NEMMCO

National Electricity Market
Management Company Ltd

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Sydney

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Mr Ian Woodward
Chairman
AEMC Reliability Panel
PO Box H166
AUSTRALIA SQUARE NSW 1215

Dear Ian

Application of Frequency Operating Standard during Periods of Supply Scarcity

In its investigation into the events involving loss of supply in Victoria on 16 January 2007 NEMMCO noted that the restoration process was constrained due to the need to ensure sufficient contingency reserve was available to cover the loss of the largest unit in the Victorian electrical island without the need for further under frequency load shedding (UFLS).

A recommendation arising from the investigation was that NEMMCO should seek clarification from the Reliability Panel as to whether it is intended, under the Frequency Operating Standards, for sufficient generation to be held in reserve to cover the loss of a generating unit during periods of load restoration following a contingency event.

Under such conditions NEMMCO has identified two possible approaches as follows:

1. While in the process of restoring load following a contingency, ensure sufficient FCAS is available to manage the power system frequency within the frequency operating standard in the event of a credible contingency taking place. A significant amount of generation reserve may have to be maintained to source this FCAS requirement, which otherwise could have been used to restore load interrupted as a result of the original incident (e.g. load shed on the operation of under-frequency load shedding relays). This approach would be expected to ensure the frequency would not fall below 49.0 Hz for mainland regions or 47.5 Hz for Tasmania.

2. Provided the estimated amount of load available for under-frequency load shedding is more than a pre-determined amount, restore the load to the extent of available generation less a pre-determined amount for frequency regulation. The amount of load available for shedding would be an amount sufficient to ensure that upon loss of the largest generating unit the frequency would not fall below the 47.5 Hz for mainland regions and 46.0 Hz for Tasmania.

NEMMCO

NEMMCO has reviewed the advantages and disadvantages for these alternatives in consultation with the Power System Security and Operations Planning Working Groups. A paper is attached setting out the results of NEMMCO's analysis.

On the basis of this analysis NEMMCO recommends that:

(a) In the case of the mainland, Approach 2 be adopted. This is because maintaining generation reserves in anticipation of subsequent contingencies with significant amounts of load remaining interrupted for extended periods is not essential unless there was insufficient load available to be shed by UFLS that would ensure that the minimum frequency remains above 47.5 Hz. It is acknowledged that the adoption of Approach 2 would result in some increase in the likelihood of a cascading failure following a credible contingency. This high impact consequence could especially be the case if generators do not comply with their required performance standards of maintaining supply down to frequencies of 47.5 Hz. However, for the mainland regions such increased risk is considered to be relatively small due to:

- the relatively low probability of such a credible contingency event during load restoration (probably no more than 5 % even if load restoration were to take 6 hours) and

- the design of the generator technical performance standards.

(b) in the case of the Tasmanian region NEMMCO believes that the increased likelihood of cascading failure for Approach 2 may be significantly greater due to the lower frequencies likely to be reached and so it would be prudent in this case to continue with the more conservative Approach 1 until a more robust assessment of the increased risk of Approach 2 over Approach 1 can be made for the Tasmanian Region.

NEMMCO thus seeks clarification from the Reliability Panel as to which of these above approaches should be adopted during times of supply scarcity. If you would like to discuss this matter in more detail please contact NEMMCO's General Manager Operations, Mr Mark Miller on (02) 8884 5020.

Yours sincerely

Brian Spalding

Brian Spalding
Chief Operating Officer

Attachment

Comparison of alternative approaches in satisfying the frequency operating standard during load restoration following a contingency event

1.0 Background

In its investigation of the 16 January 2007 incident involving loss of supply in Victoria NEMMCO recognised that a factor which prevented earlier restoration of some customer load was the need to maintain sufficient head room on generating units to ensure that the requirements of the frequency operating standard were met. As a result one of the recommendations from the investigation was established as follows:

Recommendation 12:

NEMMCO should seek clarification from the Reliability Panel as to whether it is intended, under the Frequency Operating Standards, for sufficient generation to be held in reserve to cover the loss of a generating unit during load restoration following a contingency event.

