Modelling Enhancements for CAISO Transmission Planning The Feasibility and Value of Incorporating Intertie Scheduling Constraints into CAISO's Planning Model

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The October 6 presentation was updated to clarify that the simulations covered the <u>2026 planning year</u> based on the TEPCC model developed by WECC and modified by the CAISO through its transmission planning process

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Intertie Scheduling Constraint Overview

Intertie scheduling constraints (ITCs) represent limitations on transfers between CAISO and neighboring Balancing Authorities

- ITCs are contractual limitations on power flow over the transmission system rather than the physical limitations of the transmission lines
- ITC limits are based on the magnitude of CAISO's transmission rights over the interties with neighboring balancing authorities
- Historically, ITC congestion accounts for a significant amount of CAISO market congestion
 - Northwest ITCs account for ~75% of historical ITC congestion, nearly all of which occurs on NOB and Malin

Actual DA Market Import Congestion on Interties



Source: CAISO 2016 Annual Report on Market Issues and Performance, p. 180

Historical Import Congestion on Intertie Scheduling Constraints

Import	Intertie Constraint	Import Congestion Charges (\$million)						
Region		2011	2012	2013	2014	2015	2016	
Northwest	PACI/Malin 500	\$48.9	\$84.7	\$34.0	\$88.7	\$37.7	\$51.1	
	NOB	\$25.5	\$59.2	\$27.8	\$58.9	\$12.4	\$24.3	
	Rest of Northwest	\$7.3	\$3.7	\$2.6	\$2.9	\$0.2	\$0.4	
	Northwest Total	\$81.6	\$147.6	\$64.5	\$150.5	\$50.3	\$75.9	
Southwest	Palo Verde	\$25.9	\$19.2	\$26.4	\$36.6	\$9.3	\$12.9	
	Mead	\$8.3	\$15.2	\$2.2	\$1.2	\$1.3	\$1.0	
	Rest of Southwest	\$3.9	\$8.5	\$7.4	\$4.4	\$5.6	\$2.0	
	Southwest Total	\$38.1	\$43.0	\$36.0	\$42.2	\$16.1	\$16.0	
	Other	\$0.8	\$2.3	\$0.2	\$0.1	\$0.0	\$0.9	
	Intertie Constraint Total	\$120.6	\$192.9	\$100.7	\$192.8	\$66.4	\$92.8	

Source: CAISO 2013-2016 Annual Reports on Market Issues and Performance

Study Purpose

The purpose of this study and report is to:

- Demonstrate that modeling the CAISO system with considerations for Intertie Scheduling Constraints (ITCs) would better reflect actual market conditions than the traditional approach of only modeling physical constraints
- Demonstrate the potential for incorporating ITCs into CAISO transmission planning process by applying such methods/tools to the ISO's 2016/2017 TPP dataset
- Capture scheduling congestion on the order of magnitude of observed levels of dayahead congestion, particularly on the northern ITCs of NOB and Malin
- Identify additional updates/modifications to the transmission planning assumptions that could result in a more accurate representation of ITC congestion

Limitations of Modelling Congestion in CAISO TPP Studies

The CAISO TPP simulations understate congestion and its impact on wholesale power prices in CAISO, particularly for scheduling constraints at the interfaces with neighboring systems

- GridView does not currently have the capability to model contract paths and associated scheduling constraints in a way that captures the realities of bilateral transactions (e.g., using point-to-point transmission service)
- The ISO's current modeling database does not capture certain hydro import advantages that have a significant impact on import flows and congestion
 - The 2016/2017 TPP database for 2026 captures BPA's ability to export to CA at a significantly lower carbon hurdle (based on its ACS emissions rate) than generic imports, but does not include similar assumptions for Powerex and Tacoma Power imports, both of which have excess hydro power available for exports to CA at a low CO2 import cost
 - This understates simulated imports from these entities and associated intertie congestion
- The 2016/2017 TPP database uses normal hydro, average transmission outages, and weathernormalized loads for the 2026 simulations
 - Because congestion tends to increase disproportionately during abnormal hydro, outage, or load conditions (e.g., above-average NW hydro and below-average CA hydro), the normalized assumptions do not yield simulation results that reflect the average of likely future outcomes

Study Approach

We incorporated hourly contract path limits on CAISO imports to the assumptions in the ISO's 2016-2017 TPP database, which simulates the 2026 planning year

