Amendments to the Power System Model Guidelines

Draft Report – Standard consultation for the National Electricity Market

Published: 14 April 2023

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

Australian Energy Market Operator Ltd ABN 94 072 010 327

Executive summary and consultation notice

This draft report is part of 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**) that AEMO is required to develop, publish and maintain under National Electricity Rules (**NER**) S5.5.7(a). The standard rules consultation procedure is described 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 systems, control systems and plant technologies, the data and other requirements of participants under NER S5.5.7.

AEMO received 14 submissions in the first stage of its consultation on the proposal.

Table 1 lists key material issues raised in submissions and AEMO's responses.

Table 1 Summary of key material issues raised in submissions and AEMO's responses

Material issue	AEMO response
Inclusion of load modelling	AEMO recommended that load modelling requirements are included in the PSMG, and the types of load models to be required will be determined by AEMO and network service providers (**NSPs**) on a project specific basis, considering the potential impact of the load on power system operation. The proposed changes to the PSMG will cover a range of load models with various levels of details which can be used to represent load dynamic responses.
Electromagnetic transient (EMT) modelling compatibility	Suggestions were made to consider an open standard such as IEEE/CIGRE working group B4.82 wrapper. Proposed changes to the PSMG include requirements around linking and interfacing library files containing compiled manufacturer code, with the preferred approach to implement the B4.82 wrapper.
Modelling requirements for legacy plant	Suggestions were made to consider the use of generic models to represent legacy plants. AEMO recommended that the legacy plant models should be validated as per the current R2 commissioning process, as a part of the connection process of the combined plant. Data obtained from ongoing compliance monitoring scheme should be used by the proponent to further validate the generic model, and the validated model should be provided to AEMO and NSPs within a time frame to be agreed between all parties during the connection process.
Small signal modelling requirements	Concerns were raised about ability of original equipment manufacturers (**OEMs**) to provide fully detailed block diagrams of IBR plants due to sensitive intellectual property within and several other methods were proposed such as frequency response data. Due to uncertainty around what the exact requirements should be, no new requirements are proposed to be added to PSMG; however, wording has been updated to allow for provision of other forms of small signal models such as Small Signal Analysis Toolbox (**SSAT**) models or as agreed with NSP and AEMO.

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 draft report, with a proposed effective date of **16 June 2023.**

Consultation notice

AEMO invites written submissions from interested persons on the draft proposal and issues identified in this draft report to PSMGReview@aemo.com.au by 5:00 pm (Melbourne time) on **19 May 2023**.

Submissions may make alternative or additional proposals you consider may better meet the objectives of this consultation and the national electricity objective in section 7 of the National Electricity Law. Please include supporting reasons.

Please note the following important information about submissions:

- All submissions will be published on AEMO's website, other than confidential content.
- Please identify any parts of your submission that you wish to remain confidential, and explain why. AEMO may still publish that information if it does not consider it to be confidential, but will consult with you before doing so. Material identified as confidential may be given less weight in the decision-making process than material that is published.
- Submissions received after the closing date and time will not be valid, and AEMO is not obliged to consider them. Any late submissions should explain the reason for lateness and the detriment to you if AEMO does not consider your submission.

Interested persons can request a meeting with AEMO to discuss any particularly complex, sensitive or confidential matters relating to the proposal. Please refer to NER 8.9.1(k). Meeting requests must be received by the end of the submission period and include reasons for the request. AEMO will try to accommodate reasonable meeting requests but, where appropriate, may hold joint meetings with other stakeholders or convene a meeting with a broader industry group. Subject to confidentiality restrictions, AEMO will publish a summary of matters discussed at stakeholder meetings.

Contents

Tables

1. Stakeholder consultation process

As required by the National Electricity Rules (**NER**) S5.5.7(a) and (f), AEMO is consulting on proposed changes to the Power System Model Guidelines, the Power System Design Data Sheet and the Power System Setting Data Sheet in accordance 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 indicative process and timeline for this consultation are outlined below. Future dates may be adjusted and additional steps may be included if necessary as the consultation progresses.

Table 2 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	16 June 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 on the proposal, AEMO received seven submissions, from:

- AusNet Services.
- CitiPower – Powercor – United Energy.
- Goldwind.
- Kate Summers.
- OPAL-RT.
- PGSTech.
- Tesla.

In addition, AEMO received seven late submissions, from:

- Clean Energy Council (CEC).
- CS Energy.
- GE.
- Powerlink.
- RTE.
- Siemens.
- TransGrid.

AEMO thanks all stakeholders for their feedback on the proposal to date and looks forward to further constructive engagement.

On time submissions have been considered in preparing this draft report. AEMO is not obliged under NER 8.9 to consider late submissions but has endeavoured to incorporate feedback from these submissions where time has permitted.

AEMO has briefed representatives from the transmission service providers (TNSPs) and distribution network service providers (DNSPs) with AEMO's recommendation for each consultation question, while preparing this draft report.

2. Background

2.1. NER requirements

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

- the Power System Model Guidelines, 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.

The PSMG and Data Sheets are required to be published and maintained under the rules consultation procedures in NER 8.9. As such any material modification requires two rounds of consultation with industry and interested parties.

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 Guidelines 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 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 benefit to participants and consumers that would not have been realised had the information not been provided.

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 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, in the last 10 years there has been a surge in the integration of large-scale renewable plant to the grid. Such plant includes wind turbines, solar photovoltaics and battery storage systems and cannot be interfaced to the grid through the use of a synchronous machine and are therefore known as

[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.

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) are 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 however has started to shift in the last year as interest in connections of very large, power electronic interfaced power system loads has risen. Two recent examples seen by AEMO and NSPs are hydrogen electrolysers (hydrolysers), and 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.

Whilst 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 Guidelines, with the Guidelines frequently using the wording “Generating System” which does not apply to loads. Therefore, it is considered necessary to update the Guidelines to include specific modelling requirements for large power system loads.

Note the Guidelines and thus this consultation are specific to model requirements, **NOT** performance requirements. Performance requirements and Connection Agreements for customers will not be 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 the power system models must also 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 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, as 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 for AEMO and NSPs on this matter.

2.3.5. Other matters

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

3. List of material issues

The key material issues arising from the proposal or raised in submissions are listed in Table 3.

Table 3 List of material issues

No.	Issue	Raised 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
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
3.	Other types of large loads to be considered for PSMG	AEMO, AusNet, Powerlink, Transgrid
4.	Suitability of IEEE or Composite and DER load model for data centre loads in Root Mean Square (**RMS**) and electromagnetic transient (**EMT**) simulation	AEMO, AusNet, Citipower & Powercor, Transgrid
5.	Inclusion of additional protection and control systems to be required in the models	AEMO, AusNet, Powerlink, Transgrid
6.	Levels of details required for inverter-based load (**IBL**) in RMS and EMT domains	AEMO, AusNet, Citipower & Powercor, Powerlink, Transgrid
7.	Black start simulation model requirements for large power system loads	AEMO, AusNet, Citipower & Powercor, CS Energy, Transgrid
8.	Level of R2 validation appropriate for different types of load models	AEMO, AusNet, Citipower & Powercor, Powerlink, Transgrid
9.	Requirement for model provision in Section 7.4 of PSMG for IBL	AEMO, AusNet, Citipower & Powercor, Powerlink
10.	Modelling component requirements for IBL in Appendix C of PSMG	AEMO, AusNet, Citipower & Powercor, Powerlink, Transgrid
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
12.	Provision of PSCAD model source code	AusNet, Powerlink, TransGrid
13.	Inclusion of remedial action schemes	AusNet, CS Energy
14.	Inclusion of Integrated Energy Storage Systems (**IESS**)	AusNet
15.	Requirements for legacy plant modelling	CEC
16.	Small signal modelling requirements	AusNet, Goldwind, Kate Summers, TransGrid, Powerlink
17.	Other matters	N/A

Each of the material issues in Table 3 is discussed in Section 4.

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 is 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.

AEMO has received seven submissions for this issue:

Tesla Motors Australia, Pty Ltd

> We would propose that 30MW is a suitable threshold for individual loads connected in the distribution network – above that, AEMO can expect power system modelling to be provided. This would capture the full range of assets considered in Table 3 in the Consultation Paper. It also matches the equivalent generation threshold requirements that also sit at 30MW.

