Evaluation of Production Cost Savings from Consolidation of Balancing Authorities in the U.S. Western Interconnection under High Wind and Solar Penetration

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Agenda

- Overview
- Production cost model
- Study scenarios
- Simulation results
- Conclusions

Overview

- Challenge for BAs to operate independently:
  - Increasing variability and uncertainty associated with higher penetration level of renewables
  - Higher operating cost
- Benefit from cooperation between BAs
  - Larger geographic area, distributed resources
  - Mitigate the impact of variability and uncertainty
  - More efficient unit commitment and economic dispatch
  - Sharing of contingency reserve
- Production cost analysis
  - Determine the maximum benefits that could be achieved in a consolidated WECC BA (CBA)
  - Analyze two different scenarios of variable generation (VG) penetration: 11% and 33% as percentage of WECC projected energy demand in 2020

Production cost model

- The study model is based on the WECC Transmission Expansion Planning Policy Committee (TEPPC) 2020 case
  - Nodal model of the WECC system (>17k buses, >20k transmission lines/transformers)
  - Based on the WECC 2020 high summer power flow case
  - Several modifications
- BA structure
  - 32 BAs
  - 39 load areas
  - 86 flowgates between BAs (hurdle rate can be applied)
  - Operating reserve of 4% of BAs weekly peak load

Load, wind, and solar model

- Load
  - Load shapes for 2020 are derived from the 2006 load shapes and load forecast for 2020
  - BA total load is distributed between load buses within the BA based on the 2012 heavy summer base case
- Wind and solar
  - Time series data for wind and solar production are derived from the 2006 weather models
  - Wind and solar contributions are 8% and 3% of the WECC total demand for 2020 respectively

Hydro plant model

- Hydro production is based on an average year (2006)
- For plans that do not have 2006 data available, data in 2002, 2003, or 2007 are used
- Hydro power plant modeling: 3 models
  - Proportional load following (PLF): generation schedule is based on load profile
  - Hydro thermal coordination: generation schedule is first based on PLF, and then a portion of the remain is dispatched as a thermal unit
  - Fixed shape: generation schedule is same as hourly generation profile input

Thermal plant model

- Several characteristics of thermal plant are input in the model:
  - Minimum and maximum ramp rates
  - Minimum up-times and down-times
  - Minimum and maximum generation capacities
  - Planned and forced outages, heat rate curves, emission rates
  - O&M cost and start up cost
- The median Henry Hub gas price is $7.28/MMBtu (2010 dollars)
- The average coal price is $1.69/MMBtu (2010 dollars)

Transmission model

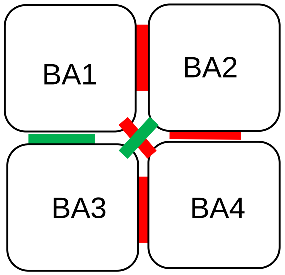
- Only include:
  - Existing transmission
  - Transmission needed for future reliability when integrate additional generation
  - Projects with high likelihood of being in service in 2020
- Add additional transmission when the capacity is not adequate to handle additional renewables
- Transmission losses are not modeled explicitly but are included in the load forecast

Comparison between Different Market Structures

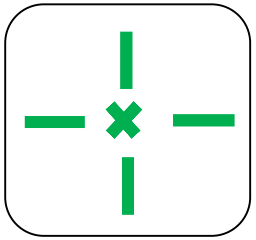
	Current hourly-scheduling between WECC BAs	Centralized Market	Intra-hour scheduling between WECC BAs	EIM
Day-ahead forecasts	UC/ED at BA level with BA exchange	UC/ED at WECC level	UC/ED at BA level with BA exchange	UC/ED at BA level with BA exchange
Hour-ahead forecasts	UC/ED at BA level with FINAL BA exchange	UC/ED at WECC level	UC/ED at BA level with BA exchange	UC/ED at BA level with FINAL BA exchange
Intra-Hour	ED to meet imbalance at BA level	ED to meet imbalance at WECC level	ED at BA level with FINAL exchange	ED to meet imbalance at WECC level
Regulation	At BA level	WECC level	At BA level	At BA level
Hurdle rate on BA to BA transactions	Yes (DA, HA)	No (DA, HA, RT)	Yes (DA, HA, RT)	Yes (DA, HA) No (RT)
Contingency and Balancing Reserves	Individual BA obligations	Consolidate BA obligation (lower requirements)	Individual BA obligation	Individual BA obligations

Basic Components of the Production Cost Analysis

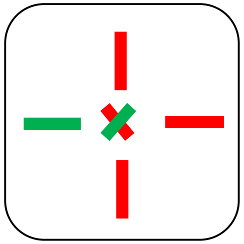
- Use PROMOD IV (scenarios 1 to 3) and PLEXOS (scenario 4) to determine production costs for the following study scenarios.



