Microgrids for Grid Security

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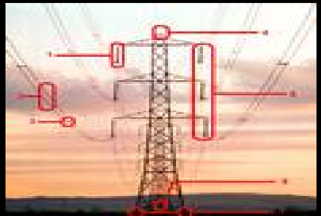
Interface of Smart Grid and Microgrids

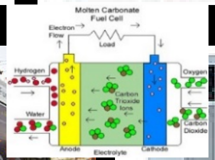
- Fossil Fuel
- Long Distance Central Station
- An Aging Infrastructure
- Out of Capacity


- Renewable Power
- On-site
- Zero Energy Building
- Smart Grid

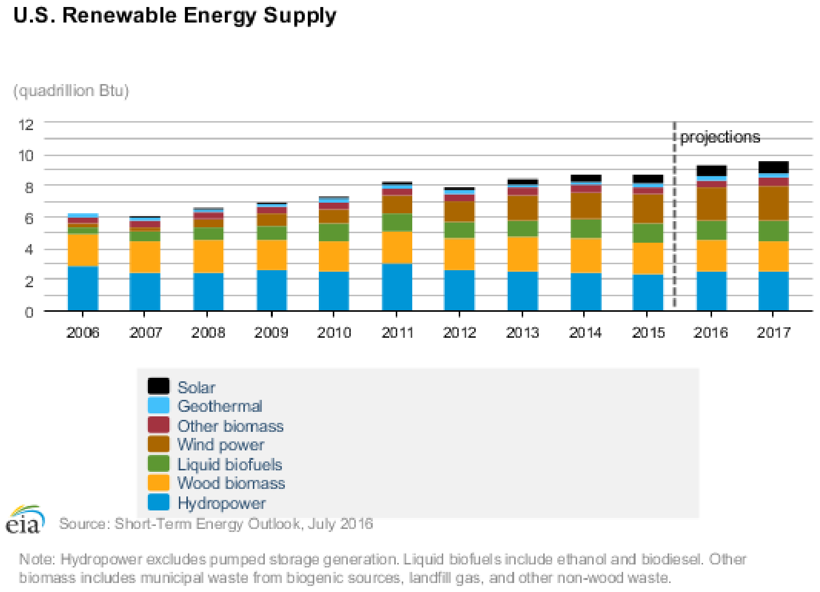


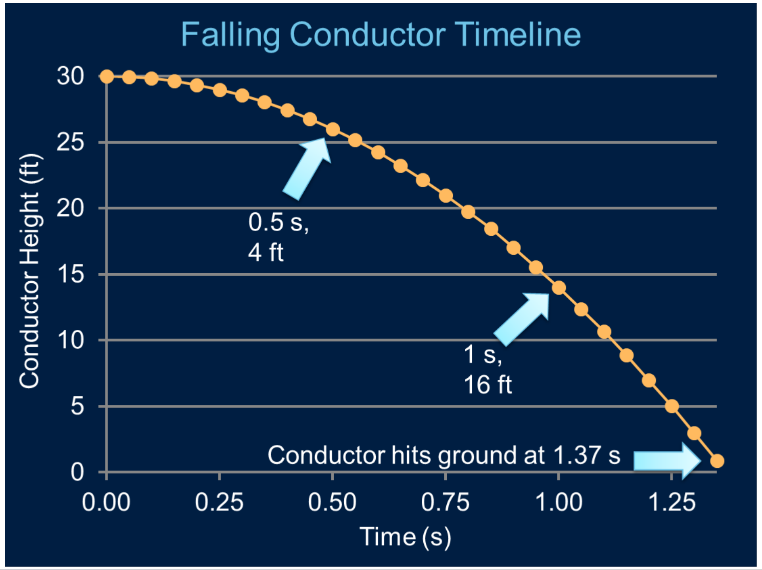



Grid Transformation Drivers

- Asset Management
  - Aging Infrastructure, Reliability, Hardening, Security (Physical & Cyber)
  - Natural Gas and Electrical Interdependency
- Distributed Energy Resources, Microgrids, Energy Storage, and Electrical Vehicles
- Smarter Grid Investments & Transformation
  - GPS Synchronized Measurements
  - Wide Area Protection coordination
  - Distribution Management Systems, automation, Volt-VAR control, etc.
  - Demand response w/smart meters
- Need for robust, hybrid T&D grid – Grid connection for reliability and market reach
- Smart Cities - Improve the livability, workability and sustainability w/ electricity





WORLD RECORD: 3-CENT WIND, SUB-4-CENT SOLAR (UNSUBSIDISED)

ONSHORE WIND

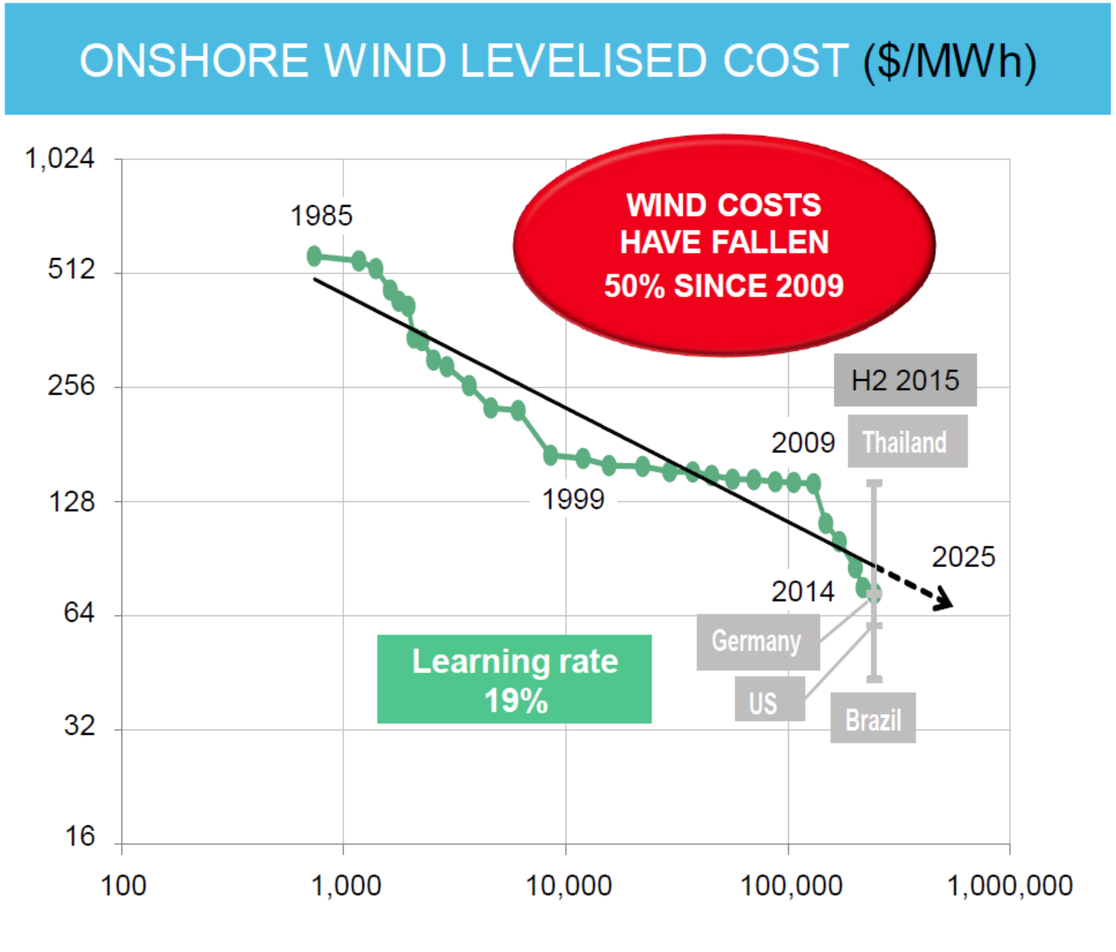
Location: Morocco
Bidder: Enel Green Power
Signed: January 2016
Price: US$ 3.0 c/kWh