AusNet Services Ltd

> In general it is difficult to define a singular criterion to be applied across all possible circumstances in the NEM. Factors to be considered include connection voltage levels, strength of the local network, and the type of grid interface used by the proposed load (e.g., IBR, induction machine, resistive). Conversely, it is important to provide a basic level of certainty to potential customers about modelling requirements such that it can be factored into the project both in terms of time and cost.
>
> If a being subject to load modelling requirements depending on the grid interface of the load, local network specifics (e.g., voltage, strength, proximity to other IBR loads) at the connecting NSP’s discretion. Currently, generators up to 30 MW are eligible to apply for registration exemption hence schedule 5.2 does not apply for such generators where demonstration of compliance to performance, which includes demonstration of performance using models. Therefore, it is reasonable to exclude loads between 5-30 MW from a general threshold that require modelling.
>
> Connections above 30 MW should require modelling to be undertaken. The modelling requirements should vary based on composition of the load. Traditional power system loads should not be subject to similar modelling requirements requested for the IBR loads.
>
> Loads under 5 MW would be subject to the local NSP’s connection requirements.

Existing loads would not be subject to updated modelling requirements unless a material change to the type of grid interface occurs.

CitiPower, Powercor & United Energy

As a starting point the threshold should be megawatt-based at 30MW as this aligns well with existing AEMO thresholds for Semi-Scheduled generators.

Location based requirements should apply between 5MW and 30MW, as 5MW aligns well with Chapter 5A load connections and the requirements for these loads should requirement agreement between the NSP and AEMO.

However this threshold should be regularly reviewed and as IBL penetration increases over time, this threshold may need to be reduced to 5MW.

CS Energy Ltd

In determining the threshold (if any) for deciding when to model a traditional large power system load in detail for power system simulations, be it megawatt-based, location-based or otherwise, AEMO needs to clearly articulate what it is expecting to achieve in the modelling studies including the objectives and requirements. CS Energy supports the consideration and development of a threshold that specifies the amount and detail of model information. The amount of model information associated with the threshold would reflect key parameters such as the material impact on the power system, size and investment. AEMO should further consider the concept and quantum of the threshold in the next stage of the consultation process on the Draft Report.

Powerlink

Depending on the location of the connection point and the other network users in the vicinity, it is important to understand the type of the load and its characteristics to analyse its impact on power system performance. Therefore, the threshold for the modelling of such load is also subject to the location and other users in the vicinity. Traditional loads that are mainly non-IBL type can be represented by a simplified aggregated model to represent its dynamic behaviour. NSP should make a decision at the time of connection agreement to request the load model.

Kate Summers

If this rule is to be applied in any meaningful way, it must be driven by good engineering practices and risk assessments. To not do so risks significant impact on future development of business and industry. Just as applying the 5.3.9 (and causing PSCAD modelling) to be reversed onto existing generators causing delays in site upgrades. The cost of modelling exceeds the capital cost of the site upgrades. This requires significant rethinking by the PMWG. Requiring any load to provide a PSCAD is not justified. The power engineers that operate the system should be talented enough to develop approximate generic models. The only time a load model ought to be developed would be if it is a fully controllable load that intends to participate in the market and provide “services”.

This is not a size or location decision. It can only reasonably be thought of within a risk framework.

Transgrid

Transgrid proposes the same threshold as Generator automatic exemption’s to be considered. The loads above 5 MW to be modelled unless no material impact from the load is observed by the Network Service Providers (NSP). Transgrid notes that increasing the number of loads or converting the conventional load modelling could increase the complexity of the models and the simulation processing time and therefore these impacts need to be considered prior finalising the thresholds.

4.1.2. AEMO’s assessment

Power system models, including load models, are required by AEMO and NSPs to fulfill their rules obligations under many circumstances which are specified by various clauses under the NER. AEMO also acknowledges that the development of a detailed computer model can be a lengthy process, therefore the introduction of a specific load modelling requirement threshold must strike a balance between AEMO and NSPs obtaining sufficient information to perform their duties and minimizing the impact of such a requirement on the broader industry.

Traditional transmission power systems are established to meet the electricity demand from loads, which all rely on stable operation of the power system with high power quality. Stable operation and high power quality are maintained by generators, which is the main reason for having stricter modelling requirements for generators than for loads, to verify the generators' capability to maintain such a stable operation. However, the emergence of large inverter-based loads (**IBLs**) can have different transient behaviour compared to that of traditional large loads, and may unintentionally impact power system operation, if such transient behaviours are left unchecked.

A few submissions proposed that, instead of introducing a fixed threshold for general load modelling requirements, a risk-based approach should be adopted determine when a detailed load model would be required during the load connection process, based on consideration of multiple variables including the load size, vicinity to other users, load types, and project investment. AEMO in general supports this proposal, which is also in line with the final determination of the System Strength Impact Assessment Guideline consultation[2], where a project-specific assessment approach is used.

This proposal is likely to be applicable to large IBLs too. The potential impact on power system operation from IBLs can depend on the load size, the presence of existing network users near the connection point, and the control strategy adopted by a specific IBL. For example, an IBL connecting to a strong part of the transmission network may pose a lesser challenge to power system operation, compared to the impact of a much smaller IBL connecting to a radial distribution network. Also, different IBLs, with differing control strategies, may present different risks to power system operation, even if they connect to points with similar grid conditions. It is challenging to prescribe a load modelling requirement threshold, based on consideration of only one or two factors.

4.1.3. AEMO's 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.

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

4.2.1. Issue summary and submissions

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.

AEMO received six submissions on this topic.

AusNet Services Ltd

> This question depends on the grid interface type and the long-term expected strength of its connection point. In general, a large power system load that is using some form of complex power electronic interface where a

[2] Available at https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/ssrmiag/final-report/ssiag-final-report-and-determination.pdf?la=en

control system tracks fast grid-side quantities (e.g., voltage waveforms) and tightly controls the performance of the load should be subjected to more detailed modelling requirements.

For simpler technology types or controllers that operate on grid-side quantities that can be reliably modelled in RMS software (e.g., RMS voltage), a correspondingly simpler model could be provided.

Simplified models are suitable for traditional large power system loads to simplify the modelling and assessment requirements for such load connections.

CitiPower, Powercor & United Energy

CitiPower, Powercor & United Energy (DNSPs in Victoria) submit that the IEEE ZIP and Composite load models (CMLD) are aggregated models, not specific models for a certain type of technology, more detail is required for large IBL loads such as large data centres or hydrogen electrolysers.

CS Energy Ltd

The proposed amendments to the Guidelines are formalising what appears to be happening in practice and will provide the required levels of certainty from a technical and investment perspective. The provision of adequate data on loads can at times be a challenge but for traditional motors, drives, resistive loads etc, the generic load modelling has been considered sufficient for most purposes.

Powerlink

Most of the non-IBL load should be able to represent using the IEEE or composite and DER load models (with the use of appropriate aggregation). However, if a load is connecting to a part of the network which has some existing limitations or foreseen issues, a detailed model might be required. On this basis, Powerlink believes that a decision to request a detailed model if required should be left with the NSP based on network experience.

Kate Summers

IEEE composite models are sufficient. Use conservatism in modelling and engineering reason and judgement and stop placing obligations on industry to suit the pursuit of “accuracy”.

Transgrid

Transgrid believes that the proposed Composite load model, subject to further benchmarking would be acceptable for accurately representing loads in power system analysis. Transgrid believes that DNSPs may be in a better position to comment on this.

4.2.2. AEMO’s assessment

Power system loads are of various sizes, locations, and configuration, therefore it is not practical to model each individual load component in detail, and certain levels of aggregation and equivalencing are required. Currently, the load modelling practice in the NEM has been utilising IEEE ZIP load models and Composite load models, with parameters tuned to reflect the collective behaviour of a group of loads connected within a certain geographical vicinity. They may prudently be accepted as a default option where explicit load models are required and have the advantage that they are relatively straightforward to configure and integrate into either a Root Mean Square (**RMS**) or electromagnetic transient (**EMT**) power system model. Hence by defaulting to generic composite models such as these, requiring a significant number of NEM customers to provide such models for their installations should not be unduly burdensome.

Generic Composite load models would also appear to be most appropriate where the loads being represented are aggregates of many smaller devices (for example electric vehicle [**EV**] chargers). Conversely, where a customer installation is made up of a small number of large, discrete items of plant, there is a strong argument that the load model should represent each of these items explicitly, with configuration that matches the best information available for the real plant. Such custom models are likely to be appropriate for large installations such as data centres, smelters, electrolysers and steel mills, as raised in submissions. These custom models should likewise include explicit representation of transformers and other balance-of-plant items, and such models should be readily available from original equipment manufacturers (**OEMs**).

