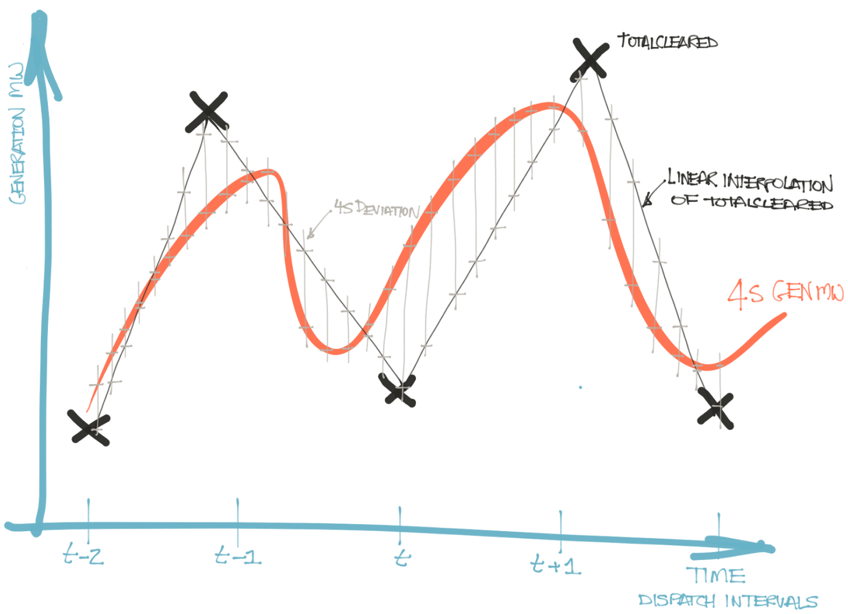
February 2017

NEM FCAS causer pays procedure

Dr. Harley Mackenzie & Jonathon Dyson
HARD software & Greenview Strategic Consulting



1. Introduction

The Wind Coalition has engaged Hard Software, assisted by Greenview Strategic Consulting, to conduct a technical assessment of the AEMO FCAS Causer Pays Procedure ("CPP"). This assessment, whilst considering the questions raised by AEMO in their Consultation Paper, will also put forward several wider concerns and issues that should be addressed as part of the wider Causer Pays Procedure arrangements.

The 'Wind Coalition' consist of the following market participants (see Table 1), covering wind generation across all NEM states except Queensland, with the following installed capacities of semi-scheduled and non-scheduled generation and average annual energy production. Importantly, each of the below participants does not own or operate any other form of generation in the NEM hence conveys a unique perspective on the issues raised in this paper.

Participants	Installed Semi-Scheduled MW	Installed Non-Scheduled MW	Average Annual Generation (GWh)
Pacific Hydro	163.5	263.1	1272
Tilt Renewables	371	15	1258
Infigen Energy	246	221	1164
Woolnorth Wind Farm Holdings	168	140	1122
Waterloo Wind Farm Pty Ltd	130	-	315

Table 1: Participant Capacity and Annual Energy (2016)

Collectively, the above Wind Coalition paid approximately $450k for regulation services in 2014: in 2016 the number was closer $15m! When compared to annual pool revenue, regulation costs were less than 0.5% of net gross pool revenue: In 2016 this number was closer to 8%. These extraordinary increases came at a time when few new significant wind farms were built in their respective regions and the AWEFS system was supposedly 'fixed' on the 7 April 2016. These costs have increased between 2014 and 2016 based on AEMO changing its operating philosophy with respect to the acquisition of local regulation FCAS under certain network conditions - factors this group of generators have very little influence over and very few options to manage this significant financial risk. In many of the Coalition organisations, board level discussions occur monthly centred around FCAS 'hits'!

Structure of this Document

This document has been broken into four distinct sections that cover the 10 issues/concerns raised by AEMO and the concerns identified through this technical analysis. The structure includes:

1. Background and Intent of Regulation Services (including CPF)
2. Issues with the Current Methodology
3. Discussion on Proposed Changes (and Alternate Considerations)

2. Background and Intent of Regulation Services

The general methodology that is used in the current CPP has been largely unchanged since its inception in 2001. The Coalition feels it is likely that, as a result of the complexity associated with this particular aspect of the market, this methodology has not been adopted anywhere else in the world.

The introduction and integration of over 5000 MW of utility scale wind and solar generation into the NEM since 2001, not forgetting over 3500 MW of rooftop PV since 2009, all contribute significantly to the second-by-second balancing that is required in any modern-day power system. The underlying control mechanism has not changed significantly over this time, but the method in which AEMO manages events has, and therefore so have the actual costs in the system.

Figure 1, using publically available AEMO FCAS data, describes the total amount paid for all Ancillary Service and the component of Regulation Costs (paid to FCAS providers) that have occurred between 2014 and 2016. It clearly shows a step change in total costs from 2015!

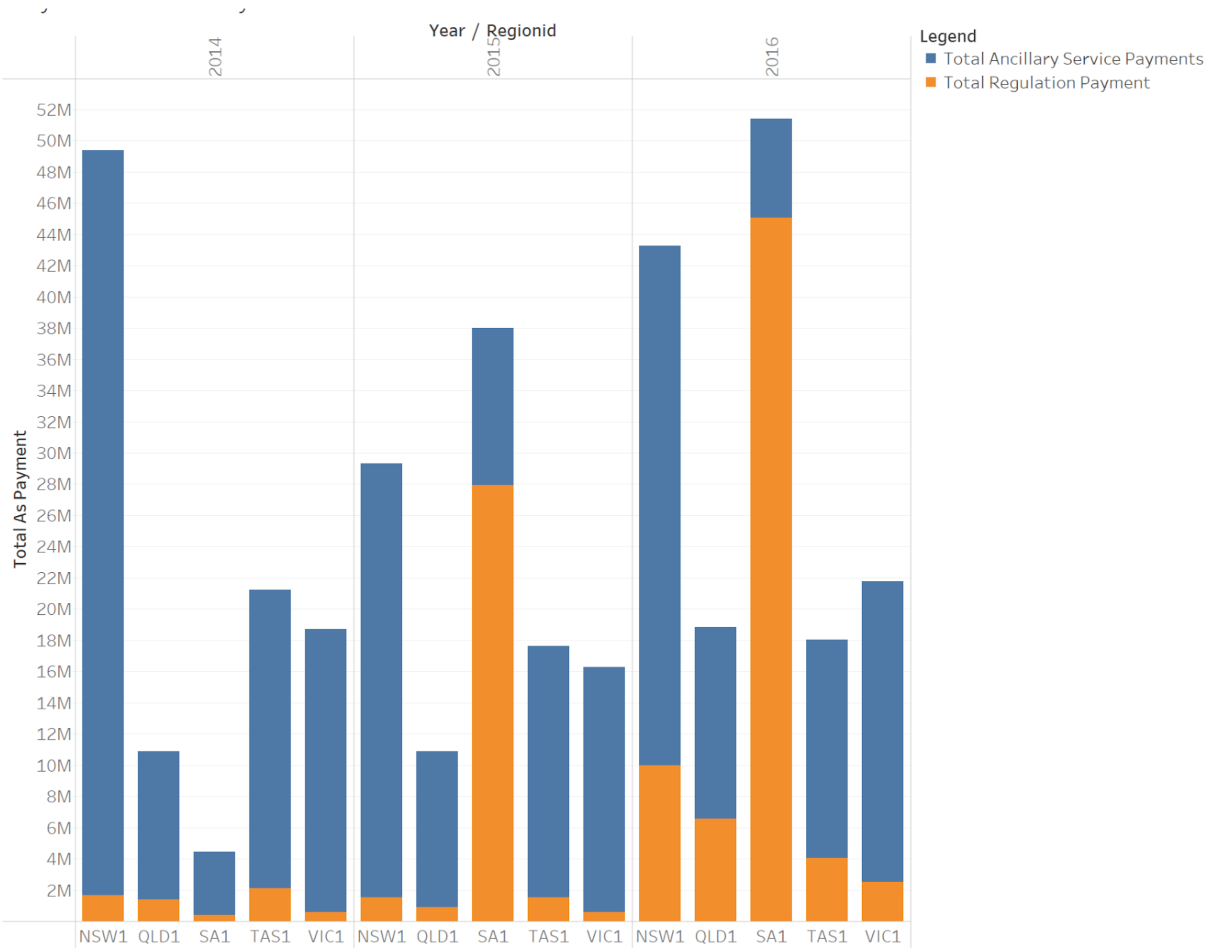


Figure 1 - Total FCAS Payments to Service Providers

Figure 1 above clearly shows SA Regulation Providers receiving over $40m more in 2016 compared to 2014, with two and threefold increases in the other regions, leading to a total regulation costs across the market in 2016 of approx. $68m. Given the regulation levels across the Mainland and Tasmania are typically 120MW and 50MW respectively and have remained at these levels between 2014 and 2016 except for specific periods of network outages, this translates to an average regulation price in 2014 of $4/MWh increasing over 1000% to over $22/MWh in 2016.

In order to recoup those payments to ancillary service providers (especially providers of FCAS regulation services in SA), AEMO has recovered those costs across a variety of customers and generators in multiple regions. Figure 2 below highlights the allocated costs of all Ancillary Services (Total Customer Recovery and Total Generator Recovery), as well as the specific recovery of the regulation costs (charted as Total Regulation Cost).

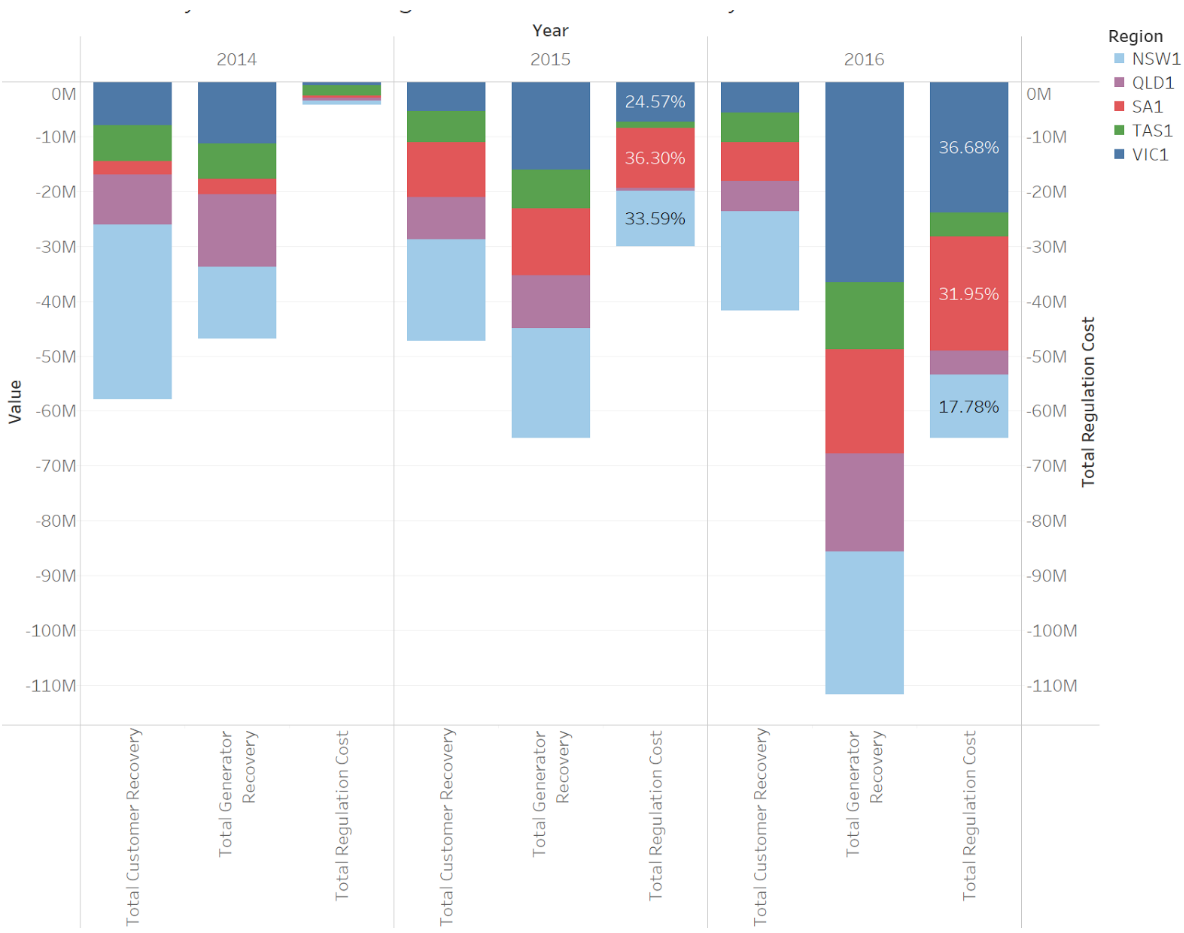


Figure 2 -Total FCAS and Regulation Service Cost Recovery

Figure 2 shows the total cost allocated for FCAS services for the past 3 calendar years (using AEMO weekly billing data), with a significant trend towards higher generator allocated costs, as well as the total regulation costs moving from less than $5m a year to greater than $60m.

Interestingly, total customer payments have decreased from approx. $58m to $41m. This rapid cost increase is further explored in this paper and potential causes identified. The most significant change to this mechanism has been the manner in which AEMO allocate local regulation services in SA: a cost that is clearly absorbed by SA and Vic generators, many of which are semi-scheduled.

