Amendments to the Power System Model Guidelines

Final Report – Standard consultation for the National Electricity Market

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New South Wales | Queensland | South Australia | Victoria | Australian Capital Territory | Tasmania | Western Australia

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Executive summary

The publication of this final report concludes the standard rules consultation procedure being conducted by AEMO to update the Power System Model Guidelines (**PSMG**), the Power System Design Data Sheet, and the Power System Setting Data Sheet (the **proposal**) under the National Electricity Rules (**NER**).

AEMO thanks all stakeholders for their feedback on the proposal, which was consulted on as required by NER S5.5.7(a), following the procedure in NER 8.9.2.

The PSMG, the Power System Design Data Sheet, and the Power System Setting Data Sheet specify, in relation to power system equipment, control systems and plant technologies, the data and other requirements to be provided and maintained by relevant participants under the NER.

AEMO received 14 submissions in the first stage of consultation on the proposal, and 7 submissions in the second stage of consultation on the proposal.

Based on the feedback received and further review, AEMO has made material changes to the draft PSMG to address the following matters:

- Provided more information on the process of determining the most appropriate load model options, including clarifying the responsible parties for such a determination would be the network service provider (**NSP**) and AEMO jointly, and the factors to be considered for making such a determination.
- Provided clarification on the definition of the composite load model, being a composite mathematical representation of a load facility consisting of multiple types of devices, rather than referring to a specific model family currently provided by any commercial simulation software.
- Added another load modelling option, for a hybrid modelling approach for load facilities consisting of both inverter-based load (**IBL**) and non-IBL components.
- Provided clarification on the requirement for electromagnetic transient (**EMT**) models for non-IBL loads, where an NSP may require EMT models to be provided for non-IBL loads, or non-IBL components of a load, and such a requirement must not result in the proponent needing to source more information than what is necessary to develop the root mean square (**RMS**) models of non-IBL loads.
- Added requirements around EMT model format to ensure future software compatibility.
- Updated wording around provision of small signal models to allow AEMO and NSPs to request other formats (such as an SSAT model) in consultation with the OEM and participant.
- Provided more information on the placement of park controller models, and the provision of description for RMS model error messages in the Releasable User Guide (**RUG**).
- Provided more information on the modelling options for legacy plants, and general guidelines on the model parameterisation for legacy plant models where vendor-specific models are used.
- Elaborated on the application of Section 8 of the PSMG, on the modelling requirements for legacy plant.
- Provided more information on the locations for load model validation, where the validation can occur at the connection point, or the aggregation point of IBL components within a load facility, or other locations within the load facility subject to an agreement between the NSP and the proponent.

- Elaborated on the accuracy requirement for RMS and EMT model benchmarking, where divergency in model response is expected following a large disturbance, however both models are expected to have close response and reach the same steady state condition, following a small disturbance, such as a voltage reference step.
- Provided more information on the modelling of protection systems for non-IBL loads, where the NSP must provide advice to the proponent on the required level of details to be modelled for the protection system of non-IBL loads.
- Added a new section, Section 6.3.4, to the PSMG to provide general guidelines on the handling of numerical instability, spike response, and other undesirable artefacts exhibited during simulation, and the potential treatment for such undesirable response depending on the nature.
- Editorial changes to the existing PSMG, including NER clause references, where appropriate replacing multiple terms relating to participant or plant types with generic or umbrella terms, and other drafting improvements.

After considering all submissions, AEMO's proposal is to make the Power System Model Guidelines, the Power System Design Data Sheet and the Power System Setting Data Sheet in the form published with this final report, with an effective date of **14 July 2023.**

Contents

Tables

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1. Stakeholder consultation process

As required by the National Electricity Rules (**NER**) S5.5.7(a) and (f), AEMO has consulted on proposed changes to the Power System Model Guidelines, the Power System Design Data Sheet and the Power System Setting Data Sheet in accordance with the standard rules consultation procedure in NER 8.9.2.

Note that this document uses terms defined in the NER, which are intended to have the same meanings. There is a glossary of additional terms and abbreviations in Appendix A.

AEMO's process and timeline for this consultation are outlined below.

Table 1 Consultation process indicative timeframe

Deliverable	Indicative date
Consultation paper published	2 December 2022
Submissions due on consultation paper	10 February 2022
Draft report published	14 April 2023
Submissions due on draft report	19 May 2023
Final report published	14 July 2023

AEMO's consultation webpage for the proposal is at https://aemo.com.au/consultations/current-and-closed-consultations/psmg-review-consultation. It contains all previous published papers and reports, written submissions, and other consultation documents or reference material (other than material identified as confidential).

In response to its consultation paper on the proposal, AEMO received fourteen written submissions including seven late submissions, and held one meeting with Goldwind Australia on 1 March, 2023.

AEMO considered these submissions and other relevant information in developing the draft report and draft determination on the proposal.

In response to its draft report, AEMO received seven written submissions, and held two meetings with Tesla on 9 May, 2023, and with Siemens on 10 May, 2023. A full list of submissions and stakeholder meetings can be found in Table 2 of this final report.

AEMO thanks all stakeholders for their feedback on the proposal throughout this consultation, which has been considered in preparing this final report.

Table 2 List of submissions and stakeholder meetings

Stage 1 submissions	Stage 2 submissions	Stakeholder meetings
• AusNet Services • CitiPower-Powercor-United Energy • Goldwind • Kate Summers • OPAL-RT • PGSTech • Tesla • Clean Energy Council (late submission) • CS Energy (late submission) • GE (late submission) • Powerlink (late submission) • RTE (late submission) • Siemens (late submission) • Transrid (late submission)	• Clean Energy Council • ElectraNet • Ergon Energy – Energex • Powerlink • TasNetworks • Tesla • Transgrid	• AEMO – Goldwind, 1 March 2023 • AEMO – Tesla, 9 May, 2023 • AEMO – Siemens, 10 May, 2023

2. Background

2.1. NER requirements

Under NER S5.5.7(a), AEMO must develop, publish, and maintain:

- the Power System Model Guidelines (**PSMG**), and
- the Power System Design Data Sheet and Power System Setting Data Sheet (referred to collectively as the **Data Sheets**).

These documents specify, for power system, control system and plant technologies, AEMO's requirements for mathematical models of such technologies, with due consideration for NER S5.5.7 (b) and S5.5.7 (c). These models must be provided by Generators, network service providers (**NSPs**), Customers, market network service providers (**MNSPs**), Network Support and Control Ancillary Services (**NSCAS**) tenderers, and prospective System Restart Ancillary Services (**SRAS**) providers to AEMO and NSPs in specified circumstances.

The circumstances under which these models must be provided are outlined in NER 3.11.5(b)(5), 3.11.9(g), 4.3.4(o), 5.2.3(j), 5.2.3(k), 5.2.3A(a), 5.2.3A(b), 5.2.4(c), 5.2.4(d), 5.2.5(d), 5.2.5(e), 5.3.9(b)(2), S5.2.4, S5.3.1, S5.3a.1 and S5.5.

2.2. The national electricity objective

Within the specific requirements of the NER applicable to this proposal, AEMO will seek to make a determination that is consistent with the national electricity objective (**NEO**) and, where considering options, to select the one best aligned with the NEO.

The NEO is expressed in section 7 of the National Electricity Law as:

> to promote efficient investment in, and efficient operation and use of, electricity services for the long term interests of consumers of electricity with respect to:
>
> (a) price, quality, safety, reliability and security of supply of electricity; and
>
> (b) the reliability, safety and security of the national electricity system.

AEMO will also take into account applicable targets for reducing Australia's greenhouse gas emissions, where consistent with the NEO and the requirements of the NER. AEMO expects any such considerations are likely to be consistent with broader objectives of efficient planning for the long-term interests of consumers of electricity.

2.3. Context for this consultation

2.3.1. Need for power system models

The PSMG and Data Sheets specify the requirements for mathematical models of plant and equipment connected or proposed to be connected to the power system. Power system models enable AEMO and NSPs to undertake power system analysis in order to fulfil a number of obligations under the NER, most critically AEMO's responsibilities to maintain power system security and AEMO's and NSPs' responsibilities to facilitate new connections to the national grid.

Power system models are used for many purposes, from the assessment of the suitability of proposed plant and capability to achieve its performance standards, to the ongoing management of power system security in near-term and operational timeframes.

There are many modes of failure for a large power system such as the National Electricity Market (**NEM**), and as such each individual piece of plant cannot be considered independently. To study the interdependencies of every power system component requires mathematical models for each piece of plant suitable for using in computer software simulations. Simulations are a very powerful tool used by AEMO and NSPs to assess the security of the power system by performing what-if scenarios on a digital reproduction of the NEM and defining operating limits for the physical system.

The format, accuracy and level of detail required of these models depends on the failure mode or phenomena being studied. For example, during system black conditions the network is highly susceptible to non-linear phenomena and assessing system restart paths needs highly specific and detailed models and information[1]. By foregoing detailed models or using only basic approximations, modes of failure are masked from the simulation – modes of failure which, if they occurred in real life, could risk the security and reliability of the power system, cause damage to physical plant, and risk safety to human life in the vicinity of any electrical devices.

On the other hand, AEMO and NSPs using accurate and up-to-date models can benefit participants and consumers. This is because the operating envelope of the power system is highly complex. Power system simulations allow AEMO and NSPs to define power system limits mathematically and then use advanced methods to optimise usage of the power system. For example, by having accurate information about generator reactive power capability, AEMO can formulate voltage stability limits that allow market benefits to participants and consumers that would not have been realised had the information not been provided.

AEMO is aware of the costs associated with the development of accurate power systems models, and AEMO will work with NSPs to ensure that models are only requested when absolutely required.

2.3.2. The changing nature of power system phenomena

As the power system develops and evolves, so do the modes of failure. In the last several years, AEMO and NSPs have observed new phenomena (such as emerging sub-synchronous control interactions) that have not been seen previously in the NEM and have little or no basis in historical power system literature.

The energy transition towards renewable sources is the prime reason for this, but it is not due to the fuel source, or even the intermittency, of the generation. Rather it is the technology that interfaces this plant with the power system that is driving the new phenomena.

Traditional large-scale sources of energy were historically based on a single technology, that of a synchronous machine. All traditional generation – including coal, gas, and even hydro – utilised synchronous generators to interface to the grid. The way this plant interacted with the power system was widely understood and was typically defined by the laws of physics through electro-mechanical coupling. As such, power systems were designed to facilitate this technology and modes of failure were widely understood.

However, over the past decade there has been a surge in the integration of large-scale renewable plant to the grid. Such plant – including wind turbines, solar photovoltaics (**PV**) and battery storage systems –

[1] Such information includes magnetic saturation characteristics of iron-core transformers, geo-spatial arrangement of transmission line towers, replication of generator prime-mover systems, protection systems and more.

cannot be interfaced to the grid through the use of a synchronous machine and are therefore known as asynchronous generators. There are many technologies available to interface these renewable resources to the grid, and new technologies are constantly being developed. However, for the most part, asynchronous generators are connected to the grid through a power electronics interface. This interface uses power electronic switches to transfer the energy from the renewable resource (typically direct current (**DC**)) to the alternating current (**AC**) power system.

The way that asynchronous generators interact with the grid is significantly different from synchronous machines:

- The first major difference is that power electronic interfaces have no electro-mechanical coupling between the energy source and the grid, and as such, concepts such as inertia and fault current (which were inherently provided by synchronous machines) have been minimal or absent from asynchronous generators. This is detrimental to the power system, as inertia and fault current improve the stability of the system and act as stabilising services to help recovery after a disturbance.
- The second is that, instead of being coupled to the grid through the laws of physics as synchronous machines are, the coupling is performed by control systems implemented as computer software. As a result, many new phenomena observed in the power system are the direct result of how the control systems have been programmed.

2.3.3. The changing nature of power system load

While over the last several years changes on the generation side have been dramatic, changes to technology of devices that consume energy, or power system loads, have been slower. Although there have been observed changes to consumer technology such as variable speed drives replacing induction machines as a technology in air-conditioning, refrigeration and many other consumer goods, and the rise of rooftop photovoltaics (PV), there have only been minor changes to methods for modelling and analysing the impact of loads in power systems. This is due to the difficulty of modelling aggregate customer load response on the transmission system.

