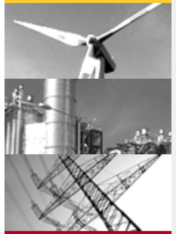
Modelling for Renewable Generation

Brad Henderson
DIgSILENT Pacific
Suite 8/437 St Kilda Road
Melbourne 3004
Email: brad@digsilent.com.au
Web: www.digsilent.com.au



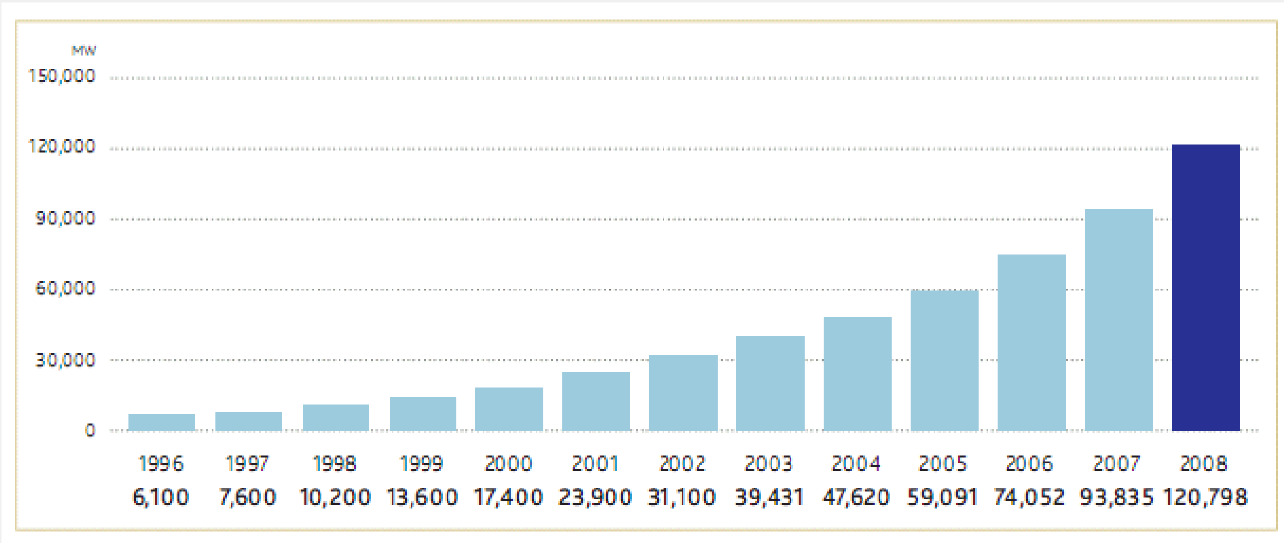
Introduction

- Renewable generation in context – the new wave?
- Key criteria for a 21st century power system
- The importance of fault ride through for renewable generation
- Review of synchronous machine generator technology
- Technologies used for renewable generation
- Fault ride through performance of renewable generation technology
- Other considerations for renewable generation

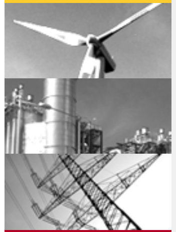
Growth in renewable generation

- Recent growth (10 years) mainly in wind – now industrial scale (1.3 % of total electricity generation worldwide) **Source BTM consult Apps**
- Solar is beginning to stir with several proposals for large scale solar generation throughout the world

Growth in wind energy capacity since 1996



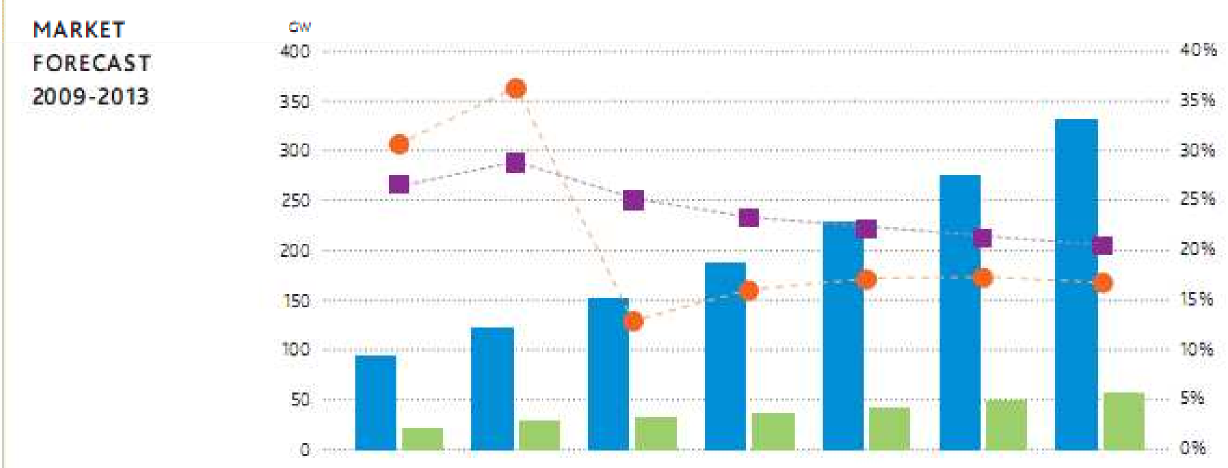
Source GWEC



Prospects for increased wind generation

- GWEC forecast for wind capacity to continue substantial growth for the next five years >20% capacity per annum
- 3.3 % of installed generation by 2013, 8% by 2018

Source BTM consult Apps



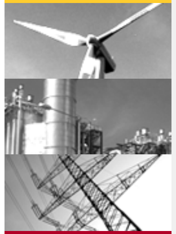
	2007	2008	2009	2010	2011	2012	2013
Annual installed capacity (GW)	19.9	27.1	30.4	35.2	41.2	48.2	56.3
Cumulative installed capacity (GW)	93.8	120.8	151.2	186.4	227.6	275.8	332.1
Annual install capacity growth rate	30.7%	36.2%	12.5%	15.7%	17.0%	17.0%	16.8%
Cumulative capacity growth rate	26.7%	28.7%	25.2%	23.3%	22.1%	21.2%	20.4%

Source GWEC

Impact on the power system

- Wind generation mostly does not use directly connected synchronous machines
- Reliance on alternative (and less well understood) generation technologies
  - Doubly fed induction machines
  - AC/DC power converters
- Displacement of traditional (and well understood) synchronous machines
- Behaviour of these devices during system disturbances is different and must be modelled

Source GWEC



Qualities for a 'good' power system

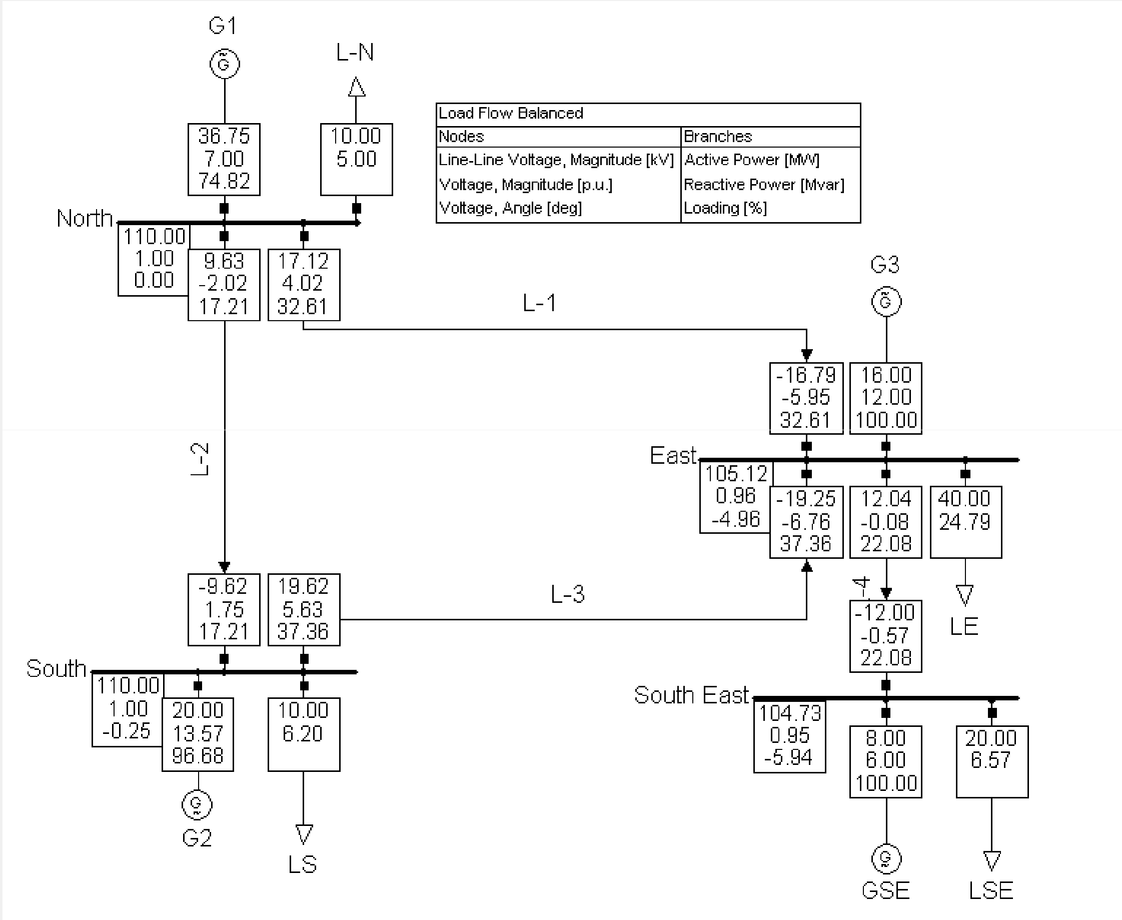
- Reliable
  - Built in redundancy to cope with equipment failure (N-1 design) and faults
- Flexible
  - Grid must be able to manage continuously varying generation and load
  - Demand management, market dispatch
- Robust
  - Ability to withstand fault events (lightning, bush fires, component failure etc)
  - FAULT RIDE THROUGH for generation

Why is fault ride through important?

