DOE/OE Transmission Reliability Program

Management of Risk and Uncertainty through Optimized Co-operation of Transmission Systems and Microgrids with Responsive Loads

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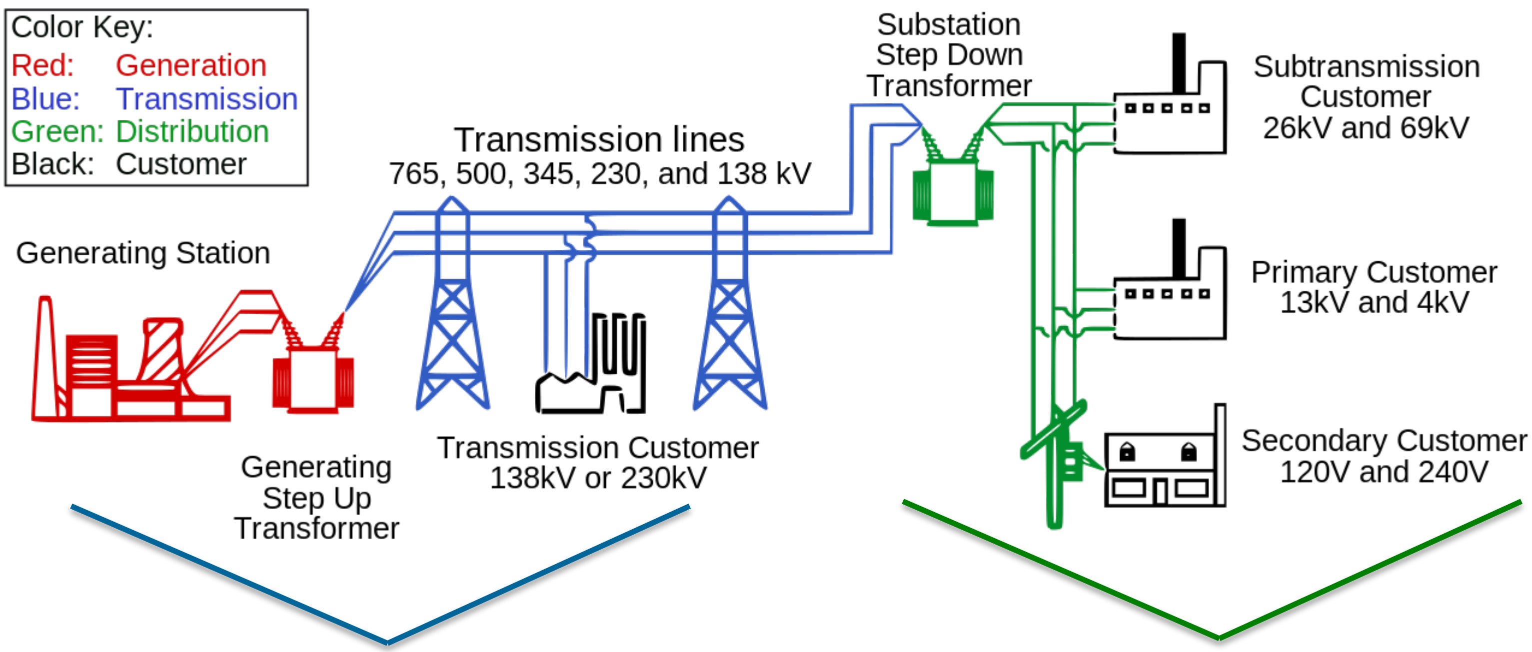
Presentation Overview

Project Objective

Progress Update: Phases II, III & IV

Looking Forward: On-going & Future Work

Project Overview



Utility scale renewables create uncertainty

Responsive loads, and distributed resources

Project Objective

Development of a comprehensive co-optimization framework that incorporates the generation and transmission system with the distribution system and microgrids to include responsive loads, distributed generation, and storage.

The approach to this objective is structured across four key phases.

Project Phases

Phase I: Characterizing uncertainty in renewables

Phase II:

Modeling demand side resources,

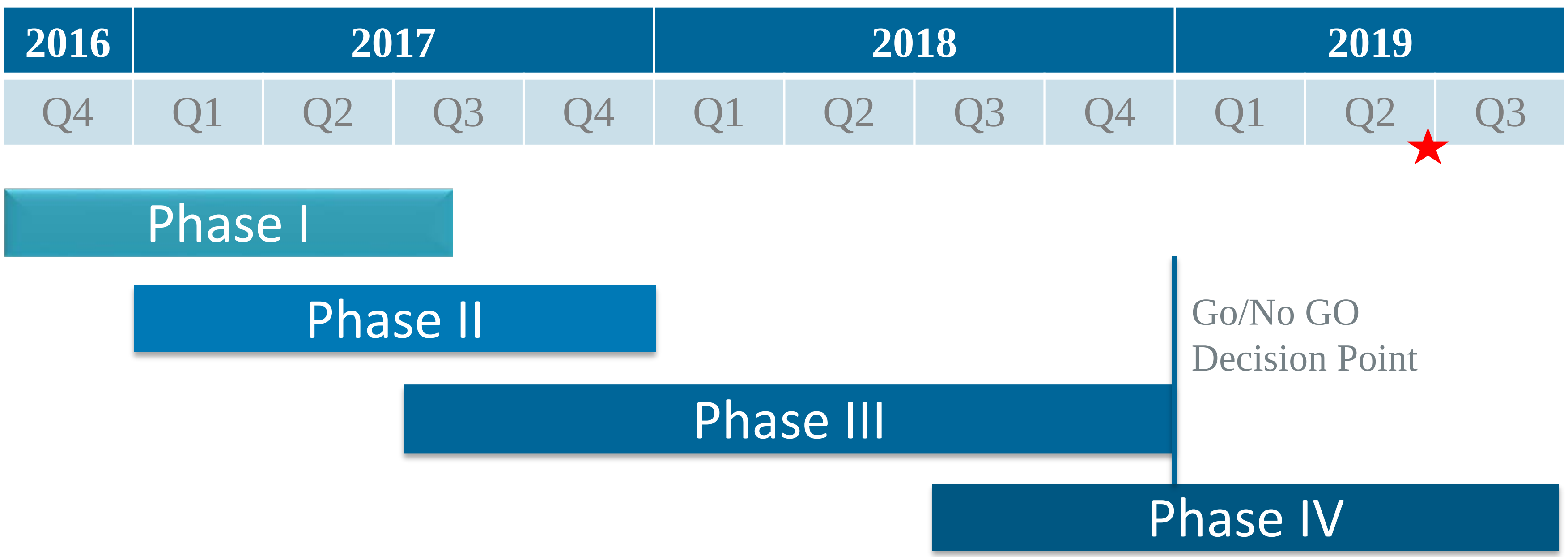
interactive effects

Phase III: Modeling system interactions

Phase IV: Co-optimization framework

Timeline

Timeline for the project was delineated in the updated PMP (Deliverable 1), summarized as follows:



Phase I: Characterizing Uncertainty

Seek to identify best methods for representing *multiple correlated wind farms*

Main contribution: review of multi-area wind modeling methods with the comprehensive comparison

Comparison:

- ✓ Ability of generated scenarios to replicate statistical properties of the historical data;
- ✓ Quality (stability) of the solutions obtained for an economic dispatch problem.