This has started to shift in the last year, however, as interest in connections of very large, power electronic interfaced power system loads has risen. Two recent examples seen by AEMO and NSPs are the emerging hydrogen electrolysers (hydrolysers), and the resurgence of very large-scale data centres. Both technologies are typically interfaced by power electronic converters, and thus many of the same modes of instability introduced by asynchronous generators can also apply to these loads.

While some large loads are obliged to provide modelling data to AEMO and NSPs under NER 5.2.4(c), 5.2.4(d), and S5.3.1(a1), no detail is provided regarding the requirements for models of large loads in the PSMG, with the PSMG frequently using the wording “Generating System” which does not apply to loads. Therefore, it is considered necessary to update the PSMG to include specific modelling requirements for large power system loads.

Note the PSMG and thus this consultation are specific to model requirements, **NOT** not performance requirements. Performance requirements and Connection Agreements for customers have not been discussed or considered in this consultation.

2.3.4. The importance of maintaining models into the future

As has been demonstrated in the previous sections, detailed and accurate power system models are critical for ensuring power system security and to produce the optimal benefit to participants and consumers. However, as plant is typically in operation for potentially decades after commissioning, so too must power system models remain up-to-date and usable by AEMO and NSPs over that lifespan.

This is a significant challenge as computer software and hardware change, simulation software packages are updated and changed, and new tools are utilised or replace older software, while models received by AEMO and NSPs are specific to a single simulation tool and cannot be easily migrated to other tools, including newer versions of the same product.

For example, the software package PSCAD™ is used by AEMO for simulation of electromagnetic transient (**EMT**) models. AEMO recently undertook a program of work to migrate all existing models developed for PSCAD™ version V4 to the current version, V5. This was required because several software dependencies used by V4 became obsolete and were no longer obtainable. Converting all models to V5 was a labour-intensive process due to the models being highly coupled to PSCAD V4, and significant testing had to be undertaken to ensure the performance of the models was identical between V4 and V5. Migrating these models to a different simulation tool or software platform altogether (for example, and purely hypothetically, if PSCAD™ was made obsolete) would be even more challenging and in some cases, due to the high level of dependency on PSCAD™, could prove impractical.

As AEMO cannot predict changes in software over the period in which plant is operational, and also taking into consideration that original equipment manufacturers (**OEMs**) may not exist for the life of the asset, some method for ensuring models remain usable and compatible for the life of the plant is required. AEMO and the NSPs propose to update the Guidelines to define a standard for how models are structured within the simulation tool that will promote ongoing compatibility.

Note this mostly applies to EMT models, because root mean square (**RMS**) models are already required to be provided as source code which can be easily recompiled for different software tools. There are currently ongoing industry initiatives to consolidate the needs and requirements of AEMO and NSPs on this matter.

2.3.5. Other matters

AEMO has identified several other minor changes to the Guidelines that are considered to be of benefit. These changes are detailed in Section 4.17.

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3. List of material issues

The key material issues arising from the proposal or raised in submissions are listed in Table 2.

Table 3 List of material issues received in Stage 1 and Stage 2 consultation

No.	Issue	Raised in Stage 1 consultation by	Raised in Stage 2 consultation by
1.	Threshold for deciding when to model a traditional large power system load in detail power system simulations	AEMO, Tesla, AusNet, Citipower & Powercor, CS Energy, Powerlink, Kate Summers, Transgrid	N/A
2.	Suitability of IEEE or Composite load and distributed energy resources (**DER**) load model for large traditional power system loads	AEMO, AusNet, Citipower & Powercor, Powerlink, Kate Summers, Transgrid	N/A
3.	Other types of large loads to be considered for PSMG	AEMO, AusNet, Powerlink, Transgrid	N/A
4.	Suitability of IEEE or Composite and DER load model for data centre loads in RMS and EMT simulation	AEMO, AusNet, Citipower & Powercor, Transgrid	TasNetworks, Transgrid, CEC
5.	Inclusion of additional protection and control systems to be required in the models	AEMO, AusNet, Powerlink, Transgrid	N/A
6.	Levels of details required for inverter-based load (**IBL**) in RMS and EMT domains	AEMO, AusNet, Citipower & Powercor, Powerlink, Transgrid	Powerlink, TasNetworks
7.	Black start simulation model requirements for large power system loads	AEMO, AusNet, Citipower & Powercor, CS Energy, Transgrid	N/A
8.	Level of R2 validation appropriate for different types of load models	AEMO, AusNet, Citipower & Powercor, Powerlink, Transgrid	Powerlink
9.	Requirement for model provision in Section 7.4 of PSMG for IBL	AEMO, AusNet, Citipower & Powercor, Powerlink	N/A
10.	Modelling component requirements for IBL in Appendix C of PSMG	AEMO, AusNet, Citipower & Powercor, Powerlink, Transgrid	Powerlink
11.	Requirements for Dynamic Linked Libraries (**DLL**) and DLL interfaces	AEMO, AusNet, CitiPower & Powercor, Goldwind, OPAL-RT, PGSTech, Tesla, RTE International, TransGrid, Siemens, Powerlink, GE	Tesla, CEC
12.	Provision of PSCAD™ model source code	AusNet, Powerlink, TransGrid	N/A
13.	Inclusion of remedial action schemes	AusNet, CS Energy	N/A
14.	Inclusion of Integrated Energy Storage Systems (**IESS**)	AusNet	N/A
15.	Requirements for legacy plant modelling	CEC	CEC
16.	Small signal modelling requirements	AusNet, Goldwind, Kate Summers, TransGrid, Powerlink	Powerlink, Tesla, CEC, Transgrid
17.	Other matters	N/A	ElectraNet, Ergon/Energex, Tesla, Transgrid, Powerlink

Each of the material issues raised in Stage 1 and Stage 2 submissions and listed in Table 3 is discussed in Section 4.

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4. Discussion of material issues

4.1. Threshold for requiring detailed model for large traditional load

4.1.1. Issue summary and submissions

As noted in the consultation paper, power system loads have historically been modelled using voltage and frequency dependent IEEE ZIP load models, which were considered sufficiently detailed for large scale transient stability studies. More detailed load models have been utilised when the need arises, for example, for load harmonic analysis. AEMO recently developed and benchmarked Composite load and distributed energy resources (DER) models to capture the transient behaviour of business and residential loads, including DER such as rooftop photovoltaics (PV), during dynamic studies, due to the rapid uptake of rooftop PV across NEM jurisdictions.

The requirement for load model details has evolved on an "as-needed" basis, which is also reflected in NER 5.2.4(c), that AEMO and the relevant NSP may require Customers to provide detailed load model information under certain circumstances, for example when the Customer's plant is likely to adversely affect the use of a network by a network user (as per NER 5.2.4(c)(2)).

However, as system strength and inertia in the power system decline, Australian power systems are facing greater challenges with voltage and frequency control, and such challenges may result in undesirable operation of large traditional loads, especially those equipped with load-tripping schemes.

The first consultation question in the PSMG consultation paper was whether there is a need to establish a threshold for future large traditional load connections, where AEMO and the relevant NSPs will require more detailed load models for load connection above this threshold, for purposes such as transient stability studies.

4.1.2. AEMO response

In the draft report, AEMO provided the following recommendation:

"The benefit of introducing a fixed threshold load requirement, such as a megawatt-based threshold, is that it provides certainty to the proponent, but may introduce additional unnecessary costs for certain large loads which present little risk to power system operations. AEMO recommends adopting a risk based approach when assessing a load connection, whereby loads with less risk are only required to provide a simplified load model, such as the IEEE ZIP or Composite load model (if a load dynamic model is deemed necessary as a part of the load connection application by NSPs and AEMO). A more detailed load model can be requested when AEMO and NSPs determine that the load connection may present significant risks to power system operation, for example, in accordance with the System Strength Impact Assessment Guidelines, which can only be assessed using detailed models."

No submission was received from the Stage 2 consultation on this matter.

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4.2. Suitability of IEEE or Composite load and DER model for large traditional power system loads

4.2.1. Issue summary

In the consultation paper, AEMO sought industry feedback on whether the IEEE ZIP load model and the Composite load and DER model are suitable for the modelling of large traditional power system loads, considering the changes currently occurring in Australian power systems.

4.2.2. AEMO response

In the draft report, AEMO provided the following recommendation:

"AEMO recommends that when AEMO and NSPs determine a load dynamic model is required, a traditional large single load should provide, as a minimum, an IEEE ZIP model or Composite load model, whereby the IEEE ZIP load model may be used for a single large traditional load with a single equipment or a processing train of a dominating size, and the Composite load model may be used for loads which are represented with aggregation of smaller components of similar sizes. AEMO and NSPs may request a more detailed load model should they jointly determine that a certain load connection could potentially cause significant impact on other network users and power system security."

No submission was received from the Stage 2 consultation on this matter.

4.3. Types of IBL to be considered in the PSMG

4.3.1. Issue summary

In the consultation paper, AEMO proposed to include a detailed modelling requirement for two types of IBLs that are currently emerging: hydrogen electrolysers and data centres. AEMO sought industry feedback on other types of loads which should be considered in the PSMG.

4.3.2. AEMO response

In the draft report, AEMO provided the following recommendation:

"AEMO recommends in this review of the PSMG focusing on the modelling requirements for large single loads, including traditional large loads, and IBLs such as hydrogen electrolysers and data centres. This will address the imminent concern regarding the potential impact on power system operation and security as these large single loads currently seek connection to the NEM."

No submission was received from the Stage 2 consultation on this matter.

4.4. Suitability of IEEE or Composite load model to represent data centres in RMS and EMT simulation

4.4.1. Issue summary and submissions[2]

In the consultation paper, AEMO sought industry feedback on whether IEEE ZIP or Composite load models are sufficient to model IBL loads, such as data centres, in RMS and EMT simulation.

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[2] Text in this font is quoted directly from submissions.

In the draft report, AEMO proposed a risk-based assessment for the NSP and AEMO to determine the most appropriate modelling option for IBLs, which could be in the form of a composite load model, or a site-specific detailed model.

AEMO received three submissions on this topic from the Stage 2 consultation.

TasNetworks

> TasNetworks supports AEMO's recommendation to consider the risks to power system operation to determine whether a detailed site-specific IBL model or a generic IBL model is appropriate. TasNetworks suggests that the wording of the final guideline explain this risk based decision and provide guidance on its application.

Transgrid

> Regarding the first paragraph of Section 3.2 (of the PSMG), Transgrid recommends the following clarification:
>
> - Is this intended to imply that the proponent has a choice between the first and the second option or, the approach will be determined by NSP/AEMO? For example, if the load model cannot be modelled as IEEE ZIP or composite load model, can the proponent still provide load model using these standard models with some inaccuracies?
> - Is the composite load model referring AEMO library load model meaning that AEMO will make these models publicly available through data request?

CEC

> We strongly recommend AEMO consult with large load customers and OEMs to understand:
>
> - What models are currently available for loads and how they do / do not meet all of the requirements of the PSMG
> - What is the cost and time required to develop models that do not currently meet all of the requirements of the PSMG

4.4.2. AEMO's assessment

As highlighted in the consultation paper, the Australian energy system is going through a once-in-a-lifetime transition, and this transition is taking place not only in electricity generation, but also in consumption, with the forecast connection of inverter-based load (**IBL**) facilities on a scale of several hundred megawatts. On the generation side, conventional fossil-fuel based synchronous generators are being displaced by inverter-based resources (**IBR**), which will significantly alter power system dynamic behaviours that are largely based on the synchronous machine physics and their controllers. On the consumer side, IBL facilities can be susceptible to converter control instability, particularly during the transition with a paradigm shift of the power system stability.

In the draft report[3] and the draft PSMG[4], AEMO proposed a set of load dynamic model requirements to be appended to the existing PSMG. In developing the proposed load dynamic model requirements, AEMO engaged with IBL OEMs through the Power System Model Reference Group (**PSMRG**) to gain an understanding of the composition of IBL devices. AEMO also considered the variety of load facilities and proposed modelling approaches for different load facilities. These approaches were identified based on a series of risk-related factors, to be considered by the NSP and AEMO, when determining the most appropriate modelling approach for each different load connection. These modelling approaches include:

- IEEE ZIP load.

