RENEWABLE ENERGY INTEGRATION:
THE GRAND CHALLENGES AND
OPPORTUNITIES TOWARDS A
SUSTAINABLE ENERGY FUTURE

presentation by
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University of Illinois at Champaign-Urbana
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PRESENTATION OBJECTIVES

- Provide an overview of the challenges and opportunities raised by the large-scale integration of renewable resources
- Provide an up-to-date assessment of the status of renewable energy implementation
- Discuss key challenges and opportunities arising from current practice and research
- Suggest directions for future research to address the specific challenges and opportunities in renewable energy integration
THE CHANGING ENVIRONMENT

- There is a growing worldwide interest in the integration into the grid of renewable resources, as well as, demand response and storage resources, to displace costly and polluting fossil–fuel–fired generation.
- The integration progress pushes the creation of sustainable paths to meet each nation’s energy needs, veering it towards energy independence.
- The context within which this progress unrolls is the restructured, competitive electricity industry, taking full advantage of the advances in the Smart Grid implementation throughout the world.
The smart grid represents a modernized electricity delivery system that monitors, protects and automatically optimizes the operation of all its interconnected elements – from the central and distributed generators through the high-voltage transmission grid and the distribution network, to industrial users and building automation systems, to energy storage devices and to end-use consumers and their thermostats, electric vehicles, appliances and other devices.
THREE SALIENT ASPECTS

- Combined digital intelligence and real-time communications: to improve the operations/control of the transmission and distribution systems
- Advanced metering solutions: to replace the legacy metering infrastructure
- Deployment of appropriate technologies, devices, and services: to access and leverage consumption information in smart appliances and system state, including the integrated renewable resources
TODAY’S ENERGY CHALLENGE: GROWING DEMAND

<table>
<thead>
<tr>
<th>Region</th>
<th>Energy Demand Growth</th>
<th>Electricity Demand Growth</th>
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<tbody>
<tr>
<td>China</td>
<td>105%</td>
<td>195%</td>
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<tr>
<td>India</td>
<td>126%</td>
<td>282%</td>
</tr>
<tr>
<td>Europe &amp; North America</td>
<td>11%</td>
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<td>M. East &amp; Africa</td>
<td>73%</td>
<td>131%</td>
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<td>South America</td>
<td>56%</td>
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<td>South America</td>
<td>56%</td>
<td>81%</td>
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</tbody>
</table>

Source: IEA forecast 2007-30
TODAY’S LEGACY GRID

centralized generation

coal

hydro

nuclear

one-way power flows

substation

high voltage transmission

medium-low voltage distribution

end use customers

residential

commercial

industrial
SMART GRID INFRASTRUCTURES

the electrical infrastructure

- renewable integration
- situational awareness
- improved productivity

the information layer

- active consumers
- emission reductions
- increased efficiencies

Source: EPRI Intelligrid
THE SMART GRID WILL...

- Improve the ability to connect new loads, such as battery vehicles, and provide new products and services
- Facilitate the integration of distributed energy resources, storage devices, demand-response resources at deeper penetration levels
- Provide the ability to collect and store information to effectively address climate change issues
THE SMART GRID WILL...

- Enable customers to become *active participants* in wholesale/retail electricity markets and able to manage/control/optimize electricity usage.
- Operate *resiliently* under cyber and human-produced attacks and in case of natural disasters.
- Provide *situational awareness* for bulk power system and distribution operations.
- Anticipate and *effectively respond* to a wide range of disturbances.
THE SMART GRID WILL...

- Reduce drastically the time for service restoration after the onset of an outage
- Improve reliability of power system operations
- Optimize resource and equipment utilization and enhance efficiency of electricity production and delivery
SMART GRID VISION

- Enhance customer value
- Empower customers through knowledge
- Utilize electricity more efficiently
- Implement cost-effective technological advancements
- Reduce future demand growth
- Support “green” environmental initiatives
- Improve reliability and system security
BEYOND THE SMART GRID...
RENEWABLES’ ROLE IN THE 2014 US ELECTRICITY SUPPLY

- coal (38.7%)
- natural gas (27.4%)
- nuclear (19.5%)
- petroleum (1.0%)
- hydro (6.3%)
- other renewable sources (6.9%)

