Egyptian Engineers Society

Benefits and Challenges of Integrating Solar/Wind Generation into the Electric Power Grid

30 November 2014
Cairo, Egypt

Professor Saifur Rahman
Virginia Tech – Advanced Research Institute, USA

Virginia Tech

ARI

Virginia Tech Research Center Arlington, Virginia, USA

ARI

2

Changing Landscape for the Electric Utility

3

Issues with Distributed Generation

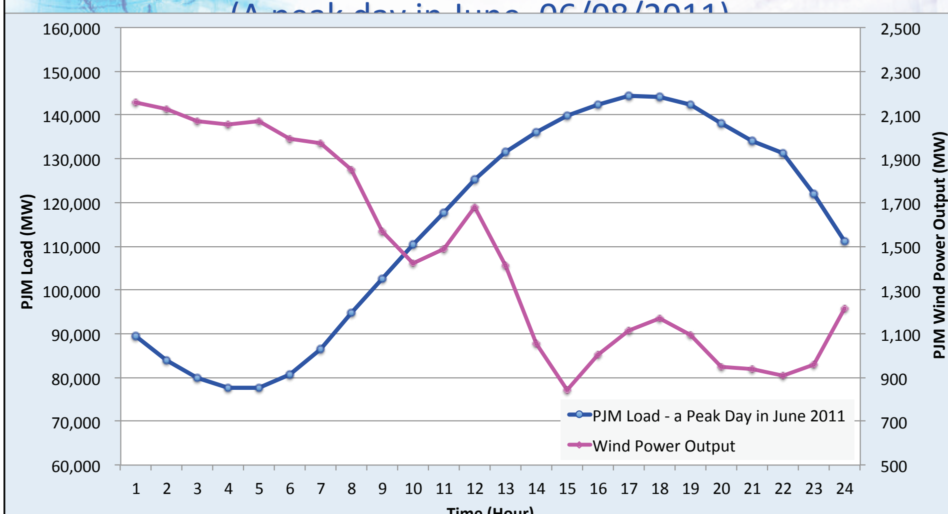
- Wind and solar are intermittent
- Hydro is space limited
- Resource is free but not always usable

Wind Energy

Off-shore Wind turbines, Blyth, U.K.

5

Wind Output & Load Mismatch (PJM)

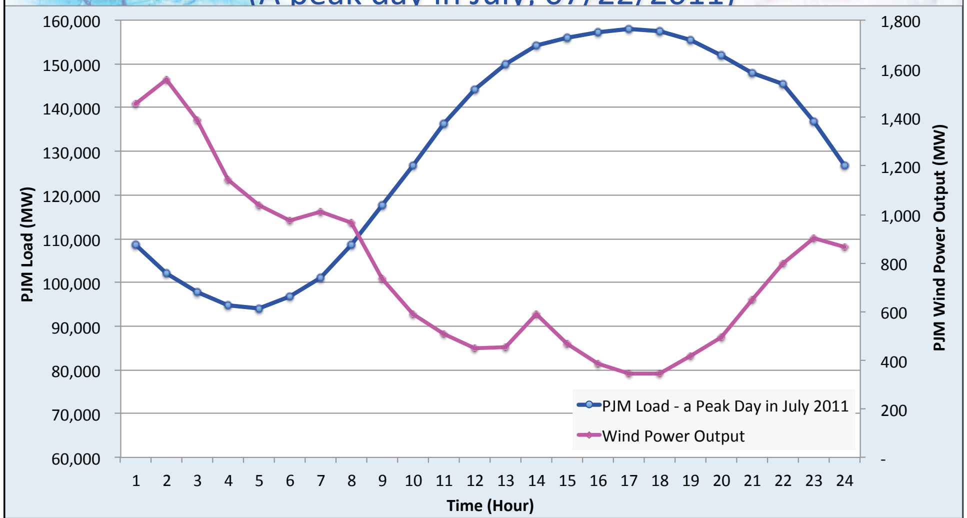


Data source: http://www.pjm.com/markets-and-operations/ops-analysis.aspx

6

Wind Output & Load Mismatch (PJM)

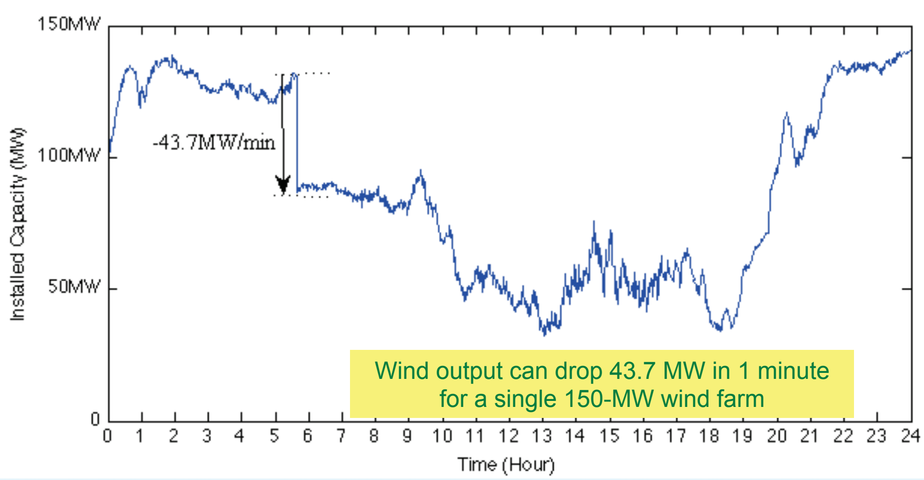
(A peak day in July, 07/22/2011)



