ELECTRANET SAET

Investigation of interim arrangements

ENTURA-10CCFE

5 February 2019

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Executive summary

Entura have supported ElectraNet with the development of a non-interconnector solution of the South Australian Energy Transformation Regulatory Investment Test for Transmission (SAET RIT-T). The PADR has concluded that the non-interconnector solution is a non-preferred option. This report focuses primarily on the non-network solutions and investment required to achieve satisfactory network performance (in terms of inertia, RoCoF and FCAS) for the current network arrangement during the interim period between now and the commissioning of a new interconnector. This could allow removal of renewable generation caps in place in SA while maintaining the 3 Hz/sec RoCoF standard at the least cost while also maintaining full interconnector capacity of ±650 MW.

ElectraNet are procuring two synchronous condensers (SCs) for connection at Davenport as an initial step to address a system strength shortfall. ElectraNet are developing the complete system strength solution and plan to present the complete solution for AEMO's due diligence in Q1 2019. In order to fully meet the system strength shortfall this analysis has assumed a requirement for two large synchronous generators to be online in South Australia (assumed 2 x TIPS B in our study). Along with the existing Hornsdale and Dalrymple batteries, these measures allow the interconnector flow to reach 650 MW without the RoCoF limit of 3 Hz/s being exceeded.

The value of additional supports in the form of heavier SCs, additional SCs and additional batteries has been considered. We have shown there is some value in considering additional supports for the interim period but that this value is mainly indirect through providing redundancy and operational flexibility.

The additional supports considered have centred around three main options:

1. Heavier SCs instead of those currently proposed for Davenport,
2. Additional SCs nominally connected to Robertstown, or
3. An additional battery nominally connected at Tailem Bend.

The value associated with the heavier SCs appears to be minimal compared to the other two options.

The overall system benefit provided by additional SCs or an additional battery is difficult to differentiate. The relative costs of these forms of support would however suggest that SCs should be considered ahead of the battery unless imports in excess of 650 MW were considered.

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1. Introduction

Entura have supported ElectraNet with the non-interconnector solution of the South Australian Energy Transformation Regulatory Investment Test for Transmission (SAET RIT-T). The PADR has clearly concluded that the non-interconnector solution is a non-preferred option. This report focuses primarily on the provision of a transition during the interim period before an additional interconnector for South Australia can be commissioned.

The high penetration of non-synchronous generation in South Australia and consequent reduction in system strength together with a system strength gap declared by AEMO has led ElectraNet to undertake the procurement of two synchronous condensers (SCs) that will be installed at Davenport. These units will provide system strength and inertia to the South Australian power system. Both of these power system supports are critical during the interim period before the commissioning of any new interconnector to ensure that the Rate of Change of Frequency (RoCoF) remains within the defined technical envelope for SA power system separation events. The critical event is the loss of the existing Heywood interconnector under high import to South Australia.

Management of RoCoF within the technical envelope can be done through various means:

- Increase the number and size of synchronous plant connected in South Australia,
- Ensure batteries are available to provide fast frequency response, or
- Limit interconnector flows.

Each of these mechanisms could affect market outcomes. If investment in additional system supports was to be brought forward to prior to construction of a new interconnector, the cost of this impact may be reduced, providing net market benefits.

The additional supports that can be delivered in the timeframe for the interim arrangements may take the form of:

- Additional SCs,
- Higher inertia SCs, or
- Additional batteries.

The system stability studies for the new interconnector indicate that some additional system supports would be required to provide the required level of dynamic reactive support in South Australia. This would nominally be provided by the addition of two more SCs at Robertstown. ElectraNet are also investigating the value of another large-scale battery at either Tailem Bend or Tungkillo that would essentially provide a line-packing function for the Heywood interconnector. This approach would make the apparent capacity of this line more compatible with that of the new interconnector. The comparison between these two system supports is described in more detail in the next section.

In addition to investing in supports such as these, alternative network support contracts with synchronous plant could be considered.

The aim of these studies differs to those presented in our previous reports on the non-network solution. This report details the solutions and investment required to achieve satisfactory network performance (in terms of inertia and RoCoF. This would potentially allow removal of the renewable generation caps currently in place in SA while maintaining full interconnector capacity of ±650 MW and the 3 Hz/sec RoCoF standard at the least cost. There is no requirement for the islanded South Australia system to maintain satisfactory operation for the non-credible double circuit trip of the Heywood interconnector. This report focuses only on the RoCoF and then the viability of the solution under credible contingencies as tests of validity.

The next section describes the system scenario that has been chosen for this work and its applicability across a range of South Australian demand and renewable generation scenarios.

Section 3 of the report describes the range of scenarios investigated and summarises the results of the studies.

Section 4 compares the contribution of the range of supports.

Section 5 makes conclusions with respect to the benefits relating to the supports and provides advice as to how this might be incorporated into the final considerations for the new interconnector project.

2. Base case

In order to assess the worst-case RoCoF conditions we consider the highest interconnector import conditions coincident with low system demand and moderate renewable generation. This leads to the lowest possible investment in system supports for South Australia. The base case includes the South Australian network as of the beginning of 2018 with the following additions:

1. 2 SCs at Davenport, and
2. The Dalrymple battery.

In addition, this study has assumed a minimum amount of synchronous generation in South Australia. At the low demand that we have in this case, the lowest cost source of this generation is assumed to be 2 x Torrens Island Power Station B units both operating at 40 MW.

The system demand is set at 1150 MW. This demand can be understood as average demand now but could also be understood as a minimum demand with high-embedded generation as discussed in the following section.

The interconnector flow is set to 650 MW import.

The remaining generation in South Australia is from wind (490 MW).

2.1 Other considerations relating to the base case

The South Australian system will inevitably change across the interim period leading up to the commissioning of a new interconnector. These changes are likely to include each of the following:

- Increase in rooftop PV,
- Increase in non-synchronous generation, and
- Further battery and/or virtual power plant developments (VPP).

None of these changes would make the results of this study less valid. The modelled inertia in the case will not be reduced by these eventualities. In fact, newer large-scale renewables will need to comply with the revised technical standards of the NER, OTR and the ESCOSA generation licence requirements. This will increase the amount of frequency control available to AEMO within South Australia. Additional batteries and VPPs will also aid frequency control compared to the base case.

The change in net demand associated with the increase in rooftop solar will not affect the network dynamics appreciably. Any change to demand will either be offset by lower imports or if wind generation was not as high then through replacement of that generation. In any event, at minimum demand and maximum import, the system dynamics remain, at worst, as bad.

We have only studied a single demand point in this study. If demand is increased above the minimum we have assumed then, with the interconnector at maximum import, the shortfall must be met within South Australia. In order to maintain the low inertia case we would simply increase the wind generation dispatch to cover the shortfall. The case would remain similar in terms of South Australian inertial and 'governing' response. In this way, we can use this base case, not just for the demand scenario that it explicitly represents but essentially any system scenario where the load and generation balance in South Australia leads to high imports from Victoria up to the maximum capacity of renewable generation in South Australia. Once the demand less import is higher than the available non-synchronous generation, then the case would require synchronous plant to be dispatched and this would start to add inertia and system strength to the case. This would reduce the impact of the loss of the interconnector.

We have concentrated on import cases as this represents the lightest possible system without needing to extrapolate generation and demand beyond current levels. The RoCoF results presented here should be representative of similar export scenarios. That is the RoCoF will be as large in magnitude for an export case with the same synchronous machine dispatch. Obviously, the range of South Australian demand over which full export is possible without the need for some synchronous generation is narrower than for import. As for import, when synchronous machines are added, the inertia that they contribute will reduce the magnitude of RoCoF for the interconnector trip.

2.2 Summary of base case characteristics

The following table summarises the base case for this study.