Lead: Cornell, with Anderson & Zéphyr

Summary

Methods that seek to reproduce statistical properties of the historical data will

✓ generate more reliable scenarios, and

✓ better dispatch decisions

Project incorporates these methods to:

- Compare performance on different types of problems,
- Assess importance of correlation to solutions, and
- Test scalability with larger number of wind sites

Phase II:
Demand Side Resources and Microgrids

Phase II focuses on the development of various categories of demand-side resources, addressing

- ✓ modeling existing DR programs,
- ✓ integration in energy management system of microgrids, and
- ✓ validation and testing to assess performance from various perspectives.

Lead: Smith College, Cardell
with support from Cornell

Modeling Demand Response

System model incorporates:

- microgrid with renewables, storage and DR
- combined DR programs for specific load classes
- stochastic rolling horizon with forecasts
- analysis of performance of various DR classes

This framework illustrates that various classes of demand response add value to the energy management strategy

Phase III: System Interactions

System model incorporates:

- microgrid with renewables, storage, DR, and meshed network
- combined DR programs for specific load classes
- stochastic rolling horizon with forecasts
- analysis of performance of various DR classes

This framework demonstrates that optimal operation of microgrids with load differentiated demand response and renewable resources add value to the energy management strategy

Phase III System Interactions: Summary

1. Each type class of DR provides cost benefits under specific conditions
2. Thermostatically controlled load (TCL) savings are proportional to both the price spikes and the TCL reduction during high prices
3. Considerable cost reduction from deferable load requires the presence of both price peaks and high quality price forecasts
4. A portfolio of DR is efficient providing flexibility and cost savings

Liu, J., Zéphyr, L., & Anderson, C.L. Stochastic Optimal Dispatch for Microgrids with Load-differentiated Demand Response. Journal of Energy Engineering *(under second review)*

Phase IV: System Co-optimization

Impact of interaction schemes on transmission and distribution/micro-grid systems:

Development of candidate co-optimization models to

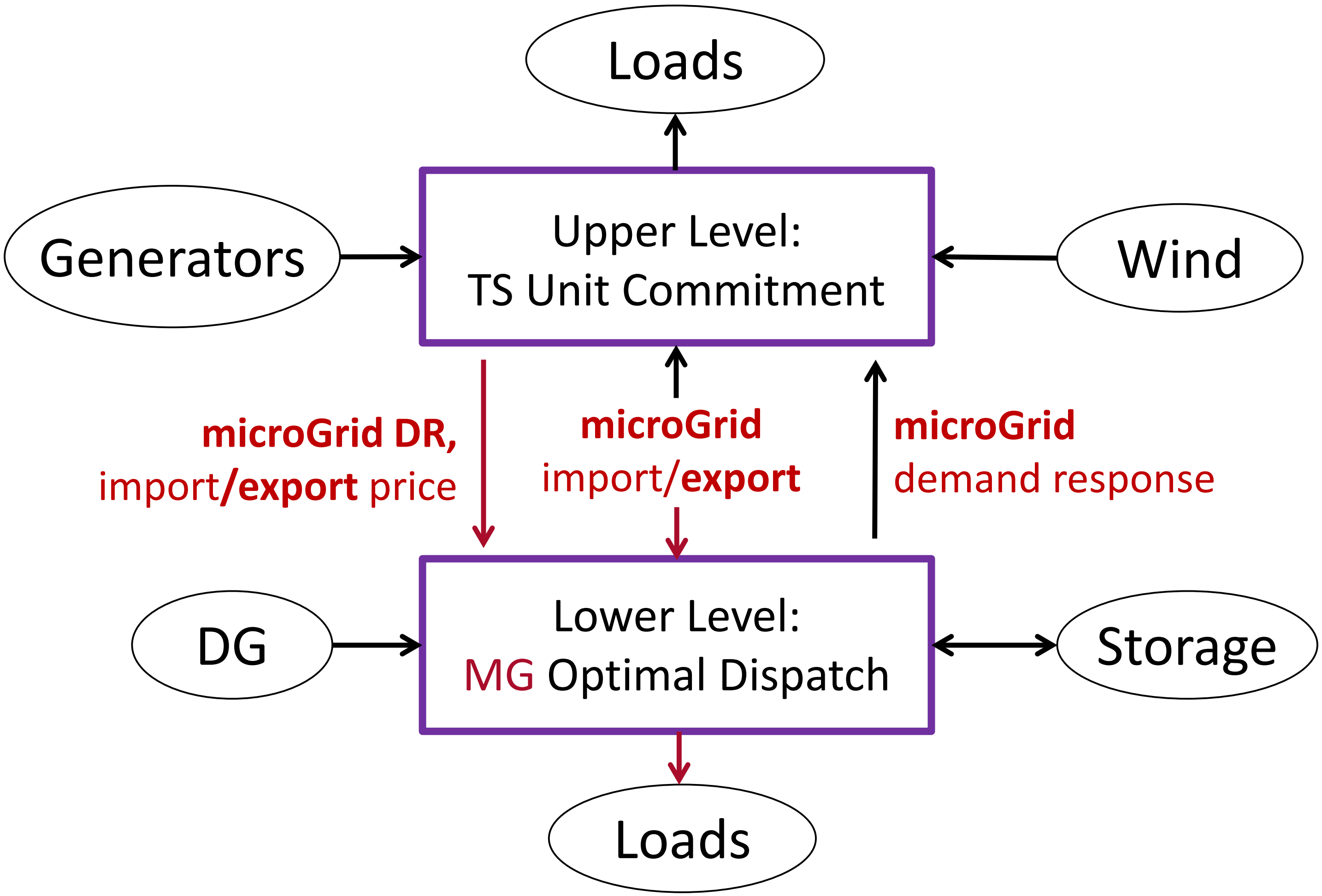
- study the interactive effect of micro-grid/distribution and transmission system behaviors
- assess the importance of microgrid location and technologies, in conjunction with co-operation strategies

Co-Lead by PI Team, Cornell & Smith College

Project Overview

- Project 1: Co-optimization of transmission and microgrid with bidirectional power flow, DG generation, storage, energy export to support renewable generation
- Project 2: Co-optimization of transmission and distribution systems, for analysis and comparison of benefits including cost, emissions, and risk

Transmission – Microgrid Interaction



Co-optimization of Transmission System & Microgrid Operations

- Coordinated-optimization to maximize benefits from renewable generation and flexible load
- Bi-level optimization between the microgrid and transmission system levels
  - A framework to co-optimize microgrid and Tx operation.
  - Characterize performance in terms of wind penetration level and system operation cost.

