Lessons Learned

• Paul Luther
  – Puget Sound Energy
Lessons Learned

• Relay work is hard and stressful, somedays you are the hero....other days you are the goat.
• Here are some true stories from the field that demonstrate more towards the goat side.....
Lessons Learned
Christopher Substation

- 115Kv-13.09Kv distribution substation
- 5 additional 115Kv circuits in transmission yard
- 25 MVA transformer with 5 feeder circuits
- Mostly commercial but some residential load
- All microprocessor relays
- 115Kv high side breaker
- Metalclad 13.09Kv switchgear
- Average load of around 20 MVA
Christopher Substation

- Car pole accident on feeder 22
- Transformer LOR rolled and tripped entire station offline
- 6000 customers out
- Pretty sure it’s not supposed to work like that!
Christopher Substation

• Arrived at substation to find two substation crews and four service linemen waiting on me to make a decision on what didn’t work correctly
• LOR was rolled and I had a 150TG target on the transformer overcurrent relay
• This relay protects for 115Kv overcurrent and 13.09Kv neutral overcurrent
Christopher Substation

• Possible causes?
  – Slow feeder breaker 22 caused bank protection to trip bus in a back up breaker failure condition?
  – Is there trouble with the transformer?
  – Is there trouble with the bus work? Possibly exposing a weak spot with the feeder fault?
  – What is with the 150TG target? It’s the only target we have to work with
Christopher Substation

• Rule out possible causes
  – No slow feeder, SOE showed all feeder breakers were “externally” tripped from bank LOR
  – Back up trip for failed feeder relay comes from differential relay
  – No transformer trouble, tested good
  – No bus work issues, tested good
  – Relay in question tested fine and is working as programmed
  – A little stumped at the moment
Christopher Substation

- From station logbook I discover a “setting change” was made to the relay in question two weeks prior to this incident
- Phone the technician about the setting change
- Protection Engineer calls about the same time
- Finally getting somewhere
Christopher Substation

• CT Connections
  – Typical connections at PSE would be all three 115Kv Phase currents connected to IA, IB, IC
  – 13.09Kv Neutral current connected to IG
Christopher Substation

• 3I0 and Ground bias for relay elements
  – 3I0 = calculated residual via imbalance
  – Ground = actual current from a single neutral CT
  – 150TN overcurrent setting should be set for “disable” and 6.0 setting was a default setting
  – The non directional 150TP setting of 12.0 was used to back up the differential relay. The relay would issue a trip for 1920 amps of 115 Kv current should the differential relay be disabled or failed
Christopher Substation
Christopher Substation

- Two weeks prior to incident:
  - Technician was doing a typical settings verification and noticed no bias on the 150TN setting. He felt this should be changed to Ground bias as he inadvertently thought this element was protecting the 13.09Kv neutral, when in fact that was accomplished with an entirely different element. He contacted an engineer and the decision was made to change the bias.
Christopher Substation

• Normal Neutral Protection
  – Set for a 4.5 amp pick up
  – Set with a 6.0 time dial and V1R curve
  – Biased Ground Input
  – CT ratio = 120:1
  – 4.5 X 120 = 540 amps of time overcurrent protection
  – This coordinates with feeder protection and will target 51G when activated
Christopher Substation
Christopher Substation

• Technician changes settings
  – Simply change “none” to “ground input” enables the element
  – Save and send
  – Nice fix for a savvy technician and engineer
  – Not so fast
Christopher Substation
Christopher Substation
Christopher Substation
Christopher Substation
Once the change was made the 150TN element was now “enabled” and set for 6.0 amp pick up with Ground bias. This will cause the element to pick up and trip the transformer on 960 amps of instantaneous non-directional 13.09Kv neutral current.
Christopher Substation

The car pole accident created more than 960 amps of non directional 13.09Kv neutral current and the 150TN element tripped the transformer instantaneously, beating out the feeder protection, and targeted 150TG with the new bias.
The relay will automatically change the target to 150N when biased 3I0, and 150G biased Ground input.
This caused some confusion.
Christopher Substation

- The setting was changed with a different engineer’s approval
- The transformer was returned to service with no trouble
- Additional feeder faults since have proven the settings correction was the proper fix
Christopher Substation

- **Conclusions**
  - Pay very close attention to the relay elements and logic
  - Understand the intended operation of each relay element
  - Always fill out the log book for even the smallest actions
Lessons Learned

wait a minute ...

