Probabilistic Simulation Methodology for Evaluation of Renewable Resource Intermittency and Variability Impacts in Power System Operations and Planning (3.4)

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MOTIVATION

- The conventional probabilistic simulation approach cannot be used to capture the time-varying nature and the inter-temporal effects required in the simulation of the storage and renewable resources nor the impacts of the transmission-constrained market environment
- Since the detailed representation of such time-dependent and uncertain phenomena is analytically intractable, we propose to address this problem via Monte Carlo simulation techniques

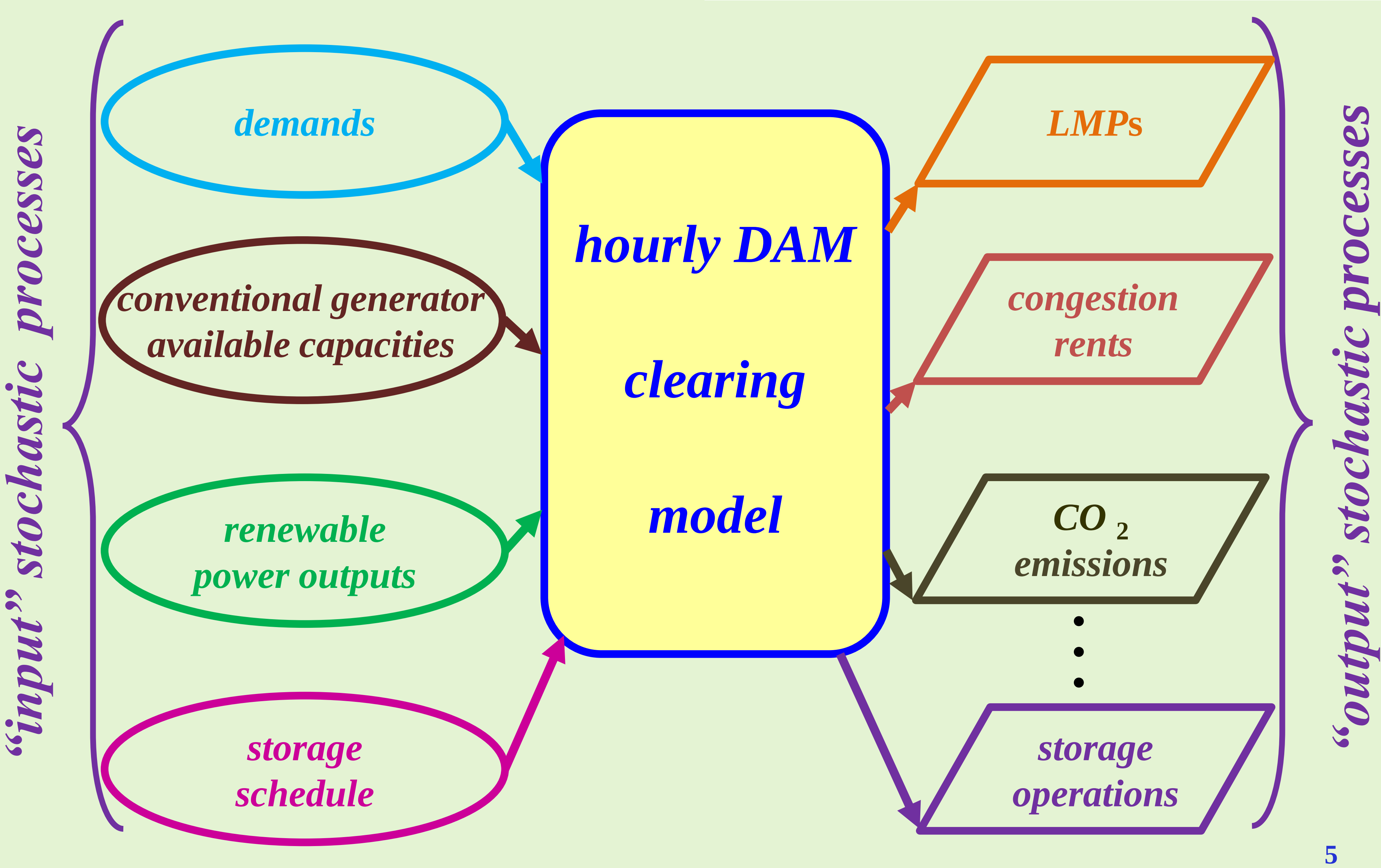
NEED TO EXPLICITLY REPRESENT

- The time-varying **demands** and their associated uncertainty
- The time-varying **supply resources** with their associated uncertainty:
  - conventional generators
  - utility-scale storage units
  - renewable resources
- The **spatial and temporal correlations** among the resources at the various sites and the demands
- The impacts of the **grid constraints**
- The hourly **day-ahead market** (*DAM*) outcomes

THRUST OF THE SIMMULATION APPROACH

- **We develop a comprehensive, computationally efficient *Monte Carlo simulation* approach to emulate the behavior of the power system with integrated storage and renewable energy resources**
- **We use *discrete-time stochastic processes* to model the system load and the resources**
- **We develop a *storage scheduler* to exploit arbitrage opportunities in the storage unit operations**
- **We emulate the impacts of the *transmission-constrained hourly day-ahead markets* (*DAM*s) to determine the power system operations**

PROPOSED SIMULATION APPROACH: CONCEPTUAL STRUCTURE



THRUST OF THE APPROACH

- We collect sample paths of the market outcome stochastic processes to evaluate the expected system variable effects
- We evaluate metrics such as:
  - nodal electricity prices (*LMP*s)
  - generation by resource and revenues
  - congestion rents
  - CO_2 emissions
  - *LOLP* and *EUE* system reliability indices

KEY CONTRIBUTIONS

- Development of a new simulation tool appropriate to address today's power industry challenges
- Salient features include:
  - quantification of the power system expected variable effects – economics, reliability and environmental impacts – in each sub-period
  - computationally tractable for practical systems

KEY CONTRIBUTIONS

- detailed stochastic models of the time–varying resources and loads allow the representation of spatial and temporal correlations
- storage scheduler for optimized storage operation to exploit arbitrage opportunities
- representation of the transmission–constrained market outcomes
- flexibility in the representation of the market environment /policy requirements

TYPICAL APPLICATIONS

- Resource planning studies
- Production costing issues
- Transmission utilization issues
- Environmental assessments
- Reliability analysis
- Investment analysis
- Various *what if* investigations