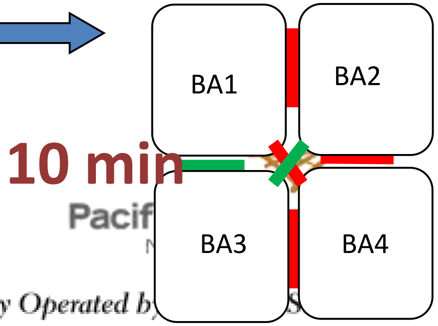
- Scenario 1: BA structure like it is today: BAs are separate, transmission congestion exists, certain patterns of scheduled interchanges



- Scenario 2: Full consolidation, copper sheet with no transmission congestion



- Scenario 3: Full consolidation, transmission congestion exists



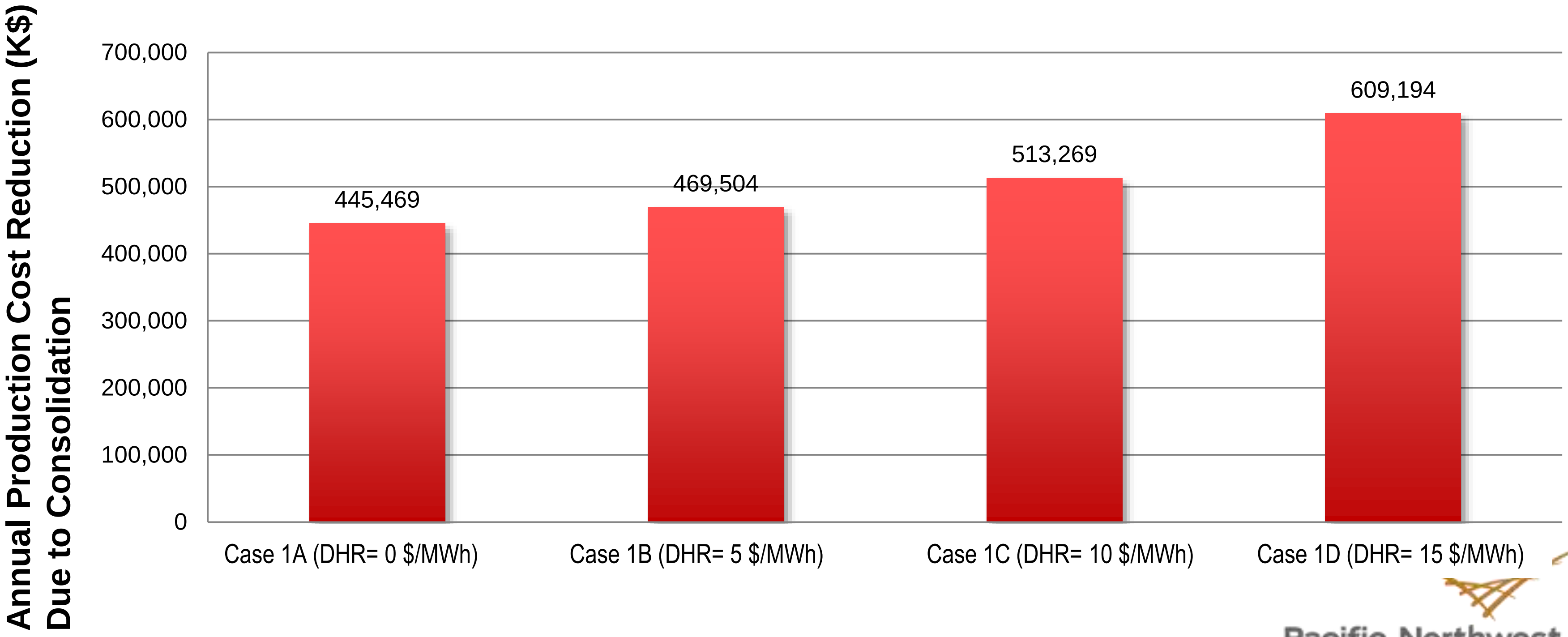
- Scenario 4: BA structure like today's with 10-min intra hour scheduling

Results Comparison between Different Simulation Cases (11% VG)

