

Protective Relay Response to Solar Storm GIC

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Outline for Today:

- ▶ Synopsis of SEL Presentation
- ▶ GIC Waveforms
- ▶ Relay Testing
- ▶ Relay Response
- ▶ Possible Actions
- ▶ Areas of Concern
- ▶ Conclusion

SEL Presentation

- ▶ NERC GMDTF, June 13, 2018 - available on ERCOT PGDTF Web Site
- ▶ Karl Zimmerman and Derrick Haas of SEL

Conclusions

- Impact of GIC on protection presents challenges but is minimal overall
- Digital filtering removes dc and harmonics
- GIC impacts CT performance, but it is short-lived
- Most relay algorithms are resilient to impact of GICs, just as they are resilient to other factors (e.g., magnetizing inrush, CT errors due to saturation, remanence)

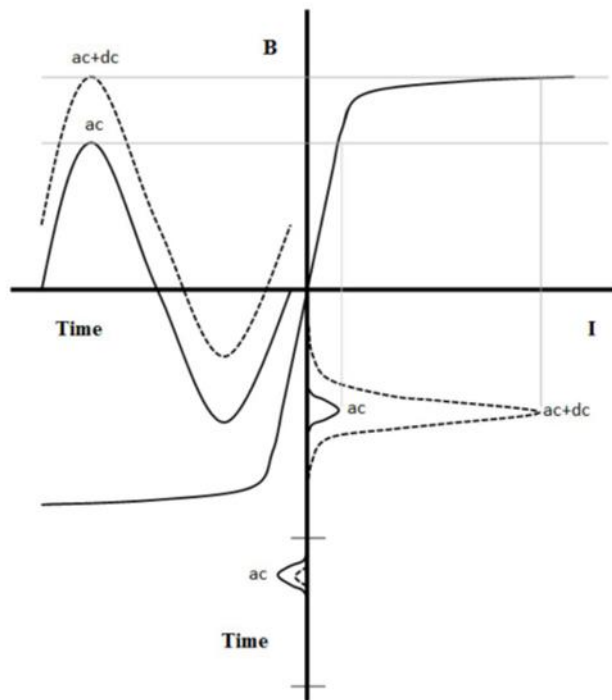
So that's it?

- ▶ These are well respected experts, I believe them.
- ▶ I want confirmation.
- ▶ In God we trust, others must provide data.

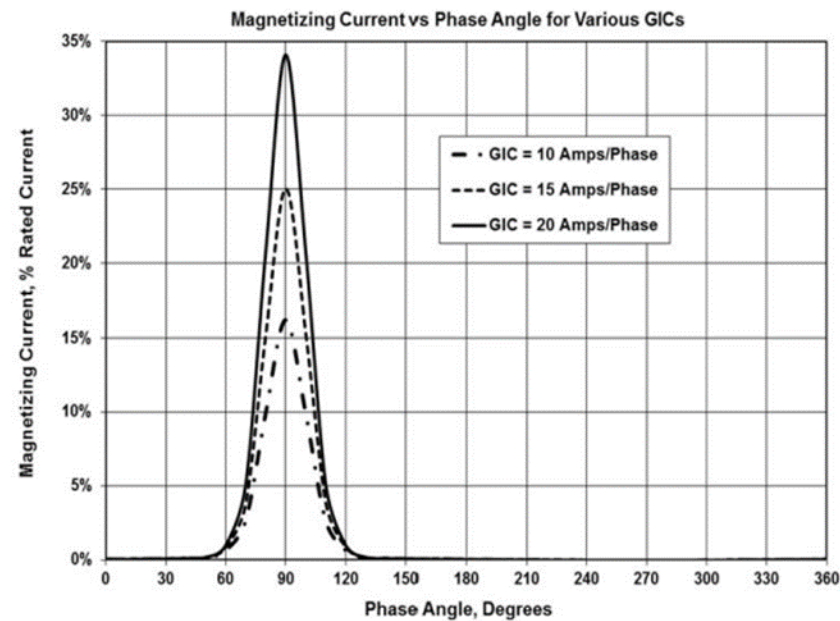
- ▶ Here's my data.