SOLAR PV

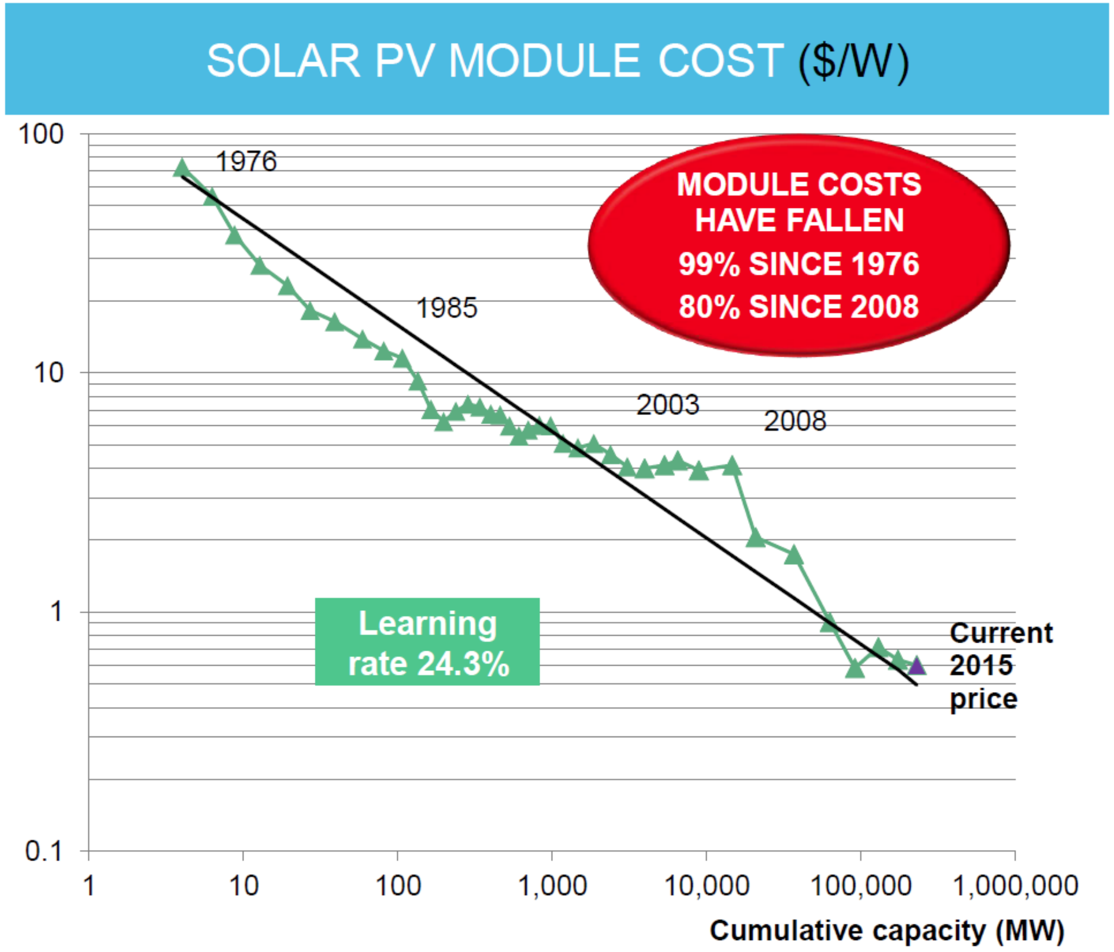
Location: Coahuila, Mexico
Bidder: Enel Green Power
Signed: March 2016
Price: **US$ 3.6 c/kWh**

Source: Bloomberg New Energy Finance; ImagesSiemens; Wikimedia Commons

Wind & Solar Experience Curves



Note: Pricing data has been inflation corrected to 2014. We assume the debt ratio of 70%, cost of debt (bps to LIBOR) of 175, cost of equity of 8% Source: Bloomberg New Energy Finance

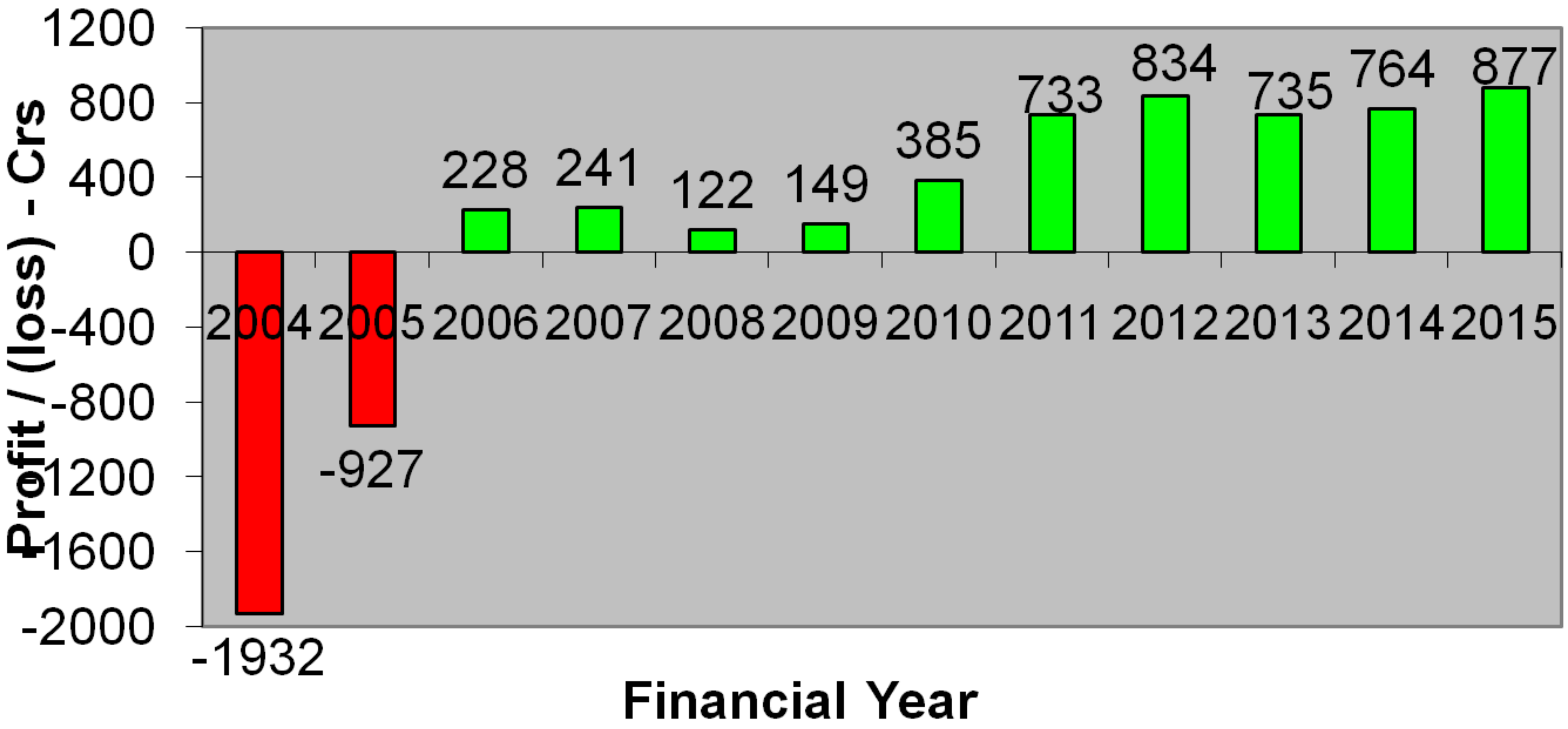


Note: Prices are in real (2015) USD. 'Current price' is $0.61/W Source: Bloomberg New Energy Finance, Maycock

A Case Study - INDIA -- Renewable Energy Initiatives

- Wind capacity – 3811 MW
- First comprehensive Solar Power Policy – 2009
- Solar capacity – 1039 MW in Gujarat (India – 4685 MW)
- State of art 500 MW Solar Park - 345 MW in operation
- Country’s first canal top project of 1 MW & another 10 MW on SSNNL canal
- 5 MW Solar rooftop Gandhinagar projects commissioned
- 4 MW Solar rooftop commissioned in Vadodara
- Gujarat Solar Policy 2015 rolled out for encouraging consumers participation towards green initiative

Gujarat Power Sector Turnaround



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Overview: What are we working on in my team at the University of Minnesota?

