Synthetic Inertia

SUPERGEN WIND CONSORTIUM 6TH EDUCATIONAL SEMINAR

LOUGHBOROUGH UNIVERSITY – 12TH SEPTEMBER 2011

Inertia

- Inertia can be seen as the "resistance to change"
- Inertia prevents the grid frequency suddenly changing and results from synchronous machines having large, heavy, rotating generators
- Asynchronous machines, such as variable speed wind turbines, do not contribute to grid inertia
- As the UK aims for 20% renewable electricity supply by 2020, power from wind turbines will make up a larger percentage of the produced power. Unless they can produce a synthetic inertia, the inertia of the grid will be reduced

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Synthetic Inertia

- Inertia can be seen as the conversion of kinetic energy of the rotating mass to electrical energy, causing the frequency to drop.

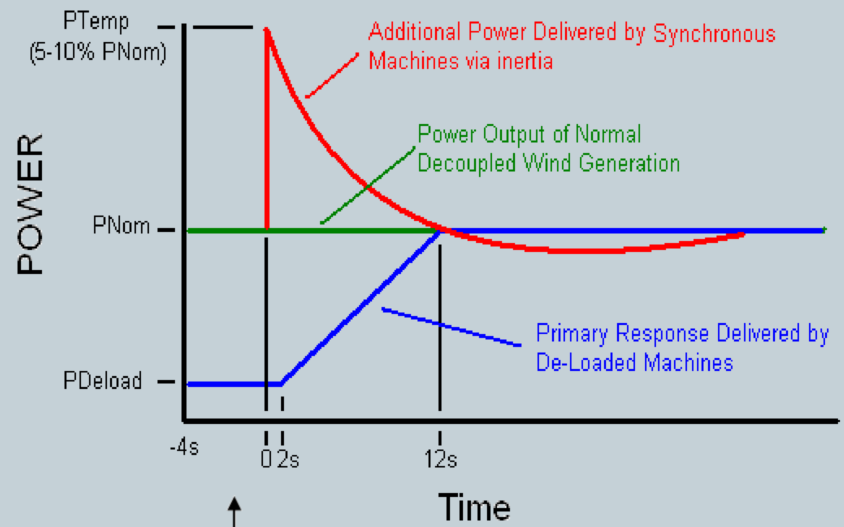
- Synthetic inertia can therefore be produced by increasing power output during a frequency drop

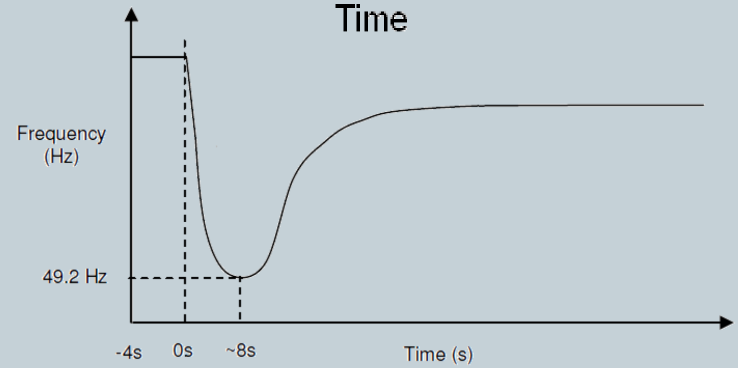
$$J\omega_m \frac{d\omega_m}{dt} = P_{Sup} - P_{Dem}$$

- Luckily, wind turbines have a large store of kinetic energy…

How much Energy is Required?

- A National Grid investigation into synthetic inertia concluded that a power increase of 5-10% during a grid frequency drop to 49.2Hz in approximately 8 seconds would be sufficient





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How much energy is available?

- A typical measure used for comparing the inertia of different generators is known as the inertia constant, *H*
- An average value for a large generator would be approximately 6s
- For the Supergen 5MW Exemplar turbine this value works out to be approximately 6s
- Hence the wind turbine has the potential to supply a similar "synthetic inertia" response as a synchronous machine's inertial response.

$$E = \frac{1}{2} J\omega_m^2$$

$$H = \frac{E}{RatedPower}$$

$$J\omega_m \frac{d\omega_m}{dt} = P_{Sup} - P_{Dem}$$

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How do we "Access" this Kinetic Energy?