- We used a commercially available production cost simulation model: Power System Optimizer (PSO), the same model used in the SB350 study
- The hourly limits are based on historical 2016 ITC limits posted on CAISO's OASIS website

For this analysis, we simulated two cases for the proof of concept:

- Case A: 2016/2017 TPP case using PSO (no ITCs incorporated)
 - Model input assumptions consistent with CAISO 2016/2017 TPP database (i.e. assumptions reflect 2026 planning year)
 - Provide a baseline against which we can compare the results of modeling the ITCs
- Case B: Case A with ITCs simulated (with updated hurdle rates and with/without enhanced Powerex hydro scheduling assumptions)
 - Represent ITCs that account for majority of imports/congestions in DA market
 - Modify hurdle rates and hydro assumptions to better capture bilateral trading friction in WECC and import flow from Pacific Northwest into California
 - Illustrate potential modelling assumption enhancements, such as capturing lower CO2 import rates for excess hydro, that can improve representation of scheduling congestion

For the rest of this report, we compare the results from Case A and Case B to illustrate a simulation of the 2026 CAISO system with consistent levels of CAISO congestion and power flow as history.

Major Constraints Between Pacific Northwest and California

A small number of constraints account for the majority of physical and intertie scheduling congestion between the Pacific Northwest and California.

Some of the constraints are physical and others are contractual. Thus, the system planning simulations should reflect both of these types of constraints.

- CAISO 2016/17 TPP: represents only the physical constraints (the first two in table below)
- Brattle Case B: represents both physical and ITCs constraints

Constraint	Туре	Limits (Import/Export from CA)	Description	
COI/PACI California-Oregon Intertie / Pacific AC Intertie	Physical	4,800 MW / 3,675 MW	Constrains physical flows on the 500-kV line connecting Captain Jack to Olinda and the two 500-kV lines connecting Malin to Round Mountain	
PDCI Pacific DC Intertie	Physical	3,220 MW / 3,100 MW	Constrains physical flows on DC line connecting Celilo in BPA and Sylmar in LADWP	
Malin (into CAISO) MALIN500	ITC	3,200 MW / 2,450 MW	Represents CAISO's transmission rights on the COI	
NOB (into CAISO) Nevada-Oregon Border	ITC	1,591 MW / 1,520 MW	Represents CAISO's transmission rights on the PDCI	

Source: CAISO 2016/2017 TPP database; CAISO Oasis

Note: The reported limits in the table represent the default limits on each constraint; hourly limits vary with outage conditions

Modeled CAISO Intertie Scheduling Constraints

In Case B, we model the six ITCs that capture the majority of CAISO import flow and congestion:

- Northwest Interface ITCs:
 - MALIN
 - NOB
- Southwest Interface ITCs:
 - PALO VERDE
 - MEAD
 - IPPUTAH
 - SYLMAR

CAISO Intertie Constraints



Summary of Key Results

Case A reasonably replicates the CAISO's 2016/2017 TPP model 2026 simulation

- We find a similar distribution of congestion hours in the Brattle Case A and the CAISO TPP model
- CAISO's 2016/2017 Transmission Plan reports \$44 million in physical congestion and 3,200 binding hours in 2026, while Brattle Case A finds \$15 million in physical congestion and 2,200 binding hours
- Lower congestion in Brattle Case A is conservative in the sense that it does not simulate more congestion than the CAISO TPP model (differences likely attributable to underlying optimization model)

<u>Case B</u> finds 15x more import congestion on the CAISO's northern interface in 2026 than the CAISO's 2016/2017 TPP model

- Scheduling congestion on both Malin and NOB is \$10-\$14 million in Case B, compared to <\$1 million in congestion on physical import constraints (COI and PDCI) in 2016-17 TPP between Pacific Northwest and California
- The Case B results also show the additional \$1 million in physical congestion on the COI and PDCI limits (consistent with CAISO 2016-17 TPP simulation results)
- The magnitude of scheduling congestion on Malin and NOB in Case B more closely aligns with historical congestion on these constraints
- Enhancing NW hydro and CO₂ cost assumptions for hydro imports into CA better align simulations with historical flows, increasing Case B congestion on Malin and NOB by about \$4 million (from \$10 million to \$14 million annually)

