Electromagnetic Transients Simulation for Renewable Energy Integration Studies

A. D. Rajapakse
University of Manitoba
D. Muthumuni
Manitoba HVDC Research Centre
N. Perera
University of Manitoba
K. Strunz
University of Washington

Introduction

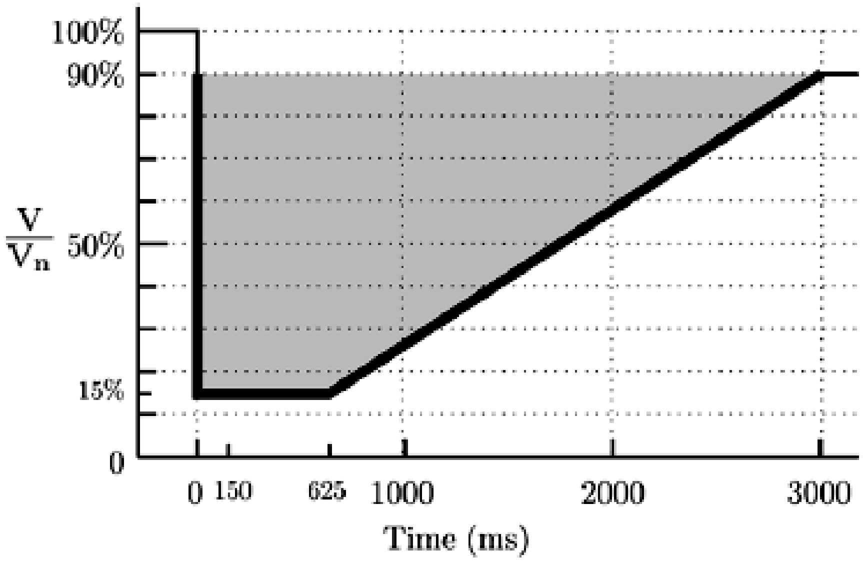
- Distributed generation (DG) is becoming increasingly popular
  - Technical and economic advantages
  - Often based on renewable energy resources
    - Contributes to reduce the environmental impacts
- Rapid growth of wind energy generation
  - Global market for wind power has been expanding faster than any other source of renewable energy
    - From 4,800 MW in 1995 to over 60,000 MW at the end of 2005.

Renewable Generation Interconnection

- Utility interconnection regulations define the required grid interface response to system disturbances.
  - Often based on IEEE Standard 1547 2003
  - Protection philosophy: In case of grid disturbances, DG will be disconnected from the network immediately
- Development of large wind farms (in excess of 100 MW) has made such a protection philosophy no longer feasible.
  - Generation rejection can lead to system instability under stressed conditions

Fault Ride Through Requirements

- Large wind farms are expected to provide a supporting role during disturbances
  - Fault ride through capability
- Studies need to be performed to ensure proper response from wind generator control and protection systems



Time Domain Simulation Studies using EMT Programs

- Electromagnetic Transient (EMT) simulation is a powerful tool for studying
  - Controller tuning
  - Protection setting
  - Power quality investigations
  - System validations
- Simulation of different type of DG interfaces
  - Directly connected synchronous/induction generators
  - Converter connected DC sources (fuel cell, PV)
  - Doubly fed induction generators (DFIG)
  - Converter connected synchronous generator

EMT Program Capabilities

- Detailed rotating machine models (synchronous, induction, permanent magnet, etc.),
- Transformers models (including hysteresis and saturation),
- Frequency dependent transmission line and cable models
- Measurement transformer (CT, VT and CCVT) models
- Models for simulating complex protection and control algorithms
- Automated multiple run and optimization routings

Applications of EMT Programs

- Fault studies to test protection, including anti-islanding
- Studies to test fault ride through capability
- Harmonics studies to test power quality and filtering requirements
- Voltage flicker studies to verify regulatory requirements
- Power electronic converter operation studies to test and verify grid interfaces
- Control operation studies to test plant behavior in meeting control objectives
- Sub-synchronous resonance
- Ferro-resonance studies

Wind Energy System Simulation

- Turbine models
  - Aero dynamic model

$$p_{mech} = \tfrac{1}{2}\rho A_r C_p(\lambda, \beta)\omega^3$$

    - Complex Cp characteristics specific to the turbine
    - Cp depends on pitch angle (β) and tip speed ratio (λ).

