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November 06, 2017

Dominic Adams
Australian Energy Market Commission
PO Box A2449
Sydney, South NSW 1235
Australia

Project Reference: ERC0222

Dear Mr. Adams,

We refer to the AEMO Electricity Rule Change Proposal – Generator Technical Requirements document issued on August 11, 2017.

GE fully appreciates the need to learn from the lessons of the South Australian Black System event of 2016 and the steps taken by AEMC and AEMO to ensure that new generating systems can be integrated into the system to reduce the risks of such events.

GE has reviewed the proposed rule changes with respect to its range of gas turbines, steam turbines, hydro turbines, generator and wind products. However, GE has concerns on several of the proposed technical requirement changes that we would like to draw your attention to and kindly ask you to take them into consideration. Please also take note that this submission is on behalf of the GE Power and GE Renewable Hydro businesses. Our colleagues from GE Renewable Wind business will lodge another submission separately as the generation technology do warrant a different technical consideration. Please therefore note that hereafter, GE refers exclusively to the GE Power and GE Renewable Hydro businesses.

Many of the proposed rule changes mandate extensive investigations to determine if these new standards can be complied with or not and therefore it is necessary to clarify the details on how these requirements will apply retrospectively.

GE has identified three changes in the rule we strongly believe need to be addressed urgently, namely:

1. Multiple low voltage disturbance ride-through capability
2. Rate of change of frequency withstand capability
3. System strength

The abovementioned three changes are discussed in detail in the attachment “GE views on AEMO Electricity Rule Change Proposal”, covering GE’s concerns, technical viability and alternatives.

Additionally, GE would like to draw attention to the following rule changes with a request for further clarification:

1. Reactive current injection and reactive power support
2. High voltage disturbance ride through

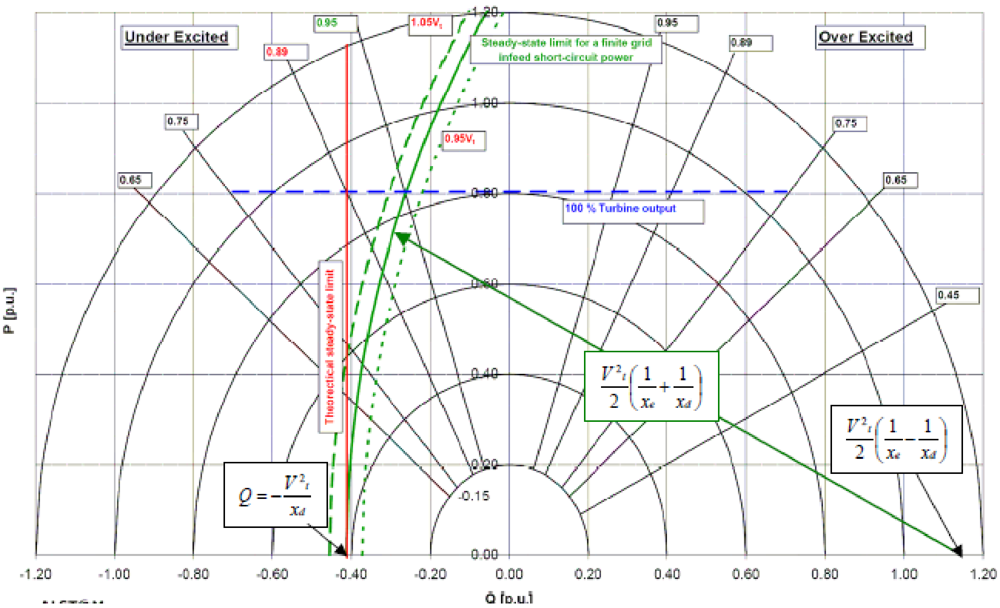
Reactive current injection and reactive power support

With reference to AEMO [1], Section 5.4.3, Figure 2, GE interprets the change as requiring synchronous generating systems to be able to absorb reactive current of up to 250% of rated current, when the voltage drops to 50%. GE’s concern is with regards to steady-state stability limits especially when operating at the leading power factor range.

Referring to the typical synchronous generating system power-chart below, the amount of reactive power that can be absorbed without violating the steady-state stability limit (red line) of the unit depends on several factors such as:

- The external reactance Xe (grid and transformer).
- The generator synchronous reactance Xd.
- Generator terminal voltage V.
- The active power P being generated.