Data source: http://www.pjm.com/markets-and-operations/ops-analysis.aspx

7

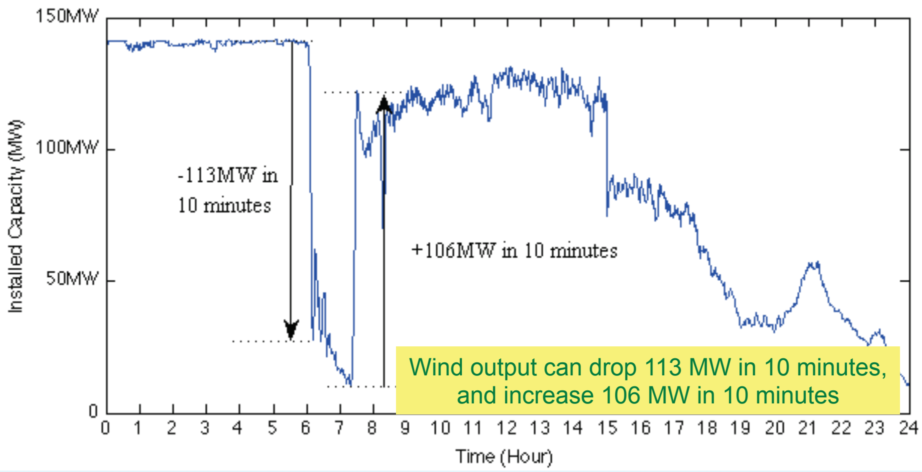
1-minute Variation of a 150MW Wind Farm Output in Texas, 2008



Source: NREL

8

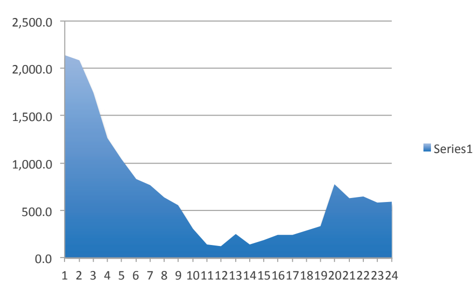
10-min Variation of a 150MW Wind Farm Output in Texas, 2008



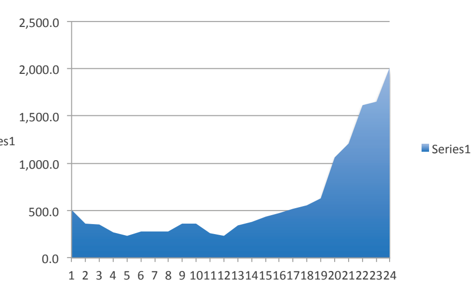
Source: NREL

9

Hourly wind power variation (MW) in Texas, USA (01 and 02 Jan 2008)



01 Jan 2008

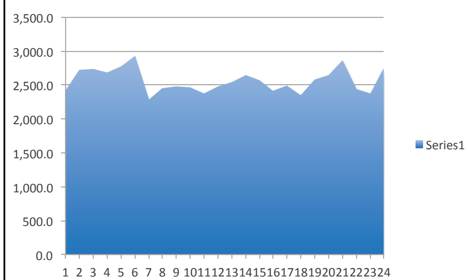


02 Jan 2008

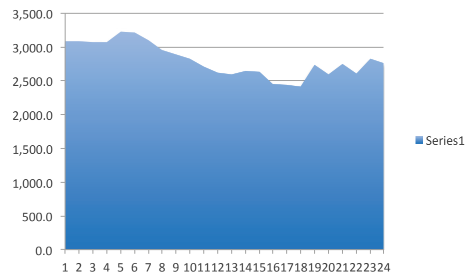
Installed Capacity 4,541 MW

10

Hourly wind power variation (MW) in Texas, USA (03 and 04 Jan 2008)



