Outage Follow Up (OFU)

What is the real cause of an outage?

17PESGM2821

IEEE/PES General Meeting – Chicago Illinois
Panel Session on Electric Reliability Best Practices
July 18, 2017
Lee Taylor – Duke Energy Reliability Governance
Outage Follow Up (OFU)

The Primary Root Cause

17PESGM2821

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Overview

• Description of the OFU process
• Sample outage investigations
• Defining the primary root cause
• Creating a quantifiable record of primary root causes to improve reliability
Duke Energy Facts

- ~7,500,000 customers
- Service territory in six states: NC, SC, Indiana, Ohio, Kentucky, and Florida
- Common outage history database translated daily from five OMS systems (three different vendors).
- ~250,000 outage records per year stored in the common outage history database.
- Outage history editor allows data correction and additions by OFU specialists (2%, 56%).
OFU Site Investigations per Year

- 2% of all outage incidents = 4,600
- 1,100 of these are MED outages
- 56% of all customer interruptions
- 1,500 vegetation outages
- 500 of these are MED outages
- 43 zone review meetings per year
Reliability Improvement based on the Outage Follow Up Process

- To improve reliability, the utility must either systematically remove fault sources or mitigate the effect of faults that cannot be removed.
- The utility must investigate in detail a significant number of outages to determine why the faults are not sufficiently controlled.
- Most initial outage reports provide very generic cause data that is not actionable and often wrong.
- Even when this outage data is correct, it is often insufficiently detailed for providing any value.
- The outage follow up process (OFU) is designed to provide actionable data about controlling faults.
A Very Low Bar

Was the outage caused by a tree?

4260 Tree Outages
Major Investigations
Duke Energy - 2013 thru 2015

- Outages correctly reported as trees originally.
- Reported as trees, but were actually something else.
- Reported as some other cause, but were actually trees
OUTAGE DASHBOARD

• Equipment
• Lightning
• Public
EQUIPMENT

A Category

It failed!

It just failed!
Quarterly assessment review - information on outage record #34

- Date/Time off – 2/13/2009 22:05
- Device out – Feeder breaker
- Cause/Problem – Equipment failure
- Equipment – connector
- #Cust Out – 1,512
- Weather – clear
- Completion Remarks – stirrup burned up, replaced, cleared, and closed breaker
Quarterly assessment review - information on outage record #37

• Date/Time off – 2/23/2009 7:05
• Device out – Feeder breaker
• Cause/Problem – Equipment failure
• Equipment – connector
• #Cust Out – 1,311
• Weather – clear
• Completion Remarks – stirrup burned up, replaced, cleared, and closed breaker

The Primary Root Cause

July 18, 2017

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ETC.
The Stirrup
The designer of the stirrup turns over in his grave.
Remington 52, Branch Hill 41 and 42, 2,600+ Customers
Remington 52, Branch Hill 41 and 42, Typical Fix
Cedarville 54, Buckwhet 41, 4,000+ Customers

Repaired with automatic splice in slack span
Cedarville 54, Buckwhet 41, Next pole, same scenario
Cedarville 54, Buckwhet 41, Typical fix
Jackson 41, 2,500+ Customers
Jackson 41, Typical Fix
Rybbolt 41, 2,700+ Customers

New stirrup
Ryb Bolt 41, Middle phase down, unfused 1 span tap
Rybolt 41 – Repaired with automatic splices in slack span.
Lateral 41, 1,600+ Customers

- Stirrup burned off, replace OH conductor
- No photo available
Issues

• Five major outage incidents over a 6 week period.
• 13,400+ customers interrupted.
• Only >1,000 CI incidents were investigated. There would be many more of these on smaller outages.
• Is it poor design, improper installation (e.g. failure to use wire brush), use of a non-calibrated connector, or just the expected failure rate?
• Other problems on these sites: Use of automatic sleeves in slack spans and unfused taps.
LIGHTNING!

A Category

Not our fault
Example of an actual outage follow up investigation.

On 6/29/2007 a 34.5 KV Feeder with 3,513 customers locked out.

The Daily Activity Report said the cause was “lightning”.
The bottom insulator on pole 124H-788 had failed. It was replaced by the trouble crew.