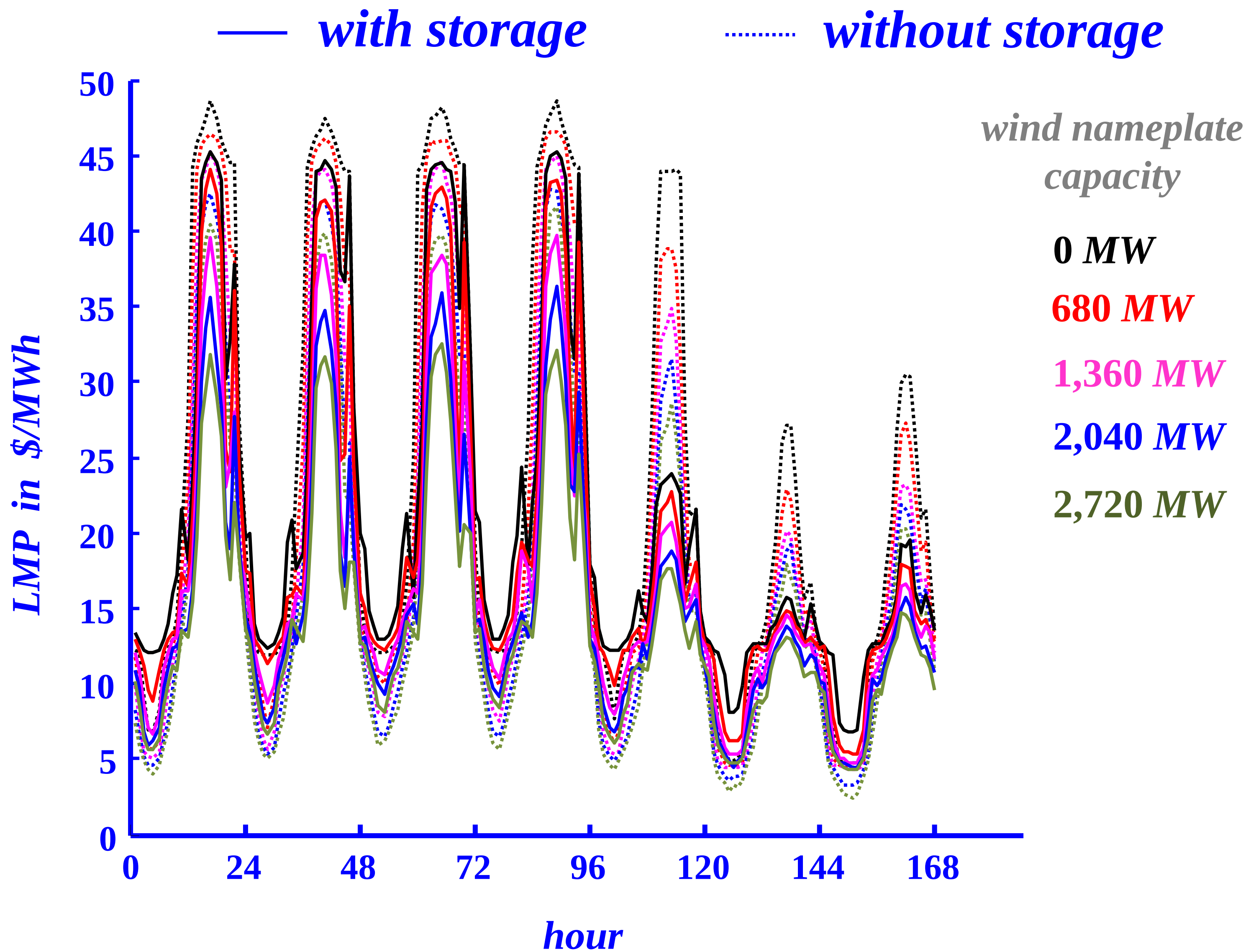
CASE STUDY: DEEPENING WIND PENETRATION

- The objective of this study is to perform a wind penetration sensitivity analysis and to quantify the enhanced ability to harness wind energy with the integration of a storage energy resource
- We evaluate the key metrics for variable effect assessment, including wholesale purchase payments, reliability indices and CO_2 emissions

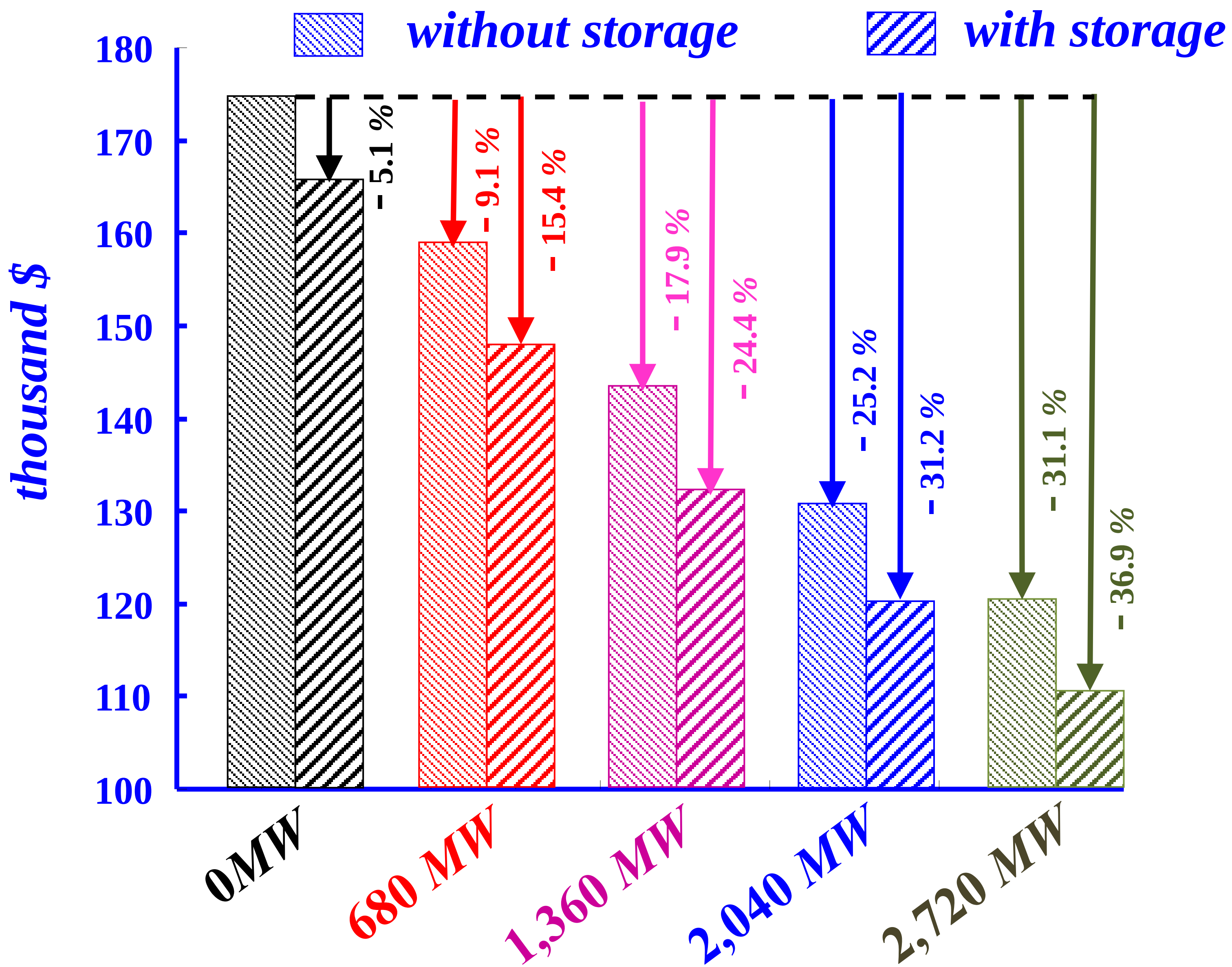
THE STUDY TEST SYSTEM: A MODIFIED IEEE 118-BUS SYSTEM

- Annual peak load: 8,090.3 *MW*
- Conventional generation resource mix: 9,714 *MW*
- 4 wind farms located in the Midwest with total nameplate capacity in multiples of 680 *MW*
- A storage unit with 400 *MW* capacity, 5,000 *MWh* storage capability and 89 *%* round-trip efficiency
- Unit commitment uses a 15 *% reserves margin* provided by conventional units *and the storage resources*
- Wind power is assumed to be offered at *0 $/MWh*

