CONNECTION OF LARGE-SCALE SOLAR FARMS TO WEAK NETWORKS

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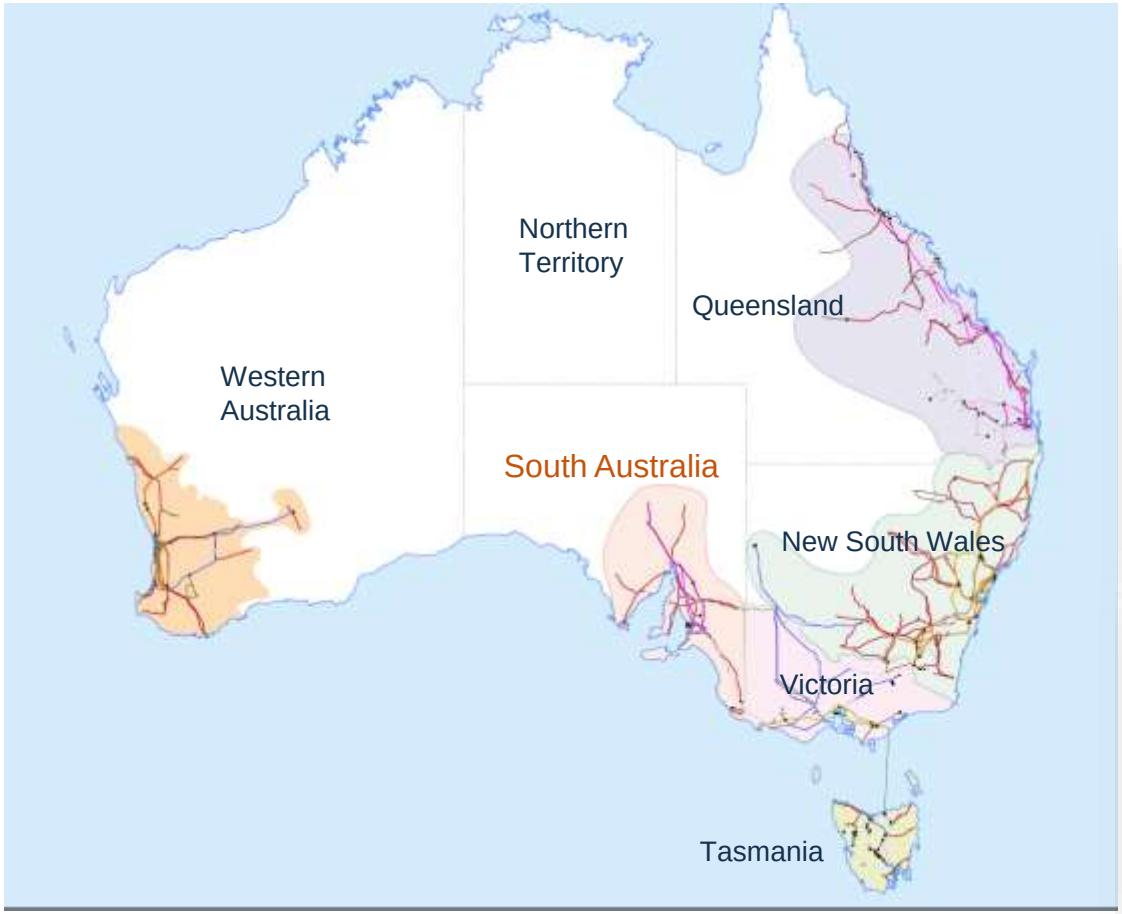
AGENDA SLIDE

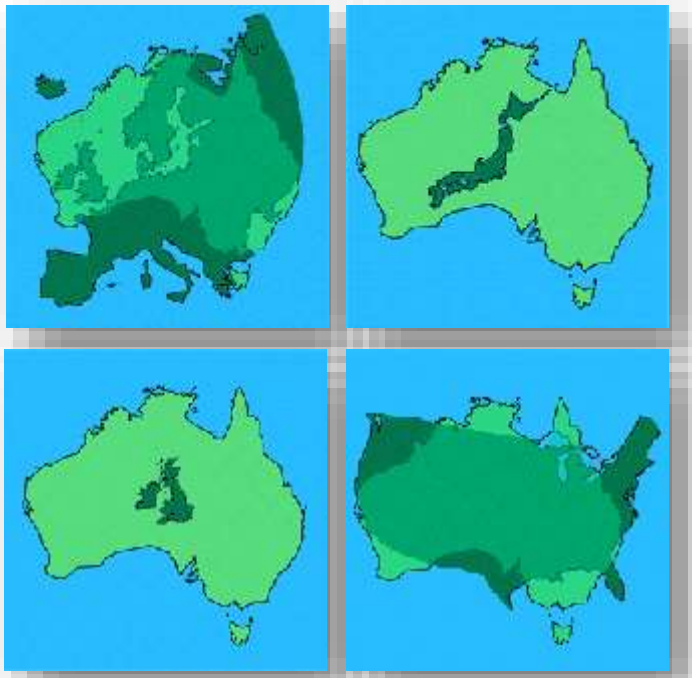
1. Large-scale solar farm developments in Australian national electricity market
2. Introduction to system strength
3. Modelling requirements for weak connections
4. Technical performance requirements for weak connections