03 Jan 2008



04 Jan 2008

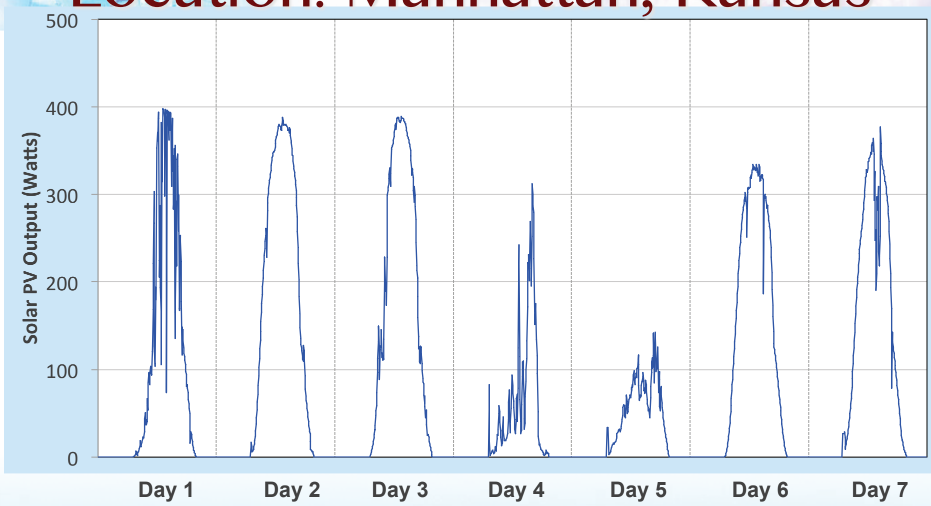
Installed Capacity 4,541 MW

11

Roof-top Solar Photovoltaics in Virginia

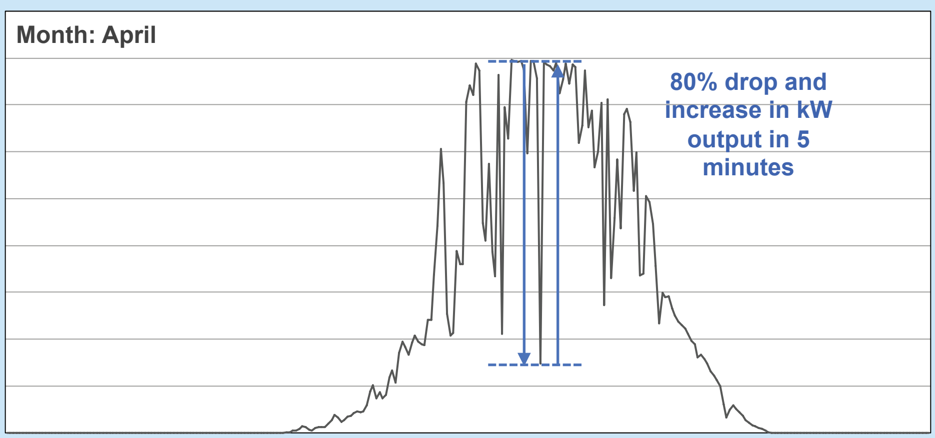
12

7-Day Solar PV Output
Location: Manhattan, Kansas



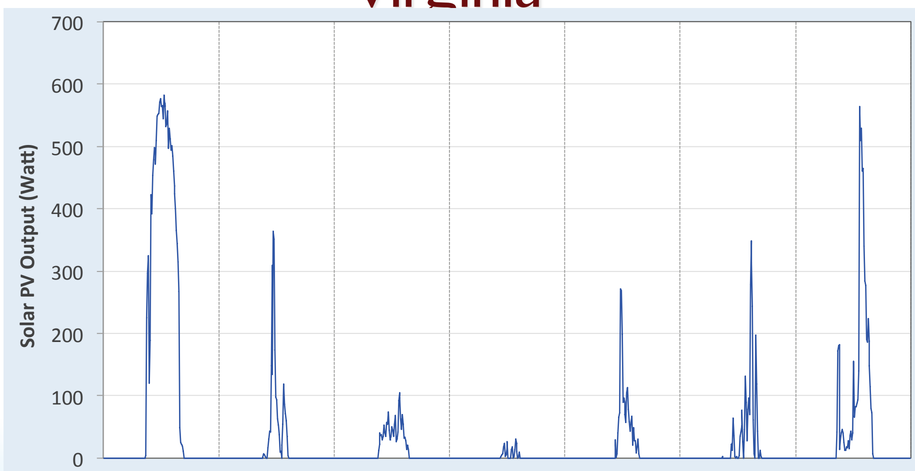
13

A 24-hour Solar PV Output (kW)
Location: Manhattan, Kansas



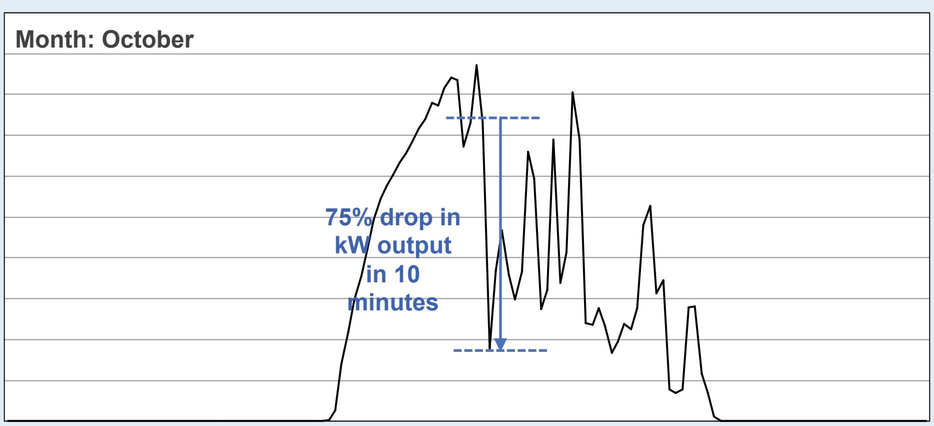
14

7-Day Solar PV Output Location: Blacksburg, Virginia



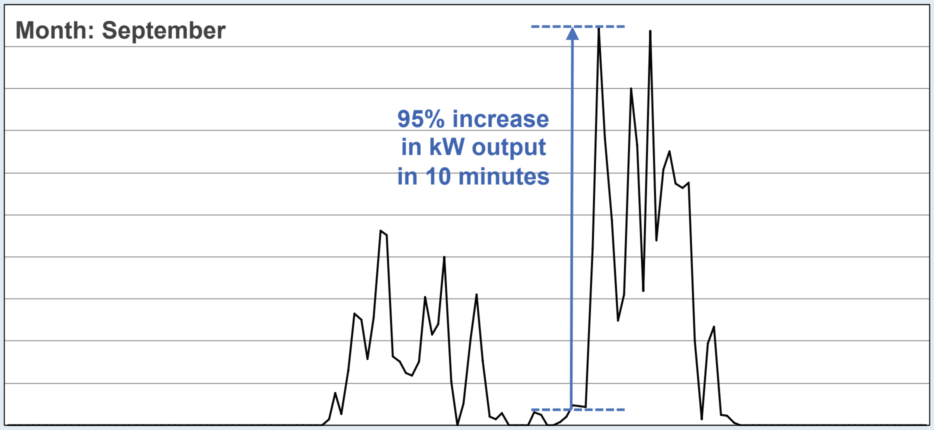
15

A 24-hour Solar PV Output (kW) Location: Blacksburg, Virginia



16

A 24-hour Solar PV Output (kW) Location: Blacksburg, Virginia



17

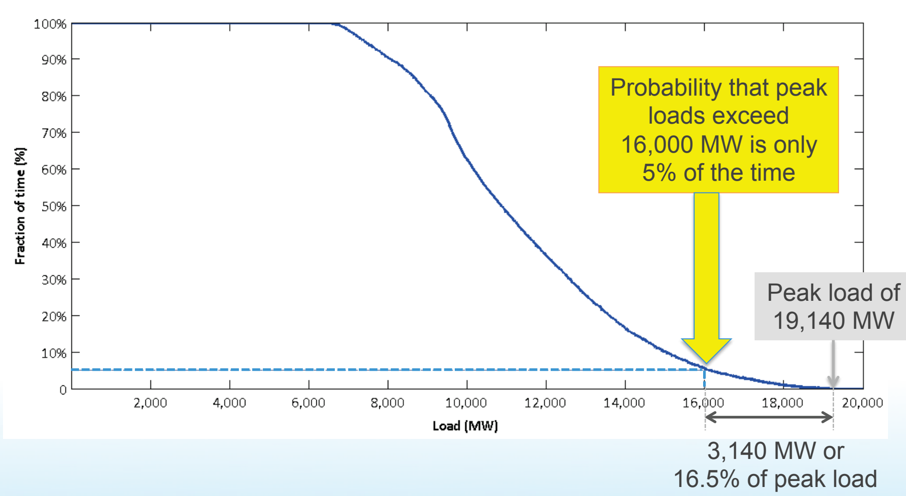
Is there a better way to give credit to renewables?

- Can the short term intermittency be absorbed by the the network?
- Storage?
  - Batteries
  - Pumped storage hydro
  - Compressed air energy storage (CAES)
- Any other options?

18

Peak Load Issue

Peak Load Reduction Dominion Virginia Power (2010)



Demand Response

"Demand Response is a customer action to control load to meet a certain target. Here the customer chooses what load to control and for how long".

This is different from Demand Side Management (DSM)where the load is controlled by the electric utility and the customer has no control beyond the initial consent.