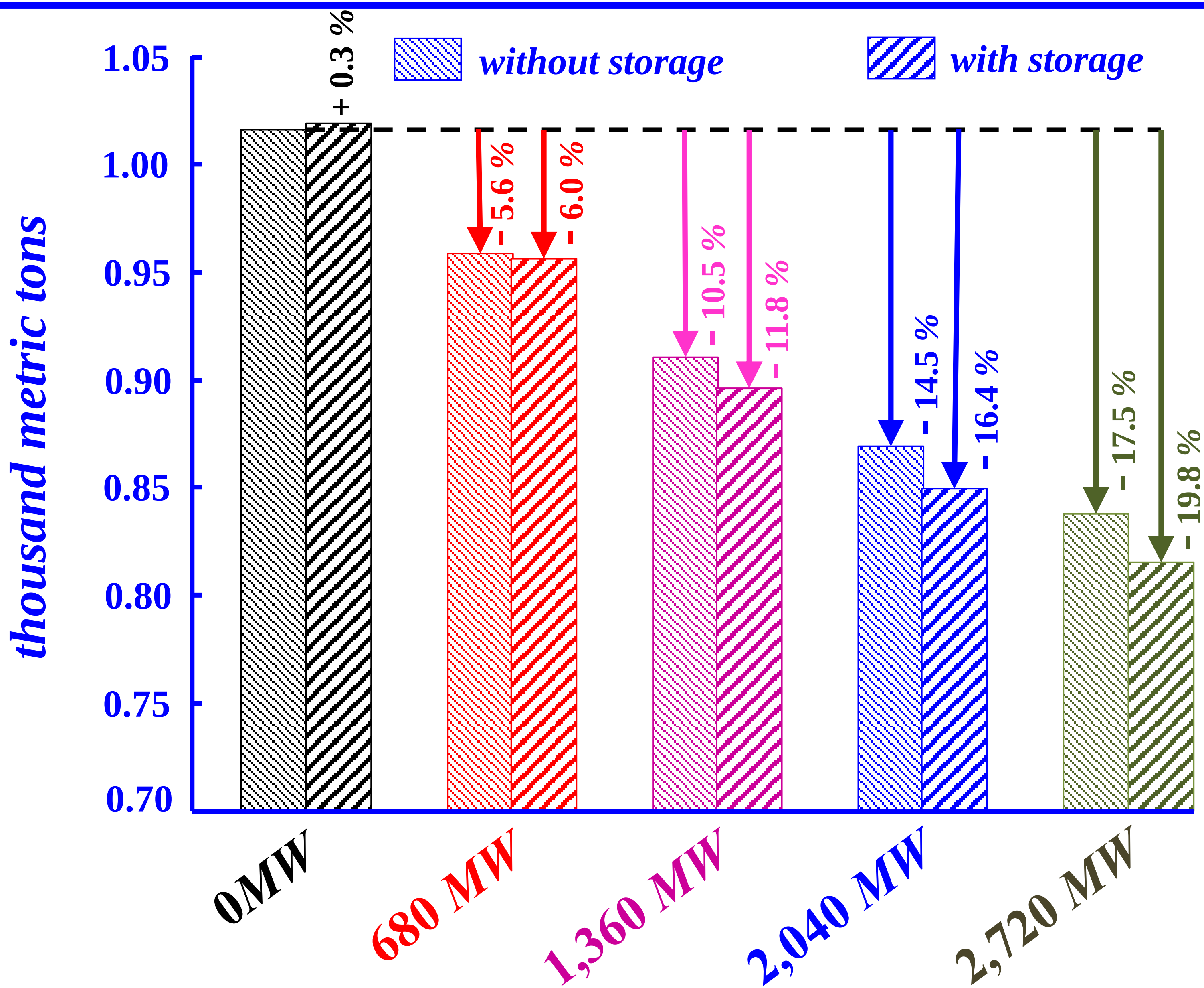
NODE 80 AVERAGE HOURLY *LMPs*



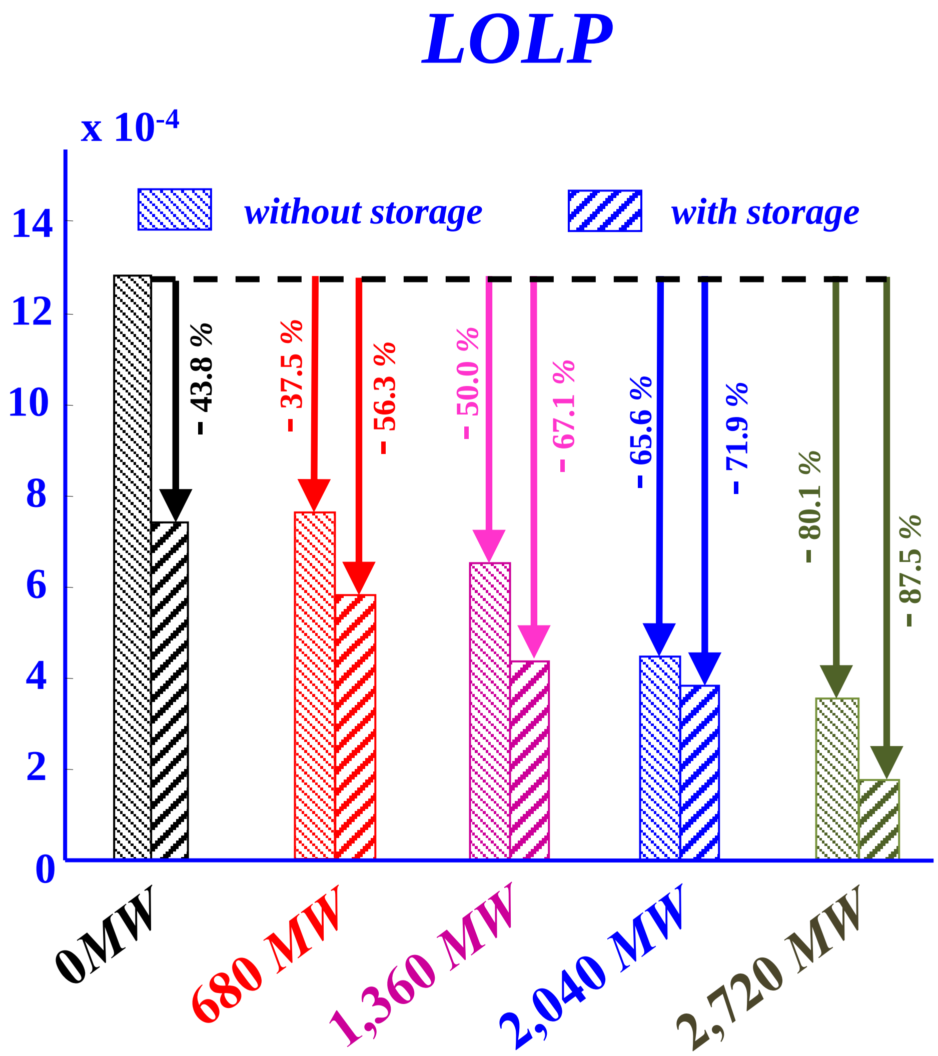
EXPECTED WHOLESALE PURCHASE PAYMENTS

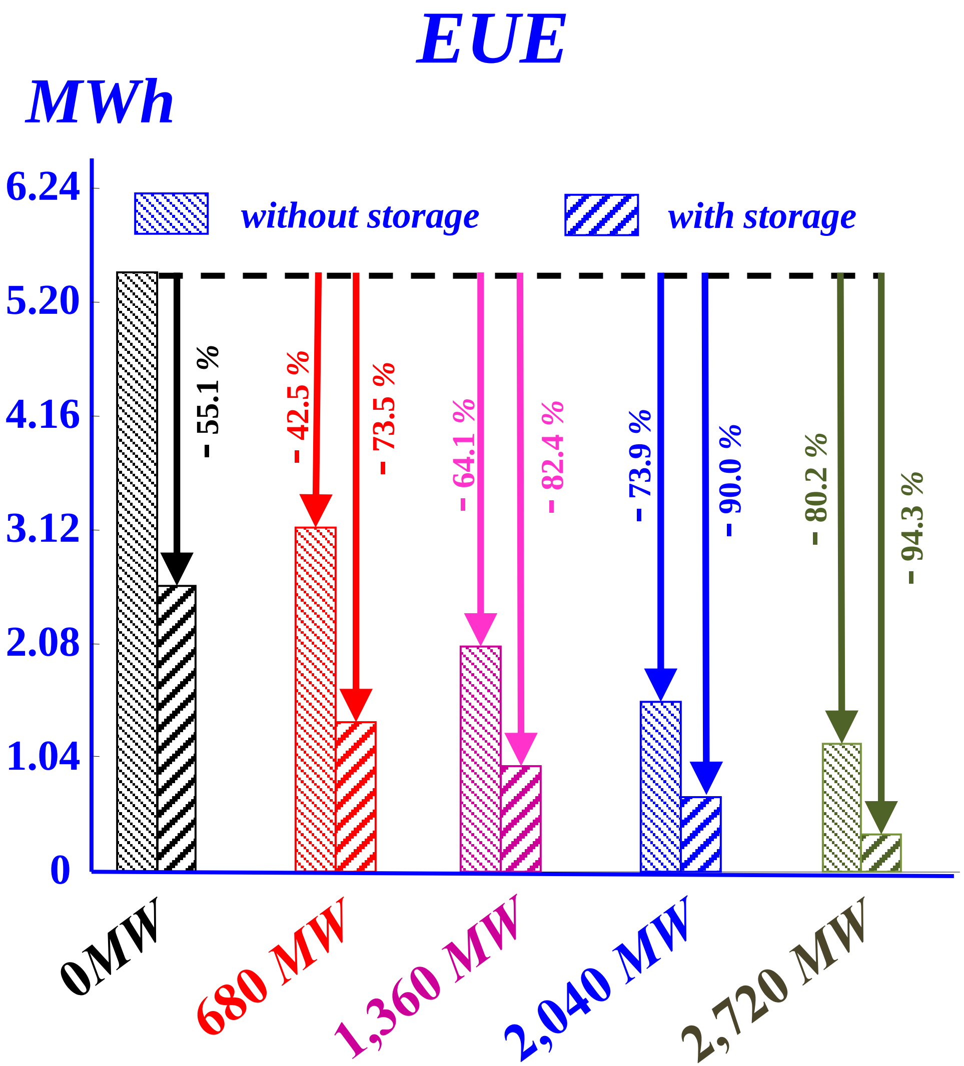


EXPECTED CO_2 EMISSIONS



ANNUAL RELIABILITY INDICES





CONCLUDING REMARKS

- Storage and wind resources consistently pair well together: they reduce wholesale purchase dollars and improve system reliability; storage seems to attenuate the “diminishing returns” trend seen with deeper wind power penetration
- The location of a storage unit can have large local impacts; siting requires case-by-case studies
- Wind resources can substitute for conventional resources to a very limited extent, even in a

SALIENT SIMULATION APPROACH CHARACTERISTICS

- A practically-oriented approach to simulate large-scale systems over longer-term periods
- Comprehensive, versatile and flexible approach to quantify the impacts of the integration of storage devices into power systems with deepening penetration of renewable resources
- Demonstration of the capabilities of the proposed approach on a wide range of planning, investment, transmission utilization and policy analysis studies

FUTURE DIRECTIONS

- **Extension of the approach to explicitly represent ramping requirements for conventional resources in the *DAM*s for systems with deepening penetration of intermittent resources**
- **Analysis of the impacts of increased ramping requirements on power system variable effects**
- **Design of a market for ramping capability service product provision by controllable resources**