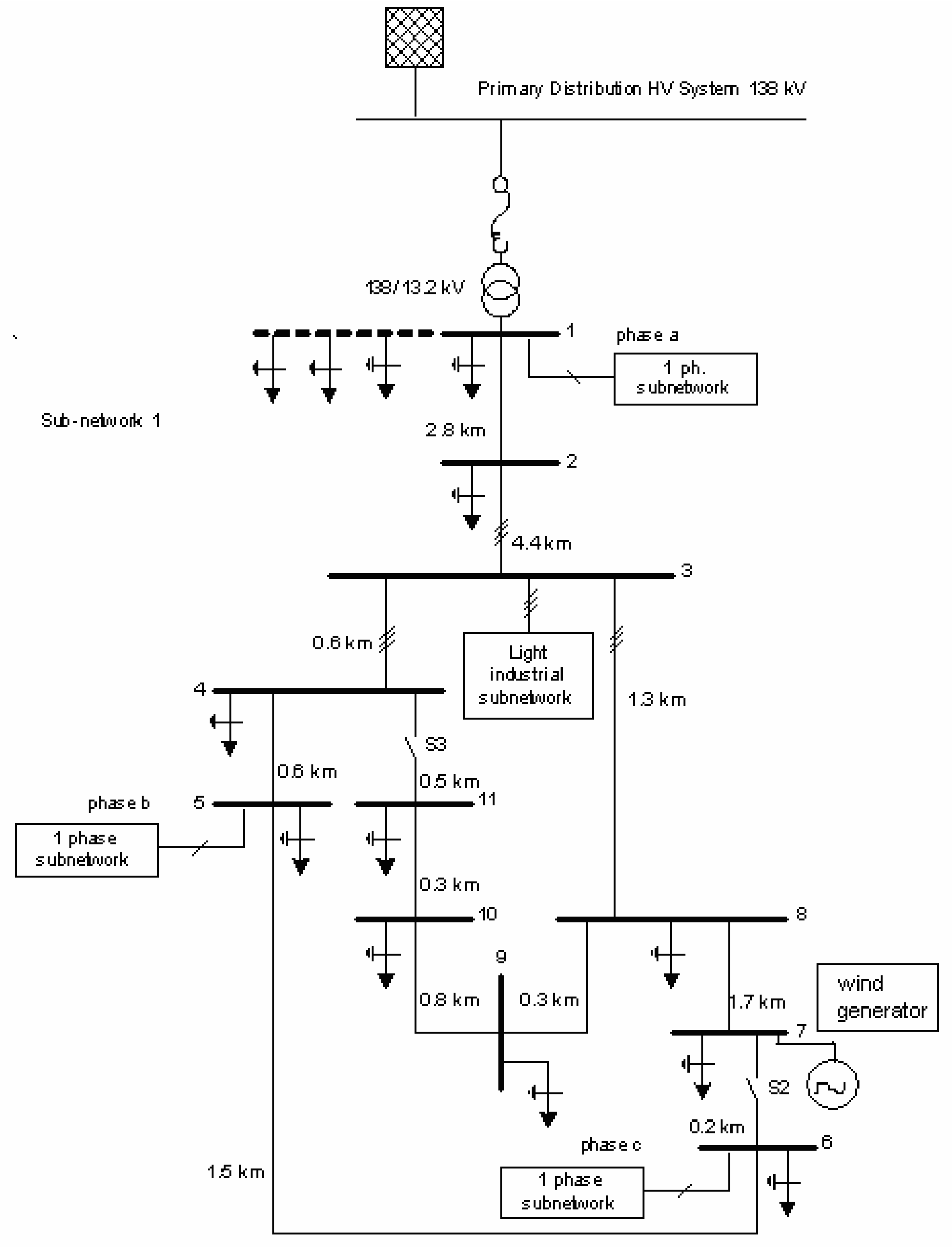
$$\lambda = \frac{\Omega_r r_r}{\omega}$$

