Pacific Northwest
NATIONAL LABORATORY

System Security: NTP AC Power Flow Analysis Update

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PNNL

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NOTICE

This presentation contains illustrative examples from preliminary modeling only; final results will differ from any results shown here.

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Steady-State AC Power Flow to Study the Reliability of the Developed Scenario Cases

- PCM simulates:
  - Hourly economic dispatch (ED) of generators to meet demand (decarbonized grid means much less thermal, ED is more about optimize storage, minimize curtailment, avoid unserved load)
  - Determine real power flows within the nodal transmission network
  - However, power flow simplified as linearized DC flow, therefore: realistic power flow solutions using non-linear AC power flow analysis should be performed
- AC power flow analysis:
  - AC power flow cases are the main models used by grid planners to perform reliability/security studies required by NERC to ensure compliance with standards
  - Reactive power support planning is needed to ensure grid voltage stability
  - Enough dispatched real power to compensate for losses
  - Enough on-line generation reserve to mitigate contingencies (do we have enough governor response to accommodate the outage of large power plants?)
  - The impact of very high penetration of Inverter Based Resources (IBRs) (wind, solar , battery storage) and the required grid services IBRs have to provide such as voltage support

NTP Modeling Framework

WECC 2030 Anchor Data Set (ADS) Production Cost Model (PCM)

Starting Models

WECC 2030 Summer and Winter Power Flow Cases

Transmission projects at advanced development stage

New wind and solar based on new lines and interconnection capacity available

High renewables Baseline Case

Selected transmission projects at advanced development stage

EI PCM model based on EIPC Revised MMWG 2031 Power Flow Model

Capacity expansion Model

Nodal to Zonal

Limited AC

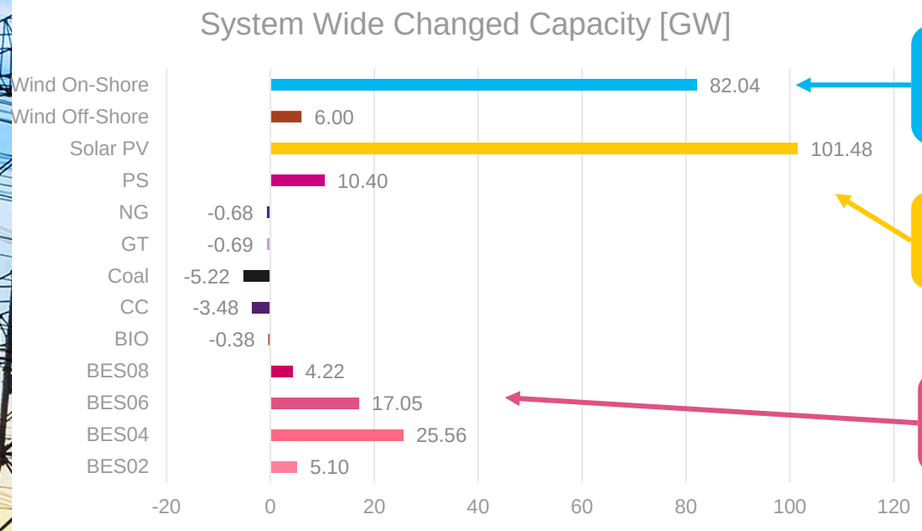
Inter-regional AC

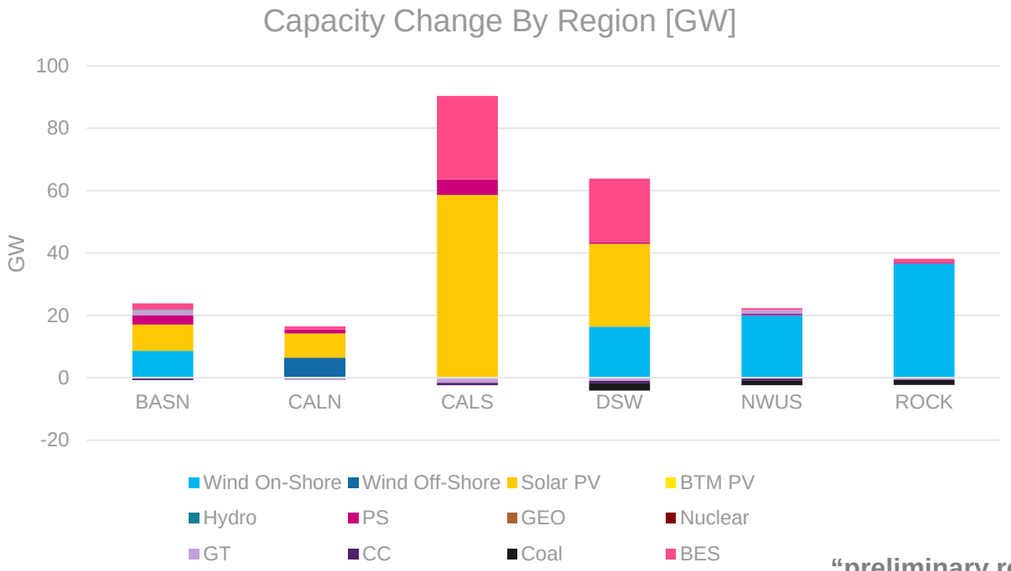
Conus WI +EI (HVDC)

New PCM and AC Power Flow Models

Changes to the Capacity Mix:
Inter-regional AC scenario has more wind but less solar and storage compared to AC limited scenario (based on Round 1 Capacity Expansion Modeling)

