Operation and Planning of the Electric Grid During Turbulent Times

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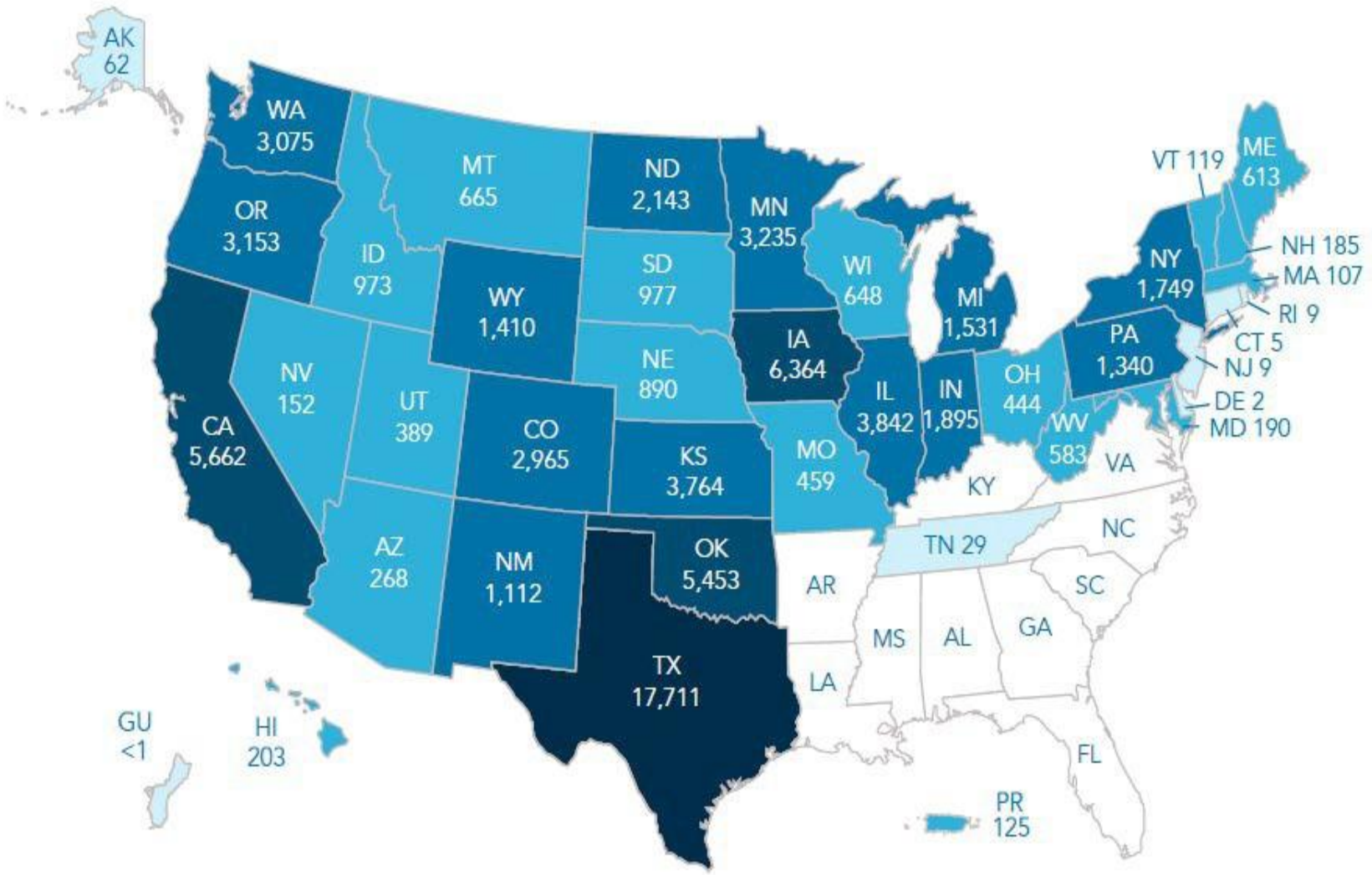
Manager, Operations Engineering Analysis & Support

