SDG&E Experience With Distribution Synchrophasors and Catching Falling Conductors

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SDG&E Distribution System

- 22,000 miles of lines
- 60% underground and 40% overhead
- 12.47, 12.0, and 4.16 kV voltage levels
- Grounded at substation with three- and four-wire systems
Advanced SCADA Planning
More Than 60 Cases Defined

• Falling conductor protection (patent pending)
• Voltage profile monitoring and control
• Selective load shedding and restoration
• Power quality monitoring
• Apparatus and system condition monitoring
• Secure communication
Advanced SCADA Features

• Increased accuracy – voltage and current sensors
• Phase angle
• GPS time-stamped data
• Remote engineering access and event reports
• High-speed, near real-time control
Advanced SCADA Features

• Advanced visualization
• Improved security
  ▪ Log and audit access
  ▪ Active directory passwords
  ▪ Network anomaly detection sensor and technology
Detect Broken Conductor and Trip Circuit Before Line Hits the Ground?

Falling Conductor Timeline

- 0.5 s, 4 ft
- 1 s, 16 ft
- Conductor hits ground at 1.37 s

\[ d = \frac{1}{2}gt^2 \rightarrow t = \sqrt{\frac{2d}{g}} \]

\[ t = \sqrt{\frac{2(30)}{32.2}} \]

\[ \text{time} \approx 1.37 \text{ s} \]
Feeder Model
Falling Conductor PMU Locations

PV

Line Monitor

Capacitor Bank

Five-Way Switch

R1
N.O.

R2

Capacitor Bank

Substation

CB

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Sequence Components Analysis

Zero Sequence
- $I_{a0}$
- $I_{b0}$
- $I_{c0}$

Positive Sequence
- $I_{b1}$
- $I_{c1}$
- $I_{a1}$

Negative Sequence
- $I_{c2}$
- $I_{b2}$
- $I_{a2}$

Single Phase
- $I_{a0} = I_{b0} = I_{c0}$

Balanced
- $I_{b1} = a^2 I_{a1}$
- $I_{c1} = aI_{a1}$

Balanced
- $I_{b2} = aI_{a2}$
- $I_{c2} = a^2 I_{a2}$
Detection Methods

- $dV/dt$ (change detection)
- $V_0$ and $V_2$ magnitude
- $V_0$ and $V_2$ angle
# Example Lab Test Results

### PV Off, Loop Open

<table>
<thead>
<tr>
<th>Load %</th>
<th>FC1</th>
<th>FC2</th>
<th>FC3</th>
<th>FC4</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>75</td>
<td>3</td>
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</tr>
<tr>
<td>25</td>
<td>3</td>
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### PV On, Loop Open

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Arc Speed and Results Comparison
Number of Test Cases Versus $dV/dt$ Pickup Times

Arc Speed = 0 m/s

Arc Speed = 5 m/s
Field Installation and Testing

- First system installation in January 2015
- Falling conductor protection (FCP) in monitoring mode
- Simulation of conductor breaks with disconnect switch opening on recloser
- 100% correct operation
- Ethernet radio tuning required
dV/dt Operation
Capacitive Voltage Sensors

<table>
<thead>
<tr>
<th>Phase A Voltage</th>
<th>dVA/dt</th>
<th>dV0/dt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Side</td>
<td>-400 V/s</td>
<td>577 V/s</td>
</tr>
<tr>
<td>Source Side</td>
<td>2.8 kV/s</td>
<td>0</td>
</tr>
<tr>
<td>Nominal</td>
<td>6.9 kV</td>
<td>11 kV</td>
</tr>
</tbody>
</table>

- dVA/dt > 1,000 V/s
- dV0/dt > 400 V/s
FCP Detects CT Insulation Failure
Nuisance Trip Diagnostics and Analysis

Phase-C current spikes at CB PMU

Phase-C current spikes at 520-1334 VR

No current spikes observed at 520-1225 VR
Ease of Application

- Key requirement achieved – no circuit-dependent application settings
- FCP logic only needs topology of circuit and PMU IEDs
Conclusions

- Falling conductor takes \( \approx 1.4 \) s to reach the ground
- FCP methods detect and isolate in \( \leq 0.7 \) s
- Change detection and steady-state detection algorithms operate in parallel
Conclusions

• Change detection picks up reliably for almost all falling conductor test cases

• Steady-state sequence methods (magnitude and angle) back up change detection in case of data packet loss

• Dependable falling-conductor detection observed in lab and field
Conclusions

• FCP tripping is being enabled at first installation
• Scalable design works on all studied circuits and needs only circuit layout information
• Twelve more circuits to be commissioned in 2016, with more to come
Questions?