Recent Utility Experience with High Impedance Fault Detection

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Introduction

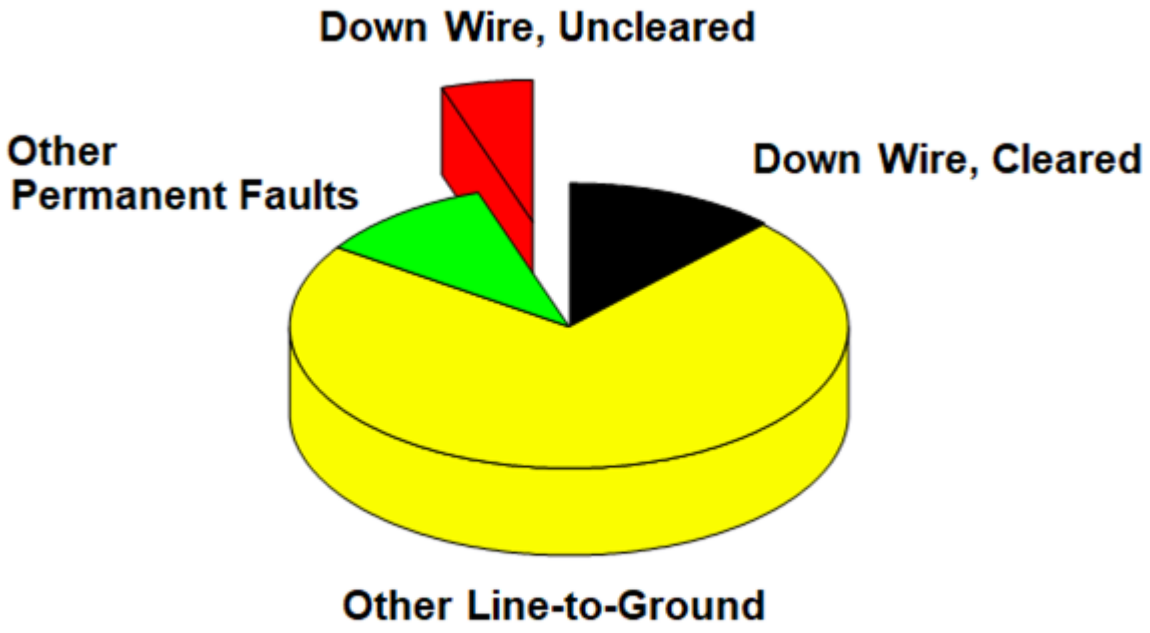
- High-impedance fault detection technology has been available in Digital Relays since the mid 1990's.
- One implementation of this technology has been adopted by Potomac Electric Power Company (PEPCO) and has been in service since the early 2000's over most of their system.
- Detection of a Downed Conductor on the PEPCO system by HiZ element Trips the associated feeder.
- Over the past 17 months, PEPCO has conducted a detailed monitoring study on the efficiency of the High Impedance fault technology installed on their system.

HiZ Faults: Misconceptions and Reality

Misconception	Reality
Properly set, overcurrent protection will clear all faults.	HiZ faults often draw less current than loads, making overcurrent protection impossible.
Sensitive ground protection will clear HiZ faults.	Unbalanced loads limit sensitivity of ground protection. Moreover a down conductor can result in more balanced loads and reduced neutral current.
Over time, fault current will increase and operate protection.	In most cases, fault current decreases as conductor burns, moisture evaporates, sand fuses, etc. O/C protection seldom operates after first minute or so.
HiZ faults always clear on <u>my</u> system.	Engineering staffs believe HiZ fault rate is low, but line crews report many downed conductors are still hot when they arrive on scene.

HiZ Element: Aim

- HiZ Element focuses on a small piece of the pie, i.e., uncleared downed conductor faults.
- Detecting 80-85% of these previously undetected faults is an accomplishment.
- The ultimate goal is to have 100% detection rate.



Approx. 30% of Down Conductors are Live (Uncleared)

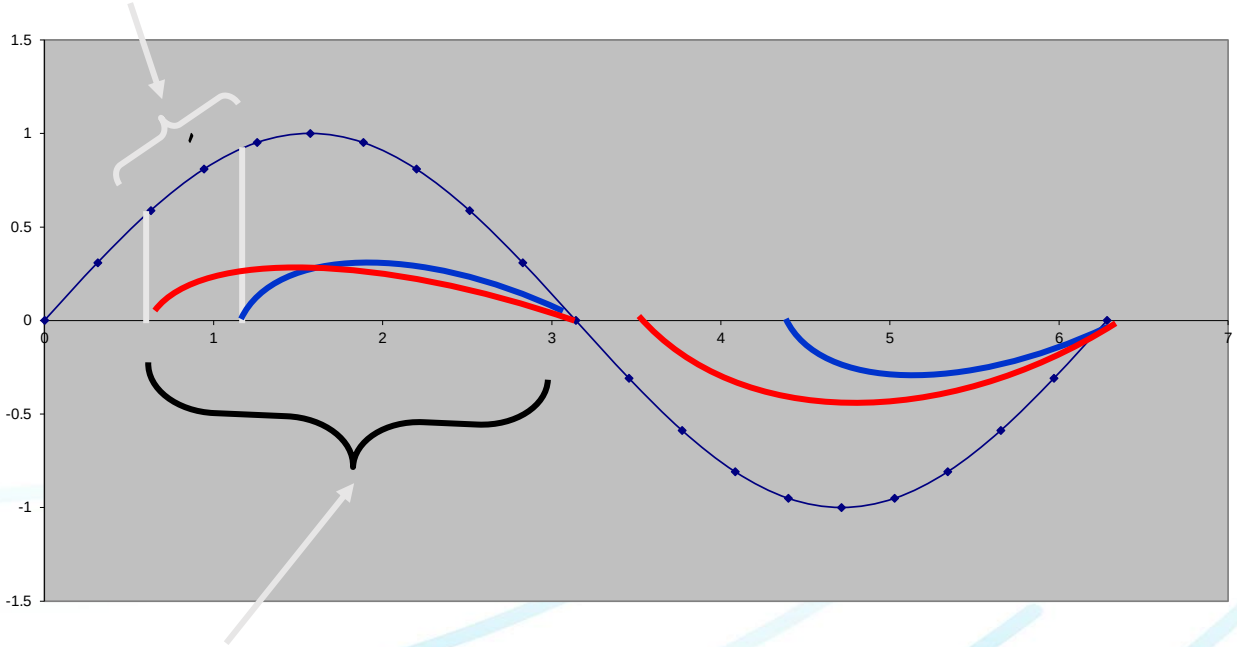
The achievement of 100% detection rate must not come at the expense of loss of security.