LARGE-SCALE SOLAR FARM DEVELOPMENTS IN AUSTRALIAN NATIONAL ELECTRICITY MARKET

AUSTRALIAN NATIONAL ELECTRICITY MARKET IN COMPARISON

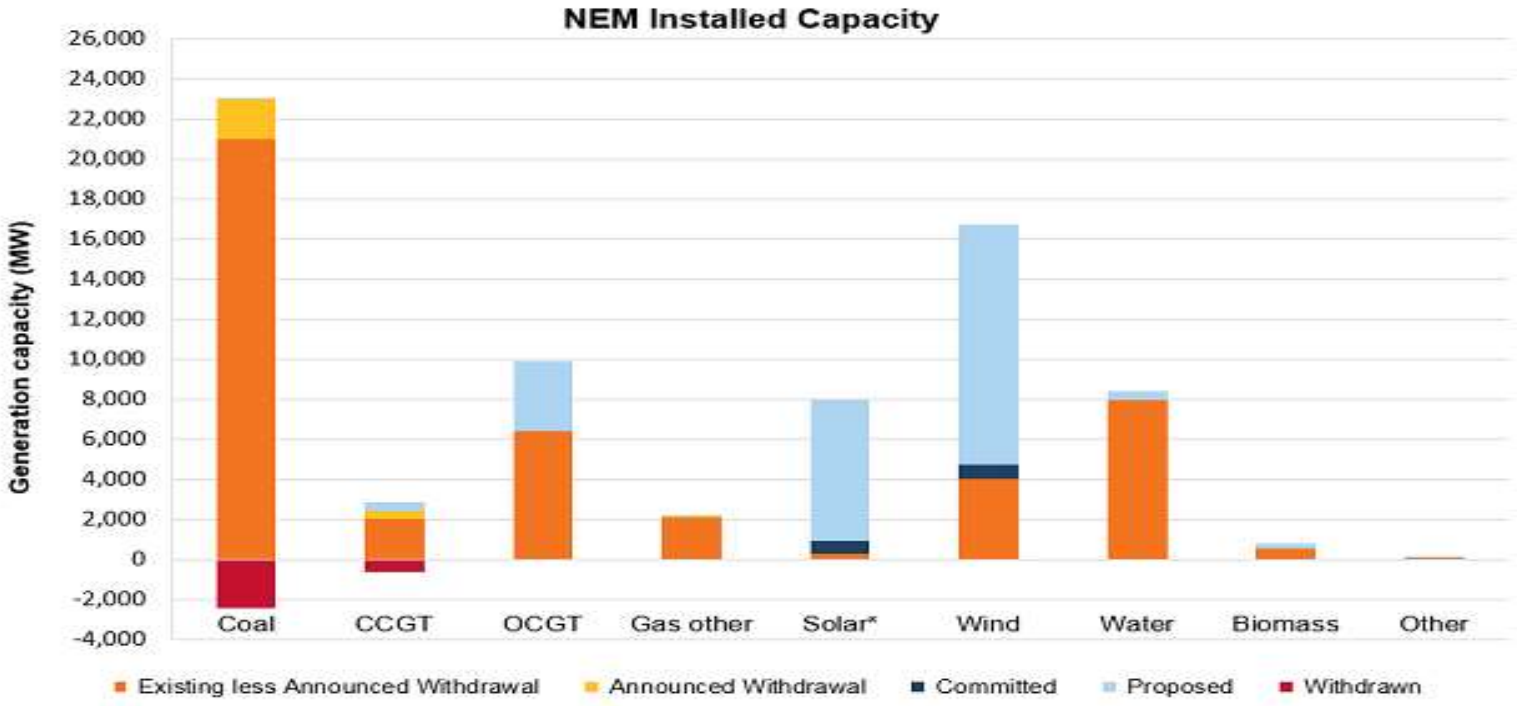


- About 4500 km long
- About 47 GW capacity
- About 35 GW peak



- AEMO Is independent power system and market operator in all Australian states
- National Electricity Market (NEM) includes all states except Western Australia

EXISTING, COMMITTED AND PROPOSED SOLAR FARM PROJECTS ACROSS THE NEM



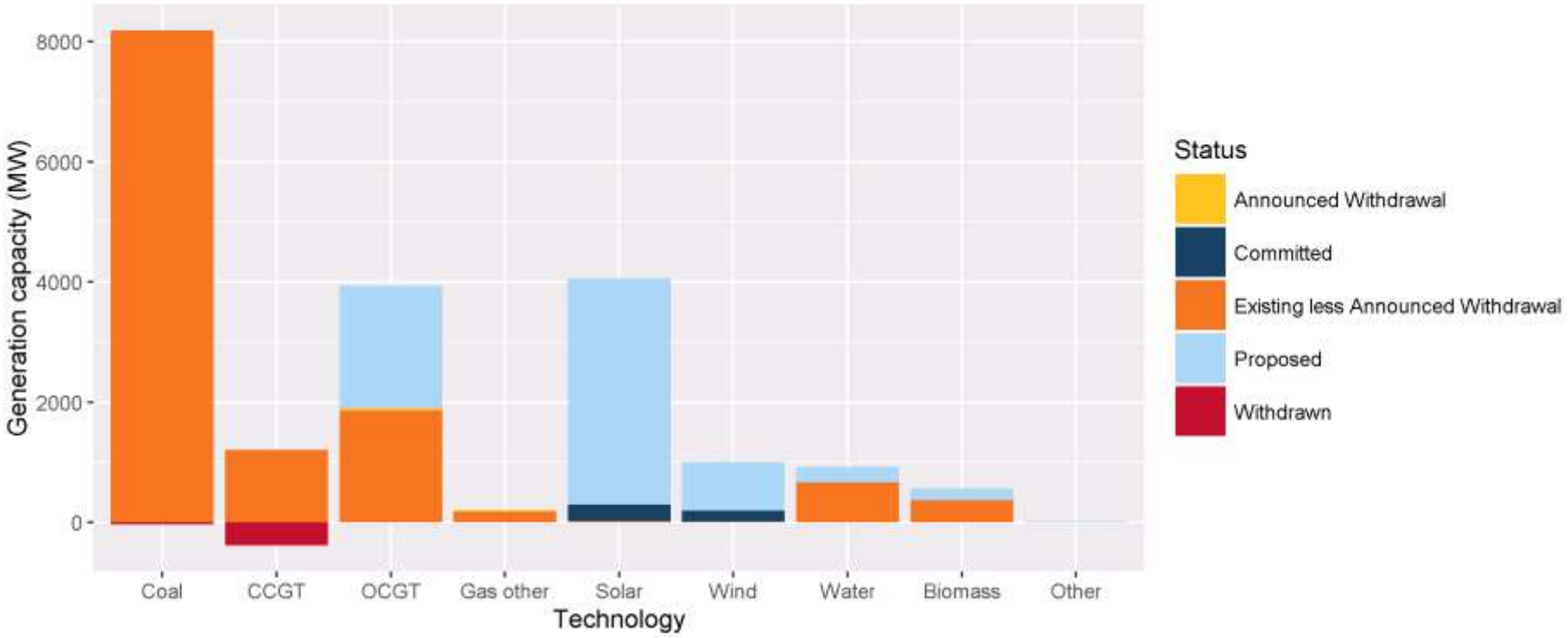
Status	Coal	CCGT	OCGT	Gas other	Solar*	Wind	Water	Biomass	Other	Total
Existing	22,976	2,449	6,434	2,159	274	4,070	7,941	574	139	47,016
Announced Withdrawal	2,000	379	34	30	0	0	0	0	0	2,443
Existing less Announced Withdrawal	20,976	2,071	6,400	2,129	274	4,070	7,941	574	139	44,573
Committed	0	0	0	0	692	690	4	0	0	1,387
Proposed	80	460	3,465	15	6,975	11,938	484	228	53	23,698
Withdrawn	-2,416	-624	0	0	0	0	0	0	0	-3,040