Wind Energy System Simulation

- Wind speed fluctuations
- Generator models
- Machine and blade controls
- Mechanical system model
- Other system equipment models

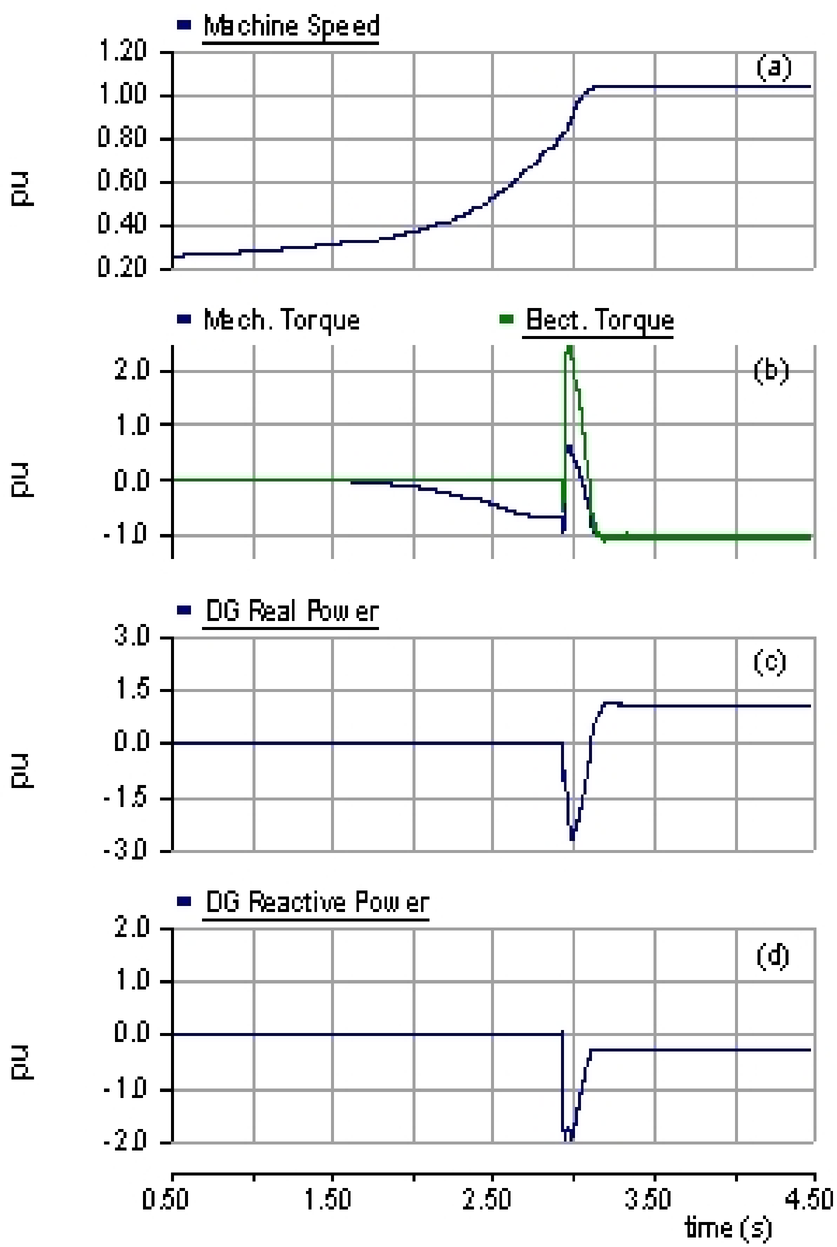
Wind Generator on a MV Grid

- Proposed CIGRE benchmark MV feeder for DG integration studies was used for the simulations