Bi-Level Approach: General Formulation

$$\min_{x \in X, y \in Y} F(x,y)$$

$$\text{st: } G_i(x,y) \leq 0, \text{ for } i \in \{1,2,...,I\}$$

$$H_k(x,y) = 0, \text{ for } k \in \{1,2,...,K\}$$

$$y \in \underset{y \in Y}{\operatorname{argmin}}\{f(x,y) : g_j(x,y) \leq 0, \text{ for } j \in \{1,2,...,J\},$$

$$h_m(x,y) = 0, \text{ for } m \in \{1,2,...,M\}\}$$

Upper Level Problem

Lower Level Problem

Single level reformulation can be used when the lower level problem is convex and satisfies Slater's conditions.

Upper Level: Unit Commitment

Objective:

$$\begin{aligned}\min_{\{x_t\}_{t=1}^T} F(\{x_t\}_{t=1}^T) &= \textstyle\sum_{t=1}^T \sum_{g=1}^G (C_{g,t}^c w_{g,t} + C_{g,t} p_{g,t} + C_g^r (r_{g,t}^{up} + r_{g,t}^{dn}) \\ &- p_t^{im} c_t^{im} + p_t^{ex} c_t^{ex} \\ &+ p_t^{dr}(dr_t^{up} + dr_t^{dn}))\end{aligned}$$

s.t:

Power flow

Generation capacity

Power balance

Reserve requirement

Lower Level: Microgrid dispatch

- Objective:

$$\min_{\{y_t\}_{t=1}^T} f(\{y_t\}_{t=1}^T) = \sum_{t=1}^{T} (C_g^{m1} p_{g,t}^m + C_g^{m2} p_{g,t}^m p_{g,t}^m + C^b b_t + p_t^{im} c_t^{im} - p_t^{ex} c_t^{ex}$$

$$+ C^{dr1}(DR_{g,t}^{up} + DR_{g,t}^{dn}) + C^{dr2}(DR_{g,t}^{up} DR_{g,t}^{up} + DR_{g,t}^{dn} DR_{g,t}^{dn})$$

$$- C_t^d l_t^d - p_t^{dr}(dr_t^{up} + dr_t^{dn}))$$

s.t:

- Generation capacity
- Dispatchable load capacity
- Demand response
- Storage operations
- Import and export limits

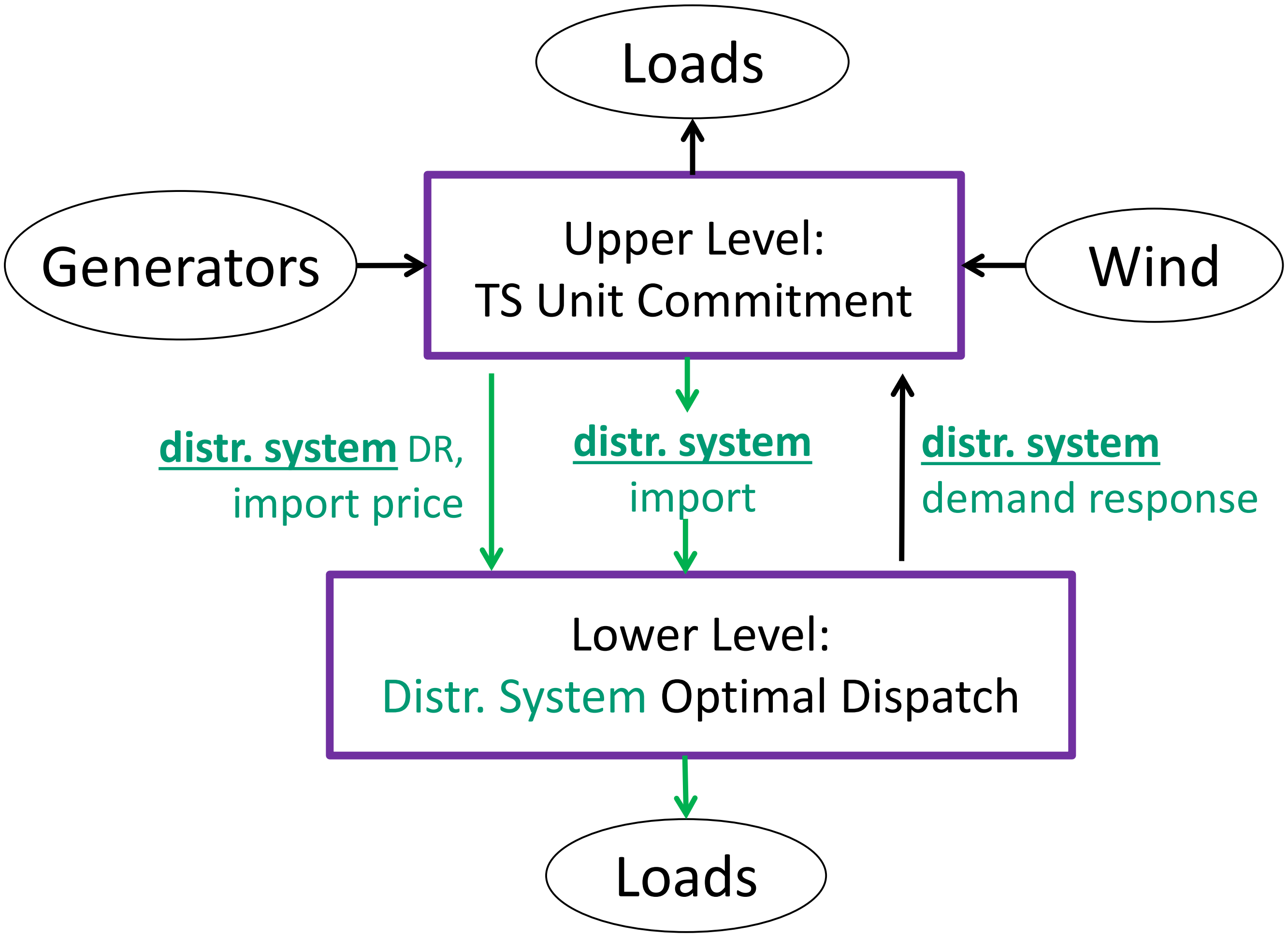
Summary: Transmission-Microgrid Interaction

