Thrust Area: Lifelines

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Cornell University

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MCEER LIFELINES VISION
AND MISSION

• Improve substantially the seismic resilience of lifeline systems
• Develop, implement, and demonstrate the next generation lifeline system
• Set future standards with a state-of-the-art decision support process for integrated lifeline management
Year 8 Research Integration: Electric Power Lifelines (1)

- Evaluation of the Robustness and Restoration Curve for LADWP’s Power System (Shinozuka)
- Evaluation of Interaction between Water and Power Systems Using Transient Water Flow Analysis (Shinozuka)
- Devised a Generic Restoration Process Model for Power Systems (Shinozuka)
- Strengthened Inventory Database for Interface Components between Power and Water Systems (Cheng and Shinozuka)
YEAR 8 RESEARCH INTEGRATION:
Electric Power Lifelines (2)

- Laboratory tests of response reduction devices for transformers and other Equipment (Feng and Saadeghvaziri)
- Models for seismically induced long-term electromagnetic degradation of transformers (Saadeghvaziri and Cheng)
- Field Measurements of Partial Discharge (Cheng)
- Inventory development and modeling of SCE Network (Cheng and Shinozuka)
Year-8 Accomplishments (Thrust 1 Power)

M. Shinozuka

- Demonstration of resilience characteristics for LADWP Power System
- Transient analysis for water supply network due to pumping station malfunction
- Innovative damage detection and localization tool
Water Head Time Histories at Node J9

Emergency Power Fails

Pump Restarts
Year-8 Accomplishments

A. Saadeghvaziri

- Impact of Seismic Load on Electro-Magnetic Performance.
  A. Rocking vibration of core-frame.
  B. Flexural vibration of core-frame.
  C. Impact of base-isolation on flexible interconnecting cables.
Year-8 Accomplishments

M. Feng

Studied seismic protective connectors for transformer bushings through 2-D shaking table tests

(a) High-damping rubber ring
(Industrial Partner: Enidine)

(b) Wire-loop isolator
(Partner: Bridgestone Co.)

Both reduced peak acceleration by at least 30% on bushing
Year-8 Accomplishments (1)  
T. C. Cheng

- Coupling effects of water and power systems
- Failure mechanisms of pump motors.
- Inventory and Modeling of Southern California Edison’s network.
Year-8 Accomplishments

T. C. Cheng

- Worked on partial discharge resulting from degradation of insulation in transformers.
- Developed AI-based software to detect the discharge in high voltage transformers.
- Cooperating with Tsinghua University, China, which developed the state of the art measuring device on partial discharges.
- USC receiving a team of researchers from China in February 2005, to measure partial discharges at various SCE Substations.
Risk and Restoration Curves

Risk Curves
1: Seirra Madre UD 6.0
2: San Jacinto MCE 7.5
3: Malibu Coast UD 6.0
4: Newport-Inglewood (S) MCE 7.0
5: Simi Santa Rosa MCE 7.3
6: Malibu Coast MCE 7.3

Partial Discharge
Retrofit
Base Isolated
Deteriorated

Annual Probability of Exceedance

Restoration Curves

Robustness (Household with Power Supply)

Time (days)

A
B
C
D

Restoration Curve

Robustness

0% 20% 40% 60% 80% 100%

0 0.2 0.4 0.6 0.8 1.0

0% 20% 40% 60% 80% 100%

0 0.5 1.0 1.5 2.0

A
B
C

Household with Power Supply

Time

0% 20% 40% 60% 80% 100% 120%

t₀ = Time at which an earthquake occurs

t₁ = Time at which power performance is restored 100%
PROPOSED YEAR 9 VISION

MCEER Decision Support System Implemented/Tested by LADWP with Full Integration of Seismic Hazard Assessment, Advanced Hydraulic Network Modeling, System Reliability, Advanced Web-based GIS, and Modeling of Social Resilience & Regional Economic Impact
### Proposed Year-9 Tasks (1)
**Completing Existing Projects**

<table>
<thead>
<tr>
<th>Task Title</th>
<th>Main Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resilience of multiple lifeline systems <em>(Shinozuka)</em></td>
<td>Complete models and apply to LADWP systems</td>
</tr>
<tr>
<td>Economic cost for restoration of lifeline systems <em>(Shinozuka and Rose)</em></td>
<td>Direct cost for repair, loss of revenue, etc. and indirect cost for system interruption</td>
</tr>
</tbody>
</table>
| Instrumentation of LADWP transformers and base-isolated reactor with fiber optic sensors *(Feng)* | Performance evaluation and cost-effectiveness assessment  
See slides # 15, 16, 17                                                             |
### Proposed Year-9 Tasks (2)

**Completing Existing Projects**

<table>
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<tr>
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<tr>
<td>Field measurement of partial discharge <em>(Cheng)</em></td>
<td>Use of Impulse current sensor and acoustic emission sensor for partial discharge measurement; see slides # 18, 19</td>
</tr>
<tr>
<td>Development of advanced SCADA for power system <em>(Shinozuka and Cheng)</em></td>
<td>SCADA system based on partial discharge measurement for power system with the aid of a communication network; see slide # 20</td>
</tr>
<tr>
<td>Verification of electro-magnetic degradation model for transformers <em>(Saadeghvaziri)</em></td>
<td>Verify the model against the field measurements</td>
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Transformer in New Sylmar Substation

Monitoring of critical substation facilities
1. LADWP’s strong interest in collaboration
2. Feng’s visit to LADWP’s new Sylmar Station
3. Start with 2 transformers

