Relay Settings Improvements at Grand Ronde, Boyer, and Tillamook

Why 125% of the protected line can be a good Zone 1 setting.

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Abstract:

The protection schemes on the Bonneville Power Administration (BPA) lines between Salem and Tillamook Oregon present an interesting case study in inter-utility coordination and how unconventional relay settings can significantly simplify complex protection coordination problems.

Between 230kV-115kV transformers at BPA's Salem and Tillamook substations, the 115kV circuit runs 27.8 miles from Salem to the Portland General Electric (PGE) Grand Ronde substation, 5.6 miles from Grand Ronde to the PacifiCorp (PACW) Boyer switching station and 31.9 miles from Boyer to Tillamook. In addition, three substations are tapped from the line between Boyer and Tillamook. Grand Ronde has two 115kV circuit breakers, load served from the 115kV bus and a 115/57kV transformer connected to PGE's 57kV system. Boyer has a single 115kV circuit breaker, and on each side of the breaker is a tapped line (Van Duzer #1 and #2) to PACW's Devils Lake substation in Lincoln City. Motor operated disconnect switches are used to separate the Van Duzer lines from the Salem-Tillamook 115kV line.

As seen by the relays at Grand Ronde (and at Salem), bus or line end faults at Devils Lake and Tillamook are essentially indistinguishable. As seen by the relays at Tillamook, bus or line end faults at Devils Lake and Salem are essentially indistinguishable. From Grand Ronde the Devils Lake end of the Van Duzer #1 line is in the protected zone, while Van Duzer #2 and Tillamook are beyond Boyer. From Tillamook, the Devils Lake end of Van Duzer #2 is in the protected zone, the Devils Lake end of Van Duzer #2 is beyond the breaker at Boyer, and Salem is beyond the breakers at both Boyer and Grand Ronde. The ability of the relays at Tillamook and Grand Ronde to determine the appropriate response for a given fault impedance is severely compromised.

Historically, BPA set the relays at Salem and Tillamook, PGE set the relays at Grand Ronde, and PACW set the relays at Boyer; each working independently of each other. In late 2007, this was recognized as a problem and a joint effort was undertaken to coordinate protection of this system to see if the protection selectivity and speed of clearing could be improved.

This paper describes protection system performance prior to the improvements and the changes made. As a result of the changes, fault isolation is improved, fault location is significantly improved as each fault will be on a radial line for at least one reclose, and the impacts to customers on unfaulted line segments are reduced. One interesting result of studying the protection issues was the realization that setting the relays at Boyer to trip instantaneously for all faults between Grand Ronde and Tillamook, resulting in overtripping for faults beyond Tillamook or Grand Ronde, would actually improve the security of the overall line protection scheme.

A Fault Happens…

On November 12, 2007 at 05:39 PST, the circuit breaker at Grand Ronde on the Grand Ronde, PGE - Salem, BPA 115kV line tripped zone 1 and reclosed for a 3-phase fault on the Liberty, PGE – Salem, BPA 115kV line.

This event set in motion a complete reevaluation of the protection coordination on a circuit that starts at Bonneville Power Administration's (BPA) Salem substation and ends at their Tillamook substation (see Figure 1). Between these two BPA substations are Portland General Electric's (PGE) Grand Ronde and Pacificorp's (PACW) Boyer substations. Salem and Tillamook are convenient boundaries for the coordination study as BPA has 230kV-115kV transformers at each location and the entire circuit is owned by BPA except a few spans on each side of Grand Ronde and Boyer substations.

The process began with an attempt to determine why there had been a zone 1 trip at Grand Ronde for a fault on an adjacent line. Relay settings from the relay event report were entered into ASPEN OneLiner to evaluate the situation. OneLiner indicated that the zone 1 reach of the relays at Grand Ronde was well beyond Salem. This was not the expected result and needed further investigation.

PGE uses a OneLiner model that is part of a cooperative effort among many utilities, shepherded by BPA, where the various utilities furnish BPA with information about their systems, BPA incorporates this information along with their own system information, and then distributes the updated model periodically. Some time between setting the relays at Grand Ronde and the time of the fault, BPA had reconductored the line between Grand Ronde and Salem. It is unknown at this point what information about the reconductoring PGE might have received or what might have been done with that information. The OneLiner model included the reconductored line data and accurately predicted the zone 1 over reach.