- Fault ride through of generation prevents cascade failure of generation and the power system
- Case Study – System with under voltage protection on generation

Case study system

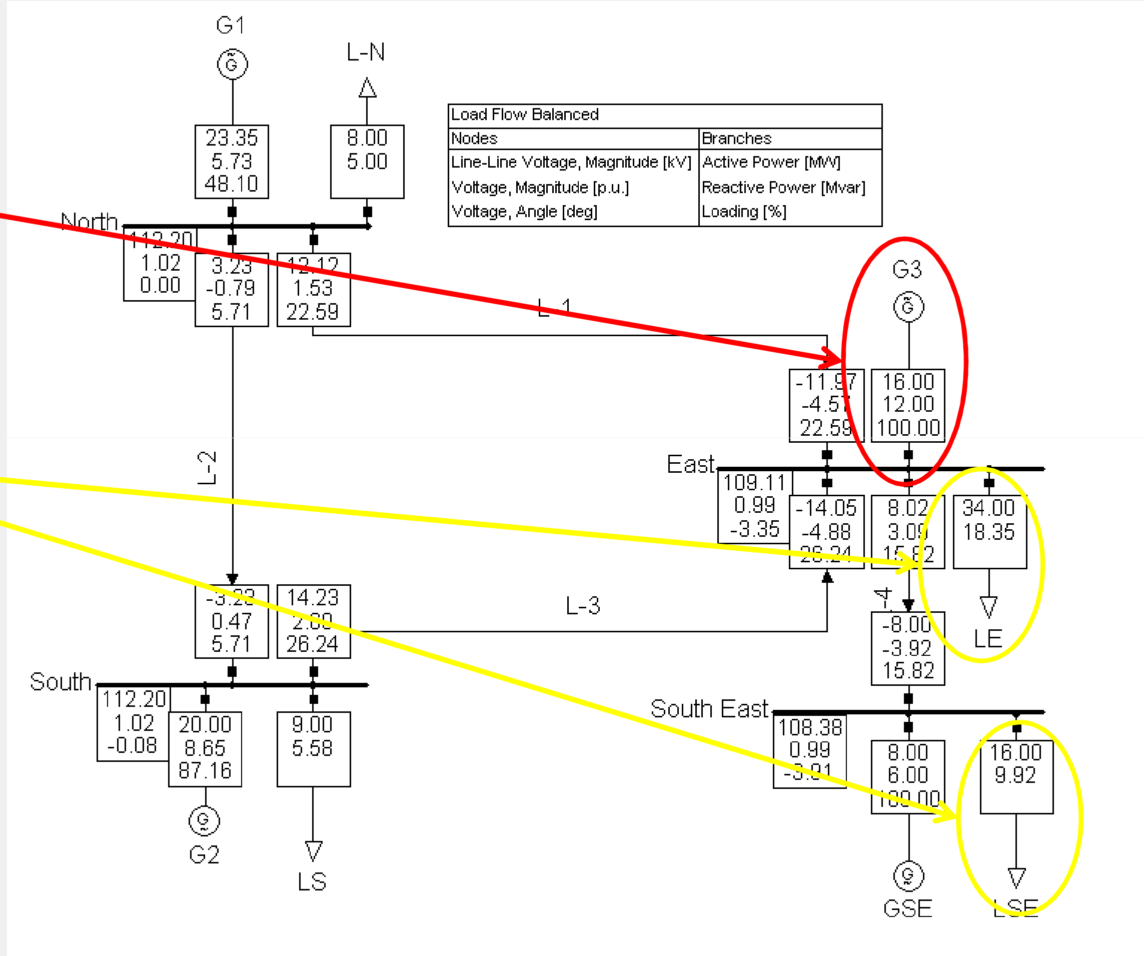
- Generation = Load + Losses = 67.4 MW
- Spinning reserve = 16.6 MW (≈25%)



Scenario 1 – No fault ride through

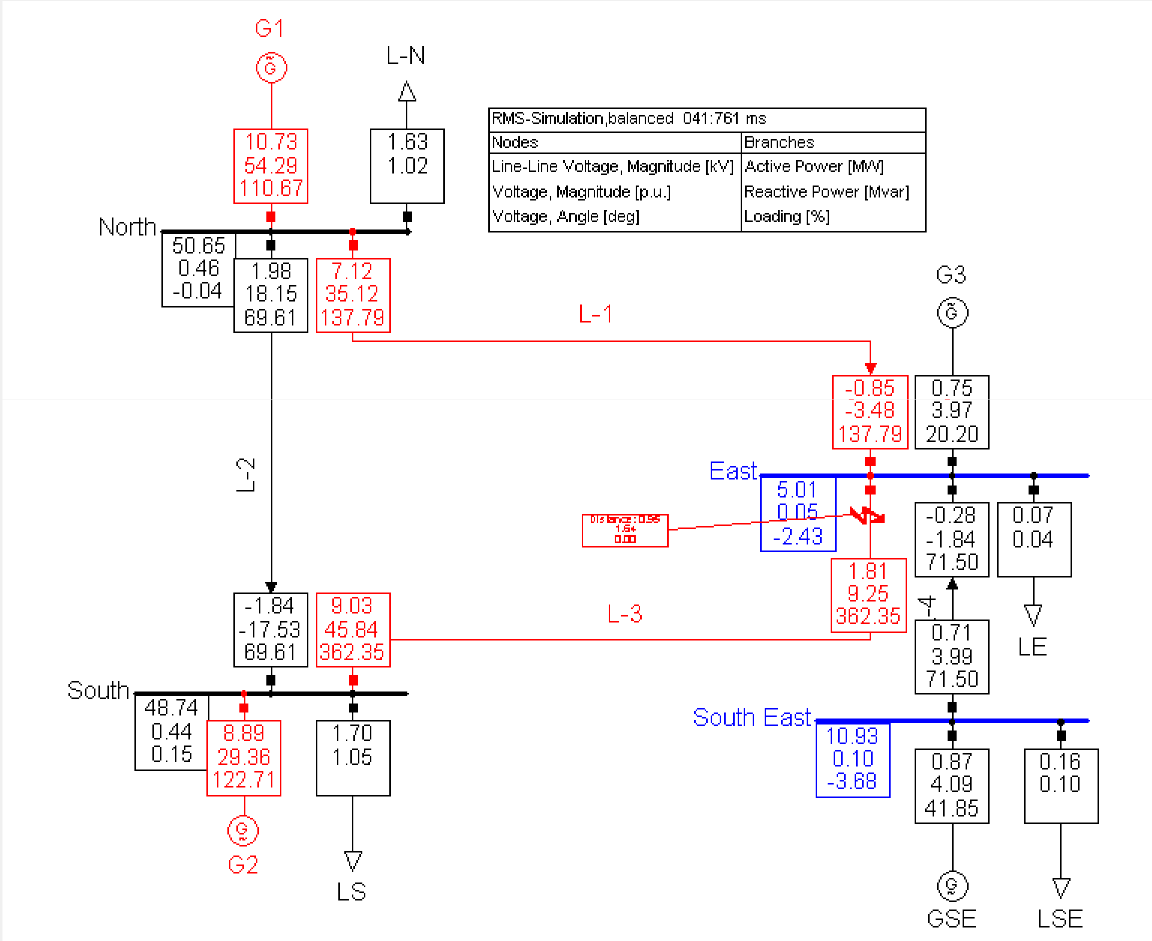
- G3 is protected by an under-voltage relay (0.2 p.u, 50 ms delay)

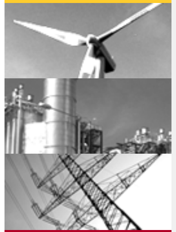
- Under-voltage load shedding on LSE and LE (0.9 p.u, 5 sec delay)