What Role Can the Smart Grid Play?

What is a Smart Grid

"Smart grid" is a concept with many elements where monitoring and control of each element in the chain of generation, transmission, distribution and end-use allow our electricity delivery and use more efficient.

FierceSmartGrid: *There are many definitions of "smart grid" -- how do you define it?*

Saifur Rahman: "Smart grid" is a concept with many elements -- it's not a physical thing. I like to say that a smart grid starts at the generator and ends at the refrigerator.

http://www.fiercesmartgrid.com/story/smart-grid-starting-generator-ending-refrigerator/2013-02-19?utm_medium=nl&utm_source=internal

23

This is the Electric Power Grid

Source: www.sxc.hu

24

Difference Between a Normal Grid And a Smart Grid

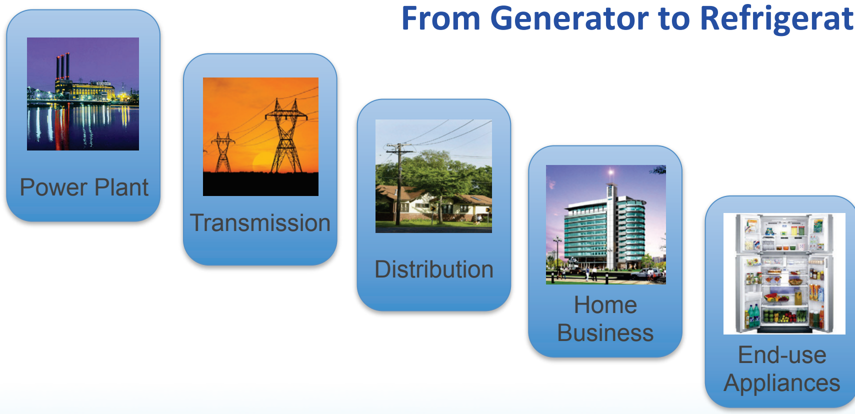
Normal Phone | Smart Phone

What is the Motivation for a Smart Grid

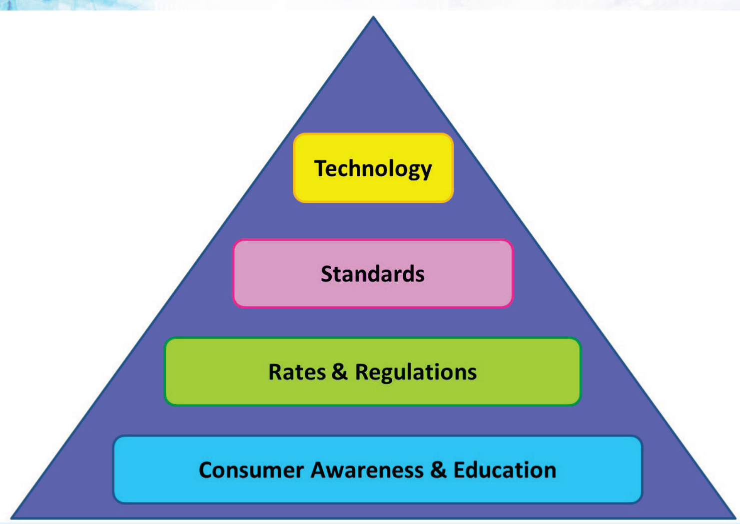
Desire to make the grid smarter, safer, reliable and more cost-effective using advanced sensors, communication technologies and distributed computing.

Starting and End Points of a Smart Grid

From Generator to Refrigerator



Building Blocks of the Smart Grid



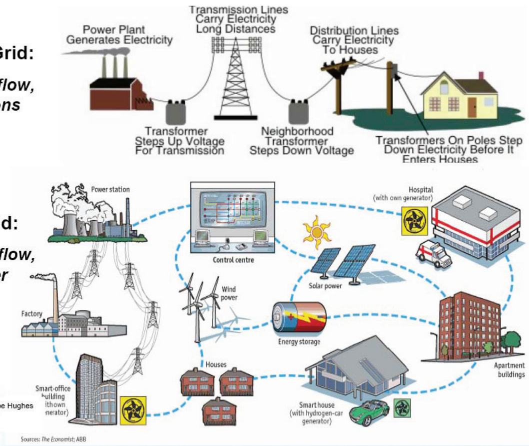
Evolution of the Grid

Before **Smart Grid:**

One-way power flow, simple interactions

After **Smart Grid:**

Two-way power flow, multi-stakeholder interactions



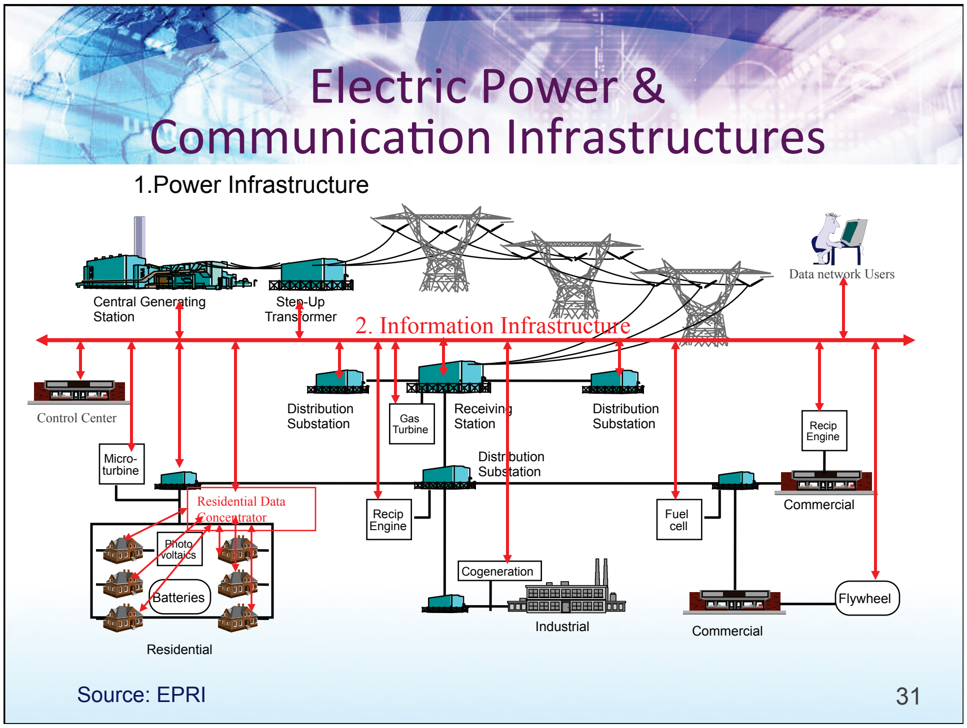
Adapted from EPRI Presentation by Joe Hughes NIST Standards Workshop April 28, 2008