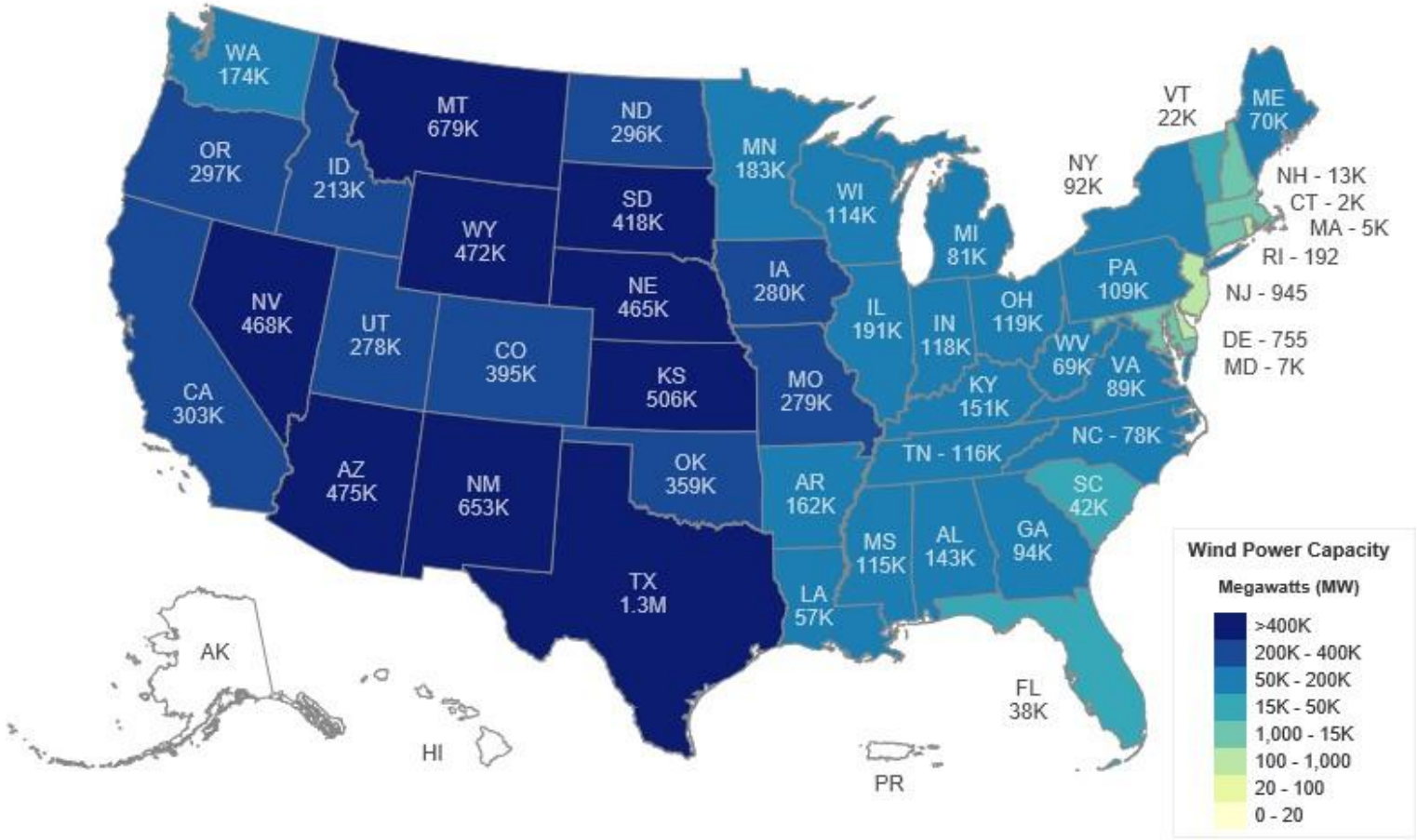
Section 1

Current Wind Situation

U.S. Wind Power Capacity, by State



U.S Potential Wind Capacity in Megawatts (MW) at 80 Meters

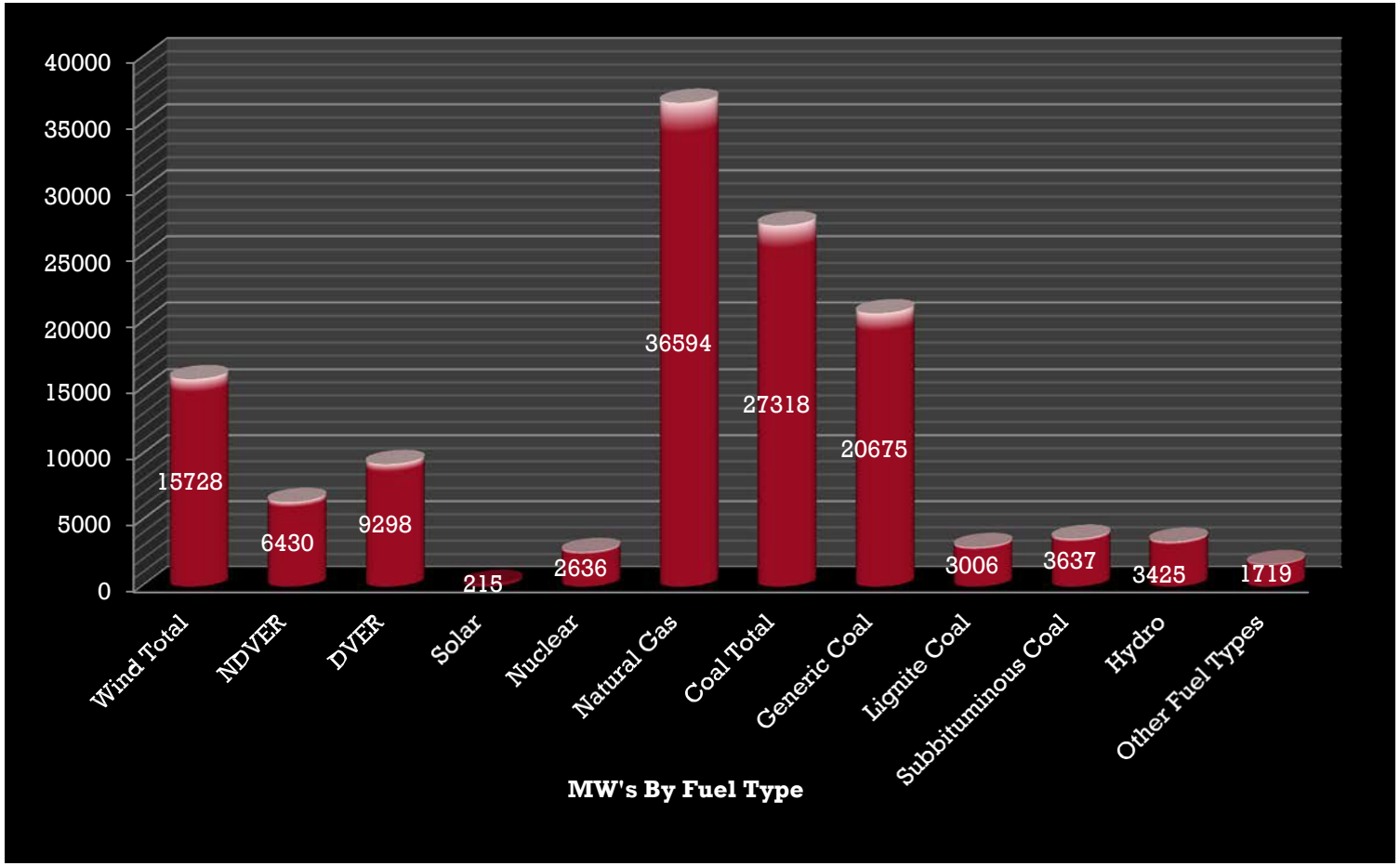


Total Potential Wind Capacity: 10,640,080 MW

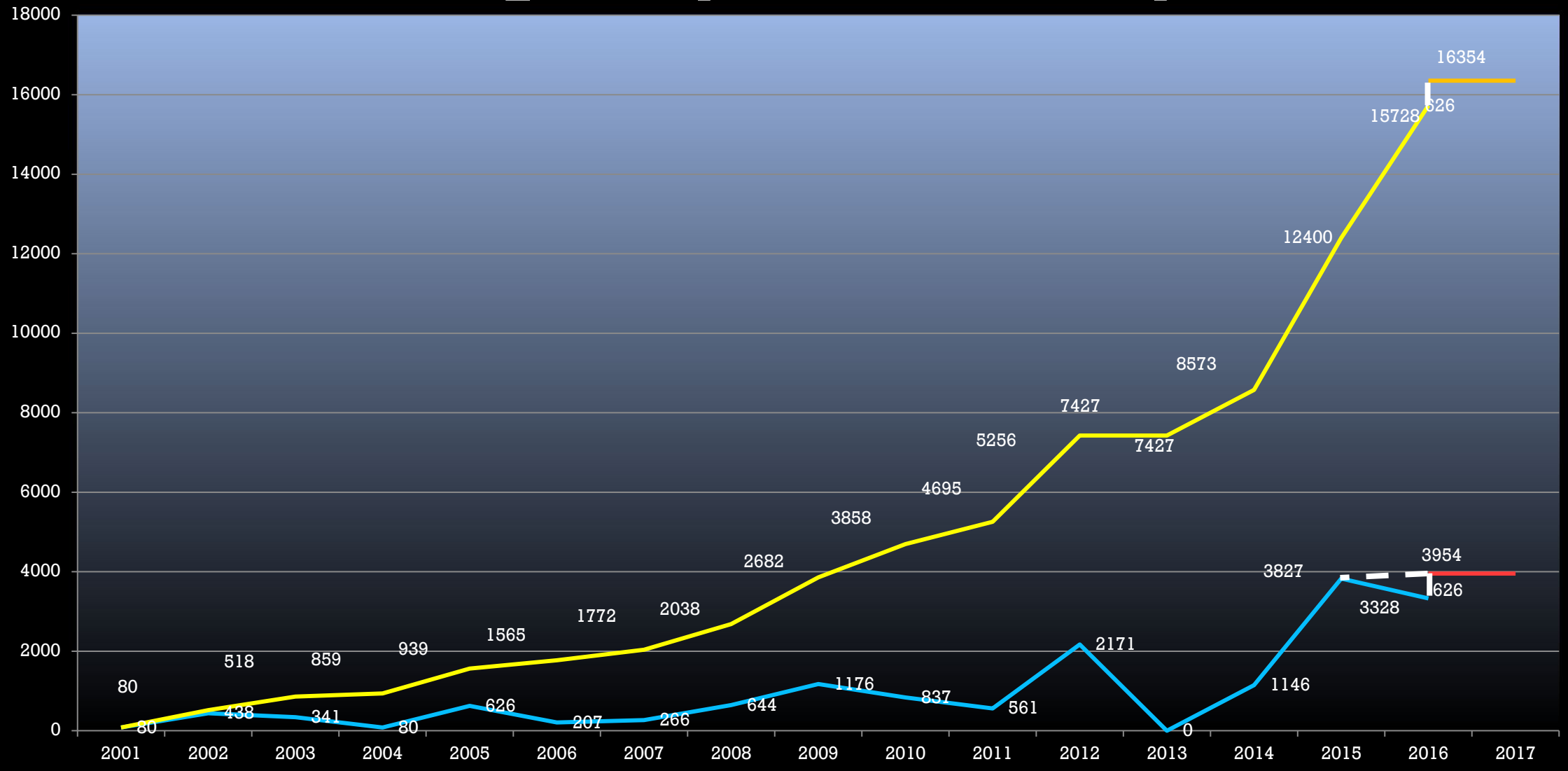
Source: AWS Truepower, NREL

Current MWs By Fuel Type

- **Wind Totals 15728 MWs**
  - NDVER 6430 MWs
  - DVER 9298 MWs
- Solar 215 MWs
- Nuclear 2636 MWs
- Natural Gas 36594 MWs
- Coal 27318 MWs
  - Generic Coal 20675 MWs
  - Lignite Coal 3006 MWs
  - Subbituminous 3637 MWs
- Hydro 3425 MWs
- Other Fuel Types (Oil, Agricultural Byproducts, Municipal Solid Waste) 1719 MWs