3. FCAS causer pays contribution factor calculation

The AEMO contribution factor calculation procedure document **[AEMO 2]** defines:

> *"Contribution factors are determined for the purpose of assigning the costs of Regulating FCAS to those Market Participants who have caused the need for those services.*
>
> *The calculations represent the deviations from a reference trajectory derived from expected dispatch or expected MW consumption. The deviations are calculated every four seconds and averaged over a dispatch interval (DI). The average results are referred to as five-minute factors.*
>
> *Contribution factors are determined based on 28 days of five-minute factors and are calculated for the following:*
>
> - *All market scheduled generating units;*
> - *All market scheduled loads;*
> - *All market semi-scheduled generating units;*
> - *All market non-scheduled generating units with appropriate metering*
> - *All market non-scheduled loads with appropriate metering.*
> - *All market small generating units with appropriate metering."*

The FCAS causer pays contribution factors calculated for each participant have a direct bearing on the proportion of the market regulation FCAS costs that are allocated to each participant and therefore can have significant financial implications for NEM participants, especially for recent high priced FCAS regulation events that have recently occurred in the SA region.

However it is not possible to reproduce the FCAS causer pays settlement factor calculations solely from **[AEMO 2]** as many essential procedures, such as the FI factor, are incompletely or not defined at all in this document and need to be documented and clarified for good market transparency.

For Semi-Scheduled generators, the FCAS causer pays contribution factor calculation essentially calculates the difference between the unit's generation and the linear interpolation of the current and previous dispatch interval TOTALCLEARED values used as the measure of expected dispatch on a 4 second basis, as shown in Figure 3 (over).

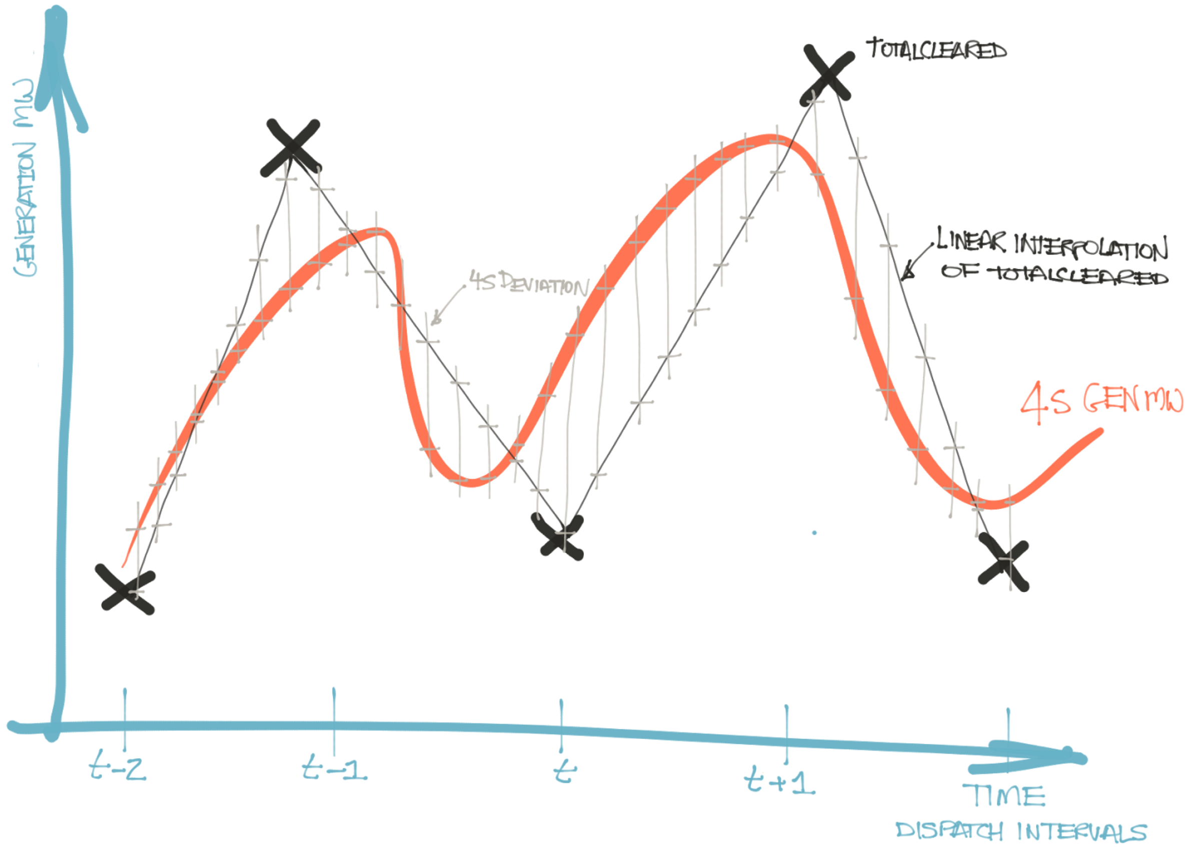


Figure 3 - Concept of 4s causer pays deviations

The 4 second deviations, calculated by measuring the difference between the units' 4-second generation to the interpolated TOTALCLEARED values (see Figure 3), are then multiplied by a factor, FI, that represents the raise or lower MW requirements in either the mainland or TAS regions for that 4 second interval. The 4 second factors are then categorised and averaged for that 5 minute dispatch interval and then all of the categorised 5 min dispatch interval averages are averaged again over a four week defined measurement period and a unit contribution factor determined and scaled according to the respective proportions of demand for the mainland and the TAS regions. These factors are aggregated for each participant and then used to determine the allocation of the FCAS regulation costs amongst all of the included loads and generators in the Australian NEM using a proportional share of pooled costs basis.

For settlement purposes, the participant FCAS causer pays settlement factors, calculated from the previous measurement period, are used to determine the allocation of regulation FCAS costs for subsequent settlement periods. Therefore historical performance is used as the basis for settlement of FCAS regulation charges and the allocation of costs does not occur at the same time as the performance measurements are being made.

The FCAS causer pays settlement factor is therefore a measure of the deviation of generation from the linear interpolated TOTALCLEARED values in the NEM dispatch process where the values of the TOTALCLEARED values are determined from the Unconstrained Intermittent Generator Forecast (UIGF) that is a direct output of the AWEFS system or dispatch targets when operating as a semi-dispatched unit as determined by the NEMDE dispatch process.

The FCAS causer pays factor base calculation methodology used in this study has been validated for all of the 4 second calculations within a dispatch interval and also validated against 5 minute dispatch interval averages that have been supplied by AEMO in May 2016. It would be very useful to conduct a more complete and thorough validation of the FCAS causer pays settlement factor calculation procedure including the aggregation and settlement procedures but that was not possible at this time due to time constraints for the consultation process.

4. Methodology Applied in this Investigation

The replication of the calculation of causer pays factors involved the processing of 4 second data for every unit in the NEM and involves the manipulation of billions of individual data points. To be able to produce results within a suitable timeframe, a limited number of 28 day sample periods and representative units was made to allow for an initial investigative study.

It was also not possible to include the calculation of factors for the Tasmanian region in the time available for this study and no complete set of excluded dispatch intervals was available from AEMO, hence have not been removed.

The dispatchable units selected for this study were included on the basis of the range of generation technology, geographical location and availability of data. Unfortunately the final selection of dispatchable units for the study did not include any gas generation and this was an oversight that was not able to be corrected before the report submission time. Any subsequent study should include representative units for gas generation.

DUID	Unit description	Type of generation	Semi-dispatched
BALDHWF1	Bald Hills Wind Farm	Wind	Yes
ER01	Eraring Unit 1	Black coal	No
GSTONE1	Gladstone Unit 1	Black coal	No
LOYYB1	Loy Yang B Unit 1	Brown coal	No
MACARTH1	Macarthur Wind Farm	Wind	Yes
MCKAY1	McKay Unit 1	Hydro	No
MOREESF1	Moree Solar Farm	Solar	Yes
MURRAY	Murray aggregation	Hydro	No
NYNGAN1	Nyngan Solar Farm	Solar	Yes
WOODLWN1	Woodlawn Wind Farm	Wind	Yes
YWPS1	Yallourn Unit 1	Brown coal	No

Table 2: Units Selected for the 4-second Analysis

The study used the six most recent 28 day sample periods from the 26 JUN 2016 to 11 DEC 2016 and each of the selected dispatchable units had causer pays calculations performed at the 4 second and then the 5 minute dispatch interval resolution. The FI factor used in the 4 second calculations was a measurement of the levels of FCAS regulation enablement across the mainland and Tasmanian regions, hence all units in each region were checked for enablement of raise or lower services and summed to produce the FI factor. The calculation of the FI factor is not adequately documented **[AEMO 2]** and required detailed consultation with AEMO to determine the exact method to be used.

Different causer pays calculation approaches were evaluated for comparison to the existing AEMO calculation methodology base case where an increase in the value of the causer pays factor was considered to be an improvement as more negative values of causer pays factors result in larger allocations of FCAS regulation service at the aggregated participant level.

The causer pays factors used in this study are unnormalised raw factors as the normalisation process is not well documented and all comparisons made in this study are made at the unit rather than the aggregated participant level. Figure 4 shown below shows the actual pattern of CPF, unnormalised, for the sample period. These results were used as the reference base case.

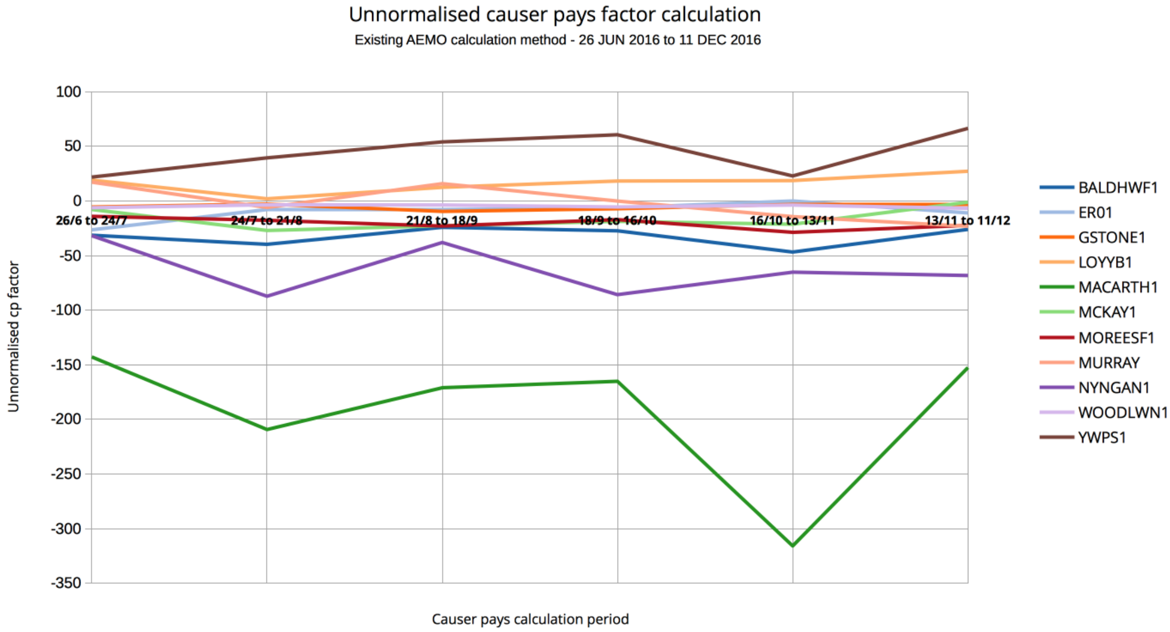


Figure 4 - Unnormalised CP factors using existing AEMO mean calculation

5. Power system frequency stability concerns

Whilst operating with 4-second data, it is easier to observe actual power system mechanics that may not be as clear at the 5-minute or 30-minute data level. Considering the Coalition was paying a high amount over the course of 2016, understanding the type of service being provided seemed appropriate.

Enclosed over the page is the frequency trace and subsequent 5min enablement levels for the NSW region recently during recent warm weather. Figure 7 shows the 4-second traces for frequency (and the subsequent frequency oscillation) following the trip of the Tallawarra unit, with Figure 8 showing the actual enablement levels for the dispatch intervals in question.

Figure 7 shows conditions at the time of the Tallawarra trip were not satisfactory, with no enabled regulation providers within NSW (see Figure 8), with a significant power system oscillation developing undamped for several minutes, mainly impacting the Snowy Hydro units, but also the LYA units, but not Bayswater. It is assumed by the group that because the Bayswater unit was not enabled for services, its control appears to have disabled a response even though the frequency is outside the normal operating band: it is the group's contention that this should not be occurring and needs to be review immediately. As a consequence of SCADA congestion of other reasons, differentials can also be observed in NEM Frequency.

