PJCI **Prakarsa Jaringan Cerdas Indonesia**
Indonesia Smart Grid Initiative

The challenges of variable renewable energy to security of power system operation

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AGENDA

- Introduction
- Frequency Stability
- Voltage Stability
- VRE Connection to Weak Grid
- Example - Blackout in Power System with High Penetration of VRE

Introduction

- The grid was designed around the concept of dispatchable generators, synchronously connected to the grid
- Variable renewable energy (VRE) generators are non dispatchable, asynchronously connected to the grid through a power electronic interface
- Increasing penetration of (VRE) such as wind and solar power has rapidly changed the way how power grid is planned and operated

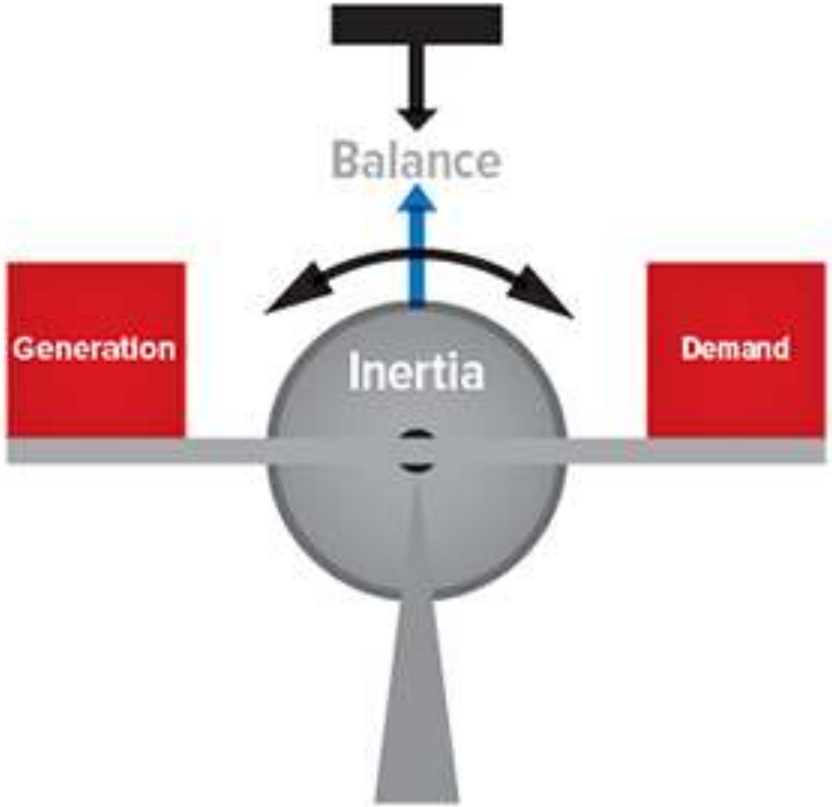
Conventional vs VRE Inverter Generators

	Conventional Generation	**Variable Renewable Generation**
Generator	Synchronous generator	Power electronic interfaced generator*
Output	Dispatchable	Variable, intermittent, fluctuates over multiple time horizons
Inertia	Provide inertial support to the grid	No inertia or hidden behind inverter
Frequency control	Fully possible	Partially possible
Short circuit current	Produce high short circuit current to increase system strength	Low high short circuit current
Voltage control	By generator excitation	By Inverter

*considered in this presentation

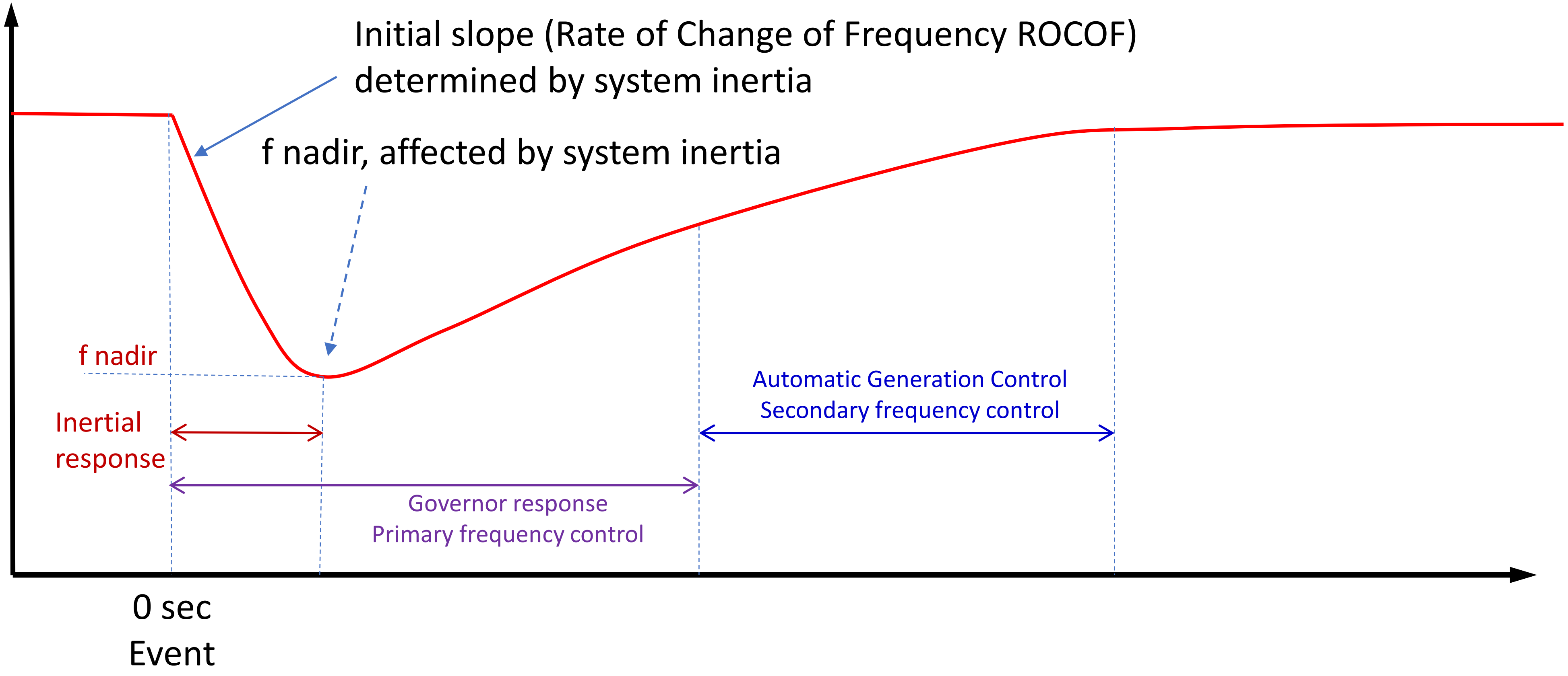
Frequency Stability

Frequency Stability



- Generation and demand balance
- Momentary demand generation mismatch
- Inertial response
- Primary and secondary frequency control

