ARENA Knowledge Sharing for Grid Forming Inverter BESS Case Study at Carwarp

Recipient Project: 2020/ARP001 Canadian Solar

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Description of Problem

The West Murray Zone due to being a high renewable resources area has an influx of renewable inverter-based power electronics generators connecting to the grid. Since the West Murray Zone is located further away from traditional based Synchronous generators and is coupled with increased Asynchronous renewable generator connections, this has reduced the available fault level in the area which in turn has negative impact on the Network power system security.

For a power grid, to remain stable, it needs to respond and return to a steady state condition following a voltage and frequency disturbance.

- During and Post these disturbances it expected the Grid remain stable and the ability to have loads and Generators ride through these faults and stay connected.
- Power systems / grids around the world are transitioning to significantly higher shares of renewable energy (inverter-based resources) with few synchronous generators remaining online.
- Unlike conventional grids where energy suppliers have synchronous generators to support their stability, grids with high renewable energy penetration require a lot more to attain stability in case of disturbances.

This has made it more difficult for Asynchronous renewable generators to connect to this network zone without having to provide system strength remediation equipment such as Synchronous condensers.

Due to their high capital and operational costs, a requirement for synchronous condensers results in any intending renewable generator project becoming un-feasible to build. Synchronous Condensers are seen as sunk costs to the project as its purpose is for network support and not actually transmitting the energy produced by the renewable energy.

Proposed Solution

With the advent of new technologies in the power electronics industry has resulted in Original Equipment Manufacturers innovating the design of their AC/DC inverters to operate dynamically in other modes that will be more suitable to integrate into a Synchronous network.

Most renewable generation inverters today used are Grid Following inverters operating as a Current source that uses the Grid Frequency and voltage as reference to transfer the energy to the network.

A Grid Forming inverter (GFI) however is a Voltage Source inverter which is controlled to behave as an AC Voltage Source with controllable Voltage, Phase and Frequency as per Figure 1.

GFI can therefore be seen as a controllable AC-Voltage Source behind a coupling reactance similar to a synchronous machine.

This is therefore modelled as Virtual Synchronous Machine that can mimic rotating machine characteristics that will support the Network dynamically during steady state and network contingency events hence enabling renewable generators to connect to weak networks

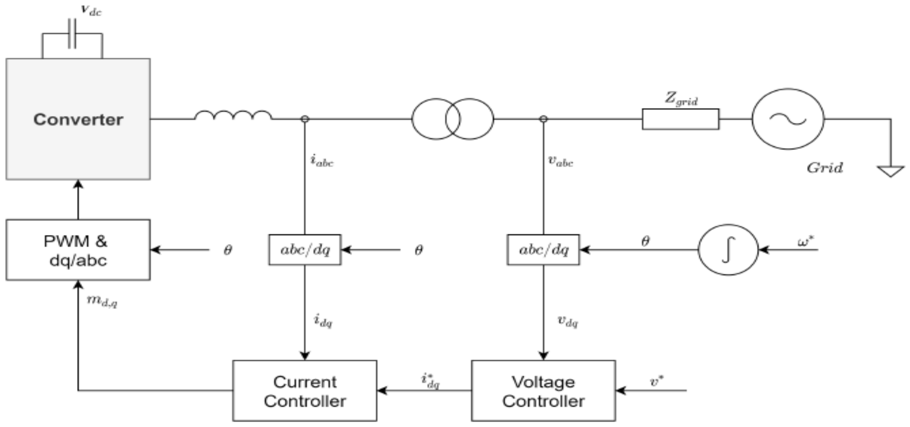


Figure 1: Concept Asynchronous Block Diagram

Case Study

Methodology

Canadian Solar in 2021 submitted a Grid Connection application for a Solar farm located in the West Murray Zone.

To ensure that the Solar Farm has a suitable system strength remediation in place, in the event one is required, Canadian Solar submitted and intent to connect a Battery Energy Storage System (BESS) using the GFI Technology to support the Solar Farm to connect to the grid.

Canadian Solar together with AEMO Victoria Connections, scoped out a Full Impact Assessment (FIA) study to be undertaken by AEMO using the Wide Area Network model (WAM) and integrating the GFI BESS model to the system. The study area is shown in Figure 2.

The Scope methodology developed was adapted from a full FIA that AEMO or a Network Service Provider (NSP) would conduct however was modified accordingly to test and tune the GFI appropriately.

As such, Power Systems Computer Aided Design (PSCAD) studies in the WAM are required to demonstrate the system strength capabilities offered by the connection of BESS is stable and able to operate under various Network system contingencies and parameters.