Summary
- 2 tri-axial accelerometers at the cantilever ends of two bushings
- 8 strain gauges at the fixed ends of the bushings
- 1 disp. sensor for the C-shaped damper

Instrumentation of the Horizontal Bushings of the Transformer
Vertical Accelerometer

Horizontal Accelerometer (E-W)

Horizontal Accelerometer (N-S)

Displacement Sensor (Fix to ground at one end)

Base Isolator

Radial Direction to the Center

Accelerometers on the Smoothing Reactor

Displacement Sensors on the one of the Base-Isolation Units
(2 Units will be instrumented)
Base Isolator
Preliminary Field Experiments for Partial Discharge (1)

Serrano Substation has 11 500kV – 220kV transformers and 2 Spares

\[ Q(pc) = \text{Pico Coulomb} \]

\[ \text{Fai} = \text{Phase Angle} \]

Result of Field Experiment

3-D Diagram at LV2
Preliminary Field Experiments for Partial Discharge (2)

Real Time Data Analysis and Visualization

Impulse Current Sensor
Communication Network for Monitoring, Control and Maintenance

Classification of Network System

- Fixed Communication System
- Mobile Communication System
- Optical Fiber Network System
- Subscriber Line Network System
- Power Line Network System

Network System

- Multiple Band Type
- Single Band Type
- Base Band Type
- Carrier Band Type
- FDM, PCM, HDSL

Transmission Lines

- Extra-high Substation
- Substation
- UM Substation
- Power Control Station

Computer Center

- HQs
- Branch Office

Communication Satellite

- Remote control
- Opt. fiber terminal station

Customer Service Center

- Video conference room
- Antennae for mobile communication

Source: Kansai Electric Power Co
## Proposed Year-9 Tasks (3)
### Timely Topics and Multi-Hazard Applications

<table>
<thead>
<tr>
<th>Task Title</th>
<th>Main Objective</th>
</tr>
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<tbody>
<tr>
<td><strong>Next Generation SCADA for real-time damage detection and localization under multiple hazard conditions (Shinozuka)</strong></td>
<td>Develop a network of DuraNode and advanced sensors for real-time lifeline system damage monitoring under multi-hazard conditions. Starting with water system subjected to power failure, earthquake, extreme temperature, excess traffic load and accidents; see slides # 22 - 25</td>
</tr>
<tr>
<td><strong>Power system performance under high wind (Cheng and Shinozuka)</strong></td>
<td>Development of next generation SCADA for power systems under wind conditions using partial discharge for damage; see slides # 26, 27</td>
</tr>
<tr>
<td><strong>Instrumentation of critical power facilities with fiber optic sensors (Feng)</strong></td>
<td>Real-time detection of damage under multi-hazard conditions; # 15, 16, 17</td>
</tr>
<tr>
<td><strong>Energy Dissipation-Based Protective Systems for Power Distribution Poles against multi-hazards (Feng)</strong></td>
<td>Develop energy dissipation-based protective systems to protect power distribution poles against wind, earthquakes, and other hazards; see slide # 27</td>
</tr>
</tbody>
</table>

**Main Objective:**

- Develop real-time damage monitoring systems for lifeline systems under multi-hazard conditions.
- Enhance power system performance and protection against various hazards.
- Improve instrumentation of critical facilities with advanced sensors.
- Develop protective systems for power distribution poles against multi-hazards.
Development of Next Generation SCADA

- DuraNode for real-time structural monitoring. The design is inherently low cost (a $100 range per channel)
- Low power requirement (an award winning mA range)
- System of DuraNodes integrated with the optical fiber network encompassing entire lifelines for communication purposes with nominal additional cost
- This system represents a major breakthrough to be used for real-time monitoring and condition assessment of buildings, bridges and other structures distributed and dispersed over this size of space and yet managed, operated and protected as a system.
- First implementation with Irvine Ranch Water District System as Testbed soliciting collaboration from Acoustic Emission Inc.
Network Overview

- Optical Fiber Uplink
- Electrical Devices
- Repeater
- Optical Transceiver
- Optical Transponder
- OADM*

Wireless Sensor Network

Backup (wireless) Uplink

*. OADM: Optical Add Drop Multiplexer
Sensor Node

- **DuraNode**
  - 3-Axis Accelerometer
  - 802.11b Wireless
  - 2000mAh Battery
  - Solar Panel

- **Eco**
  - 2-Axis Accelerometer
  - 2.4GHz GFSK Wireless
  - Ultra-Compact (<1 cm³)
  - Low Power
Contour of Water Head Gradient

Pump Lost Power
## Widespread outages stretch restoration resources

<table>
<thead>
<tr>
<th>AREA</th>
<th># CUSTOMERS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CHARLEY</td>
</tr>
<tr>
<td>Miami-Dade</td>
<td>45,000</td>
</tr>
<tr>
<td>Broward</td>
<td>40,000</td>
</tr>
<tr>
<td>Palm Beach</td>
<td>40,000</td>
</tr>
<tr>
<td>Treasure Coast</td>
<td>9,000</td>
</tr>
<tr>
<td>West Coast</td>
<td>445,000</td>
</tr>
<tr>
<td>Central FL</td>
<td>274,000</td>
</tr>
<tr>
<td>North FL</td>
<td>21,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>874,000</td>
</tr>
</tbody>
</table>
Protective systems for power distribution poles

[Diagram showing protective systems for power distribution poles, including wood pole, damper, and cable.]