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KAERI–NEA POSY Workshop · KNS 2026

Network Representation for Power-System Cost Analysis

Modeling approaches and considerations for the Korean case

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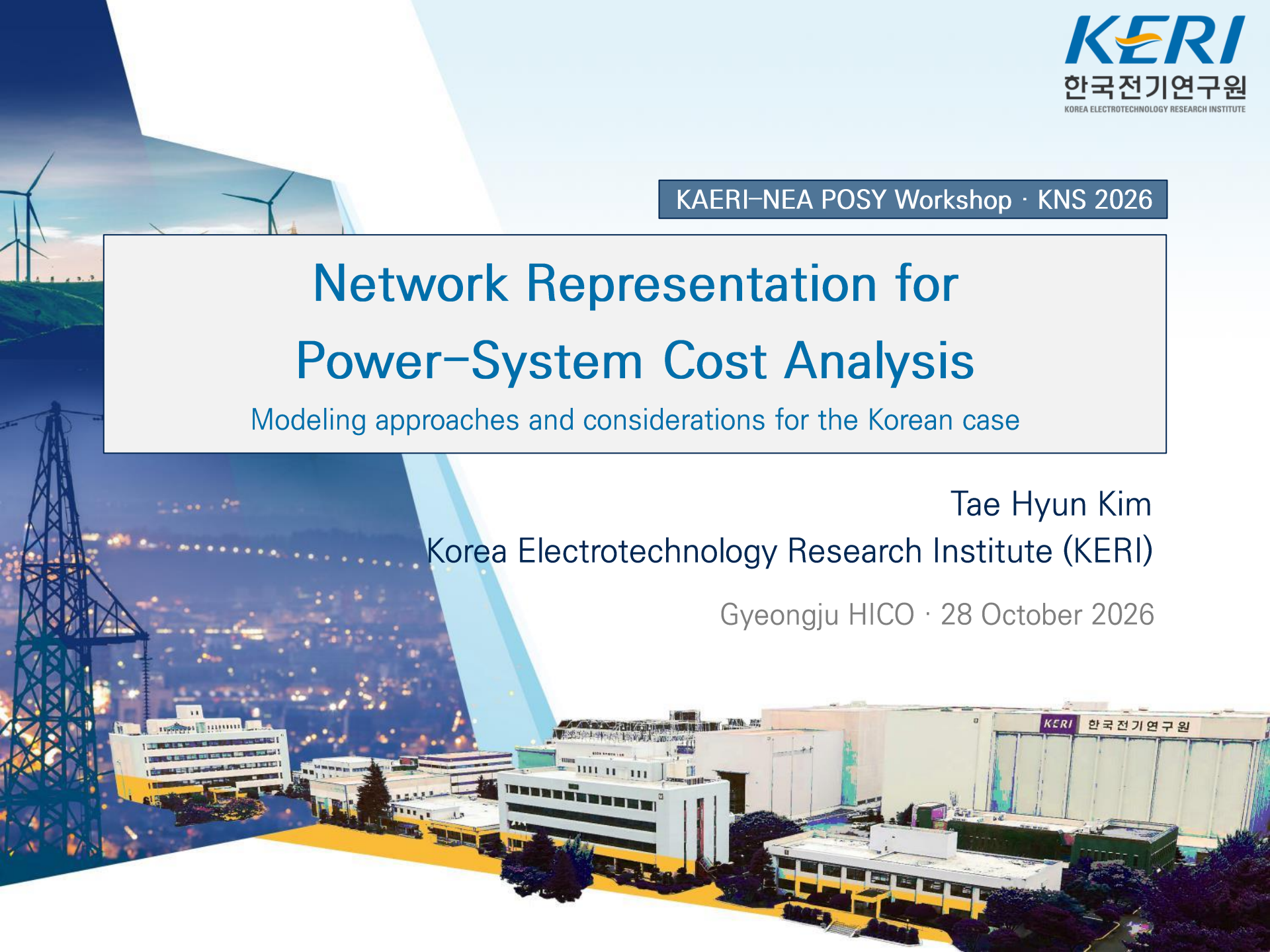


Outline

1. Why network representation matters
2. The 11–bus representation in POSY
3. Independent test on a public network
4. Implications and questions for joint work