HiZ Element: PEPCO Expectations

- Operate only if a high-impedance fault is truly present.
- Detect both intact and broken downed conductors.
- Provides an opportunity for conventional overcurrent protection to operate first.
- Use additional sources of information such as voltage, breaker operation, current change pattern in each phase to enhance security.
- Employ power system learning to baseline the background noise and harmonic content, and to adjust algorithm sensitivity, adaptively.
- Bias the system toward security.

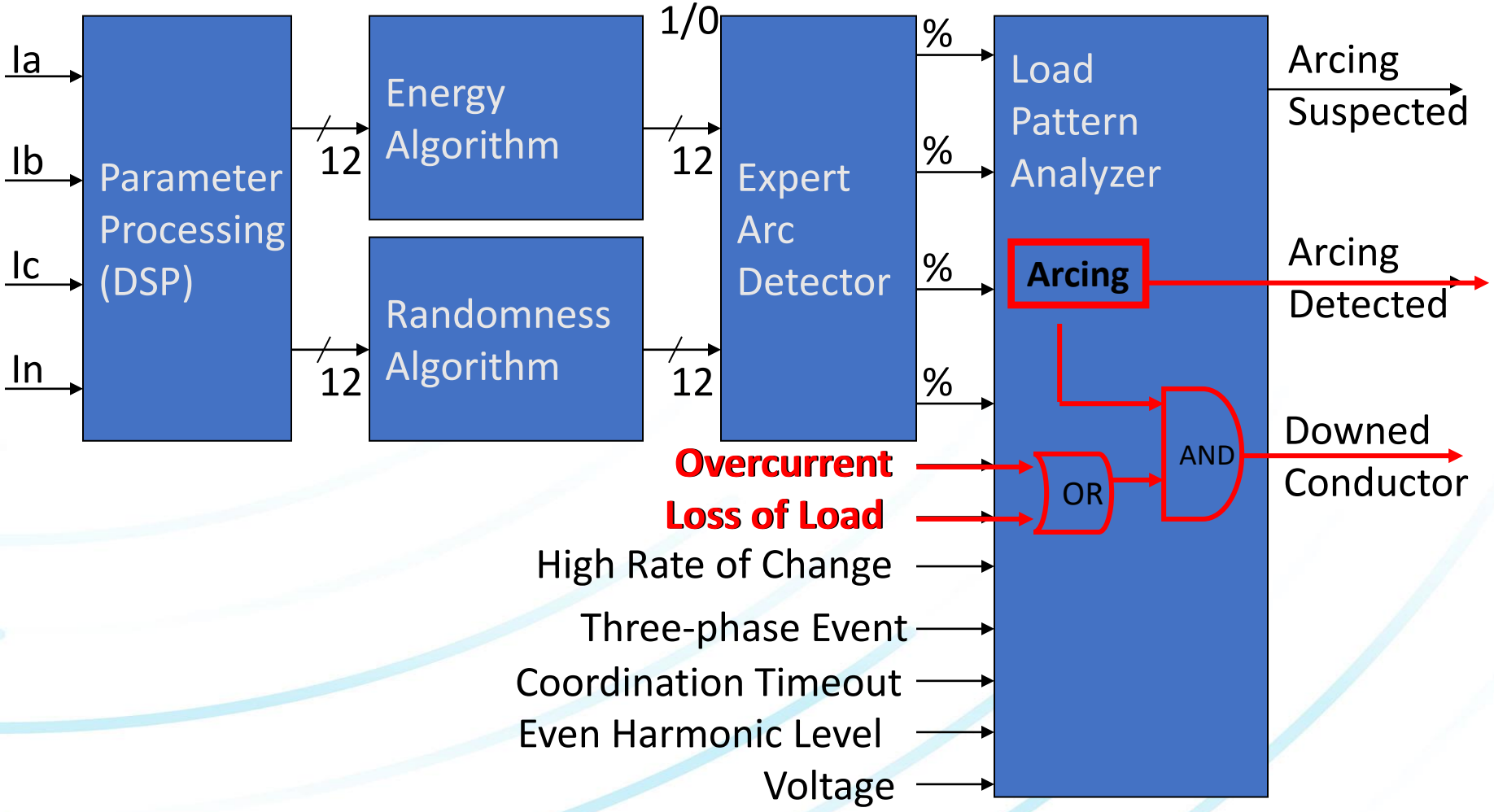
Arcing Phenomenon

- Variable Arc Inception Voltage



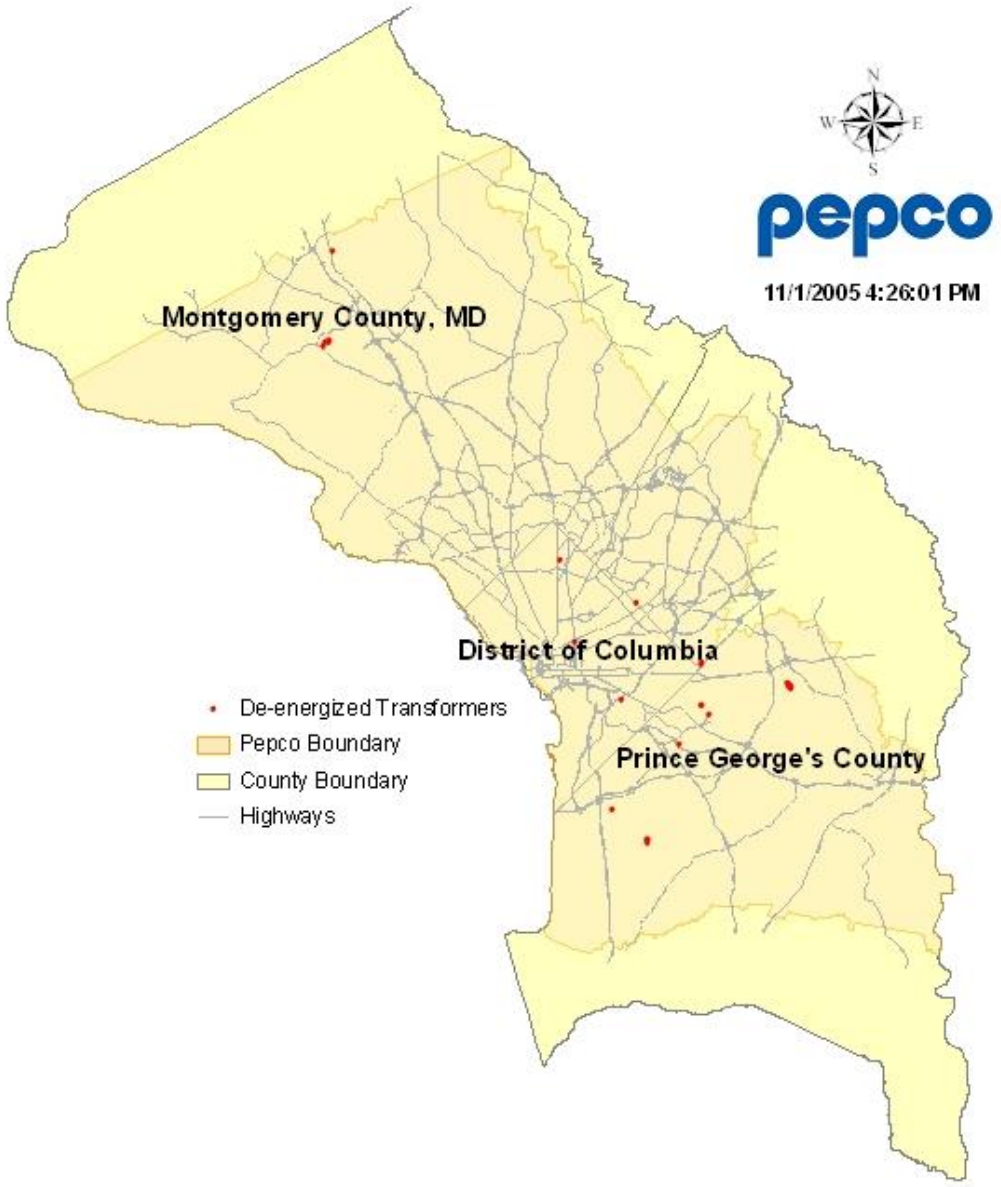
- Variable Arcing Current Shape / harmonic content
- Typically not symmetric on positive vs. negative half wave – results in even harmonics
- The relay deployed on the PEPCO system analyzes the Harmonic Content

Simplified Block Diagram



PEPCO system and HiZ Implementation

- PEPCO, incorporated in 1909 provides electric distribution service to 2.3 million people in Washington DC area.
- PEPCO distribution system consists of nearly 1500 13 kV feeders.
- Nearly half of them are in overhead 4-wire multi-grounded wye configurations.
- PEPCO began pilot for detecting downed conductor in early 2000s.



HiZ Study by PEPCO

- An evaluation of downed conductor detection was performed on the Pepco system with the aim of enhancing the safety of public, employees, and minimization of property damage.
- Pepco's evaluation involved approximately 780 relays over a seventeen-month timeframe.
- This represents 1105 relay-years of operation.
- The study had the following criteria:
  - having an indication from an operator log or from a target report, and
  - having relay data to support analysis and from which to draw conclusions about the relay's operation.

