Calculation of Minimum Reserve Levels and their Application to Maintain Reliability of Supply in the Australian NEM

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SUMMARY: NEMMCO is a non-profit organisation established in May 1996 to implement, administer and operate the wholesale National Electricity Market (NEM), continually improve its efficiency, and manage the security of the power system. The NEM comprises of six interconnected regions. One of NEMMCO's key responsibilities is to manage the reliability of electricity supply to customers of the NEM. Power system supply reliability is a measure of the power systems capability to continue to supply sufficient power to satisfy customer demand, allowing for the influence of unplanned generation failure and unplanned outages of major transmission interconnections. Demand that cannot be satisfied for a period of time is referred to as unserved energy (USE). The NEM Reliability Standard requires that the level of USE in any region of the NEM must not, on average, exceed 0.002% of the total energy consumed in that region in a year. This paper focuses on the methodology adopted by NEMMCO to ensure it manages power system reliability, in order to satisfy the Reliability Standard. It introduces the concept of a minimum reserve level, how it is calculated and the use of the minimum reserve level as an operational trigger for intervention in the market.

1. METHODOLOGY

The NEM Reliability Standard requires that the level of Unserved Energy (USE) in any region of the NEM must not, on average, exceed 0.002% of the total energy consumed in that region in a year. USE could arise through any combination of insufficient:

- generation capability;
- demand side response; and
- transmission capacity to supply major load centres.

USE can be measured historically, and is a good long-term indicator of power system reliability. USE is not, however, a practical measure for operational purposes, as it is not possible to directly estimate USE for a given set of power system conditions at any point in time. For this reason, NEMMCO determines a capacity-based reserve margin (minimum reserve level), measured in MW relative to the peak demand in a region. NEMMCO then uses a comparison of the forecast reserve margin with the minimum reserve levels to highlight potential problems in meeting the Reliability Standard in the future.

Minimum reserve levels provide NEMMCO with an operational trigger for intervention in the market to ensure adequacy of power supply. NEMMCO uses several tools which alarm when intervention in the market may be required. One of these tools is the Medium Term Projected Assessment of System Adequacy (MTPASA) [1]. MTPASA has the following inputs:

- generation availability for a two year horizon as advised to NEMMCO by the NEM generators;
- set of constraint equations which define the transfer capability of interconnectors and key circuits in the NEM;
- daily 10% POE[1] peak demand for each region; and
- the regional minimum reserve levels.

MTPASA provides an assessment of generation availability in each region and transfer capability between regions, to determine if sufficient generation capacity is available to meet the demand. The assessment is completed on a daily basis for a 2 year outlook horizon. MTPASA will determine if there is sufficient generation to meet each regions 10% POE demand + minimum reserve level.

If the reserves in a region fall below that regions defined minimum reserve level, NEMMCO is authorised by Clauses 3.12.1 (a) and 4.8.9(a)(1) of the National Electricity Rules [2] to use its powers to either:

- contract for additional reserves; or
- direct generators, scheduled loads or market network services to make their plant or facilities available to maintain reserves.

It is necessary for NEMMCO to review the minimum reserve levels from time to time, particularly following commissioning of interconnector augmentations, which provide increased ability for regions to share reserves, or significant new entry of generation capacity. It has also been shown that for a given forced outage rate, larger generators generally have a more adverse impact

[1] 10% Probability of Exceedence (POE) demand is the demand expected to be exceeded only once in ten years.

on system reliability than a number of smaller units with the same total capacity.

The main technical factors directly influencing the amount of USE experienced in any region are listed in Table 1 below:

Table 1. Main factors that influence system reliability

Description	Reliability Consideration
Generator reliability	Lower reliability increases the probability of coincident generator failures.
Generator repair time	Longer repair times increases the probability of multiple generators being unavailable.
Generator size	Many small generators provide a higher overall system reliability than a few large generators of equivalent size and reliability.
Fuel supply	Power stations that can utilise multiple fuel types are at less risk to fuel supply being curtailed than single-fuel plant.
Duration of peak demands	Power systems with short-duration peaks have lower exposure to the impact of generator failures than longer-lasting peaks.
Transmission reliability	Transmission reliability is generally a second-order effect as transmission is significantly more reliable than generation.
Level of interconnection	Stronger interconnection allows reserve sharing and means that more heavily interconnected regions require lower minimum reserve levels to meet the Reliability Standard.
Location of region	Regions at the extremes of the power system are less able to share reserves and generally require a larger minimum reserve level to meet the Reliability Standard.
Demand Diversity	Neighbouring regions with high levels of diversity are better able to support each other and deliver higher reliability through reserve sharing.

