Catching Falling Conductors in Midair – Detecting and Tripping Broken Distribution Circuit Conductors at Protection Speeds

Karl Iliev
San Diego Gas & Electric Company

Eric Udren
Quanta Technology, LLC
SDG&E Distribution System

• 22,000 miles of lines
• 60% underground and 40% overhead
• 12.47, 12.0, and 4.16 kV
• High penetration of distribution PV requires new solutions for monitoring, protection, and control
**Advanced SCADA Project Applications**

**More Than 60 Use Cases Defined**

- Driven by high penetration of distribution PV
- Voltage profile monitoring and control
- Selective load shedding and restoration
- Power quality monitoring
- Apparatus and system condition monitoring
- Falling conductor protection (patented)
Advanced SCADA Features

- Increased accuracy of voltage and current
- Phase angles from across circuit
- GPS time-stamped data
- 30 synchrophasor sets per second for fast measurement
- IEC 61850 GOOSE messaging for real-time control
- Remote engineering access and event reports
- Advanced security features
Typical SDG&E Feeder with PMU IEDs

- Substation feeder relay
- Recloser controllers
- SCADA switch controllers
- Capacitor bank controllers
- Voltage regulator controllers
SCADA System Architecture

Advanced

Wide-Area Network

Distribution Circuit Area

Substation

Security Module

PDC
SCADA System Architecture

Traditional
SCADA System Architecture
Traditional and Advanced Overlay

Mission Control Center
- Local-Area Network
- IP Gateway
- Security

Backup Control Center
- Security
- IP Gateway
- Local-Area Network

Wide-Area Network

Substation
- Security Module
- PDC

Distribution Circuit Area
- Traditional
- Advanced
Detect Broken Conductor and Trip Circuit Before Line Hits the Ground?

Falling Conductor Timeline

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

\[
t = \sqrt{\frac{2(30)}{32.2}} \approx 1.37 \text{ s}
\]
Falling Conductor Protection (FCP) Detection Methods

- dV/dt (change detection)
- V0 and V2 magnitude
- V0 and V2 angle

Diagram:
- PMU1
- PMU2
- PMU3
- PMU4
- PDC
- Central Logic Controller
- GOOSE Controls
- PMU Devices to Trip

C37.118
RTDS Feeder Model

Diagram of a feeder model with various components including:
- Capacitor (C)
- Circuit Breaker PMU (CB)
- Line Monitor PMU (LM)
- Load (L)
- Photovoltaic (PV)
- Recloser PMU (REC)
- Voltage Regulator (VR)
- Five-Way Switch (SW)

Legend:
- C Capacitor
- CB Circuit Breaker PMU
- LM Line Monitor PMU
- L Load
- PV Photovoltaic
- REC Recloser PMU
- SW Five-Way Switch
- VR Voltage Regulator
Example FCP 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>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>25</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

### PV On, Loop Open

<table>
<thead>
<tr>
<th>Load %</th>
<th>PV%</th>
<th>FC1</th>
<th>FC2</th>
<th>FC3</th>
<th>FC4</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>100</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>75</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Typical FCP trip time 200 – 500 ms

**Diagram**

- PV
- Five-Way Switch
- Line Monitor
- FC3
- R1
- R2
- FC1
- FC2
- FC4
- CB
- Substation
Trip Security Testing

- Capacitor bank switching
- Voltage regulator tap unbalance
- Largest single-phase load switching
- PV operation
- Internal / external faults
Break Detection Results

dV/dt and Magnitude Method operation
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 path tuning required
- Fault current spike detection added in 2016
Breaking Arc – Field Versus Lab Tests

Field Result

RTDS Model
Synchrophasors show detailed circuit behavior
Capacitive voltage sensor discoveries

Load Side
Source Side
Nominal 6.9 kV

6.8 kV
Nominal 6.9 kV

$rac{dV}{dt} > 400 \text{ V/s}$
$rac{dVA}{dt} > 1000 \text{ V/s}$
Zone 1 $dV/dt$ Operation

- Field Event – 28\textsuperscript{th} Feb 2016
- FC detected by $dV/dt$ between CB and R1
FCP Limitations

- Keep using HIF detection for wire down without break
- Needs fast Ethernet path to circuit PMUs
- Uses voltage from each protected circuit path end – a journey of years for full coverage
- Learning about features of new technology
Ease of Application

• Key requirement achieved – no circuit-dependent application settings

• FCP logic only needs topology of circuit and PMU IEDs
Summary

- Advanced SCADA has 60 use cases including FCP
- FCP isolates broken conductors in 0.2 – 0.5 s (half the distance to the ground) preventing the fault
- FCP is dependable in lab test including high PV penetration
- FCP mitigates HILP events – fire and hazard reduction
- Confidence built from secure and reliable field performance
- Compliments existing protection
- Scalable design needs only circuit layout information
Next Steps

• FCP of first equipped circuit commissioned on 11/18/2016
• Additional circuits will be equipped and commissioned in 2017
• Pursuing ongoing funding to reduce fire risk and enhance public safety
• Installing new IEDs with PMU capable devices with moderate additional cost
• SDG&E will be well positioned for future PV penetration
Questions?

Karl Iliev  
*San Diego Gas & Electric Company*  
kiliev@semprautilities.com  
+1 (858) 503-5128

Eric A. Udren  
*Quanta Technology, LLC*  
eudren@quanta-technology.com  
+1 (412) 596-6959