- Power is rotational speed multiplied by torque
- By artificially increasing the torque the power will also increase in proportion.
- This will cause the turbine blades to slow down
- Effectively, the kinetic energy in the blades is being converted to electrical energy

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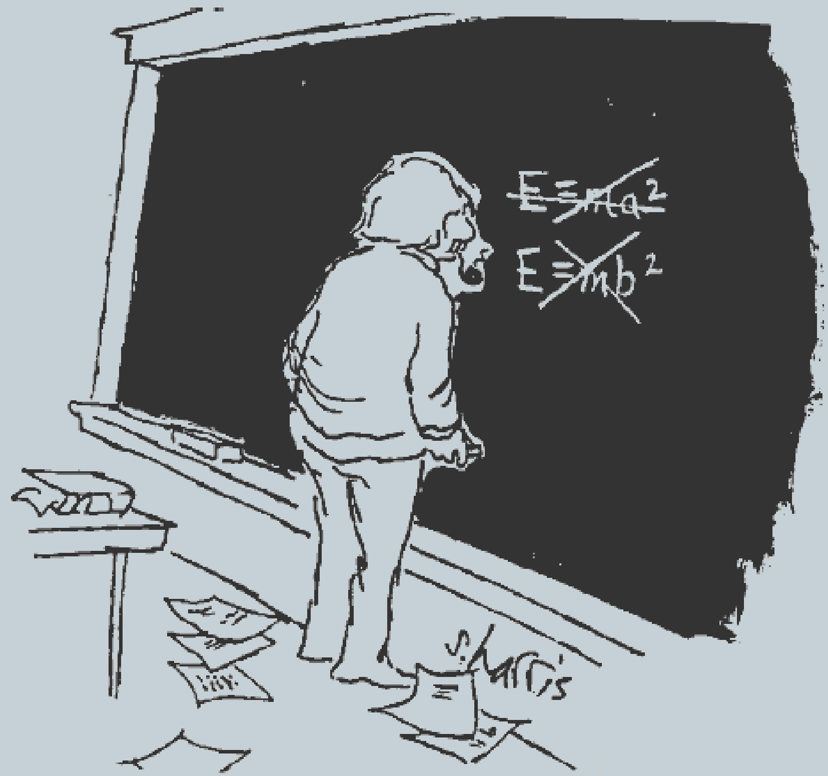
The Controller – A Conundrum

- The additional torque needs to be demanded by the controller
- The original (inner) controller will detect the reduction in rotational speed and decrease torque demand
- This will cancel out what we wanted to do!



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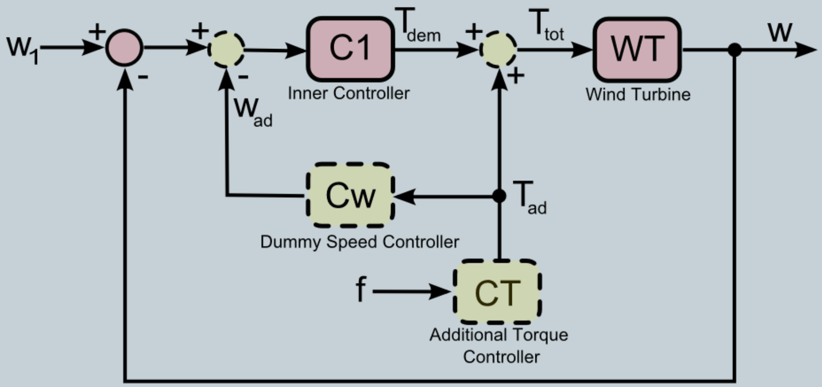
Controller Solution

- In order to “fool” the controller, a dummy speed input is required
- The dummy speed (ω_{ad}) cancels out the reduction in speed caused by the additional torque (T_{ad})



