Powering Progress: Smarter, Sustainable, More Secure, and Resilient Energy Infrastructure

S. Massoud Amin, D.Sc.
Chairman, IEEE Smart Grid
Chairman, Board of Directors, Texas Reliability Entity (TRE)
Director, Board of Directors, Midwest Reliability Organization (MRO)

Director, & Endowed Chair, Technological Leadership Institute
Professor of Electrical & Computer Engineering
University Distinguished Teaching Professor
University of Minnesota

Energy Transition Lab, University of Minnesota
Energy Storage Summit, July 15, 2015

* Support from EPRI, NSF, ORNL, Honeywell and SNL is gratefully acknowledged.
100 Years of Power Generation Development

- 92 million population increase
- 189 million population increase
- 131 million population increase
- 320 million population increase

- 186,000 MW
- 240,000 MW
- 256,000 MW
- 200,000 MW

Source: Adopted from Siemens
Power Grids Have Come Full Circle…

- DC systems
- Mini grids (AC)
- Single Transmission Grid (HVAC)
- HVDC
- Island-able smart grids (microgrids)

Historically, grids developed as isolated systems that were managed and controlled locally

These too could be viewed as microgrids

Present day changes are made possible –

- Changing economics
- Dynamic Geopolitics
- Improved Power electronics
- Better information & communication technology
- Mature renewable energy technologies...
Smart Grids: What are we working on at the University of Minnesota?

- Integration and optimization of storage devices and PHEVs with the electric power grid
- Grid agents as distributed computer
- Fast power grid simulation and risk assessment
- Security of cyber-physical infrastructure: A Resilient Real-Time System for a Secure & Reconfigurable Grid
- Security Analyses of Autonomous Microgrids: Analysis, Modeling, and Simulation of Failure Scenarios, and Development of Attack-Resistant Architectures

University of Minnesota Center for Smart Grid Technologies (2003-present)
Faculty: Professors Massoud Amin and Bruce Wollenberg
PhD Candidates/RA and Postdocs: Anthony Giacomoni (PhD’11), Jesse Gantz (MS’12), Laurie Miller (PhD’13), Vamsi Parachuri (part-time PhD candidate, full-time at Siemens), Sara Mullen (Phd’09)
PI: Massoud Amin, Support from EPRI, NSF, ORNL, Honeywell and SNL
Smart Grid Interdependencies
Security, Efficiency, and Resilience
Overview

• Microgrids
  – U of M - Morris campus project
  – UMore Park Project
  – Controller architecture
  – Resiliency and Cyber-Physical Security
  – Dollars and watts -- Prices to devices
  – Storage and Renewables integration
  – Autonomous Microgrids
  – Big Data

• Smart Grid U™
• MN Smart Grid Coalition (2008-11) /Governor’s Summit ‘14
• MRO and TexasRE Boards of Directors
• IEEE Smart Grid
  – Implementations
  – Global projects, results and lessons learned, what’s next?
Feeder Reconfiguration/Intentional Islanding

Outline

- System divided into sub-networks joined by controllable switches
- The fault is isolated for a given outage situation
- Non-faulted sub-networks are intentionally islanded to supply back-up service to local loads

Simulation

- Perform Sequential Monte-Carlo simulation to simulate outages
- Determine optimal locations to place storage elements
Energy Storage for C&I Applications

<table>
<thead>
<tr>
<th>Maturity</th>
<th>Capacity (kWh)</th>
<th>Power (kW)</th>
<th>Duration (hrs)</th>
<th>Efficiency (%)</th>
<th>Cycle Life (cycles)</th>
<th>Total Cost ($/kW)</th>
<th>Cost ($/kW-h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Lead-Acid 1</td>
<td>Demo-Commercial</td>
<td>5000</td>
<td>1000</td>
<td>5</td>
<td>85</td>
<td>4500</td>
<td>3000</td>
</tr>
<tr>
<td>Advanced Lead-Acid 2</td>
<td>Demo-Commercial</td>
<td>1000</td>
<td>200</td>
<td>5</td>
<td>80</td>
<td>4500</td>
<td>3600</td>
</tr>
<tr>
<td>NaS</td>
<td>Commercial</td>
<td>7200</td>
<td>1000</td>
<td>7.2</td>
<td>75</td>
<td>4500</td>
<td>3600</td>
</tr>
<tr>
<td>Zn/Br Flow 1</td>
<td>Demo</td>
<td>625</td>
<td>125</td>
<td>5</td>
<td>62</td>
<td>&gt;10000</td>
<td>2420</td>
</tr>
<tr>
<td>Zn/Br Flow 2</td>
<td>Demo</td>
<td>2500</td>
<td>500</td>
<td>5</td>
<td>62</td>
<td>&gt;10000</td>
<td>2200</td>
</tr>
<tr>
<td>Vanadium Flow</td>
<td>Demo</td>
<td>1000</td>
<td>285</td>
<td>3.5</td>
<td>67</td>
<td>&gt;10000</td>
<td>3800</td>
</tr>
<tr>
<td>Li-Ion</td>
<td>Demo</td>
<td>625</td>
<td>175</td>
<td>3.5</td>
<td>87</td>
<td>4500</td>
<td>3800</td>
</tr>
</tbody>
</table>

