Operation and Planning in an All-Ireland Power System with Significant Wind Capacity

Ronan Doherty

Outline of Work

Market Environment

All-Ireland System – All-Island System

Operational Issues with Wind Power

1. Uncertainty of Wind Output – Reserve
2. Dynamic Frequency Control – Inertia

Energy and Generation Planning Issues

3. Optimal plant mix

   Diversify fuel sources – $C0_2$ Emissions – Indigenous supplies

Part 1. Wind Power Uncertainty

What if the wind power suddenly goes to zero ?

Managing Wind Power Uncertainty

~~What if the wind power suddenly goes to zero ?~~

What is the probability that the wind power suddenly goes to zero ?

Managing Wind Power Uncertainty

~~What if the wind power suddenly goes to zero ?~~

What is the probability that the wind power suddenly goes to zero ?

- Probabilistic Approach Adopted
- Can't consider wind uncertainty in isolation
  - Load
  - Conventional Generation

Outline of Methodology

Required System Reliability / Willingness to Pay for Reliability

Wind Variation and Forecast Information

Load Variation and Forecast Information

Conventional Generation Inforamtion and Outage Probabilities

Probablistic Calculations

$$PLSNO_h = \left(\prod_{i=1}^{G}(1-FOP_{i,h})\right)\left(\prod_{i=1}^{G}(1-POP_{i,h})\right)\left(1-\Phi\left(\frac{R_h}{\sigma_{total,h}}\right)\right)$$

$$+\sum_{i=1}^{G} FOP_{i,h}\left(\prod_{\substack{j=1\\ j\neq i}}^{G}(1-FOP_{j,h})\right)\left(\prod_{\substack{j=1\\ j\neq i}}^{G}(1-POP_{j,h})\right)\left(1-\Phi\left(\frac{R_h-Pnafo_{i,h}}{\sigma_{total,h}}\right)\right)$$

$$+\sum_{i=1}^{G} POP_{i,h}\left(\prod_{j=1}^{G}(1-FOP_{j,h})\right)\left(\prod_{\substack{j=1\\ j\neq i}}^{G}(1-POP_{j,h})\right)\left(1-\Phi\left(\frac{R_h-Pnapo_{i,h}}{\sigma_{total,h}}\right)\right)$$

$$PLS_h = PLSNO_h + \frac{1}{2}(Hr)\left[FOP_{1,h}, FOP_{2,h}, ...FOP_{G,h}\right]\begin{bmatrix} PLSFO_{1,h} - PLSNO_h \\ PLSFO_{2,h} - PLSNO_h \\ : \\ : \\ PLSFO_{G,h} - PLSNO_h \end{bmatrix}$$

$$+\frac{1}{2}(Hr)\left[POP_{1,h}, POP_{2,h}, ...POP_{G,h}\right]\begin{bmatrix} PLSPO_{1,h} - PLSNO_h \\ PLSPO_{2,h} - PLSNO_h \\ : \\ : \\ PLSPO_{G,h} - PLSNO_h \end{bmatrix}$$

