Automatic Voltage Anomaly Detection in Fault Records at American Electric Power

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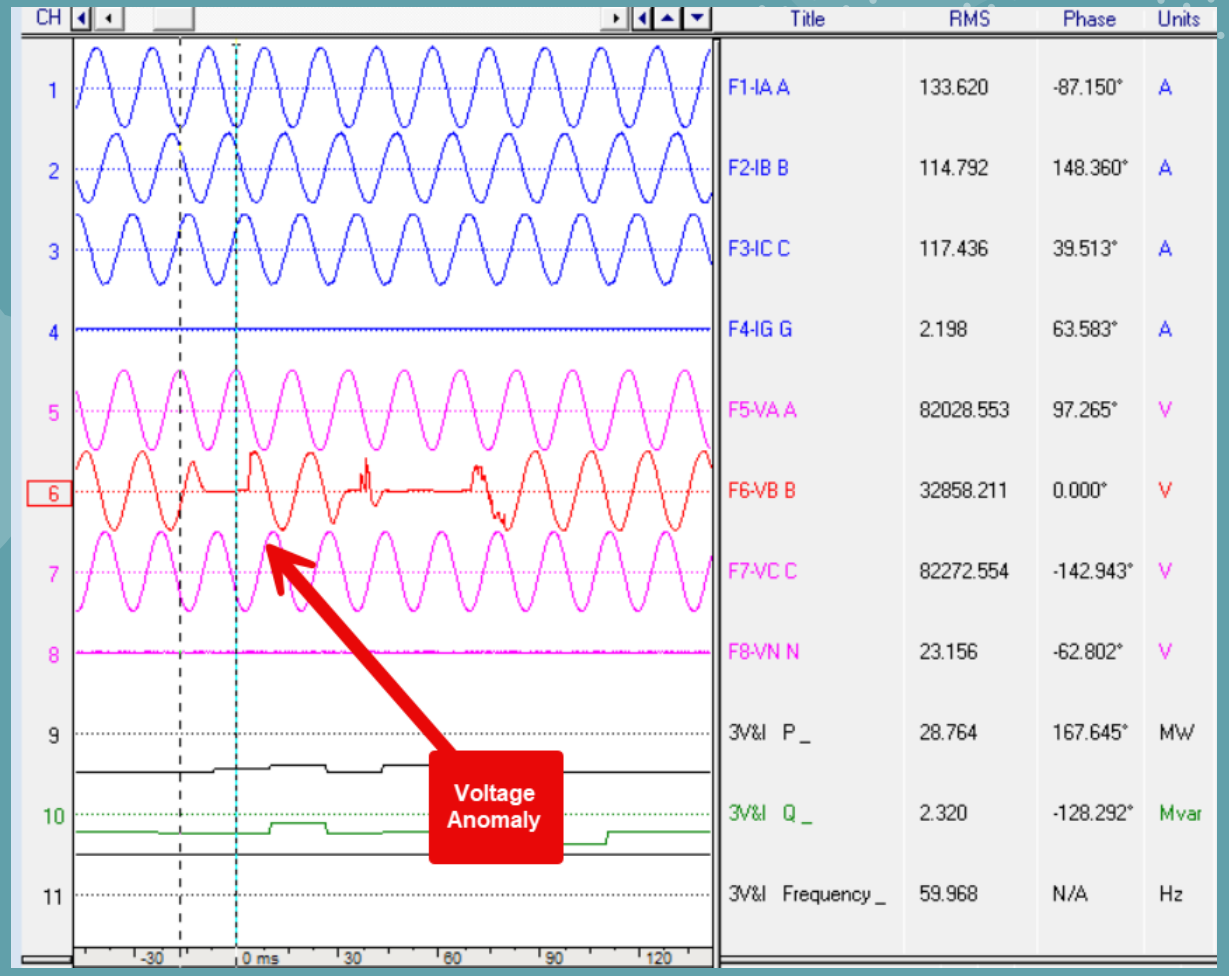
What is a Voltage Anomaly?