Simulation Scenario	Scenario 1: Current WECC BA Structure (20 $/ MWh Unit Commitment Transmission Hurdle Rate)				Scenario 2: Consolidated WECC (CBA) Copper Sheet	Scenario 3: Consolidated WECC with transmission congestion	
Category	Case 1A	***Case1B***	Case 1C	Case 1D	Case 2	Case 3A	***Case 3B***
Assumed Dispatch Transmission Hurdle Rate	0$/MWh	***$5/MWh***	$10/MWh	15$/MWh	0$/MWh	0$/MWh	***0$/MWh***
Nodal model type	Full nodal	***Full nodal***	Full nodal	Full nodal	Full nodal	Full nodal	***Full nodal***
Contingency reserve	BA level	***BA level***	BA level	BA level	Consolidate WECC level	BA level	***Consolidate WECC level***
Total Gen Cost (K$)	18,782,162	***18,806,197***	18,849,962	18,945,887	18,097,148	18,549,078	***18,336,693***

Annual Reduction in Thermal Units Production Cost between Scenario 1 and Case 3B (CBA) (11%VG)

- Reduction range from $445 Million (2.4%) with no hurdle rates for transmission to $609 Million (3.2%) with the 15 $/MWh flat dispatch hurdle rates
- In addition to that, another $240 Million of reduction can be achieved in case 2 (copper sheet consolidation)



