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

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Electrical Engineering Seminar,
ETH, Zurich, April 3rd, 2019

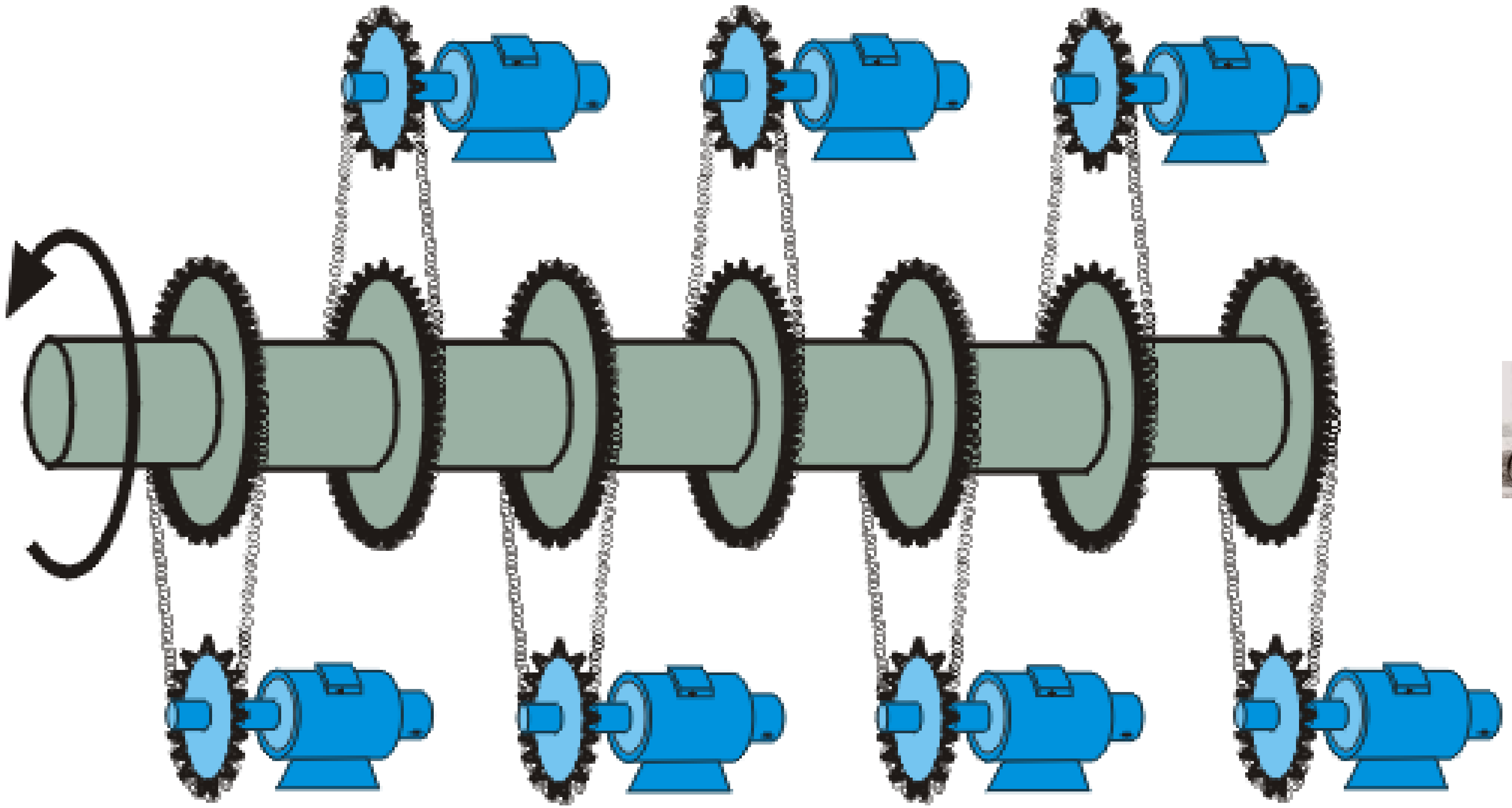
Outline

- Electrical engineering data and models over three decades
- Some recent data and models
- Future research directions
- Conclusions

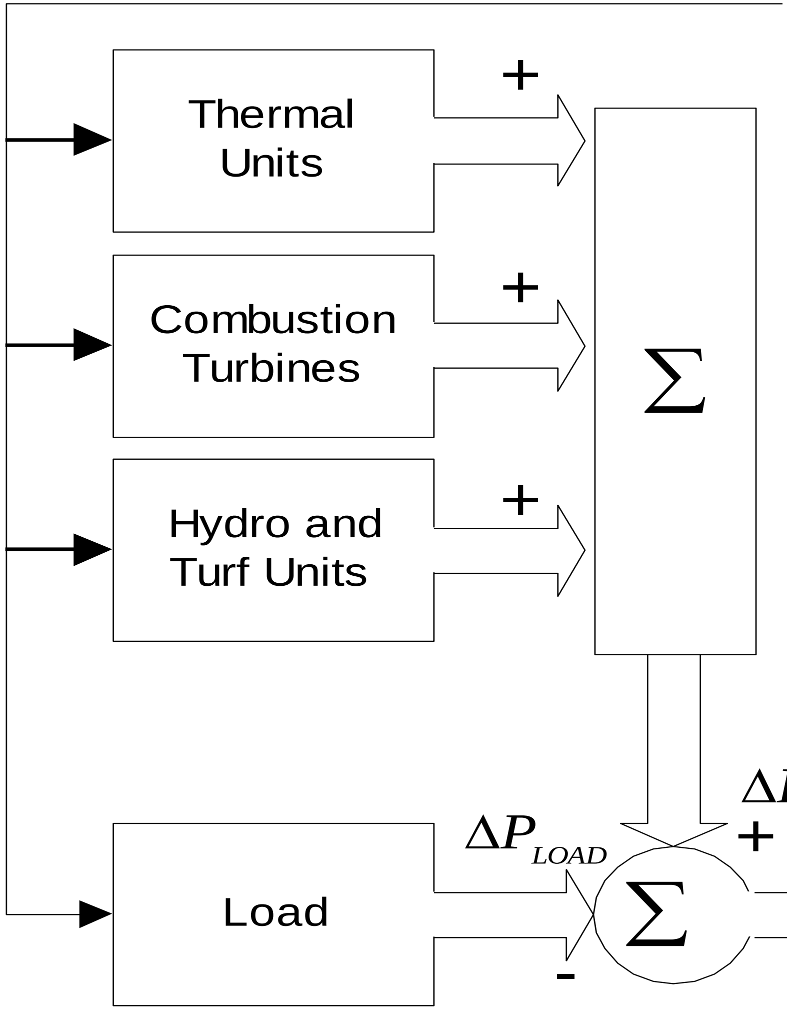
Synchronous electricity grid

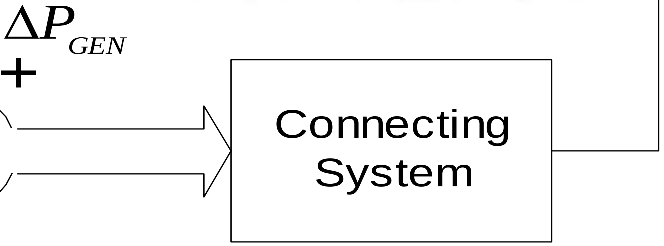
Objective: To maintain energy supply demand balance reliably on a continuous basis across time and space and to do so in the most economic way possible.