Obviously, it would be necessary to develop new settings for the relays at Grand Ronde. The relays at Grand Ronde use two settings groups. Setting group 1 was for the normal condition of a two-terminal Grand Ronde-Salem line; very much like any text book example of two-terminal line protection. Setting group 2, for use when the by-pass switch (B1157, see Figure 1.) is closed, was not so simple. Understanding what was to be protected while this setting group was active proved to be a greater challenge.

Because of the multiple owners involved, each utility shows parts of the protected circuit on their system one-line, but none showed the entire circuit. PGE, owning the smallest portion of the circuit, showed the least amount of information. BPA showed the entire circuit from Salem to Tillamook, but did not include the PACW lines from Boyer to the Devils Lake, PACW substation in Lincoln City. PACW showed the system from Grand Ronde to Tillamook, but did not include the line to Salem.

PGE's relay setting documentation indicated that relay setting group 2 at breaker W152 existed to allow W126 to be taken out of service with bypass switch B1157 closed. The documentation described this as protecting a three-terminal Boyer-Grand Ronde-Salem line. Identical settings were used in group 2 of W126 to allow W152 to be removed from service.

With the bypass switch B1157 closed, Grand Ronde has one strong source, the closed 115kV breaker, and one very weak source, a 20MVA 115-57kV transformer (WBR1), normally used to supply the 57kV system.