Note: Existing includes Announced Withdrawal. This data is current as at 19 May 2017.

* Excludes rooftop PV installations

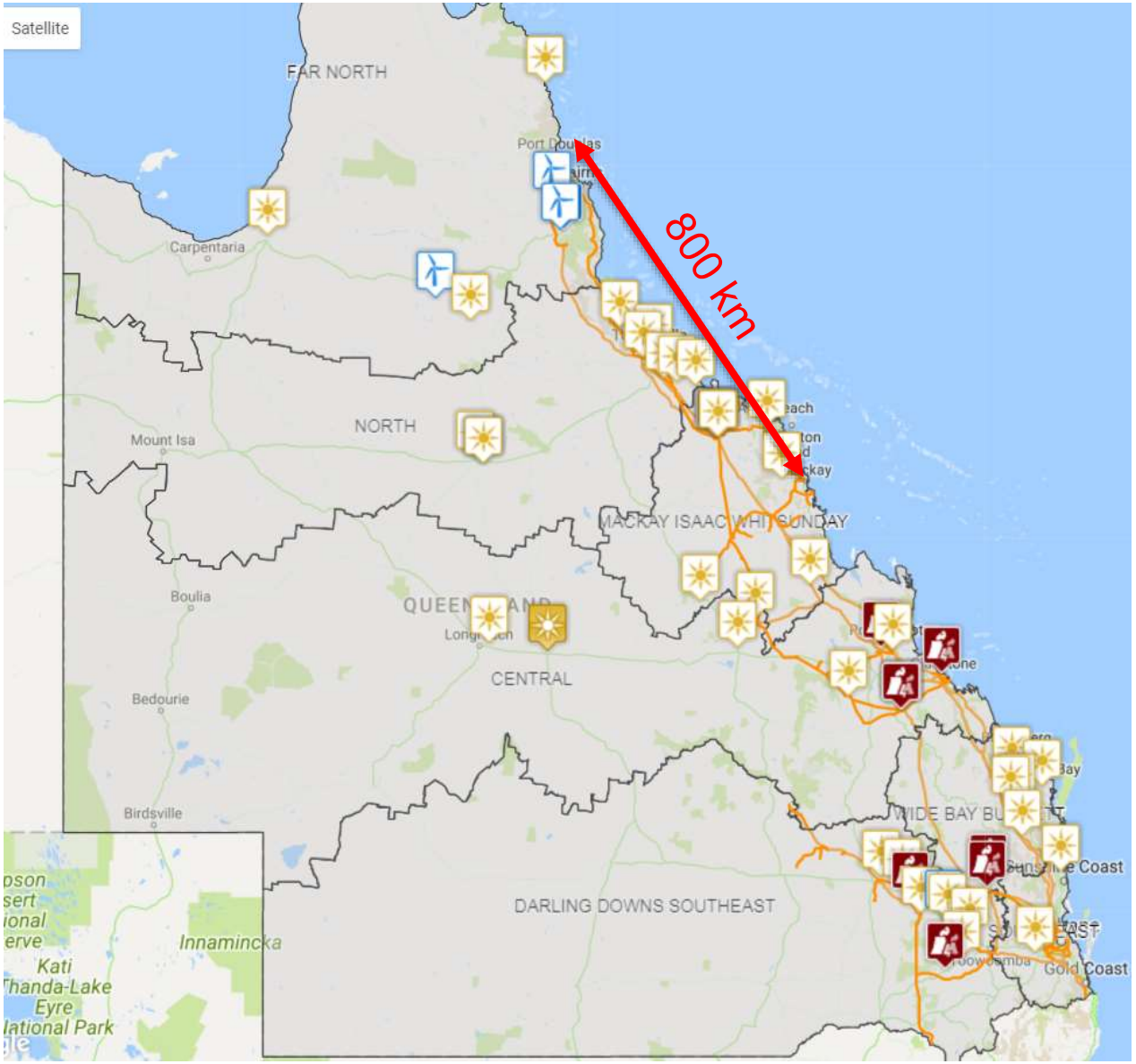
More than 8 GW of solar farm projects in various stages

GENERATION DEVELOPMENT IN QUEENSLAND



- Approximately 4 GW of solar farm projects in various stages
- Maximum and minimum demand are around 9 and 6 GW

GEOGRAPHICAL DISTRIBUTION OF SOLAR FARMS IN QUEENSLAND



- Long distances between non-synchronous generation and major synchronous generators
- Queensland is larger than Germany+ France+ Italy+ Spain

WHAT ARE THE IMPLICATIONS?

- Standard design of solar inverters may be inadequate to withstand the combination of minimum short circuit ratio and X/R in such parts of the network.

