Intermittent Generation Penetration within the Wholesale Electricity Market

WORK PACKAGE 4 –FINAL REPORT

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- Final Report

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1. Executive Summary

Sinclair Knight Merz (SKM) has been engaged by the Independent Market Operator (IMO) to undertake the Renewable Energy Generation Working Group (REG WG) Work Package 4: Technical Rules. This study evaluates the appropriateness of the existing Technical Rules and Power System Operating Procedures as applied to intermittent generators, and recommends changes to support future increased penetration of intermittent generators in the South West Interconnected System (SWIS).

This report undertakes a comparison of the Technical Rules to those used in other jurisdictions; incorporates stakeholder feedback on market inefficiencies created by the existing technical rules; and utilises PSS/E Power System Modelling and a System Frequency Response Model to determine the impact any changes to the Technical Rules may have on SWIS system reliability and integrity. This analysis has resulted in the following recommendations.

To improve the competition amongst intermittent generation equipment suppliers in the WEM, without materially impacting system reliability or integrity, SKM believe there is scope to review the following areas within the Technical Rules:

- Voltage ride through requirements or the derogation process for these requirements.
- The 6 s 52.5 Hz frequency operation capability requirement be reviewed to a target of 52 Hz or a simplified derogation process be implemented.
- Rate of change of frequency requirement, specifically the duration the rate applies for.
- The basis of the temporary overvoltage excursion.

No changes are recommended to ramp rate requirements, post voltage control requirements, and market-based mitigation mechanisms.

Depending on the approach System Management takes to improving forecasting of intermittent generation output, amendments may be required to the WEM Market Rules in order to facilitate the provision of real time, or near real time, primary energy data through the existing remote monitoring facility requirements of the Technical Rules or some other suitable mechanisms.

The critical issue of dispatch control for curtailment is heavily dependent on the market mechanisms that are selected to determine the level of curtailment required. It is recommended that consideration be given to the communication requirements of the selected market mechanism as the Market Evolution Plan develops.

Western Power has advised that they are releasing an updated version of the Technical Rules in which many of the issues discussed in this report have been considered.

2. Introduction

2.1. Background to the Report

The Renewable Energy Working Group (REG WG) has been tasked with the review and investigation of potential issues associated with high levels of penetration of intermittent renewable energy generation projects with the South West Interconnected System (SWIS). The REG WC has been established under the auspices of the Market Advisory Committee (MAC). The working group has been tasked with investigating the range of issues presented by renewable energy generators and to develop and propose solutions to the various issues.

As intermittent generation penetration levels increase, measures such as limiting ramp rates for active power, procurement and use of additional frequency control services and mandated communications to, and control by, System Management may be required. Consideration of existing SWIS Technical Rules (Technical Rules) requirements and prospective revisions to better deal with the connection of intermittent generation is essential.

The Technical Rules have been established by Western Power (separate from System Management and the IMO) as part of its Access Arrangement under the Electricity Network Access Code 2004 (Code) and are, as such, administered separately to the WEM. Any changes to the Technical Rules will need to be proposed by Western Power and approved by the Economic Regulation Authority (ERA). The Technical Rules set the minimum requirements for Users (generators and loads) to connect to the SWIS and compliance is required for WEM participants to get capacity credits.

In addition to the Technical Rules, System Management has a series of Power System Operating Procedures (PSOPs) dealing with communications and control requirements for generators, including intermittent generation sources. Additionally, these PSOPs incorporate the requirements of the Australian Electricity Market Operator (AEMO) to provide sufficient data to effectively forecast wind farm outputs.

The guiding criteria for SKM in undertaking this study were to allow the WEM to maximise the benefits associated with intermittent generation whilst:

- Seeking an economically efficient market outcome for the procurement of ancillary services.
- Continuing to protect system reliability and integrity.

2.2. Scope of Report

This report contains the Key Outcomes of Work Package 4 covered by the IMO Request for Tender No. IMO 029.

REG WG has engaged SKM to undertake a study (Work Package 4) to evaluate the appropriateness of the current Technical Rules, Market Rules and PSOPs as applied to intermittent generators, and recommend changes resulting from increased penetration of intermittent generators in the SWIS.

The scope of work for Work Package 4 covers the following:

- Evaluation of the appropriateness of the current fault ride-through requirements for intermittent generators in the Technical Rules in context of the forecast generation mix for the SWIS from Work Package 1.
- Evaluation of the appropriateness of the existing frequency excursion and rate of change of frequency requirements for intermittent generators in the Technical Rules in the context of the forecast generation mix for the SWIS from Work Package 1.
- Evaluation of the appropriateness of the current ramping rate requirements for intermittent generators in the Technical Rules in the context of the forecast generation mix for the SWIS from Work Package 1.
- Evaluation of the appropriateness of the existing voltage excursion and post fault voltage control requirements for intermittent generators in the Technical Rules in the context of the forecast generation mix for the SWIS from Work Package 1.
- Evaluation of the capability and potential system benefits of the adoption of specific communication requirements for wind farms, for the purpose of data transmission and control requirements between System Management and wind farms.
- Evaluation of market-based alternatives to an intermittent generator complying with the fault ride-through technical requirements.
- Reference to, and investigation of, other jurisdictions, in particular the NEM, where relevant.

2.3. Deliverables

Consideration of the issues outlined above will yield the following outcomes:

- Recommendation for either technical or market-based mitigation measures available to manage network stability issues associated with increased intermittent generation.
- Recommendations for changes (if any) for the fault ride-through requirements for intermittent generation.
- Recommendations for changes (if any) to the frequency excursion requirements and rate of change of frequency requirements for intermittent generators.
- Recommendations for changes (if any) to the ramping rate requirements for intermittent generators.

- Recommendations for changes (if any) to the voltage excursion and post fault voltage control requirements for intermittent generators.
- Recommendations for changes to market mechanisms resulting from any market based mitigation measures identified in this analysis.
- Recommendations for Technical Rules, Market Rules and PSOP changes resulting from this analysis.
- Supporting arguments and analysis required to demonstrate that the recommended changes are consistent with the wholesale market objectives.

2.4. Overview of Interfaces with Other Work Packages

This report is Work Package 4 of the IMO 4 packages of work relating on the Analysis of the Impacts Associated with Intermittent Generation Penetration within the Wholesale Electricity Market. This report draws on the forecasts for intermittent generation in the WEM developed in Work Package 1 and the results of analysis on the impact of those forecasts on load following undertaken in Work Package 3. This report references data solely from Work Package 3.as Work Package 3 summarises the forecasts in Work Package 1

2.5. Structure of Report

Section 4 of this report addresses each of the technical items of the scope against the three forms of analyses discussed in Section 3. The recommendations that derive from these analyses are summarised in Section 5, consistent with the deliverables discussed above. Supporting information on the analytical tools used in the report and out of scope stakeholder feedback is provided in the Appendices.

3. Methodology

This report has been developed in the context of Work Packages 1 and 3 with the most guidance taken from Work Package 3. To address the items detailed in the scope of this report, three areas of analysis have been undertaken.

The first has been to review the approaches taken in other markets around the world to deal with the challenges in increased intermittent generation.

The second has been to interview key stakeholders in the Wholesale Energy Market (WEM) to ascertain the challenges that they perceive arise in the increased penetration of intermittent generation.

The third uses information obtained to scope technical analysis to determine the impact that the technical issues raised in the scope may have on the security of supply on the SWIS.

Each of these areas of analysis are discussed in more detail below, followed by the resulting recommendations.

3.1. Approaches in Other Markets

Many electricity markets around the world are facing similar challenges to the WEM in facilitating the increased penetration of intermittent generation in an efficient manner that also maintains the security of supply. The outcome of work undertaken in other markets can provide guidance for the WEM as it negotiates the technical issues, but also directly impacts the efficiency of the development of intermittent generation technologies in WEM. This is a result of manufacturers designing technologies to meet the requirements of larger markets throughout the world; any significant deviation in the SWIS Technical Rules from the standards set in other major jurisdictions would significantly undermine competition amongst supplies of intermittent generation technologies, which undermines the overall efficiency of the WEM. However, the SWIS has unique technical challenges that must be adequately addressed to maintain the required level of system security,

The impact of increased penetration of intermittent generation on the requirements of the Technical Rules / Grid Codes is dependent on the size of the electricity market and the nature of the existing generation. The options available to the market to manage the impact are constrained by the nature of the market structures. Given this, SKM undertook a review of markets of a similar size and level of market development, with the intention of identifying the approaches taken in these markets to address the increased penetration of intermittent generation. The Technical Rules / Grid Codes considered are those for Ireland, Great Britain (GB), Germany, NEM Australia (NEM) and New Zealand. Spain is also considered for some technical issues.

The Single Electricity Market in Ireland is very relevant to the size and characteristics of the WEM. Technical requirements for wind generation are detailed in the Irish Grid Code. The Irish market has also recently been involved in a review of the arrangements to manage a system where significant levels of curtailment could occur both from a technical and a commercial point of view. A review of the arrangements and requirements applicable in Ireland was undertaken as part of this study.

The GB energy regulator (Ofgem) undertook a review of the GB Grid Code requirements for accommodating increased penetration of wind. Although the interconnected European network is very large by comparison to the WEM, there are some aspects relative to the wind farm performance and intermittency that were considered for this study. Further, the GB market and the larger markets of continental Europe are a useful reference for the technical standards being met by most equipment manufacturers.

The NEM in Australia is a larger energy market than the WEM and at a different stage of development, but it is subject to the same development drivers for intermittent generation. The NEM was reviewed for appropriate approaches to ancillary service provision and Technical Rule changes.

As part of this international review SKM identified a generic Wind Code Format for Wind Plants developed by the European Wind Energy Association. Although this document does not contain any targets it does provide a comprehensive format for Grid Codes as they pertain to intermittent generation. The format of the requirements in this document is largely consistent with that of the Technical Rules. This document is provided at

http://www.ewea.org/fileadmin/ewea_documents/documents/publications/091127_GGCF_Final_Draft.pdf.

3.2. Stakeholder Consultation

There is a vast depth of knowledge held by WA electricity market participants on the impact of the Technical Rules in the establishment of intermittent generators. SKM interviewed key industry participants, including:

- Verve.
- Western Power.
- Pacific Hydro.
- Carnegie.
- Landfill Gas and Power.

These interviews identified the key issues experienced by these participants with meeting the requirements and managing the process of the existing Technical Rules. The issues raised were analysed against approaches taken in other jurisdictions and considered in modelling the impact of any suggested changes. Appendix A includes a copy of the interview template.

Many developers stated that they did not have the technical networks knowledge to respond to the specific items that are in scope of this study. Notwithstanding this, feedback was provided and a synopsis is below. Participants also provided feedback that, although not directly relevant to the scope of this study, clearly represented useful direction for the market, these comments have been summarised in Appendix B.