In addition to the above, some submissions suggested that NSPs should reserve the right to ask for more detailed load models, instead of only relying on IEEE ZIP load models or Composite load models, based on the risk profile of a potential load connection, which may have significant impact on other network users. AEMO in general supports this view and would also like to emphasise that such loads can potentially affect power system security, in particular taking into consideration that loads of significantly larger size than ever are seeking grid connection. Therefore, AEMO and NSPs should jointly determine the need for requiring more detailed load models when the need arises.

4.2.3. AEMO's 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.

4.3. Types of IBL to be considered in the PSMG

4.3.1. Issue summary and submissions

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.

AEMO received four submissions on this topic.

AusNet Services Ltd

> The load-types indicated in the consultation (data centres, hydrolysers) are consistent with AusNet's recent experience.

Powerlink

> Technology continues to evolve and what technology advancements will be seen in future is not known at this point in time. Therefore, identifying load characteristics and its operation is important to decide whether it falls under IBL. For example, there could be large loads that are connected through active front end type converters which rely on tracking grid frequency/angle using a phase locked loop (PLL). This type of loads should also be considered as IBL.

Kate Summers

> As noted previously, the basis of the thinking rests on a flawed understanding of the problem attempting to be solved and the solutions available. One of the best things we can do to increase the robustness of our power system is to increase demand. This proposal will do the opposite and should not be expanded to further sectors.

Transgrid

> Due to potential increase to the demand of Electric Vehicles (EV) in the future and their likely application for power system controls, Transgrid believes that PSMG should include guidance on incorporating EVs in load modelling.

4.3.2. AEMO's assessment

The proposed load modelling requirements focus on two types of loads:

- Large traditional loads, such as smelters and industrial processing facilities.
- Large IBLs, such as hydrogen electrolysers.

As recommended in Section 4.1.3 of this report, the application of the load modelling requirement can be assessed on a case-by-case basis, with different levels of load model requirement for loads of different risk profile assessed by AEMO and the NSP. This would allow AEMO and NSPs to acquire necessary modelling information as prescribed in NER, while providing sufficient flexibility for streamlining the connection process of loads with minimum impact to power system operation.

In terms of the inclusion of EV loads as suggested in the submissions, the impact of such loads on power system operation and security are likely to be similar to DER (mainly in the form of rooftop PV), due to the diversified deployment location within a certain geographical region, which is likely to involve distribution substations. Compared with large single loads connected to centralised locations, such geographical diversity for EV loads can limit their impact at any specific node in the power system. Also, the aggregated impact of EV loads on a regional transmission network is not yet clear, compared to, for example, the impact on under frequency load shedding (**UFLS**) capacity from a high penetration of DER, which was the trigger for AEMO to develop the DER and Composite load models to assess the impact of DER. However, AEMO also acknowledges that the impacts of EV loads are cumulative and could be material once the deployment rate of EV has reached a certain level.

4.3.3. AEMO's 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.

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

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.

AEMO received four submissions on this topic.

AusNet Services Ltd

> In addition to IT devices behind the UPS, generally cooling equipment are controlled by decentralised variable speed drives (VSD) with filters.
>
> Where the majority of load is being fed through the UPS and VSD, RMS & EMT models of the UPS and VSD are required. UPS and VSD models can be aggregated appropriately in the site-specific model.

CitiPower, Powercor & United Energy

> CitiPower, Powercor & United Energy submit that IEEE and CMLD models are aggregate models, not specific models for a certain type of technology, they are not sufficient for large IBL loads such as large data centres or hydrogen electrolysers.

Kate Summers

> Composite models are all that is required and site specific modelling should not be necessary.

Transgrid

> The proposed composite load model seems to have enough adaptivity to broadly reflect the data centres, but more measurements may be required to best use the proposed model.
> Transgrid also note that if one specific vendor is the dominant data centre load type, perhaps a vendor specific model can be a better representative.

4.4.2. AEMO's assessment

Sensitive electronic loads such as data centres are generally protected from loss of supply using an uninterruptible power supply (**UPS**). UPS installations typically connect between the load and the network supply to provide continuous supply to the load during network interruptions. UPS installations include sufficient storage to enable supply to the load during an interruption and can include additional backup such as diesel generation.

Some UPS installations do not attempt to ride through system disturbances but rather deliberately disconnect during fault conditions to ensure continuity of supply to the sensitive load. Some other UPS installations provide continuous supply to the sensitive load while riding through most disturbances in the power system.

If the generating units of a UPS system connect to the network, these units are subject to the connection requirements of NER S5.2. The generating units only connect to the network for a very short time (2-30 seconds for resynchronisation of the load to the network) and are not intended to provide a continuous export capability to the network. Therefore, in many cases where the combined generator nameplate is greater than 5 megawatts (**MW**), the generating units may be exempt from the registration and technical requirements of NER S5.2.

A new technology-neutral category of registered participant, the Integrated Resource Provider (**IRP**), has recently been introduced for a type of connection called an integrated resource system (**IRS**). NER S5.2 will apply to IRSs, which include a range of plant combinations with two-way energy flows such as grid-scale storage, hybrid projects, and aggregators of small generation and storage units. Currently under the IRS arrangements:

- Loads and UPS loads that do not have export capability will not be recognised as IRSs;
- UPS loads that have export capability will be recognised as IRSs; and
- UPS loads that wish to provide frequency control ancillary services (**FCAS**) will also need to meet the market ancillary services specification (**MASS**).

Therefore, under the current AEMO guidelines[3] a UPS load greater than 5 MW is likely to be treated like a generating system, and under the Integrating Energy Storage in the NEM rule, the combined UPS and load centre may be treated as an IRS if the UPS is considered to be a bi-directional unit. However, it would be difficult for a UPS to meet the NER 5.2 access standards, for example continuous uninterrupted operation (CUO) under S5.2.5.4 and S5.2.5.5, reactive current injection, active power recovery time, as well as other clauses.

AEMO has decided not to treat UPS loads differently to other large loads for this review. Their technical commercial constraints have been considered in other policy positions and reflected in proposed amendments to NER S5.3[4].

4.4.3. AEMO's recommendation

Based on the above consideration, AEMO recommends the Composite load model to be the default dynamic load model template for data centre loads, and a set of suitable model parameters should be developed to represent these loads in corresponding power system studies. AEMO and NSPs may

[3] AEMO, "Guide to generator exemptions and classification of generating units", at https://aemo.com.au/-/media/files/electricity/nem/participant_information/new-participants/generator-exemption-and-classification-guide.pdf?la=en.

[4] AEMO, "Review of Technical Requirements for Connection", 4 April 2023, 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

request a more detailed model for data centre loads, especially when the data centre UPS system has the potential to interact with the power system immediately following a disturbance (that is, the UPS system would attempt to reconnect the data centre during post-contingency voltage recovery).

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

4.5.1. Issue summary and submissions

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.

AEMO received four submissions on this issue.

AusNet Services Ltd

> Similar to protection and control systems modelled in the generating system models, events that may cause undue tripping due to an upstream disturbance such as RoCoF, under and over frequency , under and over voltage , faults (inc. multiple faults), large phase angle shift, loss of phase, excessive harmonics, uncontrolled instability, commutation failure, etc.

Powerlink

> Dynamic characteristic of a load for fault ride through should be represented in the model appropriately. Therefore, it is important to model control and protection functions (e.g. voltage and frequency protection) that can affect the continued operation of a load. If the load size is significant (with respect to the network conditions), load loss during a transient disturbance and its recovery from the fault should be accurately represented in the model.

Kate Summers

> None

Transgrid

> Protection systems that impact ride through of load during frequency or voltage disturbance events need to be modelled. In this regard, the proper modelling of the voltage-slip characteristic is crucial for induction motors; and RoCoF or power angle change for IBL.
>
> Transgrid also notes the importance of On-line Tap Changer (OLTC) and capacitor banks if they exist within the load.
>
> Control systems that may impact recovery from a disturbance also need to be considered. This can include behaviour of soft-starter or variable speed drives (VSD)/variable frequency drives (VFD).