Wind Capacity Installed by Year



Overcoming operational challenges with wind generation

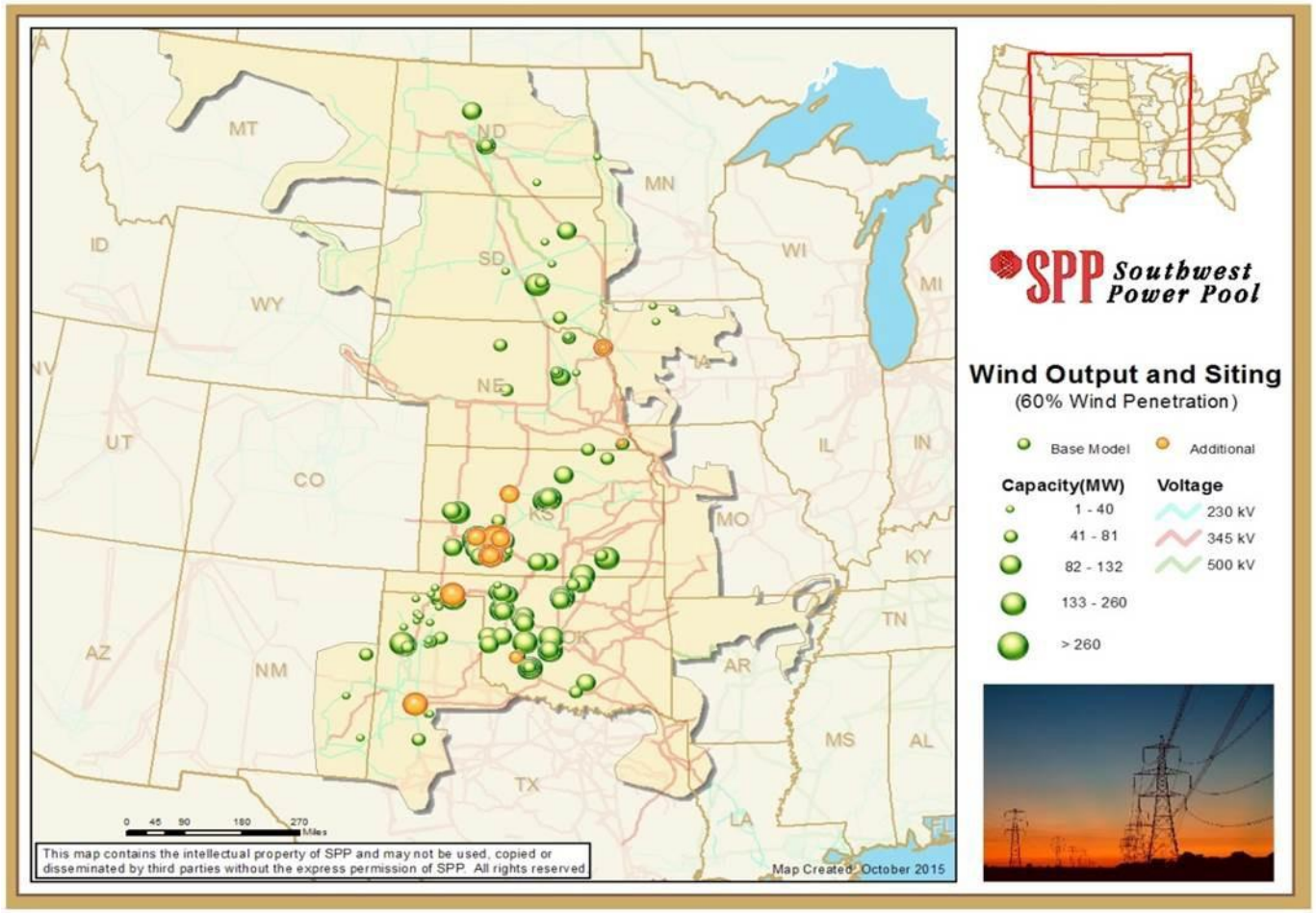
- Thermal congestion
- Voltage stability
- Transient stability
- Ramping and Regulation
- Frequency response
- Capacity management