Power system response following generation drops



VRE Impact on Frequency Stability

- VRE sources and MW output are continually changing

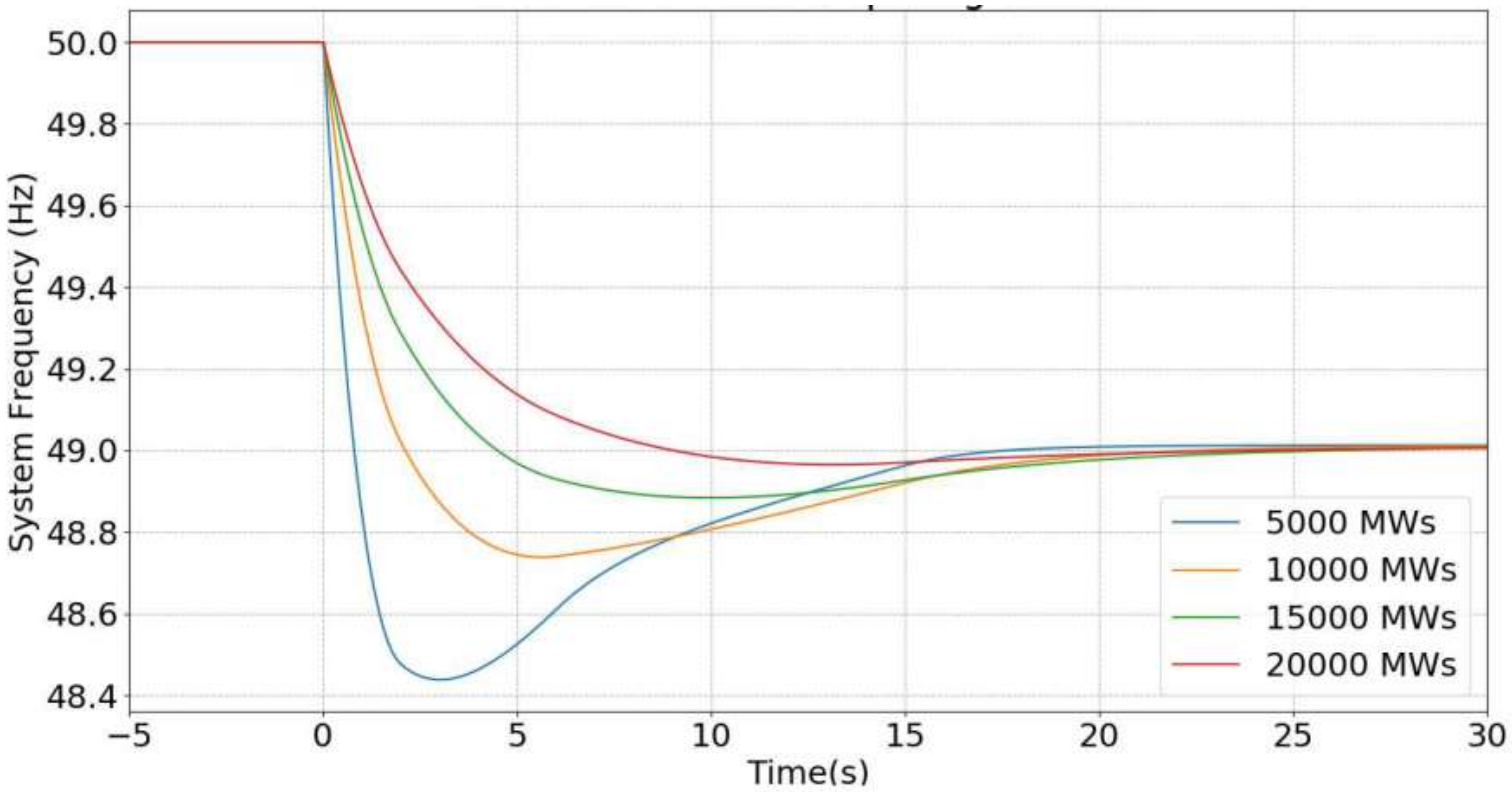
  But load demand and generation in traditional power system are also changing all the time and the traditional generator has been designed to handle these changes.

- Synchronous generators provide inertial support to the grid. Power electronic interfaced generators of VRE provide very little to none inertia support to the grid.

  VRE will potentially

  - decrease system inertia
  - increase ROCOF
  - Increase frequency drop (decrease the frequency nadir)