Scenario 1 – Fault on Line 3

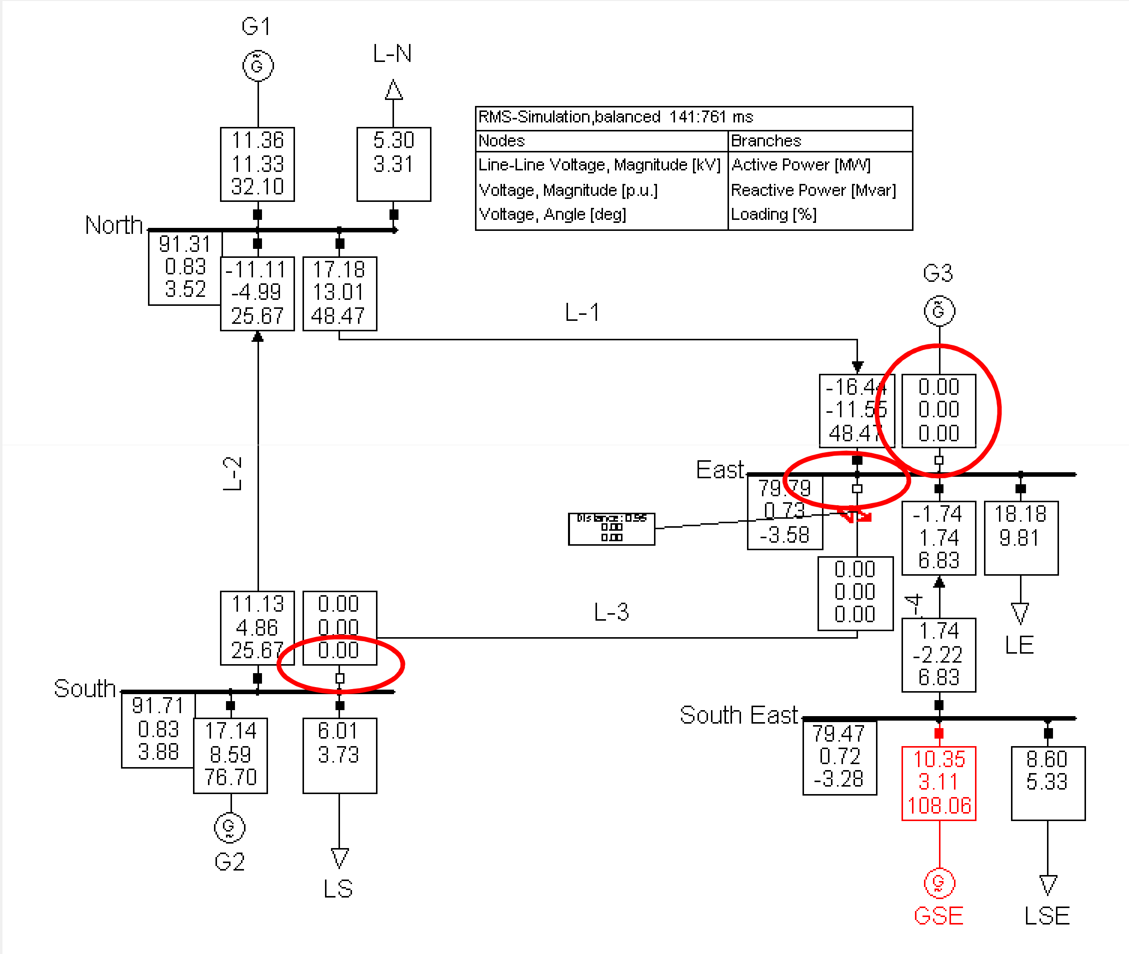
- Fault at remote end of Line L-3
- Low voltage at East and South East substations





Scenario 1 – Protection operation

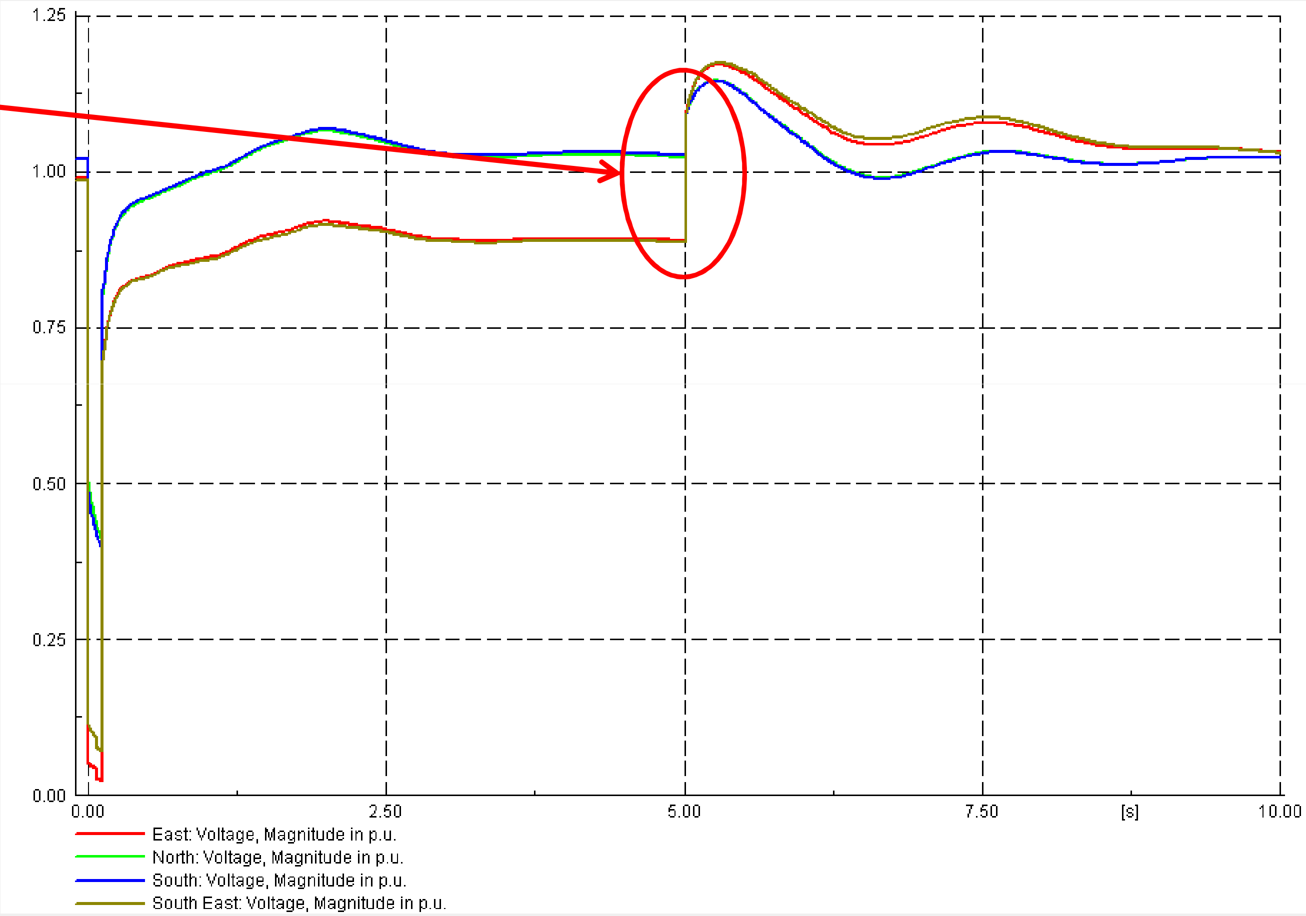
- Under-voltage relay trips G-3 in about 70 ms
- Protection clears L-3 fault in 120 ms
- Voltage remains under 0.9 p.u at East and South East substations



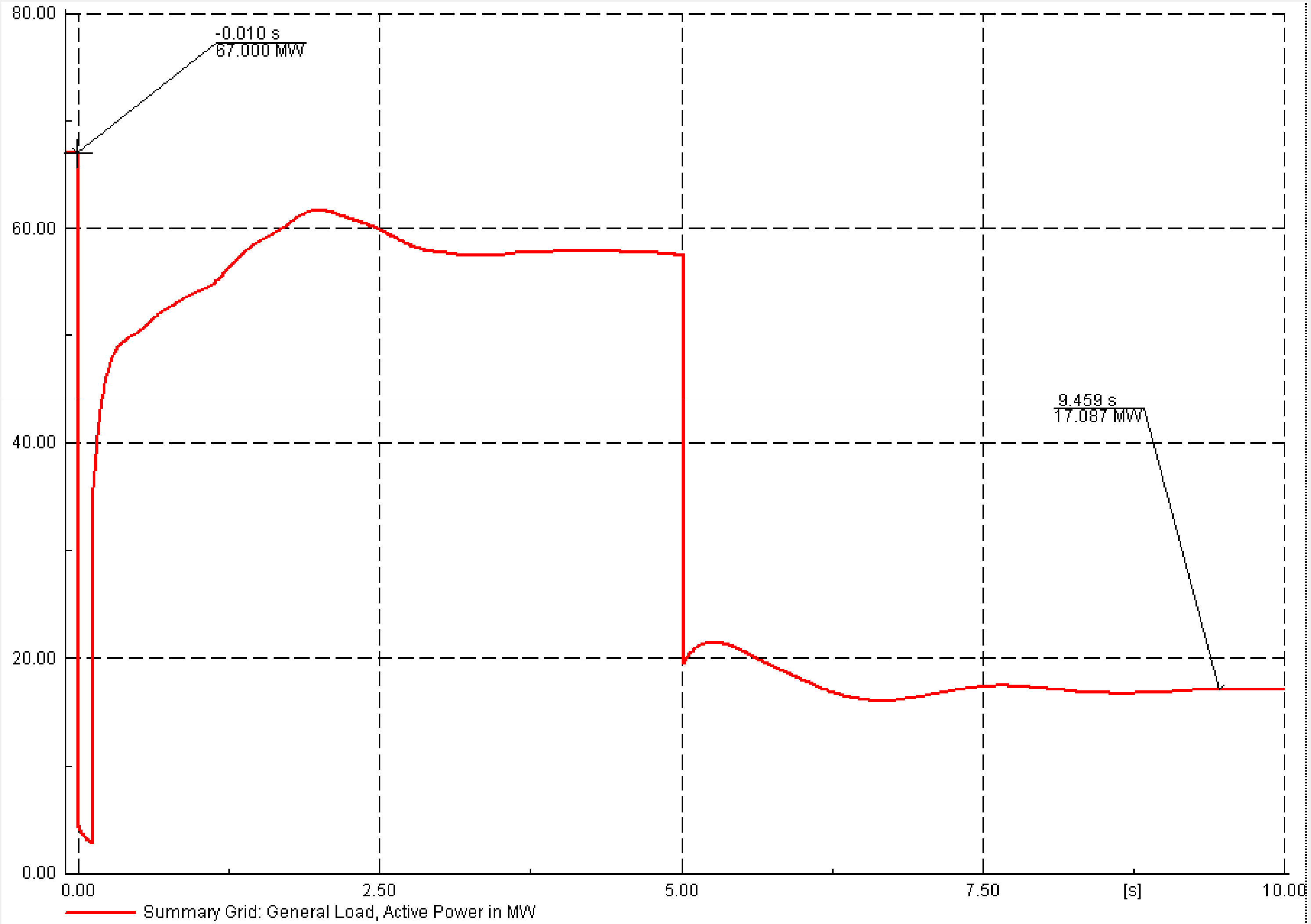
Scenario 1 – Under-voltage load shedding