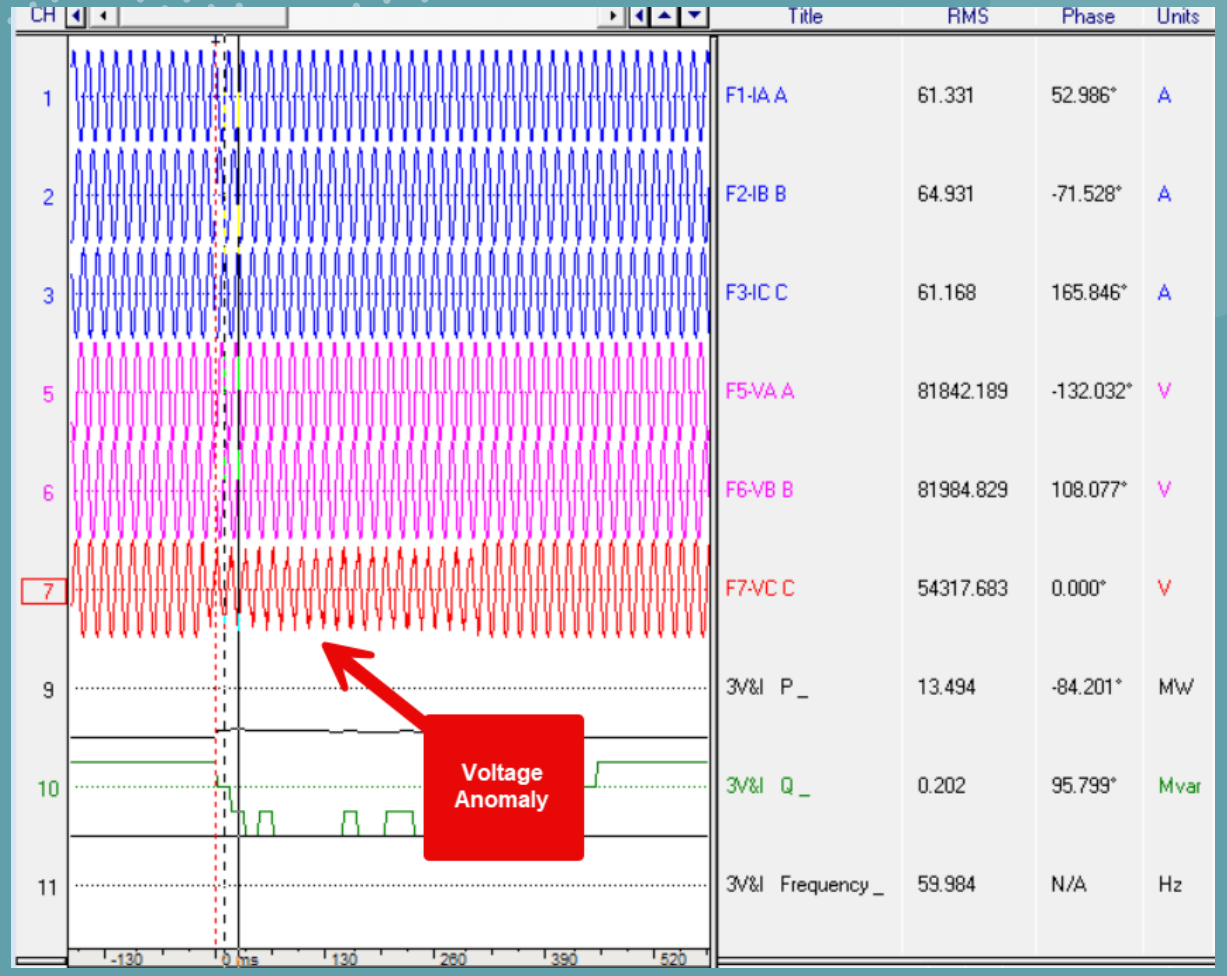
An abnormal, or distorted, voltage waveform that is present in an oscillography recording where there is no other disturbance present in the current waveforms that would indicate a valid system event has occurred.

Simply put, voltage changes with no associated current changes.

Voltage Anomaly Examples



Cause = loose connection in yard cabinet due to partially stripped bolt.



