Fault ride-through enhancement of multi-technology offshore wind farms

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Outline of presentation

- Background
- Problem description
- Modelling
- FRT control for DFIG
- FRT control for DFIG and FRC-WT
- Conclusions

Government Targets

Scottish Targets -

- **80% of power from Renewables by 2020**
- Interim target of 31% by 2011
- Currently at 25% (2008 figure)
- 20% of primary energy by 2020
- **Emission reduction target of 80% by 2050**
- Interim target of 42% by 2020

UK Targets –

- **32% of power form renewables by 2020**
- Currently at 7%
- 15% of primary energy by 2015
- **Emission reduction target 80%** by 2050

UK ROUND 3 OFFSHORE WIND SITES - 32GW

£90Bn Capex Investment over the next 10 years

6,800 wind turbines

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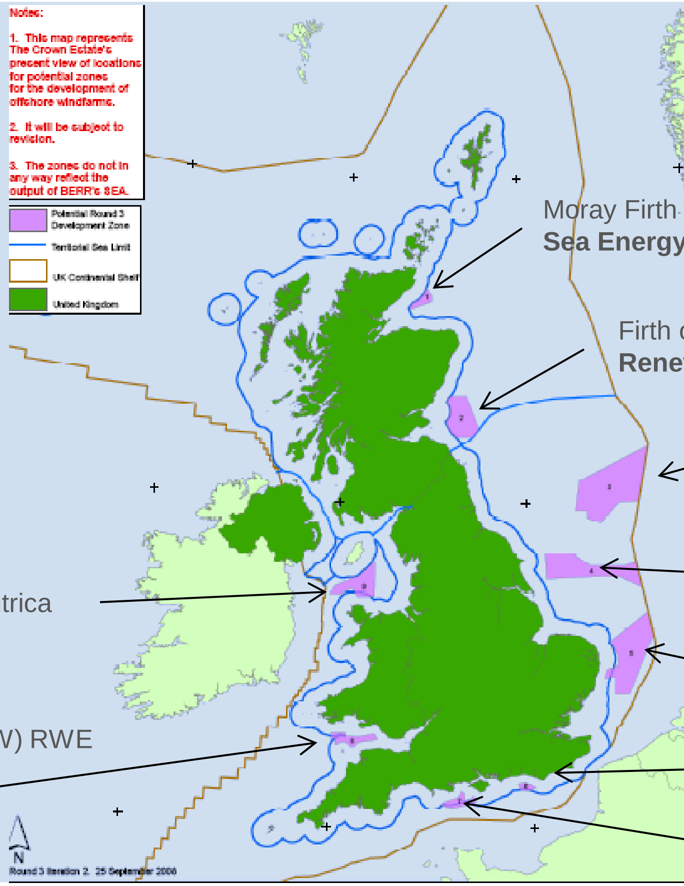
9 Development Zones of varying sizes