In order to facilitate a frank provision of issues this report does not identify the contributor of the specific stakeholder feedback.

3.3. Technical Analyses

Two main technical tools were used in this study; the PSS/E power system analysis tool and a SWIS power system frequency response model. Each of these is discussed in more detail below.

3.3.1. PSS/E Power System Model

The PSS/E Power system model was provided by Western Power and includes all generators, transmission lines and loads associated with the SWIS. This model has been used to model the potential impacts of changes in fault ride-through requirements.

3.3.2. SWIS Power System Frequency Model

The frequency response of a transmission system to a disturbance caused by the loss of connected generation or load depends primarily on the inertial response of the system, load damping and the action of governors subjected to frequency errors. However, each of these elements is in turn dependent upon a large number of other factors and higher order responses. A detailed and complete analysis of the frequency behaviour of a system requires complex and time-consuming modelling of each element of the system through software such as PSS/E. This more detailed approach is appropriate for considering a small set of system operating conditions but does not lend itself to the broad scan of conditions required by this report.

The intention of this model was to determine the average response of the SWIS for given sets of conditions and to assess the variability of the response to changes in parameters such as the mix of generation (Gas Turbines versus Steam Reheat Turbines versus Intermittent Generation) and the number of generators with active governors participating in the containment of frequency following a system disturbance. SKM's approach, which is well documented in the literature[1,2], has been to develop the lowest order model of system frequency which accurately represents average system frequency behaviour while taking account of typical turbine and governor time constants and gains. Other system dynamics such as inter-machine oscillations and transient, non-linear or discontinuous behaviour of loads were not considered.

The model has been checked against data from actual system disturbances, using data provided by Western Power, and has been shown to provide an appropriate reflection of the maximum system frequency deviations.

This model has been used to consider issues related to system frequency such as frequency ride through and rate of change of frequency requirements.

3.4. Development of Recommendations

Recommendations have been developed with reference to the outcomes of the three forms of analysis discussed in this section. The recommendations seek to achieve the guiding principles of:

- Seeking an economically efficient market outcome for the procurement of ancillary services.
- Continuing to protect system reliability and integrity.

[1] Igor Kuzle, Tomislav Tomisa and Sejid Tesnjak, "A Mathematical Model for Studying Power System Frequency Changes", *IEEE Africon 2004*, p761-764
[2] P Kundur, *Power System Stability and Control*, Mcgraw-hill 1994, Ch 11.1

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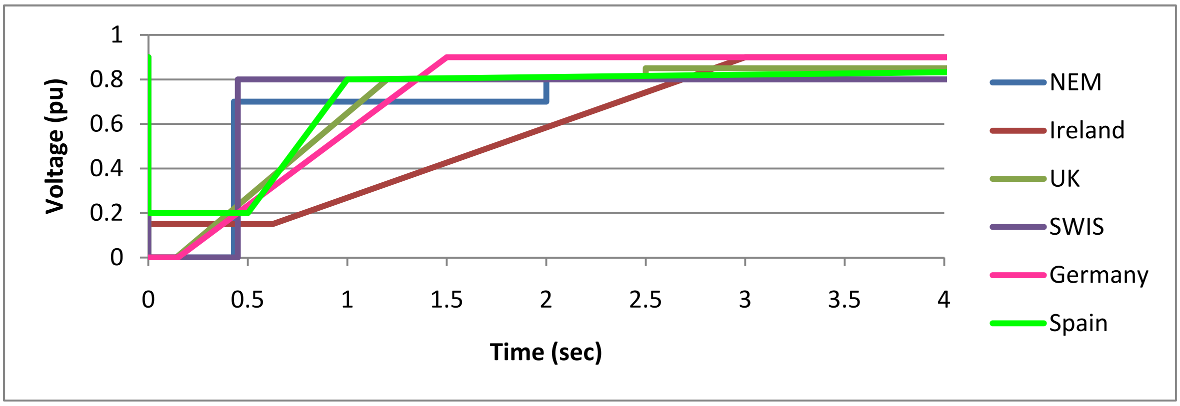
4. Technical Issues Considered

4.1. Voltage Ride Through

4.1.1. Comparison with other Jurisdictions

The immunity to voltage excursion in different grid codes is shown in Figure 1. The NEM Technical Rules Schedule S5.2.5.5 specifies the duration of the fault (e.g. 430 ms) but does not mention the voltage dip magnitude. Zero voltage for NEM is assumed by considering SWIS Grid Code, which has similar characteristics.



- **Figure 1: Voltage Ride-Through Requirements for Intermittent Generation in Different Grid Codes**

Notes on Figure1

- The NEM Standard provided is the “automatic standard”, most wind generators cannot meet this and therefore meet a lesser “minimum standard”.

Figure 1**.** This illustrates that the SWIS requirement (to remain in operation for 0 pu voltage at 0.45 sec) is the most restricted with the exception of the NEM. SKM understand that NEM requirement is a function of the large proportion of generation for the NEM connected to in close electrical proximity (effectively a single bus) in the Latrobe Valley. As discussed in section 4.1.3, this impacts on how a single bus fault endanger the security of the system.

4.1.2. Stakeholder Feedback

- This is a big issue and the rules are not seen as appropriate. Again, it is typically necessary to get a derogation, and the process can be difficult.

- 430 ms at the local end and 480 ms at the remote end should be revisited. There is also 430 ms in the NEM that is applicable for 132 kV connections as part of a framework for negotiations. The broader issue is to provide a similar structure to negotiate.
- TR 2.3.7.3 – All loads must be modelled as constant P&Q loads which is unrealistically conservative.
- TR 2.5.2.4 – Circuit Breaker fail requires clarification with Western Power.
- Under voltage ride-through is a problem for very small inverters that are not able to comply. However, in practice inverters below 150 KVA are exempted and so there is not a real problem. It used to be a problem for larger inverters but the requirement exists in other jurisdictions, the suppliers have typically caught up and can now comply.
- Voltage ride-through is normally a local issue. The 450 ms criteria is based upon the time taken for circuit breaker fail protection to operate in the event that the primary protection has not operated successfully.
- The voltage at the connection point or the generator terminals will not be as low as at the point of the fault. Typically, the voltage at the generator terminals will not fall below 30% for a system fault and this should be considered by developers.
- Western Power is able to provide voltage ride-through curves that are specific to each new connection or alternatively for predetermined locations on the network. These curves may be less onerous than the requirements in the rules. It is contemplated that a process could be developed that includes Western Power providing curves for the network that are updated at predetermined timeframes, or alternatively to provide a curve for each new connection application within a fixed time of the application being submitted.

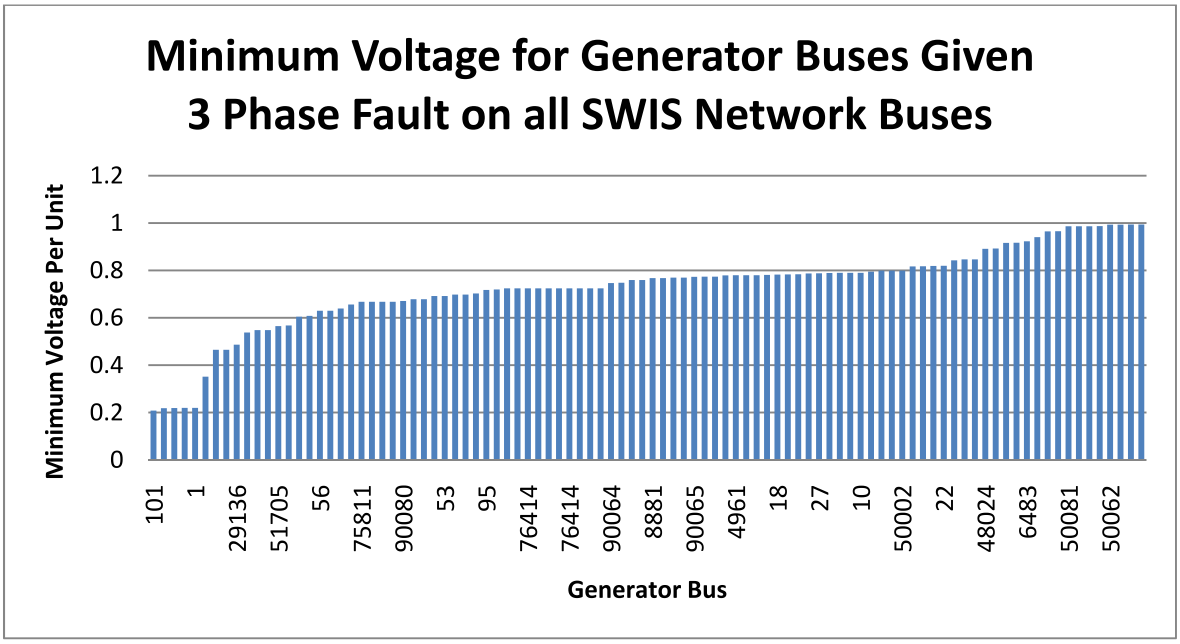
4.1.3. Technical Analysis

For a given fault the worst case conditions are at the faulted location, with the severity of the conditions decreasing with electrical distance relative to the fault. Thus, voltage ride-through, unlike frequency ride-through, is primarily a localised issue.

The Technical Rules are based on a worst case breaker fail bus fault at the connection of the generator. For many generator connections, this fault will result in the isolation of the generator as the backup protection may clear multiple zones. Larger generators, with more redundancy in the connection arrangements, may remain connected. The Spinning Reserve Ancillary Services in WEM is intended to allow for the loss of the largest machine on the system.

Based on the above discussion, SKM are of the position that the voltage ride-through requirement of the technical rules should ensure that the loss of generation for any grid fault is limited to a single generating unit, most likely the unit located in the closest electrical proximity to the grid. That is, a generator that has a fault on the point of connection can trip, but all other generators must ride through the fault. For systems such as the NEM, where a large proportion of the generation is connected in close electrical proximity, this does require more stringent fault ride-through requirements. Other systems that have a more diversified generation base, where a fault really will only significantly affect a single generator, can have less onerous fault ride-through requirements. This is reflected by the range of requirements as detailed in Figure 1.

To quantify the voltage ride-through requirements for the SWIS that will allow the loss of only one generator in the case of a bus fault, SKM have undertaken a PSS/E study. This study has modelled the fault of each bus within the Western Power model of the SWIS and recorded the resulting voltage on the 10 closest buses. From this data, the lowest recorded voltage, excluding a direct fault, for each generation bus has been extracted and is provided in Figure 2.



- **Figure 2: Minimum Voltage for Generator Buses Given a 3 Phase Fault on all SWIS Network Buses**

Given the criticality to system security, a safety factor would need to be applied to these voltages. Further, this analysis does not take into account the potential impact of faults on lines that interconnect large generators in the Collie area and this may result in lower voltage ride-through requirements for generator in that area. In addition, the above analysis is based on Western Powers steady state PSS/E model that does not provide any indication of the shape of the voltage deviation experienced at the generation buses (just the minimum voltage requirement).