Table 2.1: Base Case attributes

	Source	Value
Battery	Hornsdale Dalrymple	-50 MW 0 MW
Wind	All SA wind generation	490 MW
Synchronous generation	TIPS B 1 TIPS B 2	40 MW 40 MW
Demand		1150 MW
Interconnector flow		650 MW VIC-SA
Inertia in South Australia	TIPS B units 1 and 2 Davenport SC 1 and 2	2 x 250 x 3.76 MWs 2 x 80 x 8.125 MWs 3180 MWs

2.3 Base case performance

RoCoF

In order to calculate the RoCoF for the case, the frequency response of the SA system must be recorded for a double circuit contingency on the Heywood interconnector. The results of this simulation are shown in the following figure. The simulation excludes any load shedding or operation of the system protection scheme.

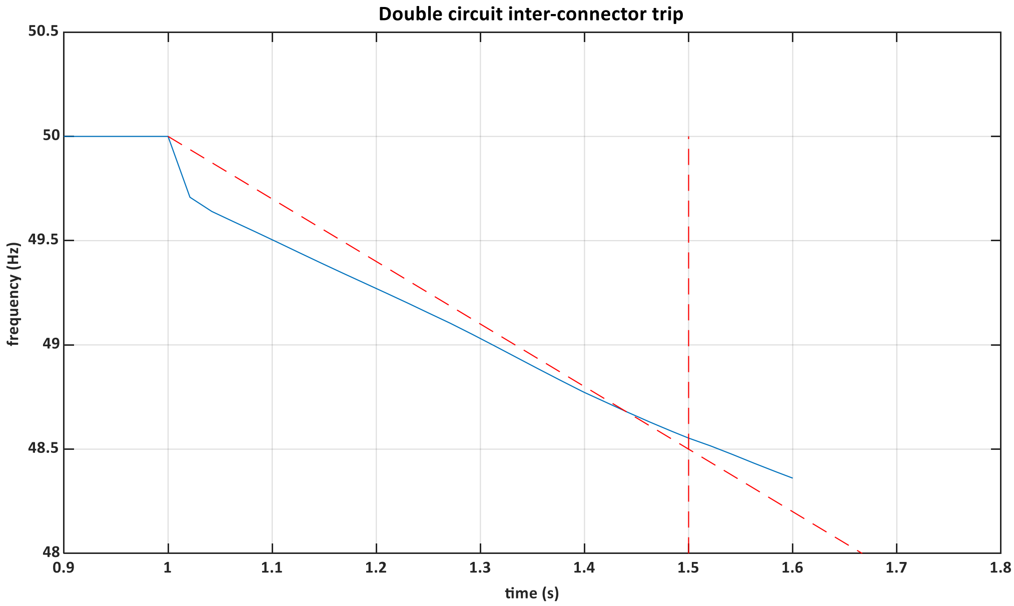

Figure 2.1: Frequency trace for the base case for double circuit loss on Heywood interconnector

The construction lines on the figure represent the -3Hz/s RoCoF limit and the time of assessment (1.5 s or 0.5 s after the event). The frequency trace shows a frequency deviation of less than 1.5 Hz in 0.5 s and so has an average RoCoF of less than 3 Hz/s as required.

Other contingencies

The following network events were applied to the base case to ensure that it provides valid results under onerous credible contingency events:

1. Trip TIPS B 1
2. 2 phase to ground fault at Tailem Bend 275 kV bus
3. 2 phase to ground fault at Torrens Island 275 kV bus
4. 2 phase to ground fault between Davenport and Robertstown at Robertstown
5. 2 phase to ground fault between Davenport and Robertstown at Davenport
6. 2 phase to ground fault at Canowie

These simulations confirm the robustness of the case and hence validate the case. The results of these simulations are shown in Appendix A.

3. Investigation

In order to assess the viability of additional or alternative supports for the interim period a range of cases have been considered as variants to the base case.

These variants are described in the following table.

Table 3.1: Description of support variants

Variant	Description
Tailem Bend Battery	A 100 MW battery is modelled at Tailem Bend and dispatched at 0 MW. The battery has the same dynamic characteristics with respect to frequency response as the Hornsdale battery.
Pelican Point	The Pelican Point CCGT is dispatched at low load
Osborne	The Osborne CCGT is dispatched at low load
Robertstown synchronous condensers	Additional SCs are added at Robertstown
Heavy synchronous condensers	The Davenport SCs have inertia added such that they are 1000 MWs inertia.

These variants were applied as combinations with the base case as shown in the table on the following page.

Table 3.2: RoCoF results

	Inertia (MWs/unit)	**Base case**	**Base Case + TB battery**	**Base Case + TB battery - 2 x TIPS B**	**Base Case - 2 x TIPS B**	**Base Case - 2 x TIPS B + heavy SCs**	**Base Case - 2 x TIPS B + PP**	**Base Case - 2 x TIPS B + PP + O**	**Base Case + RB SC**	
SCs	650	**2**	2	2	2		2	2	3	
	1000					2				
TIPS B	940	**2**	2	0					2	
O CCGT	2747.4							1		
PP	1869						1	1		
TB Battery	0		100	100						
Total Inertia		**3180**	3180	1300	1300	2000	3169	5916.4	3830	MVA
Case ID		**29**	21	31	26	32	27	28	10	
Estimated average Rate of Change (250 ms)		**-3.4**	-3.2	-4.3	-4.9	-3.8	-3.4	-2.7	-3.0	Hz/s
Estimated average Rate of Change (500 ms)		**-2.9**	-2.6	-3.8	-4.4	-3.4	-3.1	-2.3	-2.6	Hz/s
Max import for RoCoF = -3 Hz/s		**-659**	-726	-547	-436	-575	>-650	<-650	-738	MW (SA to Vic)

The NER is not prescriptive with respect to the measurement of RoCoF and so we have chosen to use two criteria for this assessment:

1. RoCoF must be less severe than an average -4 Hz/s after 250 ms post event, and
2. RoCoF must be less severe than an average -3 Hz/s after 500 ms post event.

Numbers are coloured red if their magnitude exceeds 4 Hz/s, amber between 3 and 4 Hz/s and green below 3 Hz/s.

The simulation results for each case are shown in Appendix B.

A further round of analysis has been undertaken to determine the interconnector flow that would lead to RoCoF magnitudes of 3 Hz/s. The results of this analysis are shown in the following figure.

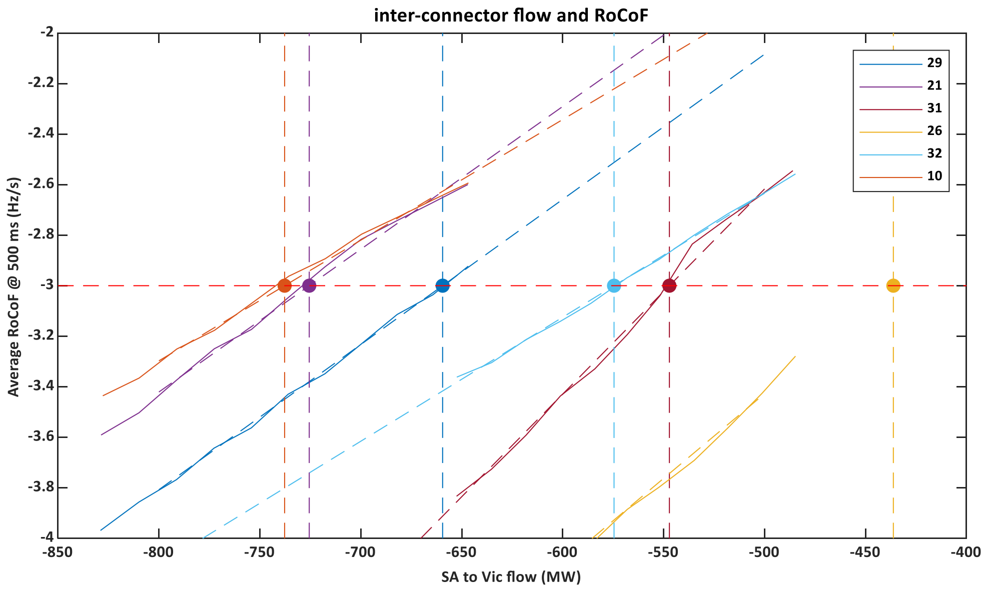

Figure 3.1: Sensitivity of RoCoF to interconnector flow

4. Discussion of Contribution

The previous section shows the variety of system responses from the base case and its variants. In order to determine which support(s) may be valuable in the interim period before any additional interconnection is in place, we have looked at the incremental improvement in RoCoF and maximum import.

