Grid Integration of Solar Energy
What Have We Learned

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PV Intermittency

Power 1 Second Data

kW
Data Analysis

SDG&E PV Penetration by Circuit

Number of Circuits

- > 30%
- 20% to 29%
- 10% to 19%
- < 10%

Modeling DER Integration
Modeling DER Integration
Modeling - Detailed PSCad Modeling
Modeling - RTDS
Modeling - Results

Clear Day

Partly Cloudy Day
Modeling - Baseline

<table>
<thead>
<tr>
<th>Bus Voltage (pu)</th>
<th># of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus 307</td>
<td></td>
</tr>
<tr>
<td>Bus 311</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Tap Changes</th>
<th>VR 1020G</th>
<th>VR 1024G</th>
<th>VR 838G</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>125</td>
<td>85</td>
<td>31</td>
</tr>
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</table>

10
Modeling - Dynamic Voltage Control

<table>
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<th>VR 1020G</th>
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</table>
Modeling - Solutions

With and without dynamic VAr device

With and without energy storage

With and without storage and 4 quadrant control

Red = With  Blue = Without
Modeling - X/R Voltage Impact

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**Graph Details:**
- **Title:** Modeling - X/R Voltage Impact
- **Diagram:** Electrical circuit diagram with labeled parameters:
  - \( P = 1966 \text{ kW} \)
  - \( Q = 1832 \text{ kVar} \)
  - \( Z = 0.069 + j1.722 \Omega \)
  - \( V = 6928 \text{ V} \)
  - \( I = 245.3 - j283.6, 375 \theta 49.1 \text{ A} \)
  - \( V_L = 6423 - j402.8, 6436 \theta 3.6 \text{ V} \)
  - \( Z = 11 + j5.328 \Omega \)

**Line Graph:**
- **X-axis:**
  - no Gen
  - Unity
  - 0.9 lag
  - 0.9 lead
  - 0.1 lead
- **Y-axis:**
  - Voltage Impact
- **Legend:**
  - Blue line: X/R Ratio = 0.61
  - Red line: X/R Ratio = 6.1
  - Green line: X/R Ratio = 25
Lessons Learned

Factors Determining Impact

- Location on the Circuit
  - Near Substation vs End of Circuit

- Circuit Rating
  - 4 kV vs 12 kV

- Type of Circuit
  - Urban vs Rural

- Circuit minimum loading
  - High vs Low

- Circuit X/R ratio at location
  - High vs Low

- Aggregate DG capacity
  - Transmission issues

- Voltage Regulation Equipment
Lessons Learned

Solutions?

• **Circuit modifications**
  – Monitoring and ensuring resource adequacy
  – Voltage regulation

• **Demand response**
  – Slower dP/dt events?

• **4 quadrant control**
  – Utility dynamic VAR devices
  – Utility storage
  – Customers inverters/storage

• **Regulatory/Standards Changes**
  – Existing rules require modification to accommodate high PV penetration
    – CA SIWG advanced functionality
Solutions - Dynamic VAr Device

DVAR Off

DVAR Off
Solutions - PV with Smart Inverter
Solar PV Capacity Challenges

- Solar does not coincide with residential distribution system peaks
- Solar output curve does not match typical residential customer daily usage profile
- Opportunity for distribution and residential energy storage
- Commercial load profile is more aligned to solar output
Control Hierarchy

- DMS
- DERMS [Master]
- SCADA
- MGC
- DRMS

Engines:
- Forecast
- Scheduling
- Pricing

DERMS [1-n] (Multiple instances)
San Diego Zoo Solar to EV Project

PV Smoothing and Peak Shifting from Battery

- PV Smoothing During Day
- Battery Discharge During Evening Peak to Offset Drop in PV

Battery Charging Off Peak
Questions?

Thank You

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