Why network representation matters

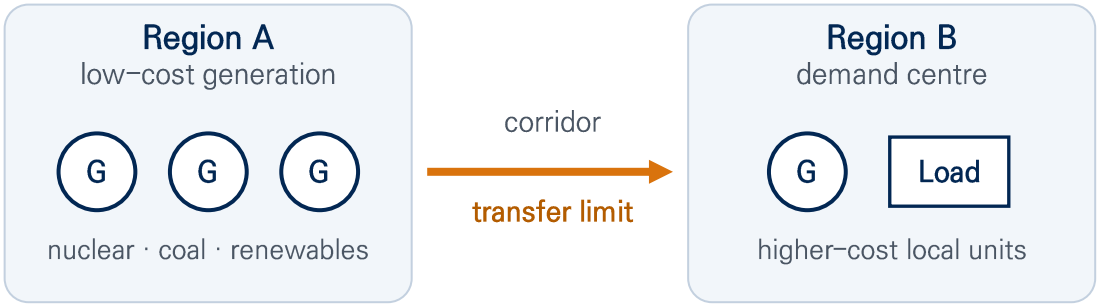
1 | Why the network matters in long–term cost analysis

Same fleet, different system cost

Schematic

- System cost depends not only on which plants are built,
- but also on where they are and whether the network can deliver their output

① A two–region example



→ When the corridor is full, low–cost output cannot reach demand

→ Higher–cost local units run, or renewable output is curtailed

② Network features that shape cost

1. Location of generation and demand
2. Connections between regions
3. Capacity of each line or corridor

How should transmission be represented in long–term planning models?

Why network representation matters

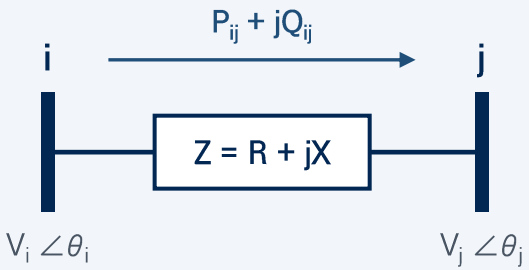
2 | Three ways to represent power flow

More network physics, heavier computation

Formulations

- The formulations differ in how much network physics they keep
- and in how hard they are to solve at planning scale

	Transport model	DC–OPF (linearised power flow)	AC–OPF
Flow on each path	Chosen freely within link limits	Set by phase–angle differences and line reactances (Kirchhoff)	Set by the full AC power–flow equations
Represents	Regional balance and transfer capacities	Active–power flows, network loops and line limits	Active and reactive power, voltages, losses, line limits
Leaves out	Loop flows; how flow splits over parallel paths	Voltage magnitude, reactive power, losses (basic form)	Dynamic and stability limits (steady state only)
Problem type	Linear	Linear	Non–linear, non–convex
Use in long–term planning	Light; physics simplified	Practical compromise for many hours and investment decisions	Data– and computation–intensive at planning scale



AC power flow (non–linear)

$$P_{ij} = V_i^2 g - V_i V_j (g \cos\theta_{ij} + b \sin\theta_{ij})$$
$$Q_{ij} = -V_i^2 b - V_i V_j (g \sin\theta_{ij} - b \cos\theta_{ij})$$

$g + jb = 1 / (R + jX)$, $\theta_{ij} = \theta_i - \theta_j$

→

DC power flow (linearised)

$$P_{ij} \approx (\theta_i - \theta_j) / X$$

$R \ll X$, $|V| \approx 1$ p.u., $\sin\theta \approx \theta$
Q, losses, $|V|$ not modelled
"DC" = linearised AC, not HVDC

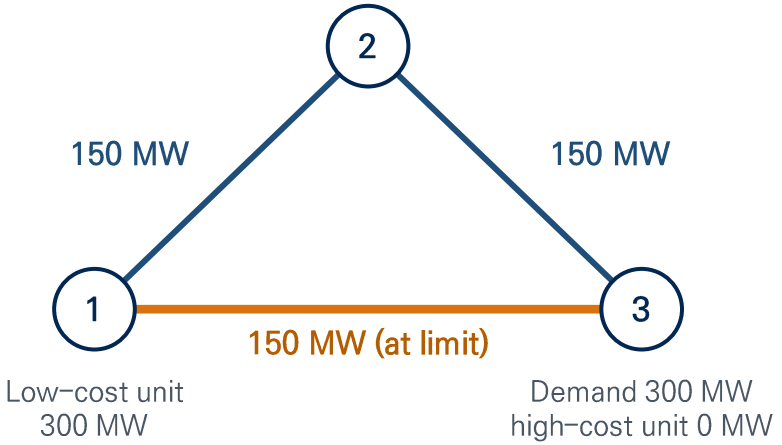
3 | Transport versus DC power flow: a three–bus example