The work represents the first 3 stages of a four-stage process for the development and acceptance of inverter based system strength technology as illustrated in the following diagram.

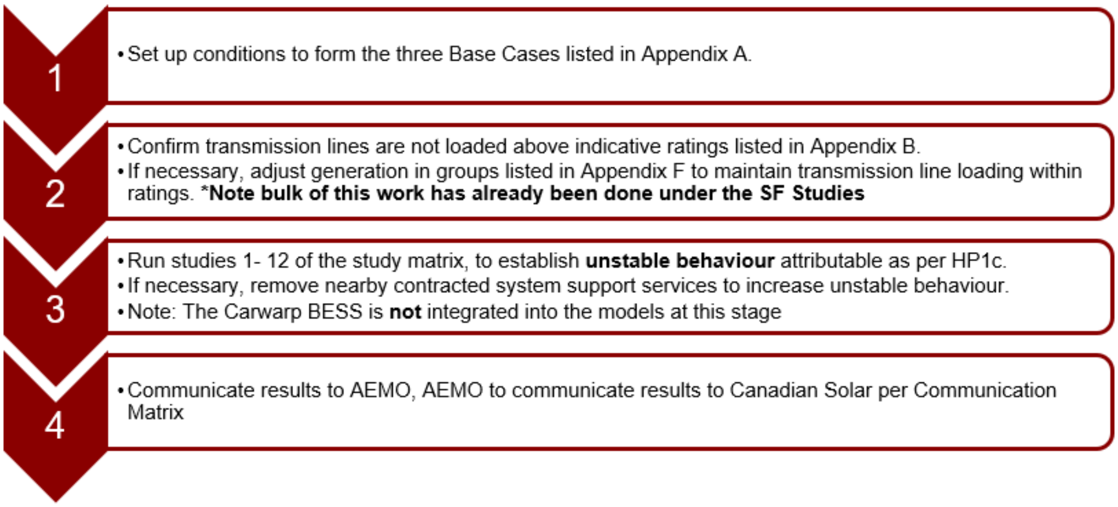
The work essentially involves configuration of the network to demonstrate the weak system and simulation of critical faults on the 220 kV transmission system using the North West Victorian PSCAD case model to determine:

- scenarios requiring system strength remediation in the existing network; and
- the adequacy of the proposed GFI BESS system strength remediating the weak system created.

Case Study Process

Running the study process in the WAM was carried out over 2 Hold points to establish a representative network in Hold Point 1 and integration of the GFI BESS model in Hold Point 2

The process for Hold Point 1 can be summarised in the following flow chart.



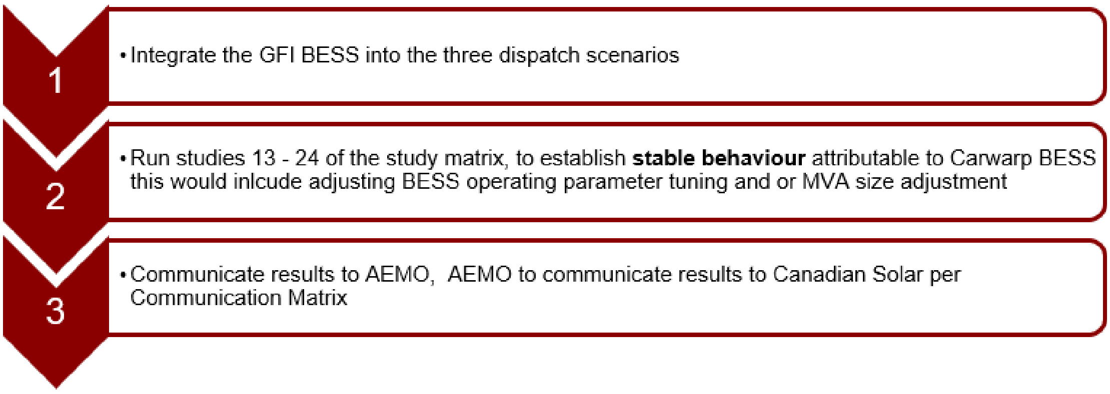
1
- Set up conditions to form the three Base Cases listed in Appendix A.

2
- Confirm transmission lines are not loaded above indicative ratings listed in Appendix B.
- If necessary, adjust generation in groups listed in Appendix F to maintain transmission line loading within ratings. ***Note bulk of this work has already been done under the SF Studies**

3
- Run studies 1- 12 of the study matrix, to establish **unstable behaviour** attributable as per HP1c.
- If necessary, remove nearby contracted system support services to increase unstable behaviour.
- Note: The Carwarp BESS is **not** integrated into the models at this stage

4
- Communicate results to AEMO, AEMO to communicate results to Canadian Solar per Communication Matrix

The process for Hold Point 2 can be summarised in the following flow chart.