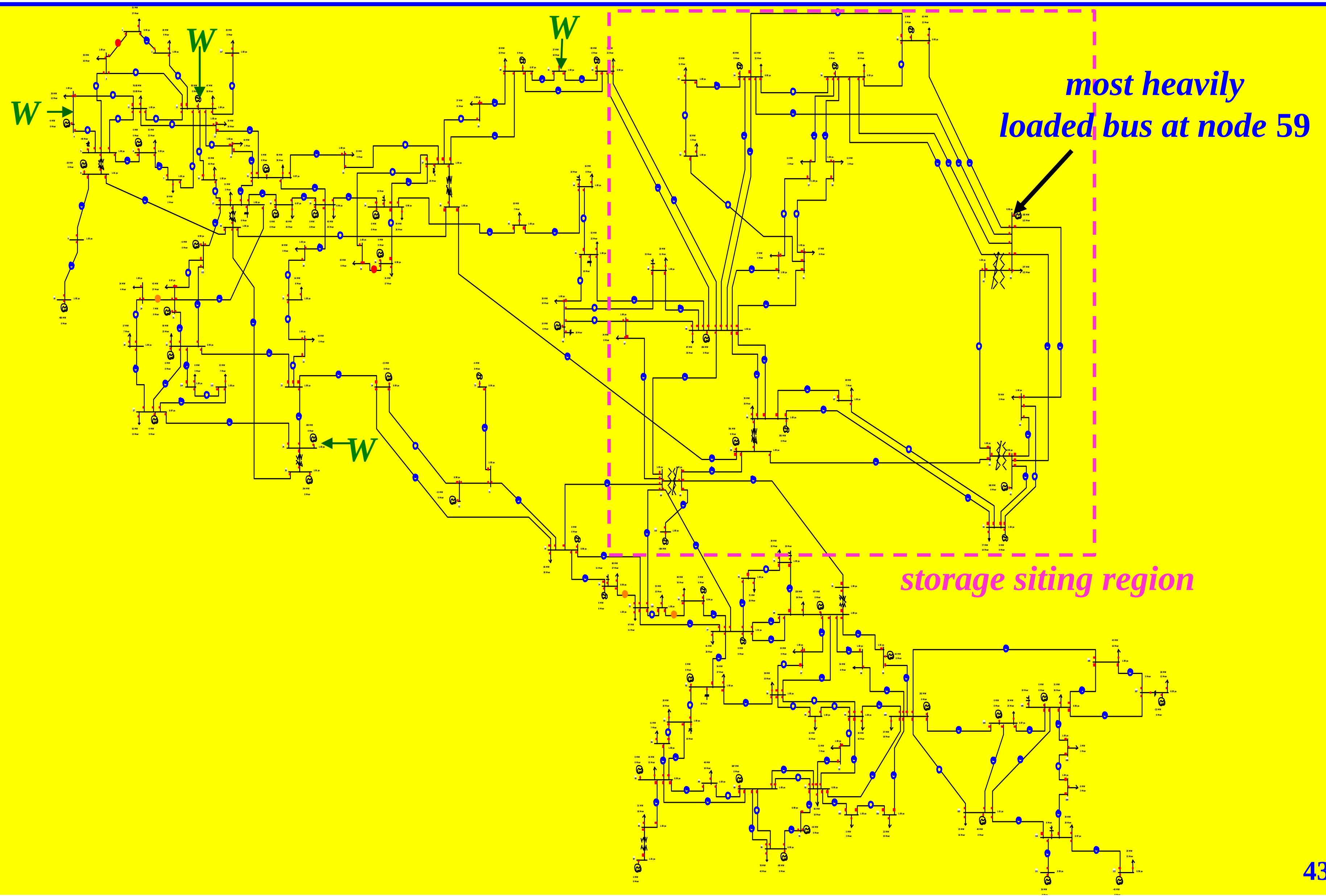
CASE STUDY: STORAGE UNIT SITING

- **The objective of this study is to perform a sensitivity analysis on the siting of 4 storage units in the system and assess its impacts on transmission usage and on the economics at the most heavily loaded bus in the network**
- **We quantify the expected *LMP*s at the load center at node 59 and the total congestion rents**

TEST SYSTEM OF THE STUDY: A MODIFIED IEEE 118-BUS SYSTEM

- Annual peak load: 8,090.3 *MW*
- Conventional generation resource mix: 9,714 *MW*
- 4 wind farms located in the Midwest with total nameplate capacity 2,720 *MW*
- 4 identical utility-scale storage units, each having 200 *MW* capacity, 5,000 *MWh* storage capability and 89% round-trip efficiency
- Reserves margin is set at 15 % and is provided by conventional *and storage* resources