Moray Firth (1.3GW) **Sea Energy Renewables** and EDPR

Firth of Forth (3.5GW),**SSE Renewables** and Flour

Dogger Bank (9.0GW) – Forewind **SSE Renewables**, RWE, Statoil, Statkraft

Hornsea (4.0GW) – Mainstream and Siemens

Norfolk (7.2GW) – **ScottishPower** and Vattenfall

Hastings (0.6GW) - EON UK

Isle of Wight (0.9GW) – Eneco New Energy

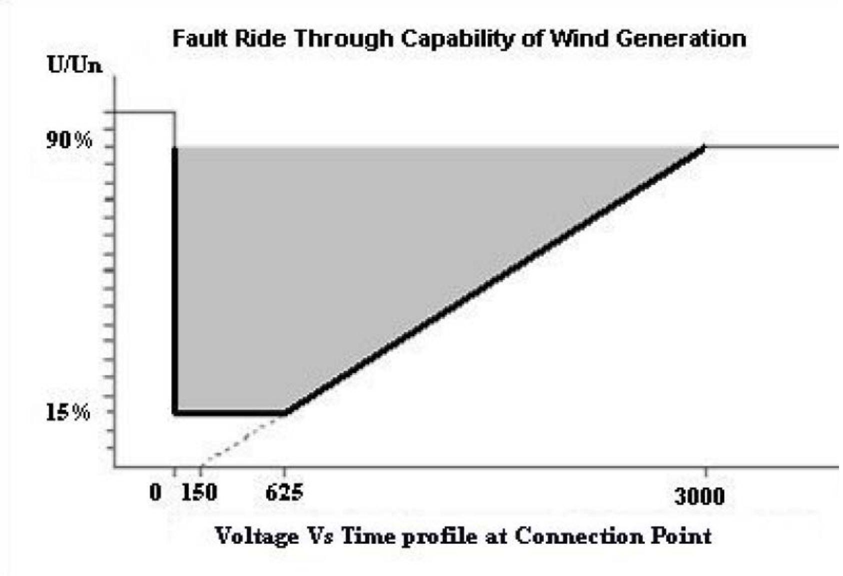
Irish Sea (4.2GW) – Centrica

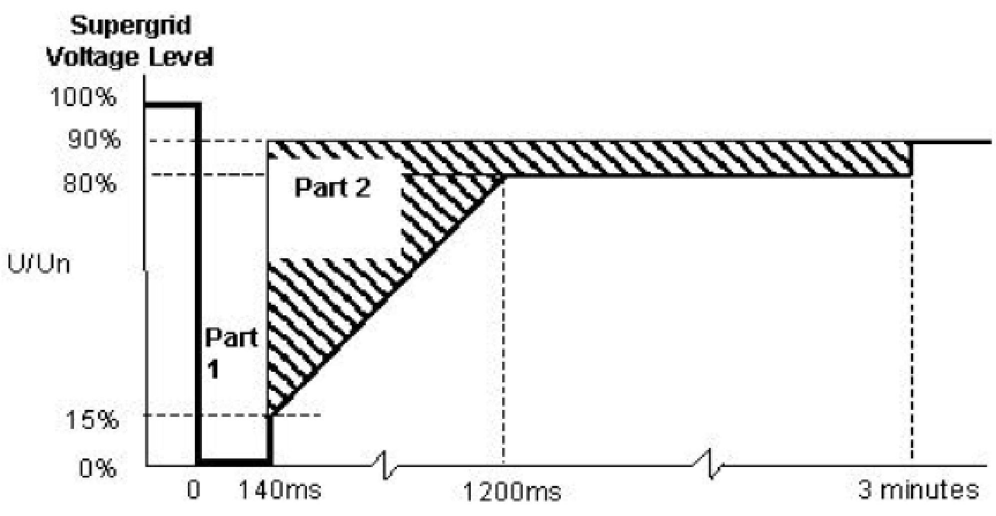
Bristol Channel (1.5GW) RWE nPower

Fault Ride-Through Capability

- Large-capacity wind farms must remain connected to the network even in the event of faults in the high-voltage network

- FRT requirements are different from country to country





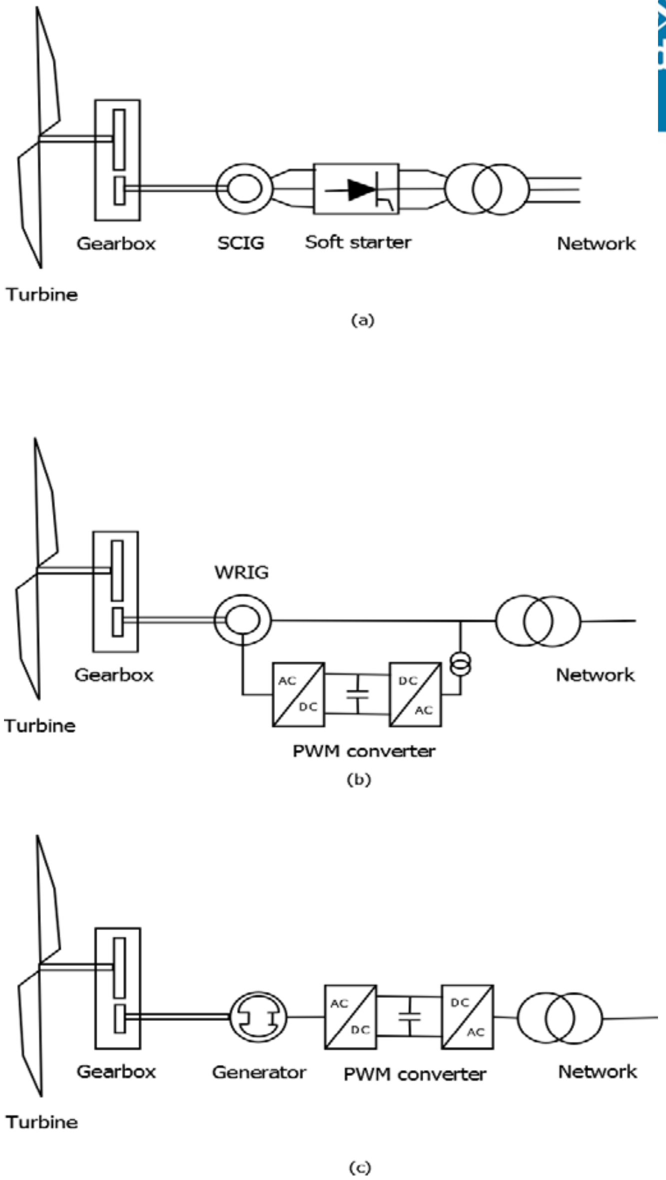
»**Voltage characteristic for Eire 'ride through' requirement**

