Bridging Gap between Modern Grid Design, Operations and Software

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Disclaimer: Highly personal take at the state of the field;
Acknowledgment to EESG Ilic group http://www.eesg.ece.cmu.edu/
The big picture

- (Electric) energy systems—the industry in evolution
- Driven by technology, changing societal goals and industry restructuring (“wicked”, ill-conditioned complex problems)
- Smart grids design, operations and software--the case of IT enabling sustainable industry evolution?
- Motivating example – Azores Islands (Flores and Sao Miguel)
- The main challenge/idea – from constraining to enabling in a multi-stakeholders environment
- A possible unifying approach?--next generation SCADA with well-defined protocols (Dynamic Monitoring and Decision Systems (DyMonDS))
- Key relevance of simulation-based scalable test beds. Smart Grid in a Room Simulator (SGRS) – NIST collaboration with CMU/EESG approach to moving forward [http://www.eesg.ece.cmu.edu/](http://www.eesg.ece.cmu.edu/)
The system works today, but...

- Increased frequency and duration of service interruption (effects measured in billions)
- Major hidden inefficiencies in today’s system (estimated 25% economic inefficiency by FERC)
- Deploying high penetration renewable resources is not sustainable if the system is operated and planned as in the past (``For each 1MW of renewable power one would need .9MW of flexible storage in systems with high wind penetration” –clearly not sustainable)
- Long-term resource mix must serve long-term demand needs well
Contextual complexity facing design and operations
Broader role of information technology (IT) in transforming ill-conditioned into well-structured design problems [3]

• Observations relevant for smart grid R&D agenda
  --Real gap between the needs and innovation methods
  --Particularly striking lack of viewing the problem as system design problem with many stakeholders and with an eye on potential for software-enabled novel architectures (new SCADA)
  --The main challenge: Making the case for systems R&D&D
  --Our belief: The main opportunity to modernize by all stakeholders (including utilities—major role); next generation SCADA as the main enabler (utility role)
Broad role of smart grids--Making the most out of the naturally available resources given socio environment?

Fig. 1. The core subsystems in a framework for analyzing social-ecological systems.

Ostrom, 2000 [3]
“Smart Grid” ↔ electric power grid and IT for enabling sustainable energy SES

**Energy SES**
- Resource system (RS)
- Generation (RUs)
- Electric Energy Users (Us)

**Man-made Grid**
- Physical network connecting energy generation and consumers
- Needed to implement interactions

**Man-made ICT**
- Sensors
- Communications
- Operations
- Decisions and control
- Protection

References: [7], [8], [17]
Integrating combination of technologies at value?

• Value is a system-dependent concept (time over which decision is made; spatial; contextual)
• Cannot apply capacity-based thinking; cannot apply short-run marginal cost thinking
• Reconciling economies of scope and economies of scale
• Value of flexibility (JIT, JIP, JIC)
• Hardware, information, decision-making software; distributed, coordinated – all have their place and value
Low hanging fruits and longer term goals

• Higher utilization of available physical capacity by embedding IT into various system components, multi-directional information exchange and IT-enabled decision making by all

• Minimal coordination could go a very long way to ensuring sustainable services (potential for avoiding blackouts)
Minimal IT coordination could have avoided 2003 blackout...[5]
Value of real-time data driven automation (PMUs, WAMS)?

- Constrained Line
- Line-to-Ground Clearance
- Transfer Capacity in Real Time
Motivating example—Azores Island, Flores

Figure 1: Satellite image of Flores Island.

Figure 2: Electrical Network of Flores Island.

Ilic et al, 2013 [7,8]
Motivating example---From old to new paradigm—Flores Island Power System, Portugal
Controllable components—today’s operations
(very little dynamic control, sensing)

H – Hydro
D – Diesel
W – Wind

*Sketch by Milos Cvetkovic
Information exchange in the case of Flores---new
(lots of dynamic control and sensing)
Opportunities/incentives for value-based innovation by all?

