IEEE PES General Meeting
Reliability Panel Session
Utility Practices and Challenges on Predicting Distribution System Reliability

Reliability & Asset Management at
Southern California Edison

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July 2014

National Harbor MD
Reliability & Asset Management at SCE:

- Introduction of SCE T&D System
- Trend of T&D equipment ageing
- Forecast circuit reliability – Credit infrastructure replacement
- Integrate cable testing with IR
- Substation Infrastructure Replacement

Summary
Introduction of SCE

Transmission and Distribution System
Southern California Edison

- 50,000 square miles
- ~ 76 billion kWh/year delivered
- 4.9 million customers
- Over 400 cities & communities with collective population of over 13 million people
Distribution & Substation Assets

1,440,000 wood poles
26,000 circuit-miles of UG primary conductor
38,000 circuit-miles of OH primary conductor
715,000 distribution transformers
87,000 padmount/subsurface switches

2,800 substation transformers
11,900 substation circuit breakers

4,600 distribution circuits (mostly radial design vs. looped)
Challenges to Reliability

2013 System Reliability SAIDI By Cause Category
Major Event Days Excluded

- OH Distribution Equip. 16.66%
- UG Dist Equip (exclude Cable) 11.31%
- UG Cable Only 18.50%
- Sub / Trans Equip. 4.27%
- Operation 10.27%
- Source Loss (Not Equip.) 0.18%
- Load Shed 0.08%
- Third Party 17.01%
- Animal 3.13%
- Vegetation 0.31%
- Weather / Fire / Earthquake 10.55%
- Other 7.73%

60% of SAIDI is caused by in-service failures of equipment.
General Rate Case Journey

PUC Authorized Spending for **Distribution Circuit IR** Over the past 4 GRCs

<table>
<thead>
<tr>
<th>Year</th>
<th>2003</th>
<th>2006</th>
<th>2009</th>
<th>2012</th>
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<tbody>
<tr>
<td></td>
<td>$16 million</td>
<td>$ 67 million</td>
<td>$ 82 million</td>
<td>$143 million</td>
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<td></td>
<td>$16 million</td>
<td>$ 26 million</td>
<td>$ 15 million</td>
<td>$116 million</td>
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</table>

← *Requested*

← *Authorized*
Current Inventory of Underground Primary Cable by Year of Installation
(as of year-end 2012)

In conductor-miles
PILC = 3,279
HMW = 1,402
XLPE = 28,369
TRXLPE = 17,129
TOTAL = 50,179

Year of Installation

PILC  HMW  XLPE  TR-XLPE
Trends of Transmission and Distribution Equipment Ageing
Infrastructure Aging

- Trend in Average Age of UG Cable
- Trend in Average Age of Padmount (PMH) Switches
- Trend in Average Age of Distribution Wood Poles
- Trend in Average Age of Underground Distribution Transformers
Time-dependent Failures (Weibull curves)

Cable Failure Rate

- PILC
- XLPE
- TR-XLPE

Cable Age (years)

Failure Rate vs Time Plot

Underground Oil Switch
Mean Life = 35 yrs
Failure Rate Line

ZOILO ROLDAN
SCE
3/30/2010
2:35:54 PM

Mean Life = 57 yrs

Cable failure/mile/yr

0.0E+00
0.1E-01
0.2E-01
0.3E-01
0.4E-01
0.5E-01
0.6E-01
0.000
20.000
40.000
60.000
80.000
100.000

Time (t)

Failure Rate, f(t)/R(t)

- Data 1-BANK XFMRS

Distribution Circuit Breaker Failure Rate

Failure Rate Line

Mean Life = 55

Time (t)

Failure Rate, f(t)/R(t)

- Data 1-BANK XFMRS

Time-dependent Failures

- Weibull curves
Forecast Circuit Reliability:

Credit infrastructure replacement
4,600 circuits

cluster analysis

20 circuits
Calculating circuit reliability

\[ P(f|t) = 0.001 \]

\[ P(f|t) = 0.002 \]

\[ P(f|t) = 0.002 \]

\[ P(f|t) = 0.004 \]

\[ P(f|t) = 0.003 \]

SAIDI = 0.88
SAIFI = 0.38
MAIFI = 0.45
Modeling preemptive cable replacement

\[ P(f|t) > 0.001 \]

\[ P(f|t) > 0.002 \]

\[ P(f|t) > 0.002 \]

\[ P(f|t) = 0 \]

\[ P(f|t) = 0 \]

SAIDI < 0.88

SAIFI < 0.38

MAIFI < 0.45
Predicted reliability with varying levels of preemptive cable replacement

SAIDI Forecast 2013 - 2032
(Excluding IEEE 1366 Major Event Days)

Minutes/Customer/year

Years

SAIDI Forecast 2013 - 2032
(Excluding IEEE 1366 Major Event Days)
### Added Benefit: Circuit Modification Analysis

<table>
<thead>
<tr>
<th>Reliability Improvements</th>
<th>SAIFI</th>
<th>MAIFI</th>
<th>SAIDI</th>
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<tr>
<td>Baseline (Before Improvement)</td>
<td>0.38</td>
<td>0.456</td>
<td>0.882</td>
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<tr>
<td>Replacing all cables (9 segments)</td>
<td>6%</td>
<td>0%</td>
<td>7%</td>
</tr>
<tr>
<td>Adding 24 fuses at all radials</td>
<td>0.213</td>
<td>0.186</td>
<td>0.701</td>
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<tr>
<td>Move RCS to mid-point and add 2 more at load-split point</td>
<td>0.259</td>
<td>0.293</td>
<td>0.727</td>
</tr>
<tr>
<td>All of the above</td>
<td>0.166</td>
<td>0.155</td>
<td>0.584</td>
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</table>
Integrate cable testing with infrastructure replacement
Cable Testing