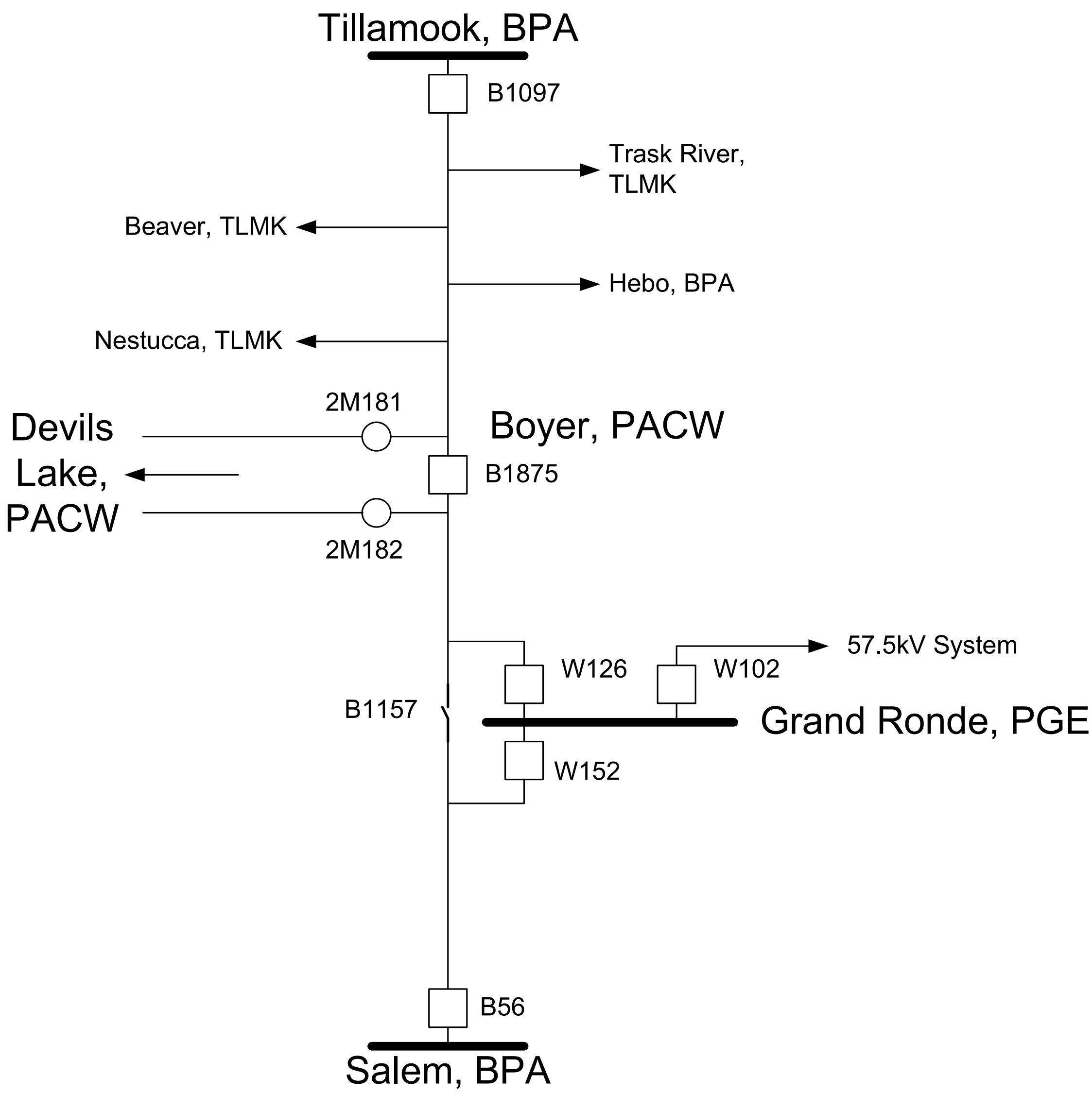

Figure 1: Circuit Configuration

At this point, it became necessary to understand the configuration and operation of Boyer substation. Boyer, PACW has a single circuit breaker with two sets of relays; one protecting the line to Grand Ronde and one protecting the line to Tillamook. In addition to the circuit breaker, there are two motor operated disconnect switches (MODs) for the Van Duzer #1 and #2 lines from Boyer to Devils Lake. The #1 line originates at MOD 2M182 on the Grand Ronde side of the circuit breaker and the #2 line originates at MOD 2M181 on the Tillamook side of the circuit breaker.

The MODs at Boyer would operate on dead line to isolate the line to Devils Lake from the Salem-Tillamook circuit. The Devils Lake substation was normally connected to the Van

Duzer #1 line and would transfer to the #2 line if the #1 line went dead. Retransfer back to the #1 line would be controlled by the dispatchers.

With this understanding, it became clear that setting group 2 for W126 and W152 at Grand Ronde didn't need to protect a 3-terminal line, but rather a 4-terminal Salem-Grand Ronde-Boyer-Devils Lake line. Four terminal lines are not generally favored by protection engineers. Looking at the documentation for setting group 1 on W126, it was also apparent that those settings were developed based on the need to protect a 2-terminal Boyer-Grand Ronde line rather than a 3-terminal Boyer-Devils Lake-Grand Ronde line.

Setting the closed bypass switch condition aside for a while, the W126 group 1 settings were evaluated. At this point, the various line and apparent impedances and their relationships began to show some interesting properties, highlighted in Tables 1-4:

Table 1: Apparent Impedances from Grande Ronde, PGE:

Terminal	Ohms (Pri)
Salem	22.45
Boyer	5.87
Devils Lake, #1	32.34
Devils Lake, #2	34.15
Tillamook	33.97

Table 2: Apparent Impedances from Boyer, PACW:

Terminal	Ohms (Pri)
Salem	34.21
Grand Ronde	5.86
Devils Lake, #1	36.8
Devils Lake, #2	28.47
Tillamook	28.23

Table 3: Apparent Impedances from Tillamook, BPA:

Terminal	Ohms (Pri)
Salem	62.5
Boyer	28.33
Devils Lake, #1	64.9
Devils Lake, #2	67.38
Grand Ronde	34.15

Table 4: Apparent Impedances from Salem, BPA:

Terminal	Ohms (Pri)
Grand Ronde	22.56
Boyer	29.36
Devils Lake, #1	61.04
Devils Lake, #2	63.14
Tillamook	61.29

From Grand Ronde looking towards Boyer, the zone 1 reach shouldn't be more than 5 ohms, 85% of the line, zone 2 should be about 12.9 ohms, and zone 3 should be around 42.5 ohms. With these settings, the end of the protected line at Devils Lake is in Zone 3. Normally, protection for a radial line would overreach the line end allowing fast tripping for the entire protected line. Here it is not possible to reliably differentiate a line end fault at Devils Lake (protected line) from a fault at Tillamook (2 terminals away).

Looking at the situation from Tillamook, the problem is even worse. Salem, which is two terminals away, has lower impedance than both Devils Lake lines end, and Devils Lake #1, which is one terminal away, has lower impedance than Devils Lake #2, which is part of the protected line. Figures 2 and 3 provide a graphical representation of the impedances.