SPP Wind Records

- 49.17% Wind serving load April 2016
- 10,989MW Wind output April 2016

2015 Wind Integration Study (WIS)

- *60% Wind Penetration Wind Output and Siting.*

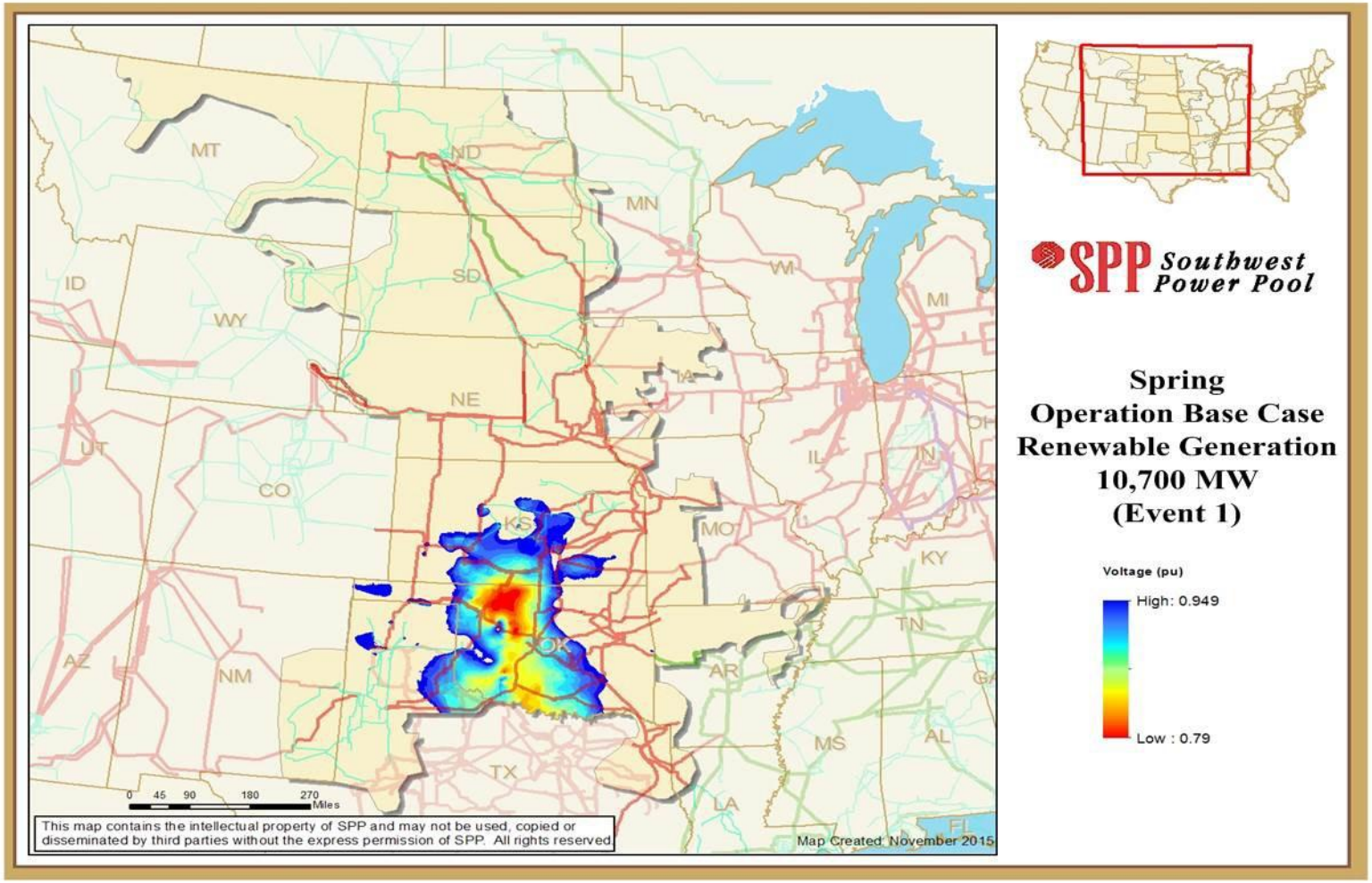


2015 Wind Integration Study results

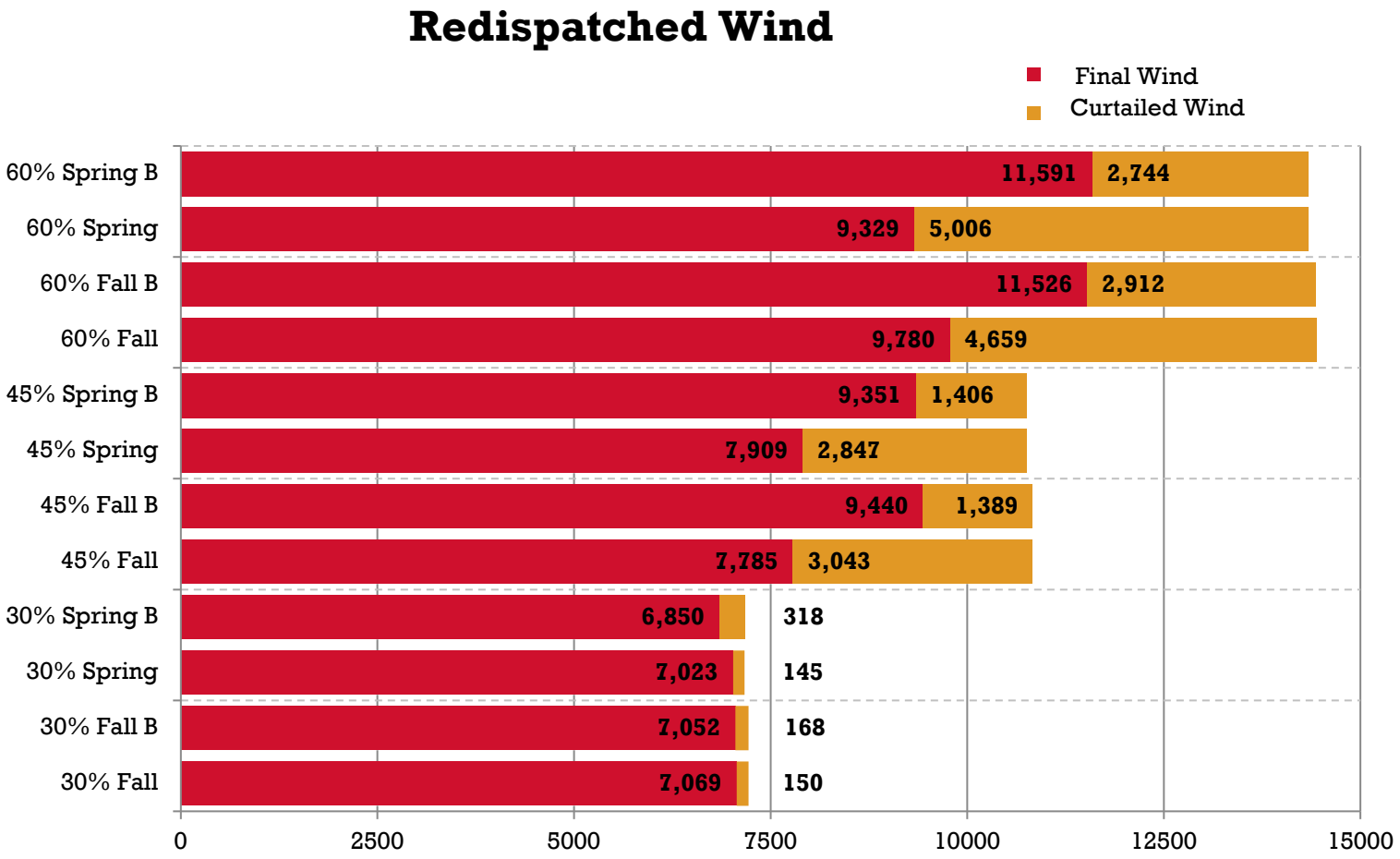
- The Steady-state thermal and voltage analysis confirms the need for approved ITP projects
  - Additional transmission needs beyond what was approved in the ITP process was discovered
  - Some approved ITP projects should be expedited and placed in-service sooner than the projects scheduled in-service date
- The Voltage stability analysis shows that renewable penetration levels are approaching current limits
- All N-1 constraints were resolved, albeit with substantial curtailments
- Ramping analysis indicates that in general, SPP has enough ramping capability to sustain 60% penetration