- Modification in solar inverters' hardware and/or software, or installation of additional balance of plant components for some projects.

- Following these modifications, changes in the control systems and/or settings of the actual generating units would be necessary if detailed simulation models exhibit uncharacteristic or unexpected responses.

INTRODUCTION TO SYSTEM STRENGTH

HOW LACK OF SYSTEM STRENGTH MANIFESTS ITSELF

Non Synchronous plant

- Need a minimum system strength to perform as designed and provide support to power system recovery following clearance of contingencies.
- Lack of system strength result in disconnection of non-synchronous plant, in particular in remote parts of the network.

Protection systems

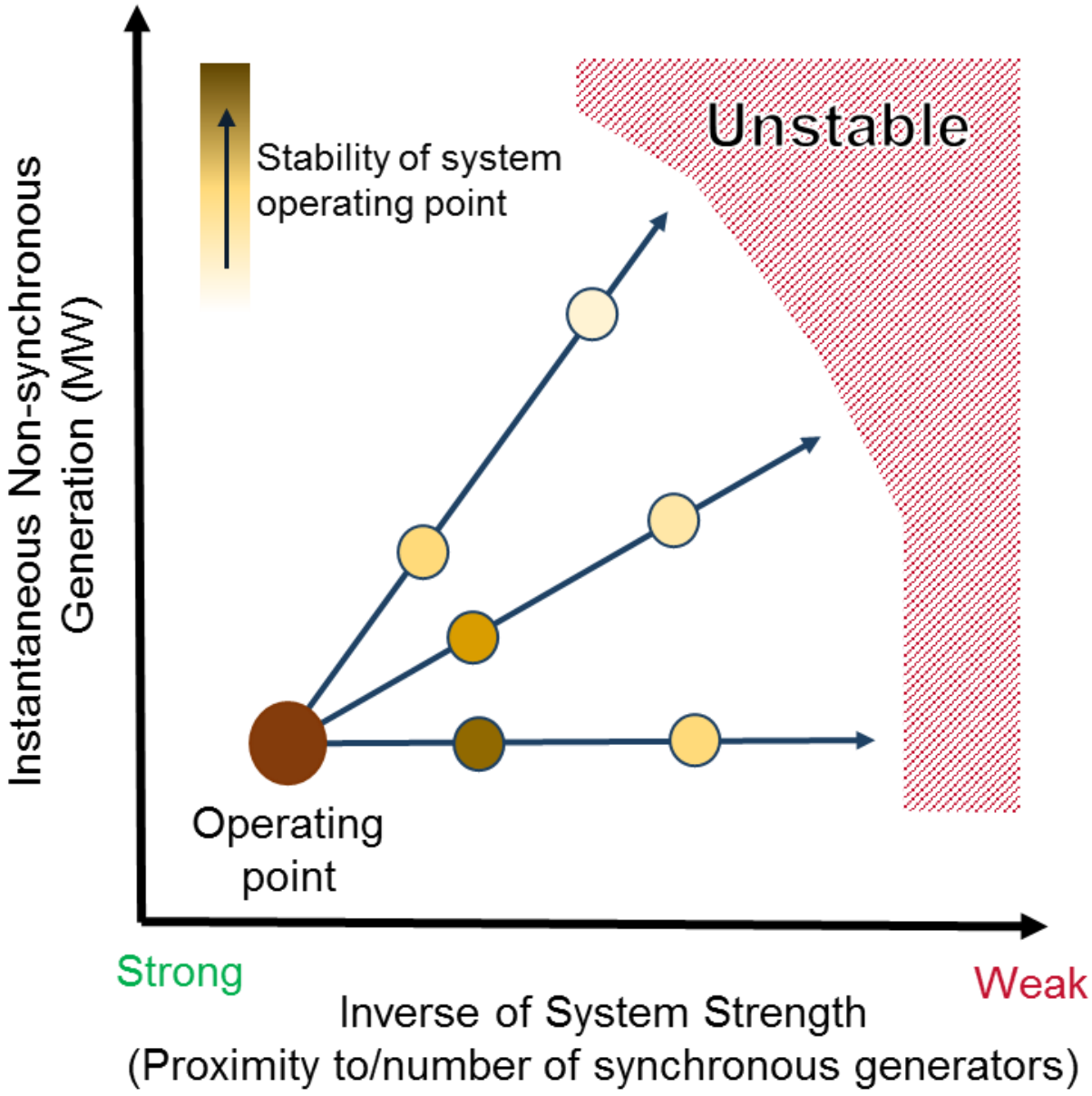
- Need a minimum fault level to operate where they should, and do not operate where they should not.
- Concerns due to declining system strength include cascaded tripping of transmission system elements, and public safety due to uncleared faults.

Synchronous plant

- Insufficient quantity of synchronous machines would result in their disconnection during credible contingencies due to operation of respective protection systems.

Stable operation of non-synchronous plant and protection systems is dependent on stable response and sufficient quantity of synchronous plant.