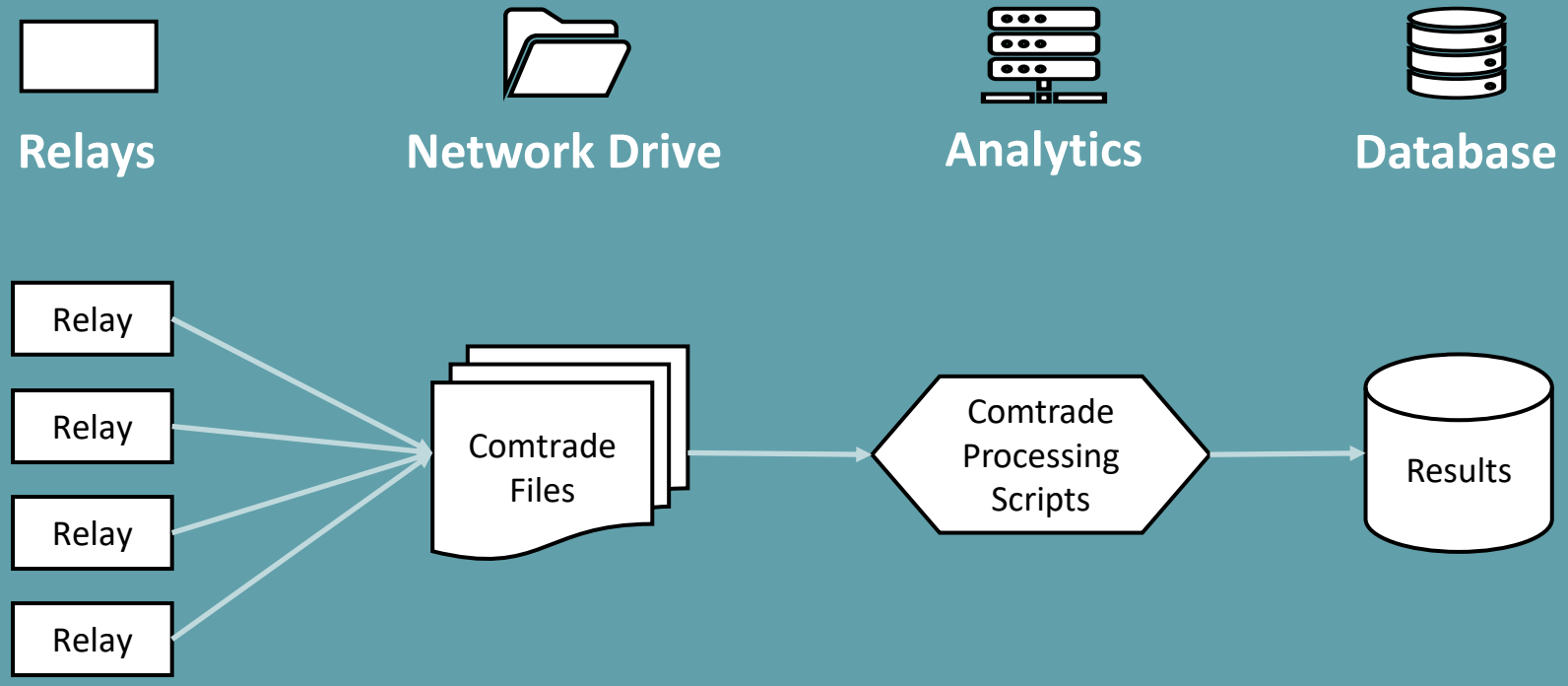
Cause = suspect the bus PT.

Historical Process

How did AEP find voltage anomalies?

1) By stumbling on and looking at non-essential relay oscillography records during event reviews.
2) By looking for oscillography records after questions by customers or other entities about local disturbances to their loads, etc.
3) When performing annual PRC-002 site review work for FR (fault recording) compliance.
4) Longer duration issues might alarm on SCADA.

Infrastructure



Channel Mapping

Analog Channel Mapping

- Newer relays have multiple current channels for each breaker
- Line current must be computed

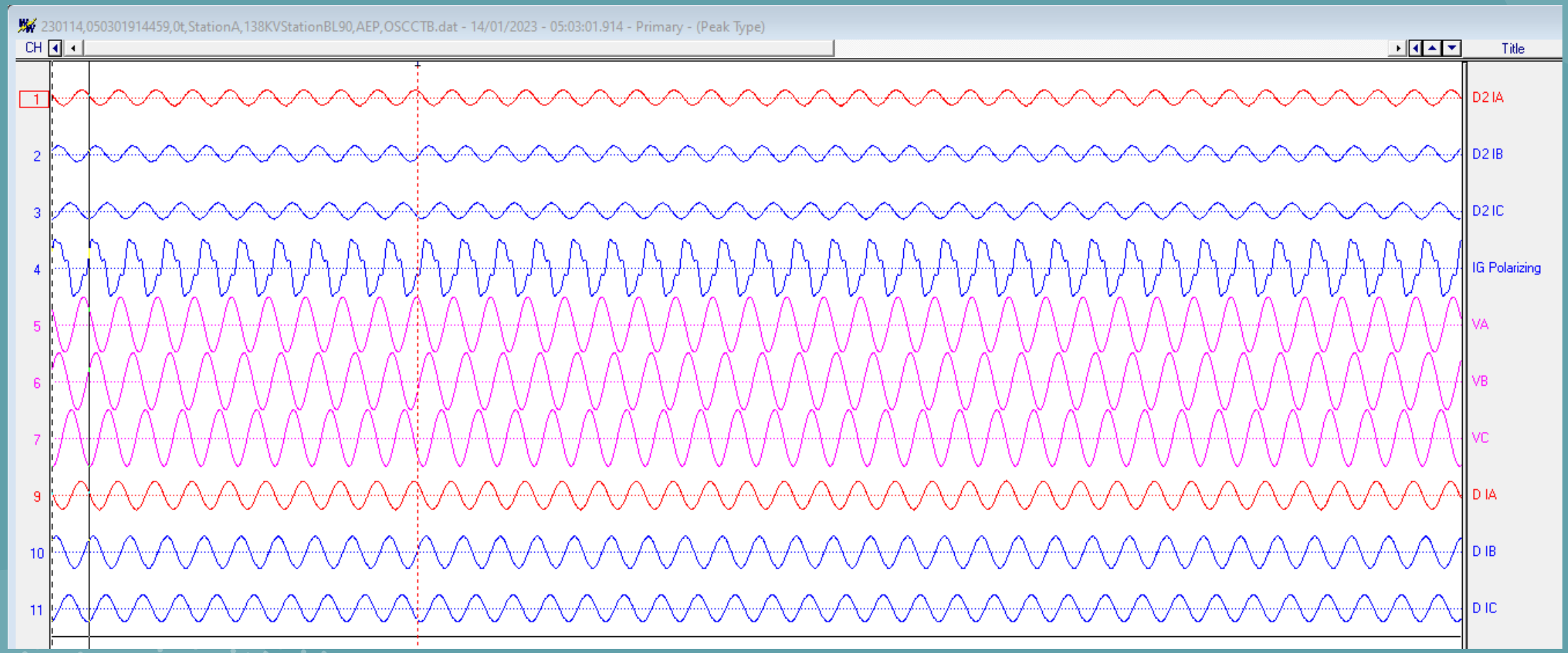
Example for computing phase A current from a GE L90:

- If name of channel 13 ends in “IA” then IA = sum(channels 1, 9, 13)
- Else if name of channel 9 ends in “IA” then IA = sum(channels 1, 9)
- Else IA = channel 1

Similar logic was developed for each line relay model

Channel Mapping Example

- For this L90, line IA = ch1 + ch9



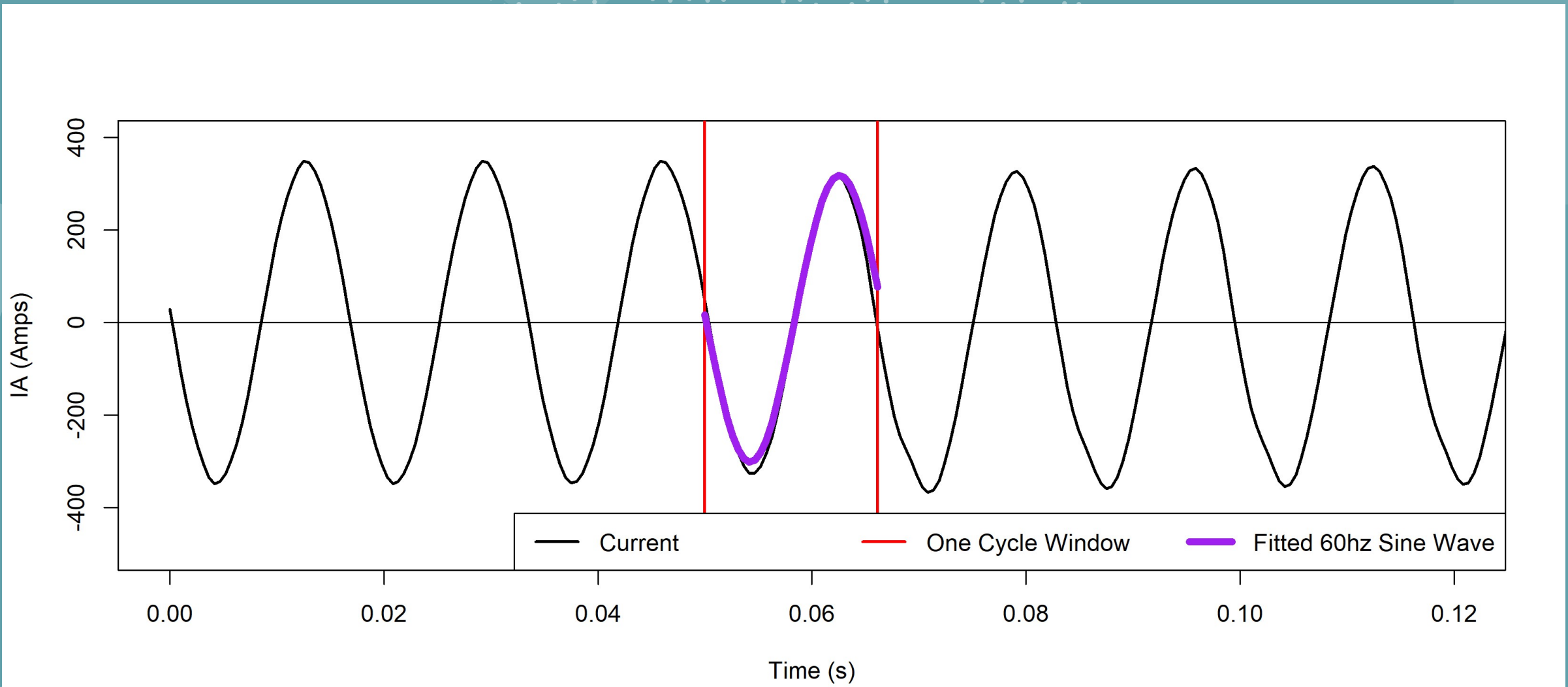
Anomaly Detection Methodology

Algorithm:

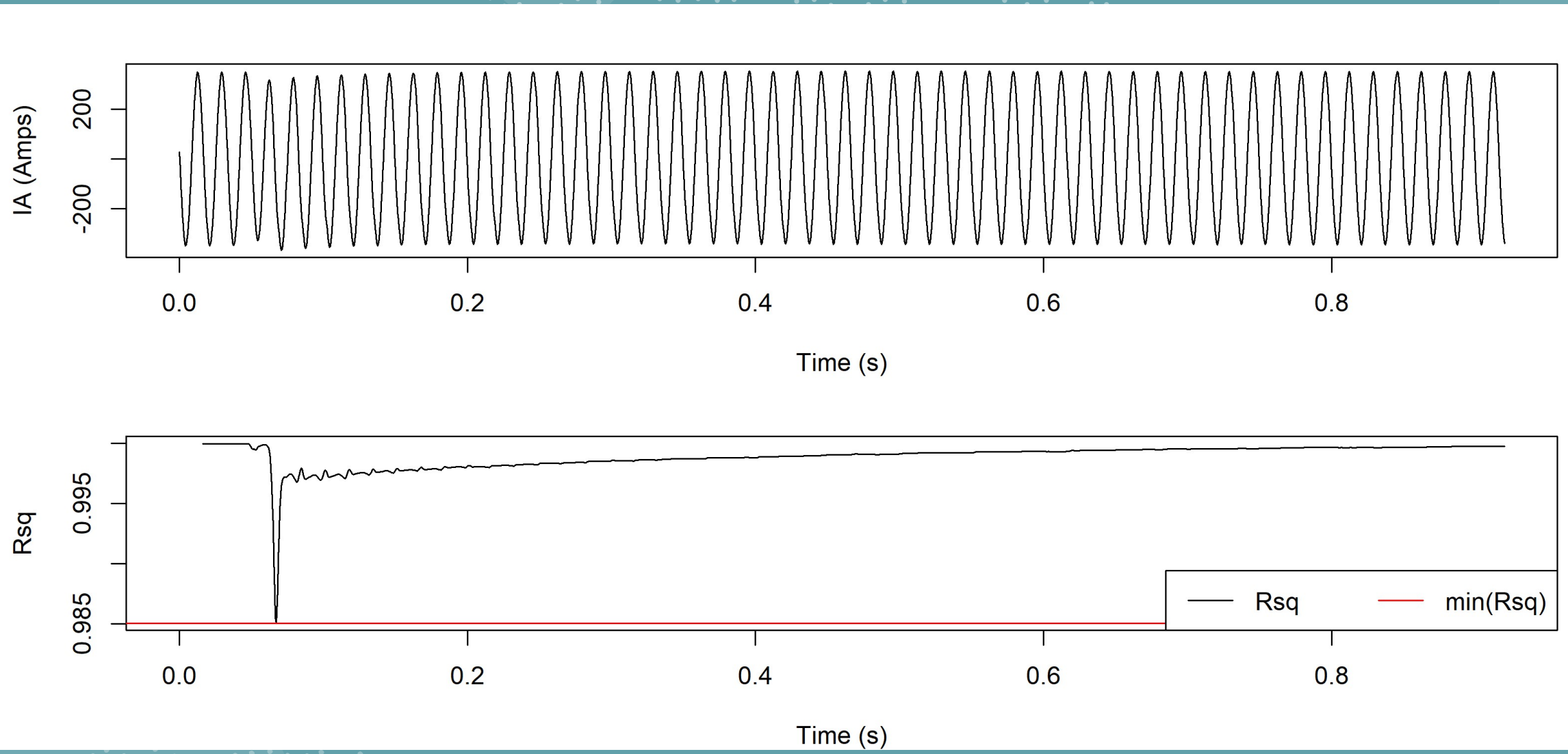
1. For a one cycle rolling window, fit a 60Hz sine wave on IA, IB, IC, VA, VB, VC
2. Compute R^2 (Rsq) of each sine wave fit
3. For IA, IB, IC, VA, VB, VC compute the minimum Rsq across all fits in the file
4. Flag files where:

   [min_rsq(IA) > 0.99 and min_rsq(IB) > 0.99 and min_rsq(IC) > 0.99] and
   [min_rsq(VA) < 0.40 or min_rsq(VB) < 0.40 or min_rsq(VC) < 0.40]

