ESOPP GUIDE

CONFIDENCE LEVELS, OFFSETS & OPERATING MARGINS - POLICY

PREPARED BY:	Ben Blake
DOCUMENT REF:	ESOPP_08
VERSION:	3
DATE:	6 July 2010

FINAL

Version Release History

VERSION	DATE	BY	CHANGES
3	6 July 2010	Ben Blake	Added AEMO disclaimer
2	30 December 2009	Ben Blake	AEMO rebranding
1	1 August 2007	Michael Lyons	Original Document

Contents

1 Disclaimer 4

2 Background 4

3 Risks and Consequence of exceeding limits 5

3.1 Transient Stability 5

3.2 Oscillatory Stability 6

3.3 Voltage Stability 6

3.4 Thermal Rating Limit 6

4 Derivation of Limit Equation 7

5 Offsets and Confidence Levels 8

5.1 Offsets 8

5.2 Confidence Level 8

6 Approximations and Errors to Be Managed By Operating Margins 8

6.1 Modelling Approximations 9

6.2 Dispatch Errors 9

6.2.1 Variation in Right Hand Side Terms during Dispatch Interval 9
6.2.2 Non-Conformance of Generators 9
6.2.3 MW versus MVA terms 9

6.3 Measurement errors 9

6.4 Definition Of Operating Margin 10

7 Application of Confidence Levels, Offsets and Operating Margins 10

7.1 Transient, Oscillatory and Voltage Stability Constraints 10

7.1.1 Confidence levels and offsets 11
7.1.2 Operating Margins 11
7.1.3 Combining Confidence levels/Offsets and Operating Margins 11

7.2 Thermal Constraints 11

7.2.1 Confidence levels and offsets 11
7.2.2 Operating Margins 11
7.2.3 Combining Confidence levels/Offsets and Operating Margins 12

1 Disclaimer

This document is made available to you on the following basis:

a) **Purpose -** This document is provided to you for information purposes only. You are not permitted to commercialise it or any information contained in it.

b) **Reliance** - This document may be subsequently amended. Any reliance on this document is at your own risk.

c) **Intellectual Property** – AEMO Limited is the owner of the copyright in this document. All rights are reserved. All material is subject to copyright under the *Copyright Act 1968* (Commonwealth) and permission to copy it, or any parts of it, must be obtained in writing from AEMO. AEMO is the owner of all other intellectual property rights in this document and the information contained in it. You must not in any way, or by any means, store, reproduce or modify it without AEMO's express written consent.

d) **No Warranty -** Neither AEMO, nor any of AEMO’s advisers consultants or other contributors to this document (or their respective associated companies, businesses, partners, directors, officers or employees) make any representation or warranty, express or implied, as to the currency, accuracy, reliability or completeness of this document, or the information contained in it.

e) **No Liability** - To the maximum extent permitted by law, neither AEMO, nor any of its advisers, consultants or other contributors to this document (or their respective associated companies, businesses, partners, directors, officers or employees) shall have any liability (whether arising from negligence or otherwise) in respect of your use of the information (including any reliance on its currency, accuracy, reliability or completeness) contained in this document.

© [2010] - AEMO Limited is the owner of the copyright in this document. All rights reserved.

2 Background

Transmission Network Service Providers (TNSPs) develop limit equations that define the technical envelope within which the power system will remain in a satisfactory operating state following any single credible contingency event. Equations are determined for both system normal and transmission outage conditions.

The types of limit that TNSPs in the National Electricity Market must consider include:

- Transient stability,
- Oscillatory stability,
- Voltage stability, and
- Thermal rating.

The consequences of exceeding a limit can be severe and include damage to equipment, injury to people and widespread blackouts. The risk of such consequences occurring depends on the probability of the triggering mechanism (fault to ground, loss of a large generator, trip of a transmission line, etc.) occurring.

For some of the above limits, a limit equation is determined directly as a function of the key variables. For example, thermal rating limits may be defined in terms of generator power distribution factors and the flow redistribution factor for the critical contingency.

For other types of limit, such as transient and oscillatory stability, a large number of cases are studied for a wide range of power system conditions, and a limit equation is then developed by fitting a multi-variable equation to these critical cases. The fit of the equation is determined such that it will cover most or all of the critical cases studied.

The adequacy of coverage is either specified as:

- an offset that ensures all critical cases are covered by the equation, or
- a confidence level that specifies the percentage of critical cases that are covered by the equation.

When applied, the confidence level is typically set to ensure the limit equation value is below the case limit for at least 95% of cases. The TNSP determines whether an offset or confidence level is to apply and specifies its value in the limit advice.

