E.S. Cornwall Memorial Scholarship
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Infrastructure Development, California ISO

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THE UNIVERSITY OF QUEENSLAND
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Contents

1.0 Executive summary

This report provides an overview of my contributions at the California Independent System Operator (CAISO) from July to December 2018 as part of the 2018 – 2019 ES Cornwall Memorial Scholarship and the impressions gained. During this period I visited the CAISO to observe the Transmission Planning Process (TPP), with most of my time focused on the TPP Reliability Assessment and the Pacific Northwest Informational Special Study. Other areas of learning included an assessment on the integration of large-scale solar generation and a distributed energy resource impact study as part of the Western Electricity Coordinating Council (WECC) Modelling and Validation Work Group (MVWG). My impressions are outlined below.

Reliability Assessment: Expanding the scope of contingencies in planning studies improves power system security and transmission network utilisation without significantly increasing cost to consumers.

The inclusion of non-credible contingencies in transmission planning studies, as is done in North America, will enhance the foresight of the national planner. In addition, the utilisation of the existing transmission network is improved through implementation of non-network options, such as special protection schemes.

AEMO's Power System Frequency Risk Review (PSFRR) provides a platform for studying non-credible events which directly impact frequency. Considering non-credible contingencies which indirectly impact frequency can enhance the foresight of the national transmission planner and improve utilisation of existing network.

Pacific Northwest Informational Special Study: Secure operation of a power system with declining thermal generation will require careful and thorough modelling of interdependencies.

In order to achieve the ambitious policy goals set in California, it is necessary to understand the capability of neighbouring systems and associated interdependences. California will increasingly require support from neighbouring systems as local base load nuclear and peaking gas retire. An example is the reliance on hydro generation in the Pacific Northwest to support supply adequacy and flexibility requirements in California.

Parallels can be drawn to Hydro Tasmania's Battery of the Nation project, in Australia. The goal of this project is to further interconnect Tasmania, through undersea cables, to mainland Australia and expand the pumped hydro capability in Tasmania to support renewable development in the NEM. Adequate technical and economic analysis is essential to ensure efficient investment.

Working with stakeholders across the power system to better understand interdependencies can enhance the outcomes of modelling conducted by the national transmission planner.

Large-scale solar integration: Opportunities will emerge for technologies capable of providing flexible ramping services.

Increasing penetration of intermittent generation in the NEM will see an increase in the reliance on thermal generation to provide flexible ramping.

As the available flexible ramping capabilities in the NEM decrease (due to decommitment and retirements) curtailment of wind and solar generation will occur. Curtailment is necessary to maintain system security and provides a signal to other technologies to participate in the energy market, such as batteries or hydro generation.

Identifying and reporting on emerging opportunities in long-term planning influences the preparedness of market participants.

Distributed energy resource impact study: The process of developing and implementing accurate distribution models requires long term consultation between AEMO, TNSP's and DNSP's.

The absence of accurate distributed generation and load models in dynamic power system studies can result in optimistic performance results when the penetration of distributed generation is high. Distributed generation, with desirable settings, can assist in maintaining system security during and after a fault by providing voltage and frequency support.

A significant effort is required to develop and validate distributed generation and load models. This work needs to be led by a working group with representation from across the industry to continuously refine the models.

The modelling of distributed generation some planning enhances the national transmission planner's capability to accurately model system events. Additionally, it provides valuable insights into desirable setting for smart devices.

2.0 Introduction

This report provides an overview of my contributions to the TPP, analysis on large scale solar integration, and contributions to distributed energy resource impact study as part of WECC's Modelling and Validation Work Group (MVWG). In addition, I have included my impressions gained from July to December 2018. This report meets the requirements of a quarterly report as part of the 2018 – 2019 ES Cornwall Memorial Scholarship.

3.0 Scholarship theme

In June, 2017 Dr. Alan Finkel, Australia's Chief Scientist, and an Expert Panel published the Independent Review into the Future Security of the National Electricity Market. The report recommends a way forward to ensure a secure and reliable energy future as the energy industry experiences significant change[1]. Four key outcomes were identified for the National Electricity Market (NEM): increased security, future reliability, rewarding consumers and lower emissions. These outcomes are enabled by three key pillars: Orderly Transition, System Planning and Stronger Governance.

Chapter 5 delivered five key recommendations focused on improving System Planning. The first two recommendations focus on the delivery of an Integrated Grid Plan, conducted by the Australian Energy Market Operator (AEMO), which have since been addressed or are underway. The third recommendation is now coming into focus, recommendation 5.3 which states:

> *The COAG Energy Council, in consultation with the Energy Security Board, should review ways in which the Australian Energy Market Operator's role in national transmission planning can be enhanced.*

AEMO's national transmission planner functions include review and advice on the development of the transmission grid across the NEM; provide a national strategic perspective for transmission planning and coordination; and have regard to the National Electricity Objective. The underlying theme of my Scholarship proposal is to find ways the national transmission planning role can be enhanced.

The purpose of transmission planning in North America is fundamentally the same as it is in Australia. Transmission planners in North America which fall under the Federal Energy Reliability Council's (FERC) jurisdiction are responsible for assessing and approving transmission network augmentations through a transmission planning process for their respective jurisdiction. The purpose of the TPP is to develop a transmission plan and approve transmission solutions, as outlined in Section 24 of the CAISO Tariff[2]. Such a process requires extensive stakeholder collaboration, technical and economic studies. For me it provides an opportunity to find potential enhancements to the national transmission planning role in the NEM.

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[1] Dr Alan Finkel, Ms Karen Moses, Ms Chloe Munro, Mr Terry Effeney, Professor Mary O'Kane. Independent Review into the Future Security of the National Electricity Market. 2017. Available here: https://www.energy.gov.au/sites/g/files/net3411/f/independent-review-future-nem-blueprint-for-the-future-2017.pdf

[2] CAISO, Tariff Sections 24 as of October 1, 2013 – California ISO. Available here: http://www.caiso.com/Documents/Section24_ComprehensiveTransmissionPlanningProcess_Oct1_2013.pdf

4.0 Major contributions

This section provides an outline of my contributions during my time at CAISO from July to December 2018. I was part of the Infrastructure Development group at the CAISO which is responsible for conducting and producing the TPP. Included in this chapter is an overview of my contributions to the TPP, large-scale integration of solar, the distributed energy resource impact study and related stakeholder consultation. In addition, impressions gained will be outlined at the end of each section.

4.1 Transmission Planning Process

During my time at the CAISO my most significant contribution to the TPP was through the Pacific Northwest Informational Special Study. This was an opportunity to conduct technical analysis, market modelling and learn about the greater Western Interconnection. In addition to the Pacific Northwest Information Special Study I also contributed to the Reliability Assessment[3] and Economic Assessment in the TPP.

4.1.1 Reliability Assessment

During my time at the CAISO I familiarised myself with the North American Electric Reliability Corporation (NERC) Reliability Standards[4,5], Western Electricity Coordinating Council (WECC) Criteria[6] and California ISO Planning Criteria[7]. These standards are the primary driver of transmission development in California.

In addition, I assisted in running studies and consolidating results for the Greater Fresno local area and the northern (PG&E) bulk area. Final results were presented to stakeholders at the 16th November stakeholder meeting[8].

4.1.1.1 Reliability Standards

As part of the Reliability Assessment, the transmission system performance is assessed against the reliability standards. As outlined in the NERC Reliability Standards (TPL-001-4), there are eight different contingency categories assessed. Each category is defined by differences in initial conditions, event type, fault type, voltage level, whether

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[3] In this report the term 'reliability' is used to refer to the performance of the system after one or more unplanned outage. This may be confused with the use of this word in the NEM to refer to system adequacy or 0.002 percent.