Frequency response on different inertia

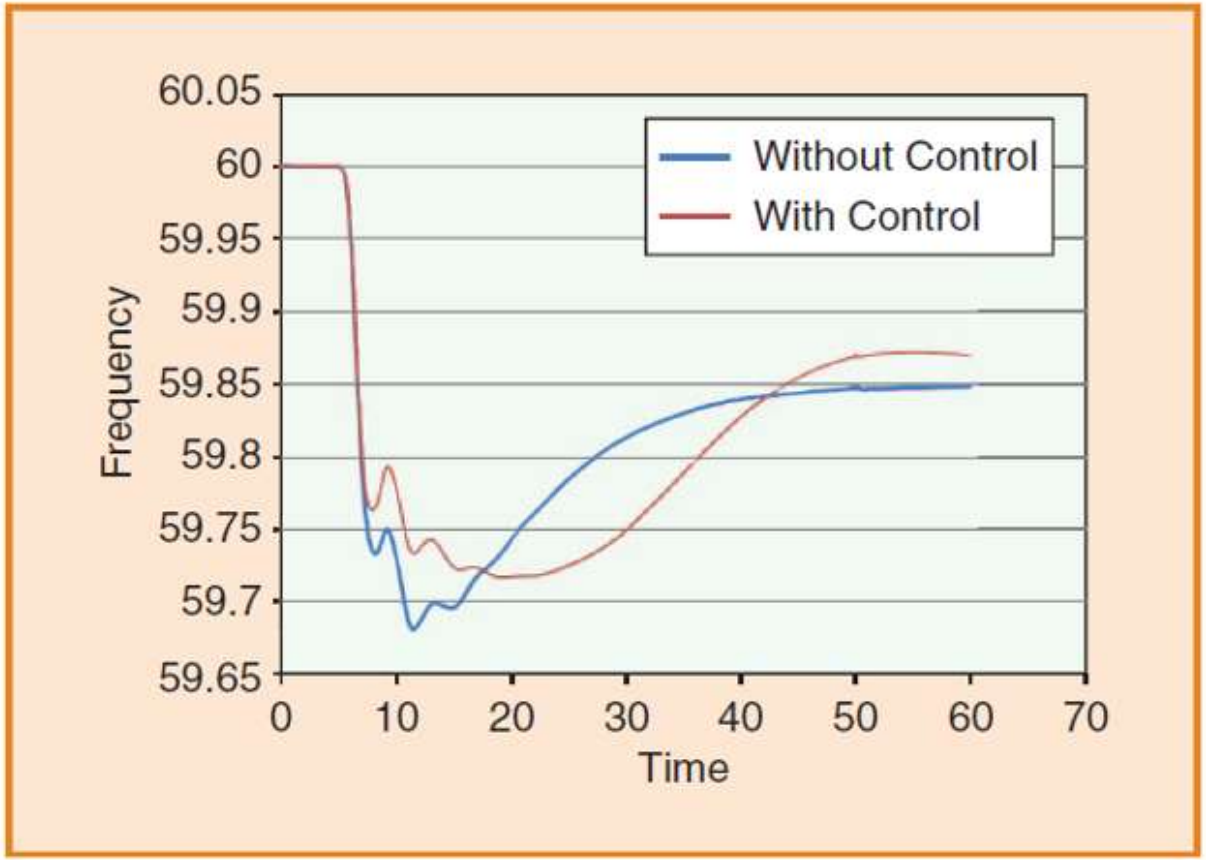


Synthetic Inertia of VRE Inverter Generators

- Active power controllers for VRE can provide a synthetic inertia response to stabilize frequency excursions.
- Wind power
  - Inertial control utilizes the kinetic energy of the rotating mass of wind turbine generators to provide an inertial response capability for wind turbines.
  - The response is provided by temporarily increasing the power output of the wind turbines by extracting the kinetic energy stored in the rotating masses.
- Solar PV
  - Curtail the PV generation to have headroom for power frequency control
- PV with battery system

Synthetic Inertia

Also refer as virtual inertia



VRE with and without synthetic inertia controls.