Interregional AC Scenario



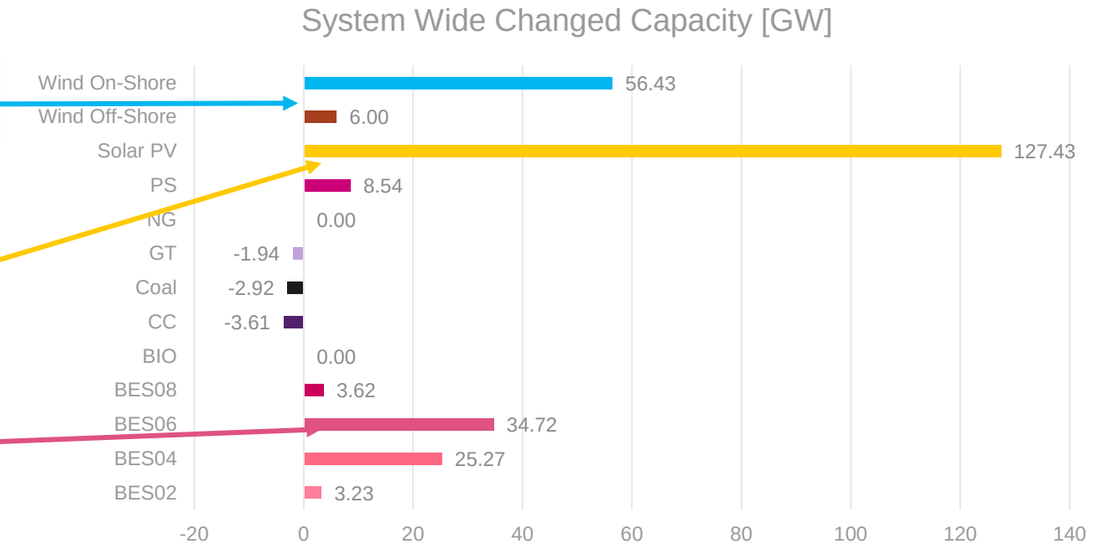


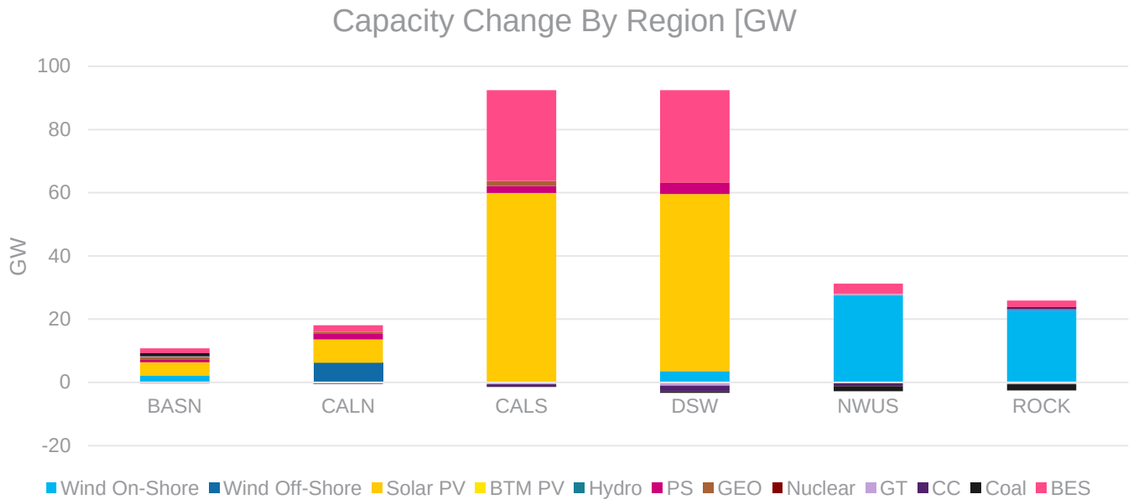
More interregional wind

Less interregional Solar

Less interregional BES

Limited AC Scenario

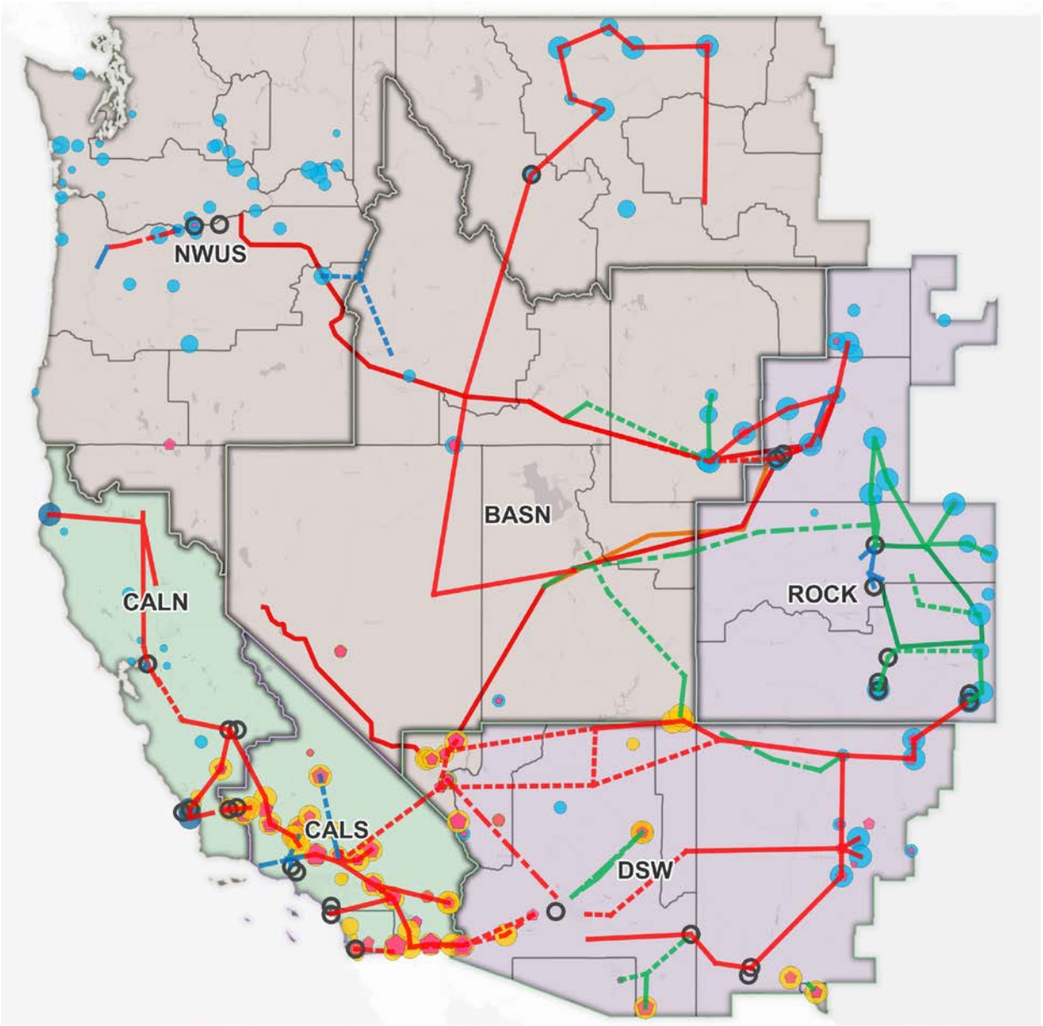




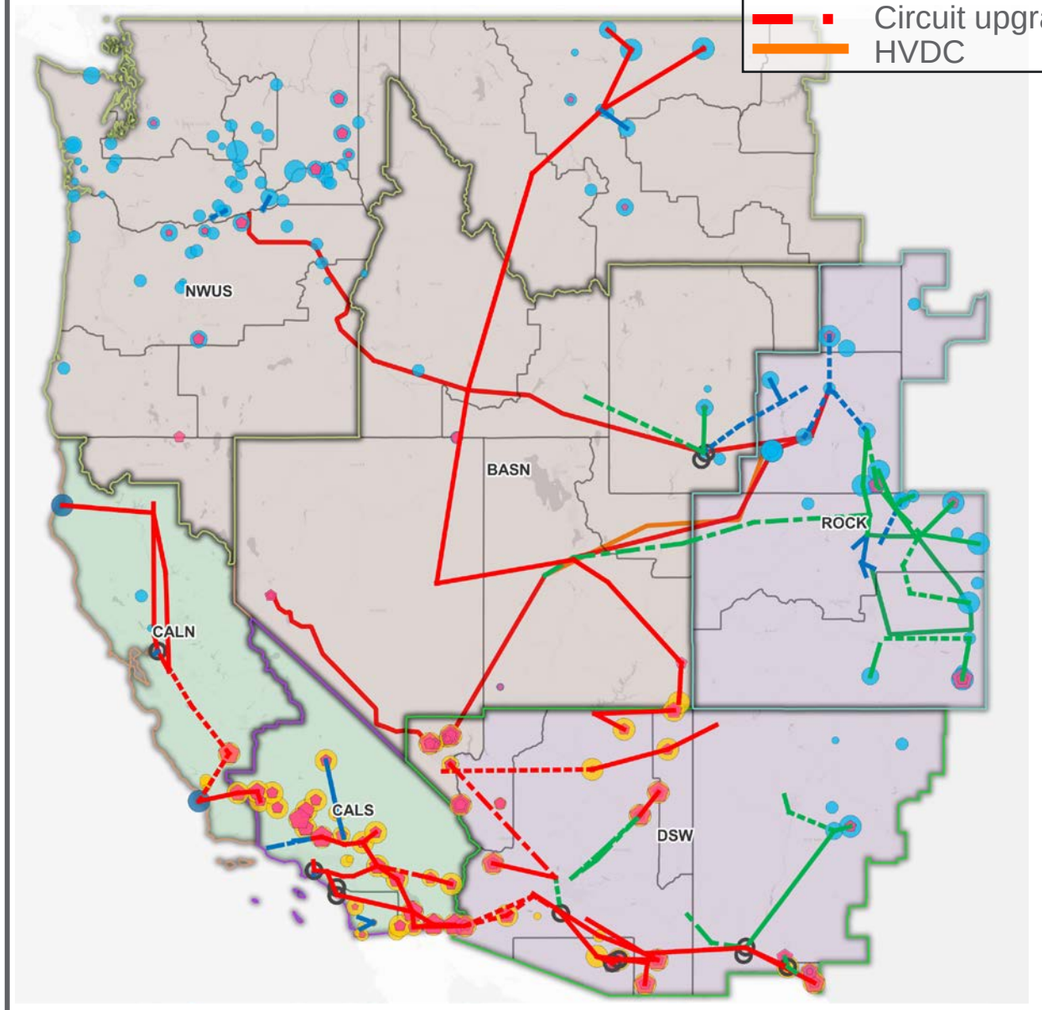
WI Transmission Expansion Overview

Interregional AC Scenario

BES PV Wind On-Shore Wind Off-Shore



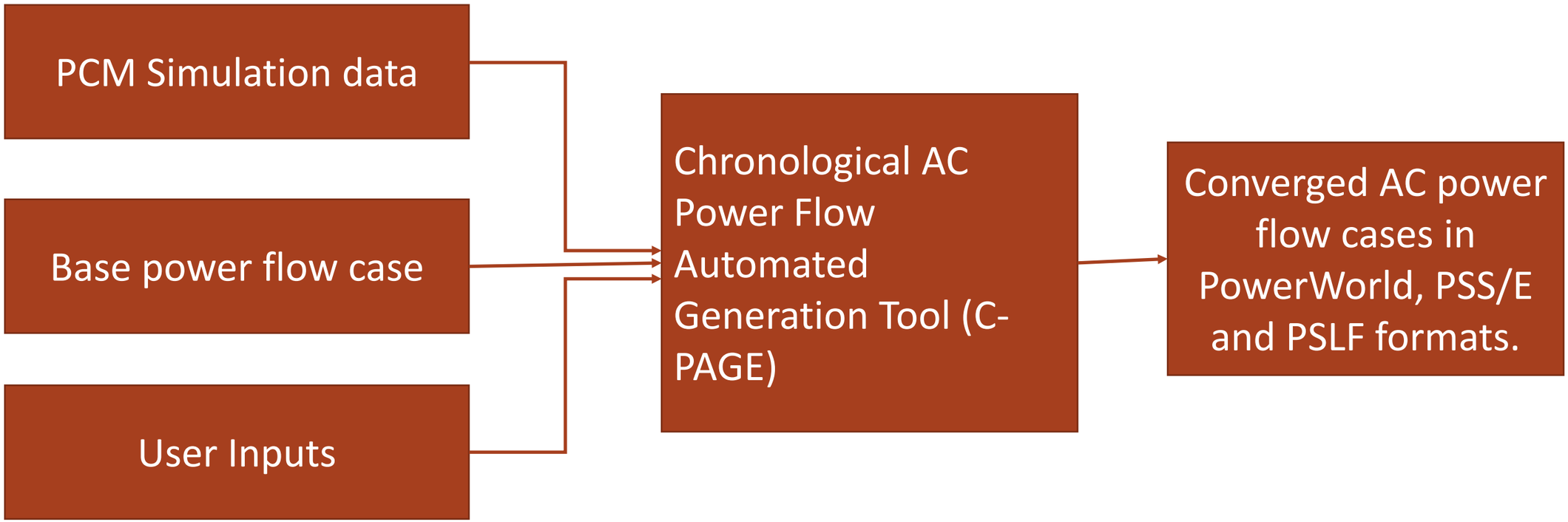
Limited AC Scenario



New circuit 230 kV
New parallel circuit 230 kV
Circuit upgrade 230 kV
New circuit 345 kV
New parallel circuit 345 kV
Circuit upgrade 345 kV
New circuit 500 kV
New parallel circuit 500 kV
Circuit upgrade 500 kV
HVDC

"Preliminary Results | Do Not Cite | Line location are illustrative only."

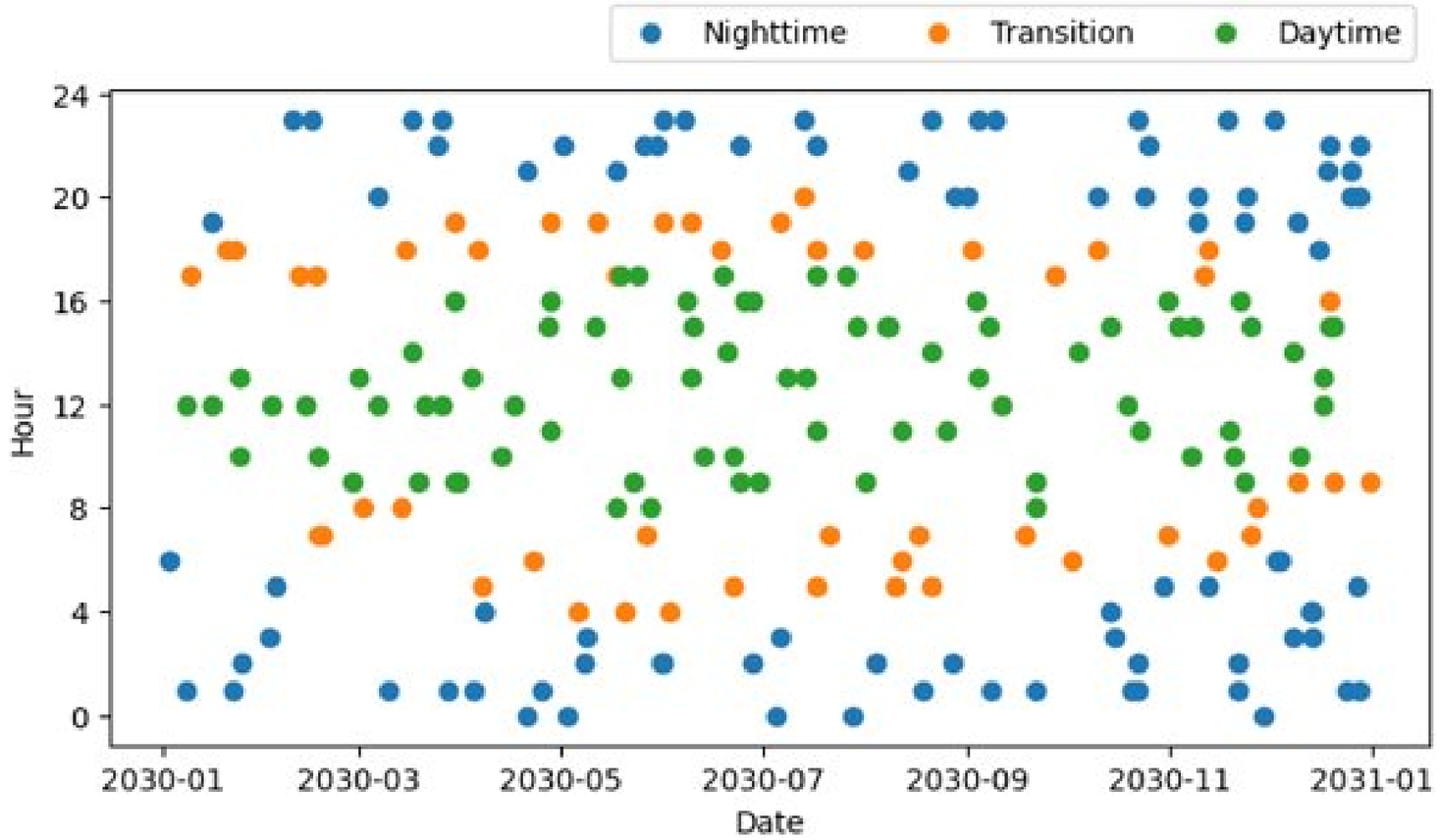
Chronological AC Power Flow Automated Generation Tool (C-PAGE) : PCM to PF



Opensource IEEE Paper:

https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9416491

Intelligent Sampling technique to identify representative hours for AC power flow analysis



Total sample size: 214 (sampling rate: 2.5%)

AC Power flow convergence process

Stage 1

- Prepare DC power flow cases using PCM results

Stage 2

- DC to AC convergence process

Stage 3

- Reactive power planning for voltage improvement

Contingency Analysis

- We run contingency analysis to examine how robust the developed scenarios are:
  - We check if the new developed nodal scenario can still operate reliably under few N-1 and N-2 contingencies
  - We are not performing a full reliability planning study, it is just a showcase of some samples
- Selecting criteria for contingencies:
  - Backbone transmission outages (500KV and above)
    - ✓ This is important to make sure outages in the 500KV system is not leading to significant flow and voltage violations
    - ✓ We also consider few 345kV lines in areas where 345kV is the backbone
  - Individual outage of newly added transmission and neighboring lines
    - ✓ This is important to make sure the new lines are not representing new critical contingencies to the system
    - ✓ Some of these lines are mainly connecting large amount of new wind and solar to the backbone
  - Large power plants 500MW or above (more than one units simultaneously)
    - ✓ This is important to understand the availability of pseudo governor response

Contingency Limit Monitoring Settings

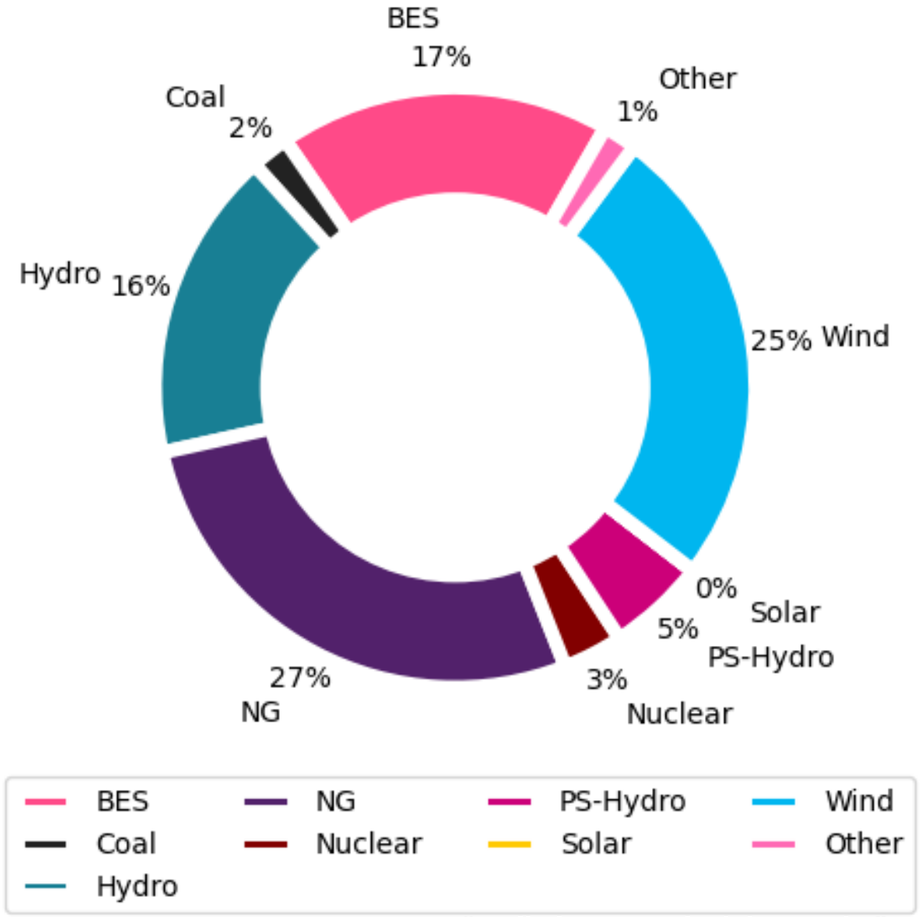
- Voltage Limits (Nominal voltage >= 230 kV)