STORAGE SITING ON THE MODIFIED IEEE 118 – BUS TEST SYSTEM

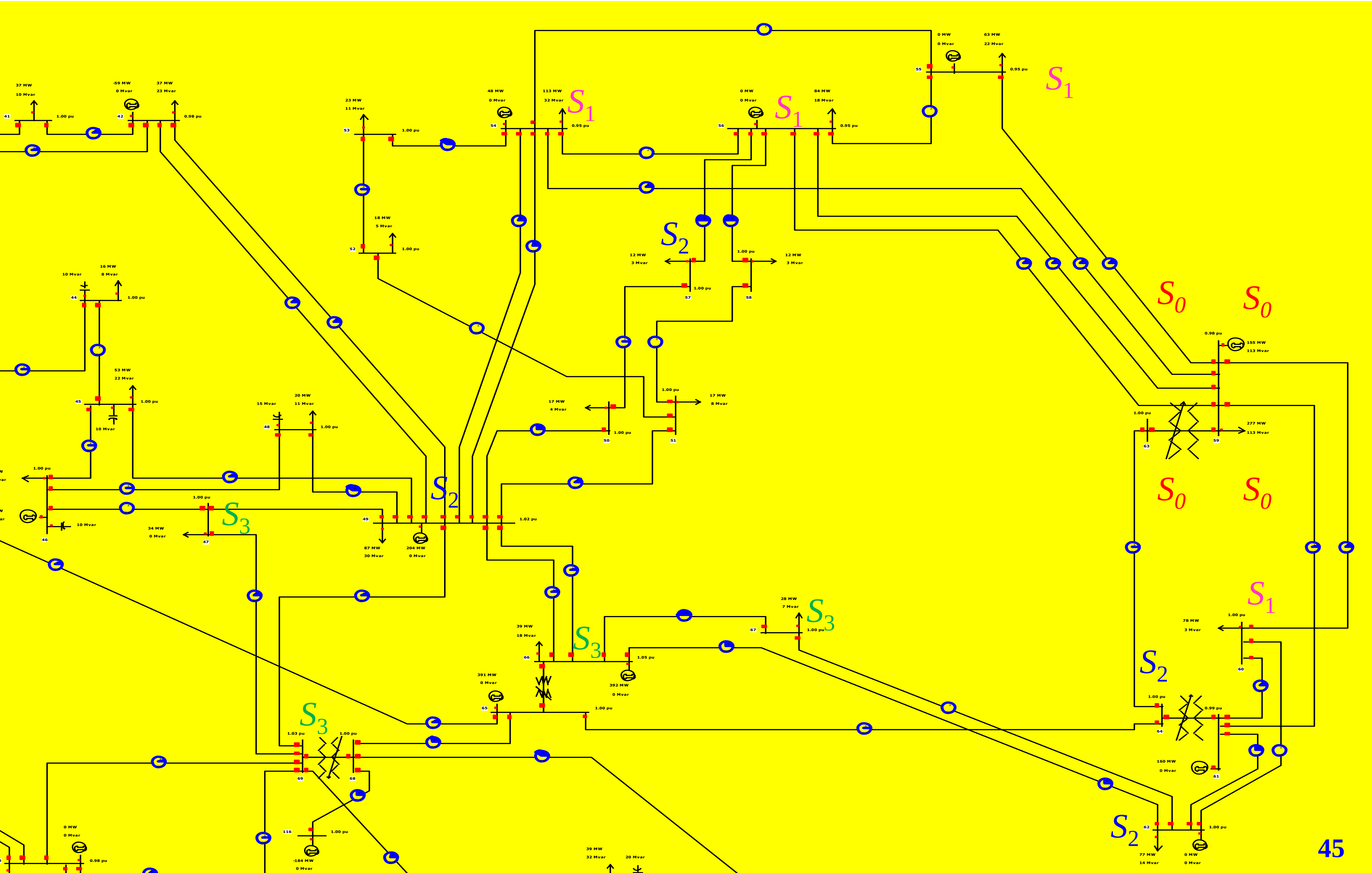


SENSITIVITY CASES IN STUDY SET II

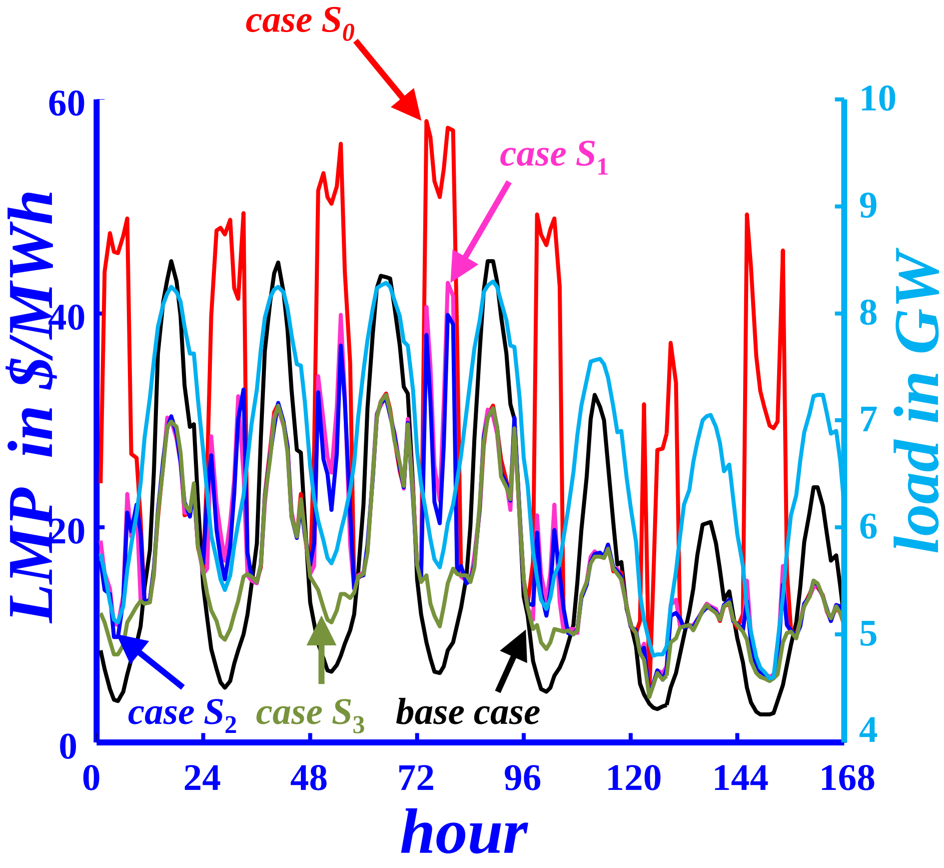
case	*siting of the storage units*
base	*no storage units*
S_0	*at the principal load center*
S_1	1 *node away*
S_2	2 *nodes away*
S_3	3 *nodes away*

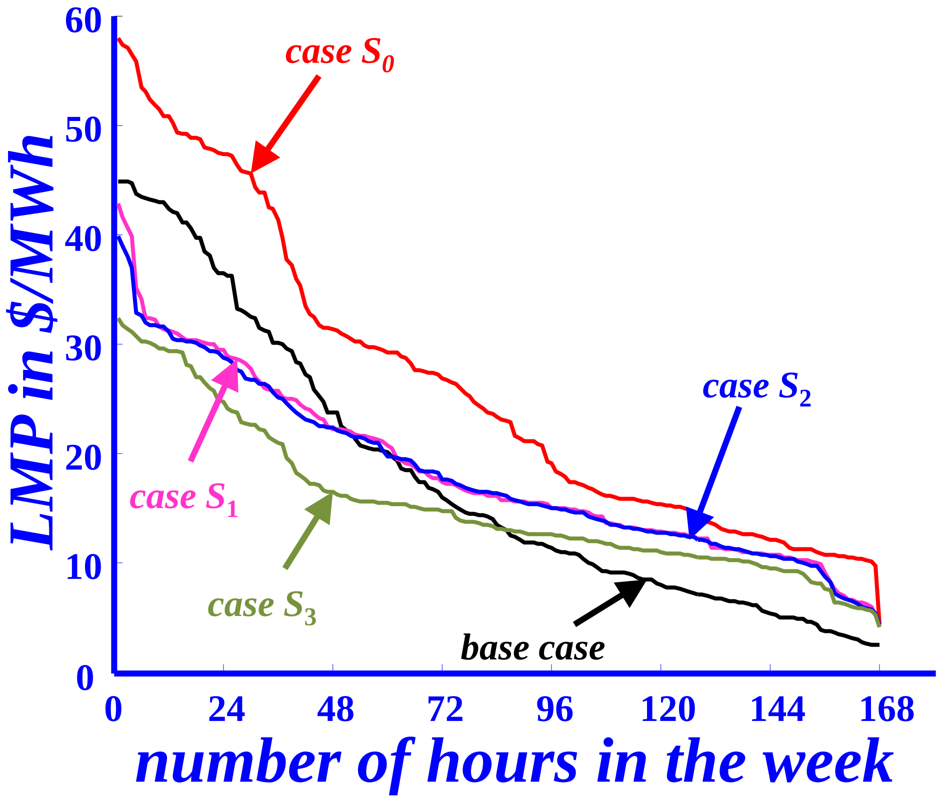
each case has 2,720 *MW nameplate wind capacity*

