Relay Performance Index for a Sustainable Relay Replacement Program

Aaron Feathers, Abesh Mubaraki, Nai Paz, Anna Nungo
Pacific Gas & Electric Company
San Francisco, CA

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Creating a Sustainable Relay Asset Strategy

- Relay Asset Strategy
  - Fleet Database & Analysis
  - Understand Impacts of Different Relay Types
  - Failure Tracking / Maint. Data Feedback
  - Simple & Inclusive Standards
  - Training & New Technology
  - Compliance
  - Resource Planning

Impacts of Different Relay Types

Failure Tracking / Maint. Data Feedback

Simple & Inclusive Standards

Training & New Technology

Compliance

Resource Planning

Fleet Database & Analysis
Today’s Discussion

- Characteristics of Relay Generations
- PG&E Relay Fleet and Performance Data
- Asset and Fleet Management Strategies
- Relay Performance Index
- Sustainability Model
- Practical or Useful Life of a Relay
- Conclusions – Guiding Principles
Relay generations - from then to now

Protection systems have evolved from:
• Assemblies of electromechanical single function devices
• Through multiple generations of analog solid state systems
• To advanced microprocessor based protection systems

Many utilities now face a complex tangle of challenges
• Managing the performance and reliability of multiple generations of relays in service
Characteristics of relay generations

Electromechanical (EM) relays

• Last as long as the primary power apparatus they protect
• Installations are designed for same longevity
• Simple - limited functionality
• Subject to drift
• Fail silently
• Require regular maintenance tests
Characteristics of relay generations

Solid State (SS) relays

- Analog solid state relays are a lost generation
- Being phased out at most utilities
- Failure rates high due to electronic component failures – sometimes with false trips
- Component failures may not be evident until routine tests are performed
Characteristics of relay generations

Microprocessor (MP) relays

- Shorter service life than EM relays (maybe half)
- Can self monitor to extend maintenance test intervals or eliminate most technician testing
- Multifunctional, highly integrated
- Flexible but complex to configure and apply
- Failures can affect a tangle of functions in the box
Questions about relay generations

- What information can we gather to manage fleets with mixed relay generations?
- What tools does the organization need to manage a mixed fleet of new and old installations?
- What are the impacts of transitioning to a MP relay fleet. Failure modes? Design considerations?
About PG&E

- 70,000 Square Miles
- 5 Million Electric Meters
- 4 Million Gas Meters
- 18,300 miles of Transmission
- 6,800 miles of 230 kV and 500 kV
- 22,544 MW Peak Demand in 2006
- 6,861 MW-Owned Generation

- 854 Substations
- 35,000 Relays
<table>
<thead>
<tr>
<th>FLEET</th>
<th>LIFE EXPECTANCY</th>
<th>AVG AGE (Median)</th>
<th>(Standard Deviation)</th>
<th>FUTURE REPLACEMENT</th>
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<tbody>
<tr>
<td></td>
<td>Microprocessor</td>
<td>15-20 Years</td>
<td>7 Years (5)</td>
<td>Microprocessor</td>
</tr>
<tr>
<td></td>
<td>Microprocessor</td>
<td>15-20 Years</td>
<td>20 Years (10)</td>
<td>Microprocessor</td>
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<td></td>
<td>Microprocessor</td>
<td></td>
<td>40 Years (41)</td>
<td>Microprocessor</td>
</tr>
<tr>
<td>EM</td>
<td>41%</td>
<td>30-40 Years</td>
<td>(41)</td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td>11%</td>
<td>15-20 Years</td>
<td>(20)</td>
<td></td>
</tr>
<tr>
<td>MP</td>
<td>48%</td>
<td></td>
<td>7 Years (5)</td>
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</table>
* 81% of relays with known install date
No Relay Asset Strategy

Don’t let your relay assets become a runaway train
Relay Performance Monitoring

Manufacturer Y - 9200 relays in service
174 relay failures from 2008 to 2013
Relay Performance Monitoring

- Failures can impact reliability (loss of grid or customers)
- How fast can a relay be fixed or replaced?
**Relay Performance – Failures and Trips**