- Microgrids
  - Storage and Renewables integration
  - U of M - Morris campus project
  - UMore Park Project
  - Controller architecture
  - Resiliency
  - Dollars and watts -- Prices to devices
  - Storage and Renewables integration
  - Autonomous Grid-connected Microgrids
  - Big Data and Predictive Analytics
  - Smart Cities - Cybersecurity, CIP, Resilience

- Smart Grid U™
- MN Smart Grid Coalition (2008-11) / Governor’s Summit ‘14
- Technological Leadership Institute (TLI), est. 1987:
  - Science & Technology assessments
  - Master of Science Energy Technologies
- IEEE Smart Grid. Complementary: Please sign up for IEEE Smart Grid
  - Implementations -- Global projects, results and lessons learned, what’s next?

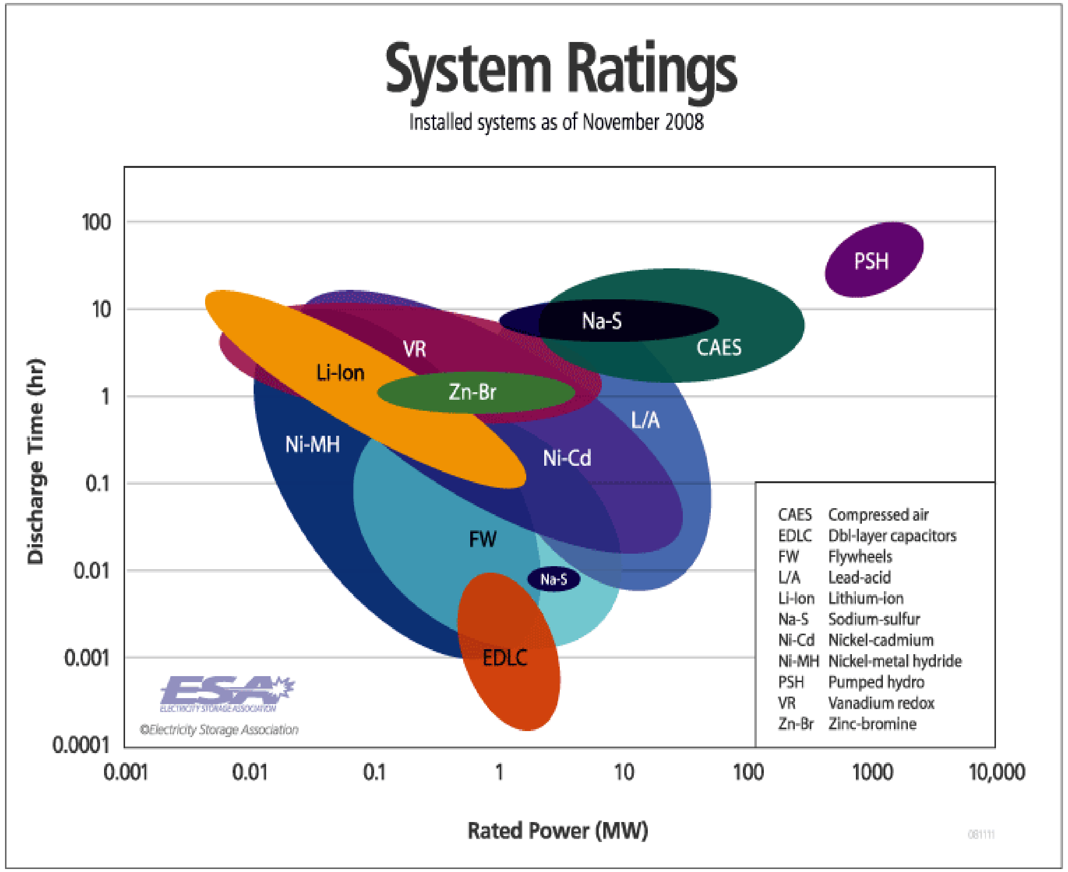
Energy Storage Technologies

Electrochemical
- Lead Acid
- Ni-MH / NI-Cd
- Li-Ion
- Sodium Sulfur (NaS)
- Flow Batteries
  - Vanadium Redox
  - Zinc Bromine

Electrical
- Supercapacitors (EDLC)

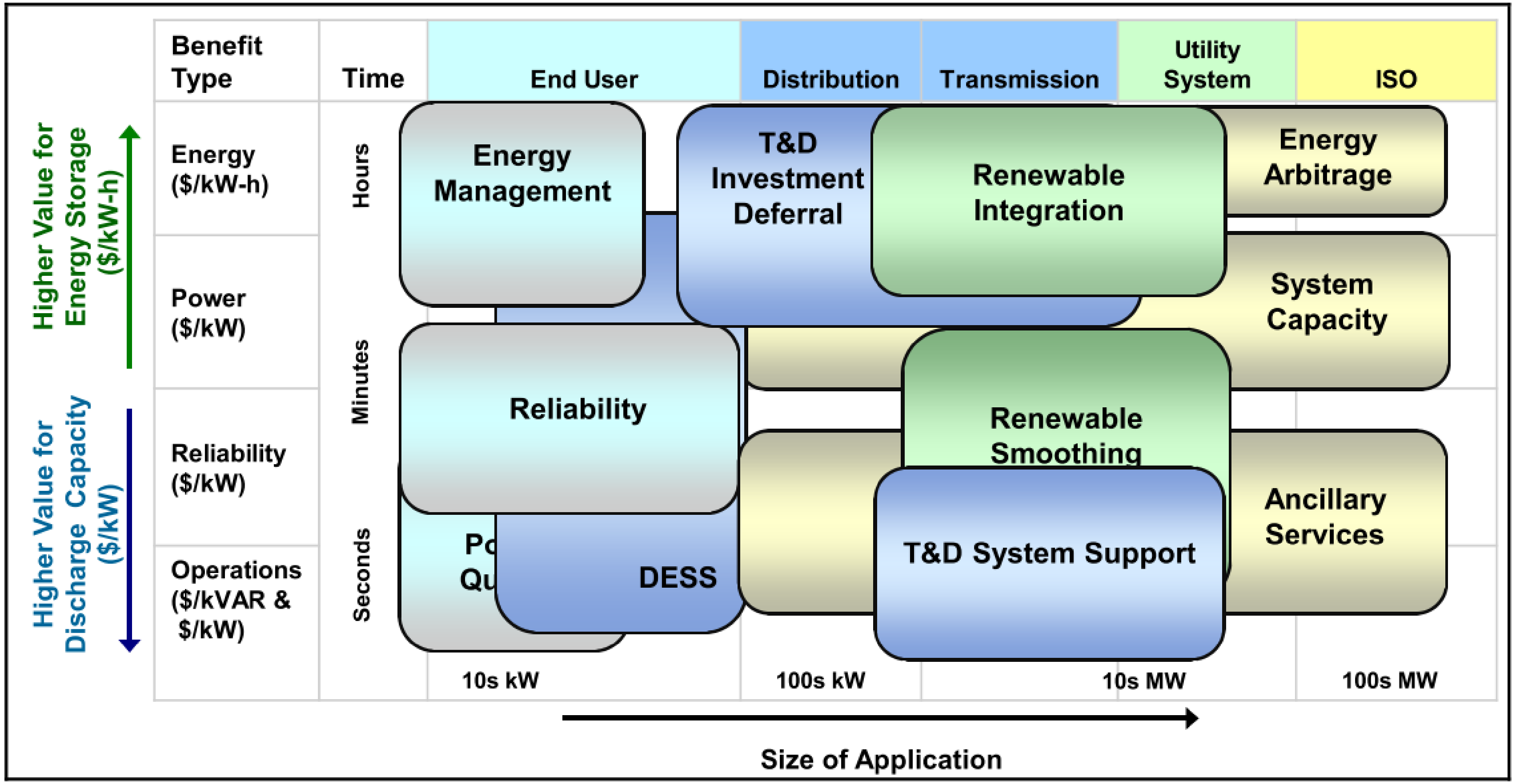
Magnetic
- Super-conducting electromagnets (SMES)