4.5.2. AEMO's assessment

Electrical protection system design and analysis has traditionally been a specialisation of secondary system engineers, including protection due-diligence checks for sensitivities and securities against power system events as well as design redundancies. In certain cases, detailed modelling of protection systems is called for when there is a threat to wide-area system security due to unintended operations. A notable example is power swing blocking on distance relays installed on key transmission interconnectors known to be susceptible to inter-area oscillations. Other common elements that are considered for system studies include under/over voltage and under/over frequency relays.

AEMO considers that load protection model requirements must be fit for purpose, and further agrees with the submission that the purpose of protection system modelling in the context of the PSMG is not to check for individual protection system design performance or grading compliance, but to capture:

- Any potential impact of one or multiple large loads tripping, with known tripping schemes in place, on post-contingent power system recovery and the stable operation of other network users and generators.
- The likelihood of load unintended tripping in future power system operating conditions, likely with newly connected loads and generators

In addition, AEMO is currently conducting industry consultation for the NER S5.3 rule change proposal[5], with the intention to establish ride-through capability performance standards for single large load facilities. AEMO's assessment for the PSMG amendment has considered the above consultation process. Under the intended rules change proposal, the proponents may need to demonstrate compliance to relevant load fault ride through performance standards using load models with relevant protection systems.

AEMO is in general supportive of NSPs' view in submissions, that relevant protection systems which can affect the ride-through capability of loads need to be modelled, especially for emerging large load connection applications where compliance to relevant ride through capability performance standards may be required under NER S5.3[4] in the future. This is in line with relevant modelling requirements for generator protection systems, where the generator's compliance to relevant ride-through capability performance standards is required under clauses including NER S5.2.5.3 and S5.2.5.4.

On the other hand, it is noted that most of the large loads which exist on the NEM are composite in nature, including complex auxiliary systems, and it is generally difficult to identify the specific group of elements within complex processing plants that can lead to the common mode of tripping. For different tripping mechanisms, different protection devices will be required, and the modelling of certain protection elements can be a complex process, particularly for EMT simulation, depending on the type of protection, and the relevant relay measurement methods and algorithm which vary between different relay OEMs. AEMO considers it is impractical to mandate a blanket requirement to include all protection relays in the load models.

4.5.3. AEMO's 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 rule change proposal[4].
- 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

[5] AEMO, "Review of Technical Requirements for Connection", 4 April 2023, 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

Guides (**RUGs**) as per the current connection application requirement, and hence will not be further discussed in the ‘protection’ category here.

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.

Five submissions were received on this issue.

AusNet Services Ltd

> Similar to what is expected for generation, potentially with an additional clarification that if harmonic emission limits will be adequately addressed by some other means, then EMT average models are acceptable (i.e. fully switched models are not needed). Models can be aggregated appropriately based on the configuration of the load.
>
> Much like generators, the RMS model will likely only be capable of representing the response of the protection and control systems that act on quantities representable by the RMS domain. The EMT model will be expected to represent more accurate protection and control systems consistent with the with the actual controllers that are relevant in terms of impact to the wider grid.

CitiPower, Powercor & United Energy

> CitiPower, Powercor & United Energy submit that RMS model will not capture the switching frequency of IBLs, this is a similar issue seen with RMS models of IBRs. Therefore the same level of detail that has been required of IBRs should also apply to IBLs.

CS Energy

> To avoid unnecessary costs and requirement for unbudgeted resources to perform or redo studies, CS Energy would support the specification of approved models consistent with the PSMG being available to the Original Equipment Manufacturers (OEM) from the onset to ensure the provision of required information fidelity and quality of data and models provided by the OEMs.

Powerlink

> IBL could have similar impact as IBR on power system performance in terms of system strength requirements, FRT performance, voltage control etc. Therefore, the accurate modelling of IBL is required and the modelling requirements similar to the requirements for the inverter based asynchronous generator models should be required in both RMS and EMT domain models.

Transgrid

> Transgrid suggested that the following details for IBL models should be considered:
>
> - Dynamics of active and reactive power response in the event of voltage and frequency disturbances in both EMT and RMS.
> - Transformer energization, saturation curves, and other impacting factors for inrush studies in the EMT domain.

4.6.2. AEMO’s assessment

The main purpose of RMS and EMT simulation is to identify potential power system stability issues and, to a certain extent, time-domain verification of small signal stability issues. High frequency phenomena, such as harmonic distortion or resonance, can be captured using other dedicated simulation platforms and models, therefore the use of average models for inverter-based resources (**IBR**) for stability analysis has been deemed appropriate, and AEMO considers that the same convention should also be applied to an IBL load model.

Under the current NER, an IBL is defined as:

> "A load that is supplied by power electronics, including inverters, and potentially susceptible to inverter control instability, and that is classified as an inverter-based load applying criteria specified in the system strength impact assessment guideline".

In addition to the modelling requirements proposed in Section 4.5.3 of this report, to capture IBLs' potential susceptibility to inverter control instability, relevant control systems (such as PLLs and other synchronisation mechanisms) must be represented in the IBL model. Other control systems that regulate the active power and reactive power behaviour of IBLs at the grid interface following voltage and frequency variations must also be represented in the IBL model. For IBLs intending to provide grid support services, all control systems which regulate the provision of such grid support services must be represented in the IBL model.

4.6.3. AEMO's recommendation

AEMO supports the view from the submissions that a similar modelling requirement for IBR should be applied to IBL models, when a more detailed IBL model is required by AEMO and NSP, instead of the IEEE ZIP model or a Composite load model. AEMO also acknowledges that IBLs may have different control strategies compared to those of IBR and may not necessarily contain all the control components which are commonly seen in IBR. AEMO recommends a case-by-case approach, with the intention that the IBL modelling must contain control systems susceptible to stability issues which are sensitive to variation of grid operation conditions, especially those control systems that rely on tracking of the grid voltage or current waveform and interact with the power system instead of only drawing energy from the grid.

4.7. Black start model requirement for large power system loads

4.7.1. Issue summary and submissions

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.

Four submissions were received on this issue.

AusNet Services Ltd

> Very large loads are unlikely to be picked up during the early stages of black start which most black start simulations cover. That is, unless that load is capable of providing Restoration Support Service by operating in a special mode or with capability that it would otherwise not operate with. For example: constant power, rampable, controllable, providing voltage support. In this case a full load meeting the requirements of a black start study would be valuable, but there would likely need to be some form of Restoration Support Service contract in place (or intent to tender). Unless a large power system load intends to enter into a Restoration Support Service contract, RMS and EMT models do not require explicit additional modelling for black start simulations.
>
> Auxiliary loads of SRAS providers should be explicitly required by the guidelines (e.g., Induced Draft Fans, Boiler Feed Pumps, etc. of coal plants).

CitiPower, Powercor & United Energy

> CitiPower, Powercor & United Energy have a diverse range of customers that connect to our networks. Some of our customers are deemed essential services and provide extremely critical infrastructure such as Hospitals, Fire Stations, Police Stations, Traffic Infrastructure, Transport (Train and Tram) Infrastructure, Water, Sewerage Treatment, and Waste Treatment.
>
> Considering these customers, CitiPower, Powercor and United Energy believe that large data centre loads, and hydrogen electrolysers may not be the most critical customers to re-energise after a system black event, and therefore black start simulation models for these customers may not be required.

CS Energy

> currently the simulation model requirements apply to parties contracted for System Restoration Ancillary Services (SRAS). Does AEMO propose to extend the modelling requirement to Local Black Start Procedures? CS Energy would expect that the simulation model requirement for large power system loads to be the same for normal operation and black start conditions.

Transgrid

> Transgrid believes that correct load rating, transformer energisation (POW or pre-insertion resistor (PIR)) and saturation characteristics, large scale motor starting and its ride through capability, auxiliary reactive plants (if any) can be critical for loads that participate in black start.

4.7.2. AEMO's assessment

AEMO agrees that certain types of IBLs, such as data centres, might not be willing to participate in the system restoration process, to minimise the risk of ongoing interruption to their services. In addition, not all loads have the capability or willingness to offer Restoration Support services. Therefore the black start model requirement for large single loads is only useful when they are participating in the restoration processes or provide Restoration Support services. In the latter case, the black start model requirement for IBLs should be similar to the requirement for IBR.

4.7.3. AEMO's 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.

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.

Four submissions were received on this issue.

AusNet Services Ltd

> As far as practicable during or immediately following commissioning, validation should occur against the load's performance standard, with ongoing permanent monitoring to validate the model's response to system disturbances throughout the life of the plant. R2 validation report (model validation) and commissioning report (performance validation) may be submitted as a single report within a reasonable timeframe following commencement of commercial operation.