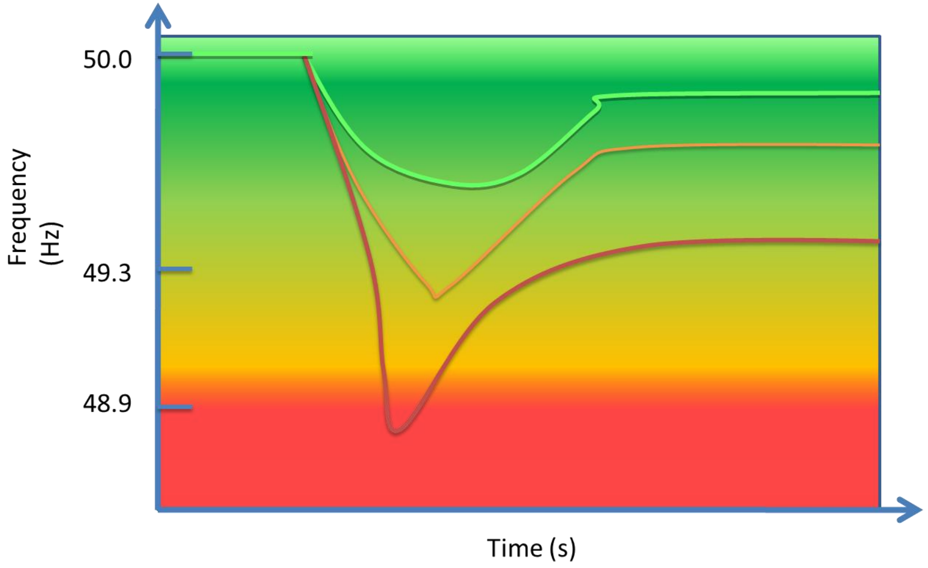
f 50/60 Hz

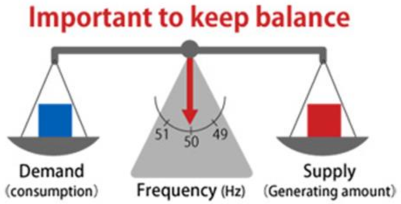


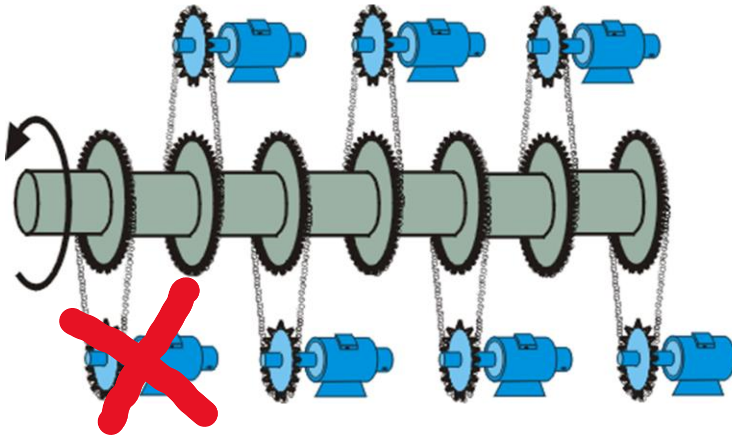
Frequency control





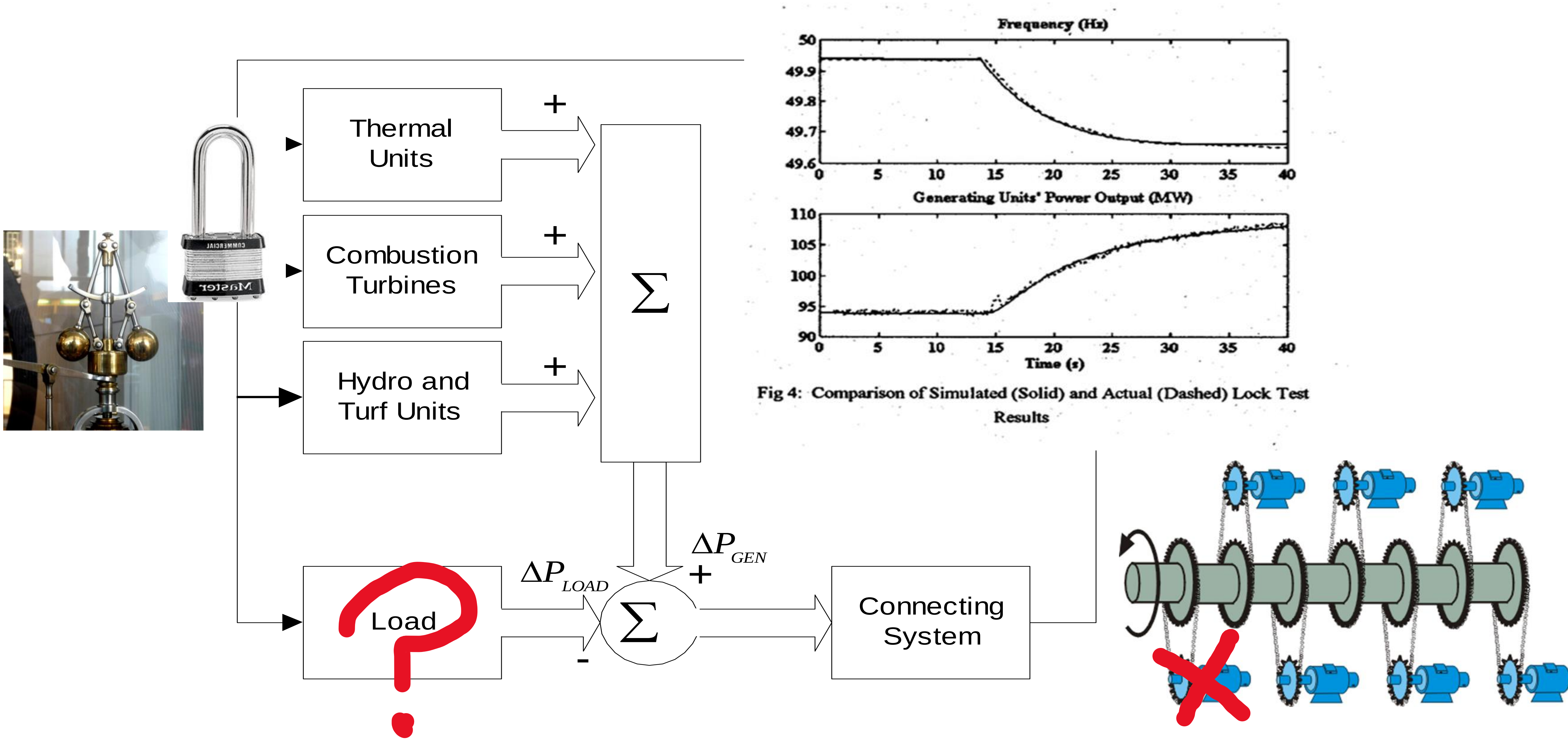






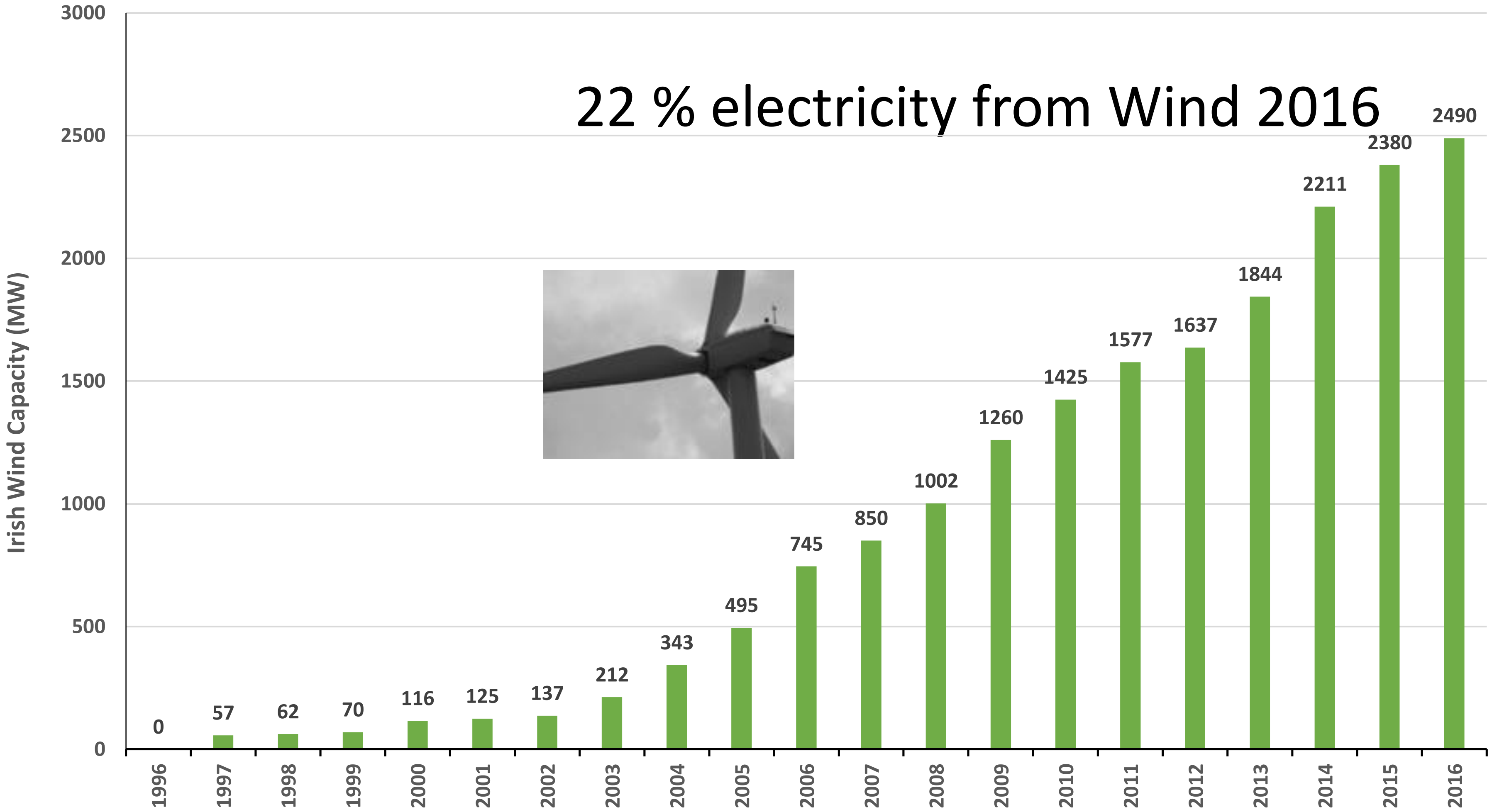
O'Sullivan, J. and O'Malley, M.J., "A new methodology for the provision of reserve in an isolated power system", *IEEE Transactions on Power Systems*, Vol. 14, pp. 519 – 524, 1999.

It all started with lock tests



O'Sullivan, J. and O'Malley, M.J., "Identification and validation of dynamic global load model parameters for use in power system frequency simulation", IEEE Transactions on Power Systems, Vol. 11, pp. 851 - 857, 1996.

Wind installed in Ireland

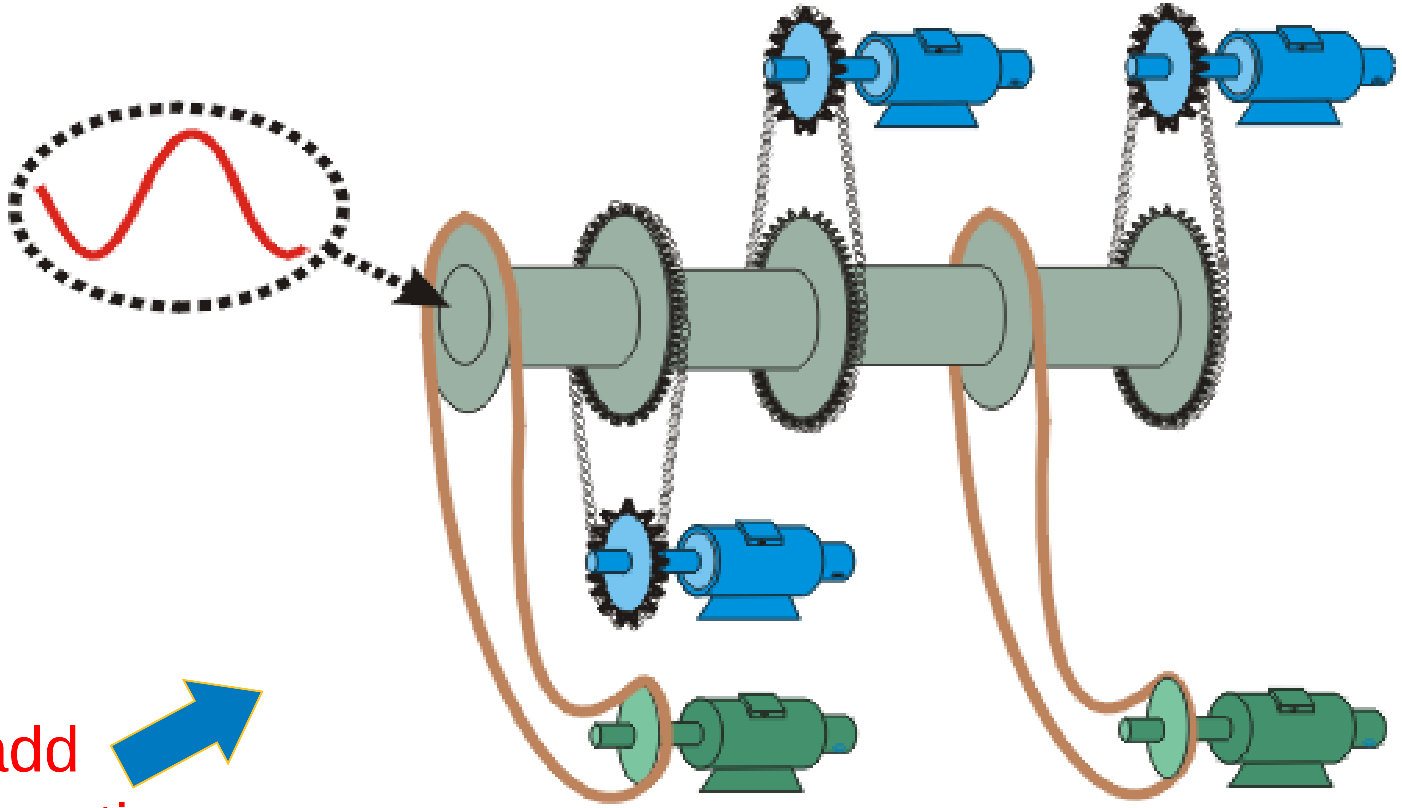


Sources: EirGrid http://www.eirgridgroup.com/site-files/library/EirGrid/4289_EirGrid_GenCapStatement_v9_web.pdf
Eirgrid Generation Capacity Statement 2017-2026 and Irish Wind Energy Association