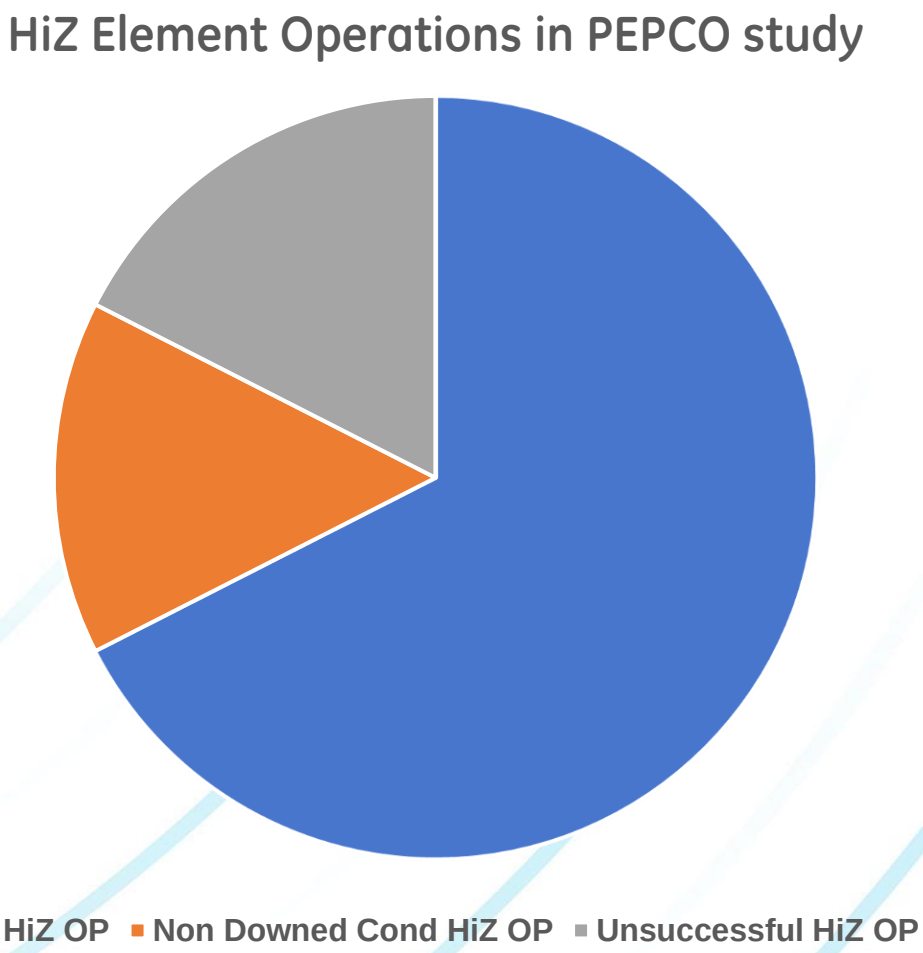
HiZ Study by PEPCO

PEPCO classified the recorded downed conductor indications into three classifications:

- Successful operation: the relay tripped for downed conductor and the operator log mentions that wires on the ground were found.
- Non-downed conductor HiZ operation: the relay tripped on downed conductor but operator log does not mention wires on ground found, only symptoms of Arcing were found.
- Unsuccessful operation: An unsuccessful operation indicated that the relay tripped for downed conductor and the operator log does not mentioned that the downed wires or other HiZ conditions were found.

HiZ Study by PEPCO: Results Overview

- Pepco recorded total 42 downed conductor indications by cross-referencing the operator log comments and relay data
- The 42 events consisted of 29 successful downed conductor operations, 6 non-downed conductor HiZ operations, and 7 unsuccessful operations.
- This results in 70% successful operation detection rate and an 83% overall HiZ detection rate, which combines successful operations and non-downed conductor HiZ operations.



HiZ Study by PEPCO: Results Overview

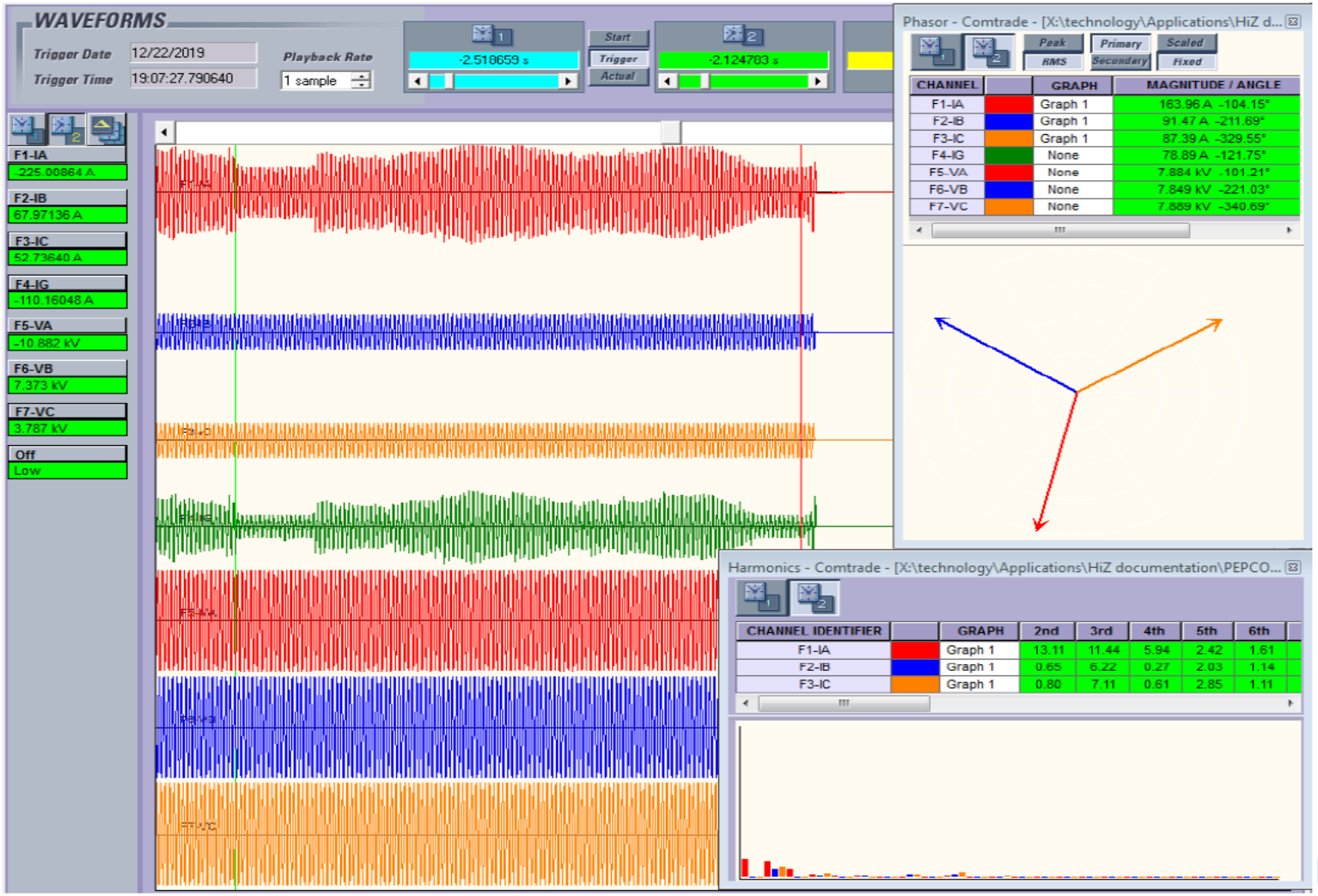
Target	Distribution System Operator Comments	Classification	Reason
DNC-B	At 10:09, circuit tripped with DNC. At 10:12, customer reports wire down. At 11:11, OH Lineman reported AØ primary down due to primary making contact with a tree limb. At 12:38, OH Lineman reported blown BØ fuse & a burnt up BØ cutout. OH Lineman reported BØ primary was off insulators at two poles. At 12:41, OH Lineman reported BØ primary is back up. OH Lineman installed a cutout with dead blade. At 13:48, OH Lineman reported BØ primary was secured to insulators.	Successful	Wires Down
DNC-A	At 16:51, circuit tripped with DNC. At 16:56 emergency personnel reported multiple broken poles and wire down due to large tree. SF6 switch will not open via supervisory for sectionalizing purposes. Close via supervisory, restoring partial load. At 18:25, OH Lineman reported broken pole and 10 spans of wire damaged and hanging low due to large tree. The next day, Mobile Operator reported 2 operations at AØ, CØ, ground, and time.	Successful	Wires Down