Fit 60Hz Sine Wave



Compute R^2 of Sine Wave Fit



Results

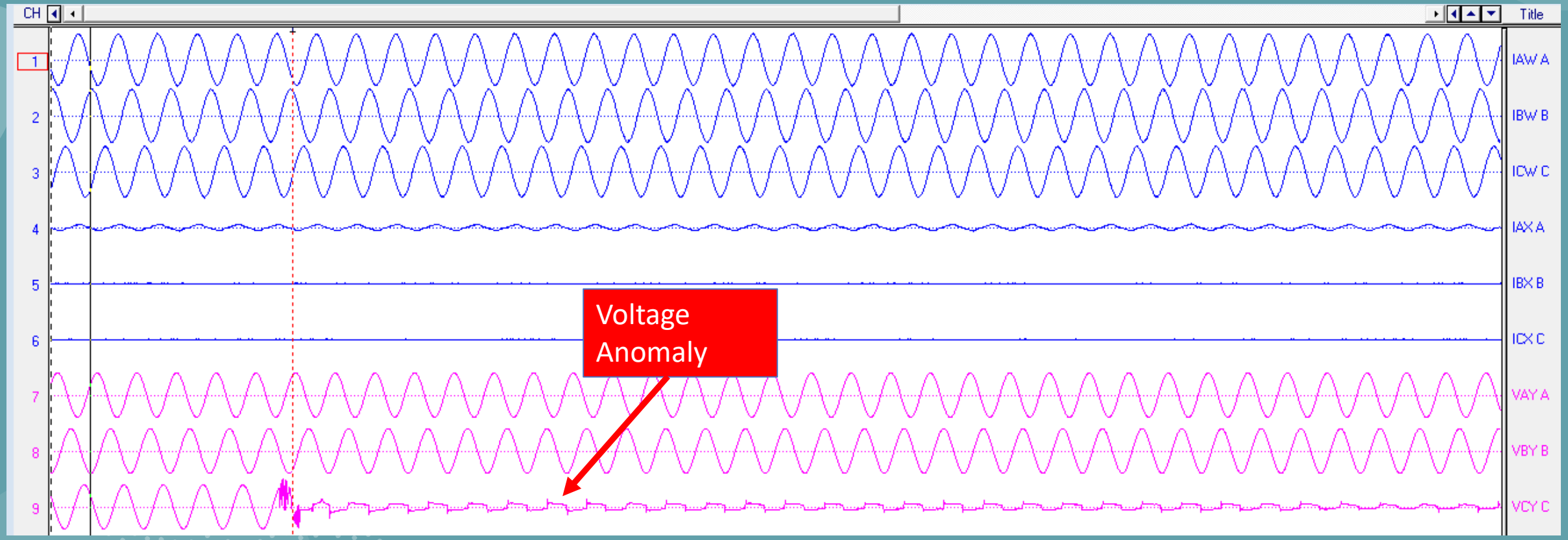
Processed all line relay comtrade files from 09/01/2023 – 01/31/2024

Files	Count
Processed	625,924
Clean currents (all Rsq > 0.99)	288,935
Flagged (any voltage Rsq < 0.4)	223
Showing voltage anomalies	61

61 records ➔ 14 Relays involved
4 Relays where cause is found and fixed
3 Relays under investigation
Others were single event issues and not recurring at this time.

