Voltage Control Strategies for Distributed Generation

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Penetrations of DG Increasing

- DG increasing all the time
- As of July 2009
  - 796 MW DG installed
  - 512 MW Wind
- How is system operation and planning affected by such a large penetration of DG?

Original DG Strategy

- Fixed power factors (0.95 ind.)
- Counteract voltage rise effect on rural networks
  - MW injection causes voltage rise
  - MVAr absorption causes voltage drop
- Now new technologies employed (DFIG)
  - Variable reactive power control capability

System Requirements

- Requirements of system will/should drive everything
- Obvious requirement for supply demand balance
- Reactive power support poses interesting questions

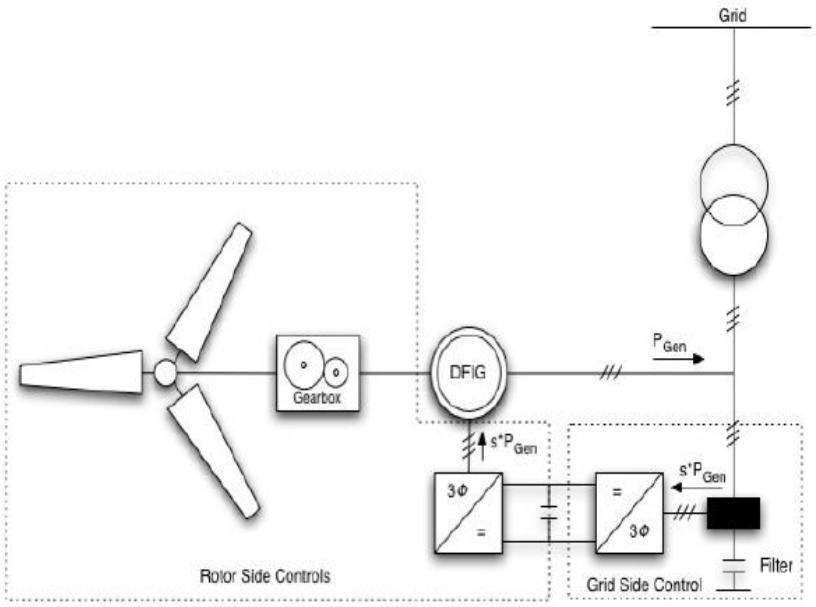
System Requirements

- Synchronous generation displaced by distributed generation
  - Not synchronously connected
  - No inertial response
  - Source of voltage support lost
- Power electronic converters can potentially provide these services
- How to manage them?

Distribution and Transmission

- Traditionally treated as separate systems independent of each other
- Distributed wind farms forcing a change in this philosophy
- DG reactive power draw will impact transmission system