- A t=5 s voltage at East and South East substations has not recovered

- Load shedding initiated to restore voltage

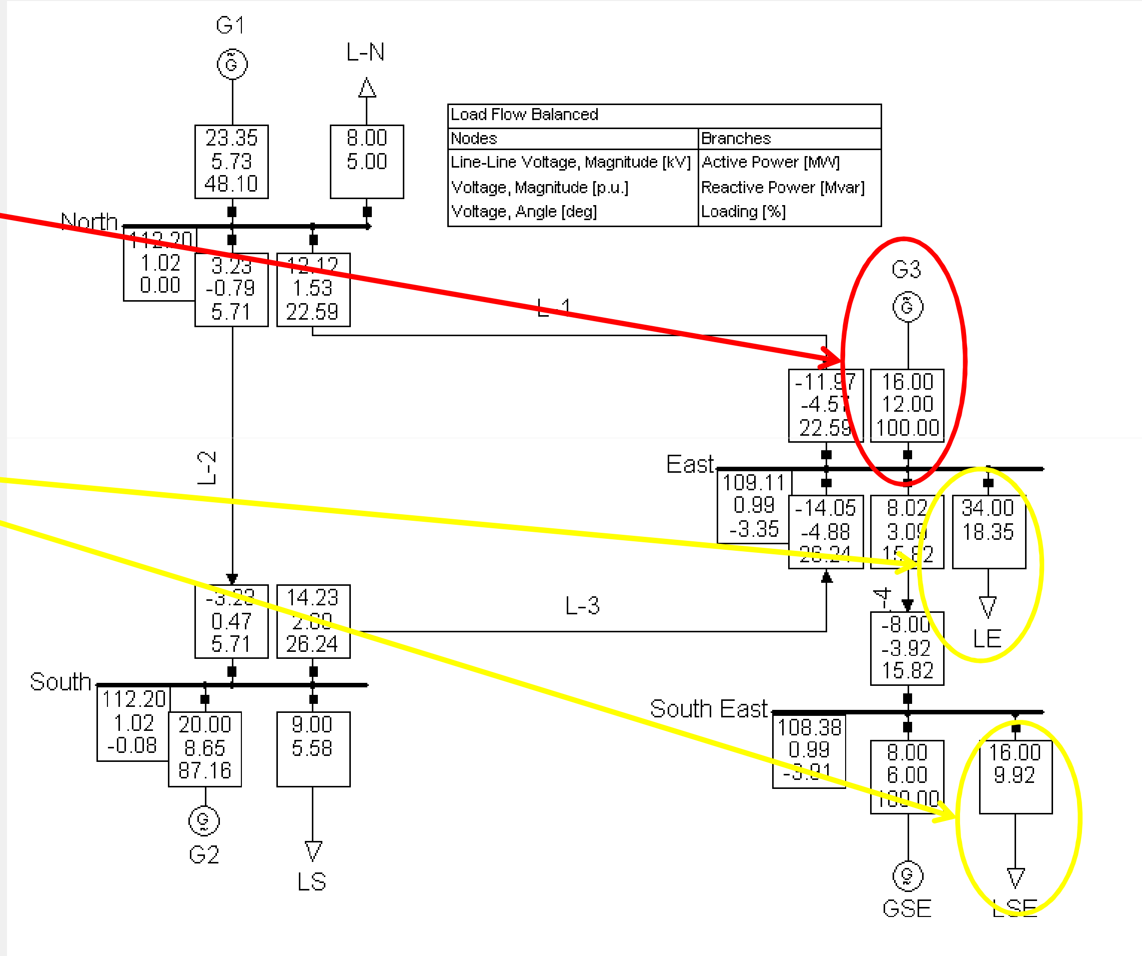


Scenario 1 – 50 MW load is lost



Scenario 2 – G3 with fault ride through

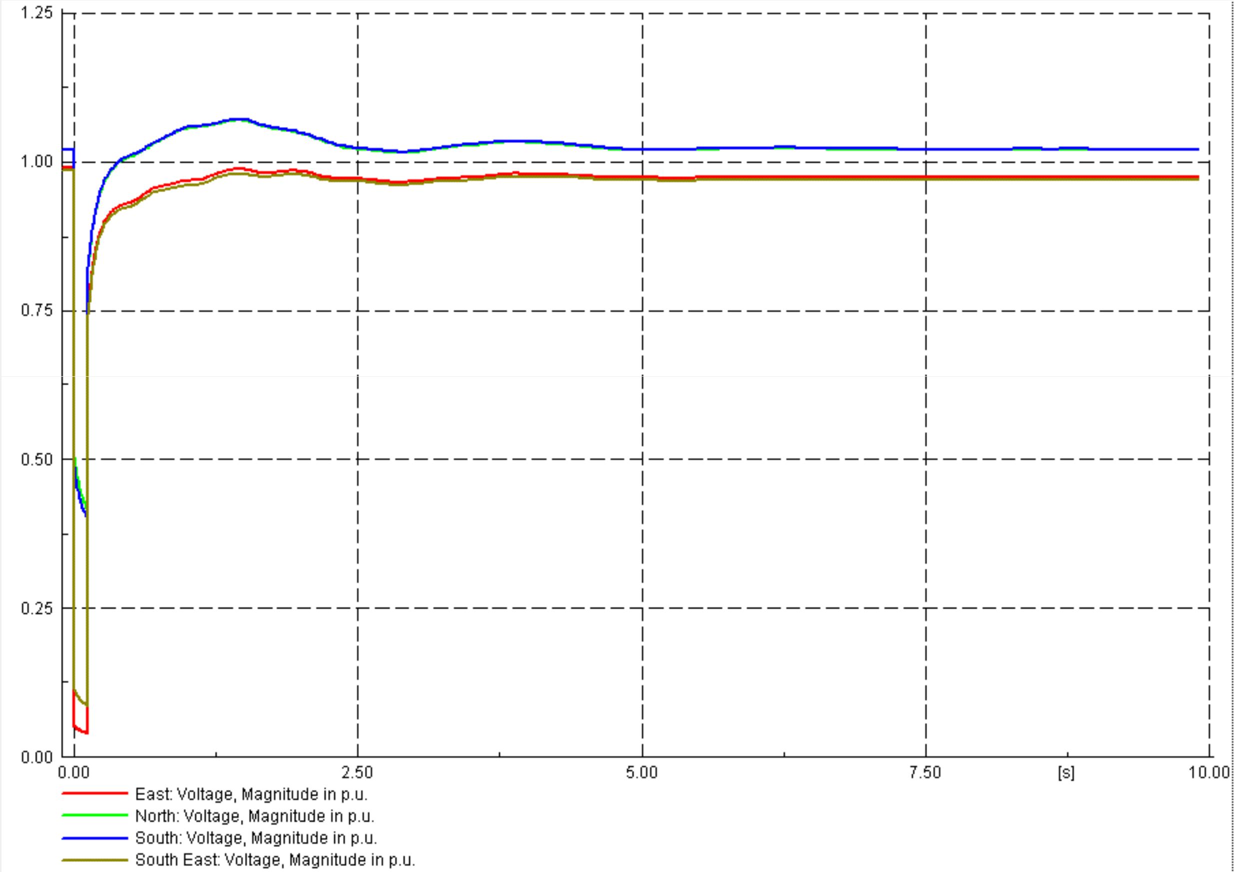
- G3 is equipped with fault ride through (0.2 p.u, 200 ms delay)
- Under-voltage load shedding on LSE and LE (0.9 p.u, 5 sec delay)