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[3] Available online at: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/psmg-review-consultation/second-stage/psmg_draft_report_2023.pdf?la=en

[4] Available online at: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/psmg-review-consultation/second-stage/power_systems_model_guidelines_2023_draft_clean.pdf?la=en

- Composite load modelling.
- Detailed load model, similar to what was required for IBR connections.

It should be noted the composite load modelling proposed in the draft PSMG does not refer to the Composite load models (**CMLD models**) provided by PSS®E or developed by WECC[5]. It rather refers to a composite load model which consists of different load components based on different load characteristics, instead of a single aggregated load element such as the IEEE ZIP load. The CMLD models provided by PSS®E can be used as templates of the composite load model, and the proponent can also develop the composite load models in other forms, provided it is agreed with the NSP and AEMO, and the composite load model meets the relevant requirement under Section 3.2 and Section 4.7 of the PSMG.

The proposed load dynamic modelling requirement would also serve as an enabler for:

1. the successful execution of System Strength Impact Assessment Guidelines (**SSIAG**)[6] for the connection of large IBL; and
2. the assessment of the intended load performance standards to be established by the NER S5.3 draft recommendation[7].

The susceptibility of the IBL to converter control instability can thereby be properly assessed and addressed during the lifetime of the IBL.

Most submissions received by AEMO from both stages of the consultation supported the proposed load modelling requirement, however some requested further information on the application of the risk-based assessment to be conducted by the NSP and AEMO when determining the most appropriate load dynamic modelling approach for different load connections.

AEMO acknowledges the difficulty of predicting all potential challenges that NSPs and AEMO would face during future IBL connection and operation. AEMO therefore proposes the following general principles on the risk factors to be jointly considered by NSPs and AEMO when determining the suitable load models:

- The susceptibility/sensitivity of the load components to controller instability and changes in power system operating conditions. A more detailed load dynamic model should be required for a more susceptible/sensitive load connection. The NSP and AEMO need to jointly assess the susceptibility/sensitivity of the load components based on information provided by the proponent, such as device specifications.
- The intended operation philosophy of the load: for example, whether it is capable/intends to operate with sustained bi-directional power or provide any dynamic demand response or other similar services.
- Size of susceptible/sensitive loads; for example, a larger IBL may present a higher risk profile.

[5] An example of this can be found online at: https://www.wecc.org/Reliability/WECC%20Approved%20CMPLDW%20Model%20with%20DG%20Spec.pdf

[6] Available online at: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/ssrmiag/final-report/system-strength-impact-assessment-guideline_v2.pdf?la=en

[7] Available online at: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/aemo-review-of-technical-requirements-for-connection-ner-clause-526a/2023-04-04_technical-requirements-review_draft-report_s53-addendum_final.pdf?la=en

- Electrical proximity to other Network Users and generators: for example, assuming all else being equal, a single, radially connected load may present a lower risk profile compared to another load connected in the vicinity of other generators and Network Users, particularly other IBR and IBLs.
- Other factors that NSPs and AEMO would reasonably consider for the execution of the System Strength Impact Assessment, and the assessment of the potential load performance standards.

When determining the most appropriate type of load model to be used for each load connection, the NSP and AEMO should jointly consider the above factors altogether without treating any specific factor in isolation. The susceptibility/sensitivity of the load should be the most critical factor, but the NSP and AEMO can permit the use of a less detailed load model, if the NSP and AEMO determine a susceptible/sensitive load would have no material impact on power system security. While making the determination, the NSP and AEMO can also consider other factors listed under Section 8.3 of the PSMG.

AEMO is aware that load dynamic models have not been historically required from connecting proponents, and understands that there are many different types of load facilities which would have different kinds of dynamic behaviour. Therefore, the proposed load dynamic model requirements should be applied with sufficient levels of flexibility to cater for different types of load connections. After the NSP and AEMO determine the most appropriate type of load model, the proponent may apply to provide modelling information alternative to the NSP and AEMO's determination, following the procedure in Section 8 of the PSMG.

4.4.3. AEMO's response

AEMO has provided the following responses to Stage 2 submissions on this matter.

Raised by	Issues raised	AEMO response
TasNetworks	Suggest the wording of the final guideline explain this risk based decision and provide guidance on its application.	As described in Section 4.4.2 of this report. Section 3.2 of the PSMG has been updated with the suggested change.
Transgrid	Is this intended to imply that the proponent has a choice between the first and the second option or, the approach will be determined by NSP/AEMO? For example, if the load model cannot be modelled as IEEE ZIP or composite load model, can the proponent still provide load model using these standard models with some inaccuracies?	It is for AEMO and the NSP to jointly determine the most appropriate type of load model to be used by the proponent. After the NSP and AEMO's joint determination, the proponent may apply to provide alternative modelling information following the procedure set as per Section 8 of the PSMG Section 3.2 of the PSMG has been updated for clarification.
	Is the composite load model referring AEMO library load model meaning that AEMO will make these models publicly available through data request?	The composite load model does not refer to any specific type of load model. Rather it refers to a composite way of modelling the load instead of using a single lumped element. Section 3.2 and Section 4.7 of the PSMG have been updated for clarification.
CEC	AEMO to consider what models are currently available for loads and how they do/do not meet all of the requirements of the PSMG.	These factors have been considered as part of Section 8.3, when the proponent applies to provide alternative model or information, in line with NER S5.5.7 (c) (1).
	AEMO to consider what is the cost and time required to develop models that do not currently meet all of the requirements of the PSMG.	

4.5. Required inclusion of additional protection and control systems in IBL models

4.5.1. Issue summary

In the consultation paper, AEMO sought industry feedback on what protection and control systems should be included as part of the modelling requirement for IBL.

4.5.2. AEMO response

In the draft report, AEMO has provided the following recommendation:

"AEMO recommends that protection systems and control systems which regulate the fault ride-through capability and post-contingency recovery behaviour for large IBL need to be modelled, especially for large IBL where compliance to relevant fault ride through performance standards is required. AEMO further recommends that only voltage-based and frequency-based protection be included in load models. Other more complex protection implementation can be required if:

- such protection element models are inherent components of the OEM models, or
- such protection elements will affect the load fault ride through behaviour, where loads are required to demonstrate compliance to the performance standards proposed in the S5.3 draft recommendation[8].
- the input to such protection elements can be acquired from simulation models which are currently used by AEMO and NSPs.

AEMO does not recommend including slower control systems, such as on-load tap changers (**OLTC**s). The modelling of OLTCs is already covered in the Voltage Control Strategy (**VCS**) and Releasable User Guides (**RUG**s) as per the current connection application requirement, and hence will not be further discussed in the 'protection' category here."

No submission was received from the Stage 2 consultation on this matter.

4.6. Level of detail required for IBL models in RMS and EMT simulation

4.6.1. Issue summary and submissions

In the consultation paper, AEMO sought industry feedback on the appropriate levels of detail required for IBL models for RMS and EMT simulation.

In the draft report, AEMO proposed that IBL which would be susceptible to power system disturbances and rapid change of power system operating conditions to be modelled with sufficient details, similar to what are required for the IBR models.

Two submissions were received on this issue from the Stage 2 consultation.

Powerlink

[8] Available online at: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/aemo-review-of-technical-requirements-for-connection-ner-clause-526a/2023-04-04_technical-requirements-review_draft-report_s53-addendum_final.pdf?la=en

It is likely that a network user or load facility with inverter based load could have a non-inverter load component as well. Under these scenarios, the hybrid modelling approach (i.e. combination of both composite and detailed model types) would be more appropriate when developing a model for the whole facility. Therefore, the model for a load could be of either category defined under section 3.2 of the draft PSMG or a combination of both categories.

Furthermore, both RMS and EMT models are required, irrespective of the load model category (IEEE/composite or detailed). Powerlink suggests that this requirement clearly be stated in section 3.2.

Powerlink supports the requirement for a RUG for both RMS and EMT load models.

TasNetworks

Section 4.3.8 of the draft Guideline includes a requirement to provide detailed site-specific electromagnetic transient (EMT) models for IBL (such as the power electronic interface and control systems). To enable the user of a site-specific IBL model to interpret model behaviour and to ensure that simulations accurately reflect the operation of real plant it is important that access to the internal quantities of these devices, not just the bi-directional devices, is provided. Thus we recommend that footnote L is reviewed to ensure that internal quantities are provided for all site-specific models of IBL, not just generating units or bidirectional units.

4.6.2. AEMO's assessment

A particular challenge in developing load dynamic model requirements is how to effectively cover a wide risk spectrum of different load facilities with proposed model requirements. AEMO has sought to achieve this by providing different modelling options for loads with different risk profiles. At the low end of the risk spectrum are loads such as traditional industrial loads which are mostly passive, for which a simple IEEE ZIP load can be used to represent the load in power system studies conducted by NSPs and AEMO. At the other end of the risk spectrum are large IBLs that are prone to interactions and susceptible to power system disturbances. For these types of loads, detailed RMS and EMT models will be required for representation in simulation. In the middle of the risk spectrum is the composite load model. As discussed in Section 4.2 of this report, the composite load model is not a specific load model, but a composite framework for developing the load model.

For example, one component in a large load facility may be classified as a large IBL under the SSIAG, while the rest of the facility consists of generally passive loads, for which historically RMS models have been sufficient. For this scenario, AEMO is of the view that a hybrid modelling approach is suitable, in which detailed models are provided for the IBL components of the load facility, while the rest of the load facility is represented using simpler load models, such as the IEEE ZIP model, or a composite load model with reasonable aggregation. The NSP may require the proponent to provide a complete EMT model of the whole load facility, containing both the IBL and non-IBL components, however the NSP should explain to the proponent why an EMT model for the entire facility is necessary for power system studies. Any EMT model requirement for non-IBL loads, or non-IBL components, should not result in the proponent needing to acquire more information than would be necessary to develop RMS models of the non-IBL loads or components. The proponent may also seek to provide alternative models and information where appropriate, following the procedure set in Section 8.3 and 8.4 of the PSMG.

4.6.3. AEMO's response

AEMO has provided the following responses to Stage 2 submissions on this matter.

Raised by	Issues raised	AEMO response
Powerlink	It is likely that a network user or load facility with inverter based load could have a non-inverter load component as well. Under these scenarios, the hybrid modelling approach (i.e. combination of both composite and detailed model types) would be more appropriate when developing a model for the whole facility. Therefore, the model for a load	AEMO is supportive of this suggestion. Section 3.2 of the PSMG has been updated to include the hybrid modelling option for Network Users.

Raised by	Issues raised	AEMO response
	could be of either category defined under Section 3.2 of the draft PSMG or a combination of both categories.	
	Furthermore, both RMS and EMT models are required, irrespective of the load model category (IEEE/composite or detailed). Powerlink suggests that this requirement clearly be stated in section 3.2.	Detailed load models will be required only for IBL loads, or IBL components of a load facility. An NSP may require the proponent to provide the EMT model for the whole facility, regardless the load composition. Such requirement should not result in the proponent needing to source more information than what is required to develop the RMS model of the non-IBL load, or non-IBL components of the load. Section 3.2 of the PSMG has been updated for clarification.
	Powerlink supports the requirement for a RUG for both RMS and EMT load models.	AEMO is supportive of this suggestion.
TasNetworks	Section 4.3.8 of the draft Guideline includes a requirement to provide detailed site-specific electromagnetic transient (EMT) models for IBL (such as the power electronic interface and control systems). To enable the user of a site-specific IBL model to interpret model behaviour and to ensure that simulations accurately reflect the operation of real plant it is important that access to the internal quantities of these devices, not just the bi-directional devices, is provided. Thus we recommend that footnote L is reviewed to ensure that internal quantities are provided for all site-specific models of IBL, not just generating units or bidirectional units.	Footnote L is removed in the final PSMG.

4.7. Black start model requirement for large power system loads

4.7.1. Issue summary

In the consultation paper, AEMO sought submissions on whether there were any other drafting or technical considerations that should be considered for inclusion or amendment in the PSMG.

4.7.2. AEMO response

In the draft report, AEMO has provided the following recommendation:

“AEMO recommends that black start model requirements should be tied to the contracting of black start services and to the prioritisation of essential service loads for consideration as part of black start schemes.”

No submission was received from the Stage 2 consultation on this matter.