The TNSP provides each limit equation to AEMO who undertakes a due diligence assessment to confirm that implementation of the limit will result in secure operation. Provided this assessment is successful the equation is then reformulated so that it can be incorporated into the dispatch process. This involves moving dispatchable terms to the left hand side of the equation and non-dispatchable terms to the right hand side. Linearization of those terms on the left hand side may also be required. The resultant equation is referred to as a constraint equation.

The ability of the constraint equation in the AEMO dispatch engine (NEMDE) to maintain the flow on an interconnector or transmission element to within the true limit is dependent on a number of factors including:

- Modelling approximations,
- Control limitations, and
- Short-term variations in loads and generator outputs.

AEMO determines the operating margins to be applied to constraint equations to manage these approximations and errors.

The dynamics of the power system are such that there will inevitably be some statistical variation of power flows around the desired operating point. As such it is not practicable or efficient to set an operating margin to eliminate all possibility of the limit being exceeded. Instead, a probabilistic approach is employed, based on an acceptable small risk of exceeding the limit.

3 Risks and Consequence of exceeding limits

The consequences of exceeding a power system limit depend on the type of limit involved:

3.1 Transient Stability

In the NEM, the transient stability limit is defined as the maximum power that can be transferred between large groups of generators while maintaining synchronism following a two-phase-to-ground fault at the critical location. Exceeding the transient stability limit can result in a partial or complete shutdown of the power system. The instability develops in a matter of seconds preventing any post-contingent action by the operator.

The likelihood of a two-phase-to-ground (or worse) fault occurring at the critical location at times of maximum power transfer is low, although significantly increased if lightning is in the vicinity. Even so, the consequences of a major power system shutdown would be severe and a conservative approach to setting confidence levels, offsets and operating margins for transient stability constraint equations is justified.

AEMO has installed a Dynamic Security Assessment (DSA) program, which runs approximately every 10 minutes and advises on-line staff whether the current system is transiently stable. In this way the performance of transient stability constraint equations can be assessed and the constraint equation adjusted if shown to be ineffective. When these cases are found they are discussed with the relevant TNSP. However, the program can only determine whether the transient stability limit has been exceeded, not how far the power system is from the stability limit.

3.2 Oscillatory Stability

The oscillatory limit defines the maximum power that can be transferred from one region to another such that any oscillations resulting from small perturbations on the power system are adequately damped. Clause S5.1.8 of the NEM Rules requires the power system to be planned and operated to ensure the halving time, being the time for the amplitude of an oscillation to reduce by half, should be less than 5 seconds. The Rules further require that when assessing or analysing power system oscillations, the TNSP must take into account statistical effects. As such real-time monitoring or test results must show that there is less than a 10% probability that the halving time will exceed 10 seconds, while the average halving time must be not more than 5 seconds.

Oscillatory instability develops more slowly than transient instability and it may be possible for some operator intervention to occur. Even so, oscillatory instability could result in a major system shutdown and a conservative approach to setting confidence levels, offsets and operating margins is justified.

AEMO has installed Psymetrix programs, which calculate the damping on the power system and advise on-line staff whether the actual non-contingent oscillatory stability limit has been exceeded. This allows the equivalent oscillatory stability equations to be assessed and adjusted if shown to be ineffective. However, the program cannot assess post-contingent conditions and can only determine whether the non-contingent oscillatory stability limit has been exceeded, not how far the power system is from it.

3.3 Voltage Stability

The voltage stability limit defines the maximum power that can be transferred from generation sources to load areas while ensuring sufficient reactive power is available to meet the load demand and maintain a specified reactive power margin from the theoretical point of voltage collapse.

Voltage instability can develop very quickly or over a few minutes and is often associated with the loss of large generating units or transmission lines. It is mostly a problem at times of high reactive power demand in summer when voltages are low and transmission reactive power losses are significant.

The probability of a major transmission line or generating unit tripping is higher than the likelihood of a two-phase-to-ground fault causing transient instability. Even if voltage instability develops slowly it is unlikely that operator action could be taken in the time available. Automatic control action would be possible and if such schemes were available they would be considered when developing the limit equation.

As with transient instability, voltage instability can result in partial or complete shutdown of the power system and a conservative approach to setting confidence levels, offsets and operating margins is warranted. However, this is mitigated to some extent through the Code requirement to include a reactive power margin when determining voltage stability limits.