Original insulators (did not fail)
Outage follow up on this site found that the remaining middle insulator had holes in the polymer skirts. **Use outage follow up to determine root causes.**

What are these spots?

Remaining middle phase insulator.
Front view of a remaining insulator.
Remaining top insulator also had a hole in a polymer skirt. The outage follow up process determined that the root cause was polymer insulation degradation caused by UV deterioration.
The outage follow up investigation also found additional conductor damage at the site on the bottom phase conductor.
You have to get out in the field and see what actually happened.
You have to get out of the vehicle and walk the line.
Overview

• Description of the OFU process
• Sample outage investigations
• Defining the *primary root cause*
• Creating a quantifiable record of primary root causes to improve reliability
Root Cause

• Anything that would have prevented the outage.

• Initiating causes are root causes.

• Most outages have multiple root causes.
Example of multiple root causes for a sustained outage on an entire circuit.

- Lightning strike
- Low structure BIL/CFO
- Breaker failed to reclose

Primary Root Cause
Expedient Root Cause
The “Expedient” Root Cause

- Expedient – Definition: Suitable for achieving a particular end in a given circumstance.
- Communications with customers
- Communications with regulators
- Benchmarking (communications with other utilities).
- Pie Charts
The Expedient Root Cause

- Lightning strike
- Low structure BIL/CFO
- Breaker failed to reclose
Primary Root Cause

- The **Primary Root Cause** is the root cause for which the utility can take corrective action in the most timely and economical manner.
- Most Primary Root Causes are **actionable**.
- Many initiating causes (e.g. lightning, traffic accident) are not actionable.
- One major purpose of the outage follow up process (OFU) is to determine and record the **primary root cause of each outage**.
The Primary Root Cause

- Lightning strike
- Low structure BIL/CFO
- Breaker failed to reclose
The ten IEEE 1782 generic cause categories. These expedient selections cast blame in a discreet manner.

- Equipment
- Lightning
- Planned
- Power Supply
- Public
- Vegetation
- Weather (other than lightning)
- Wildlife
- Unknown
- Other
# Cause Categories for Reliability Improvement

**Actionable Issues**
- Standards
- Design
- Construction
- Deterioration
- Vegetation Management
- Utility Errors

**Less Actionable Issues**
- Environment
- Work Requests

July 18, 2017
Overview

• Description of the OFU process
• Sample outage investigations
• Defining of the primary root cause
• Creating a quantifiable record of primary root causes to improve reliability

Here is the point where detailed outage data is needed.
## Preform Ties vs. Hand Ties

<table>
<thead>
<tr>
<th>On 1/0 ACSR</th>
<th>Average Holding Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Ties</td>
<td>850 lb.</td>
</tr>
<tr>
<td>Preformed Ties</td>
<td>1300 lb.</td>
</tr>
</tbody>
</table>

---

*July 18, 2017*
# Outages Caused by Breakage of Ties

## Preform Ties

<table>
<thead>
<tr>
<th>Region</th>
<th>Incidents</th>
<th>CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ohio/Ky</td>
<td>16</td>
<td>10,853</td>
</tr>
<tr>
<td>DEC</td>
<td>39</td>
<td>8,304</td>
</tr>
<tr>
<td>Indiana</td>
<td>18</td>
<td>6,533</td>
</tr>
<tr>
<td>DEP</td>
<td>8</td>
<td>2,000</td>
</tr>
<tr>
<td>Total</td>
<td>81</td>
<td>27,690</td>
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</tbody>
</table>

## Hand Ties

<table>
<thead>
<tr>
<th>Region</th>
<th>Incidents</th>
<th>CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ohio/Ky</td>
<td>42</td>
<td>35,029</td>
</tr>
<tr>
<td>DEC</td>
<td>129</td>
<td>29,658</td>
</tr>
<tr>
<td>Indiana</td>
<td>31</td>
<td>20,593</td>
</tr>
<tr>
<td>DEP</td>
<td>233</td>
<td>70,062</td>
</tr>
<tr>
<td>Total</td>
<td>435</td>
<td>155,342</td>
</tr>
</tbody>
</table>

The Primary Root Cause

July 18, 2017
A Very Low Bar
You will not learn much if this is what you get!

