

# GRID SIMULATION REPORT

## Mena Dominance Law (MDL) on CAISO ENE\_SLRS and AS\_OP\_RSRV Inputs

Prepared from the user-provided simulation outputs, source notes, and MDL paper sections on grid validation.

Simulation window	24 aligned hourly points covering 2025-01-13 07:00 UTC to 2025-01-14 06:00 UTC
Policies compared	Baseline, single-layer MDL, dual-layer MDL
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Prepared on	2026-03-26

### Executive readout

- Baseline operation was in physical deficit for 18 of 24 hours, with 18,318.12 MWh of deficit area.
- Single-layer MDL was the strongest deficit suppressor: deficit hours fell to 5 (72.2% reduction) and deficit area fell by 96.7%.
- Dual-layer MDL used reserve-admissibility gating to spend less control effort: shedding fell by 1,066 MWh versus single-layer (5.7% less), but residual deficit increased to 9 hours.
- The structural layer was active: the reserve gate dropped below 0.99 for 11 hours, reserves fell below the 7.5% floor for 1 hour, and the minimum reserve reading was 7.40%.

# 1. Scope and purpose

This report packages the grid simulation into a PDF-ready narrative: what data were used, how the Mena Dominance Law (MDL) controller was calculated, what the controller parameters were, and what the simulation produced. The report is based only on the uploaded source note, the uploaded MDL paper, and the exported simulation CSV files.

The simulation is a system-level adequacy exercise. It evaluates whether a viability-governed controller reduces sustained deficit exposure under fixed boundary definitions. It does not model line limits, topology, N-1 contingencies, or full production dispatch behavior.

# 2. Information used

The uploaded source note identifies two CAISO OASIS inputs and the exact fields retained for the simulation. The MDL paper section on grid validation states that these streams were aligned into a 24-hour hourly window for common processing.

Dataset	Original file / series	Fields used	Role in model
ENE_SLRS (DAM)	20250112_20250113_ENE_SLRS_DAM_20260207_23_01_08_v1.csv	ISO_TOT_GEN_MW, ISO_TOT_IMP_MW, ISO_TOT_EXP_MW, ISO_TOT_LOAD_MW from TAC_ZONE_NAME = Caiso_Totals	Physical supply and load balance
AS_OP_RSRV	20250112_20250113_AS_OP_RSRV_N_20260207_23_02_52_v1.csv	INTERVALSTARTTIME_GMT and MW; MW treated as operating reserves percent and resampled to hourly mean	Structural reserve-headroom gate

The exported result files used in this report are baseline.csv, mdl\_single.csv, mdl\_dual.csv, and metrics.csv. The PNG charts supplied with the upload were inserted as report figures.

# 3. MDL formulation used in the grid simulation

The uploaded paper defines a two-layer formulation. The physical layer measures system adequacy. The structural layer measures whether reserve headroom makes that adequacy operationally admissible. The dual-layer governor multiplies those two signals before it computes curtailment.

Quantity	Definition used
P_grid(t)	ISO_TOT_GEN_MW + ISO_TOT_IMP_MW - ISO_TOT_EXP_MW
L_grid(t)	ISO_TOT_LOAD_MW
L_eff(t)	L_grid(t) - u(t), where u(t) is curtailable load / demand response proxy
Δ_grid(t)	P_grid(t) - L_eff(t)

$\Delta_{\text{arch}}(t)$	$R(t) - r_{\text{min}}$ , with $r_{\text{min}} = 7.5\%$
$g(t)$	$1 / (1 + \exp(-k \cdot \Delta_{\text{arch}}(t)))$ , with $k = 4$
$\Delta_{\text{true}}(t)$	$\Delta_{\text{grid}}(t) \cdot g(t)$

Interpretation:

- Single-layer MDL controls against  $\Delta_{\text{grid}}$  only. It reacts directly to physical deficit and therefore tends to shed more aggressively.
- Dual-layer MDL controls against  $\Delta_{\text{true}}$ . When reserve headroom compresses, the gate  $g(t)$  drops below 1 and the controller treats even positive physical adequacy as less admissible.
- In practice, the dual-layer controller accepts more residual deficit than the single-layer controller, but it does so while using less curtailment energy.