V-E-T doesn't spell Bacon
Obrien Substation

- 230Kv-115Kv substation
- 2-325 MVA transformers
- Multiple 115Kv lines
- Multiple 230Kv lines
- Newly commissioned relay packages for both transformers
- Transformer #1 energized for about a week
Obrien Substation

• Beautiful summer day, easy Friday
• LOR for transformer #1 rolls
• Transformer #1 trips offline
• Overcurrent target on Primary relay
  – Possible settings issue?
  – Overloaded transformer?
    • 200MW was recorded just before transformer tripped
• Review settings in Primary relay
  – 51P element was responsible for the trip
  – Set for 2.5 amp pick up with 6.0 time dial
  – CT ratio 200:1  PT ratio 2000:1
  – The math for pick up calculation:
    • 2.5 P.U. X 200 = 500 amps x 132794 L-N = 66397000w
    • 66397000/1,000,000 = 66.397 MW X 3 = 199.191 MW
    • 199.191 MW = TRIP (we recorded just over 200MW)
Obrien Substation

• We hit 200MW and tripped
  – Bank is rated for 325 MW with an 8 hour 10% overload
  – We discovered that the settings were transposed
    • Relay was set 2.5 P.U. with 6.0 time dial
    • Should have been set 6.0 P.U. with 2.5 time dial
    • The math: 6.0 X 200 = 1200 amps X 132794 = 159352800 watts
    • $159352800 / 1,000,000 = 159.353 \text{ MW} \times 3 = 478.058 \text{ MW}$
Obrien Substation

• Transformer was restored to service about 10 minutes after tripping with new settings installed
• Technician was asked if he checked the settings in the secondary relay and he replied “yes”
• 10 minutes later the transformer tripped again!
Obrien Substation

- It was discovered that the Technician actually didn’t change the settings in the secondary relay
- Settings were changed and the transformer was returned to service
- The first trip was on System Protection Engineering...the second trip was on the Relay Technician
Obrien Substation

• Conclusions
  – Pay very close attention to the settings provided by engineering
  – Don’t hesitate to “recalculate” the engineer’s settings
  – Stay calm in situations...the technician was a bit stunned at the first trip and didn’t fully understand the question asked of him
  – Stay focused...solve the problem...learn
Lessons Learned
Novelty Hill Substation

- 230Kv-115Kv substation
- 2-230Kv circuits and 6-115Kv circuits
- 1-325 MVA 230Kv-115Kv transformer
- 115Kv yard was built and commissioned in 2007
- 230Kv transformer and circuits were built and commissioned in 2010
Novelty Hill Substation

• Scheduled work for the day:
  – Isolate the transformer breaker fail relay and test in service, in preparation for switching the transformer offline to complete trip checks
  This is often done to make the transformer outage not as long as if the relays were to be tested during the outage
  Technicians were trying to help out operations by limiting the transformer outage
Novelty Hill Substation

- Upon inserting the test block into the isolated breaker fail relay’s test switch both the transformer differential lock out relay and the 115Kv bus differential lock out relay trip!
Novelty Hill Substation

• This is nuts!
• The entire station cleared
• What could have possibly caused this much trouble?
• The relay currents were isolated from the control system with an open test switch
• The trips from the relay were isolated from the control system with an open test switch
Novelty Hill Substation

- Typical FT style test switch opened with typical FT style test block
Novelty Hill Substation
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Novelty Hill Substation
Novelty Hill Substation
Novelty Hill Substation

- Inserting the block into the test switch with the test leads attached caused a ground to be created on the current circuit via the test set.
- This diverted just enough current for the downstream differential relay to operate.
- The differential relay was discovered to be set very sensitive, a full tenth of an amp more sensitive than usual.
Novelty Hill Substation

• But wait, there is more....
  – This still doesn’t explain why the 115Kv Bus differential lock out relay tripped
  – The differential relay should have cleared only the 230Kv high side breaker and the 115Kv low side breaker
  – A wiring error was discovered
Novelty Hill Substation

• The transformer differential lock out relay should have only caused a breaker fail initiate for both the 230Kv high side and 115Kv low side breakers

• Instead the lock out relay trip was wired directly to the 115Kv bus differential lock out relay trip circuit
Novelty Hill Substation

- The wiring error was discovered and repaired.
- The untimely construction of the 115Kv side and the 230Kv side caused some confusion on the manner of which this circuit should be tested and the wiring error was missed during the 230Kv commissioning process.
- Bad day to be a relay tech doing routine maintenance.
Novelty Hill Substation