Mechanical
- Pumped Hydro
- Compressed Air (CAES)
- Flywheel



Source: *Electricity Storage Association, www.electricitystorage.org*

Energy Storage - Benefits & Applications



Source: *Electricity Energy Storage Technology Options – A White Paper Primer on Applications, Costs and Benefits, EPRI, Palo Alto, CA, 2010, Report #1020676*

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Customer Premise Energy Storage

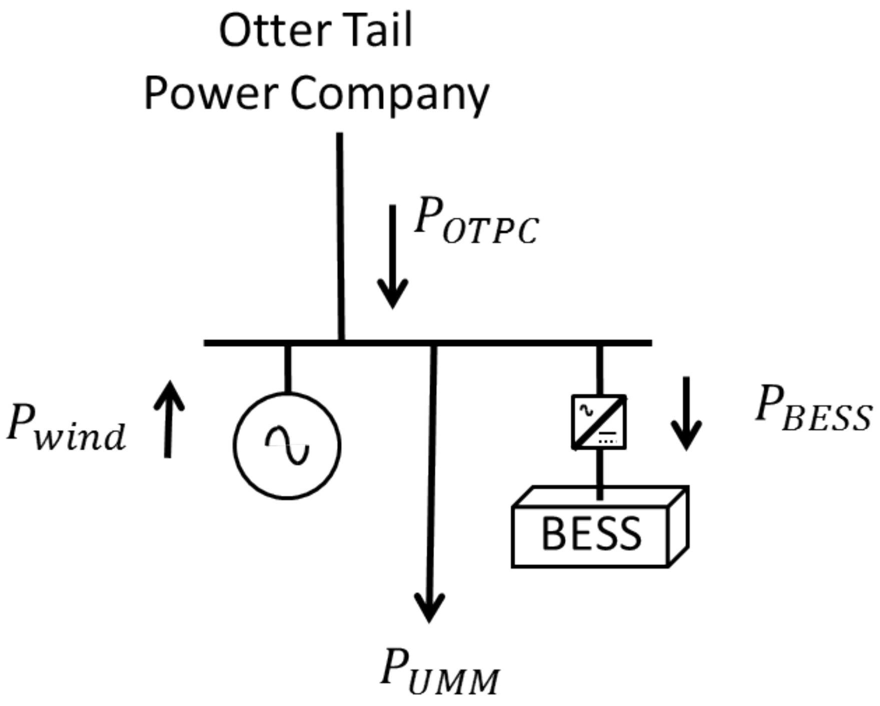
Application	Description	Requirements
Energy Management	Shifting load from high to low price periods, thereby reducing (daily) energy charges. For real-time or time-of-use rate structures.	**kWh**: medium **kW**: medium **Cycles**: high
Demand Management "peak shaving"	Reducing peak demand over a long period of time (typically one month).	**kWh**: medium **kW**: high **Cycles**: low
Reliability "emergency backup"	Supplying extended backup power to allow customer to ride through grid-side outage	**kWh**: high **kW**: medium/high **Cycles**: low
Power Quality	Filtering voltage spikes/sags, noise and other transient events. Ability to ride through momentary outages (< 1 min). (i.e. UPS)	**kWh**: medium **kW**: medium **Cycles**: low
Utility Services	Provide load control, reactive power support, voltage regulation or other services to the local utility	**kWh**: varies **kW**: varies **Cycles**: varies

Systems Selected

	Maturity	Capacity (kWh)	Power (kW)	Efficiency (%)	Cycle Life (cycles)	Cost ($/kWh)
Advanced Lead Acid 1	Demo-Commercial	5000	1000	85	4500	600
Advanced Lead Acid 2	Demo-Commercial	1000	200	80	4500	720
Sodium Sulfur	Commercial	7200	1000	75	4500	500
Zinc Bromine Flow 1	Demo	625	125	62	12000	485
Zinc Bromine Flow 2	Demo	2500	500	62	12000	440
Vanadium Flow	Demo	1000	285	67	12000	1085
Lithium Ion	Demo	625	175	87	4500	1085

Source: *Electricity Energy Storage Technology Options – A White Paper Primer on Applications, Costs and Benefits, EPRI, Palo Alto, CA, 2010, Report #1020676*

UM Morris Power System



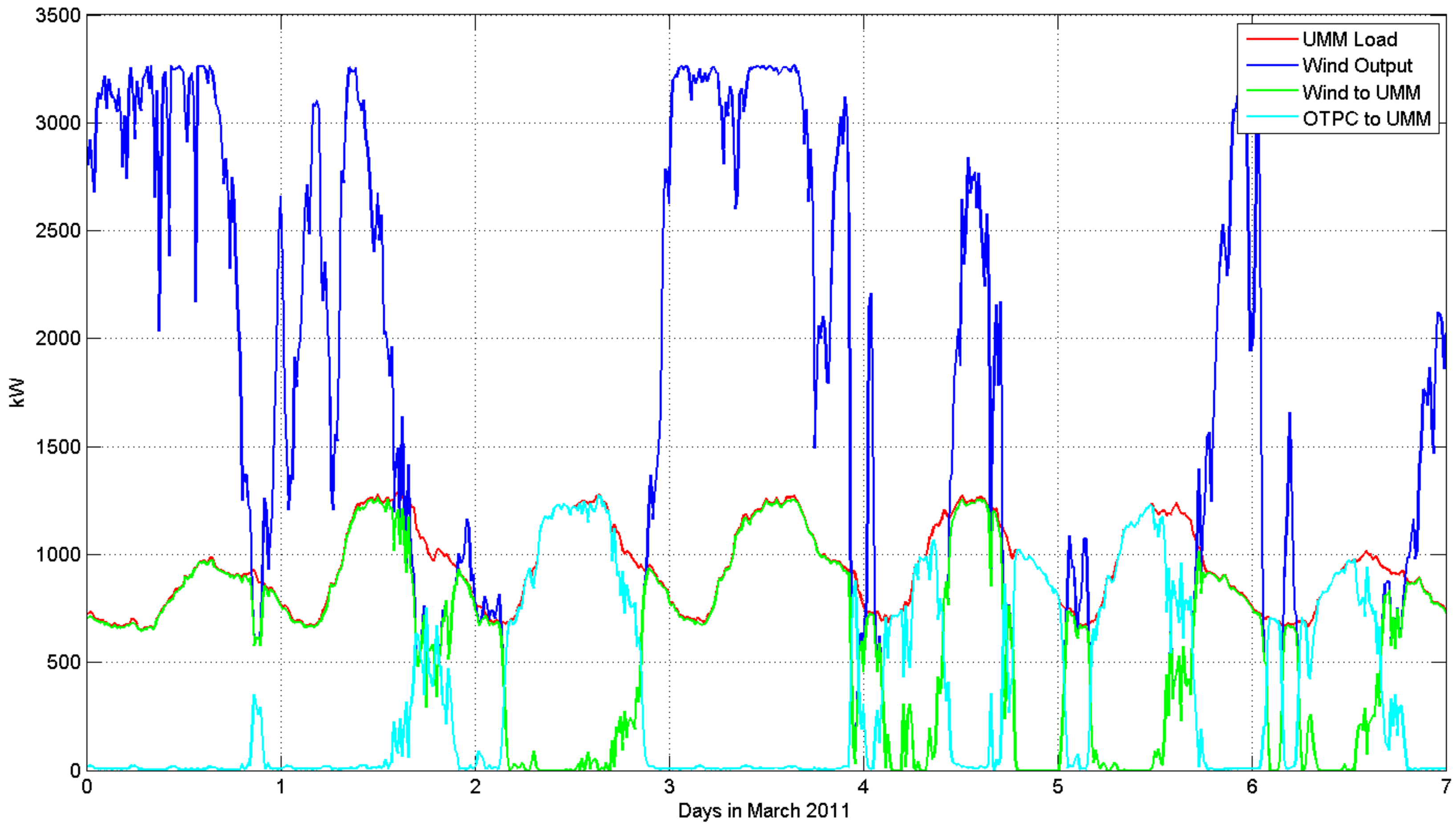
$$P_{OTPC} = P_{UMM} - P_{wind} + P_{BESS}$$