## 4. Controller logic and declared parameters

The controller adds a burden state and a protective hysteresis regime. Burden accumulates during raw physical deficit. The mode shifts into protection after one deficit hour and only exits after two consecutive hours above a positive recovery margin.

Parameter	Value	Meaning
$u_{\text{max}}$	1500 MW	Maximum curtailment command
$\lambda_{\text{B}}$	0.5	Burden carry-over factor per hour
$k_{\text{B}}$	0.002	Burden gain on physical deficit
$a_{\text{normal}}$	0.8	Normal-mode deficit response gain
$a_{\text{protect}}$	1.1	Protect-mode deficit response gain
$b_{\text{B}}$	250	Burden-to-curtailment multiplier
$N_{\text{enter}}$	1 hr	Enter protect mode after one deficit hour
$N_{\text{exit}}$	2 hrs	Exit protect mode after two consecutive hours above $\Delta_{\text{exit}}$
$\Delta_{\text{exit}}$	500 MW	Exit threshold for protect mode
$r_{\text{min}}$	7.5%	Reserve floor for structural margin

k	4	Logistic gate slope
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Burden and curtailment law used:

- $B(t+1) = \lambda_B \cdot B(t) + k_B \cdot \max(0, -\Delta_{\text{grid}}(t))$
- $u(t) = \text{clip}(a(\text{mode}) \cdot \max(0, -\Delta^*(t)) + b_B \cdot B(t), 0, u_{\text{max}})$
- $\Delta^*(t)$  is  $\Delta_{\text{grid}}(t)$  for single-layer and  $\Delta_{\text{true}}(t)$  for dual-layer.

## 5. Results

The baseline series shows prolonged deficit. Both MDL policies reduce that deficit sharply. The choice between them is a policy trade-off: single-layer MDL minimizes deficit most aggressively, while dual-layer MDL preserves some curtailment budget by respecting reserve admissibility.

Policy	Deficit hrs	Deficit area (MWh)	Shedding (MWh)	Min $\Delta_{\text{grid}}$ (MW)	Max shed (MW)
Baseline	18	18,318.12	0.00	-1,687.84	0
MDL single	5	603.62	18,852.76	-289.36	1,500
MDL dual	9	1,584.53	17,786.78	-471.75	1,500

What the table says:

- Single-layer MDL reduces deficit hours from 18 to 5 and cuts deficit area by 96.7% relative to baseline.
- Dual-layer MDL reduces deficit hours from 18 to 9 and cuts deficit area by 91.3% relative to baseline.
- Dual-layer MDL uses 1,066 MWh less shedding than single-layer, but its worst physical margin is about -182 MW lower than single-layer.
- Both MDL policies hit the 1500 MW curtailment cap; this means the cap, not just the control law, is shaping the achievable result.

### Policy interpretation

- Baseline: no actuation, so all raw supply shortfalls pass directly into  $\Delta_{\text{grid}}$  deficit.
- Single-layer MDL: best when the goal is to suppress deficit as hard as possible under the declared curtailment cap.
- Dual-layer MDL: best when the operator wants the controller to spend less effort when reserve headroom is fragile or near the reserve floor, even if that leaves more residual deficit.

## 6. Figures

The supplied figure files are included below to make the PDF self-contained.