AEMO uses its on-line Contingency Analysis (CA) program to assess whether post-contingent voltage instability could occur. This enables the performance of the constraint equation to be monitored and adjustment to be made if the equation is found to be ineffective. However, the CA program used does not include the reactive power margin required by the NEM Rules and so does not fully ensure the required security standard. The program only indicates whether the actual voltage stability limit has been exceeded, but not by how far, or how close the power system is to the voltage stability limit. Similar Contingency Analysis programmes are routinely run by a number of the TNSPs, which provides some redundancy of analysis.

3.4 Thermal Rating Limit

Thermal constraint equations are used to ensure pre- and post-contingent flows on a transmission element will not exceed rating. Nil-trip constraint equations are used to ensure the pre-contingent flow does not exceed the continuous rating of the transmission element. For those cases where a contingency event is involved, a short-term or emergency rating is often defined. These short-term ratings allow for some time to elapse before the flow must be reduced to below the continuous rating of the critical element. A rating shorter than 15 minutes is not acceptable unless some form of automatic or manual process is available to reduce post-contingency loading within the time required.

The consequences of overloading a transmission element include exceeding the minimum clearance above ground and possible damage to the transmission element through overheating or annealing. Exceeding minimum clearance could result in fires, damage to equipment and/or injury to people in the vicinity, and development of a line fault should flashover occur. If the exceedence of the thermal limit is high, cascade tripping of other circuits could result, leading to a major system disturbance or shutdown.

AEMO's on-line Contingency Analysis program can be used to assess the performance of thermal constraint equations and advise not only whether the post-contingent flow is above rating, but also how far away the limit is. Similar Contingency Analysis programmes are routinely run by a number of the TNSPs, which provides some redundancy of analysis.

Due to the accuracy with which pre- and post-contingent thermal loading conditions can be assessed and reported to on-line staff, a less conservative approach to setting confidence levels and offsets (where applicable) and operating margins may be possible. Thermal constraint equations are often created with only a small or no operating margin. The operating margin is then increased or decreased depending on observed performance.

A more conservative approach needs to be taken for constraint equations that ensure pre-contingent flow doesn't exceed continuous rating (Nil trip) compared with equations that apply to contingency events. This is to ensure that a transmission element will not be operated in the steady state beyond its continuous rating. By contrast, in the case of constraint equations that involve a contingency event, overloading will only occur in the unlikely event that the contingency occurs.

4 Derivation of Limit Equation

Limit equations are generally derived from a large number of power system studies, particularly where voltage and transient stability are concerned. To ensure an adequate level of accuracy of the limit equation for a wide range of operating conditions, a large number of study cases are studied which cover variations in the main variables likely to affect the limit. (A reduced number of study cases may be used for some prior outage cases. This will depend on the impact the outage has on the limit.) For each study case the limit is determined and saved as a critical case. Variables could include a combination of:

- the number of generators at each power station
- changes in reactive plant on-line
- different transfer levels between regions
- a range of region demand levels.

A linear form of limit equation as a function of the above variables is fitted to the critical cases. The fit of the cases to the linear equation is then examined. For those cases for which the difference between the linear equation is significant the following action would typically be taken:

- Recheck the critical case for data errors
- Consider inclusion of higher order terms in the limit equation (e.g., a quadratic term for a variable such as inter-regional transfer)
- Consider what other variables may need to be included in the analysis that had been left out. This often requires closer scrutiny of the mode of loss of stability and the creation of further study cases.

When all critical cases are deemed sufficiently close to the best-fit limit equation, that version of the equation is then adjusted by an offset or confidence level term.

5 Offsets and Confidence Levels

5.1 Offsets

The offset is used to adjust the limit equation such as to ensure the limits in all of the critical cases are covered by the limit equation. This is achieved by comparing the limit in each critical case to the limit calculated by applying the limit equation to the same system conditions, and selecting the minimum value of offset which will ensure the limits determined using the equation are within all the individual critical case limits.

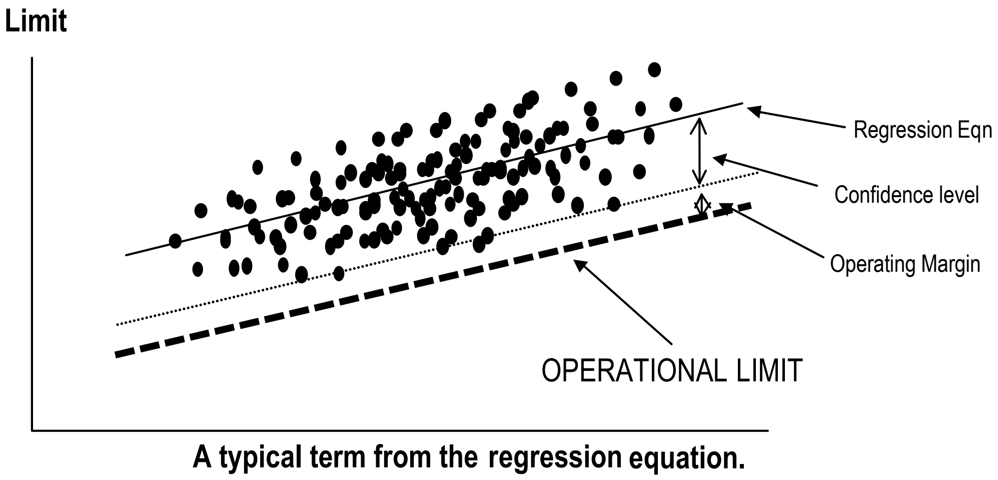
This approach has been adopted by TransGrid.