GIC Waveforms

- ▶ IEEE Guide for Establishing Power Transformer Capability while under Geomagnetic Disturbances - IEEE Std C57.163-2015



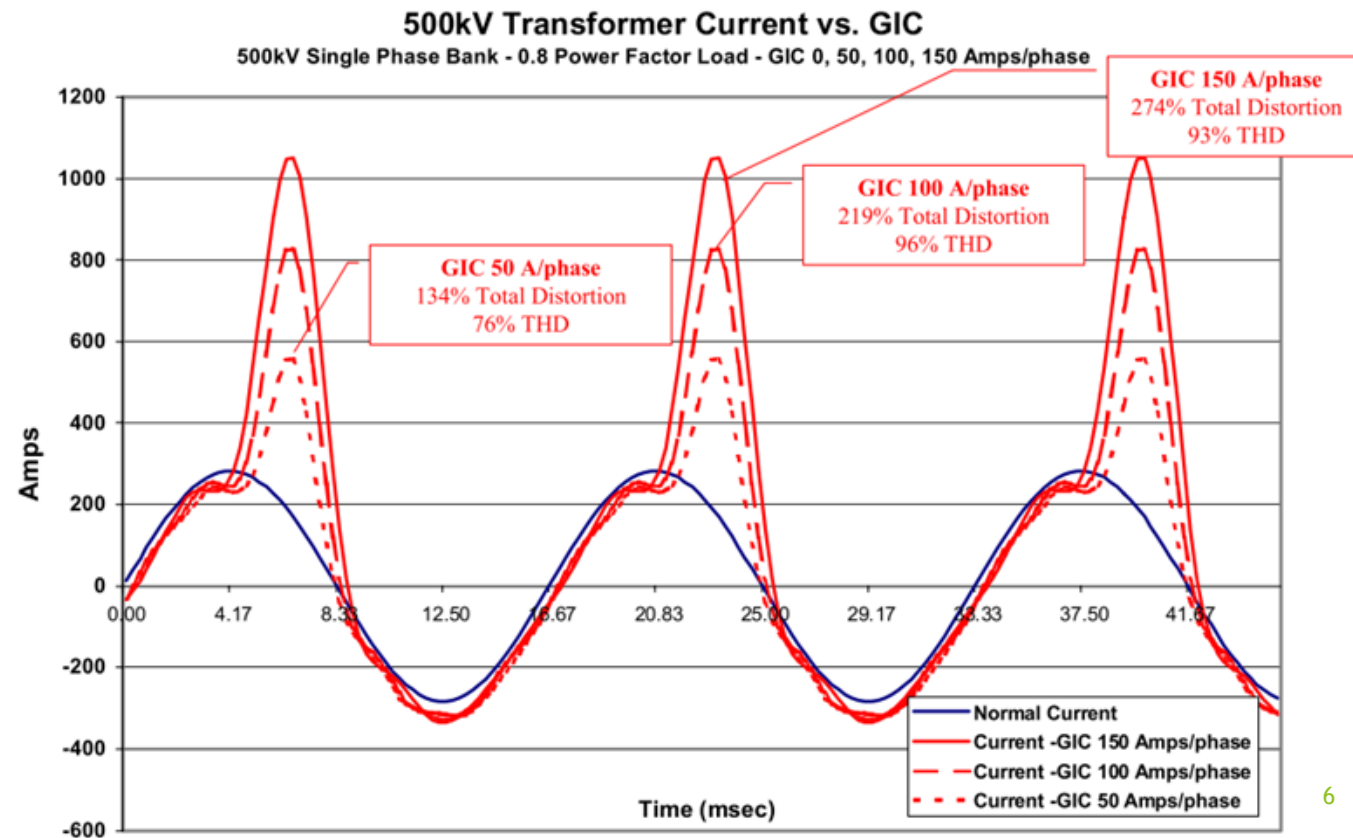
Part-cycle saturation of transformer Cores under effect of DC