In order to do that the cases are grouped to show the incremental value of each support as shown in Table 4.1.

Import improvements that are negative represent an increase in import capacity if the support is connected.

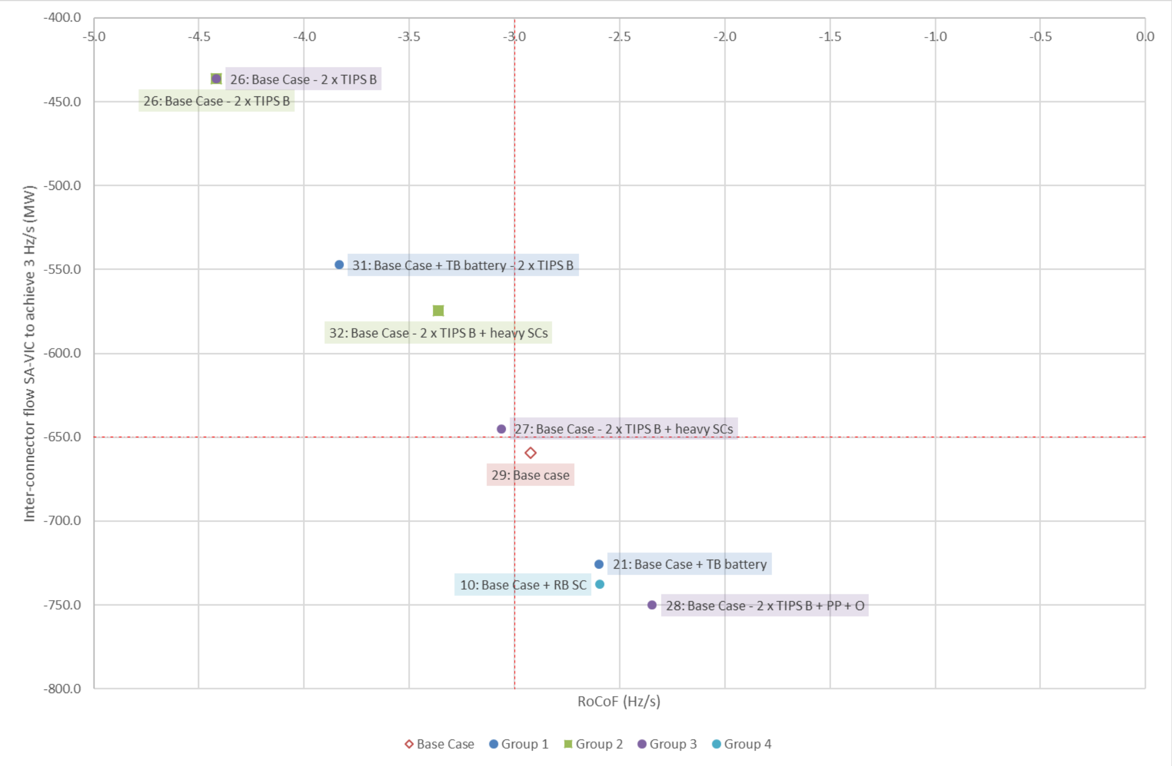

Figure 4.1: RoCoF for 650 MW vs maximum import for 3 Hz/s

Looking at the figure, the contribution of each change becomes clear within each group. For instance, the changes across Group 3 (Cases 29 and 26 – 28):

- Removing the TIPS B machines makes a massive reduction in inertia and available system strength (i.e. moving from the base case to case 26).
    - Adding the heavy SCs almost compensates for the removal of the TIPS B machines (i.e. moving from Case 26 to Case 27)
- Adding Pelican Point and Osborne instead of 2 x TIPS B machines achieves at least 750 MW import. Capacity is not calculated beyond this point. (i.e. moving from Case 26 to 28).

Table 4.1: Case groups showing incremental benefits additional supports

Group	**1**			**2**			**3**				**4**	
case	**29**	21	31	**29**	26	32	**29**	26	27	28	**29**	10
Description of variant	**Base case**	Base Case + TB battery	Base Case + TB battery - 2 x TIPS B	**Base case**	Base Case - 2 x TIPS B	Base Case - 2 x TIPS B + heavy SCs	**Base case**	Base Case - 2 x TIPS B	Base Case - 2 x TIPS B + heavy SCs	Base Case - 2 x TIPS B + PP + O	**Base case**	Base Case + RB SC
H_{sys}	3180	3180	1300	3180	1300	2000	3180	1300	3169	5916.4	3180	3830
RoCoF	-2.9	-2.6	-3.8	-2.9	-4.4	-3.4	-2.9	-4.4	-3.1	-2.3	-2.9	-2.6
$\Delta RoCoF$	0.0	0.3	-0.9	0.0	-1.5	-0.4	0.0	-1.5	-0.1	0.6	0.0	0.3
P_{lim}	-659.5	-725.5	-547.1	-659.5	-436.2	-574.6	-659.5	-436.2	-645.0	-750.0	-659.5	-737.7
ΔP_{lim}	0.0	-66.1	112.3	0.0	223.3	84.9	0.0	223.3	14.5	-90.5	0.0	-78.3
TB battery		-66.1	-44.9									
2 x TIPS B			-178.4		-223.3			-223.3				
heavy SCs						-138.4						
PP									-208.8			
O										-105.0		
RB SC												-78.3

The difference between the case's performance provides a simple summary of their effectiveness in supporting the system during the interim period.

Table 4.2: Value of supports

	Increase in maximum import (MW)		**Reduction in RoCoF (Hz/s)**
2 x TIPS B	223.3		1.5
Pelican Point	208.8		1.4
Heavy SCs	138.4		1.1
Osborne		105 (with PP)	0.7
RB SC	78.3		0.3
TB battery	66.1	44.9 (with 2 x TIPS B)	0.3

There is a clear hierarchy with two distinct groups in this list:

1. The effect of the synchronous machines

   There is not much difference between the contribution of the Pelican Point unit and the two TIPS B units. The assumption is that having synchronous generators on-line assists system strength and frequency regulation and control in South Australia. This requirement seems to suggest that there is little value in looking at supports outside of this group in the interim.

2. The SCs and batteries

   While the incremental effect of an additional SC or the TB battery is modest in comparison to the synchronous machines' contribution, the benefit in the interim period may still be sufficient to offset the cost of advancing investment.

The following section discusses the value of the SC and battery options in the interim period and their compatibility with operation once any additional interconnection is established.

4.1 Interim value of additional supports

The following table describes the contribution of additional supports in the interim period and the extent to which this support is required once any additional interconnection is in place. While the value in the interim period has been directly considered in this study from the point of view of RoCoF management, consideration of system strength support and other system benefits should also be included in any deliberations.