Adding non synchronous generation

50/60 Hz

Synchronous generator

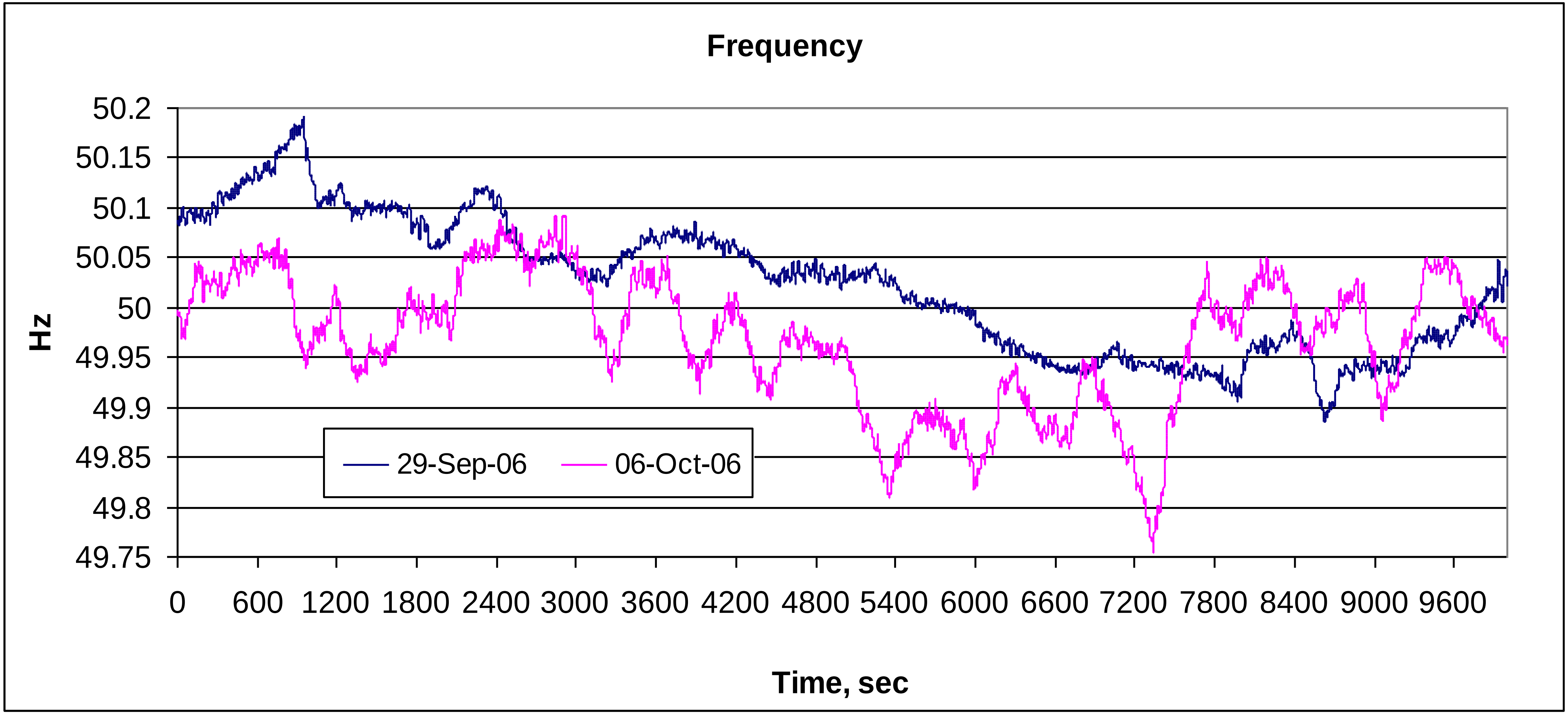


Doubly fed induction
generator wind turbine

Fixed speed wind
turbine generator

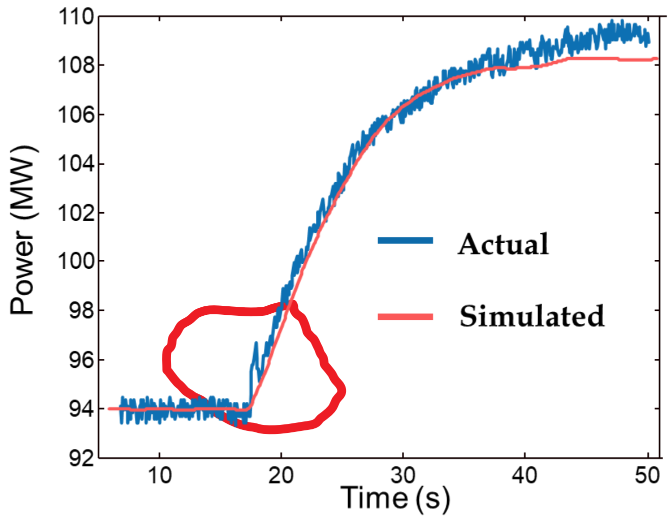
Does not add
to system inertia

Frequency variation due to wind

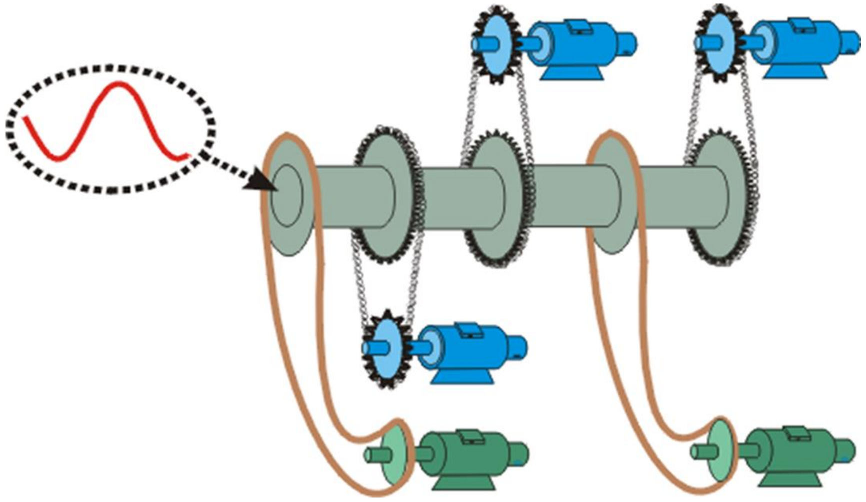


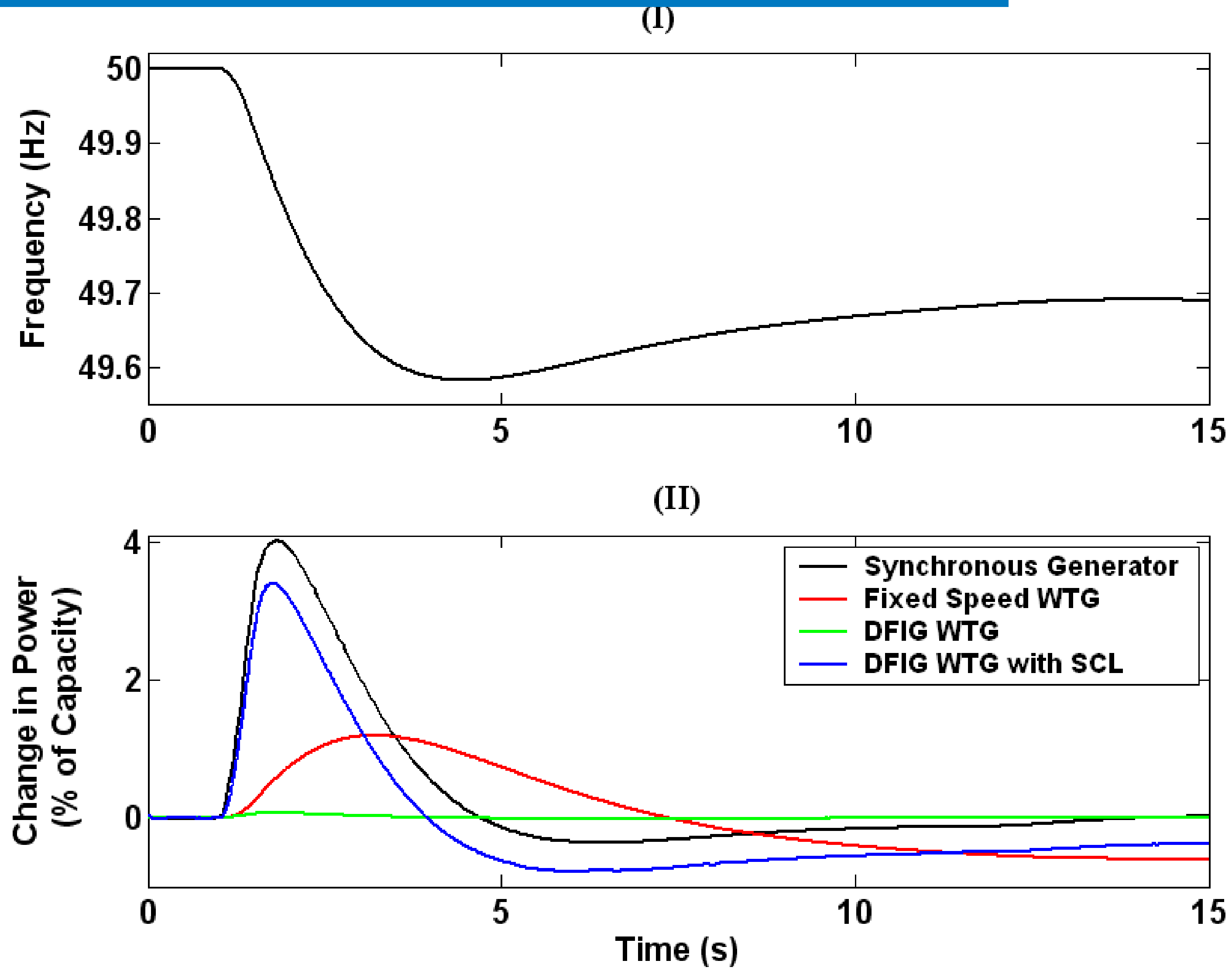
Source: EirGrid

Wind turbines inertial response



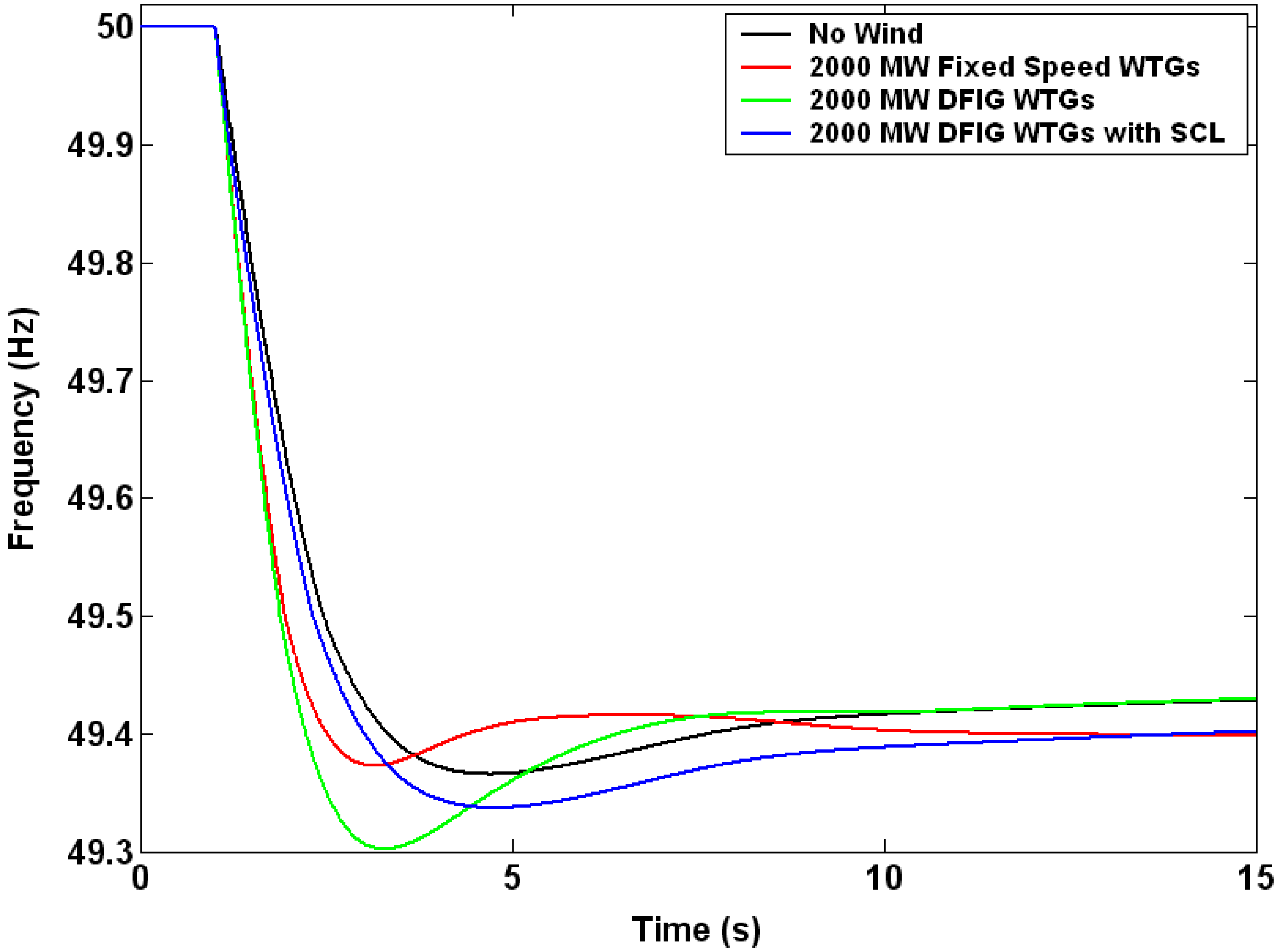
O'Sullivan, J. and O'Malley, M.J., "Identification and validation of dynamic global load model parameters for use in power system frequency simulation", IEEE Transactions on Power Systems, Vol. 11, pp. 851 - 857, 1996.





Mullane, A. and O'Malley, M.J., "The inertial-response of induction-machine based wind-turbines", *IEEE Transactions on Power Systems*, Vol. 20, pp. 1496 – 1503, 2005 .

Frequency response



Lalor, G., Mullane, A., and O'Malley, M.J., "Frequency Control and Wind Turbine Technologies", *IEEE Transactions on Power Systems*", Vol. 20, pp. 1903 – 1913, 2005.

How much kinetic energy is available?

