Resiliency of Power Systems
Earthquake, Wind, Ice, Fire

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What will be the duration of Power Outage?

- Where are we today?

- **Earthquake:** 1 Day in M 6.0 (good seismic design); 3 Days (no seismic design). 14+ Days in CSZ M 9.0; 60+ Days in Rural areas

- **Wind:** Weeks in Cities, Months in Rural

- **Ice:** Days in Cities, Months in Rural

- **Fire:** Months in Rural

These outages are based on ~1,000 year events, that happen “someplace” every couple of decades
These outage durations apply to many of the areas within the black oval, from the Mexico Border in the South to the Peace River in the North.

Nearly every 500 kV and most 230 kV substations, from British Columbia to the Mexico Border.

More than 100,000 high voltage components.
500 kV Transmission Line
Design Basis: 100 MPH Wind (45 m/sec)

Failure
Both tension legs had square shaped pullout holes

Leg 1 Bent by dragging of tower during failure
RESILIENCY

• Dictionary Definition: Restore to the way it was before

• Power Company Action: Fix it as fast as you can. No mitigation done during the restoration process.

• BUT, to get shorter outage times for future events, we need to UPGRADE and not just “fix it the way it was”
Besides disrupting transportation, heavy ice and snow can damage utilities. Power and telephone lines sagging after heavy ice storm.
Hydro Quebec, Montreal, Canada, January 5-9, 1998

1,000 steel towers collapsed.

Most are 735 kV

Why?

PLUS

30,000 distribution wood pole failures

EQUALS

6 month outage in some rural areas
△ 735 kV Substation
△ 230-315 kV Substation
■ Generation
Green: energized circuits
Dashed: out-of-service circuits
Power restored to Hydro Quebec Research Facility
Return Periods

1998 (John’s Dad says he will pay any amount to get power back on)

1998 (John broke his leg)

Maximum accumulated ice measured at Dorval airport (Montreal) in single storm, over one year.
Why did the towers fail?

- Type II Gumbel, Lognormal, etc. are all fiction. But, we use them all the time. Worse, we use 50 years of real data to project to 1,000 to 10,000 year time frames. Superstations cannot be used to reliably predict rare events.
Place Names and Populations

Urban Areas (est. population as of June 2014, or latest data)

SERA 8.4.3.3 Third Shakemap, PGA (g), Max of NS, EW

Sonoma County (491,829)

Napa County (139,045)

Santa Rosa (170,685)

Rohnert Park (41,232)

Petaluma (57,941)

Sonoma Valley (42,296)

St Helena (5,814)

Yountville (2,933)

Vacaville (94,275)

Fairfield (109,320)

Vallejo (118,837)

San Rafael (57,713)

Martinez (36,673)

Richmond (106,516)

Berkeley (116,768)

San Francisco (825,863)

Oakland (400,740)

Napa (76,915)

Sonoma Valley (42,296)

San Rafael (57,713)

Martinez (36,673)

Richmond (106,516)

Berkeley (116,768)

San Francisco (825,863)

Oakland (400,740)
Not a single item in the PG&E transmission system functionally broke. About a thousand high voltage items felt PGA ~ 0.2g to 0.4g. No 60 kV to 230 kV circuit was de-energized.

This 230 kV to 60 kV transformer felt PGA ~0.33g. No damage.

Bank 3. 230 - 60 kV. Anchorage capacity is low (V=0.3W), but PGA small enough to not overcome sliding / rocking, so no damage.
Power Outages - M 6.0 Napa Earthquake Aug 23 2014

NAPA PGA = 0.3g
VALLEJO PGA = 0.15g
SONOMA PGA = 0.15g
SANTA ROSA PGA < 0.05g
SAINT HELENA PGA < 0.05g
Key Findings

- PG&E has ZERO damage to high voltage equipment

- Still, 70,000 customers lost power. Why?

- Distribution system. Mostly overhead. Damage is correlated to SA ($T = 3.0$ seconds), NOT PGA. Why? Wire slapping causes “easy to fix” short circuits.

- CAVEAT: No liquefaction in this event. Buried cables will have a different story.
Prof Anshel Schiff

He has spearheaded power system seismic issues for 40 years.

Today, every power company in the world uses his insights

IEEE 693
Ed Matsuda
Dennis Ostrom
Ron Tognazini
Leon Kempner

2014: more than 50 engineers from dozens of companies are involved
Figure 3-4. Cable Forces (RRS = 1.0g, 0% Slack, No Brace, Narcissus)
Map of Wildland Fires, California, 10 Acres or More
1878 - 2013

18,712 Fires

Excludes Urban Fires Unreported Fires Small Fires
Total Acres Burned, San Diego, 1910-2013

Is there a trend that fires are getting larger?
Linear regression trend line: increasing with population growth. Governor Jerry Brown’s statements that the May 2014 fires in San Diego were a result of Climate Change is not supported.

