New Methods in Power Line Carrier Monitoring and Analysis – Real World Examples and Implications for Protection System Reliability

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Introduction

- Power Line Carrier has been protecting transmission lines in the US for at least 94 Years
  - 1927, Ohio Power Company, Newmark-Crooksville, 66 kV, 35 miles

- Utilities find that many records of carrier channel events, even in this era, are not adequate for misoperation event analysis
  - NERC Misoperations Report, 2013, etc.

- Continuous monitoring devices, specific to PLC protection channels, provide enhanced carrier channel data

- “Improvements in data…help entities determine areas to improve by identifying misoperation causes and proper mitigation steps”
  - NERC 2013
How is the data obtained?

<table>
<thead>
<tr>
<th>Wideband (to 5 MHz)</th>
<th>Mid-band (10 kHz BW)</th>
<th>Narrow-band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling = 20 MHz</td>
<td>Sampling = 20 kHz</td>
<td>300, 600, 1200 Hz typ.</td>
</tr>
<tr>
<td>-RF transient detection</td>
<td>-Time-domain capture</td>
<td>-Impedance</td>
</tr>
<tr>
<td>-Wideband level</td>
<td>-Spectral analysis</td>
<td>-Levels, Freq, Trend</td>
</tr>
</tbody>
</table>

“New Methods” - Summary

- Trending: long-term storage of instantaneous data points, sampled at regular intervals (once an hour is typical)
  - Levels (dBm), impedance / reflected power

- Time-domain voltage capture / fast Fourier transform (FFT)
  - 400 ms of frequency-selective voltage “on the coax”
  - 10 kHz BW at channel center frequency

- Transient Detection
  - Wideband voltage and current detected independently
  - Thresholds at ~300 V peak, ~2 A peak, min. 250 ns

- Impedance – “where reflected power comes from”
  - The impedance looking into the line tuner (typical installation)
  - Magnitude and phase (50 ohms 0 degrees ideal)
**Time-domain / FFT**

Frequency analysis of RED portion of data shows 2 Tx and 3 Rx signals.

Composite voltage signal in 10 kHz BW (steady state).
Impedance vs Reflected Power

\[ \rho = \frac{Z_{\text{TERM}} - Z_{\text{SOURCE}}}{Z_{\text{TERM}} + Z_{\text{SOURCE}}} \]

\[ R_{\text{P}}(\%) = 100 \times \rho^2 \]

Reflected Power

Phase Angle (degrees)

Impedance (Ω)
### Real-World Examples – Impedance and Phase

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mag (Ω)</th>
<th>Phase (deg)</th>
<th>RP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>49.8</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Tuner input shorted</td>
<td>24.6</td>
<td>+84.3</td>
<td>85.2</td>
</tr>
<tr>
<td>Tuner ground sw. shorted</td>
<td>173.8</td>
<td>+86.5</td>
<td>93.4</td>
</tr>
<tr>
<td>CCVT ground sw. shorted</td>
<td>179</td>
<td>+85.9</td>
<td>92.9</td>
</tr>
<tr>
<td>Tuner input open</td>
<td>117.9</td>
<td>-88.8</td>
<td>96.9</td>
</tr>
<tr>
<td>Tuner prot. unit open</td>
<td>120.3</td>
<td>-88.6</td>
<td>96.5</td>
</tr>
<tr>
<td>Line disconnect open</td>
<td>88</td>
<td>-86.1</td>
<td>89.2</td>
</tr>
</tbody>
</table>

**Graphical Representation:**

- **Z magnitude**
- **Z phase**
- **120 Ω**
- **-89 deg.**

**Legend:**
- Trending
- Baseline
- Tuner input shorted
- Tuner ground sw. shorted
- CCVT ground sw. shorted
- Tuner input open
- Tuner prot. unit open
- Line disconnect open
Power System Sources of PLC Noise

- Switching events generate transient carrier-band energy
  - “Noise”

- Transmitters/receivers are particularly helpless here
  - No time-domain picture of the carrier – what did it look like??

- New data help to observe the day-to-day interaction between PLC systems and the power system
  - Signatures and characteristics
Power System Related – Lightning

3 ms. loss of signal
Power System Related – Breaker Operations

On-Off

FSK

5 ms

6 ms
Power System Related – Line Disconnect

On-Off

8.33 ms period

17 ms loss of signal

FSK
Power System Related – Shunt Capacitor Banks

Controlled switching and re-ignition show up on carrier coax cable

Volts

2.78 ms  2.78 ms  3.84 ms
**Carrier Holes**

- “The lack of a signal where one should appear”
  - *Typically, due to some kind of flashover*

- “Tend to be a mystery”
  - *Available records show only the state of a relay contact, not the nature of the analog energy ultimately driving the relay contact*

- Block-hold timers - beware
  - *May mask carrier hole issues as they get progressively worse*

- Transient detection, time-domain, and FFT used for carrier holes
Carrier Holes

SPECTRUM

Frequency (Hz): 147,500 to 148,500

TRIP
- 250.65 Hz

GUARD
- 20 dB

dBm
DCB – Observing Operations

85 ms

Carrier hole
DCB – Observing Operations

[Diagram showing a graph with labeled points A, B, C, D, and E along a time axis in milliseconds and a voltage axis.]
DTT Misoperation

![Graph showing DTT Misoperation](image)
DTT Misoperation
DTT Misoperation

Guard 0 ms
Transient Monitoring

- Line traps isolate PLC systems from impedance changes on the bus
  - And, from switching transients on the bus !!!

- A failed trap tuning pack allows more carrier-band transient energy onto the line
  - Once on the line, the energy has a tuned path to PLC receivers

- Failing or de-rated gas tubes and spark gaps make transients worse
  - Lower flashover means more flashovers
  - Carrier holes / loss of signal last longer

- When these two factors combine – failed traps and de-rated gaps/tubes – misoperation risk is dramatically increased
Transient Monitoring

- Continuous monitoring devices can track baseline transient activity
  - And indicate when it has increased beyond normal limits
Implications for PLC Reliability

- NERC 2013 Misoperation Report (and subsequent reports)
  - 17% of misops caused by communications channel (396 of 2279)
  - 12% of misops have “unexplainable” cause

- Estimates made for the remaining groups’ share of PLC
  - 30% of all communications-related misoperations involve PLC
  - 5% of total protection misoperations

- Trends continue to this day

- Consistent use of continuous monitoring data for PLC can put a dent in this number
"To only review data after obvious misoperations is analogous to a doctor ignoring your reports of anxiety, tightness in chest, nausea, and shortness of breath and only treating you for a heart attack if you experience cardiac arrest"

- R. W. Patterson, “The Importance of Power System Event Analysis”

- By using continuous monitoring data to inform PLC operations, maintenance, and analysis, utilities accomplish the following:

  - Reduce effort, uncertainty, and costs associated with operating PLC channels for pilot protection of transmission lines
Questions ?