HiZ Study by PEPCO: Results Overview

Target	Distribution System Operator Comments	Classification	Reason
DNC-C	At 14:51, circuit tripped with CØ DNC. Received a report of wire arcing. At 15:14, OH Lineman reported nothing found at call location. At 15:22, OH Lineman reported burnt off over the arm tap. At 15:41. OH Lineman reported tap remade. Closed by supervisory; restoring all load. The next day DNC CØ targets were reported.	Non-downed Conductor HiZ	Burnt Arm Tap
DNC-B	Circuit tripped with CØ DNC. At 00:23, OH Lineman patrolled feeder and reported nothing found. Closed by supervisory restoring all load.	Unsuccessful	Nothing Found

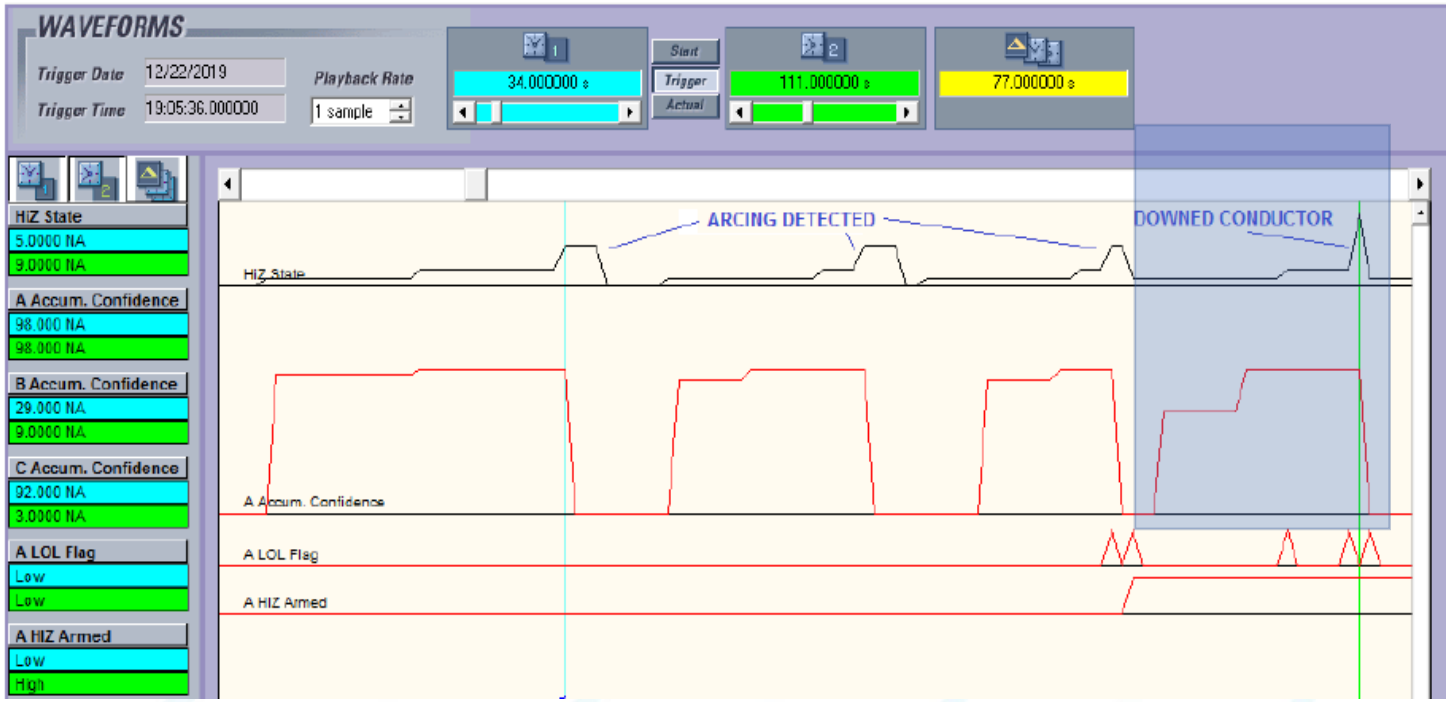
Example 1: Successful HiZ Operation

- The current in phase-A was relatively higher than the other phases with relatively higher harmonic content.
- The current waveform of phase-A shows a Loss of Load (LOL)
- Currents in healthy phases appear to be very steady with low harmonic content.
- Voltages do not show any distortion.