Magnetizing current pulse for 3 Different levels of GIC

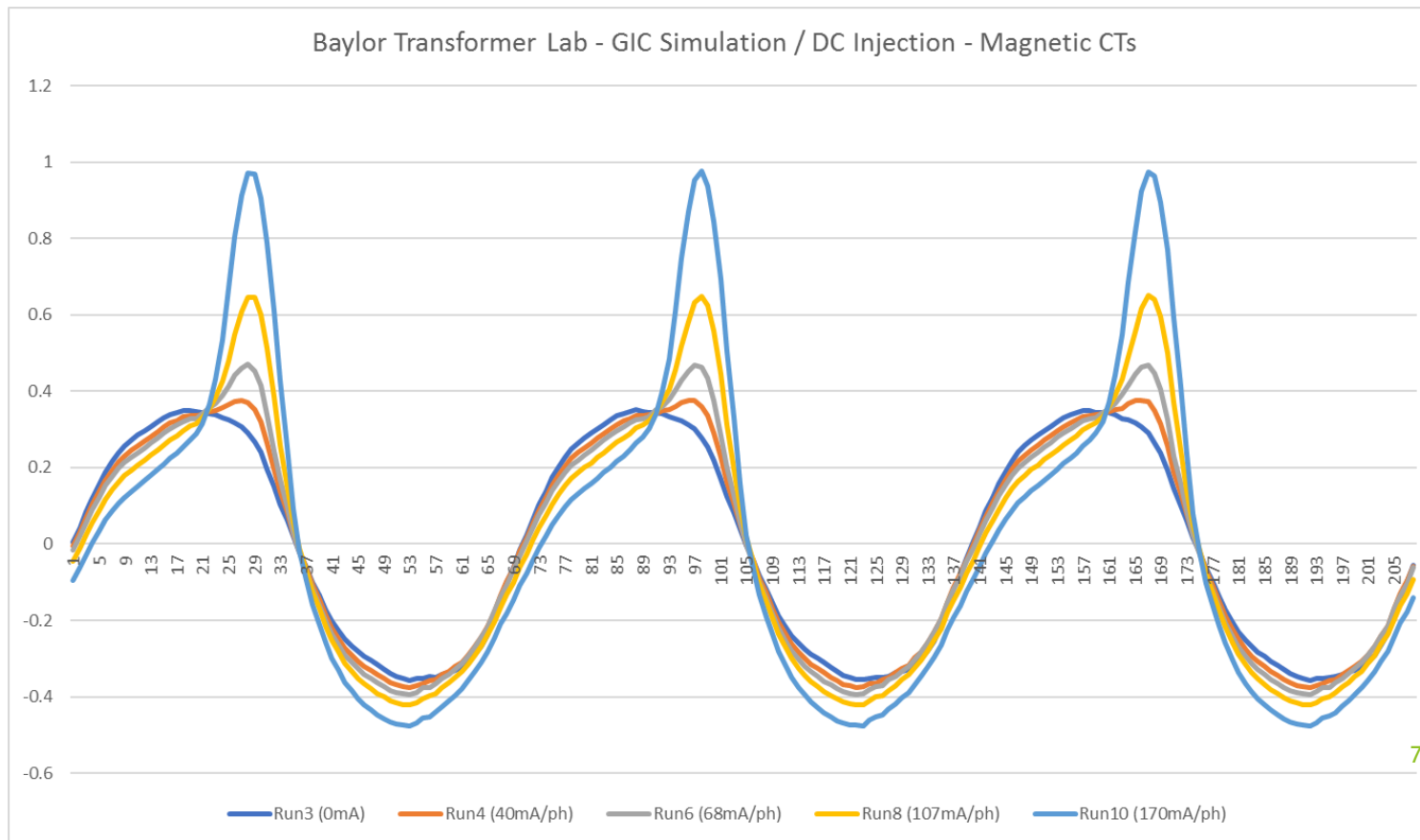
GIC Waveforms

- ▶ Gilbert, J. et.al., “The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and its impact on the U.S. Power Grid,” 2010, Available: https://www.ferc.gov/industries/electric/industryact/reliability/cybersecurity/ferc_meta-r-321.pdf.