This report sets out a possible alternative to the current practice and compares the advantages and disadvantages of this alternative with the current arrangements.

2.0 Requirements of the Frequency Operating Standard and the implications

As a part of maintaining the secure operating state NEMMCO should ensure the frequency operating standard is satisfied. The lower frequency limits set by the frequency operating standard required for a generation event can be summarised [1]as follows:

Frequency following a generation event	**Mainland**	**Island within Mainland**	**Tasmanian Region**	**Island within Tasmanian Region**
Frequency Containment	Not below 49.5 Hz	Not below 49.0 Hz	Not below 47.5 Hz	Not below 47.5 Hz
Frequency Stabilisation	Above 49.85 Hz within 5 minutes	Above 49.5 Hz within 5 minutes	Above 49.85 Hz within 5 minutes	Above 49.0 Hz within 5 minutes
Frequency Recovery	Above 49.85 Hz within 5 minutes	Above 49.5 Hz within 5 minutes	Above 49.85 Hz within 5 minutes	Above 49.0 Hz within 5 minutes

In this context a generation event is essentially the largest level of generation output within the relevant frequency control area which can be lost due to a credible contingency event involving a single generating unit or the connection of a single unit to the network.

[1] The following is a summary only of aspects of the frequency operating standard relevant to this discussion; for further details refer http://www.nemmco.com.au/powersystemops/3151.htm

The frequency lower limits set by the frequency operating standard for a network event can be summarised as follows:

Frequency following a network event	**Mainland**	**Island within Mainland**	**Tasmanian Region**	**Island within Tasmanian Region**
Frequency containment	Not below 49.0 Hz	Not below 49.0 Hz	Not below 47.5 Hz	Not below 47.5 Hz
Frequency Stabilisation	Above 49.5 Hz within 1 minute	Above 49.5 Hz within 5 minutes	Above 49.0 Hz within 1 minute	Above 49.0 Hz within 10 minutes
Frequency Recovery	Above 49.85 Hz within 5 minutes	Above 49.5 Hz within 5 minutes	Above 49.85 Hz within 5 minutes	Above 49.0 Hz within 10 minutes

In this context a network event is essentially the largest supply input within the relevant frequency control area which can be lost due to a credible contingency event within the transmission or distribution network excluding generation events or separation events.

The Rule definition of Contingency Capacity Reserve is as follows:

"Actual active and reactive energy capacity, interruptible load arrangements and other arrangements organised to be available to be utilised on the actual occurrence of one or more contingency events to allow the restoration and maintenance of power system security."

Under the current approach, the NEMMCO Rule obligation is to ensure the availability of appropriate levels of contingency capacity reserves (Rule 4.3.1 (k)) is met by sourcing FCAS to satisfy the frequency operating standard for credible contingency events at all times. This even applies during the process of restoring load following a contingency event that has resulted in load shedding.

The implication of this requirement is that some customer load may not be restored due to the need to maintain headroom on generating units to source the required FCAS. This was the case on 16 January 2007 in Victoria.

It is possible that this customer load may not be restored for considerable periods in anticipation of another credible contingency which may or may not eventuate. It is thus appropriate to assess the merits of this approach in comparison to an alternative approach which would allow restoration of more customer load that was interrupted as a result of the initial event whilst accepting the risk that a further credible contingency could well then lead to another round of load shedding. In this alternative approach, NEMMCO will still be meeting its obligation to ensure the availability of appropriate levels of contingency capacity reserves but the required level of contingency capacity reserves will be mainly sourced via load to be interrupted by the UFLS scheme.

3.0 Alternative Approaches

NEMMCO has considered potential risk factors associated with the different approaches that can be used in meeting the frequency operating standard and has assessed the degree of risk in comparison to the benefits of the approaches. NEMMCO considers there are improvements in approach giving consideration the overall benefits to NEM from the point of view of the NEM objective.

The two approaches to be compared are:

Approach 1:

While in the process of restoring load following a contingency, ensure sufficient FCAS is available to manage the power system frequency within the frequency operating standard in the event of a credible contingency taking place. A significant amount of generation reserve may have to be maintained to source this FCAS requirement, which otherwise could have been used to restore load interrupted as a result of the original incident (e.g. load shed on the operation of under-frequency load shedding relays).

