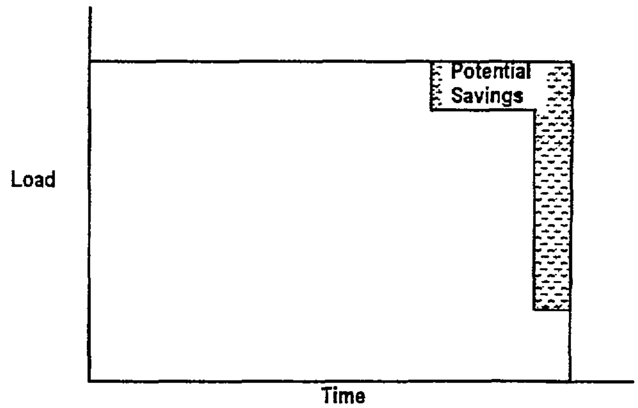
System Energy Requirements



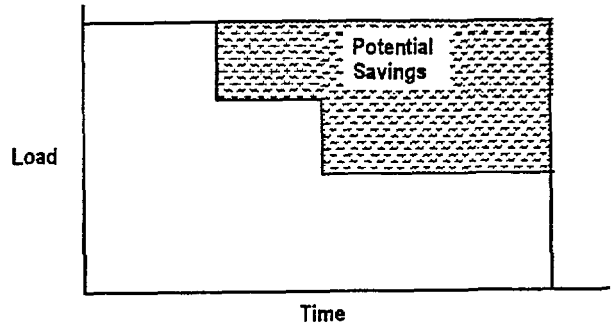
Potential for Energy Savings



Poor ASD Application

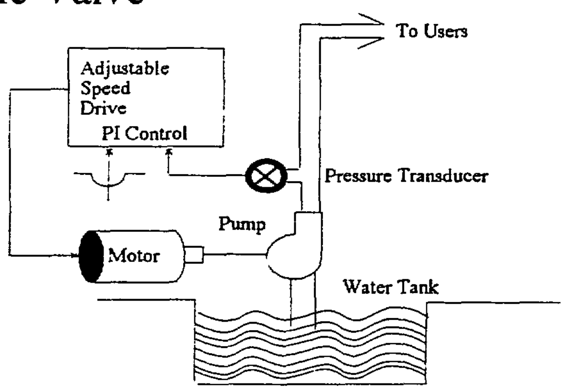


Excellent ASD Application

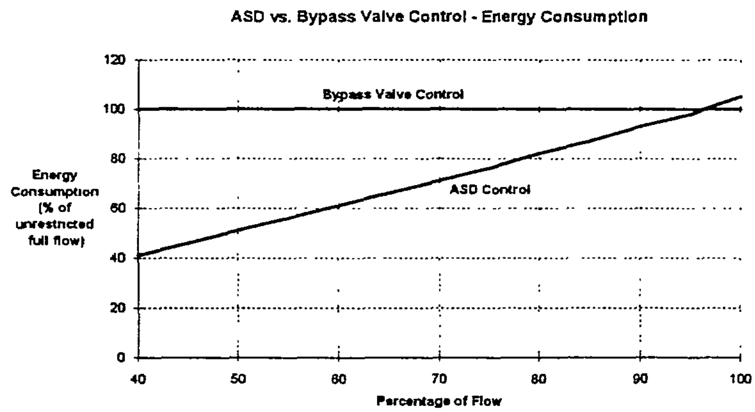


Conventional Alternatives to ASD

- Bypass Valve
- Throttle Valve
-



Energy Consumption Comparison - I



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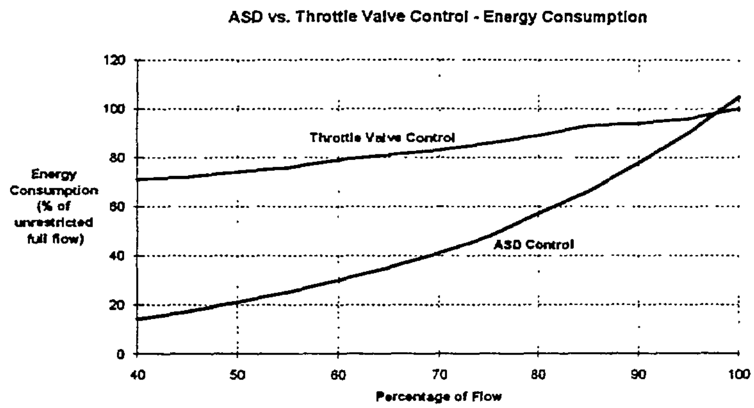
Adjustable Speed Drives - 14

Energy Consumption Comparison - II



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Adjustable Speed Drives - 15

Adjustable Speed Drives (ASD)

- ASD Applications
- Saving Money with ASD
- **Types and Characteristics of ASDs**
- Installing Reliable ASD Systems
- Power System Interfacing Considerations

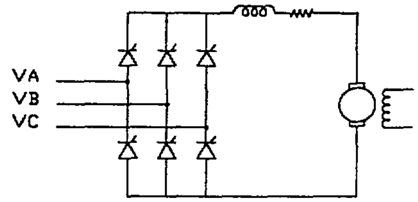
Types of Adjustable Speed Drives

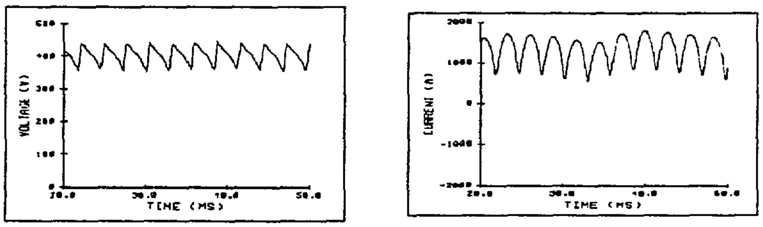
- DC Motor Drives
- Synchronous Motor Drives
- Induction Motor Drives
  - Current Source Inverter
  - Voltage Source Inverter
  - PWM Inverter
  - Field Oriented Controlled

DC Motor Drives

Characteristics:

- **Sizes range into 1000's HP**
- **DC motor drive systems can have significant reactive power requirements.**