These issues recognised, the minimum experienced voltage is of the order of 0.2 p.u. and is consistent with the requirements of other utilities as illustrated in Figure 1.

4.1.4. Recommendations

The SWIS voltage ride-through requirements are more onerous that those in most other jurisdictions. These requirements have been identified, by stakeholders, as an issue in developing interment generation that have required derogations to the Technical Rules that are time consuming to negotiate.

The requirements of voltage ride-through are highly dependent on the electrical proximity of generation units and change on a case by case basis. SKM would recommend two changes that could improve the efficiency of developing intermittent generation.

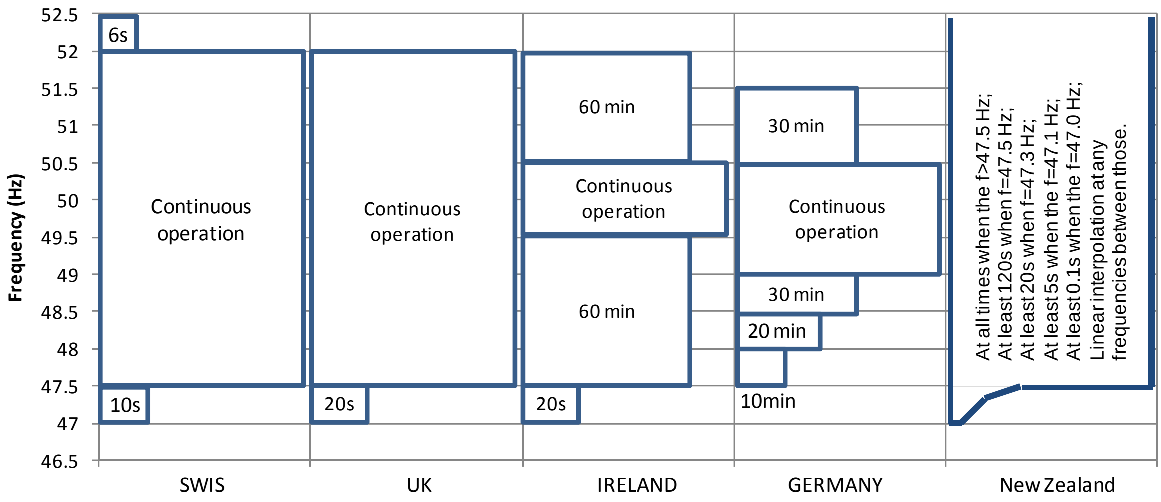
1. Western Power revisit the under voltage ride-through requirements, allowing for the loss of one generator but securing the continuity of connection of all other generators to determine a new minimum requirement.

2. Western Power streamline the process by which derogation can be provided for this item based on consideration of the location of generation and the likely electrical proximity of other generators.

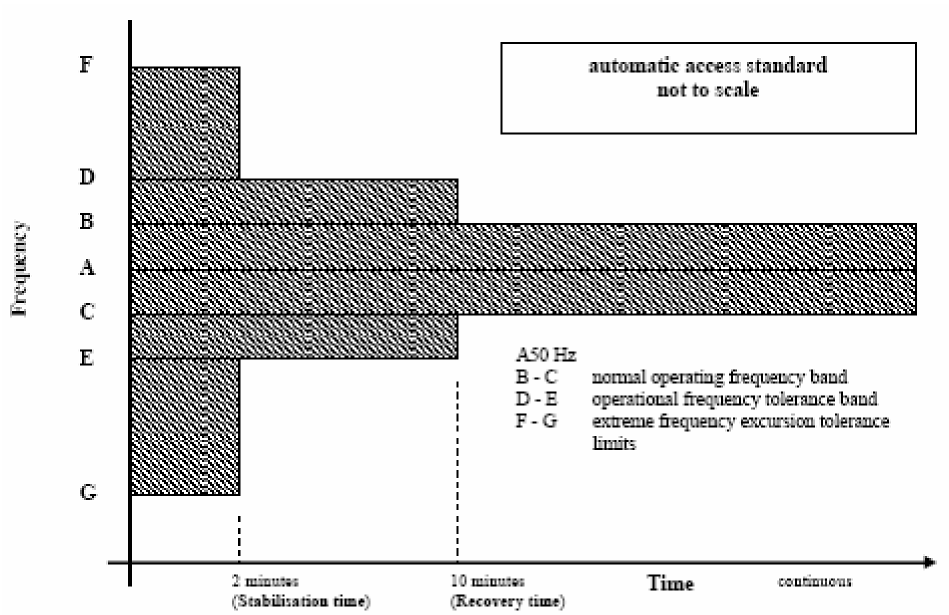
4.2. Frequency Excursion

4.2.1. Comparison with other Jurisdictions

The frequency operation capability in different grid codes is presented in Figure 3. The NEM does not specify the frequency operation requirements in a manner that can be illustrated in Figure 3and is therefore shown in Figure 4.



- **Figure 3: Frequency operation capability for Intermittent Generation in Different Grid Codes**



- **Figure 4: NEM Australia frequency operation capability for Intermittent Generation**

Figure 2 and Figure 3 indicates that SWIS grid code is relatively comparable with others. Excepting that it has additional requirement for time limited operation capability during over frequency.

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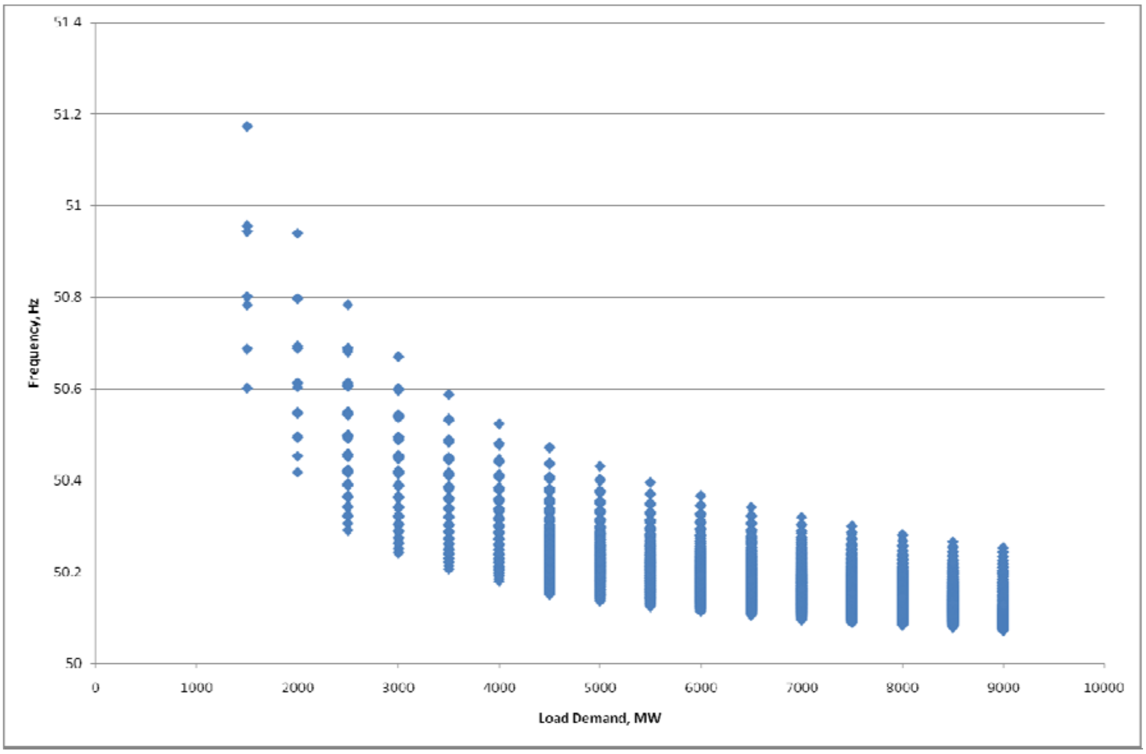
4.2.2. Stakeholder Feedback

- 52.5 Hz is higher than required in the NEM and does present an issue for PH. 52 Hz and lower is okay.
- It is not possible to meet the frequency ride-through criteria in the technical rules but all developers ask for an exemption.
- Typically it is necessary to get derogation but the process can be difficult.
- Derogation is normally sought and obtained for the frequency ride through criteria. Experienced developers will be familiar with this and so it is not a significant impediment.
- For embedded generation, consideration should be given to exempting these criteria if the generation is matched to load so that a trip will result in only a small net change.
- The 6 s criteria for 52.5 Hz is related to governor response and comes from experience in the GB. Particularly aero-derivative gas turbine response and system control.
- A high percentage of wind generation on the grid makes it difficult to maintain +/- 0.2 Hz steady state frequency control.
- Credible contingency events will not be near the system extremes. The extreme case contemplated by the 6 s / 52.5 Hz is a fault causing the islanding of part of the SWIS such as Geraldton or Kalgoorlie. The intention being to allow the system to continue operating and to re-synchronise.
- Western Power expects that wind turbines may be configured to cope with the requirement but exemptions are part of the administrative process for the rules. Exemptions are more readily granted for smaller generators.

4.2.3. Technical Analysis

From the preceding section it is clear that the issue causing inefficiency in the development of intermittent generation in the WEM is the inability for intermittent generation technologies to meet the 52.5 Hz requirement. However, as frequency events are modelled as being experienced by all generators system wide, the implications of a frequency excursion beyond that in the technical rules is the disconnection of multiple machines. This has dire consequences for system security.

It has been indicated that the 52.5 Hz requirement is based on abnormal operating conditions (splitting of the system) not conceivable single contingency events. SKM have confirmed this using the system frequency response model to model that a load rejection of 300[3] MW at various generation mixes up to 1460 MW intermittent generation[4], the result of this is provided in Figure 5.



▪ **Figure 5 Maximum Frequency for a 300 MW Load Rejection for a Range of Generation dispatches.**

Figure 5 demonstrates that for a credible single contingency, for a full range of generation dispatch possibilities up to 1460 MW renewables, the maximum frequency of the system is unlikely to exceed 52 Hz.

To investigate those scenarios that could result in a 52.5 Hz system frequency, the variables of load rejection size and wind penetration were varied without constraint. The result of this was in the case of a load rejection of 50% of system load with over 40% dispatch from wind and the remainder of generation provided predominately by steam turbines (slower response) yielded frequency deviations up to 52.5 Hz. These variables are not feasible within the current development scenarios of the SWIS.

[3] 300MW was selected to exceed the size of the largest single load on the SWIS and the transfer capacity of the Geraldton and Kalgoorlie lines.