Table 4.3: Consideration of value

Additional Support	Value in Interim period	Value post additional interconnection	Other contributions
Heavier SCs	Less reliance on synchronous generation for inertial support and so some redundancy or operational flexibility	Similar to interim period. We have not looked at the stability impact of additional inertia with the two interconnector case. We would submit, however, that the transient stability of the system would be enhanced. Whether that is a material enhancement cannot be confirmed.	Higher synchronous inertia may allow higher penetration of fast frequency response from batteries and other inverter devices.
Additional SCs	Additional SCs will provide redundancy, additional system strength and inertia. Similar to the heavier SCs case, additional SCs would reduce the reliance on synchronous generation to provide system strength and inertia in the South Australian system with similar resultant additional operational flexibility.	Location of additional SCs at Robertstown (the likely connection point for the new interconnector) would provide dynamic reactive support and system strength at that interface and up into the interconnector itself.	
Additional Battery	Operational flexibility with respect to interconnector flow limits or at least availability of stored energy to compensate for periods of reduced interconnector availability or transfer capacity. No additional system strength support. Could provide fast frequency response	Adds flexibility to the Heywood interconnector such that the contingency size across the four AC interconnector circuits can be similar.	FCAS services Arbitrage Interconnector flow regulation during contingency events enhancing the transient stability of the link.

This can be summarised in broad terms as shown in Table 4.4.

Table 4.4: Summary of value in interim period

							Weighted contribution	
	RoCoF support	**System Strength**	**Inertia**	**FCAS**	**Market flexibility**	**Redundancy**	**Interim**	**2nd IC**
Heavier SCs	✓	✓[1]	✓				0.3	0.1
Additional SCs	✓	✓	✓		✓	✓	0.9	1.0
Additional Battery[2]	✓	✗[3]		✓	✓	✓	0.7	0.5
Interim weighting	0.1	0.1	0.1	0.1	0.3	0.3		
2nd IC weighting	0	0.5	0	0	0.4	0.1		

Weightings can be assigned based on an assessment of relative value across the different aspects of support. This shows the additional SCs are preferred in terms of the support they provide in the interim period. While not an empirical assessment, the difference between the three options clearly hinges on operational flexibility. This allows differentiation between simply installing heavier SCs, installing additional SCs and the effect on system strength contributed by the battery and the additional SCs.

In each case, the difference between installing additional SCs and utilising batteries is minor and subjectively dependent on the weighting. We therefore recommend that each of these options be considered. The quantification of the market benefit of these options must be defined through market modelling which is beyond the scope of this work. Our previous reports have used the submissions that ElectraNet have received from OEMs and others to determine costs for this equipment. The following shows plausible costs associated with these supports.

[1] Minimal increase in system strength with heavier SCs in the order of 15 %.

[2] Benefits limited to market and or network support not market opportunities and so arbitrage is excluded.

[3] May have a slight negative effect on system strength

Table 4.5: Costs for supports

Supports	NPV (0.06) ($M)	Supply basis	CAPEX $M	OPEX $M/year
BESS 1	($220)	Capex + Opex + Margin	195.7	2.5
1 x Synchronous Condenser (650 MWs)	($33)	Capex + Opex	18.7	0.9

Note 1: The cost structure for the BESS units is based on a cost plus margin approach. ElectraNet have received a wide range of indicative BESS prices. We have chosen to resolve this variation by choosing suitable, mid-range offers, calculating an average NPV between these offers then back calculating for illustration purposes here.

Given the large difference in capital cost, it is highly likely that only the SCs would be justifiable in the interim period. The BESS still represents some value.

5. Conclusions

This report details the solutions and investment required to achieve satisfactory network performance (in terms of inertia and RoCoF). This could allow relief of the variable renewable generation cap (assuming the fixed, system strength, cap is managed by the SCs and dispatched synchronous generation) in place in SA while maintaining the 3 Hz/sec RoCoF standard at the least cost while maintaining full interconnector capacity of ± 650 MW.

We have shown that with 2 x SCs connected at Davenport, two large synchronous generators in South Australia (2 x TIPS B in our study) and the existing Hornsdale and Dalrymple batteries, interconnector flow can reach 650 MW without exceeding the RoCoF limit of ±3 Hz/s.

We have then examined the value of additional supports in the form of heavier SCs, additional SCs and additional batteries. We have shown that there is some value in considering installation of additional supports for the interim period but that this value is mainly indirect through providing redundancy and operational flexibility.

The value associated with heavier SCs (instead of those proposed for Davenport) is negligible. The difference in value between additional SCs (nominally connected to Robertstown) or an additional battery (nominally connected at Tailem Bend) is difficult to determine. The relative costs of these supports however suggest that while SCs should be considered ahead of the battery, the BESS still represents some value.

6. References

1. South Australian Energy Transformation 'PSCR Supplementary Information Paper' January 2017
2. AEMo website http://www.aemo.com.au/Media-Centre/South-Australia-System-Strength-Assessment. December 2018

Appendices

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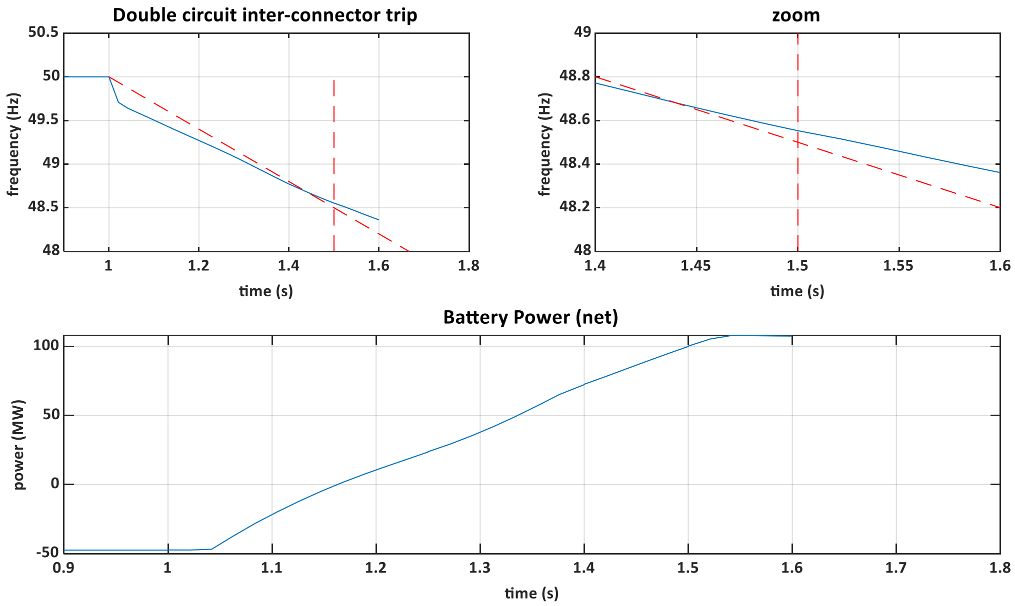
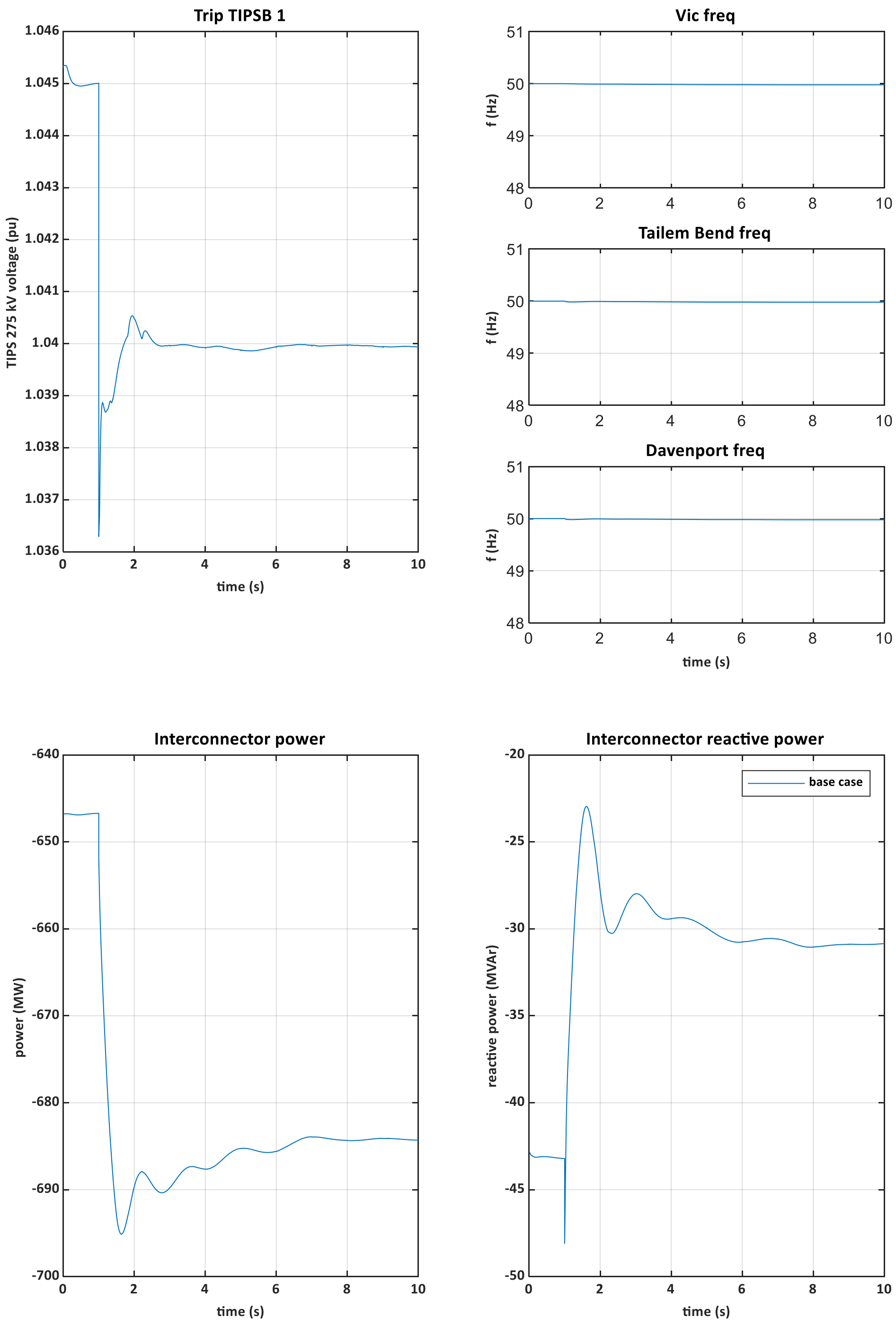
A Base case system event simulations - details