2. PROCESS

2.1. Monte Carlo Simulation

Beyond more than even a few days into the future there become too many unknowns to accurately predict the likely operation of any complex system. In this time frame the performance of the power system, in terms of holistic indicators such as reliability, can only be forecast on a probabilistic basis. *The Monte Carlo simulation technique surpasses any other mathematical modelling technique in its ability to provide a physical understanding of performance of the system in the future. This is especially the case if the simulation methodology is designed to closely reflect the actual operating characteristics of all essential elements (mainly loads, generators, transmission lines and system dispatch rules) in simulated time sequential steps* [3]. Monte Carlo simulation is used by NEMMCO for a range of purposes including calculation of minimum reserve levels. The Monte Carlo approach allows NEMMCO to conduct many simulations (iterations) each of which reflect a different generation outage scenario. The average USE resulting from all simulations provides an expected long term average USE.

By measuring the regional USE outcome from a large number of Monte Carlo simulation studies, the relationships between USE, the level of installed generation within each region and interconnector capability between regions can be established. By analysing these relationships the minimum level of installed generation in each region which just satisfies the Reliability Standard can be found. This is achieved by iteratively completing simulation studies, modifying the level of installed generation between studies until the desired USE outcome is achieved. This level of installed generation is then converted into a regional minimum reserve level. This iterative methodology leads to:

- approaching the USE Reliability Standard within each region simultaneously;
- altering the installed generation within each region to maximise the capability for reserve sharing and USE sharing between regions; and
- approaching an outcome which achieves the minimum level of installed generation within the NEM as a whole.

2.2. Adjusting Regional Installed Capacity

A logical starting point for assessing the reliability of the system is to model all existing and committed generation projects within the study horizon. This level of available generation will almost certainly exceed the minimum reserve level required in each region, otherwise the current system would already be in reserve shortfall. To find the minimum reserve level, generation plant will have to be removed from the simulation.

The choice of plant to remove from the simulation study must be carefully selected as each existing generation unit can significantly affect the dynamics of the whole NEM system, particularly through interaction with transmission constraint equations. It is desirable to select plant which will have minimal impact on the dynamics of the transmission system and the NEM as a whole. The following issues should be considered carefully:

- reduction in capacity or removal of plant which does not appear in any constraint equations is desirable. Given the large number and complex relationships between constraint equations this can be very difficult if not impossible to achieve fully;
- a balance between the proportion of existing or likely future baseload, intermediate, peaking and energy limited plant is maintained;
- the forced outage rates (FOR) of plant play a significant role in the reliability of the system. Removal of plant with a high FOR will have a smaller impact on USE than removal of very reliable plant. i.e. removal of generation with high reliability will tend to result in a higher reserve level outcome whereas removal of generation with low reliability will tend to reduce the reserve level requirement.

Targeting an even distribution of USE across the NEM can lead to additional plant requirements in some regions. That is, in some cases it may be necessary to add hypothetical plant into certain regions in an effort to just meet the Reliability Standard in all regions simultaneously. In this case notional additional generation must be included in the simulation. The choice of additional generation plant and how this plant may affect the system dynamics and USE forecast must also be carefully considered. When considering the technical elements of notional new generation plant it is important to take into account:

- plant size;
- plant type;
- plant location within the region, associated MLF[2] and possible effects on transmission constraints. Typically notional new plant would be assumed to not directly influence inter-regional transmission limits;
- plant trading behaviour and resultant merit order in dispatch; and
- plant forced outage rates are particularly significant.

The issues relating to plant selection for installed generation reduction and additional plant requirements must be carefully considered in applying the methodology for finding minimum reserve levels through Monte Carlo simulation.

2.3. Sensitivity Analysis

To assess the variability in USE that may result due to uncertainty in key system parameters, a number of simulation studies are completed. A Base Case is developed which contains the most likely set of system input parameters. Alternate simulation studies, or sensitivity cases, will have one key system parameter altered from the Base Case. For example, generator forced outage rates may be increased or demand diversity between regions may be altered.