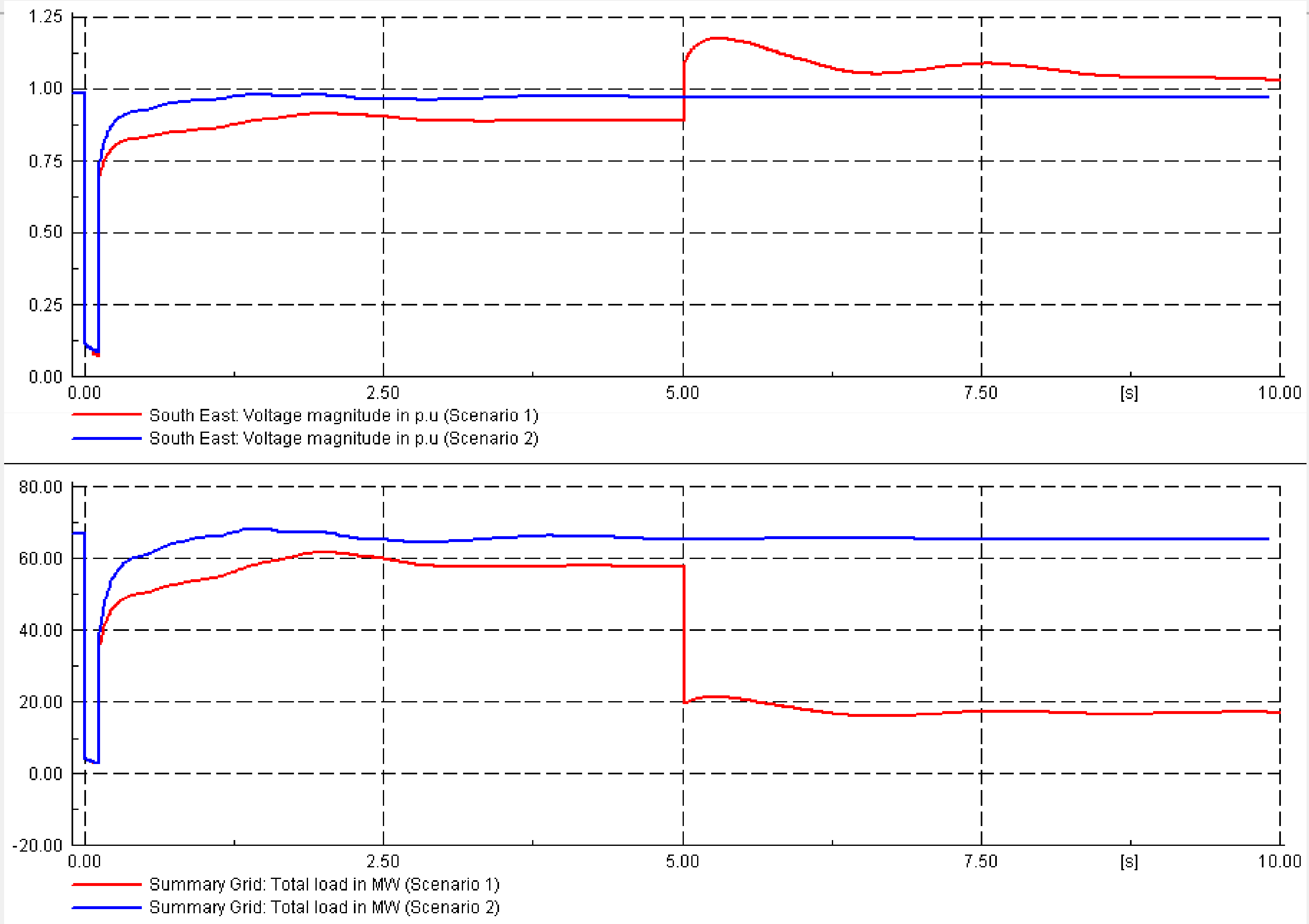
Scenario 2 – Under voltage relay on G3 does not trip

- G3 rides through the fault assisting with voltage recovery at East and South East substations

- No under-voltage load shedding initiated, all load remains connected



Comparison Scenario 1 Vs 2

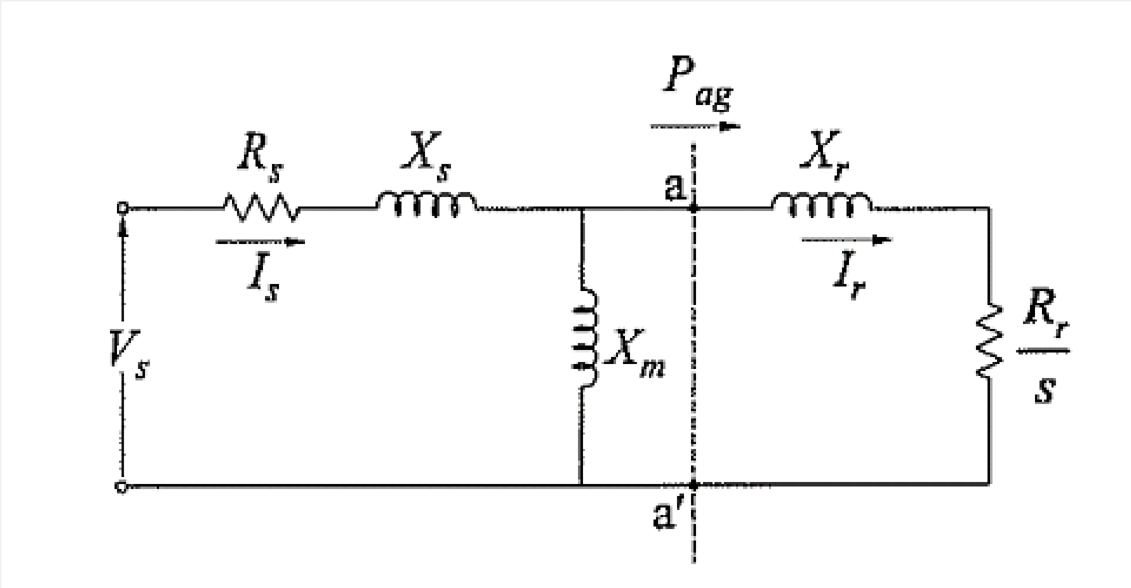


Fault ride through summary

- Fault ride through, enables generators to assist in system voltage recovery after a disturbance
- Can prevent the need for emergency measures such as under-voltage load shedding
- Less load is interrupted
- Improves the **robustness** of the power system
- Prevents (potentially costly) restart procedure for generation

Fault ride through for renewable generation

- Synchronous machines usually ride through severe power system voltage disturbances
- Asynchronous machines usually don't
  - Why not?
  - Need to examine model for asynchronous machine



Asynchronous machine performance

- Asynchronous machine has no control of reactive power output
- Reliant on the grid for magnetising current
- Draws reactive power from the system
- During a fault when voltage and speed falls the motor will draw a large amount of reactive power (up to 5-6 p.u)
- Exacerbates the low voltage problem making the disturbance worse
- We don't want them to ride through the fault…

Early wind turbines

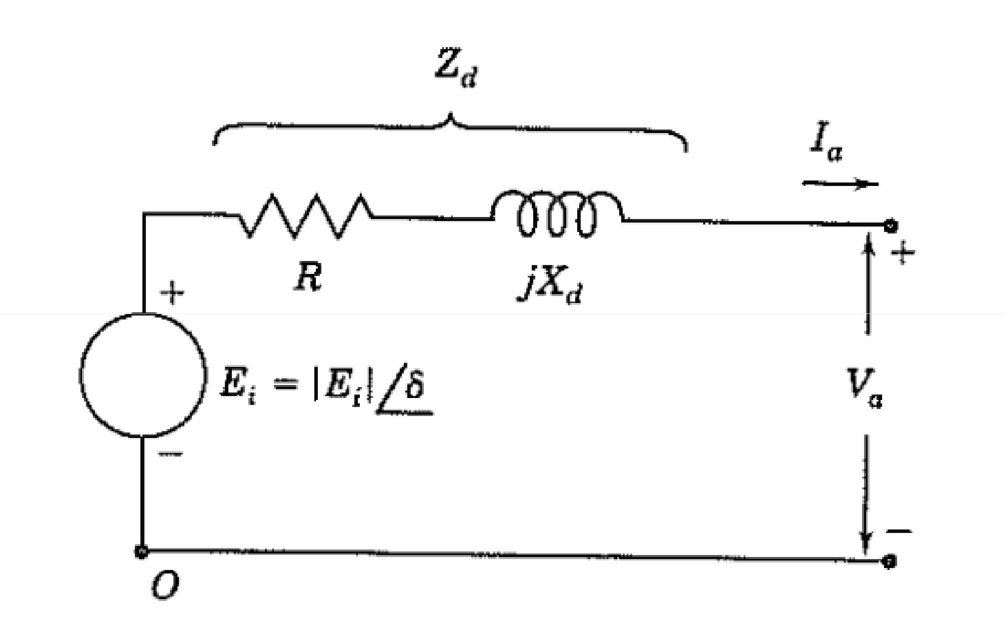
- Early wind turbines primarily used asynchronous machines
  - Often no voltage support or perhaps some capacitors
- Utilities and system operators recognised the issue with reactive power consumption during voltage disturbances
- Requirement to disconnect during low voltage