CitiPower, Powercor & United Energy

> CitiPower, Powercor & United Energy submit that an R2 validation process similar to that applicable to IBRs should be applied to IBL too.

Powerlink

> For non-IBL, sufficient data (variation in active and reactive power for voltage disturbances) should be captured for model validation during commissioning and testing of plants. Parameters in the composite and DER model should then be tuned to match the load response.
>
> For IBL, a similar accuracy level to current inverter based asynchronous generator R2 validation should be used.

Transgrid

> The key tests are the responses of the load to voltage disturbances such as system faults (under ongoing monitoring where possible), transformer tap changer or capacitor/reactor switching. The response to frequency change can only be limited to any system incident (if it happens during R2 or under ongoing monitoring).
>
> If the Composite load model is going to be used for the modelling, the key part of the R2 process should be validating the proportion of the aggregated load indices so that the model can correctly represent the proportion of each sub-component. If there is an opportunity to perform modelling of each component of composite load model (for example motor type 1 first and then type 2, and so on), it would make fine-tuning of the model parameters easier.
>
> In addition to R2 testing, Transgrid sees the value of vendor-specific hardware-in-the-loop (HIL) tests that are common in large loads such as data centres.

4.8.2. AEMO's assessment

The existing R2 validation process for generators uses on-site commissioning test results and high-speed recorded data obtained from ongoing generator compliance monitoring. In the absence of a uniformed commissioning process for load connections, it is challenging to prescribe how the R2 validation process should be carried out for load models, as the success of the R2 validation process depends on the availability of on-site commissioning results.

Subject to agreement with AEMO and NSPs, if the Composite load model is used to represent the load facility, the proportion of each Composite load model component must be selected according to the facility configuration. R2 validation can be used to verify load model dynamic response limited to active power and reactive power behaviour of such loads following voltage and frequency variation, considering the Composite load model is only a generic model which carries an inherent level of approximation to the aggregated load behaviour.

For load connection where a more detailed load model is required, it is noted the required R2 validation process in the existing PSMG is categorised under each clause of the generator performance standards. AEMO is currently conducting NER S5.3 rules change consultation[6], and this rule change proposal intends to establish load performance standards in terms of fault ride-through capability, in a similar fashion to those of the NER clause S5.2.5.3 and S5.2.5.4 for generators. There may be a future opportunity to develop further load performance standards and an associated commissioning process, following which the R2 validation process for load models can be further developed accordingly.

4.8.3. AEMO's recommendation

AEMO considers the definition of the load R2 commissioning process is beyond the scope of this PSMG review. In the absence of a load R2 commissioning process, AEMO considers the load R2 commissioning process should provide sufficient guidance for the verification of the suitability of parameters of IEEE ZIP or Composite load models when such load models are used to represent load facilities. For IBLs where more detailed load models are required by AEMO and NSPs, AEMO recommends that the R2 validation process for such IBLs be subject to the same accuracy requirement as that applicable to IBRs in the PSMG.

[6] AEMO, "Review of Technical Requirements for Connection", 4 April 2023, 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

4.9. Requirement for model provision in Section 7.4 of PSMG

4.9.1. Issue summary and submissions

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

Four submissions were received on this issue.

AusNet Services Ltd

> If the intent is to collect IBR load models that have similar capability and detail to that of generator models, then the same requirements should apply to load models. If simpler loads are adequately representable by composite or ZIP models, then the requirements should be relaxed. Essentially if the only way to properly represent the load's performance is with detailed RMS & EMT models, then similar requirements need to apply.

CitiPower, Powercor & United Energy

> CitiPower, Powercor & United Energy submit that an identical level of data required of IBLs as Generators.

Powerlink

> For IBL, a similar model provision approach to inverter based asynchronous generators should be used, as the studies would be required to agree and finalize plant performance.

Transgrid

> Transgrid believed that there are parts in Section 7.4 of the PSMG that may not apply to load models, at least not to all load models. Transgrid will provide further details in the review of the proposed guideline.

4.9.2. AEMO's assessment

Load model data, especially that of IBLs, can still include control system structure and algorithms which can be classified as intellectual property of an OEM. Load composition data may also reveal the production capacity of a certain industrial facility, which the facility owner may wish to keep confidential from its competitors.

4.9.3. AEMO's recommendation

Based on the above consideration, AEMO recommends that the existing requirement and conditions for generator model provision under Section 7.4 of the current PSMG (i.e. 2018 document[7]) be applicable to load model data, including that of IBLs.

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.

Four submissions were received on this issue.

AusNet Services Ltd

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

AusNet does not have a firm opinion at this stage, other than the expectation that this should be determined by the Power System Modelling Reference Group and drawing on any specialist consultants used during the guideline update process.

CitiPower, Powercor & United Energy

CitiPower, Powercor & United Energy submit that a similar level of validation that has been required of IBRs should be applied to IBLs, similar to "Section C.4 Converter-based energy storage system" of the current Power System Model Guideline.

Powerlink

Control and protection systems which are sensitive to grid disturbance should be appropriately modelled in both RMS and EMT domain models. For example, model of a large data centre should include grid disturbance protection system associated with the Uninterrupted Power Supply (UPS) backup system which performs transfer from grid supply to the UPS supply during a network disturbance to study the impact of load rejection/tripping on the power system stability.

Transgrid

Composite load model components can be included in Appendix C for IBL, similar to the tables under C.4.1.

4.10.2. AEMO's assessment

Certain IBLs have close resemblance to converter-based energy storage systems – for example, UPS load interfaces, and hydrogen electrolyser facilities equipped with fuel cells – which results in bi-directional flow at the facility interface with the grid.

The requirements on model components for converter-based energy storage systems are listed in Section C7.1 of the current PSMG, for both hardware components and control systems.

It is also noted that IBLs may not possess all control systems described in Section 7.1 of the current PSMG for converter-based energy storage systems. The requirement for model components must depend on the presence of each control system in the actual IBL facility.

4.10.3. AEMO's recommendation

AEMO recommends adopting the same tables for model components as in Section C.4 of the current PSMG for IBLs, subject to the presence of each control system in the actual IBL facility.

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

4.11.1. Issue summary and submissions

EMT models, in particular those for IBR, are intricate and often contain the 'real code' or firmware utilised in the actual controllers. AEMO utilises these models for assessing a plant's performance during connection and for managing power system security in the operational timeframe. As such, it is critical that these models can be used by AEMO for the lifetime of the plant, which could be several decades.

There is no official standard or guide for developing these models and the majority of models received by AEMO to date are highly susceptible to obsolescence. This is because OEMs provide AEMO with 'blackboxed' components – parts of the control system that have been obfuscated by compiling the model into non-human-readable machine code to protect the intellectual property contained in them. There are multiple methods to link the blackboxed code to a simulation tool, however, most create a heavy dependency on the specific model developer's compiler toolchain and to PSCAD itself. This means that to run the provided model requires the user to have the exact same toolchain, compiler version and version of PSCAD as was used to create the model. Migrating to newer compiler versions, newer versions of PSCAD or a different EMT simulation tool altogether (for example if PSCAD itself were to become obsolete), while still being able to use the model, is impossible in this scenario.

In the consultation paper, AEMO presented a method to avoid the issue of obsolescence. The proposal was for OEMs to provide DLLs that conformed to a standardised interface developed by AEMO. Because a DLL file is self-contained, it has no dependencies on compilers, linkers or external static libraries; it has no references to intrinsic PSCAD / EMTDC variables and functions and can be run from any software that implements the "LoadLibrary" and "GetProcAddress" functions. In addition, intellectual property is protected, as all control system code is still obfuscated as machine code inside the DLL.

Nine submissions were received on this issue. In several submissions, there was a misunderstanding that the interface code and example provided in the consultation paper were the actual interface being proposed by AEMO. The code was only provided as an example to demonstrate the concept and promote discussion, and was not intended to be the actual implementation of the interface.

AusNet

> PSCAD model with external dynamic link library (DLL) – This is the most viable option, with explicit linking. However, it would be important to ensure that the environment that DLL is expecting is future-proofed to the extent possible (i.e., 64-bit as a minimum) with required external libraries
>
> …
>
> The proposal would also need to be reconciled against any international standards (IEEE or CIGRE) for EMT modelling standards currently being developed.