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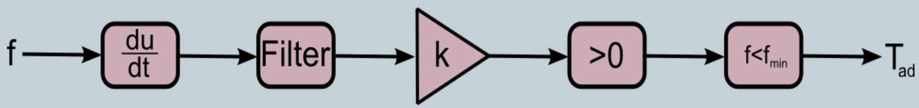
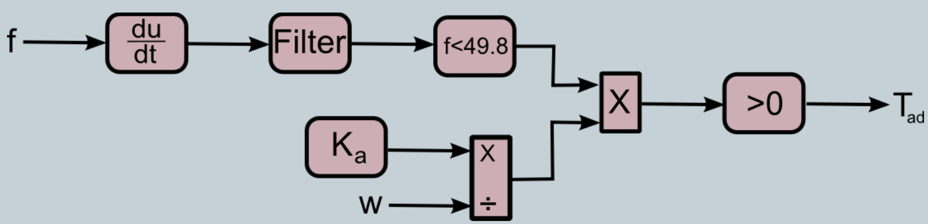
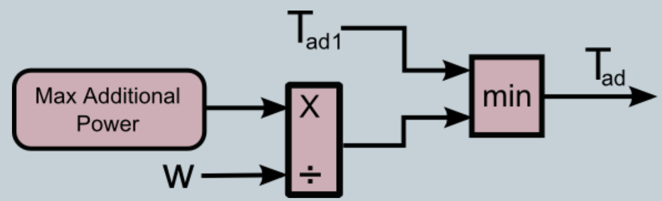
The Torque Controller

- The torque controller generates a value of T_{ad}, which is added to the original controllers demanded torque T_{dem}
- Inertia is proportional to the change in frequency
- As the turbine slows, more torque is required to maintain the same power output
- In order to avoid an unrealistic torque demand, a max power limiter is used







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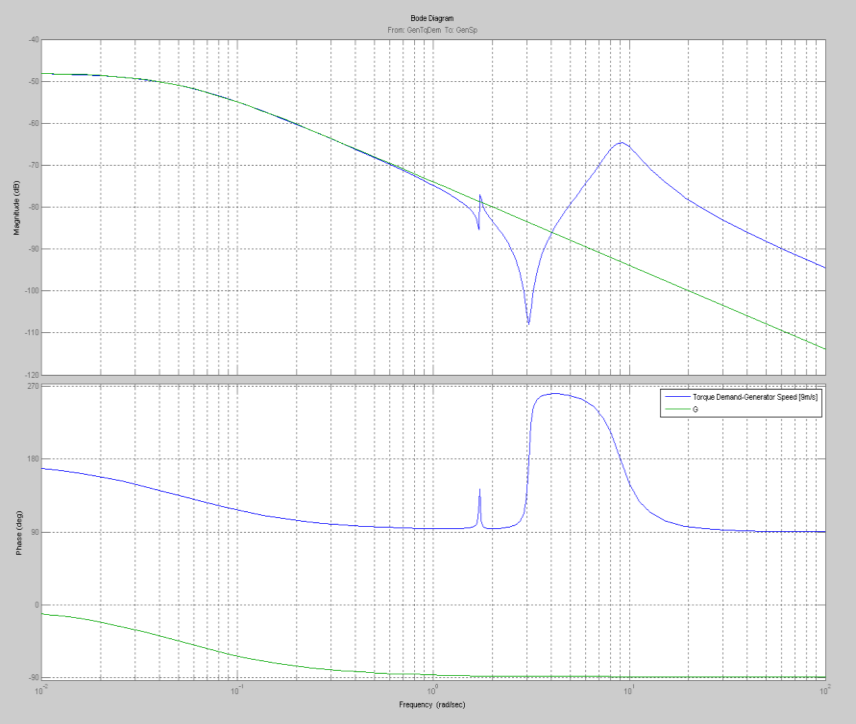
The Dummy Speed Controller

- The synthetic inertia controller must provide a dummy speed to “fool” the original controller
- By looking at the Bode plot from torque demand to generator speed, a similar, simpler transfer function can be deduced