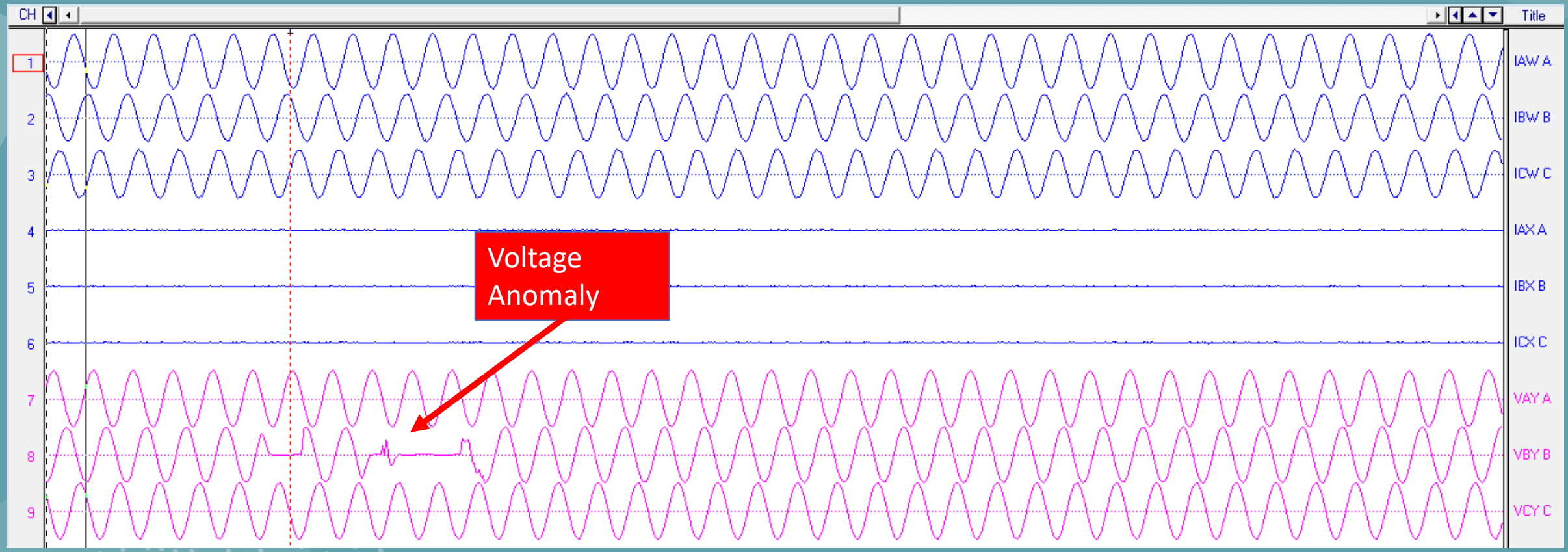
Anomaly Examples

Failed CCVT (also seen on SCADA)



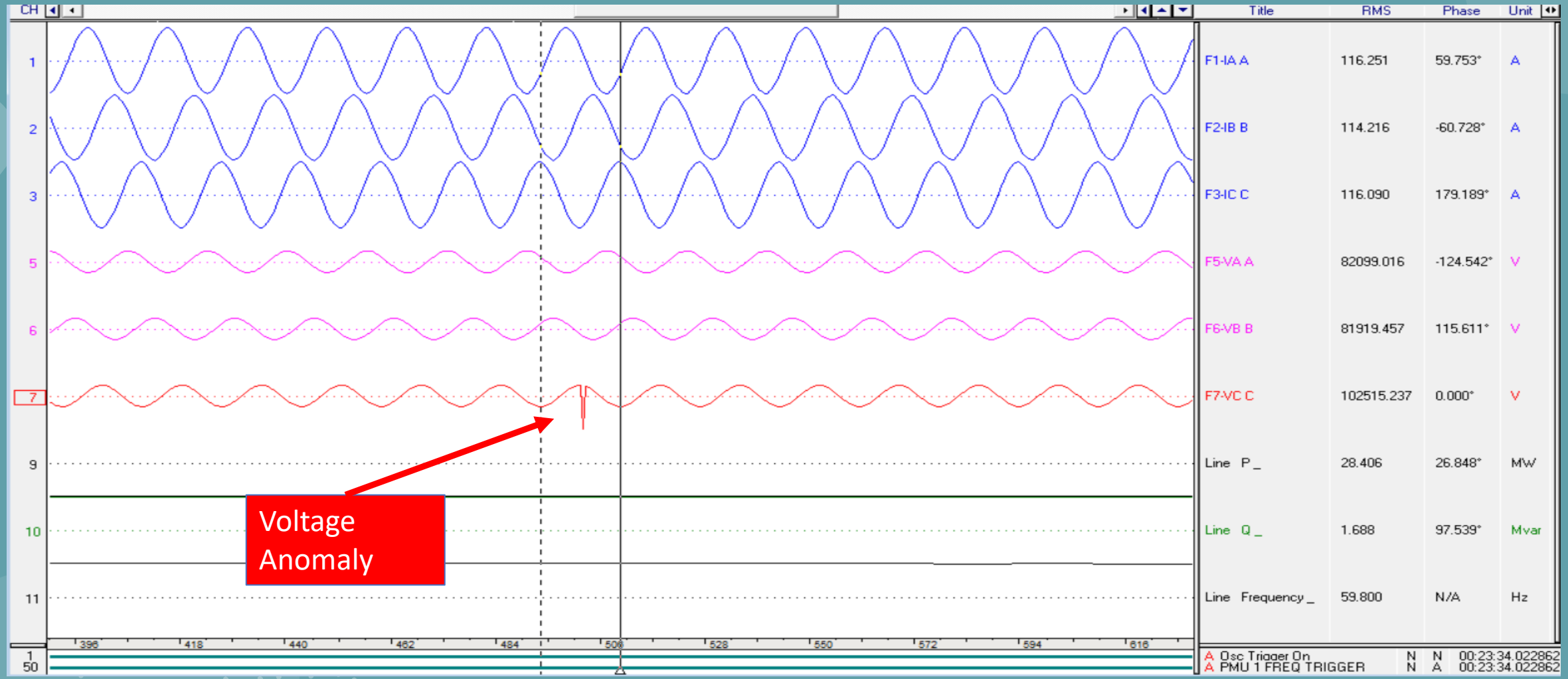
Anomaly Examples

Stripped PT Lug and Loose Connection (too fast for SCADA)