4.8. Appropriate level of R2 validation for different types of load models

4.8.1. Issue summary and submissions

In the consultation paper, AEMO sought submissions regarding which level of the R2 validation process is appropriate for each load model type.

In the draft report, AEMO proposed IBL models should be subject to the same R2 validation process which is currently required for IBR models. The level of detail required for non-IBL model validation depends on the commissioning process for non-IBL facilities.

One submission was received on this issue from the Stage 2 consultation.

Powerlink

> Powerlink suggests that demonstration of model accuracy for IBL models can occur at a different location than at the connection point when a load model comprises with both detailed IBL model and composite load model (i.e. hybrid model). Obtaining accuracy of a composite load model might not be as practical as for the detailed model. This can then impact the overall accuracy of the load model. Therefore the model accuracy for IBL model can be demonstrated at a different location such as medium voltage bus where IBL model aggregation is considered.
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> ......
>
> Powerlink suggests that detailed IBL models should also be validated by comparing model response with plant response data collected during commissioning and that should be considered as R2 model validation.
>
> Also for non-IBL loads, sufficient data should be captured during commissioning and testing of the plants for model validation. The parameters of composite load model should be adjusted accordingly to represent a reasonable plant response.

4.8.2. AEMO's assessment

In the draft report, AEMO considered the definition of the load R2 commissioning process beyond the scope of this PSMG review. AEMO considers that it is reasonable to assess the need for R2 validation for different load facilities on a case-by-case basis, based on the type of load and its associated risk profile. In principle, AEMO agrees load models should be validated to confirm they are reflective of the actual load transient behaviour. However, considering the wide variety of potential load types and configuration, and the absence of a NEM-wide load commissioning protocol, it is challenging to prescribe a generalised procedure for the model validation process. AEMO understands a few transmission network service providers (**TNSPs**) do ask load customers to conduct load model validation as a part of their connection process, therefore the NSP should be consulted for the model validation procedure, on a project-specific basis. It should be noted that these considerations should not be taken to preclude different practices that may be prescribed in any future load R2 commissioning guideline.

For an IBL, or an IBL component of a load facility, where a detailed model is required by the NSP or AEMO, and the load is required to go through a model validation process, the proponent should conduct validation in a similar fashion to the detailed model validation process for generator models. For a generator R2 validation process, the site-measured generator response, including the connection point voltage, active and reactive power, are overlaid with the simulated response from the model, and AEMO considers a similar approach should be adopted for the load R2 validation process. As there is currently no NEM-wide load R2 commissioning protocol, It is difficult to prescribe what types of measurement, other than the voltage and power, are required from the load R2 commissioning process. The NSP should be consulted in advance for the required measurement quantities, which may depend on the configuration and layout of the load facilities.

The response overlay should be conducted at the connection point of the IBL, or the connection point of the IBL component of a larger load facility. The NSP and the proponent may agree to conduct the response overlay at other locations within the load facility, with appropriate justification for the need of the overlay at such locations.

If a NSP requires model validation for a non-IBL load, or an IBL load represented by a composite load model, the proponent needs to seek the NSP's advice on what tests are to be conducted to obtain the

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field measurement, and what load model parameters should be validated using the field measurement in advance.

4.8.3. AEMO's response

AEMO has provided the following responses to Stage 2 submissions on this matter.

Raised by	Issues raised	AEMO response
Powerlink	Powerlink suggests that demonstration of model accuracy for IBL models can occur at a different location than at the connection point when a load model comprises with both detailed IBL model and composite load model (i.e. hybrid model). Obtaining accuracy of a composite load model might not be as practical as for the detailed model. This can then impact the overall accuracy of the load model. Therefore the model accuracy for IBL model can be demonstrated at a different location such as medium voltage bus where IBL model aggregation is considered.	AEMO supports R2 validation to be conducted at the connection point of the IBL, or the connection point of an IBL component of a larger load facility, if the load is required to go through an R2 commissioning process. Model overlay may be conducted at other locations of the load facility, subject to an agreement between the NSP and the proponent. Section 6.1 of the PSMG has been updated for clarification.
	Powerlink suggests that detailed IBL models should also be validated by comparing model response with plant response data collected during commissioning and that should be considered as R2 model validation.	AEMO supports this view, if the IBL load is required to go through an R2 commissioning process. Section 6.3.3 of the PSMG has been updated for clarification.
	Also for non-IBL loads, sufficient data should be captured during commissioning and testing of the plants for model validation. The parameters of composite load model should be adjusted accordingly to represent a reasonable plant response..	AEMO considers the scope of R2 validation for non-IBL loads, or IBL loads presented by composite load models are limited to the scope of the R2 commissioning process, as advised by the NSP. Section 6.3.3 of the PSMG has been updated for clarification.

4.9. Requirement for model provision in Section 7.4 of PSMG

4.9.1. Issue summary

In the consultation paper, AEMO sought submissions on the procedure for model and information provision to third parties.

4.9.2. AEMO response

In the draft report, AEMO has provided the following recommendation:

"AEMO recommends that the existing requirement and conditions for generator model provision under Section 7.4 of the current PSMG (i.e. 2018 document[9]) be applicable to load model data, including that of IBLs."

No submission was received from the Stage 2 consultation on this matter.

[9] https://aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Power_Systems_Model_Guidelines_PUBLISHED.pdf

4.10. Component modelling requirements for IBL in Appendix C of PSMG

4.10.1. Issue summary and submissions

In the consultation paper, AEMO sought submissions on what components should be included in IBL models, which would have material impact on power system simulation.

In the draft report and the draft PSMG, AEMO proposed the addition of a new Appendix C.5 to the PSMG for the component modelling requirements for IBL.

One submission was received on this issue from the Stage 2 consultation.

Powerlink

> Powerlink considers that for large non-IBL type loads, it is also very important to capture and model control and protection functions (e.g. voltage and frequency protection) that can affect the continued operation of a load. Therefore, load loss during a transient disturbance and its recovery from a fault can be accurately represented for non-IBL load model.
>
> ......
>
> Additional protection functions which might be applicable for loads include:
>
> - Loss of Main detection (e.g. for data centres) – Control and protection systems which are sensitive to grid disturbance should be appropriately modelled in both RMS and EMT domain models
> - Under frequency load shedding
> - Under voltage load shedding

4.10.2. AEMO's assessment

Correctly capturing the transient load loss of significant sizes, for example due to protection system action following a contingency, could assist the NSP with the development of the efficient power system limits. AEMO supports the view that protection systems affecting the ride-through capability of loads need to be modelled, which is also reflected in AEMO's recent draft recommendation to establish ride-through capability performance standards for single large load facilities in NER Schedule 5.3, as part of its current major review of NER technical requirements[10]. .

Again, the diversity of load types and configurations presents a challenge in determining the scope of such requirements for load protection system models. In the draft report, AEMO considered it impractical to mandate a blanket requirement to include all protection relays in the load models, noting also that most load protection devices rely on monitored quantities at the load terminal rather than at the load facility connection point. Similar to the determination of the most suitable load model types, AEMO considers a risk-based assessment by the NSP is appropriate for the purpose of determining suitable protection system model requirements on a project-specific basis, with the following general guidelines on how the risk-based assessment should be applied in practice:

- If the NSP identifies a risk of common mode load tripping by the protection systems in response to one or a few contingencies, where the load trip is of a significant size or would have a significant impact to network limits as determined by the NSP, then it is reasonable to properly model the associated protection systems in the load model, to assess the risk of such load loss to network limits.

[10] Available online at: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/aemo-review-of-technical-requirements-for-connection-ner-clause-526a/2023-04-04_technical-requirements-review_draft-report_s53-addendum_final.pdf?la=en

- The identification of a common risk of load tripping is to be conducted by the relevant NSP, for example, based on the information provided by the proponent during the performance standards negotiation, review of the protection design reports, or other relevant information which the NSP considers is critical to determine the appropriate level of protection system modelling, such as the intended operational arrangement of the load facility during power system disturbances.
- The relevant NSP should provide clear guidance to assist the proponent with providing a reasonable level of detail for the protection systems models, including the voltage levels which protection models are required, and an associated justification of why such protection system models are required.
- The input to the required protection system models should be accessible from the simulation models which are currently used by AEMO and NSPs.
- The proponent may apply to provide alternative models and information, following the procedure set in the Section 8.3 and 8.4 of the PSMG.

4.10.3. AEMO's response

AEMO has provided the following responses to Stage 2 submissions on this matter.

Raised by	Issues raised	AEMO response
Powerlink	Powerlink considers that for large non-IBL type loads, it is also very important to capture and model control and protection functions (e.g. voltage and frequency protection) that can affect the continued operation of a load. Therefore, load loss during a transient disturbance and its recovery from a fault can be accurately represented for non-IBL load model. Additional protection functions which might be applicable for loads include: • Loss of Main detection (e.g. for data centres) – Control and protection systems which are sensitive to grid disturbance should be appropriately modelled in both RMS and EMT domain models • Under frequency load shedding • Under voltage load shedding	AEMO supports the view that the protection systems which could result in large amount of load loss due to power system disturbances should be accounted for while developing power system limits. The proponent needs to seek the NSP's advice on the required level of details for the protection system models for load connections. The NSP must provide clear guidance to assist the proponent with providing a reasonable level of detail for the protection systems models, including at the voltage levels where protection models are required, and associated justification on why such protection system models are required. The proponent can apply to provide alternative information and protection system models, following the procedure set in Section 8.3 and 8.4 of the PSMG. Appendix C1.1 and C5 of the PSMG have been updated for clarification.

4.11. Requirements for Dynamic Linked Libraries (DLL) and DLL interfaces

4.11.1. Issue summary and submissions

During the first stage of the consultation, many submissions raised concerns with the proposed method of preventing EMT model obsolescence and several submissions mentioned work already being carried out by Joint Working Group (JWG) B4.82/IEEE to address this issue.

Two submissions were received from the Stage 2 consultation.

Tesla

> Reference to the B4.82/IEEE seems to be new to the Draft report. We would request that AEMO publish more information publicly as to what the specific requests coming from that group are and how the proposed "memory copying" approach works. Currently, the B4.82 standard is limited to the CIGRE B4 study committee, posing challenges for OEMs in obtaining access to the standard. There is no public information on how this can be implemented, and it appears to be critical to successfully implementing the snapshot feature.
>
> It is imperative for AEMO to publish a working example code of a simple inverter with the B4.82/IEEE wrapper and snapshot feature.
>
> Tesla is concerned that the proposed approach will have an adverse impact on model speed and result in increased modelling delays. A significant amount of renewable energy and storage capacity will be connected in the next decade, and we are concerned that slower model speeds will impact on the rate of connection that needs to happen.

CEC

> We also note references to CIGRE B4.82 and meeting requirements outlined within this document. Not all parties are members of CIGRE and have access to CIGRE publications. Hence any requirements should be contained within the PSMG rather than referring to other documents that are not publicly available.

4.11.2. AEMO's assessment

As mentioned in the draft report and the draft PSMG, the JWG B4.82/IEEE interface is a preferred method for preventing EMT model obsolescence, not a requirement. Many OEMs have already started developing models using this interface, and AEMO strongly encourages OEMs to investigate utilising the interface once the final JWG B4.82/IEEE specification and documents have been published.

However, if OEMs do not wish to purchase or acquire the JWG B4.82/IEEE specification once published, they may independently develop their own EMT model interfaces. If this is the case, however, the following requirements do apply:

- Any external *compiled* code must be provided in the format of a DLL in both 32-bit and 64-bit versions.
- The model *including the DLL interface* must not contain or utilise any static library files (.obj, .lib).
- The interface must be in the form of source code (.f, .f90 etc for PSCAD™).
- The interface must use explicit linking.
- The interface (and DLL) must be compatible with the EMT tool's snapshot function.

Regarding "memory copying", AEMO's requirements are agnostic to how values are transferred between the DLL and simulation executable on each timestep, and how the snapshot feature is implemented. It is up to the OEM to utilise a JWG B4.82/IEEE compatible interface or implement the interface themselves. AEMO believes that proper implementation of the DLL and interface will have minimal impact to simulation speed. For example, the JWG B4.82/IEEE interface allocates memory simulation side and passes it as a pointer reference to the DLL, allowing a very large number of variables to be shared without any copies or overhead.