Sensitivity analysis is used in two ways for the NEM minimum reserve level assessment. Initially, the minimum reserve levels are found for the Base Case. Applying this level of installed generation in a sensitivity case provides an indication of the USE outcome which would be experienced if the alternate input data eventuated. The sensitivity case may then be analysed further to find minimum reserve levels for the alternate data set. This will provide an indication of the effect of the change in input data in terms of physical generation capacity required to meet the same level of reliability (provide the same USE outcome).

The outcomes from a range of sensitivity cases provide the system planner with a method of risk evaluation and a higher level of understanding of the complex system. The final minimum reserve levels should be robust against a range of likely system conditions.

[2] Marginal Loss Factors are applied in the market to provide investment signals and promote a reduction in system transmission losses.

2.4. Long Term Average

The Reliability Standard defines a threshold for which the long term average USE must fall within. Monte Carlo simulation provides the expected long term average outcome of system variables, such as USE, for a given set of input system parameters. Results from the simulation also provide additional statistical information of the system variables such as standard deviation and confidence intervals. Figure 1 below shows the variability of USE for four regions of the NEM for a 100 iteration simulation study. This figure illustrates that whilst the average USE across 100 iterations may fall within the Reliability Standard, any single iteration may be well in excess of the Standard. It must be recognised that the outcome of any individual iteration is a possibility.

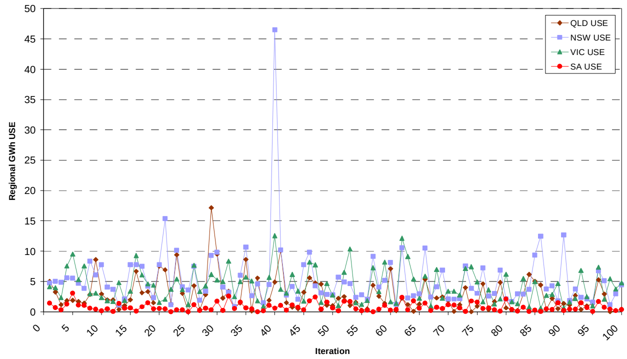


Figure 1. Variability of USE Indicator

The number of Monte Carlo iterations which are required to find the long term average (convergence) of system outcomes is a matter of considerable debate. In the calculation of minimum reserve levels for the Australian NEM, 100 iterations has been found to deliver good convergence of USE outcomes and provide a high level of confidence in this system variable. A review of the methodology applied by NEMMCO indicates that 100 iterations significantly exceeds standard international practice [4].

3. DATA REQUIREMENTS

The minimum reserve level simulations attempt to model the capability of the power system throughout the year. The power system model includes the following key inputs:

- load trace forecasts (time sequential half-hourly regional demand traces);
- demand side participation;
- transmission constraint equations (which define the allowable level of interconnector flow);
- transmission forced outage rates;
- generation capacities;
- generation energy limits;
- generation forced outage rates;
- generation maintenance; and
- generation bidding.

3.1. Load Trace Forecasts

Simulations are conducted for each half hour for every day of the year using both a 10% POE demand trace (extreme demand expected to be exceeded only 1 in every 10 years) and 50% POE demand trace (average demand expected to be exceeded every 2 years). The overall USE result from the simulations is calculated as a weighted combination of the USE outcome in the 10% POE simulations and the 50% POE simulations. The load traces are developed by NEMMCO in conjunction with advice from the transmission network service providers (TNSP).

To develop demand traces for the 10% POE scenario:

- previous years are examined and the most recent year to achieve a 10% POE weather pattern is selected as the reference year (the reference year may differ between regions); then
- the demands in each half-hour of the reference year are scaled so that the winter and summer peak demands and the annual energy match the forecast for the year being simulated.

A similar approach is used for the 50% POE scenario.

Since the scaled demand trace is based on an actual historical year, this introduces an inherent level of demand diversity between regions in the simulations.

3.2. Demand side participation

The amount of load which is able to be shed in response to change in market conditions, such as high market price, is referred to as demand side participation (DSP). DSP is modelled explicitly in the simulations as negative load. NEMMCO collects information from market participants regarding the available demand side participation and uses this information in the simulations. DSP is assumed to be 100% reliable.