Same network and limits, different dispatch

Illustrative example

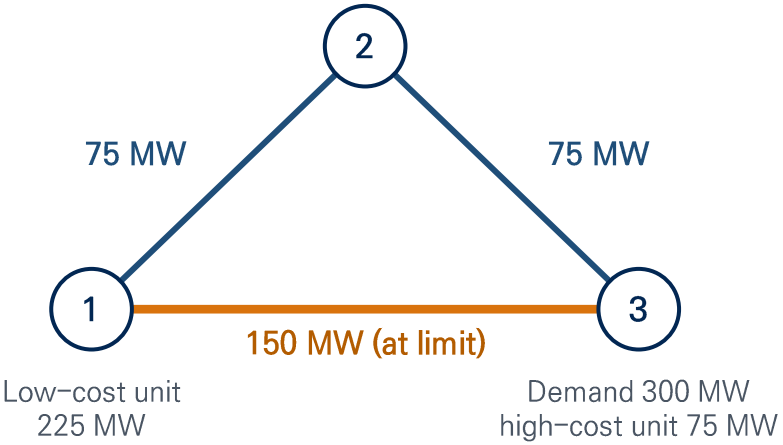
- With the same network and limits, transport can route power around a congested line
- DC power flow cannot: flows split over parallel paths by reactance

Transport model



All 300 MW from the low–cost unit

DC power flow



Transfer limited to 225 MW;
75 MW from the high–cost unit

Line limits 1–3: 150 MW · 1–2 and 2–3: 300 MW Equal reactances: the direct line carries two thirds of the transfer

4 | Two separate choices: power–flow formulation and spatial detail

Formulation and spatial detail are separate choices

Framework

- DC–OPF on an aggregated network adds Kirchhoff–consistent flows between zones
- but does not restore the transmission limits omitted within the zones

more network physics →

↑ more spatial detail

	Transport	DC–OPF	AC–OPF
Detailed nodal network	—	Kirchhoff flows and individual line limits	Full steady–state physics; heavy at planning scale
Aggregated network	—	Equivalent lines between retained buses	—
Regional / zonal model	Transfer limits between zones only	**Kirchhoff flows between zones; intra–zonal limits absent**	—

Moving right adds network physics between the retained nodes; moving up keeps the lines — and their limits — inside the zones



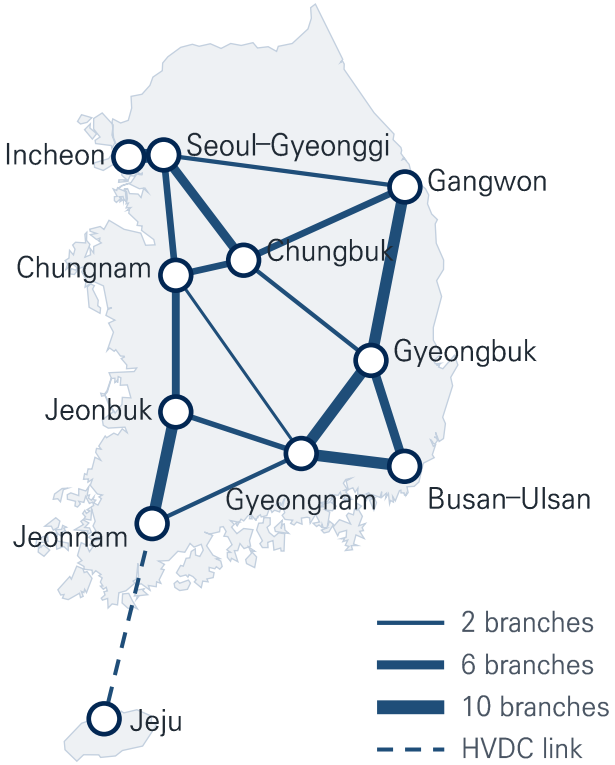
The 11-bus representation in POSY

The 11-bus representation in POSY

1 | The Korean 11-bus representation used in POSY

11 regional buses · 16 AC corridors · 1 HVDC link — POSY input

- A deliberately simple public regional network,
- chosen when validated national-scale network data were limited