Goldwind

> DLLs can still have dependencies on re distributable packages (e.g. Visual Studio 2010 Shell or C++ redistributables). We seek clarification if AEMO has particular expectations around such dependencies or whether such dependen cies would still be acceptable.
>
> …
>
> As part of the development process, we recommend that AEMO engage (if not already engaged) with the IEEE and CIGRE working group with the view to unify requirements that would come out of the working group.
>
> …
>
> In the proposed arrangement, we would expect that the open source interface block would have inherent capabilities around snapshotting.

OPAL-RT

> OPAL-RT thinks AEMO should rather use a standard interface that already exists and that is supported by various software vendors. Ex:
>
> - CiGRE B4.82 WG - Use of real code in EMT Models for Power System Analysis
> - IEC 61400-27-1 - 2015-02 - Wind turbines – Part 27-1: Electrical simulation models – Wind turbines
> - Simulink Coder / Embedded Coder
> - FMI standard (https://fmi-standard.org/)

PGSTech

> The important features mentioned above are currently missing from the AEMO standard. However, they are already available in the standard proposed by the joint IEEE TASS Task Force and Cigre B4.82 Working Group "USE OF REAL-CODE IN EMT MODELS FOR POWER SYSTEM ANALYSIS". The development of the AEMO standard will likely make it look more and more similar to the one proposed by the IEEE/CIGRE joint working group, and thus it is not clear why a new standard with similar scope and requirements is needed. A standard already exists and might be improved to accommodate further needs.

RTE International

> Only 2 types of input / output signals are possible in the proposed interface: integer and real. Strings of characters are accepted in the IEEE/CIGRE DLL interface.

TransGrid

This is a reasonable approach; however, TransGrid believes that further discussions with vendors are required to address all the possible future scenarios.

Siemens

We would like to highlight that PSCAD models are in general forward compatible for new intel compilers as highlighted by the Manitoba Hydro1 (MHI). It is likely that the model compatibility issues are only experienced for PSCAD models from some manufacturers.

…

One alternative to the options that AEMO has considered to ensure PSCAD models remain usable for the life of the plant is that service agreements for model updates and support could be entered into either directly between AEMO and OEMs, or between OEMs and market participants to ensure continued availability of model updates.

…

Having a specific .dll interface defined by AEMO may not provide any benefit regarding compatibility for OEMs who's PSCAD models are already forward compatible, yet will force PSCAD model re-work for the models, .dlls generation process and tools, for all OEMs.

…

Our proposal would be that, instead of a requirement for OEMs to adhere to a strict .dll interface template, a set of rules/specifications for the interface development are created, such as a requirement for explicit linking, and prohibition of non-Fortran code in the interface file. This allows each manufacturer to create a specific interface that best fits their needs. This would be enough to assure compatibility across versions, while imposing a lower cost on the industry to implement.

GE

AEMO's main concern seems to be that models written using intrinsic PSCAD components/functions such as control (filter, integrators, etc) and circuits (R,L,C, transformer, machine, IGBT switch, etc) will not be exportable or compatible with other EMT platforms. Therefore just having an external DLL file which only consists of the control part of the model may not be the full solution to the problem. A better approach could be to avoid using intrinsic PSCAD components as much as possible.

…

The DLLs in PSCAD might not always work with the new platform(s). Also, mention of "real code" in the guideline may be misinterpreted. The guidelines need to recognize that the model should be built based on manufacturer-written code, which could either be a direct replica of the controller firmware or could be a close match.

Tesla

Tesla proposes that 12 months from the release of the final report should be provided to industry to enable compliance.

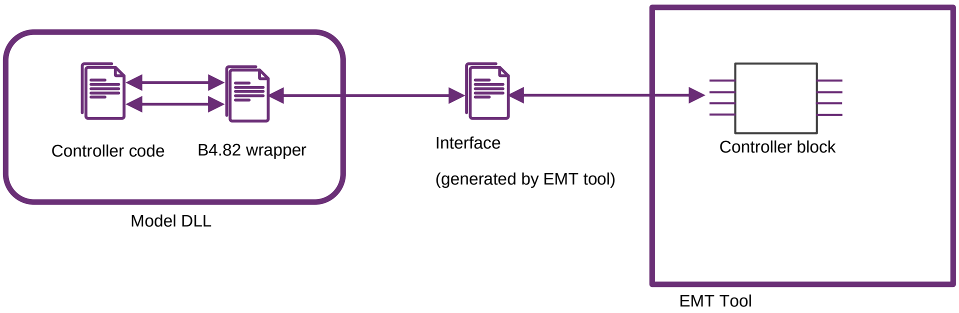
4.11.2. AEMO's assessment

AEMO agrees with several submissions that pointed out that developing a custom interface from scratch for OEMs to adhere to would add unnecessary complication for both AEMO and OEMs, especially given that the Joint Working Group (JWG) B4.82/IEEE wrapper aims to standardise the requirements for DLL provision (all inputs, outputs and parameters, and simulation time step). Many manufacturers have already started provisioning models compliant with the B4.82 wrapper. AEMO believes that the B4.82 interface will address most concerns raised about the structure of the DLL and interface.

B4.82 Wrapper

The B4.82 wrapper implementation is summarised in the figure below.

Figure 1 B4.82 wrapper implementation



Contained inside the model DLL file is the control code as generated from Matlab/Simulink or otherwise, and B4.82 wrapper code. The wrapper code exposes several standardised functions to external simulation tools and connects them to the relevant functions inside the controller code.

The following table lists some of the functions defined in the JWG B4.82 wrapper.

Table 4 Summary of some functions defined in the B4.82 wrapper

Function	Purpose	Called
Model_GetInfo	Returns information about the DLL such as model version, fixed time step, number of inputs, outputs and internal state variables. Used by the simulation software to generate the interface code.	During compilation (by simulation tool)
Model_Initialize	Allows the controller code to initialise, or to recover from snapshot data.	At T=0 or when recovering from a snapshot
Model_Outputs	Transfers port inputs / outputs between the simulation tool and the DLL, Executes a time step and updates state variables.	At each time step (time step size defined in "Model_GetInfo").

A standard data structure "IEEE_Cigre_DLLInterface_Instance" is defined to facilitate data transfer between the simulation tool and the DLL. This data structure contains storage arrays for port inputs and outputs, model parameters and states. This structure allows different data types and can therefore be used in any power system simulation program.

The implementation of the JWG B4.82 wrapper requires that the simulation software itself contains a "DLLImport" tool. This tool would automatically generate the block and interface code from the DLL by utilising the "Model_GetInfo" function. In this way model developers will ideally not even need to write an interface.

DLL external dependencies

Regarding external dependencies of DLLs, AEMO has observed a similar issue where DLLs contain external dependencies to redistributable packages. This has been identified by running the "dumpbin /imports" utility on the DLL in question. The resolution has been to include the specific redistributable DLL (for example "msvcr100.dll" for the Visual C++ redistributable) with the wide area model and linking it to the simulation using the PSCAD V5 resource manager as per any other DLL.

Custom code blocks and scope of blackboxing

In the consultation paper, AEMO proposed that all custom code be placed in a DLL and that blackboxing of electrical components be restricted, with only standard library electrical components used. The motivation for this is that the inbuilt "blackbox" functionality of the current preferred EMT tool generates a static .obj library file containing the blackboxed code. This code is tied to the compiler toolchain and specific version of this tool and therefore makes future compatibility difficult to ensure.

Two concerns were raised in submissions:

- Goldwind raised that it is common to use custom code blocks that would be too difficult to derive as a block diagram using standard library components, but not large enough to consider placing in a DLL. AEMO believes that these custom blocks can continue to be used provided the code is either purely contained as a PSCAD script segment and / or provided as an uncompiled Fortran file.
- GE raised that custom electrical components are required if the standard library models are insufficient or if the plant electrical components are to be run at a smaller timestep than the rest of the electrical solution. GE also mentioned that not blackboxing electrical components would prevent export to other EMT platforms. AEMO believes there are advantages and disadvantages to both. Custom electrical components are harder to debug, are difficult to make compatible with snapshots, and are not able to take advantage of switching interpolation for faster simulation. However, so long as there is no use of static library files AEMO may still allow these types of models.

4.11.3. AEMO's recommendation

AEMO proposes the following criteria for an EMT model package:

- Any external *compiled* code must be provided in the format of a DLL in both 32- 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.