Regarding utilising external files to facilitate the snapshot function, while this is possible, care needs to be taken to ensure the "multiple/parallel run" functionality works correctly. It is recommended to instead transfer state variables to the simulation storage arrays; as mentioned, this can be achieved efficiently for large numbers of variables using memory pointers.

For examples of how the interface can be implemented, Electranix has released the free tool EDIT which will generate a JWG B4.82/IEEE compatible PSCAD interface[11].

4.11.3. AEMO's response

AEMO would like to emphasise that the JWG B4.82/IEEE interface is not a requirement, and OEMs may independently develop their own EMT model interfaces that meet the minimum requirements set out in the previous paragraph. AEMO has updated the wording in the PSMG to clarify that the use of the JWG B4.82/IEEE interface is encouraged but that its use is not a requirement.

Raised by	Issues raised	AEMO response
Tesla	Reference to the B4.82/IEEE seems to be new to the Draft report. We would request that AEMO publish more information publicly as to what the specific requests coming from that group are and how the proposed "memory copying" approach works. Currently, the B4.82 standard is limited to the CIGRE B4 study committee, posing challenges for OEMs in obtaining access to the standard. There is no public information on how this can be implemented, and it appears to be critical to successfully implementing the snapshot feature.	The JWG B4.82/IEEE interface is not a requirement; however, it is strongly encouraged. OEMs may implement their own interface subject to the requirements set out above. AEMO's requirements are agnostic about memory management between the DLL and simulation. It is up to the model developer to utilise or implement an interface that efficiently manages memory without impacting simulation speed.
	It is imperative for AEMO to publish a working example code of a simple inverter with the B4.82/IEEE wrapper and snapshot feature.	The free EDIT tool can provide examples of implementing a JWG B4.82/IEEE interface.
	Tesla is concerned that the proposed approach will have an adverse impact on model speed and result in increased modelling delays. A significant amount of renewable energy and storage capacity will be connected in the next decade, and we are concerned that slower model speeds will impact on the rate of connection that needs to happen.	AEMO believes if the DLL and interface is written correctly there will be no or minimal speed impact, for example, by using memory pointers. The B4.82/IEEE interface utilises this technique and is efficient for large numbers of variables.
CEC	We also note references to CIGRE B4.82 and meeting requirements outlined within this document. Not all parties are members of CIGRE and have access to CIGRE publications. Hence any requirements should be contained within the PSMG rather than referring to other documents that are not publicly available.	The JWG B4.82/IEEE interface is not a requirement, but it is strongly encouraged that OEMs explore the use of the JWG B4.82/IEEE interface.

4.12. Provision of model source code

In the draft report, AEMO has provided the following recommendation:

"AEMO recommends that no change be made regarding provision of model source code in the PSMG.

For PSS®E models, it is recommended that the wording in section 4.3.11 "compatible with PSS®E version 32 or 34" be changed to "compatible with PSS®E version 34 or greater"."

No submission was received from the Stage 2 consultation on this matter.

[11] More information about the EDIT tool can be found here: http://www.electranix.com/software/about-edllimport-tool/

4.13. Inclusion of Remedial Action Schemes

4.13.1. Issue summary

On 18 July 2022, AEMO initiated a consultation on the Remedial Action Scheme (**RAS**) Guidelines. The draft RAS Guidelines outline the criteria for provision of RAS modelling information and the level of detail to be provided. There is currently no direct reference to RAS modelling in the PSMG.

4.13.2. AEMO response

In the draft report, AEMO has provided the following recommendation:

"AEMO proposes to add a section for Remedial Action Schemes under section 4 of the PSMG to include the following requirements for RAS models:

- Communication, measurement, filtering and processing delays (for example, intentional time delays like timer settings, or inherent delays like relay operating times).
- Calculation algorithms and logic/tripping sequences.
- Output actions including associated delays.
- Parameters, signals and status to be monitored.

A reference has also been added to the RAS Guidelines."

No submission was received from the Stage 2 consultation on this matter.

4.14. Integrating Energy Storage Systems rule change

4.14.1. Issue summary

On 2 December 2021, the Australian Energy Market Commission (**AEMC**) made the Final Rule on Integrating Energy Storage Systems into the NEM (**IESS Rule Change**). The majority of these rules will take effect on 3 June 2024.

The IESS Rule Change makes significant changes toward a technology agnostic two-way market model for the NEM. These changes help to prepare the NEM for the future steps being envisioned through the Energy Security Board's (**ESB**'s) Post-2025 Market Design initiative.

The updates to the NER made in the IESS Rule Change require updates to the PSMG to include modelling requirements for IRPs."

4.14.2. AEMO response

In the draft report, AEMO has provided the following recommendation:

"AEMO has proposed updates to the PSMG as part of this consultation process to reflect the IESS Rule Change.

A new sub-section has been added under Section 2 for IRPs, detailing the new rules requirements outlined in new NER clauses 5.2.5A(d), 5.2.5A(e), and 5.3.9(b)(2A) which will be added as part of the IESS Rule Change.

The references in the PSMG to generating plant to be changed to:

- generating system and/or integrated resource system (as appropriate);

- generating unit, bidirectional unit or production unit (as appropriate).

The Releasable User Guide Template has been updated to use the terminology which is consistent with the IESS Rule Change.

The Data Sheets have been updated to use the terminology which is consistent with the IESS Rule Change."

No submission was received from the Stage 2 consultation on this matter.

4.15. Requirements for legacy plant modelling

4.15.1. Issue summary and submissions

Much of the plant operating in the NEM was connected at a time when detailed models were either not required at all, or were required only for larger plant. This plant generally has a 'legacy' representation relying on generic model components built into simulation software, which provide only a crude approximation of the true plant operation. These models are generally not consistent with the PSMG requirements, which were developed subsequently.

An augmentation to existing plant (for example, to add parallel energy storage to a generating system) will generally require the provision of new models meeting the current PSMG for the augmentation, and may also necessitate updated models for the balance of the plant.

In the draft report, AEMO proposed the modelling requirement for legacy plants to be determined on a project-specific basis, and enabled the use of generic models as one pathway for the provision of legacy plant models.

In the Stage 2 consultation, one submission raised the subject of legacy model requirements and potential burden on participants.

Clean Energy Council

> Although the approach to using generic models is welcome, care should be taken in reliance on this approach as it may provide a false sense of security. Generic models can be used in the absence of an existing model or OEM to support. However, where an OEM can provide an initial model that does not meet all of the requirements of the PSMG, trying to substitute this for a generic model may actually result in more work than trying to resolve issues with the OEM model. It is noted that the members we spoke to whose project did not progress were utilising OEM provided models.
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> ......
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> Timeframes for resolving model issues generally – this is mentioned as being beyond the scope of this review in the draft report. However, the need for our members to try and resolve issues upfront has been one of the single biggest barriers for retrofitting a BESS behind an existing connection point.
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> ......
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> Following the existing process under S8.3 and S8.4 of the PSMG as per the draft report – unfortunately, the existing approach is not currently working and no change has been proposed. We note AEMO's comments in the draft report that this is to be dealt with outside of the PSMG, however we believe that items 1 (Issues with EMT models), 2 (Inconsistencies in EMT & RMS models), 3 (Unclear definitions of error bands and tolerances necessary for benchmarking EMT & RMS models) and 5 (NSP to consult with AEMO) on page 3 of the CEC submission on 14 February are relevant and can help resolve some of the challenges our members have faced.
>
> ......
> Legacy and new plant interaction – S4.15.3 (p36) of the AEMO draft report refers to the extent that: '...legacy plant and the new plant are likely to interact in a manner material for system stability and security, models for the legacy plant are to be provided in accordance with the current PSMG to the extent reasonably practicable.'

> Given the control loops of concern mentioned in the draft report, our members experience is that a reasonableness test has not been applied in the past. Thus resulting in projects failing to proceed very early in the connection process.

4.15.2. AEMO's assessment

AEMO is aware of the challenges faced by proponents due to modelling requirements for legacy plant when carrying out plant alterations. At the same time, AEMO and NSPs have obligations under the NER to conduct reasonable power system simulation to assess the performance of the plant alteration, and its impact on power system security. Therefore, a balance must be found whereby sufficient model information is provided to allow NSPs and AEMO to reliably perform the required simulations, without imposing unrealistic obligations on the proponent. AEMO considers a variety of modelling options, and sufficient flexibility for NSPs and AEMO to assess the appropriate level of modelling details to be required for legacy plant on a project-specific basis, would effectively achieve such a balance.

In the draft report, AEMO proposed new modelling options and general guidelines for legacy plant modelling to address the concerns raised in the Stage 1 submission. In making the above proposal, AEMO's view has largely aligned with the following considerations raised in the Stage 1 consultation:

- The PSMG should provide sufficient flexibility on the modelling options to be adopted by the proponent, the NSP and AEMO for modelling legacy plants, and effectively prevent the modelling requirements acting as a major disincentive for Generators and Network Users to carry out alteration work.
- Generators and Network Users should use whatever information is available to develop the legacy plant models and provide such information and models to the NSP and AEMO, to allow the NSP and AEMO to conduct necessary power system simulation involving the legacy plants.
- NSPs and AEMO should provide timely response and instruction on how to solve modelling issues with the legacy plant models developed by the proponent. The PSMG should provide general guidelines on a reasonable model validation framework to allow the NSP and AEMO to clearly distinguish issues identified simulations which are related to the modelling artefact, from issues which are related to the actual plant performance, particularly for legacy plant models.

To address the first and second points above, AEMO proposed the use of generic models as an alternative pathway for modelling legacy plants, in the absence of a vendor-specific model, and a case-by-case assessment approach to determine the necessary modelling requirements for the legacy plants, to be conducted by the NSP and AEMO. It should be noted that the use of a generic model is only one of the potential pathways for developing the legacy plant model, not the only or the preferred method, and should only be used if there are no other alternatives to model the legacy plant with reasonable engineering efforts. In general, proponents should explore multiple pathways for modelling legacy plants, depending on the level of detailed information available to them, including but not limited to:

(a) Vendor-specific model for the site-specific equipment, with site-specific parameters provided by vendor.

(b) User-defined site-specific models, with parameters derived from plant design information and historical operational measurements available to the proponent.

(c) Vendor-specific model with similar technology from the same OEM, with parameters derived from plant design information and historical operational measurements available to the proponent.

(d) Generic model, with parameters derived from plant design information and historical operational measurements available to the proponent.

When the vendor-specific model is used for modelling a legacy plant, the proponent may need to tune the parameters of the vendor-specific model, if it is not possible to obtain a set of site-specific parameters. The proponent must consider any existing commissioning data or operating measurement data, for example through the compliance monitoring scheme, and parameterise the vendor-specific model in a way that the model would demonstrate similar simulated responses to the existing field measurements. The level of accuracy for the model parameterisation should aim to achieve the accuracy requirements specified in Section 6 of the PSMG, however engineering judgement must be applied to identify a “close-enough” parameterisation outcome. For example, during the model parameterisation, one set of parameters may result in a very good correlation between the simulated response and the measurement of a specific event, but simultaneously a very poor correlation with the measurement of another event. In this case, the model parameters should be adjusted so that the model can achieve an optimal level of accuracy, considering different field measurements.

During the parameterisation of the vendor-specific model, the parameters associated with the model performance which can be validated in the R2 commissioning must be prioritised, so that these parameters can be verified in the R2 validation stage. The vendor-specific model must provide a sufficient level of access to the model parameters for the proponent to perform the required parameterisation. A vendor-specific model with all parameters hard-coded and inaccessible may be deemed insufficient, especially where an unadjustable model cannot demonstrate reasonable correlation with the historical performance of the legacy plant. The NSP and AEMO may require the legacy plant model to be validated during operation, either through the compliance monitoring scheme, or through tests conducted under NER 5.7.6, or when a power system disturbance occurs.