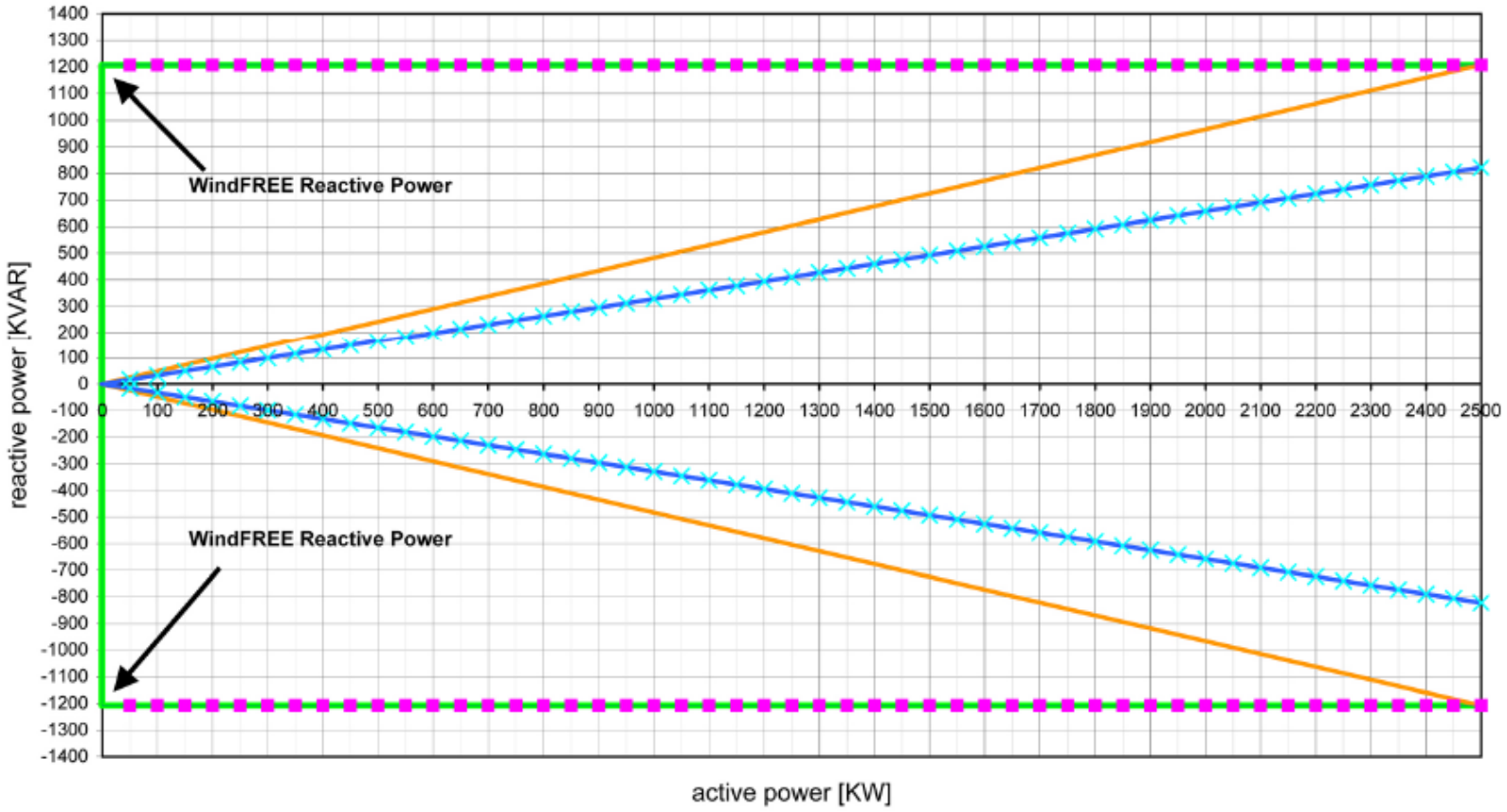
Turbine Types and Control



- The doubly-fed induction generator (DFIG) most commonly installed turbine in wind farms
  - Capable of providing voltage control
  - Operation and control of a large penetration of DFIGs will impact system stability
  - Correct implementation of voltage control can increase long-term small-disturbance stability margin of the system

Reactive Power Control Capabilities

- PQ capability curve of GE turbines



Source: www.ewea.org GE presentation

Reactive Power Control Capabilities

- What do we want to do with this capability?
  - Fixed PF
  - Terminal voltage control
  - Some other objective?

Voltage Stability

- If at 0.95 inductive
  - At times of high wind power output

  ⇒High reactive power demand from distribution network

- Excessive reactive power demands at remote locations could narrow voltage security margin

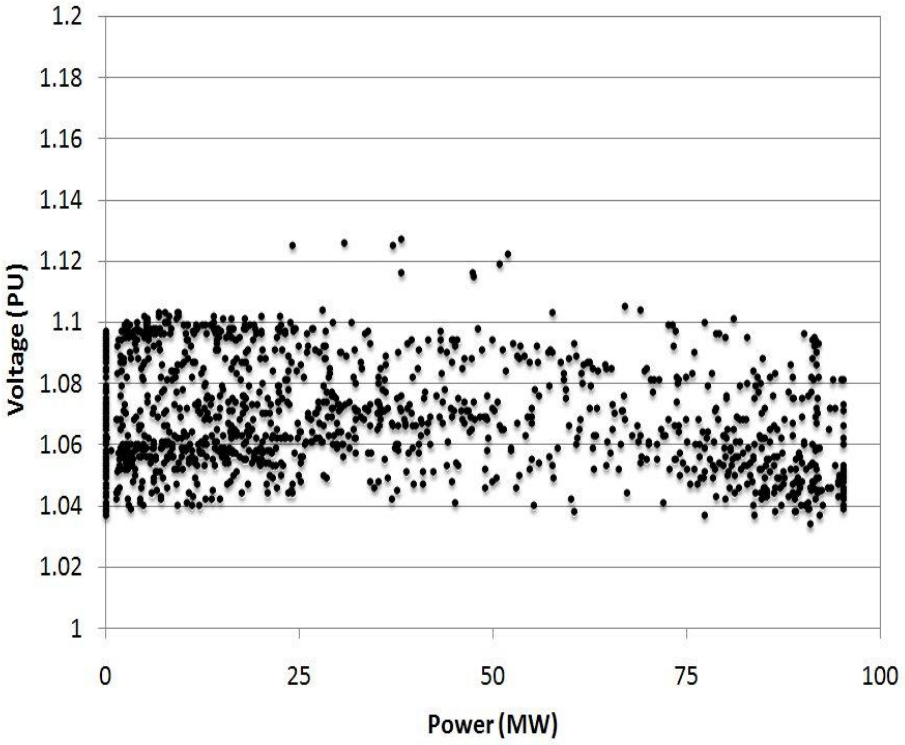
Transmission Time-Series power Flow Simulation