4260 Tree Outages
Major Investigations
Duke Energy - 2013 thru 2015

- Outages correctly reported as trees originally.
- Reported as trees, but were actually something else.
- Reported as some other cause, but were actually trees
# MED Vegetation Major Distribution Outages

All regions, Valid OFU Investigations 2014, 2015, and 2016

<table>
<thead>
<tr>
<th>Veg Equip Grouping</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Damage</td>
<td>843</td>
<td>64%</td>
</tr>
<tr>
<td>Conductor</td>
<td>223</td>
<td>17%</td>
</tr>
<tr>
<td>Pole</td>
<td>113</td>
<td>9%</td>
</tr>
<tr>
<td>Crossarm</td>
<td>97</td>
<td>7%</td>
</tr>
<tr>
<td>Other</td>
<td>19</td>
<td>1%</td>
</tr>
<tr>
<td>Insulator</td>
<td>16</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>1311</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

July 18, 2017
Non-MED Vegetation Major Distribution Outages
All regions, Valid OFU Investigations
2014, 2015, and 2016

<table>
<thead>
<tr>
<th>Veg Equip Grouping</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Damage</td>
<td>1603</td>
<td>61%</td>
</tr>
<tr>
<td>Conductor</td>
<td>503</td>
<td>19%</td>
</tr>
<tr>
<td>Pole</td>
<td>230</td>
<td>9%</td>
</tr>
<tr>
<td>Crossarm</td>
<td>136</td>
<td>5%</td>
</tr>
<tr>
<td>Other</td>
<td>101</td>
<td>4%</td>
</tr>
<tr>
<td>Insulator</td>
<td>43</td>
<td>2%</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>2616</strong></td>
<td><strong>100%</strong></td>
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</tbody>
</table>
Non-MED Vegetation Major Distribution Outages
All regions, Valid OFU Investigations
2014, 2015, and 2016

<table>
<thead>
<tr>
<th>Veg Equip Grouping</th>
<th>Limb</th>
<th>Overgrown</th>
<th>Tree</th>
<th>Grand Total</th>
<th>Limb</th>
<th>Overgrown</th>
<th>Tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Damage</td>
<td>758</td>
<td>280</td>
<td>565</td>
<td>1603</td>
<td>76%</td>
<td>80%</td>
<td>45%</td>
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<td>Conductor</td>
<td>144</td>
<td>63</td>
<td>296</td>
<td>503</td>
<td>14%</td>
<td>18%</td>
<td>23%</td>
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<tr>
<td>Pole</td>
<td>20</td>
<td>0</td>
<td>210</td>
<td>230</td>
<td>2%</td>
<td>0%</td>
<td>17%</td>
</tr>
<tr>
<td>Crossarm</td>
<td>18</td>
<td>1</td>
<td>117</td>
<td>136</td>
<td>2%</td>
<td>0%</td>
<td>9%</td>
</tr>
<tr>
<td>Other</td>
<td>44</td>
<td>7</td>
<td>50</td>
<td>101</td>
<td>4%</td>
<td>2%</td>
<td>4%</td>
</tr>
<tr>
<td>Insulator</td>
<td>11</td>
<td>1</td>
<td>31</td>
<td>43</td>
<td>1%</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td>Grand Total</td>
<td>995</td>
<td>352</td>
<td>1269</td>
<td>2616</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
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</table>

July 18, 2017

The Primary Root Cause
### Non-MED Vegetation Major Distribution Outages
#### DEP and DEC, Valid OFU Investigations
#### 2014, 2015, and 2016

