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

Arshad Ali
Fan Zhang
Olimpo Anaya-Lara

EERA Deepwind 2014
23 January 2014, Trondheim, Norway
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

- Firth of Forth (3.5GW), SSE Renewables and EDPR
- Moray Firth (1.3GW), Sea Energy Renewables and EDPR
- Dogger Bank (9.0GW) – Forewind
- Hornsea (4.0GW) – Mainstream and Siemens
- Norfolk (7.2GW) – ScottishPower and Vattenfall
- Irish Sea (4.2GW) – Centrica
- Bristol Channel (1.5GW) – RWE nPower
- Hastings (0.6GW) - EON UK
- Isle of Wight (0.9GW) – Eneco New Energy

£90Bn Capex Investment over the next 10 years
6,800 wind turbines
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 typically 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

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

- 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

Fault Detection
→ Rotor Speed Measurement

Sync. Speed

Lower than
Max. Crowbar Resistance

Higher than
Max. Torque Calculation

Torque Demand

Higher than
Demanded Torque

Lower than
Max. Torque Available

Optimal Crowbar Resistance
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

Doubly Fed Induction Generator

Fully Rated Converter Wind Turbine

575V

0.575/25KV

25KV

0.575/25KV

120KV

30km Transmission Line

Grid

crowbar

DC Link capacitor

RSC

GSC

GSC

C

NSC

switch

Resister

DC chopper
Results

Without Protection  After applying Protection

Vdc_FIG 1580V  Vdc_FIG 1220V

Wr_DFIG (pu)

Vdc_FIG 1380V  Vdc_FIG 1120V

Wr_DFIG (pu)
Conclusions

- 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.