»**Voltage characteristic for GB 'ride through' requirement**

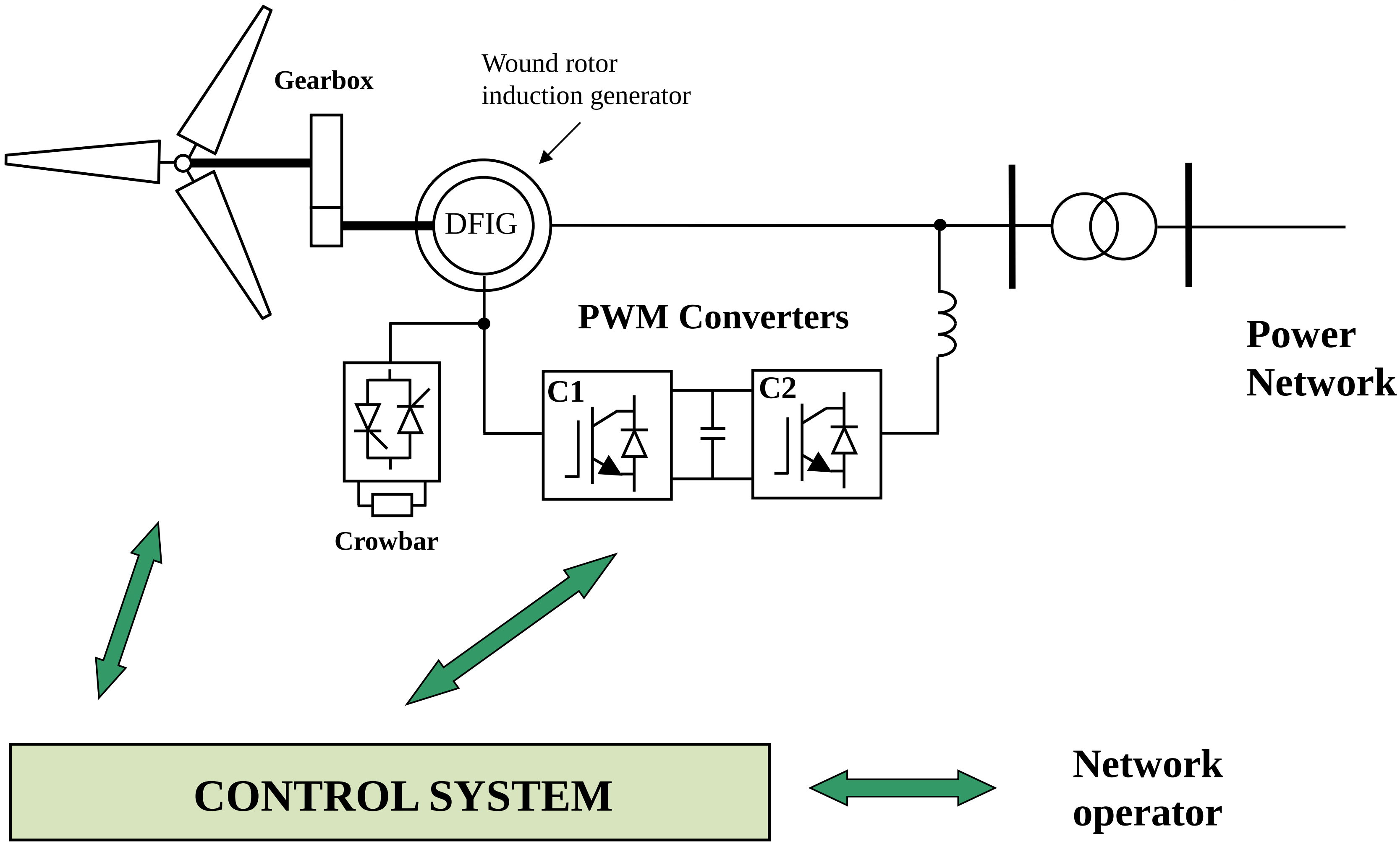
FRT depends on turbine concept

- FRT capability varies by different wind turbine concept
- Major wind turbine concepts in the market
  - (a) fixed speed wind turbine: high damping, low efficiency
  - (b) DFIG wind turbine: partially coupled to grid, low damping, low FRT capability
  - (c) PMG wind turbine: totally decoupled from grid, high FRT capability.

DFIG dominates current wind turbine market



Doubly-fed induction generator (DFIG)



Voltage sags and FRT solutions

- Voltage sags can be typical classified based on the cause, e.g.:
  - Fault related
  - Large induction motor start
  - Large induction motor re-acceleration

- DFIG-FRT problem solutions may be:
  - Modification of conventional controller
  - Active crowbar control
  - Application of dynamic breaking resistors

FRT Issues – holistic approach needed

- Mechanical
  - Consistent operation, no protection triggered
  - Loads alleviation

- Electrical
  - High voltage/current protection
  - Reactive power support
  - Stable torque generation to avoid wind turbine rotor speed-up

DFIG control during fault – crowbar with variable resistance

- Advantages
  - Wind turbine stays connected during grid fault
  - Wind turbine keeps generating power during grid fault
  - Rotor speed acceleration and drive-train oscillation are prevented
- Limitations
  - Fault level: the power generation is not possible under extremely low grid voltage
  - High power loss during fault

Crowbar with variable resistance

- During grid fault, converters are blocked, DFIG operates in SCIG mode. DFIG torque is calculated as:

$$T = \frac{3}{2}\frac{p_f R_r I_r^2}{s\omega_s}$$

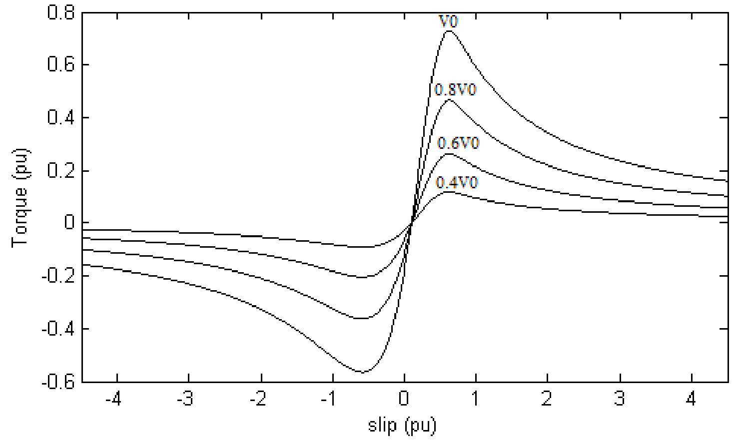
- Applying Kirchhoff's current law to SCIG equivalent circuit, The torque is expressed as