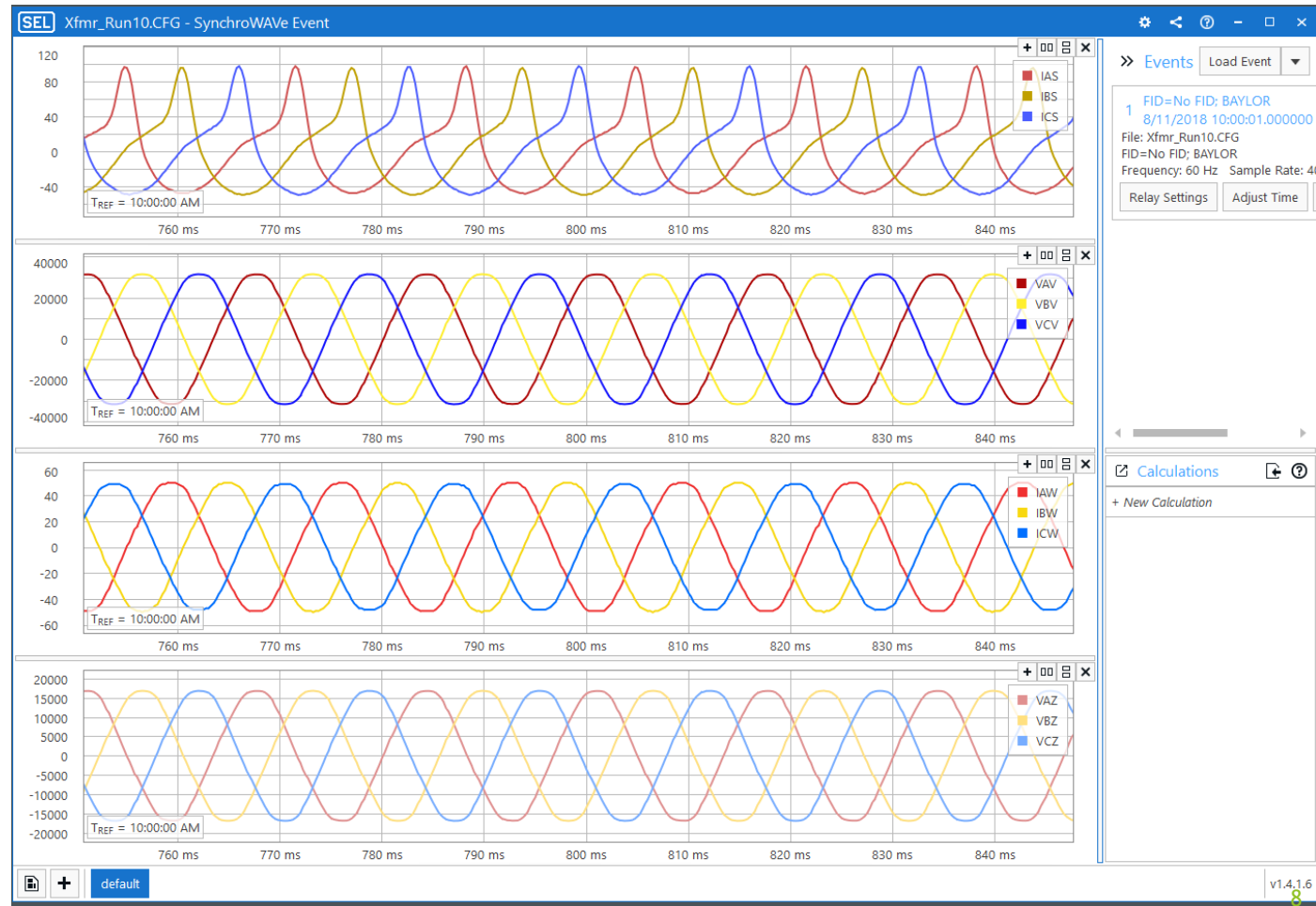
GIC Waveforms

- ▶ Baylor 3-Phase Transformer Lab with varying levels of DC current injection
- ▶ All currents & voltages acquired at 4.166 kHz (30+ channels)
- ▶ Magnetic CTs showing some saturation in graphs below (small CTs)