$$\text{if } P_{OTPC} > 0 \rightarrow P_{OTPC} = P_{LOAD}$$

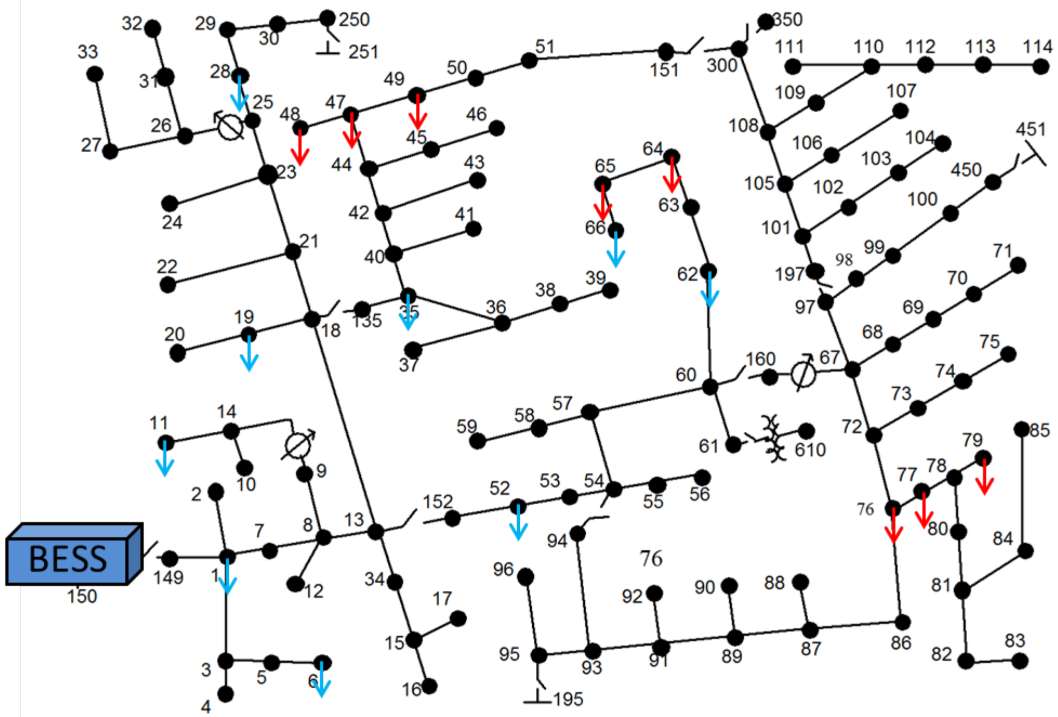
$$\text{if } P_{OTPC} < 0 \rightarrow P_{OTPC} = P_{GEN}$$

P_{wind} = 2 x 1.65 MW Wind Turbines
P_{UMM} = 1.5 MW Peak

UM Morris Power System



Priority Ride-Through



LOADS SERVED
- Small C&I ↓
- Large C&I ↓

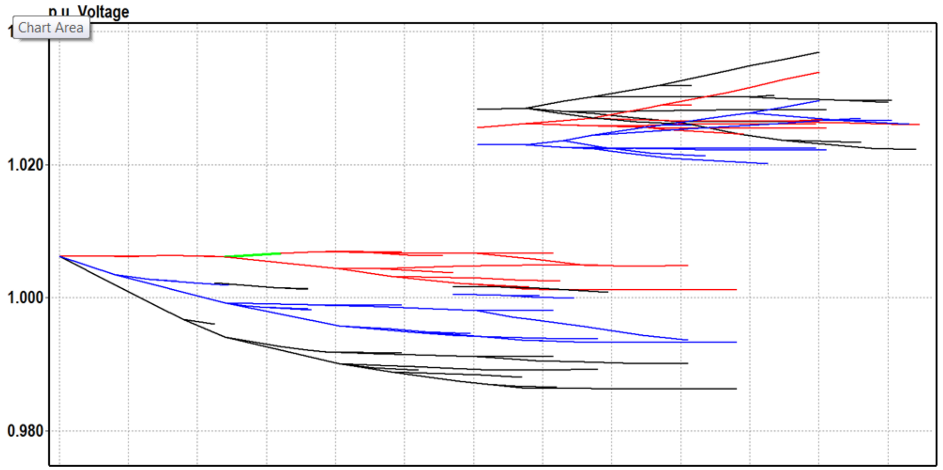
Observations:

- Only C&I customers served
- Requires remote-disconnect functionality at meters
- Reduced net demand due to priority ride-through

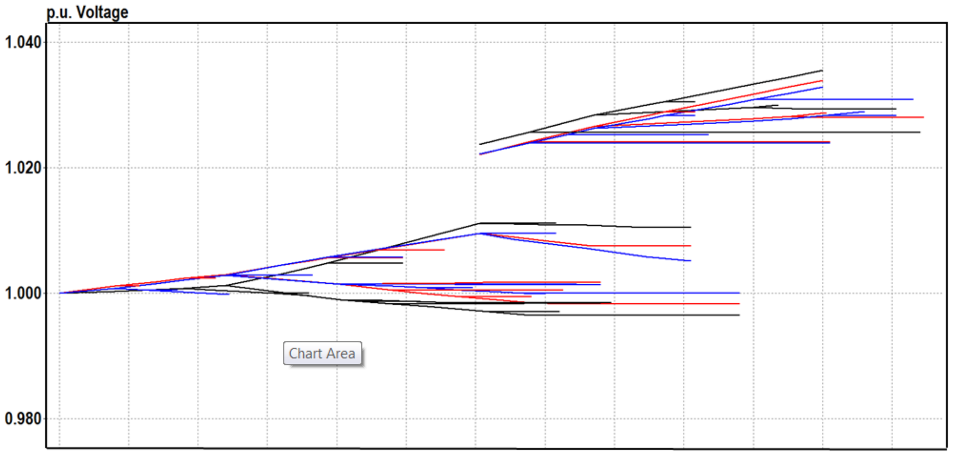
Customer Outage Costs	Large C&I	Small C&I	Res.	Total	Loads Served	BESS Load
No Storage	$ 70,822	$ 82,027	$ 2,215	$155,060	0	***0 kVA***
With Storage – All Loads	$ 46,114	$ 53,067	$ 1,708	$ 100,890	85	***1600kVA***
With Storage – Selective Service	$ 0	$ 55,567	$ 2,215	$ 57,783	17	***692kVA***