Source: http://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf; issued April 2015
RENEWABLES’ ROLE IN THE 2014 US ENERGY SUPPLY

98.5 quadrillion BTU

- petroleum 35.3%
- natural gas 28%
- coal 18.3%
- nuclear 8.5%
- renewables 9.8%

9.6 quadrillion BTU

- biomass 50%
- hydro 25%
- wind 18%
- solar PV 4.4%
- geothermal 2.3%

SOLAR ENERGY

Images From: http://www.scientificamerican.com/article.cfm?id=how-to-use-solar-energy-at-night
The global PV cumulative capacity reached 177 GW in 2014 with ability to produce 200 TWh of electricity every year.

50% of the world’s total PV cumulative capacity – 88.5 GW – is installed in Europe.

In 2014, the annual growth rate of PV has reached almost 28%, and is currently the third largest renewable energy source in terms of global, installed capacity.

2014 INSTALLED SOLAR CAPACITY

PER CAPITA INSTALLED SOLAR POWER CAPACITY ($W$)

SOLAR ENERGY DENSITY IN THE US, SPAIN AND GERMANY

2010 – 2014 GLOBAL CUMULATIVE CSP CAPACITY BY QUARTER

Source: http://www.nrel.gov/csp/solarpaces/
PV SOLAR CAPACITY PRICE DECLINE

1997 – 2014 GLOBAL WIND CAPACITY

Source: http://www.gwec.net/global-figures/graphs/
2014 INSTALLED WIND CAPACITY

- Europe 36.26%
- North America 21.14%
- Asia 38.4%
- Latin America & Caribbean 2.3%
- Africa & Middle East 0.70%
- Pacific 1.2%

Total installed capacity: 369,597 MW

2014 CUMULATIVE WIND CAPACITY: THE TOP 10 COUNTRIES

China: 114,609 MW
USA: 65,879 MW
Germany: 39,165 MW
Spain: 22,987 MW
India: 22,465 MW
France: 9,285 MW
Canada: 9,694 MW
United Kingdom: 12,440 MW
Italy: 8,663 MW
Brazil: 5,939 MW

## 2014 Wind Capacity Addition and Cumulative Total

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<thead>
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<th>added capacity</th>
<th>MW</th>
<th>cumulative capacity</th>
<th>MW</th>
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</thead>
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<tr>
<td>China</td>
<td>23,300</td>
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<td>114,760</td>
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<tr>
<td>Germany</td>
<td>5,119</td>
<td>USA</td>
<td>65,877</td>
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<tr>
<td>USA</td>
<td>4,854</td>
<td>Germany</td>
<td>39,223</td>
</tr>
<tr>
<td>Brazil</td>
<td>2,783</td>
<td>India</td>
<td>22,904</td>
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<td>India</td>
<td>2,315</td>
<td>Spain</td>
<td>22,665</td>
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<tr>
<td>UK</td>
<td>1,467</td>
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<td>1,042</td>
<td>Canada</td>
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<td>Turkey</td>
<td>804</td>
<td>France</td>
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<tr>
<td>World total</td>
<td>51,230</td>
<td>World total</td>
<td>372,112</td>
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2014 INSTALLED WIND CAPACITY IN REGIONS IN CHINA

## US–GERMANY COMPARISON

<table>
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<th>attribute</th>
<th>US</th>
<th>Germany</th>
<th>ratio</th>
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<tr>
<td>population (million)</td>
<td>321</td>
<td>82</td>
<td>3.9</td>
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<tr>
<td>area ($\text{mi}^2$)</td>
<td>3,119,884</td>
<td>137,882</td>
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<td>peak load (GW)</td>
<td>777</td>
<td>80</td>
<td>9.7</td>
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<tr>
<td>annual energy (billion kWh)</td>
<td>3,963</td>
<td>544</td>
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<tr>
<td>installed wind capacity (MW)</td>
<td>65,877</td>
<td>39,223</td>
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Wind Resources and Transmission Lines

The remaining states use data from the 1987 "Wind Energy Atlas of the United States".

Source: http://www.nrel.gov/wind/systemsintegration/images/home_usmap.jpg
2014 Q4 WIND ENERGY STATUS

Source: AWEA, Fourth Quarter 2014 Market Report, p. 5
The US installed over 4,854 MW of wind power capacity in 2014.