<table>
<thead>
<tr>
<th>Region</th>
<th>Veg Equip Grouping</th>
<th>Limb</th>
<th>Overgrown</th>
<th>Tree</th>
<th>Grand Total</th>
<th>Limb/5K Veg Miles</th>
<th>OverGr/5K Veg Miles</th>
<th>Tree/5K Veg Miles</th>
<th>Total/5K Veg Miles</th>
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<tbody>
<tr>
<td>DEC</td>
<td>No Damage</td>
<td>193</td>
<td>148</td>
<td>187</td>
<td>528</td>
<td>25</td>
<td>19</td>
<td>24</td>
<td>69</td>
</tr>
<tr>
<td>DEC</td>
<td>Conductor</td>
<td>70</td>
<td>43</td>
<td>124</td>
<td>237</td>
<td>9</td>
<td>6</td>
<td>16</td>
<td>31</td>
</tr>
<tr>
<td>DEC</td>
<td>Pole</td>
<td>5</td>
<td>100</td>
<td>105</td>
<td>1</td>
<td>0</td>
<td>13</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>DEC</td>
<td>Crossarm</td>
<td>6</td>
<td>1</td>
<td>65</td>
<td>72</td>
<td>1</td>
<td>0</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>DEC</td>
<td>Other</td>
<td>11</td>
<td>4</td>
<td>19</td>
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<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>DEC</td>
<td>Insulator</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Some Damage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>59</td>
</tr>
<tr>
<td>DEC Total</td>
<td></td>
<td>38,400 Veg Miles</td>
<td>287</td>
<td>196</td>
<td>496</td>
<td>979</td>
<td>37</td>
<td>26</td>
<td>65</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>Veg Equip Grouping</th>
<th>Limb</th>
<th>Overgrown</th>
<th>Tree</th>
<th>Grand Total</th>
<th>Limb/5K Veg Miles</th>
<th>OverGr/5K Veg Miles</th>
<th>Tree/5K Veg Miles</th>
<th>Total/5K Veg Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEP</td>
<td>No Damage</td>
<td>264</td>
<td>84</td>
<td>232</td>
<td>580</td>
<td>54</td>
<td>17</td>
<td>48</td>
<td>119</td>
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<tr>
<td>DEP</td>
<td>Conductor</td>
<td>32</td>
<td>8</td>
<td>89</td>
<td>129</td>
<td>7</td>
<td>2</td>
<td>18</td>
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<td>Pole</td>
<td>10</td>
<td>8</td>
<td>70</td>
<td>80</td>
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<td>0</td>
<td>14</td>
<td>16</td>
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<td>DEP</td>
<td>Crossarm</td>
<td>12</td>
<td>12</td>
<td>12</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>DEP</td>
<td>Other</td>
<td>10</td>
<td>1</td>
<td>19</td>
<td>30</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
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<td>5</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Some Damage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>53</td>
</tr>
<tr>
<td>DEP Total</td>
<td></td>
<td>24,412 Veg Miles</td>
<td>317</td>
<td>93</td>
<td>427</td>
<td>837</td>
<td>65</td>
<td>19</td>
<td>87</td>
</tr>
</tbody>
</table>

July 18, 2017
The Primary Root Cause
53
Tree Limb Faults

• For a tree limb to cause a fault, the limb must contact either two phases, or in some cases, a phase and the system neutral.

• If the limb remains in contact with both phases and burns a carbon path, a sustained outage occurs.

• Clearance between phases or between a phase and the system neutral is a factor in the likelihood of a tree fault due to the voltage gradient (KV per ft.). Therefore, compact spacing is more vulnerable to actual tree limb faults.
Comparison of Damage from Vegetation Outages per Vegetated Mile

Vegetation Damage per 5K Veg Miles

July 18, 2017
The Primary Root Cause
<table>
<thead>
<tr>
<th>Circuitry</th>
<th>KV</th>
<th>Spacing In Inches</th>
<th>Voltage Gradient KV/ft.</th>
<th>Veg Mi.</th>
<th>Major Limb Out per 100 Veg Mi.</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEP 23 KV</td>
<td>23</td>
<td>35</td>
<td>7.89</td>
<td>21,963</td>
<td>1.30</td>
<td>None</td>
<td>Voltage, spacing</td>
</tr>
<tr>
<td>DEC 24 KV</td>
<td>24</td>
<td>47</td>
<td>6.13</td>
<td>4,755</td>
<td>1.07</td>
<td>Spacing</td>
<td>Voltage</td>
</tr>
<tr>
<td>DEC 12 KV</td>
<td>12</td>
<td>47</td>
<td>3.18</td>
<td>32,270</td>
<td>0.71</td>
<td>Voltage, spacing</td>
<td>None</td>
</tr>
</tbody>
</table>

35 inches phase-to-phase

47 inches phase-to-phase
A proven way to improve system reliability is to collect, store and use outage data that is both detailed and correct.