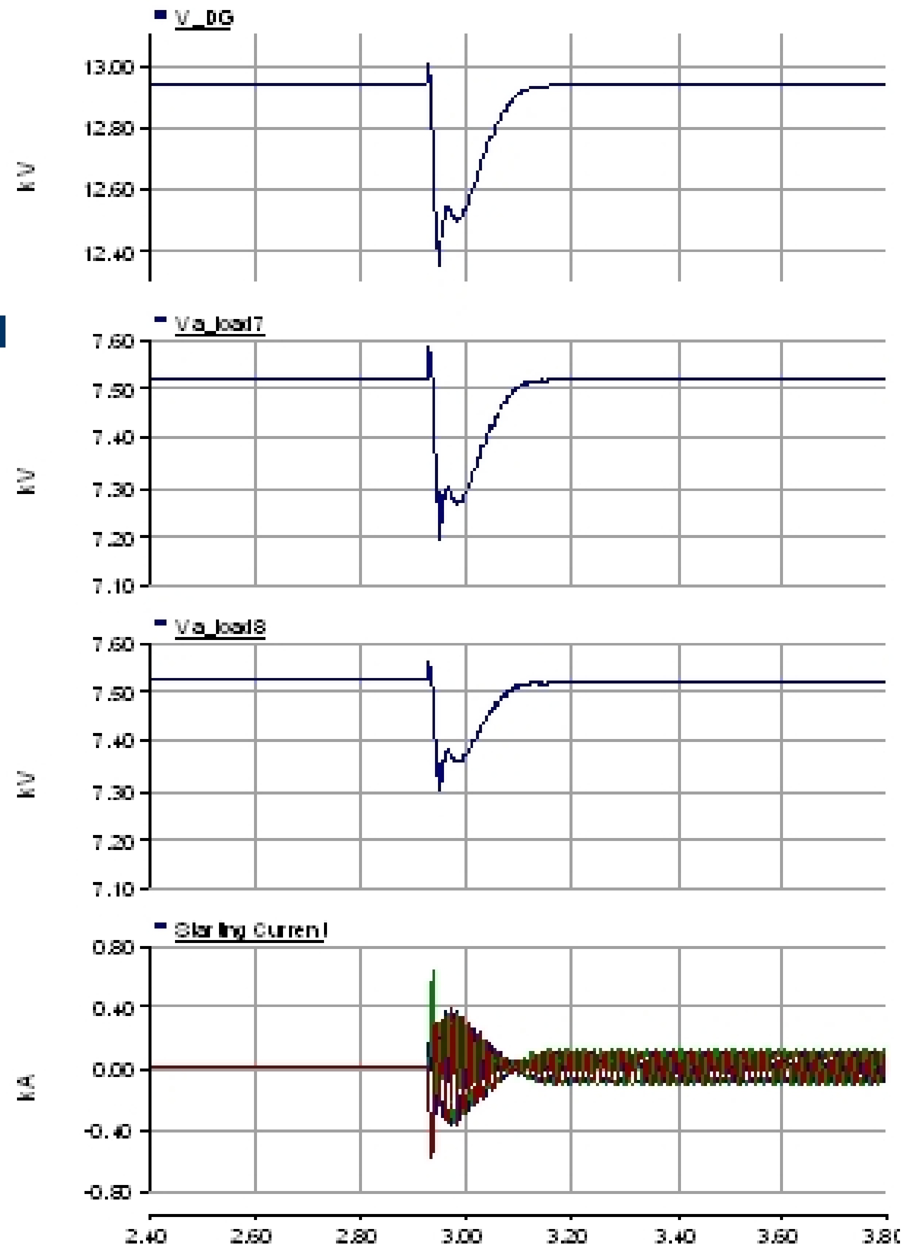
Directly Connected Induction Generator

- 1500 kVA induction generator
- Start-up and grid connection



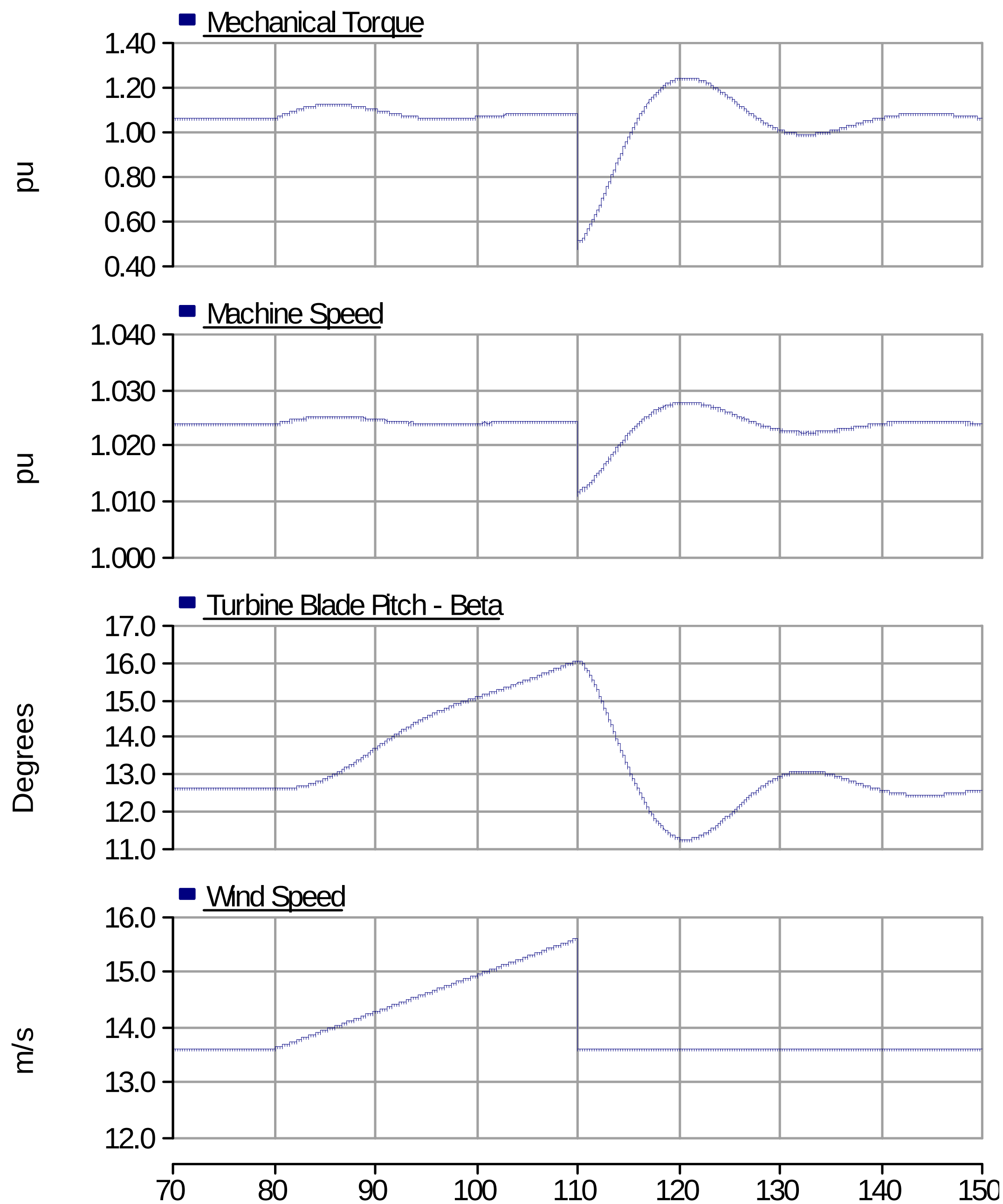