The total installed wind power capacity in the US has approached 66,000 MW by the end of 2014.

Wind power represented 24% of US electric-generating capacity additions in 2014.

RENEWABLE PORTFOLIO STANDARD (RPS) STATUS IN 2015

Source: www.dsireusa.org, June 2015

29 states + Washington DC + 3 territories have a RPS (8 states and 1 territory have renewable portfolio goals)
DOE FUNDING TARGETS FOR ARRA PROJECTS

- **energy efficiency/renewable energy (incl. transportation)**: $16.8 billion
- **Smart Grid**: $4.5 billion
- **loan guarantees**: $6.0 billion
- **WAPA/BPA**: $6.6 billion
- **other**: $8.1 billion
- **climate R&D**: $3.4 billion

Total: $45 billion
ARRA SMART GRID FUNDING

Smart Grid investment grants

$3.4 billion

Smart Grid demonstration projects

0.615

other

0.485
2008 GREEN PORTIONS OF STIMULUS

% of GDP

Source: Center for American Progress analysis of HSBC research
## GRAND CHALLENGES/OPPORTUNITIES

<table>
<thead>
<tr>
<th>challenges/opportunities</th>
<th>operations</th>
<th>planning</th>
<th>market design</th>
<th>policy</th>
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</table>
SALIENT CHARACTERISTICS OF SOLAR AND WIND POWER

- Highly **time-dependent** nature of solar and wind power:
  - **uncertain** variability characteristics
  - **intermittency** effects

- Solar power is dependent upon both solar irradiation and air temperature

- Unlike conventional generation sources that have the ability to store the primary energy prior to conversion into electricity, wind and solar energy resources are **unable to store their primary energy**
SALIENT CHARACTERISTICS OF WIND AND SOLAR POWER

- Both solar radiation and temperature levels and wind speeds are subject to a broad range of sources of uncertainty of both an atmospheric and a geographic nature.

- Such uncertainty is, typically, very difficult to analytically characterize; it also exhibits highly seasonal dependence.
PV OUTPUT AND LOAD

Sources: ERCOT and NREL
POWER OUTPUT AT THE NEVADA 70 kW POLYCRYSTALLINE ARRAY

Data collected on a 10-second basis
CAISO DAILY WIND POWER PATTERNS IN MARCH 2005

MW

Source: CAISO
ONTARIO DAILY WIND POWER OUTPUT

MW

0 100 200 300 400 500 600 700

hour

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Wind power production has limited controllability and dispatchability, thereby imposing additional burden on conventional controllable resources.

The predictability of wind speed is rather problematic and has limited accuracy; consequently, so is the predictability of wind power outputs.
## GRAND CHALLENGES/OPPORTUNITIES

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</table>
 ERCOT FEBRUARY 26, 2008
RELIABILITY EVENT CONTRIBUTORS

- A faster than expected evening load up-ramp
- A large down-ramp of wind generation which started at 15:00
- The unexpected loss of conventional generation

FORECASTING NEEDS

- More accurate forecasts are needed over shorter and longer-term forecasting periods explicitly taking into account the meteorological sources of uncertainty.
- Forecasting accuracy decreases as the look-ahead time increases.
- Tools to forecast ramps and renewable energy generator output over various time intervals are critical to ensure the reliable and economic integration of renewable energy.
## GRAND CHALLENGES/OPPORTUNITIES

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10-MINUTE WIND SPEED/OUTPUT DATA FOR 1/2/2006 AT LUBBOCK, TX

CHALLENGE: DYNAMIC SIMULATION TOOLS

- Renewable energy sources may experience wide and sudden changes during their operations.
- System planners and operators need appropriate tools to gain better understanding of, and ability to deal with, the intermittency and variability impacts on the dynamic performance of power systems over time periods as long as 15 minutes.
These needs encompass the development of models appropriate for the representation of the dynamic behavior of renewable resources and their interactions with conventional units and control elements and their incorporation into existing dynamic simulation tools.

