AEMC Rule Change - Efficient Reactive Current

Reference ERC0272

[redacted]

24 January 2023

<u>Comments on Rule Change Justification</u>

1. Item 1 -Summary

14 These numeric standards were influenced by OEM advice that the requirements help them design and tune their equipment before they are installed and commissioned and Aurecon's modelling of a hypothetical, Type 3, 500 MW wind farm.

Comment:

A Type 3 Wind Farm is for a DFIG type generator not a full inverter-based Wind Farm (or PV or BESS). The hypothetical Wind Farm should represent full inverter technology

It is not clear how modelling of DFIG generators will assist in discussions regarding full inverter technology.

2. Item 2

> The more preferable draft rule also allows generator project proponents and NSPs to agree that the reactive current response can commence in a range that is ±20% of the connection point *normal voltage,* responding to feedback from AEMO.[35] The NER currently requires generators to start a response in the range 80 – 90% of connection point normal voltage or 110 – 120% of connection point normal voltage. The existing requirement creates a barrier for inverter based resources that employ grid forming inverters (GFI) which continuously inject or absorb reactive current even if voltages are in the normal operating range. This change would make the rules more technology neutral, and support lower system security costs in the long-term by making it easier to connect generators that employ GFI.

Comment:
The current rule (NER V193) says no reactive injection is required if voltage at PoC is 5% for Automatic Access or 15% or less for Minimum Access. Reference = S5.2.5.5 (p) (1).

The discussion refers to "voltage" but what voltage? The CRI referred to shortcomings in the definition of voltage in the NER. Section 10 (Glossary) of the NER defines "voltage" as an electronic force (whatever that means). The voltage could be Phase-Neutral RMS, Phase-Phase Peak, instantaneous peak voltage, average voltage etc, etc. The continued use of an inappropriate definition of voltage (whereby proponents may face sanctions) is technically very poor.

The rules should follow the UK Grid Code example and specify "positive sequence voltage". This definition is both clear and technically meaningful.

3. Excess Voltages on healthy phases

Reactive current responses should not lead to excessive voltage rise on unfaulted phases during unbalanced faults

The CRI noted that the rules could be clearer that connecting generators should avoid responses that result in excessive voltage rise on unfaulted phases.[52] This was supported by AEMO's submission, and in discussions with the technical working group. There is a consensus that while this fact is implicit in the rules, it would make it clearer for connecting parties by explicitly codifying this requirement. The Commission considers this would result in greater clarity in the connection process.

The more preferable draft rule codifies the requirement by specifying that generators' reactive current contribution does not contribute excessively to voltage rise on unfaulted phases during unbalanced faults.

The current NER makes no reference to the impact of reactive injection on healthy phases. There is **nothing** in the rules that justifies this "consensus" and "consensus" has certainly not been forthcoming in our personal experience covering the entire market period. During the CRI discussions this was not treated as a major issue. In contrast, the UK Grid Code makes specific reference to this risk and requires the reactive compensation to specifically address this issue. Where inverter controls can be tuned and set to respond to the faulted phase/s it should do so. This requirement does not apply to synchronous units.

This aspect is a risk to power system security (via equipment damage) and as such needs to be treated very seriously by the AEMC.

4. Rise Times

Aurecon's simulations found that solar farms and battery energy storage systems were able to achieve faster rise times than wind farms.[90] However, the Commission notes that given the rule change is to revise the MAS, the proposed revision should be based on the lowest acceptable performance that is valid for all IBR technologies rather than the best response that could be expected from an IBR connection.[91]

The Aurecon finding is expected as they are basing their studies on a Type 3 (DFIG) wind farm and NOT a Type 4 (IBR) wind farm. All four quadrant inverter controllers (WF, SF and BESS) should behave in a comparable manner. Fixing rise times within the rules denies control engineering to appropriately tune for the local and system conditions. Speed of response and contribution to damping are always a compromise when tuning rotating machines[1], the same principles apply to IBR. Greater consideration has to be given to tuning to suit a wide range of operating conditions – this tuning ought to be done in the frequency domain not the time domain. Please read the NREL publication on "A reverse Impedance-Based Stability Criterion for IBR Grids": available at https://www.nrel.gov/docs/fy23osti/84000.pdf.

Requiring fast rise times on generators in weaker parts of the network is a recipe to create interactions such as the North-West Murray zone debacle. All tuning should be assessed against the

[1] SECV International "The Synchronous Generator Excitation System: Overview, Performance and Measurement. P Ravalli 1994"

natural frequencies of the network, other generators and other controllers. Stability assessment is not considered in the quest for automatic standards. Understanding stability and damping analysis in the frequency domain is critical, forcing a fixed characteristic on all IBR technology is a guarantee of interaction between controls and does not assure or assess damping for critical modes. .