AEMO's preferred approach for OEMs to achieve the above criteria is for DLLs to implement the JWG B4.82/IEEE wrapper.

AEMO will accept DLLs that utilise redistributable libraries, so long as the redistributable DLL file (for example "msvcr100.dll") can be included with the model and successfully run without having to install the entire redistributable package. All other dependencies must be linked inside of the DLL file.

AEMO will also allow custom code and electrical blocks provided that they are implemented as a PSCAD Fortran script segment or an uncompiled Fortran file.

To allow a smooth transition to these new requirements, a 12-month transition period is proposed following formal IEEE/CIGRE publication of the finalised JWG B4.82/IEEE B4.82 wrapper documentation.

4.12. Provision of model source code

4.12.1. Issue summary and submissions

Three submissions related to handling of model source code.

AusNet

In terms of model longevity, AusNet invites AEMO to consider holding the source-code of both the real device and EMT model in escrow. This is described in CIGRE Technical Brochure 881 (section 3.7.1.1.2).

…

Are there any changes needed to PSSE dynamic model source code or structures if the industry moves to compiling in 64-bit to be able to use PSSE v35+?

Powerlink

An escrow requiring connecting parties to supply either an open-source variant of the source code, or all relevant files, including dynamic-link libraries (DLLs), that will provide for the software to be compiled in a platform-independent manner, from the plant's OEM. A software escrow is a service that helps protect all parties involved in a software licence by having a neutral third party agent hold source code, data, and documentation until a mutually-agreed-upon event occurs. A further obligation on connecting parties (which would be passed on to OEMs) to update NSPs, AEMO and the AER with current source code at the time updates are made.

The proposed escrow arrangement would allow release of the files to AEMO under specified circumstances, such as where the OEM has withdrawn its presence from the Australian market or it no longer operates as a going concern. The function of the escrow agent would therefore be to hold 'legal custodianship' of the files rather than to use the models themselves.

TransGrid

TransGrid has suggested that availability of PSCAD source code is a key input into long-term compatibility of models with different simulation tools and versions. TransGrid also propose that any source code should be available to NSPs and not only AEMO.

4.12.2. AEMO's assessment

The concept of an escrow arrangement to hold model source code has been considered and discussed by the PSMRG. However, AEMO is of the opinion that such an arrangement is of a legal nature rather than technical and as such should not be placed in the PSMG. This topic is under consideration as part of the Connections Reform Initiative (**CRI**).

In regard to PSS®E source code, AEMO agrees that the PSMG should be flexible enough to allow future versions of simulation tools.

4.12.3. AEMO's 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 4.3.10 "compatible with PSS®E version 32 or 34" be changed to "compatible with PSS®E version 34 or greater".

4.13. Inclusion of Remedial Action Schemes

4.13.1. Issue summary and submissions

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.

Two submissions were received.

AusNet

AusNet generally supports the inclusion of remediation action schemes but has a number of questions. How can the models be tested and validated or would they be exempt? In PSSE, should it be provided as a Python script? And in PSCAD, built from library components only?

CS Energy

...the modelling requirements for RAS should be included in the Guidelines with a reference to the Power System Model Guidelines for the actual details and requirements.

…

The NEM technical envelope consists of the network generation systems and loads that achieves power system security partially through the utilisation and incorporation of the RAS. The number and sophistication of RAS utilisation continues to increase.

4.13.2. AEMO’s assessment

According to the RAS Guidelines, models should be developed utilising standard or generic library components if possible, in both RMS and EMT tools. If more detailed modelling is required, Fortran code is acceptable in PSS®E.

Where a model for a RAS scheme has been provided under the circumstances set out in section 2 of the Guidelines (such as an inter-trip scheme), then all sections of the Guidelines should apply as it is part of a wider plant model. Where a model has been provided at the request by AEMO from an NSP (such as for a wide-area-protection-scheme), then detailed modelling requirements should be agreed on between AEMO and the NSP and should refer to section 4 of the RAS Guidelines.

4.13.3. AEMO’s 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.

4.14. Integrating Energy Storage Systems rule change

4.14.1. Issue summary and submissions

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.

One submission was raised regarding the IESS Rule Change.

AusNet

AusNet supports the inclusion of IESS in the Guidelines. Treatment should be consistent with other technologies referenced in the guidelines.

4.14.2. AEMO's 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.

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. It is arguable that use of such legacy models is not consistent with the PSMG as developed subsequently.

In particular, an augmentation to existing plant (for example, to add parallel energy storage to a generating system) may under NER S5.5.7(b1)(1) trigger a requirement to provide new models meeting current PSMG for the entire plant, even where the legacy system is otherwise unchanged.

Two submissions raised the subject of legacy model requirements and potential burden on participants.

AusNet

> In regards to the question surrounding the use of generic models, AusNet believes it should be first demonstrated to the satisfaction of AEMO and the NSP that the cost, time or effort to obtain the actual legacy plant model is disproportionate to the benefit it will provide before approval is given to use generic models.
>
> Furthermore, if the use of a generic model is approved, there must be consideration given to install permanent high-speed monitoring at appropriate points within the plant (if it does not already exist) as it could take years if not decades to secure enough data to correctly tune the model.
>
> AusNet does not yet hold a firm opinion on the proposal to split the modelling of control system componentry in the EMT model of legacy plant, as this is likely to be specific to the plant to be modelled, and the interaction between the main control loops may be unknown. AusNet intends to engage further on this matter through the Power System Modelling Reference Group.

Clean Energy Council

> Feedback from CEC members revealed several project risks when attempting to retrofit a BESS behind an existing connection point the grid connection process.
>
> - The pursuit a 'perfect' model instead of using a 'good enough' one, could materially delay the progression of the project. In some case, this delay was so significant, or intractable, that the project was abandoned.
> - The requirement to develop a detailed EMT models for the associated legacy plant behind the connection point - even when the NER did not require EMT models to be developed at the original time of connection.

This has major cost implications where the original OEM no longer exists, or where support contracts with the OEM have expired.

- The specific risk that seeking to add a BESS to an existing plant will trigger a clause 5.3.9 review. Many members expressed concern that the legacy asset GPS would be reopened and potentially forced up to the level of capability established in the latest NER defined generator access standards (especially for pre 2018 connected plant).

...

While we look forward to addressing these issues through the PSMG consultation, we are concerned that the proposed approach of requiring only certain control loops to be represented in the new EMT model will not adequately resolve the underlying issues faced by industry:

- The control loops mentioned - voltage, reactive power and fault ride-through - are in fact the control loops that CEC members have identified as being most problematic. Hence our understanding of AEMO's indicative approach is that it may not do enough to change the status quo.
- AEMO's existing approach lacks sufficient detail on how other matters will be managed. For example, RMS/EMT model alignment issues, timeframes for resolving issues, and not meeting all the requirements of the PSMG, etc.

...

Given that it may not be feasible for a legacy plant model to meet all the current requirements, flexibility is required both in meeting all the requirements in the PSMG & DMAT as well as the timeframes for resolving these issues. The PSMG & DMAT were not written with the intent of applying to legacy assets, and expecting a legacy asset to meet the current requirements is often impractical.

4.15.2. AEMO's assessment

Although the 'grandfathered' status of legacy models and the triggering of requirements for the provision of new models are matters under NER S5.5 rather than the PSMG, it is the PSMG that prescribe the nature and extent of any new model information that must be provided.

Adding a Battery Energy Storage System (**BESS**) or other grid-supporting plant to an existing generating system or Customer installation would allow efficient use of the existing assets. This modification will require the provision of both RMS and EMT models for the 'brownfield' legacy plant, validated to current scope and accuracy requirements. From practical experience, in some instances the provision of such models by the project proponent may be challenging due to the reasons pointed out in the submissions. Sections 8.3 and 8.4 of the current PSMG have made provision for proponents to provide alternative models and information to those specified in the current PSMG, subject to AEMO's agreement. While such provision has been made under the current PSMG, the implementation of such provision, such as the timeframe to provide these alternative models and information, is beyond the scope of this review, and could be discussed in other process reviews.

However, when deciding whether to accept or reject a request made under Section 8.3, AEMO and NSPs need to assess the potential impact of the plant to be connected on power system security, including potential interaction between the new plant and the legacy plant. Without sufficient information regarding the legacy plant, AEMO and NSPs may not have enough evidence to support the decision to either accept or reject the proponent's request to provide alternative models or information. In cases where it is likely that suitable models for a legacy plant can be developed and provided without undue burden on a project proponent, the provision of this new information is likely to promote more secure and efficient operation of the NEM to the benefit of all participants. This suggests that the question of legacy plant models should be considered on a case-by-case basis, taking the specific circumstances into account.

