WHY INDUSTRY NEEDS TIME
A POWER INDUSTRY CASE STUDY

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The Bonneville Power Administration
Introduction

- Bonneville Power Administration
- Background
- Power System Transmission Applications that require Precise Time
- Examples of Power System Applications Affected by Precise Timing errors.
- BPA Plan’s for Communication Infrastructure
Bonneville Power Administration

General Information

BPA established ........................................... 1937
Service area size (square miles) ............... 300,000
Pacific Northwest population ................. 12,922,668
Transmission line (circuit miles) .............. 15,169
BPA substations ............................................ 260
BPA SERVICE TERRITORY

Transmission System and Federal Dams

LEGEND
- BPA Transmission Line
- Federal Dam
- Non-BPA Line
- BPA Service Area
## Transmission System

<table>
<thead>
<tr>
<th>Operating voltage</th>
<th>Circuit miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,100 kV</td>
<td>1</td>
</tr>
<tr>
<td>1,000 kV</td>
<td>264.8</td>
</tr>
<tr>
<td>500 kV</td>
<td>4,707</td>
</tr>
<tr>
<td>345 kV</td>
<td>570</td>
</tr>
<tr>
<td>287 kV</td>
<td>229</td>
</tr>
<tr>
<td>230 kV</td>
<td>5,326</td>
</tr>
<tr>
<td>161 kV</td>
<td>119</td>
</tr>
<tr>
<td>138 kV</td>
<td>56</td>
</tr>
<tr>
<td>115 kV</td>
<td>3,496</td>
</tr>
<tr>
<td>below 115 kV</td>
<td>282</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>15,050</strong></td>
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</table>
Power System Transmission Applications that Require Precise Time

- Phasor Measurement Units
- Line Differential Protection
- Traveling Wave Fault Location
- System Event Recordings
- Substation Local Area Networks
PMUs Synchro-phasors, or Phasor Measurement Units (PMUs), are synchronized measurement systems that provide information on phasor angles and frequency at different power system locations.
Why 1 micro-second accuracy requirement?

- Power System frequency = 60Hz
  - One period or 360 degrees = 16.6ms
  - 0.25 degrees = 11.5 micro-seconds
PHASOR MEASUREMENT UNITS or SYNCROPHASORS

WISP – Western Interconnection Synchrophasor Program
PHASOR MEASUREMENT UNITS or SYNCROPHASORS

March 2015

Phasor Measurement Units and Synchrophasor Data Flows in the North American Power Grid

Legend:
- PMU Locations
- Transmission Owner Data Concentrator
- Regional Data Concentrator
- Data up to reliability coordinator
- Data between reliability coordinators
- Peer to peer data exchange

With information available as of March 9, 2015
POWER SYSTEM TIMING REQUIREMENTS

Why PMUs

- High speed, real time data stream
  - 60 samples per second
- Time synchronized measurements
  - Wide area phase angle differences
- Flexibility in data stream
  - Analog and digital values are included
PHASOR MEASUREMENT UNITS or SYNCROPHASORS

August 2003 East Coast Blackout

![Graph showing Relative Phase Angle over time for Cleveland and West MI, with a normal angle of ~25°.](image-url)
PHASOR MEASUREMENT UNITS or SYNCHROPHASORS

PMU vs. SCADA
Abnormal Angle
Abnormal Angle

ANGLE ALARM: MONTANA-COI PATH

4/2/2013 4:39:32 PM

RETURN TO OVERVIEW

Garrison

26.74 Deg

Malin
Frequency Event Location

Insertion of 1.4 Gigawatt Load Break in Eastern Washington
Frequency Event Location
Line Differential Relays

- Compare current magnitudes, phase angles to two ends of a transmission line
- Communications and high accuracy time dependent!
- Changes in communications paths, channel delays, or timing errors can cause potential problems
Traveling Wave Fault Location

What is a power system fault?

Bakeoven Series Capacitors

Staged System Test
Feb 2-3, 2011 0151
Sequential C-Phase L-G Faults Grizzly Side
John Day Fails to Reclose
Traveling Wave Fault Location

- Drop a stone in a still pond
  - you produce a wave that moves out from the center
  - In ever increasing circles
Traveling Wave Fault Location

- Requires a sampling rate of 1.5 Mhz (500 Nano-seconds) for fault locations to be accurate within 500 feet.

\[
L - 2d = v \cdot (t_2 - t_1)
\]

\[
d = \frac{1}{2} (L - v \cdot (t_2 - t_1))
\]
Traveling Wave Fault Location

- Traveling Wave Event
System Event Recording

- Digital Events requires millisecond time-tagging
  - Equipment Alarms, Power Circuit Breaker Operations