NSW 10-02-2017

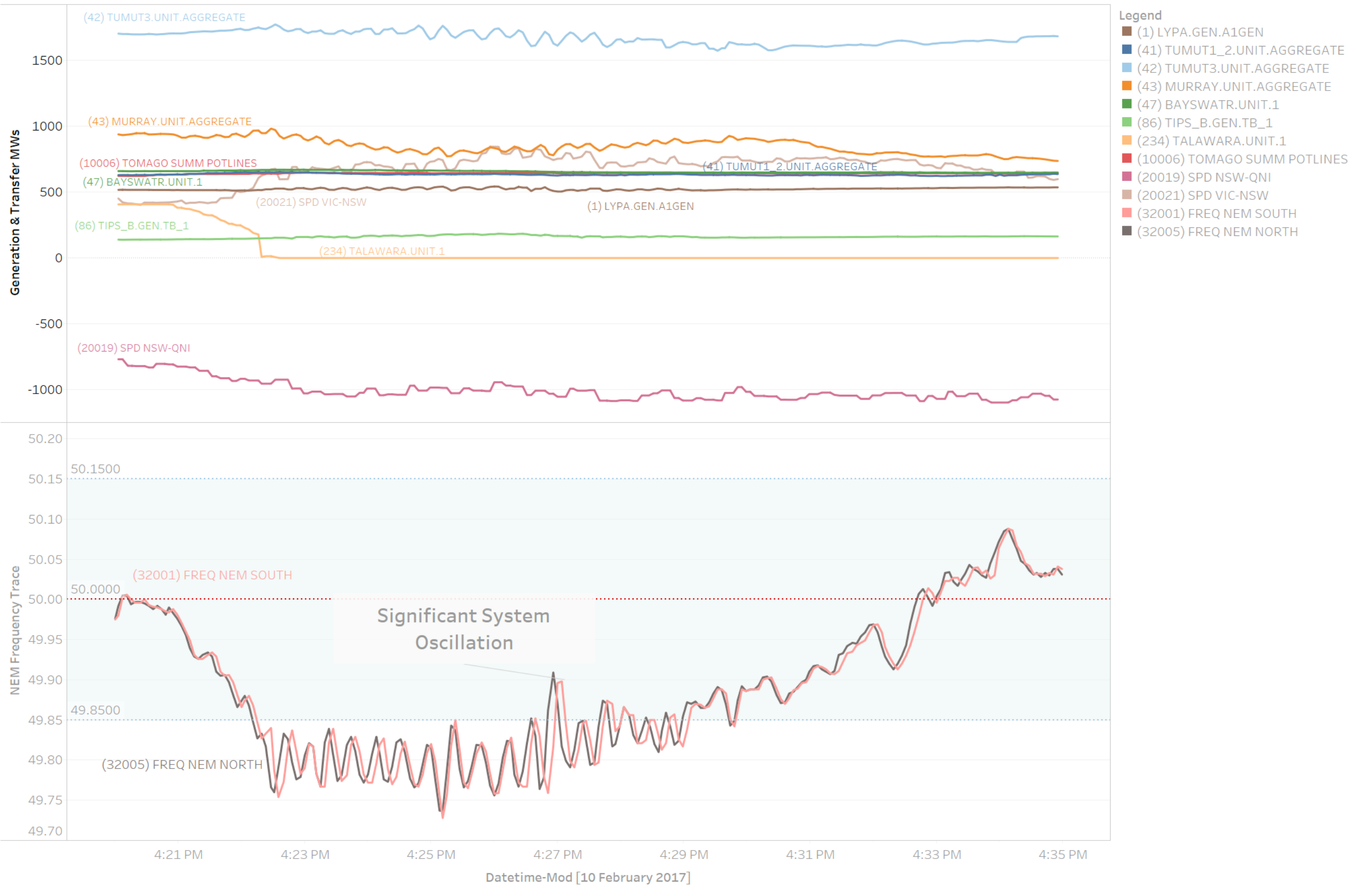


Figure 7 - NSW 4-second Data for Frequency and Generation/Transfer Details

FCAS Availability

Region / Units In Service / Duid (group)

Settlementd..		NSW1 Out of Service Not FCAS Enabled	NSW1 In Service FCAS Enabled	NSW1 In Service Not FCAS Enabled	NSW1 Total	QLD1 Out of Service Not FCAS Enabled	QLD1 In Service FCAS Enabled	QLD1 In Service Not FCAS Enabled	QLD1 Total	SA1 Out of Service Not FCAS Enabled	SA1 In Service FCAS Enabled	SA1 In Service Not FCAS Enabled	SA1 Total	VIC1 Out of Service Not FCAS Enabled	VIC1 In Service FCAS Enabled	VIC1 In Service Not FCAS Enabled	VIC1 Total	Grand Total
10-Feb 16:25	Lower5Min	0	60	0	60	0	0	0	0	0	0	0	0	0	45	0	45	105
	Lower60Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lower6Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lowerreg	0	0	0	0	0	8	0	8	0	0	0	0	0	31	3	34	42
	Raise5Min	0	0	0	0	0	123	0	123	0	0	0	0	0	66	0	66	189
	Raise60Sec	0	0	0	0	0	40	0	40	0	55	0	55	0	74	0	74	169
	Raise6Sec	0	0	0	0	0	40	0	40	0	61	0	61	0	69	0	69	171
	Raisereg	0	0	0	0	0	40	0	40	0	0	0	0	0	31	0	31	71
	# of Units	3	4	27	34	4	8	40	52	1	7	20	28	4	8	35	47	161
	Availability	0	2,565	10,603	13,168	0	2,304	8,439	10,743	0	1,145	1,244	2,389	0	3,520	5,839	9,359	35,659
10-Feb 16:30	Lower5Min	0	60	0	60	0	0	0	0	0	0	0	0	0	0	0	0	60
	Lower60Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lower6Sec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Lowerreg	0	0	0	0	0	4	0	4	0	0	0	0	0	26	3	29	33
	Raise5Min	0	0	0	0	0	123	0	123	0	0	0	0	0	61	0	61	184
	Raise60Sec	0	0	0	0	0	20	0	20	0	77	0	77	0	68	0	68	166
	Raise6Sec	0	0	0	0	0	20	0	20	0	85	0	85	0	62	0	62	167
	Raisereg	0	0	0	0	0	40	0	40	0	20	0	20	0	87	0	87	147
	# of Units	3	4	27	34	4	8	40	52	1	7	20	28	4	8	35	47	161
	Availability	0	2,565	10,603	13,168	0	2,304	8,434	10,738	0	1,145	1,244	2,389	0	3,520	5,839	9,359	35,654

Figure 8 -Enablement Levels for 16:25 and 16:30 on 10 February 2017

Further to the 10-Feb events, an analysis was conducted to test the frequency distribution across multiple months, to determine if frequency capabilities were improving. Figure 9 below highlights the consistent trend for the past 6 months. When these similar values are compared to the early days in the NEM FCAS market, an astounding trend is observed that shows the degradation of service in frequency management in the past 17 years of the FCAS markets.

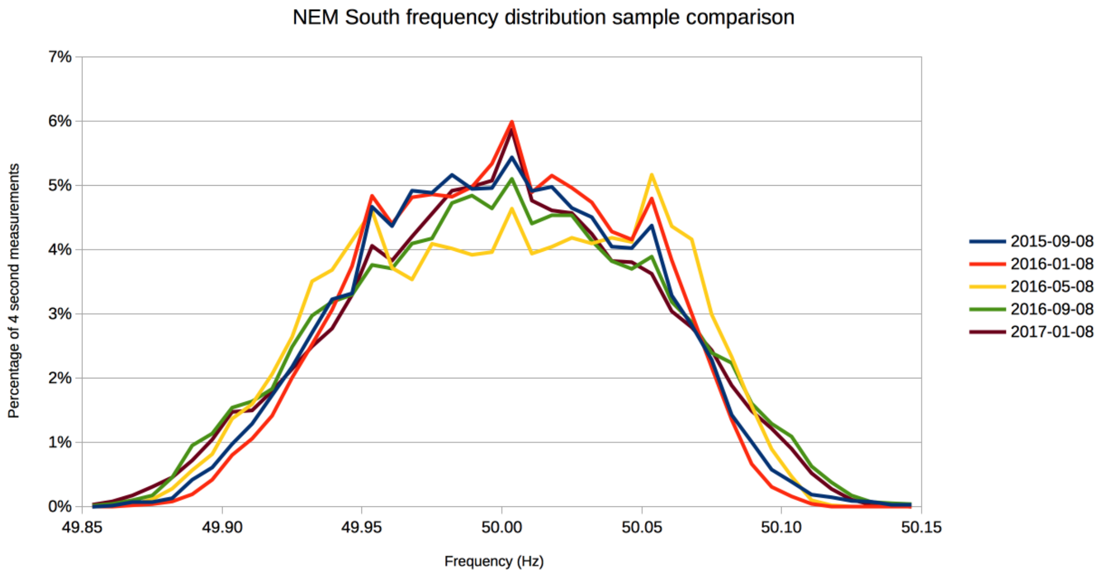


Figure 9 Consecutive Monthly Traces of Frequency Distribution-

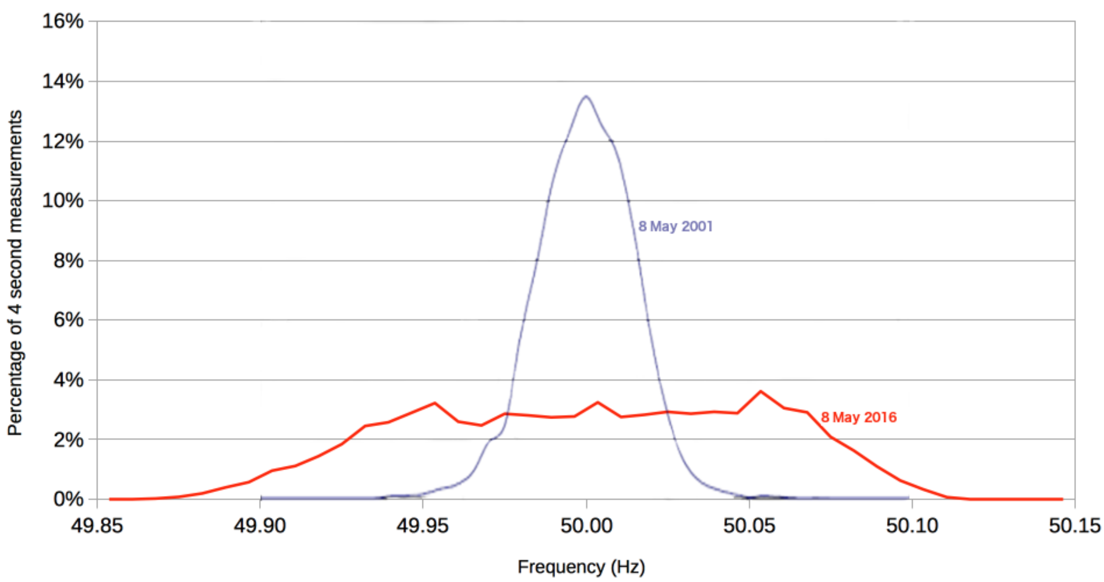


Figure 10 - Frequency distribution of 4 second data for 8 May 2016 vs 8 May 2001

The above chart provides the frequency distribution comparison for the same day fifteen years apart. The Reliability Panel referred to the frequency distribution on the 8th May 2001 [AEMO 5] when they were re-setting the frequency standards. Using the 4 second systems frequency data from the 4 second data for the 8th May 2016 and overlaying the original chart, the results highlight a significant change in the system frequency distribution.

6. FCAS causer pays issues and Potential Solutions

Given these and other issues, and in order to quantitatively contribute to the AEMO consultation, the authors were requested to investigate a number of key areas:

- Assumed interpolated profile during dispatch intervals
- System lag between SCADA and evaluation of CP factors
- Timing of calculation of causer pays factors
- The formulation of the causer pays calculation
- Economic incentives not aligned with power system stability

Influence of assumed profile on CP factors

An assumption that is used in the present AEMO calculation of the causer pays factors is that there is a linear profile of generation between the TOTALCLEARED value in the previous Dispatch Interval and the TOTALCLEARED value of the current Dispatch Interval. No justification has been provided in the AEMO documentation [AEMO 2] for the use of a linear profile and for many technologies, especially hydro generation, this assumption is known to be very unrepresentative of many forms of generation behaviour.

The start and end points of the interpolated profile were initially designed at the commencement of the FCAS co-optimised dispatch market to be representative of a scheduled generator performance where each dispatched unit is provided with a target to meet at the end of the dispatch interval. Unfortunately when Semi-Scheduled intermittent generators were introduced in into the market and included in the determination of FCAS causer pays factors, the term “dispatch target” for scheduled generators was simply replaced with “dispatch levels” for intermittent generators, where the “dispatch level” are simply the TOTALCLEARED values that are effectively the value of the semi-dispatch cap when present or more commonly simply the AWEFS generation forecast for that generator.

When the intermittent generators are not operating under a dispatch cap there is no “target” to be measured against and this simple adoption of effectively the same calculation technique as used by dispatched generation was unjustified and ill-considered. The effects of poor AWEFS forecasting on FCAS causer pays factors for intermittent generators is considered in detail later in this report.

The assumption of a linear profile between the two dispatch interval end points is a fundamental assumption in the calculation of FCAS causer pays factors and this study has investigated the significance of this profile on the resultant unit causer pays factors. Three profiles were evaluated for possible paths between the end points of the dispatch interval. The existing linear profile as used by AEMO, a unit step function implemented as a heaviside function and a logistic function that is a continuously differentiable function similar to the step function.