Implements a bi-level optimization framework to demonstrate:

- Single-level reformulation to co-optimize unit commitment with microgrid energy management decision
- Capability to include MG storage, DR, and DG
- Analysis shows
  - Reduced costs for microgrid and transmission system
  - Increased ability to integrate wind resources
  - Microgrid size and location influences efficacy for wind and cost impact

Liu, J., Zephyr, L., Cardell, J. & Anderson, C.L. Co-optimization of Transmission and Microgrid Operations: Leveraging Renewable Generation and Demand Response (under revision for IJEPS)

Transmission – Distribution System Interaction



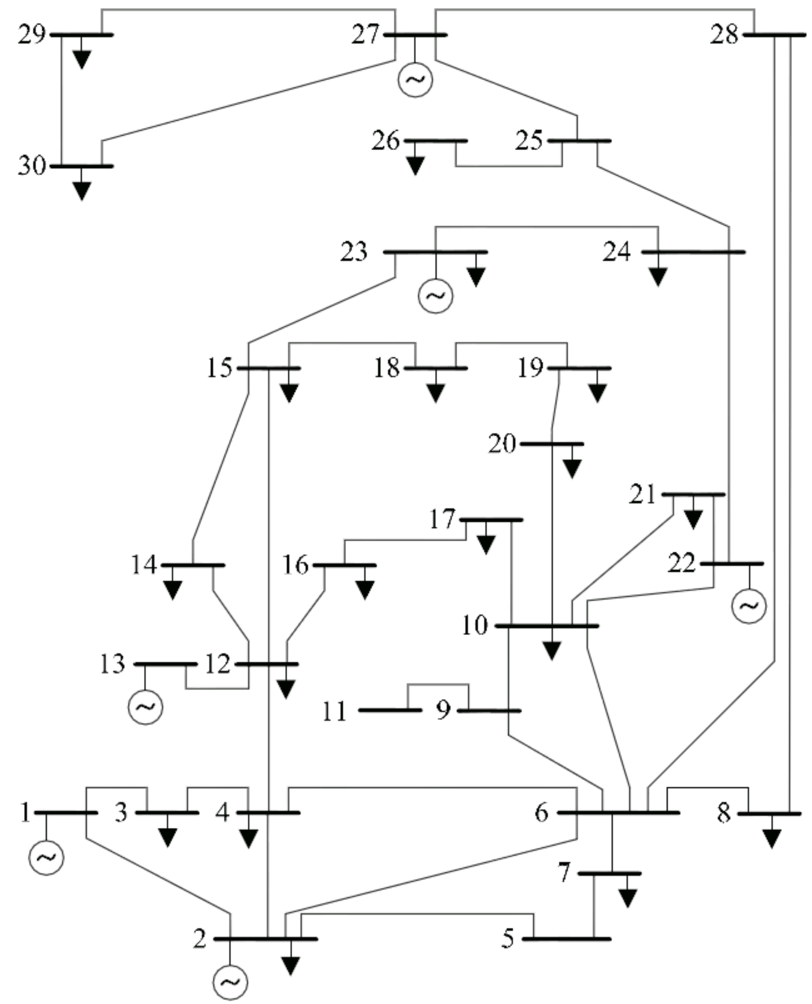
Traditional Modeling Framework

- Single level optimization problem with single objective function and constraint set
- Model Tx network with potentially binding constraints
- Distribution system details not modeled
- Minimize total system cost

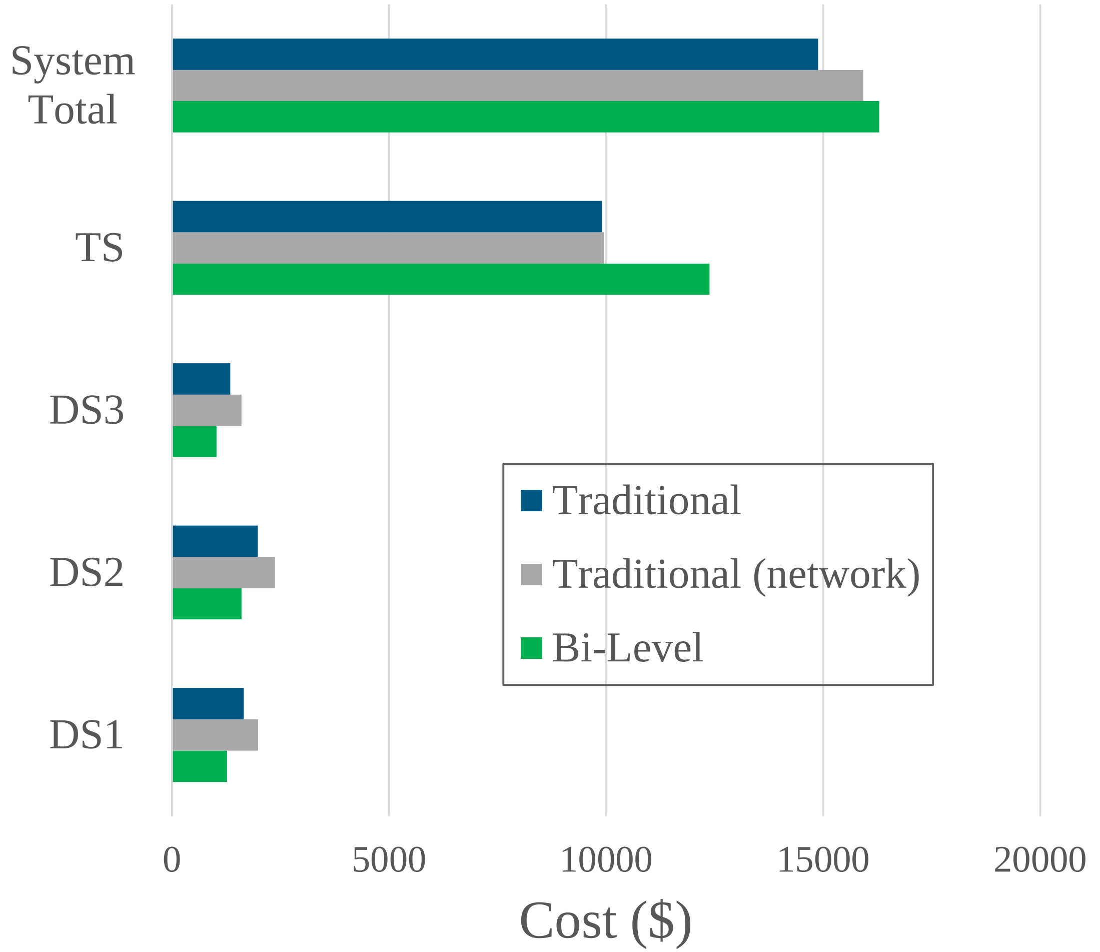
Objective was to compare bi-level framework with a representative "traditional" single-level optimization problem

