Smart Grid – What and Why??
August 2011
Malcolm S Metcalfe

The information contained in this presentation is for the exclusive and confidential use of the recipient. Any other distribution, use, reproduction or alteration of the information contained in this presentation, by the addressee or by any other recipient, without the prior written consent of ENBALA Power Networks Inc., is strictly prohibited.
Smart Grid – What is it??

An Important Development

Or

A Solution Seeking a Problem???
Common Views...

- **Utility People** – “The Smart Grid.... Whatever that is...??”
- **Public “Experts”**. “The existing grid is a mass of wires and cables that look just like they did – when Edison was around...”
- **Communications People** – “..time to revolutionize electricity delivery in the same way that the telecom industry changed...”

There are some realites and many misconceptions...
But the Opportunity is REAL!
I am going attempt to provide 3 answers...

1. What has caused this need??
2. What is the Smart Grid??
3. Why is it important...?? And what can it do??
The Impacts of Growth.

• For decades electrical energy demand grew at 6-8% - doubling every 9-12 years...
  – Half of the power generation and transmission systems were less than 12 years old at any time..
  – Transmission systems grew with new power generation, reflecting the best technology at the time.
    • Standards for reliability were established
    • Faster protection systems enabled reliable operation at near system limits...
  – Distribution systems grew with new customers..
    • New areas may have utilized better technology, but for the most part, changes were relatively small
    • Old distribution systems installed many years before were often left in place
Today’s Transmission “Grid”

What has Happened in the Last 50 Years???

- Interconnections between utilities have become a major factor in operations
- Deregulation has resulted in hourly markets for supply in many areas
- Hourly markets between utilities have matured..
- NERC* has established and monitors operating standards for system reliability and security...

* NERC – North American Electricity Reliability Corporation
Today’s Transmission Grid

• Transmission Capacity...
  – Designed to meet annual 15 minute peak – with redundant capacity..
  – Planning/Implementation requires several years – many projects are committed for construction well before they are needed...
  – The transmission grid is capacity constrained – but generally not energy constrained

• Market and Operational Needs...
  – Flexible - Trade, both within market area and through interconnections
    • Sophisticated protection systems that allow most lines to transfer power in either direction as needed...
    • Rapid fault clearing to reduce the redundancy requirements

The Transmission System, for the most part, is sophisticated, reliable, reasonably secure and certainly not something that Edison would recognize...BUT

It operates at peak capacity for short times each year – and remains capable of delivering almost double the current amounts of energy... (Unfortunately, the surplus capacity exists when there is little demand...)
The Distribution Network

• Essentially a radial network – the loss of a major feeder line results in customer outages...
• Technology is mixed (Some is REALLY OLD!!)
  – Some equipment installed more than 75 years ago remains in operation
  – System is generally designed for “one way” flow – to the users...
  – Monitoring of customer service has been limited... The utility learns about outages – often based on the dreaded customer calls... “My lights are off…”
  – Customers have been getting a monthly or bi-monthly bill (several weeks after the fact) – with no means of knowing how much power they are consuming at any time – or how much energy they have used so far this month... NO other commodity has been sold this way for many years...
  – The utility has limited means of identifying local overloads – or theft
• Until recently, most prices were fixed... Some utilities made purchases on the open market – and sold at fixed prices that were government regulated
Utilities Have Done a Terrific Job...

• “Power to Ontario – ON DEMAND…” the utility culture...
  – Meeting the demand... Supply what is needed... When it is needed...
    • Demand response, turning off selected loads for short periods has helped this...
  – The markets have been relatively inelastic... Largely driven by the pricing structure
  – Supply and demand must be in balance at all times...
    • Utilities have adjusted generation to maintain this balance... Second by second...

• Renewable Energy... The future??
  – Clean and essentially free and limitless supply of fuel...
  – Most renewable generation brings new characteristics
    • Little or NO inherent STORAGE capacity
    • Most are non firm and care must be taken in their use...
      – Some European countries have installed large amounts of renewable capacity with almost no impact on their fossil fuel use...

The Utilities have an established culture to deliver firm, reliable power – on demand...
The System Operator has Real Challenges

- Firming
- Operating & Sync Reserve
- Black Start
- Voltage Control

Demand vs. Time of Day (24 Hour Clock)

- Grid Balance

TIME OF DAY (24 HOUR CLOCK)

- 3
- 6
- 9
- 12
- 15
- 18
- 21

DEMAND
Operating a Utility is a Complex Task

- Electricity is NOT energy... It is a currency for energy delivery...
- Electricity is consumed the instant that it is created – and there is no storage on the network for electricity... The utility has the task of ensuring that they generate what is used – on a second by second basis..
- Large generators – in particular the newer ones, do not change load easily or quickly... Yet...
  - When someone turns on a stove, or even a light... A generator somewhere is adjusted to meet the demand...
- Fixed power rates have provided little incentive to conserve or shift times of use..
- Many utilities pay hourly rates to generators – and to other utilities - prices that may change by up to 10x daily... Making fixed sales charges risky...
- Most utilities have supplies that are “Power Constrained”... Added capacity at peak times is expensive... At off peak times it is very cheap..
Evolution...