System Reserve Requirements

Illustration of Results

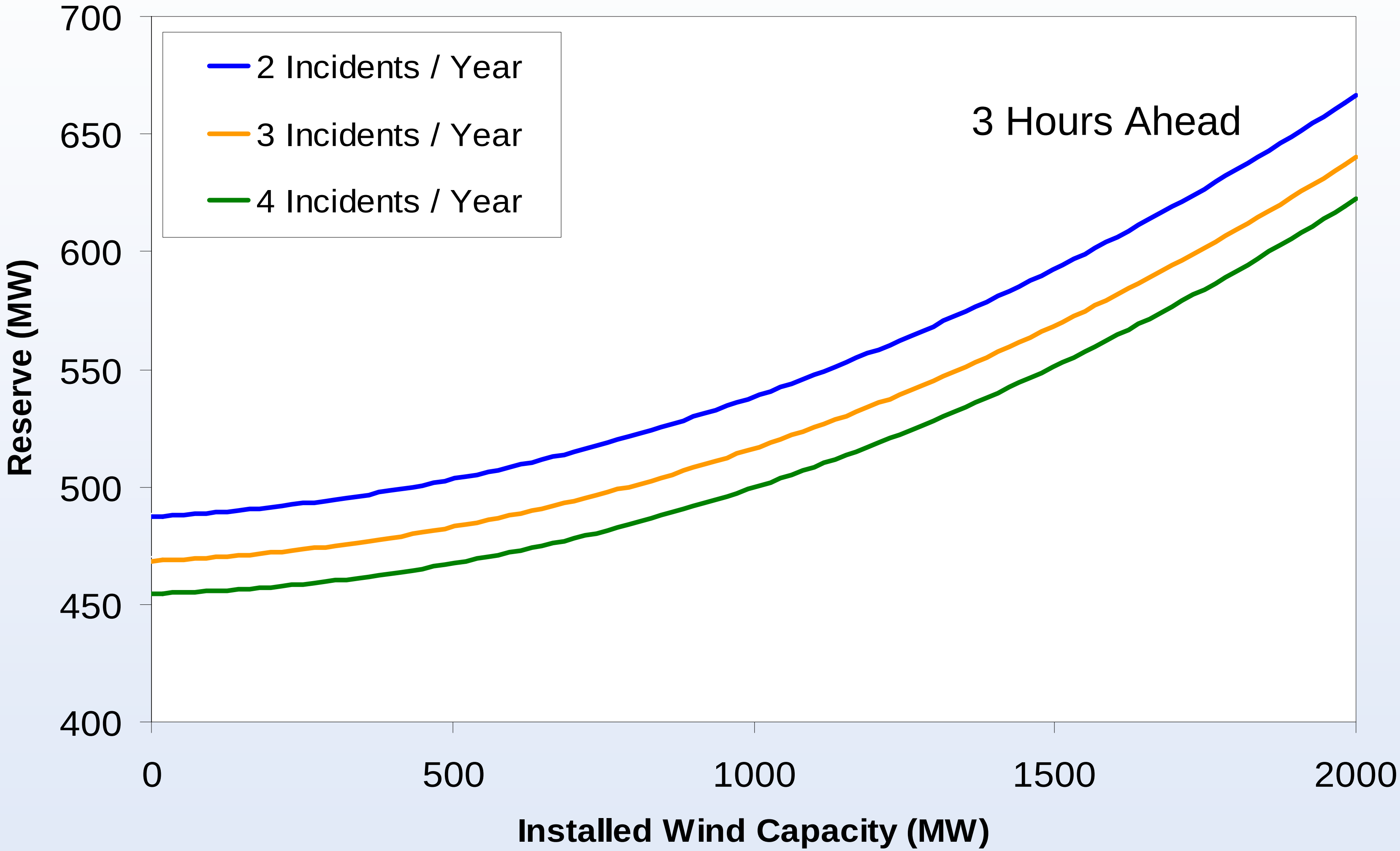
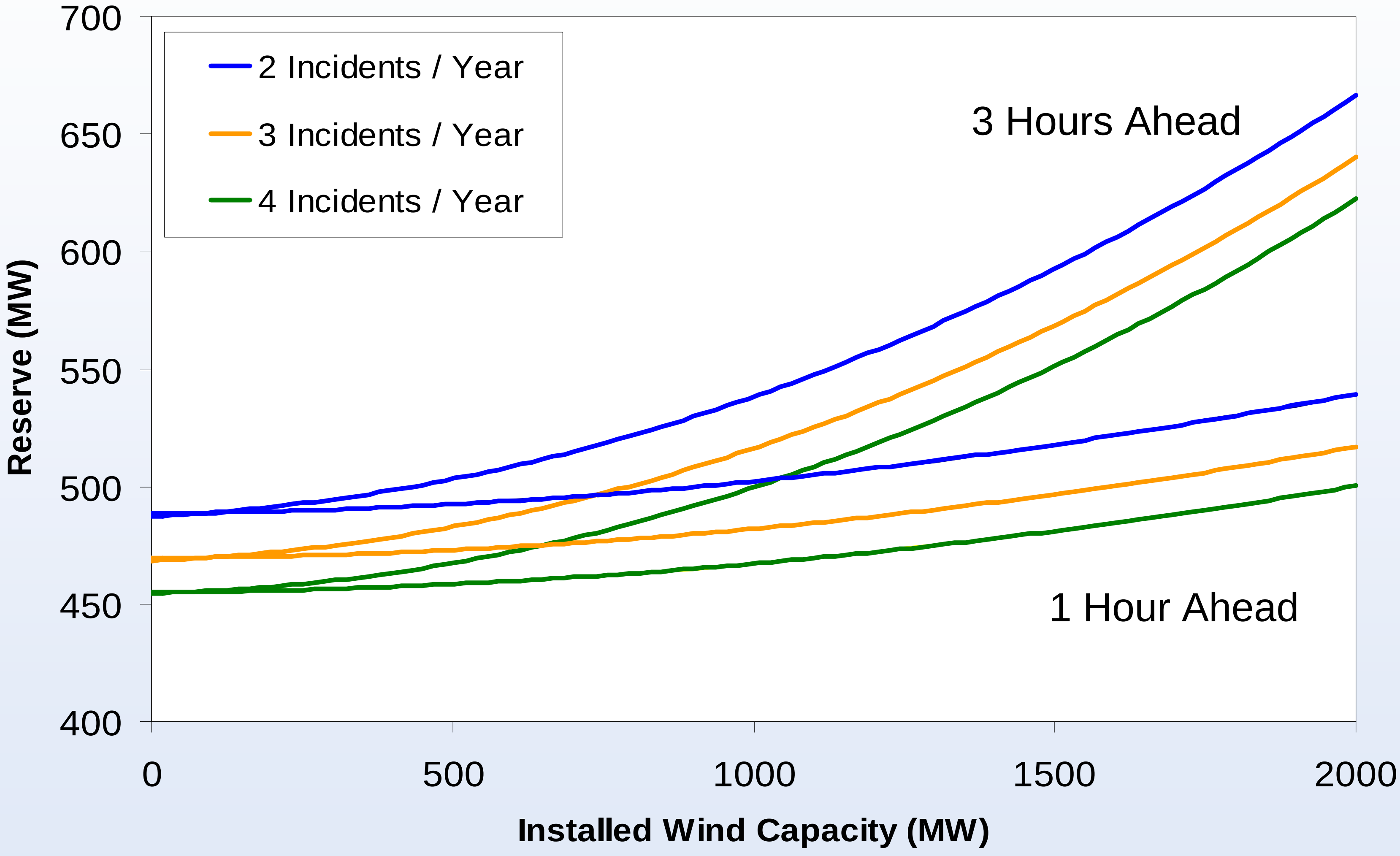
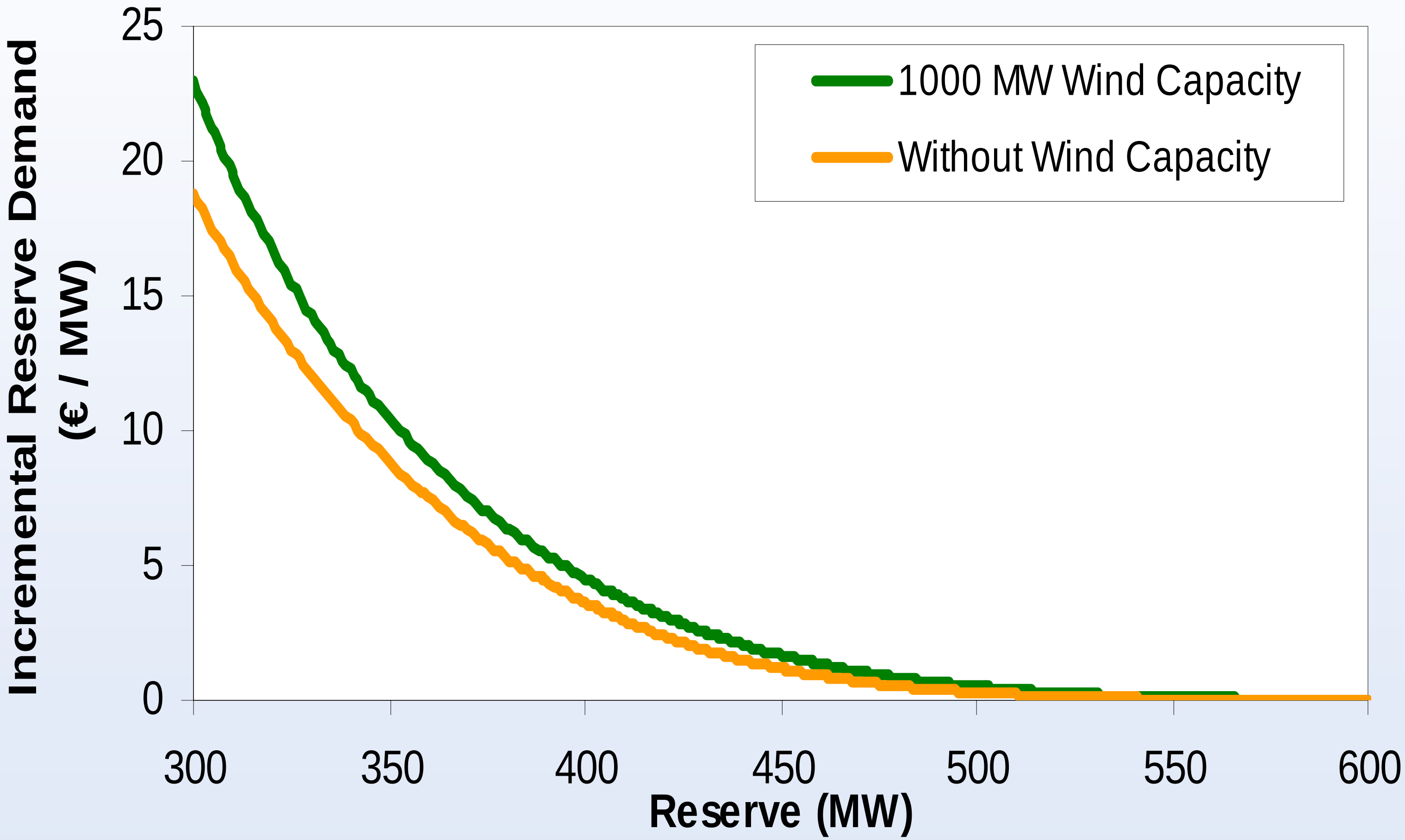