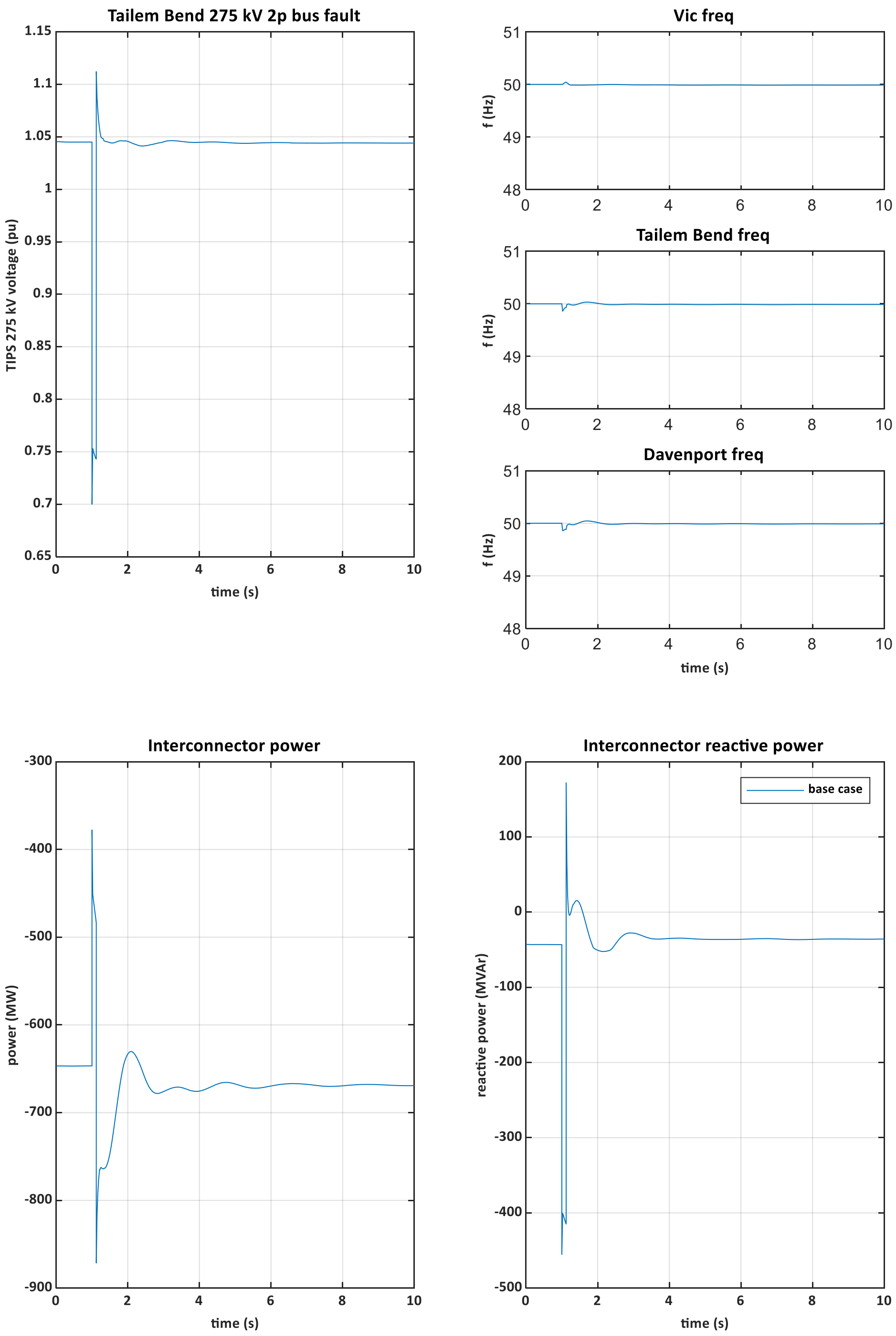
A.1 Heywood double circuit trip



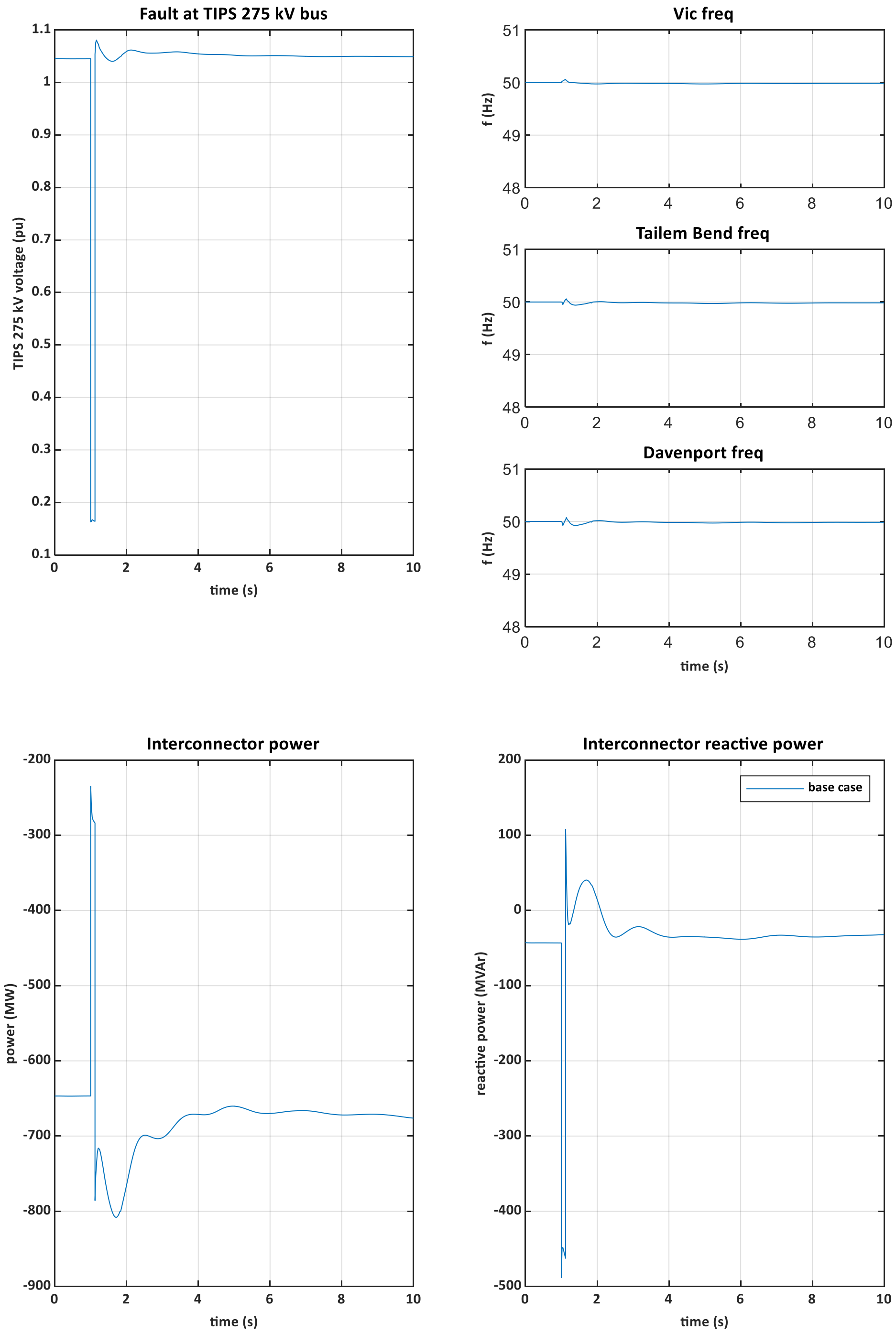