Single Customer Multi-Objective Optimization Model

Objective 1: Minimize Outage Costs

\[
\text{minimize} \quad \sum_{n=1}^{N_{\text{outage}}} CDF(t_o - P_{\text{load},n} \sum_{j=1}^{J_{\text{types}}} \frac{X_j}{S_{\text{BESS},j}})
\]

Objective 2: Minimize Energy Costs

\[
\text{minimize} \quad \sum_{t=1}^{T} (P_{\text{load},t} - P_{\text{gen},t} + P_{\text{BESS},t})C_{e,t}\Delta t
\]

Objective 3: Minimize Demand Costs

\[
\text{minimize} \quad \sum_{p=1}^{P} \left( \max(P_{\text{load},t} - P_{\text{gen},t} + P_{\text{BESS},t})p + PF_p \right)C_{d,p}
\]

Objective 4: Minimize Capital Costs

\[
\text{minimize} \quad \sum_{j=1}^{X} C_jX_j
\]

Where,
- \( n \): Outage index \( \in \{1 \ldots N_{\text{outage}}\} \)
- \( CDF_i(*) \): Customer damage function
- \( t_o \): Duration of outage (min)
- \( j \): Storage type index \( \in \{j \ldots s\} \)
- \( X_i \): Number of storage systems of type \( j \) selected
- \( P_{\text{load},n} \): Ave. load during outage, \( n \)
- \( S_{\text{BESS},j} \): kWh storage capacity
- \( S_{\text{cap}} \): kWh capacity of storage facility
- \( C_j \): Capital cost of storage unit type \( j \)
Multi-Application Energy Storage

Approach: Partition energy storage capacity according to application
Voltage Profiles

Normal Operation:
1.04 – 0.98pu voltages

Priority Ride-Through:
1.04 – 0.99pu voltages
## Optimal Mix and Placement

<table>
<thead>
<tr>
<th>No. Units Selected</th>
<th>BESS Selected</th>
<th>Location</th>
<th>Capital Cost</th>
<th>Added Savings</th>
<th>Annual Outage Costs</th>
<th>Payback Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>None</td>
<td>--</td>
<td>$ 0</td>
<td>--</td>
<td>$ 1,435,814</td>
<td>---</td>
</tr>
<tr>
<td>1</td>
<td>Zinc Bromine 1</td>
<td>M4</td>
<td>$ 303,125</td>
<td>$ 285,776</td>
<td>$ 1,150,038</td>
<td>1.06 years</td>
</tr>
<tr>
<td>2</td>
<td>Zinc Bromine 1</td>
<td>M4</td>
<td>$ 606,250</td>
<td>$ 207,749</td>
<td>$ 942,289</td>
<td>1.23 years</td>
</tr>
<tr>
<td>3</td>
<td>Zinc Bromine 1</td>
<td>M4</td>
<td>$ 909,375</td>
<td>$ 224,758</td>
<td>$ 717,531</td>
<td>1.27 years</td>
</tr>
<tr>
<td>4</td>
<td>Zinc Bromine 1</td>
<td>M4</td>
<td>$ 1,212,500</td>
<td>$ 225,395</td>
<td>$ 492,136</td>
<td>1.29 years</td>
</tr>
<tr>
<td>5</td>
<td>Zinc Bromine 1</td>
<td>M3</td>
<td>$ 1,515,625</td>
<td>$103,449</td>
<td>$ 388,687</td>
<td>1.45 years</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Index</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cust.</td>
<td>200</td>
<td>85</td>
<td>44</td>
<td>72</td>
<td>112</td>
</tr>
<tr>
<td>Cust. Served</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>35</td>
<td>0</td>
</tr>
</tbody>
</table>

| SAIDI: 3.93 (down 0.44) | SAIFI: 5.90 (down 0.66) | CAIDI: 1.5 (same) |
New Challenges for a Smart Grid