Directly Connected Induction Generator

- Voltage dip during grid connection
  - Can be minimized using soft starters



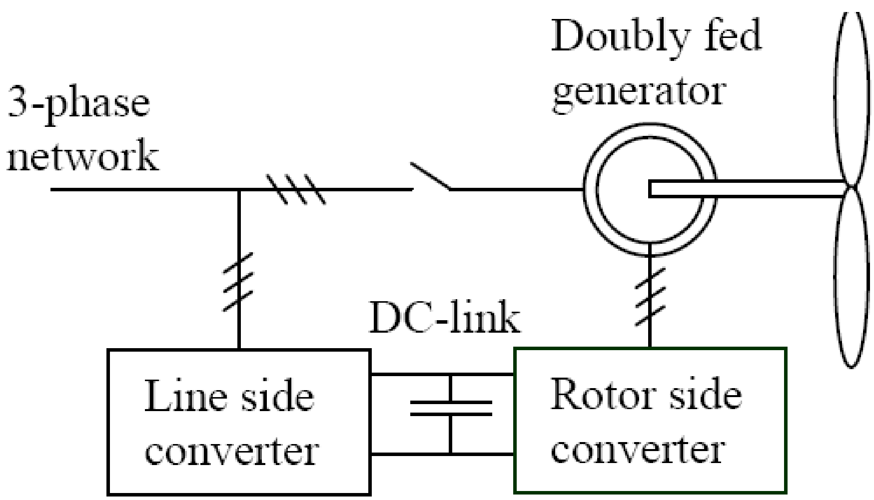
Directly Connected Induction Generator