• Proof-of-concept-low-cost clean Azores islands
• Enable integration/use of clean energy (wind, PVs) at value
• Different stakeholders bring different value
• Utilities are key to designing enabling delivery at value
  - new software/SCADA to gather binding info about who needs what and willingness to pay/be paid; minimal secure info to enable exchange to invest/operate at well-defined value; minimal coordination to optimize system performance and ensure reliability given info from grid users
  - possible to give incentives for voltage optimization of T&D equipment; reconfiguration; deployment of remote switching/control/monitoring;
  -
The need for qualitatively new paradigm

- The old ways of looking at problems no longer work.
- To understand the wicked problems requires much more sophisticated perspectives that include what previously was ignored.
- Without this understanding there will be no sustainable innovation.
- Individual actors concerned with their own objectives sub-optimize.
- Evolution of the system is/should be of interest.
- Potential for system evolution from rigid hierarchically controlled entity (dominated by (N-1) preventive approach) to a more dynamic real-time optimized and information-driven entity of greater long-term robustness and efficiency.
The main challenge/idea – from constraining to enabling in a multi-stakeholders environment

<table>
<thead>
<tr>
<th>Single optimization subject to constraints</th>
<th>Enabling (reconciling) tradeoffs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule supply to meet given demand</td>
<td>Schedule supply to meet demand (both supply and demand have costs assigned)</td>
</tr>
<tr>
<td>Provide electricity at a predefined tariff</td>
<td>Provide electricity at QoS determined by the customers willingness to pay</td>
</tr>
<tr>
<td>Produce energy subject to a predefined CO₂ constraint</td>
<td>Produce amount of energy determined by the willingness to pay for CO₂ effects</td>
</tr>
<tr>
<td>Schedule supply and demand subject to transmission congestion</td>
<td>Schedule supply, demand and transmission capacity (supply, demand and transmission costs assigned)</td>
</tr>
<tr>
<td>Build storage to balance supply and demand</td>
<td>Build storage according to customers willingness to pay for being connected to a stable grid</td>
</tr>
<tr>
<td>Build specific type of primary energy source to meet long-term customer needs</td>
<td>Build specific type of energy source for well-defined long-term customer needs, including their willingness to pay for long-term service, and its attributes</td>
</tr>
<tr>
<td>Build new transmission lines for forecast demand</td>
<td>Build new transmission lines to serve customers according to their ex ante (longer-term) contracts for service</td>
</tr>
</tbody>
</table>
A possible unifying approach?--next generation SCADA with well-defined protocols
Diverse users

A) Grandma’s House: Smart Metering, Automation for Appliances

B) Sunny Place 1: Solar Panel

C) Sunny Place 2: Solar Panel, Backup Power, Storage

D) Cold Place: Backup Power, Micro CHP

E) Green Factory: Automation, Proximity to Wind Farm
System paradigm change

From
- Preventive
- Static
- Excess capacity
- Centralized forecasts

To
- Corrective
- Information based
- Interactive buffering
- Dynamic reoptimizing

IT enabled

Figure 7.7  System paradigm change in the electricity sector
Dynamic Monitoring and Decision Systems (DyMonDS)

• From single top-down coordinating management to the multi-directional multi-layered interactive IT exchange. [7,8,17]

• At CMU we call new transformed SCADA Dynamic Monitoring and Decision Systems (DYMONDS) and have formed a Center to work with industry and government on: (1) new models to define what is the type and rate of key IT exchange; (2) new decision tools for self-commitment and clearing such commitments. \http:www.eesg.ece.cmu.edu.
T&D as an Enabler

- New dispatch of self-committed resources together with on-line power factor/voltage compensation will make it possible to fit different pieces of the puzzle together. [7,8,17]

- Much more reliance on distributed sensing, actuation and coordinated management of these resources. Real time awareness of D flows.