Example 1: Successful HiZ Operation

- The accumulated confidence in phase A rises very rapidly, due to high and varying harmonic content.
- ARCING DETECTED alarm was asserted three times.
- DOWNED CONDUCTOR was declared only when the HiZ Element was triggered by Loss of Load in phase A (A LOL Flag)

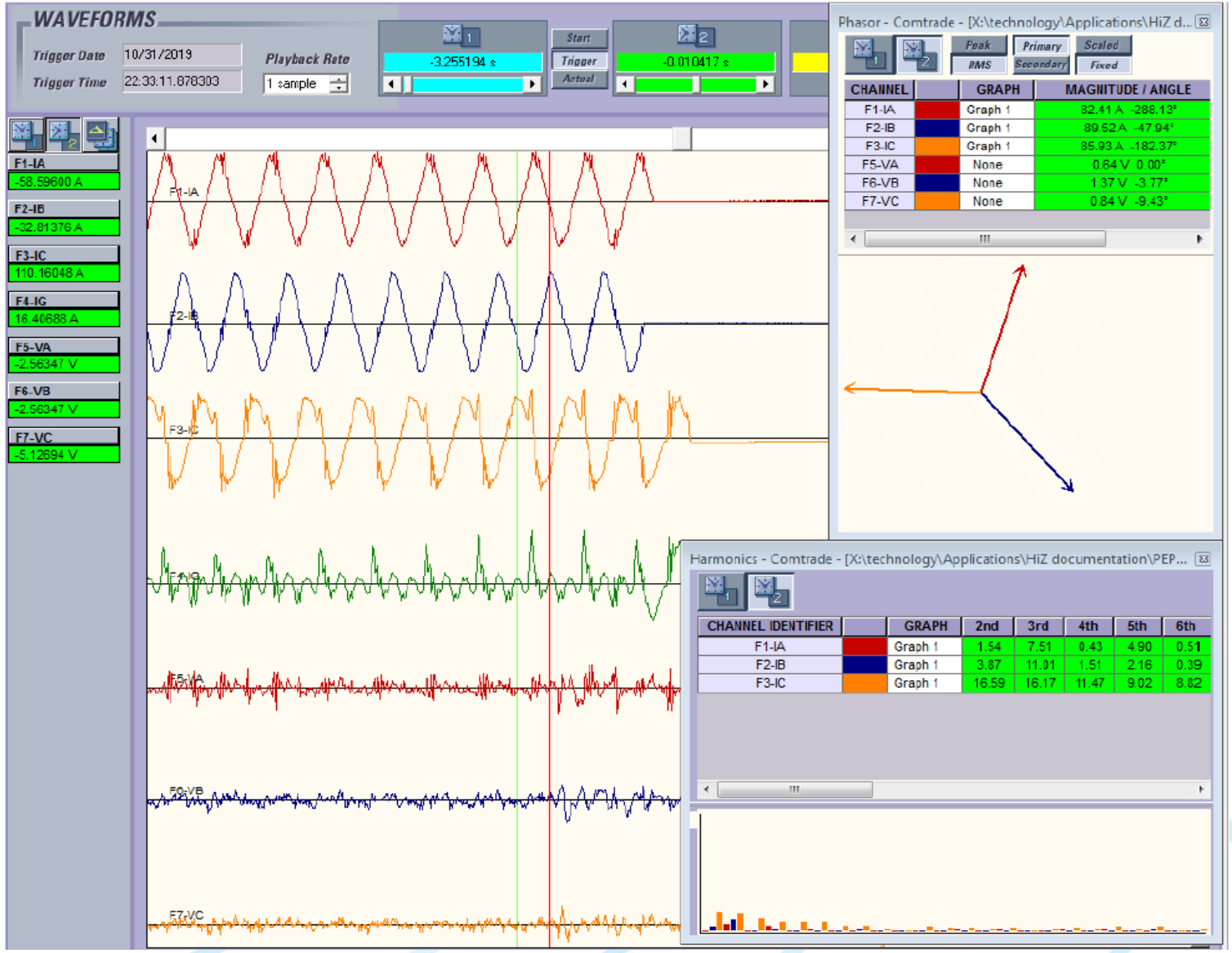


PEPCO service crew inspected the line and downed wires were found on the feeder with the conductor down on the ground in a right-of-way.

<u>Result</u>: The case was classified as <u>Successful HiZ operation</u>

Example2: Non-downed conductor HiZ operation

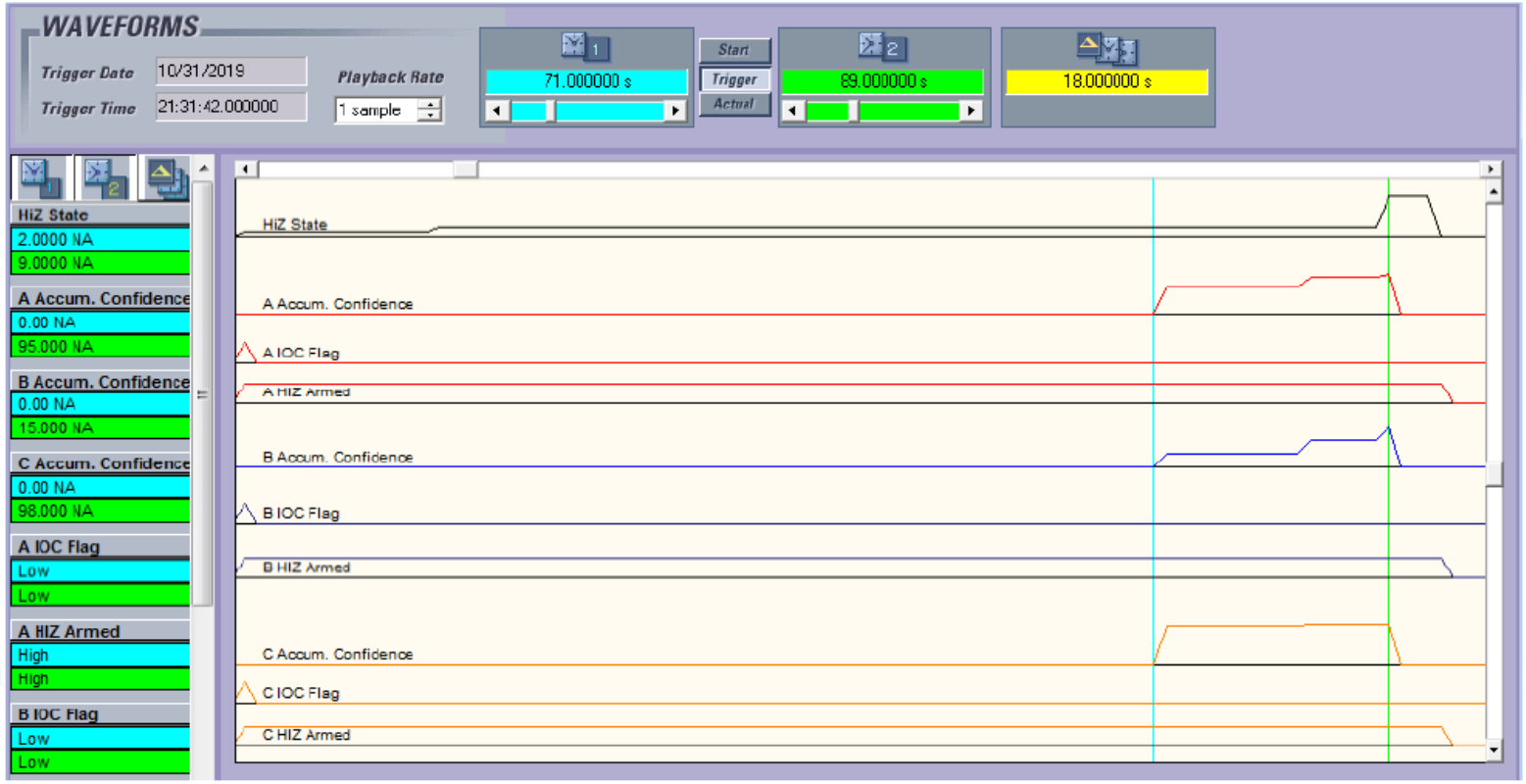
- All three phases had high content of harmonics and were carrying approximately 80A current
- Due to the stormy weather, the system was experiencing heavy switching and disturbances.
- Current in phase C showed a repeated 'glitch' in each fundamental cycle.