Illustration of Results



Reserve Demand Curve

1 Hour Reserve & VoLL = € 7000



Managing Wind Power Uncertainty

- Doherty, R. and O'Malley, M., "Quantifying Reserve Demands due to Increasing Wind Power Penetration", IEEE Power Tech Bologna, Italy, June, 2003.

- Doherty, R., Denny, E., and O'Malley, M. "System Operation with a Significant Wind Power Penetration" accepted for IEEE Power Engineering Society General Meeting, Denver, Colorado, USA, June 2004.

- Doherty, R., and O'Malley, M. "A New Approach to Quantify Reserve Demand in Systems with Significant Installed Wind Capacity", IEEE Transactions on Power Systems, (in Press) 2004.

- "Operating Reserve Requirements as Wind Power Penetration Increases in the Irish Electricity System" SEI contract by ILEX, UCD, Queen's, and UMIST

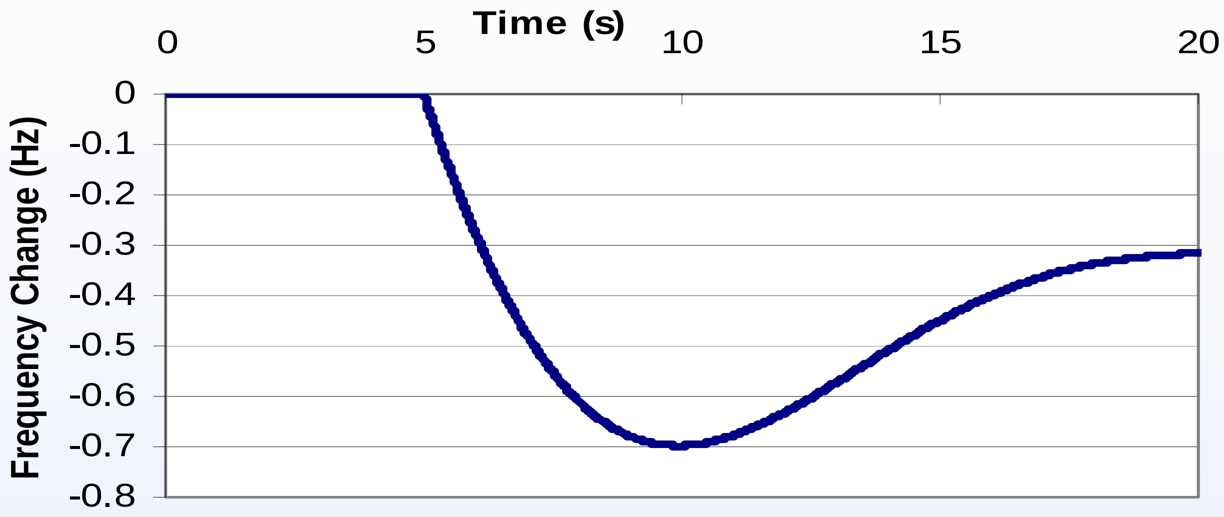
Part 2. Dynamic Frequency Control Problem

Future large amounts of generation with no "natural" Inertia and reserve providing facilities.