GIC Waveforms

- Convert 3-phase lab data to COMTRADE format - Currents & Voltages

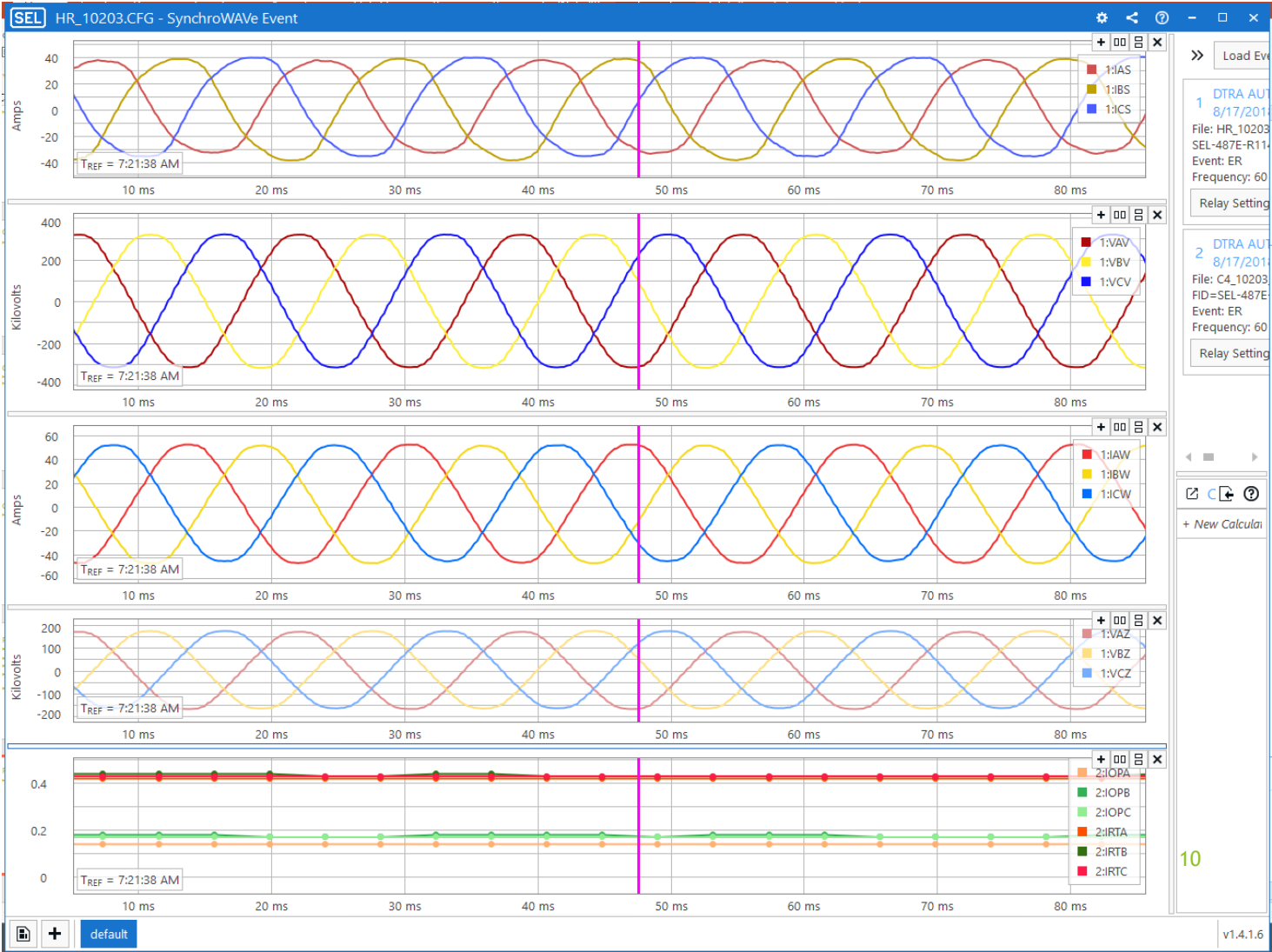


Relay Testing

- ▶ SEL-AMS running SEL-5401 Software with COMTRADE file
- ▶ 12 Analog Waveforms (6 voltage, 6 current)
- ▶ SEL-487E Transformer Differential Protective Relay
- ▶ Relay is programmed as Y-Y 2-winding using Brazos standard protection settings
- ▶ Differential-only protection (no 50/51)