Voltage Profiles

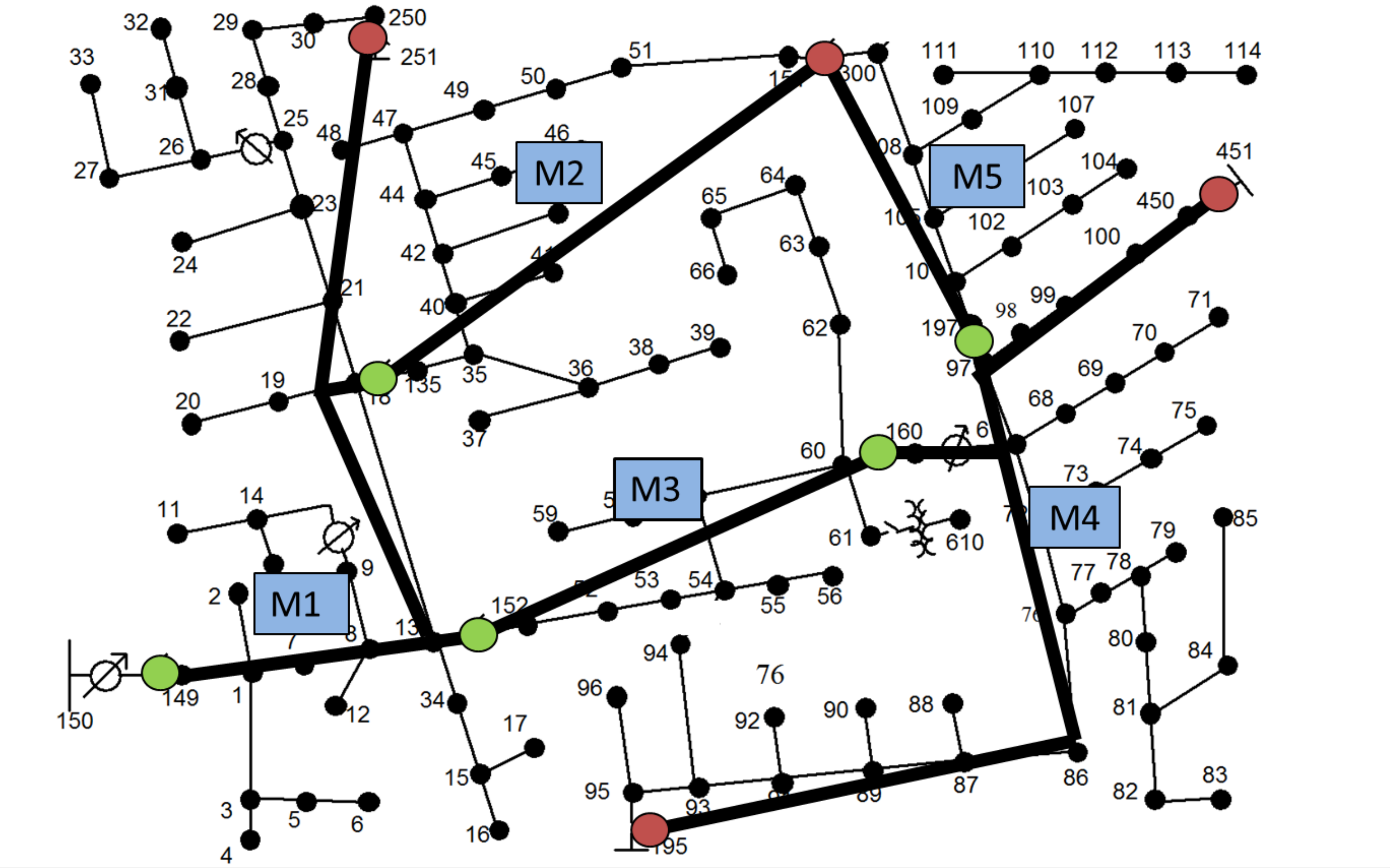
Normal Operation:
1.04 – 0.98pu voltages



Priority Ride-Through:
1.04 – 0.99pu voltages



Feeder Main Reliability Analysis



Normally Closed   Normally Open

Optimal Mix and Placement

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

Index	M1	M2	M3	M4	M5
Total Cust.	200	85	44	72	112
Cust. Served	0	0	4	35	0
SAIDI: 3.93 (down 0.44)		***SAIFI: 5.90 (down 0.66)***		***CAIDI: 1.5 (same)***	

Smart Grid U™

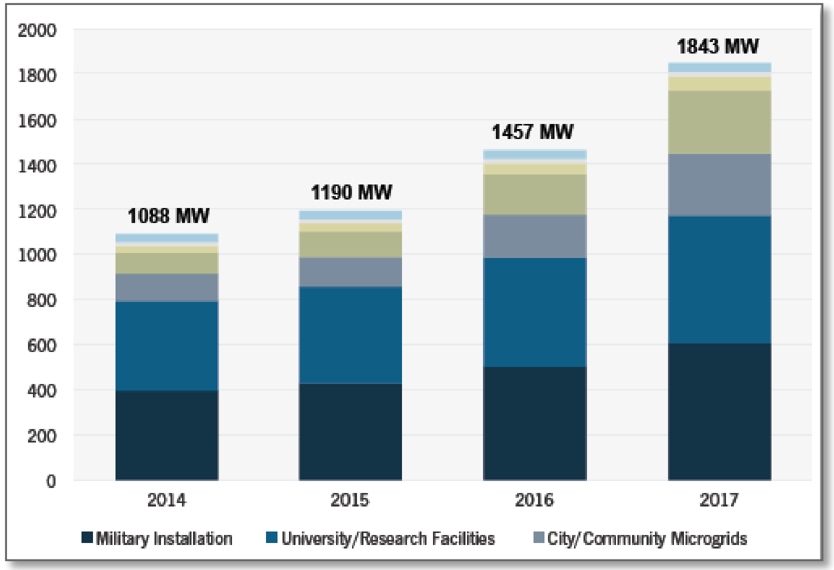
- **Lessons learned and key messages:**
  - Consider all parts together (Holistic Systems approach)
  - Focus on Benefits to Cost Payback
  - Remove deficiencies in foundations
  - The University as a Living laboratory
  - Education and Research → Implement new solutions

- **Consumer engagement critical to successful policy implementation to enable end-to-end system modernization**

- **If the transformation to smart grid is to produce real strategic value for our nation and all its citizens, our goals must include:**
  - Enable **every building and every node to become an efficient and smart energy node.**

Optimized Hybrid Microgrids

- Utility grid and microgrids must work synergistically to fulfill all the needs, e.g. serving all the load all the time
- Policy should support value creation and not unduly favor either incumbent utilities or non-utility MG sponsors
  - Assessing costs should include efficiency, reliability, safety, optimizing life-cycle costs, and resilience for the grid
  - Costs and benefits apportioned in a multi- stakeholder microgrid business case
  - Regulatory policy to reward costs incurred in planning, operational changes, and the optimal integration of assets
- New tools and Standards, e.g., IEEE 1547 Series