[4] NERC. TPL-001-4. 2018. Available here: https://www.nerc.com/_layouts/15/PrintStandard.aspx?standardnumber=TPL-001-4&title=Transmission%20System%20Planning%20Performance%20Requirements&jurisdiction=United%20States

[5] NERC. NUC-001-3. 2018. Available here: https://www.nerc.com/pa/Stand/Reliability%20Standards/NUC-001-3.pdf

[6] WECC. Transmission System Planning Performance. 2018. Available here: https://www.wecc.biz/Reliability/TPL-001-WECC-CRT-3.pdf

[7] CAISO. California ISO Planning Standards. 2018. Available here: http://www.caiso.com/Documents/ISOPlanningStandards-September62018.pdf

[8] CAISO. 2018-2019 Transmission Planning Process Meeting. 2018. Available here: http://www.caiso.com/Documents/Presentation-2018-2019TransmissionPlanningProcessMeeting-Nov16-2018.pdf

interruption of transmission network is allowed and whether or not load is allowed to be lost. Table 1 outlines the contingency and event type for each category. For this report, a transmission element refers to a transmission line, transformer, shunt device or single pole of a DC line. NERC standards also require extreme event analysis beyond what is identified below.

Category	Contingency	Event
P0	None	NA
P1 & P2	One	P1: Generator or transmission element. P2: Opening of a line, bus fault, breaker fault.
P3 to P7	Multiple	P3: Generator trip, followed by system adjustments and then a trip of a generator or transmission element. P4 & P5: Protection failure leading to multiple generator or transmission element faults. P6: Two overlapping single transmission elements. P7: Loss of two circuits on a common structure.

Table 1 - Transmission planning contingency categories

4.1.1.2 Technical studies

The 2018-2019 TPP technical studies include a planning horizon of 10 calendar years – 2019 to 2028. For the 2018–2019 TPP, three study years were chosen and include 2020 (near term), 2023 (near term) and 2028 (longer-term).

For each of these years 16 local areas and 2 bulk system areas are studied. The local areas include equipment rated from 60 kV to 230 kV and bulk area includes 230 kV and above, with some inclusions and exclusions.

As part of the Reliability Assessment steady state studies (thermal overload, voltage[9] and voltage deviation[10]) are conducted for the full range of potential contingencies discussed in the previous section. These results are used to flag breaches of the reliability standards. Transient stability studies are then conducted.

More details are provided in the 2018-2019 Transmission Planning Process Unified Planning Assumptions and Study Plan[11] published on the March 30, 2018.

[9] ‘Voltage’ refers to the acceptable voltage band. For example a standard if +- 0.05 of nominal requires the pre-contingent and post-contingent voltage to remain within 0.95 and 1.05 pu.

[10] ‘Voltage deviation’ refers to the post-contingent voltage not increasing or decreasing by 8 percent of the pre-contingent voltage.

[11] CAISO. 2018-2019 Transmission Planning Process Unified Planning Assumptions and Study Plan. March 2018. Available here: http://www.caiso.com/Documents/Final2018-2019StudyPlan.pdf

4.1.2 Pacific Northwest Informational Special Study

The Pacific Northwest Informational Special Study provided a unique opportunity to learn about the Western Interconnection, CAISO's bulk electric system and the interdependencies between the power system in the Pacific Northwest and California. The study seeks to identify opportunities to increase power transfer between the Pacific Northwest and California. This requires technical and economic analysis similar to the TPP but with an interregional focus.

This study is not required by the CAISO Tariff but was requested by the California Energy Commission (CEC) and California Public Utilities Commission (CPUC) [12]. The requests included an assessment of the role AC and DC interties can play in displacing generation whose reliability is tied to Aliso Canyon, a natural gas storage facility north of Los Angeles[13]. As a result the Pacific Northwest Informational Special Study was included in the 2018-2019 transmission planning cycle.

The scope of the study was to evaluate the impact of the following on increased capabilities for transfer of low carbon electricity between the Pacific Northwest and California.

- Increase transfer capacity of AC and DC interties.
- Increase dynamic transfer limit on AC interties.
- Automating manual controls on key Bonnevile Power Authority infrastructure.
- Assigning RA value to firm zero-carbon imports or transfers.

The Pacific Northwest Informational Special Study timeline is shown below. The study approach was presented to stakeholder at the Portland stakeholder workshop on the 6th September, 2018. On the 26th November the preliminary results were presented to stakeholders, after the presentation was postponed by 10 days. The draft 2018-2019 transmission plan was published on the 4th February, 2019[14].

- 23 May, 2018
- Assumptions and methodology for study

- 6 Sep, 2018
- Present approach and request information

- 26 Nov, 2018
- Preliminary results

- 31 Jan, 2018

The study is separated into a near-term and long-term asssessment. The purpose of the near-term assessment is to identify potential to maximise the utilisation of the existing

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[12] CPUC & CEC. 2018. Available here: http://www.caiso.com/Documents/CPUCandCECLettertoISO-Feb152018.pdf

[13] California Air Resources Board. 2018. Available here: https://ww2.arb.ca.gov/our-work/programs/aliso-canyon-natural-gas-leak

[14] CAISO. Draft 2018-2019 Transmission Plan and Appendices. 2019. Available here: http://www.caiso.com/planning/Pages/TransmissionPlanning/2018-2019TransmissionPlanningProcess.aspx

transmission system. The purpose of the long-term assessment is to identify potential benefits of increased transfer capabilities beyond the existing path ratings.

4.1.2.1 Background

The Pacific Northwest is a geographic region in the west of North America typically defined by the grouping of Oregon, Washington, British Columbia, Idaho and Montana. Figure 1 shows the Northwest and California with respect to Canada and the USA, see left figure. The figure on the right shows the expanse of the Federal Columbia River Power System (FCRPS) with respect to the five Pacific Northwest regions and California.

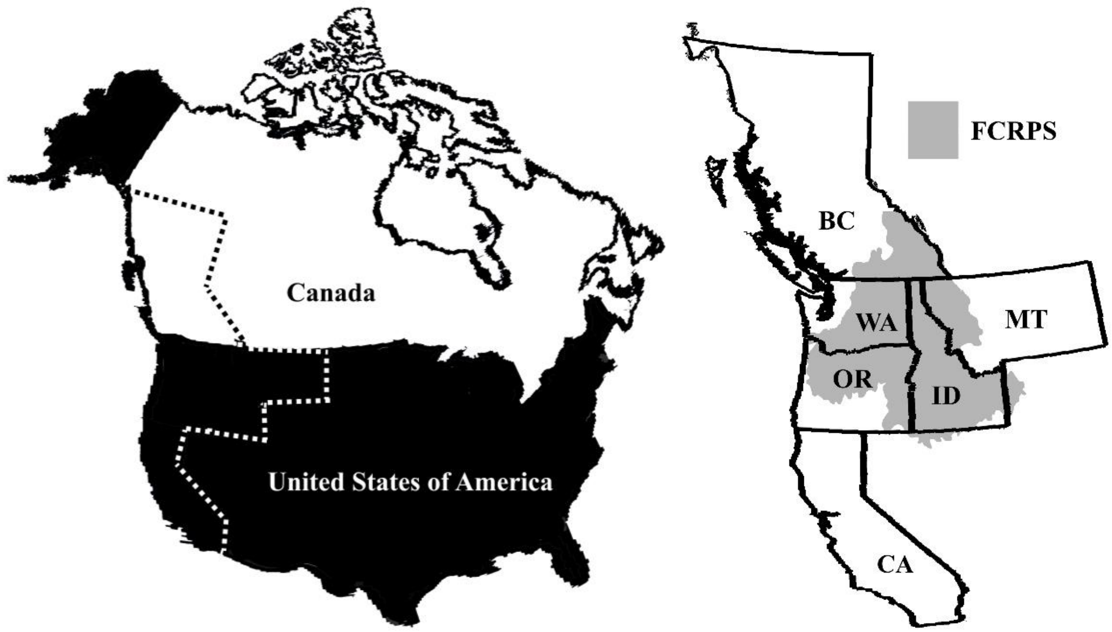


Figure 1 – FCRPS, California and the Pacific Northwest with respect to North America

