Fundamentals of Power Quality

Power Quality Through Better Wiring and Grounding Practice

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Overview of This Presentation

Elements of building infrastructure that can alleviate or cure power quality problems before they affect operations
For Today:

- A bit of theory
- Case studies
- Recommended practice
What is Poor Power Quality?

Poor power quality...

is evidenced by characteristics of the incoming power to a device that deviate from the customary “pure” 60 Hz sine wave, and that can affect reliable and safe operation of the sensitive equipment.
What the Equipment Wants
What the Equipment Gets
Real Cost

The real cost of poor power quality is in lost productivity (downtime).

- Estimated at $15-30 billion per year in US
- Exceeds $1 million/yr. at some buildings

Equipment is usually a secondary consideration
Where Are Sensitive Loads?

Manufacturing Plant

Resort Hotel
Where Are Sensitive Loads?

Office Buildings

Bakery
Sensitivity is Increasing

• Spread of microprocessors to every type of load
• Micro circuits are getting faster (radio frequency range)
• Circuits are getting smaller
• Operating voltages are lower (“1” may be 1-3 volts)
Macro View

What used to be acceptable service characteristics are no longer sufficient
Surprising Facts

Most power quality problems are related to grounding and neutral size issues

Over 80% are internally caused

source: EPRI
Major Issues

- Harmonics
- Transients
  - Internally caused
  - Externally caused
What Are Harmonics?

Harmonics are integer multiples of the fundamental frequency, i.e.:

\[ 2^{\text{nd}} \text{ harmonic} = 120 \text{ Hz} \]
\[ 3^{\text{rd}} \text{ harmonic} = 180 \text{ Hz} \]
\[ 4^{\text{th}} \text{ harmonic} = 240 \text{ Hz} \]

etc…
Fourier Analysis

A wave of any shape and amplitude can be created by some combination of sine waves of various amplitudes and frequencies
Corollary

An odd-shaped wave contains harmonics of some fundamental
No Longer Sine Waves

Fundamental and third harmonic added

Source: EC&M Practical Guide to Power Dist for IT Equipment
In 3-φ, 4-W Circuits:

Neutral carries the vector sum of the three phase currents.

Normally, the vector sum of three balanced phase currents 120° out of phase is zero.
In 3-Φ, 4-W Circuits:

“Triplen” harmonics add in the neutral.

Triplen harmonics are odd multiples of the 3rd harmonic, i.e., the 3rd, 9th, 15th, etc.
Harmonics Add in Neutral

Adapted from EC&M Guide to Power Dist. For IT Equip.
Harmonics Can Be Trouble

Cause heating
- in the neutral wire
- in motor windings
- In transformer windings

Can cause capacitor failure
Can cause nuisance tripping

Source: IEEE Emerald Book
Common Sources of Harmonics

Anything that draws current in a non-linear manner
Such As

• Anything Operated by a MICROPROCESSOR
• Switched Mode Power Supplies (computers)
• Variable Speed Drives
• SCR Controlled devices
• UPS Systems
• Arc-Operated Devices (welders, lighting)
• Capacitor Switching
• Etc.
Switched Mode Power Supply

SMPS:

Source: EC&M
Potential Cause of PQ Problems

SMPS draws current in pulses

Source: Dranetz Field Handbook
Other Causes of PQ Problems

Power Factor Capacitor Switching:

Source: Dranetz Field Handbook
Other Causes of PQ Problems

Variable Frequency Drive:

Source: Dranetz Field Handbook
Transient PQ Problems

EXTERNAL:

- Utility switching or outages
- Vehicle hits
- “Galloping conductors”
- Poor or inadequate grounding
- Intermittent connections
- Voltage reductions
- etc.
#1 Transient

Lightning
Isokeraunic Map

Thunderstorm days

Mean Annual Thunderstorm Days
Surge Suppressors

- at the service
- at the panel board
- at the load
Surge Suppressors

at the service level
Category C devices
150 kA per mode
Surge Suppressors

at the feeder level

Category B devices

75 kA per mode
Surge Suppressors

at the device level

Category A devices

25 kA per mode
Surge Suppressors

- Leads as short as possible
Surge Suppressors

All-mode protection: φ-φ, φ-G, φ-N, N-G
Listed to UL 1449, Version 2
High Joule rating
Have filtering, fuses, indication
Must be well-grounded
Other Causes of PQ Problems

- Shared circuits
- Too many outlets / uses per circuit
- Inadequate neutrals
- Poor or inadequate grounding
- Intermittent connections
- Standard equipment and wiring
- etc.
What Can We Do About It?