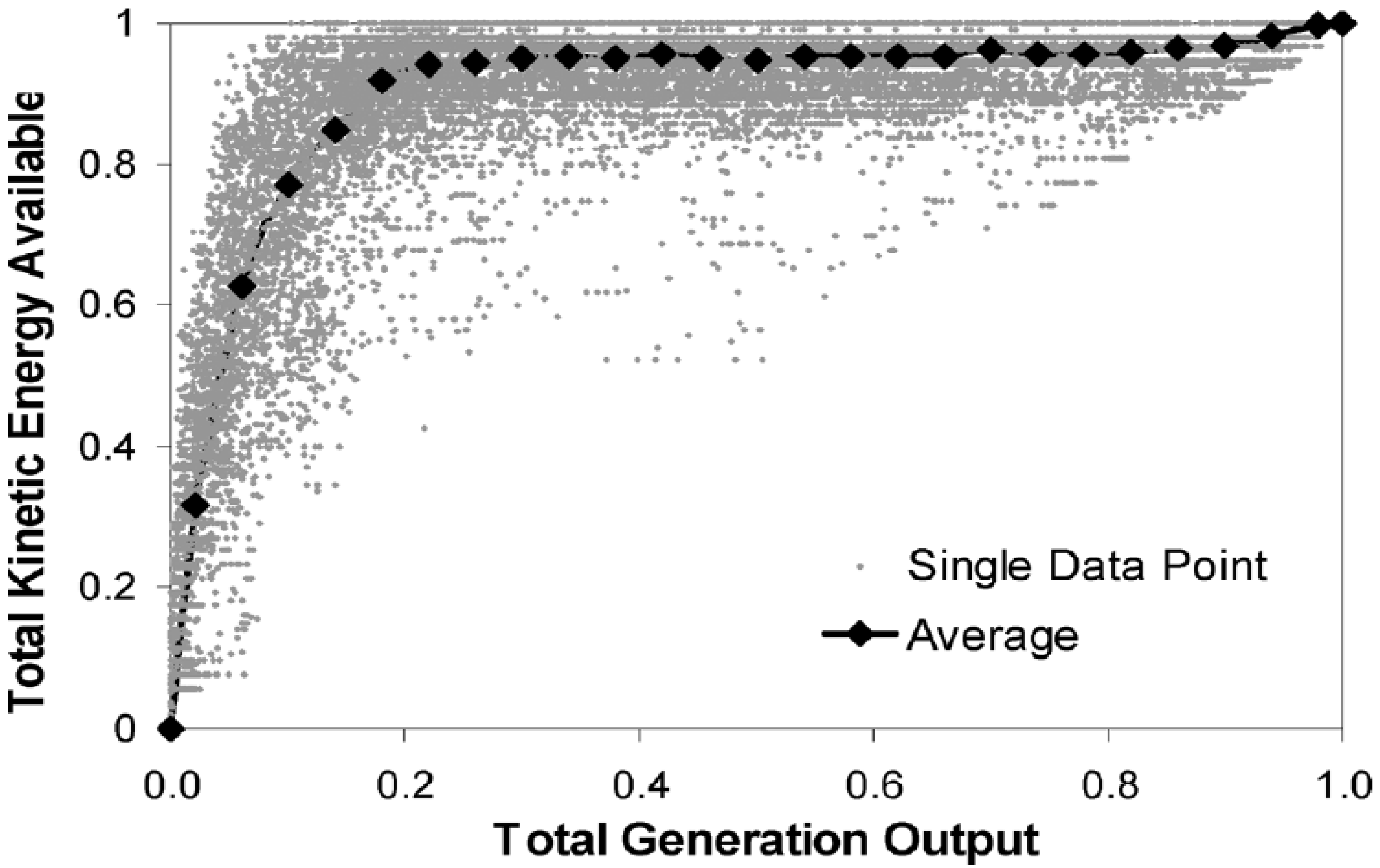
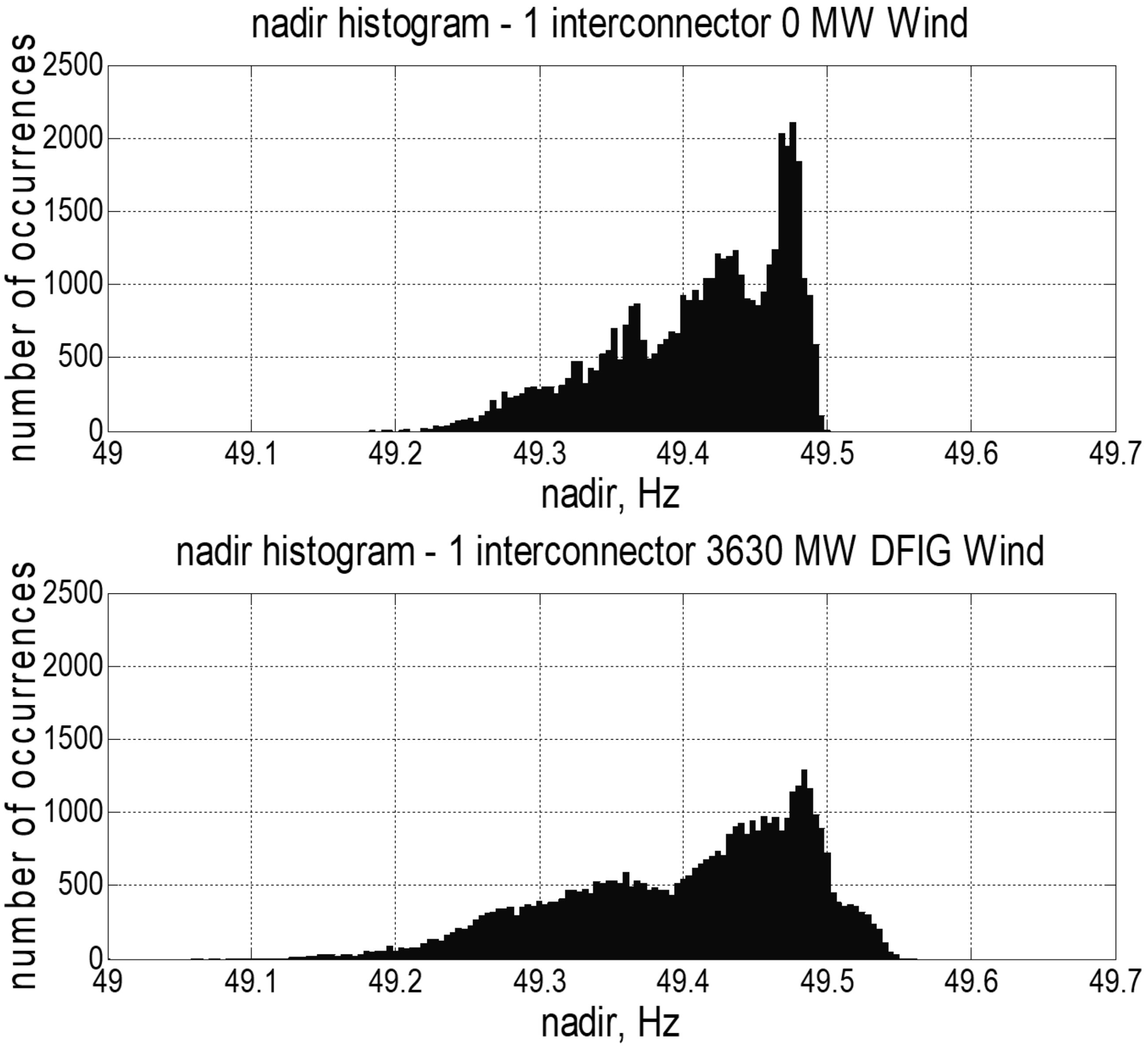


Fig. 1. Kinetic energy potentially available from wind generation as a function of wind generation output (all data normalized to unity).

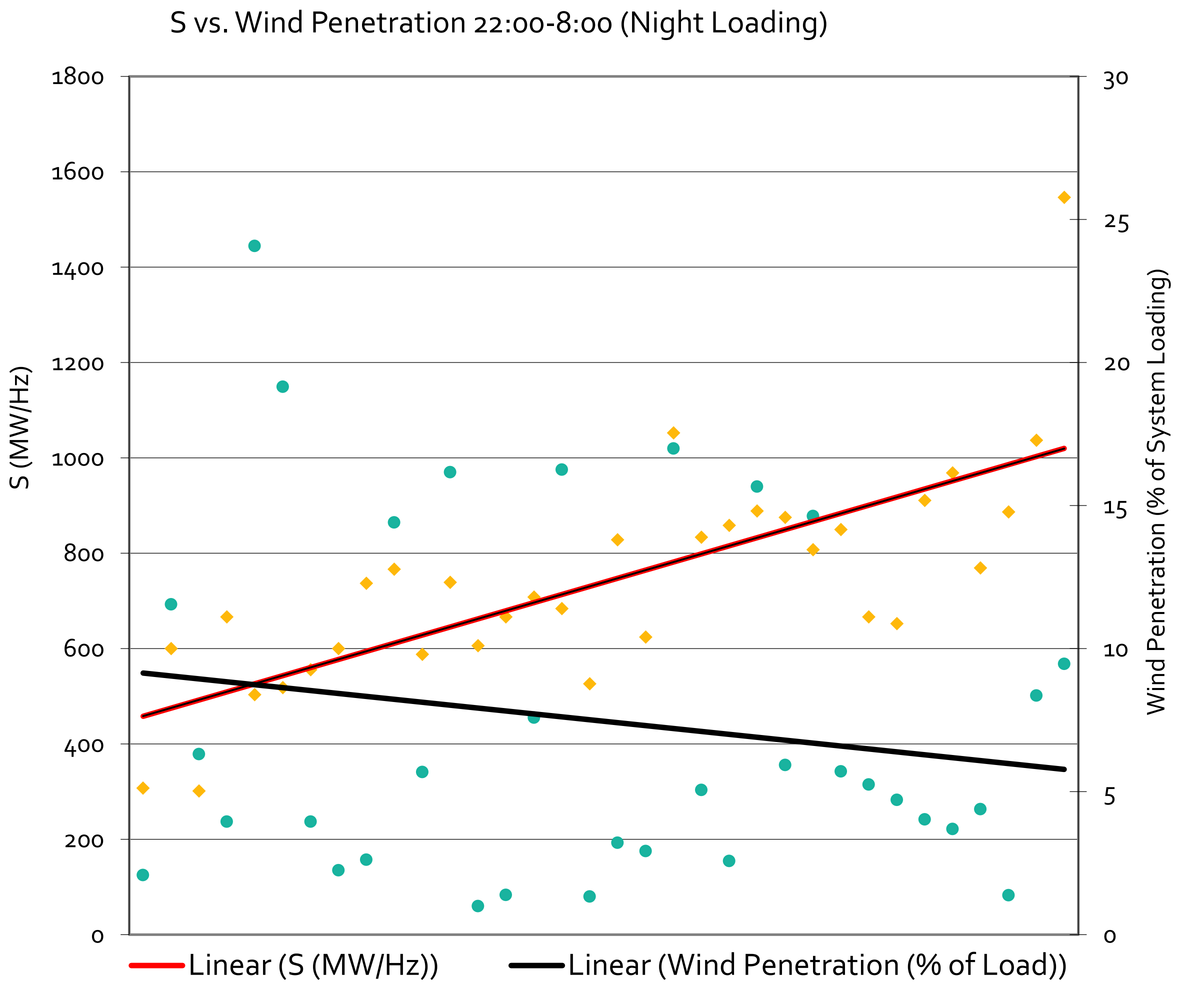
Doherty, R, Mullane, A., Lalor, G., Burke, D., Bryson, A. and O'Malley, M.J. "An Assessment of the Impact of Wind Generation on System Frequency", IEEE Transactions on Power Systems, Vol. 25, pp. 452 – 460, 2010.

Lowest frequency (nadir) reached



Doherty, R, Mullane, A., Lalor, G., Burke, D., Bryson, A. and O'Malley, M.J. "An Assessment of the Impact of Wind Generation on System Frequency", *IEEE Transactions on Power Systems*, Vol. 25, pp. 452 – 460, 2010.

Frequency response – data



Dudurych, I.M.; , "Statistical analysis of frequency response of island power system under increasing wind penetration," *Power and Energy Society General Meeting, 2010 IEEE* , vol., no., pp.1-6, 25-29 July 2010

- Frequency response

$$S = \left(\frac{MW_{Lost}}{f_{pre\text{-}event} - f_{nadir,post\text{-}event}} \right)$$

  - 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 24-28th, 2011, Detroit, USA.