[4] Based on Scenario 3 in Work Package with 1460 MW of Intermittent Generation installed by 2030.

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4.2.4. Recommendations

The requirement of the Technical Rules for intermittent generators to ride through a system frequency of 52.5 Hz is creating a need for derogations for many intermittent generators as it is not consistent with the standard in other jurisdictions. The system frequency response modelling undertaken could not yield conceivable load rejection and generation dispatch scenarios that would result in the system frequency exceeding 52 Hz.

The difficulty in meeting the 52.5 Hz requirement is specific to particular intermittent generation technologies, for example the requirement creates issues for some doubly fed induction generations but fewer issues for the full converter technologies. It is however creating issues for the most economic technologies currently being utilised. Further, given new intermittent technologies will be developed to meet the requirements of other markets first, this parameter may continue to impact the efficiency to which new technologies can be introduced into the WEM.

SKM recommend the 52.5 Hz requirement be revisited or the derogation process surrounding this parameter be streamlined for selected technologies.

4.3. Rate of Change of Frequency

4.3.1. Comparison with other Jurisdictions

Table 1 compares the rate of change of frequency requirements in the various jurisdictions.

- **Table 1 Comparison of rate of Change of Frequency Requirements**

Jurisdiction	Rate of Change of Frequency
Ireland	0.5 Hz per second
NEM Australia	4 Hz per second for 0.25 seconds
SWIS	4 Hz per second
Germany	Not explicitly stated
Spain	Not explicitly stated
Canada	0.5 Hz per second

4.3.2. Stakeholder Feedback

- Capable of continuous uninterrupted operation for any ROCOF up to 4 Hz/s. Technical rules does not mention the duration like in the NEM. Suzlon protection tests have been carried up to 2.5 Hz/s for 1 s which means if ROCOF is greater than 2.5 Hz/s for 1 s then the wind turbine will trip.
- The ROCOF criterion of 4 Hz/s has historically been an impediment and suppliers have not been able to comply. However, this criterion exists in other jurisdictions and suppliers typically have caught up and are now able to comply.
- Vestas were consulted and signed-off on the rate of change of frequency (ROCOF) rules.
- This value stems from the 1994 blackout.
- Justification, power stations should not trip due to rapid reduction in frequency in order to allow the possibility of the system recovery aided by the UFLS.

4.3.3. Technical Analysis

Using the System frequency response Model SKM modelled the frequency response for:

- A Wind Penetration of 1460 MW[5].
- Spinning reserve of 343 MW[6].
- A load rejection of 300 MW.
- A generation trip of 343 MW.

For this penetration of wind generation the variation of the load resulted in a total generation inertia (H) of 3.5 -5.1. The results of this analysis are provided in Figure 6 and Figure 7 below.

[5] Largest wind penetration detailed in Work Package 3

[6] Set at 100% of the largest machine based on position presented in Work Package 3 that the load following requirement will exceed the spinning reserve requirement and be adequately available as a spinning reserve source.

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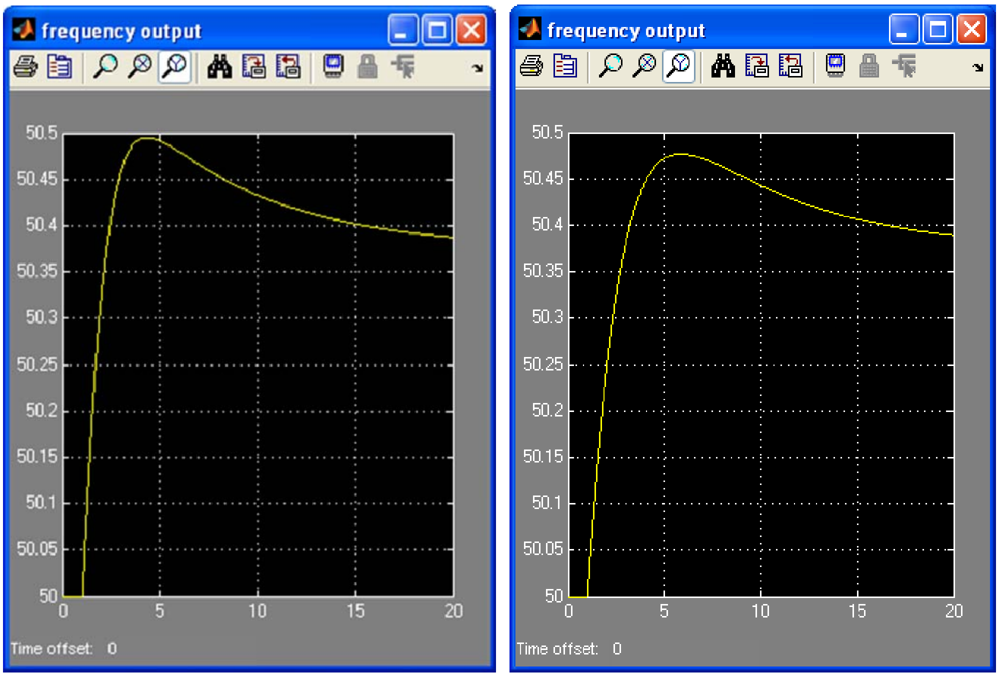
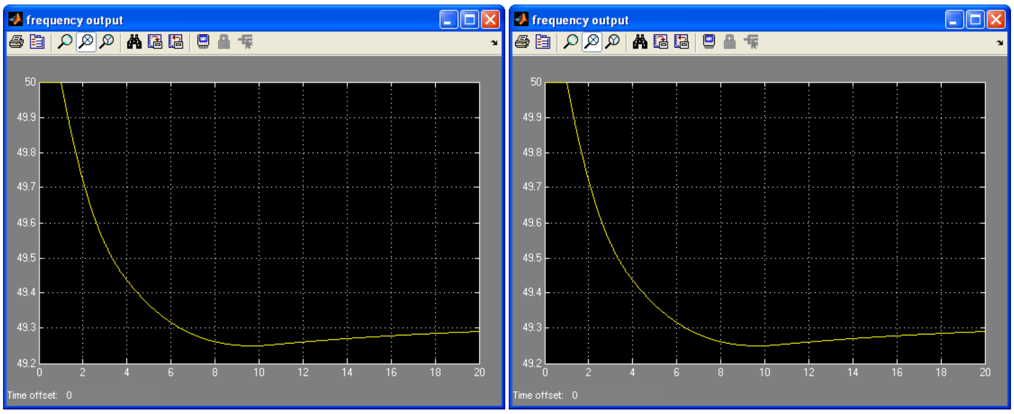


Minimum Load Maximum Load

- **Figure 6 Frequency Responses to 300 MW Load Rejection with 1460 MW of Wind Generation**



Minimum Load Maximum Load

- **Figure 7 Frequency Responses to 343 MW Generation Trip with 1460 MW of Wind Generation**

The maximum rate of change of frequency in these scenarios is 0.5 Hz / s.

To determine the impact of a catastrophic scenario, a 1500 MW load rejection was modelled for the same generation scenarios, the results of this is provided in Figure 8.

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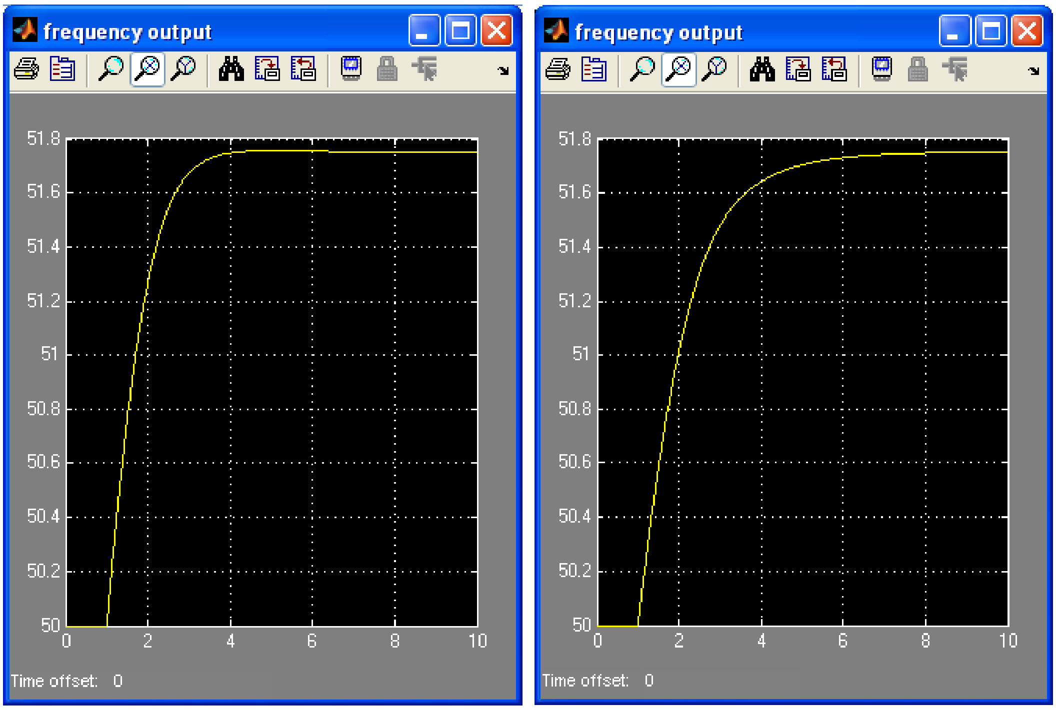

Minimum Load Maximum Load

- **Figure 8 Frequency Response to a 1500 MW Load Rejection with 1460 MW of Wind Generation**

The maximum rate of change of frequency in this scenario is 1.25 Hz / s.

4.3.4. Recommendations

It has been indicated that the existing 4 Hz / s requirement is the result of the 1994 blackout, SKM has not reviewed the data from this event. The SWIS has growth significantly since this time with increased numbers of rotating machines and loads that has likely increased the inertia on the system. SKM's analysis could not identify a credible event that would result in a 4 Hz / s rate of change of frequency. Further, the fact that the rate of change of frequency is unbound for a time makes the requirement more onerous.

On the basis of the above discussion, SKM recommends that Western Power revisit the rate of change of frequency requirement and consider the quantum of the rate and the time for which it applies.

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4.4. Ramping Rates

4.5. Ramping Rate Requirement

The ramping rate requirement in different grid codes is shown Table 2. The table indicates that SWIS ramping rate requirement is comparable to other Grid Codes.