1000 MW Interconnection

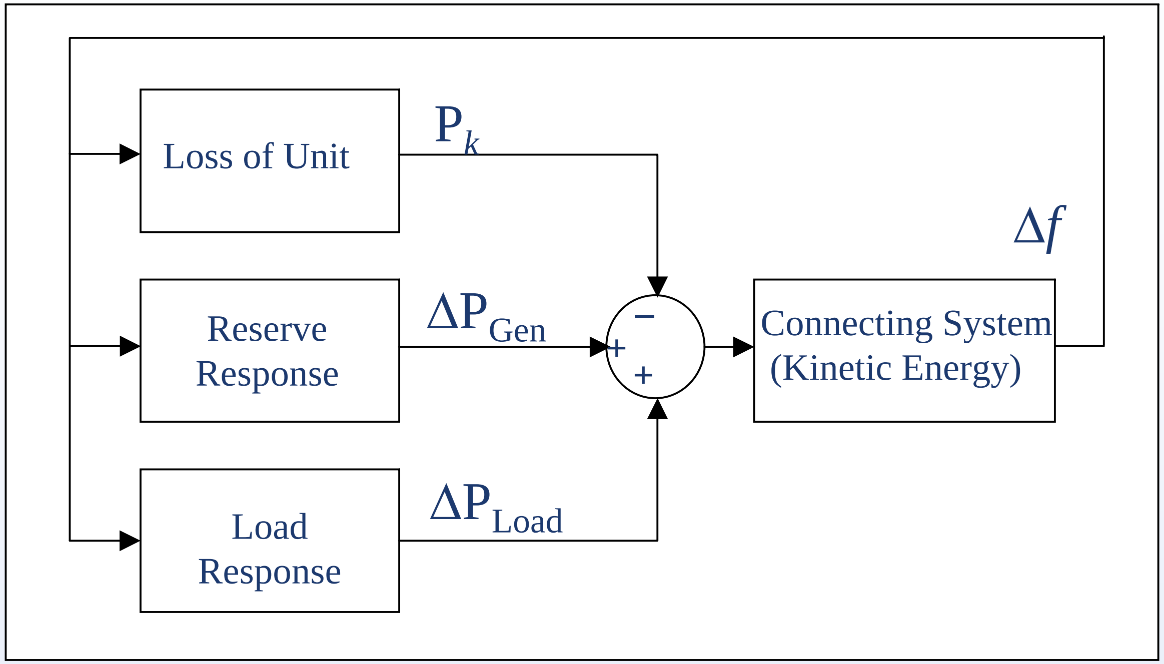
1000+? MW Wind Capacity

Establishing the Constraints

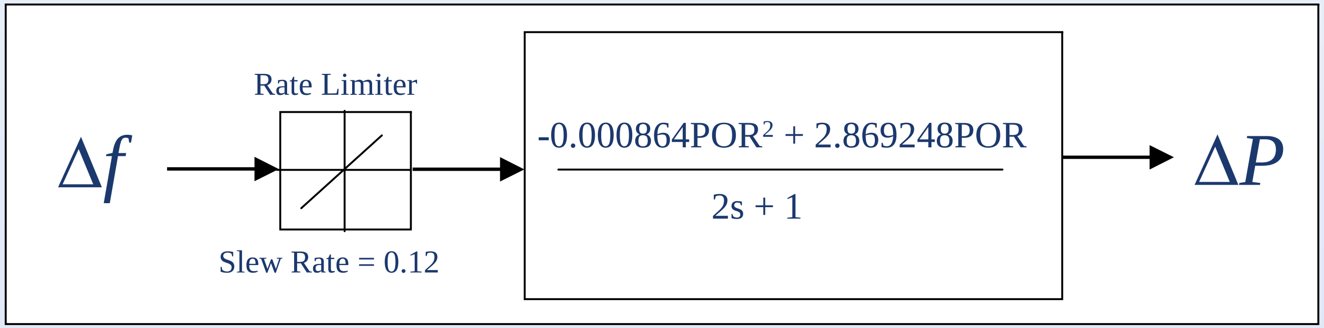


- (LOAD, P*units*, R*units*, KE*units*)
- Market Compatible (LP constraints)

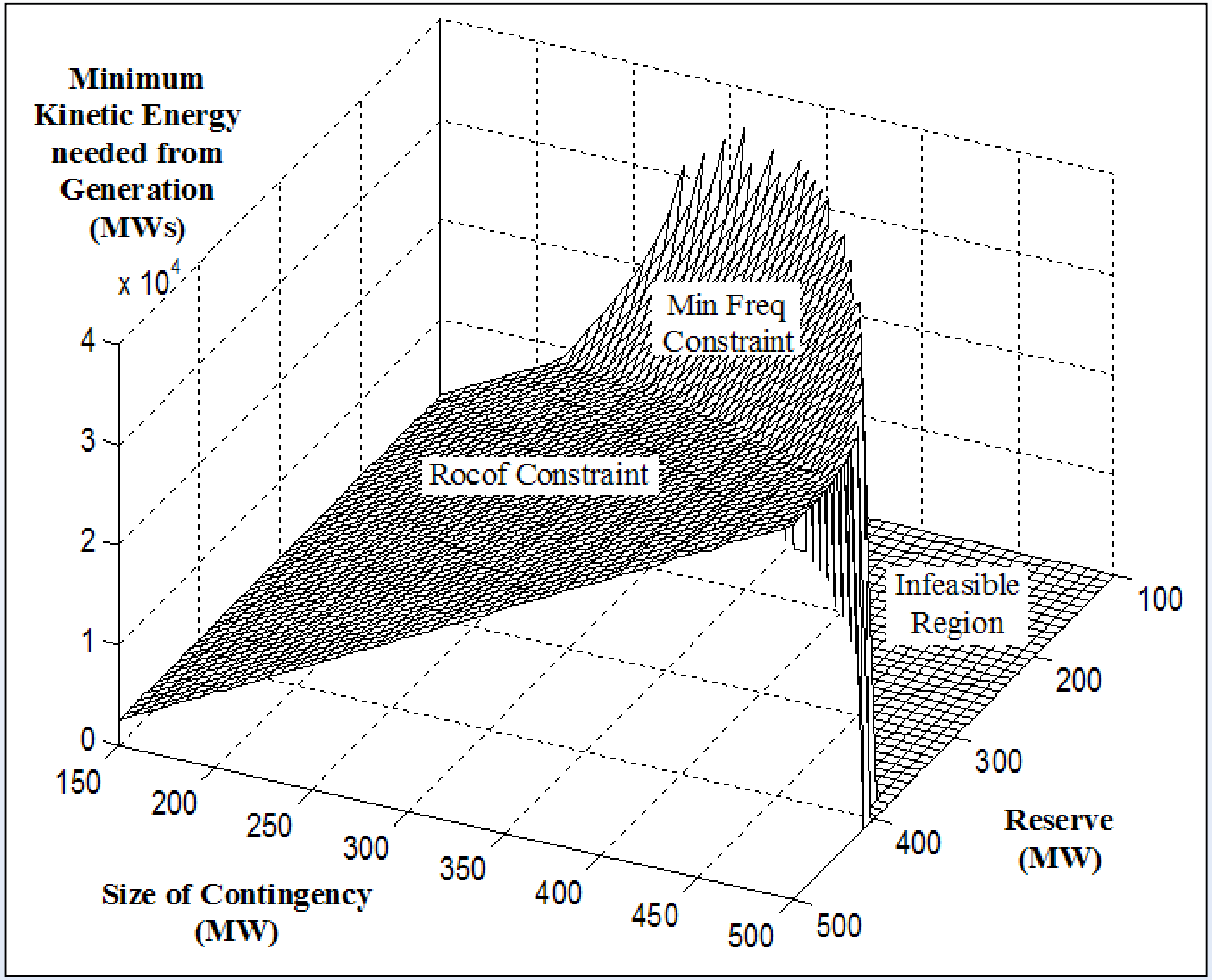
System Model



Reserve Response



4-D Constraints (in 3-D)



Formulating Constraints for LP Dispatch

- ROCOF constraint

$$\sum_{\substack{i \in G \\ i \neq k}} KE_i \geq 100P_k - 2.5L \quad \forall\, k \in G$$

- Min Frequency constraint

$$\sum_{\substack{i \in G \\ i \neq k}} KE_i \leq C_{j,1}L - 2.5L + C_{j,2}P_k + C_{j,3}\sum_{\substack{i \in G \\ i \neq k}} R_i + C_{j,4} \quad \forall k \in G, \quad \forall\, j$$

$$C = \begin{bmatrix} -5.33 & 230.93 & -124.89 & -834.79 \\ -5.56 & 248.35 & -150.80 & -580.40 \\ -4.69 & 182.40 & -67.61 & -832.85 \\ -4.84 & 198.17 & -76.98 & -2887.29 \\ -4.48 & 175.78 & -52.08 & -4143.23 \end{bmatrix}$$