- No models, no simulations, no decision tools. Without these, it will be much more costly to proceed. R&D ahead of us.
DYMONDS-enabled Physical Grid

- Hydro Gen. and Pumped Storage
- Central Mesh Network
- Generators
- Large Scale Wind Farm
- Control center
- Transmission lines
- Substation
- Battery Storage
- DYM
- Medium Size D.G.
- Industrial Load
- Substation
- Residential Load
- Residential Load
- PHEV Fleet

A) Grandma's House of the future
B) House in warm location
C) House in warm location with extreme grid conditions
D) House in cold location
E) Green factory with wind farm
Smart users

A) Grandma's House: Smart Metering, Automation for Appliances
B) Sunny Place 1: Solar Panel
C) Sunny Place 2: Solar Panel, Backup Power, Storage
D) Cold Place: Backup Power, Micro CHP
E) Green Factory: Automation, Proximity to Wind Farm
Examples of iBAs—new ways of ensuring both reliable and efficient operations
Possible to create iBAs for meeting transient stability distributed standard

\[ P_{eq} = \text{const} \]

Given disturbance
Tripping of generator 1

<table>
<thead>
<tr>
<th>CONTINGENCY (CATEGORY B)</th>
<th>DURATION (secs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tripping of generator 1 after 3-phase fault on its terminal bus</td>
<td>0.17</td>
</tr>
</tbody>
</table>

S.Baros, M.Ilic  intelligent Balancing Authorities (iBAs) for Transient Stabilization of Large Power Systems  IEEE PES General Meeting 2014
Must simplify!

• Utilities are having hard time adding all these new components and their smarts for simulating system-wide dynamics

• Is there a "smarter" way to model and define modular functionalities so that the interconnected system meets system-level performance? (university R&D role)

• Simulators to assess/demonstrate potential benefits from innovation before building

• Do not oversimplify!
Key relevance of simulation-based scalable test beds (Flores Island case) [18]

- Based on prices, market computes active power set points $P^*$ from each component
Flores Island – Essential to exchange the right binding info

• Since currently the market does not specify reactive power set points $Q^*$, data for $Q^*$ is randomly created
• Place a voltage source inverter and the variable speed drive on the hydro and diesel generator buses
• Control the sum of the power out of the hydro and diesel generators to match the active and reactive power set points
Simulation Results – Combining Dynamics and ALM

Stable Case:

Unstable Case:

Wind Generator Bus Voltages

Reactive Power Load Consumption
Transient Stabilization of Interactions Using PMUs/FACTS [13]

Implications for SGRS distributed integration of differential equations

Interactions are captured using an energy-based model
- Accumulated energy as a measure of stability
- Managing energy to ensure stability

Cooperative power electronics (FACTS) control
- Fast thyristor switching
- Flow control

Large scale interconnected power system

Transient stability problem
- Nonlinear dynamics
- Multiple time scales
- Large regions

Stable

Unstable
Response of Uncontrolled System

Short circuit at bus 3 in duration of 0.35 sec

Controlled System Response

\[ P_{\tau_3} = \frac{1}{\tau_3} \int_{\tau_2} P_{\tau_2} \, dt \]

FACTS energy has reached zero

\[ z_2 = 0 \]

States converge to a different equilibrium

Maximizing Reliable Service by Coordinated Islanding and Load Management
CMU Smart Grid in a Room Simulator (SGRS)
Integration of Smart Consumers (DER) [14,18]

- What will the price be tomorrow at 2pm?
- What is the maximum power I can draw without penalty?
- I have spare power to share. Can you store my excess power?
- I need to draw down your battery at 3:30pm. What is your anticipated demand tomorrow?

From NIST Framework Document, SP1108
Concluding thoughts—hidden value of “smarts”—

Enablers of....

• Significantly reduced spinning reserves (value of PMUs, closing the loop with FACTS; automation of storage control)

• Significant improvements in total fuel cost/customers bills while meeting (differentiated) service specifications (value of smart AC OPF software; good state estimator; smart switches)

• Customer choice/grid users choice or service

• Reduced service cost for given service specs

• Warning: It wont work without systematic physics-based modeling/software; new SCADA specifications.
References


[18] 10th CMU Electricity Conference, Pre-conference Workshop https://www.ece.cmu.edu/~electricconf/