A.2 Trip TIPS B 1



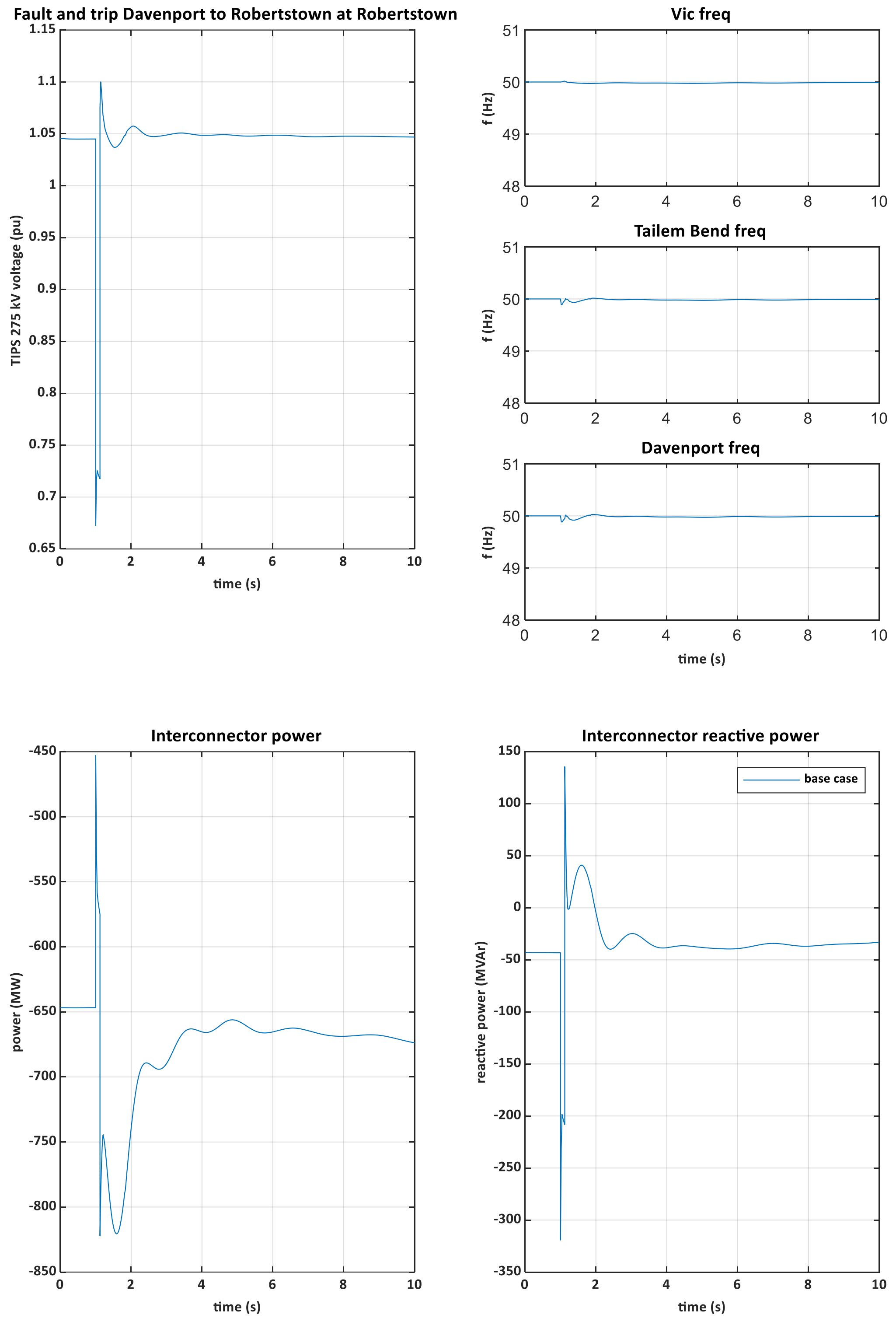
A.3 2 phase to ground fault at Tailem Bend 275 kV bus