On the third point above regarding issues identified in the model, AEMO considers the modelling requirements, and the models submitted by the proponent, should be fit for purpose, therefore there must be a pathway to verify whether a specific issue identified in the simulation is due to modelling artefacts or due to actual plant performance issues. Validation or benchmarking tests on models, as well as prospective modelling results obtained in advance of field tests, will occasionally reveal inaccuracies or undesirable behaviours that arise due to numerical factors inherent in the model software environment, and not to the performance of the actual plant. Such numerical artefacts are anticipated to arise when modelling most connections. In most cases it is expected that the artefacts will be substantially avoided through judicious model parameter settings, or OEM source code updates where practical. They are, however, occasionally unavoidable, in particular for RMS models due to the simplified approach used.

The following are examples of model behaviour that might be presumed to arise from numerical artefacts and not relate to actual plant performance, noting that these are not definitive or exhaustive, and engineering judgement must be exercised in any particular instance:

- The simulation software crashes, or otherwise cannot complete the simulation.
- The model output oscillates between two distinct values on alternate time steps.
- Spikes or large instantaneous changes in electrical quantities are observed in RMS simulations that are not reproduced in EMT simulations of the same event.

Conversely, oscillatory responses or output changes that follow reasonably smooth trajectories in time and persist for more than one or more AC cycles are more likely to reflect real plant performance, particularly where these are seen in both RMS and EMT modelling results.

Where numerical artefacts arise for modelling of new connections, proponents in consultation with OEM(s) should take all reasonable steps to resolve any inaccuracies or undesired behaviours within the model, such that their impact on key output quantities is reduced below the accuracy thresholds in the PSMG. Pre-connection model confirmation in accordance with Section 6.3.2 of the PSMG aims to ensure that model issues of this type are detected and addressed early by OEMs, to the extent practicable prior to connection studies taking place, subject to the following general guidance:

- Where a numerical artefact in a model materially restricts the conduct of reasonable due diligence on plant performance (and provision of reliable alternative evidence by the applicant is not possible), resolution is sought within the timeframe for assessment of proposed access standards by the NSP and AEMO under NER 5.3.4A.
- Otherwise, resolution is required prior to registration (where applicable), or where the proponent is not required to register, prior to commencing commissioning. It should be noted that AEMO may not be able to grant registration if it cannot be satisfied that the plant will meet both model and performance compliance requirements under the NER.

OEM remedies for modelling of new connections may not always be available when updated models are required for legacy plant under Section 4.8.4 of the PSMG. It may be that the legacy plant OEM no longer exists or is otherwise unable to support the modelling effort requested. The general guidance in these situations is as follows:

- A numerical artefact in a legacy plant model is acceptable to the extent it does not materially restrict the conduct of reasonable due diligence on plant performance.
- EMT modelling evidence may be accepted in the absence of RMS modelling evidence to assess performance for specific access standards where the RMS model evidence is precluded by model performance issues.
- Where available field test results for the existing legacy plant confirm the undesired model behaviour is not observed in reality, assessment of a new or altered connection may proceed on the basis of the test results. This does not affect the Applicant's obligations under section 4.8.4 of the PSMG.
- Any permitted undesirable legacy model behaviours should to the extent practicable be contained to specific documented study scenarios.

4.15.3. AEMO's response

Raised by	Issues raised	AEMO response
CEC	Although the approach to using generic models is welcome, care should be taken in reliance on this approach as it may provide a false sense of security. Generic models can be used in the absence of an existing model or OEM to support. However, where an OEM can provide an initial model that does not meet all of the requirements of the PSMG, trying to substitute this for a generic model may actually result in more work than trying to resolve issues with the OEM model. It is noted that the members we spoke to whose project did not progress were utilising OEM provided models.	The use of a generic model is only one of many modelling pathways for the proponent to develop the legacy plant models. The proponent should first use information available to develop the representative plant model, while the NSP and AEMO should assess what levels of modelling information can be reasonably acquired from the proponent to allow the NSP and AEMO to fulfill their obligations under the NER during the connection process. Section 4.8.4 of the PSMG has been updated for clarification.
	Timeframes for resolving model issues generally – this is mentioned as being beyond the scope of this review in the draft report. However, the need for our members to try and resolve issues upfront has been one of the single biggest barriers for retrofitting a BESS behind an existing connection point.	AEMO considers timeframe-related matters are out of scope of the PSMG, and it is more appropriate for these to be discussed in other forums, such as the connection reform initiative.

Raised by	Issues raised	AEMO response
	Following the existing process under S8.3 and S8.4 of the PSMG as per the draft report – unfortunately, the existing approach is not currently working and no change has been proposed. We note AEMO's comments in the draft report that this is to be dealt with outside of the PSMG, however we believe that items 1 (Issues with EMT models), 2 (Inconsistencies in EMT & RMS models), 3 (Unclear definitions of error bands and tolerances necessary for benchmarking EMT & RMS models) and 5 (NSP to consult with AEMO) on page 3 of the CEC submission on 14 February are relevant and can help resolve some of the challenges our members have faced.	The PSMG has offered pathways for the proponent to apply to provide alternative modelling and information, as set by Section 8.3 and 8.4 of the PSMG. In response to Point 1 to 3, Section 6.3.2 of the PSMG has been updated with model benchmarking accuracy requirement, and Section 6.3.4 has been added to the PSMG to provide general guidelines on the assessment for unexpected model behaviours. In response to Point 5 (NSP to consult with AEMO), Section 8.2 of the PSMG has been updated to consider the modelling of the legacy plants.
	Legacy and new plant interaction – S4.15.3 (p36) of the AEMO draft report refers to the extent that: '...legacy plant and the new plant are likely to interact in a manner material for system stability and security, models for the legacy plant are to be provided in accordance with the current PSMG to the extent reasonably practicable.' Given the control loops of concern mentioned in the draft report, our members experience is that a reasonableness test has not been applied in the past. Thus resulting in projects failing to proceed very early in the connection process.	Section 6.3.4 has been added to the PSMG, which provides general guidelines on the potential differentiation between modelling issues and performance issues, and the likely pathways for resolution.

4.16. Small signal stability modelling

4.16.1. Issue summary and submissions

Small signal stability analysis has traditionally been a critical tool in determining interactions of synchronous machines in the NEM. By translation of RMS block diagrams into linearised models, classical linear control theory techniques can be applied to assess and ensure adequate damping of system oscillatory modes. Software such as Powertech Small Signal Analysis Toolbox (**SSAT**) can automatically do the conversion process based on a user-defined model.

This approach has worked well for synchronous generator models, due to the simpler nature of excitation and mechanical torque control loops which can be readily expressed as block diagrams. However, this approach does not work as well for inverter-based plant as they are complex, diverse, highly non-linear and often implemented as software rather than physical control systems.

Many questions have been raised in the last few years about the impact of IBR in small signal modelling, both on impacting or degrading existing electromechanical modes, or for identifying higher frequency control modes. There is much interest in using small signal techniques to identify control system interactions that have been seen across the NEM due to reducing system strength.

In the consultation paper it was proposed that detailed block diagrams of IBR be provided as part of the connections process (in addition to what is already received) as a basis on which AEMO could develop a small signal model. However, due to confidentiality concerns, provision of an encrypted SSAT software would also be acceptable.

AEMO received four submissions regarding small signal stability modelling from the Stage 2 consultation.

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Tesla

We believe that there's already AEMO specific software – including Power Factory PSSE and PSCAD – that provides the same functionality as small signal modelling. Our preference is to use existing software and avoid redundancies in software used.

Tesla also suggests that AEMO should enhance the level of detail in the PSMG by explicitly defining the necessary information deemed sufficient for NSP to develop a small signal model. For example, details on phase-locked loop (PLL) and current control in s-domain representation should be adequate.

Powerlink

To perform the meaningful NEM wide small signal stability analysis, a consistent approach towards the small signal modelling is essential. If some plants are represented by frequency response data, certain details (e.g. participation of states) and the root cause of the potential control interactions/instabilities could be missed. Therefore, we suggest that small-signal models should be obtained in a consistent format of SSAT or the block diagrams required to develop the SSAT models.

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Powerlink suggests that benchmarking results also be included as part of the small signal model documentation. Benchmarking of results (e.g. time domain step test or frequency response) will depend on the small signal model format selected through the discussion with AEMO and the NSP.

Transgrid

Transgrid recommends distinguishing between large signal and small signal block diagrams. As AEMO and NSPs are moving towards modelling asynchronous generators, it will be very useful and necessary to receive an accurate linearised block diagram from OEM for small signal modelling.

Transgrid recommends where guidelines refer to Small-signal stability models submissions, it is noted that the submission must be in the platform nominated by the NSP. Transgrid is of the view that, any other format than SSAT model, will be extremely hard to maintain for a long period of generator's operation. If NSPs are requested by AEMO to provide SSAT model of every generator, and the NSPs must build the SSAT model from the block diagram, this will significantly increase the workload and as a result will significantly increase connection processing time. The other methods such as model identifications can be contradictory with small signal because it will not be known whether any limiter that has been reached. Additionally, it will be difficult to keep repeating the studies across many projects for different operating points. Therefore, having proper SSAT model by OEM knowing the linearities and non-linearities and maintaining over 30 years and updating it for 5.3.9 and S5.2.2 process, appears to be the most robust way moving forward.

Additionally, if NSPs and AEMO are expecting the proponents to provide the small signal model, we have added small signal model submission in section 3.1 page 16 as well. Not listing them in that section, makes it unclear on whose responsibility it is to build the models.

Clean Energy Council

The need for Small Signal Stability modelling and use of another software package is noted and we urge AEMO to consider minimising the number of software packages that are utilised, especially when existing approved packages (e.g., PSS/e, PowerFactory, etc.) have the same functionality.

4.16.2. AEMO's assessment

AEMO agrees with submissions that guidelines should be in place to govern the level of detail required to sufficiently represent IBR in the small signal domain. However, as small signal modelling techniques for IBR are relatively new and undefined, AEMO believes that a separate discussion or consultation should be established.

In the interim, the update to the PSMG will allow TNSPs and AEMO to work with OEMs and registered participants to agree on the requirements, whether it is block diagrams, an SSAT model or some other format. This includes benchmarking of small signal model information.

4.16.3. AEMO's response

Raised by	Issues raised	AEMO response
Tesla	We believe that there's already AEMO specific software – including Power Factory PSSE and PSCAD – that provides the same functionality as small signal modelling. Our preference is to use existing software and avoid redundancies in software used.	PSS®E and PSCAD™ are not equipped with the frequency domain analysis capabilities that AEMO requires. SSAT has been agreed upon as the small signal modelling tool of choice by the PSMRG, which includes representatives from AEMO and NSPs.
	Tesla also suggests that AEMO should enhance the level of detail in the PSMG by explicitly defining the necessary information deemed sufficient for NSP to develop a small signal model. For example, details on phase-locked loop (PLL) and current control in s-domain representation should be adequate.	AEMO agrees that there should be guidelines in place for modelling IBR in the small signal domain. However as small signal modelling techniques for IBR is relatively new and undefined, AEMO believes that a separate discussion or consultation should be established. In the interim, the update to the PSMG will allow TNSPs and AEMO to work with OEMs to agree on the requirements, whether it is block diagrams, an SSAT model or some other format.
Powerlink	To perform the meaningful NEM wide small signal stability analysis, a consistent approach towards the small signal modelling is essential. If some plants are represented by frequency response data, certain details (e.g. participation of states) and the root cause of the potential control interactions/instabilities could be missed. Therefore, we suggest that small-signal models should be obtained in a consistent format of SSAT or the block diagrams required to develop the SSAT models.	The wording in the PSMG allows TNSPs and AEMO to work with OEMs to agree on the format for a small signal model. Until the exact methodology for small signal modelling of IBR can be defined, no fixed requirements should be put in place. AEMO recommends a separate consultation or discussion with TNSPs, participants and OEMs to determine this methodology.
	Powerlink suggests that benchmarking results also be included as part of the small signal model documentation. Benchmarking of results (e.g. time domain step test or frequency response) will depend on the small signal model format selected through the discussion with AEMO and the NSP.	As mentioned above, until the exact methodology for small signal modelling of IBR can be defined including benchmarking and validation, no fixed requirements should be put in place yet. If an SSAT model is provided, simple step response benchmarking against another simulation tool would be adequate.
Transgrid	Transgrid recommends distinguishing between large signal and small signal block diagrams. As AEMO and NSPs are moving towards modelling asynchronous generators, it will be very useful and necessary to receive an accurate linearised block diagram from OEM for small signal modelling.	Wording around block diagrams is specified in the NER and therefore cannot be changed as part of the PSMG consultation. Under the new wording in the PSMG, TNSPs will be able to discuss with OEMs the format for a small signal model, including in linearised block diagram format if desired.
	Transgrid recommends where guidelines refer to Small-signal stability models submissions, it is noted that the submission must be in the platform nominated by the NSP. Transgrid is of the view that, any other format than SSAT model, will be extremely hard to maintain for a long period of generator's operation.	As SSAT is the nominated small signal analysis software by the PSMRG, it is expected all small signal models will be either provided as an SSAT model, or a format that can be converted into a SSAT model by AEMO and/or the TNSPs.