3.3. Transmission constraint equations

Constraint equations are extracted from the National Electricity Market Dispatch Engine (NEMDE). These equations define the network capability in the real time dispatch process managed by NEMMCO. The simulation process which determines the minimum level of installed generation in each region uses these constraint equations. The constraint equations set a dynamic transfer capability between regions, dependent on current system conditions within the simulation.

TNSP's advise NEMMCO of their committed augmentations and the impact they are expected to have on the network transfer capability. Constraint equations are then adjusted in the simulations to reflect the impact of these committed projects.

Increased network transfer capability between regions increases the ability for reserve sharing, and is a driver for lower minimum reserve level requirements.

3.4. Transmission forced outage rates

The forced outage of key circuits in a region can impact the transfer capability of interconnectors between regions. Information regarding the probability of failure of these key circuits and resulting reduction in transfer capability between regions is modelled in the simulations.

3.5. Generation energy limits

It is important to consider any energy limitations on plant in the power system when assessing power system reliability. Some plant, such as hydro power stations, may have limited reservoir capacity and are dependent on water inflow, or pumping capability to manage fuel resource. These plant are referred to as energy limited plant. NEMMCO collects information from market participants regarding energy limitations on plant and models this information appropriately.

3.6. Generation capacities

NEMMCO collects information regarding the dependable capacity of each generator in the NEM during summer and winter periods. This information is published in the Statement of Opportunities [5]. The generation capacities reported to NEMMCO are modelled in the minimum reserve level simulations.

3.7. Generation forced outage rates

Generation forced outage rates have been shown to be among the most critical inputs to the simulations. That is, step changes in generator forced outage rates can have a major impact on power system reliability. NEMMCO collects forced outage rate information on an annual basis from all scheduled generators in the NEM and uses the most recent data set in minimum reserve level simulations. The forced outage information provides for accurate modelling of the frequency of failure and time to repair each generating unit.

3.8. Generation maintenance

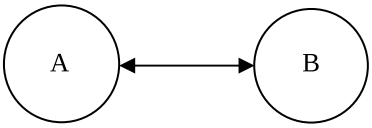
Generic maintenance schedules are developed for each class of plant within each region based on historic maintenance practices seen in the market. A maintenance schedule is then applied in the simulations to each generating unit, using a method that attempts to schedule maintenance away from peak demand periods.

3.9. Generation bidding

Simple generation bidding methods are adopted which dispatch units in a merit order based on the cost of generator fuel usage. Generation using cheaper fuel is bid into the simulations ahead of generation using higher-priced fuel, giving the former more running time throughout the year. The generation dispatch merit order is not particularly important in minimum reserve level simulations as unserved energy generally only occurs when all available generation is dispatched.

4. EXAMPLE APPLICATION

The following calculation provides a simplified example of the application of each of the elements required to establish the level of available generation in each region, so that it may be compared against the minimum reserve level requirement. This calculation is based on two regions (region A and B) connected with a single interconnector.



Suppose market simulations have been completed to find the level of installed generation required in this two region system to deliver the Reliability Standard. The market simulations resulted in a requirement of 600MW reserve level for region A and 200MW reserve level for region B assuming a net zero interconnector flow at the time of peak demand (referred to as assumed interconnector support).

Table 2. Example application of minimum reserve level

Reserve Element	Region A	Region B
Regional Minimum Reserve Level	600MW	200MW
Assumed Interconnector Support	0MW	0MW
Example 1: Regional Situation		
Regional Generation Available	8500MW	3210MW
Regional 10% POE peak demand forecast	8000MW	3000MW
Regional DSP available	30MW	60MW
Interconnector Support Limit3	500MW	500MW
Example 2: Regional Situation		
Regional Generation Available	7900MW	4000MW
Regional 10% POE peak demand forecast	8000MW	3000MW
Regional DSP available	30MW	60MW
Interconnector Support Limit	500MW	500MW

Example 1:

Firstly if interconnector support is not considered, then the reserve level in each region is:

Reserve Level Region A = 8500 + 0 + 30 – 8000 = 530MW
Reserve Level Region B = 3210 + 0 + 60 – 3000 = 270MW

On this basis region A is in reserve shortfall as the reserve level is 530MW and the minimum reserve level is 600MW. Region B however is in reserve surplus by 70MW, so can share its reserve across the interconnector:

Reserve Level Region A = 8500 + 70 + 30 – 8000 = 600MW
Reserve Level Region B = 3210 – 70 + 60 – 3000 = 200MW

In this situation, the power system has the exact minimum available plant required.