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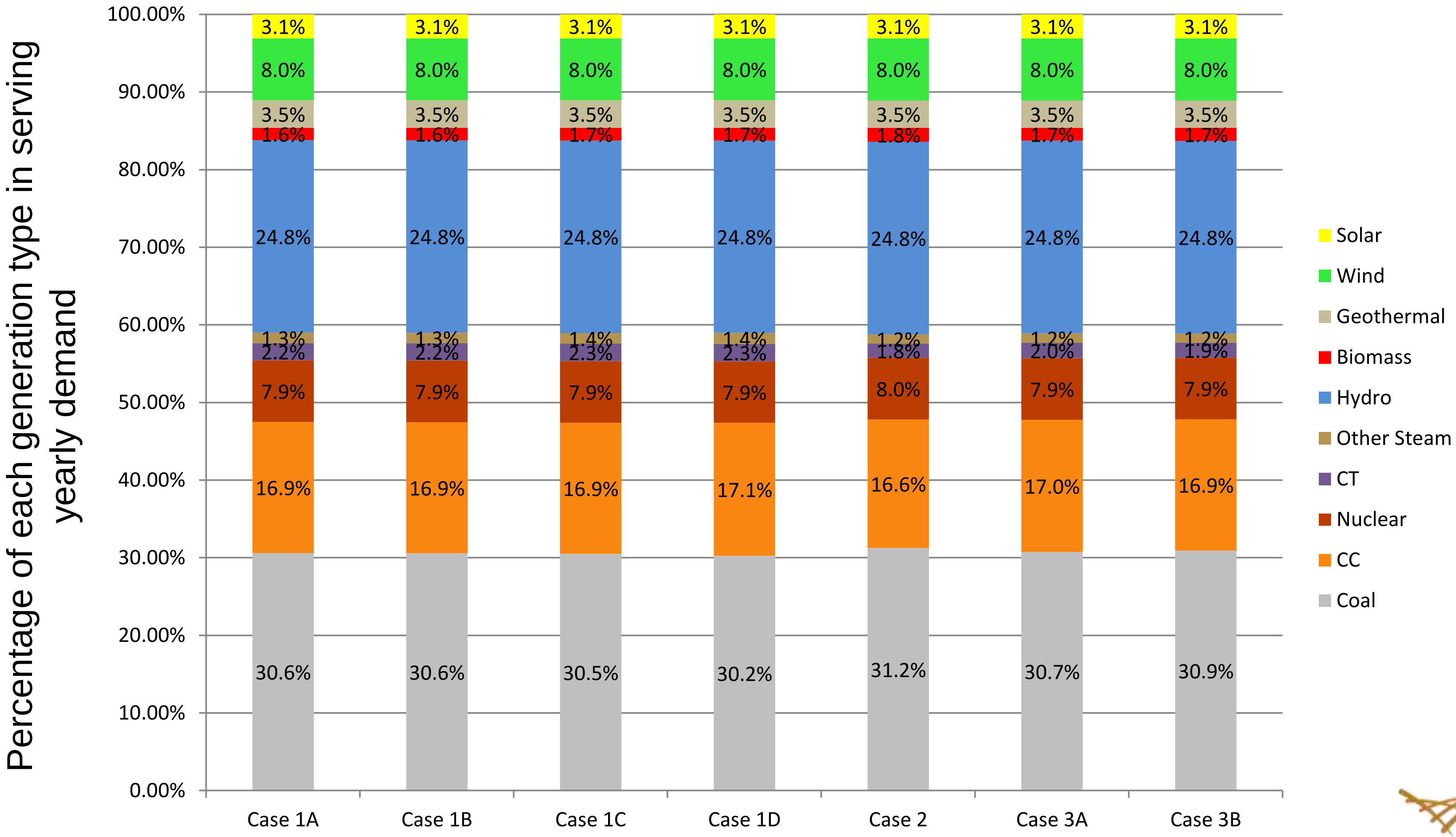
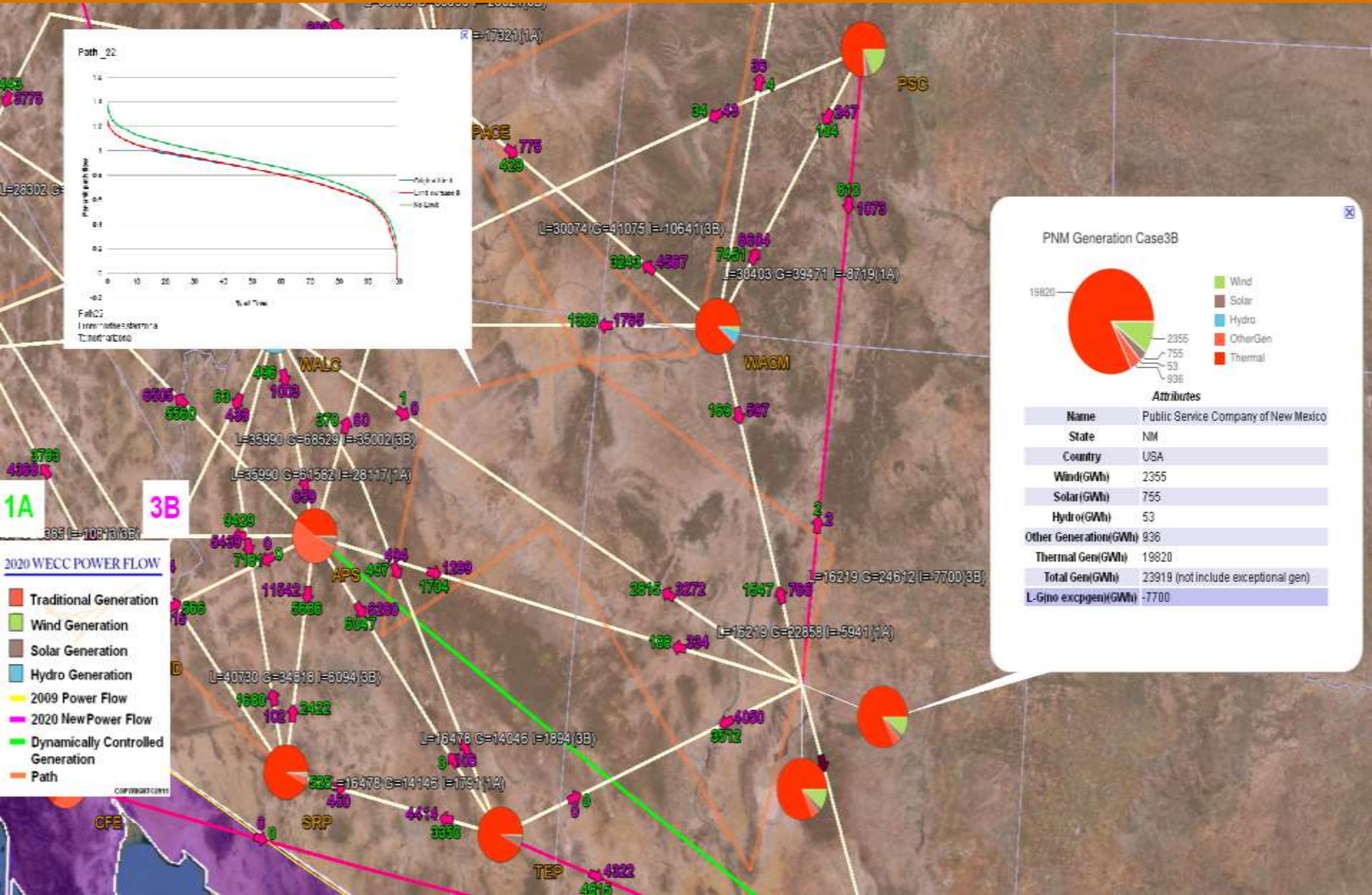
Generation Mix Comparison between Different Cases (11% VG)



A Tool Developed for Results Visualization: Comparision of 1A and 3B (GWh)