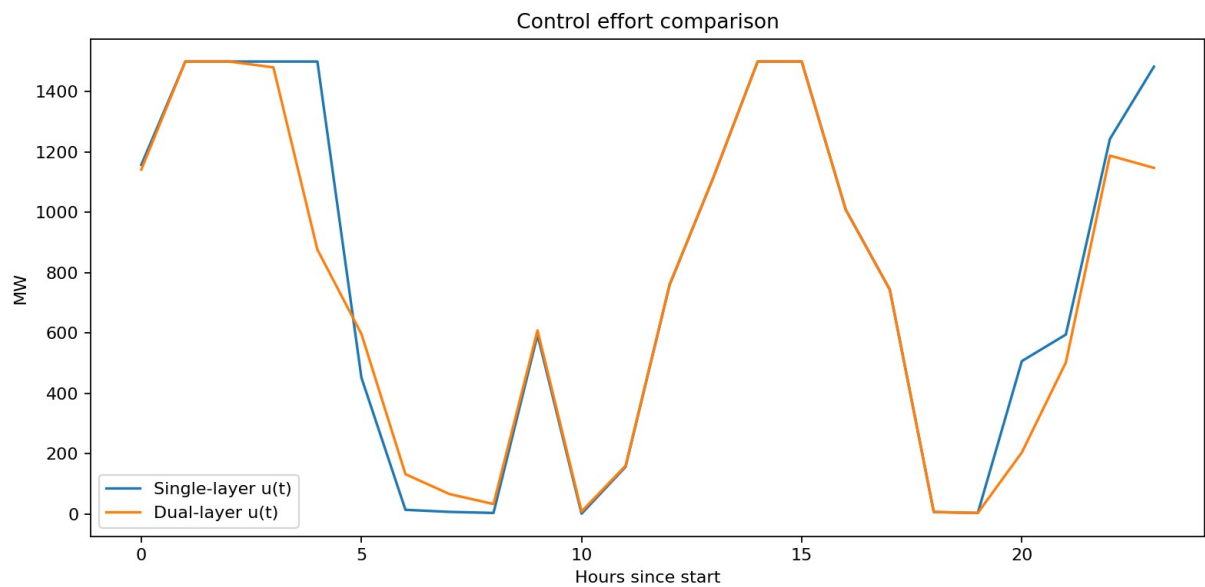


Figure 1. Control effort comparison. Single-layer MDL generally sheds more than dual-layer MDL when reserve gating compresses admissibility.

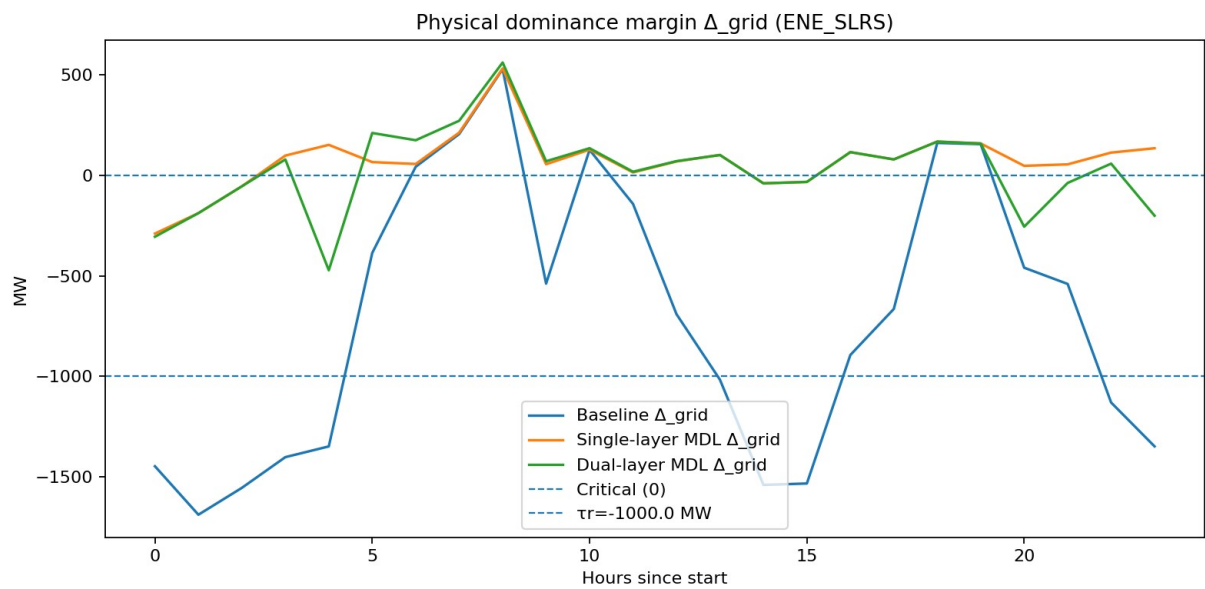


Figure 2. Physical dominance margin  $\Delta_{grid}$  under baseline, single-layer MDL, and dual-layer MDL.