The Federal Columbia River Power System

The FCRPS is collection of hydro generation stations with a total capacity of approximately 22 GW, which includes Grand Coulee (6,809 MW), The Dalles (2,080 MW), John Day (2,480 MW) and Chief Joseph (2,614 MW)[15]. Approximately 40 percent of US hydropower comes from the Columbia River System[16]. Bonneville Power Authority (BPA) is a major transmission operator in the Pacific Northwest[17] and in the FCRPS.

[15] BPA. Federal Columbia River System. 2018 Available here: https://www.bpa.gov/p/Generation/Hydro/hydro/fcrps_brochure_17x11.pdf
[16] NW Council. Dam Guide. Available here: https://app.nwcouncil.org/ext/storymaps/damguide/index.html?id=11
[17] BPA. Factsheet. 2018. Available here: https://www.bpa.gov/news/pubs/GeneralPublications/gi-BPA-Facts.pdf

Water availability is not the only factor which determines the output of hydro generation in the FCRPS. Non-power requirements are an important part of seasonal operation for hydro in the Pacific Northwest. These include the following[18]:

- Flood control
- Navigation
- Fish operations
- Irrigation
- Recreation
- Control area services

FCRPS river operations are often dictated by BPA's partners and power generation is not always the highest priority. The FCRPS includes 31 hydroelectric plants categorised into four strategic classes depending on the role they play in the system. These are as follows[19]:

- **Main Stem Columbia**: plants that provide the majority of power, ancillary services, and non-power benefits to the Pacific Northwest.
- **Headwater/Lower Snake**: plants that support services provided by Main Stem Columbia plants.
- **Area Support**: plants that do not support the region as a whole, but provide key power and non-power benefits to a sub-basin, primarily in the Williamette Valley.
- **Local Support**: plants that provide services locally, primarily in Southern Idaho.

Using information available on BPA's website[20] and plant level data on EIA's website[21] the following observations were made:

- Main Stem Columbia and Headwater/Lower Snake provide 96 percent of the energy and 80 percent of the storage from the FCRPS system.
- Main Stem Columbia alone consists of 16.2 GW of the 22 GW of hydro capacity in the FCRPS.
- Main Stem Columbia provides 76 percent of the energy and 30 percent of the storage in the FCRPS while the Headwater/ Lower Snake provides 20 percent of the energy and 50 percent of the storage in the FCRPS.

Grand Coulee and the Main Stem

By capacity Grand Coulee is the largest hydroelectric facility in the US and the fourth largest in the world. In the FCRPS, Grand Coulee provides 29 percent of total energy and makes up 31 percent of total capacity in the FCRPS

Grand Coulee and the other five Main Stem units have a unique position in the FCRPS due to their significant contribution to energy and capacity. Grand Coulee is operated to

[18] BPA. Multiple FCRPS Objectives. 2018. Available here: https://gridworks.org/wp-content/uploads/2018/09/Sharing-Power_Slide-Deck_Sept-6.pdf

[19] BPA. Asset Category Overview 2017-2030 Hydro Asset Strategy. 2016. Available here: https://www.bpa.gov/Finance/FinancialPublicProcesses/IPR/2016IPRDocuments/2016-IPR-CIR-Hydro-Draft-Asset-Strategy.pdf

[20] BPA. Wind generation & total load in the BPA balancing authority. 2018. Available here: https://transmission.bpa.gov/Business/Operations/Wind/default.aspx

[21] EIA. 2018. Available here: https://www.eia.gov/opendata/qb.php?category=1

maintain downstream flow within elevation limits and to ensure water availability for agriculture. Downstream of Grand Coulee Dam is Chief Joseph Dam which is operated in conjunction with Grand Coulee to support non-power requirements.

Transmission paths

The Western Interconnection has many intertie (shared transmission) paths. Figure 2 provides an indication of the geographic location and line definitions for each WECC path.

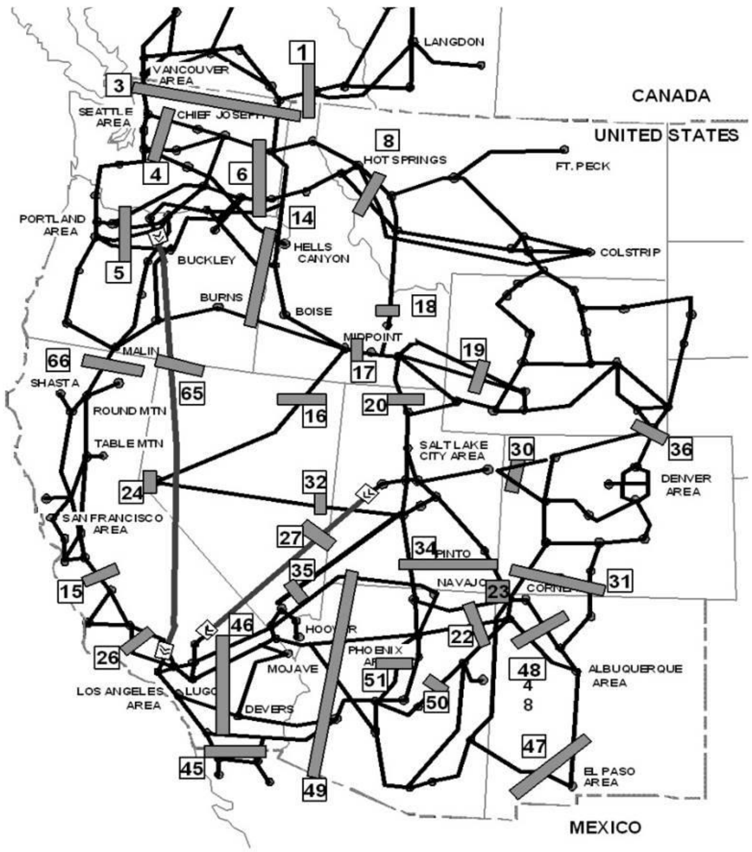


Figure 2 - WECC path definitions[22]

The paths relevant to north to south transfers for California ISO are shown in Table 2. North to south transfer limits are included in the table.