- Uses historical data to capture variability of the wind and load
- Realistically models behaviour of wind
- Unit commitment and economic dispatch
  - Balances load and variable generation
- Analysis completed around worst case operating point over a 5 year period
  - Where wind serves the largest % of load in the system
- Recorded voltage results and analyzed impact of turbine control on stability margin

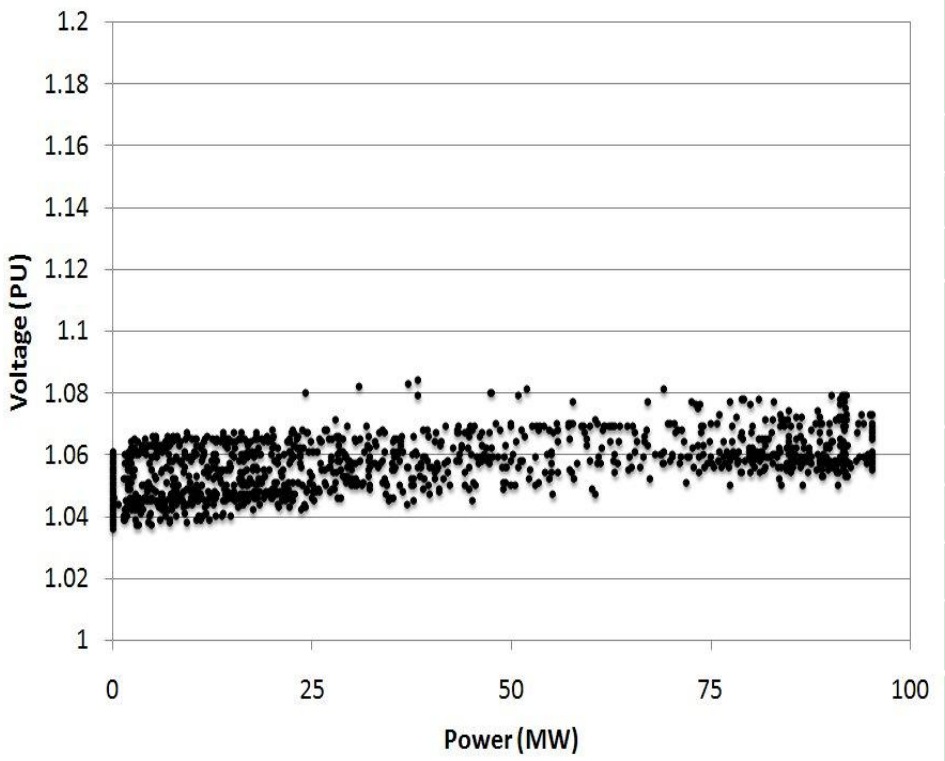
Impact of Wind Turbine Voltage Control

Two week period time series power flow simulation of Irish system

110 kV Bus –
Fixed PF Control

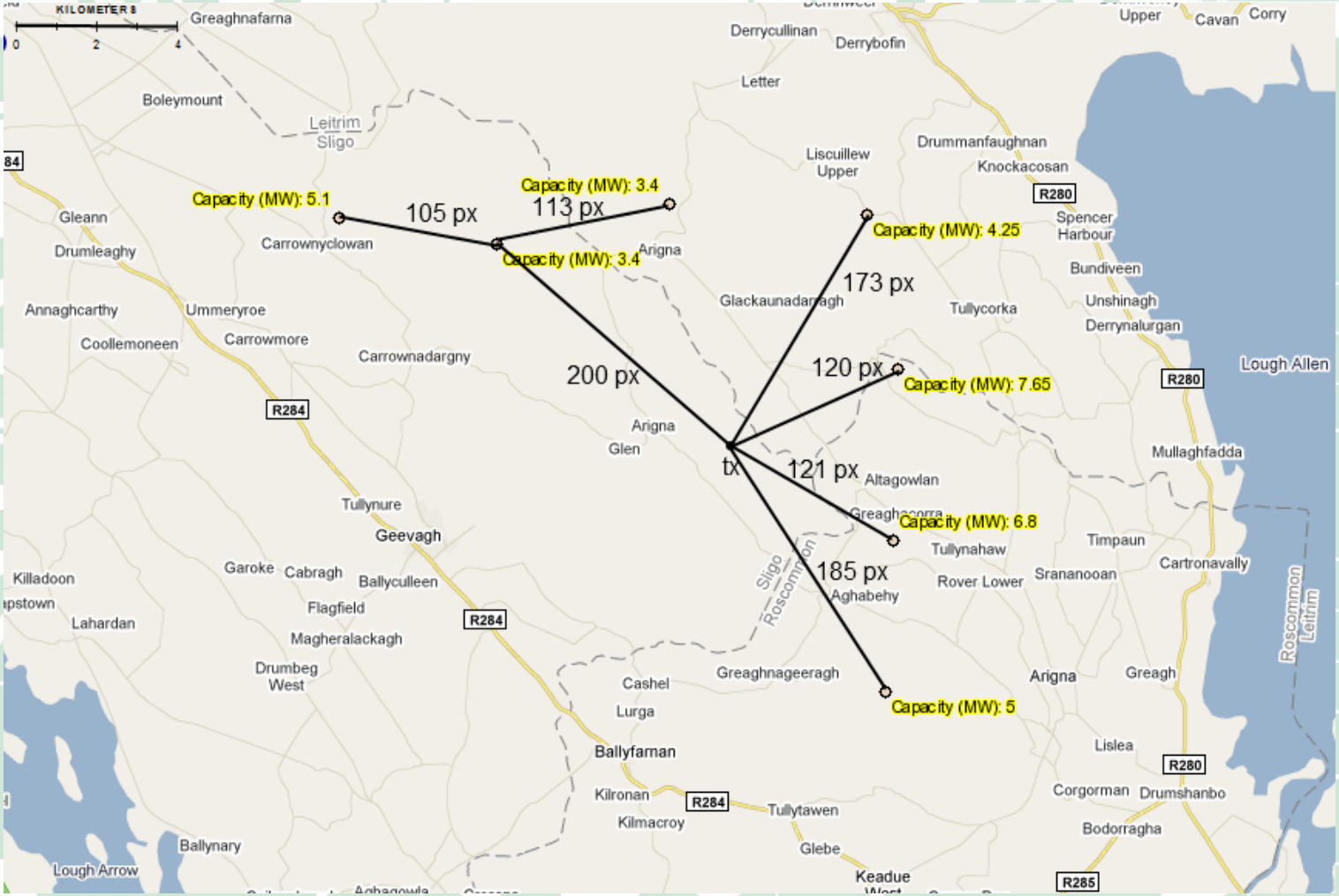


110 kV Bus –
Terminal Voltage Control



E. Vittal, M. O'Malley, and A. Keane, "A Steady-State Voltage Stability Analysis of Power Systems with High Penetrations of Wind," *IEEE Transactions on Power Systems,* vol. 25, no. 1, 2010