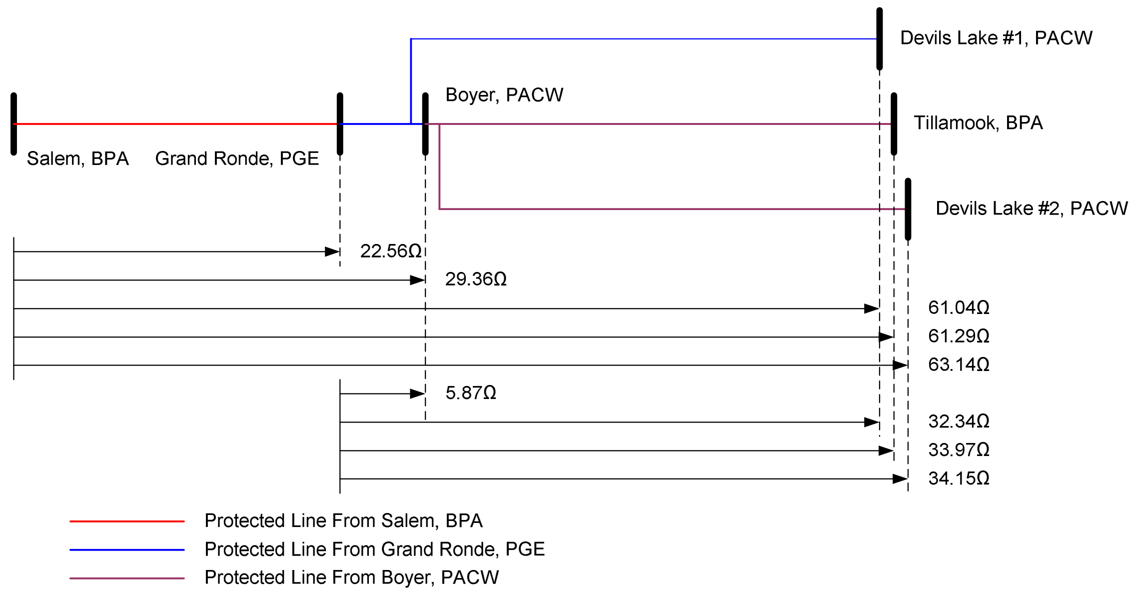

Figure 2: Apparent Impedances Salem to Tillamook

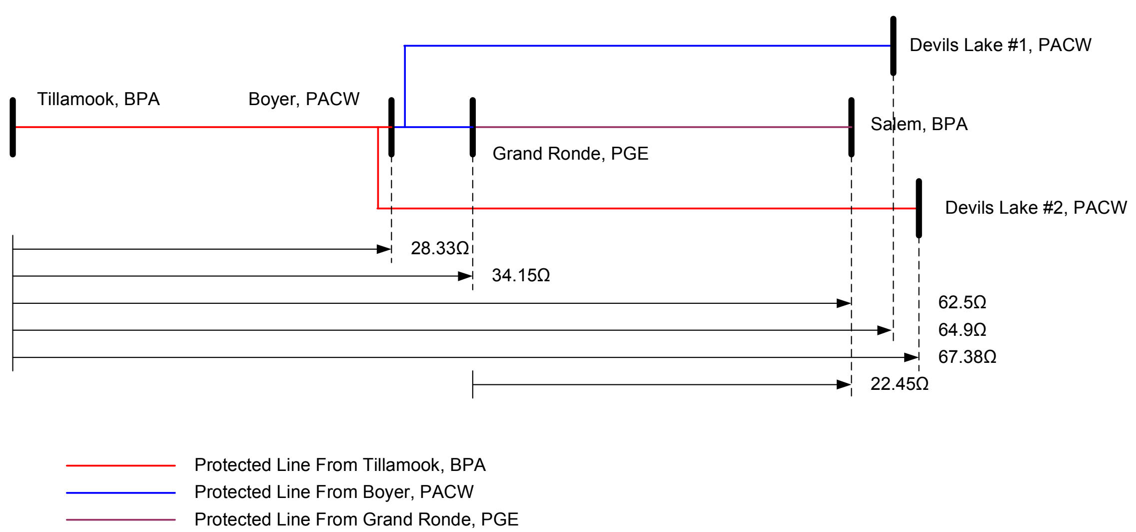

Figure 3: Apparent Impedances Tillamook to Salem

Both figures 2 and 3 show the line lengths proportional to apparent impedance. The impedances looking into Grand Ronde from Tillamook and Salem do not add up to the total circuit impedance end-to-end due to the infeed affects of the 57kV system at Grand Ronde.