WIS - Voltage Stability Analysis

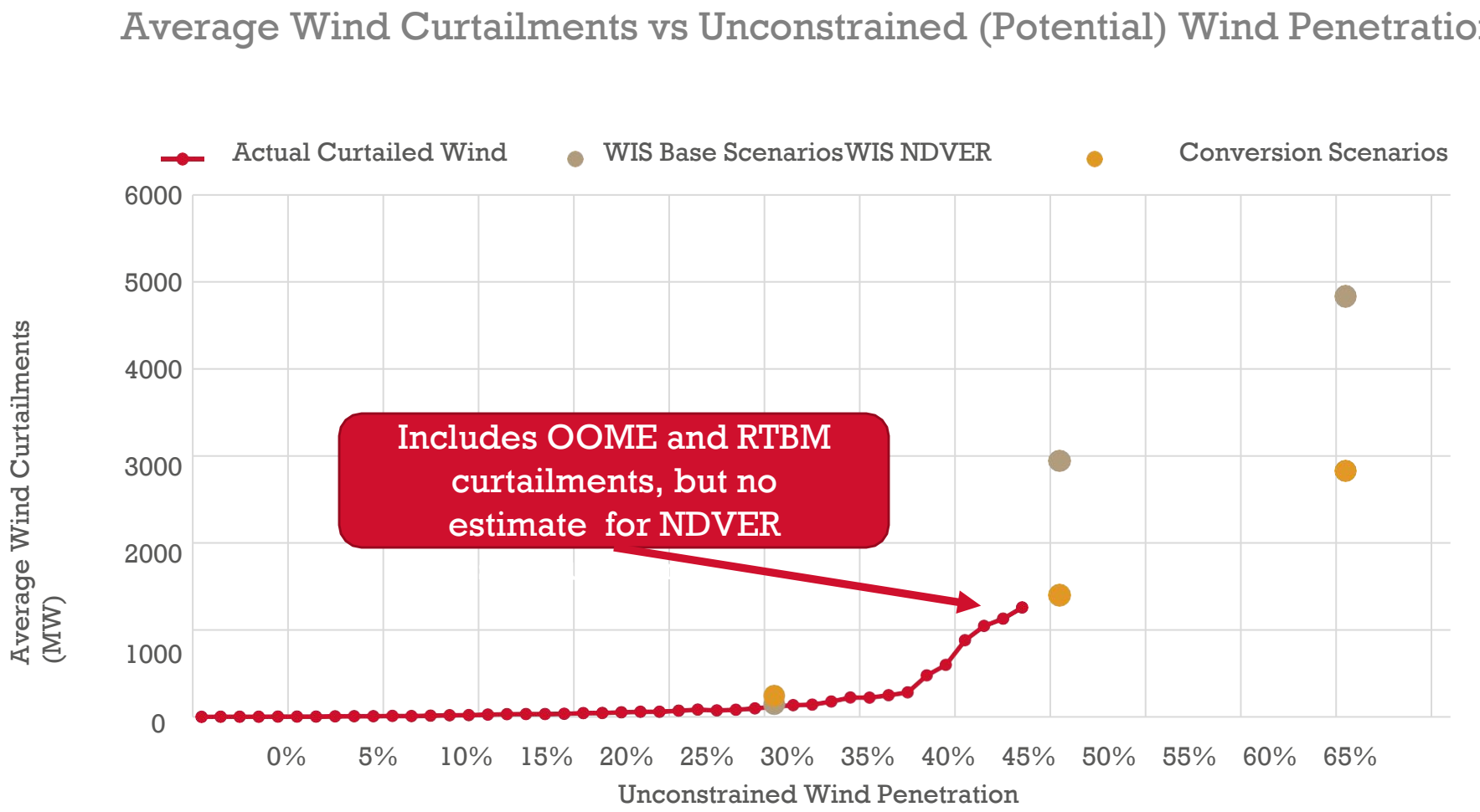
The Spring operations model



Wind Integration Study
Redispatch Analysis

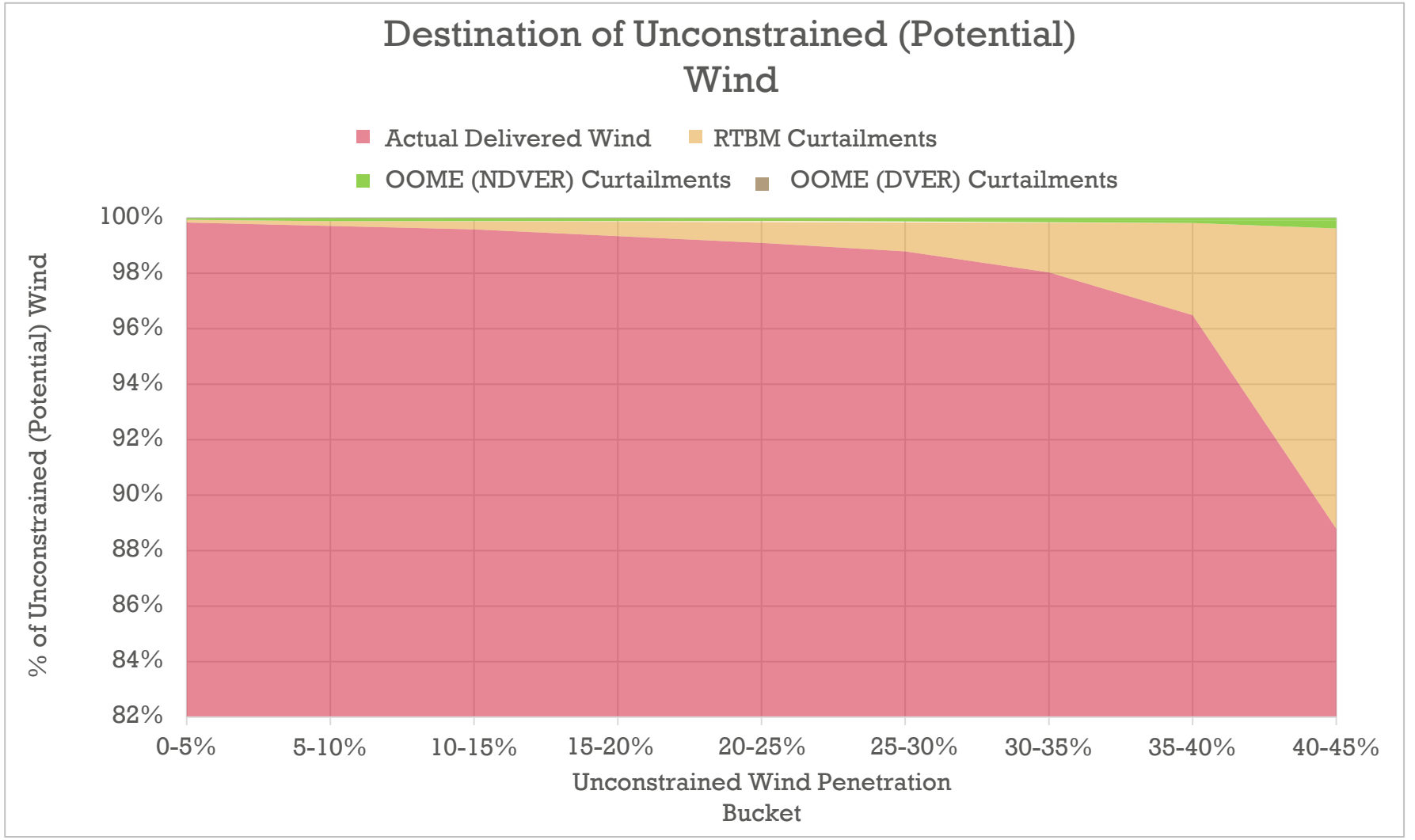


How does WIS redispatch analysis compare to actual observations from Integrated Marketplace?



*Data from 2015 Integrated Marketplace
RTBM

Where does our wind power go?



*Data from 2015 Integrated Marketplace RTBM

Section 2

WIS Analysis

Assumptions

- Models
  - Steady State power flow
  - Operations & System Intact
  - Wind penetration 30%, 45%, 60%
  - 2016 Spring & Fall peak load
- Model parameters
  - Lock switchable reactive devices (cap banks, reactors)
  - Enable voltage controlling autotransformer taps
  - Enable Static VAR Compensator (SVC) and continuous switch shunts
  - Load is constant

Power Transfer

- Increase Wind Generation
  - From 30% to 45% penetration
  - From 45% to 60% penetration
  - From 60% to maximum power or voltage collapse
- Decrease Large Thermal Generation
  - Ignore real power minimum limits
  - Honor reactive power (MVAR) limits
  - Provides reactive support at 0 MW

	Transfer Start (MW)	
Renewable Penetration	Spring	Fall
30%	7,168	7,219
45%	10,756	10,828
60%	14,334	14,438

Power Transfer

(cont.)

- Transfer to Voltage Collapse
  - Normal conditions (N-0)
  - 100 MW increments
  - Report 5 most limiting contingencies
- Single 345 kV line or autotransformer outage (N-1)

Event	Contingency	Voltage (kV)
1	Northwest to Tatonga	345
2	Holcomb to Buckner	345
3	Mingo to Setab	345
4	Mingo to Red Willow	345
5	Waverly to LaCygne	345

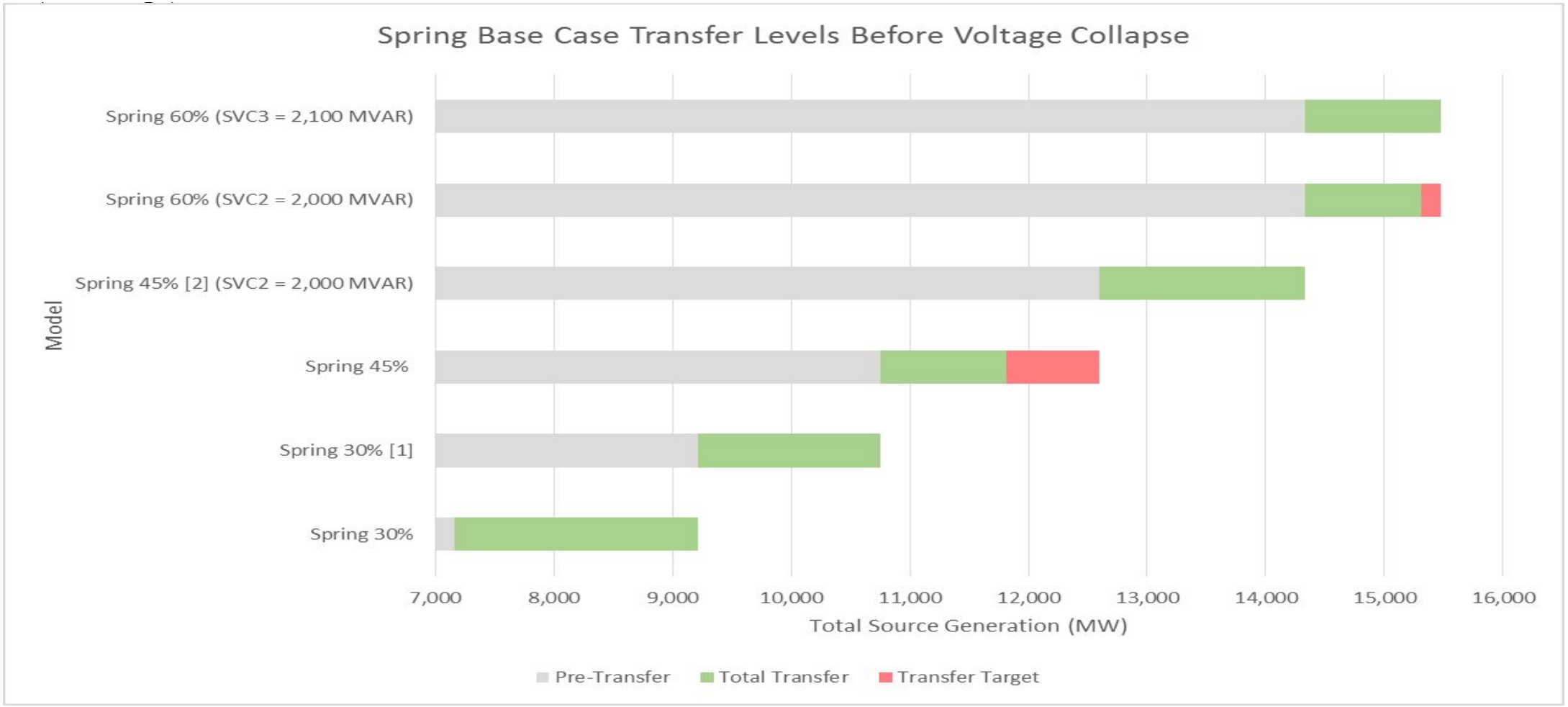
Sensitivity - Dynamic Reactive Source

- Static VAR Compensator (SVC)
  - Used for modeling purposes to measure reactive needs
  - Supplies reactive power while maintaining set voltage (1.0 PU)
- Locations
  - Washita, Spearville, Thistle, Tatonga, Smokey Hills
- Other considerations
  - Reliability
  - Costs