Numerical tractability is a key consideration in view of the longer period of simulation.
DYNAMIC SIMULATION TIME SCALES

- Electromagnetic transients
- Induction motor dynamics
- Generator/excitation dynamics
- Prime mover control
- Mechanically switched capacitors/reactors
- SVC
- Generator inertial dynamics
- DC
- First swing transient stability
- Protective relaying

Adapted from: C. Taylor, Voltage Stability Analysis
DYNAMIC SIMULATION TIME SCALES

Adapted from: C. Taylor, Voltage Stability Analysis
MODELING NEEDS FOR VER DYNAMIC STUDIES

- Under-load tap changers
- Switchable shunts
- Reactive power compensation devices
- Load dynamics, including induction motors
- Peaking units
- Utility–scale energy storage units
- Protection/control system coordination
<table>
<thead>
<tr>
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</table>
**VER INTEGRATION CHALLENGES**

- The deepening penetration of variable energy resources (**VERs**), such as wind and solar resources, reduces the need for energy from controllable resources.

- However, the highly variable and uncertain **VER** power outputs, which may be misaligned with the load, result in **steeper ramping requirements** in the net load – the difference between the system load and the total **VER** generation output.
The integration of deepening penetration of VERs results in large ramp magnitude, steep ramp rate and long continuous ramp duration requirements in the net load, which are considerably more marked than those in the system load itself.

In addition, deepening VER penetration exacerbates the number of up and down ramping events.
DEEPER WIND PENETRATION STRONGLY IMPACTS THE NET LOAD

CAISO DAILY NET LOAD CURVE UNDER DEEPER PENETRATION

net load (MW)

net load = load - wind - solar

VER INTEGRATION CHALLENGES

- The steeper ramping events occur at various time scales from *seconds* to *hours*.

- The rapid *net load* changes that occur on a time scale from *seconds* to *minutes* markedly increase the requirements for *load following*, *regulation* and *reserves services*, which are generally provided by the controllable resources and rely heavily on the units with large *ramping capabilities*. 
CAPACITY–BASED ANCILLARY SERVICES

- Regulation
- Load following; spinning reserves
- Supplemental/non-spinning reserves

Response time in minutes:
- 0
- 10
- 30
- 120

The diagram illustrates different ancillary services with their respective response times.
At deeper VER penetrations, while the power grid is less dependent on the controllable resources for energy production, operators must rely more intensely on the controllable resources to manage the steeper ramping requirements in the net load, due principally to the VER output variability and intermittency.

The controllable resources must have adequate ramping capability to compensate the rapid changes in VER outputs so that supply–demand balance is kept around the clock.
To be more specific, the controllable resources must have:

- steep ramping rates;
- longer ramping durations;
- rapid direction change ability in both the up and the down directions;
- ability to respond rapidly to a steep increase or decrease in the output level request; and
- ability to perform start-ups and shutdowns multiple times per day.

REQUIREMENTS ON THE CONTROLLABLE RESOURCES
CRITICALITY OF RAMPING

- In the absence of accurate forecasts for VER output, operators mitigate the uncertainty of a sudden rise/drop in VER outputs by requiring the committed controllable units, including storage, to maintain adequate ramping up/down capabilities.

- The incorporation of such ramping requirements into the resource dispatch results in newly added constraints and incurs additional expenses.
OPPORTUNITY COSTS

- Conventional generators incur *opportunity costs* in the provision of *ramp capability services*.

- Rather than generate at as high a capacity as each conventional unit can clear for an entire hour to sell its energy at the market clearing price, a seller may need to reserve a portion of the capacity to be used for *ramping capability service provision*.

- The foregone profits from the energy not sold are the *opportunity costs* of a conventional unit.
In addition to the *opportunity costs*, the extensive cycling of the generation units that provide ramp capability service causes considerable wear and tear, whose impacts may include additional emissions and increased maintenance costs.
CYCLING EFFECTS

base-loaded operation

cycling operation

age in years

cycling begins

equivalent forced outage rate (%)

cycling related generation loss

reduced plant life

Adapted from: Intertek APTECH, “Power Plant Asset Management”
$CO_2$ EMISSION INCREASES FOR NON-FULLY LOADED OPERATIONS (%)