Approach 2:

Provided the estimated amount of load available for under-frequency load shedding is more than a pre-determined amount, restore customer load to the extent of available generation less a pre-determined amount for frequency regulation.

The list of factors used in the comparison is:

- Minimum frequency level the power system reaches following a credible contingency.
- Rate of change at which the power system frequency reduces following a credible contingency.
- Impact of experiencing another under-frequency load shedding event if a credible contingency occurs following the initial event, which would also cause under-frequency load shedding. This has to be compared with the impact of continuing to shed load for extended periods if contingency FCAS requirements are to be maintained.
- Impact of maintaining a reduced headroom on generators on frequency and voltage control.
- Insufficient FCAS being available, thereby requiring output from the largest generator to be reduced.
- Overall benefits from the point of view of the NEM Objective.

4.0 Comparison of the two different approaches

This section concentrates on the impact for the mainland. The special circumstances for the Tasmanian Region are discussed in Section 5.

For this comparison a situation involving the South Australian region has been analysed in detail in Appendix 1. This example has been chosen as the islanding of the South Australian region is seen as the biggest challenge for frequency control on the mainland.

Factor	**Approach 1**	**Approach 2**	**Observations from the example (Refer Appendix 1)**
Minimum frequency level following a subsequent contingency	The minimum frequency is relatively higher compared to the Approach 2	The minimum frequency is relatively lower but so long as the minimum frequency is not lower than that defined in technical standards for generators the additional risks to the power system should be acceptable	Minimum frequency in Approach 1 is above 49.0Hz. Minimum frequency in Approach 2 is 48.26Hz (case 2).
Rate of change at which frequency reduces following another contingency	Given that there is sufficient FCAS to manage contingencies, the rate at which the frequency declines would be relatively lower.	The initial rate of frequency decline is higher but with UFLS available at higher frequency settings, rate of frequency decline will be reduced with the operation of UFLS	The rate of decline of the frequency may be considerably higher for Approach 2 than currently would be seen for a single contingency event, but this is not seen as a significant issue except in the case of UFLS relays with df/dt triggers (Tasmania only)
Impact of experiencing multiple UFLS events	Risk of UFLS following a credible contingency is very low	UFLS following a credible contingency is likely. UFLS is generally coarse in its selection of customers shed.	In Approach 2, about 200 MW load would be interrupted on the operation of UFLS following the second event of the loss of 250MW.
Impact of not restoring previously interrupted load for extended periods	The amount of load that will remain interrupted for extended periods is higher. Depending on duration there is some potential to restore critical customers at the expense of others.	The amount of load that will remain interrupted for extended periods is relatively lower.	In Approach 1, 484MW will be interrupted for an extended period whereas in Approach 2 approx. 350MW will not be able to be restored.

Impact of reduced headroom of generation on frequency and voltage control	More headroom on generators, hence more flexibility of frequency control.	Given that sufficient regulation FCAS will be maintained, experiencing difficulties in frequency control is unlikely.	234MW of generation reserve is maintained in Approach 1 whereas 70MW of regulation reserve is maintained in Approach 2. As regards voltage control since load would be significantly lower than normal the need for additional headroom on generating units to allow increased Var generation is considered unlikely.
Insufficient FCAS requiring output of largest generating unit(s) to be reduced?	Sufficient FCAS will be maintained in this approach but would be at the expense of an increase in the amount of unrestored load.	Reduction in output of the largest generator consistent with the FCAS availability is unlikely since this approach does not rely on FCAS but on UFLS	If in the scenario set out in Appendix 1, under Approach 1 both Northern PS units were required to be reduced then the effect on the level of unrestored load would be doubled.
Risk of cascading failure of generating units following a credible contingency event	In this approach since the minimum frequency following the credible contingency would not fall below 49.0 Hz, the risk of subsequent failures of generating units would be considered very low.	Provided that the minimum frequency remained above 47.5 Hz then, based upon the generator performance standards, the risk of cascading failure should be low. However realistically there is always some likelihood of an individual generating unit not meeting its standard and this likelihood would increase with the decrease in the minimum frequency following the credible contingency event. The consequence of a cascading failure is large and could result is a black system for several hours.	Approach 2 would carry additional risks compared to Approach 1. However the magnitude of such additional risks is difficult to quantify and will depend on generator performance.
Overall benefits from the point of view of NEM Objective	Given that the amount of load that can be restored is likely to be lower, this option delivers relatively less overall benefits with a higher level of security from the point of the NEM Objective.	Given that the risks involved in this approach are manageable, this approach delivers more overall benefits from the point of view of the NEM Objective.	Approach 2 enables relatively higher level of load restoration without posing unacceptable level of risk and delivers more benefits to the NEM from the point of view of the NEM Objective.