Typical steady-state stability limit and power chart for synchronous generators



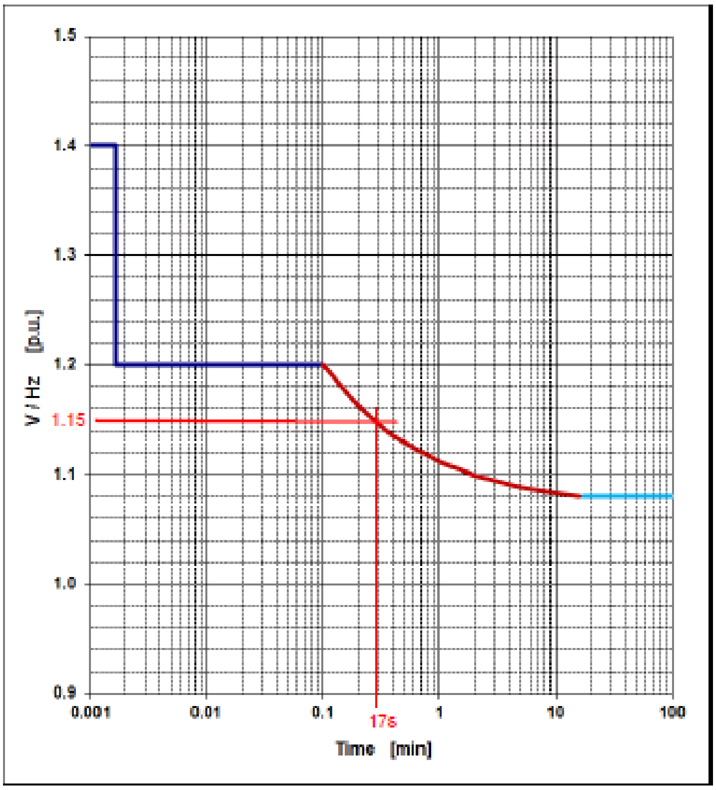
GE would like to have further clarification on how the abovementioned technical limitation and operating constraints are considered in this rule change and if further technical parameters will be provided for generators to assess compliance to this proposed standard.

High voltage disturbance ride through

With reference to AEMO [1], Section 5.6.3, Figure 5 and Table 6, GE interprets the change as requiring synchronous generating systems to be able to withstand over-voltages in the range of 110-115% for 1200s. GE's concern is with regards to V/Hz over-fluxing design of transformers and generators. According the IEEE [2], a typical V/Hz protection for synchronous generator is shown in the figure below. The proposed change does not mention if this standard also requires the consideration of simultaneous under-frequency disturbance. If an under-frequency disturbance of 47.5 Hz for 2 minutes, according to NER Rules S5.2.5.3, is considered with an overvoltage of 115%, this will lead to a V/Hz of 1.21pu, causing the V/Hz protection relay to trip the unit.
GE would like to have further clarification on how the abovementioned technical limitation and operating constraints are considered in this rule change and if further

technical parameters will be provided for generators to assess compliance to this proposed standard.

Typical V/Hz protection for synchronous generators.



GE furthermore provides in this submission, our opinion to the Questions 3 and 4 tabled by AEMC in [3].

<u>Question 3: Proposed changes to generator access standards</u>

For each of AEMO's technical recommendations set out in Appendix B:

- Do you agree with AEMO's analysis of the issue in relation to the proposed change to the access standard?
  GE – We have our concerns. Please refer to the attachment of our submission "GE views on AEMO Electricity Rule Change Proposal".
- Would the proposed change address the issue raised by AEMO? If not, what alternative solutions are there?
  GE – We have proposed some alternatives. Please refer to the attachment of our submission "GE views on AEMO Electricity Rule Change Proposal".
- Does the proposed change represent an unnecessary barrier to entry, having regard to the costs imposed by the change and the technical capabilities of different technologies?
  GE- We believe some of the rule changes (e.g. multiple low voltage disturbance ride through) will incur significant cost and technological challenges. Please

refer to the attachment of our submission “GE views on AEMO Electricity Rule Change Proposal”.

- Can you provide an indication of the costs associated with the proposed change?
GE – To be able to estimate a cost of the rule change it is necessary to understand clearly the requirements proposed. GE’s opinion is there are still important technical details that have not be fully addressed in the proposed rule changes.