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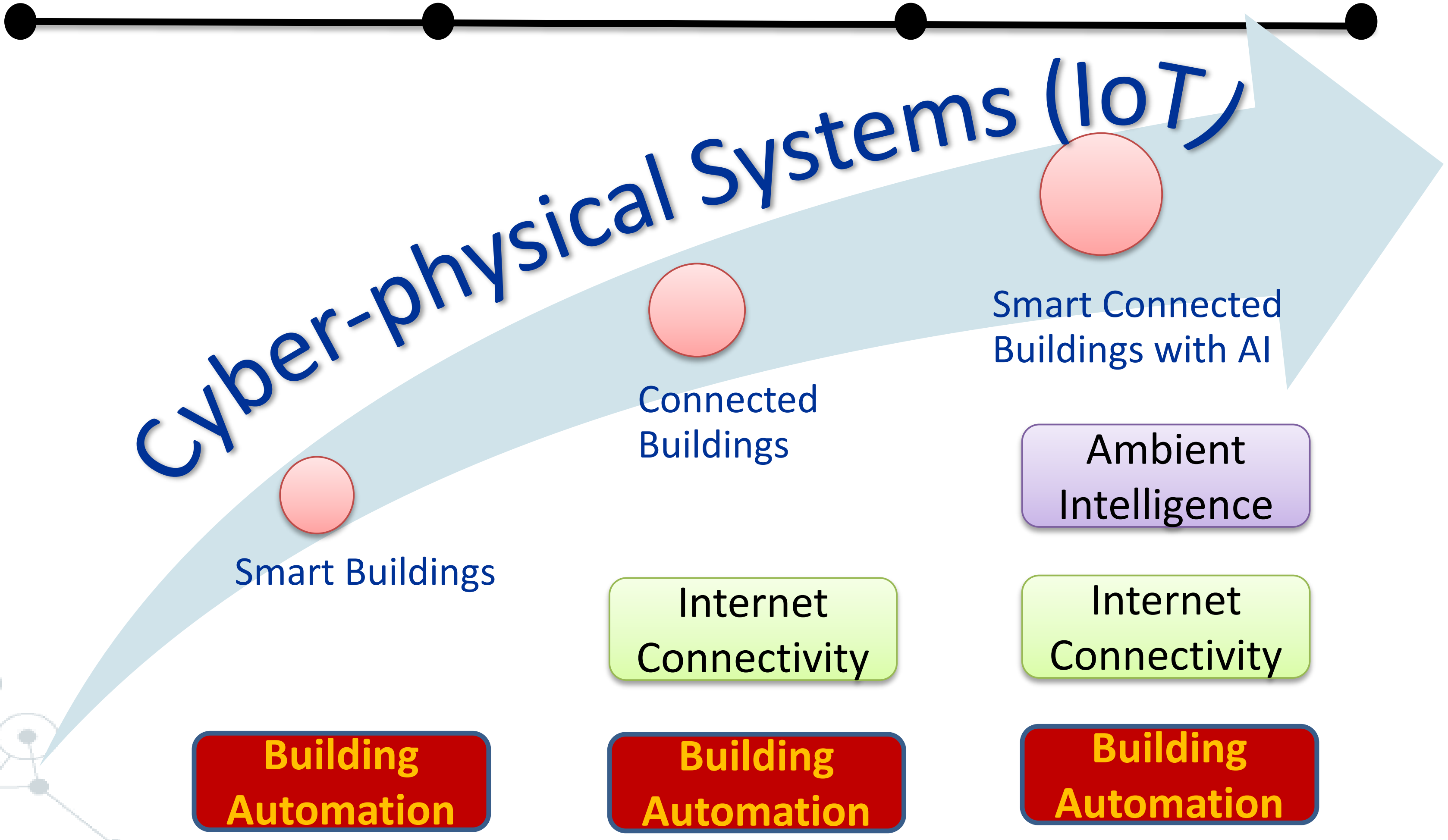
Example: Evolution of Building Technologies



MOVING AWAY FROM CENTRAL POWER

Asset management evolves as microgrids play various roles

BY MASSOUD AMIN,
Institute of Electrical and Electronics Engineers (IEEE)

Microgrids, as many readers are aware, are small power systems of several megawatts (MW) or less in scale that possess three primary characteristics: distributed generation with optional storage, autonomous load centers and the capability to operate interconnected with or islanded from a larger grid. These small-scale systems offer a variety of benefits in the Smart Grid era.

Microgrids that localities build to serve campuses, communities, and cities can contribute to Smart Grid's sustainable benefits. They are wonderful examples of the "think globally, act locally" principle. They draw their energy from locally available, preferably renewable, resources. They use Smart Grid technologies to continually monitor customer demand and they can enable innovative pricing and other programs to manage the load and encourage customers to conserve energy. Moreover, microgrids can export and sell excess capacity back to the grid, in support of high-voltage (100kV-800kV) bulk power systems.

Depending on local demand and available, local power resources, microgrids can be almost entirely self-sustaining. In fact, in most applications they can produce as much energy as they consume and generate "zero net" carbon emissions. We're building a microgrid at the University of Minnesota Morris (UMM) campus that uses biomass from nearby farms, as well as solar and wind resources.

Thus, microgrids are akin to and supportive of Smart Grids with regard to the potential to substantially reduce energy consumption and CO_2 emissions. In fact, CO_2 emissions alone could be reduced by 58 percent by 2030, compared to 2005 emissions, if Smart Grids, aided by microgrids, were to become the norm.

Certainly, the 450,000-mile-long, high-voltage North American power grid backbone, which is 97 percent efficient, needs to be strengthened with HVDC lines that can integrate wind, solar and other domestic energy resources—including microgrids—into the centralized grid. The upgraded backbone, combined with microgrids, will help us meet our goals for an efficient and eco-friendly electric power system that relies less on fossil fuels.

To achieve these goals, microgrids will need to be managed for optimal performance, security and resilience, whether by a utility or a third party seeking energy self-sufficiency for financial or reliability reasons. Furthermore, it is possible to connect multiple microgrids in a cellular architecture to increase reliability, redundancy, and resiliency, which can serve utilities, end-users and society as extreme weather and other anomalous events stress the high-voltage grid.

In a "cellular power network", each microgrid possesses numerous independent, intelligent, decision-making agents in a multi-agent architecture. These intelligent agents gather and exchange information with each other in real-time or near real-time in order to provide coordinated protection and to optimize system performance.

Asset management in this context requires more than just the sensors that enable condition-based maintenance, as is the case elsewhere on the grid. Asset management means understanding how a cellular power network behaves and how it can be managed and maintained for optimal performance.

Thus, asset management, when applied to microgrids, will become a more flexible concept as microgrid sensors and controls reach beyond each individual microgrid to communicate with other, similarly equipped microgrids. In fact, asset management in the microgrid context will depend greatly on how the microgrid is configured and the role it plays. The success of asset management for microgrids also depends on economies of scale; as microgrids proliferate, their components presumably will drop in price. We will further explore market drivers in a moment.

"locality" for an autonomous microgrid implies that it operates with maximum independence from other microgrids and minimal interdependencies. To place this notion of autonomy in context: a cellular power network is a large-scale dynamic-topology power network composed of autonomous microgrids that each exhibit self-similar properties to enable scale-up, but which can default to locality to continue functioning if and when other microgrids in the network fail.

The architecture for the autonomous microgrids and microgrid assemblies being modeled in my research is based on a multi-agent architecture for operating cellular power networks. In the architecture, each autonomous microgrid, and resulting cellular power network, is composed of numerous independent, intelligent, decision-making agents. These intelligent agents gather and exchange information with each other in real-time or near real-time in order to provide coordinated protection and to optimize system performance.

We have tested microgrids that incorporate a dynamical systems perspective of threat and uncertainty to investigate the performance of the multi-agent architecture for autonomous microgrids and microgrid assemblies as part of cellular power networks. As opposed to the computer science perspective that focuses on securing information, the focus of this work is on analyzing the actions or dynamics of network components and their overall management. The goal of such assessments is to determine the expected performance of such systems, including the effects of failure, repair, contention for resources, attacks and other uncertainties. Again, asset management in this fluid, network environment must remain a flexible concept.

Simulation models capture detailed system behavior, but they require a great deal of time to run. Analytical models, in contrast, create an abstraction of the system, but once set up, they make it easier and faster to carry out trade-off studies, perform sensitivity analyses, and compare design alternatives.

CURRENT RESEARCH

Research that serves the Smart Grid will also benefit microgrids. During the past two decades, my research efforts have focused on a better understanding of the true dynamics of complex and interdependent energy and communications networks and their economics in order to enable stronger, greener, more secure and smarter power grids—whether they're large and centralized or small and local in nature, such as microgrids.

Our on-going R&D projects include work on distribution system automation, security and resilience, smart power delivery and utilization systems and cyber-physical security. Of particular relevance to microgrids, we also have a project focused on security analyses of autonomous microgrids which includes analysis, modeling, and simulation of failure scenarios and development of attack-resistant architectures.

The objective of this cluster of projects is to model, design, and develop reconfigurable and distributed smart energy systems supported by secure sensing/wireless communication network overlay and fault-resilient, real-time controls. The results will aid in the development of Smart Grids and microgrids.

In fact, university microgrid projects offer very practical environments for testing Smart Grid systems. Our Smart Grid Assessments for communities at the UMM campus and UMore Park is a case in point. Building and managing our own microgrid provides direct experience on microgrid management and it serves as a test bed for consumer- and community-scale Smart Grid-related innovations. These projects engage faculty, postdoctoral students, researchers, undergraduates, and consumers from across the local community, as well as utilities from a wider Smart Grid coalition in Minnesota.