Figure 3. Governed viability margin  $\Delta_{\text{true}}$  for the dual-layer simulation, shown against  $\Delta_{\text{grid}}$  after reserve gating.

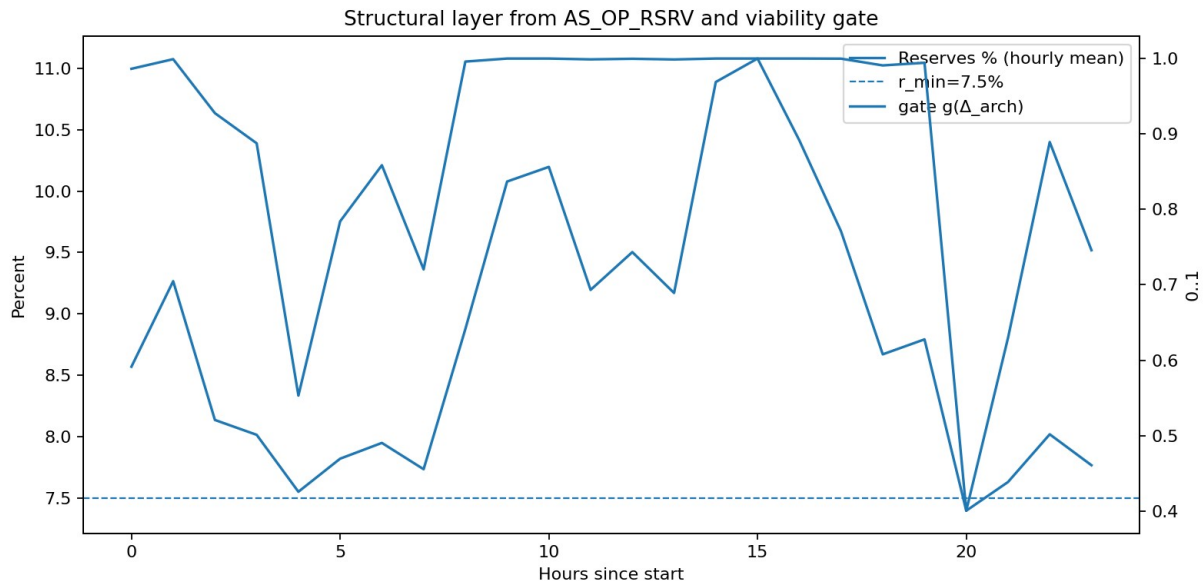


Figure 4. Reserve series and the structural admissibility gate  $g(\Delta_{\text{arch}})$ , with the 7.5% reserve floor shown as the viability threshold.

## 7. Limits and recommended next steps

- This is a system-total adequacy simulation. It is useful for comparing controller logic, not for claiming dispatch-feasible operations on the actual grid.
- Because  $u(t)$  is modeled as curtailable load, the simulation should be read as an aggregate demand-response / non-essential shedding proxy, not a literal hour-by-hour CAISO dispatch schedule.
- The next logical extension is sensitivity testing: vary  $u_{\text{max}}$ , reserve floor  $r_{\text{min}}$ , gate slope  $k$ , and burden gains to trace the trade-off frontier between residual deficit and control effort.
- If you want this packaged for formal submission, add one appendix page with the exact filenames, timestamps, and code version used to generate the CSV exports.

## 8. Source files referenced in this report

This appendix lists the uploaded files that the report relied on and the role each one played in the analysis.

File	How it was used
Information_used.txt	Declared the original CAISO extracts and the exact fields used.
The_Mena_Dominance_Law__Viability_Governed_Control_Under.pdf	Provided the grid-embodiment equations, controller parameters, evaluation metrics, and stated limitations.
baseline.csv	Hourly baseline trace with no curtailment.
mdl_single.csv	Hourly outputs for the single-layer MDL controller.
mdl_dual.csv	Hourly outputs for the dual-layer MDL controller.
metrics.csv	Policy-level summary metrics used in the executive summary and result table.
control_real.png, delta_grid_real.png, delta_true_real.png, reserves_gate_real.png	Inserted as report figures to make the PDF self-contained.