Mitigating Carrier Holes in Power Line Carrier

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Carrier Holes – What are they?

• Carrier holes is the name given to the loss of power line carrier signal when it should be present.

• They are usually associated with miss-operations due to the lack of receive carrier signal during a fault.

• They do not occur very often, but when they do they are a “pain”.

Carrier Holes – Why Do We Care?

• Carrier holes can cause the Protective Relay system to miss-operate depending on how long they last.
• Unexplained miss-operations due to carrier holes require much time/resources to be spent in investigation and troubleshooting.
• In what ways can carrier holes cause miss-operations:
  1. In DCB ON-OFF systems during an external fault when blocking carrier needs to be sent, loss of carrier signal will cause an over-trip.
  2. In DTT & POTT FSK systems during an internal fault, a Trip will be delayed or will not get through.
  3. In an unblock DCUB FSK system a loss of carrier signal can cause a false Trip permission output window that can result in an over-trip if caused by an external fault.
Carrier Holes – Possible Causes

• Spark gaps firing
• Coax cable flashover from center to outer conductor
• Contact bounce with EM protective relays
• Incorrect settings or calibration of Power Line Carrier receivers.
Carrier Holes – Mitigation Methods

- **Spark gaps** – Maintain or replace them.
- **Coax cable** – Megger, checking for high voltage flashover. Replace deteriorated coax cable. Use better types of coax.
- **Contact bounce** – Use normally closed contacts that open to key the carrier, or use digital protective relays.
- **Incorrect RX settings or calibration** – Double check settings/cal & train personnel.
Carrier Holes – Mitigation Methods

• **Special Settings** – To “ride through” a carrier hole.
  
  – DCB systems: Can add received blocking extension (hold) timers to protective relay or carrier unit.
  
  – DCUB systems: Can delay trip permission window in the carrier unit to wait until a spark gap clears or whatever caused the carrier hole.
Carrier Holes – Unexplained Ones

• Normal testing of the protective relaying and power line carrier system shows no problems.

• What now??
Carrier Holes – A Dominant Cause

• When a line to ground fault occurs there is normally a transient at the beginning of the fault that usually causes spark gaps to fire.
• How long does it take the spark gap to clear?
• **Tests showed a surprise.** The spark gaps could take extended times of 2-20 msec to clear.
Location of Spark Gaps

Gaps that can cause carrier holes
Spark Gap Study

Researching the internet and talking with surge protection experts revealed a surprise.

• **Gas discharge tubes (GDTs)** fire at a much higher voltage than is required to keep them firing. (Typical GDT fires at 5 kV but can keep firing at less than 180V across it.) This is called their holding voltage (or glow voltage).

• What can keep them firing/holding on?
  1. The PLC Transmitter RF power signal (10W – 100W)
  2. The residual 60 Hz voltage across the drain coil that makes it through the CCVT. (30Vrms max by CCVT standard)

• **Air gaps** don’t have this issue of having a holding voltage lower than their firing voltage.
Present Spark Gaps in Tuners & CCVTs

Gas Discharge Tubes - Advantages

• Being used on many line tuners & CCVTs as they are more precise and sealed therefore not being exposed to contamination and do not require setting.
Present Spark Gaps in Tuners & CCVTs

Gas Discharge Tubes – Disadvantages

• Have the holding voltage phenomenon and tend to have slower clearing times.
• More difficult to tell if damaged due to ceramic enclosure. May need to shine high power light through them to clearly see if darkened.
• When they start to fail the inside of the gas tube will first have dark spots and then completely blackens with time.
• Failed 8mm gas tube that has been broken to reveal inside discoloration.
Present Spark Gaps in Tuners & CCVTs

**Air Gaps - Advantages**

- Still popular due to being able to physically see and clean the gap.
- They extinguish arcs faster than gas tubes when in good condition.
- There are various types ranging from simple metal washers spaced apart to more sophisticated types.
- White arrow shows the thin gap.
Present Spark Gaps in Tuners & CCVTs

Air Gaps - Disadvantages

• Get worse with time from carbon build up and pitting that occur during arcing, humidity/moisture/dust, oxidation, & insects. They can also be misadjusted.

• Photo shows corrosion and non-parallel surfaces of a poorly maintained air gap.
Lab Testing - Spark Gap Setup

- Real world can only be approximated using single pulse surge generator (1.2 x 50 µsec pulse) & dummy power line/CCVT. All other items were actual typical equipment. Carrier unit set to continuously transmit and to receive.

- Recording scope triggered on surge current going through line tuner gap with other scope input measuring hi-speed receiver output. SOEs in PLC also checked.

- **3 variables**: Type of spark gap, transmitter power and 60 Hz residual power coming through CCVT.

- Worst case condition was applying TX power = 100W and 60 Hz voltage = 30V.

- Tens of thousands of surges were applied, 1 at a time, with any loss of carrier > 2msec being counted as a carrier hole.
Lab Test Setup

- PLC TX/RX
- FSK
- Special Hi-speed RX

- 10W - 100W Amp
- Skewed Hybrid

- IN 1, IN 2
  - Recording Scope

- Coax Cable
- LINE TUNER

- Coax Cable
- Surge Generator
- 8kV 2Ω source

- HV Lead-in
- Coupling Capacitor

- Hi-frequency, Test CT
- Drain Coil

- 1 µF bypass

- 60 Hz Adjustable Source
Lab Testing - Spark Gap Results

• **Air gap in line tuner** – Carrier holes were only produced with the a “compromised” gap (set wrongly, damaged, or dirty). Otherwise no carrier holes under any conditions.

• **Normal Gas discharge tube gap (GDT) in line tuner** – Under worst case conditions there were carrier holes occurring 50% of the time.

• **Special High-holding voltage GDTs** in line tuner – No carrier holes ever occurred under any conditions.

• Reducing the RF from the PLC transmitter and the 60 Hz voltage across the CCVT drain coil reduced the % of carrier holes but did not stop them.

• When carrier holes occurred they lasted from 2 – 20 msec with the majority over 8 msec long.
Field Testing - Spark Gap Setup

• A crank disconnect switch was manually opened and shut to create transients close to where the CCVT and our setup was located at one end of the line.

• Recording scope triggered on surge current going through line tuner gap with other scope input measuring hi-speed receiver output. SOEs in PLC also checked.

• **2 variables**: Type of spark gap and transmitter power (60 Hz residual power coming through CCVT was <10V).

• Worst case condition was applying TX power = 100W with GDT gap.

• Disconnect switch was opened/closed over 20 times.
Field Test Setup

Control House

PLC TX/RX
FSK
TX
RX

Special
Hi-speed RX

10W - 100W Amp

Skewed Hybrid
TX
RX

LINE TUNER
IN
OUT

Coax Cable

Recording Scope
IN 1
IN 2

Coax Cable

Hi-frequency, Test CT

Drain Coil

HV Lead-in

Line Trap

Coupling Capacitor
Field Testing - Spark Gap Results

- The disconnect switch opening or closing created about a 2 second long volley of closely-spaced-in-time surges.
- The SOEs in the carrier set showed loss of receive signal ranging from 3 – 13 msec when the normal GDT was in the line tuner or CCVT. Hi-speed RX output monitored by scope was in agreement.
- All gaps in line tuner and CCVT – Had to be either properly set air gaps in good condition or special high-holding voltage GDTs to prevent any carrier holes.
- Reducing the RF from the PLC transmitter reduced the % of carrier holes occurring.
Field Test Results with Normal GDT

Tuner gap current

RX level

RX Drop-Out level
Field Test Results with Hi-Holding voltage GDT
Questions

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