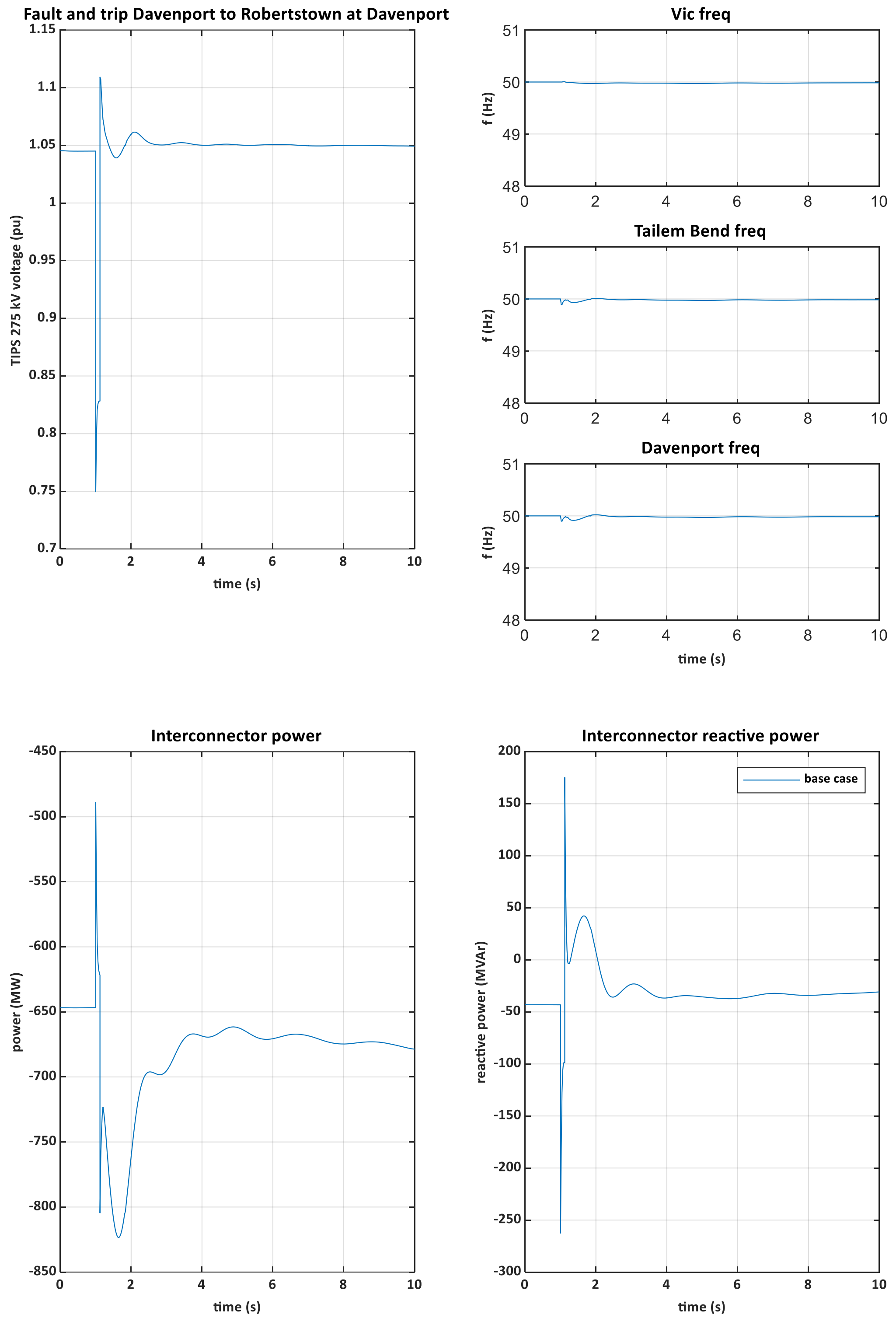
A.4 2 phase to ground fault at Torrens Island 275 kV bus



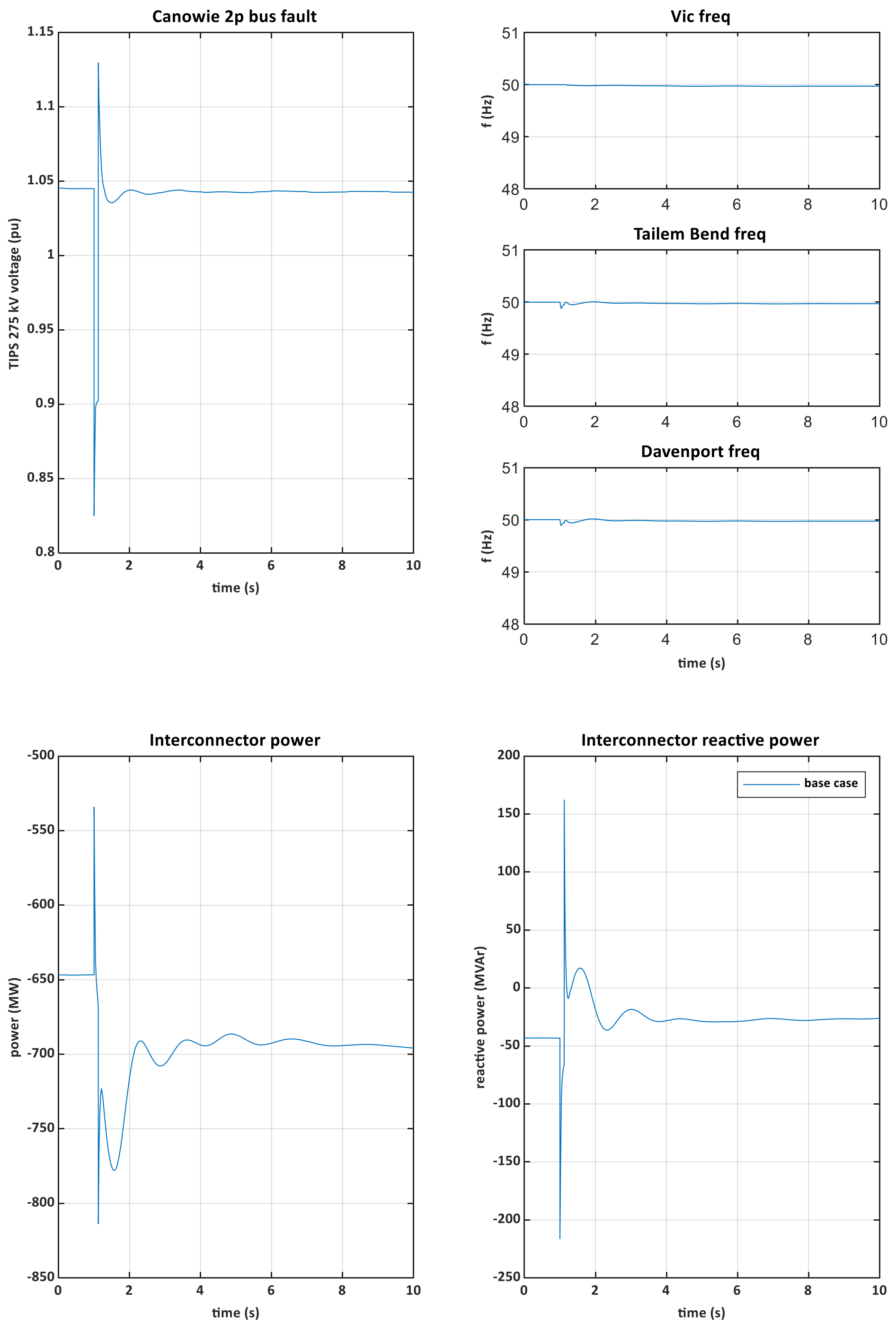
A.5 2 phase to ground fault between Davenport and Robertstown at Robertstown