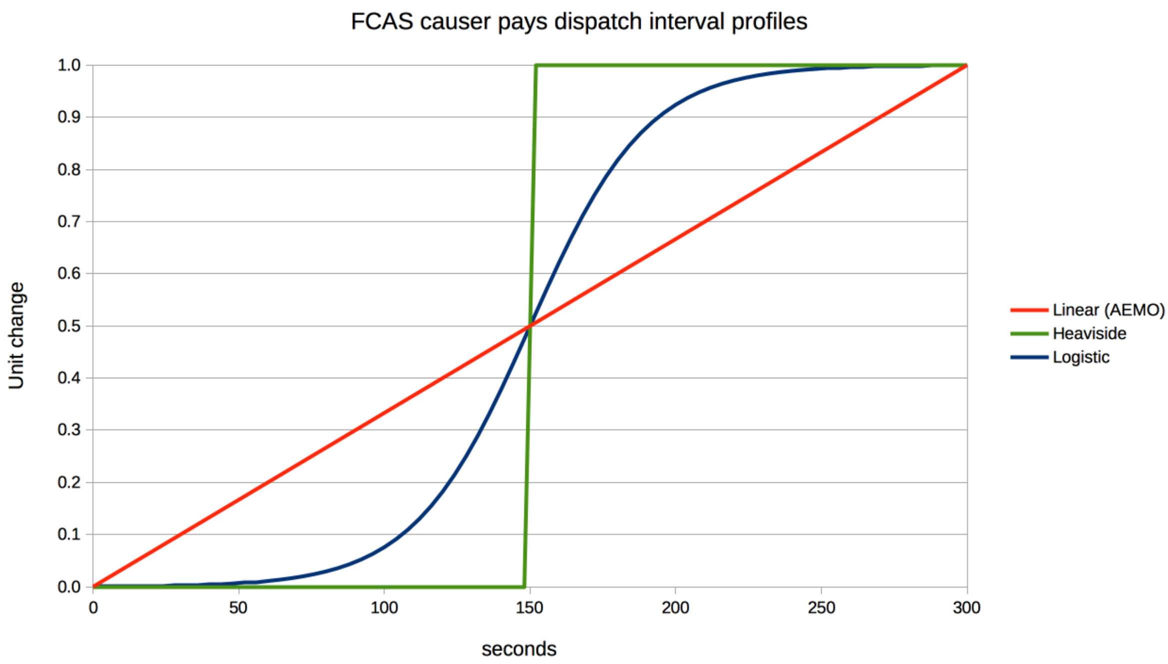


Figure 11 - Studied interval profiles for dispatch trajectory

The purpose of the investigation was not to identify the "best" profile to be used for the calculation of FCAS causer pays factors but rather to determine the significance of the linear profile assumption in the calculation on the resultant calculated causer pays factors.

Each profile was used to calculate the 4 second factors and then averaged to produce the 5 minute dispatch interval factors, aggregated at the unit level for each 28 day sample period and then compared to the 5 minute base case using the existing AEMO calculation procedure.

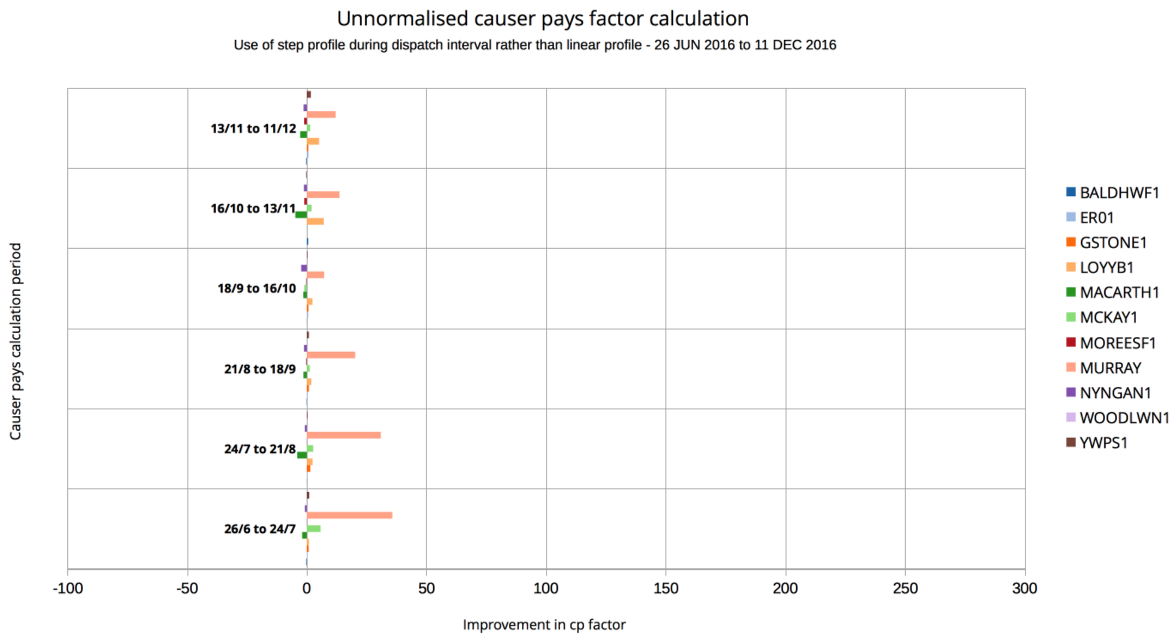


Figure 12 - Change in causer pays values calculated using step profile

For the case of the step or heaviside dispatch interval profile, it can be seen from the above graph that for most generators they are relatively insensitive to the linear assumption with the exception of an improvement in the causer pays factor for the MURRAY unit and minor improvements to MCKAY1 and LOYYB1 units with a minor negative result for the MACARTH1 and other units.

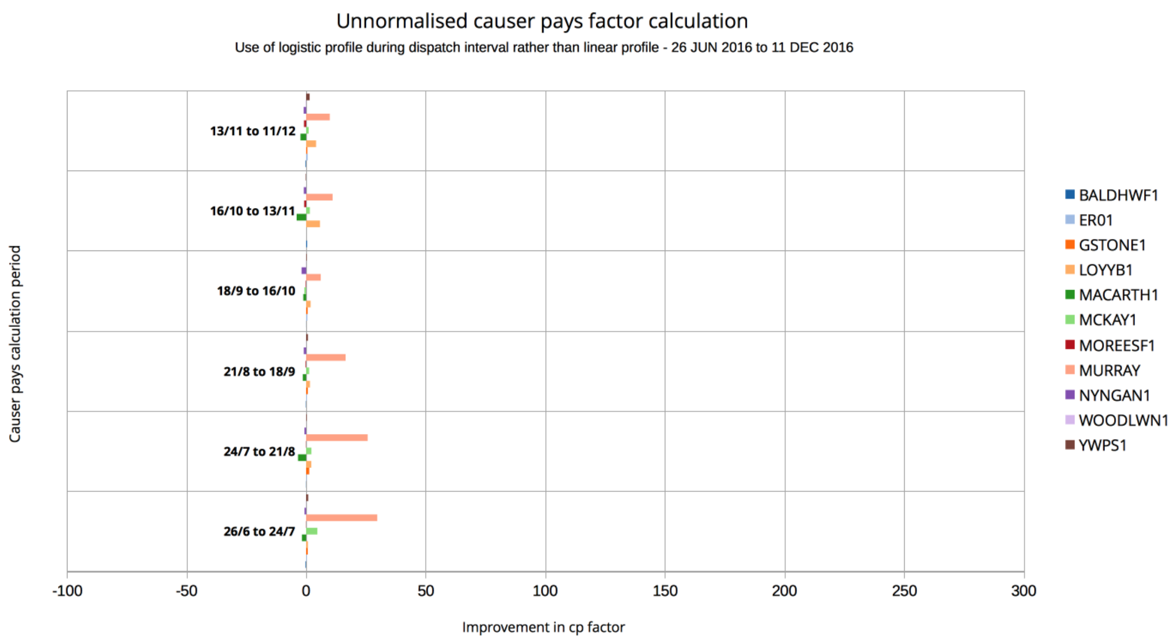


Figure 13 - Change in causer pays values calculated using logistic profile

As the logistic function is less of a dramatic change from the linear profile, as expected the changes in causer pays factors are less pronounced for each of the units and no discernible fundamental change in performance could be observed.

As an overall conclusion about the assumption of the linear profile on the calculation of the causer pays factors, it is suggested from these results that most generation technologies are relatively insensitive to the profile used with the possible exception of the hydro units that were the only generation technology to show any significant change in causer pays values.

Influence of possible SCADA time lag

One of the unanticipated consequences of the recent SA blackout was that a very significant event occurred at a precisely known time that can then be cross-checked back to the 4 second SCADA measurements for every generating unit in the SA region.

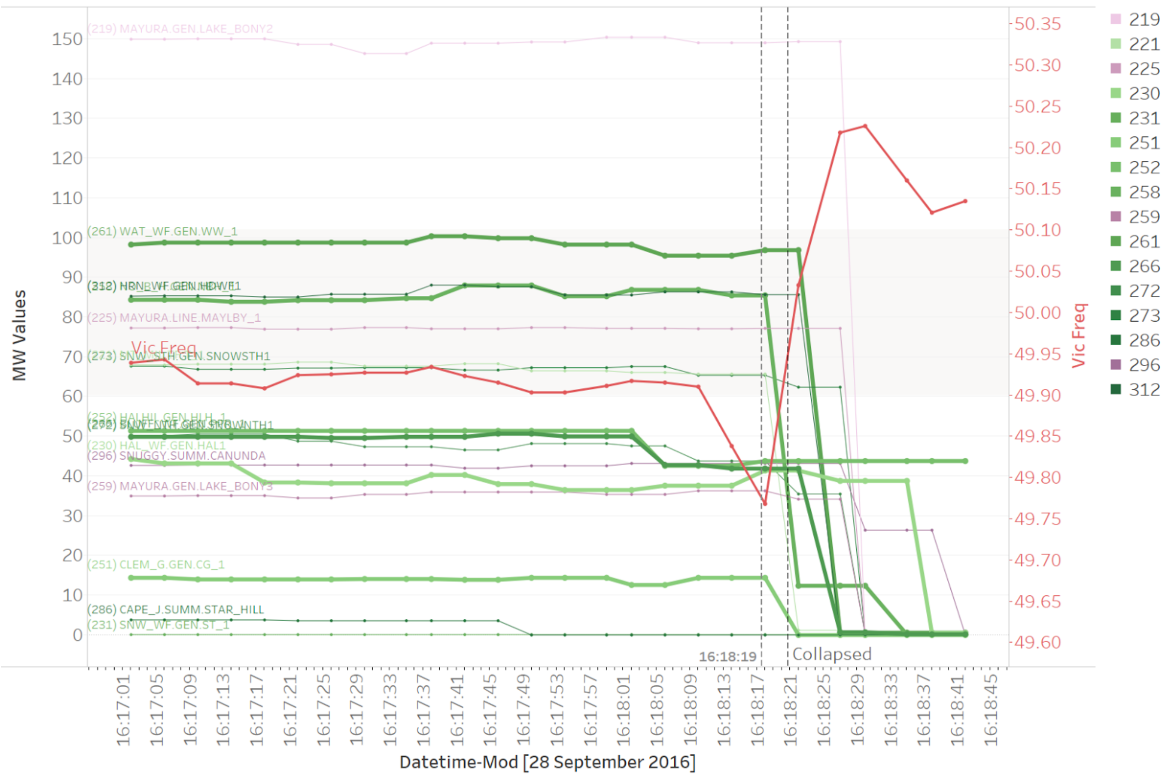


Figure 14 - Measured 4 second generation results for SA units after blackout

As can be seen by the graph shown in Figure 14, there is a considerable lag between the occurrence of the SA region blackout and the generation recorded in the 4 second data for each of the SA units and suggests that there is up to a 16 second lag between the time of the blackout and the recording of zero generation for many of the units.

As the SA blackout could be considered to be an extraordinary event with a lot of other factors in play at the time of the event, additional verification was used to establish if there was a measurable time lag between an event at a generator and the 4 second data under more normal operating conditions.