Test case assumptions

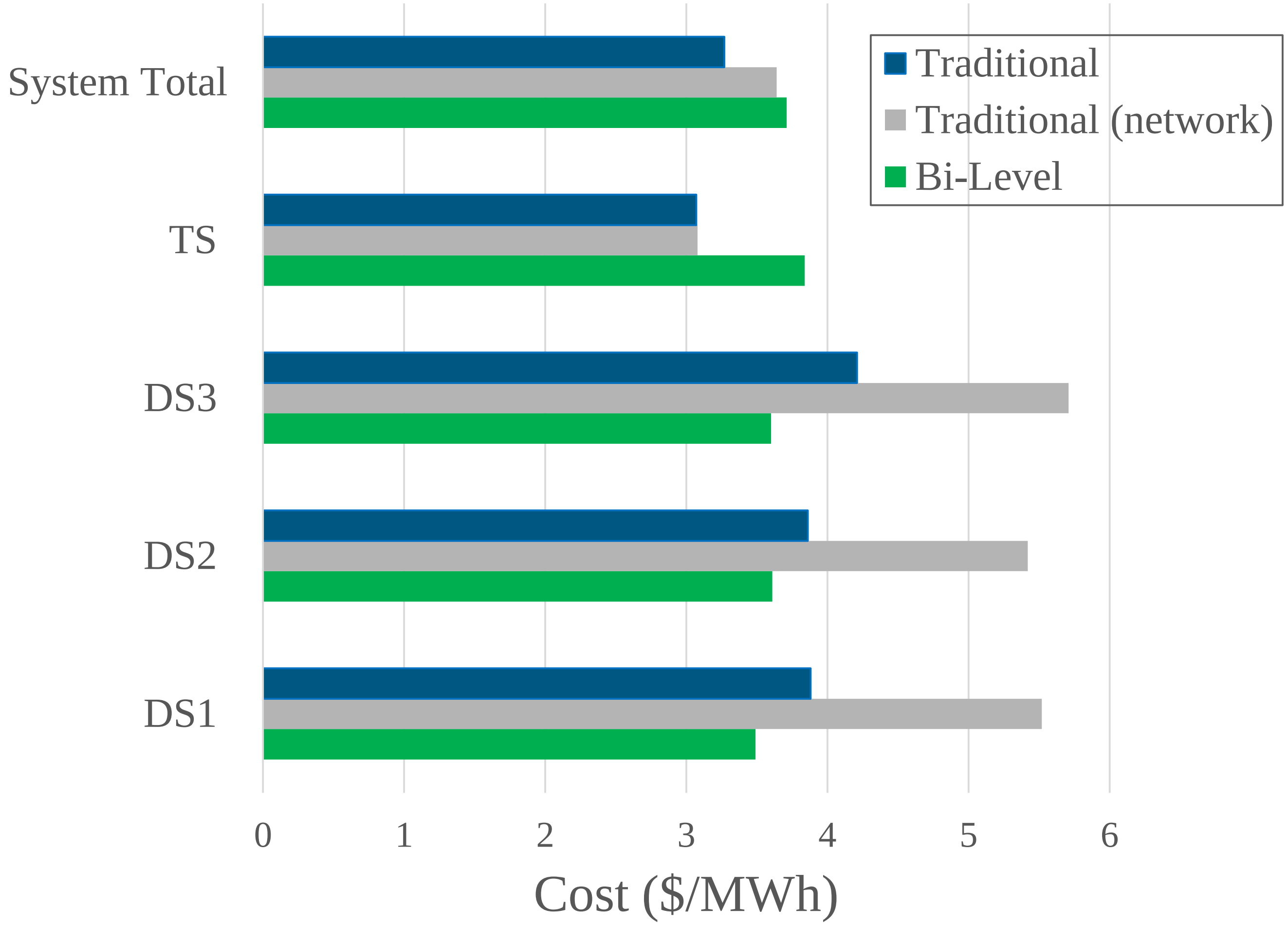
- IEEE 30 bus system for the TX
- 3 connected distribution systems
- 2 wind farms
- 3 optimization frameworks:
  - o Bilevel optimization
  - o Traditional framework
  - o Traditional with network constraints



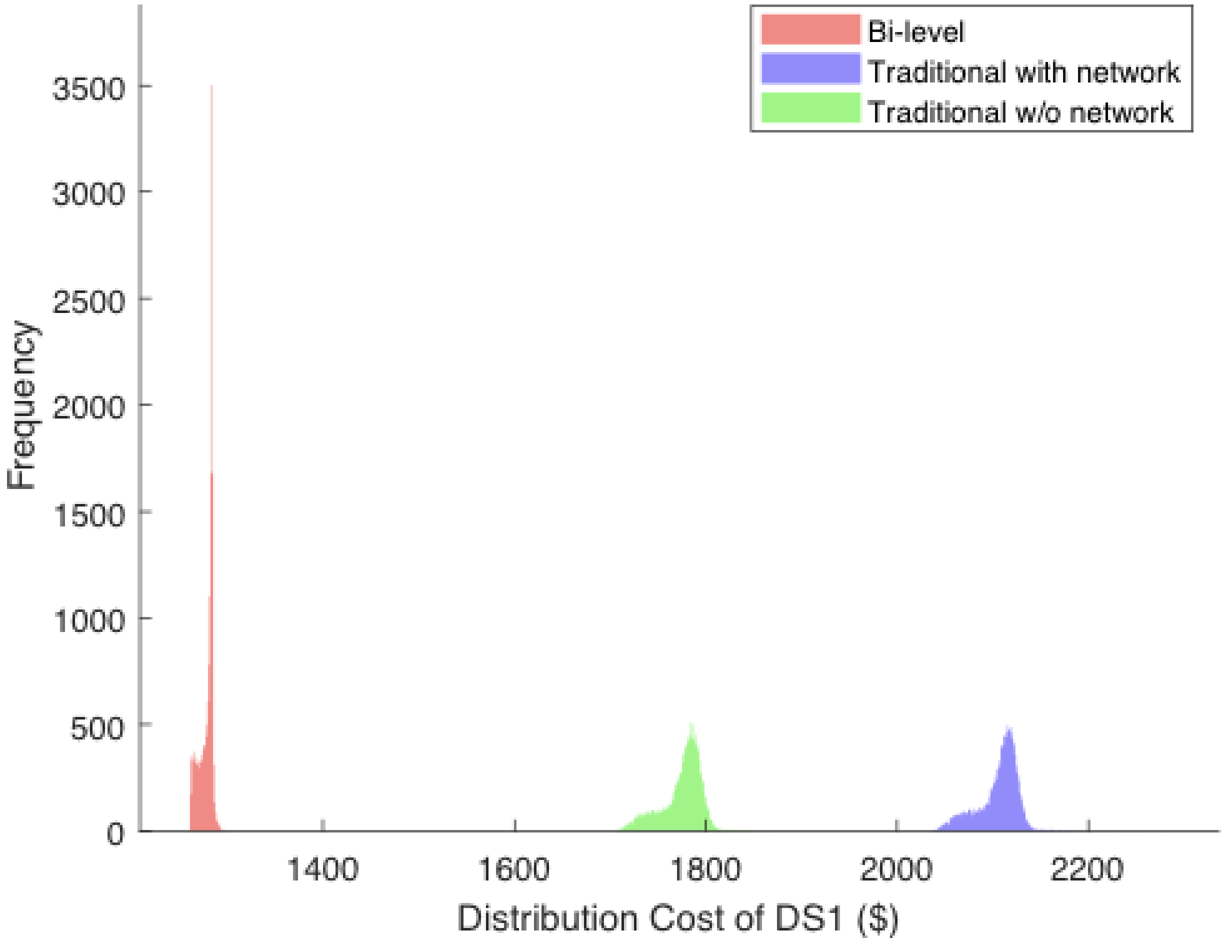
Results: Comparing Cost for Distribution and ISO