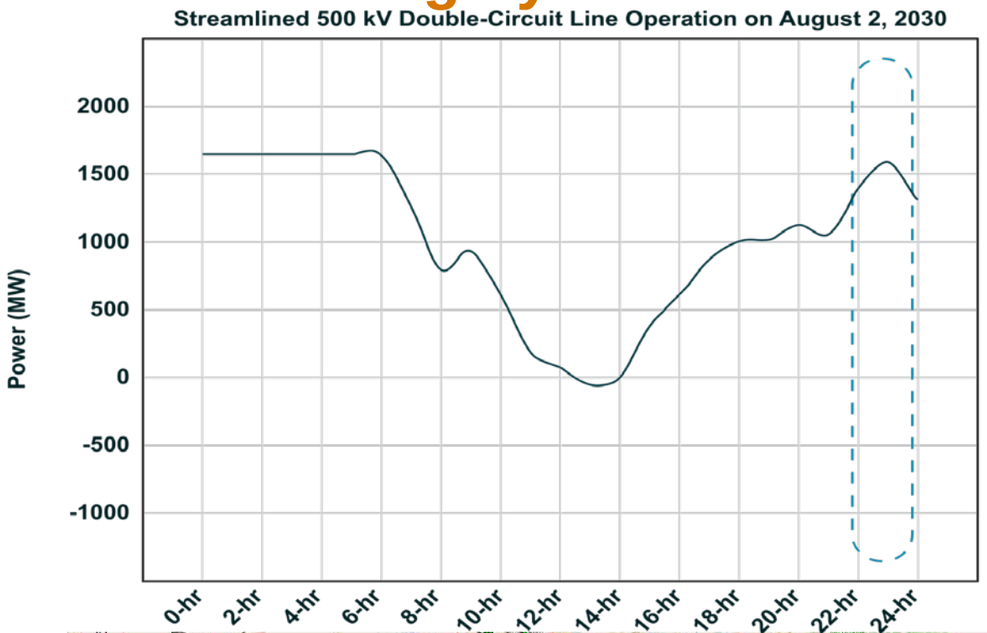
	Low	High
Normal	0.95	1.05
Contingency	0.9	1.1

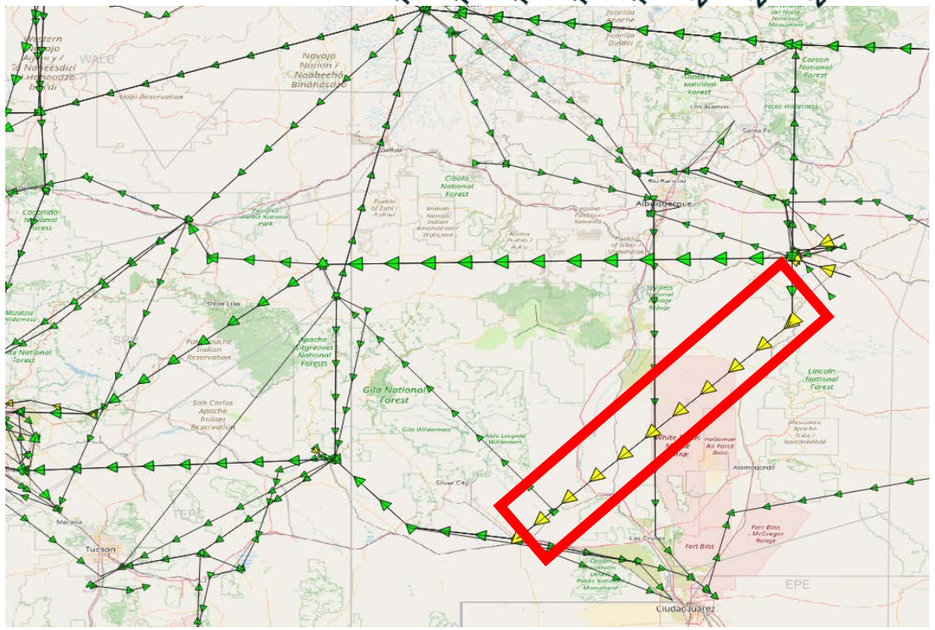
- Lines Power Flow Limits (Nominal voltage >= 230 kV)
  - Normal limits: 100% of Rate A, enforced in the PCM model
  - Contingency overload limits: minimum of 135 % of Rate A or Rate B (if given)

Example 1, Interregional-AC: Selecting an hour with a highly loaded new line (Aug 2nd, Hour: 10pm MST)

Generator Output [MW]
2030-08-02 10:00 PM MST
Total load (native load – BTM): 163 GW







New double circuit 500KV line, connecting from central New Mexico new wind hub to Luna substation (NM), two lines outage (N-2)

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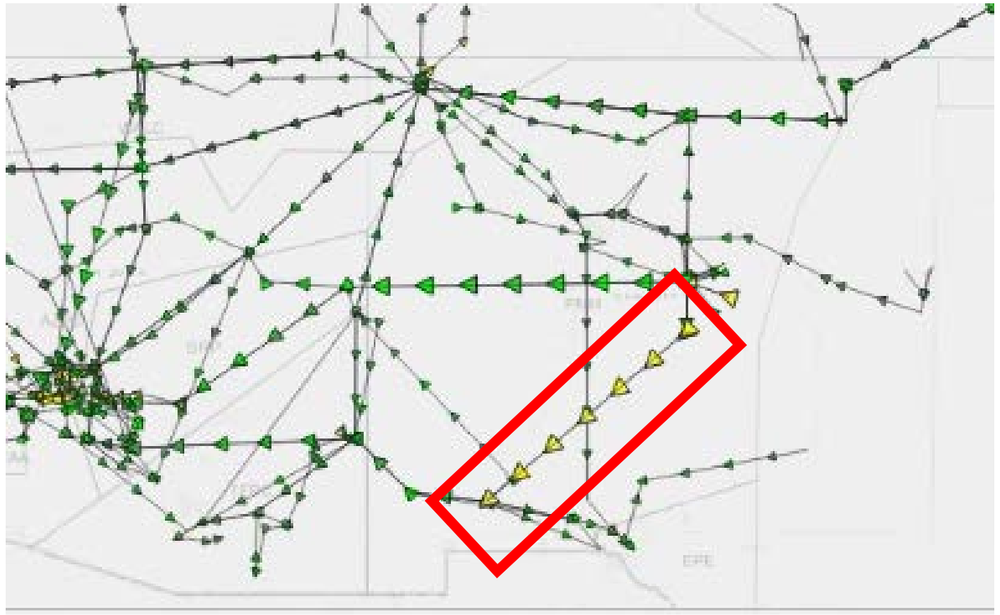
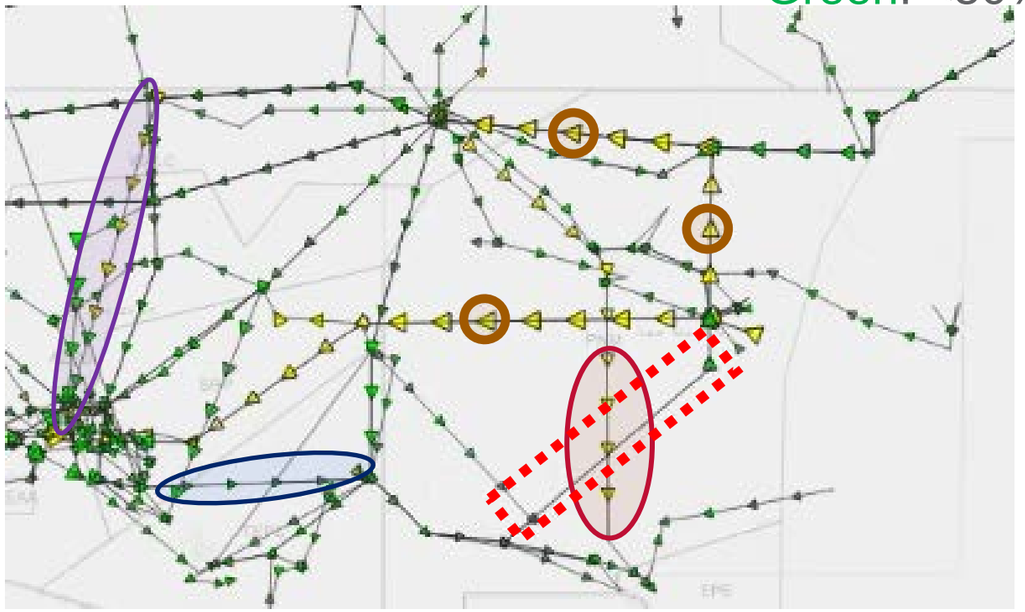
Example 1: Interregional-AC (cont.): New Double Circuit Transmission Line outage, Flows Before and After Contingency

Red: >90%
Yellow: 50-90%
Green: <50%

Before Contingency



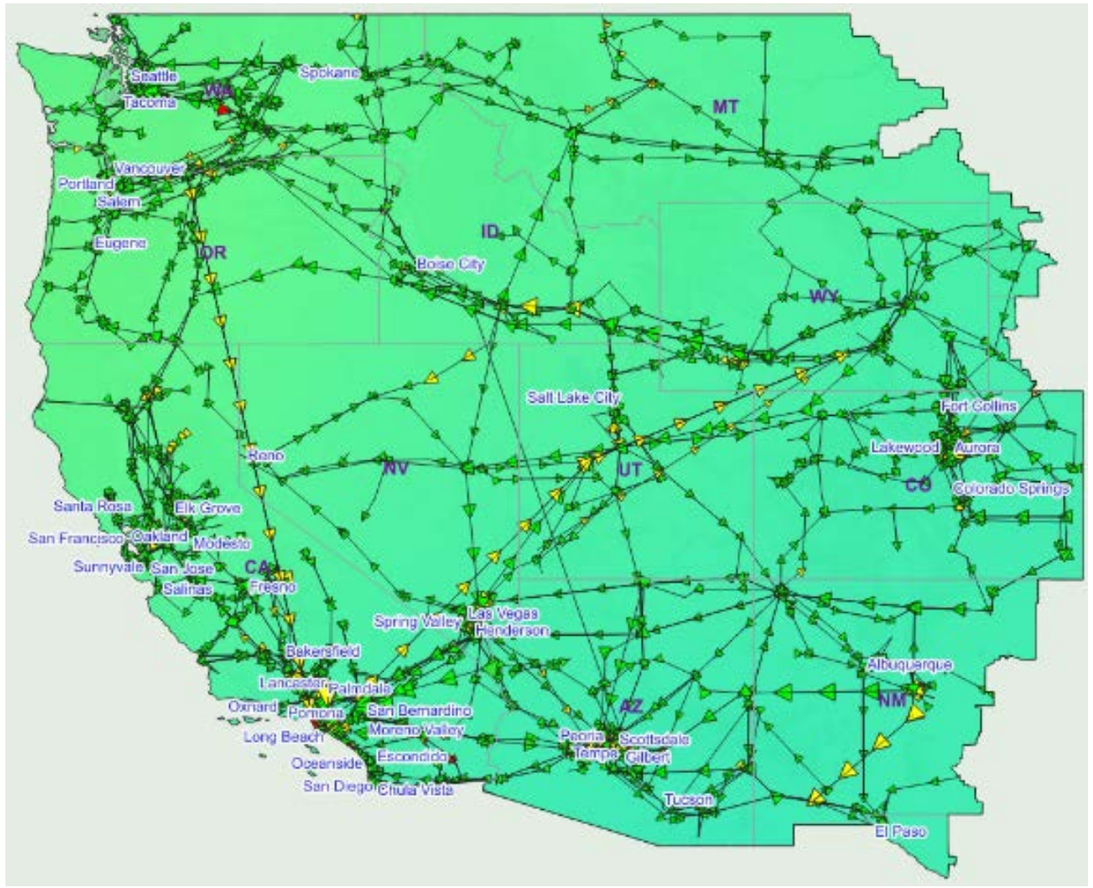
After Contingency



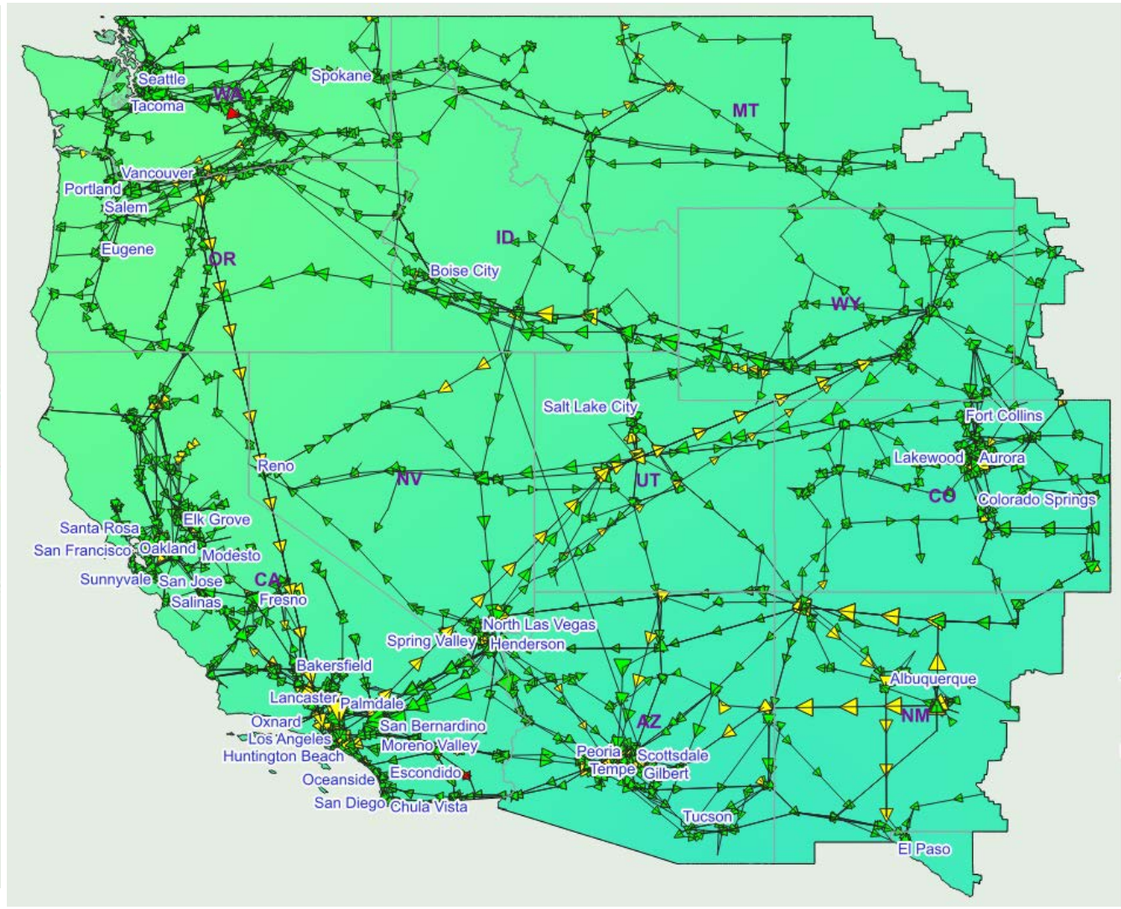
- Flow increase or reverse into southeast NM (EPE area)
  - In Southern NM flow reverse on 500/345 system to into NM
  - Albuquerque to EPE flow increase
- Flow increase from Central NM Wind through western and northern path (Coronado and Four Corners)
- The flow Phoenix received from Southern NM is replaced with increased flow from Navajo