FACTORS INFLUENCING SYSTEM STRENGTH

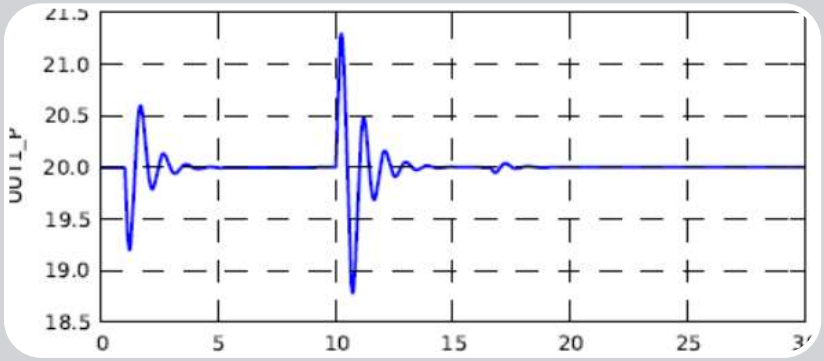


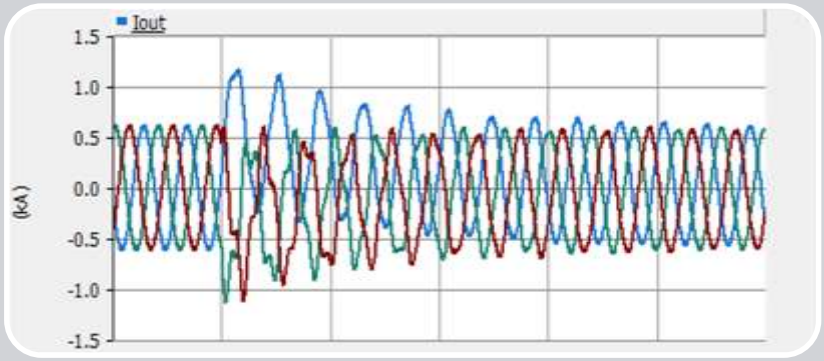
IMPACT OF MULTIPLE CONCENTRATED NON-SYNCHRONOUS GENERATION

- Adjacent connections should be thought as one large virtual installation from the impact to power system perspective.
- Adverse interaction between multiple concentrated converter connected generating systems could arise as the system strength declines.
- The use of aggregate short circuit ratio (SCR) calculation methods, e.g. CIGRE TB 671, provides some insight on the likely issues.
- However, actual power system performance must be confirmed by detailed modelling and simulation.

MODELLING AND SIMULATION REQUIREMENTS

RMS- AND EMT-TYPE MODELLING





PSS/E (RMS)

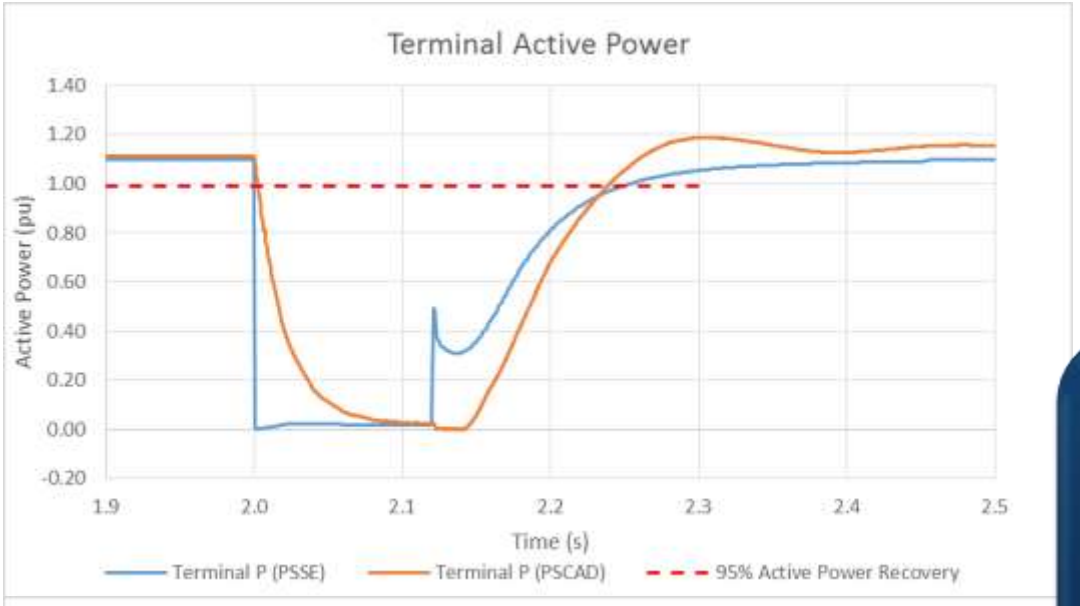
- Simplified representation of power electronic converter controls
- Fast speed of simulation
- Reasonable accuracy in conventional power systems
- Unstable in extreme conditions

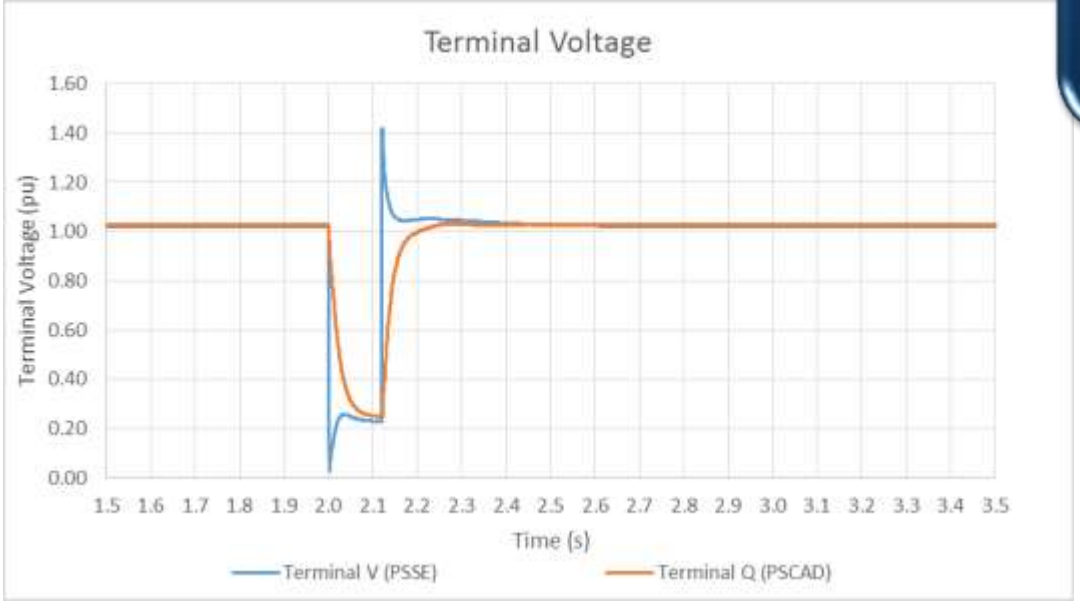
PSCAD/EMTDC (EMT)