• Lessons learned
  – Fully commission all aspects of a new system
  – Possibly test relays when transformer is out of service, although in this case the first trip test would have cleared the 115Kv bus anyway
  – Install test block into test switch without test leads attached
  – Stay focused and professional
  – Solve the problem
Lessons Learned
Obrien Substation

- 230Kv-115Kv
- 2-325 MVA transformers
- 2-230Kv circuits
- 12-115Kv circuits
- 115Kv Bus is split 2 times
- Mixture of Oil breakers and Gas breakers
- Mixture of electromechanical relays and microprocessor relays
Obrien Substation

- PDN 0942
  - Oil breaker
  - 25 Years old
  - Operating almost every morning and every night for three months for line project across Vashon Island in Puget Sound
  - Operated properly in the morning, but breaker failed in the evening when switching back in
Obrien Substation

- 115Kv South Bus section cleared properly with the exception of the bank low side breaker
- Breaker fail at PSE is set to 10 cycles
- PDN 0942 opened in about 13 cycles
- Bank low side breaker did not open, but PDN 0942 did open, just a bit slow, or else we would have lost the bank high side as well
Obrien Substation

• What could have caused the bank low side breaker to not open when the lock out relay clearly tripped?

• It turns out the wires from the lock out relay to the trip circuit for the bank low side breaker were never installed
  – Which also means they were never tested
Obrien Substation

• New wires were ran and tested
• PDN 0942 was ready to be changed out as it obviously is not working properly, is old...
  – Trip checks proved the continuity of the trip circuit
  – Breaker fail was isolated during trip checks
  – One last look from the maintenance crews discovered a gummy trip latch
  – A little TLC and good as new
Obrien Substation

• Lessons Learned
  – Properly commission all aspects of the job
  – Bus was split years ago, and obviously no trip checks were ever done properly
  – Drill down to the actual cause of a failure
  – Don’t assume anything
Lessons Learned

nice to know
Rolling Hills Substation

- 25 MVA transformer with LTC
- 4-13 Kv distribution circuits
- 6000 residential and commercial customers
- Electromechanical relays for feeder and bank protection
- 1970’s vintage
Rolling Hills Substation

- Transformer trips offline
- LOR rolled opening high side protective device
- Substation operator is dispatched
  - Reports neutral overcurrent target on transformer relay
  - Reports all distribution breakers were found closed
  - Reports no other targets
Rolling Hills Substation

• Original assumptions:
  – Stuck or ratcheted neutral overcurrent relay causing miscoordination between transformer and feeder protection
  – Wrong settings applied to neutral overcurrent relay after last maintenance cycle
  – Possible feeder breaker failure
Rolling Hills Substation

• Background and Observation
  – Discovered multiple phase and ground targets on multiple feeder breakers
  – Upon questioning, the operator notes that one feeder breaker would not open electrically, he had to use the mechanical trip
  – That would have been nice to know!
Rolling Hills Substation

• Conclusions
  – Feeder breaker had bad trip solenoid causing it to not trip on feeder fault
  – Breaker failure
  – Transformer protection worked perfectly as backup for failed feeder breaker
  – Listen, but keep an open mind
  – Reset targets in a timely manner
Lessons Learned
Fredonia Generating Station

- 4-50 MW gas turbine generators
- 2-16Kv to 115KV GSU
- 2-16Kv to 230Kv GSU
- 115Kv switch yard
- 230Kv switch yard
- Located near Anacortes, Washington
Fredonia Generating Station

• Unit 4 down for maintenance
• Unit’s 1, 2, 3 all offline, but available
• Around 8 pm unit 4 GSU trips
• Substation and Generation personnel dispatched
Fredonia Generating Station

• One responder from Substation group
  – New wireman...been with PSE for 3 months
  – Two relay technicians working at substation 100 miles away are called to help, no response locally
  – Over the phone diagnosis provides no information
  – No targets on any relays was reported
  – Relay technicians will complete their work...get a few hours of sleep, and head towards FGS
Fredonia Generating Station

• Arrive at FGS
  – Meet with Substation and now Generation personnel
  – AHHHH! It gets worse now…in the six hours it took the relay technicians to sleep for a bit and drive to FGS…the batteries have gone completely flat!
  – Unit 4 provides it’s own station service
  – All relays and RTU are completely dead
  – Do see lock out relay rolled….
Fredonia Generating Station

• Troubleshooting
  – Ask Generator folks to please back feed some station service from anywhere to get the batteries back up....
  – Inexperienced Generation staff...not sure how to go about getting us station service
  – I will not be deterred...Use small generator to power my test set, and use test set to power relays...HA!
Fredonia Generating Station