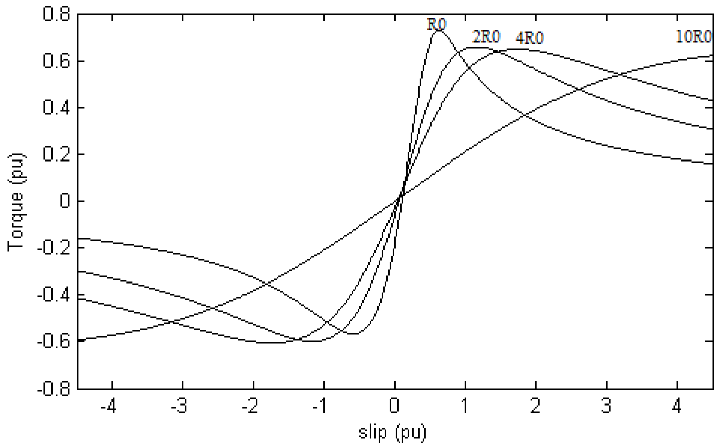
$$T = \frac{3}{2}\frac{p_f R_r V_s^2}{s\omega_s\left[\left(R_s + \frac{R_r}{s}\right)^2 + (L_s + L_r)^2\right]}$$

- Torque is expressed in terms of rotor resistance

Crowbar with variable resistance – T/Slip curve

- Torque-slip curve of induction machine changes under different rotor resistance and grid voltage