Around 2% of total incidents, if carefully investigated, provides a useful amount of fault data.
The Line of Knowledge

The Illusion of Knowledge  -  Knowledge

Ignorance
Need Additional Information?

- Lee Taylor, Duke Energy
  - Phone 704-382-4253
  - E-mail lee.taylor@duke-energy.com
Appendix:
Most Initial Outage Reports are Misleading

- Initial Report - Circuit locks out - unknown cause.
- OFU – Goose flew into 2 phases beyond a line recloser (wires were slack due to a corroded guy), but locked out station breaker instead because it failed to reclose.

- Initial Report – Circuit locks out from lightning.
  - OFU – A live limb from a white oak fell on the three phase main line.

  - OFU – Pole leaned over due to poor guying, primary contacted a light, and since the tap was unfused, locked out the station breaker.
  - [Note: The light was on a public building.]
Most Initial Outage Reports are Misleading

- Initial Report - Circuit locks out - unknown cause.
- OFU - Automatic splice on slack span fell out. (Outage was completed still coded “unknown”.)

- Initial Report – Tree locks out circuit.
  - OFU – Tree was downstream of line recloser but failed to interrupt fault due to incorrect settings.

- Initial Report – Tree locks out circuit.
  - OFU – Tree was downstream of line recloser but wires got together upstream due to magnetically induced conductor motion and poor clearances.

July 18, 2017

The Primary Root Cause
Most Initial Outage Reports are Misleading

- Initial Report - Circuit locks from cable dig in.
- OFU – Fused cutout on UG riser pole failed to interrupt fault due to barrel corrosion.

- OFU – Company crew working on line made contact with primary with bucket truck.

- Initial Report - Circuit locks from a tree.
- OFU – It was a dead limb from an Oak tree 23 feet from the line.
Most Initial Outage Reports are Misleading

- Initial Report – Circuit locks out – unknown cause.
- OFU – It was a maple tree that had grown up into the line.

- Initial Report -Circuit locks from a tree.
- OFU – An oak tree 48 feet from the line fell because a developer had cut the roots when building new townhouses

- Initial Report – Planned outage on circuit.
- OFU – Defective maple 21 feet off line fell on the circuit, but did not trip it off. So crew did.
Most Initial Outage Reports are Misleading

- Initial Report – Circuit out - equipment failure.
- OFU – A construction crew dug into the 1000 MCM UG circuit exit cable.

- Initial Report – Circuit locks out due to “weather”.
- OFU – A pole was relocated because of a new sidewalk. A guy on the pole was installed incorrectly, and the wind blew it into a phase conductor. Crew had not bonded guy, so it set the ground on fire, and blew smoke everywhere at a busy intersection. Bystanders posted the incident on the internet.

- Initial Report – Recloser subfeeder locks out due to a traffic accident.
- OFU – Car hit pole on tap line, but tap fuse failed to clear. Electronic recloser appeared to lock out. First reclose interval had been set for 900,120 cycles (four hours) instead of 120 cycles.
Portion of 60 Circuit Outages (>1000 Cust) reviewed in a three month period for Region X

<table>
<thead>
<tr>
<th>Primary Root Causes – Protective Devices that did not work.</th>
<th>Cust Off</th>
<th>Incidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuse not on tap pole</td>
<td>10,774</td>
<td>4</td>
</tr>
<tr>
<td>Unfused tap</td>
<td>7,995</td>
<td>4</td>
</tr>
<tr>
<td>Fused cutout - fail to interrupt</td>
<td>4,762</td>
<td>3</td>
</tr>
<tr>
<td>Fuse had been jumpered</td>
<td>3,833</td>
<td>2</td>
</tr>
<tr>
<td>Recloser too far down tap</td>
<td>3,486</td>
<td>1</td>
</tr>
<tr>
<td>Needed main line recloser</td>
<td>2,698</td>
<td>2</td>
</tr>
<tr>
<td>Recloser failure</td>
<td>2,292</td>
<td>1</td>
</tr>
<tr>
<td>Recloser by-passed</td>
<td>1,753</td>
<td>1</td>
</tr>
<tr>
<td>PD location, absence, or failure Total</td>
<td>37,593</td>
<td>18</td>
</tr>
</tbody>
</table>