• Troubleshooting
  – All microprocessor relays show no events
  – AH HA! 59N Bus Neutral overvoltage relay has a target
  – Now that it is daylight...dead crow on ground just below GSU low side switch
  – Two things don’t belong in this substation....59N target and dead crow
Fredonia Generating Station

• Troubleshooting
  – Diagnosis
    • Crow flew onto GSU low side bus
    • When the bird attempted to fly away, it went A phase to ground
    • This caused A phase voltage to collapse, in turn causing both B and C phase voltages to rise
    • The open Delta connection of the low side PT’s creates enough voltage to trigger relay
    • Relay trips properly
Fredonia Generating Station

• Problem solved...
  – Not quite
  – Generation personnel are unable to restore station service to unit 4
  – Decision was made to energize unit 4 GSU with dead relays! Are you kidding me!
  – We got lucky...bank energized with no issues and battery charger nearly jumped off the wall with all the current it was drawing
Fredonia Generating Station

• Conclusions
  – Inexperienced personnel will pose challenges
  – An alternate station service needs to be available
  – The battery bank was woefully undersized for the application...replace batteries
  – The dead crow was not visible until daylight hours
  – All targets from all relays should be noted
  – I will never accept energizing a transformer unprotected for as long as I work, never again
Talbot-Obrien 230Kv Line

TROUBLE SEEMED SO FAR AWAY

- MADONNA (LOVE DON'T LIVE HERE ANYMORE REMIX)
Talbot-Obrien 230Kv

- TOP-006 testing
  - New Breaker installation at Talbot Hill substation
  - TOP-006 Testing was not completed at time of installation
  - Decision was made to return after line was energized to perform TOP-006 testing
  - Primary relay was removed from service and test set was connected
Talbot-Obrien 230Kv

• TOP-006 testing
  – Test set had minor issue...every now and then the three current channels would not all start at exactly the same time.....
  – This was the case this time and caused the relay to issue a trip...but hey no worries, the trip is isolated
  – The phone rings.......
Talbot-Obrien 230Kv

• TOP-006 testing
  – Load Dispatcher asks if “I meant to do that”
  – “Do what?” I ask
  – “867 tripped” he says...
  – “867 is at Obrien...I’m at Talbot” I tell him
  – Oh wait....867 is the other end of the line that I am testing....
  – Darn it!
Talbot-Obrien 230Kv

- TOP-006 testing
  - What could have happened?
  - TAL-OBR has transfer trip
  - I forgot to turn transfer trip off...
    - Relay issues a trip from misfiring test set
    - Relay sends a transfer trip to opposite end
    - All systems worked as designed
Talbot-Obrien 230Kv

• TOP-006 testing
  – Conclusions
    • Understand the complete operation of the line/scheme under test
    • Turn transfer trip off while testing relays with line in service
    • Possibly test TOP-006 while line is out of service
    • Be humble….things happen….do your best to respond to the issue
Fairwood Substation
Fairwood Substation

- Single 25MVA transformer
- 4-13.09 Kv Feeder circuits
- 3000 customers
- Mix of commercial and residential
- Nice summer day
- Down the street from our friend Rolling Hills Substation
Fairwood Substation

• Just before noon, calls start coming in about blinking lights and voltage trouble all over the Fairwood neighborhood area
• With trouble on all circuits, we head to substation to examine LTC
• Arrive at substation and no visual trouble inside substation
Fairwood Substation

• Start by measuring PT voltages
• LTC source voltage is on A phase
• Station service is on A phase
• Operating LTC doesn’t seem to cause any trouble at the substation
• Getting hungry...foreman volunteers to go get tacos across the street
Fairwood Substation

- Operating LTC numerous times and no trouble detected
- Foreman calls from taco shop
- Asks me to turn around...I see him across the street
- Tells me to operate the LTC
- WHOA! Entire shopping complex goes dark and then comes back
Fairwood Substation

- How can that be?
- Shopping complex on C phase...we are measuring A phase during troubleshooting
- We measure C phase during an LTC operation...and low and behold the voltage disappears and returns
- Switch station offline...open LTC...hole burnt through C phase collector ring
Fairwood Substation

• Conclusions
  – Check all three phases when troubleshooting voltage issues
  – Understand/ask information about what phase the customer complaints were most heavily receiving calls on
  – When Foreman is buying tacos for lunch order two extra even if you can’t eat them
Thank You