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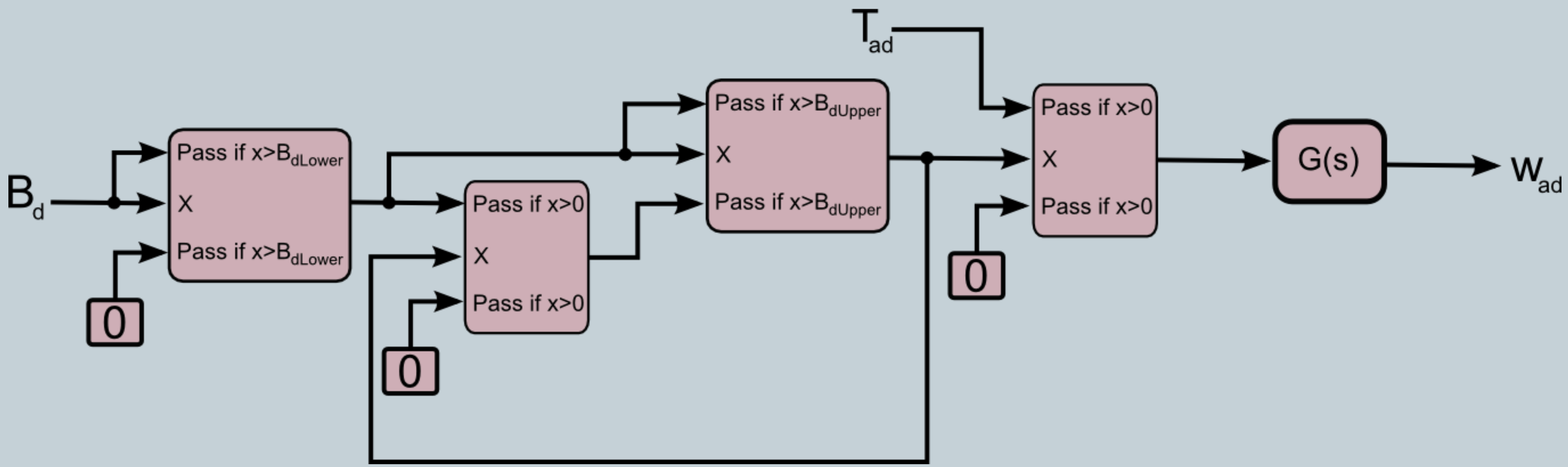
Hysteresis Loop



- The dummy speed controller is only required below rated wind speed
- It is undesirable for the controller to turn on or turn off during a frequency drop so a hysteresis loop is put in place
- The values of B_{dLower} and B_{dUpper} are set so that the likely hood of the turbine passing into the other mode of operation is low

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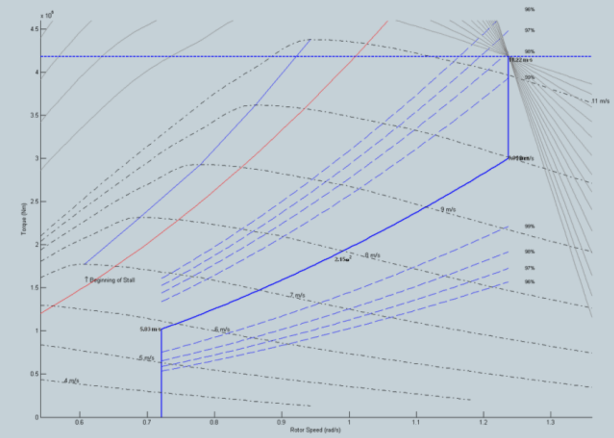
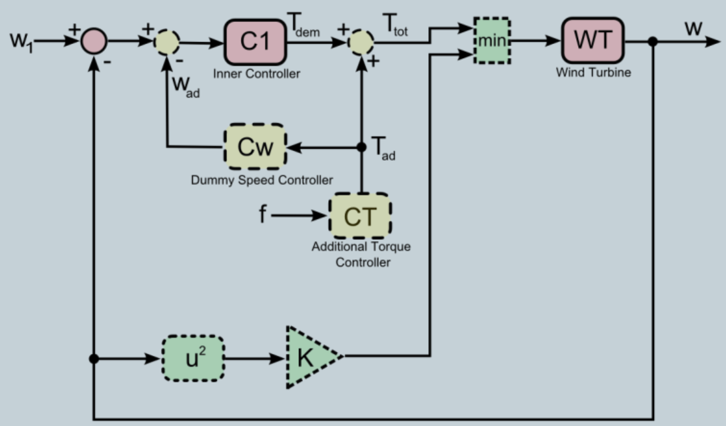
Anti-Stall Control

- An addition to the controller is required to ensure that the machine does not enter stall
- The red line is described by $T = K\omega^2$
- This value is normally higher than T_{tot}
- On the line the values are equal and above the line the T_{tot} is the higher value