FAMOUS LAST WORDS

Recent disruptions of high-voltage grids and traditional distribution systems—Hurricane Sandy's first anniversary just passed—illustrates that if electricity supplies were not so dependent purely on centralized power plants and assets, and on the one-way flow of electrons and information, then customers would experience greater electrical reliability. That, in a nutshell, is the promise of microgrids. ET

Dr. Massoud Amin directs the Technological Leadership Institute (TLI) at the University of Minnesota. At TLI, Dr. Amin leads university staff and faculty, in conjunction with industry executives and government officials, to develop local and global leaders for over 400 technology enterprises.

Applying limited resources to critical infrastructure

BY MASSOUD AMIN, IEEE Smart Grid, University of Minnesota

The Smart Grid's contributions to improving electric utilities' means of monitoring the condition of assets, providing enhanced situational awareness, and faster actionable intelligence have transformed the power industry's concept of asset management from a largely passive, time-based approach to a more proactive, condition-based assessment.

Condition-based asset management offers a big leap in accuracy, improved and, therefore, greater power grid reliability, as it is a sounder method for asset maintain/repair/replace strategies and related investments. Unfortunately, this "new" approach remains wholly inadequate to meet the challenge.

As the Smart Grid has evolved, so has the need for a much more robust and wide-ranging view of the critical nature of our power infrastructure and how to best manage it. Currently, condition-based asset management is simply one aspect of a more holistic quality management approach that weighs the relative risks and economics of asset maintenance, repair, and replacement to advance end-to-end power grid reliability, resilience, security, and modernization.

This holistic approach will require new, strategic alliances between the public and private sectors in which carrots are used more often than sticks. Moreover, it will require utilities to transform their cultures and organizations and, possibly, adopt new business models to monetize new services and achieve savings.

A FUNDAMENTAL SHIFT

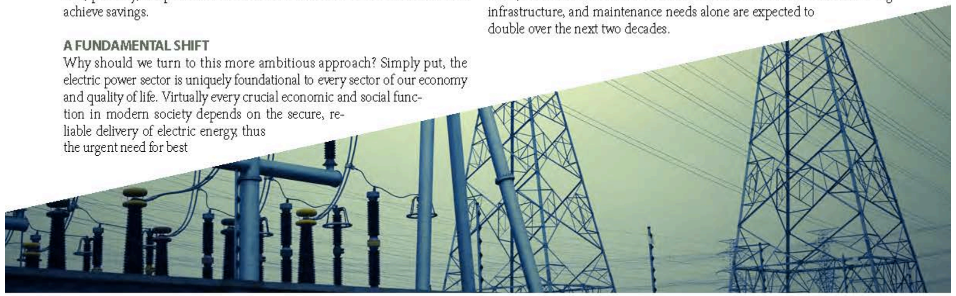
Why should we turn to this more ambitious approach? Simply put, the electric power sector is uniquely foundational to every sector of our economy and quality of life. Virtually every crucial economic and social function in modern society depends on the secure, reliable delivery of electric energy, thus the urgent need for best practices in the operation of power and energy infrastructures. With a largely aging power infrastructure in the United States—particularly underground city networks—and limited resources to address the issue, we need a rational, evidence-based foundation for its operational integrity and security.

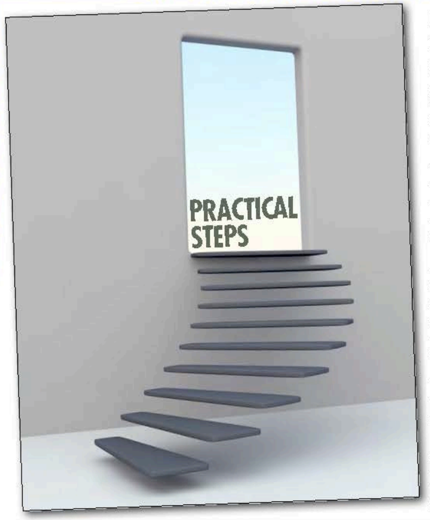
Trends such as urbanization, the power grid's interdependencies with other infrastructures (for example, water, gas, telecommunications) the extreme weather events that come with global climate change and the advent of terrorism all bring added urgency to our collective challenge.

The approach outlined in this feature is based on the familiar trio of technology, policy, and standards, but it also embraces a completely new outlook by all stakeholders towards our power infrastructure. Therefore, this feature closely reflects a report that an IEEE Joint Task Force provided to the U.S. Department of Energy (DOE) in the summer of 2014 on high priority issues for the White House's Quadrennial Energy Review (QER) to guide U.S. energy policy.

A GROWING NEED

In the U.S., the average system age is 40 to 60 years old. Fully 25 percent of our power assets are of an age in which condition is a concern. Power infrastructure build-outs in the U.S. largely ended in the 1980s. Moreover, according to the recently published book, "*Aging Power Delivery Infrastructures*", the current focus is on the maintenance and modernization of existing infrastructure, and maintenance needs alone are expected to double over the next two decades.





PRACTICAL STEPS

Achieving hardening and resiliency on the ground should be based on a particular utility's customers' needs, its legacy systems, location, and technology roadmap. Given the disparities between individual utilities, it is difficult to generalize, but a few universal concepts are worth discussion. Never forget that "resiliency" and "customers' needs" also cover the timely notification, through customers' preferred channels, of estimated time to restoration, which increases customer satisfaction.

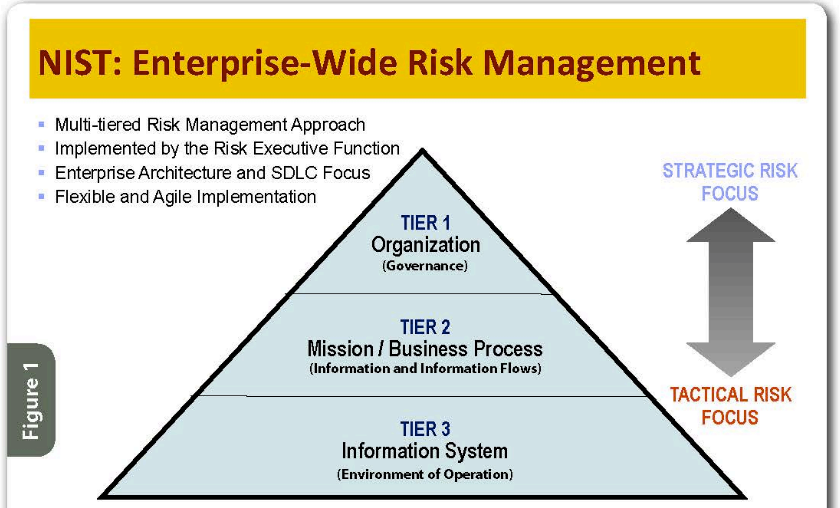
Risk assessment of existing assets provides a data-based identification of weaknesses and a means of prioritizing maintenance, repair and replacement. Component and system failures are difficult to predict. However, it is possible to identify the components that, as a result of their location, configuration and electrical characteristics, pose the greatest risk for large-scale outages. Understanding these vulnerabilities can guide power grid investments.

Because the risk landscape is dynamic, risk assessment must be a perennial task. Additionally, adaptation strategies will shift as a utility invests in new technologies and operational practices change. Current and future investments in advanced metering infrastructure and distribution automation signal the beginning of a multi-decade, multi-billion-dollar effort to achieve an intelligent, secure, resilient, and self-healing system. The risk landscape will change as the power grid evolves.

Fortunately, risk assessment methods are well established, and they can be tailored to specific circumstances. Three figures offer insights related to this task. Figure 1, from the National Institute of Standards and Technology (NIST), provides a conceptual model for enterprise risk management.

Figure 2 is based on an adaptation of Dr. Steve Lee's work at EPRI on probabilistic risk assessment (PRA) as a part of the EPRI Grid Operations and Planning Task Force's Power Delivery Reliability Initiative, and my published works entitled, "*Fast Look-ahead Simulation, Modelling and Validation, January 2001 to May 2003*".

Photo credit (stairs and door): Sigurd Decroos



Enterprise risk management (conceptual model)
Source: ***National Institute of Standards and Technology (NIST)***


LEADERSHIP

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