1
- Integrate the GFI BESS into the three dispatch scenarios

2
- Run studies 13 - 24 of the study matrix, to establish **stable behaviour** attributable to Carwarp BESS this would inlcude adjusting BESS operating parameter tuning and or MVA size adjustment

3
- Communicate results to AEMO, AEMO to communicate results to Canadian Solar per Communication Matrix

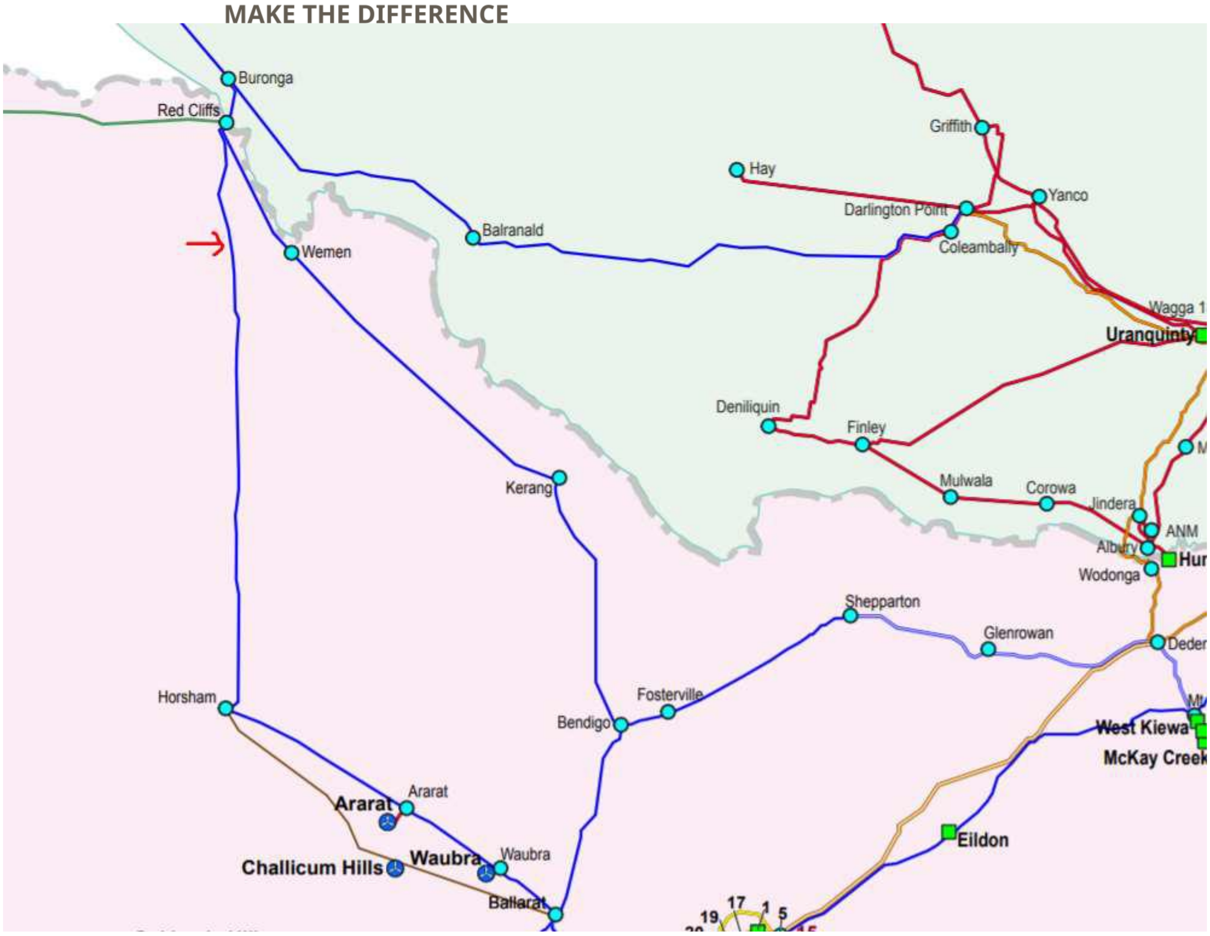


Figure 2: Map of Study Area

Results

The study had undergone Several iterations to create a suitable base case for the GFI Studies.

GFI BESS Model set-ups had to under-go several tuning exercises of PSCAD model parameters and or changing the MVA size of the BESS to achieve the desired model case responses.