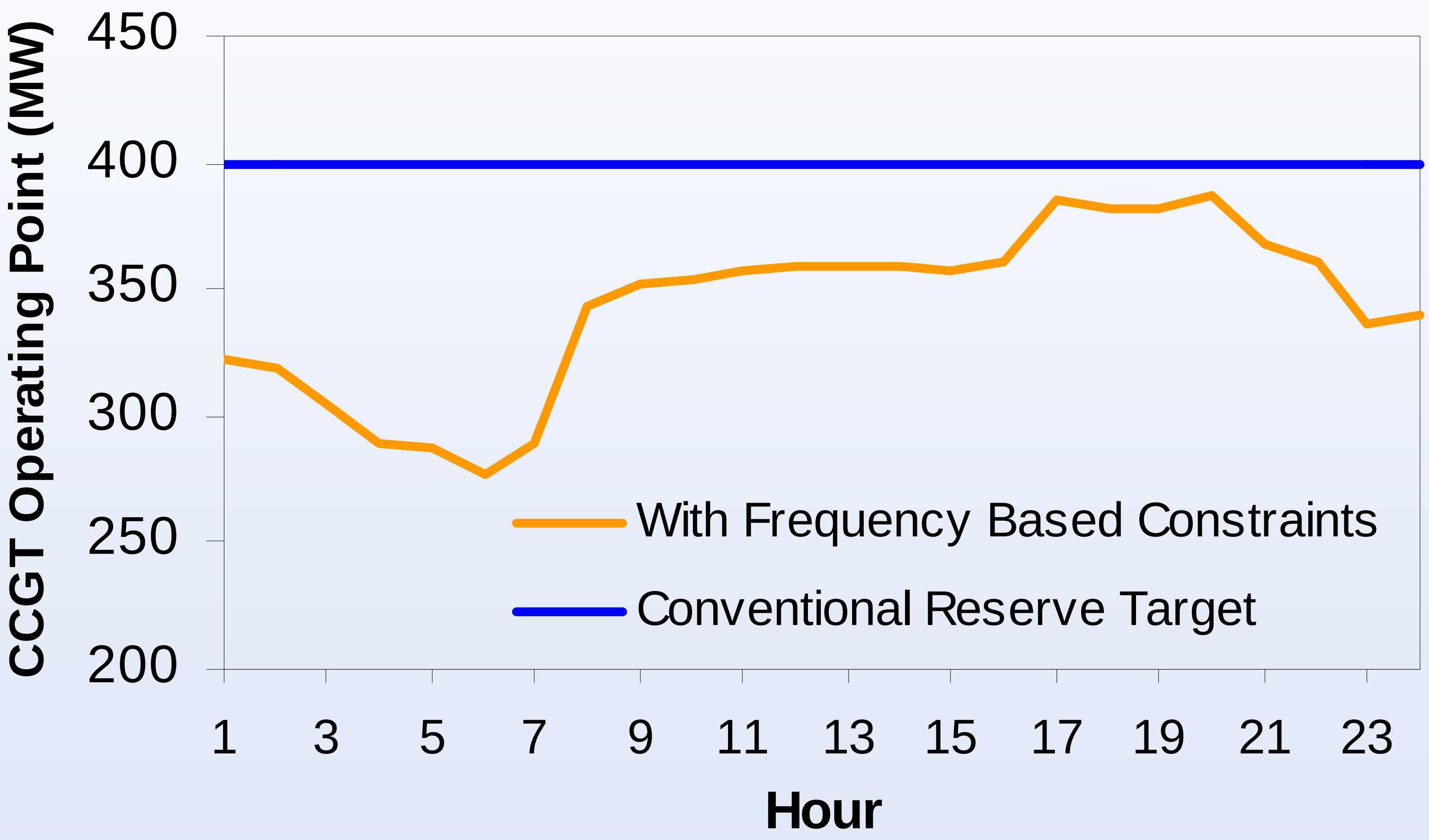
Performance on All-Ireland System

0.3% Increase in Cost of Dispatching the System over the Test Days

Reserve Target Approach cannot Ensure System Security

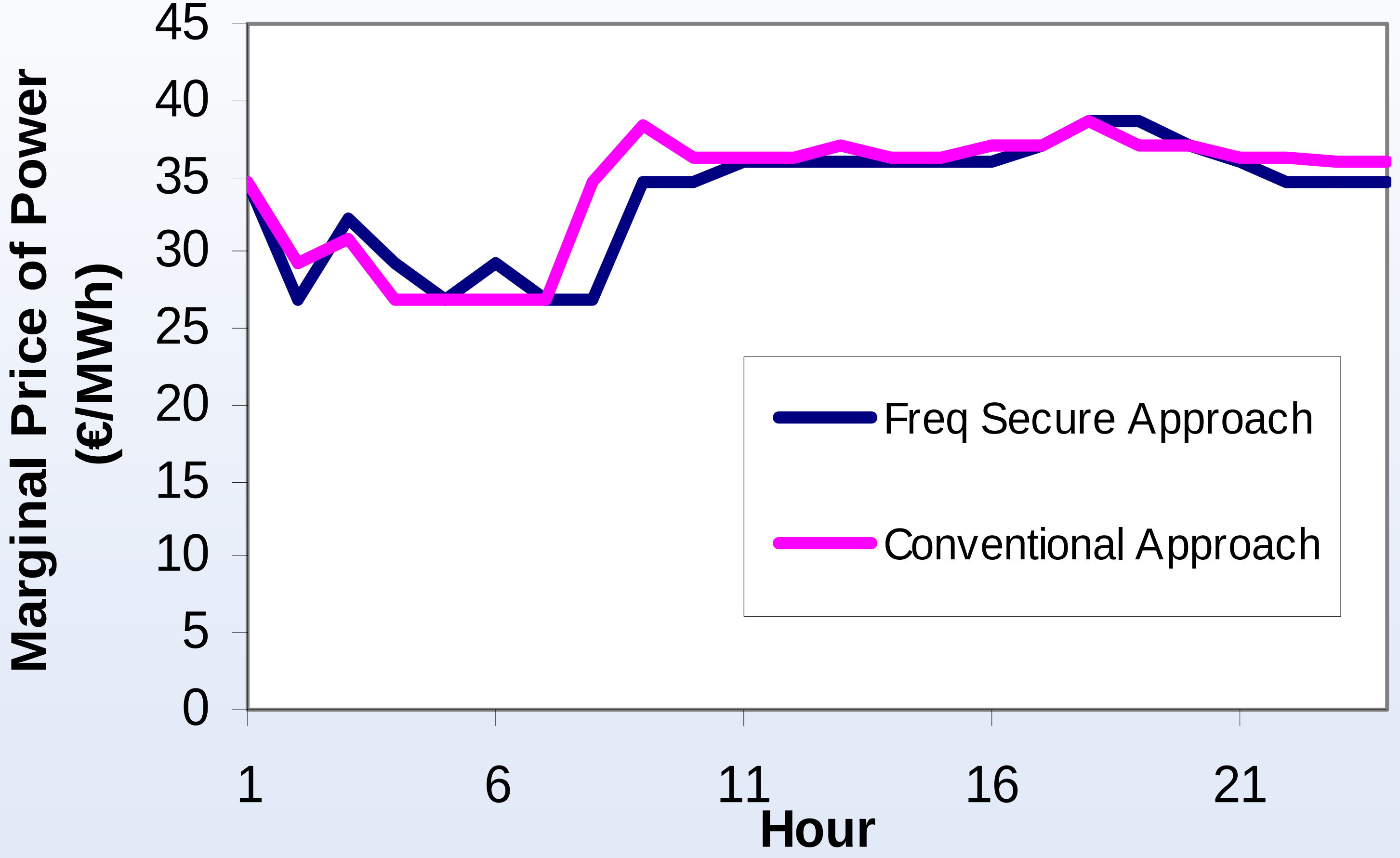
Performance of Frequency Security Constraints