- Control systems identical to those actually used on-site
- Slow, however improvements are being made rapidly
- Can be made to provide the required accuracy for any power systems
- Generally stable for all conditions

Remember that three-phase RMS is still RMS

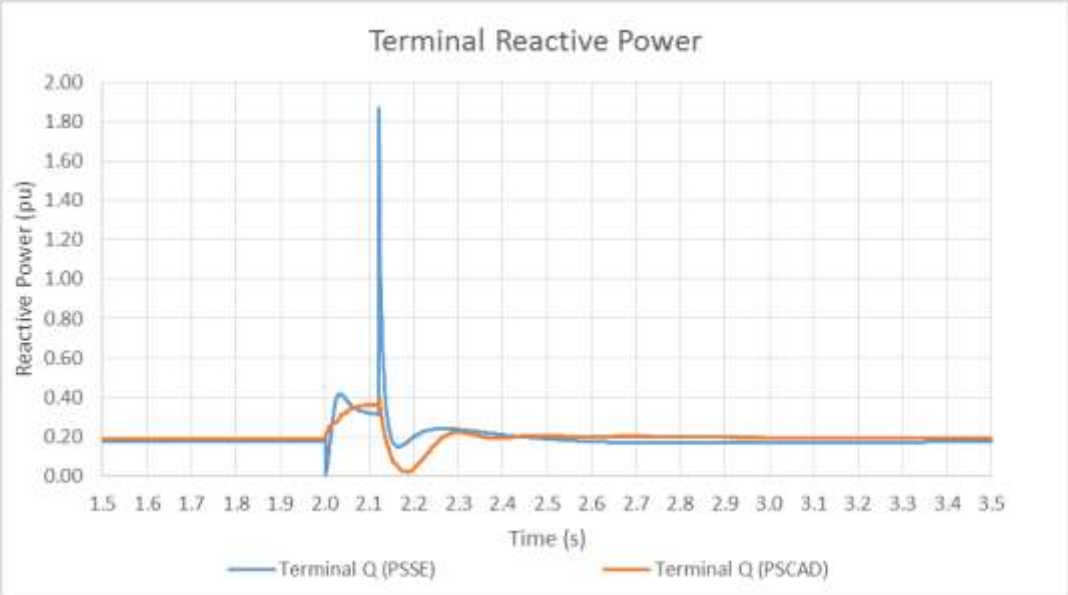
COMPARISON BETWEEN RMS- AND EMT-TYPE MODELS: INVERTER TERMINAL QUANTITIES

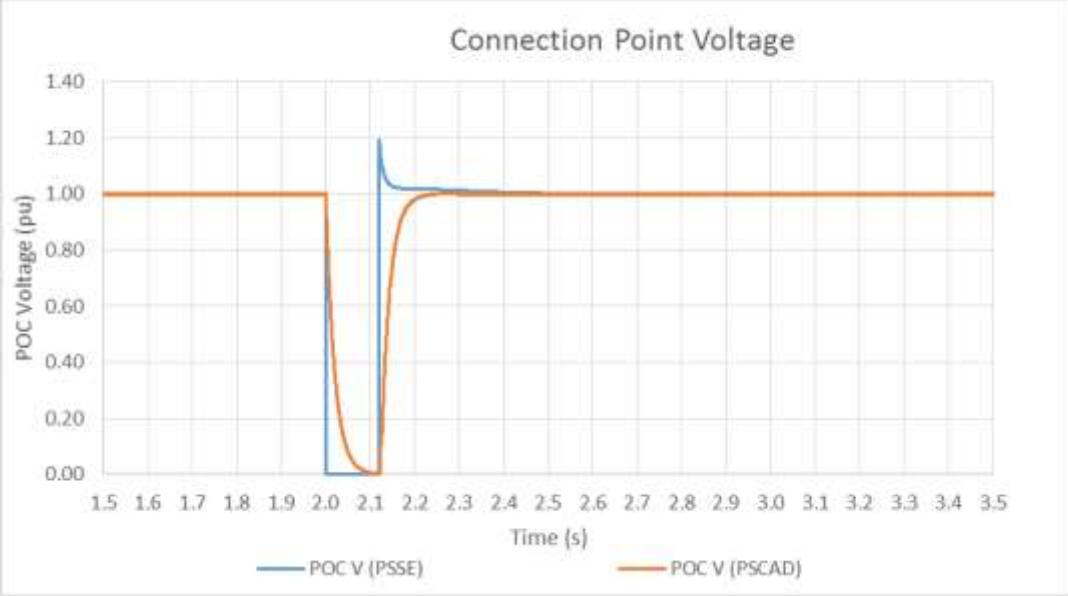




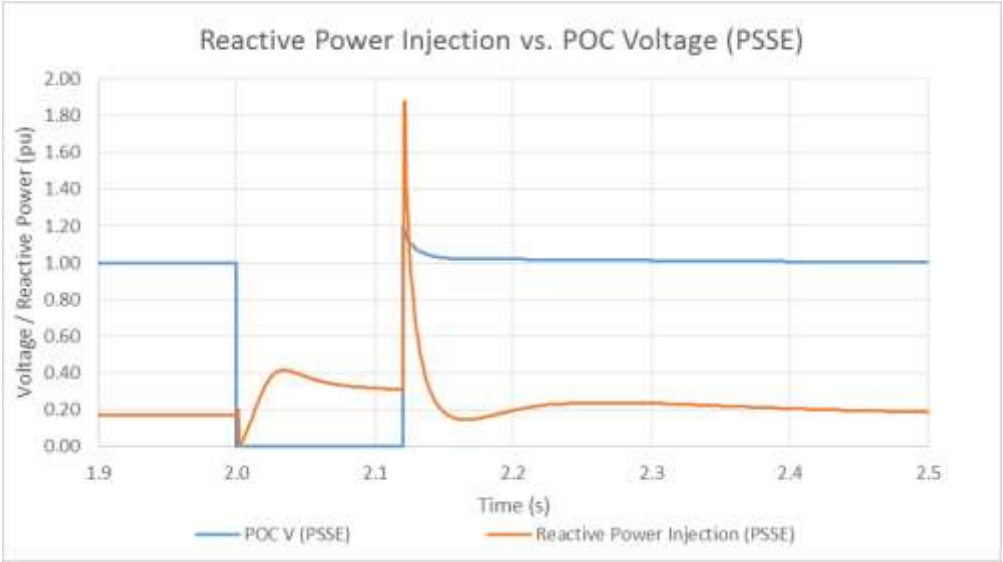
- Response to a three-phase-to-ground fault for 120 ms
- Slower active power recovery in the EMT-type model.
- Voltage spikes in the RMS-type model on fault inception and removal