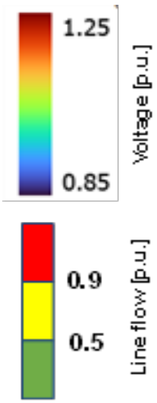
Example 1: Voltage Profiles and Real Power Flows

Pre-Contingency: Inter-regional AC



Post –Contingency: Inter-regional AC

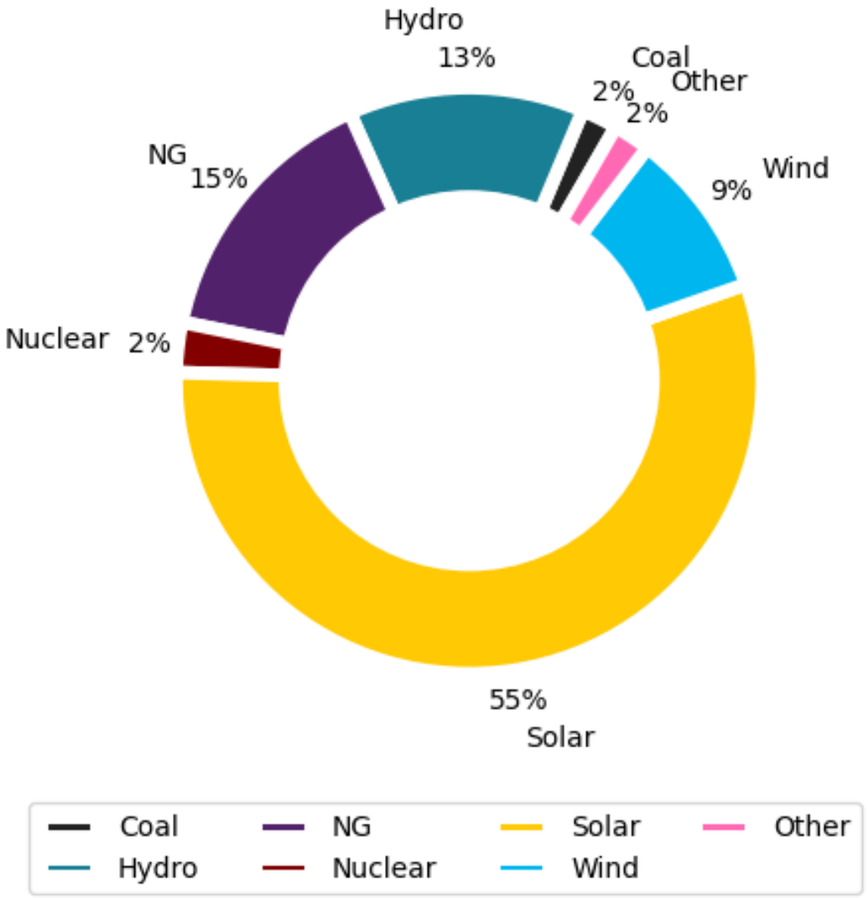


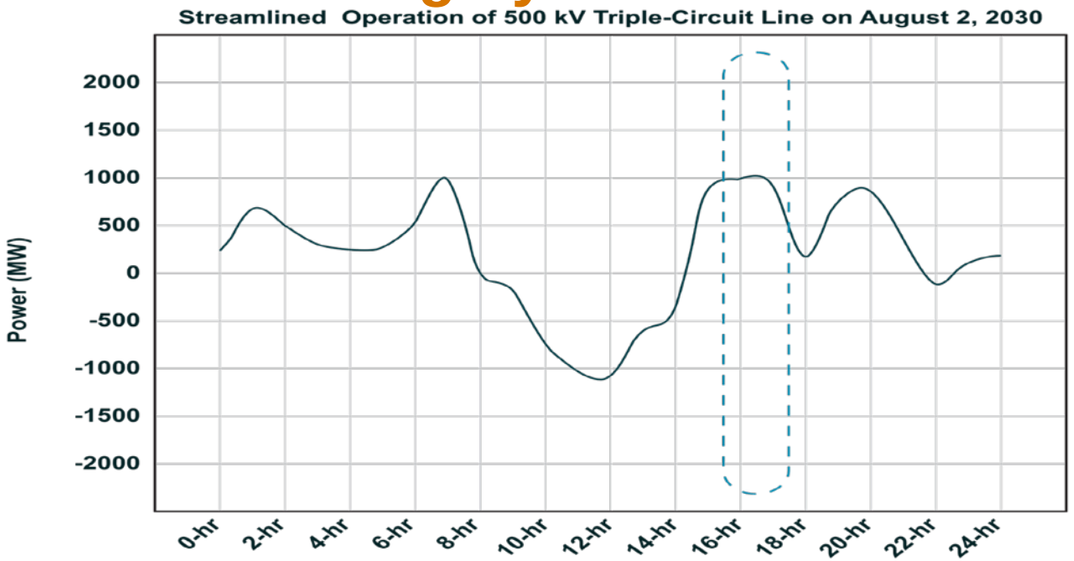


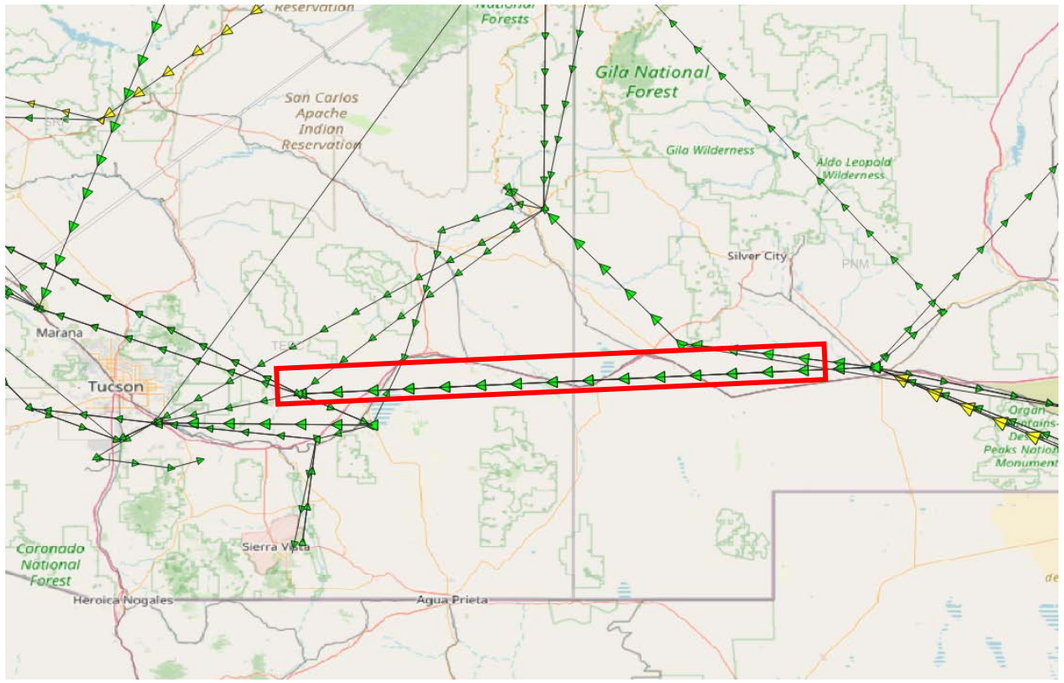
- We tried our best to get good voltage profiles across WECC for different imported hours from PCM
- Overall, no additional voltage violation in post contingency cases beyond what is observed in the pre-contingency cases

Example 2:Limited AC: Selecting an hour with a highly loaded new line, (Aug 2nd, Hour: 4pm MST)

Generator Output [MW]
2030-08-02 4:00 PM MST
Total load (native load – BTM): 172 GW







New triple circuit 500 KV line, connecting between Luna (NM) to Winchester substation (AZ), two lines outage (N-2)

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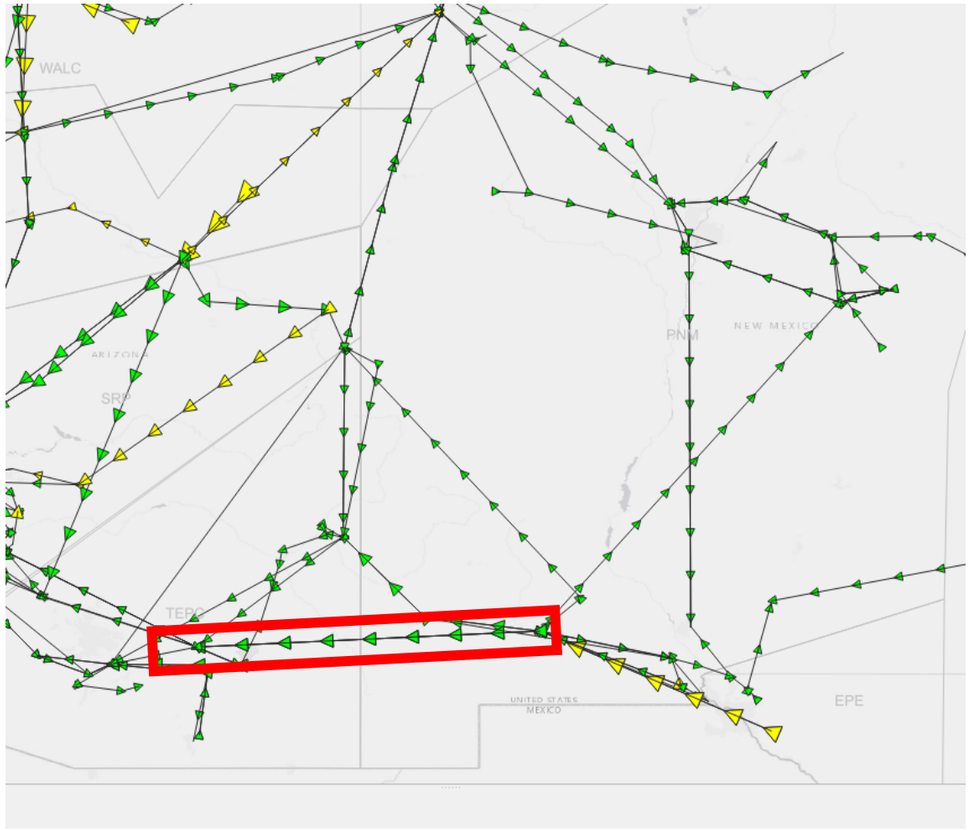
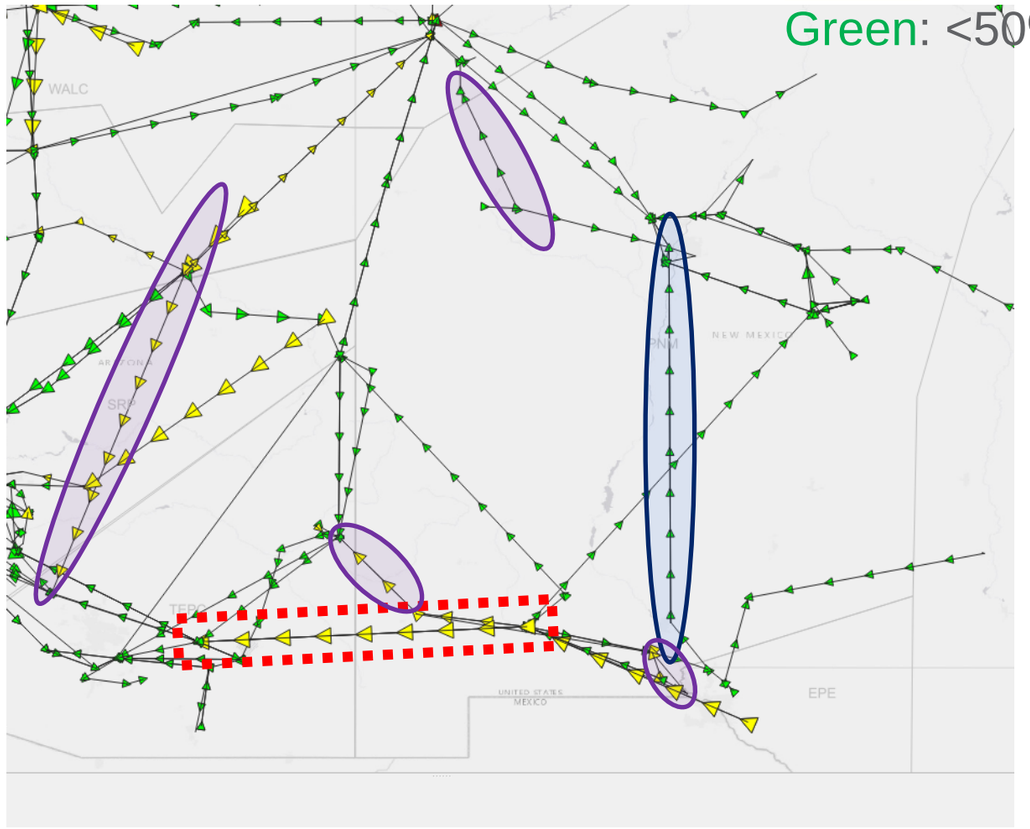
Example 2, Limited AC: New Double Circuit Transmission Line outage Flows Before and After Contingency