- **Table 2: Ramping Rate Requirement**

	Ramping Rate Requirement
SWIS	Minimum 5% of the generator machine's nameplate rating per minute for a scheduled generating unit. Maximum 15% of the generator machine's nameplate rating per minute for a non scheduled generating unit. Maximum of 6% of the generator machine's nameplate rating per minute in the PSOP on dispatch.
NEM Australia	Ramping down, equal or exceeds the least of: ▪ 20% of maximum operating level times the frequency difference between the system frequency and the upper limit of the normal operating frequency band. ▪ 10% of maximum operating level. Ramping up, equal or exceeds the least of: ▪ 20% of maximum operating level times the frequency difference between the system frequency and the lower limit of the normal operating frequency band. ▪ 5% of maximum operating level. ▪ 1/3 of the difference between the maximum operating level and pre-disturbance level (zero if the difference is negative).
Ireland	There shall be two maximum ramp rate settings. The first ramp rate setting shall apply to the MW ramp rate average over one minute. The second ramp rate setting shall apply to the MW per minute ramp rate average over ten minutes. It shall be possible to vary each of these two maximum ramp rate settings independently over a range between 1 and 30 MW per minute.
Germany	10% of the grid connection capacity per minute.

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4.5.1. Stakeholder Feedback

No specific feedback on this issue

4.5.2. Technical Analysis

The ramp rates limitations that apply most directly to intermittent generation are the maximum ramp rate requirements. The Irish Grid Code has limited the ramp rates of intermittent generation to reduce the impact of intermittent generation on the operation of the system.

The work undertaken by Roam Consulting in Work Package 3 has indicated that, for the SWIS, the ramp rates would need to be limited to 0.2% per minute to effectively reduce load following requirements, this would result in significant curtailment of the wind resource and would be below the minimum ramp rate requirement.

4.5.3. Recommendations

Given the ineffectiveness of this approach to minimising the load following impacts on the system, SKM can identify no reason why these requirements should change.

4.6. Voltage Excursion

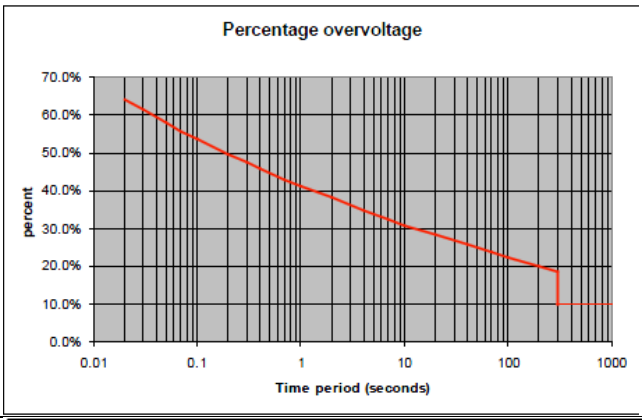
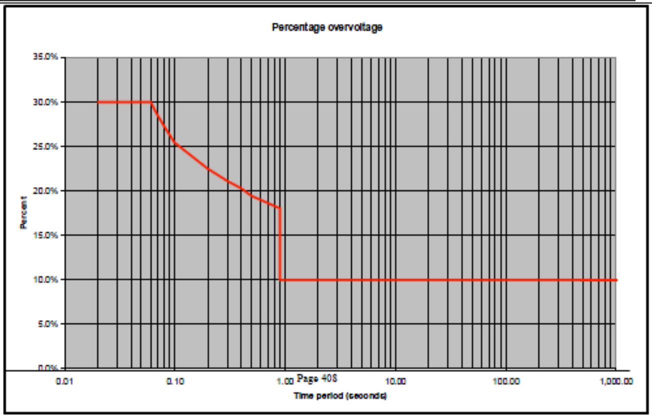
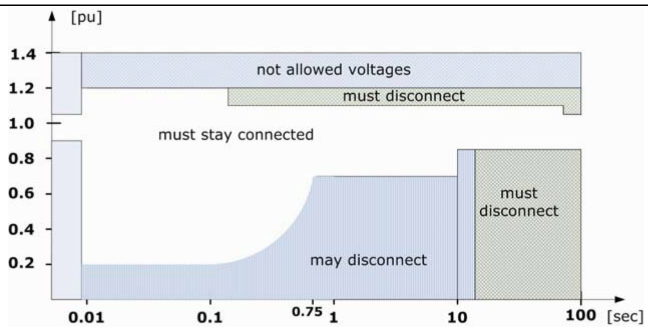
4.6.1. Comparison with other Jurisdictions

The steady state overvoltage requirements of the Technical Rules are largely consistent with those in other Grid Codes.

The overvoltage requirement in different Grid Codes is shown in Table 3. The table indicates that SWIS overvoltage requirement is very onerous compared to other Grid Codes.

SKM

- **Table 3: Overvoltage Requirement**

<table>
<tr><td>SWIS</td><td>
</td></tr>
<tr><td>NEM Australia</td><td>
</td></tr>
<tr><td>Denmark</td><td>
</td></tr>
<tr><td>GB</td><td>The 132 kV and above systems is designed to have overvoltage rise up to 140% nominal voltage in England, Wales and Offshore. The voltage rise would last only for the time that the fault (short circuit) conditions exist.</td></tr>
<tr><td>Germany</td><td>If the voltage on the low voltage side of each individual transformer rises and remains over 120% of the upper value of the voltage band (the upper value of the voltage band is 1.05 pu), the generator affected must disconnect itself from the grid with a time delay of 100 ms.</td></tr>
</table>

SKM

4.6.2. Stakeholder Feedback

- TR 2.2.10 - The highest acceptable phase to phase overvoltage appears to be very high (130% for 10 s when the NEM is 100 ms). It requires further clarification with Western Power and is not clear to which point in the system it applies.

4.6.3. Technical Analysis

The temporary over-voltage are the result of a range of Power System Phenomenon. The IEEE Paper on Temporary Over Voltages[7] provide guidance on the causes and effects of these over voltages. The guidance provided on causes deemed to be relevant to the SWIS (not special cases) is as follows:

Fault Application:

- Parameters: Fault location, System XO/X 1 ratio[8], Fault current magnitude;
- Over Voltage magnitude: 1 .O to 1.4 pu;
- Duration 2 to 10 cycles;
- Control usually not necessary.

Load Rejection: Parameters:

- Power flow, system short circuit MVA, system capacitance, machine automatic regulators;
- Magnitude: 1.0 to1.6 pu;
- Duration seconds;
- Control by: switched reactors, SVS, generator controls.

Line Energizing:

- Parameters: Line capacitance, System short circuit MVA;
- Magnitude 1.0 to 1.2 pu;
- Duration: Seconds;
- Control by: switched reactors, SVS Generator controls.

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7 ClGRE WG 33.10 and IEEE Task Force On TOV*, IEEE Power Engineering Review, June 1990

8 XO/X1 Not applicable to single phase faults as described by TR 2.2.10

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Line Dropping and Fault Clearing:

- Parameters: Fault conditions, line capacitance, shunt reactors, trapped charge levels, fault conditions; breaker opening sequence;
- Magnitude 1.O to 1.5 pu;
- Duration less than 1 second;
- Control: Shunt reactors, Relaying, SVS.

Reclosing:

- Parameters: Line capacitance, shunt reactors, trapped charge levels, fault conditions;
- Magnitude 1 .O to 1.5 pu;
- Duration: seconds;
- Control: shunt reactors, relaying, SVS.

Transformer Energizing:

- Parameters: system short circuit MVA, transformer saturation characteristics, frequency response characteristics, system voltage levels;
- Magnitude: 1.0 to 1.5 pu; duration: 0 to 2 seconds;
- Control: Switched reactors, SVS, Harmonic filters, breaker closing resistors.

It is noted that none of the guiding bounds provided above exceed 1.5 p.u.

Of these, the cause that is solely a function of the configuration of the network (that cannot be mitigated by other means) is the Fault Application. The Annex A of IEC 60099-5 provides guidance on the calculation of this over voltage. SKM has not undertaken these calculations for the SWIS as it is considered beyond the scope of this study.

4.6.4. Recommendations

The steady state voltage requirements of the Technical Rules are largely consistent with that in other jurisdictions and do not require change.

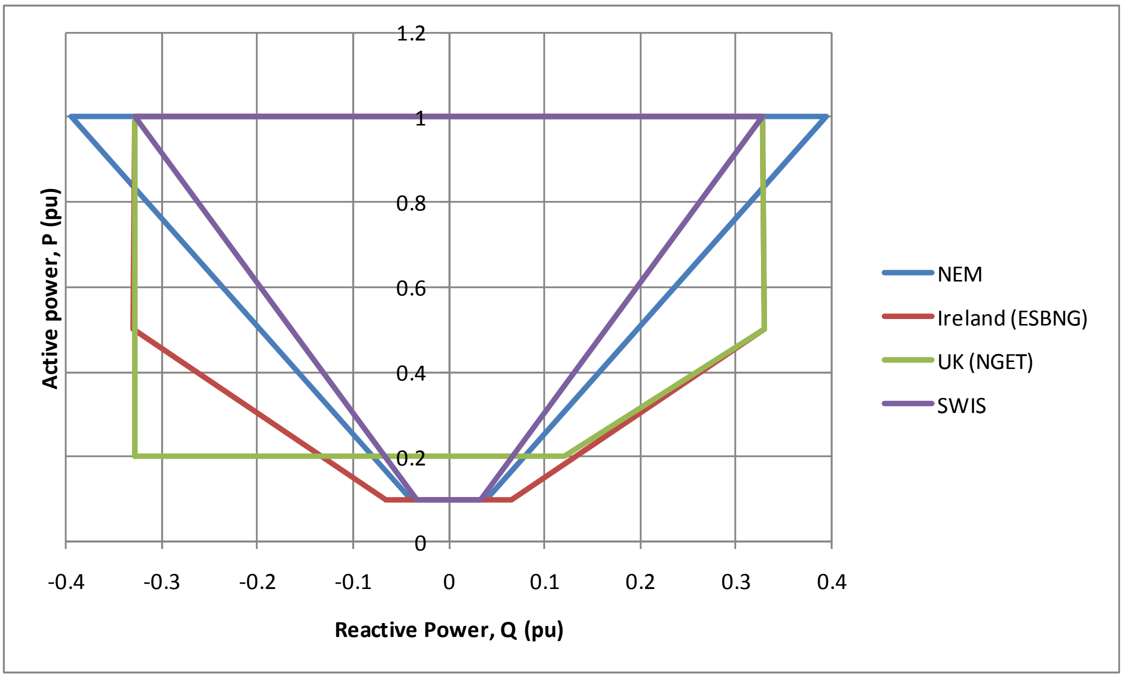
The overvoltage withstand requirement of the SWIS are significantly more onerous that those in other jurisdictions. Western Power has advised that the voltage withstand curve is based on a typical surge diverter protection voltage curve. However, this issue remains a concern to developers of intermittent generation. SKM would recommend that this requirement be revisited.

SKM

4.7. Post Fault Voltage Control

4.7.1. Steady State Reactive Power

The steady state reactive power provision in different grid codes is shown in Figure 8, where the reactive power is presented as a function of active power. The German (EON) steady state reactive power provision is shown inFigure 9**.** In this, the reactive power is specified as a function of voltage.