**Relay Failure Totals by Year**

- **MP Relay**
- **SS Relay**
- **EM Relay**

**Microprocessor relays alarm when failed – EM relays fail silently**

**Relay Failure Trips by Year**

- **Relay Trips**
- **Resulting Outages**

**Microprocessor relays don’t always fail securely – some trip**
Relay Performance Monitoring

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<tbody>
<tr>
<td>Relay failures contribution to substation SAIFI (%)</td>
<td>11%</td>
<td>5.4%</td>
<td>8.9%</td>
<td>8.6%</td>
<td>18.1%</td>
<td>10.3%</td>
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<tr>
<td>Relay failures contribution to substation SAIDI (%)</td>
<td>5.1%</td>
<td>2.7%</td>
<td>9.6%</td>
<td>6.5%</td>
<td>33.3%</td>
<td>10%</td>
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</table>

- Failures can impact reliability (loss of grid or customers)
- How fast can a relay be fixed or replaced?
Relay Failures

Unusual events may not be as rare as you think
Relay Failures
Some MP relay failures will result in a trip

- All failures can’t be detected by relay self monitoring
- Early generation MP relays have less sophisticated self monitoring
- Analog-to-digital related failures – probably most susceptible
- Power supply failures – degraded voltage supplied to A/D comparators can fool some relays
- Upgrading relays – unforeseen compatibility issues
Relay Failures

High impact schemes should consider insecure relay failure modes in their design

- Bus Differential
- Wide Area RAS
- Breaker Failure?

Consider

- External relay supervision (fault detector, etc.)
- RAS – for line outage monitor both ends of line
- Voting scheme?
Relay Data Analytics

Applying analytics to relay data will help you:

• Understand information in the data
• Identify most important data to the business
• Identify missing data.
Missing Data – Electromechanical Relay Health

Maintenance as-found condition
• Within calibration?

• PRC-005-2 Countable Events – Valuable relay health data even if you do not have a performance based maintenance program requiring tracking this information.
Relay Life Cycle Replacement Strategy
Targeted relay replacements

- Age based
  - This approach may not be adequate due to limited funding, limited support from asset management, sheer number of relays
- Performance based (failure rate, misoperation rate)
- Risk based – Combination of above plus other factors
Relay Life Cycle Replacement Plan

Risk Based - Look at relay performance (health) and associated risk

➢ Relay Health
  • Failure rate
  • Misoperation rate
  • Age (tiered by relay class)
  • Other countable events

➢ Risk Factors (Criticality)
  • Critical Substation
  • Customer Counts
  • Bus Arrangement
  • Scheme Type

High Risk Bus Arrangement
Relay Life Cycle Replacement Plan

Risk Based - Look at relay performance (health) and associated risk

- Apply weighting factors for each category and use a formula for prioritization across the entire relay asset
- Target highest risk relays with available funding
- Reassess impact of replacement program each year

<table>
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<tr>
<th>Age SS/MP</th>
<th>Age EM</th>
<th>Points</th>
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<tr>
<td>&gt; 20 yrs</td>
<td>&gt; 40 yrs</td>
<td>5</td>
</tr>
<tr>
<td>15 – 20</td>
<td>30 - 40</td>
<td>4</td>
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<tr>
<td>10 – 15</td>
<td>20 - 30</td>
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<td>2</td>
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<td>&lt; 5</td>
<td>&lt; 10</td>
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<table>
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<th>Bus Config</th>
<th>Points</th>
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<tbody>
<tr>
<td>DBSB</td>
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<tr>
<td>Main/Aux</td>
<td>7</td>
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<tr>
<td>Loop</td>
<td>5</td>
</tr>
<tr>
<td>Ring</td>
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<tr>
<td>BAAH</td>
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<table>
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<th>Scheme</th>
<th>Points</th>
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<td>Bus Diff</td>
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<tr>
<td>Bkr Fail</td>
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<tr>
<td>DTT</td>
<td>7</td>
</tr>
<tr>
<td>Dir Distance</td>
<td>4</td>
</tr>
<tr>
<td>Non-Dir OC</td>
<td>1</td>
</tr>
</tbody>
</table>
Relay Performance Indice