Red: >90%
Yellow: 50-90%
Green: <50%

Before Contingency



After Contingency

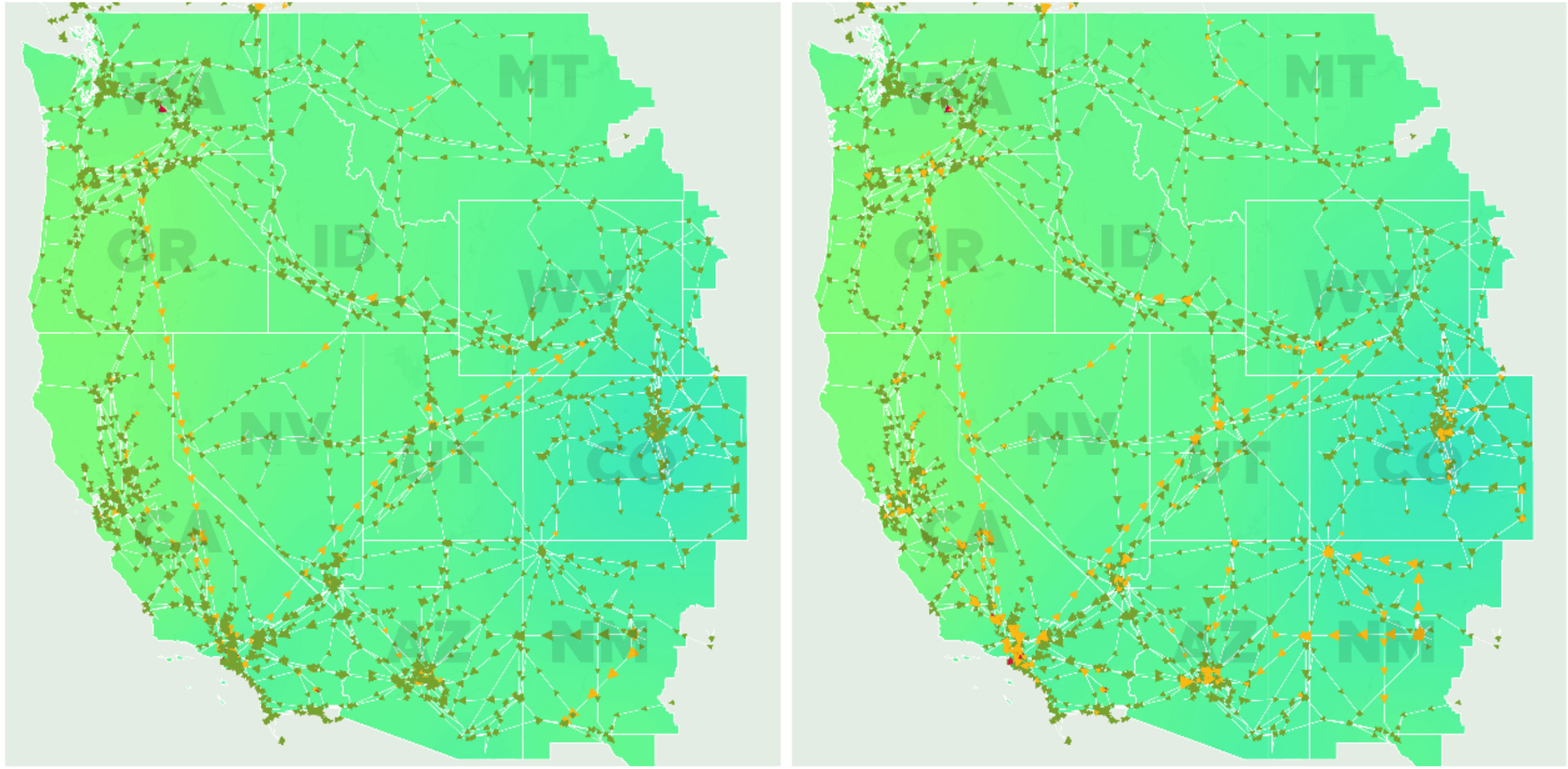


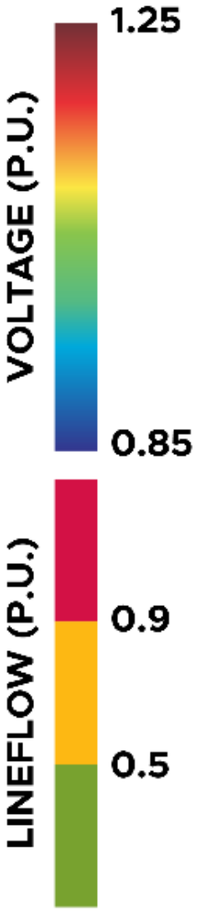
- Outage of two out of the three 500 kV lines that carry power from Luna to Winchester.
- The path from EPE solar hub to the West is limited, so the flow is diverted to the North before heading West through:
  - North-South flow reverses direction through east of Albuquerque before heading West to Arizona
  - Increased flow through Gila

Example 2 : Voltage Profiles and Real Power Flows

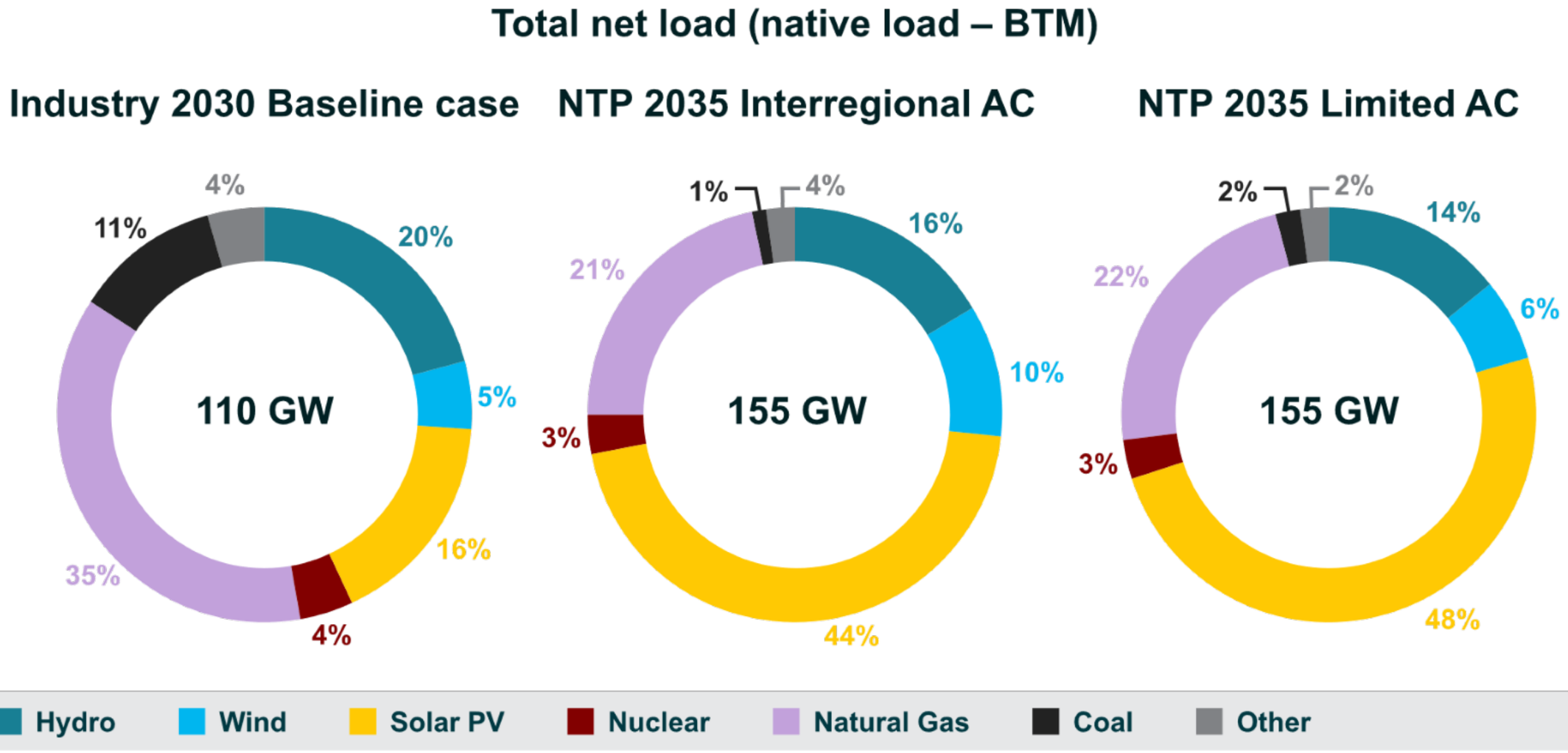
Pre-Contingency: Limited AC

Post-Contingency: Limited AC

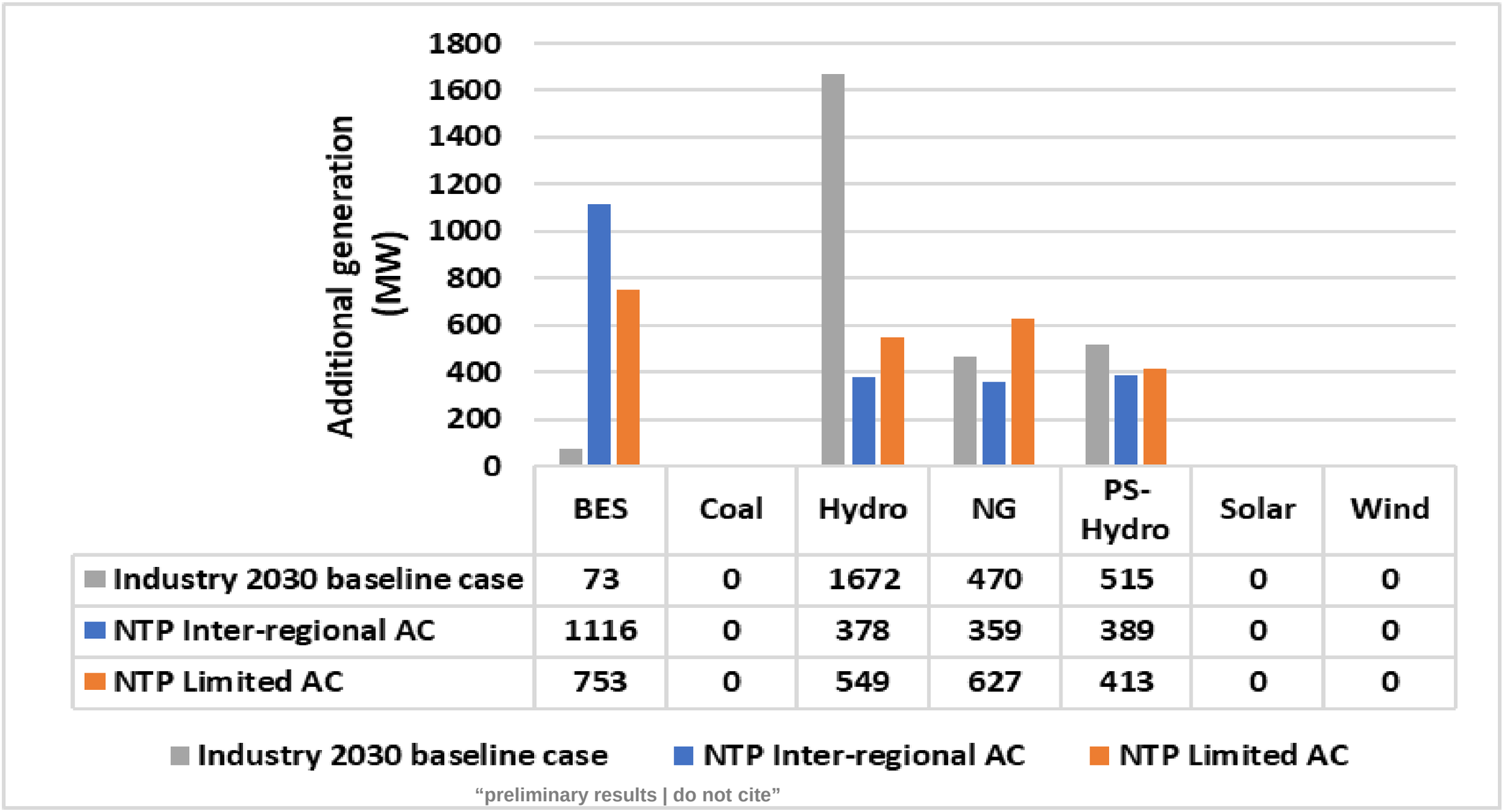




Example 3: Gen Mix (July 21, hour: 8 AM MST)