A.6 2 phase to ground fault between Davenport and Robertstown at Davenport



A.7 2 phase to ground fault at Canowie



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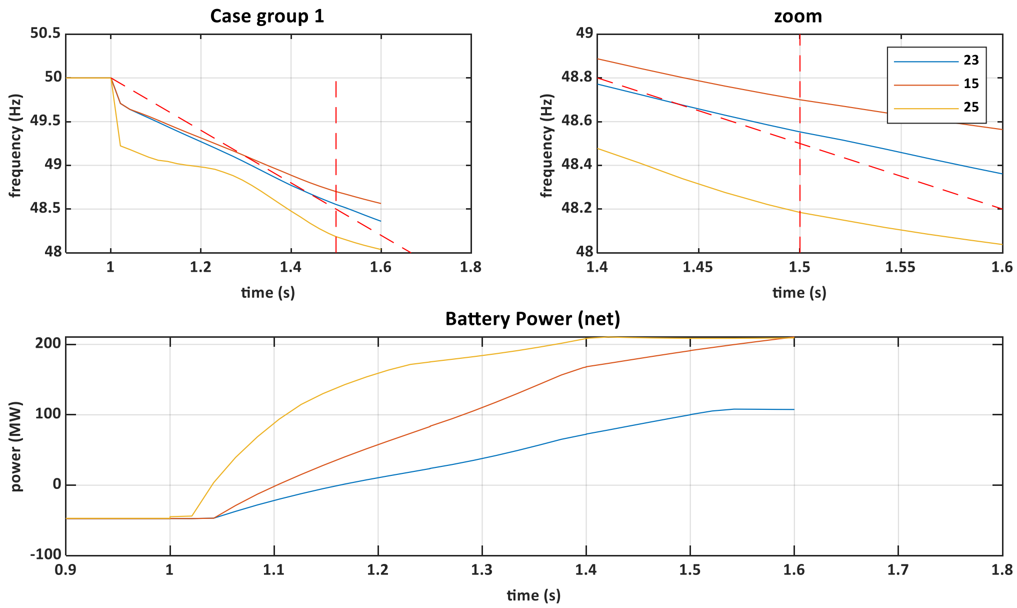
B Case variant system simulations – details

B.1 Heywood double circuit trip

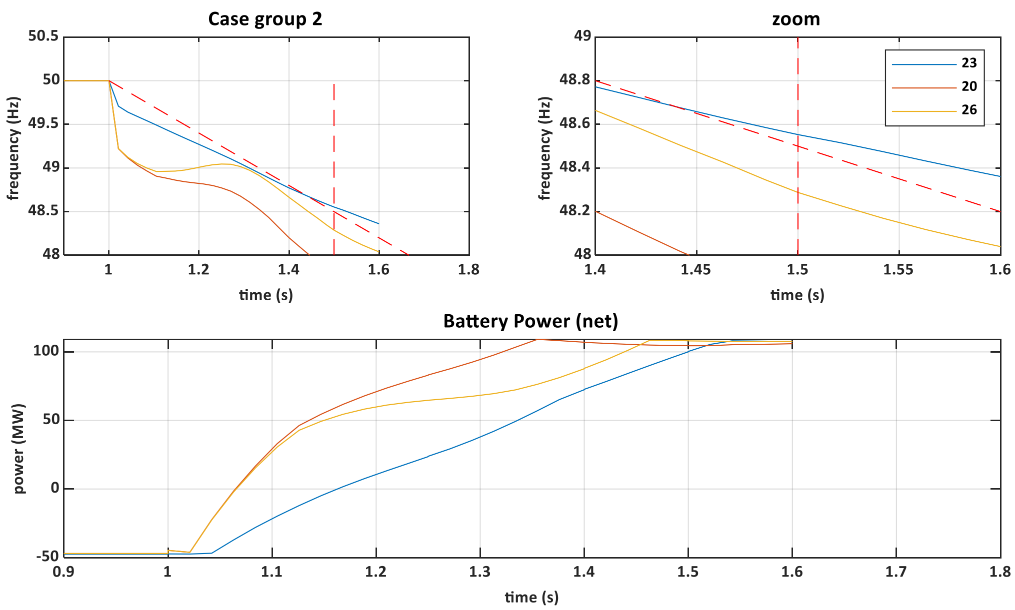
Case group 1

case	**29**	21	31	
Description of variant	**Base case**	**Base Case +** **TB battery**	**Base Case +** **TB battery** **-** **2 x TIPS B**	
H_{sys}	3180	3180	1300	MVA
$df/dt\|_{\alpha}$	-2.9	-2.6	-3.8	Hz/s
P_{lim}	-659.5	-725.5	-547.1	MW to Victoria
ΔP_{lim}	0.0	-66.1	112.3	Change in flow to Victoria (MW)
TB battery		-66.1	-44.9	Value of support in MW to Victoria
2 x TIPS B			-178.4	
heavy SCs				
PP				
O				
RB SC				



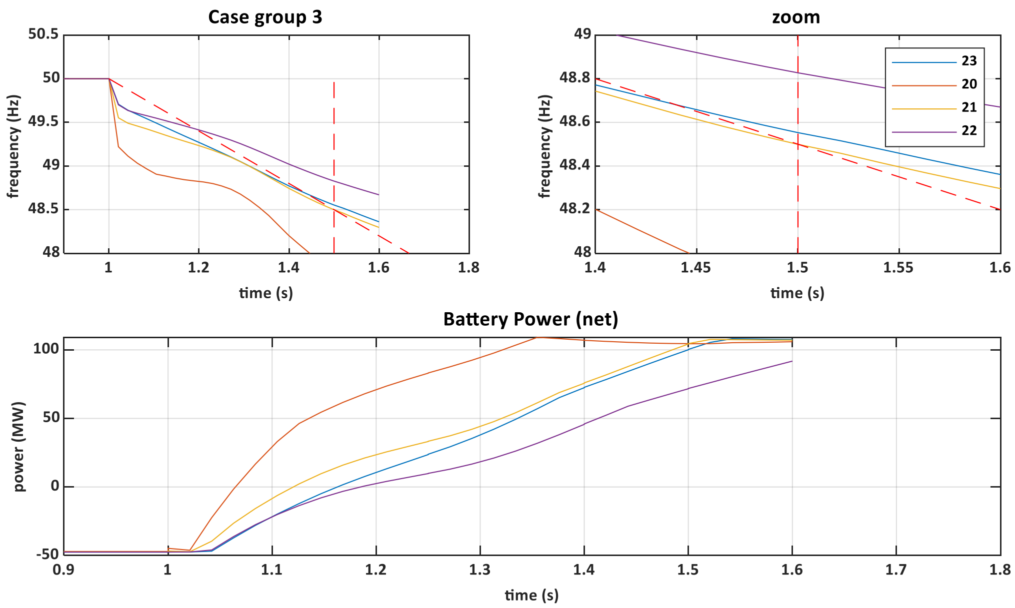
Case group 2

case	**29**	26	32	
Description of variant	**Base case**	**Base Case - 2 x TIPS B**	**Base Case - 2 x TIPS B + heavy SCs**	
H_{sys}	3180	1300	2000	MVA
$df/dt\|_a$	-2.9	-4.4	-3.4	Hz/s
P_{lim}	-659.5	-436.2	-574.6	MW to Victoria
ΔP_{lim}	0.0	223.3	84.9	Change in flow to Victoria (MW)
TB battery				Value of support in MW to Victoria
2 x TIPS B		-223.3		
heavy SCs			-138.4	
PP				
O				
RB SC				



Case group 3

case	**29**	26	27	28	
Description of variant	**Base case**	**Base Case - 2 x TIPS B**	**Base Case - 2 x TIPS B + heavy SCs**	**Base Case - 2 x TIPS B + PP + O**	
H_{sys}	3180	1300	3169	5916.4	MVA
$df/dt\|_a$	-2.9	-4.4	-3.1	-2.3	Hz/s
P_{lim}	-659.5	-436.2	-645.0	-750.0	MW to Victoria
ΔP_{lim}	0.0	223.3	14.5	-90.5	Change in flow to Victoria (MW)
TB battery					Value of support in MW to Victoria
2 x TIPS B		-223.3			
heavy SCs					
PP			-208.8		
O				-105.0	
RB SC					



Case group 4

case	**29**	10	
Description of variant	**Base case**	**Base Case** **+** **RB SC**	
H_{sys}	3180	3830	MVA
$df/dt|_a$	-2.9	-2.6	Hz/s
P_{lim}	-659.5	-737.7	MW to Victoria
ΔP_{lim}	0.0	-78.3	Change in flow to Victoria (MW)
TB battery			Value of support in MW to Victoria
2 x TIPS B			
heavy SCs			
PP			
O			
RB SC		-78.3