<table>
<thead>
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<th>technology</th>
<th>startup</th>
<th>partial loading</th>
<th>ramping</th>
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<td>coal</td>
<td>110</td>
<td>5.1</td>
<td>0.4</td>
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<tr>
<td>gas CC</td>
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<td>15.6</td>
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<tr>
<td>gas CT</td>
<td>32</td>
<td>14.4</td>
<td>0.3</td>
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</table>

Source: NREL, “Emission Impact of Fossil Fuel Unit Cycling”
CYCLING EFFECTS AND RESEARCH NEEDS

increased duty cycle

- maintenance
- capital spending
- power costs due to forced outages
- startup fuel
- labor
- heat rate

- cost quantification?
- cost allocation policy?
- availability impact assessment?
- emission impact evaluation?
The quantification of the additional controllable unit costs, maintenance expenses, reduced lifetime and emission increases that result from renewable energy–induced ramping requirements is a key need.

The development of cost allocation mechanisms for the additional controllable unit costs needs to be addressed.
The market for ramp capability design needs to:
- incentivize investment in flexible resources including storage through payments for the capacity provided;
- incentivize provision of ramping capability services in the operations; and
- incorporate transparency in the compensation of the conventional generation units to ensure reimbursement of opportunity costs for the ramping capability service provision.
<table>
<thead>
<tr>
<th>scheduling function</th>
<th>typical objective</th>
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<td>levelize reserves</td>
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<td>minimize production costs including system losses</td>
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There is a need for the development of resource scheduling tools that explicitly represent the uncertain renewable resource outputs.

In addition, there is a need for new market design, such as sub-hourly markets, which explicitly consider the VER uncertain and intermittent nature.
PV POWER OUTPUT OF 1-MW CdTe ARRAY IN GERMANY

samples collected on a 5-minute basis
SURPLUS BASE-LOADED GENERATION

Source: IESO
STOCHASTIC SCHEDULING TOOLS

- The additional sources of uncertainty associated with renewable resources necessitate the deployment of stochastic methods for unit commitment scheduling.

- Such methods need to take into account the sources of uncertainty in resource variability/intermittency, correlation with load variability and correlation among the renewable resources.
The development of stochastic and/or robust optimization methods for the solution of unit commitment problems for large-scale systems is a high priority.

Key considerations are the issue of computational tractability and the investigation of the applicability of parallel computing.
Storage and demand response resources (DRRs) provide the system operator additional flexibility in reliably and economically managing the supply–demand balance.

Storage and DRRs may also provide system services such as regulation, load following and reserves.
LACK OF STORAGE CAPACITY

- The lack of utility-scale storage in today’s power system drives
  - electricity production to be the prototypical *just-in-time* manufacturing system; and
  - electricity to be a highly *perishable* commodity
- Storage capacity is primarily in the pumped storage plants; there are only two *operational CAES* units in the world
- Pace of energy storage development has been very slow in the past
STORAGE TECHNOLOGIES

![Diagram showing different storage technologies and their discharge time (h) vs rated power (MW)]
STORAGE POLICY ISSUES

- The regulatory treatment of storage units is an open question and needs to be addressed by policy analysts and regulators.
- The regulatory framework will guide the operation and control of storage issues and set the stage to ensure storage resource profitability.
- The treatment of short-term storage may differ from that of longer-term energy arbitrage-based storage.
DRRs

- **DRRs** are demand–side entities which actively participate in the markets as both buyers of electricity and sellers of load curtailment services.

- **DRRs** effectively reduce the load during peak hours and/or shift the demand, in part or in whole, from peak hours to low–load hours.
DEMAND RESPONSE RESOURCES (DRRs)

passive loads

DRRs

resources

market clearing

transmission scheduling
MARKET WITH DRRs

Suppose a demand-side bid gets accepted to curtail $\Delta \ell$ MW.

- Shift in demand curve
- New market clearing price $\rho'$
- Supply-side payments
- Demand to be met $= (\ell - \Delta \ell)$
SYMBIOSIS OF RENEWABLE RESOURCES WITH STORAGE/DRRs

- The flexibility of storage and DRRs may be deployed to take advantage of the renewable output whenever available.