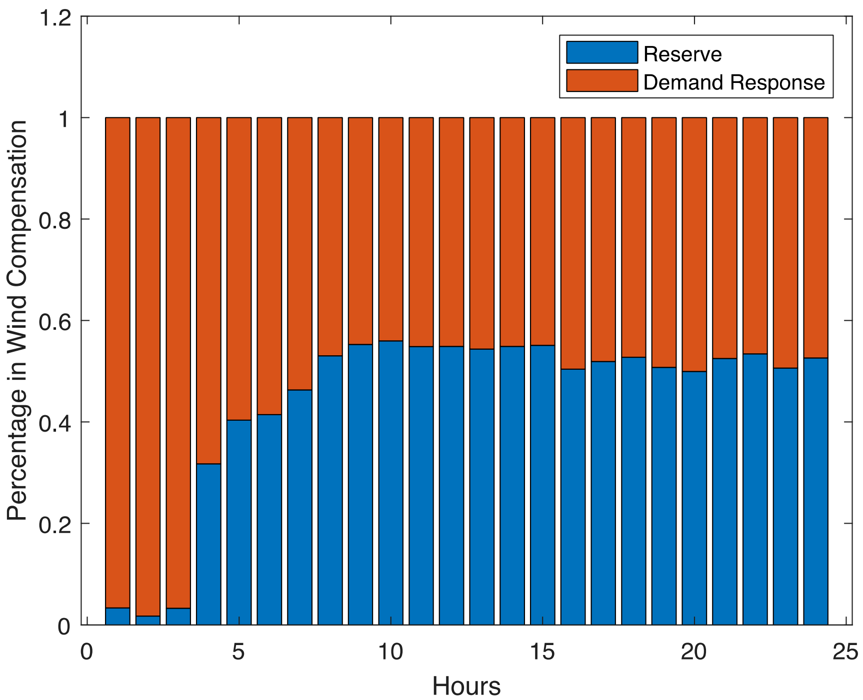
Results: Comparing Normalized Cost for Distribution and ISO



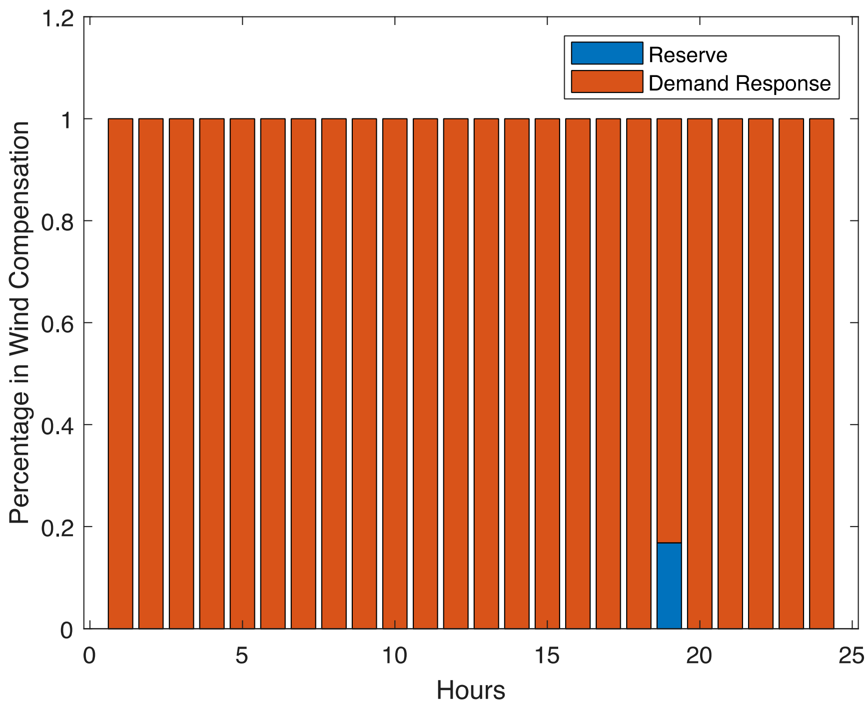
Results: With bi-level framework, operations are more risk averse.