Case A Simulation Metrics

Case A Case A vs. 2016/2017 TPP Results

Congestion on Constraints Reported in CAISO 2016/2017 Transmission Plan

	2016/2017 TPP		Case A		
Transmission Constraint	Congestion Charges (M\$)	Duration (hr)	Congestion Charges (M\$)	Duration (hr)	
BOB SS (VEA) - MEAD S 230 kV line	\$23.72	600	\$7.41	437	
PG&E LCR	\$9.73	684	\$2.83	403	
Path 26	\$5.03	320	\$1.78	650	
PG&E /TID Exchequer	\$1.68	651	\$0.02	12	
J. HINDS-MIRAGE 230 kV line #1	\$1.09	187	\$0.44	120	
COI	\$0.84	120	\$1.11	363	
Path 45	\$0.63	655	\$0.20	27	
SCE LCR	\$0.49	34	\$0.00	0	
Path 15/CC	\$0.44	32	\$1.64	90	
Reported CAISO 2016-17 Total:	\$43.65	3,283	\$15.44	2,102	

Source: CAISO 2016/2017 Board Approved Transmission Plan, pp. 179

Note: We exclude from the table constraints that show < \$0.1 million in congestion in both Case A and the 2016/2017 Transmission Plan

Case A congestion amounts to \$15.4 million over 2,102 hours on the set of constraints reported in the CAISO's 2016/2017 Transmission Plan for the 2026 planning year

- COI congestion in Case A is similar to that in CAISO's TPP model at ~\$1 million
- Pattern of congestion across constraints in Case A is similar to the CAISO's TPP model
- More than 50% of the difference in congestion is attributable to two constraints:
 - BOB SS-MEAD line constraint (286 MW line in Nevada) and PG&E LCR constraints
- Remaining differences in congestion in the simulations likely due to differences in underlying modeling frameworks (such as using physical vs. contractual wheeling rates and heuristic vs. mixed integer programming optimization unit commitment in GridView vs. in PSO)

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We are unable to compare congestion on constraints that are not in the CAISO-reported list

Case A Comparison of Simulated COI Path Flows





- COI flows are similar between Case A and CAISO's 2026 simulations, but greater hourly variations in Case A compared to the CAISO's 2016/2017 TPP model
- We have not analyzed the drivers of the difference in flows (Will need more detailed results from the TPP model to be able to compare)
- Potential drivers of differences:
 - Realized operation of phase shifters, in particular the Path 76 phase shifter at Alturas
 - Regional commitment patterns due to underlying unit commitment approach

Case B Simulation Metrics

Case B Overview of Case B

Brattle Case B simulates the ITC limitations, enhances the use of hurdle rates over contract paths and hydro scheduling assumptions to demonstrate that congestion over ITCs can be simulated with a more accurately representation of WECC system

Case B1: Simulate 2026 with ITC Implementation

- Add to Case A intertie scheduling constraints based on 2016 limits and relax CAISO net-export constraint
 - Assume that explicitly representing the contractual limits between CAISO and its neighbors via the ITCs supersedes need to enforce net-export constraint
- Also updated hurdle rates to those used in SB350 Study (increases hurdle rates by \$2-\$9/MWh)
 - SB350 hurdle rates based on 2016 short-term, off-peak wheeling charges and also capture other trading friction and scheduling fees not captured in the 2016/2017 TPP database hurdle rates

<u>Case B2</u>: Simulate 2026 with Illustrative Enhanced Hydro Scheduling and Hurdle Rate Assumptions

- Simulate BC Hydro's scheduling against weighted average of CAISO and BC net load (15% CAISO, 85% BC)
 - Represents incentives for BC hydro to capture higher prices in CA during CAISO peak net load
- Add zero-hurdle contract path from BC Hydro to Malin/NOB based on historical levels of Powerex transactions at these interties
 - Implemented rough proxy for Powerex long-term transmission contracts (assumed ~1000 MW to Malin and NOB)
- Add low CO₂ charges for hydro imports to CA from BC Hydro (similar to treatment of hydro imports from BPA)
 - Amount of hydro imports varies monthly; based on quantity of modeled hydro in excess of modeled load in BC
 - Reduced CO₂ charges for a limited quantity of imports from \$14.74/MWh to Powerex rate of \$0.66/MWh
- In the absence of publicly-available data, Case B2 only utilized informed placeholder assumptions for known market conditions that demonstrate importance of these inputs and, if refined, could more accurately capture scheduling congestion