- Pitch controller performance during change of wind speed



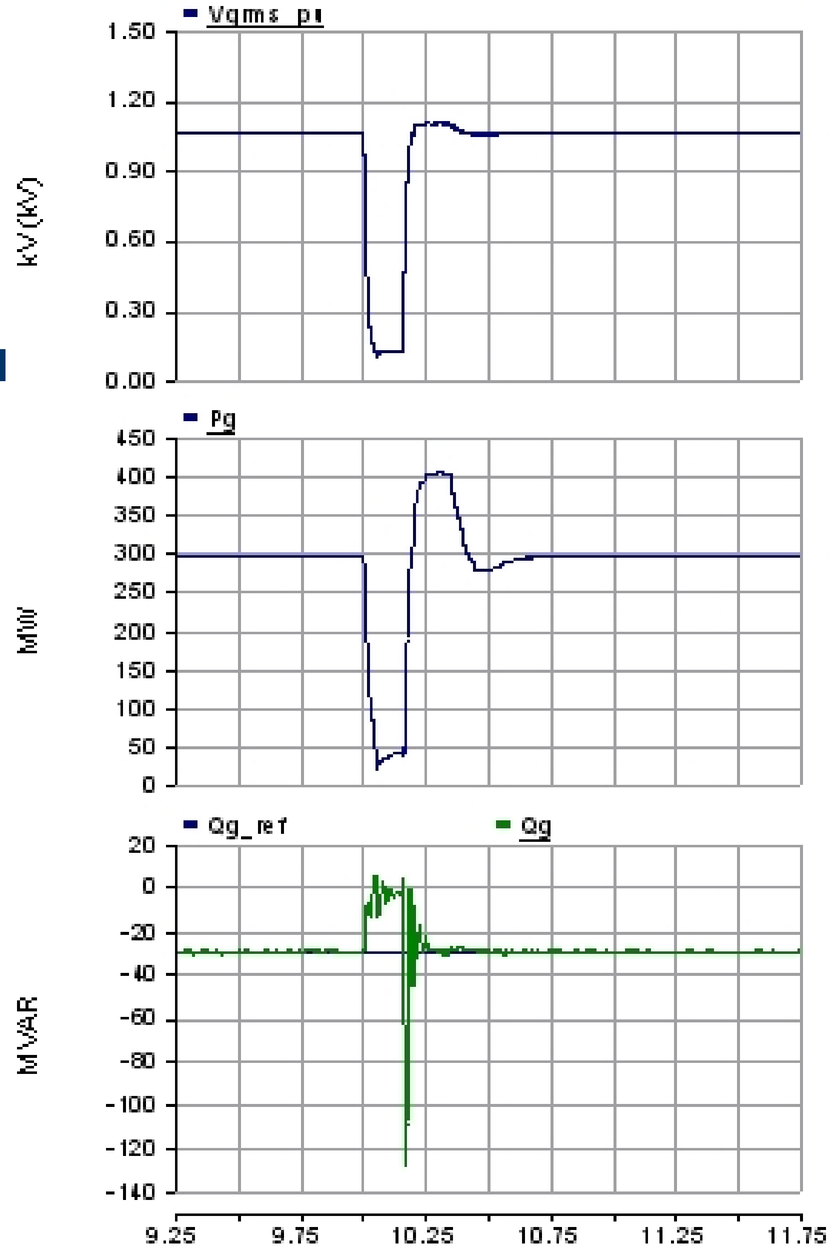
Large Wind Farm Connected to HV Grid

- Proposed CIGRE benchmark HV network
- Doubly Fed Induction Generator (DFIG)