After many attempts at developing relay settings for Grand Ronde, it became clear that Grand Ronde could not be considered alone, but rather it would be necessary solve the coordination issues as a whole. PGE invited BPA and PACW to meet and discuss the circuit from Salem to Tillamook as a whole with the intent of achieving a single, unified approach at all terminals. The authors met at PGE, and over the course of the meeting, discussions kept coming back to Boyer, and how much easier the problem would be to solve if Boyer just wasn't there. Recognizing this, the group decided to look at a scheme where Boyer would sectionalize the line for any fault between Grand Ronde and Tillamook. "What if Boyer were set at 125% of the line rather than 85% of the line?"

The group recognized that sectionalizing at Boyer could have many benefits. If Boyer were to sectionalize for all faults, Tillamook would be protecting a radial line to Devils Lake on the Van Duzer #2 line and Grand Ronde would be protecting a radial line to Devils Lake on the Van Duzer #1 line. With Boyer open and two-shot reclosing at both terminals, it would be possible to trip for a fault, reclose once to test through to Devils Lake, trip again if the fault remained, allow the MOD on the dead line at Boyer to open, and then reclose again to test the line between the breaker and Boyer.

Grand Ronde had one-shot reclosing, and used relays requiring portions of the reclose logic to be accomplished through wiring between output and inputs of the relay. To achieve two-shot reclosing would require some wiring changes, but the benefits were seen to out-weigh the costs.

As reclose coordination was discussed, it became clear to the group that not only had the fault clearing never been coordinated, but that reclosing had also never been coordinated. It was determined that the MODs at Boyer could be opening just as the breakers at Grand Ronde were reclosing. It was also recognized that the lack of reclose coordination meant that Boyer could open and reclose before Grand Ronde or Tillamook operated to clear a fault on the Van Duzer lines causing Boyer to lockout without opening the MOD on the faulted line. This would occur when Boyer responded to the fault with a faster zone than Grand Ronde or Tillamook. The relays at Boyer were set for an instantaneous reclose supervised by hot line on each side. If B-phase was not involved in the fault, the reclose conditions could be met allowing Boyer to close back into the fault, causing the second trip and the lock out.

The authors agreed that BPA would take a first pass at protection coordination, PGE would take a first pass at reclosing coordination, and PACW would investigate the operational changes at Boyer necessary for the implementation of the protection and reclosing changes discussed. Tables 5-8 show the reach settings for the protective relays at each terminal.

Table 5: Reaches from Grand Ronde, PGE

Zone	Reach	% Boyer	% Tillamook	% Devils Lake #1	% Devils Lake #2
1	5Ω	85			
2	12.5Ω	213	37	39	37
3	42.625Ω		125	132	125
4	96.125Ω		283		

Table 6: Reaches from Boyer, PACW towards Tillamook

Zone	Reach	% Tillamook	% Devils Lake #2
1	2.74Ω	121	121
2	6.82Ω	302	300
3	7.45Ω	330	328

Table 7: Reaches from Boyer, PACW towards Grand Ronde

Zone	Reach	% Grand Ronde	% Salem	% Devils Lake #1
1	3.48Ω	740	126	118
2	4.46Ω	949	162	151
3	7.45Ω	1585	270	253

Table 8: Reaches from Tillamook, BPA

Zone	Reach	% Boyer	% Grand Ronde	% Devils Lake #1	% Devils Lake #2
1	3.85Ω	85	71	37	36
2	13.06Ω	288	239	126	121
3	15Ω	331	275	144	139
4	20Ω	442	366	192	185

The reclosing coordination considerations included BPA capacitors at Hebo, necessitating an initial open interval of at least 90 cycles, and the operating time of the MODs at Boyer. There were no reclosing modifications required at Salem. At Grand Ronde and Tillamook, the first open interval was set at 90 cycles and the second open interval was set at 20 seconds. At Boyer, the breaker will reclose after both lines have been energized for 4.8 seconds.