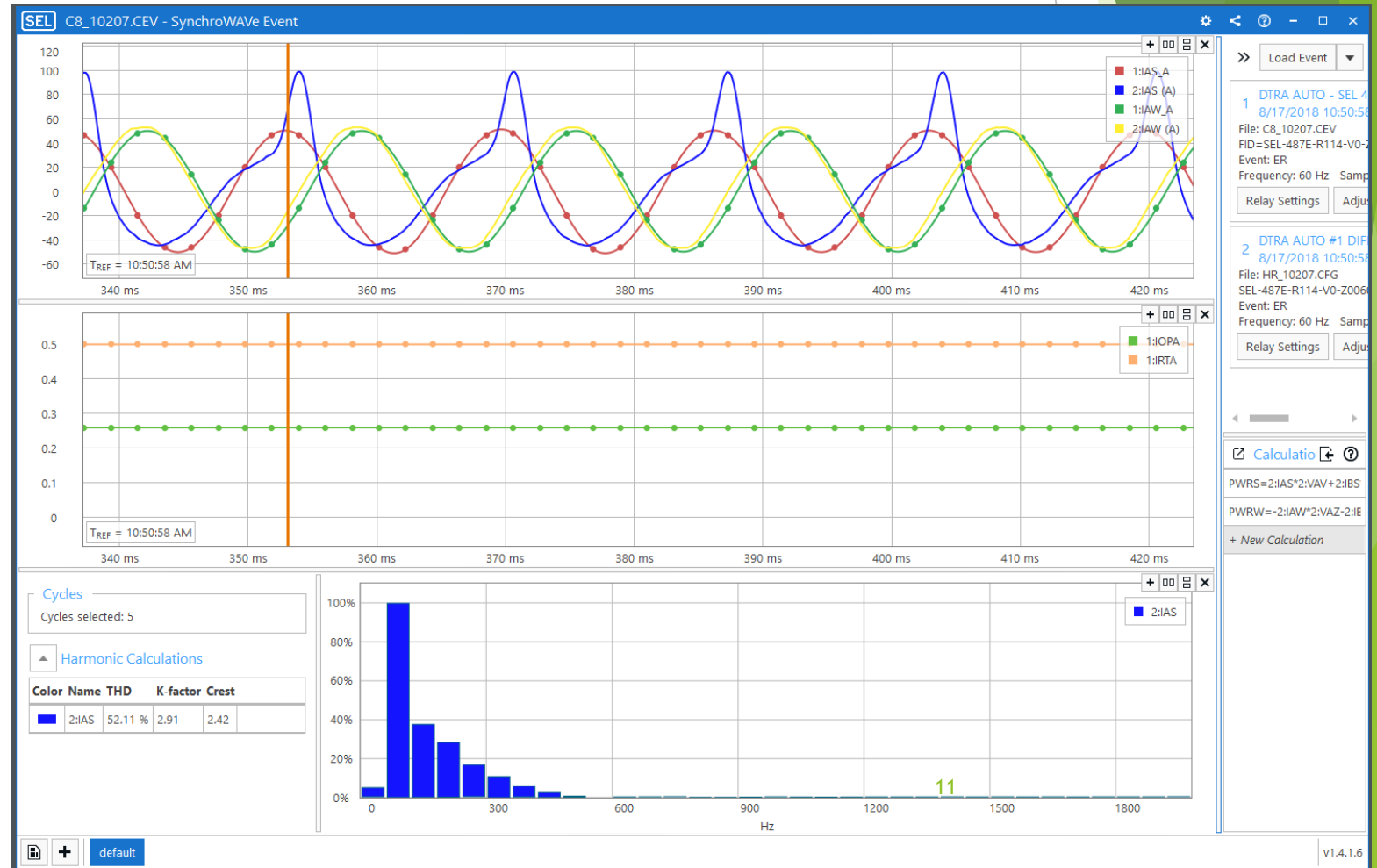
Relay Testing

► Baseline test (no DC) - looks fine; $IRT > IOP$; Relay COMTRADE Graphs (4kHz)



