Challenges in Clean Energy and Opportunities for Mathematicians

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Outline:

• Technological and social drivers in the clean energy
• Smart Grid (moving from central to distributed energy systems),
• Decision making-Algorithm to improve efficiency,
• Improve Quality of Service,
• Safety concerns for equipment and system level,
• A non-intrusive condition monitoring,
Conventional Energy Systems:

Energy Sources

Electro-mechanical Devices (Generators)

Transmission Line

Load (Converts Electricity into different forms of work)
Future Electric Energy Systems:

Energy Sources

Electro-mechanical Devices (Generators)

Transmission Network

Load (Converts Electricity into different forms of work)

PHEVs

Demand Response

Photo-voltaic Device

Electro-mechanical Device

Energy Sources
Technological and social drives in energy systems:

- Multiple objective (reliable, efficiency and environmental)
- Non-homogenous and non-utility-owned resources
- Renewable resources and demand response
- Technology drivers: Cost-effective ICT, GPS synchronized wide-area measurement systems (WAMS).
- Emergence of electricity market,
- Technologies for plug-&#38;-play deployment
Clean Energy drives and concerns:

- Increasing presence of renewable energy resources which are **environmentally attractive** 😊 with **fast rate of response** 😊 but **Intermittent** 😞.

- 3 major questions for reliability and efficiency:
  1. **Better Prediction** of Intermittent Resources
  2. **More efficient utilization** of intermittent resources
  3. **More reliable operation** of intermittent resources
Moving from Central to Distributed Socio-Ecological Systems [1]:
The changing role of decision making:

<table>
<thead>
<tr>
<th>Today’s Power Grid</th>
<th>“Smart Grid”</th>
</tr>
</thead>
<tbody>
<tr>
<td>(centralized objective subject to many constraints (externalities))</td>
<td>(multi-layered interactive coordination of objectives)</td>
</tr>
<tr>
<td>Deliver supply to meet given demand</td>
<td>Deliver power to support supply and demand schedules in which both supply and demand have costs assigned</td>
</tr>
<tr>
<td>Deliver power assuming a predefined tariff</td>
<td>Deliver electricity at QoS determined by the customers willingness to pay</td>
</tr>
<tr>
<td>Deliver power subject to predefined CO₂ constraint</td>
<td>Deliver power defined by users' willingness to pay for CO₂</td>
</tr>
<tr>
<td>Deliver supply and demand subject to transmission congestion</td>
<td>Schedule supply, demand and transmission capacity (supply, demand and transmission costs assigned); transmission at value</td>
</tr>
<tr>
<td>Use storage to balance fast varying 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 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>
“Smart Grid” ↔ electric power grid
Measurement and Modelling:

What is the minimum number of measurement and a sufficient (accurate but not complex) model?
Interaction Variable:

- A means of going from very coarse to granular model and back.
- framework for relating **engineering design, financial & environmental objectives**.
Decision-Making Algorithm: Efficient Utilization
Economic Dispatching (ED):

Given a mixture of energy resources, how to determine the output of individual energy resources so that:
(1) power supply always balances demand (2) total generation cost is minimized.

Economic Dispatch (ED): Choose output levels from conventional power plants to meet the “net load” at minimum cost [2].
Model Predictive Control (MPC)[2]:

At each step, a finite-horizon optimal control problem is solved but only one step is implemented.

Markove Model to predict wind, ad demand).
Numerical Example (New):

<table>
<thead>
<tr>
<th>Gen ID</th>
<th>Type</th>
<th>Capacity</th>
<th>Marginal Cost</th>
<th>Ramp Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Natural Gas</td>
<td>5000MW</td>
<td>1000$/MWh</td>
<td>100MW/5 min</td>
</tr>
<tr>
<td>2</td>
<td>Coal</td>
<td>9000MW</td>
<td>500$/MWh</td>
<td>1000MW/hour</td>
</tr>
<tr>
<td>3</td>
<td>Wind</td>
<td>3500MW</td>
<td>0$/MWh</td>
<td>150MW/5 min</td>
</tr>
<tr>
<td>4</td>
<td>Photovoltaic</td>
<td>1500MW</td>
<td>0$/MWh</td>
<td>100MW/5 min</td>
</tr>
<tr>
<td>5</td>
<td>Coal</td>
<td>8000MW</td>
<td>300$/MWh</td>
<td>800MW/hour</td>
</tr>
</tbody>
</table>