Results: Bi-level leads to balanced use of reserves and demand response



Bi-level



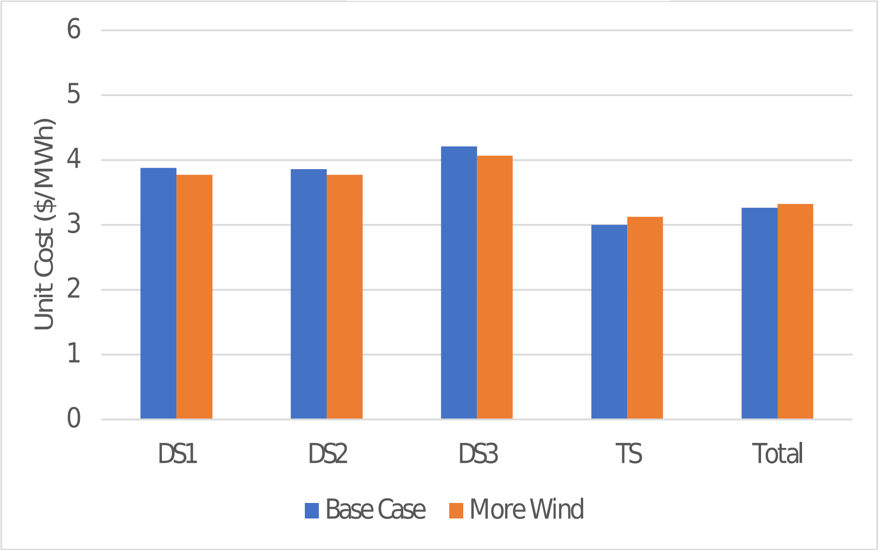
Traditional

Results: CO_2 reduction from wind

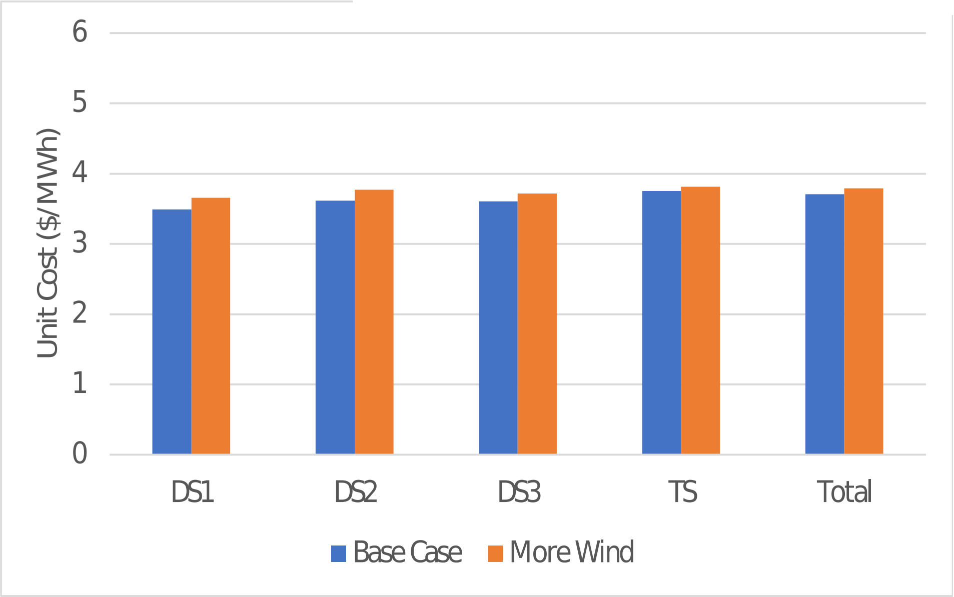
	Bi-level	Traditional with Network	Traditional w/o Network
DR (MW)	68	192	194
Reserves (MW)	130	6	4
CO_2 Reduction (tons)	13	0.6	0.4