STORAGE SITING REGION

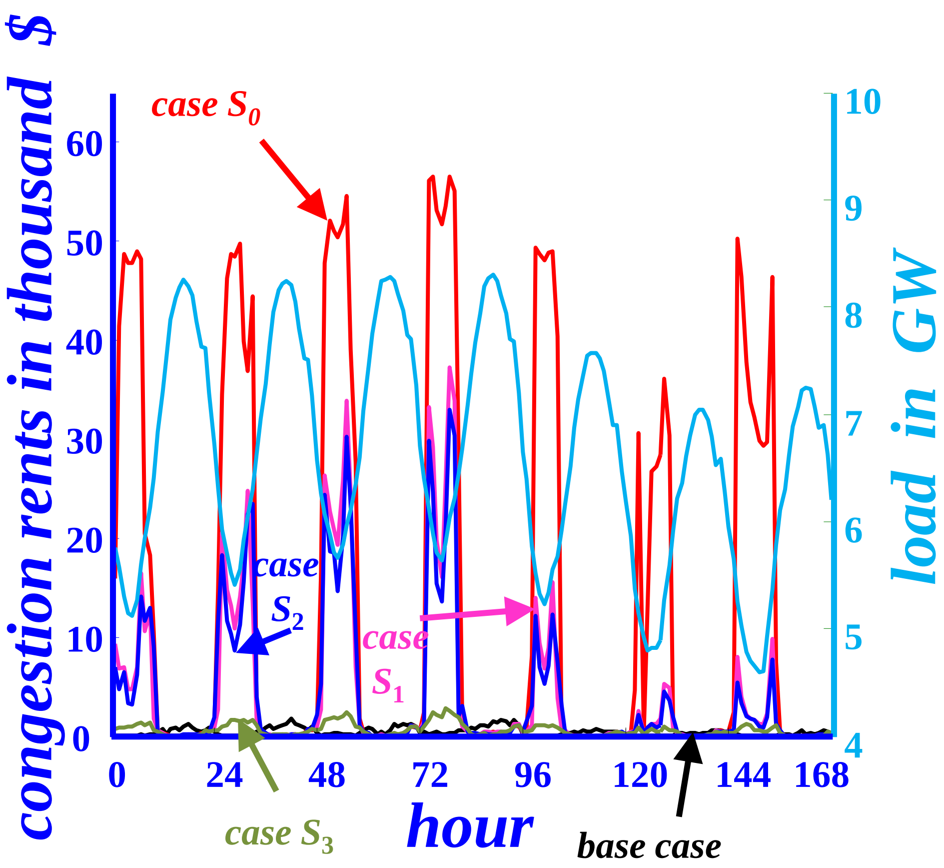


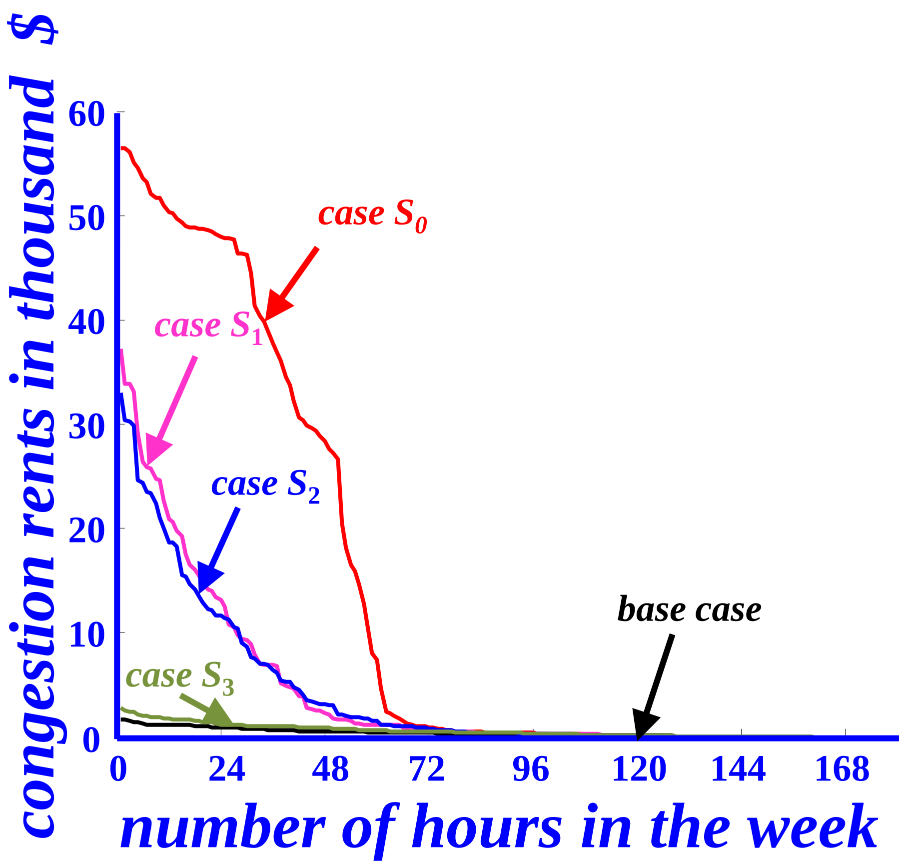
NODE 59 EXPECTED HOURLY *LMP*s



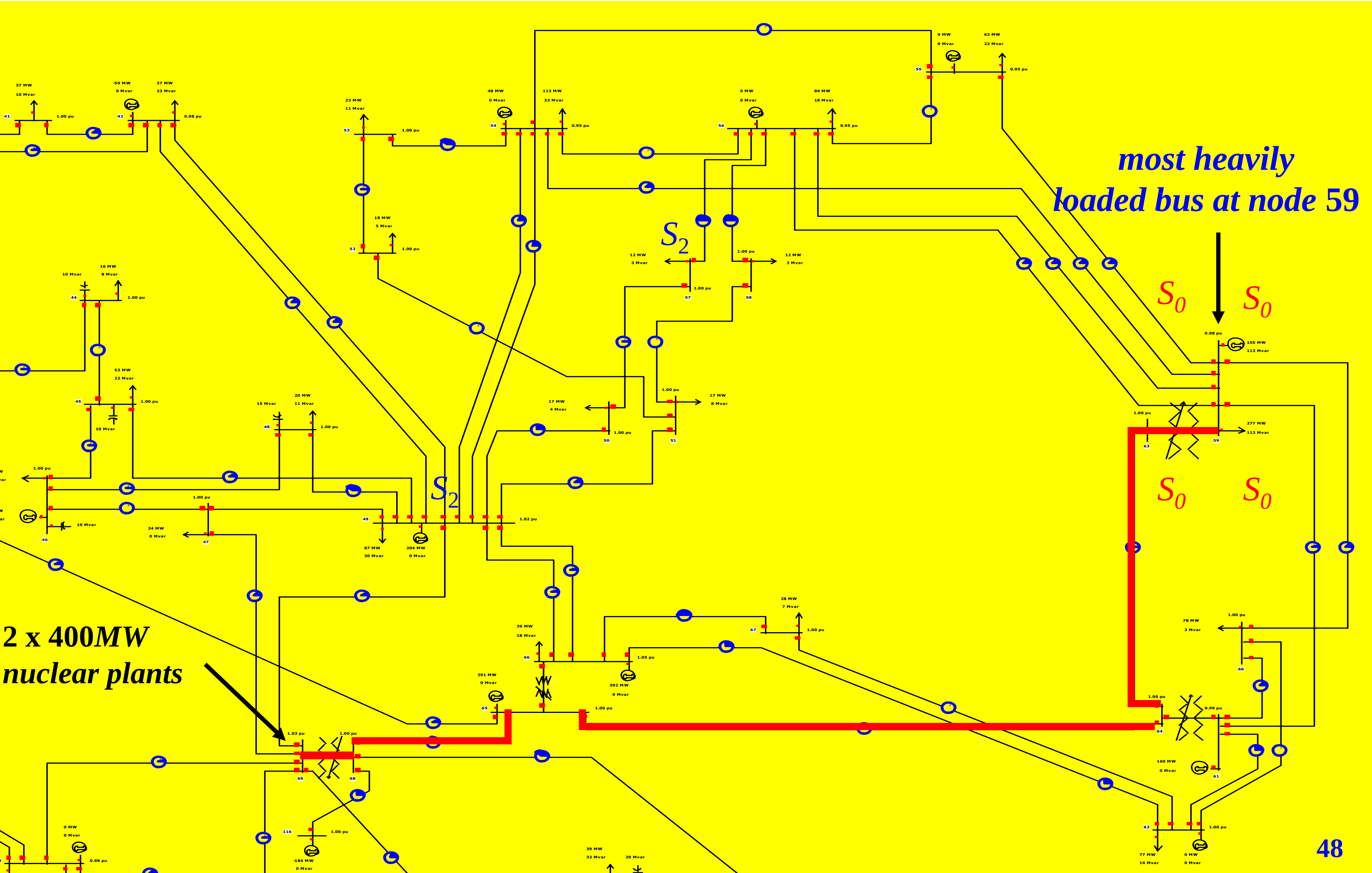


EXPECTED HOURLY CONGESTION RENTS

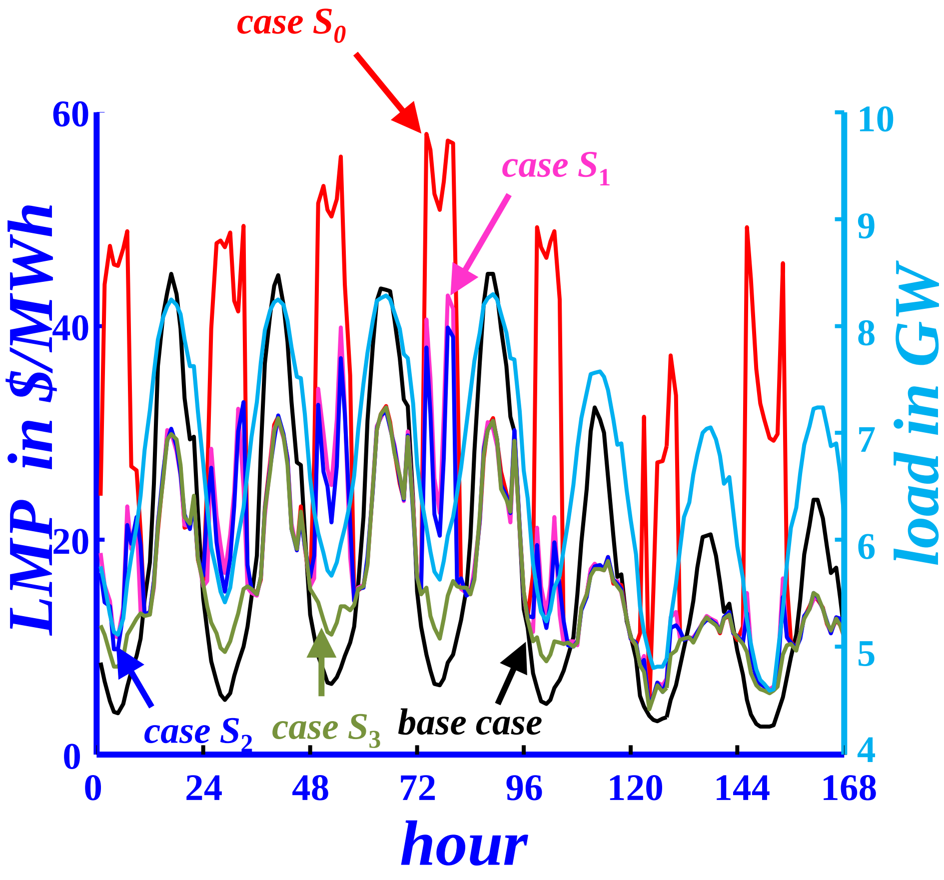


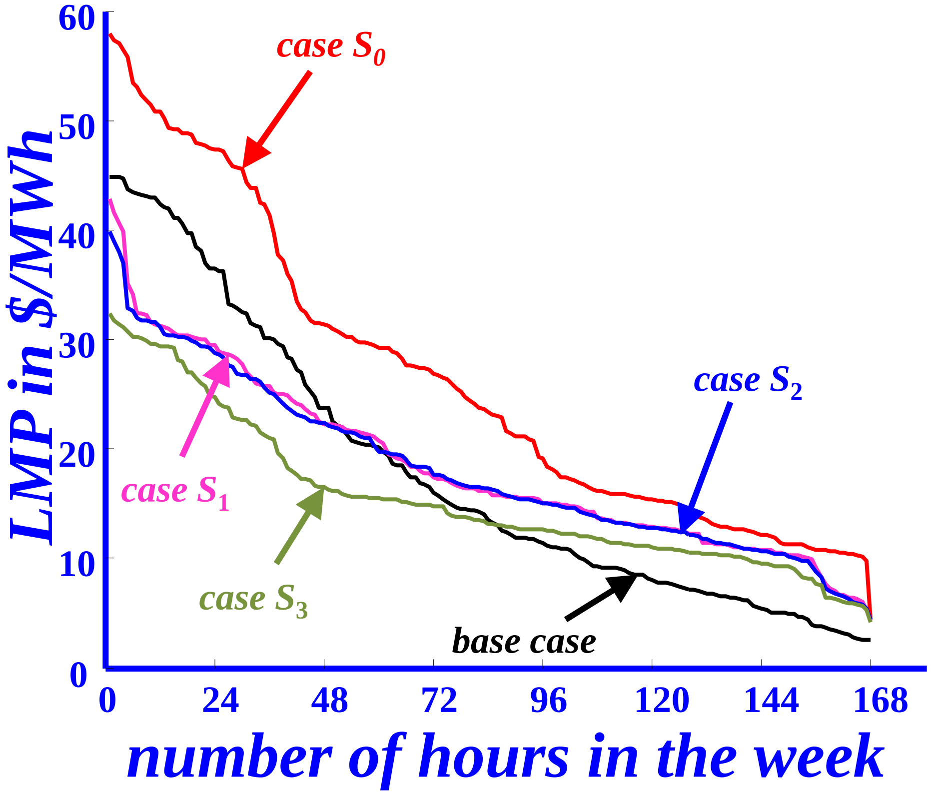