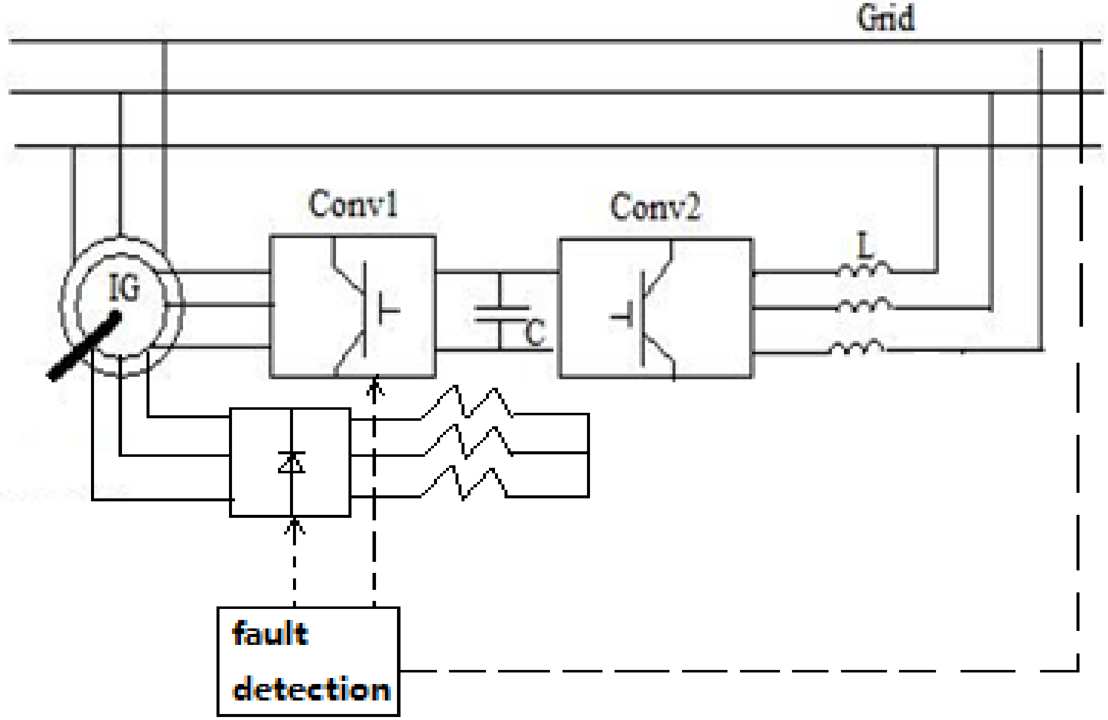




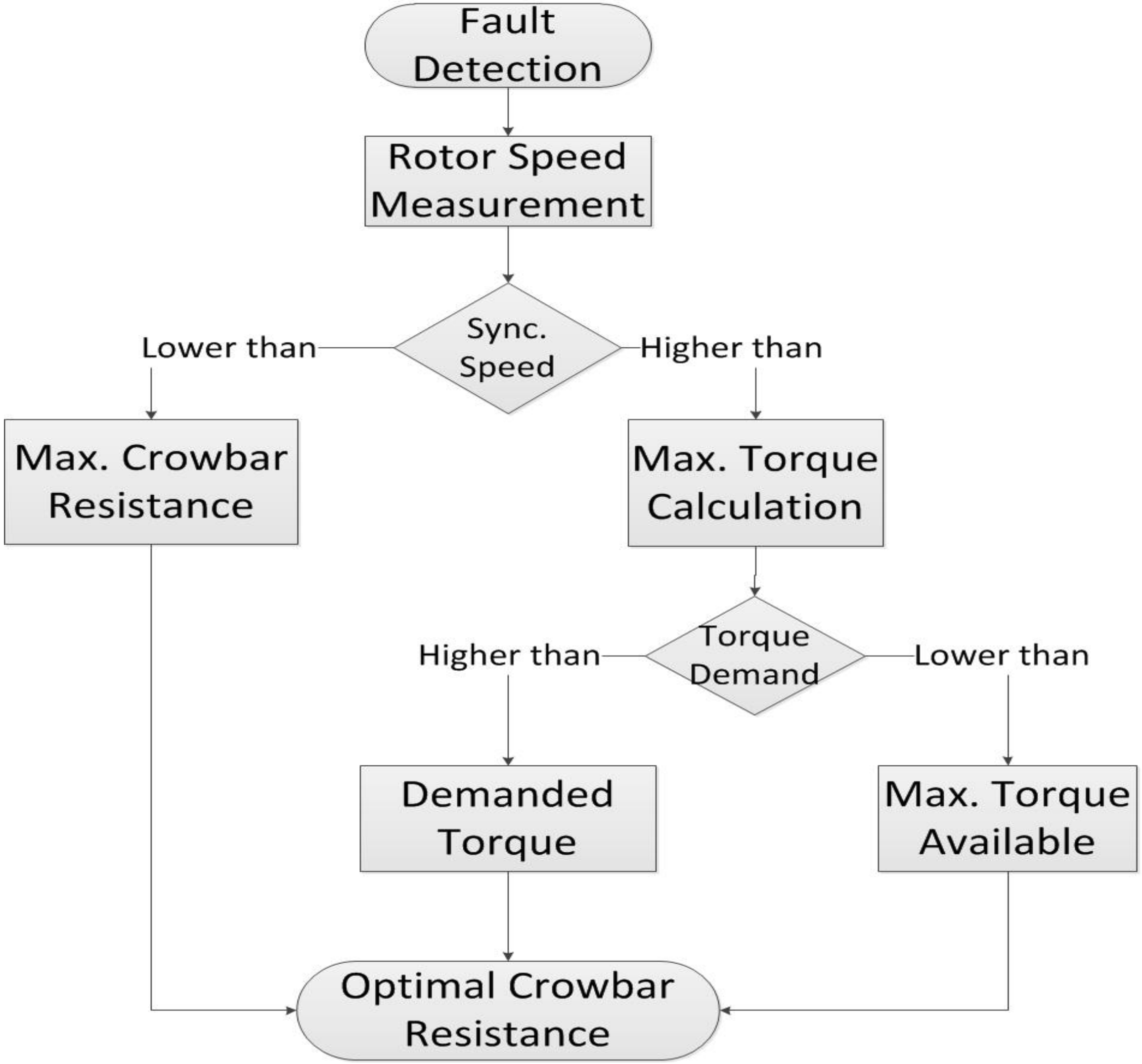
- By controlling the rotor resistance, reference torque can be produced under certain grid voltage

Implementation

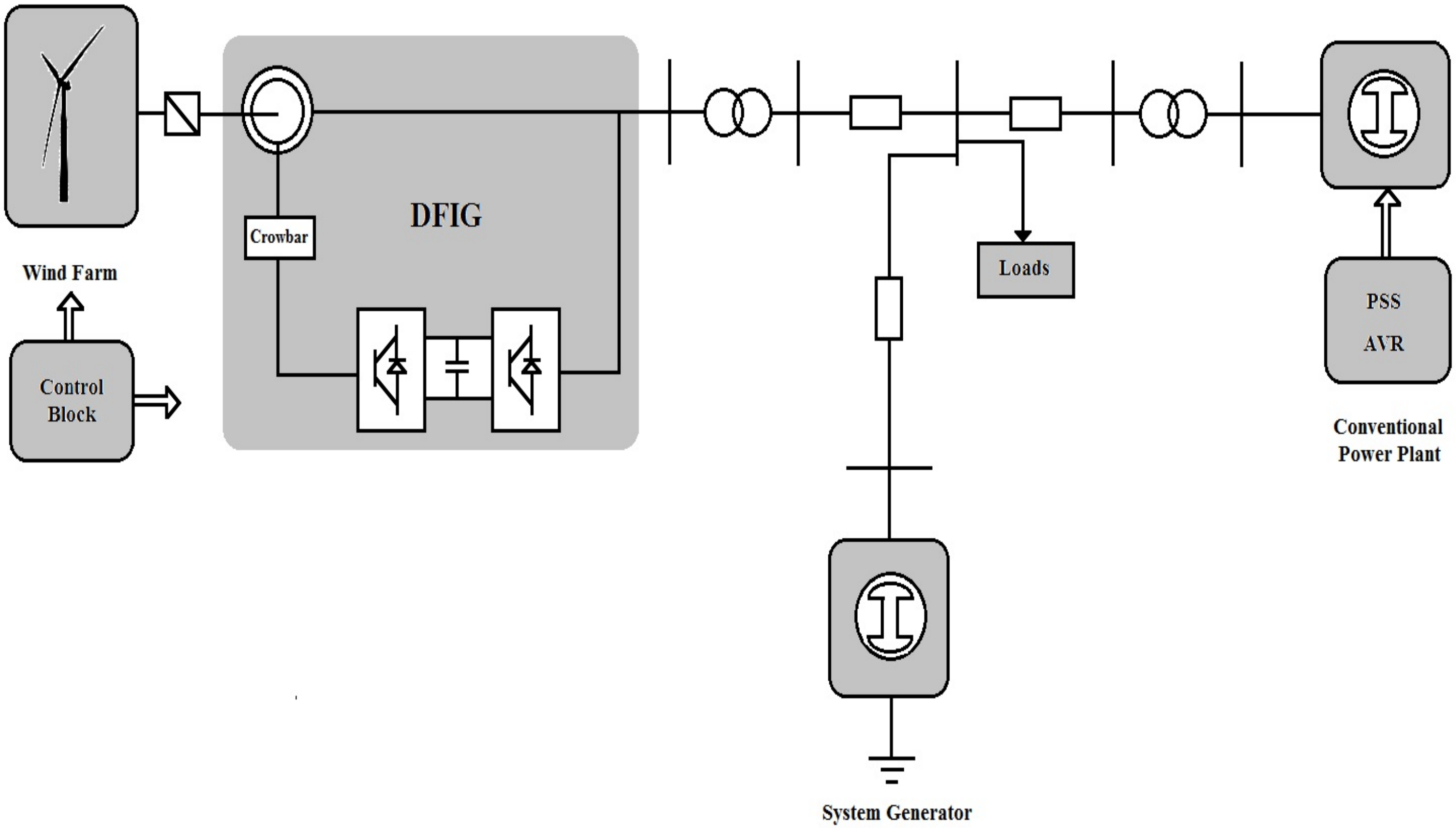
- Switching by grid voltage level
- Normal operation: external resistor bypassed
- Fault case: IGBT switched to connect variable resistor to DFIG rotor