Relay Testing

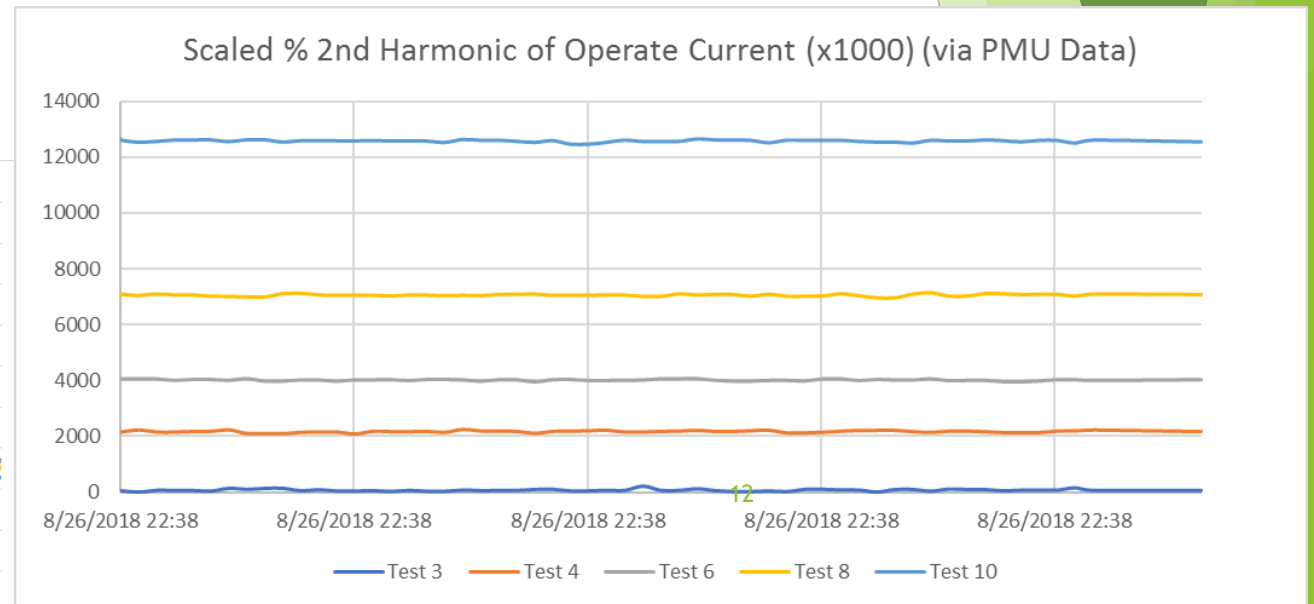
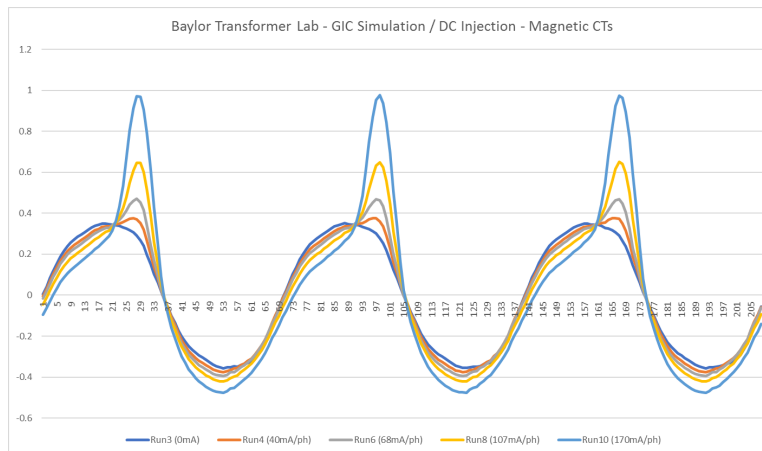
- ▶ COMTRADE (blue trace) and Filtered (Red Trace) from SEL-487E Relay test
- ▶ 2nd Harmonic at 37% THD *continuous* - 87nBK2 asserts (if PCT2 < 37; I use 15)
- ▶ Signals are from the relay
- ▶ No operation
- ▶ Not even close
- ▶ Harmonics are filtered out



Possible Actions

▶ SEL-487E:

- ▶ 2nd Harmonic Pickup PCT2 setting can be used to assert a programmable logic variable, passed to a timer, and then sent as a status point via SCADA to an alarm log when time/threshold is reached
 - ▶ 13: PCT01PU := 30.000000 #30 cycle delay timer, can be much longer
 - ▶ 14: PCT01IN := (87ABK2 OR 87BBK2 OR 87CBK2) #assert when 87nBK2 > PCT2 setting
 - ▶ OUT101 := PCT01Q #if timer completes, assert OUT101 (or any other status point)
- ▶ Monitor IAM2/IBM2/ICM2 via SCADA (multiply by large scalar and pass data)
 - ▶ 2nd harmonic content of operate current