Initial choice

- Validated public network data for national long-term planning were limited
- KPG193 then had a limited validation record; the CNU model was familiar, and one bus per region keeps results interpretable

Preparation for POSY

- Original public data: 11 regional buses, 82 inter-regional branch records (incl. the Jeju connection)
- 81 AC records → 16 AC corridors by region pair (summed ratings, parallel-equivalent R/X)
- Jeju: Gyeongnam bus in the original record → Jeonnam-Jeju HVDC link in the POSY input
- Initial data transfer: transfer capacities; recent POSY2 DC-OPF uses the equivalent reactances (confirmed with KAERI, Oct 2026)

POSY2 supports multi-node networks; the 11-bus case is a data choice, not a software limit.

The 11-bus representation in POSY

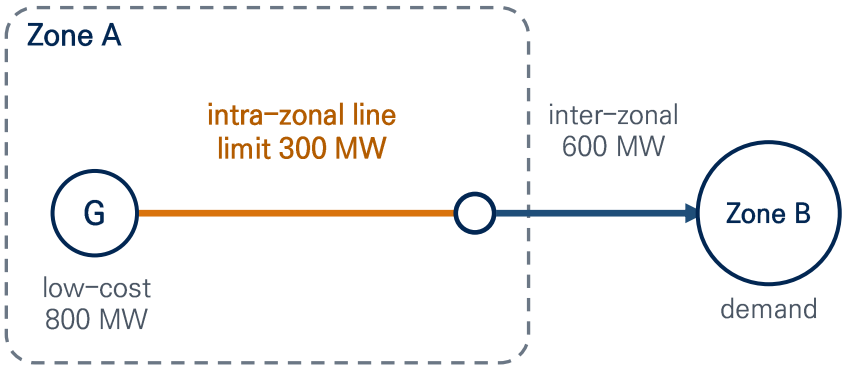
2 | What spatial aggregation removes

Links between zones stay, limits inside them go

Illustrative example

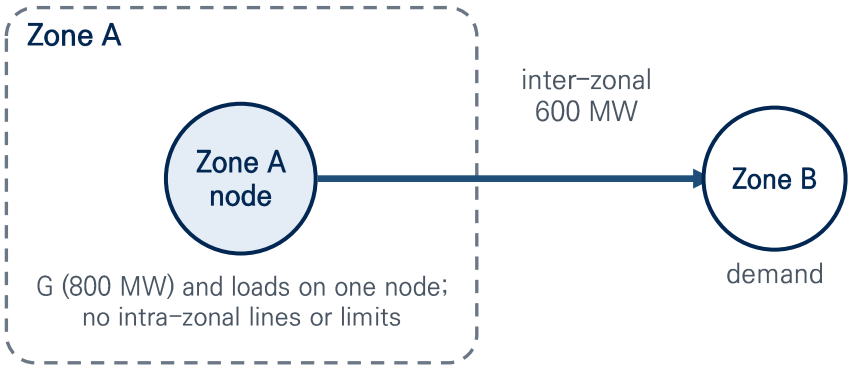
- Aggregation keeps the links between zones but drops the lines inside each zone
- Output constrained inside a zone can appear deliverable to demand elsewhere

Detailed network



Low-cost output that can reach Zone B: 300 MW

Aggregated (zonal) model



Low-cost output that appears deliverable: 600 MW

→ Affects dispatch, curtailment and system cost

→ Summing corridor ratings and using parallel-equivalent R/X do not preserve each line's own thermal limit



Independent test on a public network

1 | Detailed and zonal models of the same public network

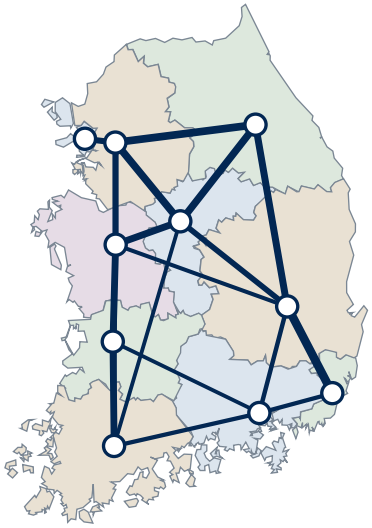
Same system at nodal and zonal resolution