Question 4: System strength access standard

- Do you agree with AEMO’s analysis of the issue related to system strength?
GE – We have our concerns. Please refer to the attachment of our submission “GE views on AEMO Electricity Rule Change Proposal”.
- Would the proposed changes address these issues, particularly in light of the Commission’s Managing system fault levels rule change final determination? If not, what alternative solutions are there?
GE – We have proposed some alternatives. Please refer to the attachment of our submission “GE views on AEMO Electricity Rule Change Proposal”.
- Would the proposed changes relating to system strength represent an unnecessary barrier to entry, having regard to the costs imposed by the change and the technical capabilities of different technologies?
GE - We believe system strength also has an impact on multiple low voltage disturbance ride through, rate of change of frequency withstand capability, etc. Therefore, one must consider all these rule changes as a global and not separate issues. Please refer to the attachment of our submission “GE views on AEMO Electricity Rule Change Proposal”.

References

1. AEMO ELECTRICITY RULE CHANGE PROPOSAL - GENERATOR TECHNICAL REQUIREMENTS, August 2017
2. IEEE C37.106 – Guide for Abnormal Frequency Protection for Power Generating Plants, 2003
3. AEMC CONSULTATION PAPER – National Electricity Amendment (Generator Technical Performance Standards) Rule 2017, 19 September 2017

We request AEMC and AEMO to kindly review and take account of our submission and concerns. Please do not hesitate to contact us if you have any queries.

GE looks forward to a fruitful technical discussion and will provide any constructive support wherever feasible.

Yours sincerely,

Kevin Chan
Consulting Engineer, Generator Technology
GE Power

Project Reference: ERC0222
GE views on AEMO Electricity Rule Change Proposal

GE - Urgent Technical Concerns

GE hereafter refers exclusively to the GE Power & Renewable-Hydro businesses

- Multiple low voltage disturbance ride-through (MLVDRT)
- Rate of change of frequency (ROCOF) withstand capability
- System strength

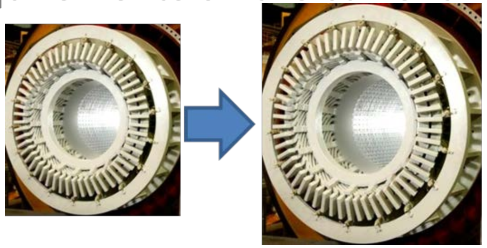
Will describe today: Issues/ Risks/ Alternatives.

Technical Discussions

Multiple Low Voltage Disturbance Ride Through

As is

- Multiple Low Voltage Disturbance Ride Through (MLVDRT) capability as proposed in the Rule Change has not been proposed anywhere in the power industry. No other grid operator has to our knowledge expressed such a need, based on their power infrastructure, grid users and operation guidelines. GE has no operational experience with such requirements on the current fleet of synchronous and non-synchronous power plants.
- Requirements… non-exhaustive, subject to misinterpretation.
- MLVDRT profile not defined with a voltage vs time profile as is common in other grid codes.



Risk

- Over-redesign of equipment based on unclear requirements only for the Australian energy market.
- To achieve MLVDRT, could result in increase generator short-circuit ratio (increase gen. weight), increase shaft line inertia (weight), increase ceiling factor (modify rotor insulation & exc. transformer)… thus requires **hundreds M€ of development and installation**
- No-type certification possible…Complex dynamic analysis needed for **each project**…and then, what if the results are not satisfactory ?
- **Nearly impossible to test**…if units happen to be damaged (shaft-line) due to the successive cumulative nature of these events, possibly resulting in a major forced-outage. Practically impossible to avoid by design of turbine and generator, and difficult to monitor.

Alternative

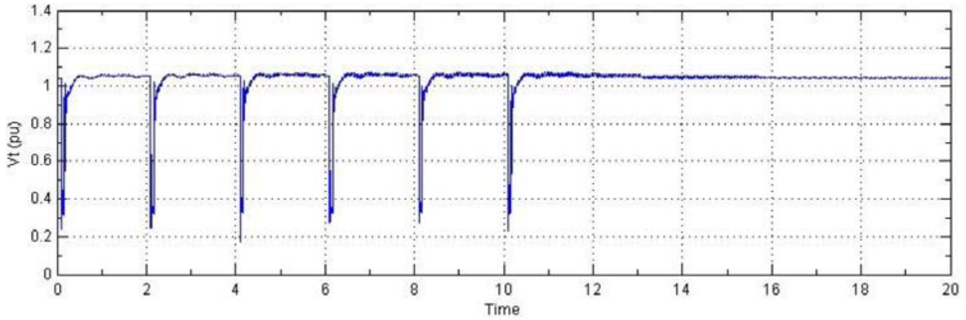
- Keep and define clearly existing requirements.
- Work with manufacturers to find optimum solutions (on generation OR transmission sides)