5.2 Confidence Level

The confidence level is expressed as the percentage of critical cases that are covered by the limit equation. A confidence level of 95% means that 95% of critical cases had less restrictive limits than predicted by the limit equation, and 5% had more restrictive limits. It should be noted that since the critical cases are not statistically related to actual operating conditions, this confidence level does not represent the probability of operating within the true limit whenever the limit equation is binding.

The confidence level is determined by multiplying a factor times the Standard Error of the fit and subtracting this value from the base limit equation. For example, to achieve a 95% confidence level a factor of 1.65 is used.

The application of a confidence level is illustrated below:



This approach has been adopted by AEMO Transmission Services, Powerlink, Transend and ElectraNet SA.

6 Approximations and Errors to Be Managed By Operating Margins

The sources of approximation and error that must be taken into account when determining an operating margin include:

6.1 Modelling Approximations

Modelling approximations include:

- Estimation of load indices for voltage and frequency deviation
- Assumptions about the response of control schemes for tap changing, capacitor bank/reactor switching, etc.
- Assumptions about system conditions such as voltage profile, switching of non-critical transmission elements, buses, etc.
- Uncertainty in generation parameters
- Approximations to models of generator control systems

A conservative approach is generally taken when defining models to be used for analysis purposes.

6.2 Dispatch Errors

Errors associated with the dispatch of generating units and interconnectors can result in flow exceeding the limit in the following ways:

6.2.1 Variation in Right Hand Side Terms during Dispatch Interval

When determining the constraint limit to apply for the five-minute dispatch interval NEMDE assumes the RHS line flow, generator output and load values remain constant during the interval. However, it is likely that at least some of these values will vary over the 5 minutes. There is additional uncertainty in the value of the limit within the 5-minute dispatch interval because the limit is calculated to apply only at the end of the dispatch interval. These variations could result in the flow exceeding the limit for at least part of the dispatch interval.

6.2.2 Non-Conformance of Generators

Errors may arise due to generators not following dispatch instructions or being required to move away from the target value due to Frequency Control Ancillary Service (FCAS) requirements, particularly if the generator is providing raise or lower regulation service. The persistent non-conformance of a generator is managed by applying a constraint equation to inform AEMO’s Dispatch Engine (NEMDE) of the non-conformance. Non-conformance due to contingency FCAS events need not be considered as they only arise immediately following a contingency event. The amount of non-conformance resulting from the provision of regulation service should generally only be small.

Generator non-conformance may not only affect the calculation of the limit but also result in the flow across an interconnector or transmission line exceeding the limit.

6.2.3 MW versus MVA terms

NEMDE can only change MW flows on interconnectors and MW outputs on generating units. This is acceptable for voltage, transient and oscillatory equations which are derived by regression analysis in terms of a MW limit. However, thermal limit equations are often not implemented as regression equations. In these cases the LHS variables are MW terms while the RHS includes an MVA rating term, and line flow terms that can either be MW or MVA. Errors arising from this mismatch are managed by adjusting the magnitude of the operating margin.

6.3 Measurement errors

Measurement errors can affect many terms used in constraint equations including interconnector flows and generator outputs. This can result in errors when determining the left and/or right hand side values of the constraint equation. Errors arising from differences between actual and measured values of line flows can result in limit violations, particularly when interconnectors are comprised of a number of transmission lines.

6.4 Definition Of Operating Margin

Based on the above discussion, the operating margin can be defined as:

Operating Margin = Modelling Approximation + Dispatch Error + Measurement Error

As discussed in Section 5.1 a conservative approach is generally taken with modelling approximations. That is, where uncertainty is involved, a value or approach is assumed that is inherently conservative rather than optimistic. It is therefore proposed that this term not be considered when defining the magnitude of the operating margin.

The dispatch error can be quantified for interconnectors by comparing the actual flow values with the target value set by NEMDE when the interconnector is binding. This provides a statistical variation of flow around the limit.