Section 3

WIS Results

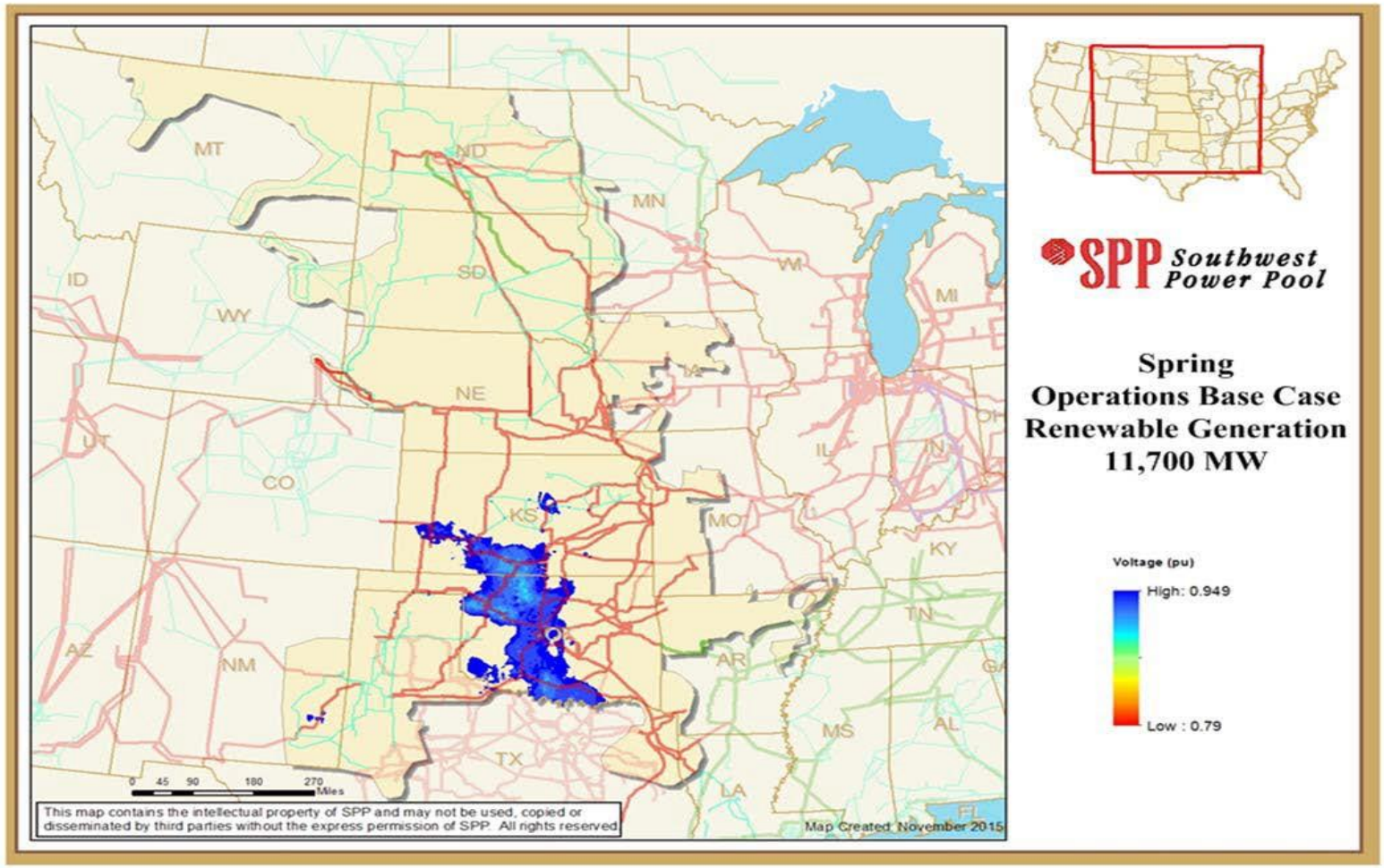
Operations model – Spring



SVC[2] locations are Washita, Spearville, Thistle, Tatonga.
SVC[3] locations are Washita, Spearville, Thistle, Tatonga, Smokey Hills.

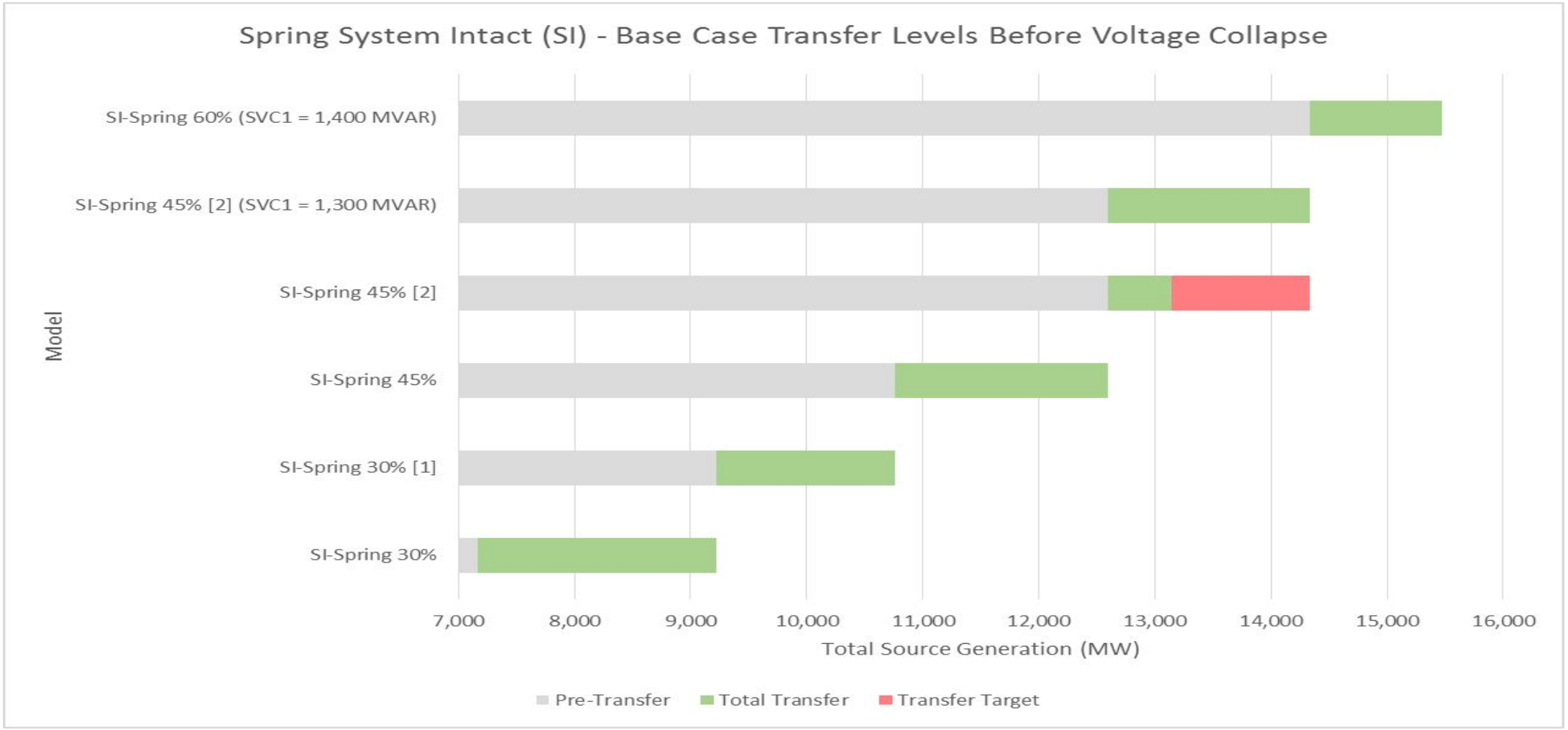
1 Turn on and scale Spring 45% wind generation not in Spring 30% model.
2 Turn on and scale Spring 60% wind generation not in Spring 45% model.