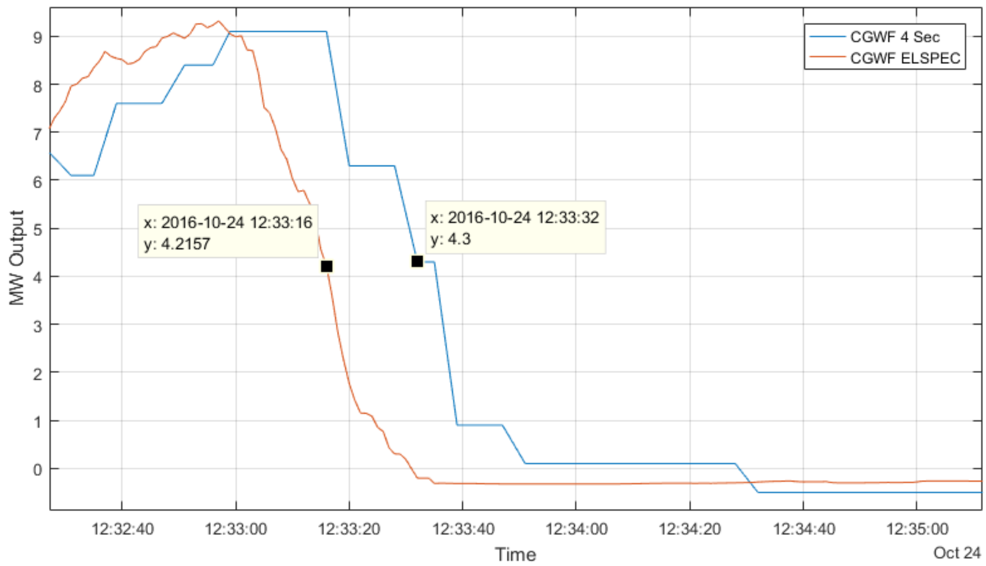


Figure 15 - SCADA time measured generation and 4 second measurements

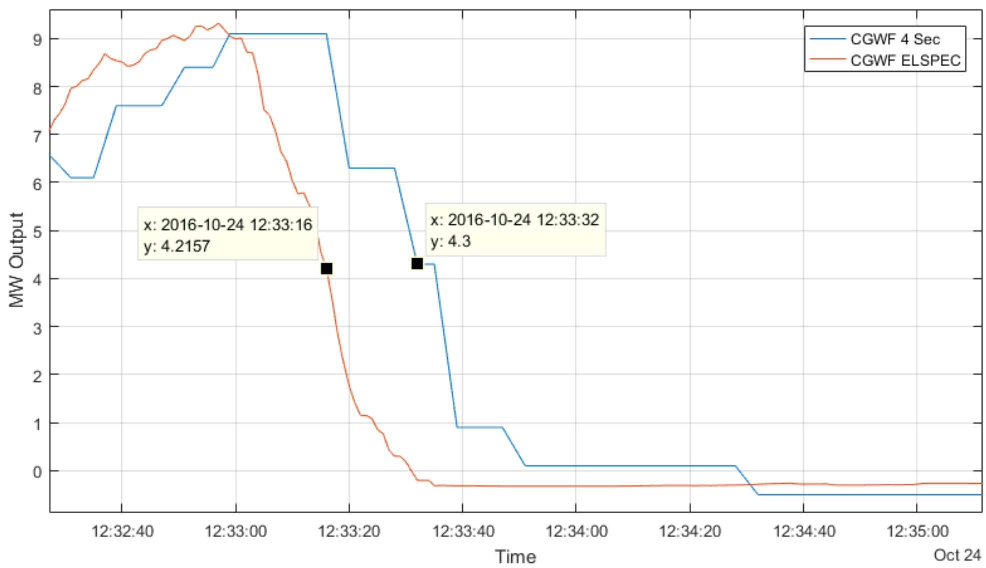


Figure 16 - SCADA time measured generation and 4 second measurements

The above two graphs show a similar 16 second time lag observed during a ramp rate test for a wind farm in the SA region. The SCADA timings used for these graphs could be considered to be at least to be within +- 2 seconds of actual time and therefore there is an observed time lag of between 14 to 18 seconds in these two examples.

Whilst the examples included in this report do not provide conclusive proof of a time lag for all generators or for other regions, this study does not seek to prove that there is a time lag in the AEMO 4 second data used to calculate FCAS causer pays factors. Rather this study seeks to determine how significant any time lags that may be present would be on the calculation of the unit causer pays factors to consider if further investigation and measurement of time lags is warranted.

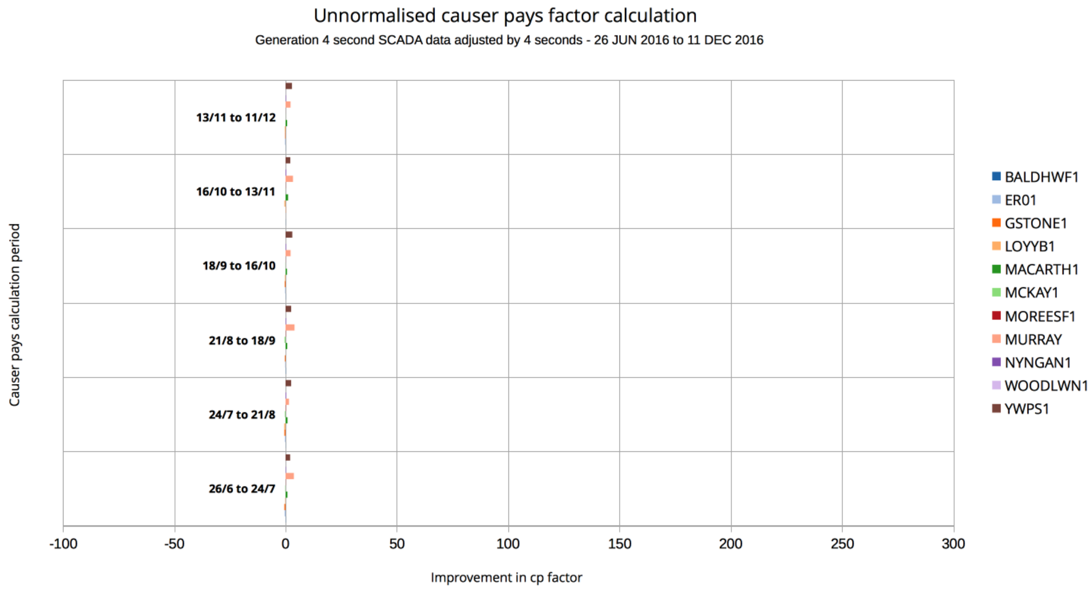


Figure 17 - Change in FCAS causer pays unit factors for a 4 second lag

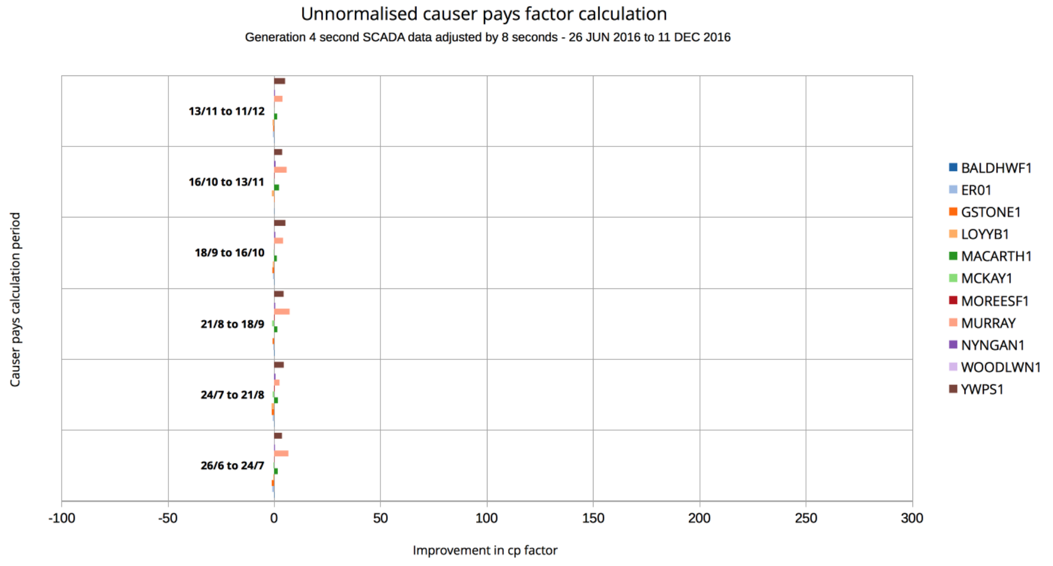


Figure 18 - Change in FCAS causer pays unit factors for an 8 second lag

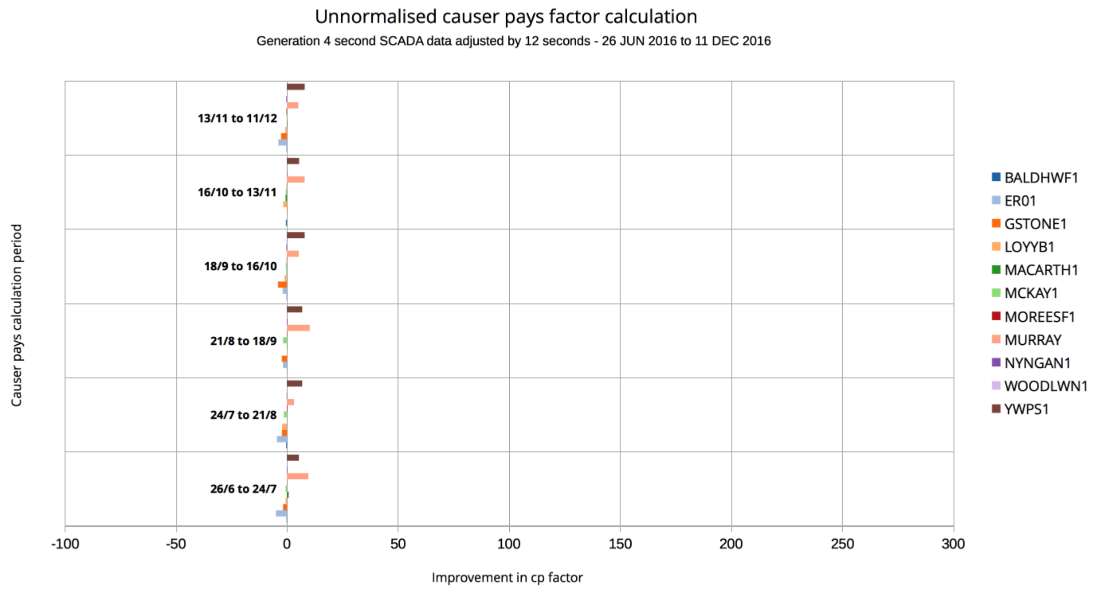


Figure 19 - Change in FCAS causer pays unit factors for a 12 second lag

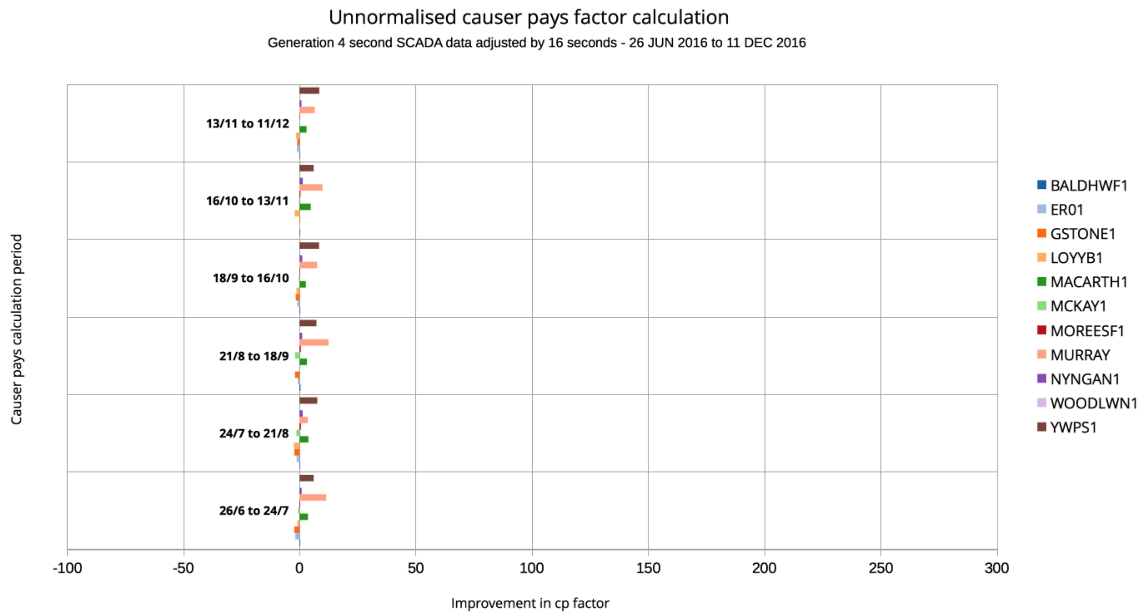


Figure 20 - Change in FCAS causer pays unit factors for a 16 second lag

As can be seen from the above graphs, the present AEMO FCAS causer pays calculation is relatively insensitive to any time lag between actual time and the 4 second data and on the basis of this evidence, further investigation of the effect of any possible system time lag is not justified for time lags of up to 16 seconds.

Timing of calculation of causer pays factors

Since the introduction of the causer pays methodology and associated settlement processes at the commencement of the FCAS co-optimised dispatch, technology has advanced to a point where the calculation of the FCAS causer pays factors in a sample 28 day period prior to the settlement week is no longer justified and is a significant financial risk to all generators.

The present 4 second data is published to the market approximately two days after the day of operation and could easily be incorporated into the normal settlement week schedule, with the possibility of subsequent revision in the normal settlement revision process to account for any excluded dispatch intervals that were not known at the time of the preliminary or final settlement dates.

Calculating the causer pays factor for the actual week is a much more consistent application of the principle of causer pays as the performance of that unit during the week is used to finally determine the proportion of FCAS regulations service costs that will be allocated to the unit's participant.

Also calculating the causer pays factor for the actual settlement week would possibly allow a generator the opportunity within the settlement week to change their unit performance to reduce the risk of a large financial loss due to the occurrence of an FCAS event that occurred earlier in the settlement week.

At the moment, the causer pays factors are set before the commencement of the settlement week period and there is no relationship between the unit's performance during the settlement week when large FCAS regulation costs are incurred by the market and how the unit has performed during that same period and therefore is not a true implementation of the causer pays principle.