January 2004



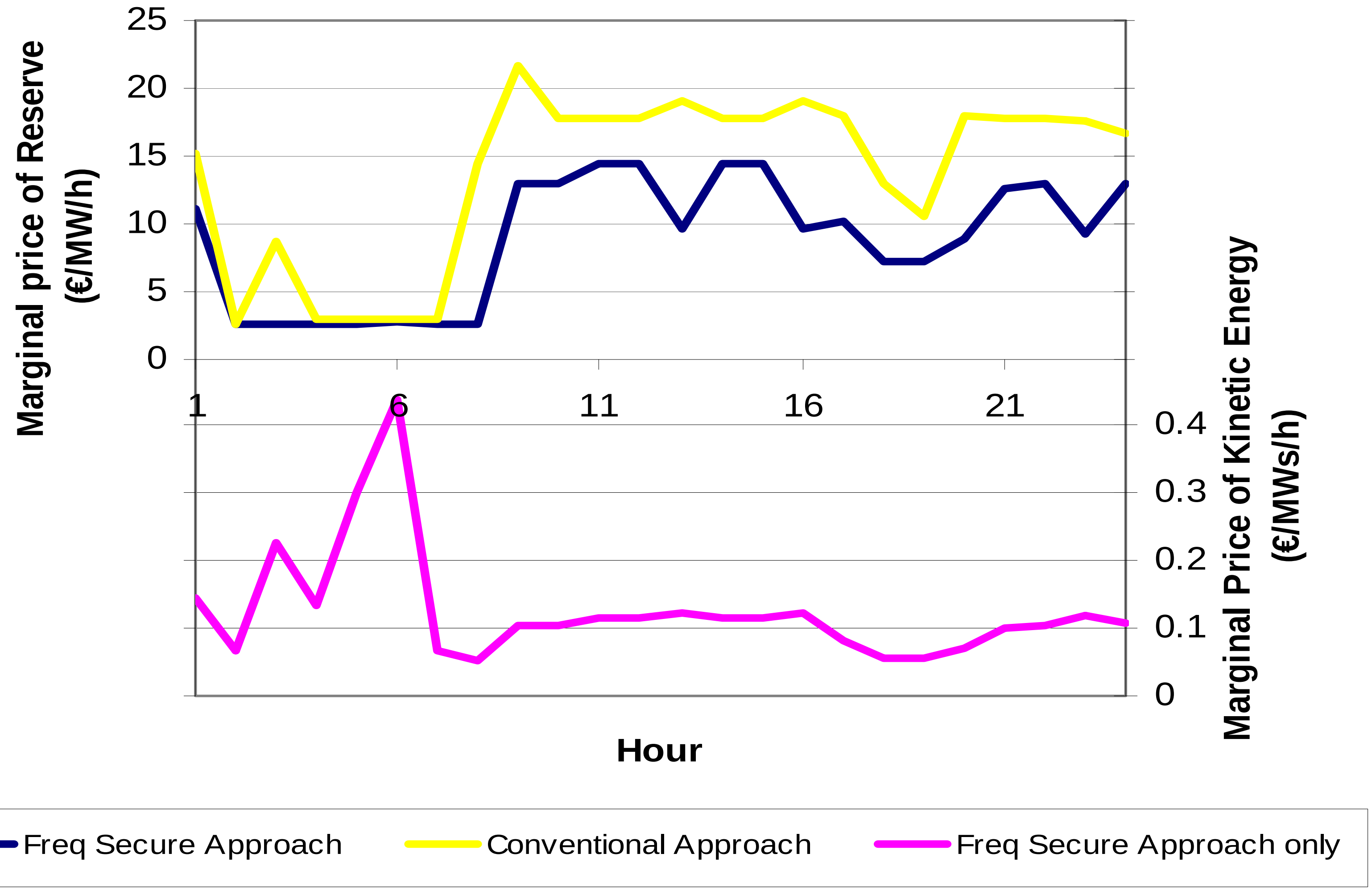
Market Prices

January 2004



Market Prices

January 2004



Dynamic Frequency Control Problem

- Doherty, R. Lalor, G. and O'Malley, M., “Frequency Control in Electricity Market Dispatch", IEEE Transactions on Power Systems (in Press) 2005.

Part 3. Energy and Generation Planning

Optimal plant mix:

- Diversify fuel sources
- $C0_2$ Emissions
- Indigenous supplies
- Year 2020

Different Type of Problem

No Single Solution – Several Assessments and Insights into Problem from Different View Points

Approach to Work

Dual Approach

1. Formal Optimisation Algorithm to Solve for "Optimal" Generation Portfolio

2. Series of smaller studies on aspects of generation planning
    1. High Level Analysis of Generation Planning and Policy
    2. Uncertainty and Discounting
    3. Portfolio Management and Multi Objectives
    4. Primary Energy Infrastructure