Frequency response USA

LBNL-4142E

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

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

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December 2010

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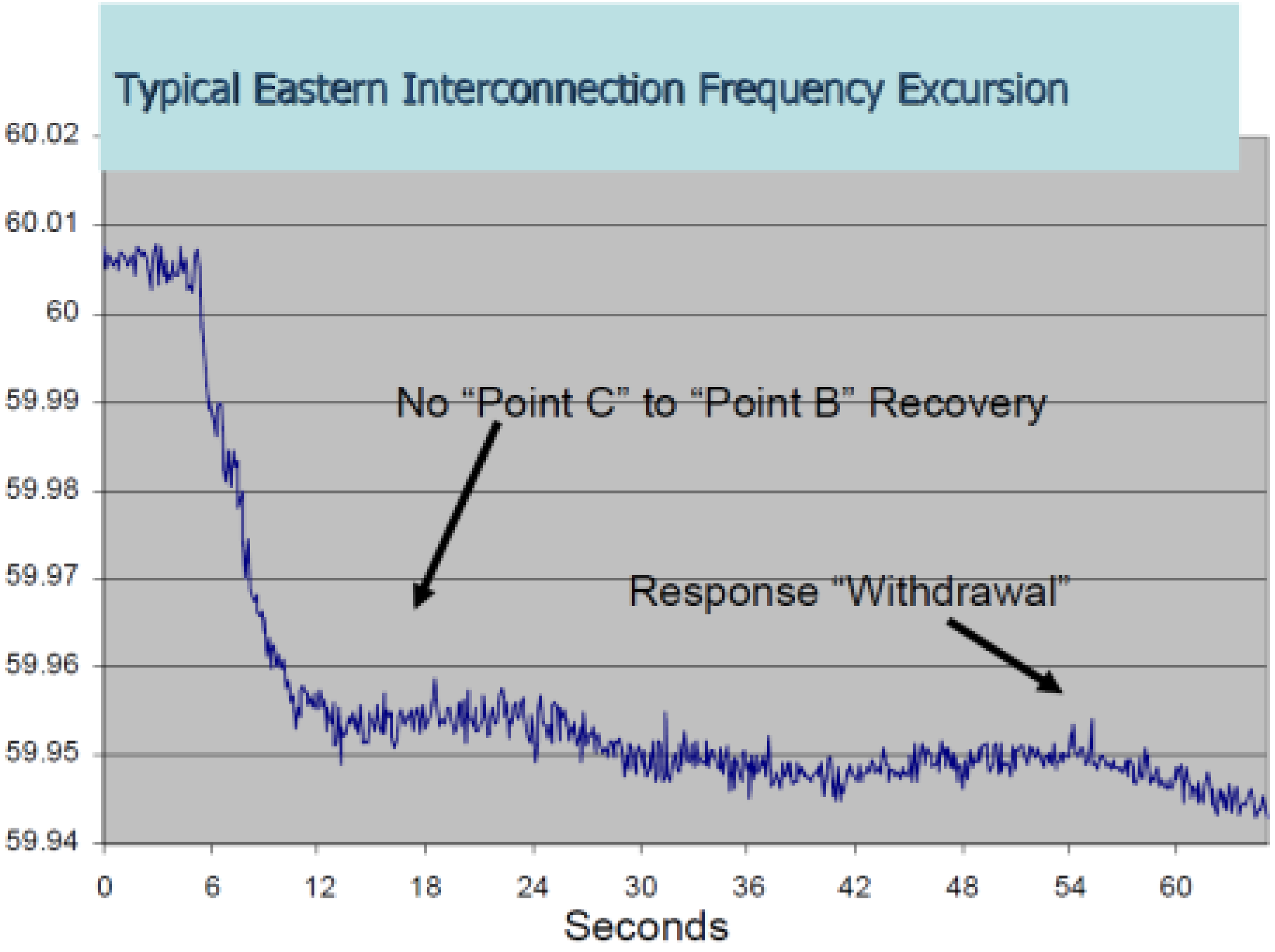
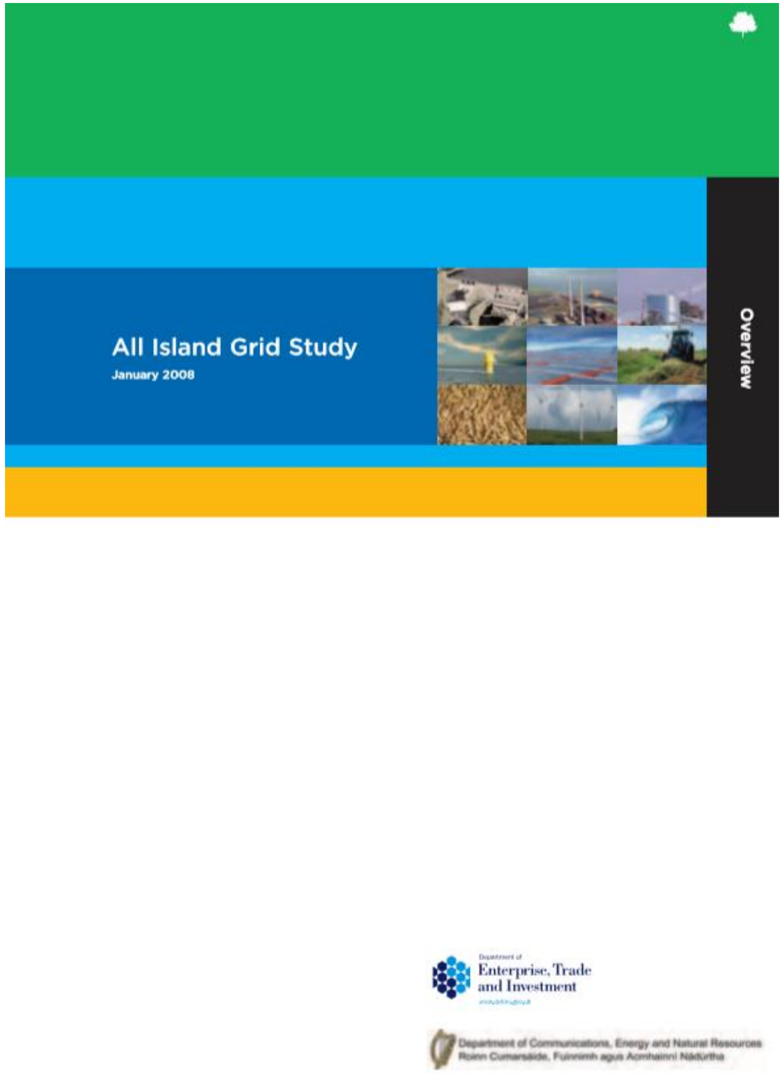
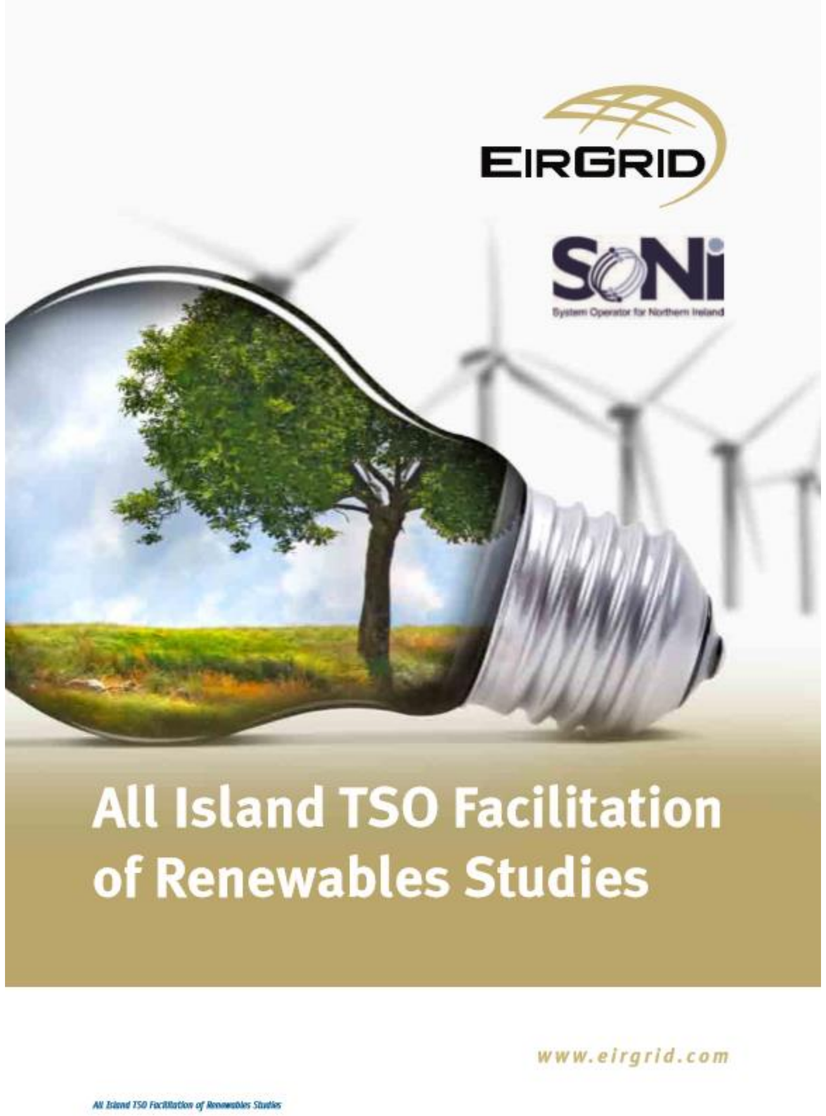


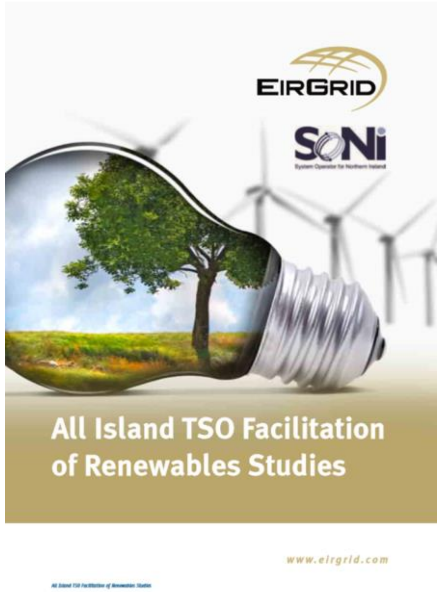
Eto, J., J. Undrill, P. Mackin, R. Daschmans, B. Williams, B. Haney, R. Hunt, J. Ellis, H. Illian, C. Martinez, M. O'Malley, K. Coughlin, and K.H. LaCommare,""Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Renewable Generation", Lawrence Berkley National Laboratory, Berkeley, 2010. http://www.ferc.gov/industries/electric/indus-act/reliability/frequencyresponsemetrics-report.pdf

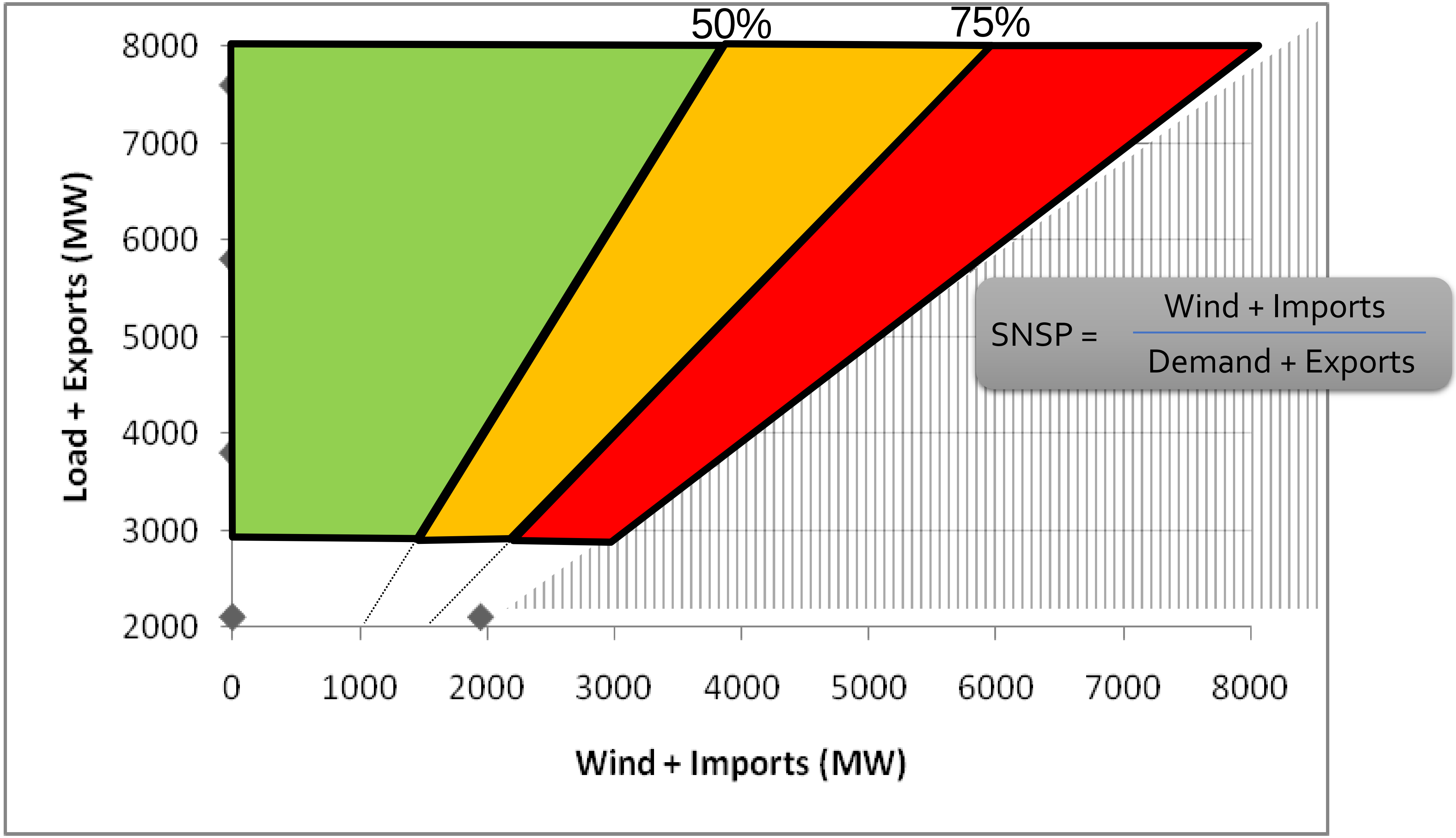
When Irish government asks .....





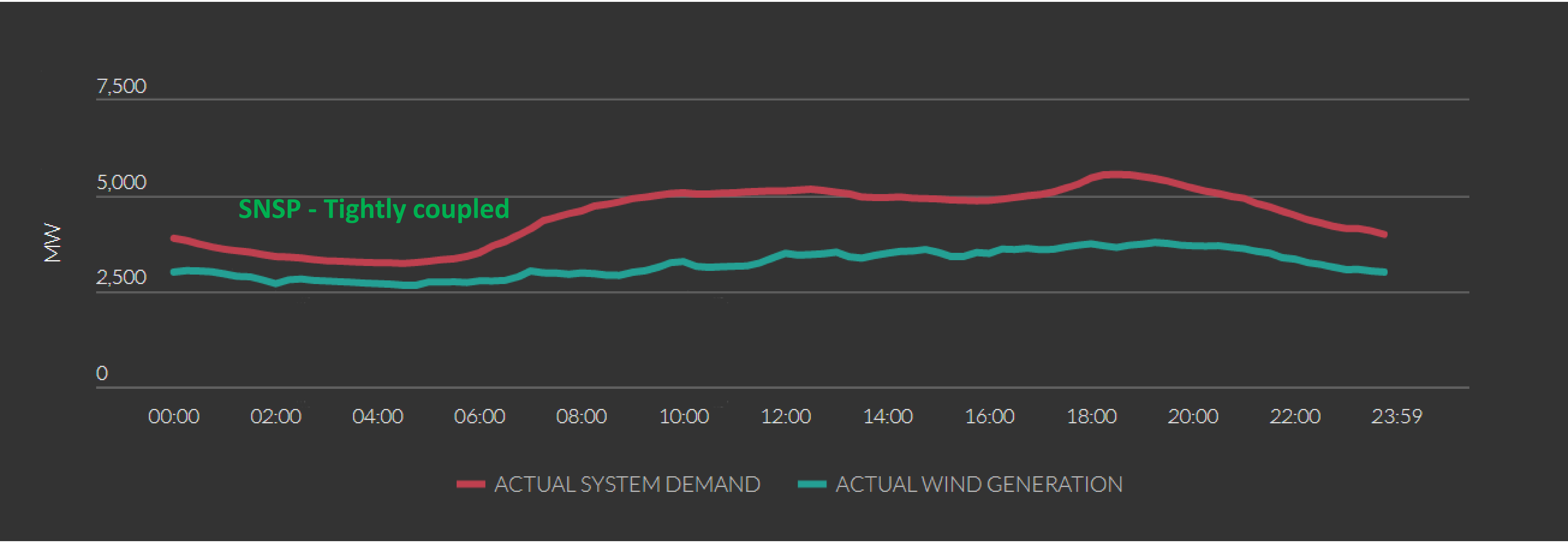
System Non Synchronous Penetration (SNSP) Limit





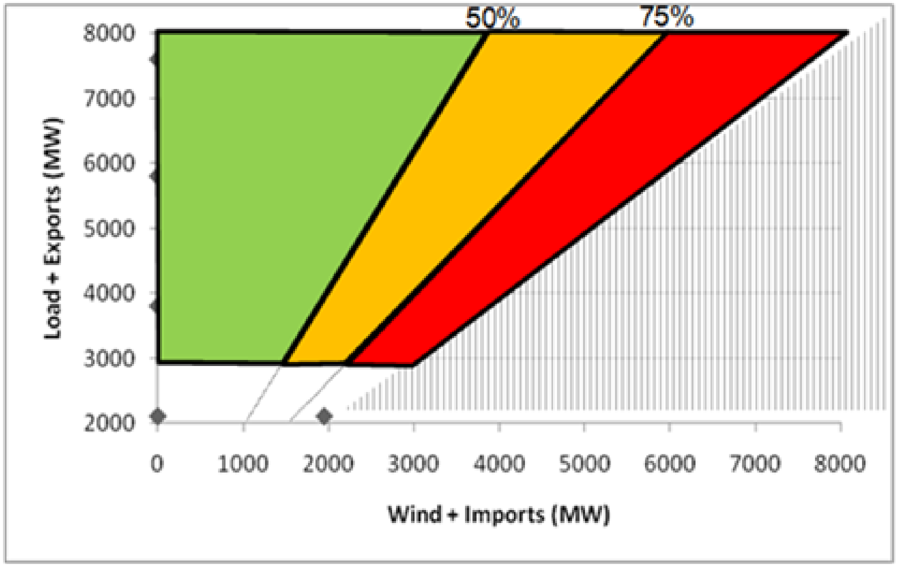
O'Sullivan, J., Rogers, A., Flynn, D., Smith, P., Mullane, A., and O'Malley, M.J., "Studying the Maximum Instantaneous Non-Synchronous Generation in an Island System – Frequency Stability Challenges in Ireland", *IEEE Transactions on Power Systems*, Vol. 29, pp. 2943 – 2951, 2014.