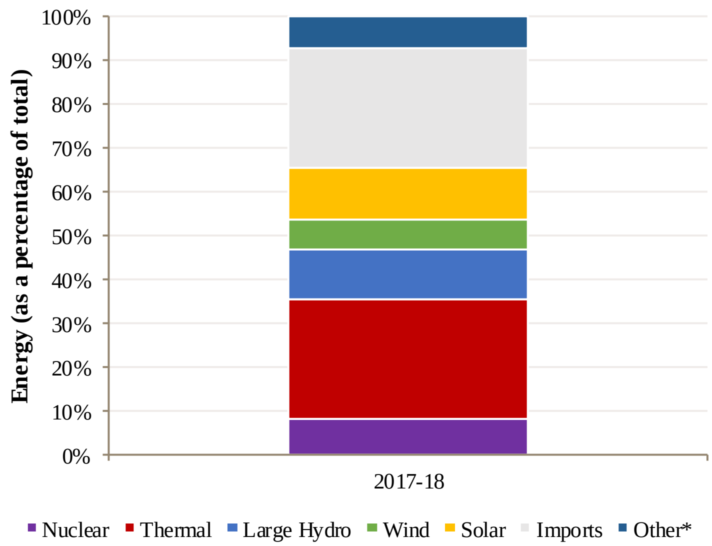
Table 2 - CAISO transmission paths

Path	North to South Transfer Capability (MW)
Path 26	4,000
Path 65/PDCI (HVAC)	3,220
Path 66	4,800

[22] WECC. Western Interconnection Transmission Path Flow Study. 2007. Available here: https://www.wecc.biz/Reliability/2007_WI_TransPath_UtilizationStudy.pdf

Major generation sources

CAISO load is met by a mix of thermal, nuclear, solar, wind, hydro, biomass, biogas and generation from neighbouring systems. Figure 3 provides a breakdown of the energy by generation type required to meet CAISO responsible load from July 2017 to July 2018. This figure was prepared with data available on CAISO's website[23]. Local thermal generation and generation outside of California provide the largest supply of energy, 27% each. Renewables provide a large proportion of energy, totaling 30% for this period. Nuclear generation is planned to fully retire by 2025.



*Other includes geothermal, biomass, biogas and small hydro.
Figure 3 - Energy by technology type in 2017-18 for CAISO balancing area

Policy goals

The state of California has one of the most ambitious renewable energy policies in the world. California established its Renewable Portfolio Standard (RPS) in 2002[24]. Several key changes have occurred over time, most recently in September 2018 with the introduction of 100% RPS by 2045. The current policy codifies 50% RPS by 2026, 60% RPS by 2030 and 100% RPS by 2045. Hydro generation is not counted until after 60% RPS has been achieved. California is well ahead of its trajectory to achieve the goal for 2020.

[23] CAISO. Managing oversupply, 2018. Data available here: http://www.caiso.com/informed/Pages/ManagingOversupply.aspx
[24] CEC. 2015. Available here: https://www.energy.ca.gov/portfolio/

4.1.2.2 Near-term assessment

This assessment involved preparing five power system study cases in GE PSLF, two for north to south flows and three for south to north flows. My contributions focused on the two north to south cases. One case reflected favourable conditions for energy transfer during summer evening while the other reflected resource shaping during the spring evening. These cases were prepared with the load, dispatch and path flows described in the table on page 9 of the November presentation[25].

The current California-Oregon Intertie (COI) rating is 4,800 MW and the limiting contingency is a double circuit outage (category P7, extreme event) of the Malin to Round Mountain 500 kV parallel lines. The contingency is not a category P7 as the two lines do not share a common tower, however operationally the contingency is treated as a P7.

The study also considers treating the contingency as a P6, to ascertain the increase in path rating if the contingency category were to change.

Results

In the energy transfer study there is thermal overloading of 10 percent above the emergency rating. There were no other thermal or stability violations in this study.

In the resource shaping study there is a thermal overload of 18 percent on Captain Jack to Olinda 500 kV line. Additionally, voltage at Maxwell 500 kV bus drops to 469 kV. There were no other thermal or stability violations.

Potential mitigation

For the energy transfer case the mitigation option is to only limit COI to 4,800 MW if the contingency is considered credible (bush fires in the area), in operations horizon. Other options include additional generation tripping in the Northwest or load shedding in California.

For the resource shaping case mitigation options are the same as for the energy transfer case except additional voltage support in California is required or the use of Fast AC Reactive Injection (FACRI) to increase the voltage and reduce the overload if the contingency is not credible.

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[25] CAISO. Pacific Northwest Informational Special Study. 2018. Available here: http://www.caiso.com/Documents/Presentation-2018-2019TransmissionPlanningProcess-PacificNorthwestInformationalSpecialStudy.pdf

4.1.2.3 Long-term assessment

The long-term assessment involved reviewing existing production simulation hydro models for the September stakeholder workshop followed by preparing the hydro scenarios for the production cost model (or market model) for the year 2028 to be presented at the November stakeholder meeting. The WECC Anchor Data Set (ADS) assumptions and inputs were used as inputs into the production simulation model. The ADS is a compilation of load, resource and transmission topology information used by the Regional Planning Groups in the Western Interconnection as part of their regional transmission plans[26].

6th September stakeholder workshop

In preparation for this workshop, the existing production simulation model, specifically for hydro generation in BPA, California and other Pacific Northwest BA's were reviewed. Using 10 years of historical BPA hydro data, the capacity and flexibility of BPA's hydro fleet was compared against the model output for the year 2028. The review was presented at the Pacific Northwest workshop and published on the Gridworks website[27]. The relevant slides are 14 to 36. The following outcomes were as follows:

- Hydro generation from the production simulation model reflect historical data. Careful consideration of the input data for Northwest hydro is required when developing different hydro scenarios.
- Hydro operation is unique by month, rather than season. Defining hydro profiles or scenarios should be done on a monthly basis. Hydro scenarios are not just defined by total energy but also the timing of high energy months.
- Inputs from BPA and the Northwest Power and Conservation Council (NWPCC) in subsequent months resulted in the development of three scenarios and improved hydro parameters in the model.

Upgrades to the production simulation model

Hydro model parameters in the existing ADS input assumptions include the monthly minimum output, maximum output and energy for each hydro unit. Working with the vendor of the production simulation model software the monthly daily average operating range (DailyAverageOR) was built into the model. This metric constrains the change in hydro output over 24 hours and provides more control over the behaviour of hydro generation.

Updating Northwest model parameters

Development of three hydro scenarios was the main focus leading up to the November stakeholder meeting. The NWPCC provided 80 years of historical data for river flows in the Northwest. The years 1997 (95th percentile), 1960 (50th percentile) and 1931 (5th percentile) were chosen as the high, medium and low years, respectively, to build hydro

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[26] WECC. Anchor Data Set (ADS). 2018. Available here: https://www.wecc.biz/SystemStabilityPlanning/Pages/AnchorDataSet.aspx

[27] CAISO. 2018-2019 Transmission Planning Process Informational Study: Increased Capabilities for Transfer of Low Carbon Electricity between the Pacific Northwest and California. 2018. Available here: https://gridworks.org/wp-content/uploads/2018/09/Sharing-Power_Slide-Deck_Sept-6.pdf

scenarios from. Figure 4 illustrates the scenarios monthly energy for Northwest hydro generation. The existing ADS monthly energy values are shown by the yellow broken line. Northwest hydro generation includes all Pacific Northwest hydro except those located in Canada.