- When effectively deployed, storage and DRRs reduce the operational costs and emissions, arising from increased unit cycling, by displacing controllable units.
CYCLING UNITS WITHOUT DRR

Source: ISO-NE
CYCLING UNITS WITH DRR

Source: ISO-NE
## GRAND CHALLENGES/OPPORTUNITIES

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The most effective approach to determine the economic, reliability and environmental impacts of the integration of renewable resources over longer–term periods is probabilistic simulation.

The appropriate representation of resources such as wind, solar, demand response and storage, in the simulation of the power system over longer–term periods requires the explicit consideration of the:
QUANTIFICATION OF INTEGRATION IMPACTS

○ interactions of the existing resource mix and the transmission grid with the integrated units
○ the sources of uncertainty associated with the integration of the time–dependent resources, together with those typically represented in conventional probabilistic simulation
○ the time–dependent transmission–constrained market outcomes

☐ There is a need for a computationally tractable simulation schemes
TYPICAL APPLICATIONS

- Resource planning studies
- Production costing issues
- Transmission utilization issues
- Environmental assessments
- Reliability analysis
- Investment analysis
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PHASOR MEASUREMENT UNITS (PMUs)

- GPS–based monitoring devices sample voltages and currents 30–60 times per second and serve as data acquisition tools.
- PMUs require analytics to provide the capability to store, manage, retrieve, and protect the huge sets of data collected and information generated.
- In addition, PMUs require new tools for the reliable and economic operation of the electrical grid, as well as applications software for visualization and analysis.
PHASOR MEASUREMENT UNITS IN NORTH AMERICAN POWER GRID

Source: NASPI, PMU status, updated March 9, 2015: https://www.naspi.org/sitesearch#searchResultSection
PMU vs. SCADA DATA: APRIL 5, 2011 EVENT

PMU vs. SCADA DATA:
FEBRUARY 7, 2010 EVENT

Event occurred at 8:16:41 PM. 4 second SCADA data showed a small change.

PMU data showed a much larger frequency swing associated with the event where frequency oscillations lasted several seconds.

Source: NERC, Report on Real-Time Applications of Synchrophasors for Improving Reliability, October 17, 2010
SYNCHROPHASOR MEASUREMENT APPLICATIONS

- The PMU installations are opening up a broad range of useful applications in real-time operations, control and analysis, as well as planning.
- The PMU measurements provide a rich trove of data and create huge challenges in data storage, processing, security and management/utilization.
- The advances in addressing these challenges will facilitate the smoother integration of renewables.
PMUs are simply one source of data collection, but throughout the power system there are myriad sensors that collect massive volumes of data and create huge data silos in various formats.

The performance of analytics on such huge data sets may be impossible on a central processor; distributed processing on parallelized multi-processors may be an effective alternative.

As various sources continually generate data in real time, analytics may frequently be carried out heuristically and without an opportunity to revisit past entries of generated data.
BIG DATA ANALYTICS CHALLENGES

- In light of their disparate nature and measurement, massive datasets are often incomplete, prone to outliers, noisy and vulnerable to cyber-attacks.
- Techniques are needed to solve vast data storage, analysis, management and distribution issues, as well as the schemes to handle the practical issues: mega data analytics.
- The collected data and generated information can be used, when integrated with domain expertise, to address identified gaps in today’s planning, operations and analysis tools.
CHALLENGES IN PMU APPLICATIONS

- Power system operations
  - VER integration
  - Islanding schemes
  - Missing data replacement
  - Remedial action schemes
  - Special protection schemes
  - Power oscillation detection
  - Power system restoration
  - Protection and control schemes for distributed generation resources
CHALLENGES IN PMU APPLICATIONS

- Real-time system operations
- Situational awareness
- Visualization
- Transient stability
- Voltage stability
- Operation margin monitoring
- Frequency stability monitoring
- Static estimation and PMU data
- Dynamic line ratings
- Congestion management
- Wide-area monitoring
CHALLENGES IN *PMU* APPLICATIONS

- Power system planning applications include
  - event analysis
  - static model validation
  - dynamic model validation
  - new metric formulation
  - new tool development
  - inter-area oscillation damping control
  - disturbance classifier
### GRAND CHALLENGES/OPPORTUNITIES

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**Quantification/Tools**

- forecasting
- dynamic simulation
- controllable resource impacts
- economic/reliability impacts
- environmental impacts
- data analytics
- cyber security
- transmission expansion
Cyber security is essential in the development of the *Smart Grid* to protect customer information and the physical grid from cyber vulnerability.