Extreme MLVDRT interpretations violate physics and state-of-the-art.
Requirements shall be made technically-consistent

Automatic Access MLVDRT

The automatic access standard is that a generating system and each of its generating units and reactive plant must maintain continuous uninterrupted operation for up to 15 voltage disturbances in any 5-minute period causing the connection point voltage to drop below 90% of normal voltage for a total duration of 1,800 milliseconds.

- AEMO:
- Define the voltage-time curves referenced by the automatic access standard.
- Define in detail, the type of fault (3, 2 or 1ϕ), fault duration and the number of faults. (see diagram right).
- Define pre-fault condition and post-fault condition.



AEMO could define conditions that cannot be fulfilled with present status-of-the-art synchronous generating systems

Factors influencing LVDRT capabilities

Typical External Conditions that impact LVDRT Capabilities

- **Short-circuit Power (Scc) of the Grid:**
  The weaker the strength, the lower the capacity of the generating group to fault ride through. Scc value has a very strong influence on the capacity of LVDRT, for example on weak grid or MV system. A low Scc can also lead to steady-state stability limits to be reached.
- **The maximum active power output of the power plant:**
  The higher the plant output, the lower the LVDRT capability.
- **The operating power factor of the PGM as pre-fault condition:**
  Operating in leading power factor lowers the LVDRT capability. When the generating unit is running under-excited (leading power factor and eventual low voltage condition) its fault ride through capability is much reduced.

MLVDRT capability are significantly affected by external conditions beyond the OEM control.

Factors influencing LVDRT capabilities

Typical Generator Internal Conditions that impact LVDRT Capabilities

- **Short Circuit Ratio of the Generator:**
  Increasing short circuit ration of the generator means a complete redesign with increase weight of the generator by up to 35% or more. The cost of redesign would be substantial.
- **Rotor Inertia:**
  Increasing rotor inertia means a redesign and increase in weight and dimensions. The cost of redesign would be substantial. It would be impossible for aero-derivative turbines to match the requirements.
- **Excitation Ceiling Factor:**
  Increasing the ceiling factor has an impact on rotor insulation and excitation transformer. The cost of redesign of rotor insulation would be substantial.

MLVDRT of up to 1800ms on non-exhaustive boundary conditions would be near impossible to meet on current state-of-the-art of synchronous generating systems.

GE Proposal

- **MLVDRT curve(s) to be defined and used as reference for simulation**
  Requirements for simulation against detailed voltage-time profiles and related results can be used as a mean to check/keep and define clearly existing requirements for a specific point of connection. A case by case assessment is a necessity. Protection against damage of the shaft-line must also take precedence as this is a safety issue.
  Shaft integrity assessment would be similar in scope as line auto-reclosing investigation to ascertain the magnitude of shaft torsional experienced during the events are within the mechanical design of the generating unit.

- **Work with manufacturers to find optimal solutions (on generation OR transmission sides)**
  Manufacturers clearly understand the need for a stable and reliable transmission and distribution system.
  Manufacturers are absolutely on board on finding solutions and tackle realistic challenges based on reliable technologies. Manufacturers can provide reliable technical solutions.

Rate of change of frequency withstand capability

As is

- Requirements… non-exhaustive, subject to misinterpretation.
- ROCOF profile not defined with a frequency vs time profile.

Risk

- Over-redesign of equipment based on unclear requirements
- Possible instability issues causing unit to trip
- No-type certification possible…Complex dynamic analysis needed for **each project**…and then, what if the results are not satisfactory ?
- **Nearly impossible to test**…if units happen to be damaged (shaft-line), will impact generation capacity and incur long downtime.

Alternative

- Reasonable ROCOF values close to those proposed by EirGrid Ireland.
- Work with manufacturers to find optimum solutions (on generation OR transmission sides)

High ROCOF withstand capability must consider the current state-of-the-art of synchronous generating systems.