Control implementation – Flow Chart



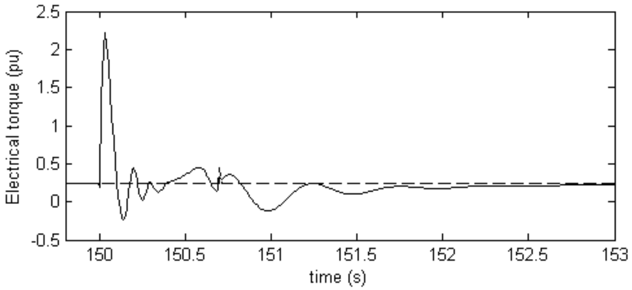
Test model construction



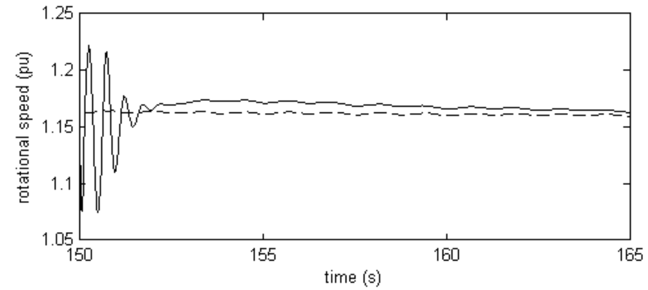
Model construction (const)

- Wind Turbine Model
  - Dynamic model of rotor, tower and drive-train
- DFIG Model
  - Induction machine model
  - DFIG controller in d-q frame
- Grid Model
  - Generic network model comprising wind farm, conventional power plant with AVR, PSS and etc, Local Grid