Work So Far

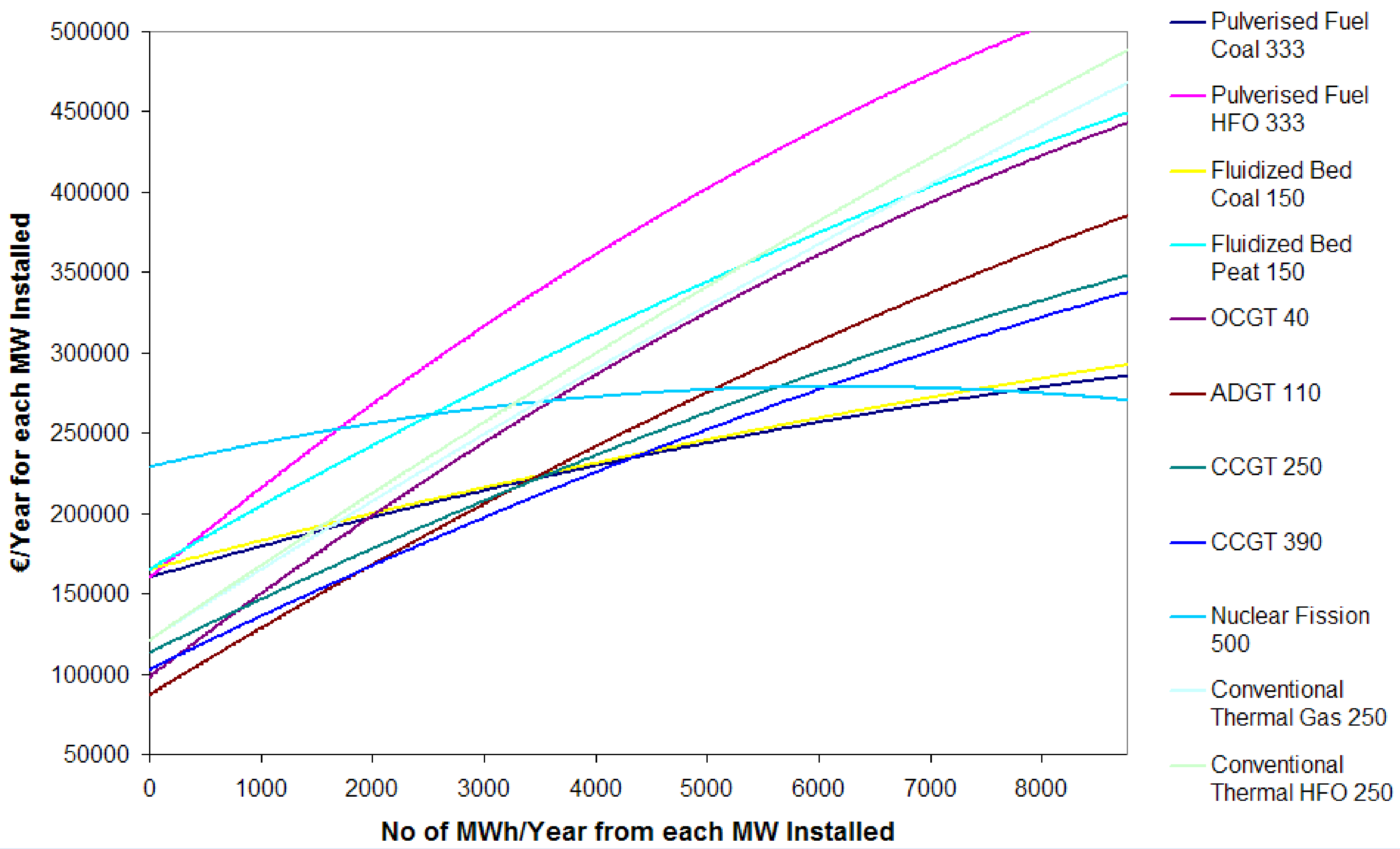
Extensive Input Data Collected Inputs:

- Plant costs, characteristics, projected utilization
- Capacity credit, & start-up costs
- Load, Wind and Tidal profiles
- Fuel price characteristics
- Emissions characteristics

- Insight into the stochastic nature of the problem
- Comprehensive capacity studies for wind and tidal
- Developed an Optimisation Algorithm for solving for the optimal generation plant portfolio

