Defining System Strength Zones: A methodology for the National Electricity Market

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Technical Report

FOR PUBLICATION

Important notice

PURPOSE

AEMO, in consultation with a number of network service providers, has developed a methodology to define the extent of an area of the power system to be considered as impacted by stability issues resulting from low system strength.

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1. Background

Since 2017, many technical requirements in the National Electricity Rules (NER) for new generating systems have been introduced in response to low system strength issues seen in the National Electricity Market (NEM).

The black system in South Australia in 2016 highlighted the need for highly detailed simulation model assessments for inverter-connected generators and was a catalyst for the NER changes for minimum fault level at key nodes to ensure the system remains stable. The NER changes sought to define minimum system strength and included standards to facilitate generator operation under low system strength scenarios.

However, the rules did not envisage interactions causing oscillations potentially involving connected equipment within a wide area around the immediate system strength issue.

AEMO developed this technical report in consultation with a number of affected network service providers (NSPs). It proposes a method to define the area impacted by a low system strength issue, to facilitate the development and progression of connection evaluation processes with increased levels of certainty for proponents, NSPs and AEMO.

The need for a methodology to define system strength zones was identified as a result of post-fault system strength oscillations along the Kerang, Wemen, Red Cliffs, Buronga and Broken Hill 220 kilovolt (kV) transmission line path, denoted as the West Murray Zone (WMZ) encompassing parts of Victoria and New South Wales regions. In September 2019, AEMO applied network constraints to limit the output and online inverters of five generators in this area by 50%, to bring the oscillations within secure limits. AEMO worked closely with the generator owners, original equipment manufacturer (OEM), and connecting NSP to determine new settings and inverter functionality that would allow increased output while maintaining power system security. These changes, coupled with services obtained to meet a declared system strength gap at Red Cliffs, are expected to restore stability and adequate system strength to the WMZ. The process of re-establishing stability across the WMZ has affected the progress of projects in the area.

Defining system strength zones could help avoid additional delays to projects, by establishing a method to distinguish which nodes are likely to exacerbate known high frequency[1] instabilities with additional generation. This approach recognises that projects remote to the unstable nodes are unlikely to exacerbate related instabilities, and should not be constrained or delayed for that reason in the connection, registration or commissioning process.

2. Objective

The objective of this technical report is to propose a simple, reliable and repeatable methodology to define the area affected by low system strength interactions, demonstrating the application of the methodology to the WMZ as a case study.

[1] High frequency instability assumed to be related to system strength.

3. Proposed zoning method: Residual Voltage Test

Residual Voltage Test is the proposed method to ascertain how much of the system strength in one area is transferred to an adjacent location. Applying this method will enable the assessment of the potential for a new generator connection to adversely interact with other generation due to low system strength, causing or exacerbating instability. It is possible that while system strength issues could be isolated, other issues may still be present. This method does not assess all technical aspects of the power system or dynamic interactions such as thermal, voltage, and transient stability.

The following sections describe the methodology and its application to design the WMZ around the system strength issues that are presently bound between Red Cliffs/Buronga and Kerang.

3.1 Methodology

Determining the system strength zone around a low system strength bus involves applying a fault to the bus and measuring the residual voltage at the surrounding buses. For the WMZ, the low system strength area identified is bounded by the Buronga and Kerang 220 kV buses[2].

The residual system voltage on buses from a three-phase solid fault from 1 p.u. pre-fault voltage has been assessed.

This method enables a standard process to be followed that will provide consistent results quickly and simply regardless of load flow, voltages, trip schemes, contingencies, or transformer taps. The main factors that affect the results are the number of generators online and any network augmentations that change the impedances around the low system strength area.

To ensure the network configuration is consistent, a standard AEMO snapshots package was used. This ensures the network is "system normal" and doesn't include line outages, split busses or other abnormal network configurations. The dispatch scenario has an impact on the fault calculation. Therefore, the number of synchronous generators should be reduced to reflect minimum dispatch, with all other generators offline.

AEMO proposes using a voltage depreciation of 20% (0.80 p.u. residual voltage from a fault at a low system strength bus) to define the boundary. A fault at the low system strength bus will cause the voltage at that bus to go to 0 p.u. and depreciate surrounding voltages from 1.00 p.u. A bus where the residual voltage is above 0.80 p.u. would be considered outside the boundary and unlikely to cause any detraction of the system strength provided to the low system strength bus. This fault calculation ignores control system interaction, but rather provides an accurate impedance comparison.