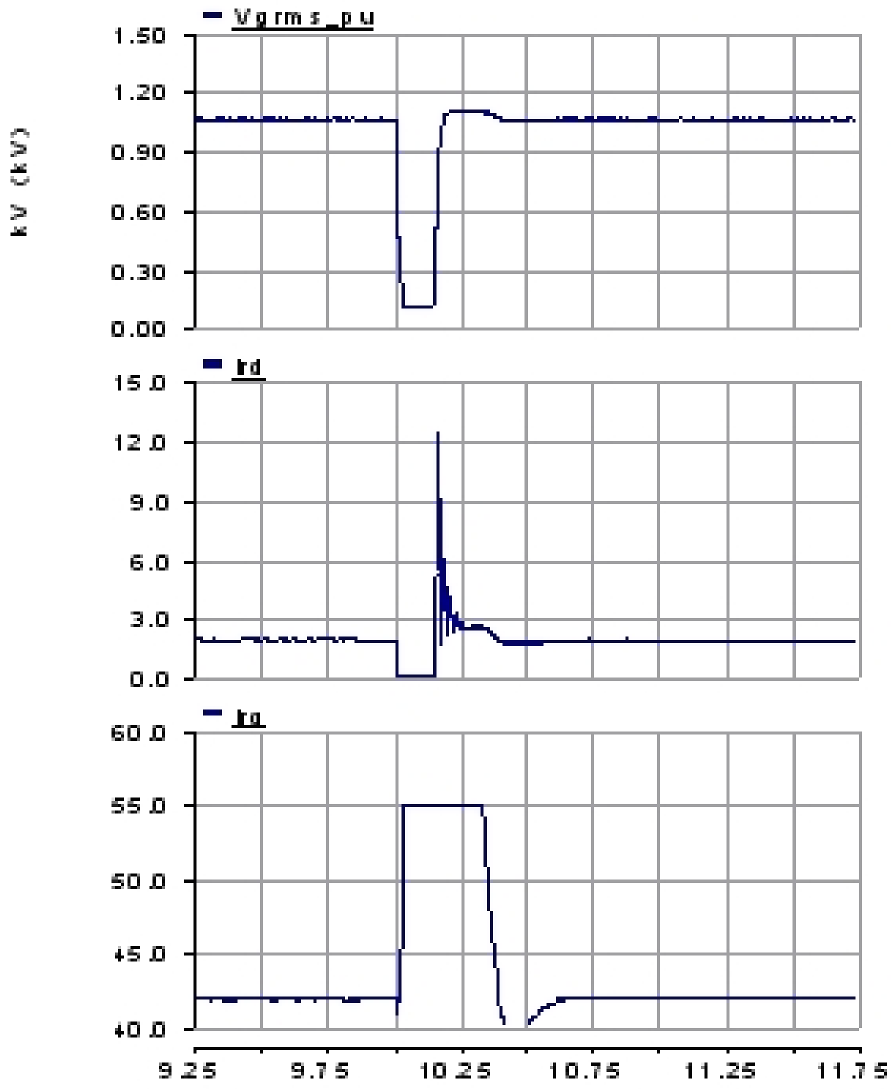
DFIG

- Low voltage ride through
  - A fault in the HV network for a duration of 200ms
  - Voltage, real and reactive power exchanges at PCC