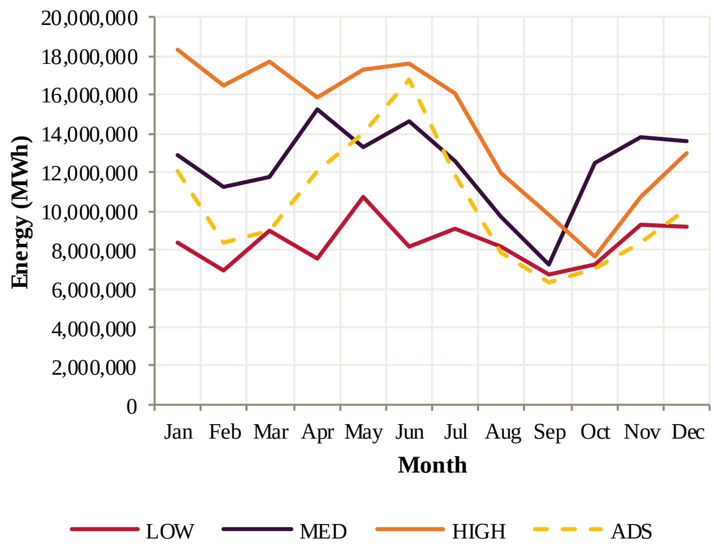

Figure 4 - Northwest hydro energy by month compared with 2008 ADS inputs

Each Northwest hydro generator was assigned a share of total Northwest monthly energy weighted by its rated capacity. For example, a generator with a rated capacity of 350 MW is 1% of total Northwest capacity and will receive 1% of total Northwest monthly energy. The same approach was used for the other parameters: daily operating range, minimum output and maximum output.

BPA provided public data on Main Stem hydro generator output in the FCRPS. This provided an opportunity to improve the model by estimating the model parameters using historical data.

Main Stem model parameters

The six FCRPS Main Stem generators were assigned monthly energy the same way as the other Northwest generators. However due to their significance in the FCRPS and the Northwest power system their parameters were estimated using mathematical models derived from historical operational data.

Using historical data[28] from 2004 to 2018 for each Main Stem generator, an ordinary least squares model was fitted by month. Below shows the polynomial specifications for daily operating range (3rd order), minimum output (2nd order) and maximum output (2nd order). The model specification was consistent for each scenario.

$$\boldsymbol{y_{DOR} = \beta_3 {x_E}^3 + \beta_2 {x_E}^2 + \beta_1 x_E + \beta_0}$$

[28] US Army Corps of Engineers. Dataquery 2.0. 2018. Available here: http://www.nwdwc.usace.army.mil/dd/common/dataquery/www/#

$$y_{MIN\ or\ MAX} = \beta_2 {x_E}^2 + \beta_1 x_E + \beta_0$$

x_E: $monthly\ energy$
y_{DOR}: $estimated\ daily\ operating\ range$
$y_{MIN\ or\ MAX}$: $estimate\ minimum\ or\ maximum\ output$
$\beta_{3,2,1}$: $coefficient\ of\ regression$
β_0: $intercept = 0$

One exception to the assignment process described above is Grand Coulee's high scenario parameters. These were calculated using actual data available for 1997.

Figure 5 illustrates the estimated model parameters for each generator for the medium scenario. The yellow line indicates the rated capacity of the unit. The red and blue solid lines represent the estimated maximum and minimum output. The broken lines represent the original ADS equivalent values. The orange bar shows the daily estimated operating range.

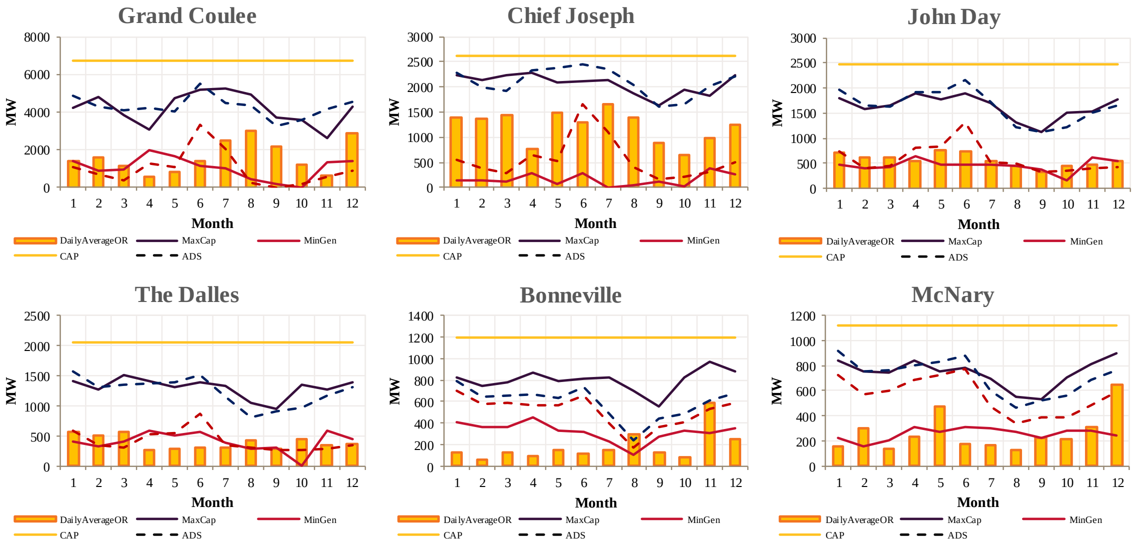

Figure 5 - Resultant model parameters for Main Stem generators – medium

The following observations were made:

- Significant change to the maximum and minimum output parameters for Bonneville and McNary. Subtle differences exist for other generators.
- Generally, minimum output decreased across the units while maximum output increased for Bonneville and remained unchanged for the remaining units.

Figure 6 compares the model parameters of Grand Coulee for each scenario. The following observations were made:

- Maximum output is generally unchanged in each scenario.
- Minimum output is higher in the high scenario, particularly in the spring to summer period.
- Daily operating range is low in the high and medium scenario for spring months when non-power requirements increase the cost of holding water.
- There exists a 'pinch point' where max and min are close together and daily operating range is close to zero. This exists in June for the High scenario and in

April and November for the Medium scenarios. During these months the Main Stem generation are least able to provide flexible ramping services.

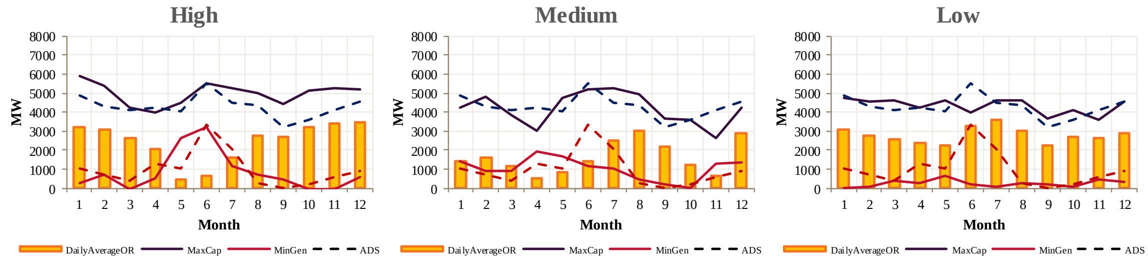

Figure 6 - Comparison of Grand Coulee model parameters by scenario

In addition to updating the hydro parameters a few other production simulation inputs were updated. These include:

- Resource and load assumptions in neighbouring states and provinces
- Transmission topology
- HVDC model

Results

The purpose of the study is to identify opportunities to increase transfer capabilities. Observation were made from the outputs of the production simulation. Table 3 shows the number of hours in the year COI is congested for the original ADS model and the three scenarios outlined above when the COI pathing rating is 4,800 and 5,100. Generally, COI congestion is higher than what would have been seen with the original ADS model. The original ADS model is comparable to the medium scenario in terms of likelihood of occurring and COI congestion is double in the medium scenario. Congestion is not entirely solved by increasing the COI rating due to congestion in the lower voltage network located near COI.