Distributed Wind Farm clusters

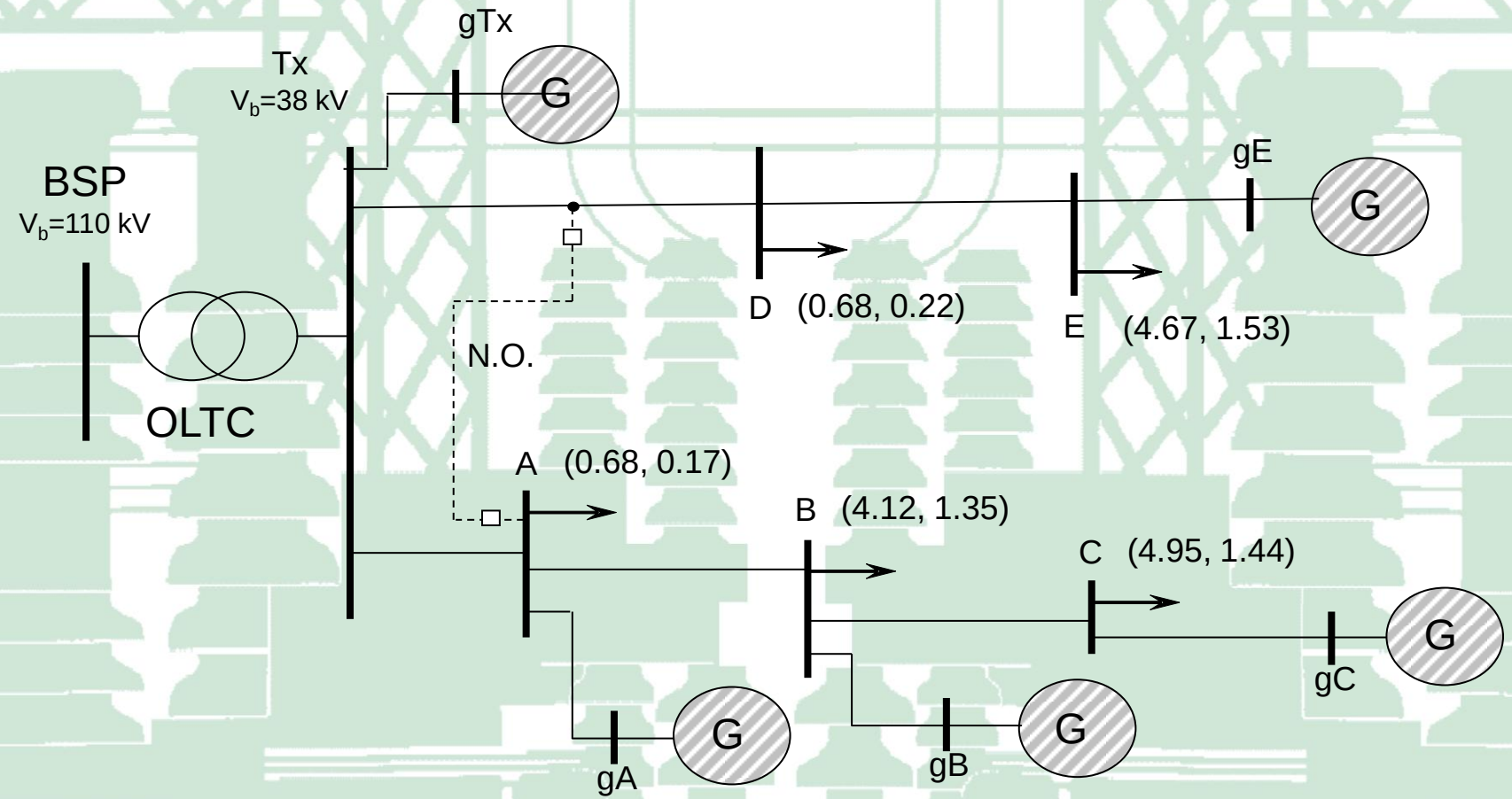


Power Factor selection

- Optimisation method to select DG power factors
- Maximise the reactive power export from distribution network section
- Subject to distribution voltage constraints
- Wind farm Q and trafo tap changer are variables

A. Keane, L. Ochoa, C Dent, E. Vittal and G. Harrison, "Enhanced utilisation of voltage control resources with distributed generation", IEEE Trans. Power Syst. (in press), 2010

Test Network



LEGEND	
A	Node Index
(P, Q)	Demand (MW, MVAr)

Optimised PF settings

Bus	P (MW)	PF
A	6	0.90 (Cap.)
B	5	0.93 (Ind.)
C	7	0.90 (Ind.)
D	0	-
E	8	0.94 (Ind.)
Tx	6	0.90 (Cap.)