Operations model – Spring (N-0)



Spring 45% plus 1,000 MW renewable generation - Voltage Contour.

Planning model – Spring (N-0)



SVC[1] locations are Washita, Spearville, Thistle.

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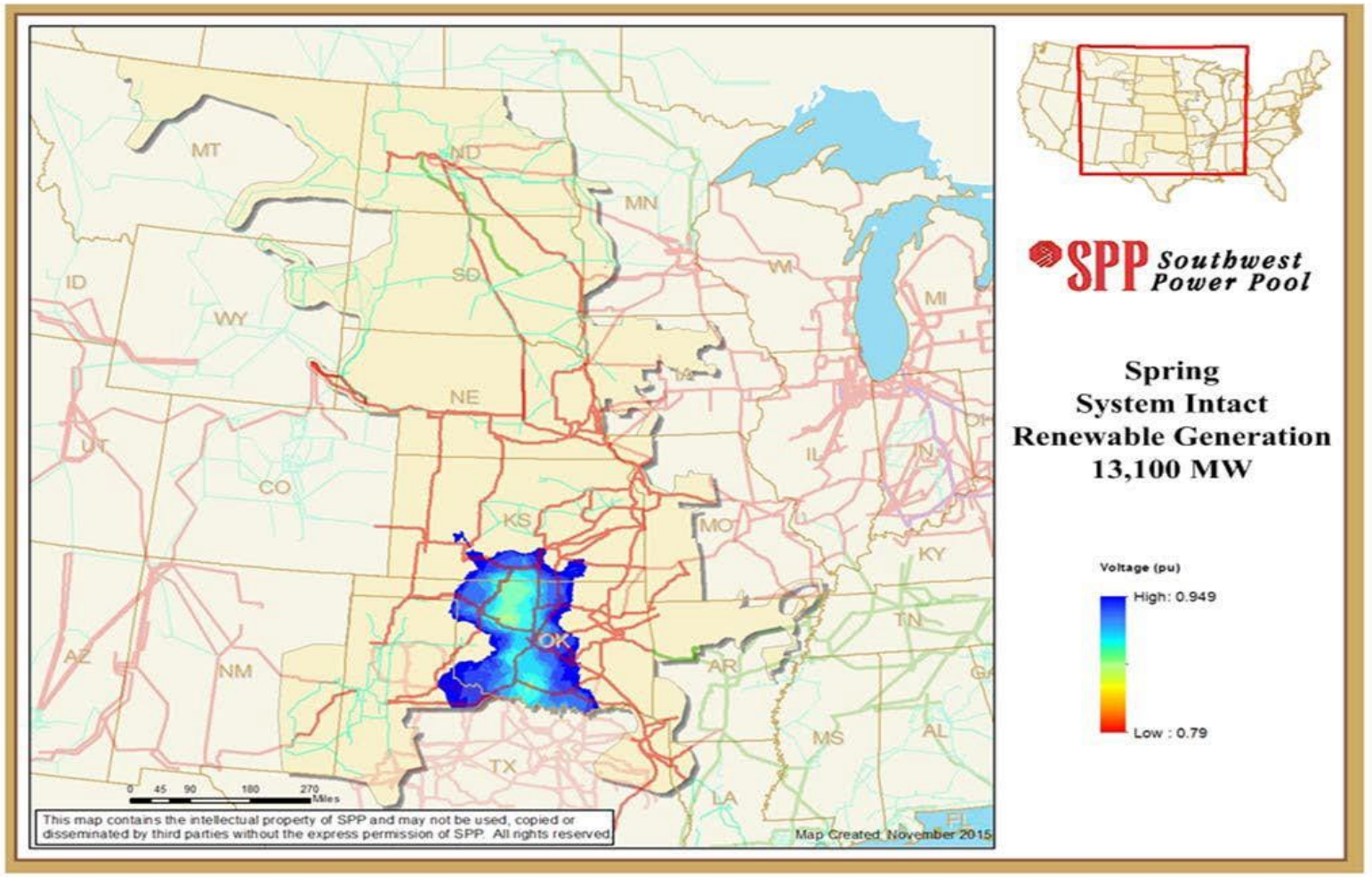
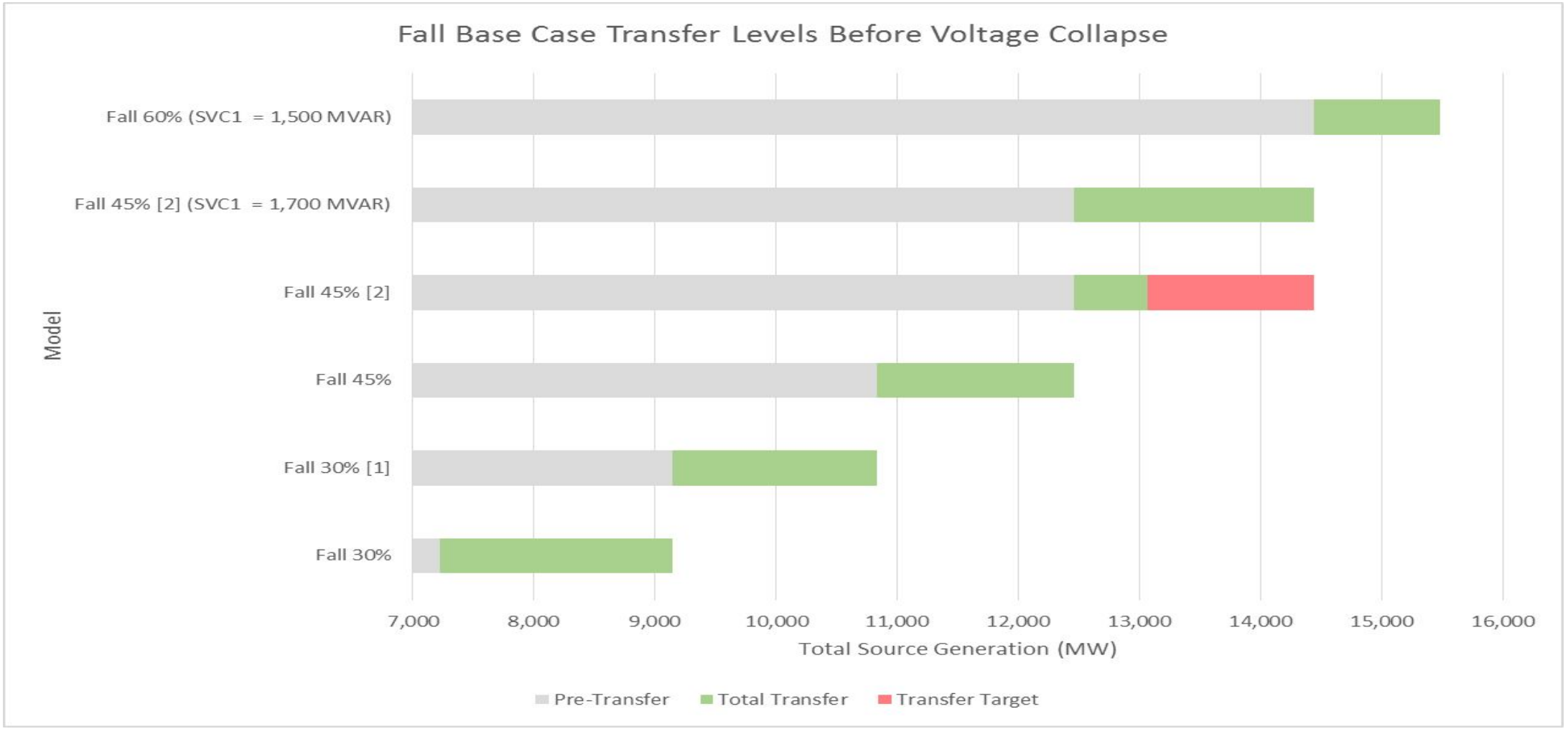
Planning model – Spring (N-0)