Example 3 (cont.) : Generation redistribution to make up for the loss of 2600 MW, Pseudo–Governor Response Industry baseline case vs Inter-regional AC vs Limited AC



	BES	Coal	Hydro	NG	PS-Hydro	Solar	Wind
Industry 2030 baseline case	73	0	1672	470	515	0	0
NTP Inter-regional AC	1116	0	378	359	389	0	0
NTP Limited AC	753	0	549	627	413	0	0

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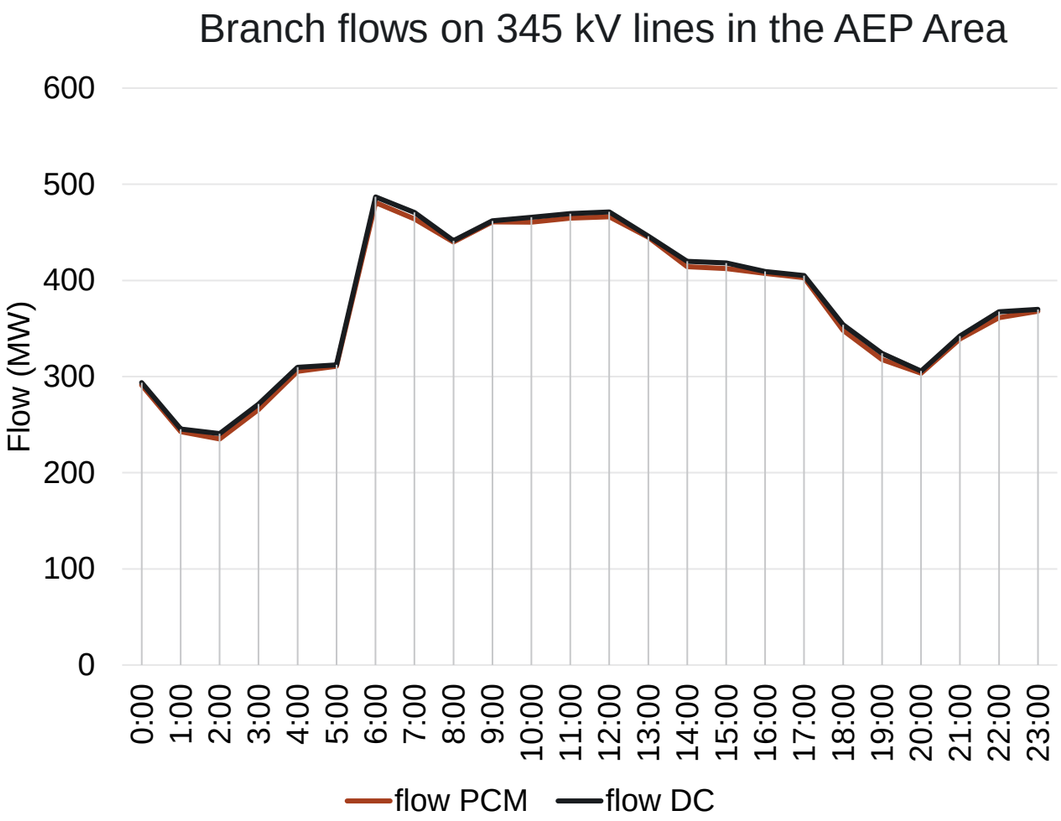
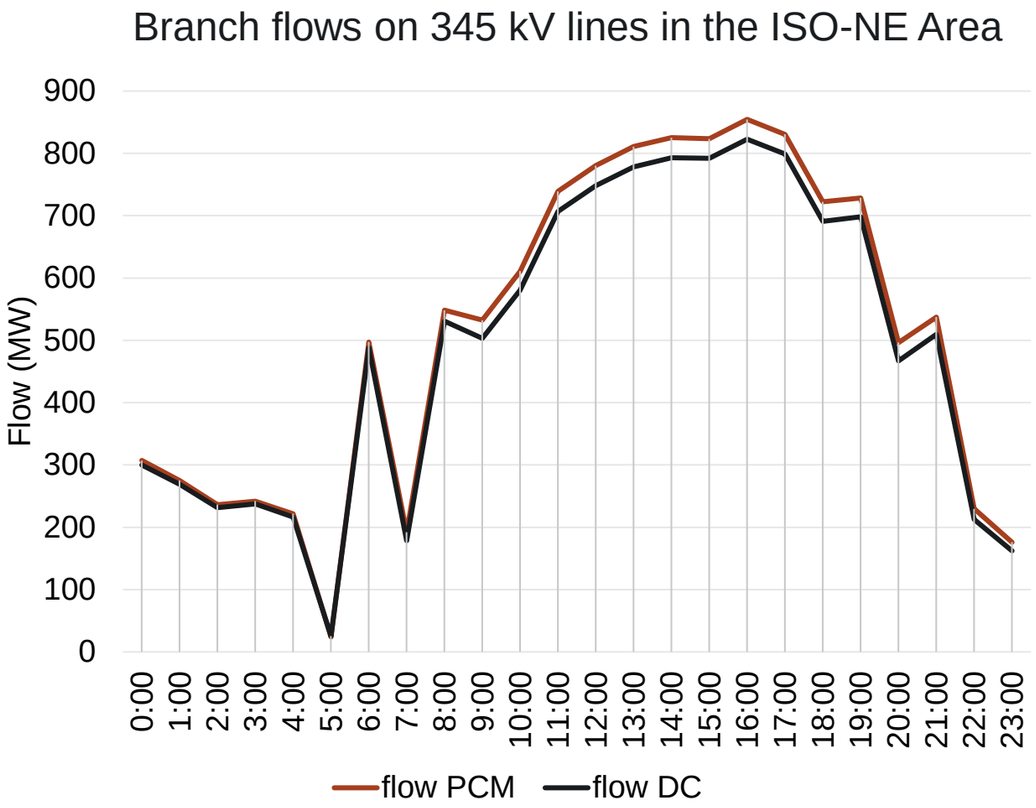
AC Power Flow Analysis for EI Baseline Case:

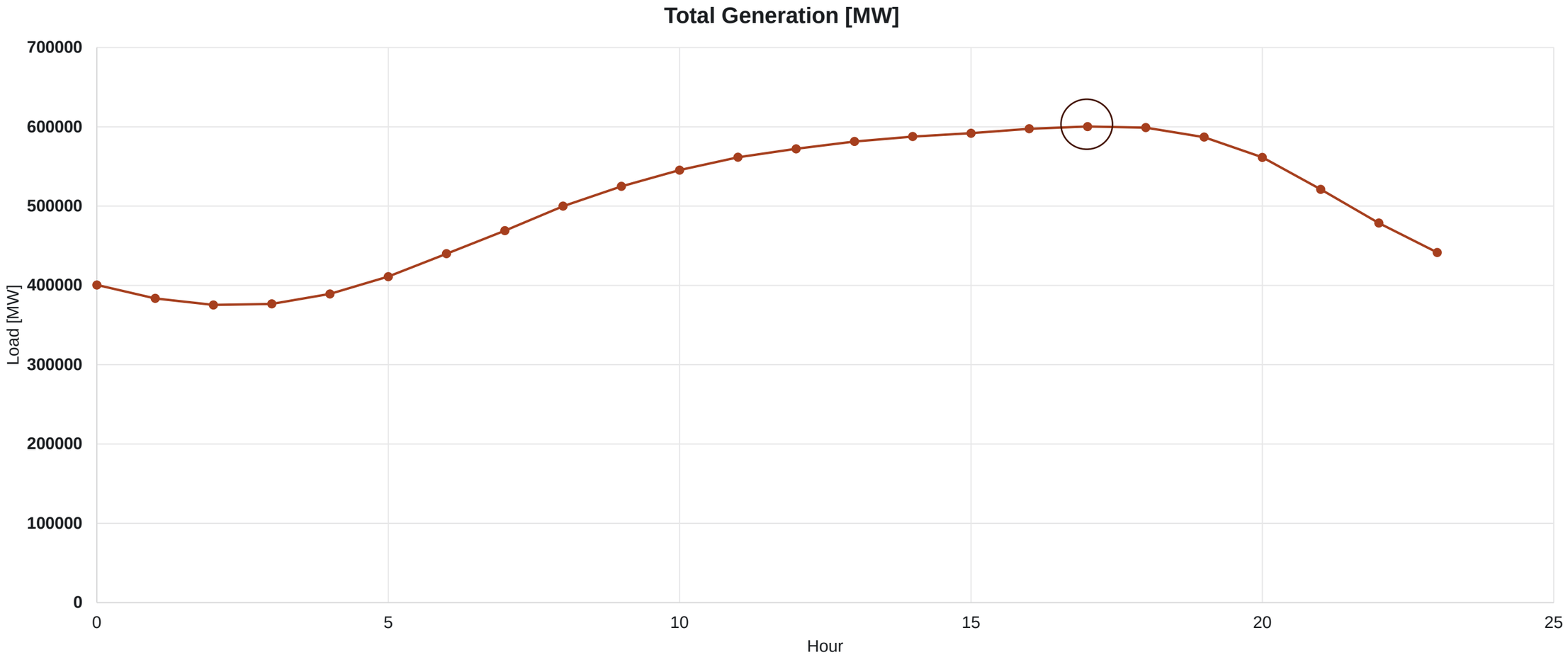
- The EI baseline case is based on EIPC revised MMWG 2031 power flow case
- NTP team developed EI baseline PCM model in Plexos, GridView, NREL Sienna
  - We developed DC and AC power flow cases for base-line analysis based on PCM runs that were shared with EIPC members
- We developed a baseline CONUS PCM model in Gridview
  - Combine the WECC 2030 ADS and EI 2031 base-line industry cases
  - Extract Baseline CONUS AC Power Flow Model in Power World and PSSE
- These models are the foundation for
  - The build of the CONUS scenario 3 multi-terminal HVDC scenario Zonal to Nodal work
  - AC power flow analysis for this scenario

Validation of EI PCM vs DC Power Flow: Branch flow comparison for one Day

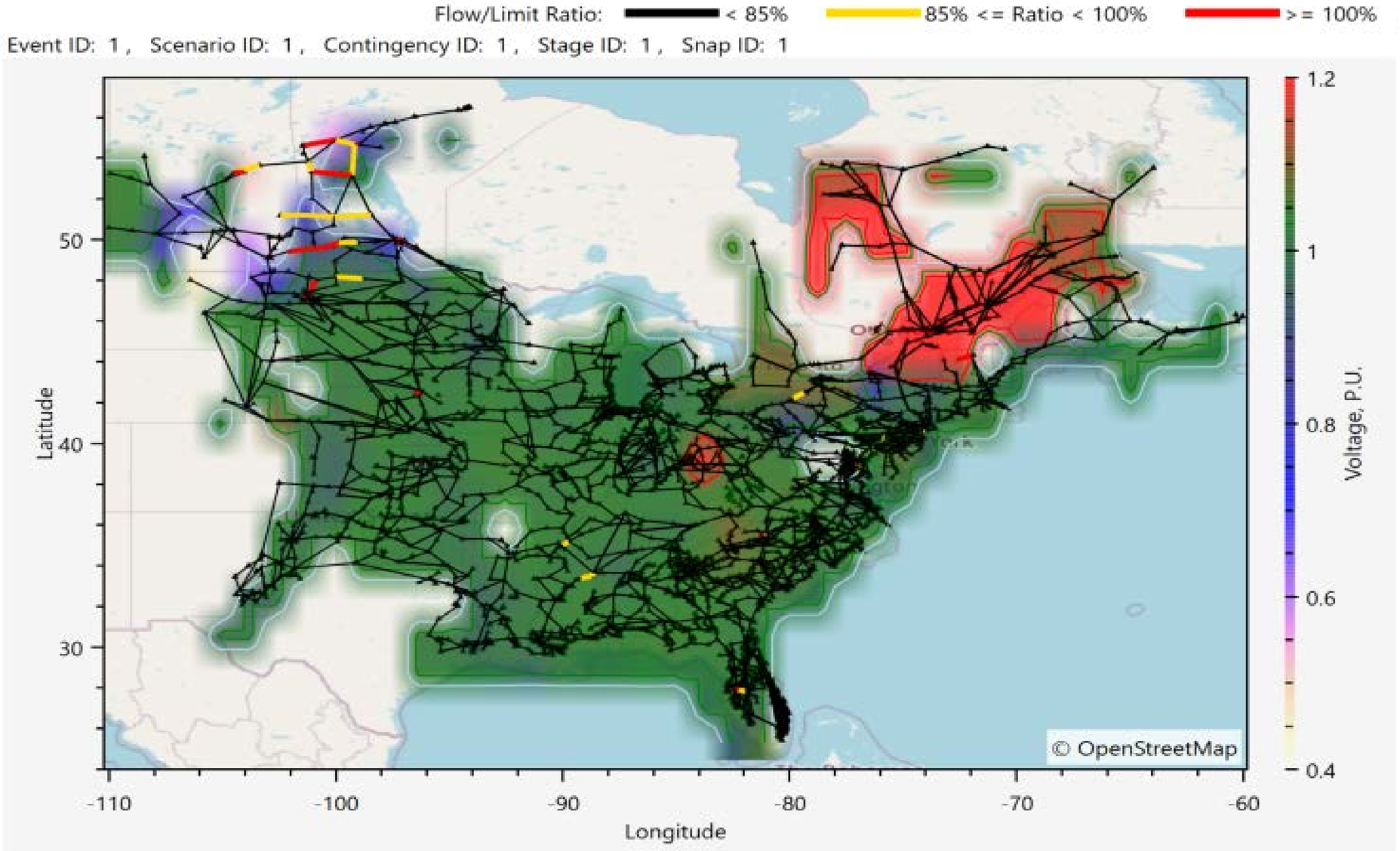




EI Base-line PCM case Generation profile on Aug 10, 2035



Voltage profile EI- base line case （Aug 10, Hour: 5 PM EST)