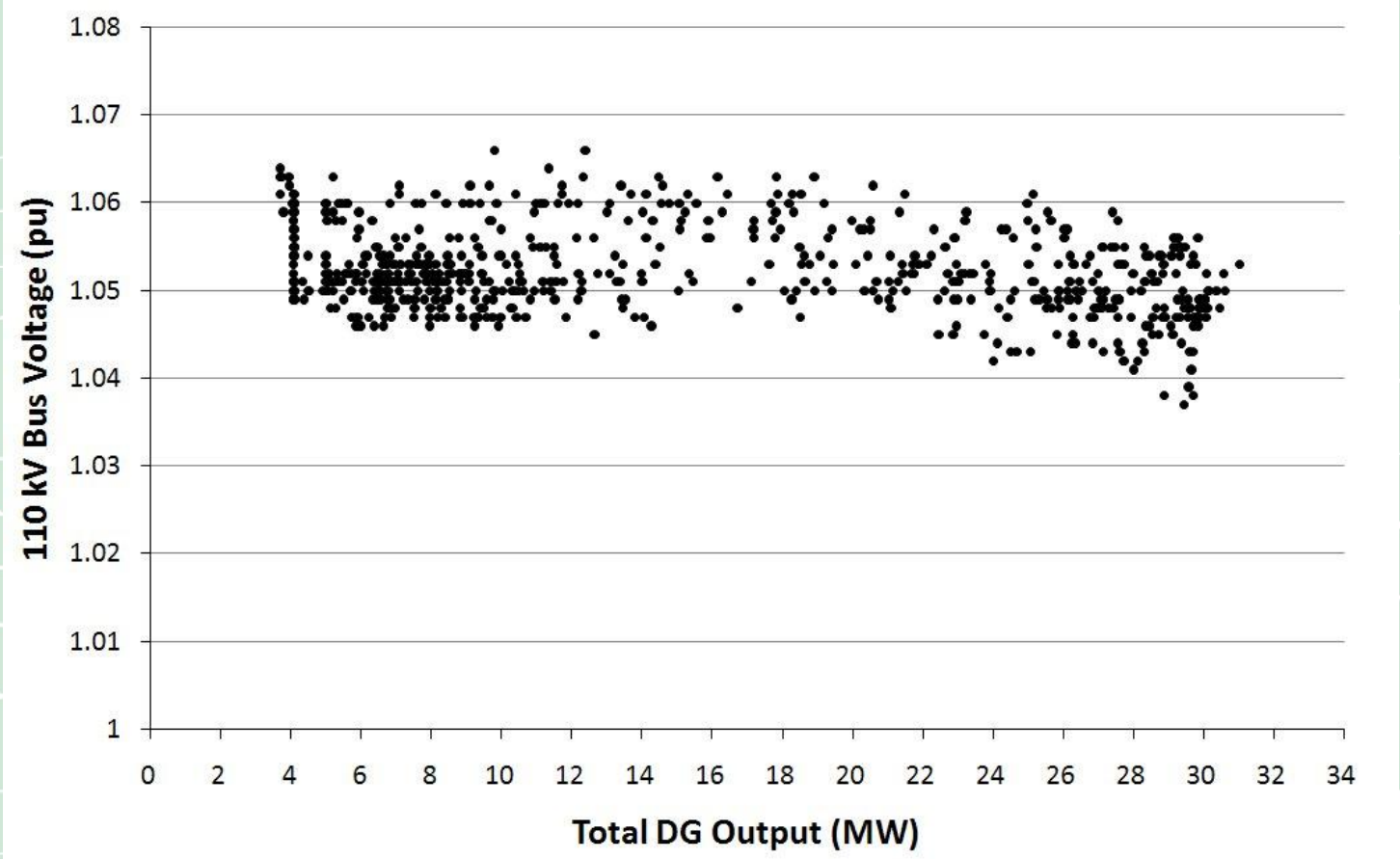
DG Capacity and Reactive Power

Enhanced PF	0.95 (Ind.)	Unity PF
32 MW	29.3 MW	22.4 MW