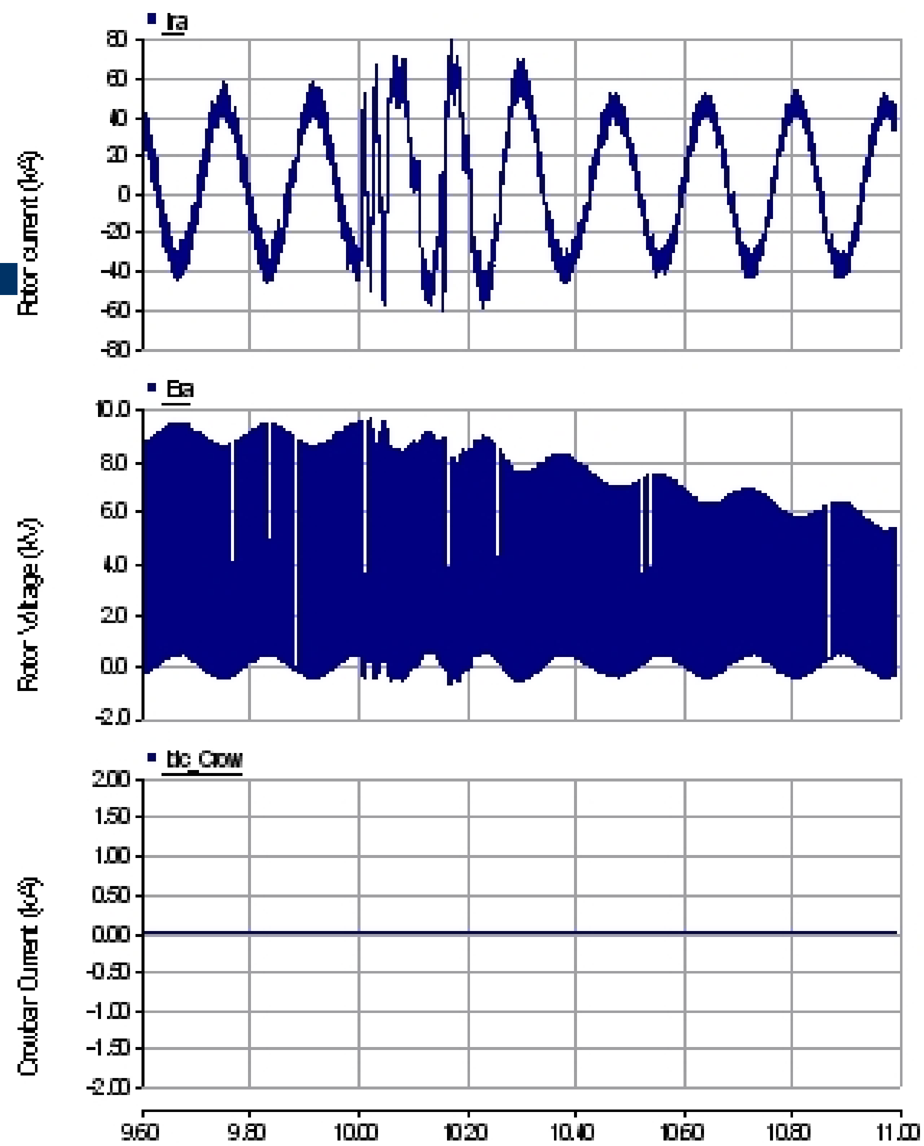
DFIG

- Rotor current order in d-q domain
  - I_{rd} and I_{rq} are the DFIG current orders derived from its control loops.
    - I_{rd} controls the reactive power
    - I_{rq} controls the real power



DFIG

- Rotor current and voltage
  - Useful in investigating crow bar protection settings



Hardware Testing Using Real-time Playback

- Analog and digital signals from time domain simulations are recoded into a file
  - voltages, currents, breaker status, etc,
  - COMTRADE format
- Teal-time playback instruments can reproduce the signals in real time
  - Controller and protection hardware testing
  - Limited to open-loop testing
  - Cheaper solution compared to real-time digital simulation when acceptable

Conclusions

- Power system studies with appropriate dynamic models are needed to verify new renewable energy systems interconnection requirements.
- Electromagnetic transient simulation is a very powerful tool for such studies
  - Adequate models of DG, network, power electronics, control and protection devices are available in time domain
  - System protection can be simulated precisely
- Benchmark network models can be greatly beneficial for DG integration studies
  - simulation results using such benchmarks can be compared to each other and verified using different software packages