5.0 Special Case – Tasmania Region

The similar issues apply for the Tasmanian Region. There are however significant differences due to the different frequency bands set for the Tasmanian Region.

The settings of under-frequency load shedding in Tasmania are within the narrow range of 47.4 - 46.1Hz. Approximately 850MW of load is connected to the under-frequency relays in Tasmania compared to the largest single generating unit of 144 MW.

Hence careful attention is required in assessing the pre-determined amount of under-frequency load shedding required to justify the restoration of load without meeting the FCAS requirements.

6.0 Conclusions

Approach 1 ensures the generation reserves meet FCAS requirements and may results in relatively higher amounts of customer load not restored for extended periods. This may be a too conservative approach but it does minimise the likelihood of cascade failures of generating units. Cascade failures may also result from impacts flowing from the initial generating unit loss other than the magnitude of the frequency disturbance (eg voltage disturbance or negative phase sequence currents).

Approach 2 on the other hand allows more load to be restored with a possibility of subsequent UFLS in the event of a contingency taking place. There is however a higher risk of a resulting cascade failure if more generation is lost in the resulting further frequency disturbance. The level of this additional risk is difficult to quantify as it depends upon the degree of compliance to the generator performance standard regarding frequency disturbances that would be seen in practice. Recent major frequency events in August 2004, May 2006 and January 2007 did show evidence of individual generating units tripping following the initial event, some due to the resulting movement in frequency but others related to associated changes such as increase in the negative phase sequence currents or voltage fluctuations caused by the loss of the initial generating units. Thus it is considered that any increased likelihood of cascade failure due to adopting Approach 2 over Approach 1 would be relatively small.

This cascade failure risk is seen as considerably higher for the Tasmanian region, not due to any perception that Tasmanian generating units would be less likely to meet their performance standards, but rather due to the differences in the frequency bands set down in the frequency operating standard. This results in the frequency band for UFLS in Tasmania (47.4 to 46.1 Hz) being considerably narrower than the band for mainland regions (49.0 to 47.0 Hz).

Thus NEMMCO's views are as follows:

Mainland Regions

In the case of the mainland, maintaining generation reserves in anticipation of subsequent contingencies with significant amounts of customer load remaining interrupted for extended periods is not essential unless there was insufficient load available to be further shed by UFLS that would ensure that the minimum frequency remains above 47.5 Hz[2].

It is acknowledged that such an approach would result in some increase in the likelihood of cascading failure following a credible contingency. This high impact consequence could especially be the case if generators do not comply with their required performance standards of maintaining supply down to frequencies of 47.5 Hz.

However for the mainland regions such increased risk is considered to be relatively small due to:

- the relatively low probability of such a credible contingency event during load restoration (probably no more than 5 % even if load restoration were to take 6 hours) and

- the design of the generator technical performance standards.

Thus NEMMCO believes that in the case of the mainland regions the increased risk of adopting Approach 2 over Approach 1 would not justify the cost to the community of delaying restoration of some customer load for significant periods. NEMMCO believes pursuing an approach similar to Approach 2 delivers more benefits to NEM from the point of view of the NEM objective.

One option might be to add an increased safety margin into Approach 2 by requiring that load restoration be managed such that at all times there is a sufficient combination of enabled FCAS and UFLS load to ensure that the frequency for a mainland region should not fall below 48.0 Hz following a credible contingency event.