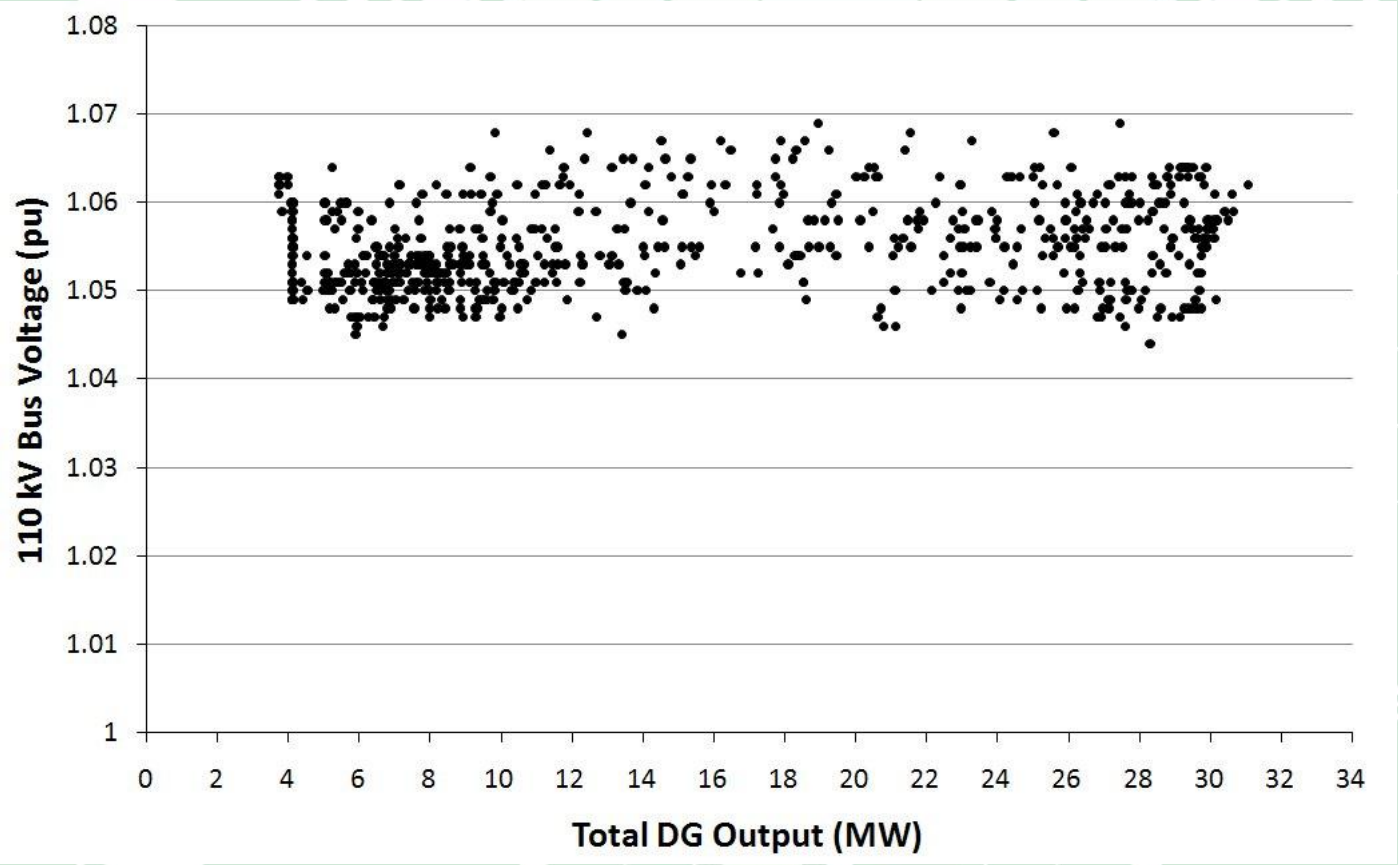
Q (MVArh)	No Wind	0.95 (Ind.)	Enhanced PF
Max	4.56	15.88	7.48
Min	1.01	1.02	1.02
Total	**22,110**	**66,069**	**39,919**