Better wiring and grounding will prevent or alleviate most problems at little cost

(Power quality need not be expensive)
National Electrical Code

Good starting point

But not usually sufficient for power quality
More Useful

ANSI/IEEE 1100
Recommended Practices are needed for power quality.
Elements of Power Quality Design

- System Grounding (earthing)
- Equipment Grounding (bonding)
- Neutral Sizing
- General Wiring
- Extra Effort Steps
System Grounding

Needed for:

• Establishing a voltage reference
• Discharge high transient voltages (esp. lightning)
• Static Discharge
• Personnel Safety
To Meet Code

To Meet Article 250-50(a)(2):

Water Pipe and 2 ground rods, even if result exceeds 25 ohms.
For Power Quality

Desired Grounding Resistance:

• 5 ohms or less desired for power quality

• Many mfgrs. specify under 2 ohms

• IEEE Std. 142 recommends 1-5 ohms (Green Book)
Low Impedance

- Ring ground
- Ufer Grounds
- Multiple, deep rods
- Moisture (bentonite)
Deep Earth Electrodes

Diagram:
- Deep Electrode
- Two layers:
  - Less Stable: Moisture / Temperature
  - More Stable: Moisture / Temperature
- Measurements:
  - 10 ft
  - 20 ft
Ground Rods

How to Minimize Resistance:
Preferred spacing = 2 X rod length
System Grounding Example

Mt. Washington, NH

Before:
3-4 major events in 2 years (lightning)
$120,000 avg damage per year
Plus lost ad revenue (station downtime)

Source: Ground Testing, Inc.
System Grounding Example

Difficult Case: Mt. Washington, NH

Two 600 feet deep copper rods placed in 8 inch diameter well casings

Backfill with bentonite grout

Interconnect with 500 kcmil copper cable

Achieved 6 ohm resistance
System Grounding Example

- 500 kcmil ring grounds
- 2-600 ft deep vertical electrodes
System Grounding Example

After:

No damages or disruptions in 5 years since improved grounding

Source: R. Cushman, Chief Engineer, WMTW-TV
Las Vegas Casino/Hotel

• Each slot machine is a computer
• High Resistivity Soil
• High Cost of Failure
System Grounding

Las Vegas Casino Hotel
Ground Bus

Interior ground bus for easy connections:

Source: Allegro Corp.
“Halo” Grounding

Interior “halo” ground for easy connections:

Note large radii bends

Source: Power & System Innovations,
Ground Loops

Earth cannot be ground path:

[Diagram showing the concept of ground loops]
Ground Loops

There should be ONE central point connecting the interior wiring to the ONE exterior grounding electrode system

Source: Dranetz Field Handbook
Recommended Wiring Practice

Sensitive loads should be separated:
- Separate branch circuits
- Separate panelboards
- Separate feeders
- Separate transformers
Isolate Sensitive Loads

source: IEEE
Emerald Book
Isolate Sensitive Loads

source: IEEE
Emerald Book
Isolate Sensitive Loads

source: IEEE Emerald Book
Safely Handling Harmonics

Use double size neutral or one neutral per phase conductor
Safely Handling Harmonics
Safely Handling Harmonics

Use K-Rated transformers, panelboards.
Case Study: M.I.T.

Current Design Standards:

• Separate computer feeders, panels, and branch circuits

• 4 outlets per 20 amp. Branch circuit
Case Study: M.I.T.
Case Study: M.I.T.