Intermittent generator causer pays issues

The existing FCAS causer pays calculation method as defined by AEMO has recently resulted in very significant cost increases for intermittent generators in the Australian NEM, especially if they have been located in South Australia, or are part of a participant aggregation with generation assets in that State. It is anticipated that without a change in the approach, the FCAS regulation costs will continue to be an ever increasing cost of generation in the NEM and that intermittent generators will continue to be allocated an inappropriate proportion of the FCAS regulation costs. Considering that intermittent generators have been subjected to continual poor AWEFS forecasting performance and that the causer pays calculation method was adapted from application to dispatched generators and then applied to intermittent generators, there has been little consideration of the true nature of the causer pays principle.

As distinct from dispatched generators in the NEM that are required to dispatch generation that meets the target generation of the TOTALCLEARED value, when not operating under a semi-dispatch cap, Semi-Scheduled Generators have no requirement to meet any targets and are free to generate in an unconstrained manner as determined by the availability of the local wind or solar resource. Even when operating under a semi-dispatch cap, the AWEFS system will often have significant influence on the need for a semi-dispatch cap and the magnitude of the semi-dispatch cap if set, especially when the cause of the semi-dispatch cap is due to binding intra-regional constraints.

The fact that Semi-Scheduled Generators not operating under a semi-dispatch cap are being performance measured against a target that they are not required to meet, ensures that Semi-Scheduled Generators are being allocated a disproportionate share of the FCAS regulation costs compared with dispatched generators and other market participants.

The current poor performance of the AEMO AWEFS system for providing dispatch forecasts of generation for Semi-Scheduled Generators has contributed to excessive FCAS causer pays settlement factors that have recently caused significant financial loss to Semi-Scheduled Generators after recent high priced regulation FCAS events that have occurred in the SA regions.

However, any comparison of forecast to actual generation used in the calculation of FCAS causer pays settlement factors provides a useful measure of the performance of the AWEFS systems in comparison to any alternative approaches as the causer pays 4 second data provides publicly available unit generation data for all participants in the NEM and has a direct influence on the financial settlement of FCAS regulation charges for participants.

AWEFS issues

The forecasting results that the AWEFS system produces have a direct influence on the dispatch of Semi-Scheduled Generators, application and magnitude of the Semi-Scheduled Generator semi-dispatch caps and indirectly on measures such as FCAS regulation causer pays factors that have had a significant financial impact on Semi-Scheduled Generators.

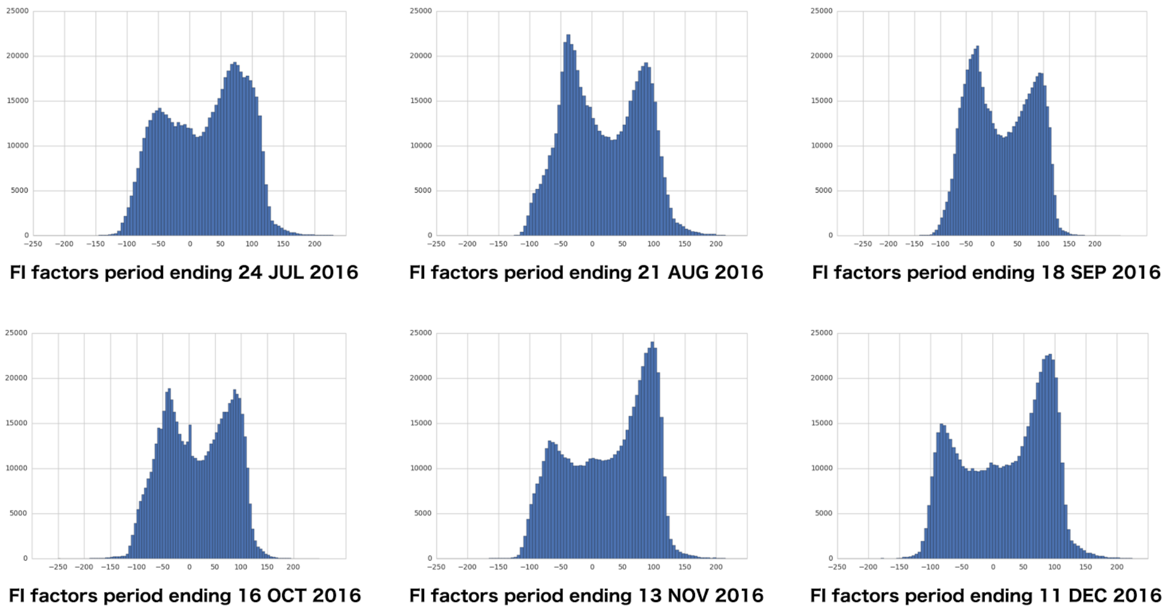


Figure 21 - Distribution of mainland FI factors for 28 day causer pays sample periods

As can be seen from the distribution of mainland FI factor histograms in Figure 21, the distribution of FI factors for each of the 28 day causer pays sample periods are highly asymmetrical, with a significant skew towards the enablement of raise rather than lower services. Given that AWEFS forecasts predominantly over estimates the generation of wind farms, it can be seen to be a significant contribution to the increase in the requirement for raise FCAS regulation services and that wind farms will more often be contributing to the problem side of the causer pays calculation leading to large causer pays factors.

The underlying method used for the AWEFS forecasting of generation of Semi-Scheduled Generators is known to be a machine learning approach where the generation is forecast on the basis of a number of generator supplied inputs including meteorological mast measurements, representative turbine meteorological measurements, number of available turbines and current unit generation.

The AEMO discussion paper for the current AWEFS consultation [AEMO 1] proposes a number of changes to the model inputs such as more timely inputs, combined measurements and including

“Estimated Power” calculations that would allow Semi-Scheduled Generators to effectively produce their own forecasts. Each of these proposals would appear to be useful changes to the AWEFS application, but do not address some of the fundamental limitations of a centralised and generic forecasting system except for the Estimated Power generator supplied forecast value proposal if that proposal is widely adopted by intermittent generators throughout the NEM.

Many of the issues associated with AWEFS that have been identified in [AEMO 3] and are caused by AWEFS attempting to infer the state of the Semi-Scheduled Generators and assume that there are local constraints to the generation when in fact none exist. Also there are system conditions that are not well modelled or inferred such as high wind conditions leading to reduced generation, single MET measurements attempting to represent a diverse range of turbine conditions or undetected generator or distribution imposed constraints that produce forecasts that poorly reflect the actual levels of generation.

The current AWEFS consultation [AEMO 1] recommendations initially only proposed changes to the inputs for AWEFS that reflected the perceived needs of AEMO and system management considerations rather than address the significant financial losses being imposed on intermittent generators through poor AWEFS forecasts. More recent consultation recommendations have now included, at the participants insistence, the implementation of generator supplied Estimated Power values to AEMO and this proposal is the only realistic initiative proposed so far that can enable the forecasts of intermittent generation to be realistic and not to lead to subsequent excessive FCAS regulation service requirements and costs due to centralised forecasting errors.

In contrast to the approach of AWEFS to forecast the Semi-Scheduled Generator dispatch using the SCADA measurements of the unit generating conditions, this report proposes consideration of two simple state estimation approaches to short term forecasting based on recent generation history that are more reliable and produce better predictions of generation than the current AWEFS approach.

Finally, a modification is suggested to the NER to ensure an as bid available capacity from a semi-scheduled generator, as a representation of the current capability of the plant, is used within NEMDE dispatch. This rule change should be implemented as non-controversial.

INITIALMW as dispatch interval forecast

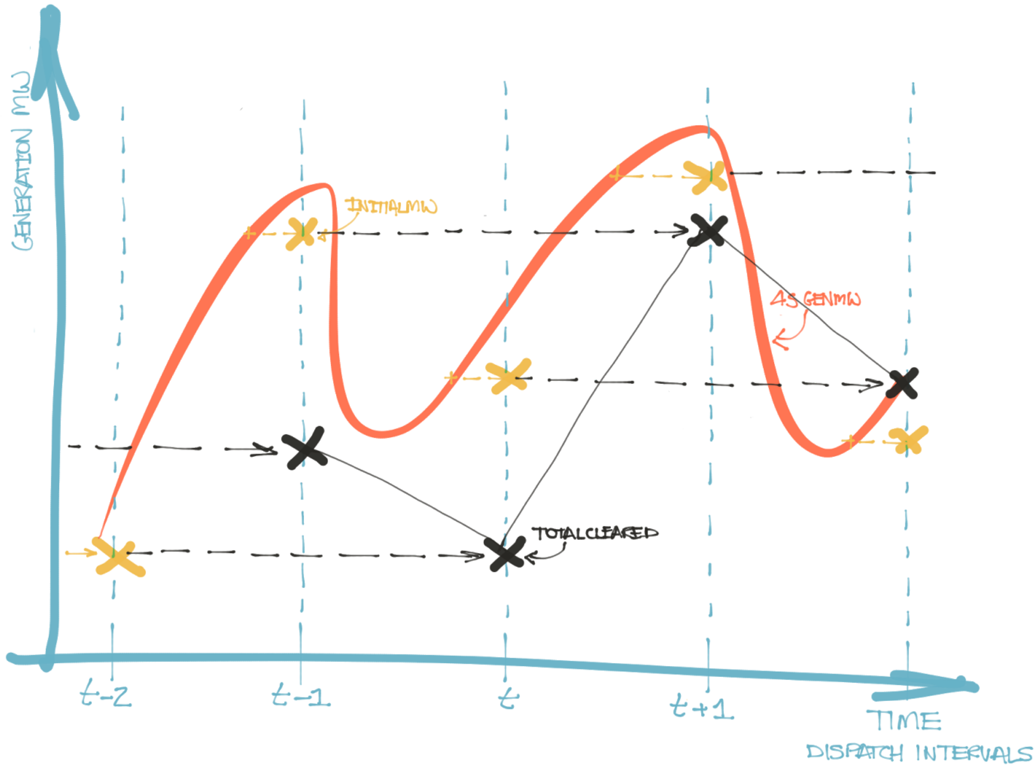


Figure 22 - Dispatch targets using previous DI value of INITIALMW

The first proposed approach for determining a reliable short term generation forecast for a Semi-Scheduled Generator unit, is to use the last available value of INITIALMW, that is determined by the dispatch process as the current level of generation as the "target" for the end of the dispatch interval. The only time that the TOTALCLEARED "dispatch level" is an actual target for a Semi-Scheduled Generator unit is when a unit is operating in the presence of a semi-dispatch cap and therefore when the semi-dispatch cap is absent, the final TOTALCLEARED "dispatch level" is simply an indication of expected dispatch, although it is used for the interpolated standard used to determine FCAS causer pays settlement factors as shown in Figure 22.

The INITIALMW method is by design a lagging indicator as the INITIALMW value is the current measurement of generation at the start of the previous dispatch interval and is then used as the target for the current dispatch interval as shown in Figure 22. However, it should be noted that the AWEFS forecasts are lagging predictions, although the current discussion paper [AEMO 1] proposes improving the timing of the generation state inputs and therefore reducing the lag in the AWEFS forecasts.

The principal advantage of this INITIALMW approach, is that the intermittent generation forecasts always represent actual recent history and can never significantly deviate from the unit's generation for long periods of time that have been observed with the AWEFS forecasts. The INITIALMW proposal would also be very simple modification to implement as the value is already part of the existing dispatch data.

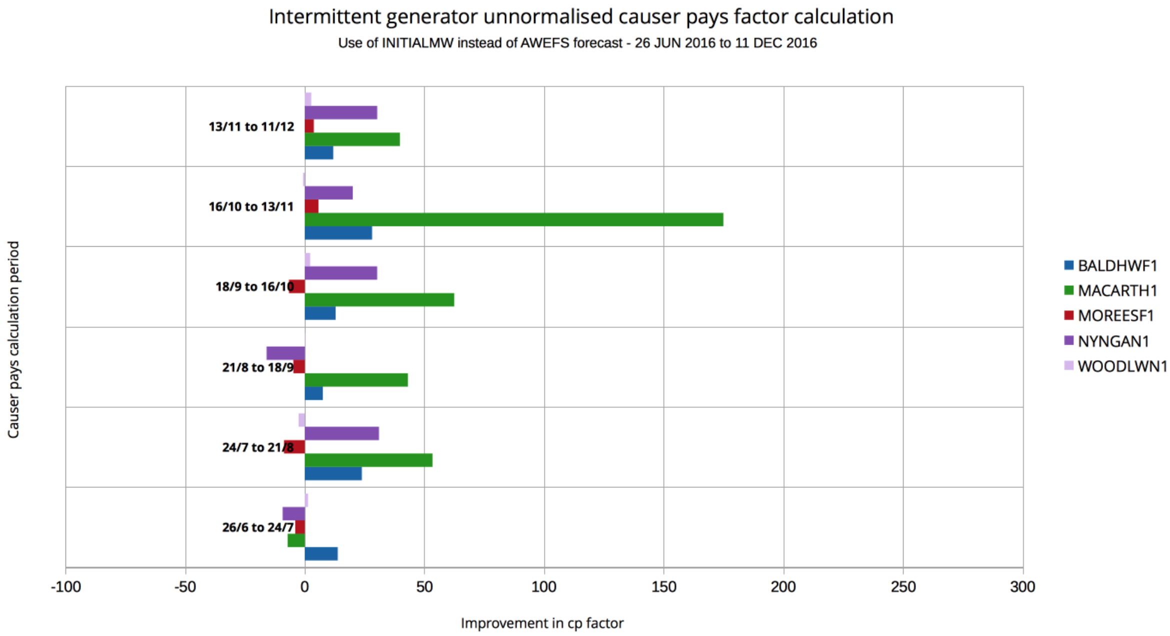


Figure 23 - Change in FCAS causer pays unit factors using INITIALMW as final target

It can be seen from these results, simply using a very crude forecasting tool such as the INITIALMW as the dispatch target at the end of the dispatch interval resulted in significant improvements to all of the wind farms except for one sample period for MACARTH1, and slightly worse causer pays factors for the solar farms.