Table 3 - COI congestion hours (MW [percent change from ADS])

Path rating	ADS	Low	Medium	High
4,800	175	49 [-72%]	349 [100%]	1,597 [813%]
5,100	-	-	265 [51%]	-

26th November stakeholder meeting

On the 26th November the preliminary results were presented to stakeholders[29] (the presentation was postponed by 10 days). The development of the hydro scenarios and the tuning of the hydro parameters have provided improvements to the modelling of interregional transfers between California and the Pacific Northwest. As a result, other areas of improvement have been identified which will be addressed in subsequent studies.

[29] CAISO. Informational Study: increased capabilities for transfer of low carbon electricity between the Pacific Northwest and California. 2018. Available here: http://www.caiso.com/Documents/Presentation-2018-2019TransmissionPlanningProcess-PacificNorthwestInformationalSpecialStudy.pdf

4.1.3 Impressions

Reliability Assessment

The CAISO transmission planning Reliability Standards consider a broad range of potential contingencies as part of a single planning process. Through my contributions to the Reliability Assessment, and through the technical analysis as part of Pacific Northwest Informational Special Study, I developed the following impressions:

- The inclusion of multiple contingency categories exponentially increases the volume of study work required to complete a Reliability Assessment of a transmission system.
- The visibility and foresight of potential security issues in the power system is enhanced due to the broader range of potential system events studied.
- Cost of maintaining system security does not necessarily increase proportional to the study scope. Low cost mitigation options such as special protection schemes are often utilised to solve breaches of the Reliability Standards for multiple contingency events. This does depend on the performance criteria in place.
- AEMO's PSFRR[30] is a platform for studying non-credible events which directly impact frequency. Considering non-credible contingencies which indirectly impact frequency can enhance the foresight of the national transmission planner and improve system security in the NEM.

Pacific Northwest Information Special Study

In order to achieve the ambitious policy goals set in California, it is necessary to understand the capability of neighbouring systems and the associated interdependences. California will increasingly require support from neighbouring systems as local base load nuclear and peaking gas retire.

Parallels can be drawn to Hydro Tasmania's Battery of the Nation project in Australia. The goal of this project is to further interconnect Tasmania, through undersea cables, to mainland Australia and expand the pumped hydro capability in Tasmania to support renewable development in the NEM. Adequate technical and economic analysis is essential to ensuring the least cost options are chosen. This requires understanding the capabilities of hydro through each month and year and modelling these capabilities in production simulation studies. Other impressions gained through this work included:

- Collaborating with experts around the Western Interconnection provided significant benefit to the accuracy of the technical and economic work. This reaffirms the value of the stakeholder process and encourages me to do more to engage with experts around the NEM and Australia.
- Production simulation modelling of integrated HVDC transmission lines require careful consideration of assumptions. Examples in Australia include Terranora and Murraylink.

AEMO. 2018 Power System Frequency Risk Review. 2018. Available here: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/PSFRR/2018_Power_System_Frequency_Risk_Review-Final_Report.pdf

4.2 Large scale solar integration

Since 2012, California has seen a significant increase in the connection of solar generation. Figure 7 shows the average hourly solar generation in CAISO's jurisdiction for July from 2014 to 2018. Year on year the July solar output has increased by an average of 1400 MW, starting at approximately 4,000 MW in 2014. In the spring months of 2018 large-scale solar generates more than 50 percent of demand in the CAISO's jurisdiction.

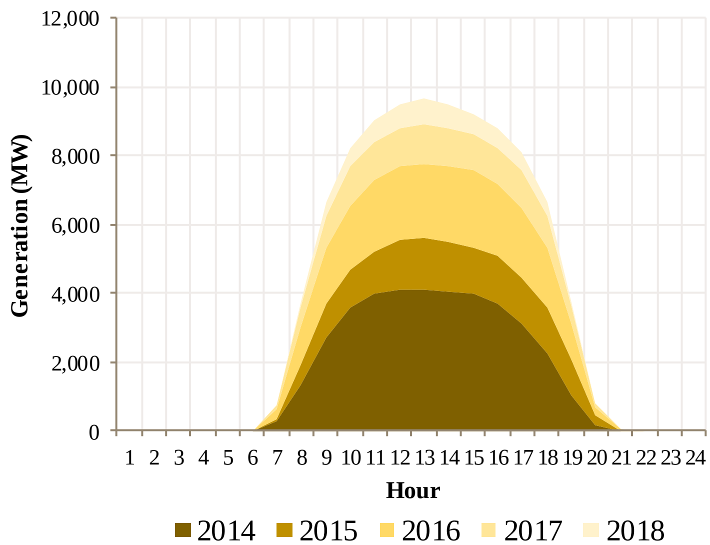

Figure 7 - Average hourly generation of large-scale solar in California in July

In March 2018 solar PV output reached a record of 10,429 MW and resulted in maximum afternoon 5 minute, 1 hour and 3 hour ramps of 581 MW, 5,306 MW, and 9,561 MW, respectively[31].

During periods of high solar ramps which coincide with low to moderate demand solar generation may be curtailed. This is due to the decommitment of gas generation which provides the flexible ramping services in the morning and evening. This curtailment has increased over time in California[32] as more large-scale solar has connected.

The NEM has (as of July 2018) 960 MW of utility-scale solar with another 2,300 MW committed in the coming years. In addition, there is another 21,900 MW of proposed connections.

Using solar generation data for California it is possible to predict the aggregate ramping of utility-scale solar in the NEM. This section introduces an approach for predicting future 5 minute, 1 hour and 3 hour ramping.

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[31] CAISO. Managing oversupply, 2018. Data available here: http://www.caiso.com/informed/Pages/ManagingOversupply.aspx
[32] CAISO. Renewable Curtailment. 2018. Available here: http://www.caiso.com/Documents/HistoricalCurtailment.pdf

4.2.1 Ramp ruler

Using data made available on the CAISO website[33] the 5 minute, 1 hour and 3 hour ramps were calculated from 2014 to 2018. The 99.5 and 0.05 percentiles were calculated for each ramp interval by year by season. This gives the positive and negative ramp of which only 1% of ramps exceed. Figure 8 illustrates the ramp of solar generation in the California bulk electric system. For the purpose of this work, the maximum output is used as a proxy for installed capacity.

The relationship is shown by the solid fitted lines while the dots represent the actual data. It is evident that for all ramp intervals there is a linear relationship between installed capacity and ramp magnitude. Deviation from the line is explained by seasonal variations (ramps are higher in months when solar output is higher) but generally they do not vary too much.

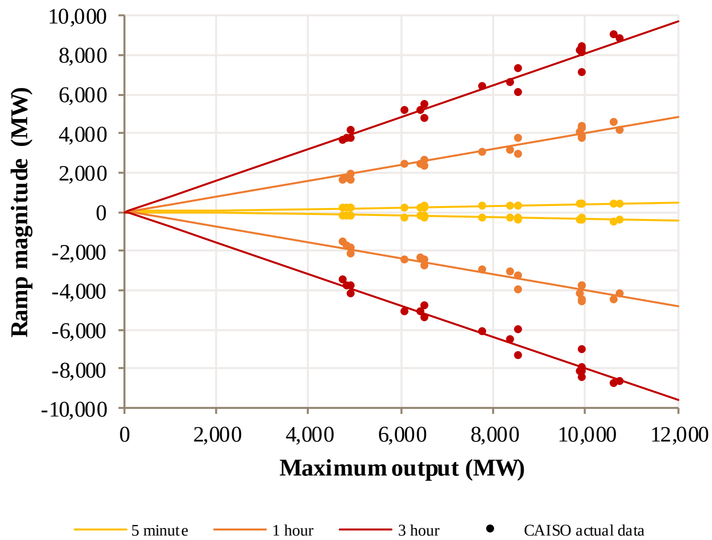

Figure 8 - 1% probability of exceedance solar ramping in California

The approach was applied to NEM solar data made available through AEMO's NEMWEB market data portal[34]. Figure 9 shows the fitted line calculated from the CAISO actual data and the diamonds represent NEM actual data.