It is proposed that the dispatch error contribution to the operating margin for interconnectors be set at the average amount by which the flow values must be offset, to ensure that they will not exceed the limit for more than an agreed percentage of the time that the constraint binds. The dispatch error value may need to be further increased to ensure the maximum value by which the flow exceeds the limit does not exceed a threshold agreed between AEMO and the TNSP(s).

The dispatch error for intra-regional transmission cut-sets will most likely be different to the value determined for the interconnectors. In these cases it is proposed that either:

- The dispatch error be determined in the same manner as for interconnectors; or
- Where this is not practical a value to be assumed as agreed between AEMO and the TNSP.

The measurement error for a single transmission element can be determined by comparing the state estimated (SE) value with the measured value. Where groups of transmission elements are involved, such as in the case of interconnectors, the error can be determined as the difference between the summated individual line SE and measurement values.

For interconnectors it is proposed that the contribution of the measurement error to the operating margin be set at the value that will ensure the measurement does not exceed the state estimated value for more than a percentage of the time as agreed between AEMO and the TNSP(s).

For intra-regional transmission cut-sets or individual transmission elements it is proposed that the measurement error be either:

- Determined in the same manner as for interconnectors; or
- Where this is not practical a value to be assumed as agreed between AEMO and the TNSP.

7 Application of Confidence Levels, Offsets and Operating Margins

Taking into account the risks and consequences associated with each type of limit it is proposed to apply confidence levels, offsets and operating margins as follows:

7.1 Transient, Oscillatory and Voltage Stability Constraints

The consequences of a partial or complete power system shutdown are severe and a conservative approach is proposed as follows:

7.1.1 Confidence levels and offsets

To be implemented as advised by the relevant TNSP. The TNSP to give consideration to the additional technical margin that is applied to voltage and oscillatory stability limits as required by the Rules when determining the appropriate confidence level or offset.

7.1.2 Operating Margins

Unless specified by the TNSP, to be determined by AEMO using the approach discussed in Section 5.4:

Operating margin = Dispatch Error + Measurement Error

Where

Dispatch Error is defined as the average amount by which the flow values must be offset, to ensure that they will not exceed the limit for more than a percentage of the time as agreed between AEMO and the TNSP(s) that the constraint binds. The Dispatch Error value may need to be further increased to ensure the maximum value by which the flow exceeds the limit does not exceed a threshold agreed between AEMO and the TNSP(s).

Measurement Error is defined as the average amount by which the flow values must be offset, to ensure that they will not exceed the State Estimated value for more than a percentage of the time as agreed between AEMO and the TNSP(s).

Separately determined operating margins will apply to each interconnector. Where practical, separate operating margins will also be determined for individual intra-regional cut-sets. In all other cases a value will be assumed as agreed between AEMO and the TNSP.

7.1.3 Combining Confidence levels/Offsets and Operating Margins

The confidence level or offset and operating margin will be added, rather than combining the sum of the squares of their standard deviations. This is because the curve fitting process used to derive the limit equation does not represent a true statistical distribution of system operation around the limit equation, which invalidates the approach of combining the standard deviations.

7.2 Thermal Constraints

7.2.1 Confidence levels and offsets

Where the constraint equation is implemented based on a regression equation a confidence level or offset is to be applied as advised by the relevant TNSP. For other forms of equation such as feedback types a confidence level or offset will not apply.

7.2.2 Operating Margins

Thermal equations are subject to continual assessment of performance through AEMO’s Contingency Analysis (CA) program. Thermal constraint equations that bind when CA is not reporting a binding condition or that are not binding when CA is showing that pre- or post contingent flow is at or above rating are referred back to the appropriate constraint builder for review. As such, AEMO generally applies only a small operating margin to newly created thermal constraint equations to take into account the impact of dispatch and measurement errors. The operating margin is then increased or decreased depending on the performance of the constraint equation against CA. It is proposed that, unless an operating margin is specified by the TNSP, this approach be continued. In all cases monitoring of the applicability of the operating margin should continue to be performed.

AEMO re-assesses the operating margin when CA (or off-line load flow assessment) indicates that the constraint equation has resulted in under-utilisation of the constraint, or limit violation has occurred more often than acceptable. It is proposed that re-assessment be triggered if violation of the limit has occurred more frequently than a threshold agreed between AEMO and the TNSP.

The threshold used may vary depending on whether the constraint applies to a continuous or short-term rating and whether the rating has been determined using a probabilistic or deterministic approach.

7.2.3 Combining Confidence levels/Offsets and Operating Margins

The confidence level or offset and operating margin will be simply added