Observations of the results are as follows and as per Appendix 1:

Base Cases

The base case was created by removing majority of the synchronous condensers from the Network model to create an unstable network.

Murra Warra WF 2 sync con, with a 20 MVA capacity, creates a suitable base case for the following contingencies:

1. Kerang – Bendigo 220 kV
2. Ararat – Waubra – Ballarat 220 kV
3. Kiamal – Murra Warra – Horsham 220 kV
4. Darlington Point – Balranald 220 kV (base case used is with all five sync cons out of service)

BESS in Service

Using the above base cases, a 40 MVA BESS sufficiently reduced voltage oscillations to less than 0.5% in the following cases:

- Ararat – Waubra – Ballarat 220 kV
- Darlington Point – Balranald 220 kV
- Kiamal – Murra Warra – Horsham 220 kV

Using the above base cases, an 80 MVA BESS was required to sufficiently reduced voltage oscillations to less than 0.5% in the following case (D5.3):

- Kerang – Bendigo 220 kV

Using the most onerous case (D5.3) and setting the BESS to full generation (80 MW) with only a 20 MVA sync con at Murra Warra WF 2 in service – a 3% voltage oscillation was observed when the MWs in the network were reduced by:

- 80 MW
- 90 MW and,
- 100 MW

Using the most onerous case (D5.3) and setting the BESS to full generation (80 MW) with all five synch cons in service – voltage oscillations were sufficiently reduced to less than 0.5%.

Using the most onerous case (D5.3) and setting the BESS to full charging (-80 MW) with only a 20 MVA sync con at Murra Warra WF 2 in service – voltage oscillations were sufficiently reduced to less than 0.5%. This was also observed when all sync cons were in service.

Conclusions

Based on the 13 Case Scenarios run, 9 cases demonstrated suitable network damping post fault recovery thereby stabilising the Network appropriately. With the most onerous case showing good results similar to when all the Synchronous condensers where in service.

It is expected that the balance of the 4 cases that did not pass the network stability threshold could benefit from further tuning of the site-specific model.

Depending on the severity of the contingency disturbances on each case it was observed that varying amount of GFI MVA size was required to stabilize the network, ranging from 40MVA to 80MVA.

From the evidenced results of this Wide Area Network study, it can be sufficiently concluded that the GFI operating in the Virtual Synchronous Mode is able to support the network sufficiently without the need of a large supply of conventional Synchronous Condensers.

Also noting that this study was undertaken in the West Murray Zone, an area which exhibits poor system strength characteristics therefore more onerous than other parts of the NEM.

The recipient project has not proceeded with the GFI case at this time due to various factors and market conditions. The funding agreement case is predicated on the need to support system strength through a GFI and BESS structure. In the time since entering the funding agreement, the NEM has seen the installation of some synchronous condensers in the area which support the grid and have closed the gap in system strength. Additionally, there are economic challenges with the business case given the current commodities market and that GFI procurement options are still quite limited.

Recommendations

This case study has created a path forward for actual implementation because this technology has passed the litmus test of operating in a mode that will support and stabilise the Network similar to the behaviour of a Synchronous condenser and it has gained traction and knowledge internally in AEMO.

The next step is to proceed with formal procurement and network connection for GFI based BESS systems with the intention to economically support the penetration of renewable energy.

The open collaboration amongst AEMO, NSP, OEM and the project was vital to this success of this case study therefore future implementation of this technology will require the same level of engagement and transparency amongst all stakeholders.

It will be highly recommended that technical working groups be created in conjunction with AEMO, NSPs, OEMs and generators on potential impact on assessments of the Generator Performance Standards with the integration of GFI in the NEM.

Appendix 1

The network contingency scenarios (network faults) studied are listed and summarised in Table 1. The size of the Murra Warra WF 2 sync con and the connection of the BESS is provided in the “Additional Contingency Information” column of Table 1. The outcome of the study is considered acceptable (Pass) when the voltage oscillation is observed to be under 0.5