Two minute generation sample as dispatch interval forecast

To improve the performance and timeliness of the previous INITIALMW case, a simple improvement can be made to the forecasting technique by taking a sample of the wind or solar farm generation closer to the end of the previous dispatch interval. As can be seen from Figure 20, the INITIALMW value from the previous dispatch interval is a relatively old measurement of generation, especially when it is considered that the AEMO dispatch process typically determines the present level of generation prior to the end of the previous dispatch interval.

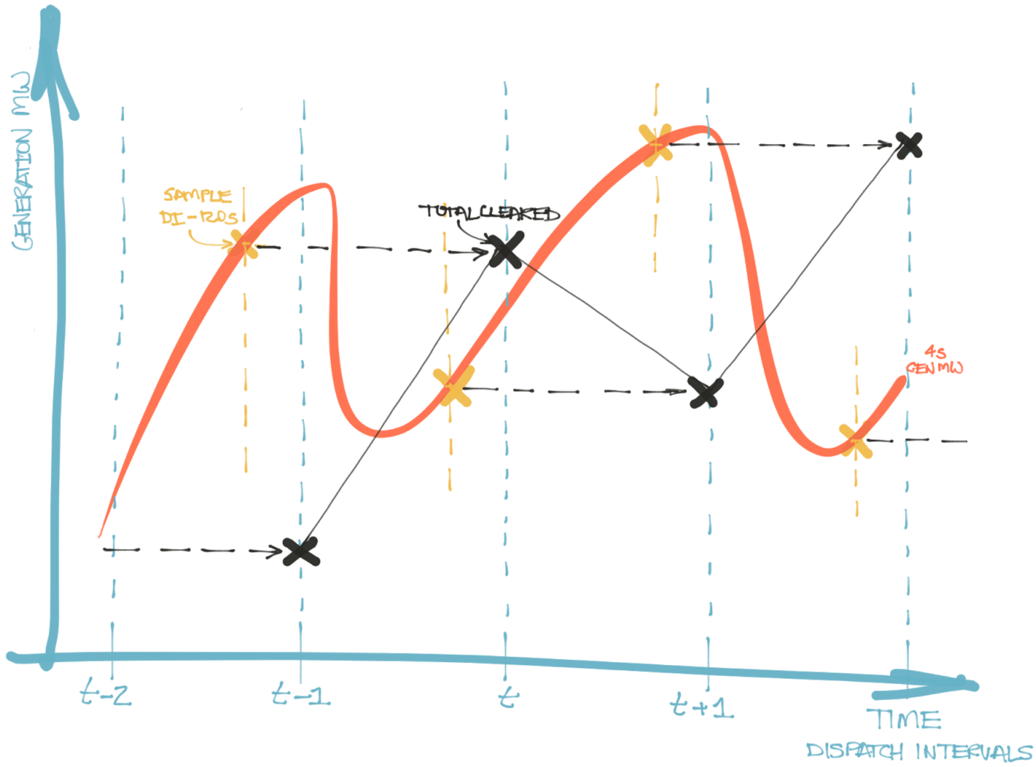


Figure 24 - Dispatch targets using samples 2 minutes prior to start of DI

The Sample 2 min method uses a measurement of generation from the 4 second SCADA values that is closer to the start of the current dispatch interval than the INITIALMW approach, but earlier enough prior to the current dispatch interval that the value of the measurement would be available to input into AWEFS and prior to start of the the dispatch process for the next dispatch interval. For the purposes of this study the minimum time required before the start of the dispatch interval to be included in the dispatch process has been estimated to be 2 minutes. If the 2 minute sampling prior to the dispatch interval of the generation measurement is shown to provide a significant improvement to the forecasting, then it may be possible to reduce the lag even further with a lower dispatch interval offset such as 1 minute, but the feasibility of reduced sample timing would need to be determined with respect to the entire intermittent generator forecasting and dispatch process.

The Sample 2 min method has the same advantages as the INITIALMW approach in that it is based on the actual performance of the unit, but would be more complex to implement.

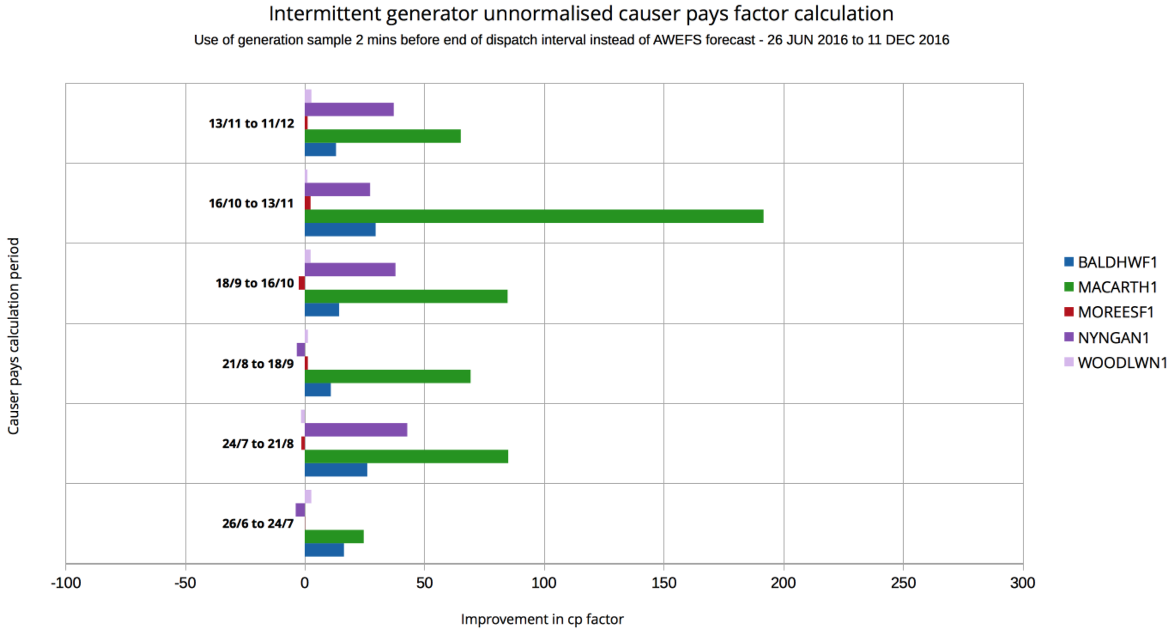


Figure 25 - Change in FCAS causer pays unit factors using 2 min sample as final target

It can be seen from the results of the study that the use of either the INITIALMW or the 2 minute sample of wind farm generation rather than the AWEFS forecast that is presently used to determine a large proportion of the TOTALCLEARED targets leads to very significant reductions in FCAS causer pays factors for all of the wind farms, especially for those intermittent generators that are known to have poor AWEFS forecasts, and has relatively little influence on the causer pays factors for the solar farms. As the 2 minute sample technique uses a generation sample closer to the start of the dispatch interval, it produced more significant improvements in causer pays factors for wind farms than the INITIALMW approach, as was expected.

The implementation of Estimated Power as proposed during the recent AEMO AWEFS consultation would allow wind farms to use an improved form of generation forecast, even such as the crude forecasting techniques used in this study based on current levels of generation, that would lead to substantial improvements in the magnitude of that intermittent generator's causer pays factors.

Given that only simple state estimation techniques were used for this study and the use of those techniques resulted in significant improvements in the causer pays factors for these wind farms, strongly suggests that the poor performance of the AWEFS forecasting system presently used by AEMO is a very significant factor in the allocation of a disproportionate amount of the NEM FCAS regulation costs to the wind farms that have no present way of improving or replacing the AEMO derived forecasts. The poor AWEFS forecast are also a significant cause of increased FCAS regulation services and thereby contributes to diminished system security.

The proposed implementation of generator derived Estimated Power inputs to AEMO is clearly a very necessary requirement and does not need to be a sophisticated implementation to deliver significant improvements to causer pays factors for many intermittent generators.

Aggregation in the calculation of causer pays factors

As defined in Section 5.8 “Sum the five-minute factors” the calculation of the **FCAS** causer pays factor **[AEMO 2]** specifies:

> *“At the end of the 28-day sample period, average the 5-minute factors for each category for each causer type of generating unit or load. The averaging of the five-minute factors is done separately for the Tasmania region and mainland regions.*
>
> *For Causer Type 1, Causer Type 2, generating units and loads, calculate sub-totals of the 5-minute factors at the Market Participant level.*
>
> *Positive performance within a category by a generating unit or load in a Market Participant’s portfolio can offset poor performance of another generating unit or load belonging to the same Market Participant.*
>
> *Define a function, f, and calculate a resultant factor for a Market Participant that identifies the generating units or loads that are causers of the need for Regulating FCAS according to the following equation:*
>
> ***Equation 13 -*** *f(LEF, LNEF, REF, RNEF) = min[0, { RNEF + LNEF + min(0, LEF) + min(0, REF) }]”*

The calculation methodology states that at the unit level, all of the 5 minute factors for that unit are averaged over the 28 day sample period without any explanation or justification for that approach. The 5 minute factors are themselves averages of the 4 second periods within the dispatch interval and so the calculation of the LEF, REF, LNEF, RNEF factors for each unit is determined as an average over 28 days of all of the 5 minute averages with some dispatch periods specifically excluded for technical reasons.

Averages of averages do not in fact produce an overall average of any quantity, a fact that is easily proved mathematically, and so it is not clear what this averaging of the 5 minute averages is attempting to calculate. In the case of FCAS causer pays factors, each 5 minute dispatch interval will only have either one or two of RNEF, LNEF, REF and LEF depending on the system conditions and any FCAS enablement that occurred in the dispatch interval for that unit, and yet these zero values for the quantities that are not relevant for those dispatch intervals affect the calculation of the 28 day averages if the calculation of these quantities is simply the sum of each quantity divided by the number of dispatch intervals in the 28 day sample period.

Periods of non-generation where the unit is unavailable or cannot possibly run (say for solar plants when it is not daylight) are also included in the number of dispatch intervals used for calculating the average with no justification provided for their inclusion.

It is hard to understand the justification for the inclusion in the number of dispatch interval divisor of any of the zero values for factors that are not relevant to that dispatch interval or when no generation occurs in the dispatch interval in the calculation of the 28 day sample period average for each of the individual causer pays factor RNEF, LNEF, REF and LEF quantities.

Of more concern for many intermittent generators that presently experience poor AWEFS forecasts and therefore considerable dispatch errors is that the calculation of averaging of the 5 minute factors over the 28 day sample period, like all average aggregations, will be significantly influenced by the presence of large 5 minute factor outliers and lead to unrepresentative causer pays factor calculations for that unit and hence have a significant influence on the aggregate causer pays factors.

Consider the following distribution plots of unit rather than aggregate causer pays factors (AEMO FCAS causer pays calculation equation 13 applied at the dispatch unit level) against INITIALMW generation for the sample periods from the 26 JUN 2016 to 11 DEC 2016 and for the selection of some of the dispatch units studied in this report and that represent a broad range of generation technologies in the Australian NEM.