Conventional cost over 1 year * | Proposed cost over the year | Difference | Relative Saving |
$129.74 Million | $119.62 Million | $10.12 Million | 7.8% |

Numerical Example (New) [3,4]:

Elastic demand that respond to time-varying price.
Optimal Control of Plug-in – Electric Vehicles: Fast v.s. Smart Charging (Rotering, 2009)
Decision-Making Algorithm:
Improve the Quality of Service (QoS)
Example: Flatness Systems for Automated Control Generation (AGC)

**AGC** is a system for adjusting the power output of multiple generators in response to changes in the load.

A system is **differential flat** if we can define the system *inputs* and *states* based on a so-called “flat” output and a finite number of its *differentiations*. (A tool to transform a nonlinear system to linear control problem).
Reliable Operation (Safety & Protection)
Harmonic Resonance & Su-Synchronous Harmonics

Peculiar safety challenges at the system level:

- **Harmonic resonance problem** (transformer destroyed by the resonance of specific harmonic);
- **Sub-synchronous resonance (SSR)** between turbine shafts and series capacitor banks (long transmission lines).
Safety Problem Caused by Harmonic Resonance [5,6]

IEEE 14-Bus System

System-dependent; disturbance-dependent

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Nonlinear Load connected to Bus 3

Harmonic Propagation for the 5th harmonics.
The Percentage of Harmonic Voltage to Normal Voltage at each Bus
Harmonic Source at Bus 6

Harmonic Propagation for the 5th harmonics.
The Percentage of Harmonic Voltage to Normal Voltage at each Bus.
Harmonic Source at Bus 8

Harmonic Propagation for the 5th harmonics.
The Percentage of Harmonic Voltage to Normal Voltage at each Bus
Reliable Operation (Safety & Protection)

Fast Dynamics Matter!

For more details contact info@cognitivesystems.ca
A Data-Driven Solution for Fast Dynamics:

\[ P_r > 0 \text{ for } \omega < \omega_s \]
\[ P_r \leq 0 \text{ for } \omega \geq \omega_s \]
Non-Intrusive Harmonic Monitoring:

Output Voltage

Harmonic Distortions
Non-Intrusive Health (Condition) Monitoring:

Calculated Machine Torque
Non-Intrusive Health (Condition) Monitoring:
Non-Intrusive Health (Condition) Monitoring:

- Bearing faults;
- Blade problems;
- Low efficiency, heat effect;
- Gearbox/transmission problems;
- Unbalance/misalignment shaft;
- Rotor/stator faults like cracked rotor;
- Electrical (Distortions, Current imbalance);
- Loose windings, foundation, connections/contactors;
- Various Vibrations (e.g. cavitation, Stick-Slip, loose foundation, etc.).
Conclusion:

• Moving from a central system to a distributed systems,
• Challenges and Opportunities for Mathematicians (decision making),
• Peculiar case of sub-harmonics and the fast dynamics,
• Non-Intrusive Condition monitoring and data-driven modelling (as a part of servoc offered by Cognitive Systems to improve machinery reliability).

Thank You!

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Reference:


Harmonic Dampening:
Model Predictive Control:

[Graphs showing output of Natural Gas Power Plant and Wind Power under two cases, with MPC and Conventional Dispatch compared.]
New Technical Problems:

• The energy system, including its communication and control, does not readily enable choice and multi-participant information exchange and processing for aligning [often] conflicting goals.

• It is essential to design intelligence for T&D operations to align these goals and consequently to make the most out of available resources while simultaneously offering robust and affordable quality of service.

• New flexible energy processing equipment will also be needed to handle increasing variety and bandwidth of many participants requests.