Automatic Access ROCOF

Automatic access standard : ±4 Hz/s for 250 milliseconds and ±3 Hz/s for 1 second

— AEMO:

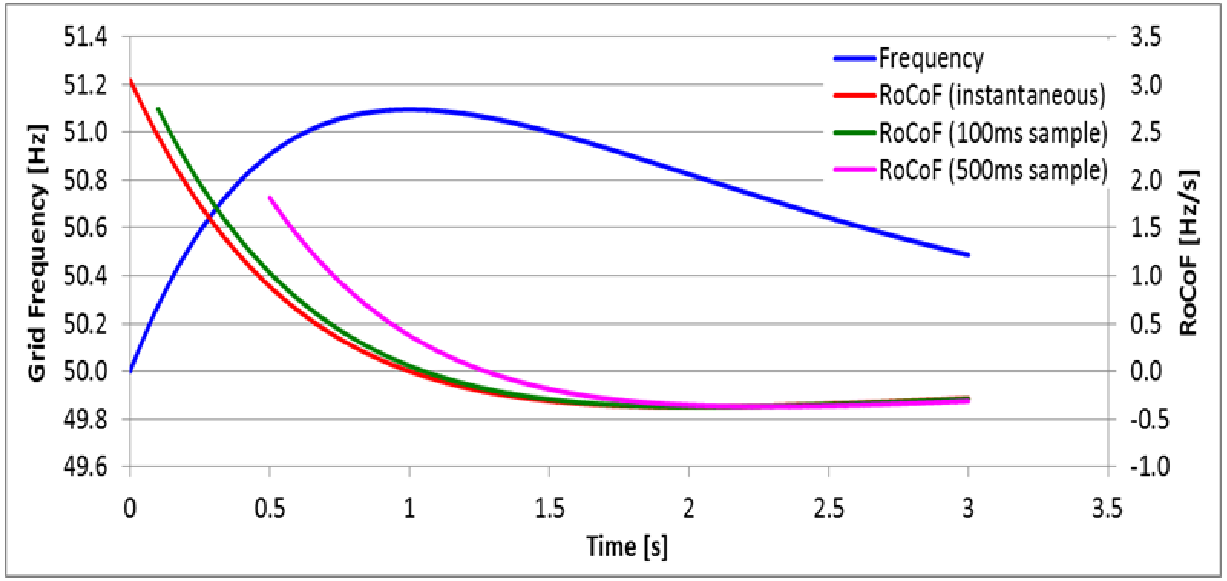
- Define the frequency-time curves referenced by the automatic access standard. See proposals on next slide.
- Define pre-fault condition and post-fault condition.

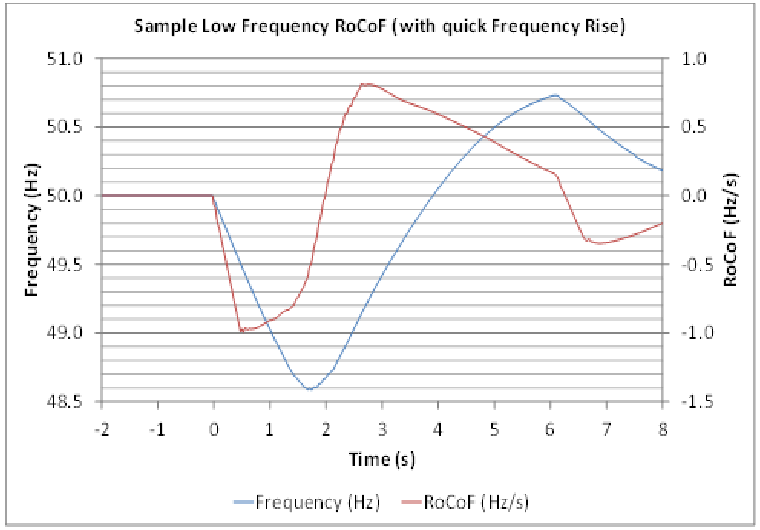
AEMO could define conditions that cannot be fulfilled with present state-of-the-art synchronous generating systems.