Raised by	Issues raised	AEMO response
	Additionally, if NSPs and AEMO are expecting the proponents to provide the small signal model, we have added small signal model submission in section 3.1 page 16 as well. Not listing them in that section, makes it unclear on whose responsibility it is to build the models.	The responsibility of building the model and timeline for provision will depend on the agreed format between the OEM, AEMO, TNSPs and the *registered participant* as per revised Section 5.
CEC	The need for Small Signal Stability modelling and use of another software package is noted and we urge AEMO to consider minimising the number of software packages that are utilised, especially when existing approved packages (e.g., PSS/e, PowerFactory, etc.) have the same functionality.	PSS®E and PSCAD™ are not equipped with the required frequency domain analysis capabilities that AEMO requires. SSAT has been agreed upon as the small signal modelling tool of choice by the PSMRG, which includes representatives from AEMO and NSPs.

4.17. Other suggested updates

AEMO received a few submissions in the Stage 2 consultation which suggested other updates to the PSMG.

4.17.1. Suggested rules references correction in the PSMG

Two submissions were received which suggested a few corrections and updates to Rules clause references in the PSMG.

Raised by	Section of PSMG	Issues raised	AEMO response
ElectraNet		The glossary term 'R2' incorrectly references NER S5.5.6. ElectraNet considers that the intended reference should be NER S5.5.2 Categories of data. Noting this, AEMO is encouraged to undertake a complete review of all references in the PSMG as part of this update to ensure alignment with the NER.	The rules reference for the glossary term 'R2' has been amended.
	2	The description provided under Section 2 of the draft PSMG does not adequately describe the Rules process and hierarchy for updating models and information and is potentially misleading. ElectraNet suggest the following updates: a) Inclusion of a reference to NER S5.2.4(d) and a corresponding description of the obligations on Generators to update models and information 1) within 3 months of commissioning tests or following tests to demonstrate compliance with connection requirements; 2) at any time that the Generator becomes aware that the information is incomplete, inaccurate or out of date; and 3) on request by AEMO or the relevant NSP where it is considered that the information is incomplete, inaccurate or out of date. b) Redraft the description for the use of NER 5.7.6, noting that the use of this clause is considered to be a last resort considering the other obligations on Generators to maintain and update their models. Additionally, the current text states that the Generator is responsible for the costs of tests under NER 5.7.6. However, it is our understanding that all parties involved in this type test (i.e.	For point a), reference to NER S5.2.4(d) has been included in the PSMG. For point b), changes have been made to Section 2 to refer to key NER provisions while removing the detail. This clause is not intended to be an operative part of the guideline, it simply provides context to illustrate the importance of accurate models and the potential consequences of inaccuracy.

Raised by	Section of PSMG	Issues raised	AEMO response
		AEMO, the Generator and the NSP) are responsible for their own associated costs.	
Ergon/Energex	2.1	In Section 2.1's requirement (d) and (e), generators apply for connection to DNSPs under the National Electricity Rules (NER) clause 5.3A.9, not clause 5.3.4; and	Reference to NER 5.3.4 has been removed in Section 2.1 and 2.2 of the PSMG.
	2.2	In Section 2.2's requirement (d) and (e), again, for connection to DNSPs the relevant NER clause is 5.3A.9 rather than clause 5.3.4. For systems under 5 megawatts, unless the integrated resource provider is opting to connect under Chapter 5, the relevant clause is 5A.D.3.	

4.17.2. Suggested clarification

One submission was received which seeks further clarification to be provided in the PSMG.

Raised by	Section of PSMG	Issues raised	AEMO response
Transgrid	3.1	If the statement "pre-commissioning model confirmation test report26 "refers to pre-test simulation that are done prior to hold point testing, Transgrid suggests this item to be also added to AEMO's published check list of R1 package for consistency.	As the name suggested, the pre-commissioning simulation are referring to simulations to be performed by the proponent prior to the hold point test. Section 3.1 of the PSMG has been updated for clarification.
	3.1	Transgrid suggests the wording of this page where it states the "platform" to change to "the platform nominated by the NSP and AEMO". This will assist the NSPs who heavily use modelling platform other than PSSE and PSCAD.	AEMO supports this as an NSP-specific requirement.
	3.2	Regarding the first paragraph of section 3.2, second sentence, should the "an NSP" change to "the connecting NSP"?	We do not believe this change is necessary, as it is simply establishing that the requirements apply whenever information is to be provided to an NSP.
	3.4	Does table 3, which describes the exemption criteria, mean all the connections above 5 MVA or below 5 MVA with SCR of less than 10, cannot be exempt? Transgrid believes adding some examples in the guideline for some generators with 1-4.9 MVA and SCR of 1-9.99 might be useful.	Table 3 nominated a few conditions where model exemption may be granted to the proponent by the NSP and AEMO. Section 3.4 of the PSMG also permits a proponent whose plant does not meet the conditions specified in Table 3, i.e. sub 5 MVA, with SCR of 9.99 as described in Transgrid's submission, to seek the NSP's advice as to whether model exemption can be granted by the NSP and AEMO. AEMO considers this procedure is reasonable and appropriate, and does not intend to change this process, as currently set out in Section 3.4 of the PSMG.
	4.0	Can AEMO also refer to DMAT guideline in this section as there are some overlapping areas between the two guidelines?	There is not significant overlap between these two guidelines. It should be noted that the PSMG is bound by the Rules, while the DMAT is a derivative of the PSMG.
	4.3.1	Transgrid suggests adding some examples to clarify the term "Numerical Stability".	Numerical instability can be seen as instability resulting from algorithmic limitations within computer software that is designed to perform numerical integration. It may occur despite the power system being simulated is actually stable in reality. The underlying mechanisms of instability can have many origins, from the more obvious inappropriate selection of the numerical integration time step, to

Raised by	Section of PSMG	Issues raised	AEMO response
			inappropriate parameterisation exceeding the intended use of the model. AEMO considers providing only a few such examples of numerical instability would be prescriptive and therefore is out of the scope of PSMG. Many research references are available, and the occurrence and the nature of the numerical instability needs to be determined case-by-case, with reasonable engineering judgement. Numerical instability refers to any instability observed in the simulation which is not a result of the intended controller or plant behaviour. Unlike controller instability, or transient instability which would follow a similar pattern with different settings of the simulation environment, the numerical instability is highly dependent on the simulation configuration and model presentation, therefore needs to be analysed on a case-by-case basis. Section 6.3.4 has been added to the PSMG to provide general guidelines on this matter.
	4.3.1	Transgrid finds "at least five minutes" more appropriate than "up to five minutes" for the numerically stable performance of the model without disturbance.	The PSMG have been updated to reflect this change.
	4.3.1	With regards to the existence of a characteristic in the model where it does not have an equivalent in the actual plant, Transgrid suggests further notes or adding examples to this section may assist further in better understanding of this requirement.	The PSMG has a requirement that a model should not contain any characteristic which does not exist in the actual plant.
	4.3.1	Transgrid suggests the section that references to modelling to be initiated at any power down to 0 megawatts, to be changed to "any active power over the operating range of the plant".	The PSMG have been updated to reflect this change.
	4.3.1	Transgrid suggests the reference to the available power from the fuel to change to available power from the energy source.	The PSMG have been updated to reflect this change.
	4.3.5	Transgrid suggests that the guidelines include details of how the warning should be raised and the interpretation of it to be explained in the RUG. Currently, some models provide error with no explanations in the warning message or in the documentation.	As this issue is raised for Section 4.3.5 of the PSMG which addresses the RMS model, AEMO assumes it relates to model warning messages for RMS models. AEMO generally supports the view that the model RUG should provide certain explanation or information on whether the model has any user defined error or warning message, and sufficient guidance on how to interpret such warning or error messages by the model users, particularly the NSPs and AEMO. It should be noted that although model source codes are provided to AEMO, it is provided at a much later stage of the connection process, and it would be far more sufficient to include certain explanation of the user defined error / warning messages, than NSPs and AEMO needing to gain such understanding from the model source code. Section 4.3.5 of the PSMG has been updated for clarification. It is an expectation under the PSMG that the models provided to NSPs and AEMO are without an error, and it is the responsibility of the proponent to resolve any modelling error which would prevent the NSPs and AEMO to

Raised by	Section of PSMG	Issues raised	AEMO response
			perform necessary power system simulations to fulfill their obligations under the NER.
	4.3.5	Transgrid highly recommends including a discussion on the requirement of spike mitigation implementation, the necessity of it under certain conditions and the acceptable methodologies. This will bring more consistencies that currently exist across the industry.	The challenges associated with spikes identified in the simulation, usually voltage spikes or reactive power spikes following a rapid change of power system operating conditions, for example at the instant of fault clearance, include three aspects, i) whether such spikes are within a tolerable range, ii) whether such spikes are due to a modelling artefact, or actual power system or device behaviour, iii) how to mitigate undesirable spikes. Under NER S5.2.5.4, the generators are required to withstand certain transient overvoltage as per their Performance Standards. In simulation, it is not expected that generators will be tripped by transient overvoltages within their withstand capability. If a transient overvoltage spike caused any generator to trip in the simulation, and the voltage spike exceeded the withstand capability of the generator, the voltage spike and the resulting generator trip should be investigated. Generally, it is common to observe voltage spikes in the RMS SMIB simulation, compared to the EMT SMIB simulation. In such cases, the spike is most likely due to the artefact of the RMS modelling platform, rather than a device-originated response. A spike may be observed in wide area EMT simulations too, and the source of the spike can be identified by repeating the simulation with and without the generator under test, to verify whether the spike is introduced by adding the generator, or due to underlying power system model behaviour. Regardless of the cause of the spike, if such a spike caused the incorrect tripping of a generator, it must be mitigated. For spike behaviour observed in SMIB simulations, the proponent is required to provide solutions for the mitigation. For spike behaviour observed in wide area EMT simulations, the underlying wide area model and the simulation setup need to be revisited, for example, by selecting a realistic circuit breaker opening time to mitigate the transient recovery voltage. Section 6.3.4 has been added to the PSMG for clarification.
	4.3.6	Transgrid recommends that the guideline provides the details of requirement regarding the average model versus full IGBT modelling and accuracy criteria for when these two modelling are claimed to be interchangeably used.	The selection of average models and full switching models is largely determined by two factors: i) what phenomenon the model is used to study, and ii) the desired simulation speed. For EMT transient stability analysis where the EMT models are mainly used for, the average model and the fully switched model are expected to have the same transient response trajectory, therefore are expected to result in the same conclusion in terms of the transient stability of the IBR and its impact on power system operation, with the proper averaging mechanism. The average model can cope with larger simulation time steps and therefore requires

Raised by	Section of PSMG	Issues raised	AEMO response
			less computational overhead and exhibits a faster simulation speed than a comparable full IGBT switching model. However, average models should not be over-simplified compared to the counterpart fully switched model, by neglecting certain controllers, other than the switching pulse generator, in the model. Average models are still expected to include all controllers and quantities as required in Section 4 of Guidelines. With reasonable doubt about the adequacy of the average model, the NSP and AEMO may require the proponent to provide the fully switched model of the plant, and the performance overlay between the average model and the fully switched model. Section 4.3.6 of the PSMG has been updated for clarification.
	4.3.12	Transgrid recommends excluding the RMS and EMT specific model versions. Perhaps other AEMO's guidelines or web-interfaces may be more suitable protocol for communicating this requirement.	The PSMG needs to specify the minimum model version requirement for RMS and EMT models, to prevent incompatible models to be provided which do not work with the current version of the simulation platforms used by NSPs and AEMO. AEMO intends to keep the currently wording in the Guidelines regarding minimum model versions.
	6.2.1	Transgrid seeks clarification on the requirements under section 6.2.1(b)(iii): 6- It seems to refer to the comparison between measurement and simulated quantities, but instead it refers to phase angle between different quantities e.g. P and Q which does not necessarily mean any inaccuracy of the model. 2- Additionally, with high bandwidth of inverter controllers, 5 Hz to be upper limit of this requirement seems very generous. 3- "Damping with footnote 53" may need to either refer to adequately damped or at least "positively damped". However, again, undamped or damped, does not directly relate to model accuracy.	For the first point, the phase angle difference should be applied to the measured response and the simulation response of the same quantity. For the second point, the damping behaviour may be extended to 25 Hz for IBR models. For the third point, as suggested in the submission, the Guidelines are referring to model accuracy, rather than performance standards, i.e. damping adequacy.
	6.3.3	Transgrid notes that one of the issues in the commissioning stage is that the tests noted in table 6 are often interpretated incorrectly with the tests requested to be undertaken and overlayed in Hold Point testing versus R2 model validation report. Therefore, Transgrid recommends an additional note clarifying that these are the minimum requirement would be helpful.	The PSMG have been updated to confirm Table 6 specifies the minimum requirement for model overlay in the R2 validation report, not the minimum requirement for tests to be conducted in R2 commissioning process.
	C.1.2	Transgrid assumes that this statement applies to type 3 wind turbines, and for this we recommend to also include Grid Side Converter (GSC) quantities.	The PSMG have been updated to reflect this change.