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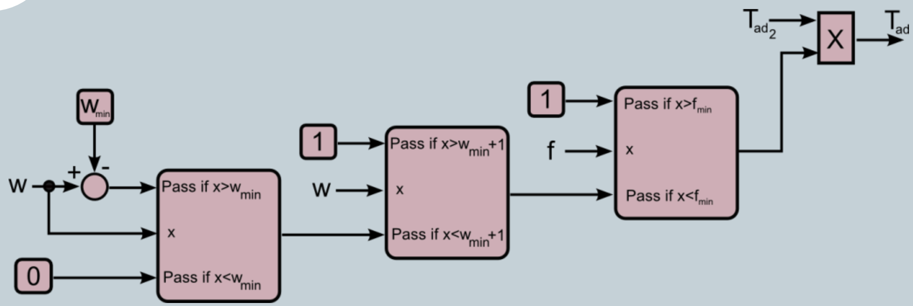
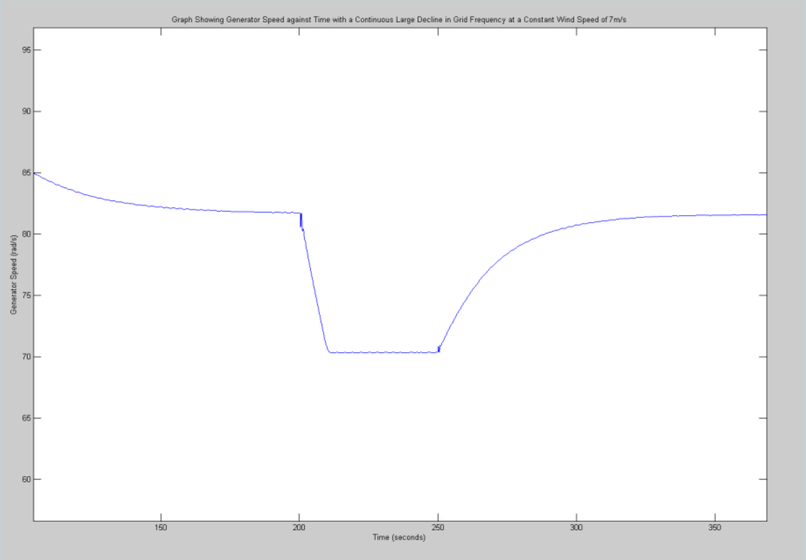
Minimum Generator Speed

- It is desirable to prevent the wind turbine operating below its minimum generator speed
- This addition to the controller gradually reduces the torque demand as the generator approaches its minimum speed
- Once at the minimum speed, no additional torque is requested





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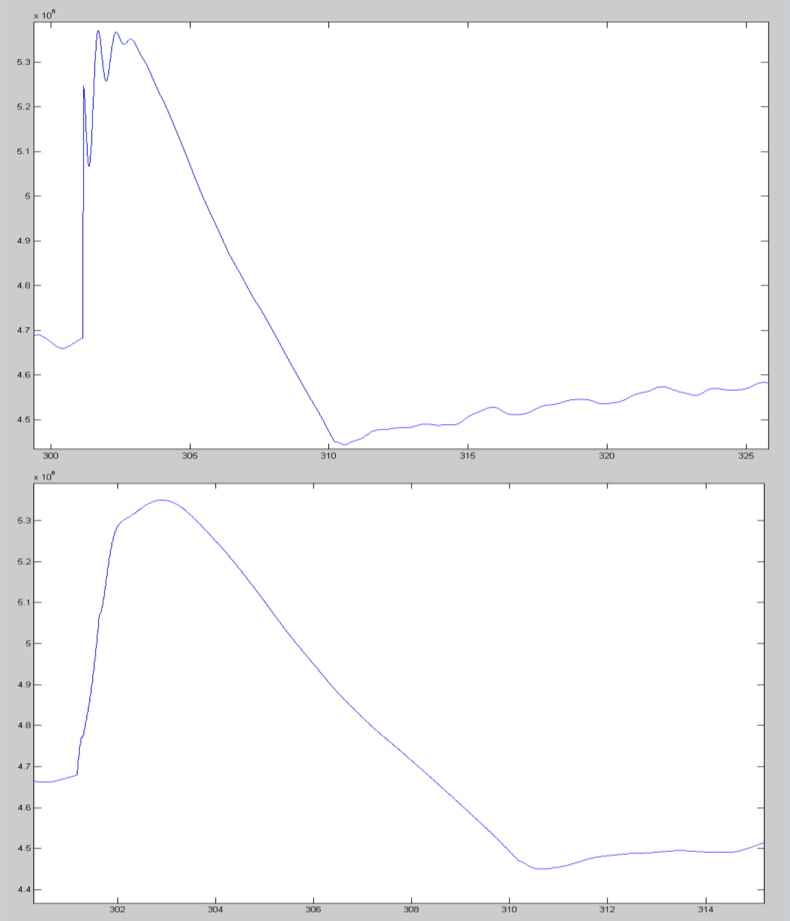
Interaction With the Drive-Train Frequency