Example 2: Non-downed conductor HiZ operation

From HiZ Oscillography:

- A three phase IOC event armed the DNC logic in all three phases.
- No signature of HiZ fault was detected for next 70 seconds.
- Suddenly signature of Hi-Z fault appears, and enough confidence is built in next 18 seconds window to declare a DNC in phase-C.



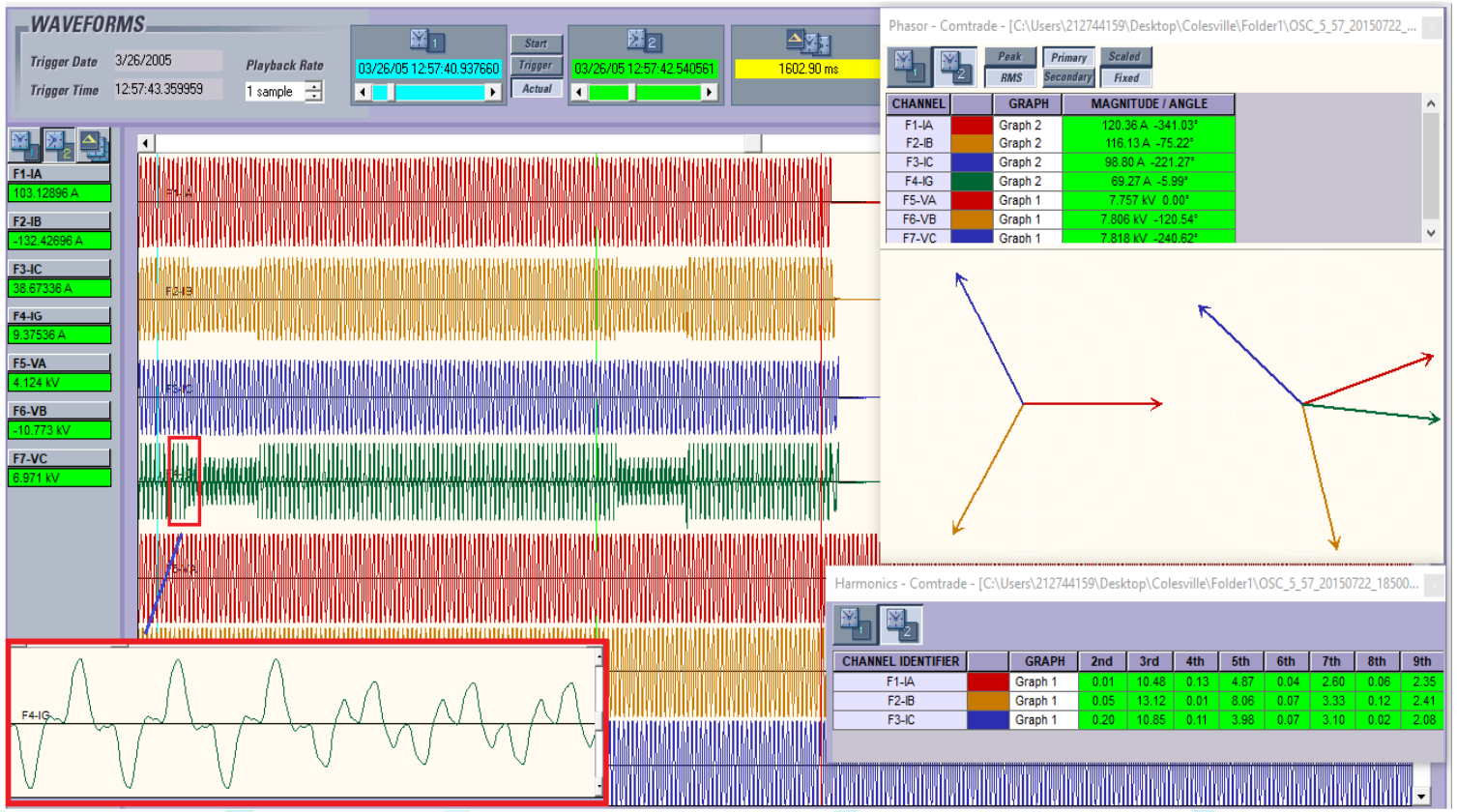
Example 2: Non-downed conductor HiZ operation

- The case was initially classified as False Downed Conductor Event.
- About half an hour after the DNC operation, it was found that a tree limb was hanging on the phase C of the tie.
- Another significant observation was that 8 minutes prior to DNC operation, HiZ element asserted 'Hi-Z ARC DETECTED Phase C alarm, 5 times within the window of approximately 3.5 minutes.
- HiZ algorithm was rightly yielding 'Hi-Z ARC DETECTED Phase C repeatedly; however system conditions armed the DNC logic and resulted in DNC operation.

