Data and models, their role in the design and operation of future electricity grids

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ETH, Zurich, April 3rd, 2019
• Electrical engineering data and models over three decades
• Some recent data and models
• Future research directions
• Conclusions
Synchronous electricity grid

Objective: To maintain energy supply demand balance reliably on a continuous basis across time and space and to do so in the most economic way possible.

f 50/60 Hz
Thermal Units
Combustion Turbines
Hydro and Turf Units
Load

\[ \sum \Delta P_{LOAD} + \Delta P_{GEN} \]

\[ \sum \Delta P^{\text{LOAD}} + \Delta P^{\text{GEN}} \]

It all started with lock tests

22 % electricity from Wind 2016

Wind installed in Ireland

Eirgrid Generation Capacity Statement 2017-2026 and Irish Wind Energy Association
Adding non synchronous generation

50/60 Hz

Does not add to system inertia

Synchronous generator

Doubly fed induction generator wind turbine

Fixed speed wind turbine generator

50/60 Hz
Frequency variation due to wind

Source: EirGrid
Wind turbines inertial response


How much kinetic energy is available?

Fig. 1. Kinetic energy potentially available from wind generation as a function of wind generation output (all data normalized to unity).
Lowest frequency (nadir) reached

- Frequency response

\[ S = \left( \frac{MW_{Lost}}{f_{pre-event} - f_{nadir\ post\ event}} \right) \]

- Wind penetration increases
- Stiffness decreases

- Indicates increased vulnerability to a loss of generation event
- Also being observed in ERCOT. Sharma, S. Huang, SH. Sarma, NDR, “System Inertial Frequency Response Estimation and Impact of Renewable Resources in ERCOT Interconnection.” *IEEE Power and Energy Society Meeting*, July 24-28\(^{th}\), 2011, Detroit, USA.

Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Renewable Generation

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When Irish government asks .....
System Non Synchronous Penetration (SNSP) Limit

\[ \text{SNSP} = \frac{\text{Wind + Imports}}{\text{Demand + Exports}} \]

Feb 22\textsuperscript{nd} 2019 Ireland

http://smartgriddashboard.eirgrid.com/
Where is this going now

Illustration of the main concept of the MIGRATE project. The abscissa represents the PE penetration where L1 and L2 are asymptotes where severe stability problems could be met within the existing framework. The ordinate axis represents a generic stability index.
All island grid study 2006 – 2008 (Scientific Advisor)

WS1: Resource
- Geo-spread scenarios
- Portfolio scenarios

WS2A: Generation Portfolios

WS2B: Management Study
- Emissions savings
- Costs

WS3: Network
- Costs
- Stakeholder impact

WS4: Economic

WS: Workstream
Portfolio choices (WS 2A)

All island grid study – societal cost of adopting portfolios

<table>
<thead>
<tr>
<th>Portfolio</th>
<th>RE share of demand</th>
<th>CO2 emissions [Mt/a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portfolio 1</td>
<td>16%</td>
<td>20</td>
</tr>
<tr>
<td>Portfolio 2</td>
<td>27%</td>
<td>18</td>
</tr>
<tr>
<td>Portfolio 3</td>
<td>27%</td>
<td>18</td>
</tr>
<tr>
<td>Portfolio 4</td>
<td>27%</td>
<td>22</td>
</tr>
<tr>
<td>Portfolio 5</td>
<td>42%</td>
<td>15</td>
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</table>
All island grid study

Share of Renewables

<table>
<thead>
<tr>
<th></th>
<th>Portfolio 1</th>
<th>Portfolio 2</th>
<th>Portfolio 3</th>
<th>Portfolio 4</th>
<th>Portfolio 5</th>
<th>Portfolio 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>23 %</td>
<td>36 %</td>
<td>36 %</td>
<td>36 %</td>
<td>47 %</td>
<td>59 %</td>
</tr>
<tr>
<td>Energy</td>
<td>16 %</td>
<td>27 %</td>
<td>27 %</td>
<td>27 %</td>
<td>42 %</td>
<td>59 %</td>
</tr>
</tbody>
</table>

- CCGT (old and new)
- Old Coal_Peat
- Old Gasoil
- Conv. Gas
- New OCGT
- Storage
- New ADGT
- Base renewables
- Wind
- Other renewables

Maximum load: 9600 MW
Minimum load: 3500 MW

https://www.esig.energy/resources/irish-island-grid-study-2/
Demand side has a portfolio effect

“This also highlights the need on the demand-side for market design frameworks that reflect system investment requirements to aggregators and/or consumers.”

Fig. 6. Least-cost electricity investment portfolios for different gas prices, carbon prices, HP and ICE investment costs with both electricity and heat demand.

Centralised optimization may not be valid modelling paradigm

- DR involves a large number of self-interested decision makers and stakeholders e.g the TSO, Load Aggregator/retailer, consumers etc.
- Centralized models assume a perfectly competitive market and, thus, do not take into account the objectives of these stakeholders.
- It is important to reflect the strategic objectives of these various stakeholders within a single framework.

Impact of increasing consumer flexibility

Fig. 3. 1. Impact of TES penetration on the system performance relative to CIFD (in terms of operation costs (Panels A - C), wind curtailment reduction (Panel D), peak load reduction (Panel E)) and the retailer’s profits (Panel F).

*CIFD: Centralized Inflexible Demand  *CFD: Centralized Flexible Demand  *MPM: Multi-perspective Model

Maximising distribution network as an energy harvesting device

Data from: ESB Networks

Distribution network – it makes a difference where you put it

How do you design a connection policy that is optimal?

<table>
<thead>
<tr>
<th></th>
<th>Net Benefit</th>
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<tbody>
<tr>
<td>Firm</td>
<td>€191,000,000</td>
</tr>
<tr>
<td>Non Firm</td>
<td>€327,000,000</td>
</tr>
<tr>
<td>Firm + Non Firm</td>
<td>€292,500,000</td>
</tr>
</tbody>
</table>

Data and models their future role

Planning, operations, markets, people, smarts, cyber, etc.
Future electricity grids will require better/new data/models to deliver reliable, sustainable and cost effective electricity to society.

The need is on supply and demand side and across all aspects planning, operations, markets, people, cyber, smart ......

We are not alone – industry have the data and practical models.