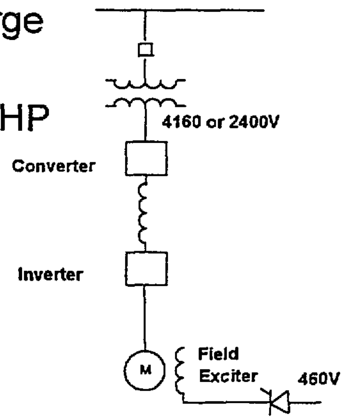




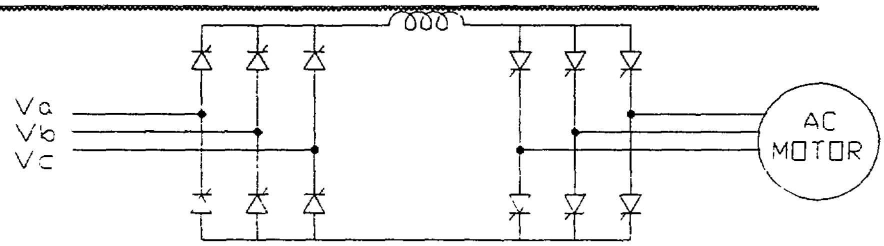
Motor Voltage & Current

Synchronous Motor Drives

- Most cost effective large HP drive
- Available above 1000HP
- Usually operates at 2300V or 4160V

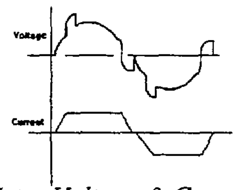


Current Source Inverters (CSI)



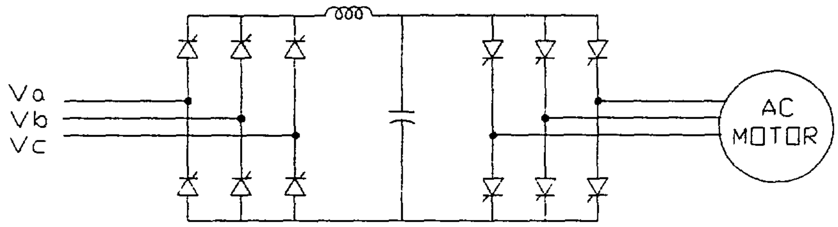
Characteristics :

- **DC inductance maintains constant dc current for inverter**
- **CSI drives used for very large motors and high-inertia load**



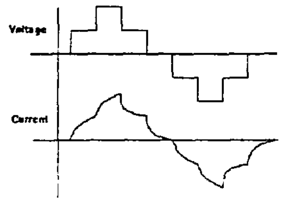
Motor Voltage & Current

Voltage Source Inverters (VSI)



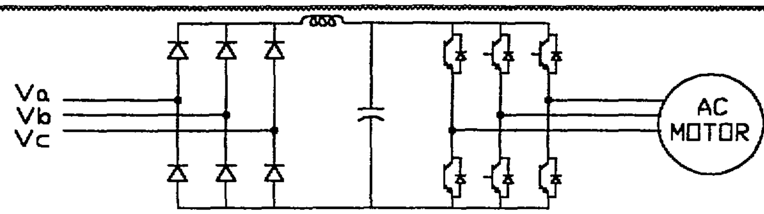
Characteristics:

- & **simple design, can handle multiple motors**
- & **rectifier operates without control**



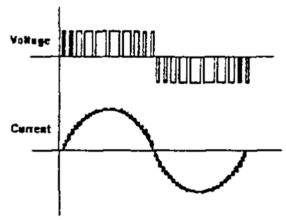
Motor Voltage & Current

Pulse Width Modulated (PWM) Drives



Characteristics:

- **used in all types of applications (e.g. HVAC) for motors < 500 Hp**
- **rectifier operates uncontrolled**



Motor Voltage & Current

Vector Controlled AC Drive

- Vector control allows control of the torque as well as the speed.
- Removes oscillation of torque and speed.
- Servo drives and positioning control
- Tight speed control
- Field-oriented control
- Good in hazardous locations, no DC motor or brushes

Summary
Drive Type Considerations

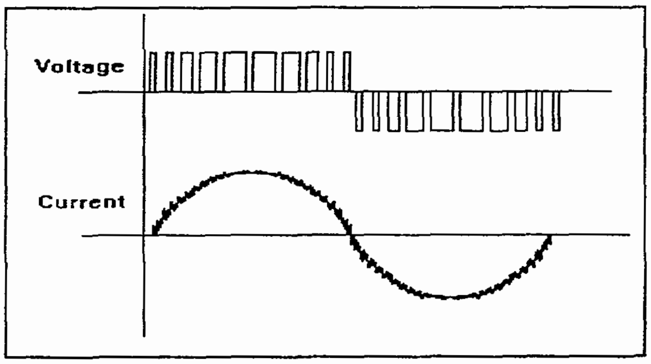
- All types of adjustable speed drives have advantages and disadvantages.
- Newer AC drive technologies are replacing DC drives.
- PWM drives are widely used in a variety of applications.
- Cost, performance, and maintenance considerations apply toward selecting a drive type.

Adjustable Speed Drives (ASD)

- ASD Applications
- Saving Money with ASD
- Types and Characteristics of ASDs
- **Installing Reliable ASD Systems**
- Power System Interfacing Considerations

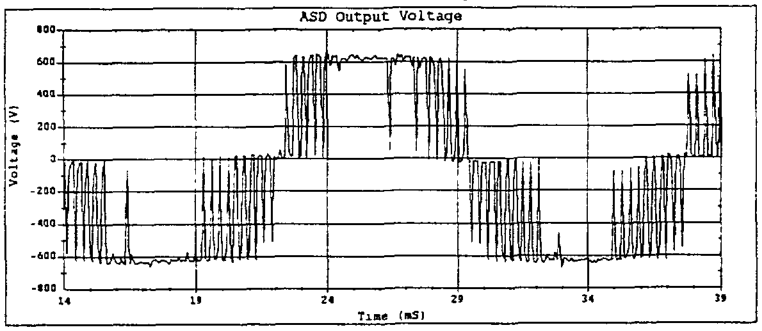
ASD Impacts on the Motor
Harmonics

- PWM ASDs significantly reduce harmonic heating in the motor - derating is not usually required
- Other types of ASDs must be coordinated with the motor rating



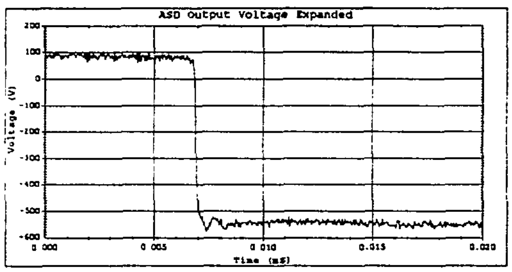
ASD Impacts on the Motor Transients

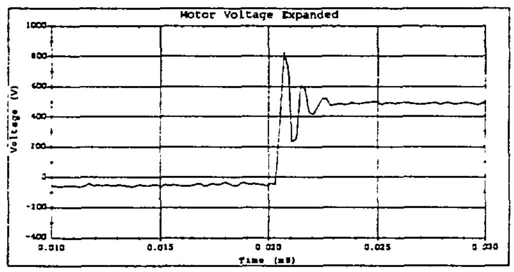
- PWM inverters output pulses with very fast rise times
- these wavefronts can cause insulation failure in the first turn of the motor winding due to unequal voltage distribution across the winding