Industry experience further suggests that material interactions between plants in the system, potentially requiring detailed modelling and investigation, can at least arise from one of the following four control subsystems:

- Outer control loops for voltage and/or reactive power within a plant.

- Inner control loops driving unit-level voltage and current, including fault ride-through modes and PLL dynamics for electronic equipment.
- Outer control loops for dispatch and regulation of active power production or consumption by the plant.
- Outer control loops for frequency response and control.

AEMO supports the proposal from the submissions that generic models can be used to represent legacy plants when detailed site-specific models cannot be obtained to the best of proponent's effort. The generic model should at least include, where practical, all information related to the control systems listed above.

AEMO also noted from the submissions that the most challenging part in developing a generic model for a legacy plant tends to be associated with modelling the accurate fault ride-through (FRT) behaviour of the plant. Where relevant information for a control system regulating the plant's FRT behaviour cannot be obtained or reasonably assumed – for example, PLL configuration – the generic model can include information pertaining to all other control systems which can be tested at the R2 validation stage for the plant, as a part of the connection process of the new plant. Relevant components of the generic model will be validated in this R2 process. Other components of the generic model, which cannot be validated during the R2 validation process, can be validated by the proponent through the ongoing compliance monitoring scheme, and the validated model should be provided to AEMO and NSPs within a time frame to be agreed with AEMO and NSPs.

4.15.3. AEMO's recommendation

AEMO recommends that the requirement for legacy plant models be considered on a case-by-case basis, in accordance with Sections 8.3 and 8.4 of the current PSMG. AEMO would have regard to a balance between the following principles:

- Models for new plant continue to be provided in accordance with the current PSMG.
- To the extent that the 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.
- The requirement for updated model provision for the legacy plant shall not act as a material disincentive to Generators and Network Users undertaking augmentation works.

In summary, when considering requirements for legacy plant models on a case-by-case basis, risk factors including plant location and size may be considered when deciding which control elements are to be included or excluded. Consideration should also be given to the availability within the NEM of models for similar equipment which might be adapted to the legacy plant through parameter reconfiguration.

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 on 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 theoretically 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 (above what is already received) as a basis for which AEMO could develop a small signal model. However due to concerns around confidentiality, provision of a DLL compatible with the SSAT software would also be acceptable.

AEMO received five submissions regarding small signal stability modelling.

AusNet

AusNet is supportive of the proposal to reinforce the need for accurate and detailed block diagrams suitable for development of a linearised small signal model.

Goldwind

We understand that AEMO's preferred way forward on the topic of small signal model is the provision block diagrams suitable for small signal analysis rather than DLL models developed in SSAT. Our preferences would align, particularly since a set of block diagrams are already provided as part of the connection process. In the issues paper, AEMO has suggested more detailed block diagrams are required and we note that AEMO also rightfully point out the challenges with OEMs releasing very detailed block diagrams which may expose intellectual property. We would like to note that even internally, such detailed descriptions of the generators are only available to select few members of the organisation (generally restricted to research and development).

Our suggestion, in an effort to facilitate sharing of more detailed block diagrams and avoid a situation where OEMs have to adopt another modelling platform (SSAT) to enable connections to the NEM, is for AEMO and the NSPs to define the gaps that exist in the current (relatively standard) approach to development/provision of PSSE block diagrams. Such a list would allow OEMs to evaluate the IP risk of the additional detail required and help inform our assessment on the tradeoffs of providing more detailed block diagrams vs. developing SSAT DLLs internally.

…

We propose an alternative to providing the block diagrams, bypassing the concerns around IP confidentiality, could be for OEMs to provide a table of transfer functions that they derive from their models. Goldwind has developed a method for deriving small signal transfer functions of its generating system using PSCAD. We welcome any feedback from AEMO on whether this would be a feasible approach.

Kate Summers

The continued reliance on time domain models, and simply expanding the detail contained within them is resulting in a loss of awareness and familiarity appropriate control engineering practices that ensure controls are damped for all known system and local modes across a wide range of operating conditions. Transfer function analysis, impedance scans, Bode and Nyquist plots to mention a few necessary methods.

TransGrid

Transgrid supports to remove the references to RMS in the context of PLL or other functions.

Transgrid also suggests PSMG to introduce methods for the validation of small signal models during commissioning of the plant.

…

Transgrid also proposes that each individual project provides a fully unencrypted SSAT model to assist with long term compatibility issues between different revisions and model platforms.

Powerlink

Powerlink supports the requirements for the small signal models for the Inverter Based Resources (IBR). We believe that small signal models for IBR that include details of inverter level (e.g. current control loop, PLL etc.) and plant level control would be able to provide insight into the source of any instabilities/control interactions that are being experienced in the NEM.

4.16.2. AEMO's assessment

Regarding comments about reliance on time domain simulation, AEMO is continually investigating methods such as impedance scanning and small signal modelling of IBR for use in the NEM and believes use of small signal analysis tools such as SSAT could help reduce reliance on time domain simulations.

Multiple discussions with OEMs have indicated that OEMs are not willing to provide full detail block diagrams and even if they did, many aspects would be very difficult to linearise. AEMO agrees that more discussion is needed to determine (i) what aspects are critical to modelling IBR in the small signal domain for the frequency range of interest; and (ii) the specific gaps preventing development of small signal models.

Following discussions with the vendor of SSAT, AEMO has concluded that provision of an SSAT-compatible DLL is no longer a preferred option. AEMO also agrees that placing another software requirement on NEM participants and OEMs is not justifiable at this stage without fully understanding the small signal model requirements.

Deriving transfer functions empirically from impedance scans is an interesting method that warrants further investigation. However, due to the limited research in the area, it would be premature to enforce it as a requirement at this stage.

4.16.3. AEMO's recommendation

Due to not understanding fully what the requirements would be for modelling IBR in the small signal domain, and the limited research and use of small signal modelling of IBR, AEMO concludes that no additional requirements be made. Instead, the proposed wording around small signal modelling has been generalised to allow AEMO and NSPs to investigate multiple approaches to small signal modelling as follows:

- For asynchronous technologies, AEMO suggests that small signal models represent all sub-synchronous frequencies.
- Small-signal stability models are submitted as part of the model package. This is to be in the form of block diagrams, an SSAT model, frequency response data, or some other format. The format is to be determined through discussion between AEMO, NSPs, participants and OEMs.

4.17. Other matters

4.17.1. Inclusion of generator capability curves

No material issues were raised about the inclusion of generator capability curves in load flow modelling requirements. This has been added to Table 4 with the wording “Active / reactive power capability curve in PSS®E .gcp (preferred) or text format”.

4.17.2. Removal of references to representing three winding transformers as equivalent two winding transformers

No material issues were raised about removing references to represent three winding transformers as equivalent two winding transformers. Several table footnotes in appendix C were changed to reflect this.

4.17.3. Inclusion of voltage/reactive droop characteristics in the load flow model

AusNet proposed the PSMG include a specific requirement to specify any applicable voltage/reactive droop characteristic as part of the supplied load flow model, which is recommended by AEMO. This recommendation is made by way of clarifying current practice rather than introducing new requirements.

4.17.4. Materiality of model behaviour and flexibility in planning stage assessments

The Clean Energy Council (CEC) proposes that guidance be provided to NSPs as to when performance assessments for new connections may proceed in the face of unexpected behaviour of models in isolated instances, provided such behaviour is assessed as unlikely to reflect actual plant performance, and provided a timeframe for resolution is agreed in the interval between NER 5.3.4 acceptance of performance standards and commissioning of the plant.

AEMO considers this is a process matter to be dealt with outside the PSMG, and notes the Connections Reform Initiative is currently considering similar matters as part of a review of the pre-connection process. The CEC submission also notes the existence of the Section 8 of the PSMG provides an alternative pathway to resolution.

4.17.5. Other changes

There may be further changes not listed in this document, that arise through the next stage of the consultation process, or identification of appropriate corrections or clarifications. Any such changes identified will be listed in the final report to be published on 16 June 2023.

5. Draft determination on proposal

Having considered the matters raised in submissions to the consultation paper, AEMO's draft 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 draft report, in accordance with NER S5.5.7.

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