Distribution Harmonic Issues: Telephone Noise

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**Balanced system, no harmonics**

Balanced phase currents
\[ I_a + I_b + I_c = 0 \]

Neutral current
\[ I_n = 0 \]

Multi-grounded neutral (MGN)
Unbalanced system, no harmonics

Unbalanced phase currents
\[ I_a + I_b + I_c \neq 0 \]

Neutral current
\[ I_n = I_a + I_b + I_c \]

Multi-grounded neutral (MGN)
Return current

40% neutral

pole ground

60% earth
Balanced system, harmonics

Phase currents with harmonics

Neutral current
In = triplen harmonics

Multi-grounded neutral
(MGN)
Neutral current flows in MGN

increases net disturbing magnetic field

Phase currents

Neutral current

Multi-grounded neutral (MGN)
Net disturbing field couples with telephone conductors, induces noise
Shielding

Number of phase conductors changes

Feeder changes direction

Telephone cable sheath bonds to power system neutral wherever exposure changes.

Other devices and techniques help, but none can completely mitigate high noise levels.
Harmonic current flows from and returns to its source:

Looking for low impedance return path

Harmonic current source
Harmonic return path

Inductive:
\[ X = 2\pi fL \]
increases
with frequency

Other loads
in facility
Capacitive: \[ X = \frac{1}{2\pi fC} \]

decreases with frequency

Low voltage capacitors
First ground

Transformer
(high Z)
**Delta-Y transformer**

*Balanced 3rd, 6th, 9th ... harmonics circulate in delta winding*

- Reduced triplen harmonics
- Harmonic source
Delta - Y transformer
Delta - Y transformer
Other customers' loads

Earth current
Distribution capacitors

Earth current
*Triplen harmonics* (3, 6, 9, 12 ...) *flow in neutral and earth*

All harmonics

balanced

1, 2 _ 4, 5 _ 7, 8 ...

sum to zero

3, 6, 9, 12, 15 ...
Substation Transformer

Earth current
Case Study
Exposure to power distribution
Characteristics:

Higher harmonic current at one frequency
Change in harmonic current at capacitor bank
Significant change in harmonic current when bank switches off
Capacitors: parallel resonance

\[ LC = \frac{1}{2\pi f} \]

Very high impedance at frequency “f”
Capacitors: parallel resonance

Source impedance

in
resonance
with

High
harmonic
voltage

power factor
correction
capacitor

Harmonic
current
Parallel resonance worse with light loads

Load damps resonance
Capacitors: series resonance

\[ LC = \frac{1}{2 \pi f} \]

Very low impedance at frequency “f”
Capacitors: series resonance

Line reactance in resonance with power factor correction capacitor.
Series resonance worse with light loads

Load damps resonance
Move capacitors to detune resonance

Open neutral or apply harmonic suppression reactor to stop harmonic current flow to earth
Open fuses on one or two capacitors causes large neutral/earth current.

Diagram:
- Distribution Feeder Conductors
- Power System Neutral
- Telephone Cable
- Harmonic Sources 1- or 3-phase
LARGE HARMONIC SOURCE

Distribution Feeder Conductors

Large Harmonic Generator

Power System Neutral

Telephone Cable
Saturated transformers
Distribution Feeder Conductors

Harmonic Sources
1- or 3-phase

Open Neutral

Power System Neutral

Telephone Cable

All current through earth

Characteristics:

Significant increase in noise between two earth connections
Small harmonic sources

Multiple dispersed single-phase harmonic sources on Circuits 1 and 2

Circuit 1

Telephone

1.5 miles

Circuit 2

Electric Power Substation
Model the system
SMALL HARMONIC SOURCES: SOLUTION

Existing capacitor bank converted to 540 Hz filter
Convert capacitor to shunt filter

earth current is reduced

harmonic current returns
Shunt harmonic filter

Filter frequency:

\[ 2\pi f = \frac{1}{\sqrt{LC}} \]

Example:

\( f = 540 \text{ Hz (9th harmonic of 60 Hz)} \)

C is 7200 V, 600 kVAR bank: \( C = 10.2 \mu \text{F} \)

\( L = 8.5 \text{ mH} \)
Harmonic filter

Three-phase capacitor bank

2.8 mH iron-core inductor
Telephone noise causes/solutions

- Capacitor resonance
  - Move capacitor
  - Open capacitor neutral
  - Harmonic suppression reactor

- Open capacitor fuse
  - Replace fuse

- Large harmonic source
  - Mitigate at source

- Saturated transformer
  - Repair or replace transformer
  - Reduce feeder voltage

- Small distributed harmonic sources
  - Reconfigure feeder
  - Upgrade phone to fiber
  - Filter
Questions or Comments?

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Further reading: