A Reliable Power-Line Carrier-based Relay System

Avoiding Mistakes That Cause PLC Systems to Misoperate or Fail to Operate

Miriam P Sanders, PE
(Quanta Technology, LLC)
Outline

- Review the PLC Channel.
- What is reliability?
- Review systems utilizing PLC channels.
- Designing the PLC system for better reliability.
- Installing the PLC system for better reliability.
- Maintaining the PLC System for better reliability.
- After Final Checkouts.
- Summary and resources.
The PLC Channel

Signal:
30 to 500 kHz
1 to 100 Watts
(7 to 70 V rms)

✓ Received Signal Level
✓ Signal to Noise Ratio

Diagram:
- Protective Relay System
- Control House
- Coaxial Cable
- Line Trap
- Station A Bus
- Fault
- Switchyard
- Coupling Capacitor Voltage Transformer (ccvt)
- Drain Coil
- Line Tuner
Reliability

Transmission Line Protection PLC based systems tend towards the Dependability side

Dependability
Trip when it should

Security
Not trip when it shouldn’t
Transmission Line Protection

- Directional Comparison Systems.
  - Compares fault current direction to make trip/no trip decision.

- Phase Comparison Systems.
  - Compares the fault current phase angle to make trip/no trip decision.

- Blocking Systems.
  - Blocks for external faults, no signal required for internal fault.

- Permissive Systems.
  - Provides “permission” to trip.
  - Unblock Logic – provides a short window of permission on LOC.
21S at Sub B keys the channel to send a block signal to Sub A to prevent tripping because 21P is armed to trip.

Stop Channel if initiated locally

Coordination Timer

21P

BLOCK

TRIP
Directional Comparison Unblocking (DCUB)

21P at either end keys the channel to send a trip signal to other end to give permission to trip and local 21P is armed to trip.

Coincidence Timer
Unblock Logic

Loss of Guard AND
Low Level results in Unblock window
Equipment Protection – Direct Transfer Trip

- Breaker Failure.
- Transformer Protection.
- Reactor Protection.

High Security Required!
Designing a PLC System

- How many line protection channels are needed?
- What types of line protection channels are desired? This can be on-off, FSK or a combination of both.
- Is DTT required?
- If DTT is required, a single or a dual channel system?
- Is coupling redundancy required? This will be dictated by the criticality of the circuit usually.
Single DCB system

Line Trap

1200 or 600 Hz BW

Single Frequency or Wideband Tuner

CCVT
DCB and DTT

Line Trap

CCVT

Line Relay
ON-OFF
XMTR
RCVR
Breaker Failure System
FSK DTT 300 Hz BW

R Hybrid
X Hybrid
LT
Single Frequency or Wideband Tuner
DCB and DTT w/Skewed Hybrid

- Line Relay
- ON-OFF
- XMTR
- R Hybrid
- XMTR port
- Single Frequency or Wideband Tuner
- LT
- S Hybrid
- Rcvr port
- Line Trap
- Breaker Failure System
- FSK DTT 300 Hz BW
- Relay
- CCVT
- OCVT
DCUB with DTT

Line Relay

Breaker Failure System

FSK DCUB 600 Hz BW

FSK DTT 300 Hz BW

Line Traps

CCVTs

R Hybrid

XMTR port

S Hybrid

Rcvr port

LT
DCUB with Dual DTT

- XMTR
- RCVR
- FSK DTT 300 Hz BW
- XMTR
- RCVR
- FSK DTT 300 Hz BW
- XMTR
- RCVR
- DCUB 600 Hz BW

- R Hybrid
- Line Trap
- CCVT
- Single Frequency or Wideband Tuner

- S Hybrid
- LT
- XMTR port
- RCVR port
Coupling Options

- Single Phase to Ground Coupling.
- Dual Phase Coupling.
- Three Phase (Mode 1) Coupling.
- Economics.
- Redundancy.
- Reliability.
Dual Phase Coupling

Line Trap

CCVT

Balance XFMR

Single Frequency or Wideband Tuners
These 2 transmitters see only about a 5 to 10 dB isolation at most.
Better Coupling Redundancy

1st Primary Relay System
- Line Relay
- XMTR
- RCVR
- FSK DCUB 600 Hz BW

2nd Primary Relay System
- Line Relay
- XMTR
- RCVR
- FSK DCUB 600 Hz BW

Balance Combiner

CCVT
LT
DTT Security

- Narrowband Channels provide 3 dB improvement of S/N.
- Pre-trip delays add to security.
  - The longer the delay, more security.
- Dual Channels.
  - Both channels required to trip (AND).
- Add some dependability back in with revert to single channel on loss of one.
Revert To Single Channel DTT Scheme

*Loss of Channel, Relay Normally Energized
DTT Security

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- Dual Channels.
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- Add some dependability back in with revert to single channel on loss of one.
- Unblock Window disabled.
  - New technology has provided flexibility.
FSK Security

Low Level = 0

Noise = 1

HF=1

Guard

LF=1

Trip

All timers in ms

Pre-Trip Timer

N=0 to 30

Guard before Trip Timer

120 0

Trip After Guard Window Timer

120 0

Channel Requirements:
Guard Before Trip
Trip After Guard
Pre-Trip Timer
For this system to trip, the relay must first see a forward fault AND receive the trip frequency.

\[ \text{TRIP RECEIVED} \times \text{TRIP} \]

\[ \text{Coincidence Timer} \]

\[ \frac{X}{0} \]

\[ \text{TRIP Output} \]

\[ \text{Drop out of guard starts timer} \]

\[ \frac{0}{N} \]

\[ \text{Unblock Trip} \]

\[ \text{Unblock Timer} \]

\[ 0 = \text{Disabled} \]

\[ N = 0 \text{ to 500} \]

\[ 1 \text{ ms increments} \]

\[ 0 = \text{Disabled} \]

\[ N = 0 \text{ to 100} \]

\[ 1 \text{ ms increments} \]

\[ \text{Unblock Delay} \]

\[ + \text{ Dependable} \]

\[ + \text{ Security} \]

\[ \text{GBT} \]

\[ \text{Low Level} = 0 \]

\[ \text{TRIP Received} \]
Words of Caution

- Use the PLC channel’s logic for Unblock.
  - Well proven logic since mid-1960’s.
  - More accurate.
  - Source of the information.
  - More timely and accurate information.
  - Demarcation for operational analysis.
Increasing Security in DCB

- Automatic Checkback systems.
  - Verifies channel under non-fault conditions.
  - May not undercover “carrier holes”.

- Carrier Hole Filling logic adds security, at the expense of dependability.
  - Be careful.
  - Review all logic.
  - Tripping for cross over faults.

- Need more security – go with a DCUB.
DCB Keying Logic

- Carrier STOP must have priority.
  - Removing Start does not equal Stop.
- NC reduces contact bounce.
- NC monitors integrity of start circuit.

(a) Key transmitter with opening of normally closed contact
(b) Key transmitter with closing of normally open contact
Installation/Commissioning

- Tuning/Calibration.
  - Transmitter.
    - Tune terminated in a 50 ohm load.
    - Not connected to hybrids and tuner (not a 50 ohm load!).
  - Line Tuner.
    - $GMF = \sqrt{f_l \times f_h}$
    - Max Power Transfer $\Rightarrow$ Min Reflected Power.
Installation/Commissioning

- Receivers
  - After transmitters, line tuners and hybrids.
  - 15 dB margin typical.
  - = level received – 15 dB signal loss.
  - Margin for weather and signal degradation.
  - Icing will result in no signal
  - Setting it absolute minimum level will allow noise to operate it.
  - FSK systems usually boost another 10 dB to ride thru faults.
Installation/Commissioning

- Proper Grounding:
  - Chassis Grounding.
    - Braided cable or heavy conductor.
    - Direct Connection to ground bar (no daisy-chains).
Coax/Triax Grounding

- **Coax Grounding:**
  - Outer Shield ground in house, not at tuner.

- **Triax Grounding:**
  - Inner shield ground in house.
  - Outer shield ground in house and at tuner.
Knife Switch

Center Conductor

Coax to Line Tuner

Braided Shield

Coax to PLC Equipment
Maintenance

- Monitored vs. Interval Testing
- Revisit practices, particularly when upgrading systems
- Reduce manual testing by including more monitoring
  - Margin Levels
  - Reflected Power trends
- Automated Testing where possible
ON-OFF Channel Maintenance

- Automatic Checkback Testing
  - Alarms if the system becomes non-functional
  - Can revert to step-distance if so desired
  - Does not normally run during internal or external faults
  - Integral systems may not verify interface to relay
  - Interval determined by utility practice
Transients on transmission line can:

- Cause flash-over of equipment
  - Coax/Triax Cable
  - Lead-in cables
  - GAPS
GAPS

- Air Gaps
- Gas Tube
- Other limiting device
- Coordinate GAPS
FSK Channel Maintenance

- Self Monitored Channel
- Not self-monitored equipment
  - Will the transmitter shift?
  - Will the receiver see the shift?
- DTT or DCUB systems could fail to trip
Before you lock the door

- Check all knife switches
  - In house
  - In tuner
  - On ccvt

- Check all selector switches
  - 85CO
  - Pilot Selection
Summary

- Understanding the PLC Channel
- Pros and Cons
- Flexibility
- New Technologies
Questions