Transmission system expansion for 33% VG

- With 33% of VG introduced, the existing transmission is not adequate and needs to expand
- Initial expansion is based on past reports (zonal)
- More detailed expansion is iterated using the components of LMP at buses where VG is introduced
- $LMP_{bus} = LMP_{reference} + LMP_{loss} + LMP_{congestion}$
- Decomposition of $LMP_{congestion}$ provides which transmission lines/transformers/paths need to be upgraded (increase their limits)
- How much to increase their limits? Engineering judgment with some iterations

Implementation of the expansion for 33% VG

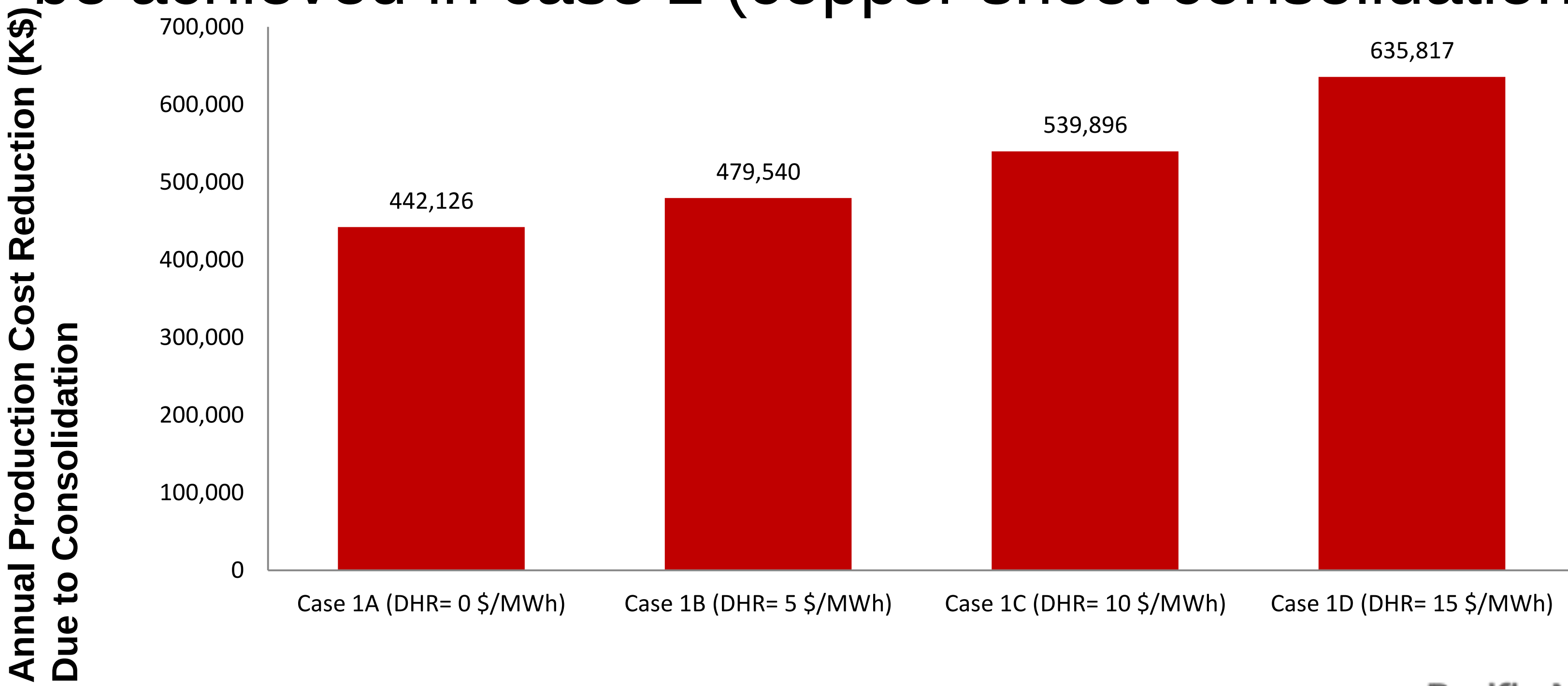
- Transmission lines/transformers:
  - Increase lines/transformer limits
  - Scale line resistance, reactance, and charging accordingly
- Transmission paths:
  - Increase the path limits if its components are not at their thermal limits
  - Increase both the path limits and its component limits if its component(s) is at thermal limits

Results Comparison between Different Simulation Cases (33% VG)