The MODs at Boyer were set to open after 10 seconds of dead line. With this timing, the MODs will stay closed through the fault and the first reclose. If the fault is still present and the line trips for a second time, the MOD on the dead line will open during the 20 second open interval.

With the revised reaches and reclosing times, both Grand Ronde and Tillamook will be protecting a radial line to Devils Lake as soon as the Boyer breaker opens. The expected results for various fault types and locations are shown in Table 9. This information has been provided to the PGE dispatchers to assist with fault location.

Table 9: Expected System Response to Circuit Faults

Temporary Fault - Between Grand Ronde & Boyer, or Boyer & Devil's Lake on Van Duzer #1 Line

Approx Time (sec)	Grand Ronde	Boyer			Tillamook
	W126	B-1875	2M182	2M2181	B1097
Initial	Closed	Closed	Closed	Closed	Closed
0	Trip	Trip			May Trip[1]
1.5	Reclose				Reclose
6.5		Reclose			
Final	Closed	Closed	Closed	Closed	Closed

Temporary Fault - Between Boyer & Tillamook, or Boyer & Devil's Lake on Van Duzer #2 Line

Approx Time (sec)	Grand Ronde	Boyer			Tillamook
	W126	B-1875	2M182	2M2181	B1097
Initial	Closed	Closed	Closed	Closed	Closed
0	May Trip[1]	Trip			Trip
1.5	Reclose				Reclose
6.5		Reclose			
Final	Closed	Closed	Closed	Closed	Closed

Permanent Fault - Between Grand Ronde & Boyer

Approx Time (sec)	Grand Ronde	Boyer			Tillamook
	W126	B-1875	2M182	2M2181	B1097
Initial	Closed	Closed	Closed	Closed	Closed
0	Trip	Trip			May Trip[1]
1.5	Reclose				Reclose
1.5+	Trip				
10			Opening		
15			Open		
21.5	Reclose				
21.5+	Trip & Lockout				
Final	Trip & Lockout	Open	Open	Closed	Closed

Permanent Fault - Between Boyer & Devil's Lake - Van Duzer #1 Line

Approx Time (sec)	Grand Ronde	Boyer			Tillamook
	W126	B-1875	2M182	2M2181	B1097
Initial	Closed	Closed	Closed	Closed	Closed
0	Trip	Trip			May Trip[1]
1.5	Reclose				Reclose
1.5+	Trip				
10			Opening		
15			Open		
21.5	Reclose				
Final	Closed	Closed	Open	Closed	Closed

Table 9 (cont): Expected System Response to Circuit Faults

Permanent Fault - Between Boyer & Devil's Lake - Van Duzer #2 Line

Approx Time (sec)	Grand Ronde	Boyer			Tillamook
	W126	B-1875	2M182	2M2181	B1097
Initial	Closed	Closed	Closed	Closed	Closed
0	May Trip[1]	Trip			Trip
1.5	Reclose				Reclose
1.5+					Trip
10				Opening	
15				Open	
21.5					Reclose
Final	Closed	Closed	Closed	Open	Closed

Permanent Fault - Between Boyer & Tillamook

Approx Time (sec)	Grand Ronde	Boyer			Tillamook
	W126	B-1875	2M182	2M2181	B1097
Initial	Closed	Closed	Closed	Closed	Closed
0	May Trip[1]	Trip			Trip
1.5	Reclose				Reclose
1.5+					Trip
10				Opening	
15				Open	
21.5					Reclose
21.5+					Trip & Lockout
Final	Closed	Open	Closed	Open	Trip & Lockout

Notes:

1. Zone 2 time setting based on 5 cycle or faster tripping of Boyer B-1875. Slow operation at Boyer may result in overtripping. Impact of overtripping limited to PACW Customers at Devil's Lake.