ASD Impacts on the Motor Transients

- the PWM transients are made worse when the drive and the motor are separated by a significant distance (e.g. > 50 feet) due to travelling wave doubling at the motor



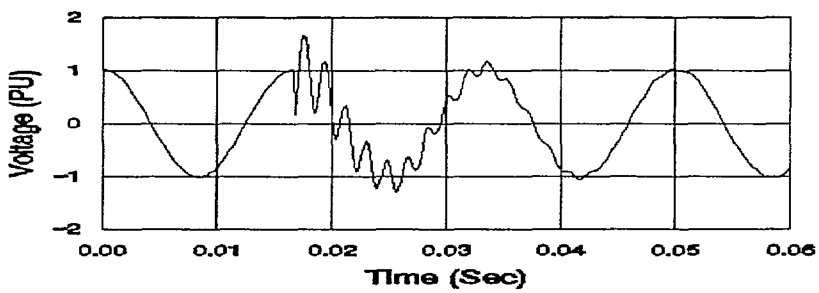


ASD Impacts on the Motor Transients

- Solutions to the motor insulation failure problem:
  - it may be possible to protect the motor using an output choke or a surge capacitor on the motor
  - new motor designs are available with increased insulation on the first few turns to handle this concern

ASD Sensitivity
Power System Transients

- power electronic components may be rated 1200 Volts and can be susceptible to failure for high magnitude transient voltages
- most common problem is nuisance tripping caused by capacitor switching on the utility system - causes rise in dc link voltage that exceeds control setting (e.g. 760 Volts)

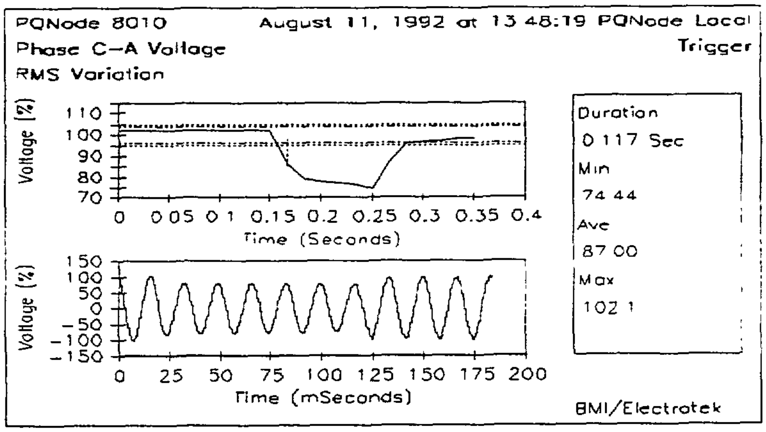


ASD Sensitivity
Power System Transients

- nuisance tripping problem can be minimized with input choke inductance (3% choke on the drive base is usually sufficient)
- many newer PWM type ASDs are incorporating the choke inductance in the dc link as part of the standard design

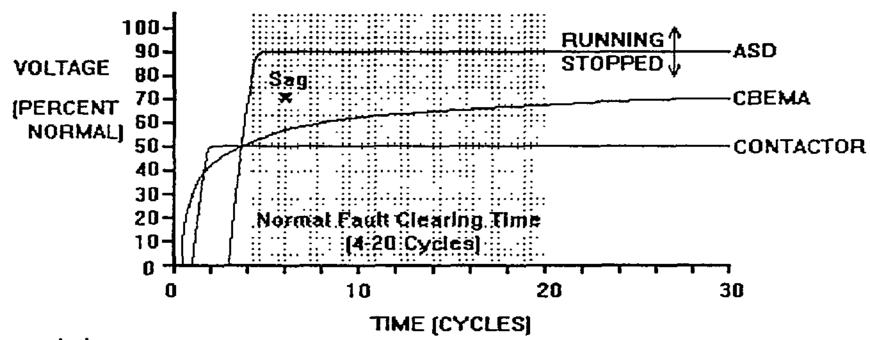
ASD Sensitivity
Voltage Sags

- voltage sags are caused by faults on the power system



ASD Sensitivity
Voltage Sags

- ASDs can be one of the most sensitive types of loads in a facility (e.g. ASD trips if the voltage goes below 90% for more than one cycle)



Electrotek Concepts Inc.

Adjustable Speed Drives - 33

ASD Sensitivity
Voltage Sags

- solutions to voltage sag problem are difficult because the whole drive usually must be protected
  - UPS
  - SSD
- modern PWM type ASDs can use the motor inertia to ride through voltage sags - automatically resynchronize when normal voltage is restored

Power Quality and ASDs Summary

- Control of input current harmonics will become increasingly important for ASDs
  - ASD Design (choke, pulse number, advanced power electronics)
  - filters
- Power factor of PWM ASDs is related to the harmonic current distortion, not the phase angle between the voltage and current
- Motors can experience insulation failures of they are separated from the drive by a significant distance

Power Quality and ASDs Summary cont.

- Nuisance tripping of ASDs can usually be prevented with a choke on the input or in the dc link
- Voltage sag sensitivity of ASDs is probably the most important concern - newer designs use the controls to provide increased ride through capability

Adjustable Speed Drives (ASD)

- ASD Applications
- Saving Money with ASD
- Types and Characteristics of ASDs
- Installing Reliable ASD Systems
- **Power System Interfacing Considerations**

Electrotek Concepts Inc.

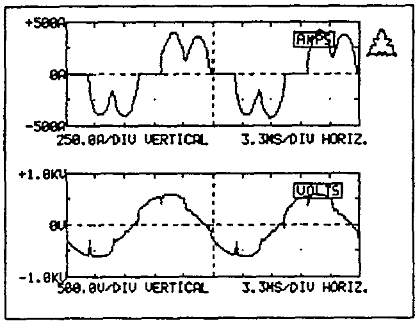
Voltage Notching

- The simplest solution to notching problems is the addition of a choke or isolation transformer on the input to the drive.
- This inductance does not prevent notching, but limits the notching to the ASD side of the inductance.