Case B Modeled vs. Historical Congestion over the Interties

Case B's hours of congestion and congestion costs over Malin+NOB in 2026 are still below historical levels, but are more consistent with the observed historical congestion levels than the current CAISO simulation results

- Case B2 finds 15x more congestion at Malin+NOB than ISO finds on COI and PDCI
 - CAISO simulations show less than
 \$1 million in physical congestion on COI
 and PDCI in 2016/17 Transmission Plan
 - We find similar physical congestion on COI, as well as an additional \$10-\$14 million in congestion on the Malin and NOB intertie scheduling constraints
- Case B2 results in 2,309 total binding hours on Malin+NOB in 2026, compared to 2,800-4,700 hours historically
 - CAISO simulations show only 120 congested hours on COI, none on PDCI

Cases B1 and B2 Simulated 2026 Congestion and Historical Congestion on Malin and NOB Interties



Source: Historical data downloaded from CAISO OASIS; Cases B1 and B2 based on PSO simulations

Case B Modeled vs Historical Flows over the Interties

Case B flows over Malin+NOB intertie in 2026 are not as high as historical levels, but are similar in high-hydro months:

- Case B1 and B2 flows are lower than historical in the daytime partly due to higher solar generation in 2026 than in historical years
- Allowing BC Hydro/Powerex to import at the reduced CO₂ emissions rate in Case B2 increases the flows over NOB and Malin, more consistent with historical flows
- Case B2 simulations show the importance of capturing assumptions about hydro scheduling and CO₂ costs to align modeled system with actual system experience



2026 Average CA Imports at the Low CO2 Rate by Month and Hour-of-Day



Source: Historical data downloaded from CAISO OASIS

Average 2016 and 2026 Flows on Malin+NOB by Month and Hour-of-Day

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Case B Modeled vs Historical ITC Congestion over Time

Case B's simulated 2026 congestion pattern over Malin+NOB track 2016 historical levels

 The number of binding hours is closely aligned between modeled Case B and historical levels

But the congestion costs are lower in Case B compared to historical levels

 The periods of highest modeled congestion coincide with the high hydro periods



Modeled vs. Historical Malin+NOB Congestion Cost by Month and Hour-of-Day



Case B Modeled Hydro and ITC Congestion

Hydro conditions in the Pacific Northwest are a significant driver of scheduling congestion over the NOB and Malin ITCs

- Highest congestion periods over Malin and NOB in the 2026 simulation year occur in the spring when hydro output from the Pacific Northwest is peaking
- Periods of lower Malin and NOB congestion coincide with lower hydro output from the Pacific Northwest

Case B2 Simulated 2026 Monthly Pacific Northwest Hydro Output and NOB+Malin Congestion



Case B Historical Hydro Patterns

Over the past five years California and Pacific Northwest hydro have moved in different directions (for example, in 2012, CA had a low hydro year, but the Pacific Northwest experienced a high hydro year)

- The simulated 2026 year uses "average" (2009) hydro levels for both CA and the Pacific Northwest. Thus, other hydro conditions are not captured in the simulation
- However, actually hydro conditions observed historically since 2011 (high NW and/or low CA hydro) contribute significantly to high flows and congestion over Malin and NOB intertie constraints



Historical Annual Hydro Output

Historical CA and PNW Hydro

	Hydro Output (GWh)		Percent Ch 2001-2016 A	ange from Avg Output	Hydro with Respect to Avg		
	CA	PNW	CA	PNW	CA	PNW	
2012	26,837	152,740	-10.5%	16.8%	Low	Very High	
2013	23,755	130,580	-20.8%	-0.2%	Very Low	Avg	
2014	16,409	135,494	-45.3%	3.6%	Very Low	High	
2015	13,861	125,952	-53.8%	-3.7%	Very Low	Low	
2016	28,945	131,986	-3.5%	0.9%	Low	Avg	

Source: EIA 906/920/923 filings and Brattle Analysis

Case B

Impact of Solar on Congestion over Malin and NOB ITC

The magnitude of California's installed solar generation is not a major driver of congestion over the Northern ITCs under the simulated 2026 conditions

- The majority of Malin and NOB ITC congestion in Case B2 occurs during periods of low/no solar output in California (when net load peaks and during the night)
- Increasing solar capacity in the California will have a limited impact on reducing import congestion on Malin and NOB ITCs