There would still need to be sufficient generating unit headroom to maintain adequate frequency regulating capability at the expense of load restoration. However, as seen in the example in Appendix 1 the level of load involved would be considerably smaller than for Approach 1.

Tasmanian Region

In the case of the Tasmanian region NEMMCO believes that the increased likelihood of cascading failure for Approach 2 may be significantly greater and so that it would be prudent in this case to continue with the more conservative Approach 1 until a more robust assessment of the increased risk of Approach 2 over Approach 1 can be made.

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[2] 47.5 Hz is chosen as there are a number of generating units in mainland regions which are likely to trip if the frequency falls below 47.5 Hz. As part of the outcome of the UFLS setting review all trip settings for UFLS relays in mainland regions will be reset at or above 47.5 Hz.

NEMMCO Rule Obligations and the Frequency Operating Standard

NEMMCO's Rule obligation is to ensure the availability of appropriate levels of contingency capacity reserves (Rule 4.3.1 (k)) is met in both approaches as explained in this document. The Approach 2 sources a larger portion of the contingency capacity reserves via loads connected to the UFLS scheme.

The frequency operating standard requires the frequency to be contained within 49.5-50.5Hz for generation or load events. The frequency operating standard for islands within the mainland requires the frequency to be contained within 49-51Hz for generation event, load event or network event. The containment of frequency following a generation event in Approach 2 is likely to be below 49Hz in some circumstances (e.g. if an island was formed following the initial contingency) hence NEMMCO believes that the frequency operating standard should be suitably amended to reflect these potential circumstances.

Further, NEMMCO also envisages that the frequency operating standard should acknowledge the need for applying NEMMCO's judgement in identifying the power system conditions under which the Approach 2 will deliver benefits without taking undue risks to the power system. This is because NEMMCO is responsible for restoring load following variety of multiple contingency events including restarting the power system following a black system condition.

Implementation of the proposed approach

While in the process of load restoration following a contingency, NEMMCO would initially start with Alternative 1 until a sufficient level of under frequency load shedding is restored to the pre-determined requirement as well as the restoration has progressed to level where NEMMCO believes that the risk involved in adopting the Approach 2 is minimal. Then NEMMCO can commence adopting the Approach 2.

The methods of enhancing the process for determining the amount of load available for under-frequency load shedding following major contingencies will be developed if the Reliability Panel supports the adoption of Approach 2.