Voltage Stability

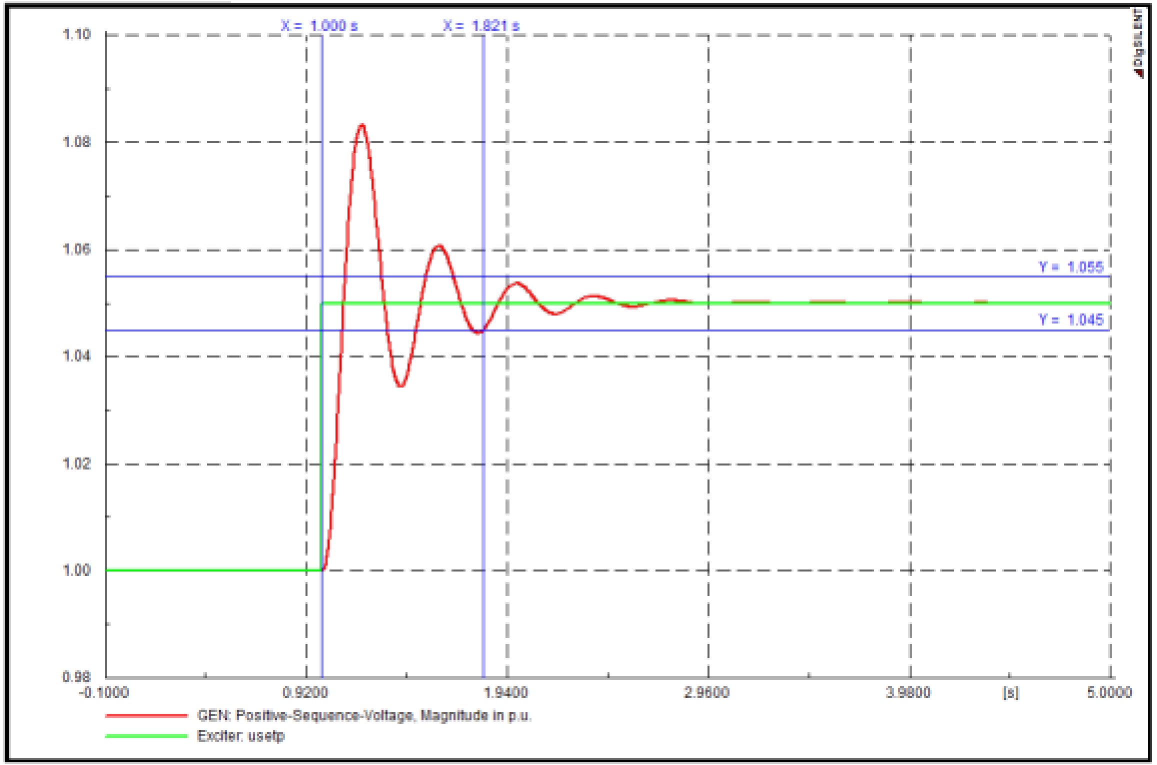
Voltage Stability

With proper design, VRE inverter generators can

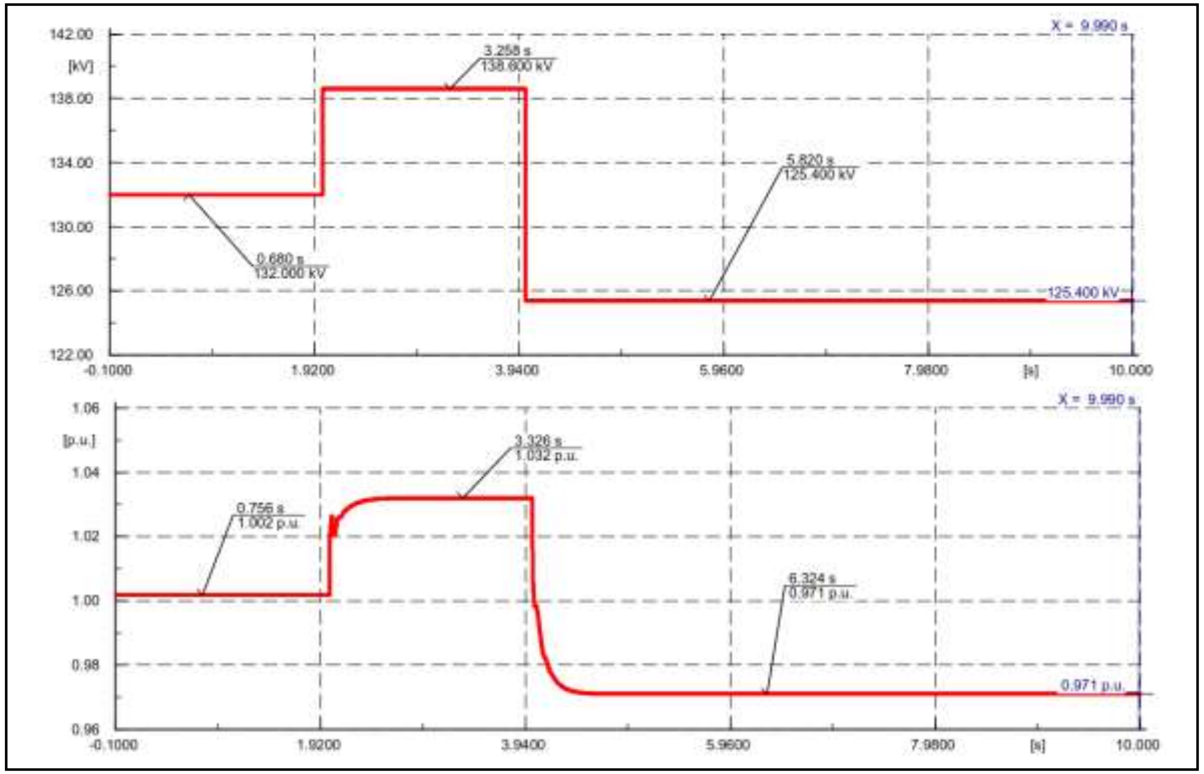
- Ride through various types of balanced and unbalanced under/over voltage faults
- Inject desired amount of reactive power during the fault to assist in faster voltage recovery
- Provide faster response in voltage stabilisation than synchronous generators

Voltage Step Response Tests – Example

Synchronous generator



Solar Farm Inverter



VRE Providing Voltage Support

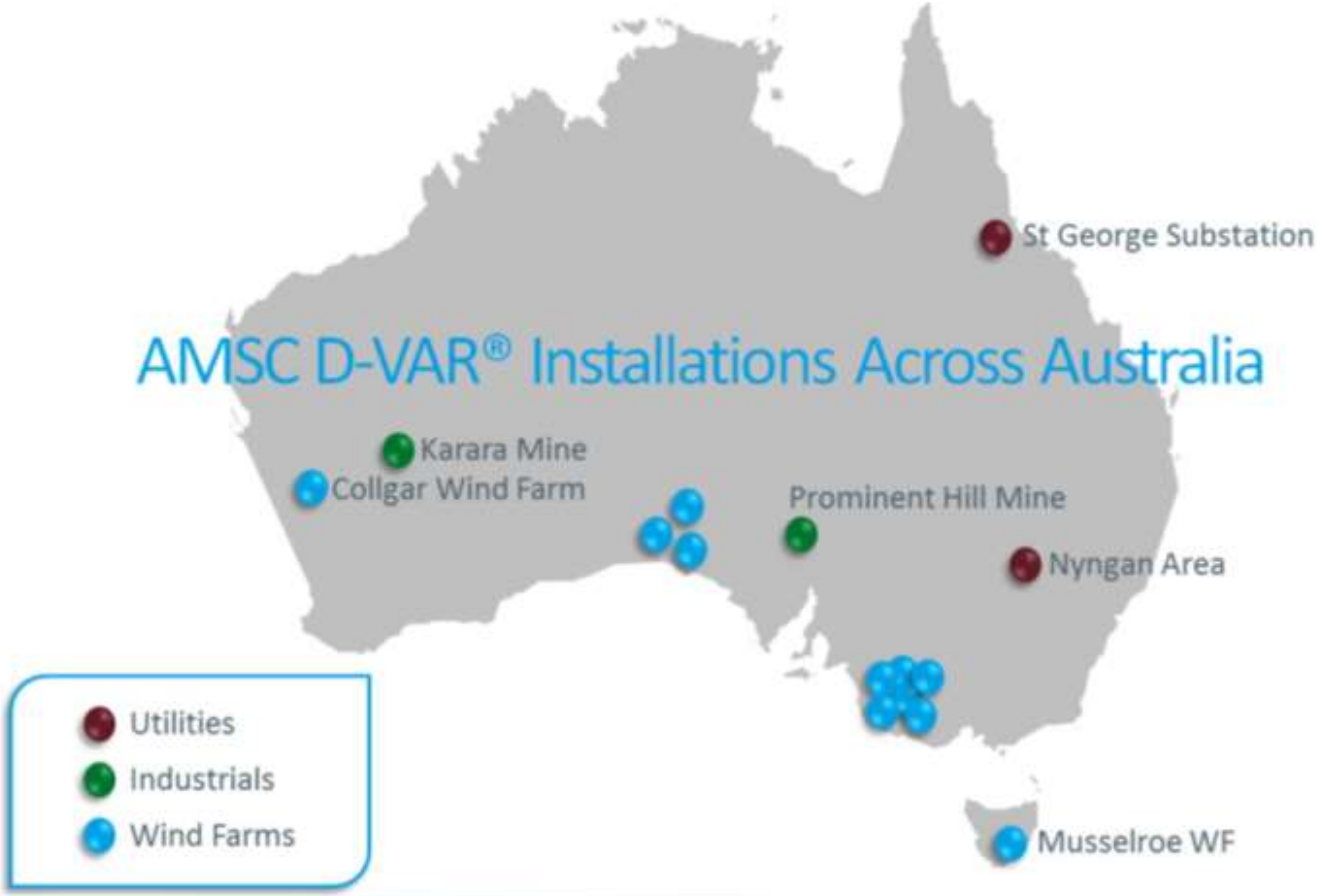
Issue :