Example 2:

Again if interconnector support is not considered, then the reserve level in each region is:

Reserve Level Region A = 7900 + 0 + 30 – 8000 = -70MW
Reserve Level Region B = 4000 + 0 + 60 – 3000 = 1060MW

On this basis region A is in reserve shortfall by 670MW as the minimum reserve level is 600MW and the actual reserve level is -70MW. In this example region B has significant excess reserve generation so can share its reserve across the interconnector, but only up to the interconnector limitation of 500MW:

Reserve Level Region A = 7900 + 500 + 30 – 8000 = 430MW
Reserve Level Region B = 4000 – 500 + 60 – 3000 = 560MW

In this situation, the power system has sufficient reserve generation overall, however reserve generation is unable to be shared between regions due to interconnector limitations. As such, region A remains in reserve deficit by 170MW and region B maintains a reserve excess of 360MW.

5. CONCLUSIONS

The NEM Reliability Standard requires that the level of USE in any region of the NEM must not, on average, exceed 0.002% of the total energy consumed in that region in a year. To facilitate this standard NEMMCO determines a capacity-based reserve margin called a minimum reserve level, measured in MW relative to the peak demand in a region. The minimum reserve level provides NEMMCO with an operational trigger to identify when intervention in the market is required. The methodology used by NEMMCO to determine the minimum reserve is presented in this paper.

6. REFERENCES

[1] NEMMCO, 2002, Medium Term Reserve Assessment. http://www.nemmco.com.au/powersystemops/so_op3702v004.pdf

[2] Australian Energy Markets Commission, 2005, National Electricity Rules, 2005 ed.

[3] Rose, Bones & Pimentel, 2005, Monte Carlo simulation and its application in modelling electricity market behaviour, *Institution of Engineers, Australia 2005, Australian Journal of Electrical & Electronics Engineering*, Vol 2, No.3.

[4] KEMA, 11 January 2005, Review of Methodology and Assumptions Used in NEMMCO 2003/04 Minimum Reserve Level Assessment

[5] NEMMCO, 2005, 2005 Statement of Opportunities

[3] The interconnector support may be limited by:

1. the dynamically calculated limit from the constraint equation set; and/or
2. a minimum level of plant which must be sourced through local generation. i.e. maximum import limit = demand – minimum local generation requirement.

BEN VANDERWAAL

Ben is ROAM Consulting's Forecasting Manager, with degrees in Electrical Engineering and Information Technology. He has been a core member of the ROAM Consulting team since the company was formed in early 2000. Ben has been intensively involved in the delivery of numerous market forecasting assignments for a wide range of clients inside and outside the Australian NEM. His experience covers a wide range of market analysis from detailed power flow analysis to the 30 year planning time frame. Prior to the formation of ROAM Consulting Ben was employed as an undergraduate in the Queensland Government owned Austa Energy, the engineering consulting arm responsible for generation planning of the Queensland State owned electricity grid. His combined experience equates to more than 8 years in the industry.

Ben's specialisation is algorithm development and data processing techniques for large analytical models. He has been the primary software designer and developer of the 2-4-C® electricity market simulation model. The 2-4-C simulation model has previously been applied to calculate Minimum Reserve Levels for the Australian NEM which were consequently endorsed and have applied in the NEM since 2004.

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Adam works with the National Electricity Market Management Company (NEMMCO) in the Power System Planning and Development Team. He is actively involved in the development of the annual NEM Statement of Opportunities and has experience working on power system security and reliability based projects. Adam's primary role involves advanced power systems analysis and he is a key member of the market simulation team at NEMMCO.

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ROAM Consulting

ROAM Consulting is a leading provider of expert services in energy market systems for participants in the Australian National Electricity Market and for customers in other networks around the world.

Based in Brisbane, ROAM comprises a team of highly experienced power engineers, system analysts, software developers, economists and mathematical modellers. In addition, we employ a number of part time specialists with expertise in coal resources, plant efficiency and design, contract development and negotiation.

Our focus is on detail. Our server room is stocked with several banks of dedicated high-speed processing machines upon which our suite of advanced simulation software engines are deployed.

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