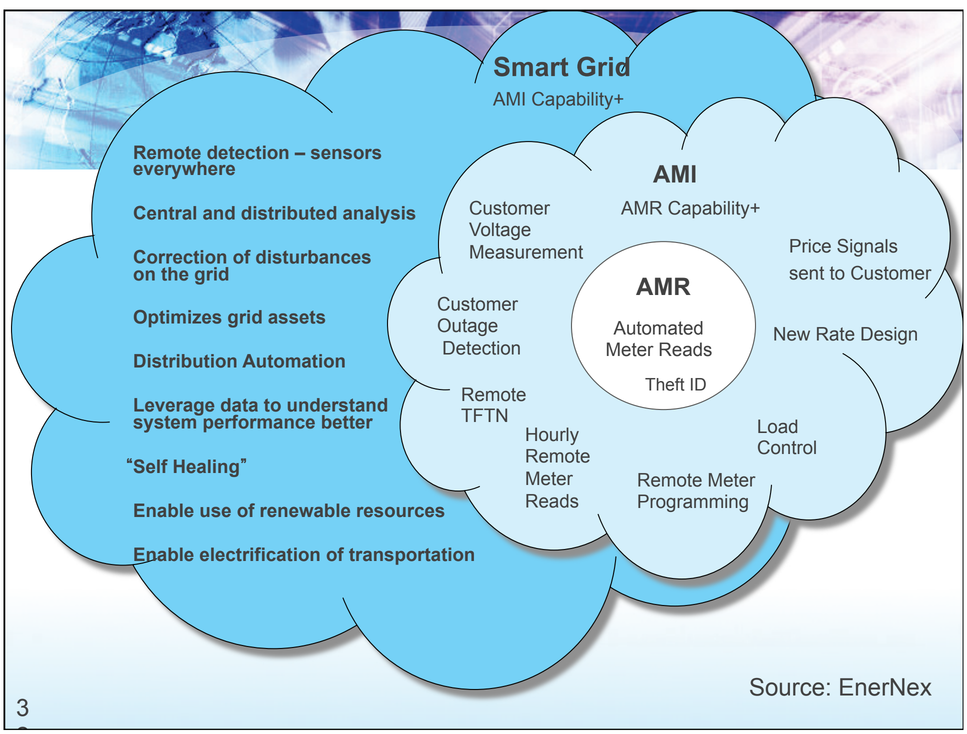
Source: Altalink, Alberta, Canada

Merging Power Flow with Information Flow:

Integrated Communications

30


Electric Power &
Communication Infrastructures
1.Power Infrastructure
Central Generating Station
Step-Up Transformer
2. Information Infrastructure
Data network Users
Control Center
Distribution Substation
Gas Turbine
Receiving Station
Distribution Substation
Recip Engine
Micro-turbine
Distribution Substation
Residential Data Concentrator
Photo voltaics
Batteries
Recip Engine
Fuel cell
Commercial
Cogeneration
Industrial
Commercial
Flywheel
Residential
Source: EPRI
31


Smart Grid
AMI Capability+
Remote detection – sensors everywhere
Central and distributed analysis
Correction of disturbances on the grid
Optimizes grid assets
Distribution Automation
Leverage data to understand system performance better
"Self Healing"
Enable use of renewable resources
Enable electrification of transportation
AMI
AMR Capability+
Customer Voltage Measurement
Price Signals sent to Customer
Customer Outage Detection
New Rate Design
Remote TFTN
Hourly Remote Meter Reads
Remote Meter Programming
Load Control
AMR
Automated Meter Reads
Theft ID
Source: EnerNex
3

Technical Issues

- Renewables integration
- Demand response application
- Peak load reduction
- Remote meter reading & billing
- Transformer/Switchgear loading
- Service monitoring and recovery

Technical Benefits

- Conservation Voltage Reduction
- Peak Load Reduction
- Faster Outage Recovery
- Renewables Integration

Faster Recovery from Outages

Smart meters allow automated outage information notification

Distribution automation and advanced switching capability allow sectionalizing and faster distribution circuit reconfiguration to restore healthy sections to service

Benefits of the smart grid

Peak load reduction, generator efficiency improvements and distributed generation integration are major benefits of the smart grid

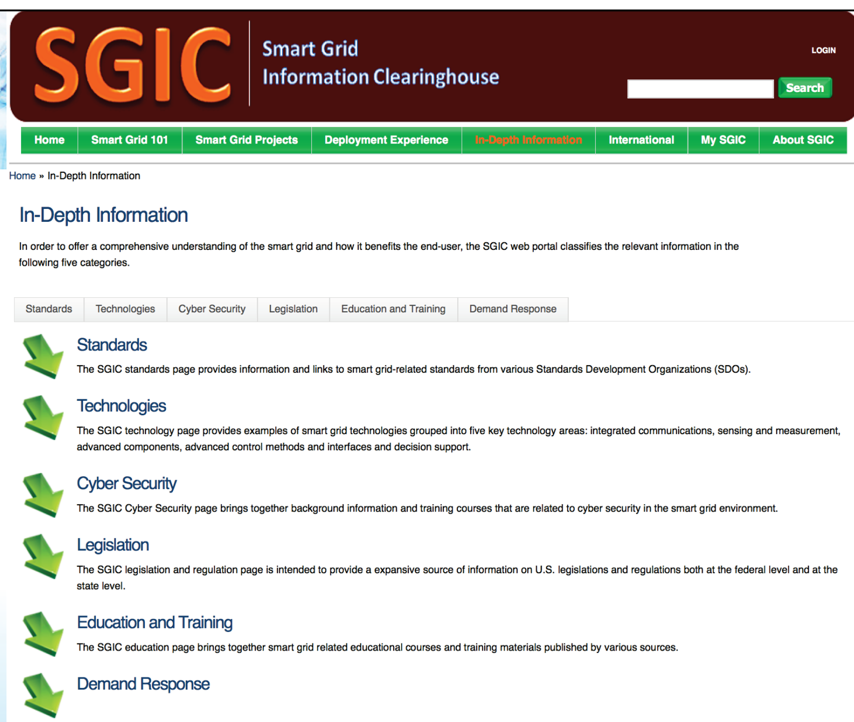
Demand response can provide significant peak load reductions