VRE inverter generators share the inverter in producing active and reactive power. When providing voltage support, ability to provide active power decreases

- May not be designed to provide voltage support (or only provide minimal support) if Grid Codes do not ask to
- Optimisation of inverter for active power production vs voltage support
- Additional means of voltage support (capacitor, SVC, STATCOM) may need to be installed at VRE generator plants

Example, STATCOM Installation in Australia

from one manufacturer



VRE Connection to Weak AC Network

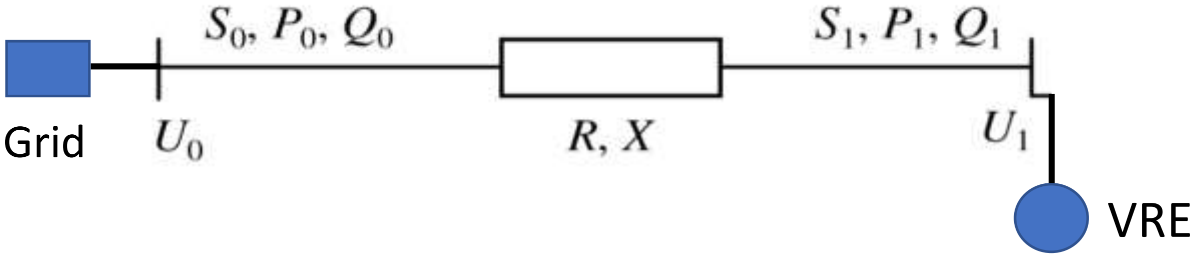
Definition

- The “Strength” or “weakness” of a power system is associated with
  - Grid short circuit capacity or grid impedance
  - Ability to transfer power in steady state at acceptable voltage
  - Resilience in maintaining the supply frequency

- Short circuit ratio is normally used to quantify the network strength

$$SCR_{POC} = \frac{MVASC_{POC}}{MW_{VRE}}$$

Voltage Sensitivity (at VRE Terminal)



- In low SCR area ("weak system")
  - System impedance & power high
  - U_1 is highly sensitive to changes of active and reactive power.
- In high SCR area ("strong system") :
  - System impedance & power low
  - U_1 is insensitive to changes in active and reactive power.

$$\Delta U \approx \frac{RP_1 + XQ_1}{U_1}$$

Issues associated with VRE connection at weak network

- Failure of the plant to regulate its terminal voltage adequately
- Ability of the controllers to adequately follow the connection point system frequency and phase immediately after a fault, decreases significantly
- Failure to ride through faults
- Electromechanical oscillatory stability, undamped oscillation
- Control interactions and instability

Solution examples

Augmentation of the transmission system with series capacitors

Installation of synchronous condenser

Synchronous Condenser – Example application

HVDC

- Provides short circuit strength
- Dynamic reactive power support (voltage regulation)
- Reduces local harmonic distortion (filter)

Wind/Solar

- Improves or increases short circuit ratio (SCR)
- Dynamic voltage support
- Can improve and extend wind plant capacity ratings
- Provides inertia to improve frequency regulation

Source : GE, “Synchronous Condenser Systems”

Study case
Solar farms connected to a weak network

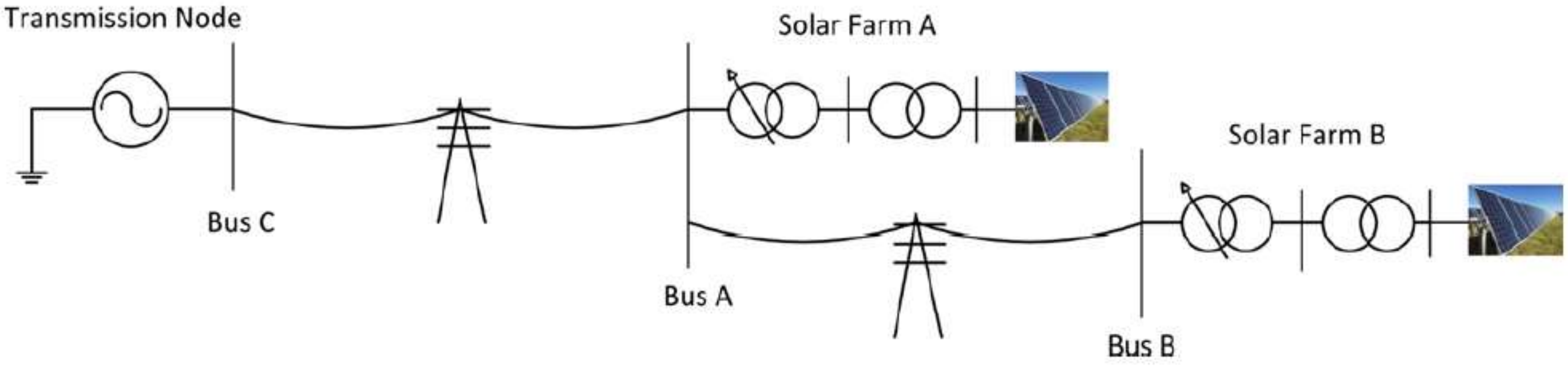
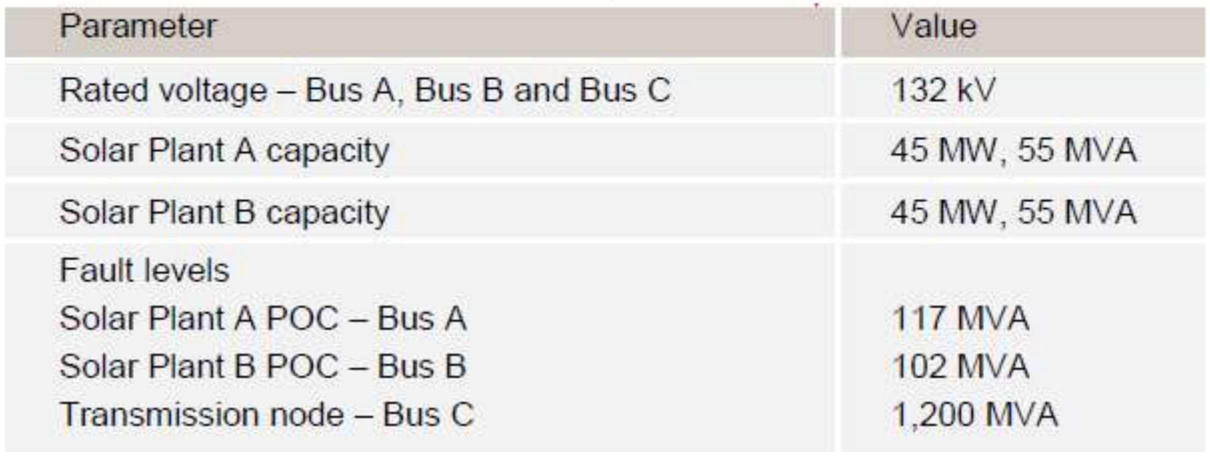