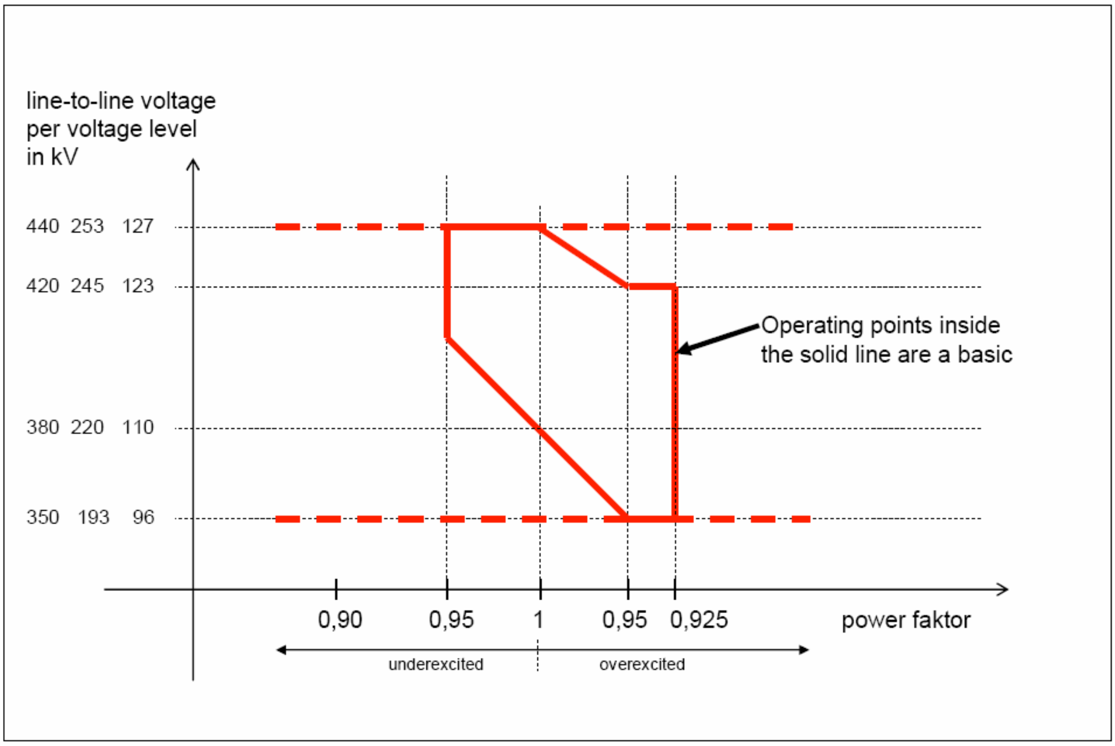


- **Figure 9: Steady State Reactive Power Provision for Intermittent Generating Plant in Different Grid Codes**

Notes for Figure 8:

- For Irish Grid Code, the reactive power output during operation below 10% active power production must be altered if the voltage limit is reached.
- For NEM Australia and SWIS, 10% active power production is the assumed minimum active power production.

Figure 8 indicates that the SWIS reactive power provision is comparable with the others for nominal active power production. However, the requirements at lower active power production are less onerous than other jurisdictions.



- **Figure 10: Steady State Reactive Power Provision for Intermittent Generating Plant in the German (EON) Grid Code**

4.7.1.1. Reactive Current Following a Grid Fault

The reactive power provision following a grid fault in different grid codes is shown Table 3.

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Table 4: Reactive Current Provision Following a Grid Fault

	Reactive Current Provision	Timing
Ireland	Maximize the reactive current.	600 ms or until recovers to normal voltage, whichever is sooner.
GB	Maximize the reactive current. [9]	
NEM Australia	Pre-fault reactive current or 4% rated current for each 1% each percent of the voltage dip, whichever is greater.	During and after the fault.
SWIS	Control systems must provide regulation to within 0.5% of the selected set point value. A sustained 0.5% error between the reference voltage and the sensed voltage must produce an output change of not less than 100% of the reactive power generation capability of the generating unit, measured at the point of control. This shall be achieved with a rise time of 1.5 s.	During and after the fault.
Germany	2% of the rated current for each percent of the voltage dip.	During 10% or more voltage dip and must be maintained for a further 500 ms.
Spain	Linearly increase from 0% to 90% of the rated current for the decreased of remaining voltage from 85% to 50% (of the nominal voltage), and then remain 90% of the rated current for further lower voltage.	Within 100 ms of the drop voltage and 150 ms of the grid recovery.
New Zealand	Operate continuously in the voltage control mode when synchronised.	-

[9] Based on M. Tsili, Ch. Patsiouras and S. Papathanassiou, "Grid Code Requirements for Large Wind farms: A Review of Technical Regulations and Available Wind Turbine Technologies", European Wind Energy Conference and Exposition 2008.

For NEM Australia, it is noted that the behaviour of the intermittent generator during and immediately after clearance of the fault may not meet the specified requirements. Consequently the wind farms need to negotiate to meet the minimum requirement (Technical rules schedule S5.2.5.5(c)(2)).

The GB, Irish and New Zealand requirements are very similar to the SWIS requirements with the full reactive power capability required to be delivered until voltage returns to the normal voltage range.

4.7.1.2. Active Power Following a Grid Fault

The active power provision following a grid fault in different grid codes is show in Table 5.

- **Table 5: Active Power Provision Following a Grid Fault**

	Active Power Provision	Timing
Ireland	90% of maximum active power	As quickly as possible and within 1 s of the Transmission System Voltage recovering to the normal operating range.
NEM Australia	95% of pre-fault active power	from 100 ms after disconnection of the faulted element
GB	90% of pre-fault active power	Within 0.5 s of the voltage restoration to 90% of nominal
SWIS	Pre-fault active power	200 ms after the voltage has returned to between 80% to 110% of the nominal voltage
Germany	Increase to the pre-fault active power with a gradient 20% of the rated power per second	Immediately after fault clearance

The Technical Rules recognise the impact of primary energy source variability in the ability to return to pre fault active power.

The table indicates that the timing for Technical Rules active power provision is relatively comparable to other grid codes. However the amount of active power to be provided (e.g. equal to the pre-fault active power) is relatively more onerous than in other jurisdictions with the exception of the NEM.

4.7.2. Stakeholder Feedback

- Pre-fault reactive power absorption has to be terminated within 200 ms after disconnection of faulted element. This is particularly dependant on wind turbine and reactive support technology and interaction with the system. It may not be an issue but studies should reveal the need for compliance in each case.
- TR 3.3.3.3 (h) – Continuous uninterrupted operation is dependent upon wind turbine and reactive support technology. Active power returning to its pre-fault level within 200 ms after the voltage has returned to between n 0.8 and 1.1 pu cannot be complied with even if the wind is blowing.
- The requirement of the rules is for a generator to be capable of delivering active or reactive power following a fault but not for it to have its governor and AVR set to actually do it. An embedded renewable generator (or any small generator) will be overwhelmed by the load and will not have the capacity to control voltage as required by 3.3.3.3 (g). This requirement is a common derogation and perhaps the rule should be changed to limit the performance requirement to the maximum capacity of the facility.

4.7.3. Technical Analysis

The provision of post fault voltage support can be viewed as a service provided by generators to the network. The amount of service required by the network will vary from location to location. The Technical Rules set the minimum service standard, with any service level above this procured through Network Control Services under the WEM Market Rules. Thus, specific technical analysis on this issue on the impact of any recommended changes to the reliability and integrity of the SWIS cannot be undertaken. In effect, Western Power will procure any location specific requirements above those specified in the Technical Rules, driven by non-generation system components, as a Network Control Service to ensure the reliability and integrity of the system.

The more stringent requirement to return to pre-fault active power instead of 90-95% of pre fault active power has been raised as an issue by stakeholders. Given the variability in the primary energy source, network planning could not be undertaken on the basis that generation will return to 100% of pre faulted active power and therefore the difference between 100% and 95% appears reasonably academic. SKM has identified no information that this additional 5% requirement is creating a significant additional cost burden to developers.

4.7.4. Recommendations

The SWIS requirements are generally consistent with those in other jurisdictions. Given the “stringy” nature of the SWIS, with long transmission lines and low load and generator densities, SKM believe the post fault voltage requirements of the Technical Rules are appropriate minimum requirements.

SKM note the stakeholder feedback on the application of rule 3.3.3.3g to small generators. Western Power may wish to revisit the 150 kVA limit in table 3.5 of the Technical Rules to minimise the administrative burden associated with numerous derogations. However, if embedded generation becomes a significant part of the generation pool, increasing this requirement may reduce the post fault voltage support available on the network. SKM have undertaken no analysis on this topic as it is out of the scope of this report and as such have not made a recommendation.

The reactive power capability requirements of the Technical Rules are slightly less demanding than that of other jurisdictions; this may be an indication that additional support is available forms many intermittent technologies. This additional support can be realised through two mechanisms:

1) Increase reactive power capability requirements in the Technical Rules; or
2) Procure the services as required as a Network Control Service.

SKM is not been made aware as to whether Western Power has procured such services through the Network Control Services mechanism or has otherwise indicated a need for additional post fault reactive power support across locations on the system. On this basis, SKM assume the existing reactive power provision in the Technical Rules are sufficient at this time for the majority of system locations given additional support can be procured as required.

4.8. Communication

4.8.1. Comparison with other Jurisdictions

Great Britain

The GB communication requirements are similar to Western Power, except that wind farm specific data such as wind speed may be required. There is little or no impact on communications assuming remote monitoring is already in place.

Denmark (Eltra and Elkraft)

In Denmark, communication regulations differentiate between Wind Turbines Connected to Grids above and below 100 kV. The requirements are specific re communication system standards and data protocols.

For < 100 kV the communication system must meet IEC 61400-25.

For > 100 kV the requirements stipulate remote control (e.g. for active power regulation) by the System Operator and specifies data protocols. The System Operator has the ability to “control the wind farm’s total active production power”. The wind farm can be disconnected if remote control is lost or not working.

Canada

AESO has a specific wind power facility technical requirements whereby Wind Power Facilities (WPFs) must comply with AESO SCADA requirements which in turn specify communications related items such as latency (Section 4.0) and communications requirements (Section 6.0). Again this specifies detailed requirements with regards to communication design and capability.

NEM

National Electricity Rules V35 specify a semi-dispatch system for wind farms which in turn places requirements on communications and control facilities to meet dispatching, remote monitoring and remote control requirements.