Fixed Inductive Power Factors

Two week time series power flow



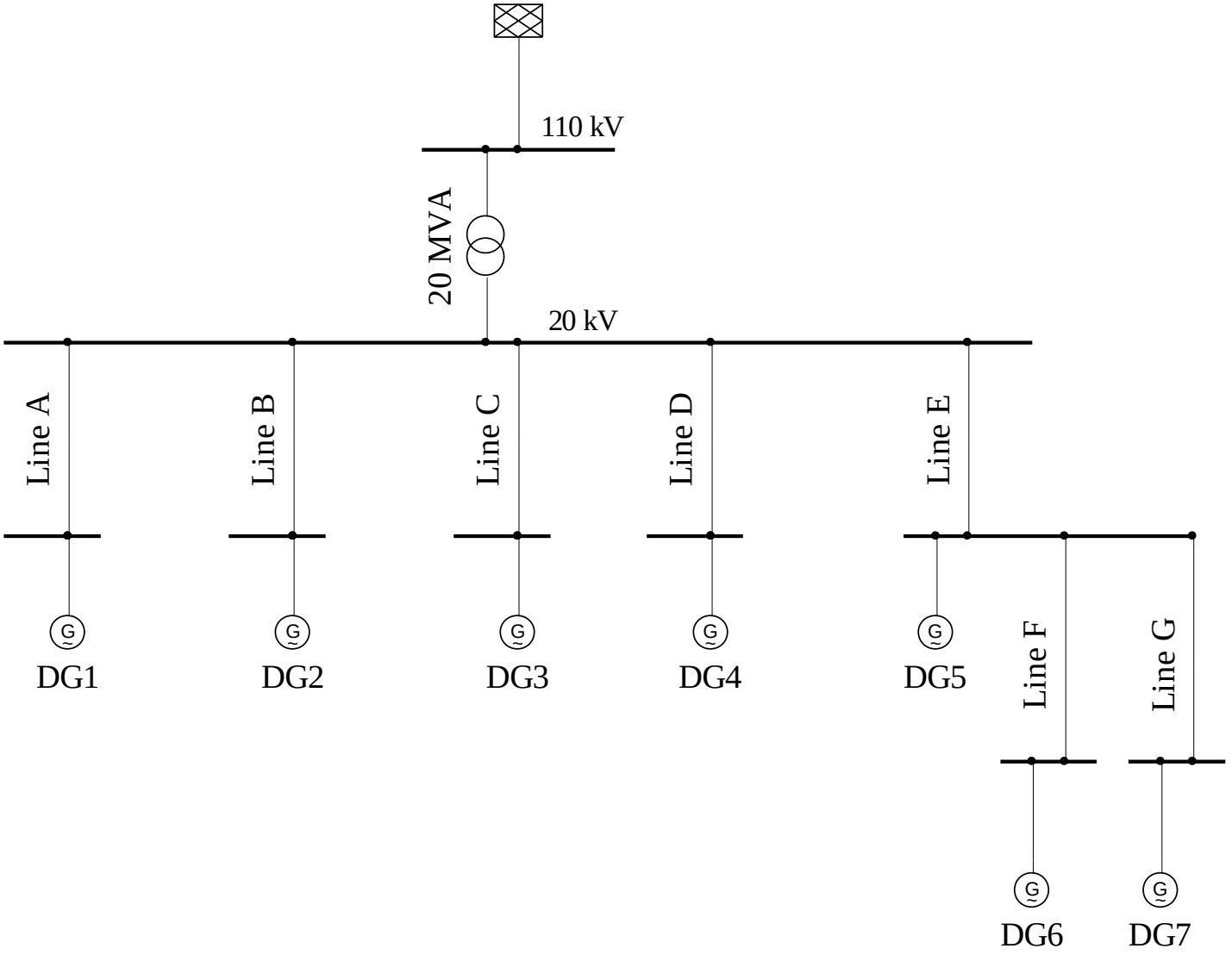
Optimised Power Factors



Network Dependency

- Reactive power dependent on a variety of factors
  - Network
  - Machine type
  - Active power output
- To what extent do these factors affect P-Q capability?

Sample Wind Cluster

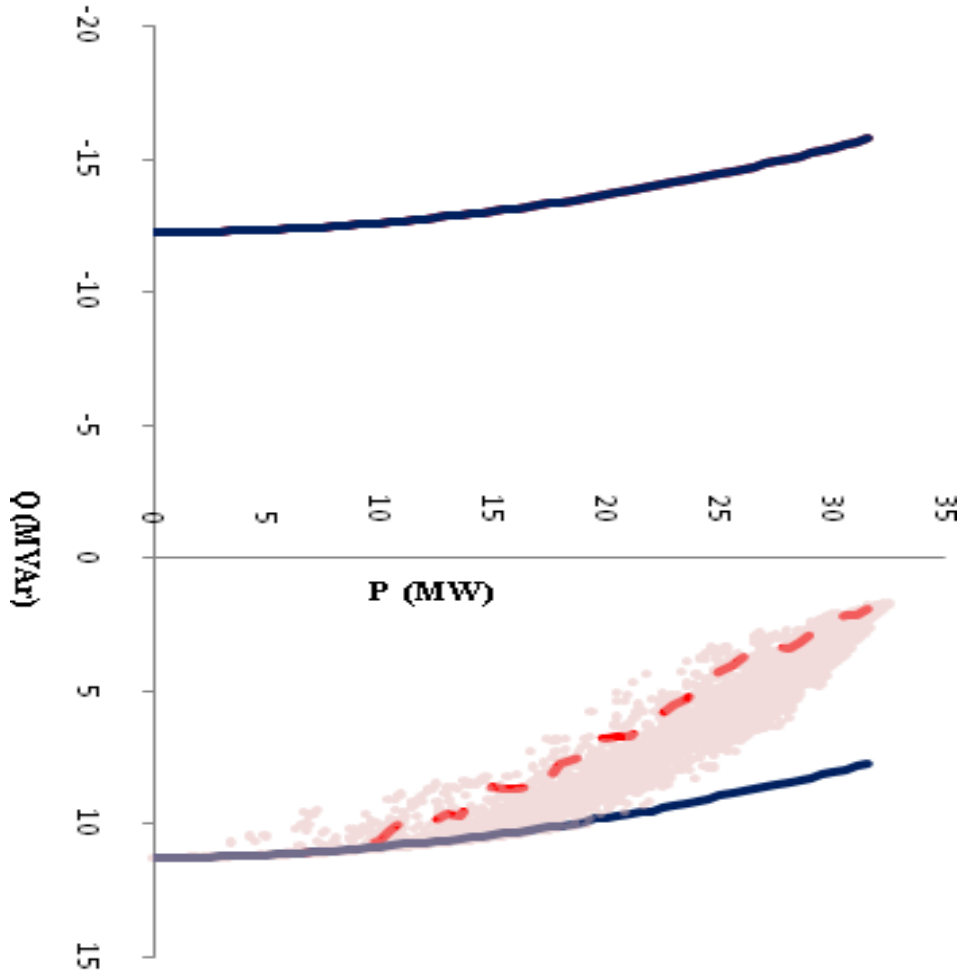


Method

- Enable active voltage control at each wind farm
- Control local voltage to max allowable level (1.07 pu)
- Run annual time series power flow to assess impact

Network Dependency

Annual time series power flow



Reactive power statistics

Time series power flow calculation for a single year

Network A	Max Q export (MVArh)
Distribution Voltage Constrained	82,445
Not Voltage Constrained	91,528
0.95 ind.	-

Summary Results

- Terminal voltage control is a good idea
- Distributed wind can support transmission system and distribution system simultaneously
  - Limits to this capability
- Need complete assessment of system performance

Acknowledgements

erc
electricity research centre

http://ucd.ie/erc

EirGrid

EPRI

ESB Networks

sfi
science foundation ireland
fondúireacht eolaíochta éireann

NDP
National Development Plan 2007 - 2013