Table 6 **System data used for the study**

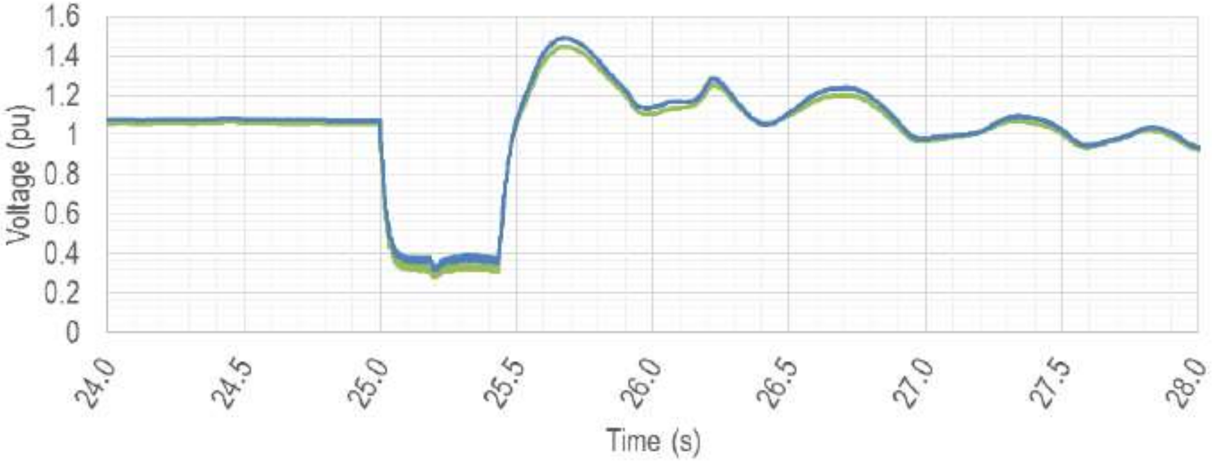


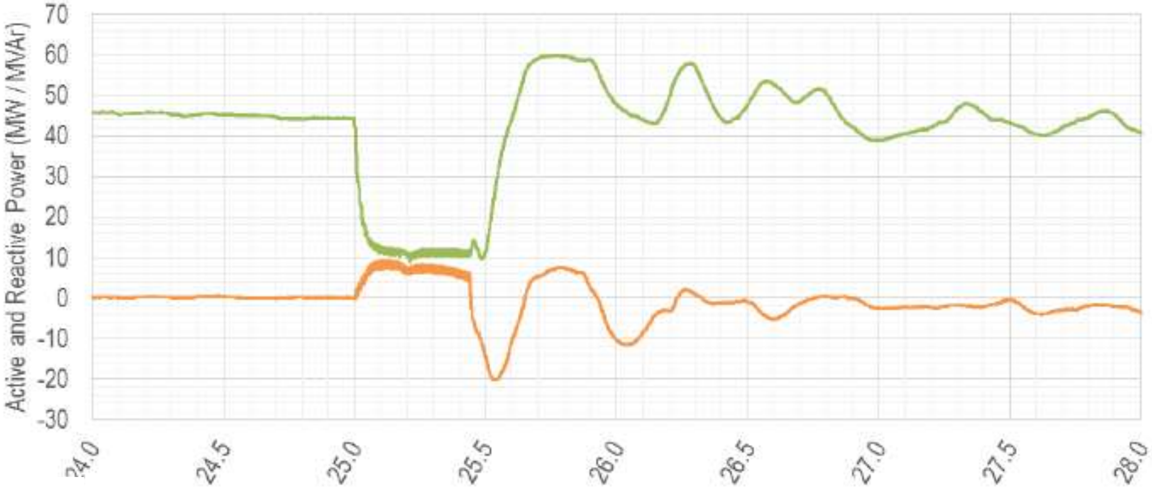
Parameter	Value
Rated voltage – Bus A, Bus B and Bus C	132 kV
Solar Plant A capacity	45 MW, 55 MVA
Solar Plant B capacity	45 MW, 55 MVA
Fault levels Solar Plant A POC – Bus A Solar Plant B POC – Bus B Transmission node – Bus C	 117 MVA 102 MVA 1,200 MVA