- This technique requires a sudden increase in torque
- Interaction with the natural frequency of the drive train causes power oscillation
- Techniques to minimise this cause an unacceptable delay in producing the increase in power



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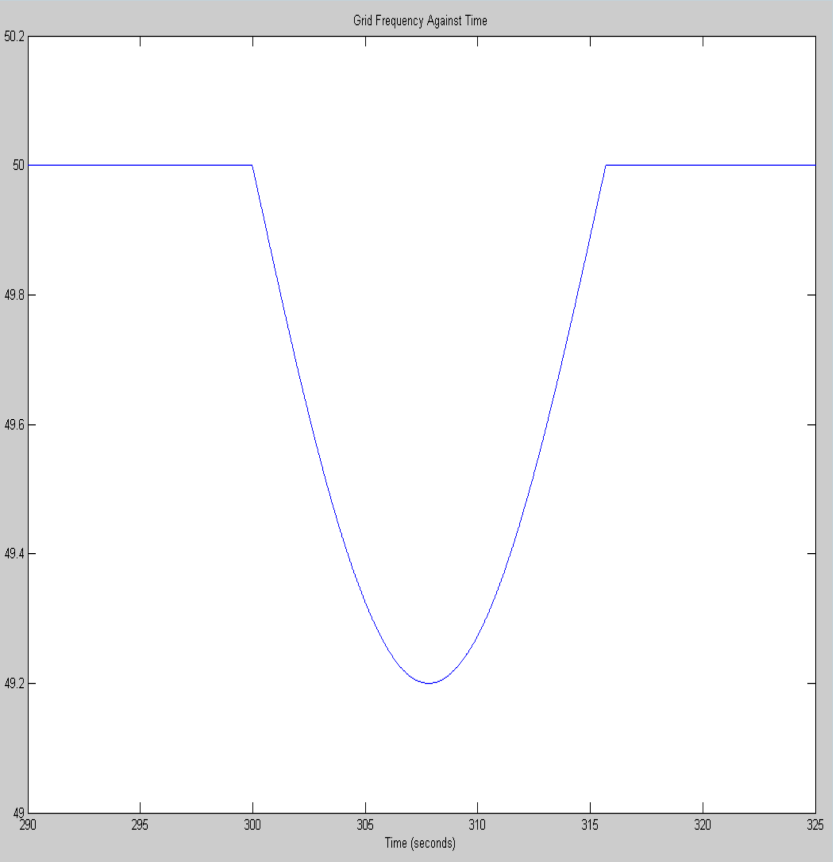
Test Simulations

- Simulations run using Simulink software

- Frequency drop modelled as shown. Based on the worst case detailed in the National Grid Report