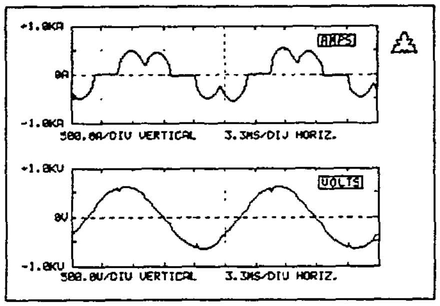
Voltage Notching - Snapshot #1

400 HP dc Drive Input (ac) Current and Voltage Waveforms:

Drive Side of Input Reactor



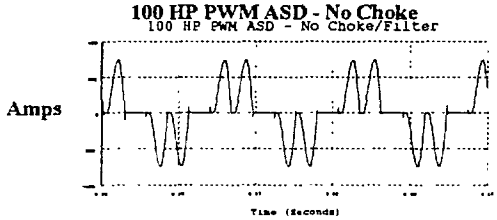
Bus Side of Input Reactor



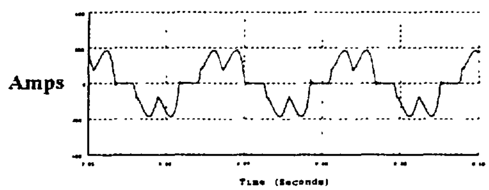
ASD Impacts on the System
Harmonics

- control of harmonic current generation - input choke inductance
- note that the choke inductance could also be in the dc link before the capacitor

100 HP PWM ASD - No Choke



100 HP PWM ASD - 3% Choke

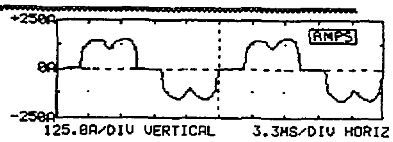


Transformer Derating

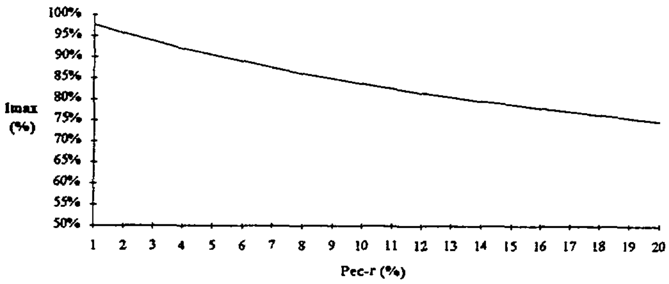
- ANSI/IEEE Standard C57.110-1986
  - Derating method that starts with a given load current spectrum and then determines the amount of this current that would cause the same losses as a purely sinusoidal current.
  - K - Factor UL 1561
  - Ability of a transformer to withstand increased eddy current losses due to harmonic load current.

Example of Derating for ASDs

- K = 5.7



Transformer Capability for Delivery to an Adjustable Speed Drive With 5% Line Reactance
K=5.7

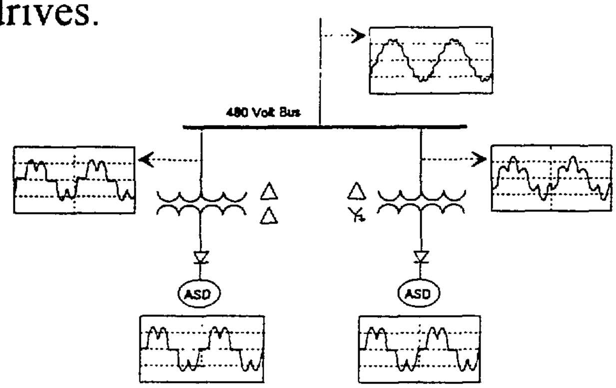


General Methods for Harmonic Control

- Control the source characteristics (IEC 555-2)
- Cancellation
- Passive harmonic filters
  - Individual loads
  - Filtering for groups of loads (e.g. service entrance)

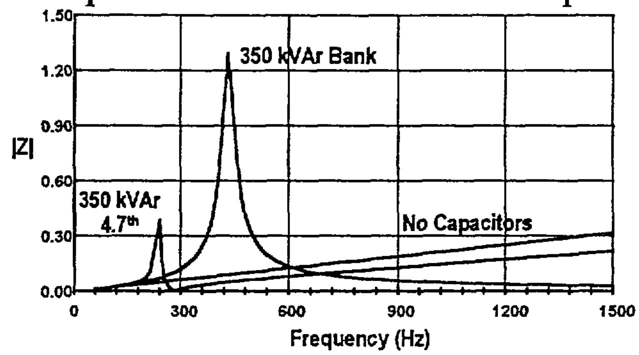
Designing for Cancellation

- Transformer connections can be used to get cancellation of harmonics from different drives.