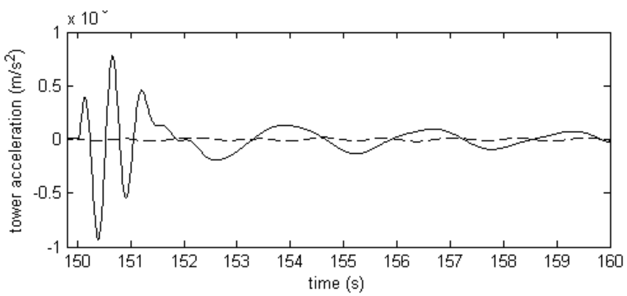
Simulation results



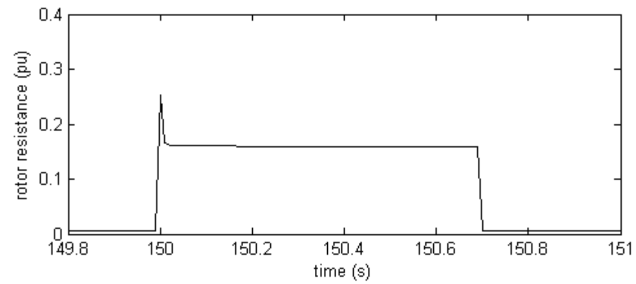
Electrical torque



Rotor speed



Tower acceleration

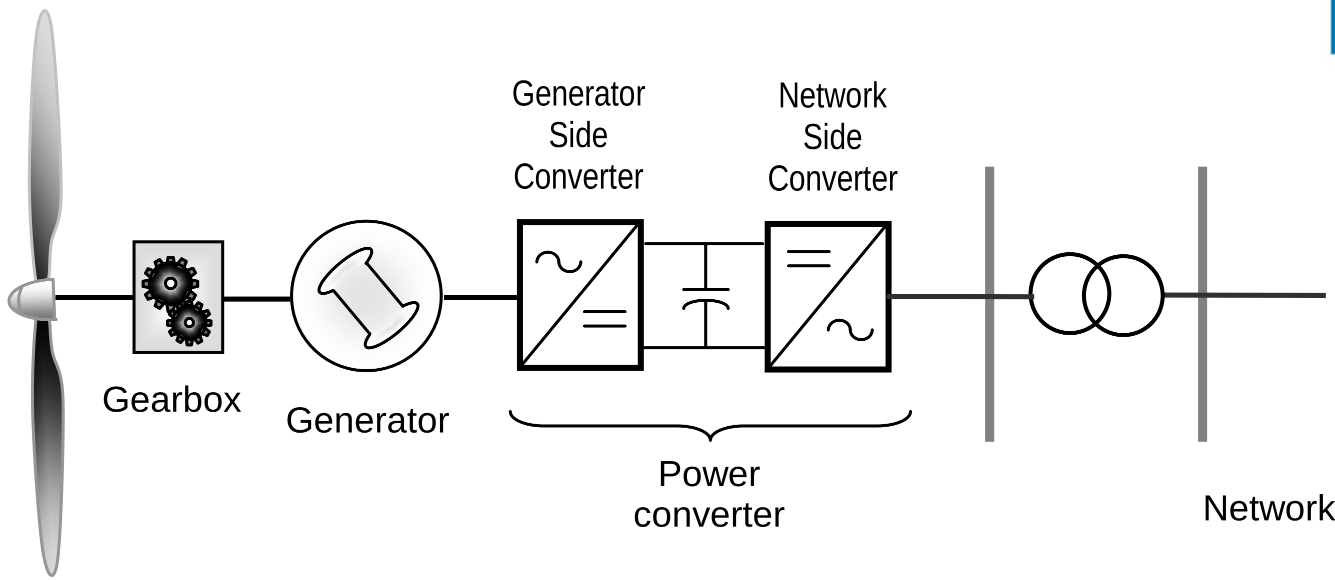


Rotor resistance

Solid line: with normal crowbar protection

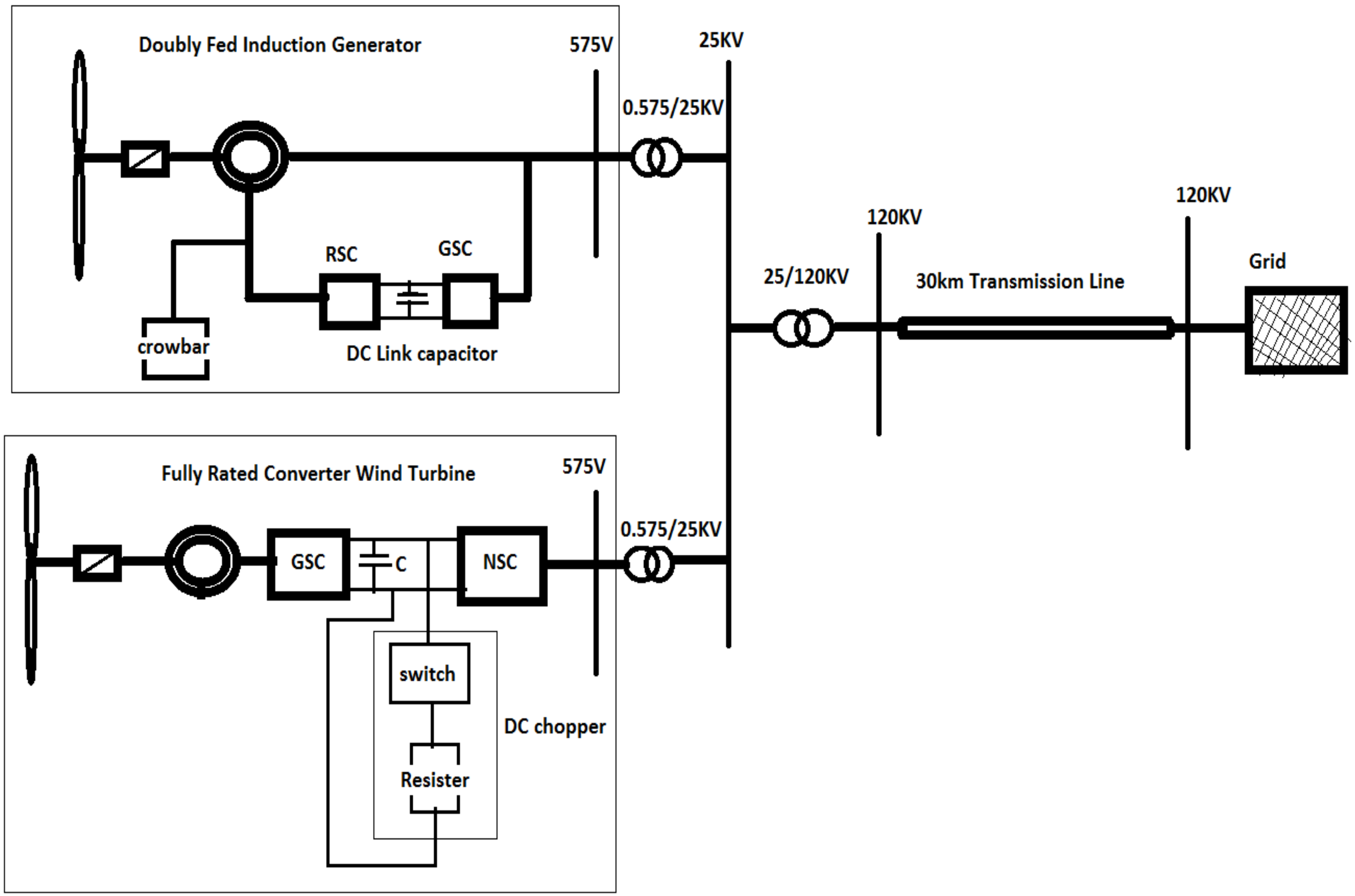
Dashed line: with variable resistance crowbar control

Fully-Rated Converter-based wind turbine



- Uses either an induction generator or a synchronous generator (it can either be an electrically excited synchronous generator or a permanent magnet machine.
- The converter completely decouples the generator from the network, enabling variable-speed operation.
- The rating of the power converter in this wind turbine corresponds to the rated power of the generator.