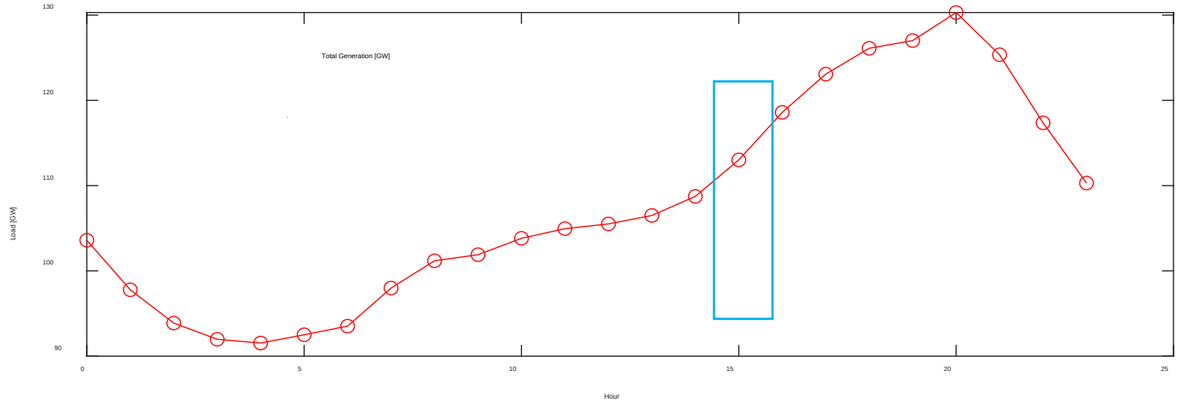


- Reasonable voltage profiles and flows across EI for the imported hours from PCM
- More work needs to be done to improve the voltage profiles in the Canadian part of EI

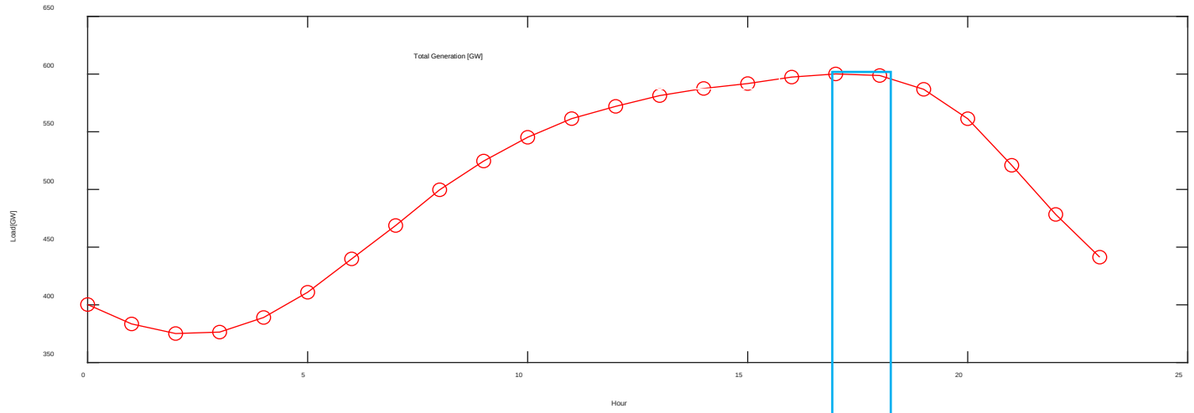
Creating the CONUS Baseline AC Power Flow Case

- Implement B2B as short HVDC lines between EI and WI
- Different component with same identification in both EI and WI:
  - Same bus number, change duplicate bus numbers in WECC with certain logic
  - Same impedance correction table number
- CONUS baseline case: Use PCM results for August 10th,
  - 5 pm EST for EI
  - 3 pm MST for WI case
  - Use as the baseline power flow case to build CONUS Multi-Terminal HVDC scenario for AC power flow analysis

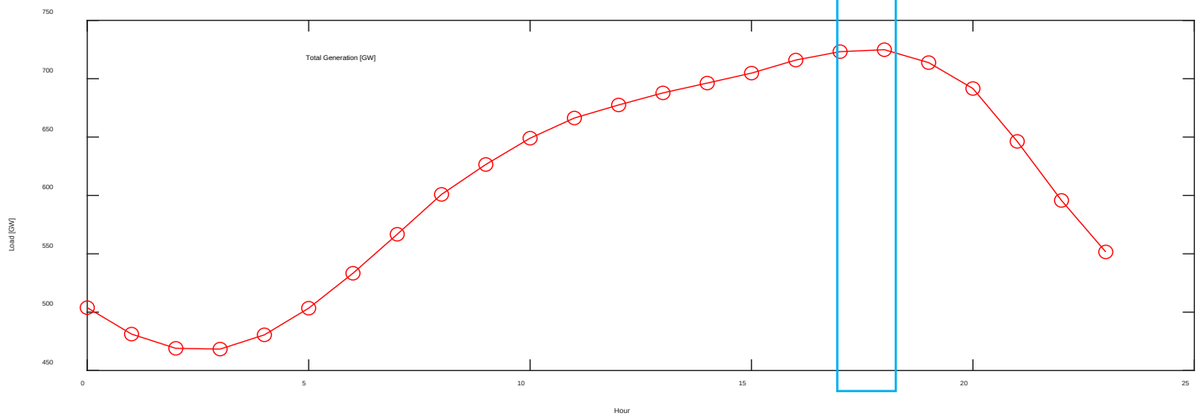
Generation profile on Aug 10th, 2035



WI (MST)



EI (EST)



WI+EI (EST)

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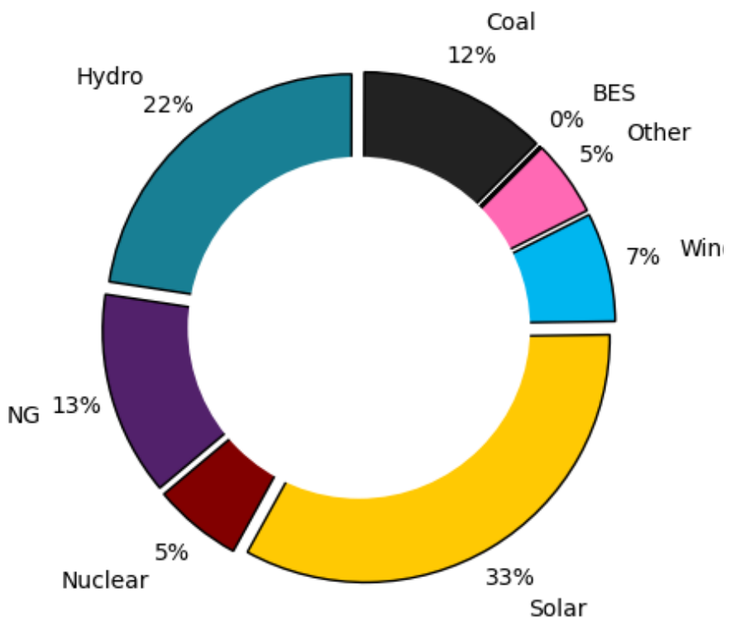
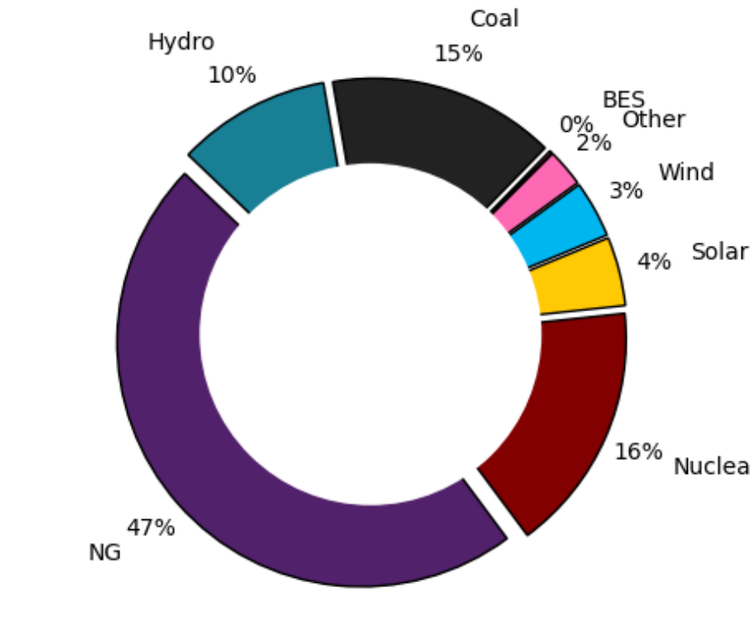
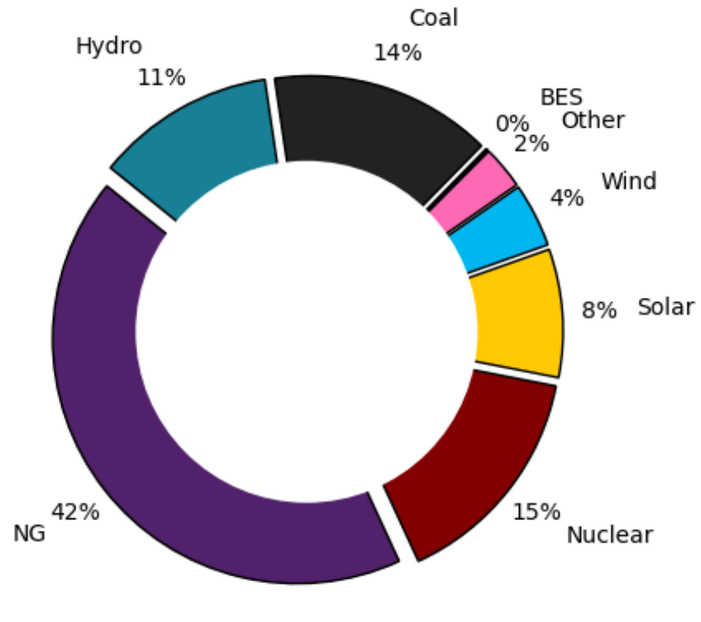
CONUS Baseline: Example Hour (Aug 10, Hour: 5 PM EST)