5. Item 5 Appendix D

> In the same way that active power affects frequency, reactive power affects voltages, albeit on a locational basis. If reactive power is injected when the network is in equilibrium, then voltages will rise, and vice versa if reactive power is absorbed. Consequently, the provision of reactive power, through reactive current during faults, reduces the size of the voltage change, and reduces its propagation in the power system. This has the effect of reducing the amount of equipment in the power system that experiences large changes in voltage and the negative outcomes associated with doing so.

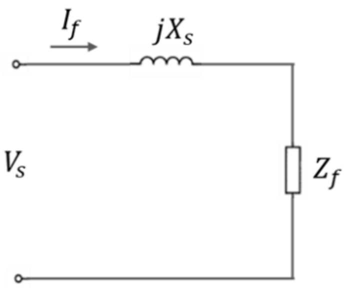
This is not entirely correct. For a bolted fault, an **<u>infinite</u>** amount of reactive power injection will not improve voltages at the faulted point. See also NER S5.2.5.5 (p) (1) where reactive injection is NOT required if PoC voltages fall below 15%.

It is not clear why a 15% voltage doesn't require reactive injection, but 16% voltage does require reactive injection. Perhaps AEMC and Aurecon could provide some commentary on this disjointed approach.

AEMC/Aurecon don't make any reference to system SVC's that freeze thyristor firing angle during faults (when voltage dips are less than ~70%). The SVC manufacturers have long determined that the benefits of reactive contribution during faults is outweighed by the overvoltage risks after fault clearance.

6. Short Circuit Current

Figure D.1: Simplified equivalent circuit for a short circuit



Source: AEMC

Note: V_s is the upstream voltage (V), X_s is the upstream short circuit impedance (Ω), Z_f is the fault impedance (Ω) and I_f is the fault current (A). Note that X_s is represented here as a pure reactance to reflect the typical characteristics of a transmission network and illustrate that the fault current is mostly reactive (or capacitive) in nature.

- If Zf = 0 then current will be inductive
- This example assumes that **<u>reactive power</u>** is inductive, and that capacitive current is something else. It should say "illustrate that the fault current is mostly <u>inductive</u> in nature. It is not clear how the fault current can be capacitive? Perhaps AEMC/Aurecon could explain this?

7. Three-Phase bolted fault

> In the theoretical three-phase bolted fault, the short circuit impedance is zero and voltage at the fault location will also tend towards zero (unless there is infinite short circuit capacity availability upstream, i.e. $X_S \approx 0$). However, real faults are never quite so severe and there is always some non-zero short circuit impedance. Most real faults also tend to be asymmetrical, e.g. phase-to-earth or phase-to-phase.

- For a bolted three-phase fault, the voltage **<u>will be zero</u>** at the fault location, regardless of the source fault level.
- The statement "However, real faults are never quite so severe and there is always some non-zero short circuit impedance" is not correct.
  - There is a specific class of faults related to closing onto operational earths which contradict this assertion.
  - Tower collapse can also result in bolted three-phase faults (see 2016 storm-related network failure in SA and also in Vic (separate 500kV and 330kV events).
  - Bus Failures (falling structural members) can also result in bolted three-phase faults

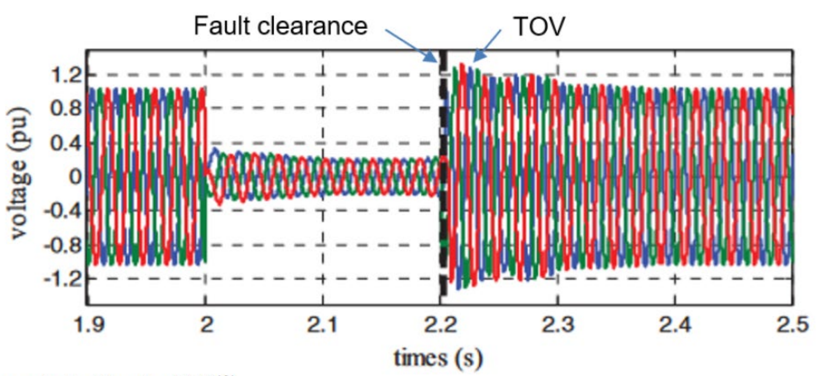
The narrative provided by the AEMC is therefore not a true representation of the physical outcome on the system. This is an example of the simplifications or beliefs that explain faults in a manner that suits an argument to justify rule outcomes which ignore reality.

8. Fault Current

The AEMC has considered Total Current as a means of determining reactive requirements. However, they only consider Positive and Negative sequence currents. This is conceptually incorrect as it ignores Zero sequence currents.