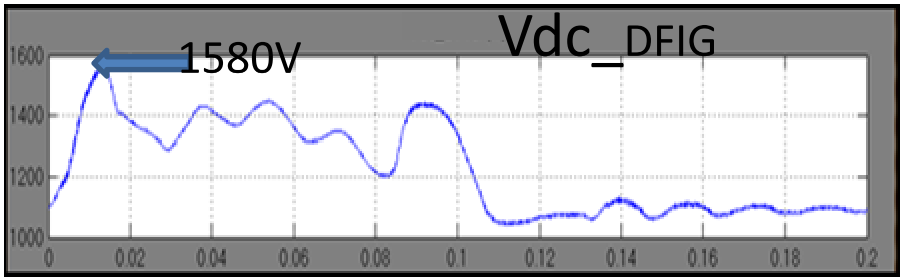
Block Diagram of Proposed System

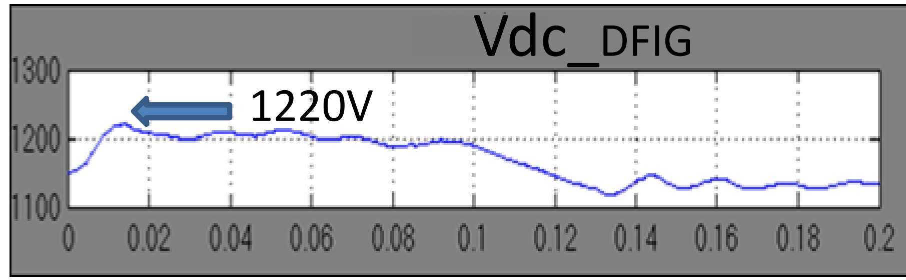


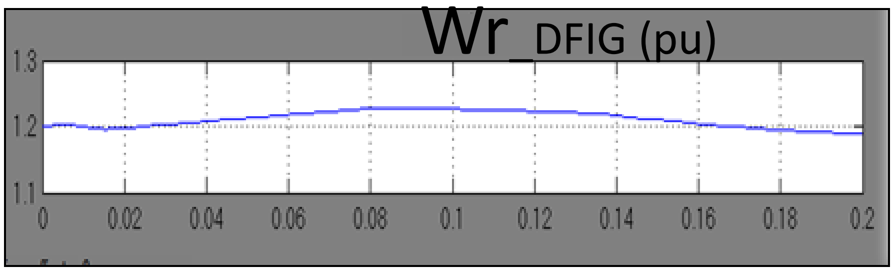
Results

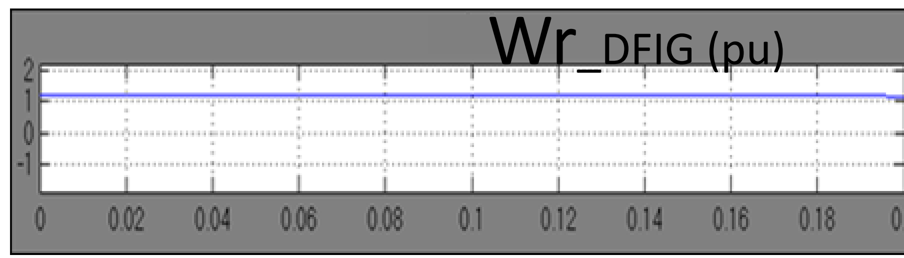
Without Protection

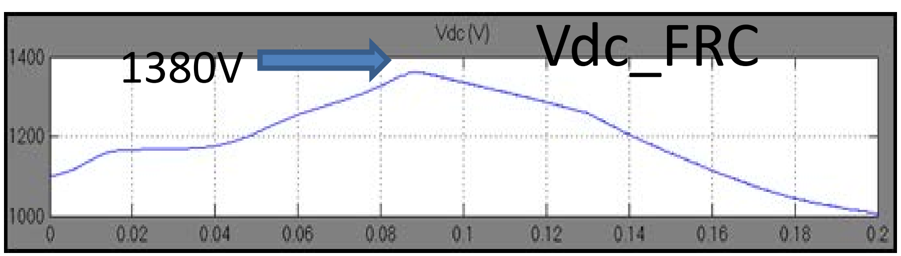
After applying Protection

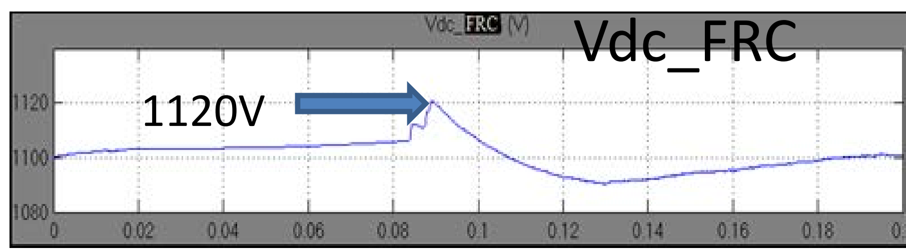












Conclusions

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- The multi technology wind farm eliminate the need of STATCOM at the point of common coupling (PCC).

- Proposed strategy is applied to multi-technology wind farm to eliminate current and voltage transients during grid faults.

- The DC link voltage and high rotor currents are controlled within limits after applying the protection scheme.

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