- Growth patterns changed in the 1980-83 period...
  - Two oil shocks in the 1970-80 time frame changed people’s views on energy
  - In 1982, a deep recession almost stopped growth in electricity demand...
  - By 1985, the US had more than 25% “reserve capacity”
  - It took much of the next 2 decades to fully absorb the surplus...

- Times Changed...
  - New regulations made project approvals much more difficult..
  - Interest in conservation, GHG emissions, and efficiency increased

- The world is slowly moving towards electrification...
  - Industrial use has declined – and energy use is shifting to electricity
  - Density in residential areas in increasing
  - The introduction of electric cars may cause a huge shift in energy sources

**We are seeing a dramatic change in the supply, delivery and use of energy..**
A Flow Chart of US Energy Use...

Estimated U.S. Energy Use in 2009: ~94.6 Quads

Source: LLNL 2010. Data is based on DOE/EIA-0384(2009). August 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant “heat rate.” The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527
<table>
<thead>
<tr>
<th>Category</th>
<th>1980</th>
<th>2009</th>
<th>Chg</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric System Efficiency</td>
<td>34.1%</td>
<td>31.6%</td>
<td></td>
<td>System Efficiency is DECLINING</td>
</tr>
<tr>
<td>% Total Energy Supply – Electricity</td>
<td>18.8%</td>
<td>30.5%</td>
<td></td>
<td>Electricity provides a GROWING Share</td>
</tr>
<tr>
<td>Transportation Efficiency</td>
<td>25.3%</td>
<td>26.6%</td>
<td></td>
<td>Car efficiency is improving!!</td>
</tr>
<tr>
<td>Electricity Used (Quads)</td>
<td>7.8</td>
<td>12.08</td>
<td>+54.9%</td>
<td>Electricity use is growing at more than twice the rate of overall energy use</td>
</tr>
<tr>
<td>Transportation Fuel Used (Quads)</td>
<td>4.7</td>
<td>6.74</td>
<td>+36.1%</td>
<td>Transportation is a growing sector</td>
</tr>
<tr>
<td>Industrial Energy Use (Quads)</td>
<td>18.6</td>
<td>17.43</td>
<td>- 6.3%</td>
<td>Industrial Use is Shrinking</td>
</tr>
<tr>
<td>Total US Energy Use (Primary Demand – Quads)</td>
<td>75</td>
<td>94.6</td>
<td>+26.1%</td>
<td></td>
</tr>
<tr>
<td>Total Energy Efficiency</td>
<td>48.3%</td>
<td>42.25%</td>
<td></td>
<td>Overall Efficiency is DECLINING</td>
</tr>
</tbody>
</table>

Sources – US DOE and Lawrence Livermore Laboratories
Power System Control..

- Power Systems Operators can Control...
  - Generation
  - Transmission
  - Distribution
  - Demand Response – Limited control of loads to reduce peak loads
- Loads, for the most part are uncontrolled...
  - Most customers can turn on or off based on needs
  - Existing (Pre-AMI) metering systems do not provide customers with information needed to monitor and avoid peak periods

*Utilities control the supply of energy – but have very limited control over the demand...*
What does this all Mean?

• Volatility – System demand can be very volatile – and the supply system is specifically designed to meet the demand, including volatility
  – System loads may vary more than 50-60% between peak and off-peak daily..
  • Large generators may be incapable of following this pattern (High ramp rates)
  • Most utilities are capacity constrained...
    – Purchasing energy during peak periods may be difficult and expensive – there are few sellers...
    – Selling surplus during off-peak periods may be difficult – there are few buyers
  • A few utilities are energy constrained (typically large hydro storage – BC, Manitoba & Quebec), and they can capitalize on their ability to store and return at optimum times
  • During off-peak periods, the only generation that can be shut down may be renewable sources such as wind. (Murphy says that wind blows best at off-peak times)
    – Prices at transmission levels may vary dramatically on a daily basis
• System Capacity Additions are expensive
  – Capacity that may be needed for only a few hours each year can be costly...

Storage can play a big role to improve operation
Enter the Smart Grid!!!