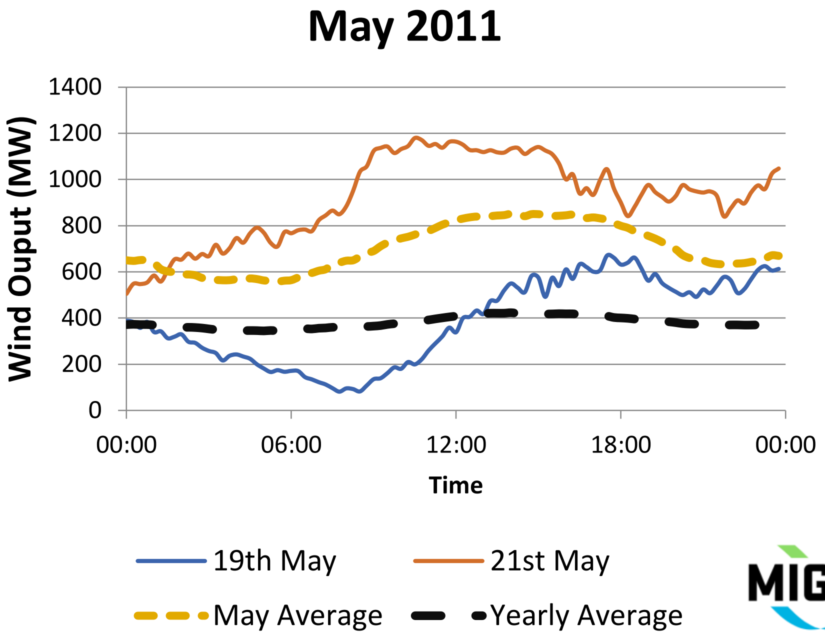
Feb 22nd 2019 Ireland



http://smartgriddashboard.eirgrid.com/

Where is this going now





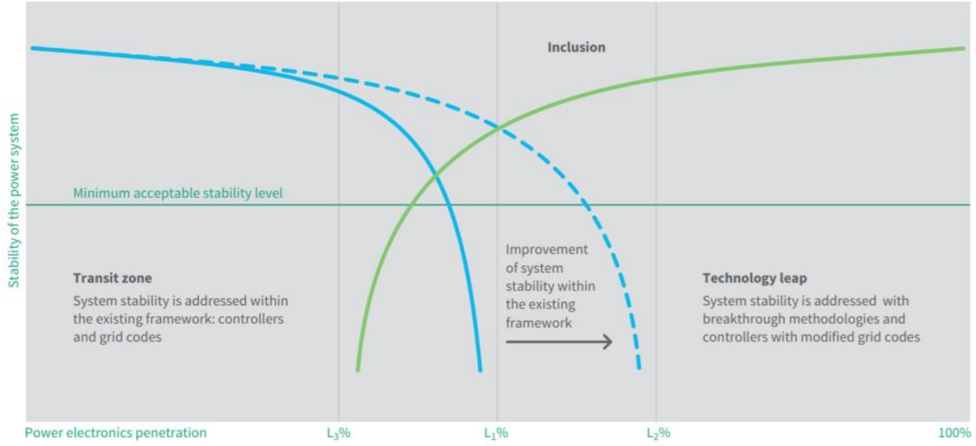
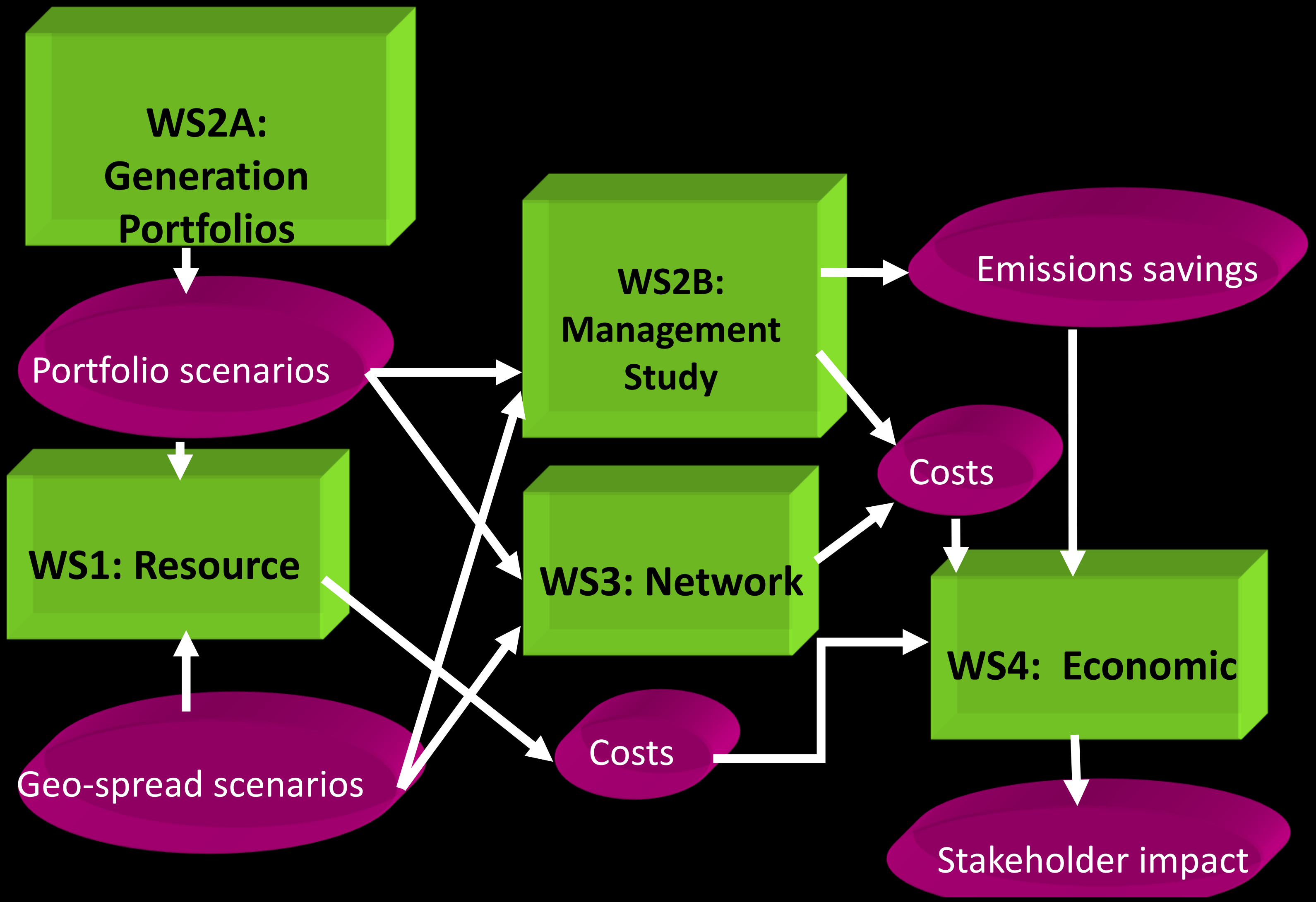
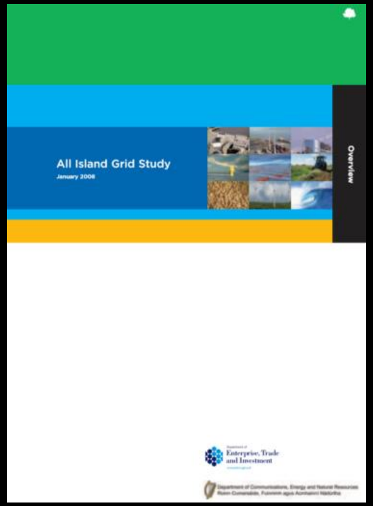


Illustration of the main concept of the MIGRATE project. The abscissa represents the PE penetration where L1 and L2 are asymptotes where severe stability problems could be met within the existing framework. The ordinate axis represents a generic stability index

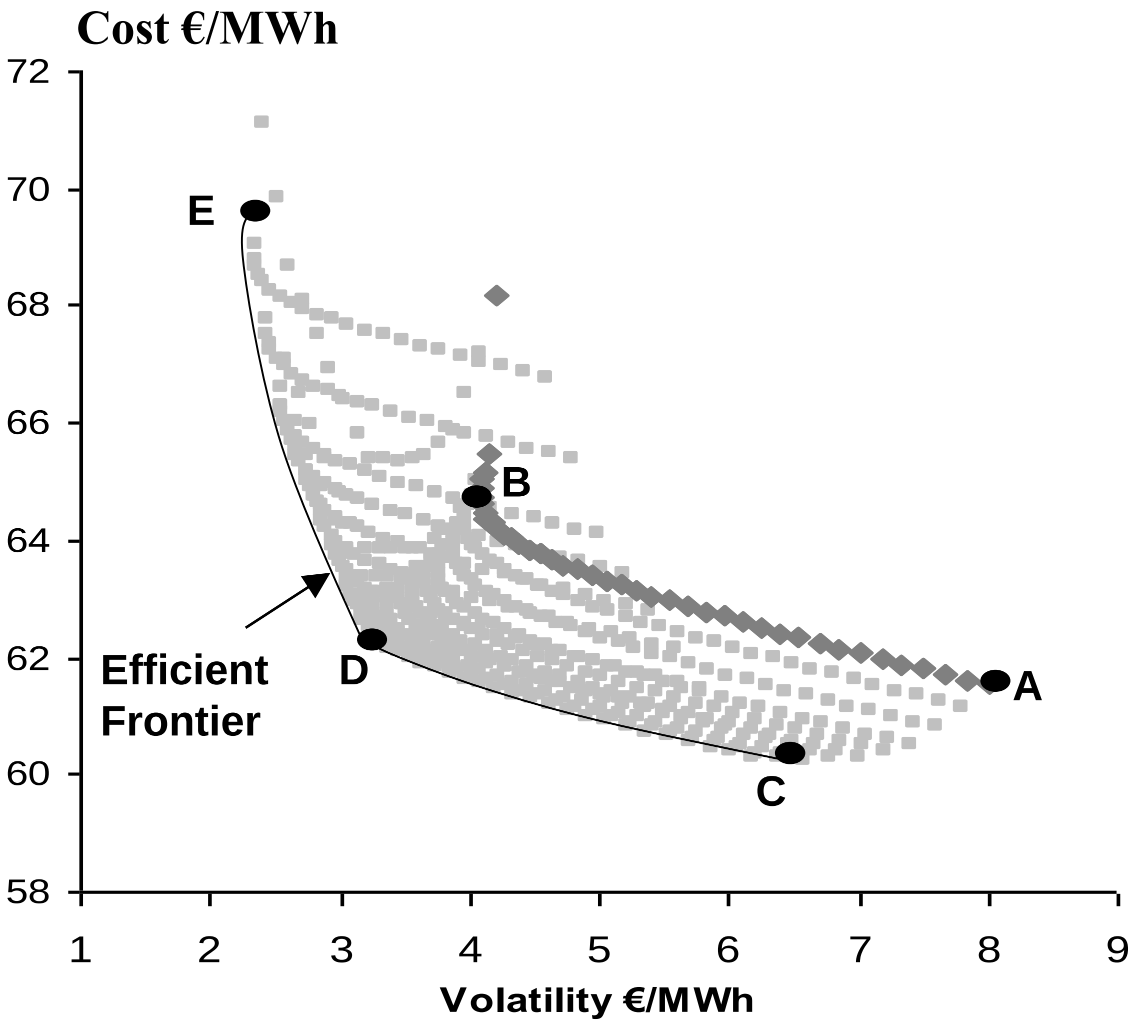
All island grid study 2006 – 2008 (Scientific Advisor)