WECC
Total Net Load :113,016 MW
Native Load: :136,893 MW
BTM: :23,877 MW

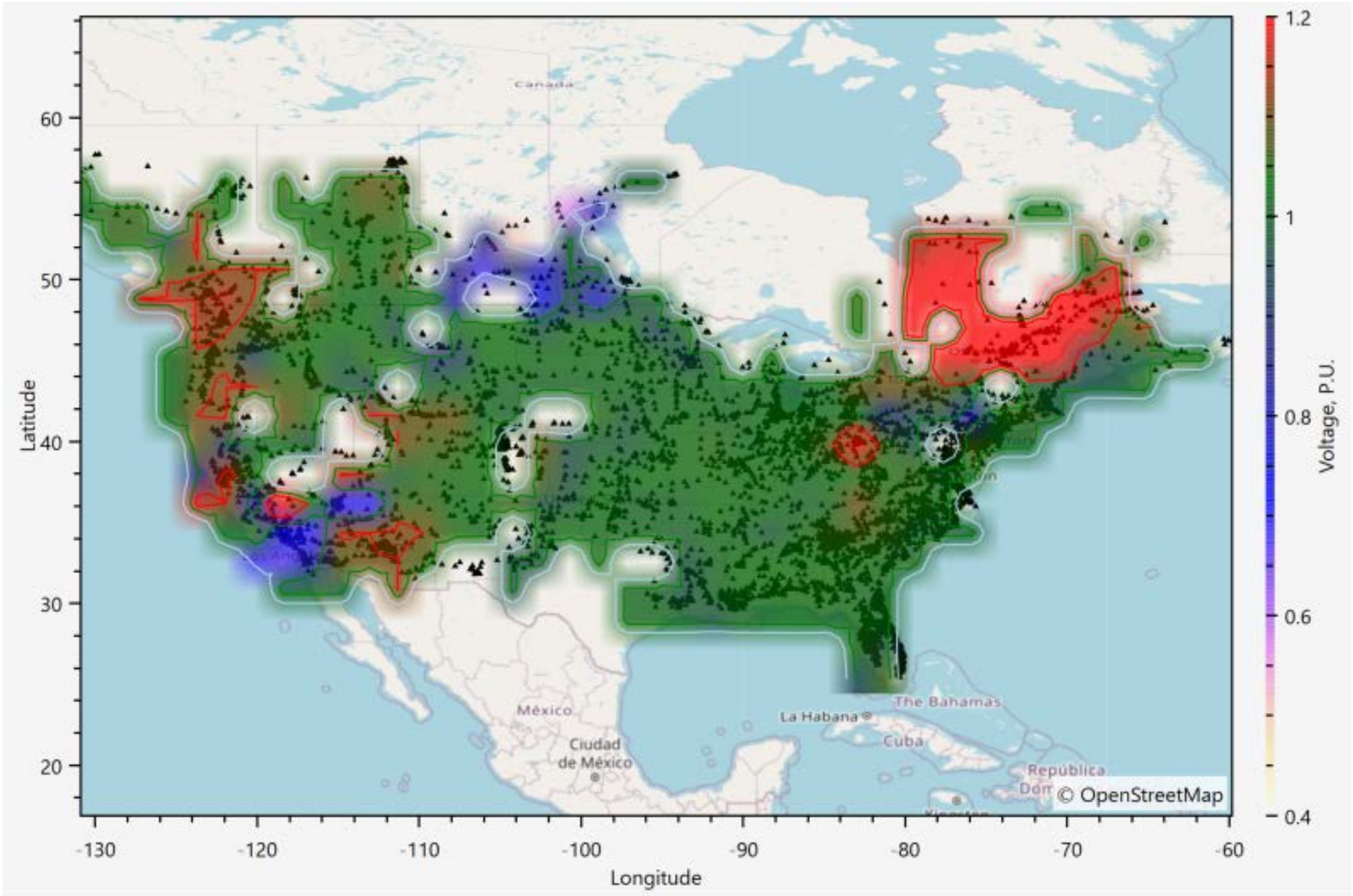


EI
Total Net Load : 600,117 MW
Native Load : 60,9032 MW
BTM : 89,15 MW



WECC+EI
Total Net Load :713,133 MW
Native Load :745,925 MW
BTM :32,792 MW

Voltage Profile Conus Baseline Case

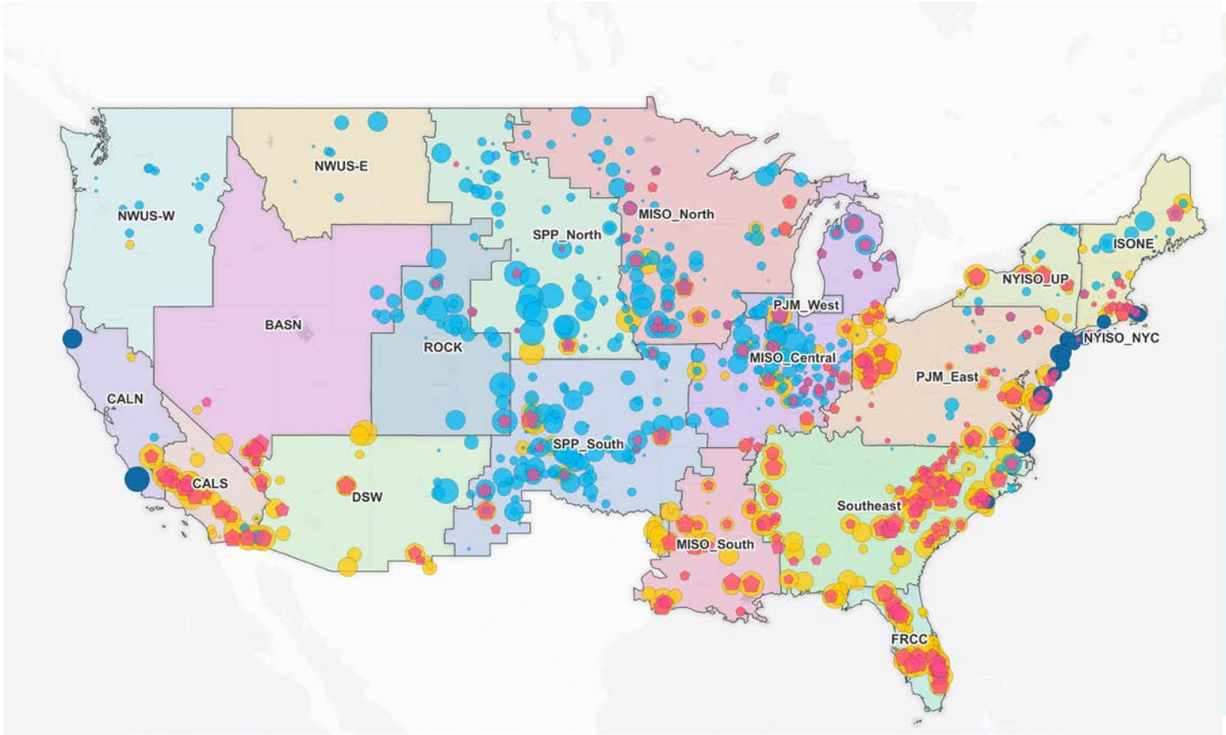


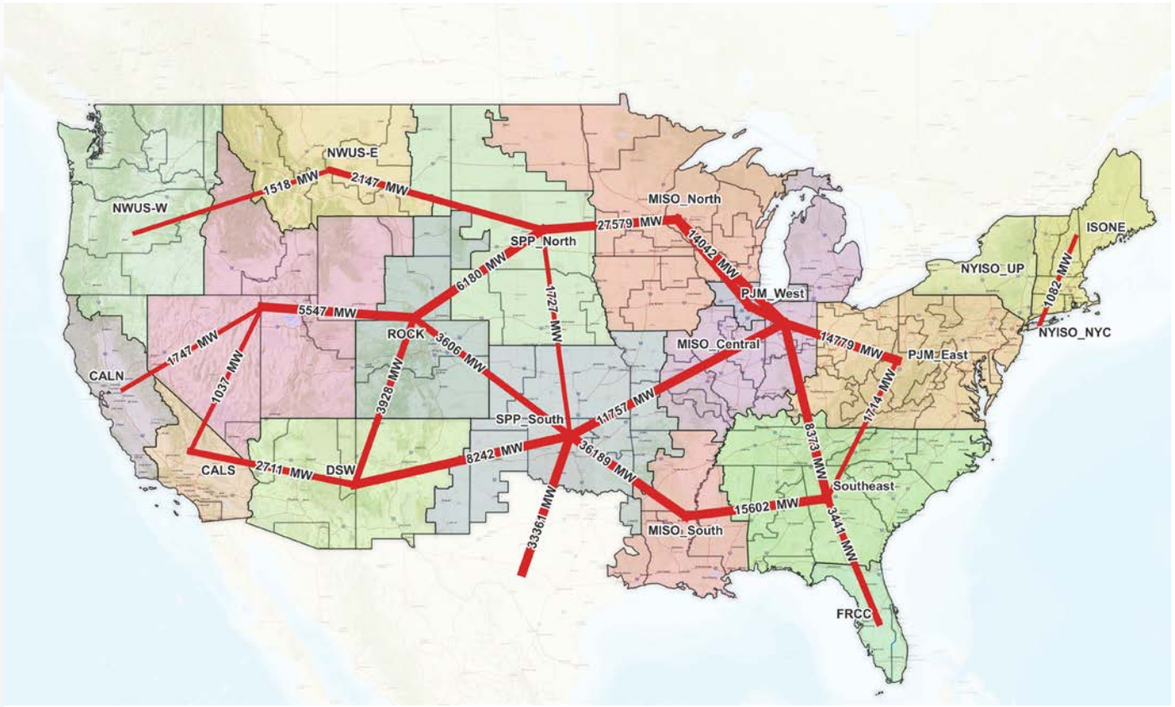
- Work is still in progress to further improve voltage profiles

CEM Round 1 Implemented for CONUS (WI+EI only) into Nodal Transmission Expansion

Production cost modeling → Power flow

- MTDC is mainly collecting wind in the middle of the country and moving to load centers
- Fewer MTDC lines are leveraging solar diversity from SE and CA, solar is more matched with storage
- A total of180 bi-polar HVDC pairs were added (85 sections, each could have 1 to 4 circuits) in the model using new GridView models developed by Hitachi/PNNL
- 20 GW Seams MTDC transmission between EI and WI

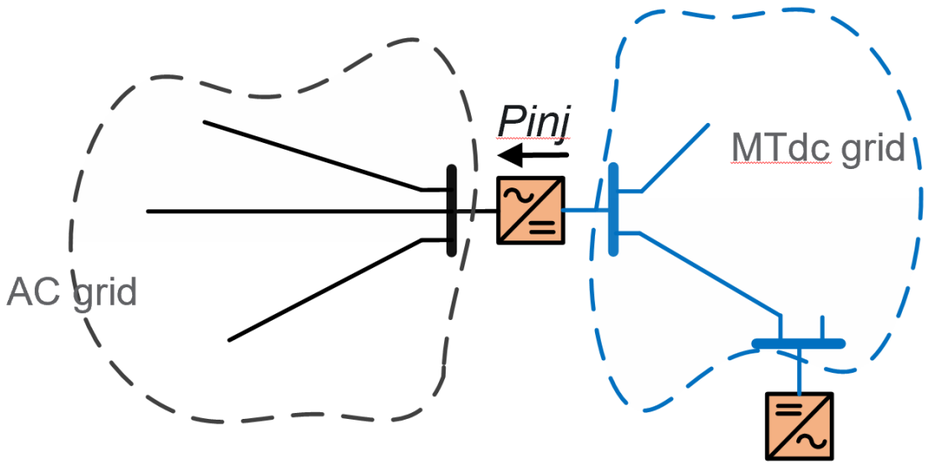


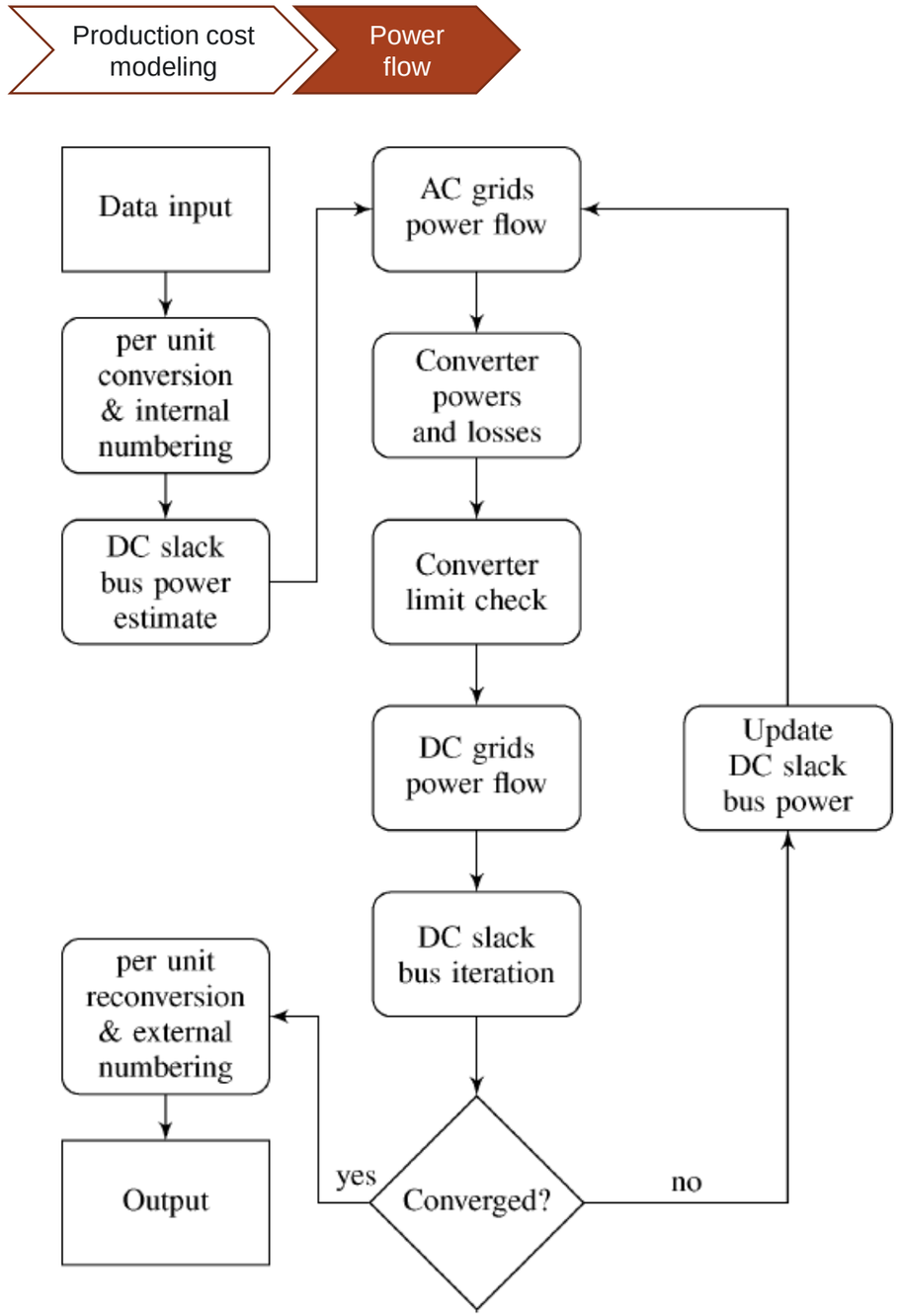


Zonal Model

Coordinated AC / DC Power Flow Model for MTDC

- PSSE currently does not have a powerflow solver for the multi-terminal VSC-based HVdc systems
- We built a solution that requires iteration between the AC and DC networks until convergence is reached
  - There is a slack converter in the DC network that control the DC network voltage, while the real power output is unknown





J. Beerten, S. Cole and R. Belmans, "Generalized Steady-State VSC MTDC Model for Sequential AC/DC Power Flow Algorithms," in *IEEE Transactions on Power Systems*, vol. 27, no. 2, pp. 821-829, May 2012

Next Steps for Power Flow Analysis (CONUS Multi-Terminal HVDC)

- Zonal to Nodal PCM work is just finalized
- Start to build the AC power flow case using the coordinated AC / DC Power Flow Model approach,
  - Select interesting hours
  - Additional contingencies of interest
    - ✓ Look for seams HVDC contingencies
    - ✓ Outage of large MTDC 4,000 MW under high loading conditions

Takeaway Messages for Power Flow Analysis

- Linkage between PCM and PF
  - Provide planning engineers with many different power flow cases with different load, wind, solar and on-line generation mix that can be used for grid reliability analysis
  - Intelligent sampling can be used to selected interesting hours from PCM for Power Flow analysis
- We tested few large contingencies at different hours with different generation mix on-line
  - The results show the developed scenarios can withstand such contingencies, as a preliminary proof of how robust the developed scenarios are.
- To thoroughly understand and analyze system behavior under large amounts of AC power flow hours and associated contingencies
  - Developed database management system
  - Developed interactive visualization that can help planning engineers to visually explore and analyze system behavior.

Thank you

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