4.8.2. Stakeholder Feedback

- The real-time communications obligations of the codes are onerous. Particularly, generators should trip if communications are lost for 7 s (not verified by SKM). Telstra has recently withdrawn its low cost communication service and so compliance with the requirement is expensive.
- The requirements for SCADA can be unnecessarily onerous particularly for generators that are just over 1 MW. Highly detailed visibility in these cases is often not warranted and a substantial barrier to a project. As a comparison, visibility is not required for similar sized loads. The SCADA requirement should be benchmarked to other jurisdictions.

- Western Power notes that after nearly six months of operation, the new Telstra's system (IP cloud) does not seem to have shown inferior performance to the old system. Western Power has been monitoring and testing the performance of the new Telstra's system for own reasons. The results, so far, have been satisfactory.

4.8.3. Technical Analysis

The communication requirements in the Technical Rules include:

- Specification of the remote monitoring requirements for integration into Western Power’s SCADA system.
- Requirement for the ability to remotely disconnect the generator.
- Requirement for primary and backup speech communication services.

These requirements meets the condition of the day before market of the WEM, with dispatch outside the resource plans developed on a day before basis occurring as an exception.

Communication of Data for Forecasting

The data requirements in the Technical Rules for remote monitoring do not include existing primary energy data for use in forecasting by System Management. However, the remote monitoring requirements to transport this data to the Western Power SCADA system are specified in the Technical Rules. WEM Market Rule 7.2.5 requires intermittent generators to provide "its most current forecast" of the following day's half hourly generation output. SKM understand that System Management are working with AEMO to improve the forecasting of Intermittent Generation to provide more certainty around fluctuations and therefore reduce Load Following Requirements. These improvements would likely require access to real time, or close to real time, primary resource data. These improvements can be implemented by System Management taking on the energy forecasting function to by requiring intermittent generators to improve the quality of the forecasts already being provided. Each solution will put a different requirement on the communication requirements.

Communication for Curtailment

The current PSOP on dispatch identifies that System Management may have "Operation Control" of a generator or issue a dispatch notice by telephone with "sufficient time for the market participant to confirm and respond". In the case of System Management having operational control of a generator it is assumed a separate agreement is reached on the communication requirements for dispatch control, although SKM have not viewed such an agreement.[10]

Work Package 3 identifies that Intermittent Generation "of consequence" will need to be curtailed. Indeed System Management advises that is already the case. Given:

- The low overnight loads.
- Frequency of coincidental high wind resources.
- The proportion of generation that cannot be cost effectively turned on and off daily.

The decision on when to curtail wind and when to cycle dispatchable generators on a daily basis, is a complicated high value decision that will likely require a market-based solution. The specification of communication requirements to achieve curtailment of intermittent generation securely and efficiently will be highly dependent on the market mechanisms that are selected to determine when intermittent generation should be curtailed. If moves are made to strengthen the capability of the day before market to drive appropriate generator behaviour regarding curtailment, the existing communication requirements may remain adequate. However, if curtailment decisions

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[10] Western Power has advised that all existing wind farms have SCADA control. However, SKM have not confirmed the level of curtailment control this includes.

are to be made on the basis of the existing pay-as-bid dispatch decisions within the balancing market, or a real time market is to be introduced, increased specification of control requirements may be required.

At the core of this process is the differential treatment of Verve with the WEM. In response to the Oates Review, which has identified other implications of this differential treatment, the IMO has issued the Oates Review Implementation Concept Paper. This paper includes four options to address the adverse consequences of the differential treatment of Verve in the WEM. These options range from implementing Balancing Contracts already envisaged in the WEM Market rules, through to the implementation of a full net market. The result of the direction recommended by the Market Advisory Committee will significantly affect the specification of communication requirements. SKM have not identified any existing discussion on the market solution that will optimise the curtailment of intermittent generation against the requirement to 2 shift dispatchable generators.

4.8.4. Recommendations

Within the Technical Rules and the WEM Market Rules there appears to be adequate specification to facilitate the collection of the data required to improve the forecasting of intermittent generation. However, the identification of the real time, or close to real time, data required for System Management to undertake the forecasting function in place of the intermittent generators does not exist. System Management may decide that to optimise system security and minimise load following they must take on the function of forecasting Intermittent Generation (and not enforce increased accuracy from Generators). If this is the case, SKM suggest that the best place for this specification of the required data inputs would be in the WEM Market Rules, where participants can use the remote monitoring infrastructure specified in the Technical Rules, or other agreed means, to deliver this data to System Management within the required timeframe.

Changes to the operation of the market will be required to more effectively determine the extent to which intermittent generation should be curtailed. The specification of dispatch communication requirements is highly dependent on the manner in which the market evolves to meet this challenge. In determining these market changes, SKM recommend that consideration be given to the communication requirements of the recommended market solution.

5. Summary of Recommendations

The recommendations below are made with reference to the deliverables of the report detailed in Section 2.3.

Recommendation for either technical or market based mitigation measures available to manage network stability issues associated with increased intermittent generation.

The technical rules require Generators to have equipment characteristic and control systems to ensure that by connection they do not result in:

- Reduced rotor angle stability.
- Reduced frequency stability.
- Reduced voltage stability.

This requirement ensures the management of network stability issues on a case by case basis. However, the analyses in this report provides some insight into whether the increased penetration of intermittent may, by its cumulative effect, apply pressure on frequency and voltage stability.

Frequency Stability

Work Package 3 has identified that the load following requirements will exceed the spinning reserve requirements and will be available as spinning reserve. Section 4.3.3 demonstrates that with:

- The maximum intermittent generation case of 1460 MW.
- Dispatched for a system low load of approximately 3000 MW (worst case for system inertia).
- Spinning reserve set at 343 MW.

The system frequency remains within the bound set with the existing Technical Rules and conceivable rate of change of frequency events remain well within those specified within the existing technical rules. The use of the system frequency response analysis to determine frequency response does not allow the conclusion that the frequency stability of the system is unaffected by the increased penetration of intermittent generation. It does however demonstrate that with the increased spinning generation resulting from the increased load following requirements the first order system frequency response remains within bounds. All other system frequency requirements are beyond the scope of this study and must be considered on a case by case basis as specified in the Technical Rules.

Voltage Stability

SKM believes that the requirement for post voltage reactive power support in is line with that required from other jurisdictions and is well defined to facilitate support from intermittent generators. Further, if this support is not sufficient for a particular area, the Network Control Service procurement process within the WEM Market Rules allows for the provision of additional reactive power services.

Therefore, based on the existing requirements in the Technical Rules and the analysis in this report no change is recommended.

Recommendations for changes (if any) for the Fault Ride-Through requirements for intermittent generation.

To improving the competition amongst intermittent generation equipment suppliers in the WEM, without materially impacting system reliability or integrity, SKM believe there is scope to review the voltage ride-through requirements or the derogation process for these requirements.

Recommendations for changes (if any) to the Frequency Excursion requirements and Rate of Change of Frequency requirements for intermittent generators.

To improving the competition amongst intermittent generation equipment suppliers in the WEM, without materially impacting system reliability or integrity, SKM believe there is scope to review the 52.5 Hz frequency operation capability to a target of 52 Hz or a simplified derogation process be implemented.

It is recommended that the rate of change of frequency be reviewed for quantum and duration.

Recommendations for changes (if any) to the Ramping Rate requirements for intermittent generators.

No changes are recommended to ramping rate requirements.

Recommendations for changes (if any) to the Voltage Excursion and Post Fault Voltage Control requirements for intermittent generators.

To improving the competition amongst intermittent generation equipment suppliers in the WEM, without materially impacting system reliability or integrity, SKM believe there is scope to review the basis of the temporary overvoltage excursion.

No changes are recommended to post fault voltage control requirements.

Recommendations for changes to market mechanisms resulting from any market based mitigation measures identified in this analysis.

The market based mitigation mechanisms recommended are adequately captured by the existing market mechanisms. No changes are recommended

Recommendations for Technical Rules, Market Rules and PSOP changes resulting from this analysis.

Depending on the approach System Management takes to improving forecasting of intermittent generation output, amendments may be required to the WEM Market Rules. These would be to facilitate the provision of real time, or near real time, primary energy data through the existing remote monitoring facility requirements of the Technical Rules or some other suitable mechanism.

Western Power has advised they are soon to release a new version of the Technical Rules in which many of the issues raised in this report have been considered.

6. Suggested Areas of Further Investigation

SKM believe the most critical area for the effective management of the increased penetration of intermittent generation is improvement in transparency of the market and also the market's ability to dispatch (curtail) the most economically appropriate option in low load scenarios. These are intimately entwined in the Market Evolution Plan and the Oates Review Implementation Process. Indeed, the Oates Review discusses this issue on page 36 and the issue is addressed by the options A2, B and C in the Oates Implementation Review Paper. The outcome of this process will significantly impact dispatch communication requirements for intermittent generation and therefore it is recommended that the specification of these communication requirements be revisited as part of the Market Evolution process.

7. Abbreviations

AEMO	Australian Electricity Market Operator
BETTA	British Electricity Trading and Transmission Arrangements
Cogen	Cogeneration Facility (generation waste heat used for other purposes)
DSM	Demand Side Management
ENAC	Electricity Network Access Code 2004
ERA	Economic Regulation Authority
FCAS	Frequency Control Ancillary Service
GB	Great Britain
GJ	Giga Joule
IMO	Independent Market Operator
kA	Kiloamps
kV	Kilovolts
kW	Kilowatts
kWh	Kilowatt-hours
ms	Milliseconds
MW	Megawatts
MCAP	Marginal Cost Administered Price
NEM	National Electricity Market
NEMMCO	National Electricity Market Management Company
PASA	Projected Assessment of System Adequacy as defined in the Market Rules
PLC	Programmable Logic Controller
PSOP	Power System Operating Procedure
SCADA	Supervisory Control And Data Acquisition
SIL	System Interruptible Load

SKM	Sinclair Knight Merz
STEM	Short-Term Energy Market
SWIS	South West Interconnected System
WA	Western Australia
WEM	Wholesale Energy Market

Appendix A Template of Key Stakeholder Comments

The template used for stakeholder consultation is over the page.

Appendix B Further Issues raised by Stakeholders

B.1 Other Rule Elements

A review of the small generator sizing is recommended. Small induction generators include from 1 W to 10MW and that is too great a range to be covered by a single set of rules. Small photovoltaic includes up to 30 kW. There is need for a break in the range so there can be a relaxation in some rules for the smaller generators to more closely align the rules with what is commercially available or part of standard equipment packages.

The rules surrounding duplicate islanding protection should be represented as performance requirements rather than equipment specification. The requirement is mainly to prevent back energising of power cables and lines to protect the safety of people working on the lines. This should make it easier to comply whilst maintaining an appropriate standard.

Presently the protection must comply with IEC 60255 but this rule has been inconsistently applied. The requirement should be reviewed and widened to include other acceptable standards.

There are some rules where discretion is provided to Western Power. There have been cases where there is an automatic insistence by Western Power upon the most onerous requirement but without justification being providing. In these cases the automatic requirement should be the least onerous and where Western Power has a more onerous requirement then the justification should be transparent.