Table 1: Study Results

Test ID	Line	Fault near	Fault Type	Clearance Times (ms)	Additional Contingency Information	Outcome
D1	Ararat – Ballarat – Waubra 220 kV	Ararat	3PH	120/220	• 20 MVA Murra Warra WF2 Sync Con • BESS Disconnected	• Voltage oscillations are observed to be greater than 7%.
D2	Kiamal – Murra Warra – Horsham 220 kV	Kiamal	3PH	120/220	• 20 MVA Murra Warra WF2 Sync Con • BESS Disconnected	• Voltage oscillations are observed to be greater than 10%.
D3	Kerang – Bendigo 220 kV	Kerang	3PH	120/220	• 20 MVA Murra Warra WF2 Sync Con • BESS Disconnected	• Voltage oscillations are observed to be greater than 5%.
D4.1	Darlington Point – Balranald 220 kV	Darlington Point	3PH	120/220	• 20 MVA Murra Warra WF2 Sync Con • BESS Disconnected	Pass
D4.2	Darlington Point – Balranald 220 kV	Darlington Point	3PH	120/220	• 10 MVA Murra Warra WF2 Sync Con • BESS Disconnected	Pass
D4.3	Darlington Point – Balranald 220 kV	Darlington Point	3PH	120/220	• 0 MVA Murra Warra WF2 Sync Con • BESS Disconnected	• Voltage oscillations are observed to be greater than 10%.

Test ID	Line	Fault near	Fault Type	Clearance Times (ms)	Additional Contingency Information	Outcome
D5.1	Kerang – Bendigo 220 kV	Kerang	3PH	120/220	• 20 MVA Murra Warra WF2 Sync Con • 40 MVA BESS	• Voltage oscillations are observed to be greater than 20%.
D5.2	Kerang – Bendigo 220 kV	Kerang	3PH	120/220	• 20 MVA Murra Warra WF2 Sync Con • 60 MVA BESS	• Voltage oscillations are observed to be greater than 10%.
D5.3	Kerang – Bendigo 220 kV	Kerang	3PH	120/220	• 20 MVA Murra Warra WF2 Sync Con • 80 MVA BESS	Pass
D6	Ararat – Ballarat – Waubra 220 kV	Ararat	3PH	120/220	• 20 MVA Murra Warra WF2 Sync Con • 40 MVA BESS	Pass
D7	Darlington Point – Balranald 220 kV	Darlington Point	3PH	120/220	• 0 MVA Murra Warra WF2 Sync Con • 40 MVA BESS	Pass
D8	Kiamal – Murra Warra – Horsham 220 kV	Kiamal	3PH	120/220	• 20 MVA Murra Warra WF2 Sync Con • 40 MVA BESS	Pass
D9.1	Kerang – Bendigo 220 kV	Kerang	3PH	120/220	• 20 MVA Murra Warra WF2 Sync Con • 80 MVA BESS • BESS: Full Generation • Reduced network 80 MW by lowering Karadoc SF, Yatpool SF, Kiamal SF & Wemen SF	• Voltage oscillations are observed to be greater than 3%.

Test ID	Line	Fault near	Fault Type	Clearance Times (ms)	Additional Contingency Information	Outcome
D9.2	Kerang – Bendigo 220 kV	Kerang	3PH	120/220	• 20 MVA Murra Warra WF2 Sync Con • 80 MVA BESS • BESS: Full Generation • Reduced network 80 MW by lowering Yatpool SF & Kiamal SF	• Voltage oscillations are observed to be greater than 3%.
D9.3	Kerang – Bendigo 220 kV	Kerang	3PH	120/220	• 20 MVA Murra Warra WF2 Sync Con • 80 MVA BESS • BESS: Full Generation • Reduced network 90 MW by lowering Yatpool SF & Kiamal SF	• Voltage oscillations are observed to be greater than 3%.
D9.4	Kerang – Bendigo 220 kV	Kerang	3PH	120/220	• 20 MVA Murra Warra WF2 Sync Con • 80 MVA BESS • BESS: Full Generation • Reduced network 100 MW by lowering Karadoc SF, Yatpool SF, Kiamal SF & Wemen SF	• Voltage oscillations are observed to be greater than 3%.
D10	Kerang – Bendigo 220 kV	Kerang	3PH	120/220	• 20 MVA Murra Warra WF2 Sync Con • 80 MVA BESS	Pass

Test ID	Line	Fault near	Fault Type	Clearance Times (ms)	Additional Contingency Information	Outcome
					• BESS: Full Charging • Increased network 100 MW by increasing Karadoc SF, Yatpool SF & Kiamal SF	
D11	Kerang – Bendigo 220 kV	Kerang	3PH	120/220	• All five Sync Cons in service • 80 MVA BESS • BESS: Full Generation • Full Generation • Reduced network 100 MW by lowering Yatpool SF & Kiamal SF	Pass
D12	Kerang – Bendigo 220 kV	Kerang	3PH	120/220	• All five Sync Cons in service • 80 MVA BESS • BESS: Full Charging • Full Generation • Increased network 100 MW by increasing Karadoc SF, Yatpool SF & Kiamal SF	Pass