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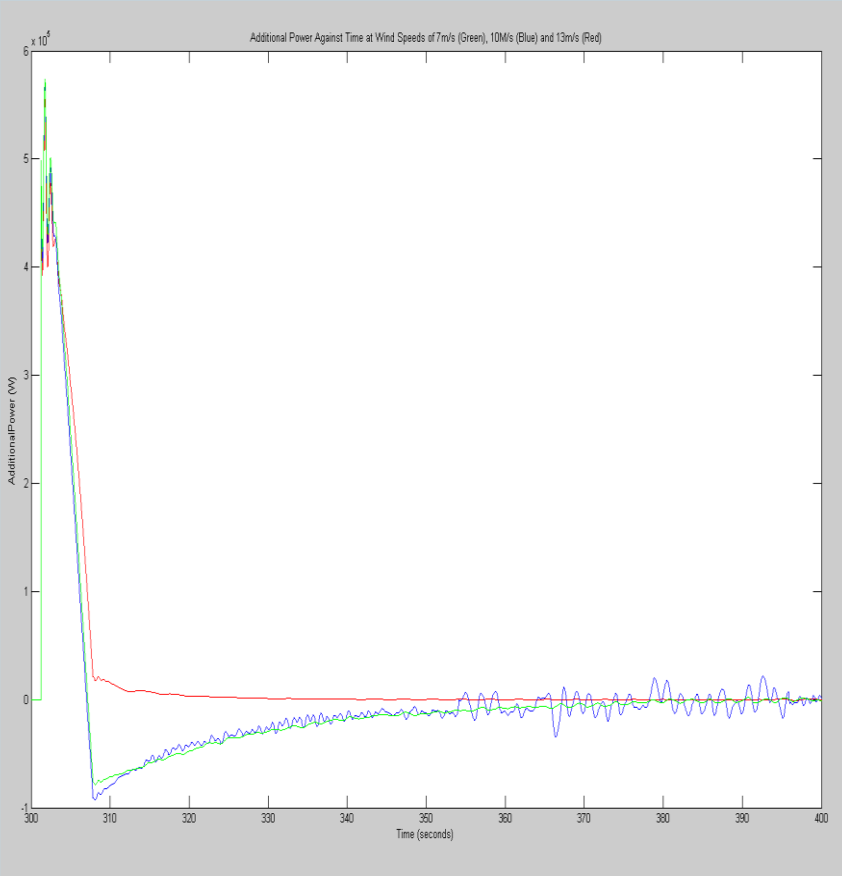
Graph Displaying Additional Power Generated

- Red – 13m/s wind
  Blue – 10m/s wind
  Green – 7m/s wind
- The additional power peaks at approximately 500kW, 10% of the rated power
- When below rated speed there is a recovery period of 40 – 60 seconds



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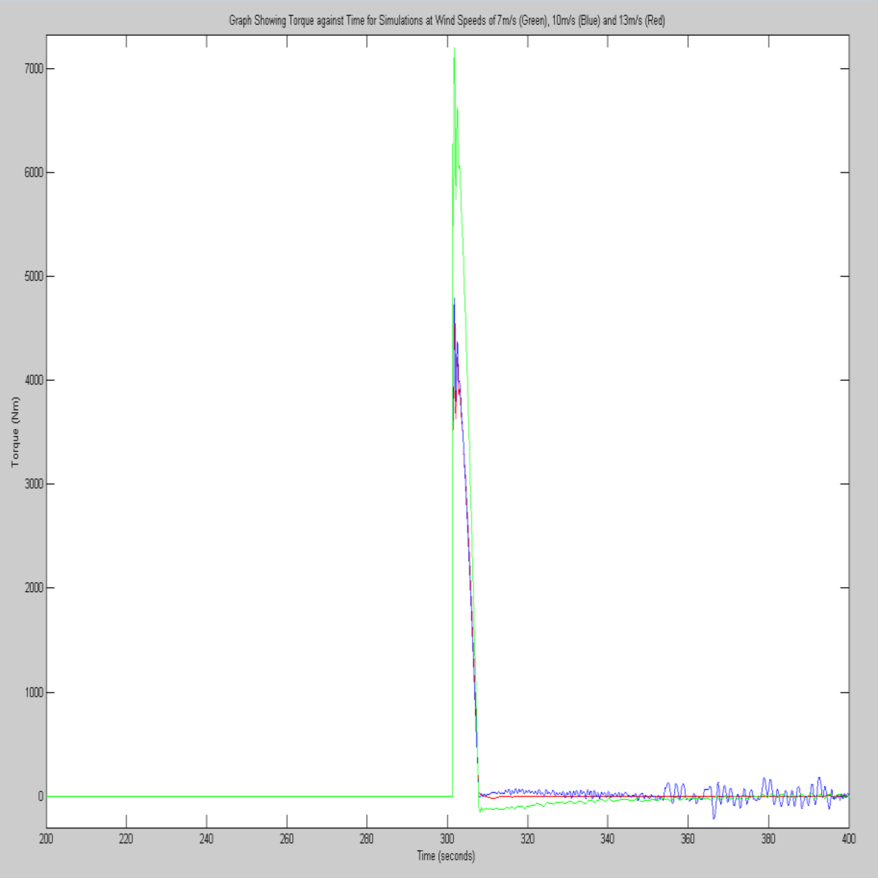
Graph Displaying Increase in Total Torque Demand