Grand Ronde, PGE Bus Fault

During the evaluation of the protection coordination, Grand Ronde suffered a storm related bus fault at 2032 PST on December 3, 1007. At the time, the 115kV bus protection was a partial differential scheme consisting of overcurrent relays with CTs paralleled from the two 115kV line positions and the high side of the 115-57kV transformer, but not the high side of the 115-13.2kV distribution transformer. At the time of the bus fault, the Boyer breaker was open, providing no fault current from that direction. Without contribution from Boyer, the total current into the partial differential was below the instantaneous setting and the relays started timing. The settings in the line relays on the Salem position included a high-set instantaneous phase overcurrent element in the unconditional trip equation. Without a source from Boyer, this non-directional overcurrent element could not distinguish a close-in forward fault from a close-in reverse fault. The relays on the Salem line tripped and reclosed the breaker and then tripped again to lockout. After the loss of the Salem line, the bus differential relays had only the contribution from the 115-57kV transformer, which was below the pickup of the relays. Eventually, the transformer backup overcurrent relays operated to clear the fault.

The corrective actions from this event included connecting CTs on the high side of the distribution transformer to the bus differential scheme and changing it from a partial differential to a full differential. The corrective actions also included moving the non-directional overcurrent element from the unconditional tripping conditions to the Switch-On-To-Fault tripping conditions.

Grand Ronde, PGE Voltage Collapse

During the initial evaluation of the settings at Grand Ronde, it was noted that should the line to Salem be lost, Grand Ronde would become the source for the south end of the circuit to Tillamook. With only a 40MVA transformer connected to the 57kV system, Grand Ronde is not capable of carrying the load on the 115kV circuit to Tillamook. Upon the loss of the source from Tillamook, there would be a voltage collapse on all of the 115kV system that remained connected to Grand Ronde. It was determined that PGE should do something to address this possibility.

Before there was an opportunity to implement protection against this condition, fate intervened. On January 30, 2008, the Grand Ronde, PGE – Salem, BPA 115kV line tripped and locked out. The relays at Grand Ronde indicated a distance to the fault of 1.5 miles. BPA crews spent the day patrolling the line looking for possible fault locations, and nothing was found during the day. The line was tested at dusk with the hope that the fault might provide a visible arc. There was indeed a visible arc, but the arc was from the flash-over of an insulator on one of the two PGE spans between Grand Ronde substation and the BPA portion of the line. Given the time of day, a PGE crew was dispatched the following day.

In the mean time, revised settings for the relays on the Boyer line at Grand Ronde were developed to trip the line prior to voltage collapse should anything happen to the source from Tillamook. Given the time of year and the location of the line to Tillamook through the Oregon Coast Range, it was not unrealistic to consider the loss of both ends of the Salem, BPA – Tillamook, BPA 115kV line.

With input from Transmission Planning, an undervoltage element setting was developed and a relay technician was dispatched to Grand Ronde to implement the revised settings. With no status information into the Boyer line relays from the Salem line breaker (W152), the relay settings were intended to be operational only until the line to Salem was restored.

While the line to Salem was out, there were no further events. Once the line was repaired and put back in service, the relay technician was dispatched once again to Grand Ronde to remove the temporary setting. He was scheduled to be at Grand Ronde on the morning of February 1, 2008. At 0508 PST that very same morning, there was a fault on BPA's Buckley-Marion 500kV line that caused the voltage to momentarily fall below the temporary undervoltage set point. Grand Ronde W126 on the line to Boyer tripped and reclosed for an out of zone fault.

The long term solution was to provide a 52a contact from the Salem breaker (W152) to the Boyer line relays (W126). With the Salem breaker open, the Boyer relays will trip for an undervoltage condition, but the undervoltage protection will not be active if the Salem breaker is closed.

On December 10, 2008, the necessary outages took place, the rewiring of the relays was completed, and the revised relay settings were implemented at Grand Ronde. PACW had completed their settings revisions during August of 2008, and BPA had completed their settings changes in March of 2009.

Subsequent Operations

Since the implementation of the new protection scheme, there have been five circuit faults that resulted in operations. Details are shown in Table 10.