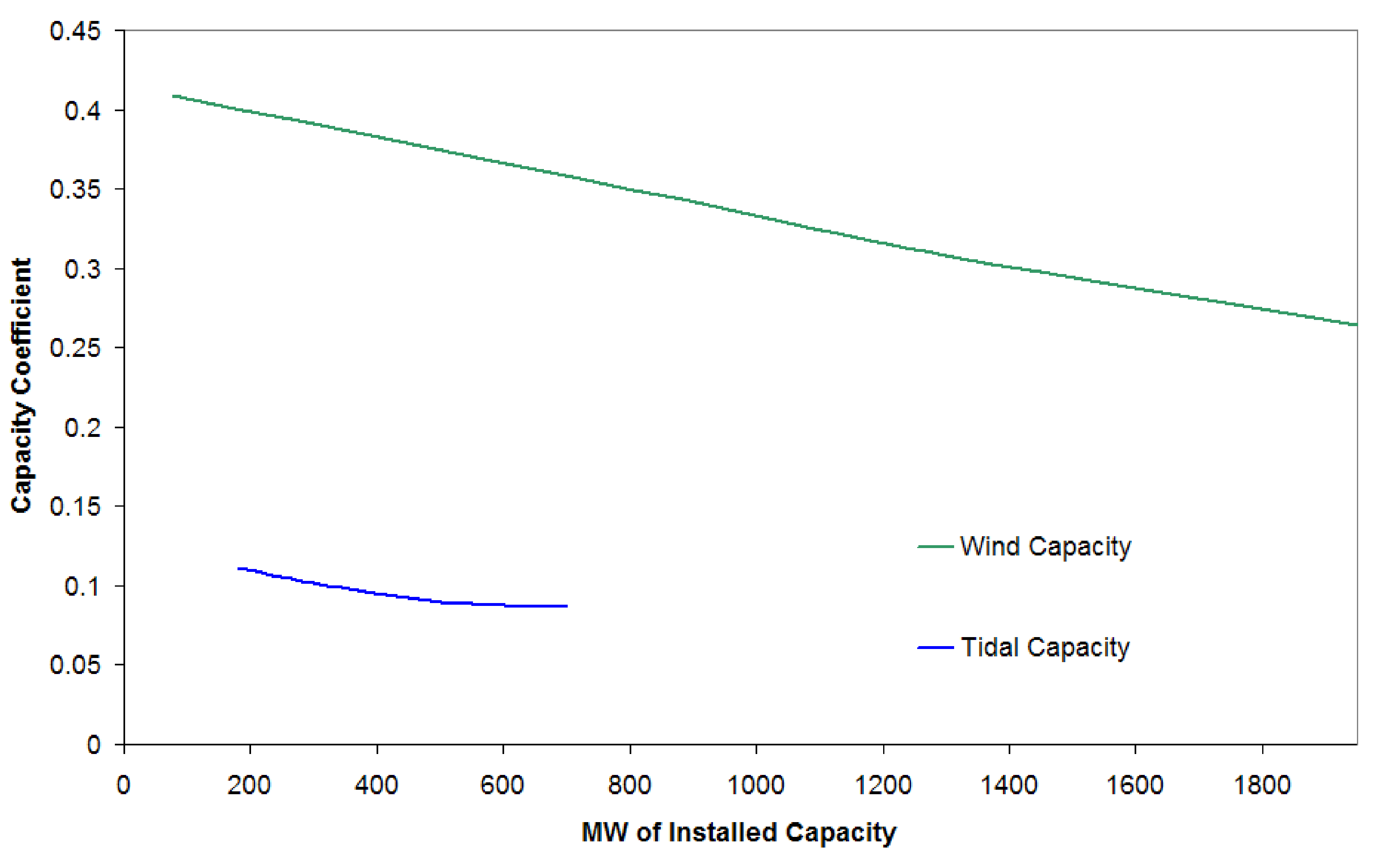
Work and Preliminary Results

Generation Inputs – Includes Quadratic Approx of Start Costs



Work and Preliminary Results

Capacity Studies for Wind and Tidal



Preliminary Results

Preliminary Results from LP Algorithm

Assuming: Current Fuel Prices

Current Hydro and 800MW Interconnection

Scenario 1 : No Carbon Tax

6031 MW – Coal	
286 MW – CCGT	**Average Cost**
2475 MW – OCGT	**37.16 €/MWh**

Preliminary Results

Scenario 2 : Carbon Tax: 20€ / Tonne $C0_2$

6593 MW – Nuclear   Average Cost

2199 MW – OCGT   38.08 €/MWh

Scenario 3 : 20€/ Tonne $C0_2$ & No Nuclear

6317 MW – CCGT

2475 MW – OCGT   Average Cost

1200 MW – Wind   47.97 €/MWh

Preliminary Results

Scenario 4 : 20€/ Tonne $C0_2$ & No Nuclear & 45% Limit on Energy from Single Fuel

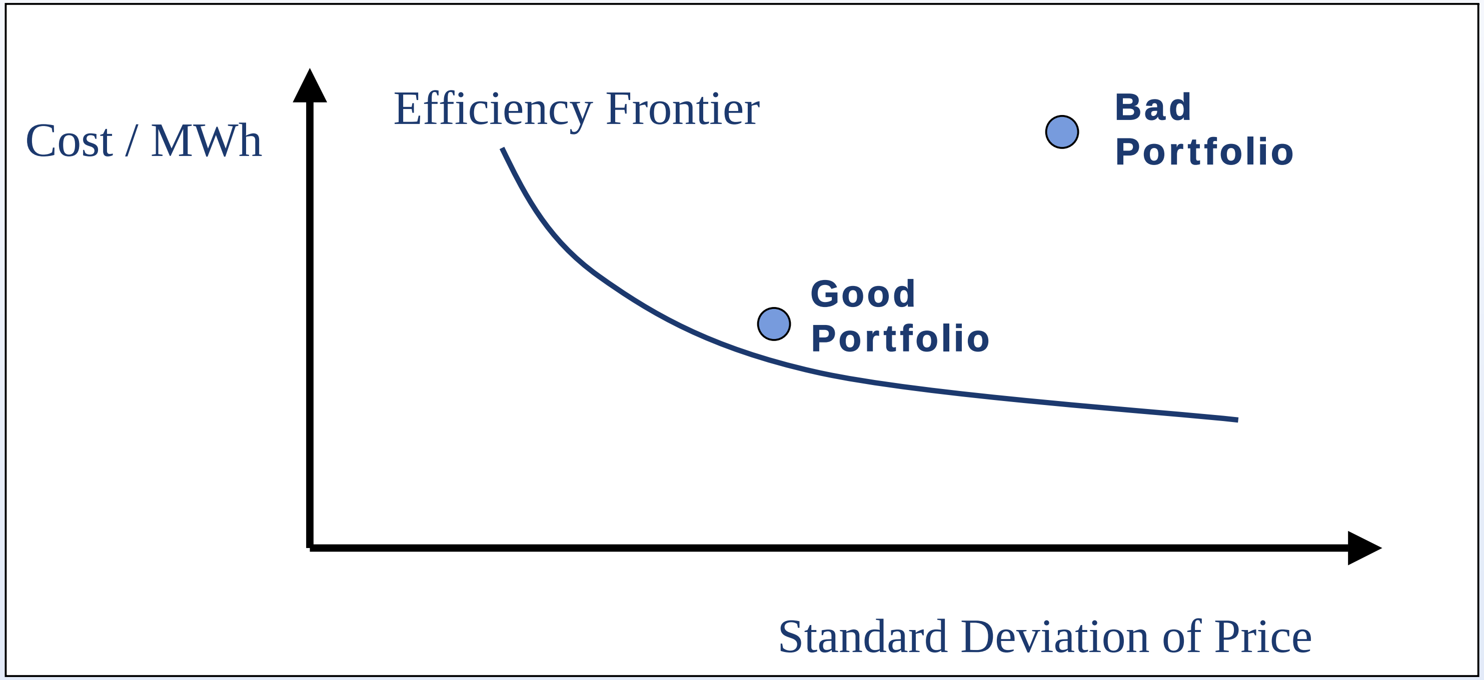
3231 MW – Coal	
2498 MW – CCGT	
2475 MW – OCGT	Average Cost
1600 MW – Wind	51.08 €/MWh

Nuclear Option: 38.08 €/MWh

Further Work on Optimisation

Use a QP algorithm:

Other Objectives



Other Policy Considerations

Process of Generation Planning

What is needed in Ireland ?

Limitations of Market Based "Planning" in Ireland

- Carbon Tax
- Diversity of Energy Supply

Setting and implementing policy

- Market Design
- Direct Investment
- Subsidisation

Other Policy Considerations

Investment Uncertainty and Discounting

High Uncertainty in Sector:

- Dominance
- Market Implementation & Design
- No Capacity Markets – No Constrained off Payments

Shortfalls of Standard Economic Techniques

- CER BNE Paper
- Discounting and Beta

Other Policy Considerations

Portfolio Considerations and Infrastructure

Examine the extra cost of having several Peat Stations

Benefits of Enabling Plant to Fuel Switch

- Price Benefits
- Storage Benefits

Contingency Planning

- e.g. Moyle Gas Outage
- Storage & Indigenous Energy
- Gas Infrastructure

Need and Benefits of LNG Infrastructure

- UK LNG Infrastructure

Summary

No Simple Set of Answers

Understand the Nature of the Challenges that Lie Ahead

"Illuminate the choices" that must be made in Energy Policy