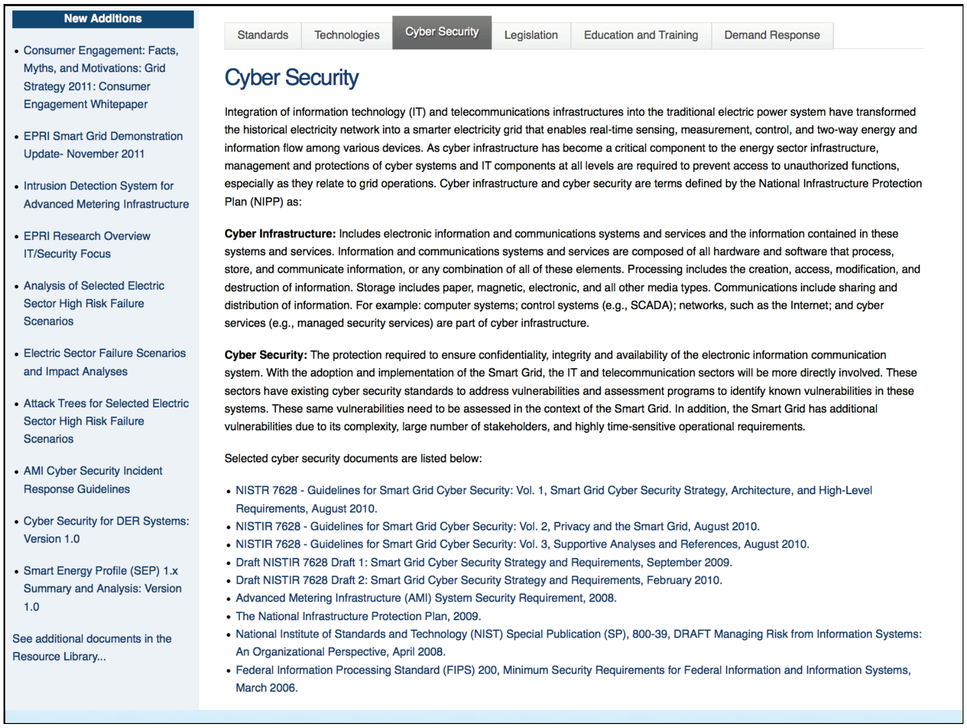
A smooth load shape allows better asset utilization

36

Smart Grid Information Clearinghouse

www.sgiclearinghouse.org





New Additions

- Consumer Engagement: Facts, Myths, and Motivations: Grid Strategy 2011: Consumer Engagement Whitepaper
- EPRI Smart Grid Demonstration Update- November 2011
- Intrusion Detection System for Advanced Metering Infrastructure
- EPRI Research Overview IT/Security Focus
- Analysis of Selected Electric Sector High Risk Failure Scenarios
- Electric Sector Failure Scenarios and Impact Analyses
- Attack Trees for Selected Electric Sector High Risk Failure Scenarios
- AMI Cyber Security Incident Response Guidelines
- Cyber Security for DER Systems: Version 1.0
- Smart Energy Profile (SEP) 1.x Summary and Analysis: Version 1.0

See additional documents in the Resource Library...

Standards | Technologies | Cyber Security | Legislation | Education and Training | Demand Response

Cyber Security

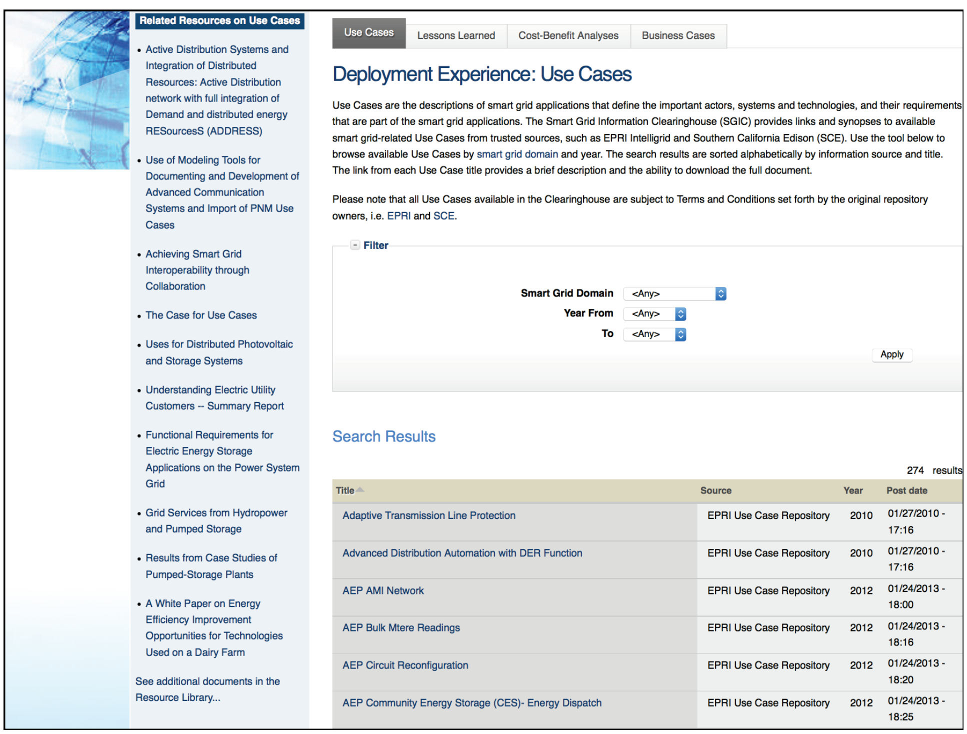
Integration of information technology (IT) and telecommunications infrastructures into the traditional electric power system have transformed the historical electricity network into a smarter electricity grid that enables real-time sensing, measurement, control, and two-way energy and information flow among various devices. As cyber infrastructure has become a critical component to the energy sector infrastructure, management and protections of cyber systems and IT components at all levels are required to prevent access to unauthorized functions, especially as they relate to grid operations. Cyber infrastructure and cyber security are terms defined by the National Infrastructure Protection Plan (NIPP) as:

Cyber Infrastructure: Includes electronic information and communications systems and services and the information contained in these systems and services. Information and communications systems and services are composed of all hardware and software that process, store, and communicate information, or any combination of all of these elements. Processing includes the creation, access, modification, and destruction of information. Storage includes paper, magnetic, electronic, and all other media types. Communications include sharing and distribution of information. For example: computer systems; control systems (e.g., SCADA); networks, such as the Internet; and cyber services (e.g., managed security services) are part of cyber infrastructure.