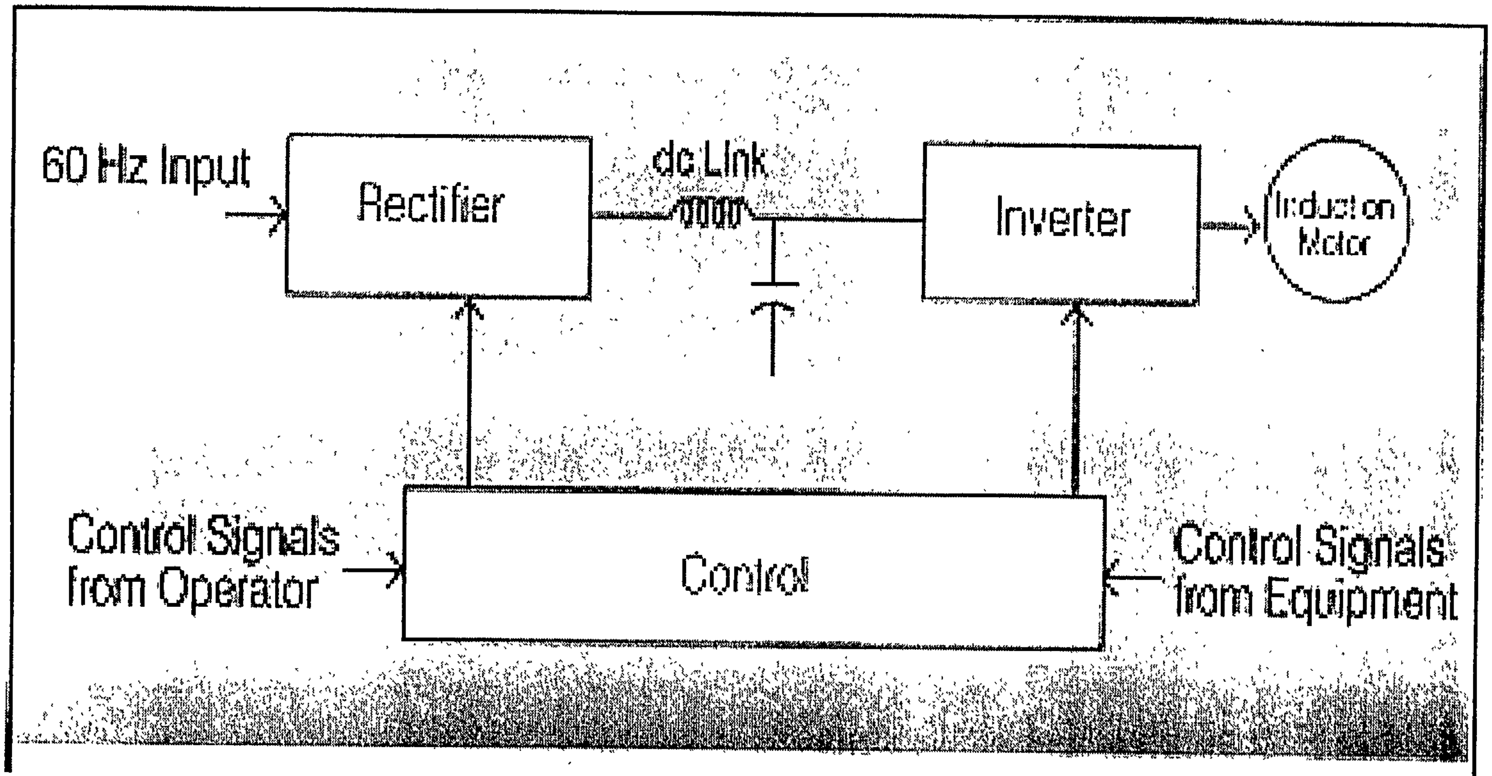
Power Factor Correction as Filters

- Power factor correction can be applied as harmonic filters to solve both the power factor problem and the harmonic problem.



Clarification Slides

ASD Components



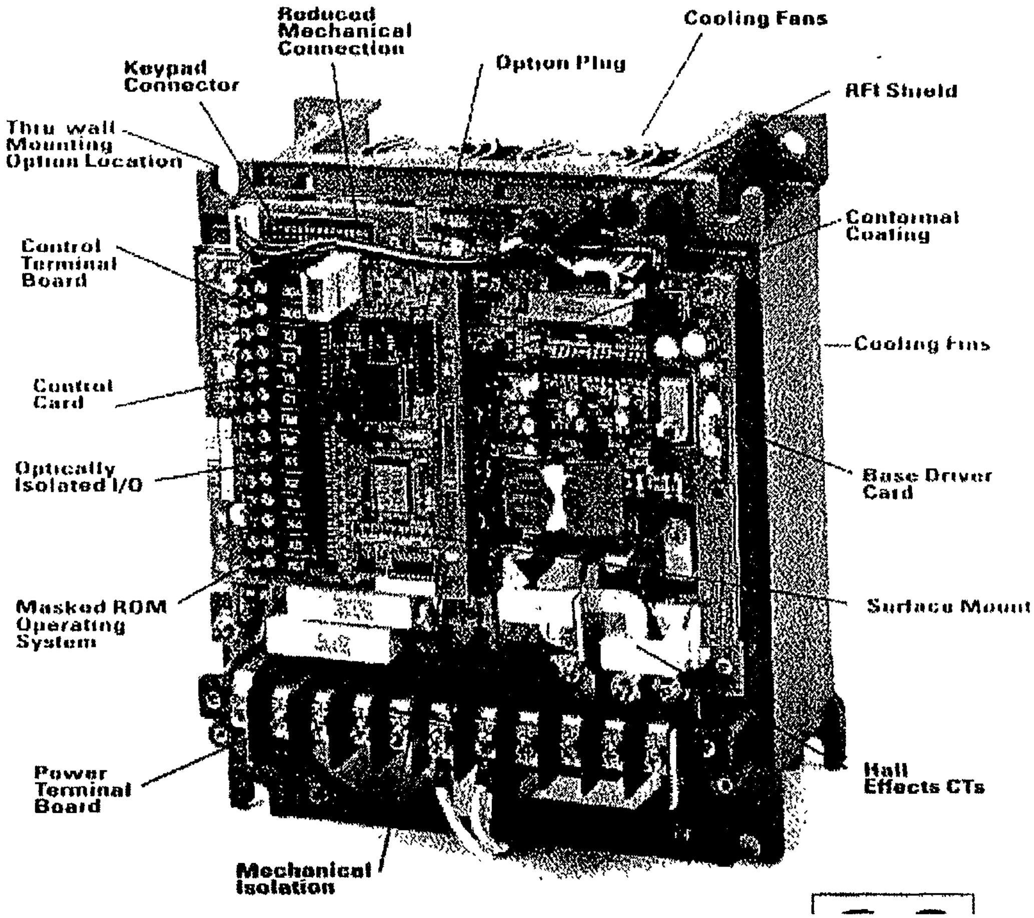
ASD Size and Weights (460 V)

HP	Weight (Lbs)	Height (Inches)	Width (Inches)	Depth (Inches)
1	8	10	6	6
30	27	16	10	8
300	463	57	27	14

ASD Size and Weights (460 V)

HP	Weight (kGram)	Height (Meter)	Width (Meter)	Depth (Meter)
1	3.6	0.25	0.15	0.15
30	12	0.41	0.25	0.20
300	210	1.45	0.69	0.36

ASD Insides


Reduced Mechanical Connection
Cooling Fans
Option Plug
Keypad Connector
RFI Shield
Thru wall Mounting Option Location
Control Terminal Board
Conformal Coating
Cooling Fins
Control Card
Optically Isolated I/O
Base Driver Card
Masked ROM Operating System
Surface Mount
Power Terminal Board
Hall Effects CTs
Mechanical Isolation

Design Considerations for ASDs

» Harmonic Distortion (both motor & supply side)