KERI study · not POSY

- A detailed nodal model and zonal models of the same system
- were solved under identical conditions (independent KERI study, not POSY)



Detailed nodal reference
1,115 buses · 3,359 AC lines
7 HVDC links



Example zonal model
10 administrative zones
18 zone pairs

Common setting

- 2038 public network, generation fleet and demand (633 TWh)
- DC–OPF; one year as 9 weeks × 3–hour blocks (504 periods)
- Capital–region interface limit 14,372 MW; CO_2 cap 83.1 Mt
- Same generators, demand and storage in every model

Nine zonal models

- 3 zone definitions: administrative, network–based (PTDF), congestion–based
- × 3 inter–zonal representations: transport, equivalent DC network, aggregated PTDF

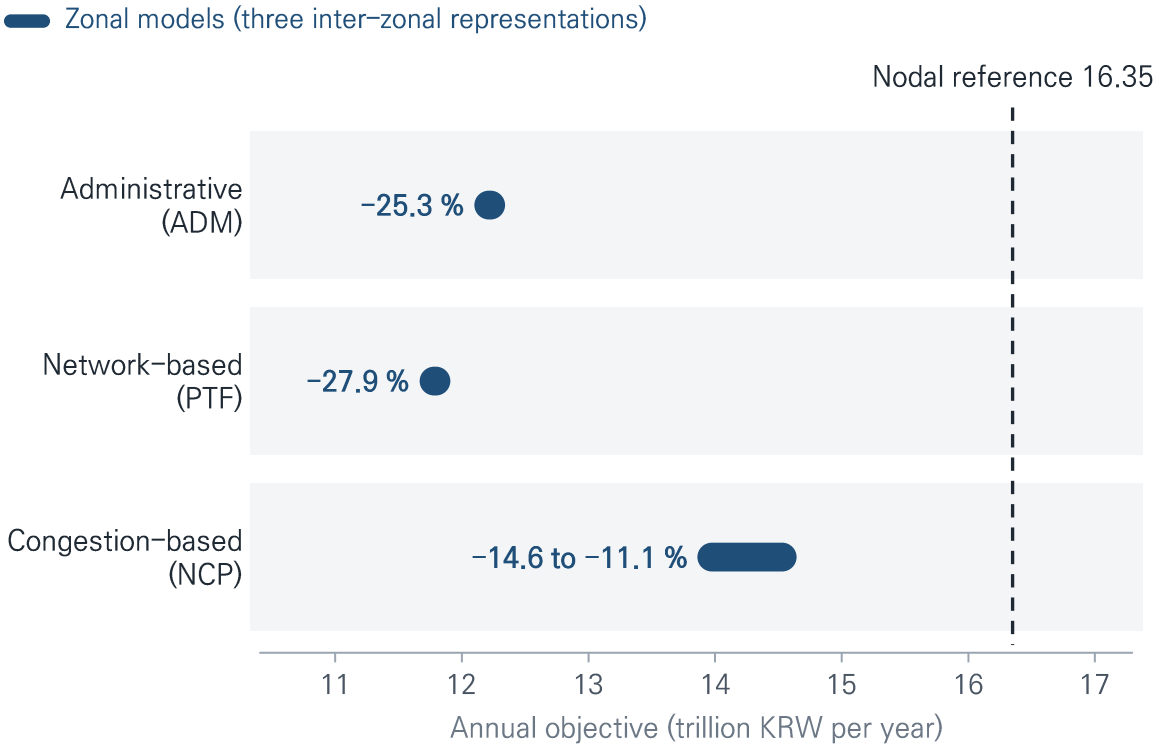
Independent test on a public network

2 | Zonal models estimated lower operating costs

−11.1 % to −27.9 % against the nodal reference

KERI study · not POSY

- All nine zonal models estimated a lower annual operating cost than the nodal reference
- A lower cost does not indicate a better model



- Part of the gap can come from constraints the zonal model no longer sees
- Results differed by up to 16.8 percentage points across zone definitions, and by at most 3.5 points between representations within one definition