TRANSMISSION PATH CONGESTION AND ITS REENFORCEMENT

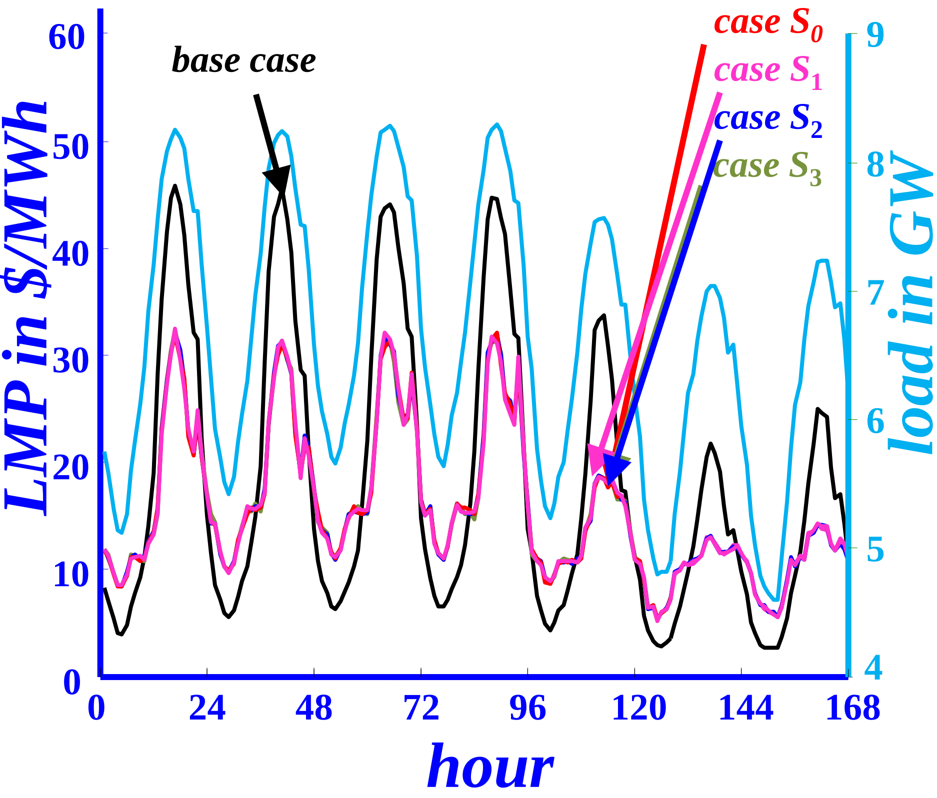


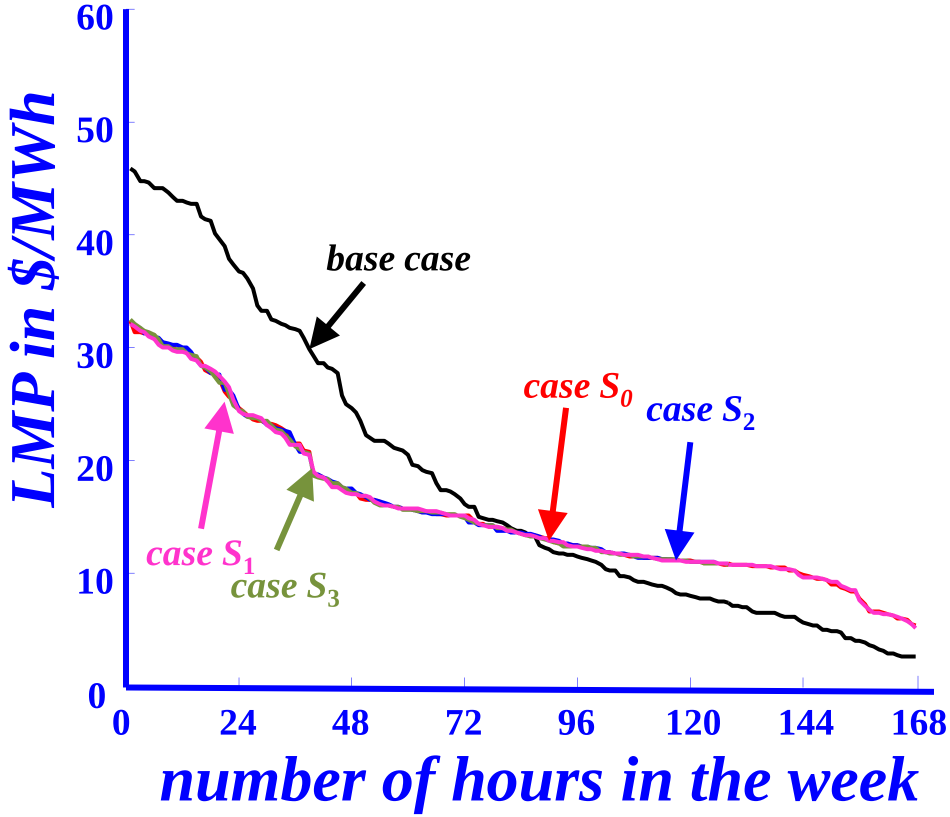
PRE – PATH – REENFORCEMENT NODE 59
AVERAGE HOURLY LMPs





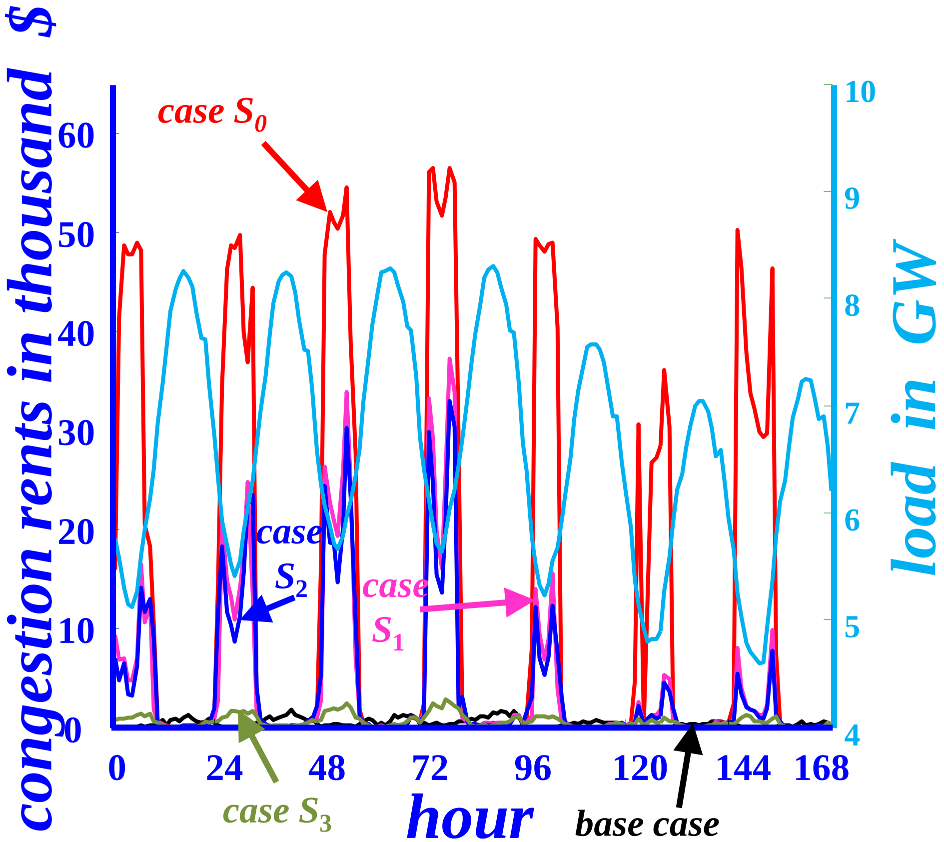
POST – PATH – REENFORCEMENT NODE 59
AVERAGE HOURLY LMPs