Result: The case was classified as <u>Non-downed conductor HiZ operation.</u>

Example 3: Unsuccessful HiZ operation

- The phase currents were significantly unbalanced.
- Two ‘dips’ visible in phase B and neutral currents, simultaneously.
- Both ‘dips’ lasted about 250ms and involved identical change in the phase B and neutral fundamental currents.
- The fundamental component of the neutral current was reduced significantly during the ‘dips’.



Example 3: Unsuccessful HiZ operation

- "HiZ- Loss of Load-B" was logged multiple time before HiZ algorithm declared the "HiZ-Downed Cond-B".
- This unusual disturbance in phase-B lasted for about 3.5 hours, before the operation of "HiZ-Downed Cond-B" (not fully shown in Event log)

0 days 1 h : 8 m : 43.539251 s

Event Number	Date/Time	
39573	Mar 26 2005 12:57:43.357874	HI-Z DOWNED COND-B
39572	Mar 26 2005 12:57:30.358908	HI-Z LOSS OF LOAD-B
39571	Mar 26 2005 12:57:07.357990	HI-Z LOSS OF LOAD-B
39570	Mar 26 2005 12:57:05.360885	HI-Z ARC DETECTED DPO
39569	Mar 26 2005 12:57:04.275886	HI-Z ARC DETECTED-B
39568	Mar 26 2005 12:55:55.285836	HI-Z ARC DETECTED DPO
39567	Mar 26 2005 12:55:54.209098	HI-Z ARC DETECTED-B
39566	Mar 26 2005 12:55:53.207357	HI-Z LOSS OF LOAD-B
39565	Mar 26 2005 12:55:51.208051	HI-Z LOSS OF LOAD-B
39564	Mar 26 2005 12:55:49.208758	HI-Z LOSS OF LOAD-B
39563	Mar 26 2005 12:55:47.207322	HI-Z LOSS OF LOAD-B
39562	Mar 26 2005 12:55:43.208456	HI-Z LOSS OF LOAD-B
39561	Mar 26 2005 12:55:34.208683	HI-Z LOSS OF LOAD-B
39560	Mar 26 2005 12:55:31.207347	HI-Z LOSS OF LOAD-B
39559	Mar 26 2005 12:55:28.208116	HI-Z LOSS OF LOAD-B
39558	Mar 26 2005 12:55:09.158934	HI-Z LOSS OF LOAD-B
39557	Mar 26 2005 12:55:07.157408	HI-Z LOSS OF LOAD-B
39556	Mar 26 2005 12:54:57.158319	HI-Z LOSS OF LOAD-B
39555	Mar 26 2005 12:53:27.092154	HI-Z ARC DETECTED DPO
39554	Mar 26 2005 12:53:26.090374	HI-Z ARC DETECTED-B
39553	Mar 26 2005 12:52:25.092558	HI-Z ARC DETECTED DPO
39552	Mar 26 2005 12:52:24.026475	HI-Z ARC DETECTED-B
39551	Mar 26 2005 11:59:58.935737	HI-Z LOSS OF LOAD-B
39550	Mar 26 2005 11:59:54.933861	HI-Z LOSS OF LOAD-B
39549	Mar 26 2005 11:59:27.934285	HI-Z LOSS OF LOAD-B
39548	Mar 26 2005 11:59:25.935360	HI-Z LOSS OF LOAD-B
39547	Mar 26 2005 11:55:41.933936	HI-Z LOSS OF LOAD-B
39546	Mar 26 2005 11:54:30.934678	HI-Z LOSS OF LOAD-B
39545	Mar 26 2005 11:50:09.900014	HI-Z ARC DETECTED DPO
39544	Mar 26 2005 11:50:08.900067	HI-Z ARC DETECTED-B
39543	Mar 26 2005 11:48:59.818623	HI-Z ARC DETECTED DPO

Example 3: Unsuccessful HiZ operation

- It is highly likely that a relatively high-power electronic device (such as a Variable Frequency Drive or an inverter) was malfunctioning in Phase B.
- This false DNC operation occurred due to extra-ordinary system operating conditions.
- It satisfied loss of load criteria and the randomness, and energy algorithms of the HiZ algorithm.
- PEPCO crew patrolled the feeder and did not find any downed conductor or any evidence of other HiZ fault.

Result: The case was classified as Unsuccessful HiZ operation

Conclusion

- Downed wire detection is an inherently challenging task and there is no present technology can achieve 100% reliability.
- The characteristics of high-impedance faults are variable, unpredictable and depend on many factors such as surface, system grounding, weather etc.
- These challenges call for a balance between safety and reliability.
- High-impedance faults will continue to be an electric utility issue going into the future.
- Experiential learning has identified key areas for enhancements in the technology.

Conclusion

- PEPCO field experience indicates fairly high percentage of the successful operations of HiZ element:
  - nearly 70% successful operation downed conductor detection rate
  - an 83% overall high-impedance faults detection rate.
- Future improvements identified are:
  - to enhance supervision by using other elements available in the relay.
  - reducing reliance on the current harmonics in the ground channel.
  - to differentiate between harmonics from industrial processes and ones resulting from the true high-impedance faults.

Thank You

Questions?