WS: Workstream



Portfolio choices (WS 2A)



A – Gas

B – Coal

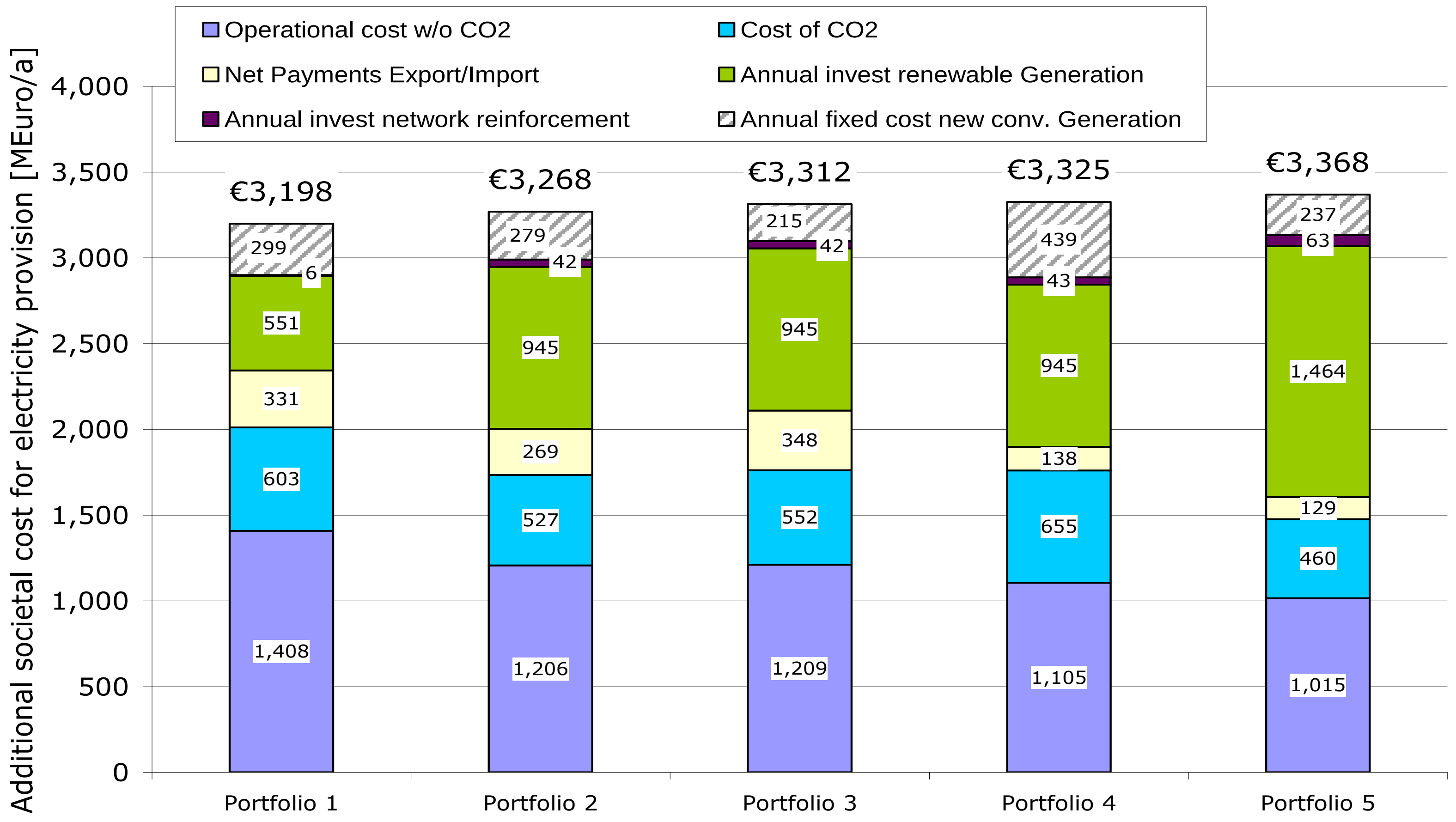
C – Gas, wind

D – Coal, wind

E – Coal, wind, peat, biomass

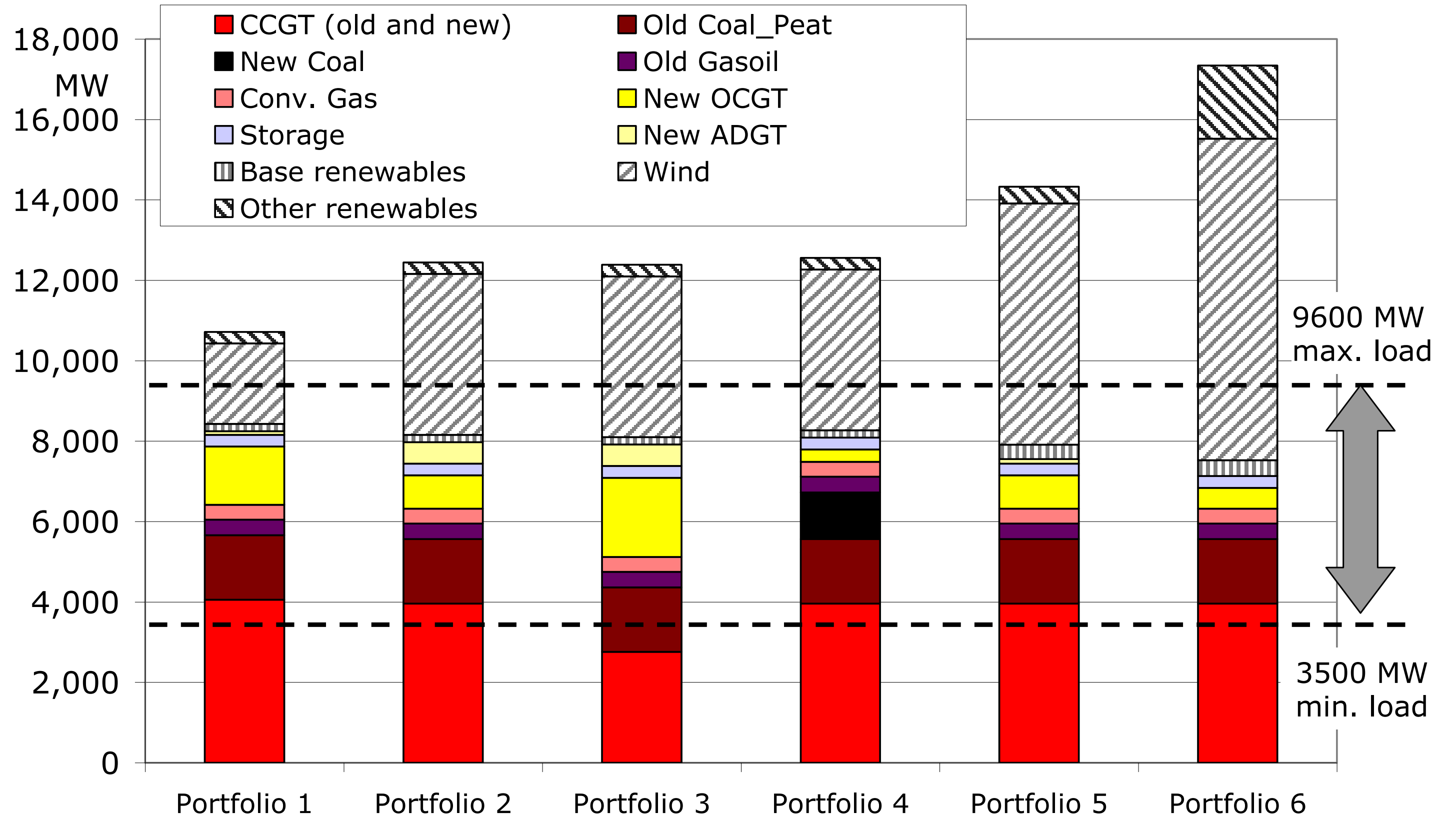
Doherty, R and M.J. O'Malley, "Establishing the role that wind generation may have in future generation portfolios", *IEEE Transactions on Power Systems*", Vol. 21, pp. 1415 – 1422, 2006.

All island grid study – societal cost of adopting portfolios



RE share of demand	16%	27%	27%	27%	42%
CO_2 emissions [Mt/a]	20	18	18	22	15

All island grid study



Share of Renewables

Capacity	23 %	36 %	36 %	36 %	47 %	59 %
Energy	16 %	27 %	27 %	27 %	42 %	59 %

https://www.esig.energy/resources/irish-island-grid-study-2/

Demand side has a portfolio effect

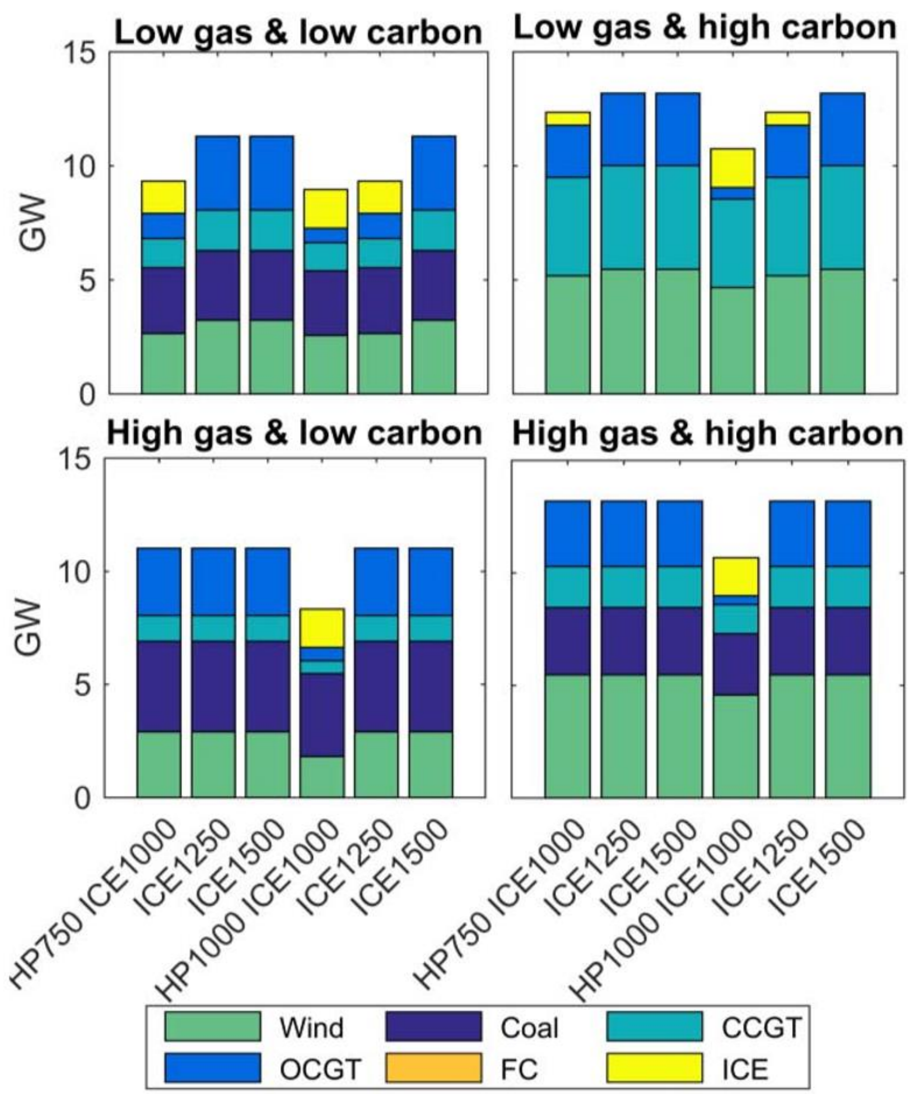


Fig. 6. Least-cost electricity investment portfolios for different gas prices, carbon prices, HP and ICE investment costs with **both electricity and heat** demand.

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

Heinen, S. and M.J. O'Malley, "Complementarities of supply and demand sides in integrated energy systems", *IEEE Transactions Smart Grids*, Vol. 10, pp. 1156 - 1165, 2019.

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.

M. B. Anwar, D. J. Burke and M. O'Malley, "A Multi-perspective Model for Evaluation of Residential Thermal Demand Response," IEEE Transactions on Smart Grid, in press, 2019.