Anomaly Examples

Single event: single cycle with negative spike in VC channel



Next Steps

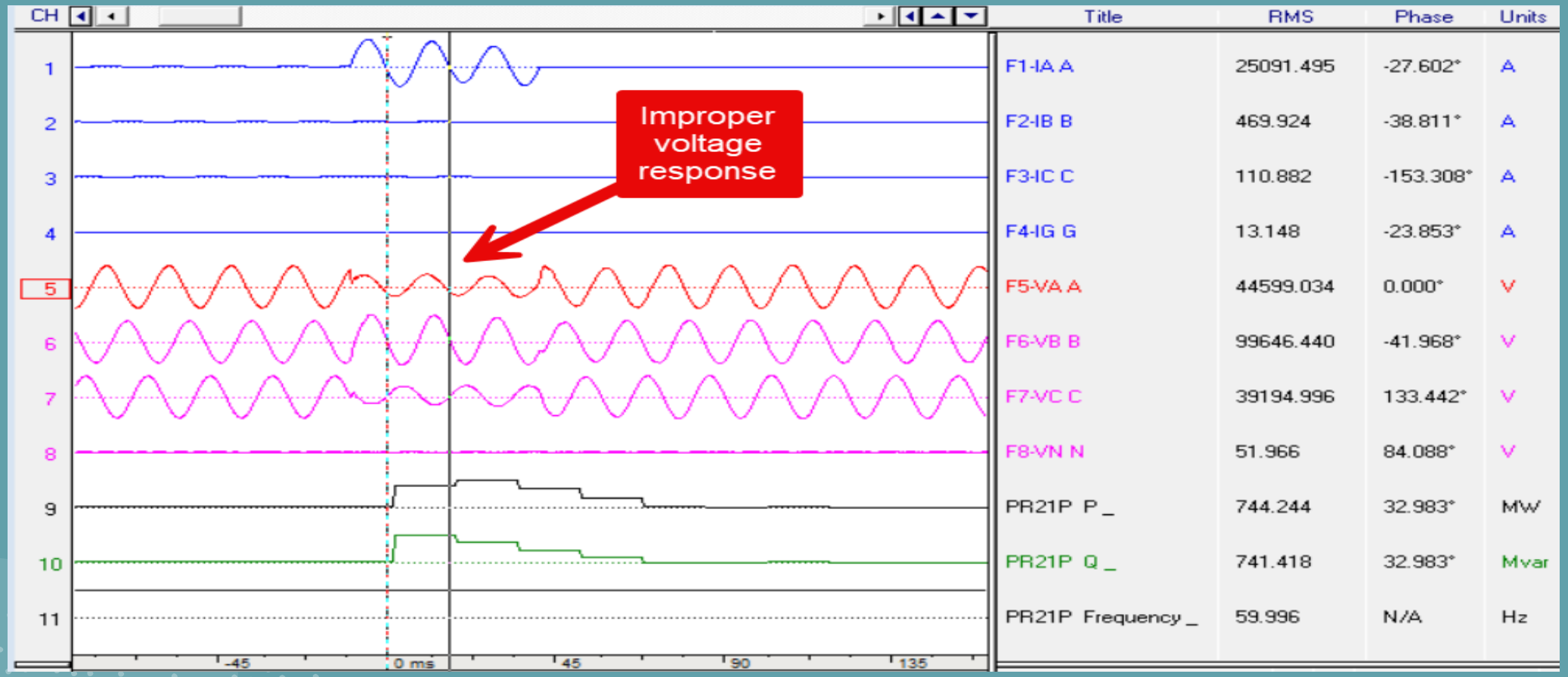
- Filter out test files
  - make sure voltage is close to nominal
- Tune Rsq thresholds
  - The thresholds of 0.99 and 0.40 were a first pass
- Build web app UI
  - Allow on-demand viewing
  - Allow file labeling for tuning thresholds
- Other anomalies

What Else is out there?

Can we find abnormal voltage response for a nearby LG fault?

Cause = 2 grounds in PT neutral circuit (1 in yard cabinet, 1 in control house). Over time, this degraded the neutral conductor between yard and house.

No protection misoperation had occurred yet!



Title	RMS	Phase	Units
F1-IA A	25091.495	-27.602°	A
F2-IB B	469.924	-38.811°	A
F3-IC C	110.882	-153.308°	A
F4-IG G	13.148	-23.853°	A
F5-VA A	44599.034	0.000°	V
F6-VB B	99646.440	-41.968°	V
F7-VC C	39194.996	133.442°	V
F8-VN N	51.966	84.088°	V
PR21P P _	744.244	32.983°	MW
PR21P Q _	741.418	32.983°	Mvar
PR21P Frequency _	59.996	N/A	Hz

Questions?