Cyber Security: The protection required to ensure confidentiality, integrity and availability of the electronic information communication system. With the adoption and implementation of the Smart Grid, the IT and telecommunication sectors will be more directly involved. These sectors have existing cyber security standards to address vulnerabilities and assessment programs to identify known vulnerabilities in these systems. These same vulnerabilities need to be assessed in the context of the Smart Grid. In addition, the Smart Grid has additional vulnerabilities due to its complexity, large number of stakeholders, and highly time-sensitive operational requirements.

Selected cyber security documents are listed below:

- NISTR 7628 - Guidelines for Smart Grid Cyber Security: Vol. 1, Smart Grid Cyber Security Strategy, Architecture, and High-Level Requirements, August 2010.
- NISTIR 7628 - Guidelines for Smart Grid Cyber Security: Vol. 2, Privacy and the Smart Grid, August 2010.
- NISTIR 7628 - Guidelines for Smart Grid Cyber Security: Vol. 3, Supportive Analyses and References, August 2010.
- Draft NISTIR 7628 Draft 1: Smart Grid Cyber Security Strategy and Requirements, September 2009.
- Draft NISTIR 7628 Draft 2: Smart Grid Cyber Security Strategy and Requirements, February 2010.
- Advanced Metering Infrastructure (AMI) System Security Requirement, 2008.
- The National Infrastructure Protection Plan, 2009.
- National Institute of Standards and Technology (NIST) Special Publication (SP), 800-39, DRAFT Managing Risk from Information Systems: An Organizational Perspective, April 2008.
- Federal Information Processing Standard (FIPS) 200, Minimum Security Requirements for Federal Information and Information Systems, March 2006.



Related Resources on Use Cases

- Active Distribution Systems and Integration of Distributed Resources: Active Distribution network with full integration of Demand and distributed energy RESourcesS (ADDRESS)
- Use of Modeling Tools for Documenting and Development of Advanced Communication Systems and Import of PNM Use Cases
- Achieving Smart Grid Interoperability through Collaboration
- The Case for Use Cases
- Uses for Distributed Photovoltaic and Storage Systems
- Understanding Electric Utility Customers -- Summary Report
- Functional Requirements for Electric Energy Storage Applications on the Power System Grid
- Grid Services from Hydropower and Pumped Storage
- Results from Case Studies of Pumped-Storage Plants
- A White Paper on Energy Efficiency Improvement Opportunities for Technologies Used on a Dairy Farm

See additional documents in the Resource Library...

Use Cases | Lessons Learned | Cost-Benefit Analyses | Business Cases

Deployment Experience: Use Cases

Use Cases are the descriptions of smart grid applications that define the important actors, systems and technologies, and their requirements that are part of the smart grid applications. The Smart Grid Information Clearinghouse (SGIC) provides links and synopses to available smart grid-related Use Cases from trusted sources, such as EPRI Intelligrid and Southern California Edison (SCE). Use the tool below to browse available Use Cases by smart grid domain and year. The search results are sorted alphabetically by information source and title. The link from each Use Case title provides a brief description and the ability to download the full document.

Please note that all Use Cases available in the Clearinghouse are subject to Terms and Conditions set forth by the original repository owners, i.e. EPRI and SCE.

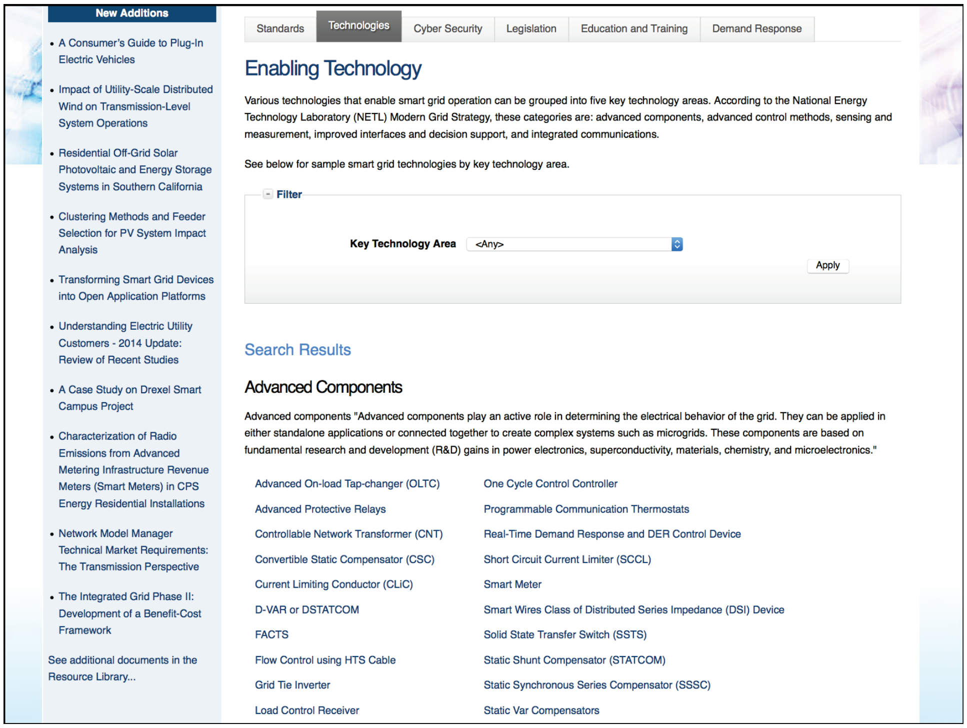
Filter

Smart Grid Domain <Any>
Year From <Any>
To <Any>
Apply

Search Results

274 results

Title	Source	Year	Post date
Adaptive Transmission Line Protection	EPRI Use Case Repository	2010	01/27/2010 - 17:16
Advanced Distribution Automation with DER Function	EPRI Use Case Repository	2010	01/27/2010 - 17:16
AEP AMI Network	EPRI Use Case Repository	2012	01/24/2013 - 18:00
AEP Bulk Mtere Readings	EPRI Use Case Repository	2012	01/24/2013 - 18:16
AEP Circuit Reconfiguration	EPRI Use Case Repository	2012	01/24/2013 - 18:20
AEP Community Energy Storage (CES)- Energy Dispatch	EPRI Use Case Repository	2012	01/24/2013 - 18:25