Appendix 1 – Comparison of Approaches 1 and 2 Using a South Australian Example

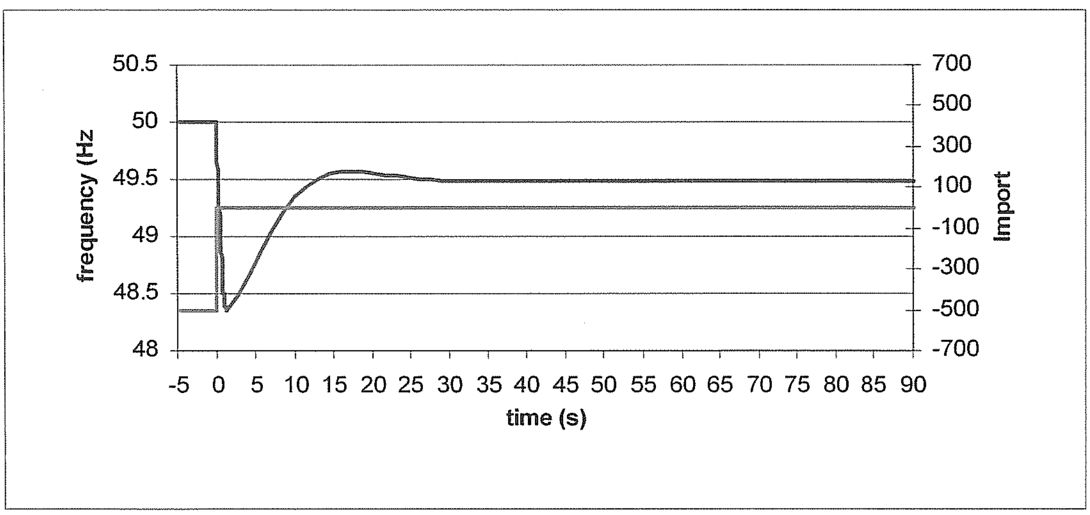
1.0 Prior Conditions

- Murraylink out of service
- Heywood interconnector loaded to 500 MW
- SA Region Demand 1600 MW
- 1100 MW of plant synchronised in SA and fully loaded
- most heavily loaded generating unit 250 MW
- 250 MW of fast start plant available in SA but not on line
- SA Region is thus just at or just above an LOR2 condition
- Assume the proposed settings for SA UFLS have been implemented

2.0 Separation event - Loss of Entire Heywood Interconnector due to a major fault such as tower collapse

Conditions immediately after the event

- Initially 459MW of UFLS takes place in SA and the SA frequency reduces to 48.348Hz.
- SA Regional Demand falls to 1141MW at the settling frequency of 48.484Hz.
- Further 41MW of SA load has to be manually shed to restore frequency to 50Hz
- SA Region demand falls to 1100MW
- Start up of fast start plant initiated



The power system frequency and the SA import during and immediately following the separation event are shown in the above graph.

3.0 Options available at end of restoration, including the return to service of 250MW of fast start generation:

3.1 Approach 1 - Sufficient reserves maintained to ensure frequency will remain above 49.0 Hz even if a generating unit loaded at 250 MW trips

The following constraint equations are used schedule FCAS in islanded SA:

R 5Min >= Largest I/S Gen in SA – 0.015 * SA Demand – SA1 AGC Raise
R 6 >= Largest I/S Gen – 0.03 * SA demand
R 60 >= Largest I/S Gen in SA – 0.03*SA Demand
Raise Regulation >= 70

250MW being the largest in service generator in islanded SA and with approx. 1100MW of SA regional demand (SA1 AGC Raise scheduled at the beginning of the dispatch interval in this scenario would be close to 0MW).

R 5Min >= 234
R 6 >= 217
R 60 >= 217
Raise Regulation >= 70

These equations require approximately 234MW of generation maintained as reserve.

Hence the amount of load that can be supplied after the fast start plant is on-line

	= 1100 + 250 – 234 MW
	= 1116 MW
The amount of load yet to be restored	= 484MW

Maintaining 234MW of generation reserve will ensure the frequency operation standard for the islanded SA is satisfied.

3.2 Approach 2 - Maintain only 70MW of generation reserve for regulation

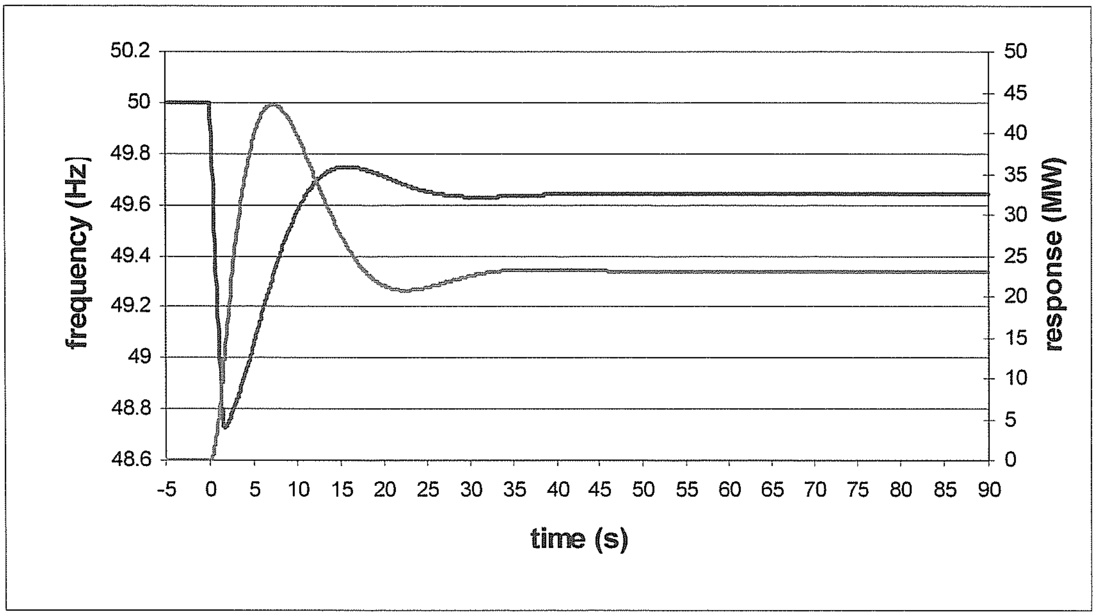
At the end of restoration process we would have:

Generation dispatched	= 1100 MW + 250 -70 MW
	= 1280MW
Total load supplied	= 1280 MW
Load yet to be restored	= 320 MW

3.2.1 Case 1

While SA islanded with 1280MW of load being supplied, if a generation contingency of loss of 250MW occurs in SA, the frequency reduces to 48.727Hz resulting in 217MW of UFLS ***if the load interrupted on the operation of UFLS as a result of the islanding event has been restored (i.e. replaced with other load) so that it is again available for UFLS.***

The power system frequency recovery (blue trace) and the assumed governor response (pink trace) in SA are shown in the graph below.

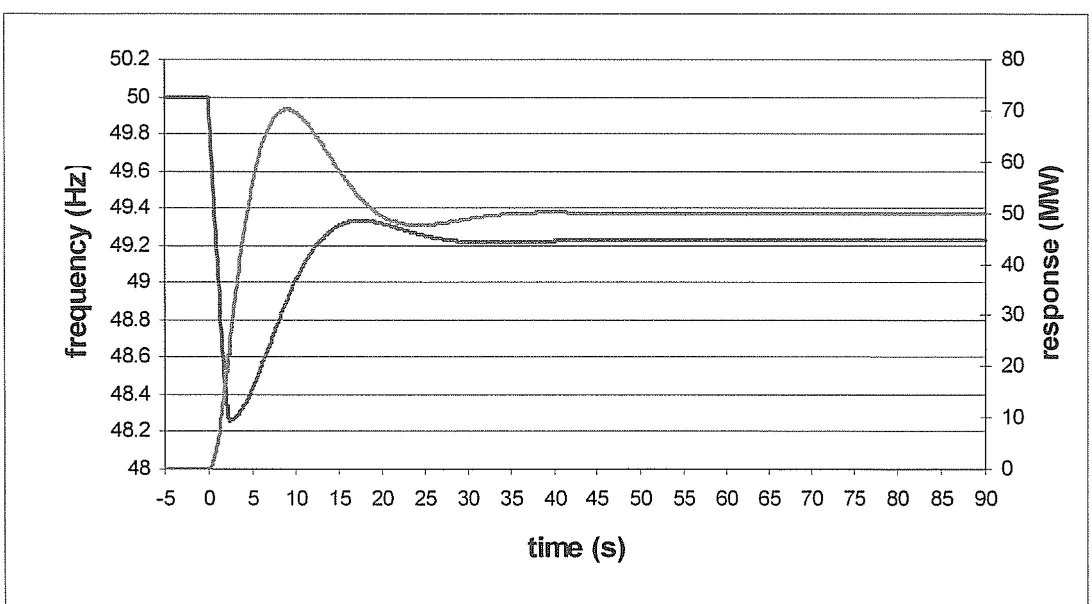


3.2.2 Case 2

If only some of the load interrupted on the operation of UFLS as a result of the islanding event has been restored, the power system frequency recovery and the governor response in SA are as shown in the graph below.

Note that with 70MW of generation reserved for regulation, 180MW of generation will be available to restore load following the return to service of 250MW of fast start generation. After restoring 41MW load shed manually, it would be possible to restore 139MW of load shed on the operation of UFLS.

The power system frequency reduces to 48.260Hz resulting in further interruption of 178MW on UFLS. Further load may then have to be shed to restore the frequency to 49.5 Hz in 5 minutes.



After the operation of UFLS on the loss of a 250MW generator, further 456MW of UFLS would be available in SA.