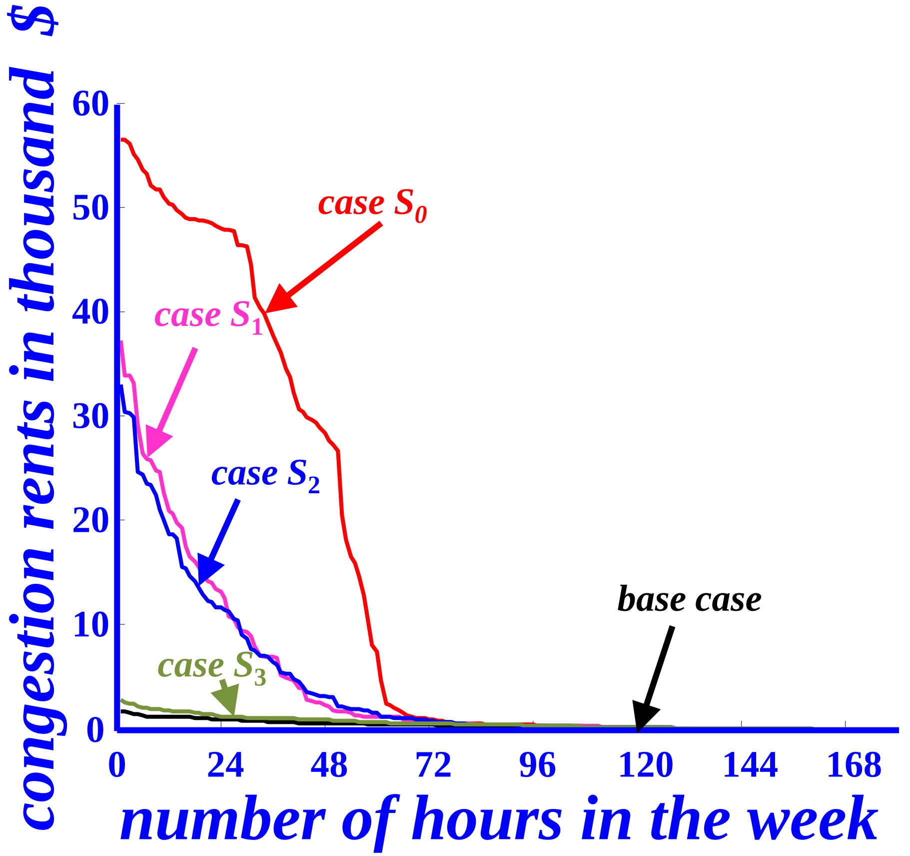




PRE – PATH – REENFORCEMENT

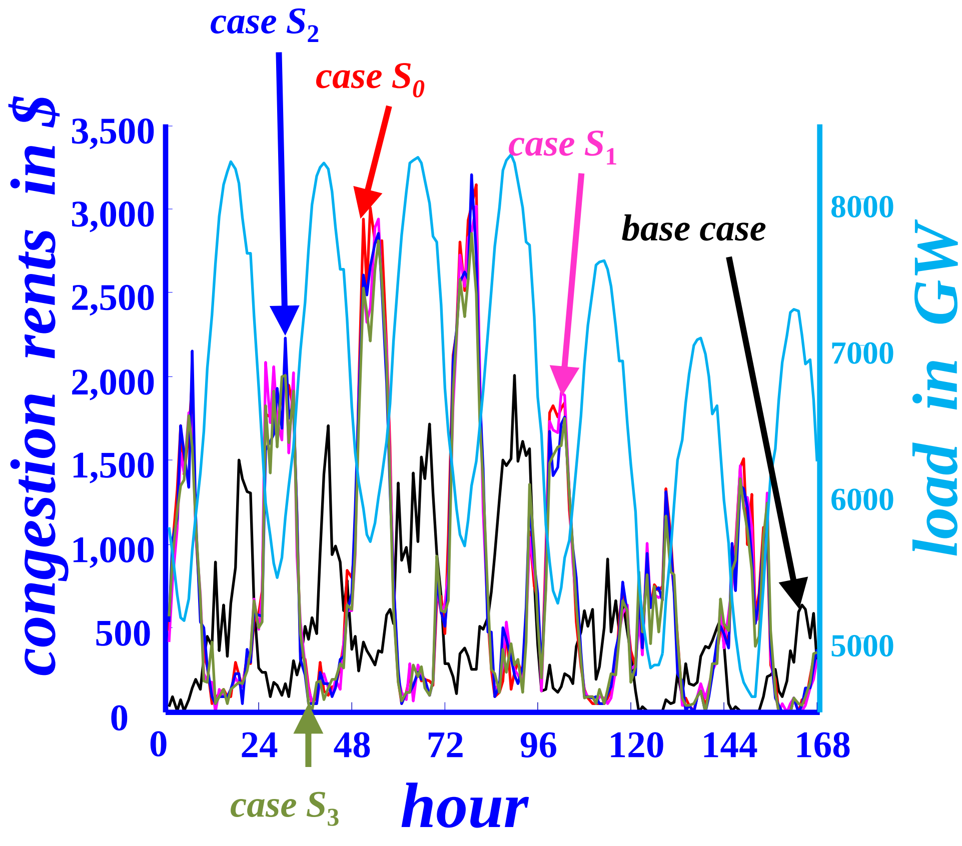
AVERAGE HOURLY CONGESTION RENTS

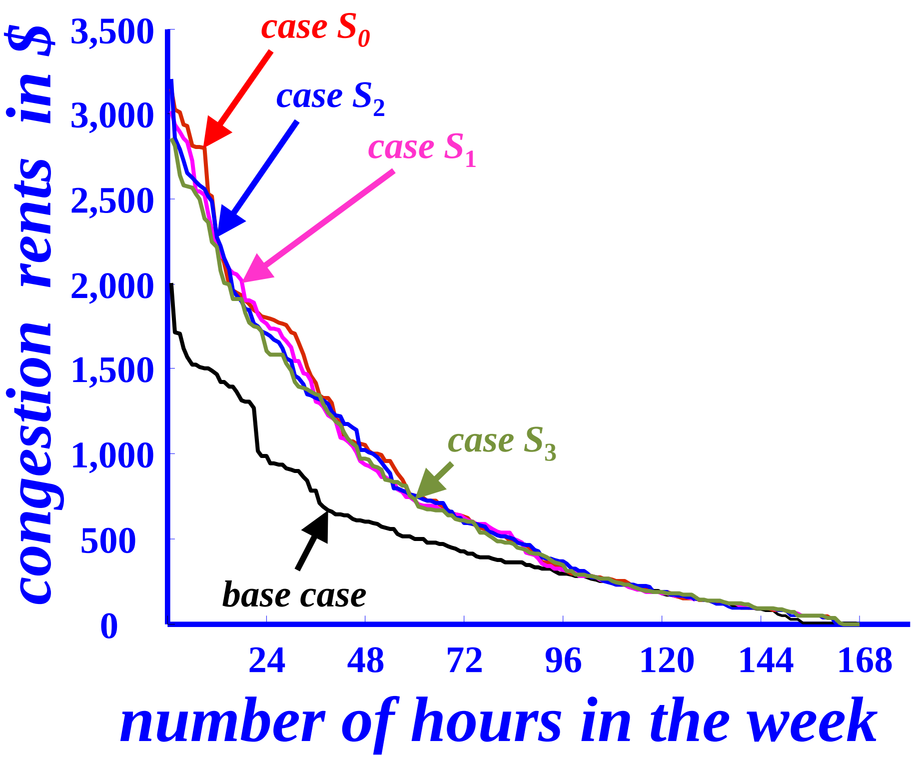




POST – PATH – REENFORCEMENT

AVERAGE HOURLY CONGESTION RENTS





STUDY SET III: SUBSTITUTION FOR THE CONVENTIONAL RESOURCES

- The aim of this study is to quantify the extent, from a purely reliability perspective, wind resources can substitute for conventional generation capacity in a power system with integrated storage resources
- We deem storage units to be firm capacity and use them to meet the desired reserves margin
- As the wind resources are integrated, we decrease progressively the system reserves margin, retire conventional unit capacity and assess the impacts

THE STUDY TEST SYSTEM: A MODIFIED IEEE 118-BUS SYSTEM

- Annual peak load: 8,090.3 *MW*
- Conventional generation resource mix: 9,714 *MW*
- 4 wind farms located in the Midwest with total nameplate capacity of 2,720 *MW*
- 4 units: each has a 100 *MW* capacity, 1,000 *MWh* storage capability and 89 *%* round-trip efficiency
- The unit commitment is performed to ensure the desired reserves margin is attained from the conventional *and storage* resources

SET IV SENSITIVITY CASES

case	*retired conventional generation (MW)*	*reserves margin in %*
base (no wind, no storage resources)	**0**	**15**
R_0	**0**	**15**
R_1	**80**	**14**
R_2	**160**	**13**
R_3	**240**	**12**
R_4	**320**	**11**
R_5	**400**	**10**
R_6	**480**	**9**
R_7	**560**	**8**
R_8	**640**	**7**

WEEKLY RELIABILITY INDICES vs. RESERVES MARGINS