<table>
<thead>
<tr>
<th>Alm</th>
<th>Point</th>
<th>Date/Time</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>369</td>
<td>05/16/14, 23:30:34.741</td>
<td>SICKLER # 1 SET # 2 RECEIVE SIGNAL FAIL</td>
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<tr>
<td>N</td>
<td>370</td>
<td>05/16/14, 23:33:13.347</td>
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</tr>
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<td>5132 PCB (25E) PHASE C OPERATED</td>
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<tr>
<td>A</td>
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<td>500 KV TRIPPED BY RELAY ACTION</td>
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<tr>
<td>A</td>
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<td>SICKLER LINE 1 SET 1 HOT LINE INDICATION</td>
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<td>DIGITAL FAULT RECORDER OPERATE</td>
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<td>1105</td>
<td>05/16/14, 23:33:14.614</td>
<td>5132 PCB (25E) TRIP SIGNAL SENT</td>
</tr>
</tbody>
</table>
Substation Local Area Networks

- IEC – 61850 GOOSE Messages – 1ms accuracy
  - SNTP – 1ms accuracy

- IEC – 61850 Sample Values - 1 micro second accuracy
  - 1PPS Sync Source
  - C37.238 / 61850-9-3 PTP
Power System disturbances caused by un-synchronized time

- 500kV transmission line outage caused by Bad GNSS data
  - Line current differential during GPS testing
  - Investigation revealed Airforce GPS satellite testing
  - Some GPS receivers were affected
  - Official Notice: Since March 15, 2014, the Air Force has been conducting functional checkout on a GPS satellite, designated Space Vehicle Number (SVN) 64. SVN 64 broadcasts a data message that clearly indicates SVN 64 is unusable for navigation.

Power System disturbances caused by un-synchronized time

- 500kV transmission line outage caused by Bad GNSS data
  - Line current differential during GPS testing
Resolutions and joint learning
- Track planned GPS testing notices
- Use GPS receivers that detect test mode
- Use in-channel timing as source/backup
- Desensitized differential phase preferably above load and below internal fault
- Utilize zero and negative sequence differential elements
Power System Disturbances Caused by Un-Synchronized Time

FLIGHT ADVISORY
GPS Interference Testing
CHLK GPS 16-08
07-30 June, 2016
China Lake, California

GPS testing is scheduled as follows and may result in unreliable or unavailable GPS signal.
Example of PMU bad data caused by un-synchronized time

- Several PMU lost GPS Sync on 3/15 for several minutes
- During the event, there were multiple instances of both PMUs reporting that the synch had been re-established and that their status was good - even though it wasn't.
- Redundant PMU did not experience this problem.
- We are confident that the synch was not re-established because the phase angle for these PMUs jumped by 40 degrees each time the status cleared.
Example of PMU bad data caused by un-synchronized time

Synchronization Accuracy monitoring relies on system data.
BPA Communications

- BPA covers 4 states with thousands of command and control circuits on legacy systems.
- The legacy communications systems are going EOL
- Maintenance is also becoming an issue
What do we have?

The BPA communication system consists of Microwave (MW) and Synchronous Optical Networking (SONET) over Fiber Optics (FO). All of these communications systems utilize Time Division Multiplexing (TDM) technology to share the total bandwidth. Though functional, this implementation is inefficient and costly when supporting IP networks.
What do we need?

We need a system with the reliability of SONET but the ability to make use of idle bandwidth for other applications. We need traffic to travel across the transport at the maximum speed the physical medium supports, to allow new applications of technology. We need a system requiring less overall impact.

Video conferencing needs 384 kbps. Assume 4 hours use per day = 5.5 Gbit. 20 hours of idle time = 27.5 Gbit.

80% of the bandwidth is wasted daily!

100 byte travel time

- DS-0 12.5ms
- T-1 0.5ms
- Gigabit 0.0008ms
After exhaustive evaluation we chose Carrier Ethernet as our next Transport Infrastructure.

- PBB-TE supports SONET like switch times with some notable constraints. 16/1200
- PBB-TE deterministic, connection oriented services
- Carrier Grade reliability and availability
WhatProtectionEngineersNeedtobeasking

- Latency Requirements for Services requested
- Asymmetry (Packet Jitter) specification
- How does switch time spec affect function
- What connections are going to be provided – physical fiber connector types
- Blocking mechanisms a sufficiency on links that can appear active with as much as 20% packet loss
Conclusion

- Background on BPA Power System
- Precise Timing Applications
- Events that show how sync affect protection were discussed
- Power Systems cover large areas requiring accurate timing to keep the system balanced.
- Evolution of com system is coming
  - Along with it are the timing requirements
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Questions?