3 | Relaxing intra–zonal transmission constraints

Intra–zonal limits removed: 16.35 → 11.85–14.89

KERI study · not POSY

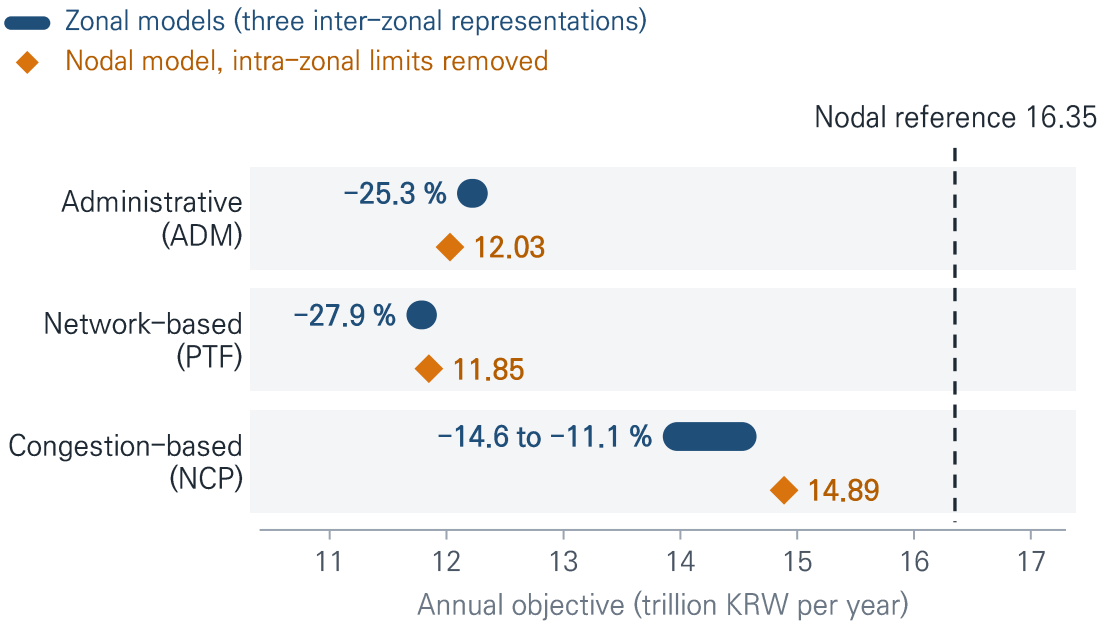
- Removing only intra–zonal line limits lowered the detailed model's annual objective
- to a magnitude similar to the zonal results (trillion KRW per year)

The experiment (detailed network)

- Kept: all buses and lines, DC power–flow relations, inter–zonal line limits, interface and CO_2 limits
- Removed: thermal limits of AC lines inside each zone
- Not a re–optimised zonal model — a counterfactual on the detailed network

Intra–zonal lines above their removed limits

Zones	ADM	PTF	NCP
Lines	337	312	207



Omitting intra–zonal transmission limits can materially change the cost outcomes of an aggregated model.



Implications and questions for joint work

1 | What this evidence shows — and what it does not

An independent test, not a validation of POSY

Interpretation

- The GIST study is an independent test on a synthetic public network
- POSY and GIST differ in year, inputs, network, resources and constraints

Shown in this study

- Spatial aggregation and the inter–zonal representation changed operating–cost results
- Removing intra–zonal transmission limits alone changed the cost substantially
- Zonal results should be read together with the network constraints they omit

Not established

- The size or sign of any cost error in POSY 11–bus results
- Whether intra–zonal transmission limits materially affect POSY scenario results
- Effects on POSY long–term generation mix or total system cost
- Behaviour under all operating and stability conditions of the real Korean grid

The study does not validate POSY — it shows why network representation matters when cost results are interpreted.

2 | Questions for joint work

Representation should follow the research question

Discussion

- Zonal models can be useful for long–term cost analysis
- With intra–zonal limits omitted, interpretation depends on the research question

1. Which POSY generation–mix and system–cost comparisons can be interpreted with the current network representation?
2. For which research questions do intra–regional transmission limits and spatial resolution matter?
3. What level of network representation and validation would suit future POSY objectives?

Any validation scope and work plan would be defined jointly, after agreeing on the research objectives.