- The Smart Grid is about:
  - Upgrading the Distribution Network
    - Customers - near real time data
    - Utilities
      - Better monitoring of loads and devices
      - Better distribution protection – allow remote generation (Distributed Generation & Micro grids)
      - Reduction of theft
  - Controlling demand:
    - Improved load factor
      - Losses are “parabolic” – reduced losses
      - Increased energy delivery on existing facilities
    - Real time or time of use pricing
      - Reflect the real cost of the energy used
      - Encourages use pattern to conserve and time shift
Objectives

- Improve Efficiency
- Reduce total GHG Emissions
- Increase utilization (defer capital expenses)
- Maintain or improve reliability and security

The Smart Grid is bringing an Opportunity to Optimize the Entire System... Including Generation, Delivery, and Loads...
A Few of the Technologies

- Advanced Meter Infrastructure (AMI)
  - First step in providing real time system monitoring
  - Improved utility service
  - Isolation of theft
  - Partially Implemented

- Storage... Three types...
  - Fuel storage – pre generation (water, fossil fuel etc.)
  - Grid storage
  - “Post electricity” – Process storage

- Alternative forms of Generation
  - Solar
  - Wind
  - Gas turbines
  - Distributed generation

- The use of DC to replace AC???
Storage – a Key Technology?

• We start with a description of storage...

  A device or system that either delivers or consumes a fixed amount of energy over a period of time, that has the capability to alter the pattern of use without impacting the long term energy delivered or used has capability to store energy.

• Many systems can be used to provide storage under this definition...
  – Hydroelectric storage
    • Plant with reservoir with storage (no pumps) – stores by NOT generating..
    • Pumped storage
  – Fossil fuel or nuclear powered generation with fuel storage capability
  – Batteries, flywheels and other grid based storage
  – Processes such as cold storage, water pumping, heating and cooling systems are examples of Process Storage
• **Fuel Storage**
  – Used for many years... Pre-generation (Hydro storage – Quebec, Manitoba and BC) This does NOT include pumped storage... (Stores by NOT generating)
  – *Efficiency is close to 100%*

• **Grid Storage**
  – Batteries, flywheels, pumped storage systems – convert electricity into a media that can be stored.... Then convert it back to electricity...
  – At max transfer capacity, storage efficiency (including conversion) is (80-95%), but at lower rates, efficiencies may fall as low as 50-75%.
  – Challenge - low cost natural gas and new CCGT systems* and a flat efficiency curve provides stiff competition for grid storage)

*Process Storage*
  – Uses storage inherent in some loads (stores by NOT consuming)
  – Transparent to users, marginal cost is minimal
  – *Efficiency close to 100%*

* Marginal cost of electricity from new CCGT at 60% efficiency and gas at $5/GJ can deliver energy at $30/MWh and can deliver storage capacity at a very low cost
Current Applications...

- Utilities have used “Fuel Storage” for many years...
- Great Interest in Grid Storage at present...
  - Flywheels
  - Batteries
  - Vehicle to Grid (V2G)
- Enbala Power Networks has developed and is implementing a load based system that optimizes loads to provide “process storage” for ancillary services
  - Currently used to provide Regulation Service
  - Can be extended to provide all ancillary services
  - Transparent to users
  - Accurate, fast and robust control for utilities
  - High efficiency, low marginal cost
Alternate Generation

- Renewable Sources
  - Most do not have inherent storage and are intermittent in nature
    - Firming is needed...
  - Most require conversion to electricity for use... (PV generates DC and must be converted to AC – and this reduces efficiency...)
    - Solar PV is less than 30% efficient...
    - Solar Thermal may be more than 60% efficient...
    - Opportunities to use DC at load sites, reducing conversion losses??.
- Local (Distributed) Generation can help to reduce system losses...
  - Transmission and distribution losses are quadratic in nature ($I^2R$)
    - Micro-grid that manages grid supply can minimize system loss

New Methods of Control – Optimizing Power Flow – through voltage control can be used to reduce system losses and increase potential capacity
The Smart Grid

- Provides a means of integrating control of loads into system operation...
- Can offer a path to a more efficient means of delivering energy..
- Can provide customers with opportunities to optimize their costs and operations..
Historical Look back...

- The Power System started by Thomas Edison:
  - New York City
  - DC System that provided electricity for a small number of users
- The “War of the Currents” started...
  - Edison believed in DC Power delivery
  - Westinghouse and Tesla claimed that AC was safer..

Edison lost this battle – and AC Power has been used, for the most part... for delivery...
A Few Years Later...

- In 1904, Car Sales in North America were made up of:
  - 40% Electric Powered Vehicles
  - 40% Steam Powered Vehicles
  - 20% Internal Combustion Engine (ICE) Vehicles

- The first Hybrid Car was patented in the US in 1906
- In 1908, Henry Ford introduced the “mass produced” Model T Ford

By 1910 – the ICE had captured the entire market for Automobiles...
After More than 100 Years...

- Electric and Hybrid Cars are coming back – with real power...

- Will the Smart Grid drive the grid back to DC???
  (Was Edison right???)
Thank You

Malcolm S. Metcalfe, LVO, P. Eng.
Founder & CTO
ENBALA Power Networks
www.enbala.com