Wind turbine disconnection during disturbance

- No fault ride through by design
- Disconnection from system prevents making the problem worse
- HOWEVER!
  - This is fine when wind turbine penetration is low
  - But if penetration reaches a certain threshold then can cause sustained low voltage just by tripping (Scenario 1 case study)
- Low voltage tripping is not a solution to asynchronous machine limitations during low voltage events
- Need turbines that support the voltage during a fault like normal synchronous machines

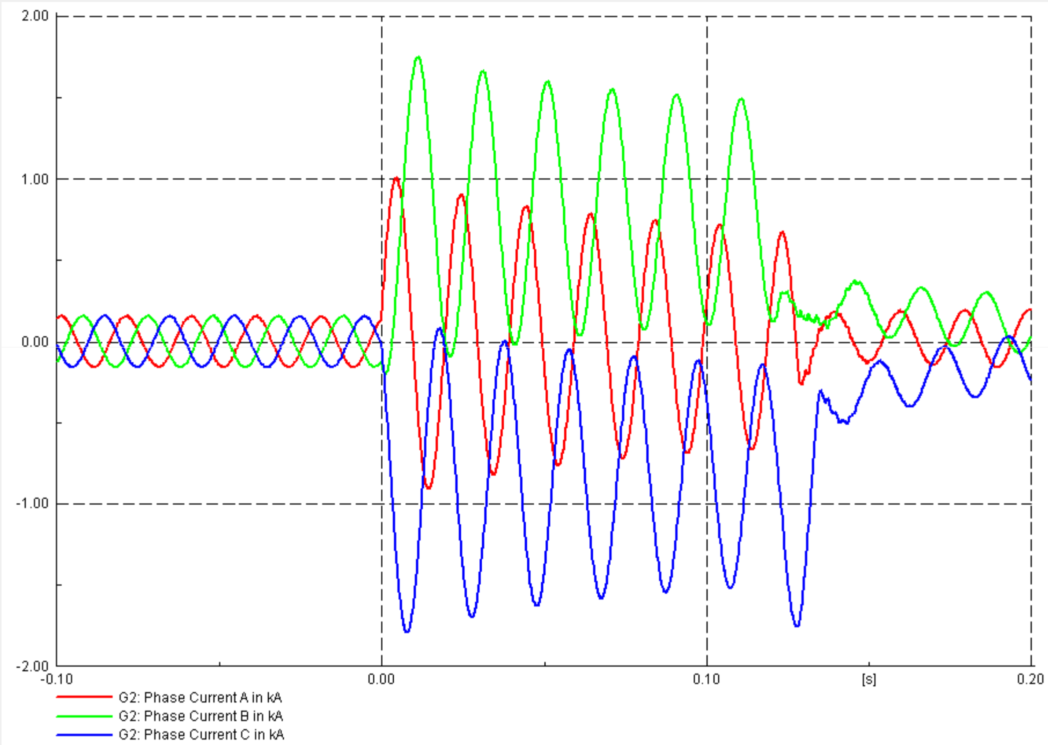
Synchronous machines – synchronous equivalent circuit

- Voltage source 'behind' a synchronous impedance
- Reactive power controlled by varying machine excitation, in turn controls machine terminal voltage
- Real power controlled by mechanical torque on the shaft (turbine power)
- Independent control of P & Q
- Not reliant on the grid for excitation



Synchronous machines – response to a short circuit

- Synchronous machines respond to a short circuit with a (temporary) increase in current up to 5 p.u
- Can provide a sustained increase in reactive power output post fault (if there is some reactive reserve)
- Response is limited by excitation and turbine dynamics
- Helps system voltage recovery after a disturbance



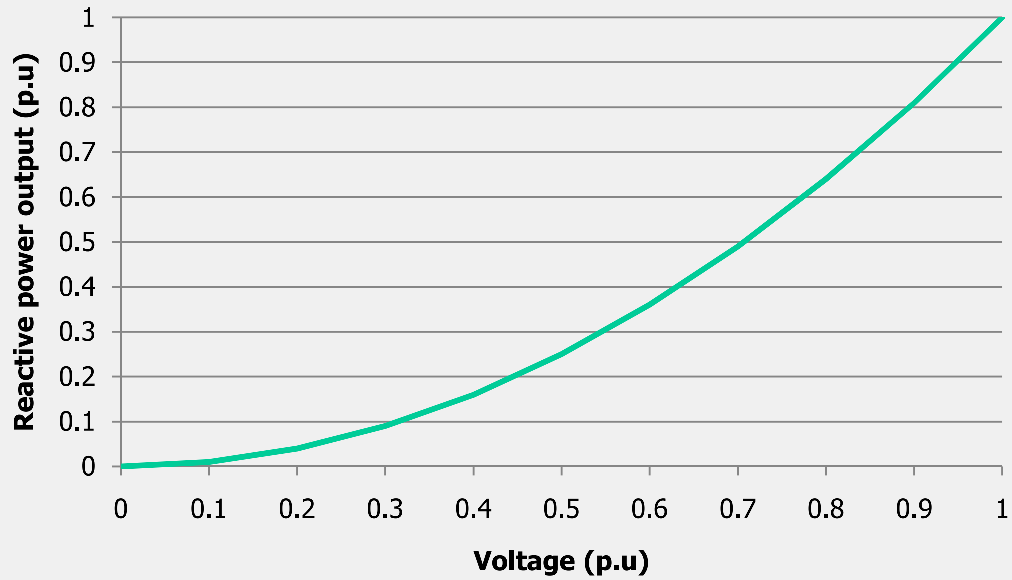
Wind generation technology

- Practical and economic considerations mean that it is difficult to use directly connected synchronous machines with wind turbines
  - Variation in wind-speed results in fluctuations in shaft torque causing high mechanical stresses (Requires a special torque limiting gearbox)
  - Asynchronous machines much cheaper than synchronous machines

- However there are solutions to the voltage support problem
  1. Auxiliary equipment to 'shore up' system voltage (STATCOMs, capacitors, SVCs)
  2. Doubly Fed Induction Machines
  3. Variable speed synchronous machines connected through AC/DC converters

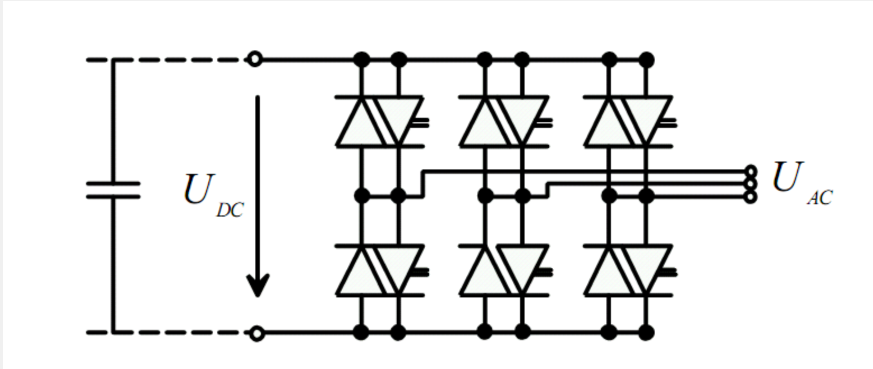
Voltage support with capacitors

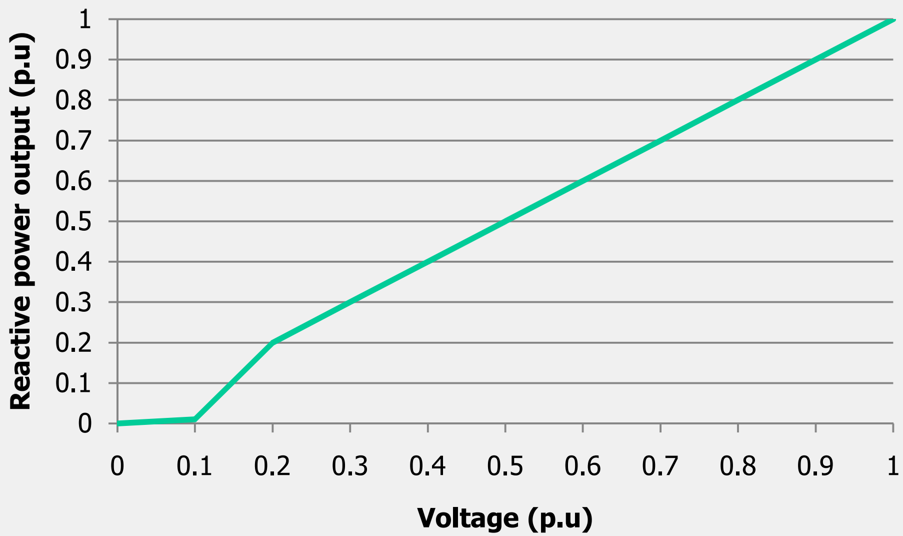
- Capacitors can be used to compensate the reactive power load of asynchronous machines
- Fine for steady state
- But what happens during low voltage system disturbances?
- Reactive output ~ V^2
- 0.9 p.u voltage, capacitor output falls by ≈ 20 %