**Criticality Score**

\[= 40\% \text{ Substation Tier} + 30\% \text{ Scheme} + 30\% \text{ Bus Config}\]

**Health Score**

\[= 85\% \text{ Performance} + 15\% \text{ Age}\]

**Total Score**

\[= 40\% \text{ Criticality Score} + 60\% \text{ Health Score}\]
Relay Life Cycle Replacement Plan

PG&E Fleet Total Score

Total Score (Criticality & Health) vs. Number of Relays (cumulative)
2013 Replacements:
- 1,541 units in association with “other work”
- 52 units due to relay age and performance issues
Relay Life Cycle Replacement Plan

Are the right relays being replaced?

- Replacements not driven by relay lifecycle plan
  - Capacity
  - New interconnections
  - Automation
  - Protection deficiencies
  - Compliance

Approximately 2000 relays removed per year and 1500 new relays replacing them.
* 81% of relays with known install date
Sustainability Model

Looking to the future
Sustainability Model

Developed to help determine the replacement strategy.

➢ Statistics to:
  • Forecast expected failures
  • Life expectancy
  • Average age over time
  • Survivability (Sustainability)

➢ Models non-targeted relay replacements as well as targeted
➢ Separate model developed for each relay class
Sustainability Model

**INPUTS**
- Replacement Profile
- Replacement Rate by Others (4%)

**OUTPUTS**
- Failures + Forceouts
- Life Expectancy
- Fleet Waterfall Profile
- Asset Count as F(x) of Age
- Failure Rate
- Proactive Replacements (# of units/yr)
- Probability # Failures
- Average Age

MP MODEL SIMULATION
Asset Base – Population Waterfall

Fleet Waterfall Curves*

* Curves exclude relays of unknown ages
• EM relay removal rate of 4% (440 per year) used.
• Failures are expected to hold steady for the first 15 years and then decrease over time as more relays are removed and the fleet size decreases.
Failure Forecast - MP Relays

- MP relay removal/replacement rate of 4% per year by others.
- Targeted MP relay replacement at age 20 years (up to 1500).
- Failures are expected to increase over time as more MP relays are installed – Overall failures for all classes is flat.
• MP average age increases from 8 years to 12 years over 50 years time span
• MP life expectancy (simulated): 30 years
EM average age increases each year
EM life expectancy (simulated): 77 years
Life Expectancy and Practical Life

Practical / Useful Life Factors Include:
- Device technology
- Spare parts availability
- Time/cost to repair
- Design life (by manuf)
- Environment
- Regulatory issues
- Interoperability
- Outdated configuration software

Relay model life expectancy predictions

<table>
<thead>
<tr>
<th></th>
<th>Life Expectancy (years)</th>
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<tbody>
<tr>
<td>Electromechanical</td>
<td>77</td>
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<tr>
<td>Solid State</td>
<td>38</td>
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<tr>
<td>Microprocessor</td>
<td>30</td>
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IEEE PSRC WG I-22 “Condition Assessment of P&C Devices”
WG drafting report to determine end-of-useful-life for protection devices
Summary – PG&E Key Strategy Elements

Short Term (1-2 years)

- Target high failure rate relay models for replacement (100-200 units/year)
- Improve data collection and data quality in asset register.
- Consolidate databases (relay, settings, maintenance)
- Simplify relay standards to support relay change-outs.

The secret of getting ahead is getting started
– Mark Twain
Medium & Long Term (3+ years)

- Establish program to replace SS and MP relays at age 20.
- Continue monitoring relay performance to confirm strategy or initiate adjustments.

"Even if you're on the right track you'll get run over if you just sit there." — Will Rogers
Establish a sustainable relay life cycle replacement strategy

Prevent run to failure and address high failure rate relays.

Consider insecure relay failure mode when designing high impact schemes

Design schemes to facilitate easier and quicker relay replacements.

Practical or Useful Life of MP relays may be shortened by various factors – See IEEE PSRC WG I22 report “Condition Assessment of P&C Devices”

*It’s a work in progress – Reassess and refine as you go*
Any Questions?