Impact of increasing consumer flexibility

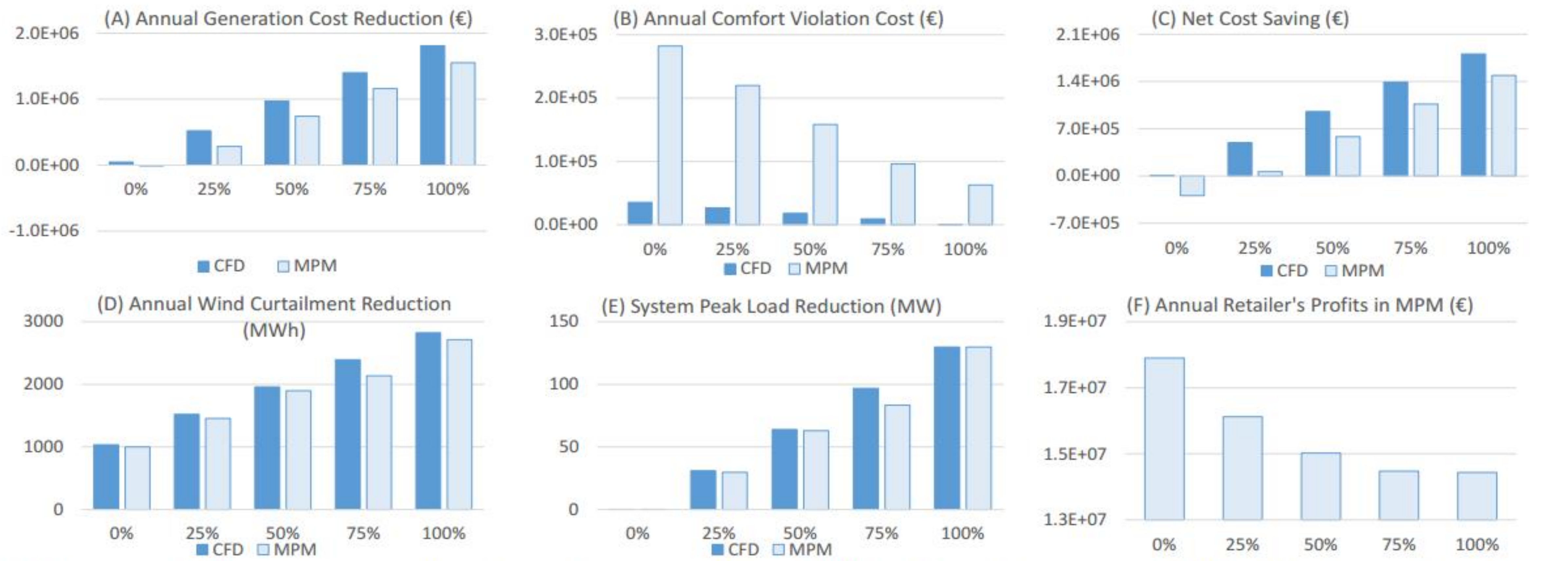
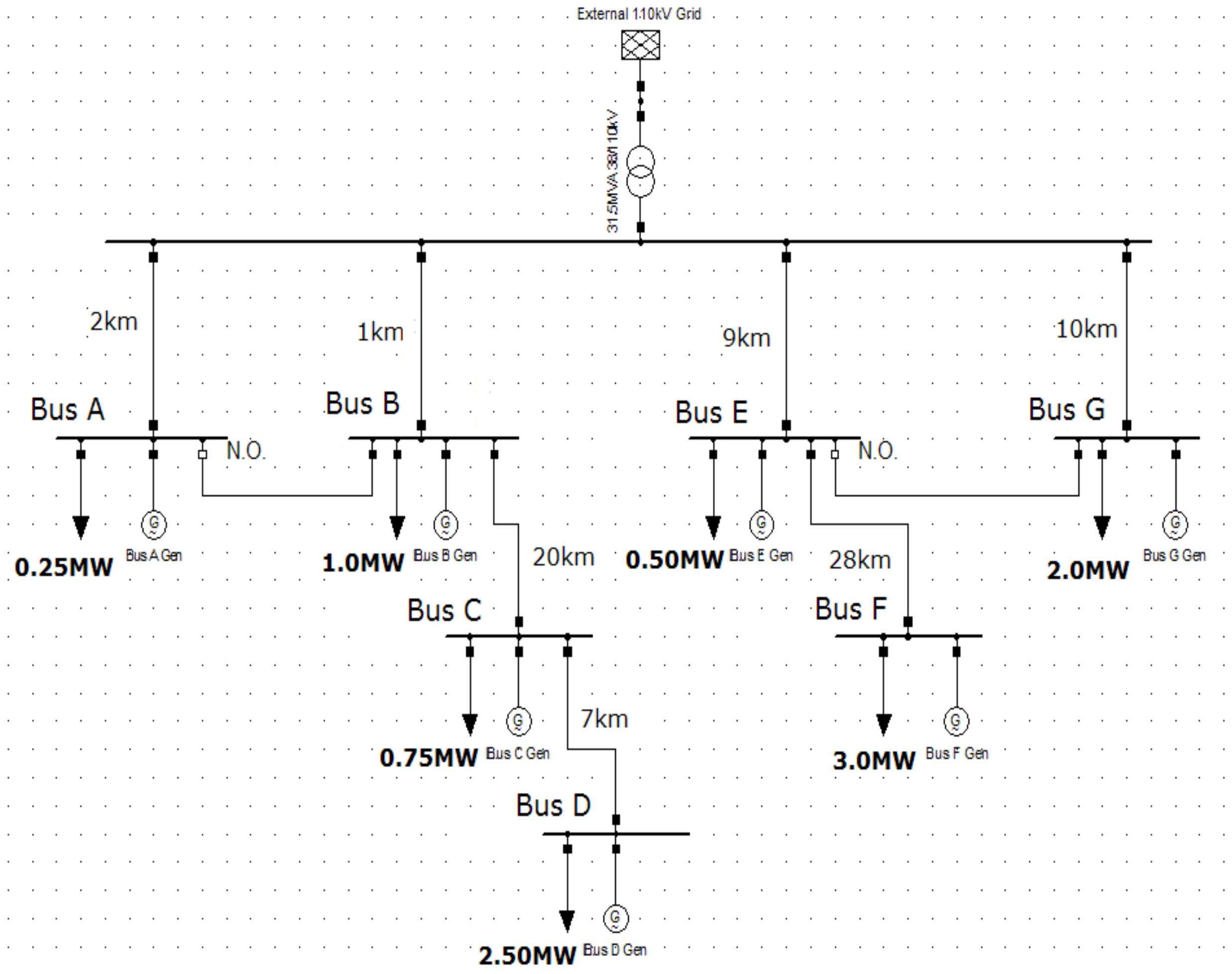


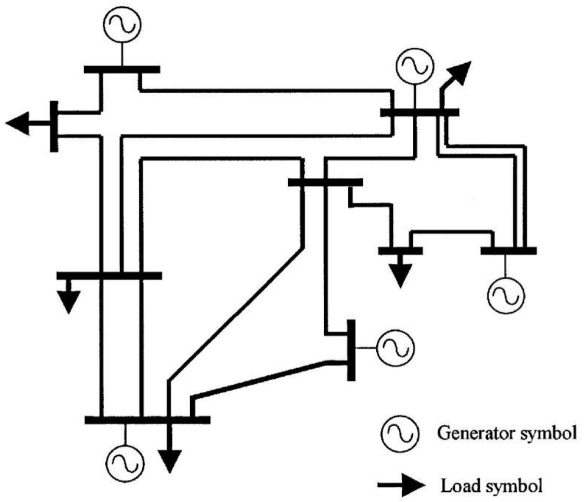
Fig. 3. I of TES penetration on the system performance relative to CIFD (in terms of operation costs (Panels A - C), wind curtailment reduction (Panel D), peak load reduction (Panel E)) and the retailer's profits (Panel F)

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

M. B. Anwar, D. J. Burke and M. O'Malley, "A Multi-perspective Model for Evaluation of Residential Thermal Demand Response," IEEE Transactions on Smart Grid, in press, 2019.

Maximising distribution network as an energy harvesting device

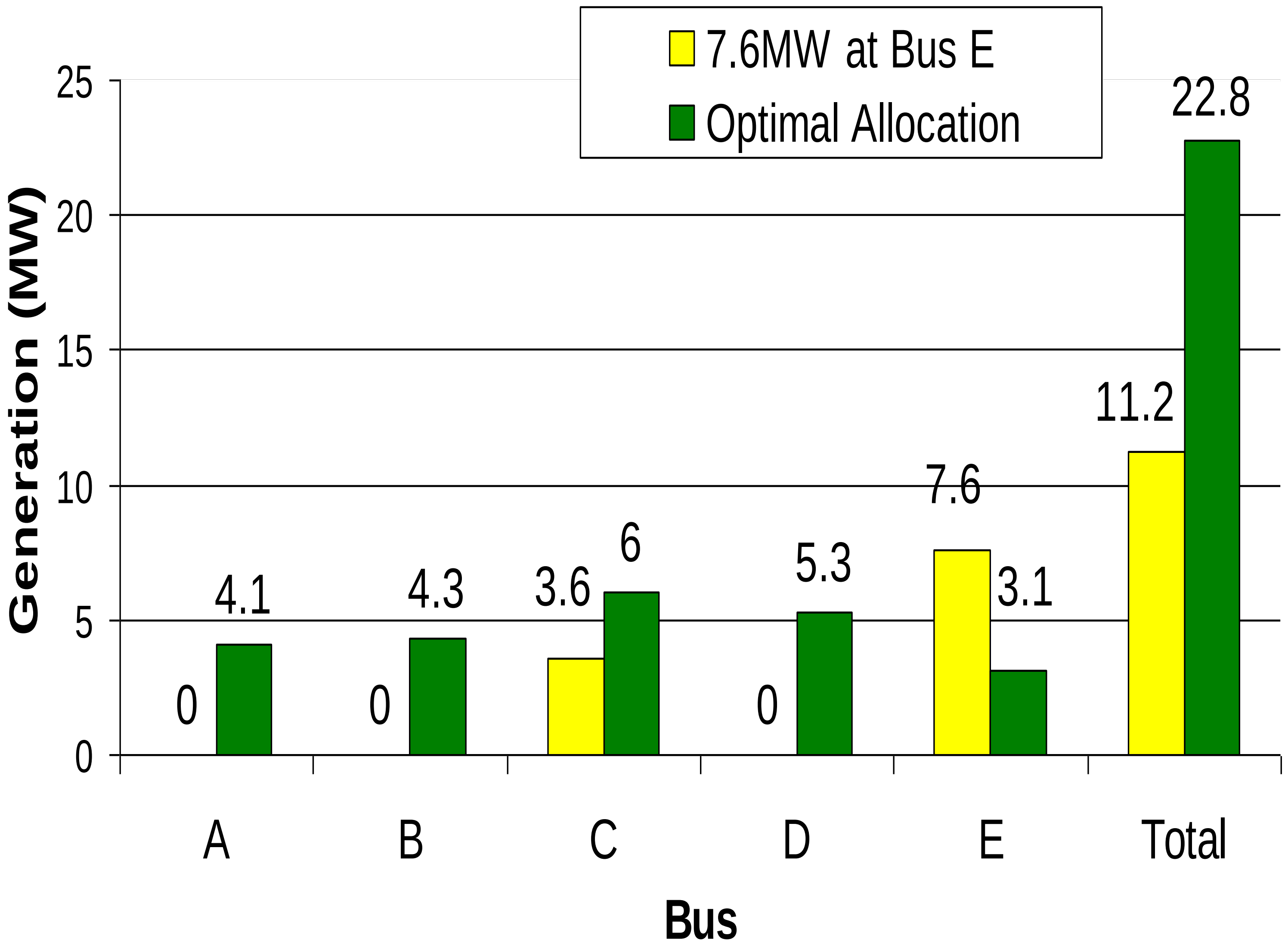




Data from: ESB Networks

Keane, A and M.J. O'Malley, "Optimal Allocation of Embedded Generation on Distribution Networks", *IEEE Transactions on Power Systems*", Vol. 20, pp. 1640 - 1646, 2005.

Distribution network – it makes a difference where you put it



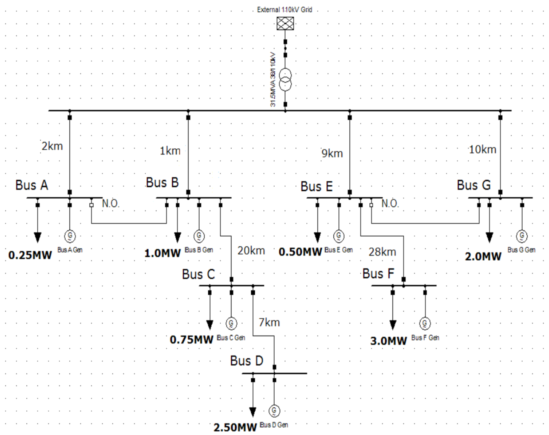
Keane, A and M.J. O'Malley, "Optimal Allocation of Embedded Generation on Distribution Networks", *IEEE Transactions on Power Systems*", Vol. 20, pp. 1640 - 1646, 2005.

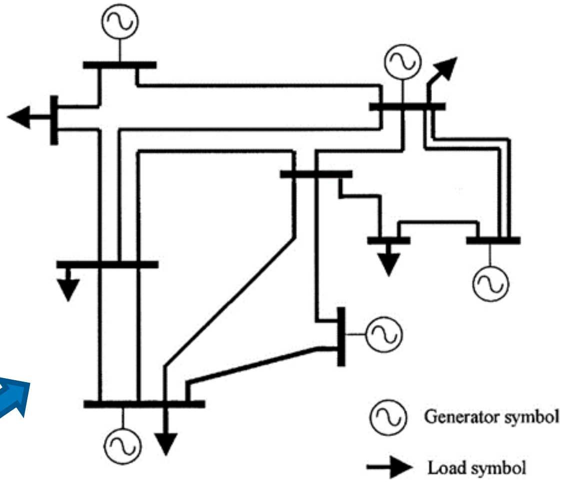
How do you design a connection policy that is optimal?

	Net Benefit
Firm	€191,000,000
Non Firm	€327,000,000
Firm + Non Firm	€292,500,000

Keane, A., Denny, E. and O'Malley, M.J. "Quantifying the Impact of Connection Policy on Distributed Generation", *IEEE Transactions on Energy Conversion*, Vol. 22, pp. 189 - 196, 2007.

Data and models their future role





Data & Models

Planning, operations, markets, people, smarts, cyber, etc.

Conclusions

- 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