Results: Increasing Wind Capacity

Traditional

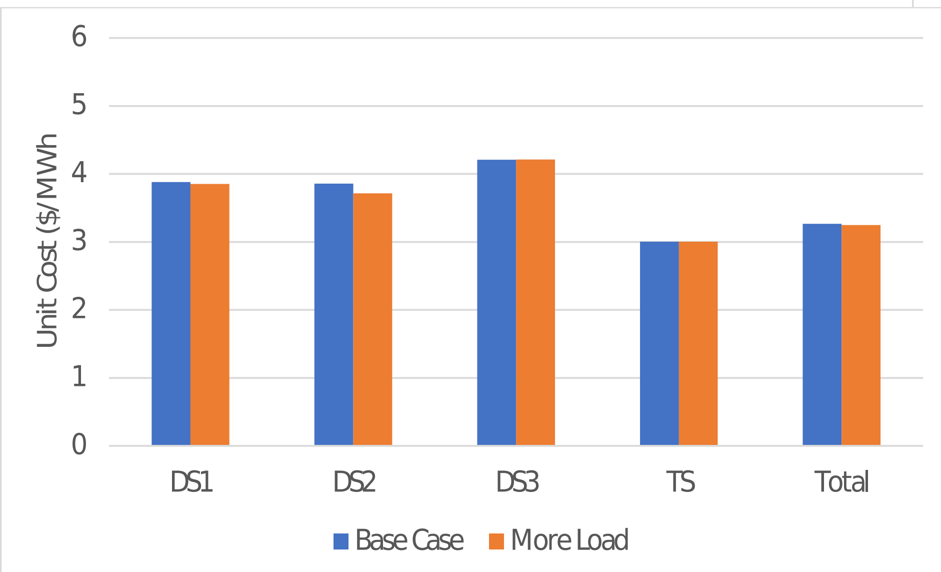


Bi-level

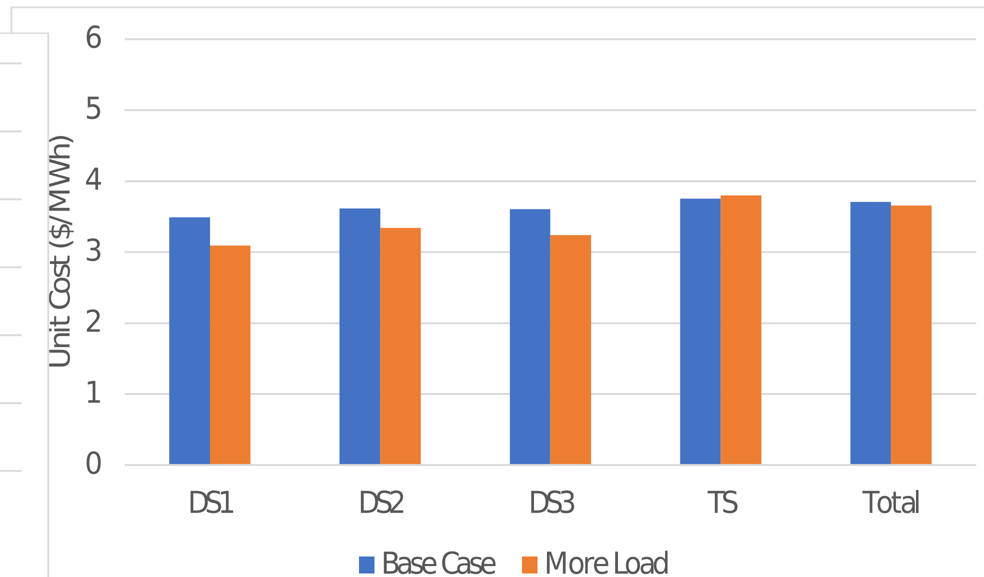


Results: Increasing Flexible Loads

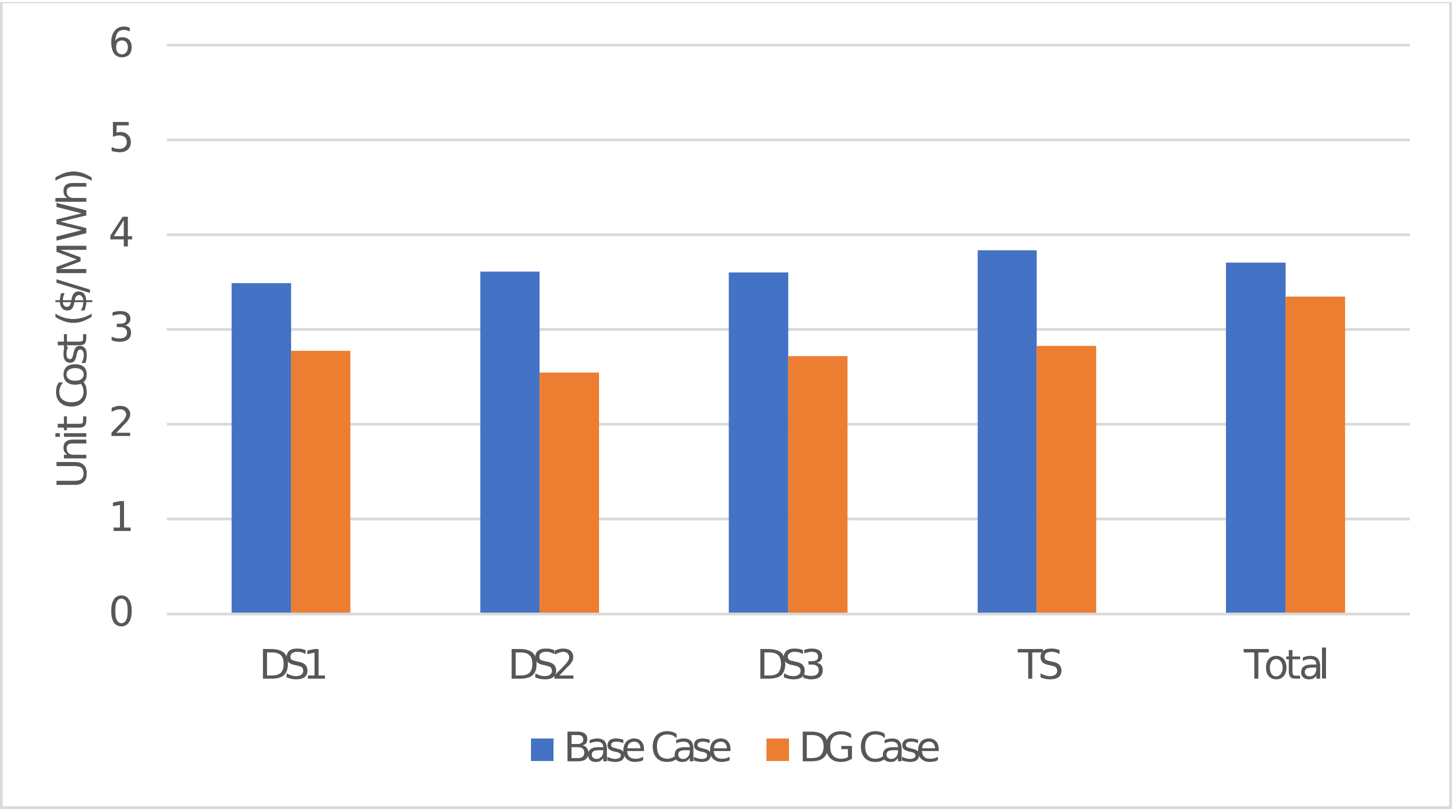
Traditional



Bi-level



Results: Distributed Generation



Summary and Conclusions

- The bi-level framework has flexibility to incorporate transmission and distribution/microgrid
- Distribution decisions are directly optimized based on system needs, resources available
- Incorporates distribution and microgrid expansion and integration
- Supports economic behavior of energy market transactions
- Future distribution characteristics are effectively incorporated into the bi-level framework.

Ongoing and Future Work

Key focus of 2019:

1. Exploring scalability for increasing distribution/microgrids within framework
2. Extending renewable scenario analysis for alternative patterns
3. Continuing to communicate and solicit input from industry stakeholders

Comments and Questions?

Accepted Publications/Presentations

- Tupper, L. L., Matteson, D. S., & Anderson, C. L. (2017). Band Depth Clustering for Nonstationary Time Series and Wind Speed Behavior. Technometrics. https://doi.org/10.1080/00401706.2017.1345700
- Cardell, J.B., Zephyr, L., & Anderson, C.L. (2017) A Vision for Co-optimized T&D System Interaction with Renewables and Demand Response. Proceedings of the 50th Hawaii International Conference on System Sciences. (8 pages).
- Liu, J., Martínez, M.G., & Anderson, C.L. (2016) Quantifying The Impact Of Microgrid Location And Behavior On Transmission Network Congestion. Proceedings of the 2016 Winter Simulation Conference (7 pages)
- Anderson, C.L. *Research Needs for Co-optimization of Multi-level Integrated Electricity Systems*. Closing Plenary Panelist. Utilities Variable Integration Group Spring Technical Meeting. March 13-15, 2018. Tuscon, AZ.

Accepted Publications/Presentations

- Aravinthan, V., Anderson, C.L., Cardell, J.B., and Jewell, W. (2017) Investigating Optimal Model Coordination for Integrated Transmission and Distribution Systems. Power Engineering Research Center (PSERC) Industrial Advisory Board Meeting, Phoenix AZ. December 3, 2017.
- Anderson, C.L. Incorporating Wind and Distributed Storage into Stochastic Economic Dispatch Solutions. Power Engineering Research Center (PSERC) Webinar. November 21, 2017.

Publications Under Review/Revision

- Zéphyr, L., Liu, J., Gupta, A., & Anderson, C.L. Multiarea Wind Scenario Generation for Planning under Uncertainty, Renewable and Sustainable Energy Reviews (under review)
- Liu, J., Zéphyr, L., & Anderson, C.L. Stochastic Optimal Dispatch for Microgrids with Load-differentiated Demand Response. Journal of Energy Engineering (under review)
- Liu, J., Zephyr, L., Cardell, J. & Anderson, C.L. Co-optimization of Transmission and Microgrid Operations: Leveraging Renewable Generation and Demand Response (under revision for IJEPS)
- Liu., J., Guo, G. & Anderson, C.L. Bi-Level Co-optimization of Transmission and Distribution Operations under Uncertainty (submitted)

Industry Feedback and Input

We have shared our approach and preliminary results with industry stakeholders including:

- ✓ California ISO
- ✓ ISO New England
- ✓ New York ISO
- ✓ GE
- ✓ ABB