To assess the impacts of different generation dispatch patterns, AEMO conducted sensitivity analysis studies and compared the residual voltage under different minimum dispatch scenarios.

3.2 Case study – West Murray Zone

To demonstrate the methodology of the Residual Voltage Test, AEMO used the WMZ as a case study. The fault was applied to two buses at the bounds of the location of system strength issues, one at Buronga and

[2] Broken Hill is considered an extension of Buronga as a radial (Figure 1).

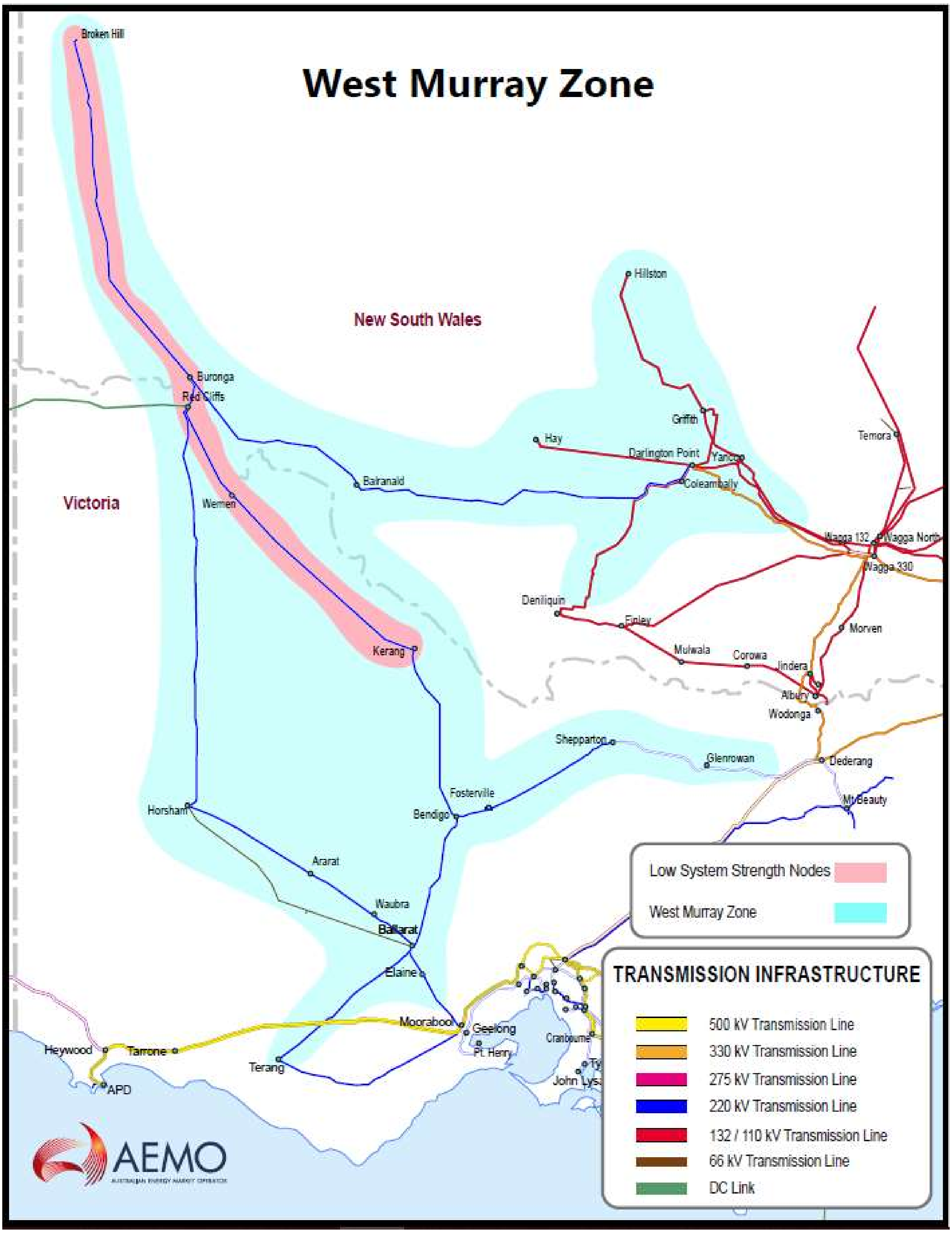
another at Kerang 220 kV buses. Table 1 below shows the residual system voltage for each of these faults at transmission buses; in the table, buses that are highlighted red are considered as part of the system strength zone and buses highlighted green are not considered as part of the system strength zone. Results have been rounded to two decimal places; for some transmission paths the boundary may be at a point along a line.