- Need to integrate:
  - Large-scale stochastic (uncertain) renewable generation
  - Electric energy storage
  - Distributed generation
  - Plug-in hybrid electric vehicles
  - Demand response (smart meters)

- Need to deploy and integrate:
  - New Synchronized measurement technologies
  - New sensors
  - New System Integrity Protection Schemes (SIPS)

- Critical Security Controls
Pivotal and Emerging Technologies

1. Energy storage
2. Microgrids
3. Cyber-Physical Security
4. Advanced Controls with Secure Communications
   - Operating Platform – Advanced EMS/DMS
   - Sensors, Monitoring, and Diagnostics
   - Smart Breakers
5. In-home Technologies
   - Smart homes and Demand Response

The next phase of power grid evolution is managing demand through consumers as part of a well-managed, secure, and smarter grid.
Smart Grid: Technological Innovations

Customer

- Smart Appliances
- Electric Vehicles
- Energy Efficiency
- Demand Response
- Distributed Energy Resources
**IEEE: The expertise to make smart grid a reality**

Search

You searched for **storage** in the smart grid category

**storage**

About 354 results (0.19 seconds)

**What Next for Energy Storage? - IEEE Smart Grid**
Prospects for wide integration of energy **storage** into grid systems will be enhanced with the development of market mechanisms that allow for coordinated ...

**Storage: An Indispensable Ingredient in Future Energy - IEEE Smart ...**
Energy **storage** can contribute to the smart grid by facilitating integration of renewable sources and provision of important ancillary services. At the same time, ...

**Substation-Scale and Community Energy Storage - IEEE Smart Grid**
Energy **storage** systems, essential for balancing dynamic sources and loads across electric power grids worldwide, can
<table>
<thead>
<tr>
<th>Utility</th>
<th>Location</th>
<th>Rating</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Battery Storage For Utility Load Shifting Or For Wind Farm Diurnal Operations And Ramping Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duke Energy</td>
<td>Goldsmith, TX</td>
<td>24 MW</td>
<td>Proprietary</td>
</tr>
<tr>
<td>Modesto Irr. District</td>
<td>Modesto, CA</td>
<td>25MW / 75MWh</td>
<td>Zn-Cl Flow</td>
</tr>
<tr>
<td>SoCal Edison</td>
<td>Tehachapi, CA</td>
<td>8MW / 32MWh</td>
<td>Lithium Ion</td>
</tr>
<tr>
<td><strong>Frequency Regulation Ancillary Services</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PPL Corp/Midwest Energy</td>
<td>Tyngsboro, MA; Hazle Township, PA</td>
<td>20MW / 5MWh</td>
<td>Flywheel</td>
</tr>
<tr>
<td><strong>Distributed Energy Storage For Grid Support</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Painesville Municipal</td>
<td>5 locations in OH, PA, VA, IN, MA</td>
<td>1MW / 6-8MWh</td>
<td>Vanadium Redox</td>
</tr>
<tr>
<td>Detroit Edison</td>
<td>Hanover, MA; West</td>
<td>25kW / 50kWh (20)</td>
<td>Lithium Ion</td>
</tr>
</tbody>
</table>
Over the next five years, smart microgrids will play a growing role in meeting local demand, enhancing reliability and ensuring local control of electricity. Emerging developments and challenges the smart grid community must address:

For a brief overview and some details on microgrids, and this transition, please see: [http://smartgrid.ieee.org/search?searchword=Microgrids&category=smart_grid&x=0&y=0](http://smartgrid.ieee.org/search?searchword=Microgrids&category=smart_grid&x=0&y=0)

Possible Transitional and Hybridization Options in a Wide Range of Assessed Scenarios: Short- and Long-term Strategies, Decision Pathways, ROI, Economic and Societal Objectives, Policies, and Disruptions (including dollars, watts, GHG emissions, risks/benefits – private and public)

Depending on assessments noted herein, we:
- Modernize, Retrofit, and Hybridize Legacy Infrastructure
- Leap-Frog for Isolated Localities or for Clean Slate Designs
Technology development, transition and Implementation: ... the really hard part

- Steps in STEM-based R&D to enable secure, efficient, resilient and adaptive infrastructure
- Markets and Policy framework, implementation, and evaluation
- Wind-tunnel testing of designs, markets and policy
- Making the business case for the opportunity
- Decision Support Dashboard: Have a plan ...
THANK YOU