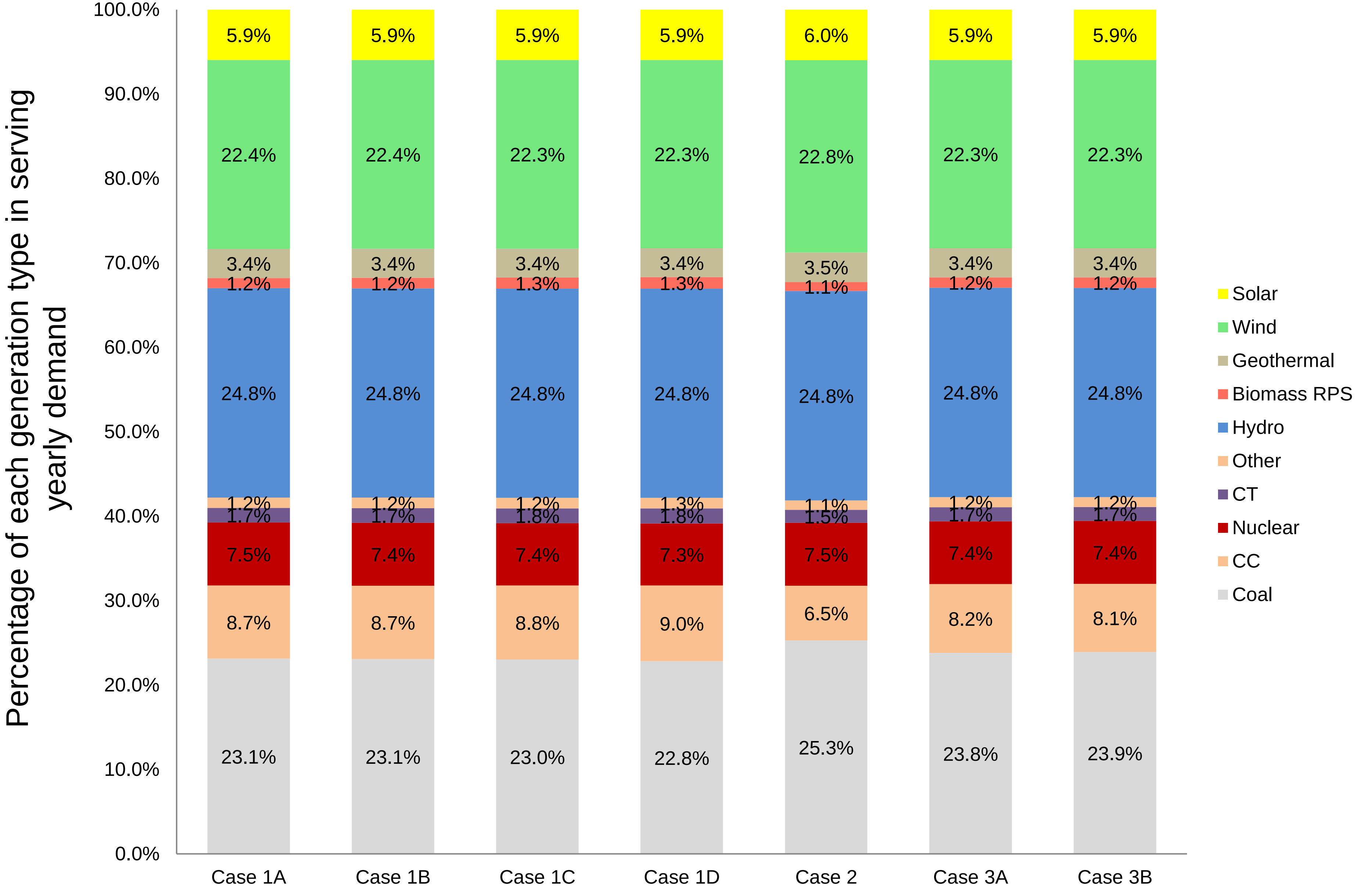
Simulation Scenario	Scenario 1: Current WECC BA Structure (20 $/ MWh Unit Commitment Transmission Hurdle Rate)				Scenario 2: Consolidated WECC (CBA) Copper Sheet	Scenario 3: Consolidated WECC with transmission congestion	
Category	Case 1A	**Case1B**	Case 1C	Case 1D	Case 2	Case 3A	**Case 3B**
Assumed Dispatch Transmission Hurdle Rate	0$/MWh	**$5/MWh**	$10/MWh	15$/MWh	0$/MWh	0$/MWh	**0$/MWh**
Nodal model type	Full nodal	**Full nodal**	Full nodal	Full nodal	Full nodal	Full nodal	**Full nodal**
Contingency reserve	BA level	**BA level**	BA level	BA level	Consolidate WECC level	BA level	**Consolidate WECC level**
Total Gen Cost (K$)	12,299,308	**12,336,721**	12,397,077	12,492,999	10,877,487	12,026,894	**11,857,182**