There is a critical need to understand the potential grid vulnerabilities and the impacts of cyber attacks on the grid.

There is also a need to develop infrastructure and policies which shield the grid from, and reduce the impacts of, cyber attacks.
An analysis by *USA Today* of the reports submitted by federal officials and contractors since late 2010 to the Department of Energy's *Joint Cybersecurity Coordination Center* shows a stream of attempts to breach the security of critical information systems that contain sensitive data about the nation's power grid, nuclear weapons stockpile and energy labs.

These reports indicate DoE components reported a total of 1,131 cyber attacks over a 4-year period ending in October 2014, with 159 of them successful.

The US Congress Committee on Science, Space and Technology noted “As the electric grid continues to be modernized and become more interconnected, the threat of a potential cybersecurity breach significantly increases.”
CYBER SECURITY CONCERNS

- Cyber security is a top priority for the electricity industry, given the need for compliance with NERC standards and the utility obligation to serve.
- There is a serious need for a “seal of approval” to ensure compliance with cyber security standards.
- Effective coordination of stakeholders – NERC, NIST, FERC, states and industry – can address cyber security vulnerabilities and threats by judiciously harnessing the smart grid capabilities.
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"ANTIQUATED" TRANSMISSION SYSTEM

- The existing power grids in the US incorporate, by and large, technology developed before the 1950s
- About 70% of all transmission lines and power transformers are 25 years old or older, and 60% of all circuit breakers are more than 30 years old
- The small number of new transmission projects implies that the many technology advancements and the smart grid implementation have not been deployed by the legacy grid
CHARACTERISTICS OF TODAY’S GRID

- The grid was planned and built by utilities to connect the distant generation sources to the load centers so as to meet their native customers’ demands reliably and cost effectively.

- As the grid was designed for different purposes, its adequacy for its new role in the market environment requires its expansion and modernization.
“COMMON CARRIER” TRANSMISSION

transmission system

self generation

utility generation

broker / marketer

EWG

QF

IPP

other utility

broker / marketer
TRANSMISSION IN THE COMPETITIVE ENVIRONMENT

- Congestion situations result whenever the demand for transmission services exceeds the capability the grid has to provide; such situations occur frequently in electricity markets.

- Despite the more intense utilization of the grid by the many established and new players, developments in transmission expansion have failed to keep pace with the increasing demand.
CONGESTION RENTS

PJM
MISO

million $

2,500
2,000
1,500
1,000
500
0

2006 2007 2008 2009 2010

milliion $
TRANSMISSION EXPANSION: KEY DRIVERS

- Environmental concerns
- Deepening penetration of renewables
- Transmission expansion
- Smart grid technologies
- Congestion
- Reliability
U.S. POPULATION DENSITY AND RENEWABLE RESOURCE LOCATIONS

Source: http://www.census.gov/popest/data/maps/2009/PopDensity_09.jpg
total wind in queue at the end of 2014

wind represents about 30% of all electricity capacity within these queues in 2014

solar capacity that entered queue in 2014

TRANSMISSION EXPANSION: THE AWEA VISION

- Large-scale integration of renewable energy will require substantial transmission expansion.
- Cost allocation mechanisms are needed to incentivize transmission expansion.
- There is a need to develop appropriate planning tools, which take explicit account of renewable energy uncertainty.
POLICY CHALLENGES

- Policy considerations are important for all aspects of grid planning and operations.
- Sound technical knowledge is needed to formulate good policy and provides the basis for creating the blueprint for policy making.
- Policy directives are explicitly considered in the analysis.
EMERGING AND STANDING RELIABILITY ISSUES, 1-5 TO 6-10 YEARS

- Energy storage
- Cybersecurity
- Variable generation
- Transfer capability
- Workforce issues
- Reactive power
- GHG legislation
- Smart grid & AMI

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The growing worldwide interest in renewable resource integration presents rich opportunities and challenges for system operators, planners and researchers. The effective solutions to address these challenges/opportunities will bring about sustainable paths to meet the world’s future energy needs.