[33] CAISO. Managing oversupply, 2018. Data available here: http://www.caiso.com/informed/Pages/ManagingOversupply.aspx

[34] NEMWEB Market Data. AEMO, 2018. Available here: http://www.nemweb.com.au/

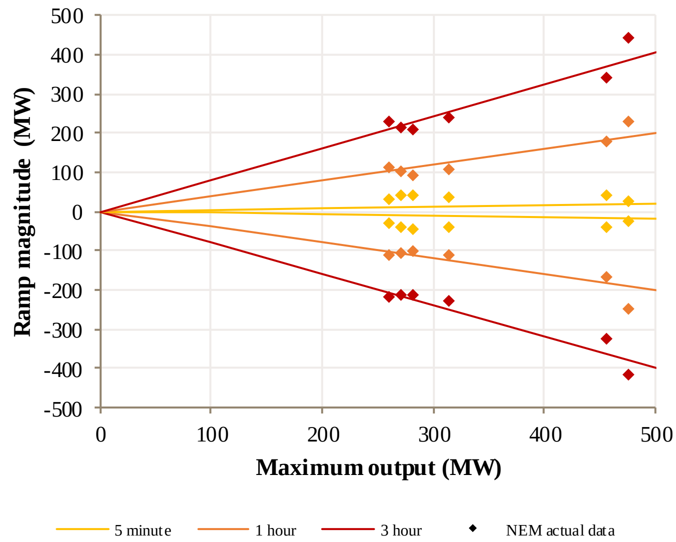

Figure 9 - 1% probability of exceedance solar ramping in the NEM with California fitted line

For 1 hour and 3 hour ramping, the relationship determined from California solar is consistent with NEM solar. Even at a low installed capacity the relationship is useful in estimating the top 1% of ramps expected in the NEM for up to 12GW of maximum output. The fitted line slightly underestimates the five minute ramp at low installed capacity however the data progressively converges to the fitted line at just under 500 MW. For 5 minute ramping, geographic diversity benefits are maximised after the connection of a handful of solar farms. There is no geographic diversity seen for 1 hour and 3 hour ramp magnitudes.

4.2.2 Impressions

This analysis is an extension of the Regulation Frequency Control Ancillary Service (FCAS) projection work done as part of the National Transmission Network Development Plan which began in 2016[35]. The impressions gained from this work are as follows:

- Increasing penetration of intermittent generation in the NEM will see an increase in the reliance on thermal generation to provide flexible ramping.
- As the available flexible ramping capabilities in the NEM decrease (due to decommitment or retirements) curtailment of wind and solar generation will occur.
- This is necessary to maintain system security and may provide a signal to other technologies to participate in the energy market, such as batteries or hydro generation.

[35] AEMO. 2016 National Transmission Network Development Plan. 2016. Available here: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NTNDP/2016/Dec/2016-NATIONAL-TRANSMISSION-NETWORK-DEVELOPMENT-PLAN.pdf

4.3 Distributed energy resource impact study

This section outlines a DER sensitivity analysis I conducted as part of the NERC Load Modelling Task Force and the WECC Modeling and Validation Work Group (MVWG). Preliminary results were presented to the NERC task force on November 6, 2018 and expanded results were presented at the WECC MVWG conference in Salt Lake City on November 28th, 2018[36].

4.3.1 Background

Since the 1980's delayed voltage recovery has been observed in California due to the stalling of residential air-conditioners[37]. In 2001 WECC introduced an Interim Load Model to better reflect post-contingency oscillations observed in the system and better model the impacts of induction motors. In 2014 this model was superseded with the composite load model.

Composite load model

The composite load model (CMPLDW) included a distribution network equivalent component and a motor, static load and electronic load component. WECC implemented a phased introduction of the composite load model. Phase I had some features disabled and Phase II (approved in 2015) incorporated improvements to the model related to stalling parameters of load[38] and is currently used by WECC.

Distributed generation model

In January 2018, WECC approved the use of a standalone distributed generation (DG) model, DER_A[39], for use in power system studies[40]. The use of CMPLDW with DER_A is expected to be approve at the end of 2018. The DER_A model captures the requirements on DG connected in California. These requirements are outlined in California Rule 21[41].

Model parameters

The DER_A model is a simplified version of a utility-scale PV model with a reduced set of parameters. The model includes the following functional features[42]:

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[36] CAISO. Studies of Composite Load Model with DER_A Module. 2018. Available here: https://www.wecc.biz/Administrative/CMPLDWG%20DER_A%20CAISO-%20Green.pdf

[37] BPA. Composite Load Model Development and Implementation. 2015. Available here: https://gig.lbl.gov/sites/all/files/3-composite-load-model-development.pdf

[38] Composite Load Model with Distributed Generation Approval. 208. Available here: https://www.wecc.biz/Administrative/Composite%20Load%20_with%20DG%20Model%20Approval.docx

[39] DER_A is approved in GE PSLF and PowerWorld. DERAU1 is approved in PSS®E.

[40] WECC. WECC Approved Dynamic Models Library May 2018. 2018. Available here: https://www.wecc.biz/Reliability/WECC%20Approved%20Dynamic%20Models%20Library%20May%20 2018.pdf

[41] PG&E. Electric Rule No. 21. 2018. Available here: https://www.pge.com/tariffs/tm2/pdf/ELEC_RULES_21.pdf

[42] NERC. DER_A Model. 2017. Available here: https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_-_DER_Modeling_Parameters_-_2017-08-18_-_FINAL.pdf

- Frequency control with droop control and asymmetric deadband
- Voltage control with proportional control and asymmetric deadband (may be used to either represent steady-state voltage control or dynamic voltage support, depending on chosen time constants)
- Constant power factor and constant reactive power control modes
- Inverter cutout at low and high voltage, including a four-point piecewise linear gain used to model the aggregate response from a large number of resources
- Representation of a fraction of resources that re-energize following a low/high voltage condition (representation of legacy trip and modern ride-through resources in a single model)
- Representation of a fraction of resources that re-energize following a low/high frequency condition (representation of legacy trip and modern ride-through resources in a single model)
- Ramp rate limits and active power recovery limits following a fault or during frequency response
- Active-reactive power priority options (may be used to represent dynamic voltage support during abnormal voltage conditions)
- Capability to represent generating resource or inverter-based energy storage resources

4.3.2 Description

The purpose of this study was to analyse the local and system impact of distributed generation (DG). The peak 2020 high renewable sensitivity case was used in this study, see slide 3 of the Fresno presentation[43]. This study tested the following components of the DER_A model.

- Voltage recovery settings
- Voltage support (deadband and gain)
- Fraction of DER which returns as the voltage recovers
- Prioritising frequency support over voltage support

Other parameters were consistent with California Rule 21.

A three phase fault was applied to the 230 kV Arco to Gates line and the dynamic response was measured at the 230 kV monitored bus in PG&E's transmission network (northern California), refer to Figure 10. The Greater Fresno area is supplied by the BES through two 500 kV Gates and Los Banos substations and 230 kV Wilson substation.