4.17.3. Suggested changes for model benchmarking

One submission was received which recommended a few changes to sections of the PSMG which relate to model benchmarking.

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Raised by	Section of PSMG	Issues raised	AEMO response
Powerlink	6.3.2	Powerlink supports the view to include accuracy guidance of RMS and EMS model benchmarking within the PSMG. Powerlink agrees that divergences between model responses should be expected, and that some of these divergences may exceed 10%. However, Powerlink also suggests that a 10% margin between RMS and EMT model is not appropriate for many simulations. For example, both RMS and EMS models should provide effectively (to within calculation tolerances) identical responses for a voltage reference step.	AEMO is generally supportive of the view that different accuracy requirements can be applied for different scenarios for RMS and EMT model benchmarking, as long as engineering judgement is applied in determining the reasonably practical accuracy requirement. AEMO considers 10% accuracy is a general guideline for model benchmarking, which may be exceeded during a portion of the transient window as defined in Appendix E of the PSMG. AEMO considers for small disturbance response, such as a control system reference step change, both RMS and EMT should provide reasonably close responses (<10% discrepancy) in terms of rise time, overshoot and settling time, and should achieve the same steady-state value following the same reference step change. If this accuracy cannot be achieved, the proponent should provide justification to the NSP and AEMO. Section 6.3.2 of the PSMG has been updated for clarification.
	6.3.2	If a 10% accuracy requirement between RMS and EMS is maintained for pre-connection model confirmation tests, then Powerlink notes that such accuracy requirement is not relevant after connection; after connection, only accuracy between the models to field data is relevant.	The 10% accuracy requirement has always been applied to the R2 model validation in the past. AEMO considers the current PSMG sufficiently addressed this point.

4.17.4. Suggested changes to model provision

Three submissions were received regarding suggested changes to model provision.

Raised by	Section of PSMG	Issues raised	AEMO response
Powerlink	3.2	Powerlink supports the requirement for a RUG for both RMS and EMT load models.	AEMO is supportive of this view.
Tesla	5	As noted in our earlier submission, we also recommend that AEMO remove the need to submit functional block diagram under 5 Model documentation. If an OEM choose to develop all models, and no reason for AEMO to receive functional block diagrams If the OEMs meet the modelling interface and library requirements for PSCAD, PSSE, and SSAT models, there should be no requirements for providing an open box model, model source code or detailed controls block diagrams.	As the provision of functional block diagram is part of the NER requirement, AEMO cannot remove it from the PSMG.
Transgrid	4.3.5	Park controller models should be required to be attached to the controlled bus/es and not a particular generator bus. This is to account for when generators are offline/disconnected which have those models connected to them.	AEMO considers it is a good practice for the park controller to function with any (but not all) generator element under its control being out of service. AEMO understands this specific requirement raised in the submission is related to RMS modelling software such as PSS®E and DIgSILENT/PowerFactory. The park controller needs to be removed from the simulation, if the whole facility under its control is out of service. AEMO is also aware that OEMs have developed RMS models which might not align with this requirement at the moment. AEMO considers it is reasonable to allow sufficient

Raised by	Section of PSMG	Issues raised	AEMO response
			time for the OEMs to adjust the models to align with this requirement. Such a timeframe should be agreed among AEMO, NSP and the proponent for each project. Section 4.3.5 of the PSMG has been updated for clarification.
	4.3.5	Transgrid suggests the guideline include the requirement of temperature dependencies.	All simulation models contain certain levels of approximation to the actual plant behaviour, and AEMO considers the simulation models must be fit for purpose for the phenomenon of interest. AEMO considers that it is not necessary or practical to model every aspect of the actual device, considering the time and effort required to develop such detailed models, the necessary computation power required to simulate with these detailed models, and the potential gain of knowledge from using these models. The inverter's temperature derating, unlike gas turbine generators, is applied on decentralised, individual inverters. Also other atmospheric conditions such as wind speed would play role in the ambient temperature experienced at the inverter or turbine level. Considering most IBR dynamic models are developed with certain levels of aggregation, the aggregated effect of the temperature derating will depend on the size of the generator (particularly for large wind farms), the site layout, and will vary from site to site, even the same inverter is utilised. In addition, the temperature derating will affect the magnitude of response provided by IBRs, but is unlikely to change the shape of the transient response. Other factors, for example wind turbine blade weight balancing, may have a bigger impact on the dynamic behaviours of the wind turbines. The modelling of such mechanical factors are not generally required for any IBR model, but is required to analyse a specific phenomenon. Similarly, AEMO considers the modelling of IBR temperature dependency be treated on a case-by-case basis, instead of as a general requirement in all cases. In addition, the temperature affects the capability of many other types of devices, including transformer cooling, transmission line rating. Currently many of these temperature dependencies are not captured in the modelling, and it wouldn't be effective to only model the temperature dependency of the generators.
	4.3.5	Transgrid recommends the inclusion of the requirement of OLTC dynamic modelling more clearly in this section as it can improve the initialisation of the models placing the tap changer in the correct position.	In the draft PSMG[12], AEMO did not support the inclusion of the On-load Tap Changer (**OLTC**) dynamic model as a general modelling requirement, as the action timeframe of OLTC is much longer compared with the transient time window of simulation. The utilisation of OLTC for model initialisation should not be adopted as a generalised approach for model initialisation. As the model needs to be initialised sufficiently quickly (i.e. less than 3 seconds), the OLTC response

[12] Available online at: https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/psmg-review-consultation/second-stage/power_systems_model_guidelines_2023_draft_markup.pdf?la=en

Raised by	Section of PSMG	Issues raised	AEMO response
			time needs to be shortened, and such an OLTC model is not reflective of the actual OLTC behaviour. Normally, such OLTC models need to be disabled within a certain time period, and be redundant for the rest of the simulation. Furthermore, these OLTC models may need to be tuned for a specific model initialisation condition, but may not be adaptive to other conditions, and may introduce unforeseeable consequences of tap hunting, as each of these OLTC model is only developed and tuned locally. If the model can only be initialised with a specific tap position, and such a tap position cannot be estimated from pre-simulation load flow analysis, it normally indicates there may be underlying issues with the IBR models. Generally, AEMO considers the IBR models should have sufficient robustness to be initialised with a reasonable range of transformer tap positions. AEMO supports the use of certain mechanisms to search for the most optimal tap position for the model initialisation, as long as such a search mechanism does not introduce unnecessary burdens or fluctuation to the initialisation process, and would not interfere with the normal IBR transient response. However, this should not be a generalised requirement for every model to be equipped with such a search mechanism for the optimal tap position for model initialisation.
	4.3.5	Transgrid recommends modelling the temperature dependencies in both RMS and EMT modelling platforms. This will remove the challenges during the commissioning, R2 model validation and ongoing compliance of the plant.	This has been discussed in the above response. Generally, AEMO supports capturing such temperature dependencies in the model RUG, and expects such a temperature dependency relationship would be an estimation only.
	4.7.3	Transgrid recommends further clarifications to be provided regarding the below quoted statement on whether main grid-connected power transformers can be aggregated or not. To be able correctly capture the impact of the transformer on many aspects of power system modelling including power quality, static and dynamic performances, non-linear behaviour during saturation of the transformer on voltage and more, in normal operation as well as outages and contingencies, Transgrid suggests the transformers of the high voltage plant connecting directly to the transmission network to be explicitly modelled and not in an aggregated arrangement.	AEMO is generally supportive of modelling explicitly each high voltage transformer connecting the generator to the transmission network, particularly in the cases where a tripping scheme would only trip a portion of the IBR supplied by particular main transformers. However, the impact on the simulation speed of the above modelling practice should be also considered, and a balance to be struck between the necessary model representation and the desirable simulation speed. This has been captured by the current PSMG, under Section 4.7.3, where it stated "high voltage plant connecting directly to the transmission network is to be explicitly modelled".

4.17.5. Suggested changes to harmonic modelling

Two submissions were received regarding suggested changes to modelling for harmonic analysis.

Raised by	Section of PSMG	Issues raised	AEMO response
Powerlink	4.6	Powerlink suggests that an adequate model of reticulation system for large IBL and non-IBL loads should be provided in a format that is compatible with the harmonic	AEMO considers there are NSP-specific requirements, and should be agreed between NSP and the proponent.

Raised by	Section of PSMG	Issues raised	AEMO response
		analysis software nominated by the Network Service Provider (NSP).	Section 4.6.1 of the PSMG has been updated for clarification.
Transgrid	4.6	Transgrid recommends this section makes reference to the 240-page CIGRE Technical Brochure 766, entitled "Network Modelling for Harmonic Studies".	

4.17.6. Other changes

AEMO has made a number of other minor drafting changes in the PSMG for readability, formatting and clarification. AEMO has published with this final report a change-marked version of the PSMG against the previous version determined in 2018.

5. Final determination on proposal

Having considered the matters raised in submissions to the draft report paper, AEMO's final determination is to make the Power System Model Guidelines, the Power System Design Data Sheet, and the Power System Setting Data Sheet in the form published with this report, in accordance with NER S5.5.7.

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Appendix A. Glossary

Term or acronym	Meaning
AEMC	Australian Energy Market Commission
BESS	Battery Energy Storage System
CRI	Connections Reform Initiative
CUO	continuous uninterrupted operation
DER	distributed energy resources
DLL	Dynamic Link Library
DNSP	distribution network service provider
EMT	electromagnetic transient (simulation / model)
EMTDC	Electromagnetic Transients with DC
ESB	Energy Security Board
EV	electric vehicle
FCAS	frequency control ancillary services
HIL	Hardware-in-the-loop
IBL	inverter-based load
IBR	inverter-based resource/s
IESS	Integrated Energy Storage System
IRP	Integrated Resource Provider
IRS	Integrated Resource System
JWG	Joint Working Group
MASS	Market Ancillary Services Specification
MNSP	Market Network Service Provider
NEM	National Electricity Market
NEO	National Electricity Objective
NER	National Electricity Rules
NSCAS	Network Support and Control Ancillary Services
NSP	Network Service Provider
OEM	original equipment manufacturer
OLTC	On-load Tap Changer
PIR	Pre-insertion resistor
PLL	Phase-locked-loop
POW	Point-on-wave
PSMG	Power System Model Guidelines
PSMRG	Power System Modelling Reference Group
PV	Photovoltaics
RAS	remedial action scheme
RMS	Root Mean Square (simulation / model)
RUG	Releasable User Guide
SRAS	System Restart Ancillary Services
SSAT	Small Signal Analysis Toolbox

Term or acronym	Meaning
SSIAG	System Strength Impact Assessment Guidelines
UPS	uninterruptible power supply
VCS	Voltage Control Strategy
ZIP	Constant impedance (Z), current (I), power (P) load model