Table 1 Post fault voltage results for faults at Kerang and Buronga 220 kV

State	Substation	Bus #	Post Fault Voltage		
			Kerang 220 kV	Buronga 220 kV	Lowest value
VIC	Ballarat	32040	0.75	0.80	0.75
NSW	Balranald	23010	0.54	0.25	0.25
VIC	Bendigo	32080	0.47	0.69	0.47
NSW	Broken Hill 220 kV	23040	0.41	0.00	0.00
NSW	Buronga	23081	0.41	0.00	0.00
NSW	Coleambally	23510	0.81	0.76	0.76
NSW	Corowa	16782	0.84	0.84	0.84
NSW	Darlington Point 220 kV	22201	0.77	0.68	0.68
NSW	Darlington Point 330 kV	21200	0.80	0.75	0.75
VIC	Dederang 220 kV	32180	0.82	0.86	0.82
VIC	Dederang 330 kV	33180	0.85	0.87	0.85
NSW	Deniliquin	23561	NA	0.81	0.81
VIC	Elaine	32090	0.77	0.81	0.77
NSW	Finley	23602	NA	0.82	0.82
VIC	Fosterville	32230	0.53	0.71	0.53
VIC	Glenrowan	32240	0.77	0.83	0.77
NSW	Griffith	23670	0.82	0.77	0.77
VIC	Horsham	32280	0.61	0.52	0.52
VIC	Kerang	32380	0.00	0.48	0.00
VIC	Moorabool 220 kV	32480	0.82	0.85	0.82
VIC	Moorabool 500 kV	35483	0.84	0.87	0.84
NSW	Mulwala	25136	NA	0.83	0.83
VIC	Shepparton	32700	0.73	0.81	0.73
VIC	Terang	32800	0.78	0.82	0.78
NSW	Wagga 132 kV	22890	0.85	0.84	0.84
NSW	Wagga 330 kV	21893	0.85	0.84	0.84
NSW	Yanco	25931	0.82	0.78	0.78

Figure 1 illustrates the results from Table 1. The pink area shows the low system strength nodes, and the blue area represents the zone where buses with residual fault voltage below 0.80 p.u., that is, the WMZ.