STATCOM for reactive support

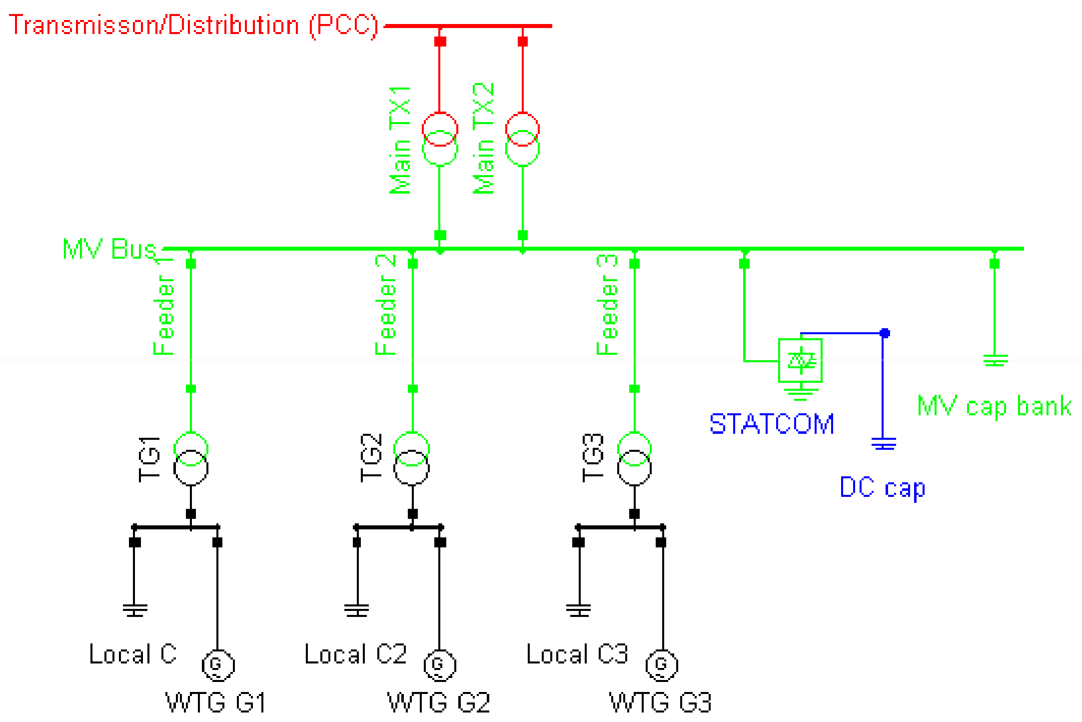
- STATCOM is a constant current power electronics device
- 'Voltage source converter'
- Reactive power response during under-voltage is linear and closer to a synchronous machine
- Some limitations due to harmonic impact
- Usually some dynamic reactive overload capability





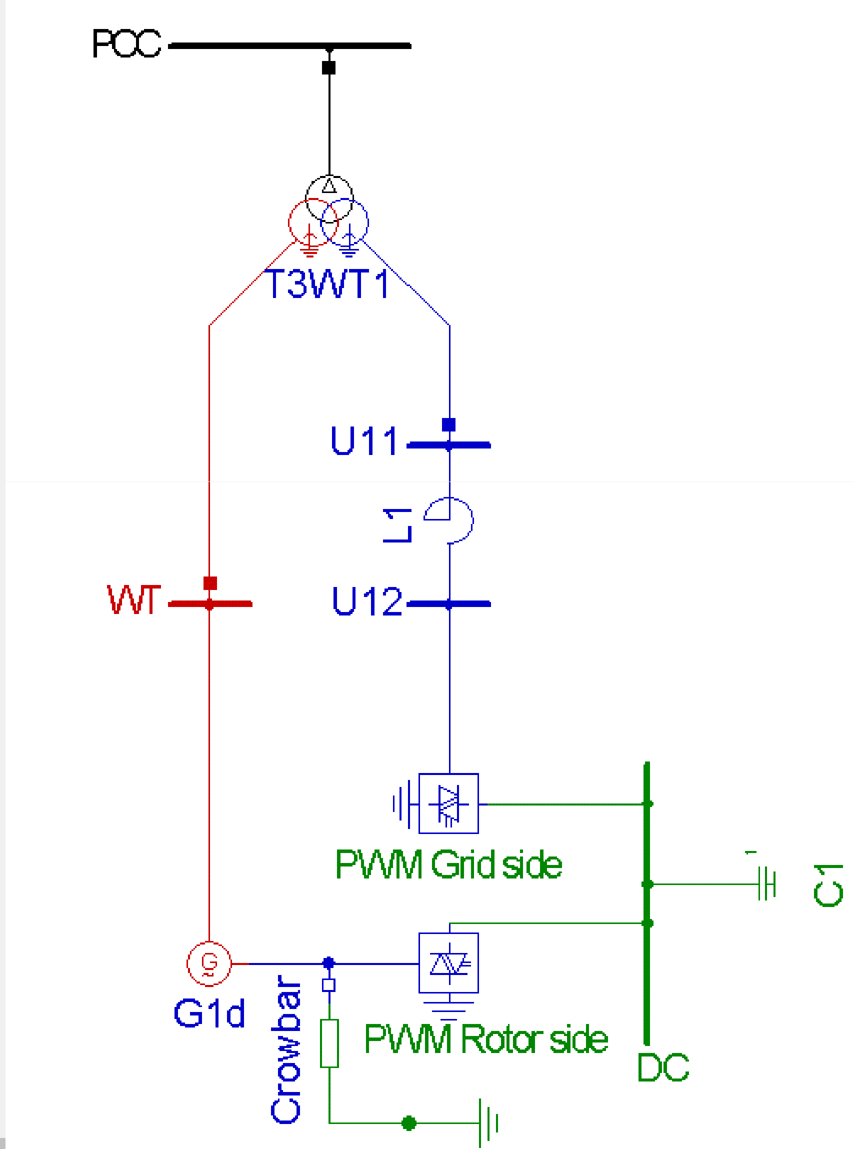
Large wind-farms: STATCOM + capacitors

- Combination approach for large wind-farms
  - Capacitors for static reactive power requirements
  - STATCOM for dynamic requirements



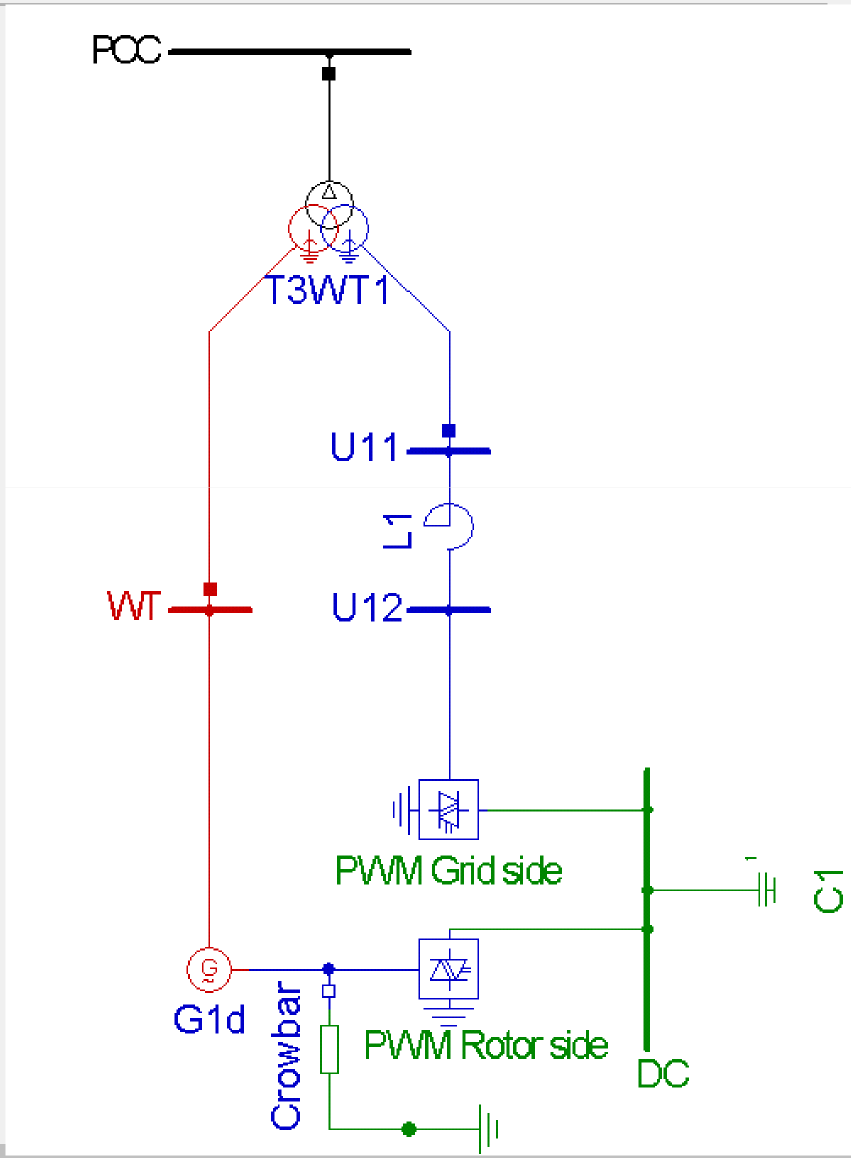
Doubly fed induction machine - diagram

- Alternative to asynchronous machine with STATCOM and capacitors
- Wound rotor asynchronous machine
- Rotor voltage controlled by power electronics