ROCOF requirements

- AEMO to define:
  Measurement conditions for the RoCoF value (see diagram left)

  Expected wave shape(s) of the frequency excursion (see diagram right)





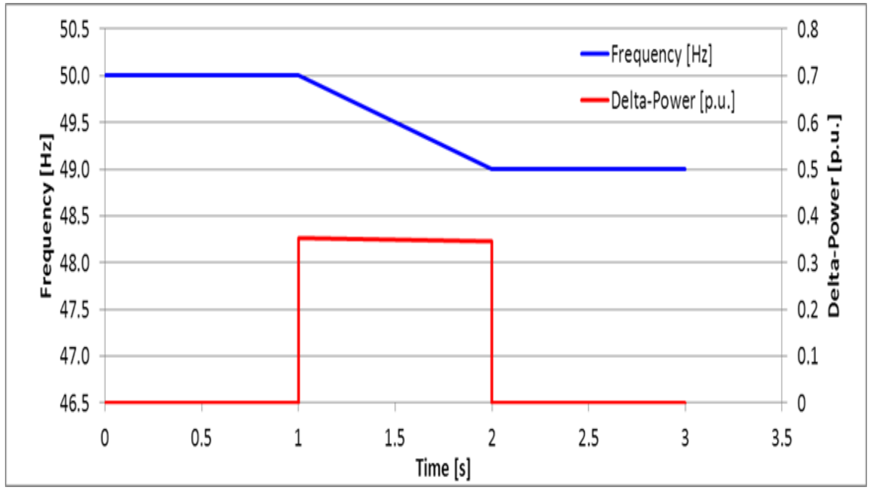
ROCOF – Effects on synchronous generator

ROCOF general evaluation by simplified representation:

- Frequency changes with constant gradient
  → immediate power step (inertial response) request at generator terminals.
- Step is deceleration or acceleration power of shaft line
- Negative frequency gradients are critical:
  → generator load angle increase
  → exported power increase

Rate of Change of Frequency	Resulting immediate Power Step ΔP (example, typical GT single drive shaft train)
0.5 Hz/s	17.5 %
1.0 Hz/s	35 %
2.0 Hz/s	70 %
3.0 Hz/s	105 %
4.0 Hz/s	140 %

High ROCOF values can result in the unit pole-slipping.



Generator inertial response

GE Proposal

- **ROCOF profile(s) to be defined and used as reference for simulation**
  Requirements for simulation against the detailed frequency-time profiles and related results can be used as a mean to check/keep and define clearly existing requirements for a specific point of connection. A case by case assessment is a necessity. Both transient stability and shaft integrity issues must be addressed. Protection against out-of-step operation and damage of the shaft-line must also take precedence as this is a safety issue.

- **Consider reasonable ROCOF withstand capability**
  As in the case of EirGrid, a value of 1 Hz/s measured over 500ms could be considered. If higher values are needed, then these should be justified with a detailed study.

System Strength

As is

- Only a minimum access standard is defined. What is foreseen as the automatic access standard.
- ESCOSA requires a value of 1.5.

Risk

- As discussed above, MLVDRT, ROCOF withstand capabilities, for example are dependent on system strength. As system strength changes with the generation mix, the difficulty would be to maintain these withstand capabilities in a future where system strength are declining significantly.
- A low system strength may result in steady-state stability limits to be reached for synchronous generating systems.
- A low system strength also will impact the power transfer capability and reduces the synchronizing torques of generating systems leading to increase risk of transient stability issues.

Alternative

- Ensure that users capability and system operation rules maintain a sufficient system strength level, e.g. via synchronous compensation, additional interconnection or tie-lines where it is needed.

Withstand capabilities such as MLVDRT and ROCOF are dependent on system strength.

Minimum Access System Strength

The minimum access standard is a generating system and each of its generating units must be capable of continuous uninterrupted operation for any short circuit ratio to a minimum of 3.0 at the connection point

— AEMO:

- A clear and consistent definition of short circuit ratio that is applicable for asynchronous and synchronous generating systems. GE has previously proposed the composite short-circuit ratio (CSCR) for wind farms.
- Clearly state that a value of no lower than 3 will be applied. Coordinate with ESCOSA to agree on a minimum value of 3.
- If this value impacts the MLVDRT, ROCOF or other disturbance withstand capability requirements, then some guideline should be proposed on how to address this requirement.

GE Proposal

- **Minimum system strength to be defined**
  A clear and consistent definition of short circuit ratio that is applicable for asynchronous and synchronous generating systems.
  A value of not lower than 3 should be adhered to be applied for all Australia.

- **Consider the impact on disturbance ride through performance**
  Work with manufacturers to ensure that the present state-of-the-art power generating units are capable of operating with the defined system strength and provide guidelines if there is a mismatch in performance.

- **Consider reinforcing the power system**
  Reinforce the transmission system with further interconnections and improve network reliability, this will increase system strength and lower the probability of system separation (islanding).