» ASD component failures - transient voltages

» Nuisance tripping of ASD

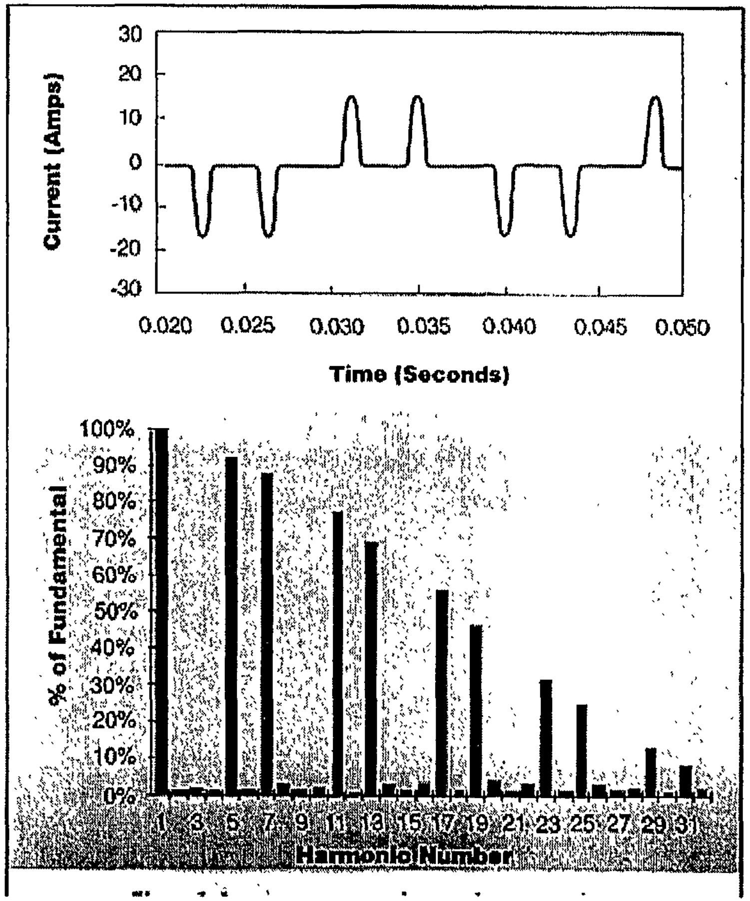
- (dc overvoltages)
- voltage sags

» Notching and transient oscillations

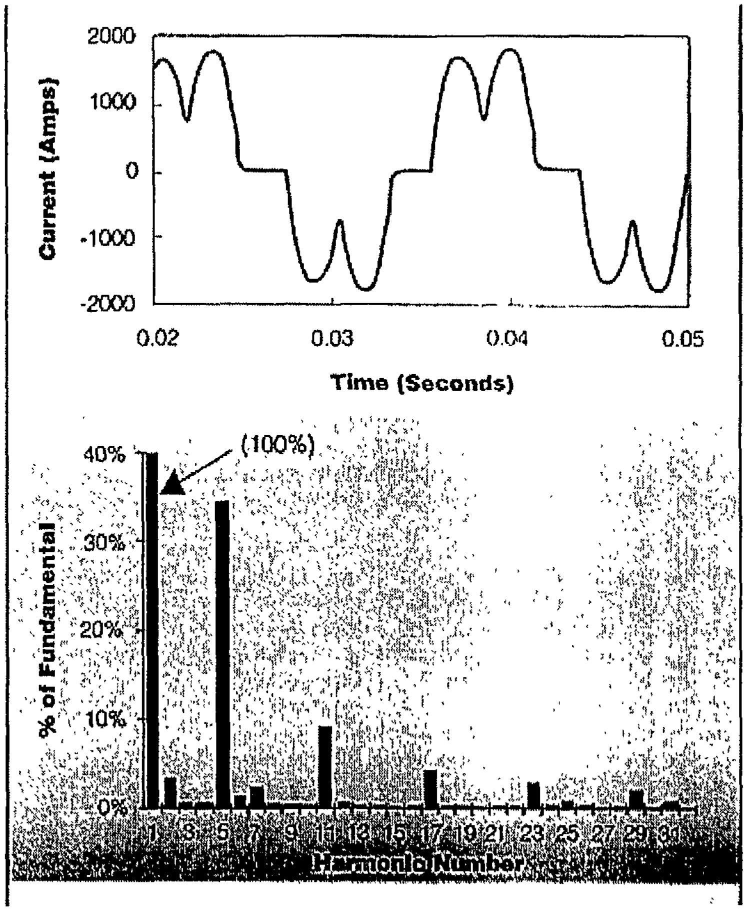
» Motor Overheating

» Audible Noise

Harmonic Distortion ASD - VSI



Harmonic Distortion ASD - CSI



Harmonic Current Limits

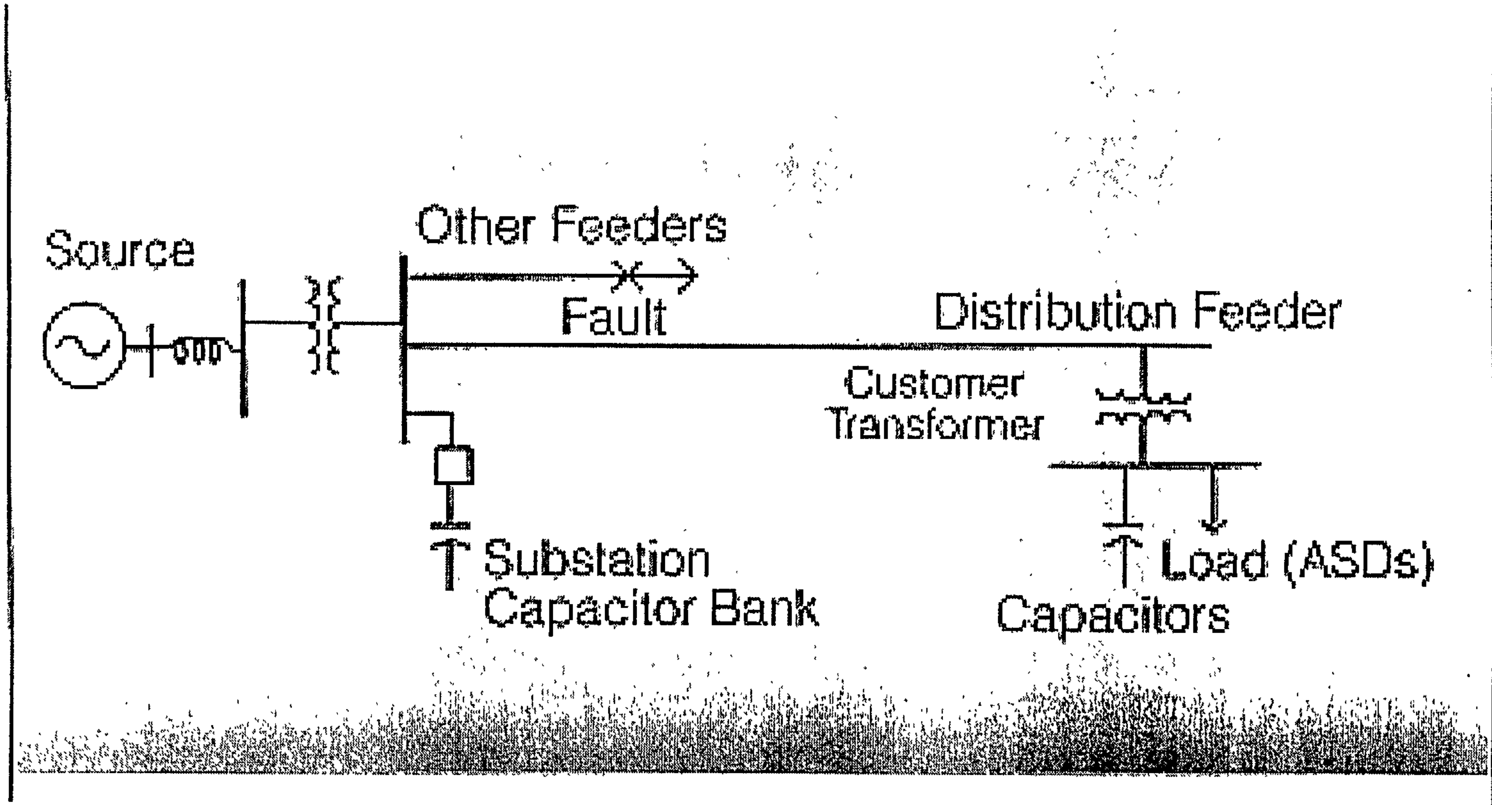
Harmonic Current Limits - Customer Responsibility