Annual Reduction in Thermal Units Production Cost between Scenario 1 and Case 3B (CBA) (33%VG)

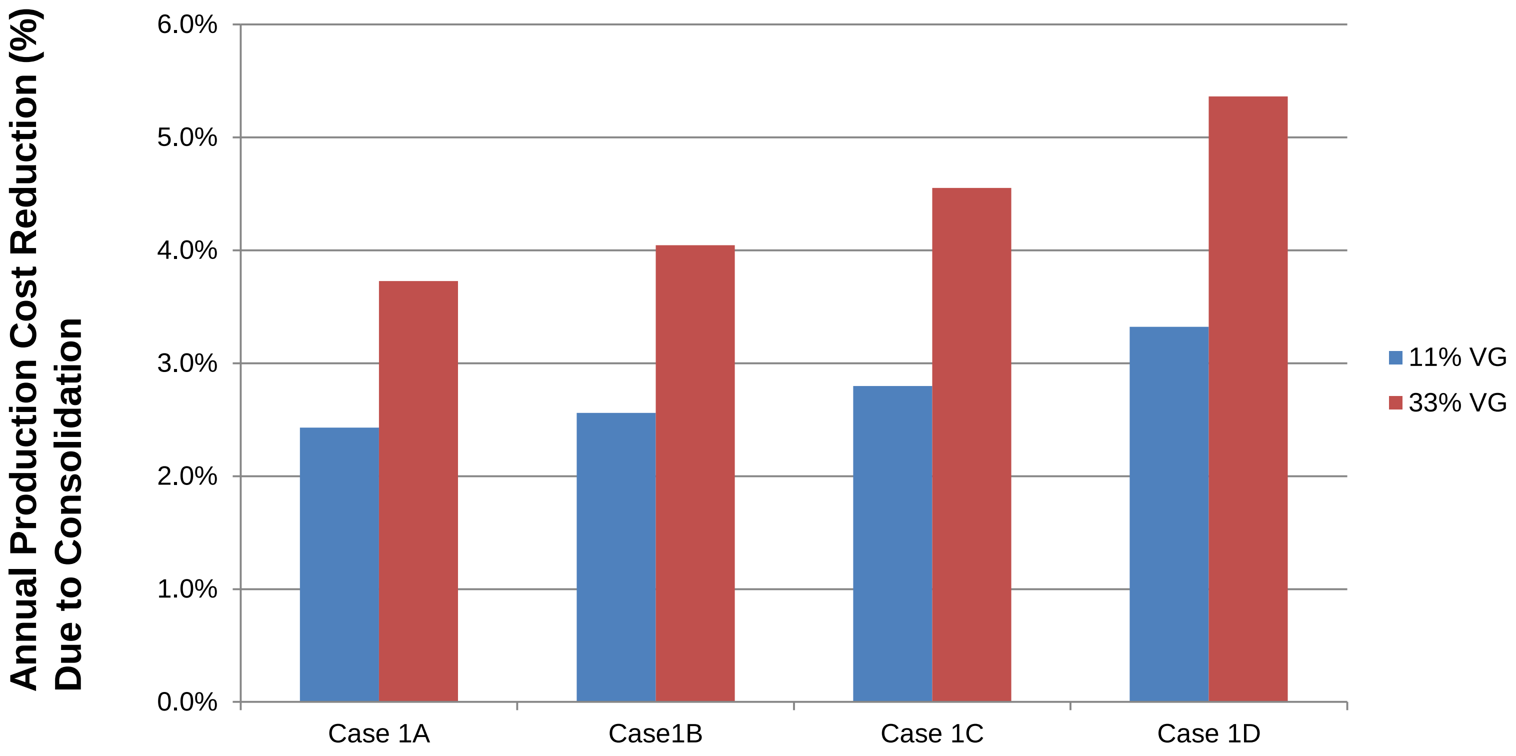
- Reduction ranges from $442 Million (3.7%) with no hurdle rates for transmission to $636 Million (5.2%) with the 15 $/MWh flat dispatch hurdle rates
- In addition to that, another $980 Million of reduction can be achieved in case 2 (copper sheet consolidation)



Generation Mix Comparison between Different Cases (33% VG)



Compare Annual Savings in Production Cost between Scenario 1 and Case 3B for 11% and 33%VG



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Production Cost Simulation Approach to Determine the Benefit of 10min Scheduling

Day Ahead

- **24-hour** optimization window
- **Day-ahead forecast hourly** load profiles
- **Day-ahead forecast** hourly wind and solar profiles
- **BA** level contingency reserve.
- **BA** level flexibility (load following and regulation reserves)