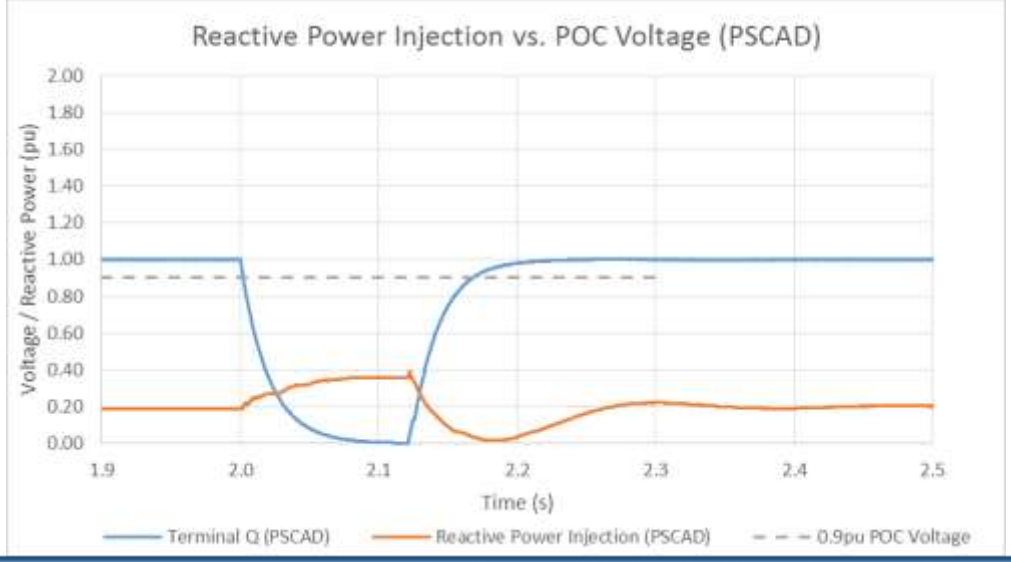
COMPARISON BETWEEN RMS- AND EMT-TYPE MODELS: CONNECTION POINT QUANTITIES





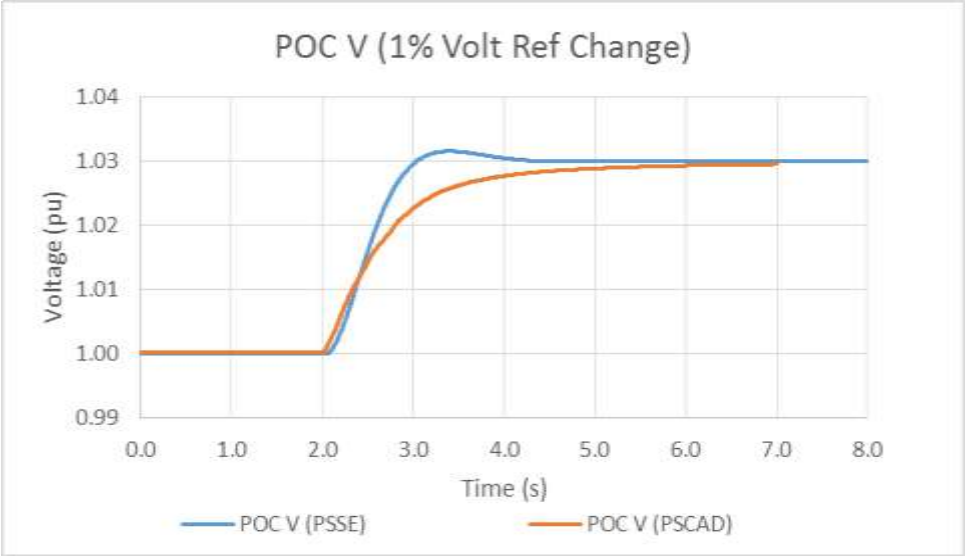
COMPARISON BETWEEN RMS- AND EMT-TYPE MODELS: REACTIVE CURRENT INJECTION

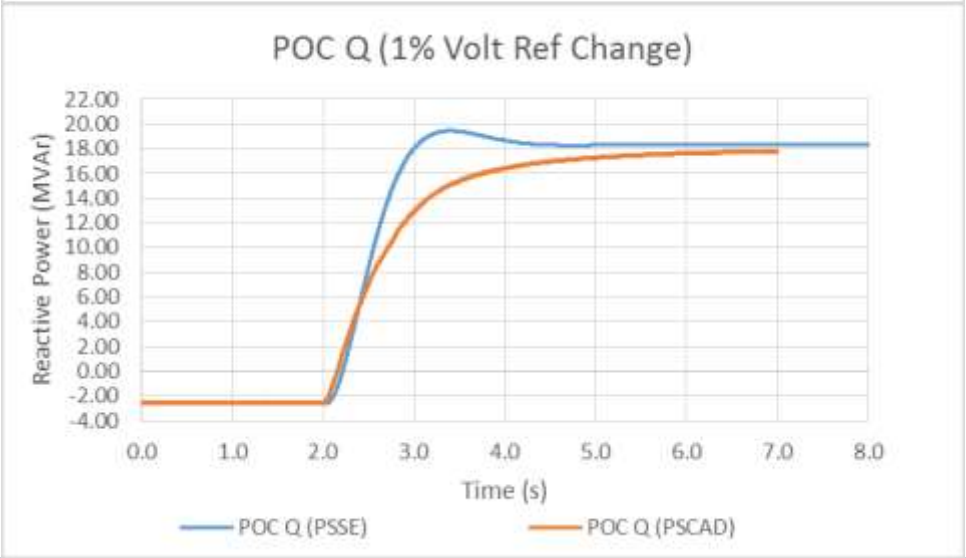




Faster and higher injection in the RMS-type model

VOLTAGE SET-POINT STEP RESPONSE





Rise time determined by the RMS model is smaller

PRE-COMMISSIONING MODELLING REQUIREMENTS FOR VERY WEAK CONNECTIONS (WHEN DEPARTING FROM STANDARD DESIGN)

- When the RMS-type models cannot replicate the response of actual plant down to the required SCR and X/R ratio, EMT-type models should be used for assessing technical performance requirements.

- The accuracy of EMT-type models for individual items of plant must be confirmed against the response of actual plant with identical control system and settings for the minimum SCR and X/R.

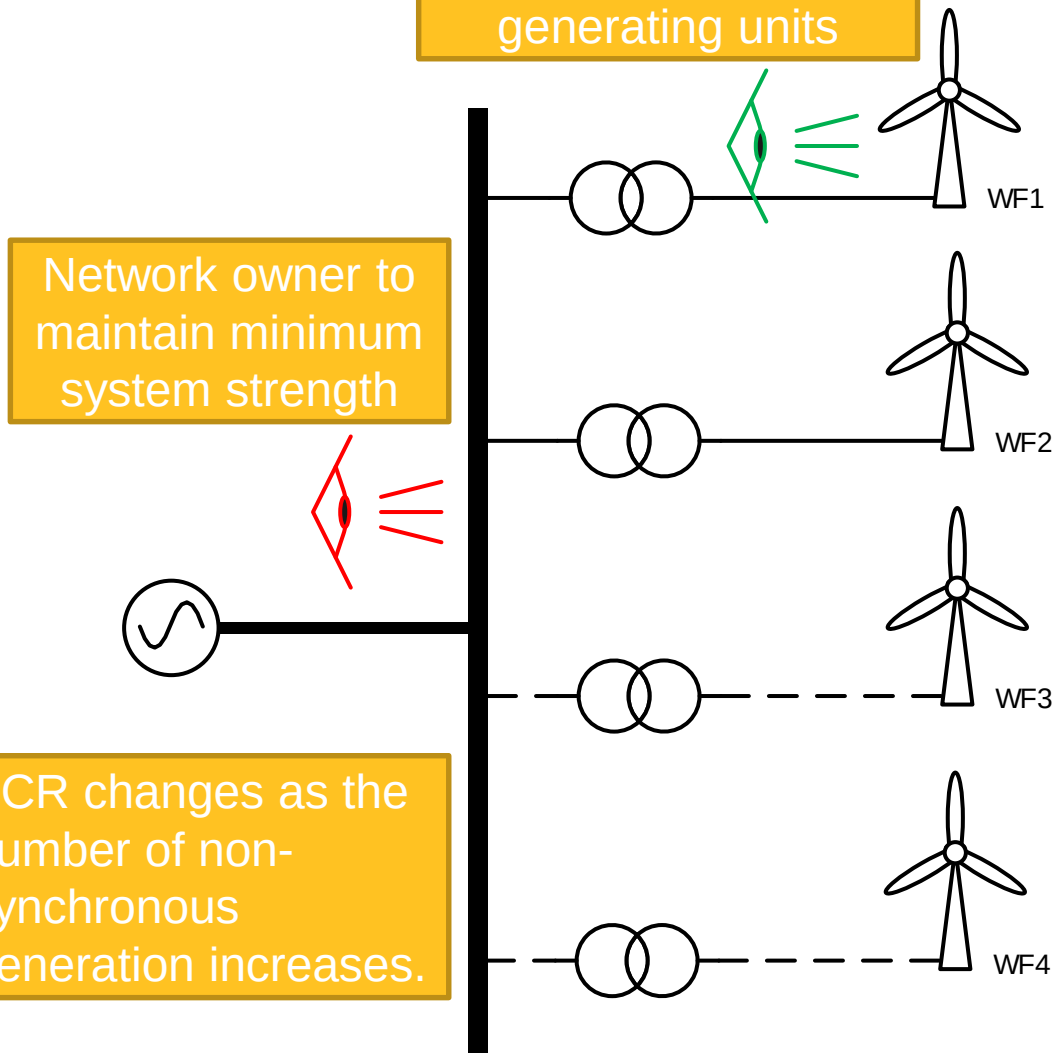
- The entire model of generating system must be validated against measurements conducted on-site following plant commissioning.

TECHNICAL PERFORMANCE REQUIREMENTS FOR WEAK CONNECTIONS

REQUIREMENT FOR GENERATING UNITS/SYSTEMS IN ISOLATION

Developers to use adequately designed generating units

- **Minimum SCR**
- **Minimum X/R**



Network owner to maintain minimum system strength

SCR changes as the number of non-synchronous generation increases.

Applies to all susceptible items of plant such as individual generating units, dynamic reactive power support plant, and storage interface units

REQUIREMENT FOR GENERATING SYSTEMS AS PART OF THE WIDER POWER SYSTEM

- The aggregate impact and interaction between multiple concentrated non-synchronous generation should be studied with EMT-type models.

- *System strength impact assessment guidelines* is currently being developed, covering items such as:
  - Definition of *adverse system strength impact*
  - *System strength remediation scheme*

- This will be supplemented by a more comprehensive guideline that develops methodologies for assessing minimum system strength and inertia gaps on the overall system.

DISCUSSION