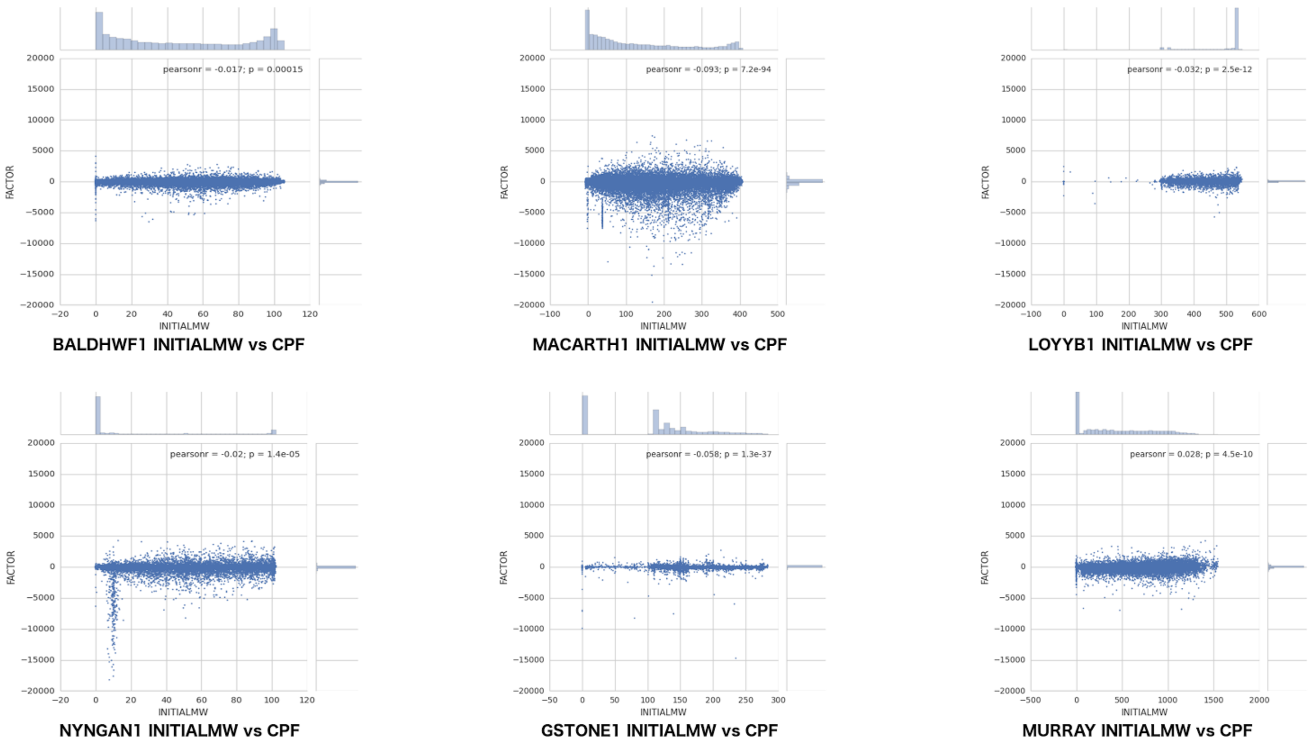


Figure 26 - Distribution of unnormalised CP factor vs INITIALMW generation

As can be seen in the distribution plots of causer pays factors against generation in Figure 26, the intermittent units (BALDHWF1, MACARTH1 and NYNGAN1) have a wide spread of causer pays factors and many outliers in comparison to the coal units and to a lesser degree the MURRAY hydro unit. The size of the resultant causer pays factors should also be considered with respect to the levels of respective maximum generation as the intermittent generators BALDHWF1 and NYNGAN1 have about 100 MW capacity in comparison to 500 MW for LOYYB1. The significant disadvantage of poor AWEFS and ASEFS forecasts on the revenues of intermittent generators and overall system stability and poor dispatch outcomes has been well documented and discussed in the present AEMO ECM consultation process [AEMO 1] and has led to very poor causer pays factor values for intermittent generators and hence substantial financial losses and leads to an unfair proportion of the costs of regulation services being allocated to intermittent generators.

A more appropriate aggregation of 5 minute causer pays factors would be to use the median calculation of the 5 minute factors, as this method of aggregation is less influenced by the presence of significant outliers and is more representative of the 28 day sample than the averaging process that is being presently used in the causer pays calculation. Medians are a standard economic aggregation used when it is important to represent a sample and not be inappropriately influenced by outliers, such as the standard reporting of median wages or house prices that would otherwise produce nonsensical mean values due to no upper bound on a small number of observations.

Also those periods that do not have a factor calculated or are zero due to non-generation have not been included in the median calculation as they have no role in determining the performance of the unit to its dispatch target or forecast generation. For units that provide FCAS services, there will be a substantial reduction in the value of the individual causer pays factor components for those units for the present average aggregation process as the number of dispatch intervals included in the averaging process when the REF and LEF is calculated rather than the LNEF and RNEF leading to lower averages of those component values.

The individual unit causer pays factors have been calculated using the median aggregation for the representative sample of dispatch units for the same set of 28 day sample periods from 26 JUN 2016 to 11 DEC 2016.

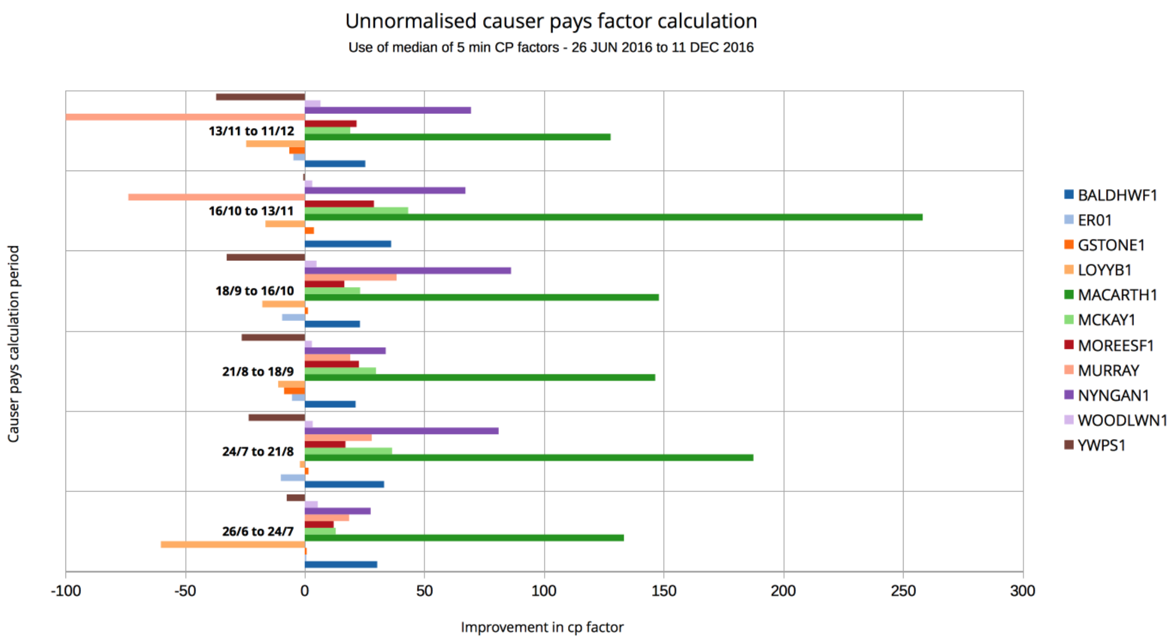


Figure 27 - Improvement in unnormalised CP factor using median calculation

As can be seen in the above graph, using the median aggregation of 5 minute causer pays factors has led to substantial improvements in the FCAS causer pays factors for the intermittent generators in the unit samples that can be directly attributed to the elimination of non-relevant dispatch intervals and the insensitivity to outliers caused by extremely poor dispatch forecasts.

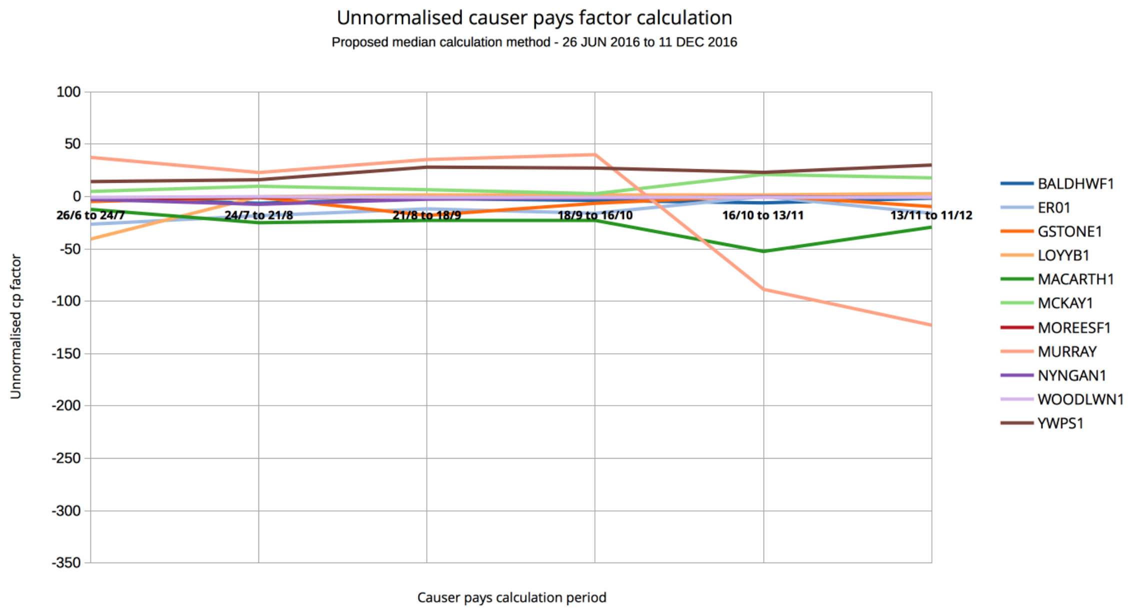


Figure 28 - Unnormalised CP factors using median calculation

The graph in Figure 28 shows the range of unnormalised FCAS causer pays factor for the entire study period and can be directly compared to the existing AEMO FCAS causer pays methodology results are shown earlier in this report and also included below.

There is an increase in the value of the FCAS causer pays values for dispatched generators, but in the studied period this was only significant for the MURRAY unit and this may be more due to the method of dispatch interval interpolation as discussed above rather than the median method of aggregation. The original graph of causer pays factors calculated using the existing AEMO mean aggregation is again show below for direct comparison.

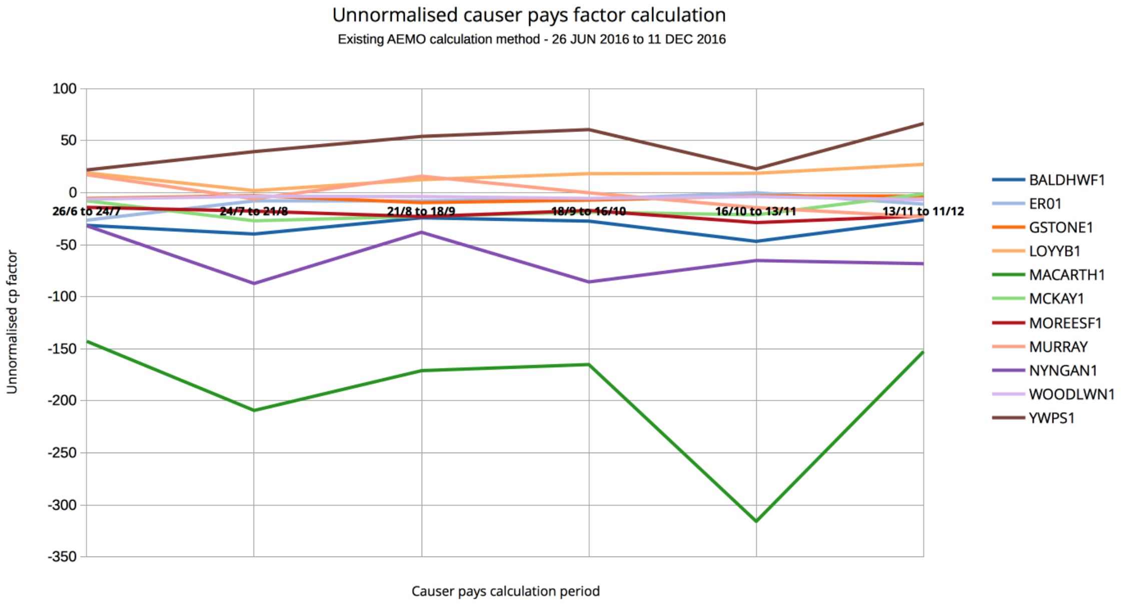


Figure 29 - Unnormalised CP factors using existing AEMO mean calculation

7. Conclusions & recommendations

- The existing AEMO documentation **[AEMO 2]** for the calculation of the causer pays factors is incomplete and does not document key methods used in the calculation of important components used in the causer pays calculation procedure and this information should be publicly available;
- Most generation technologies are relatively insensitive to the present AEMO assumption of a linear profile between two generation dispatch interval values with the possible exception of hydro units;
- Observed time lags of up to 16 seconds did not have any discernibly significant effect on the calculated unit causer pays factors for the studied units and sample periods;
- Causer pays factors should be calculated for the same period as the actual settlement week to implement a much fairer implementation of the principle of causer pays;
- Data should be published such as the FI and other critical parameters used in the causer pays calculation should be published as part of the dispatch load data.
- Implementation of Estimated Power for intermittent generators is an urgent and essential requirement for all intermittent generators to address the serious shortcomings of the present AEMO AWEFS system that is causing excessive financial losses to wind farms who are being charged a disproportionate allocation of the FCAS regulation costs and to improve system stability;
- A rule to change should be made to allow available capacity bids to be reflected in NEMDE dispatch targets;
- A more appropriate, representative and fairer method of aggregating the 5 minute causer pays factors would be to use a median calculation approach that only considers the dispatch interval factors that are active or relevant; and
- Each of the recommendations of this study should be further investigated and validated using a larger number of sample periods and selection of dispatchable units.

8. References

[AEMO 1] AEMO Forecasting (2016), “WIND AND SOLAR ENERGY CONVERSION MODEL GUIDELINES CONSULTATION - ISSUES PAPER - 2016”, version: 1.0.

[AEMO 2] AEMO Systems Capability (2013), “CAUSER PAYS: PROCEDURE FOR DETERMINING CONTRIBUTION FACTORS”, no: 160-0379, 4.0.

[AEMO 3] AEMO (2016), “SCHEDULING ERROR REPORT: AWEFS UNCONSTRAINED INTERMITTENT GENERATION FORECAST (UIGF) SCHEDULING ERRORS – 2012 TO 2016”, February 2016.

[AEMO 4] AEMO (2016), “Ancillary Services Market Causer Pays Elements File”, January 12 2016.

[AEMO 5] AEMO (2001), “ Reliability Panel Frequency Operating Standards Determination”, September 2001, page 5

Acknowledgments

The authors acknowledge and are grateful for the important support of Pacific Hydro, Infigen Energy, Tilt Renewables, Woolnorth Wind Farm Holdings and Waterloo Wind Farm and the earlier support of Bald Hills Wind Farm for this research.