Doubly fed induction machine - properties

- Independent control of P and Q like a synchronous machine
- Crowbar operates to short circuit the rotor and protect the rotor side converter from high transient currents

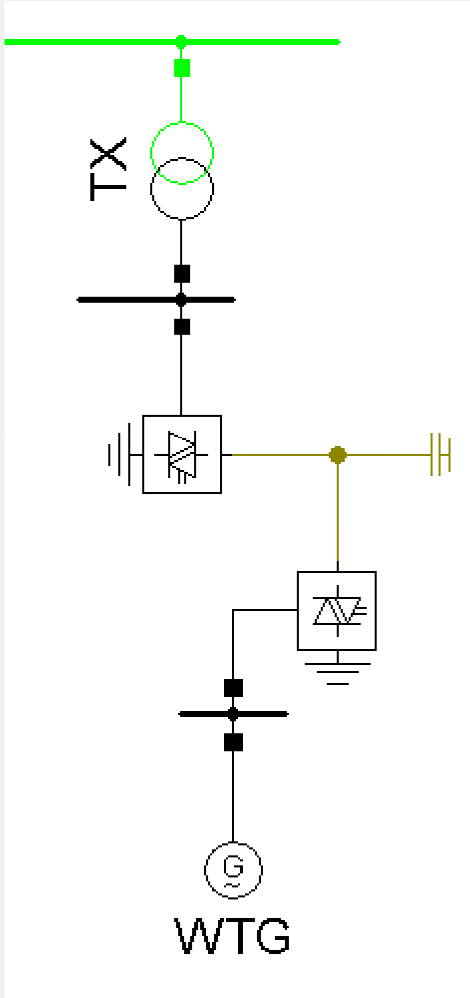


Doubly fed induction machine – fault ride through

- Can have excellent fault ride through performance
- Crowbar operates to short circuit the rotor and protect the rotor side converter from high transient currents
- Provides dynamic reactive support when crowbar is not in operation
- No need for auxiliary capacitors and STATCOMs

Fully rated AC/DC/AC converters

- WTG connected to the system through an AC/DC/AC converter
- Electrically the WTG is decoupled from the power system
- Can use either synchronous machine or asynchronous machine for generation
- Grid side response similar to a STATCOM (with real power also)
- Control of P and Q inherent



Fault ride through - comparison

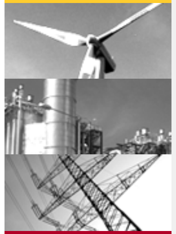
	Induction generator	DFIG	Fully rated converter
Static reactive power support	No	Yes	Yes
Dynamic reactive power support	No	Yes	Yes
Fault Ride Through	No	Yes	Yes
Cost	Cheap	More expensive	Most expensive

Fault ride through studies

- Ultimately fault ride through performance must be confirmed with detailed simulations
- Differences in manufacturer design will effect the response
  - For example in DFIG machines the crow bar control strategy will differ
  - Power electronics control scheme will be different
- Reactive power output varies depending on the ‘package’
- There are issues obtaining detailed models due to confidentiality and Intellectual property

Other considerations for renewable generation

- Renewable generation tends to be intermittent
  - Solar and wind for example rely on the fickleness of the weather
- Renewable generation generally makes heavy use of power electronic converters
- Two consequences of this
  - Harmonic generation
  - Flicker



Harmonics from renewable generation

- Power electronic converters always generate some AC harmonics
- Effects on the network requires simulation and study using an appropriate analysis tool such as PowerFactory
- Mitigation measures such as filters may be required
  - Adds to the project cost

Voltage Flicker

- Intermittent generation can cause voltage fluctuations within the connected system
  - This is known as flicker due to the visible flickering of incandescent lights this can cause
- Smoothing of rapid power changes due to wind/solar fluctuations is possible
  - Batteries
  - Energy storage device

PowerStore – flywheel energy storage

- The PowerStore is a flywheel energy storage device capable of storing up to 18 MWs of energy
- AC-DC-AC PWM converter
  - Operation principle similar to STATCOM but with real power output

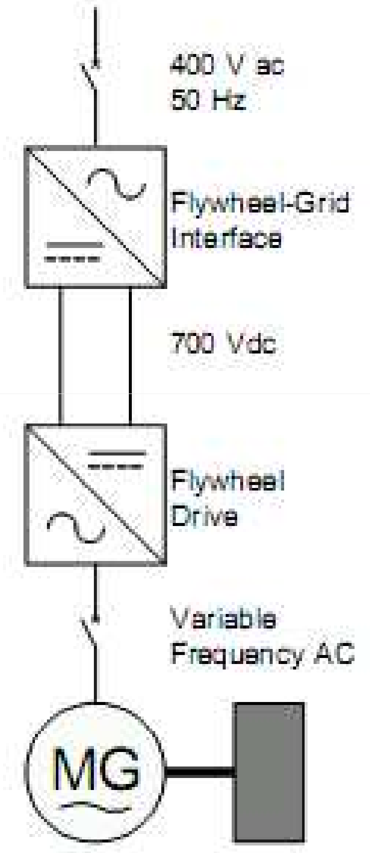
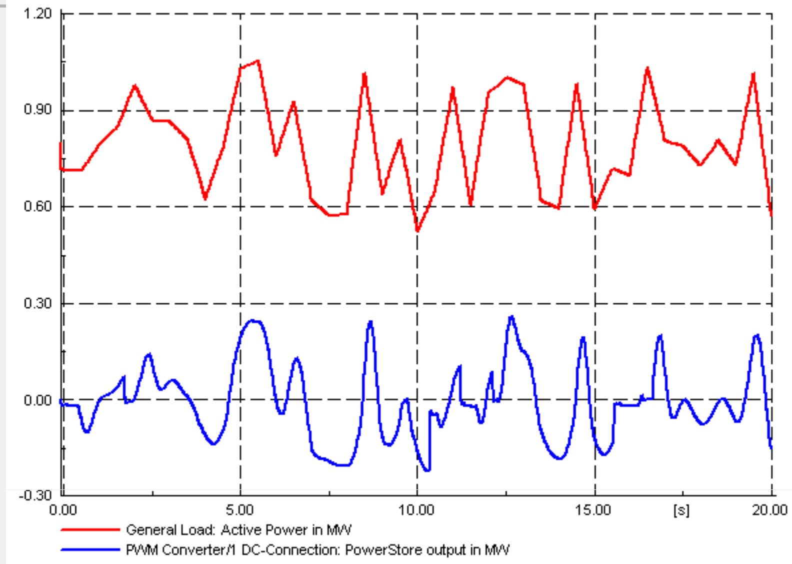
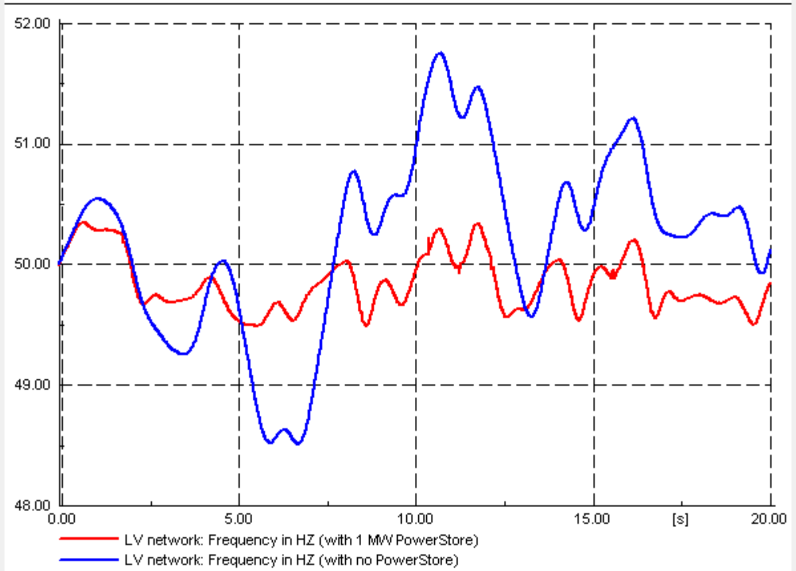


Figure 1 - PowerStore Single Line Diagram

PowerStore - applications

- Minimising frequency variation
  - Island systems (wind/diesel etc)
- Flicker mitigation
  - Smoothing of power variations
- Example system
  - Island system
  - Time varying random load ± 300 kW (0.5 s)
  - Lower traces show network frequency without the PowerStore (blue) and with the PowerStore (red)





Conclusion

- Wind power installed capacity continues to grow exponentially
- Fault ride through of wind-farms is important to ensure a robust power system
  - Especially as the penetration increases
- There are several competing generation technologies
  - Induction machine, DFIG, fully rated converter
  - Each has different fault ride through performance
  - Detailed models and studies are required to confirm performance during low voltage conditions
- Solutions exist!