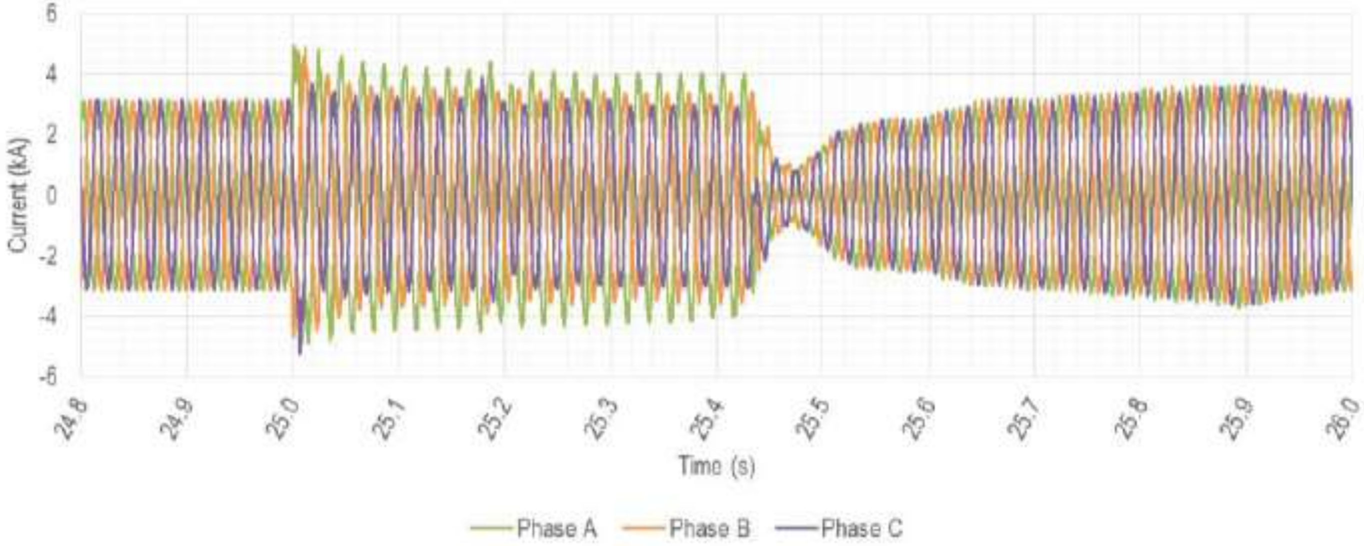
Low SCR at Solar Farms Point of Connection

Source : AEMO, System Strength Impact Assessment Guidelines, 29 June 2018

Solar Farms Performance after the fault

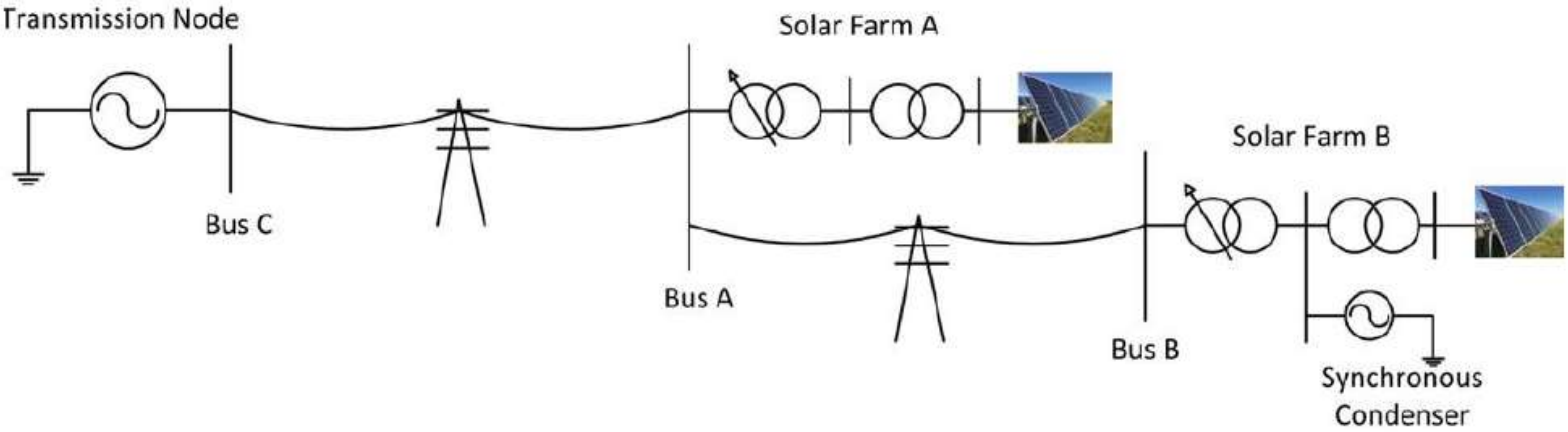




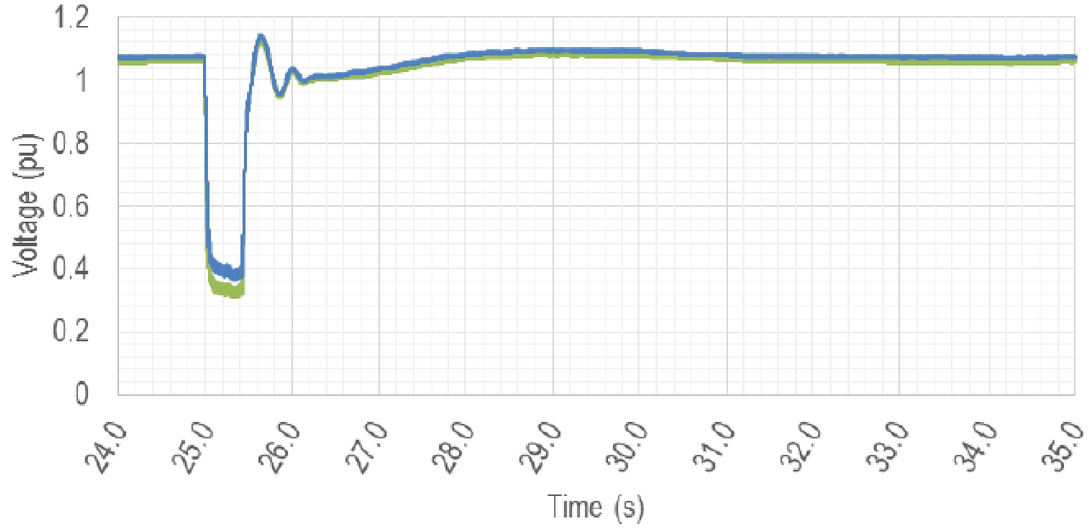


Voltage and inverter outputs unstable

Mitigation Example



Solar Farms Performance after the fault, with mitigation



Stable !!