Figure 1 Graphical representation of the results defining the West Murray Zone

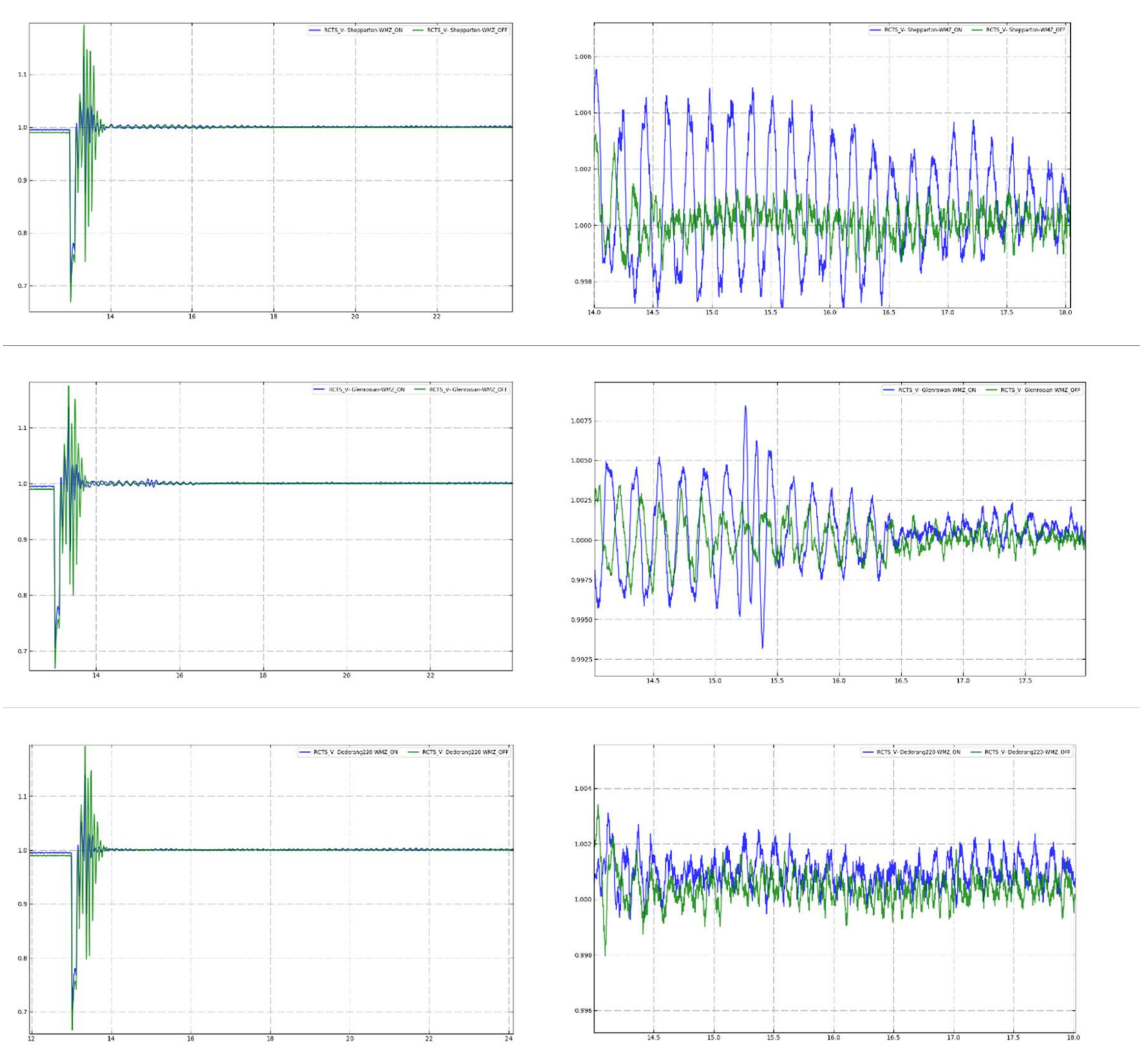


3.3 PSCAD studies

To validate the results of the Residual Voltage Test method, AEMO conducted PSCAD studies at buses that form the WMZ boundary with a fictious generator connected at Shepperton, Glenrowan and Dederang. The generator is a solar farm with a control system similar to the five generators constrained in WMZ[3], scaled up to 1,400 megavolt amperes (MVA). This consisted of multiples of seven 88 megawatt (MW) generators with 80 inverters (200 MVA).

The example below shows the connection of the 1,400 MVA generator with (blue) and without (green) the five constrained WMZ generators[4] connected. Removing these five generators improved stability, which shows that adding generation to this bus has a negative impact on the WMZ and should be in the zone. The residual voltage value associated with that bus would then be used to define the zone. Figure 2 shows results for Shepparton, Glenrowan and Dederang. The left plots are of the fault, the plots on the right are zoomed in to show the undamped oscillations.

Figure 2 Voltage at Red Cliffs for Kerang Bendigo fault, with 1,400 MVA (Shepparton, Glenrowan, Dederang)



[3]The five generators constrained in WMZ, prior to rectification through tuning.

[4]The five generators constrained in WMZ have been included at their constrained stable operating point, prior to rectification through tuning.

These results show that a generator at Shepparton has a significant impact on the undamped oscillatory response to generation at Red Cliffs. This impact is diminishing at Glenrowan and indiscernible at Dederang. Therefore, as the residual voltage at Glenrowan and Dederang is 0.77 p.u. and 0.82 p.u. respectively, a residual voltage of 0.80 p.u. was determined as the boundary point.

3.4 Application

When the zone has been determined, consideration needs to be given on how the assessment for generation may differ. An example of how to assess a generator that falls in or out of the zone has been outlined below, and Appendix A1 has a high-level process map on how the NSP and AEMO would assess a generator.

These two scenarios have been described to help illustrate how this can be used:

- Inside the zone:
  - A generator connecting inside the defined zone will be considered to having an impact on the low system strength area and need to be assessed with all generators online at full output (generators are only constrained for other operational constraints, for example, if line ratings are exceeded or dispatch for night/day operation).
- Outside the zone:
  - A generator connecting outside the zone will be considered not to have an impact on the low system strength area regardless of size. For wide area network studies, the base case should be stable with the new generator offline and all committed generators included with dynamic plant that is part of the operation of the generating system. This will likely require generators inside the zone that are exhibiting system strength issues to be constrained. The level of the constraint should be determined in agreement with all impacted NSPs and AEMO National Connections to a level where the area is stable for any fault. Curtailment should be applied by reducing the number of inverters of the generators. With the base case stable, the new generator can then be assessed as per standard practices.