DA UC Pattern

Hour Ahead

- **1-hour** optimization window with 5 hour look ahead
- **Hour-ahead forecast hourly** load profiles
- **Hour-ahead forecast** hourly wind and solar profiles
- **BA** level contingency reserve.
- **BA** level flexibility (load following and regulation reserves)
- Allow the commitment and decomitment of units that can start/shutdown in less than 6 hours

HA UC Pattern

10-min Real Time, 10min BA interchange (10-min schedules)

- One 10-min plus five 10-min look-ahead optimization window
- **Actual** 10min average loads profiles
- **Actual** 10min average wind and solar profiles.
- BA level contingency reserve.
- **BA** level regulation reserves
- **DA Unit Commitment**
- **Allow the 10-min exchanges between BA's**

10-min Real Time, Hourly BA interchange (BAU)

- One 10-min plus five 10-min look-ahead optimization window
- **Actual** 10min average loads profiles
- **Actual** 10min average wind and solar profiles.
- BA level contingency reserve.
- **BA** level regulation reserve.
- **DA Unit Commitment**
- **Freeze the hourly exchanges between BA's (within L10 of BA)**

Conclusions

- BA consolidation is one approach to mitigate challenging problems for operators, especially for systems with high renewable generation
  - More efficient UC/ED
  - Lower reserve requirement
  - Smaller load and renewable forecast error
- Significant reduction in production cost: $440 M - $610 M for the studied year (2020)

Questions?

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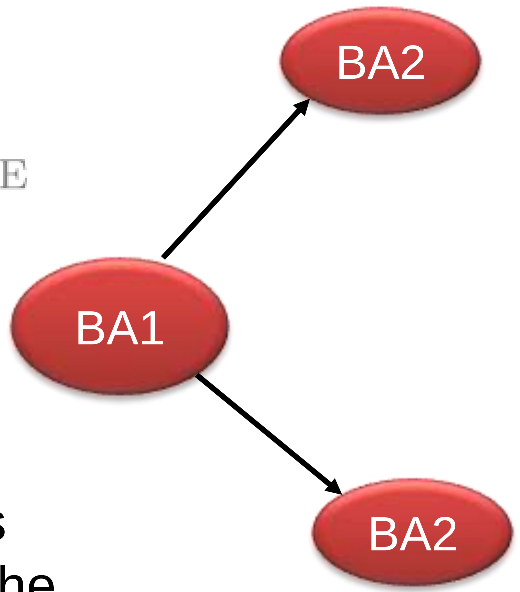
Modeling of Net Exchange Constraint in BAU
(1) ACE Definition for a Balancing Authority

$$\mathrm{ACE} = (\mathrm{NI_A} - \mathrm{NI_S}) - 10\mathrm{B}(\mathrm{F_A} - \mathrm{F_S}) - \mathrm{I_{ME}}$$



where:
ACE – Area Control Error
NIA – Sum of actual flows on tie lines
NIS – Sum of pre-scheduled flows on tie lines
B – Frequency Bias Setting (MW/0.1 Hz) for the BA
FA – Actual frequency
FS – Scheduled frequency
IME – Meter error correction factor

Modeling of Net Exchange Constraint
(2) ACE Requirement

$$\mathrm{AVG}_{\text{10-minute}}(\mathrm{ACE}) \le L_{10}$$

"Each Balancing Authority shall operate such that its average ACE for at least 90% of clock-ten-minute periods (6 non-overlapping periods per hour) during a calendar month is within a specific limit, referred to as *L*10."

$$L_{10} = 1.65\epsilon_{10}\sqrt{(-10\mathrm{B}_i)(-10\mathrm{B}_s)}$$

ε_{10}: Constant derived from the targeted frequency bound
B_i: Frequency Frequency Bias Setting for the BA under study.
B_S: Sum of Frequency Bias Settings of BAs

Source: NERC Standard BAL-001-0.1a—Real Power Balancing Control Performance, http://www.nerc.com/files/BAL-001-0_1a.pdf

RT 10min Net interchange Constraint (3)Implementation in PLEXOS

- Scheduled hourly net interchange for each BA (NIS) is calculated from HA simulation
- The following constraint is imposed on the 10-min net interchange for each BA (NIA):

$$\text{NIS} - L10 \leq \text{NIA} \leq \text{NIS} + L10$$

- The addition of this constraint results in more realistic presentation of BAU case
- Penalty of violating this constrain needs to be carefully coordinated with USE and maximum monthly hydro energy violation constraints

Benefit of 10min schedules vs. hourly schedules