9. Temporary Over- Voltages

Figure D.10: Temporary over voltage



Source: Saad and Dennetiere (2019)[131]

The fault shown here is a balanced three-phase fault and yet TOV is greater than 120%. Why doesn't AEMC/Aurecon show the impact of reactive injection on the healthy phases of a single phase-ground fault? The original AEMO rule for 4% ΔQ/1% ΔV never considered this issue, yet it impacts significantly on power system security and can stress and damage equipment.

10. Ideal Reactive current response

D.6 Principles of an ideal reactive current response

A "good" reactive current response during a voltage disturbance would be **the maximum reactive current that can be supplied by the facility delivered as quickly as practicable**, subject to the following conditions:

1. The reactive current response is proportional with voltage
2. The reactive current response is internally stable (e.g. sufficient gain and phase margins) and adequately damped
3. The response is quickly attenuated (while still being proportional to voltage) when the fault is cleared or the voltage disturbance ends
4. The facility provides appropriate negative sequence current injection into the faulted phase/s during unbalanced faults (and provides minimal or no reactive current injection into unfaulted phases)
5. Active power withdrawal is minimised where practicable (e.g. in cases where active power withdrawal is physically unavoidable due to low voltages)
6. The response is limited based on locational circumstances to prevent undesirable behaviours (e.g. LVRT re-triggering during shallow faults) or grid impacts (e.g. post-fault temporary overvoltages after exiting LVRT mode)

- Part 4 above implies individual phase control. Such controls will add considerably to the cost of Inverter-fed generation and contrasts with normal synchronous generation controls. Thus, it could be argued that this would represent a barrier to entry to inverter technology.

- The UK Grid Code specifies that the inverter-based generation should contribute to reactive power during a fault **subject to considerations of over-voltages on healthy phases**. Rather than relying on single phase controls, I think the UK approach is more pragmatic and cost effective.

- The limitations outlined in 6 above merely highlight how inappropriate the whole question (of reactive current injection during a fault) actually is.

- "the maximum current that can be supplied by the facility as quickly as possible" These words taken at face value, ignore the need to tune control systems to be stable against all other controls within the network. Maximum and fast as possible is not reasonable across the broad for voltage control behaviour, this attitude of everything has to be fast and max fails to assess in the frequency domain the stability and damping contribution of the controllers and will lead to network modes being excited.

COMMENTS ON PROPOSED RULE:

1)

[12] S5.2.5.5 Generating system response to disturbances following contingency events

After clause S5.2.5.5(u)(1), insert a new clause S5.2.5.5(u)(1A) as follows:

(1A) the reactive current contribution must not contribute excessively to *voltage* rise on unfaulted phases during unbalanced faults;

Comment:
This is a welcome addition as it at least acknowledges the issue of reactive injection on healthy phases. However, the wording is imprecise and subjective. What is meant by "excessively"? Isn't this just opening yet another requirement for interpretation by AEMO, NSP's and their engineers? Perhaps it should be tied into explicit reference to S5.1.a4 as this describes expected transient Over – Voltage)

1. Definition of Voltage
   At present, Voltage is a defined term under the Chapter 10 of the NER rules (Glossary). Unfortunately, "Voltage" is defined as an "electronic force" which is totally incorrect. **<u>There is no such thing as an electronic force</u>** (at least not in any textbook we can find).

   Any rule based on this definition would not be capable of being interpreted and hence there would be no way of enforcing any technical requirements relating to voltage. The AER should be consulted on how they would enforce the NER given this definition of "voltage".

   The NER uses the term "voltage" in several areas, but the meanings are different. For example, the UK Grid Code chooses to relate the reactive current injection to positive sequence voltages, and this is definition is recommended in these comments. Other voltage-related areas clearly refer to RMS voltages. It would be appropriate to designate each voltage reference in the NER with a clear definition of what is meant.

2. The AEMO interpretation of the NER is for proponents to meet the Automatic Access Standard (or as close as possible). Generally, this approach is reasonable. However, the issues raised in the discussion paper about the impacts of X/R ratio and appropriateness of a Q-Response show that the AEMO AAS interpretation may lead to inappropriate system outcomes. The rules should remove this interpretation risk in this matter.

For this rule, the NER should specifically state that the Automatic Access does not necessarily ensure the best outcome for the system as a whole and that the Access Standard should be agreed with AEMO, NSP and proponents - based on the appropriate response given the particular circumstances such as location, generator capacity, network strength, proximity to other generation etc. Overall, the controls need to be assessed for stability and the response is always a compromise between speed and damping, regardless of the technology.