New Additions

- A Consumer's Guide to Plug-In Electric Vehicles
- Impact of Utility-Scale Distributed Wind on Transmission-Level System Operations
- Residential Off-Grid Solar Photovoltaic and Energy Storage Systems in Southern California
- Clustering Methods and Feeder Selection for PV System Impact Analysis
- Transforming Smart Grid Devices into Open Application Platforms
- Understanding Electric Utility Customers - 2014 Update: Review of Recent Studies
- A Case Study on Drexel Smart Campus Project
- Characterization of Radio Emissions from Advanced Metering Infrastructure Revenue Meters (Smart Meters) in CPS Energy Residential Installations
- Network Model Manager Technical Market Requirements: The Transmission Perspective
- The Integrated Grid Phase II: Development of a Benefit-Cost Framework

See additional documents in the Resource Library...

Standards | Technologies | Cyber Security | Legislation | Education and Training | Demand Response

Enabling Technology

Various technologies that enable smart grid operation can be grouped into five key technology areas. According to the National Energy Technology Laboratory (NETL) Modern Grid Strategy, these categories are: advanced components, advanced control methods, sensing and measurement, improved interfaces and decision support, and integrated communications.

See below for sample smart grid technologies by key technology area.

Filter

Key Technology Area <Any>

Apply

Search Results

Advanced Components

Advanced components "Advanced components play an active role in determining the electrical behavior of the grid. They can be applied in either standalone applications or connected together to create complex systems such as microgrids. These components are based on fundamental research and development (R&D) gains in power electronics, superconductivity, materials, chemistry, and microelectronics."

Advanced On-load Tap-changer (OLTC)	One Cycle Control Controller
Advanced Protective Relays	Programmable Communication Thermostats
Controllable Network Transformer (CNT)	Real-Time Demand Response and DER Control Device
Convertible Static Compensator (CSC)	Short Circuit Current Limiter (SCCL)
Current Limiting Conductor (CLiC)	Smart Meter
D-VAR or DSTATCOM	Smart Wires Class of Distributed Series Impedance (DSI) Device
FACTS	Solid State Transfer Switch (SSTS)
Flow Control using HTS Cable	Static Shunt Compensator (STATCOM)
Grid Tie Inverter	Static Synchronous Series Compensator (SSSC)
Load Control Receiver	Static Var Compensators

Selected Publications

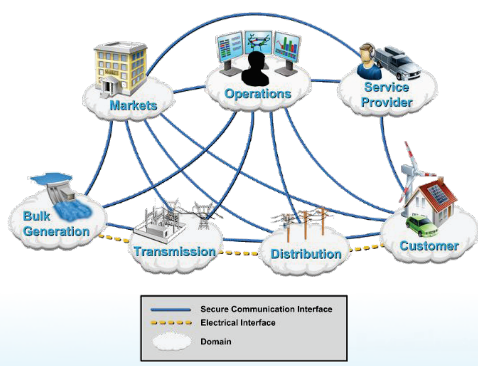
1. "Smart Grid Networks: Promises and Challenges", A. Yarali and Saifur Rahman, special Issue on Future Directions on Computing and Networking, *Journal of Communications* (JCM, ISSN 1796-2021), Vol. 7, No. 6, June 2012, pp. 409-417.
2. "Development of Physically-Based Demand Response-enabled Residential Load Models", S. Shao, M. Pipattanasomporn and Saifur Rahman, *IEEE Transactions on Power Systems*, Vol. 28, No. 2, May 2013, pp. 607-614, Digital Object Identifier: 10.1109/TPWRS.2012.2208232
3. "An Algorithm for Intelligent Home Energy Management and Simulation for Demand Response Analysis", M. Pipattanasomporn, M. Kuzlu, and S. Rahman, *IEEE Transactions on Smart Grid,* Vol. 3, No. 4, December 2012, pp. 2166-2173.
4. "Flywheel Energy Storage Systems for Ride-through Applications in a Facility Microgrid", R. Arghandeh, M. Pipattanasomporn, and S. Rahman, *IEEE Transactions on Smart Grid*, Vol. 3, No. 4, December 2012, pp. 1955-1962.
5. "Impacts of Ice Storage on Electrical Energy Consumptions in Office Buildings", F. Sehar, S. Rahman, and M. Pipattanasomporn, *Energy and Building Journal*, Vol. 51, 2012, pp. 255-262.

Selected Publications, contd.

1. "Hardware Demonstration of a Home Energy Management System for Demand Response Applications", M. Kuzlu, M. Pipattanasomporn and S. Rahman, *IEEE Transactions on Smart Grid,* Vol. 3, No. 4, December 2012, pp. 1704-1711.
2. "Load Profiles of Selected Major Household Appliances and their Demand Response Opportunities", M. Pipattanasomporn, M. Kuzlu, S. Rahman, and Y. Teklu, *IEEE Transactions on Smart Grid*, Vol. 5, No. 1, March 2014, pp. 742-750, DOI:10.1109/TSG.2013.2268664
3. "Communication Network Requirements for Major Smart Grid Applications in HAN, NAN and WAN", M. Kuzlu, M. Pipattanasomporn and S. Rahman, Accepted for Publication in *Computer Networks,* March 2014, 8 p.
4. "Engineering Design and Assessment of a Demand-Sensitive LED Streetlighting System", M. Pipattanasomporn, S. Rahman, Isaac Flory and Yonael Teklu, accepted for publication in *International Journal on Sustainable Energy Technologies and Assessments,* April 2014, 9p.
5. "A Human Expert-based Approach to Electrical Peak Demand Management", D. Bian, M. Pipattanasomporn and Saifur Rahman, accepted for publication in *IEEE Transactions on Power Delivery*, 2014, 9p.

Thank you

Prof. Saifur Rahman
www.saifurrahman.org



Virginia Tech

ARI