We need science, not political dogma!
<table>
<thead>
<tr>
<th>Ignition Cause</th>
<th>Countywide</th>
<th>California Statewide</th>
<th>Ratio, San Diego County / California</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightning</td>
<td>72</td>
<td>2,989</td>
<td>2.4%</td>
</tr>
<tr>
<td>Equipment Use</td>
<td>49</td>
<td>995</td>
<td>4.9%</td>
</tr>
<tr>
<td>Smoking</td>
<td>9</td>
<td>326</td>
<td>2.8%</td>
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<tr>
<td>Campfire</td>
<td>54</td>
<td>319</td>
<td>16.9%</td>
</tr>
<tr>
<td>Debris</td>
<td>10</td>
<td>651</td>
<td>1.5%</td>
</tr>
<tr>
<td>Railroad</td>
<td>1</td>
<td>80</td>
<td>1.3%</td>
</tr>
<tr>
<td>Arson</td>
<td>49</td>
<td>805</td>
<td>6.1%</td>
</tr>
<tr>
<td>Playing with Fire</td>
<td>14</td>
<td>168</td>
<td>8.3%</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>665</td>
<td>3,125</td>
<td>21.3%</td>
</tr>
<tr>
<td>Vehicle</td>
<td>6</td>
<td>267</td>
<td>2.2%</td>
</tr>
<tr>
<td>Power line</td>
<td>9</td>
<td>279</td>
<td>3.2%</td>
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<tr>
<td>Firefighter training</td>
<td>0</td>
<td>5</td>
<td>0.0%</td>
</tr>
<tr>
<td>Non-firefighter training</td>
<td>0</td>
<td>11</td>
<td>0.0%</td>
</tr>
<tr>
<td>Unknown / unidentified</td>
<td>482</td>
<td>8,553</td>
<td>5.6%</td>
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<tr>
<td>Structure</td>
<td>1</td>
<td>14</td>
<td>7.1%</td>
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<tr>
<td>Aircraft</td>
<td>0</td>
<td>11</td>
<td>0.0%</td>
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<tr>
<td>Escaped prescribed burn</td>
<td>2</td>
<td>80</td>
<td>2.5%</td>
</tr>
<tr>
<td>Illegal Alien Campfire</td>
<td>15</td>
<td>21</td>
<td>71.4%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,438</strong></td>
<td><strong>18,699</strong></td>
<td><strong>7.7%</strong></td>
</tr>
</tbody>
</table>

*Table 2-8. Comparison Statistics, San Diego County and State of California*
230 kV lattice towers. No damage. Substantial burned fuel under and within ten feet. No charring, no smoke on steel.

Nearby 138 kV wood poles. More damage.
3 wood poles in fire.
  1 no damage.
  1 minor damage.
  1 extensive damage.
Nearby house burned.
Extensive damage
Wood pole replaced
### Wind Gust Data

#### Regression Analysis - Lindbergh Field

#### Maximum Gust Recurrence at Lindbergh Field

**Data From 1969 - 2013**

<table>
<thead>
<tr>
<th>Maximum Gust Speed (mph)</th>
<th>50-year wind gust prediction: 67.6 mph</th>
<th>72.4 100-year wind gust prediction: 72.4 mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical Data</td>
<td>Log. (Historical Data)</td>
<td></td>
</tr>
<tr>
<td>Postulated Based On Best Fit Line</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- $y = 6.8164\ln(x) + 40.964$
- $R^2 = 0.90577$
- 1000-year wind gust prediction: 88.1 mph
- 100-year wind gust prediction: 72.4 mph
- 500-year wind gust prediction: 83.3 mph
- 1000-year wind gust prediction: 88.1 mph

*Note: SDGE 50-year gust at Lindbergh = 55 mph max*
Bay 1 Looking south
In 2008, these surge arrestors were seismically qualified for PGA = 0.5g with a Factor of Safety of 3, by a world leading company, doing it “on the cheap”

In April 2010, with PGA = 0.30g, 4 of 4 broke.
Bay 1 Phase C
A note about Buried Cables in Liquefaction zones

Performance of XLPE Cables in Liquefaction Zones

New Zealand
Performance of XLPE Cables in Liquefaction Zones

New Zealand
XLPE 66 kV Cable

- Metallic Screen
- XLPE Insulation
- HDPE Sheath
- Copper Core
- Lead Sheath

XLPE 66 kV Cable
500 kV
Unanchored
What have we learned?
What Can We do to Shorten These Outages?

- Earthquake. IEEE 693. After 20 years, look what it got PG&E in NAPA. Still, nothing for distribution, buried cables. If we want 1+ day, the cost is about $4 per month increase in electric rates, forever.

- Wind: GO 95. $V = 56$ mph for design in California. If we want $1,000+$ wind design, Add $2 per month

- Ice: Choice 1, like Hydro Quebec. Choice 2. Design for 3 inches of radial ice. Add $1 per month.

- Fire: Months in Rural. Underground? Add $20 per month for rural customers…. won’t happen....
How can we pay to reduce power outages?

• Growing Economy. Rate Making. For $1 Billion per year to expand the network for increasing power demand, we can solve substations in <40 years.

• No Growth Economy. For long-lived items (towers, buried cables), there will be no mitigation.... unless....

• GUIDELINES are written by the industry, and the industry self-regulates, and we have 40 years. Example: IEEE 693.

• or.... the GOVERNMENT imposes requirements, and the GOVERNMENT allows 25% rate increases.
Thank you!