Table 10: Circuit Operations with Improved Protection Coordination

Date	Time (PST)	Operations	Disturbance
12/16/2008	1900	Grand Ronde W126 (Boyer) tripped and reclosed twice. Boyer B1875 tripped then reclosed onto dead line.	Grand Ronde relays indicated BG fault 4.8 miles out.
01/3/2009	0747	Grand Ronde W126 (Boyer) tripped and reclosed once.	No Information
02/23/2009	2209	Grand Ronde W126 (Boyer) tripped and reclosed twice then locked out.	Tree into line between Grand Ronde and Boyer.
05/14/2010	1641	Grand Ronde W126 (Boyer) tripped and reclosed twice.	Car into pole near Boyer.
08/24/2010	1922	Grand Ronde W126 (Boyer) tripped and reclose twice, W152 (Salem) tripped and reclosed. Boyer B1875 tripped and reclosed, 2M182 tripped and stayed open, 2M181 was already open. Salem B56 (Grand Ronde) tripped and reclosed. Liberty, PGE W236 (Salem) tripped and reclosed. Chemawa, BPA B104 (Salem) tripped and reclosed.	See Below

The 8/24 event did not make sense from the initial description. The initial reports did not include information about Boyer 2M181 or Chemawa B104. Given the operation of Boyer 2M182, initial suspicions focused on a fault between Boyer and Devils Lake on the Van Duzer #1 line. It would be very difficult make sense of this without some information from the relays. Multiple attempts to dial into the relays at Grand Ronde during the late evening were unsuccessful. The first hint, which arrived late in the evening, was missed in a quick analysis – at Grand Ronde, there were indications of a ground fault and one operation on the Salem line while the Boyer breaker counter indicated two operations with no targets on the relay. The Grand Ronde relays were remotely accessed in the morning and things began to fall into place. The relays for the Boyer line showed the relay issuing two trips from the 3P27 relay element, but no line protection elements operated. The relays for the Salem line showed the relay issuing one trip on instantaneous directional ground overcurrent.

So, the fault was toward Salem, but why were there operations at Boyer and on the Boyer side of Grand Ronde? The breaker at Boyer operated because the fault was closer to Boyer than the Devils Lake end of the Grand Ronde-Boyer-Devils Lake line. This was as intended to keep the Tillamook to Devils Lake (via the Van Duzer #2 line) circuit intact. But because the #2 line to Devils Lake was out of service, the load at Devils Lake was on the #1 line. Once the breaker at Boyer opened, Tillamook could no longer supply the load at Devils Lake. With the Salem side of Grand Ronde open due to the line fault, Grand Ronde was attempting to supply the Devils Lake load from the 57kV system and was unable to support the voltage. The reclosing interval on the Salem line at Grand Ronde is 5 seconds, but only 90 cycles on the Boyer line at Grand Ronde. This resulted in a reclose and second trip during the open interval on the Salem line. Following this second trip of the Boyer line, the MOD at Boyer on the #1 line opened as it would for a fault between Boyer and Devils Lake.

Meanwhile, the relays on the Grand Ronde line at Salem took what was later determined to be 4.1 seconds to issue a trip on directional time overcurrent for currents that should have caused a trip to be issued in 350 ms. Both relays were tested and found to time slowly; they have since been removed from service. At this time, further information is not available. Because of the slow operation at Salem, other sources into Salem began to trip to provide backup clearing. Normally, there are five sources into the Salem 115kV bus besides the Grand Ronde line. At the time of the fault, two of the 115kV lines were either completely or partially out of service and could not provide fault current. Liberty and Chemawa were the only two 115kV sources remaining, and both line breakers tripped as a result of the slow clearing at Salem.

The remaining source into Salem was a 230kV line to a 230-115kV transformer. The expected operating time for this source exceeds the actual tripping time of the Grand Ronde line breaker.

Interestingly, the Liberty breaker tripped in 1 second for fault current that should require 1.36 seconds. The information on fault current at Liberty are limited to about 11 cycles at the beginning of the fault and about 7 cycles at the end of the fault, or 18 cycles total. Once the fault was established, the fault current magnitude is the same, within a few amps, for the entire time information is available. If the fault current for the missing portion of the event matches the current at the beginning and end, the relay tripped 360ms faster than it should have. The relays were tested the following day using the measured fault current, and they operated well within the tolerance of the manufacturer's specifications.

Conclusions

This experience has highlighted several key aspects of protection coordination:

- Protection of circuits with multiple owners requires significant coordination between all interested parties.
- Coordination must be done for reclosing as well as tripping associated with fault detection.
- Sectionalizing complex circuits can significantly improve system response and fault location.
- Maximizing the benefits of circuit sectionalizing can result in unconventional relay reaches.
- Close analysis of operational events can provide information about the effectiveness of protection coordination on existing installations.
- Utilities should not just accept poor coordination on existing installations, but take every opportunity to think outside the box to find improvements.