Lumped large intermittent generation is far more problematic for the network than distributed small units. However, the regulations discriminate against small generators by providing insufficient concessions that relate to the network benefits they provide.

Small generators often provide network support services and allow the deferral of network investment, particularly if static VAR compensation is installed but there is no mechanism for this service to be paid for. A payment mechanism for services should be developed.

The capacity credit mechanism does not provide signals, location, geographic diversity or peak load coincidence and this should be reviewed. Some intermittent generation has comparatively more peak coincidence (such as comparing solar to wind, and even between wind facilities) and more peak coincidence should be encouraged within the capacity credit process.

The Western Power queuing policy does not work well for small generators and does not support policy outcomes or projects of community merit. The processes and regulations should be developed to support policy outcomes if the SWIS is to grow in the best way for the consumers and state.

B.2 Rule Changes and Management

There is no process for stakeholders to recommend or trigger a review or changes to the Technical Rules and it is felt that a process is needed.

It is difficult to retrospectively apply new standards to existing or old facilities. There should be some method of grandfathering and tracking the standards applicable to each facility so that new standards can be introduced fairly.

A process is recommended for the ongoing review of the rules, maybe by convening every 6 months or so. There is a process that is used by the Standards Association of Australia that might suit. The review process at present is overly bureaucratic and expensive.

Some rules are or should be technology specific and there might be merit in slitting those rules into specific sections, for example, inverter connected generators (or loads) or photovoltaic generators.

The rules have evolved over time and are now can be difficult to read and navigate. Generally, information is distributed throughout the rules without being as well structured or logically presented as it could be. Section 3.6 of the rules applies to small generators but developers are not able to read the section in isolation since there is substantial overlap with other parts of the rules. It is recommended that even without altering any content the rules would benefit by from a technical writing and editorial review.

The Technical Rules have for some time been in the hands by a very competent but small number of people within Western Power. As a result there is a narrow range of views brought to the rules. Either by a more regular handing over of responsibility or a larger team should be responsible for the rules in order to bring a wider and balance range of views.

B.3 Derogation Process

Derogations are routinely required for the connection of wind turbines but the process can be difficult. PH has one derogation being processed that is presently unresolved after 12 months, it has not been vigorously pursued but the expectation is that the process should follow a timeline without the need for expediting.

There is a question of what the correct order of things is, does the derogation come first or the vendor negotiations? Network connection approval is a critical milestone in project development and is normally required ahead of “serious” negotiations with vendors and committing substantial resources to procurement. Most vendors are not willing to enter negotiations in cases where network access is not certain.

From the developers perspective an understanding of any derogations is required prior to procurement.

Derogations to the technical rules (particularly common ones) should be recorded and transparent so that they can guide future developments.

B.4 System Planning, Studies and Data

It was noted that Western Power has discussed the possibility of allowing accredited consultant to be provided network data and to undertake power system analysis studies. The purpose is to reduce reliance on Western Power. There should be strong competition between consultants to promote high performance and to keep a lid on prices. Stakeholders should also be able to be accredited to undertake their own studies if they have the capability.

The obligation to solve connection issues should not be entirely with Western Power or entirely with the developer. Applicants must take some accountability for planning and design for connection applications.

The NEM has had problems with managing data for network modelling, in some cases individuals were relied upon to understand the network or provide the correct data rather than a controlled and tracked process. Power facilities might have been altered and not had it reflected in the data. It was necessary for the NEM to “institutionalise” the collection and management of system data for the record and to facilitate study quality. The same process is recommended for Western Power.

B.5 Transparency

Network information should be more transparent to stakeholders that are able to use it.

Transparency is critical in an efficient market. Scheduling, system models and other key information is not transparent. WEM and SWIS rules prescribe and limit what can be published and sometimes it is not in the market interest.

B.6 Western Power Culture

There is a sense that Western Power is excessively rigid in its interpretation and application of the rules and presents a difficult culture for developers to deal with. A more collaborative approach would assist in project development and network connection.

It is prefer that Western Power be more positively disposed and to cooperation with proponents to help solve network connection problems.

The developer feels that there needs to be an open dialogue with Western Power for developers of alternative technologies. The process should facilitate a joint development of a network connection solution that initially uses imperfect information and has hold points for when required data must be verified. The financing and testing requirements of new technology require this approach.

The key issue was the network access process. It was felt that each project was unique and proponents needed better access and collaboration from Western Power when preparing the concept design and access applications. By doing this it is hoped that project concept designs can be optimised early to suit the needs of the network and problems can be dealt with before applications are submitted.

Western Power is necessarily conservative in its approach, particularly in light of legal responsibilities. However, Western Power is overly conservative in relation to new technologies and this can be a substantial barrier.

B.7 Further Issues Raised by Western Power

It is also contemplated that to expedite a connection application, Western Power may within a defined time of receiving a connection application, provide a scope for the necessary studies to be undertaken. The developer might then wait until Western Power is able to undertake the study or alternatively arrange for an approved consultant to do the work.

Distributed generation on a large scale has the potential to materially impact the network. The network operator should know how much distributed generation is on the system at 1 minute intervals.

Appendix C Details of Frequency Response Model

The frequency response of a transmission system to a disturbance caused by the loss of connected generation or load depends primarily on the inertial response of the system, load damping and the action of governors subjected to frequency errors. However, each of these elements is in turn dependent upon a large number of other factors and higher order responses. A detailed and complete analysis of the frequency behaviour of a system requires complex and time-consuming modelling of each element of the system. This more detailed approach is appropriate for considering a small set of system operating conditions but does not lend itself to the broad scan of conditions required by this report.

The intention of this study is to determine the average response of the SWIS for given sets of conditions and to assess the variability of the response to changes in parameters such as the mix of generation (Gas Turbines versus Steam Reheat Turbines versus Intermittent Generation) and the number of generators with active governors participating in the containment of frequency following a system disturbance. SKM's approach, which is well documented in the literature[11,12], has been to develop the lowest order model of system frequency which accurately represents average system frequency behaviour while taking account of typical turbine and governor time constants and gains. Other system dynamics such as inter-machine oscillations and transient, non-linear or discontinuous behaviour of loads are not considered.

Fundamentally, the model to be used represents the Laws of Motion which state that any unbalance in forces result in acceleration. In this case, an unbalance between the mechanical torque provided by the turbines and the electrical torque required by the loads results in an accelerating torque which causes the speed to deviate:

$$T_a = T_m - T_e$$

Power is given by torque multiplied by rotational speed and for small deviations of torque where the system was initially in equilibrium, it is possible to demonstrate that:

$$\Delta P_m - \Delta P_e = \Delta T_m - \Delta T_e$$

Using these principles combined with Newton's Laws of Motion, a low order system model can be developed which aggregates the response of individual machines into single machines representing

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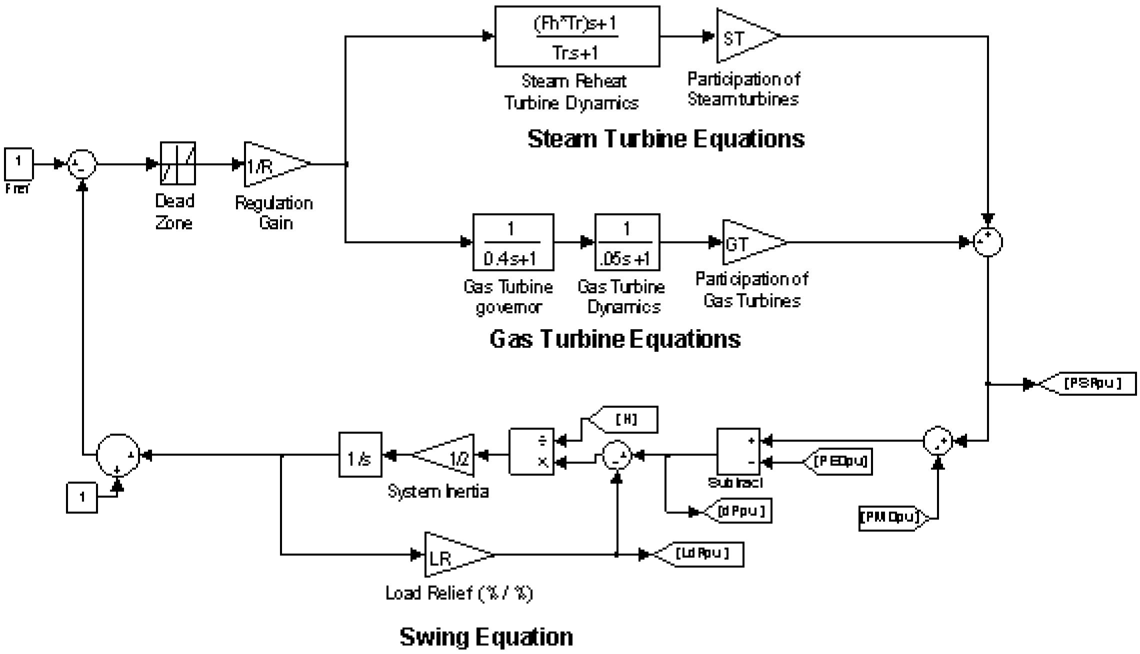
[11] Igor Kuzle, Tomislav Tomisa and Sejid Tesnjak, "A Mathematical Model for Studying Power System Frequency Changes", *IEEE Africon 2004*, p761-764
[12] P Kundur, *Power System Stability and Control*, Mcgraw-hill 1994, Ch 11.1

Gas and Steam turbines and represents load damping at the aggregate level rather than at the individual load level.

SKM has used Matlab Simulink to develop the following low order model of system frequency.



Due to the range of technologies that could be considered, intermittent generation has been modelled without a contribution to inertia or governor response as a conservative assumption.

Based on detailed model data provided by Western Power and SKMs experience and knowledge of power systems, the following parameters were used in the simulation

SINCLAIR KNIGHT MERZ SKM

Table 6 Modelling Variables

Term	Description	Value
LR	Load relief due to frequency dependency of load	1 % load reduction per 1% frequency variation
H	System inertia constant	Calculated based on the level of dispatch from each generation type resulting in a variation from 3.5 to 5.1 MW s /MVA
R	Governor droop	5%
Fh	Percentage of steam turbine power emanating from HP shaft	30%
Tr	Steam turbine reheat time constant	10 seconds

This model has been compared to data for system trips provided by System Management. Some adjustment of the proportion of governor response was required to achieve the same maximum frequency variation and this limited governor response was considered in the scope of studies moving forward. However, it is expected as the market evolves contribution to governor response from non Verve generators will increase as the restrictions of resource plans are eased.

The model has also been confirmed against single generation network models in Digsilent Power Factory to confirm the appropriateness of the turbine equations.