[43] CAISO. Day 1 Presentation 2018-2019 TPP meeting. 2018. Available here: http://www.caiso.com/Documents/Day1-Presentations-2018-2019TPPMeeting-Sep20-21-2018.pdf

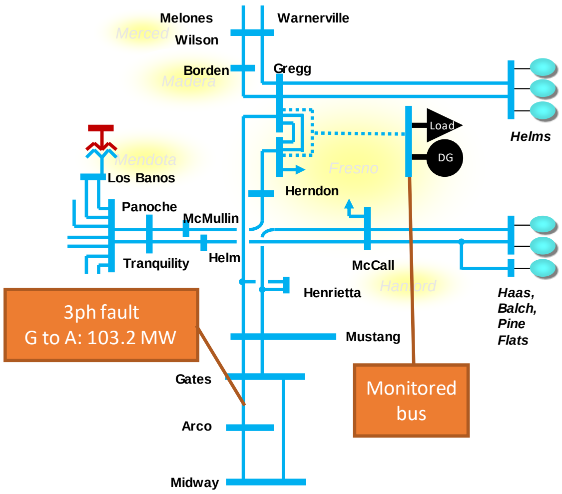

Figure 10 - Greater Fresno 230 kV network

The monitored bus was chosen due to the high load and distributed generation connected in the area. Across the northern California region there is approximately 4,400 MW of DG output in the case, with 911 MW in the Fresno local area and 14 MW at the monitored bus.

4.3.3 Outcomes

This analysis provided insights into the local and system impact of distributed generation (DG) and load response during and after a network fault. Figure 11 (left) compares the net load and DG response when voltage support (blue) is prioritised and when frequency response (orange) is prioritised. This is one of six sensitivities outlined in the presentation slides. The 'No model' (red) response indicates the result when the DER_A model is absent.

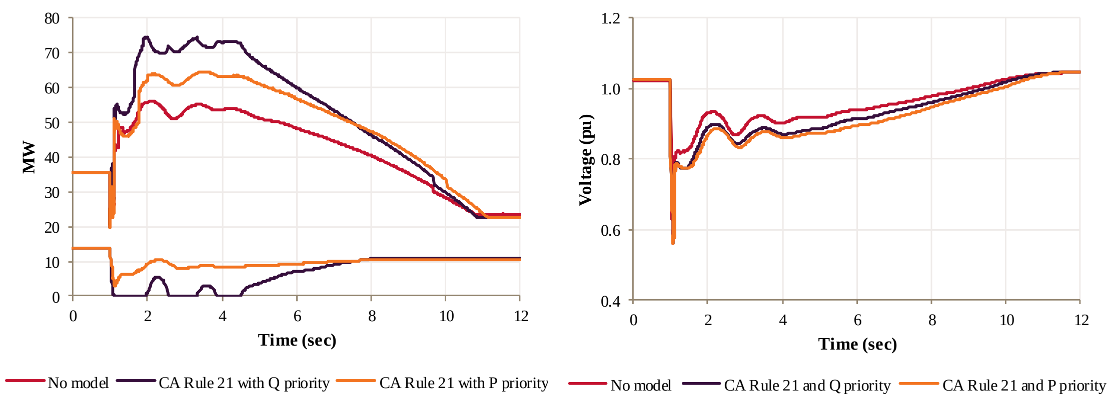

Figure 11 - Active power response (left) and voltage response (right) at the monitored bus

To understand the system wide impact of this fault the change in gross load, DG and net load was reported in four sub-regions across northern California. Across northern California the net load lost was 633 MW with no model, 567 MW with frequency support prioritised and 541 MW with voltage support prioritised.

The key outcomes are outlined below.

- Using the CA Rule 21 DER_A modelling parameters it is evident that a local network fault can result in a supply-demand imbalance (a frequency event).
- Studies with the DER_A module absent result in optimistic outcomes.
- The results are sensitive to the model parameters. Careful tuning of the parameters requires extensive work across utilities.
- DG should prioritise voltage support. This assists in reducing the amount of DG and load tripped across the system which reduces the impact locally and system wide.
- Consideration must be given to the types of studies which include DG modelling. For planning purposes, system-wide approximations of model parameters are useful for understanding the potential system impacts. Developing a system-wide approximation of load and DG is a good first step. Sensitivities can provide results for boundary conditions. Local studies require a combination of system-wide approximations and more detailed local area tuning. This should be led by local transmission and distribution owners.

4.3.4 Impressions

This study outlines the importance of developing load models, DG models and the significance of setting requirements on smart devices connecting to the grid. Continued efforts in California, the Western Interconnection and across North America to develop, validate and implement accurate load and DG models has improved the understanding of the changing dynamic performance of the grid. The impressions made through this work are outlined below.

- Load and DG models both influence the local and system wide dynamic performance of the grid. Modelling one alone is not adequate.
- It takes many years of collaboration between transmission utilities, distribution utilities, system operators, software vendors and manufacturers to develop a useful load and DG model.
- DG can support local voltage which inherently supports system frequency by reducing the load and DG tripped in the distribution network. More work is necessary to understand how the system responds in off peak scenarios.
- The capability of Siemen’s PSS/E version 34 is being validated and should be available for use soon. This will require continuous, granular system monitoring at the transmission-distribution interface.

4.4 Training, workshops and opportunities

Below is a list of training, workshops and presentations I have been involved.

- *Energy+Environment, Economic* (E3) training on Revenue Requirement Calculations for Transmission Planning Process.
- CAISO provided a Two day ‘Get to know the ISO’ training workshop. This provided an overview of all the major business areas, a lot like AEMO’s ‘NEM Overview’ course.
- Southern California Edison (SCE) provided a two day training workshop on PowerWorld. This workshop focused on User Interface and running contingency analysis studies.
- Presented ‘The Australian Experience’ to the Regional Transmission – North and Regional Transmission – South teams. This provided an overview of AEMO, the transmission planning cycle in the NEM and an overview of the power system.
- Presented to the Pacific Northwest review group on preliminary findings from the review of BPA’s hydro modelling results.
- Assisted in the presentation of results of study titled ‘DER System Impact Assessment in CALISO’ to NERC Load Modelling Task Force. November 6 - 7, 2018.
- Assisted in the presentation of results of the ‘Studies of Composite Load Model with DER_A Module’ at Salt Lake City on the 28th November, 2018[44].
- Assisted in the presentation of preliminary results of the Pacific Northwest Informational Special Study to stakeholders at the 26th November, 2018, stakeholder meeting[45].

[44] CAISO. Studies of Composite Load Model with DER_A Module. 2018. Available here: https://www.wecc.biz/Administrative/CMPLDWG%20DER_A%20CAISO-%20Green.pdf

[45] CAISO. Presentation 2018-2019 Transmission Planning Process Meeting Nov 16 2018. Available here: http://www.caiso.com/Documents/Presentation-2018-2019TransmissionPlanningProcessMeeting-Nov16-2018.pdf

5.0 Conclusion

This report provided an overview of the work completed from July to December 2018 as part of the 2018 – 2019 ES Cornwall Memorial Scholarship. During this time I contributed to the Transmission Planning Process, analysed the integration of large scale solar, and conducted a distributed energy resource impact study as part of WECC's MVWG. In addition, I outlined my impressions gained from July to December 2018. This report meets the requirements of a quarterly report as part of the 2018 – 2019 ES Cornwall Memorial Scholarship.