When applying the Residual Voltage Test method in other parts of the network, there may be isolated cases where this method is not applicable. Good engineering judgment should always be used when using screening tools such as the Residual Voltage Test method described here.

4. Conclusion

The purpose of this report was to propose a simple, reliable and repeatable methodology to define the area affected by low system strength interactions.

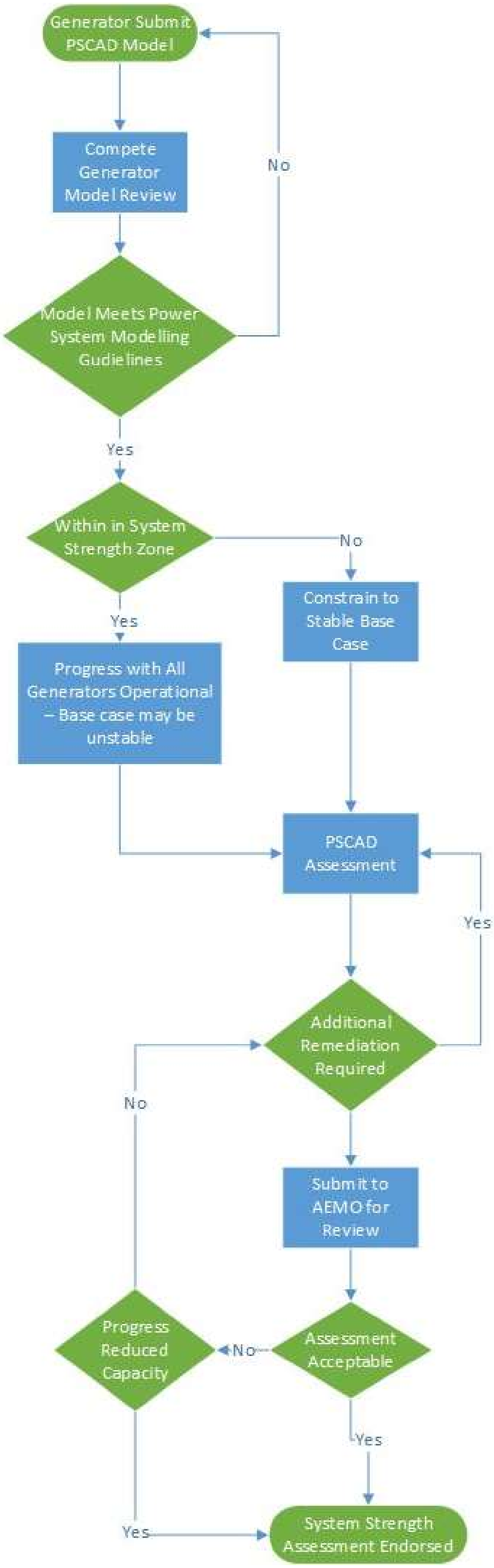
The Residual Voltage Test is reliable and repeatable as it uses the network impedance to define the electrical distance from a weak bus and how close it is to a strong bus (synchronous generators). By using a standard AEMO snapshot, the network will be consistent if repeated with different cases. The main factors that affect the results are the synchronous generators that are online and any network augmentations that change the impedances around the low system strength area. Using the minimum dispatch for each state improves the consistency of the results.

After the case is set up, the study can be conducted quickly and simply using standard PSS®E loadflow.

For the WMZ case study demonstrated in this report, to ensure an appropriate voltage threshold was used, PSCAD studies were conducted by connecting a large marginally stable generator to each bus along the Bendigo to Dederang line. These results show that a generator at Shepparton has a significant impact on the oscillatory response to generation at Red Cliffs. This impact is diminishing at Glenrowan and indiscernible at Dederang. The residual voltage at Glenrowan and Dederang is 0.77 p.u. and 0.82 p.u. respectively, hence a residual voltage of 0.80 p.u. was determined as the appropriate boundary point.

Using the Residual Voltage Test proved to be a simple and reliable metric to define the impacted area of a system strength issue to aid in deciding how to setup the wide area network PSCAD cases to assess generators. This can be used to determine generator connections that are sufficiently remote to the unstable nodes to be excluded from evaluation, together with projects that fall within the determined system strength zone.

A1. Process map



Note: A "Stable Base Case" refers to a wide area network PSCAD model where constraints have been applied to stabilise the network.