SCR = I_{sc}/I_L	<11	11<h<17	17<h<23	23<h<35	35<h	TDD
<20	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

Values shown are in percent of "average maximum demand load current"

SCR = short circuit ration (utility short circuit current at point of common coupling divided by customer average maximum demand load current)

Basic Circuit for problems with Transient Voltage Magnification



Transient Voltage Magnification

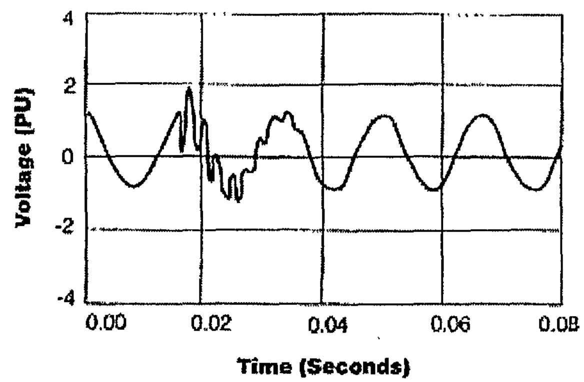


Figure 8. Capacitor-bank energizing transient

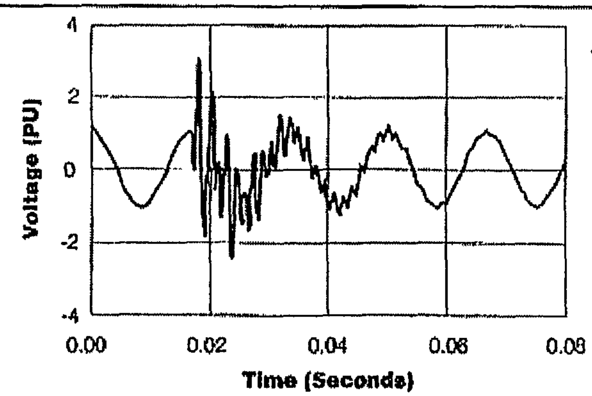


Figure 9. Magnified transient at 480-volt bus during capacitor switching on the utility system

Nuisance Tripping due to Capacitor Switching Transients

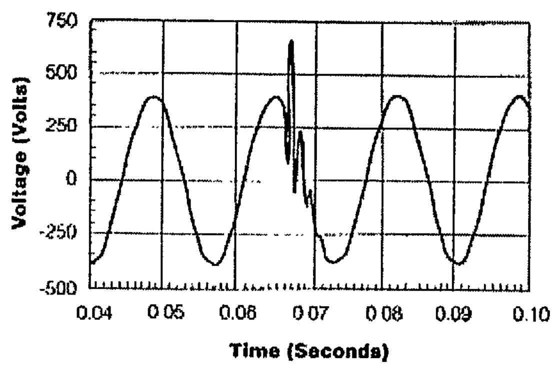


Figure 11a. Transient voltage at the 480-volt bus caused by capacitor energizing on the utility system

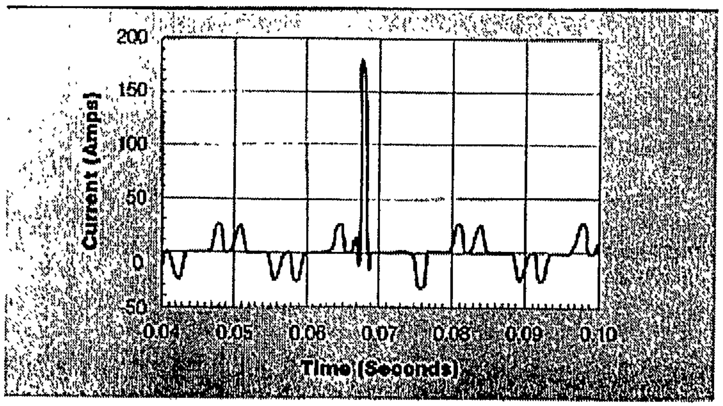


Figure 11b. Ac drive line current waveform at the input to the ASD, illustrating the current surge caused by capacitor energizing