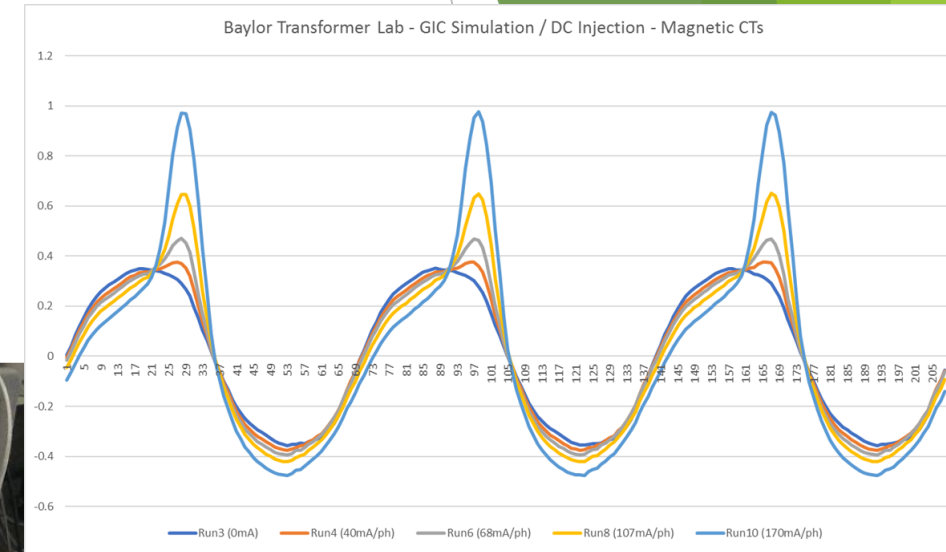
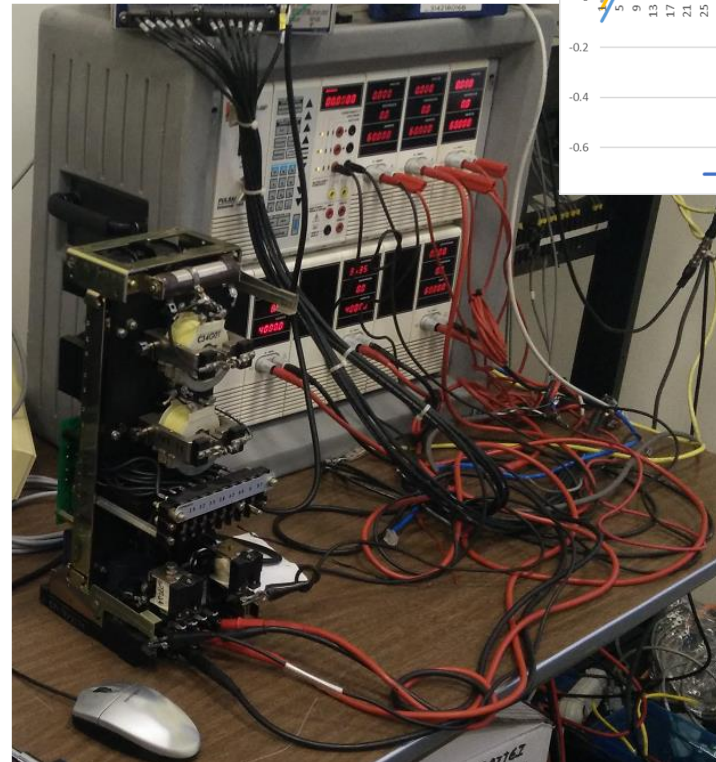


Areas of Concern

- ▶ In 2-1/2 years of SCADA logging of harmonics on four BEPC autotransformers, no noticeable increase in harmonics have been observed for any solar events on any of the transformers.
- ▶ We are worried about electromechanical and possibly older Solid State Relays that use RMS values / no harmonic restraint
- ▶ Many EM's still in service in the industry
- ▶ Brazos Electric still has EM on capacitor banks

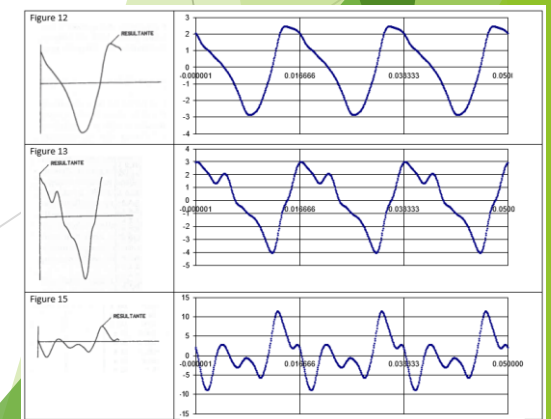
Electromechanical Relay Testing

- ▶ Westinghouse HU Relay (Transformer Differential, one per phase, with harmonic restraint)
- ▶ Run3 = no trip, just a nudge on differential portion of relay
- ▶ Run4 = no trip, small buzz
- ▶ Run6 = buzz, diff coil moved, but restraint coil did not; no trip
- ▶ Run8 = diff coil moves, restraint coil does not; no trip
- ▶ Run10 = diff coil moves, restraint coil moves towards 'more restraint' (*away* from tripping); no trip



Conclusion

- ▶ For solar GIC levels of DC injection, microprocessor relays filter GIC-related harmonics and transformer differential will not trip ($IRT > IOP$)
- ▶ 2nd Harmonic Blocking in transformer diff relays is **active** during GIC event, but SEL relays have unrestrained differential settings that cannot be deactivated. If an actual transformer fault occurs while 2nd Harmonic Blocking is active, the relay will trip on 87U (U87P element). Tested and confirmed.
- ▶ 2nd Harmonic elements in relay can be used to detect influence of GIC in transformer via either event logs or SCADA
- ▶ EM relays with harmonic restraint do not trip.
- ▶ Future work: additional testing on EM relays, particularly capacitor bank voltage relays. Simulations using the 1989 GIC waveforms is also “on the list”.



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