Thank you

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Appendix



Appendix

A | Case–study specification

Item	Specification
Network	GIST Korea Test System v6.2.0, mainland 154 kV and above, public 2038 transmission overlay: 1,115 buses, 3,359 AC branches, 7 HVDC/back–to–back links
Fleet and demand	Public 2038 fleet (nuclear 35.5, coal 23.6, gas 62.7, solar 75.8, onshore 14.3, offshore 24.8 GW, …); demand 633 TWh (11th Basic Plan target year)
Time	9 representative weeks × 3–hour blocks = 504 periods (weights sum to 8,760 h); storage chronology by week
Constraints	DC power flow with Kirchhoff constraints; line limits; capital–region interface 14,372 MW (14 elements); CO_2 cap 83.1 Mt
Cost basis	2024 monthly fuel prices (KPX/EPSIS) × heat rate; value of lost load 5×10^6 KRW/MWh; comparable only within this study
Zonal models	10 zones; 3 zone definitions × 3 inter–zonal representations; inter–zonal capacity = summed ratings of the cut branches
Reference result	Objective 16.349 trillion KRW/yr; unserved energy 2,075 MWh in one local pocket of the study network (not an adequacy statement)

Appendix

B | Zone definitions and the relaxation comparator

Element	Definition
Administrative (ADM)	Ten administrative regions (Seoul+Gyeonggi; Incheon; Gangwon; Chungbuk; Chungnam+Daejeon+Sejong; Jeonbuk; Jeonnam+Gwangju; Gyeongbuk+Daegu; Gyeongnam; Busan+Ulsan)
Network–based (PTF)	Ward clustering of nodal PTDF columns, with a connectivity repair
Congestion–based (NCP)	Clustering on the PTDF columns of the 85 congested branches of the reference, under a connectivity constraint
Transport (TRN)	One link per zone pair; capacity = summed ratings of the cut branches
Equivalent DC network (PEQ)	One line per zone pair with the parallel–equivalent reactance and the same summed rating; Kirchhoff constraints between zones
Aggregated PTDF (DPA)	Zone–pair flows = aggregated PTDF × zonal net exports (load–weighted shift keys); same summed ratings
Relaxation comparator	Full nodal network with intra–zonal thermal limits removed. For DC flows it equals a Ward/Kron–type reduction to the boundary buses — a comparator for this study, not an evaluation of Ward/Kron reduction methods in general

Appendix

C | Annual objective of all cases

Case	Zones	Inter–zonal representation	Objective (trillion KRW/yr)	vs reference	Unserved energy (MWh)
Detailed nodal reference	—	—	16.35	—	2,075
Zonal model	Administrative	Transport	12.22	−25.3 %	0
Zonal model	Administrative	Equivalent DC	12.22	−25.2 %	0
Zonal model	Administrative	Aggregated PTDF	12.22	−25.3 %	0
Zonal model	Network–based	Transport	11.79	−27.9 %	0
Zonal model	Network–based	Equivalent DC	11.79	−27.9 %	0
Zonal model	Network–based	Aggregated PTDF	11.79	−27.9 %	0
Zonal model	Congestion–based	Transport	13.96	−14.6 %	0
Zonal model	Congestion–based	Equivalent DC	14.54	−11.1 %	0
Zonal model	Congestion–based	Aggregated PTDF	14.20	−13.2 %	0
Intra–zonal limits removed	Administrative	(nodal network)	12.03	−26.4 %	0
Intra–zonal limits removed	Network–based	(nodal network)	11.85	−27.5 %	0
Intra–zonal limits removed	Congestion–based	(nodal network)	14.89	−8.9 %	0

Appendix

D | Public 11–bus model and the POSY input

AC corridor	Original branch records
Seoul–Gyeonggi – Gangwon	2
Seoul–Gyeonggi – Incheon	10
Seoul–Gyeonggi – Chungbuk	6
Seoul–Gyeonggi – Chungnam	4
Gangwon – Chungbuk	4
Gangwon – Gyeongbuk	8
Chungbuk – Chungnam	4
Chungbuk – Gyeongbuk	2

AC corridor	Original branch records
Chungnam – Jeonbuk	5
Chungnam – Gyeongnam	1
Gyeongbuk – Gyeongnam	8
Gyeongbuk – Busan–Ulsan	6
Jeonbuk – Jeonnam	8
Jeonbuk – Gyeongnam	3
Jeonnam – Gyeongnam	2
Gyeongnam – Busan–Ulsan	8

- Jeju connection — original public record: Gyeongnam–Jeju branch record (630 MW). POSY input: Jeonnam–Jeju HVDC link (630 MW), revised by the project team to match the actual grid (project first-year report).
- 16 AC corridors aggregate 81 original AC branch records; each corridor rating equals the sum of its branch ratings.