Current Design Standards:

• 10 ohms or less grounding resistance
• Double (and sometimes triple) neutrals
• K-rated transformers
• Always a separate grounding conductor
• Always copper conductors
M.I.T. Basic Grounding Layout

500 kcmil ring ground around each building

1000 kcmil spine
Case Study: M.I.T.

Cost for all PQ improvements:
Add about 1 1/2% added to the overall cost of construction, but....

Never has to revisit infrastructure for foreseeable future
Case Study: “Clean Grounds”

McAfee Tool and Die
Case Study: McAfee Tool & Die
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Case Study: McAfee Tool & Die

Note loosely draped comm. cable (antenna)
Case Study: McAfee Tool & Die

“Supplemental” electrodes abandoned
Case Study: McAfee Tool & Die

Cabinets retrofitted with 4/0 copper bonding, aluminum removed

Everything bonded to building steel using 4/0 copper
Case Study: 911 Center Retrofit

4/0 AWG ring ground completely surrounds building

Source: Power & System Innovations, Inc.
Case Study: 911 Center

Tower on municipal land
Built by Telco
Shared with emergency services

Source: Power & System Innovations, Inc.
Case Study: 911 Center

Coax braid grounding

Note location on vertical run
Vertical Coax Grounding

29X lightning cable then connects to 4/0 vertical to 4- 50 ft. electrodes under tower
Firewall

Outside copper firewall
4/0 vertical to ring ground
Halo Ground

Inside copper firewall
4/0 connects to “halo”
and grounding electrode system

Note large radii
Every Joint Jumpered
Equipment Grounds

Every joint, tray and cabinet bonded and jumped with #2 to plate, then 4/0 connects to “halo”
TVSS

TVSS at the service and all branch panels

All cabinets bonded with copper jumpers then to ring ground with 4/0 copper
Installed 4/0 ring
20 ft rod
every 20 ft.

4- 50’ rods under tower
Suncoast Schools FCU
ATM Network
Service Drop
Meter Socket
Electric Meter
TVSS Worked
Examples of TVSS
Good Grounding Mandatory
Review

Recommended practices

Getting toward the end
Low R Grounding
Network of Air Terminals

Network of air terminals

Layout per Code NFPA-780

Panelboard

CDA
System Grounding

To the Ground Ring:
- multiple ground rods
- tie-in building steel
- connect all metallic underground pipes
- lightning protection system
Surge Suppression
Equipment Grounding Conductor

Use a full-sized EGC and 200% neutral, or separate neutrals.

Don’t rely on conduit.
Equipment Grounding

There should be ONE central point connecting the neutral to the ONE exterior grounding electrode system.

Source: Dranetz Field Handbook
No Ground Loops Allowed

EARTH MUST NEVER BE USED AS A CONDUCTOR
Separate wiring

At least, separate circuits

If possible:
- separate panels
- separate feeders
- separate services
- shielded isolation trans.
- UPS
Handle Harmonics

Interior:

- Always use a full size copper equipment grounding conductor
- Use a 200% rated neutral
- Use harmonic rated panels
General Wiring

Interior:

• Limit receptacles to 3-6 per circuit
• Limit voltage drop to <3% or less
  — wire gage
  — circuit length
• Check for ground loops
• Check for N-G bonds
General Wiring

Interior:

• Bolt-in circuit breakers

• Twist-lock plugs/receptacles
General Wiring

Use proper connections
Double Nuts and Lockwashers
Star Pattern
General Wiring

Shielded isolation transformer

or

K-rated transformer (K-13 or higher)
General Wiring

Harmonic rated panels
System Grounding

Bentonite is the only recommended backfill

Be wary of anything containing graphite
Retest System Ground

Retest resistance of grounding electrode system annually (or more often as conditions dictate).

Use fall-of-potential method if possible
Human Failures

People make changes to the electrical system all the time

They seldom document the changes
Tip

You can exceed the Code, but don’t violate the Code!

“There should be no reason why you cannot design for power quality and still stay within the Code” – Warren Lewis
Before I go…. 
Thanks for your attention.

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