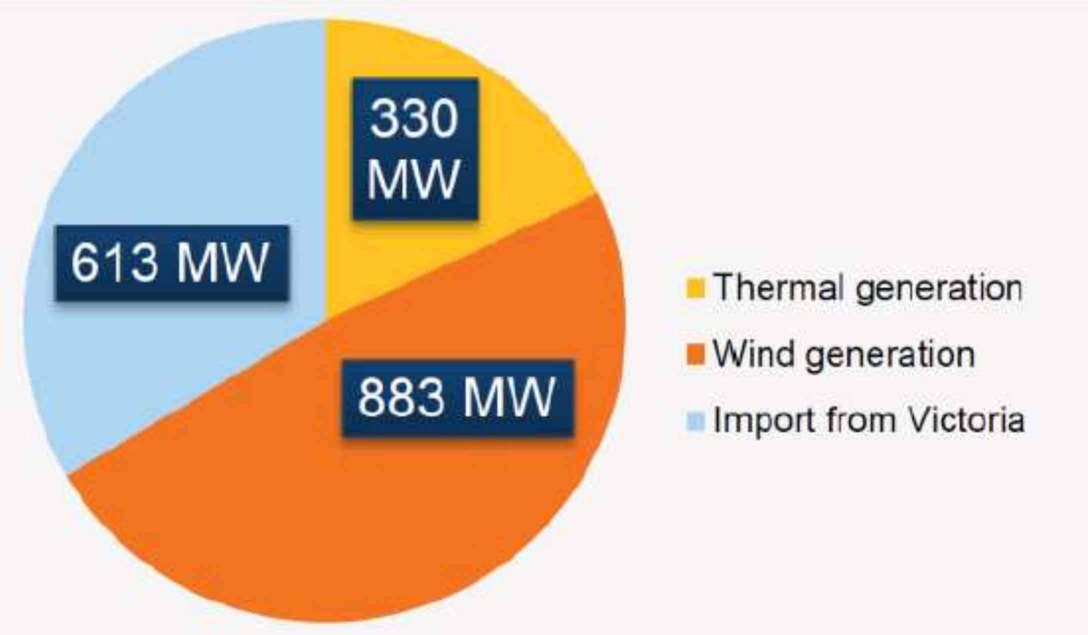
Example –
Blackout in Power System with High Penetration of Renewable

South Australia Blackout, 28 September 2016

Source : AEMO Integrated Final Report, SA Black System – 28 September 2016

South Australia Blackout, 28 September 2016

Generation mix prior to event



275 kV Heywood interconnector
between Victoria (Heywood Substation)
South Australia (South East Substation)

Event summary

- Extreme weather conditions resulted in five system faults on the SA transmission system in the 87 seconds, with three transmission lines ultimately brought down
- Following these faults, and the resulting six voltage disturbances, there was a sustained reduction of 456 MW of wind generation in SA.
- Increased flows on the Heywood Interconnector counteracted this loss of local generation by increasing flows from Victoria to SA.
- Reduction in generation, and immediate compensating increase of imports on the Heywood Interconnector, resulted in the activation of Heywood Interconnector's automatic loss of synchronism protection mechanism at South East Substation, leading to the 'tripping' (disconnection) of both of the transmission circuits of the Heywood Interconnector.

Event summary

- As a result, approximately 900 MW of supply from Victoria over the Heywood Interconnector was immediately lost
- Sudden and large deficit of supply caused the system frequency to collapse more quickly than the SA under frequency load shedding (UFLS) scheme was able to act.
- Blackout as the consequence

Some Lessons Learned

- High shared of wind generation has caused system inertia to be insufficient to prevent rapid decline in frequency drop. This resulted in the under frequency load shedding (UFLS) to be unable to act
- Issue associated with wind farms reducing MW output following voltage drops
- Issue associated with wind farms did not provide fast frequency response

Some Lessons Learned

- Minimum number of thermal generator running to provide sufficient frequency control (fast frequency response) needs to be identified
- When VRE shares increase further, different ways of frequency control to contribute to power system security need to be identified
    - Batteries and other storage technologies
    - Inverter connected generators with different control strategy
    - DC interconnectors
    - Demand side management
    - More/stronger cross border AC interconnectors

Example – The Hornsdale Power Reserve BESS

- 100 MW discharge
- 80 MW charge
- 129 MWh storage capacity

- Operational since 1 December 20017

Source : AEMO, Initial Operation of the Hornsdale Power Reserve Battery Energy Storage System, April 2018

The Hornsdale Power Reserve BESS

Services:

- Energy arbitrage :

  Some discharge capacity for commercial operation in the National Electricity Market

- Reserve energy capacity

  Some discharge is reserved for power system reliability purposes.

  This capacity will not be dispatched ahead of other generation in South Australia.

- Network loading control ancillary services

  To detect high flows on the Heywood Interconnector and trigger the BESS to start discharging as quickly as possible

- Frequency Control Ancillary Services
  - Regulation FCAS
  - Contingency FCAS

SOME REFERENCES

- AEMO, Integrated Final Report, SA Black System, 28 September 2016
- AEMO, Initial Operation of the Hornsdale Power Reserve Battery Energy Storage System, April 2018
- AEMO, System Strength Impact Assessment Guidelines, 29 June 2018
- IEEE Power and Energy Magazine, “Achieving a 100% Renewable Energy Grid”, March/April 2017
- CIGRE Working Group B4.62, Connection of wind farms to weak AC networks, December 2016
- GE, “Synchronous Condenser Systems”

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Thank you