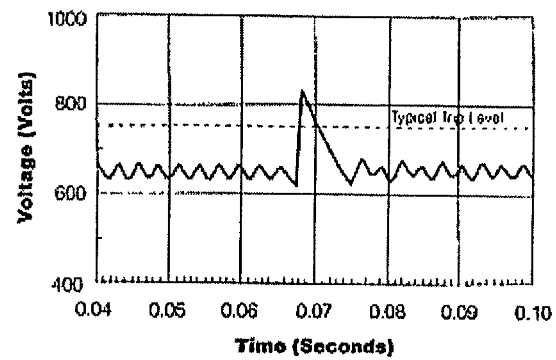
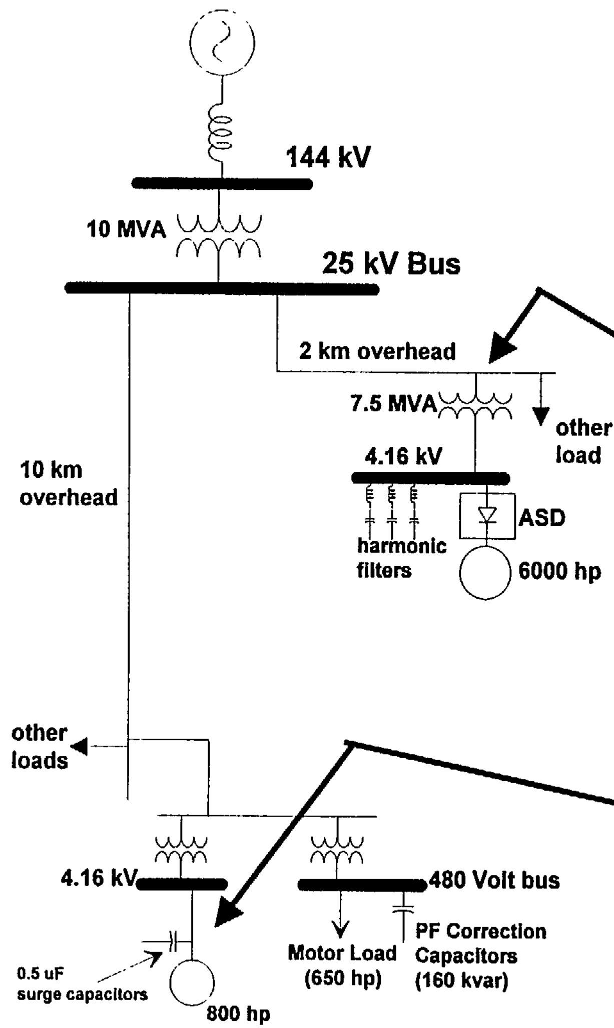
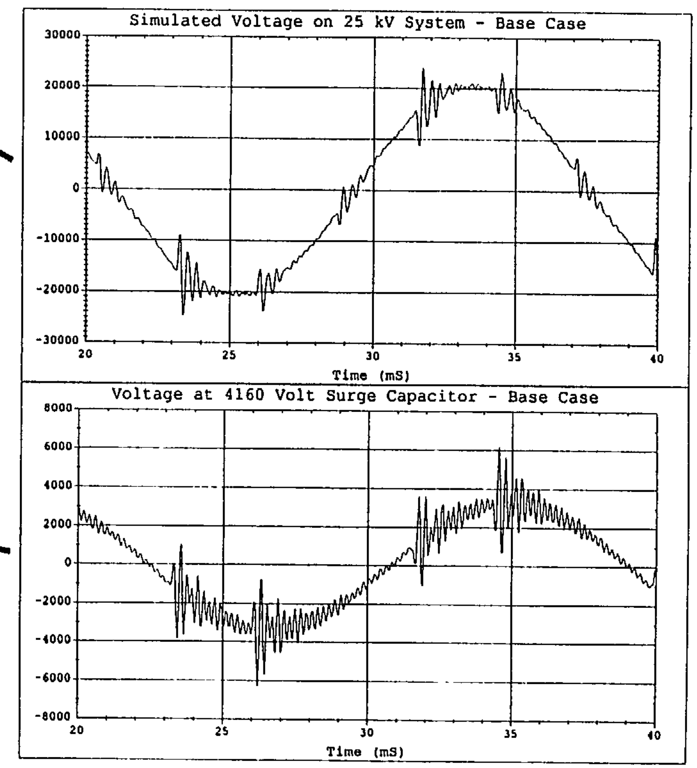


Figure 11c. Dc bus voltage waveform seen by the dc overvoltage control of an ASD during capacitor energizing

Voltage Notching



- Notching can excite high frequency oscillations on the distribution system that may affect other customers



True Power Factor

- PWM ASDs have excellent displacement power factor characteristics
- harmonic current distortion results in poor true power factor
- therefore, power factor control for ASDs means harmonic control

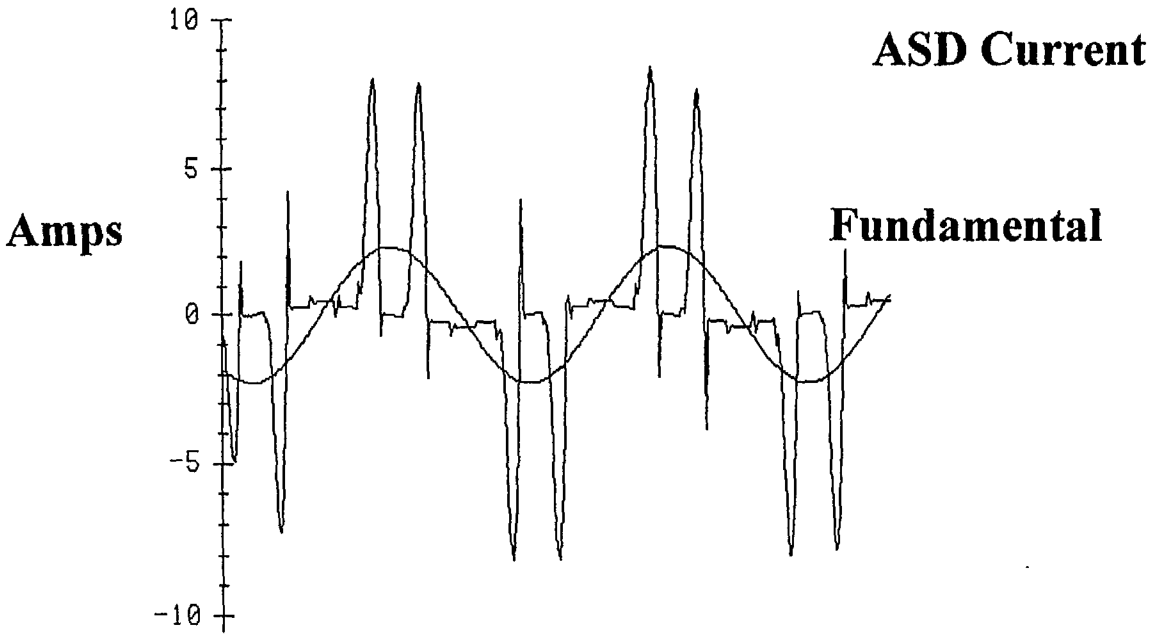
True Power Factor - is defined as the ratio of real power over total volt-amperes.

$$TPF = \frac{\text{Real Power}}{\text{Total Voltamperes}} = \frac{P}{V_{rms} \cdot I_{rms}}$$

Example of ASD - PWM power factor

Displacement Power Factor close to unity

True Power Factor = 56%



Change in Load for Energy Efficient Motor Replacement