50,000 conductor-miles of distribution UG primary cable

37,000 miles in rigid duct (e.g., PVC, transite, soapstone, etc.)
most unjacketed

13,000 miles in polypropylene tubing => Cable in Conduit
all unjacketed

i.e., CIC
Results of tests on 6,021 cable segments (574 cond-miles):

1% Insulation failure & emergency replacement

18% Identified for short term replacement
  ↓
  24% insulation
  73% concentrics
  33% splice/termination
  *not exclusive

27% Identified for long term replacement.
  ↓
  52% insulation
  35% concentrics
  30% splice/termination
  *not exclusive

54% No replacement needed.
Testing is Cost-effective

Compare NPV of the revenue requirements:

a) Replace all cable immediately without test,

versus

b) Test all cable, replace immediately only the “bad” cable, and replace the “good” cable 10 years later
Cable Testing: Conclusions

• Expect cable related outages and reliability metrics to increase significantly over the next 20 years without preemptive replacement of cable.

• Replacing cable in the worst performing circuits as function of age would still be unaffordable.

• Identifying, via testing, cable which is at the end of its service life, is a cost-effective asset management strategy.
Substation Infrastructure Replacement:
Based on health index to derive risk informed replacement ranking

- Transformers
- Circuit breakers
- Auto Reclosers
- Switches
Distribution Circuit Breaker Profile

Distribution Circuit Breaker Histogram

Number of Distribution Circuit Breakers

Year of Installation

Weights of CB HI Parameters

- Operating Mechanism: 23%
- Interrupter: 15%
- Age: 24%
- Notifications: 14%
- OCBA: 8%
- Expert Opinion: 6%
- Spare Part Availability: 10%
Determining “Effective Age”

Relationship between Health Index and Effective Age
<table>
<thead>
<tr>
<th>Replacement Rank</th>
<th>TDBU #</th>
<th>Voltage</th>
<th>Substation</th>
<th>CB Description</th>
<th>CB Type</th>
<th>AGE</th>
<th>Hi</th>
<th>Effective Age</th>
<th>POF</th>
<th>Criticality Multiple</th>
<th>Risk Ratio (Criticality * POF)</th>
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<tr>
<td>1</td>
<td>200007561</td>
<td>4</td>
<td>PAULARINO</td>
<td>INLET 4KV CB</td>
<td>MAG</td>
<td>56.2</td>
<td>30.7%</td>
<td>79</td>
<td>9.88E-01</td>
<td>1.3824</td>
<td>1.3655</td>
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<td>2</td>
<td>200005815</td>
<td>16</td>
<td>NEWMARK</td>
<td>MERCER 16KV CB</td>
<td>OIL</td>
<td>56.2</td>
<td>22.2%</td>
<td>79</td>
<td>9.88E-01</td>
<td>1.3087</td>
<td>1.2927</td>
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<td>3</td>
<td>200005904</td>
<td>16</td>
<td>FELTON</td>
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<td>19.8%</td>
<td>79</td>
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<td>1.3042</td>
<td>1.2882</td>
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<td>200005118</td>
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<td>PIONEER</td>
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<td>POINT 4KV CB</td>
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<td>79</td>
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<td>1.2750</td>
<td>1.2595</td>
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<td>6</td>
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<td>16</td>
<td>FAIRFAX</td>
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<td>74</td>
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<td>1.3037</td>
<td>1.2569</td>
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<td>OXNARD</td>
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<td>8</td>
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<td>ERIC</td>
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<td>41.7</td>
<td>33.9%</td>
<td>75</td>
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<td>SANTA BARBARA</td>
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<td>COSTA MESA</td>
<td>NO.1 BANK 4KV CB</td>
<td>OIL</td>
<td>55.7</td>
<td>28.1%</td>
<td>79</td>
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<td>1.2434</td>
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<td>COSTA MESA</td>
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<td>14.1%</td>
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<td>FRIENDLY HILLS</td>
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<td>22.2%</td>
<td>79</td>
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<td>KEYSTONE 4KV CB</td>
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<td>LINDSAY</td>
<td>TOWT 4KV CB</td>
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<td>27.9%</td>
<td>79</td>
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<td>ARRO</td>
<td>NO.2 BANK 4KV CB</td>
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<td>1.2338</td>
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<td>ROCHA 4KV CB</td>
<td>MAG</td>
<td>50.3</td>
<td>34.6%</td>
<td>74</td>
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<td>41.7</td>
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<td>74</td>
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<td>1.2777</td>
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</table>
Ageing of power delivery system is real and needs be managed

Infrastructure replacement is an effective tool against ageing but needs be managed with quantitative approach

Regulators appear to understand the need for infrastructure replacement to manage system reliability

Quantitative risk assessments help understand the challenges and enable approval funding requests

Risk assessments may not be optional in the future

Risk assessments are within the ability of any utility

Health index model integrates quantified parameters and can generate risk informed ranking for infrastructure replacement