- Red – 13m/s wind
  Blue – 10m/s wind
  Green – 7m/s wind

- The increase in torque is, as expected, higher at lower wind speeds



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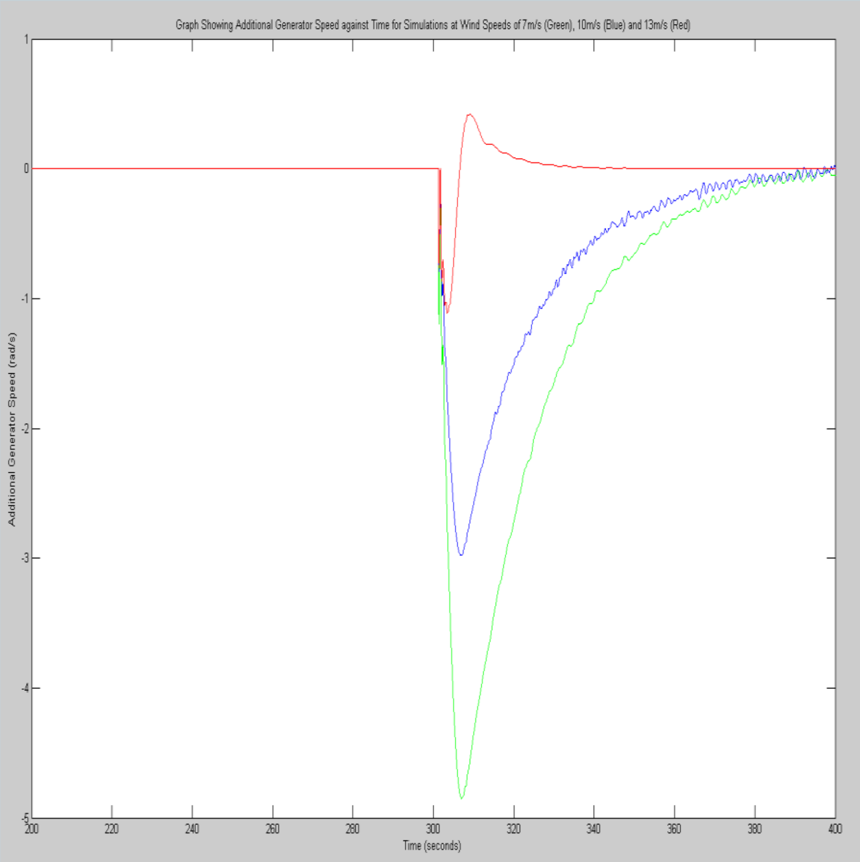
Graph Displaying Increase in Generator Speed

- Red – 13m/s wind
  Blue – 10m/s wind
  Green – 7m/s wind

- Due to greater torque increase, the generator speed dips lower at 7m/s than at 10m/s
- At 13m/s there is an oscillation caused because pitch controller is slower than the torque demand controller



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Conclusions

- The controller appears to be fairly robust and able to attain the desired 10% increase in output power within 0.2 seconds at wind speeds above 7m/s
- Below 7m/s the turbine would be slowed to below the minimum generator speed and so the required kinetic energy cannot be extracted
- The controller is able to prevent stall from occurring as a result of its use
- Wind turbines of this design operating above 7m/s wind speed can give similar inertial characteristics as a traditional plant

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Future Work

- Additional work could be done to investigate the impact of this technique on the lifetime of the turbine and/or on the power electronics

- It would be interesting to see how this technique could be applied over a whole wind farm, maybe some turbines producing more “extra power” than others depending on conditions?

- It would also be of interest to investigate if wind turbines could supply some of the primary response as well as the inertial response – especially as they increase in size

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Any Questions

- Any Questions?