Case B2 Simulated 2026 Hourly Average California Solar Output and NOB+Malin Congestion



Conclusions and Recommendations

Conclusions and Recommendations

We demonstrate the capability to represent realistic levels of CAISO intertie scheduling congestion in transmission planning models

We find \$10-\$14 million in congestion on the Malin and NOB ITCs for 2026, which is over 15x higher than the NW import congestion in CAISO's 2026 simulations

We show that enhancing Northwest hydro modeling assumptions can improve the representation of system conditions on Malin and NOB

- Illustrative simulations with lower-carbon charges for imports from Powerex better align modeled and historical flow and increase modeled Malin and NOB ITC congestion by \$4 million (from \$10 million to \$14 million)
- Additional enhancements to hydro and hurdle assumptions could represent the system more realistically, and potentially increase the \$14 million in Malin+NOB simulated congestion in our Case B2 to more closely align simulation results with the historical congestion ranges of \$49-\$149 million for these ITCs

We recommend CAISO explore incorporating intertie scheduling constraints and an enhanced NW hydro representation into its simulation of future TPP Economic Studies to more accurately assess benefits of the future CAISO transmission system

Additional Factors Not Yet Simulated

Other factors that could align simulation results with historical system conditions:

- Model additional hydro condition scenarios (e.g., high/low hydro from Pacific Northwest)
 - Every year since 2011 deviated significantly from "average" hydro conditions, driving more power flows from the north into California
 - Modeling CA and Pacific Northwest hydro as "average" will understate the actual flows into CA
- Capture low CO₂ costs for all Asset Controlling Supplier (ACS) improves the accuracy of the simulations
 - Imposing full carbon charges on CA imports from all BAAs except BPA dampens flows into CA
 - Should model Powerex and Tacoma hydro sales flowing into CA at low carbon charges
 - The potential high impact of improving this assumptions is demonstrated in Case B2
- Model scenarios with more extreme load conditions
 - Model currently uses weather-normalized load for all areas. This is an unlikely "average" case
 - More extreme load conditions in the Pacific Northwest and CA would reflect greater volatility in power flows and congestion
 - Simulating only weather normalized load levels likely understates flows and congestion levels
- Model scenarios with more severe transmission outage conditions
 - Some historical years, such as 2014, had extended high-impact transmission outages that are not reflected in the "average year" outage data used in transmission planning,
 - Such above-average outage conditions will reoccur in the future and tend to have a disproportionately high impact on congestion which is not captured in simulations

Modeled vs. Real-World Bilateral Friction

Conventional modeling of contract paths typically assumes each balancing area is a single scheduling point (the green BPA bubble in the figure)

- Provides unlimited capability and flexibility for scheduling transactions within each BA to reach interconnections with other BAs
- The bilateral frictions encountered when moving power from one point to another are not fully captured
 - e.g., going from Malin to NOB in the figure requires just two transactions in the simulations—into and out of the BPA bubble

In reality, BAs are composed of multiple scheduling points (see map of WECC scheduling points in the figure) with limited ATC

- Transfers between scheduling points through a BA may require several transactions
 - e.g., the purple bubbles and arrows in the figure
- Even when modeling limitations on BA-to-BA transactions (as represented by the ITCs), this still understates the frictions and more limited flexibility encountered by bilateral transactions within/between BAs

Modeled vs Real-World Bilateral Scheduling



Power System Optimizer (PSO)

PSO is a state-of-the-art nodal production cost simulation model developed by Polaris Systems Optimization, Inc.

- Similar to GridView, Promod, GE-MAPS, Plexos, Dayzer
- Simulates security-constrained commitment and economic dispatch of generation interconnected to transmission system
- Detailed transmission representation (path ratings, thermal constraints, contract path limits, contingency constraints, etc.)
- Contract path layer (captures realities of point-to-point scheduling)
- Highly flexible reserve modelling (spin, regulation, load following, userconfigurable timing and parameters)
- Configurable "decisions cycles" simulate availability of information and timeframes of operations and (e.g., day-ahead, hour-ahead, real-time)
- Detailed energy storage representation (MW capacity, MWh capacity, ramp rates, efficiency)

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Note:

The views expressed in this presentation are strictly those of the presenter and do not necessarily state or reflect the views of *The Brattle Group, Inc.*

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