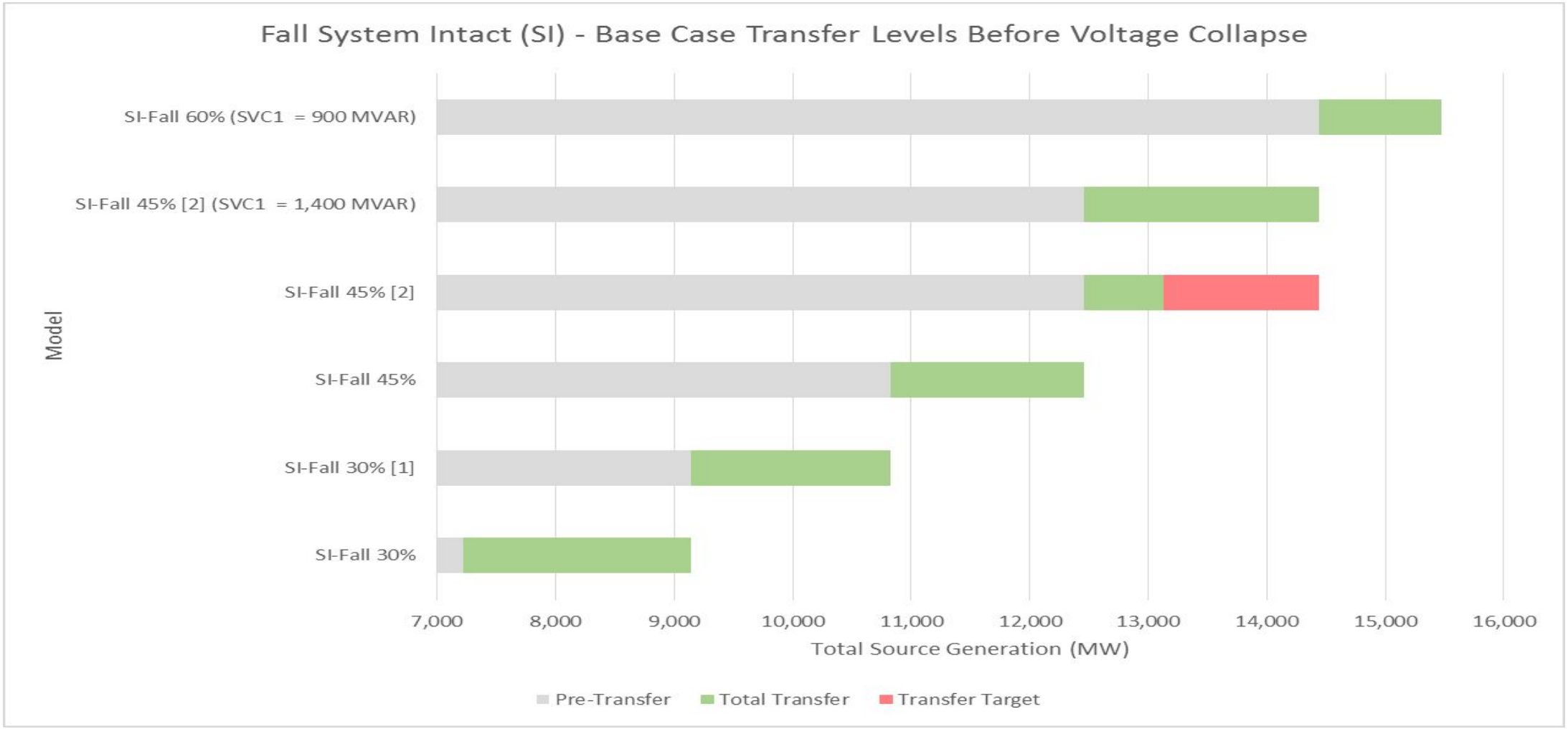
Spring System Intact 45% Penetration plus 2,400 MW - Voltage Contour.

Operations model – Fall (N-0)



SVC[1] locations are Washita, Spearville, Thistle.
[1] Turn on and scale Spring 45% wind generation not in Spring 30% model.
[2] Turn on and scale Spring 60% wind generation not in Spring 45% model.

Planning model – Fall (N-0)



SVC[1] locations are Washita, Spearville, Thistle.

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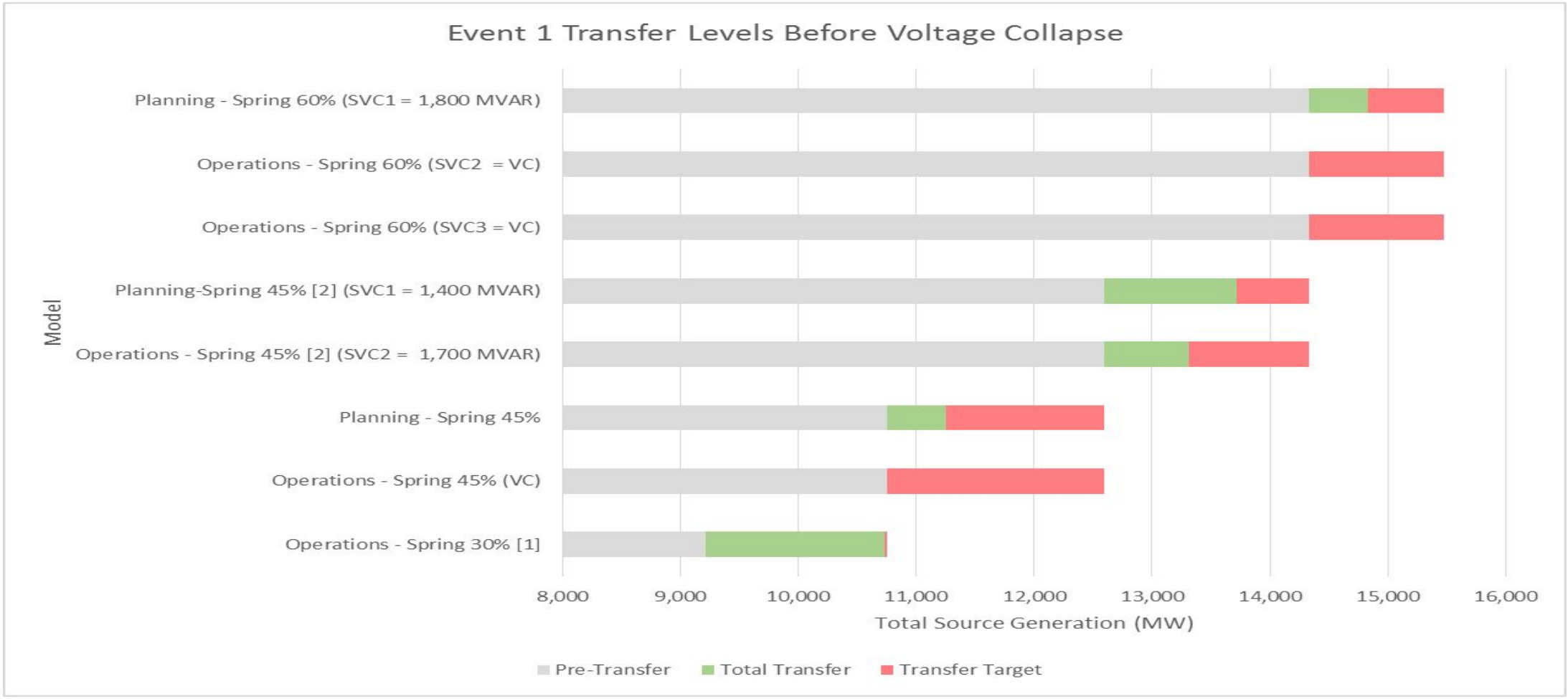
Event 1: Transfer Levels to Voltage Collapse



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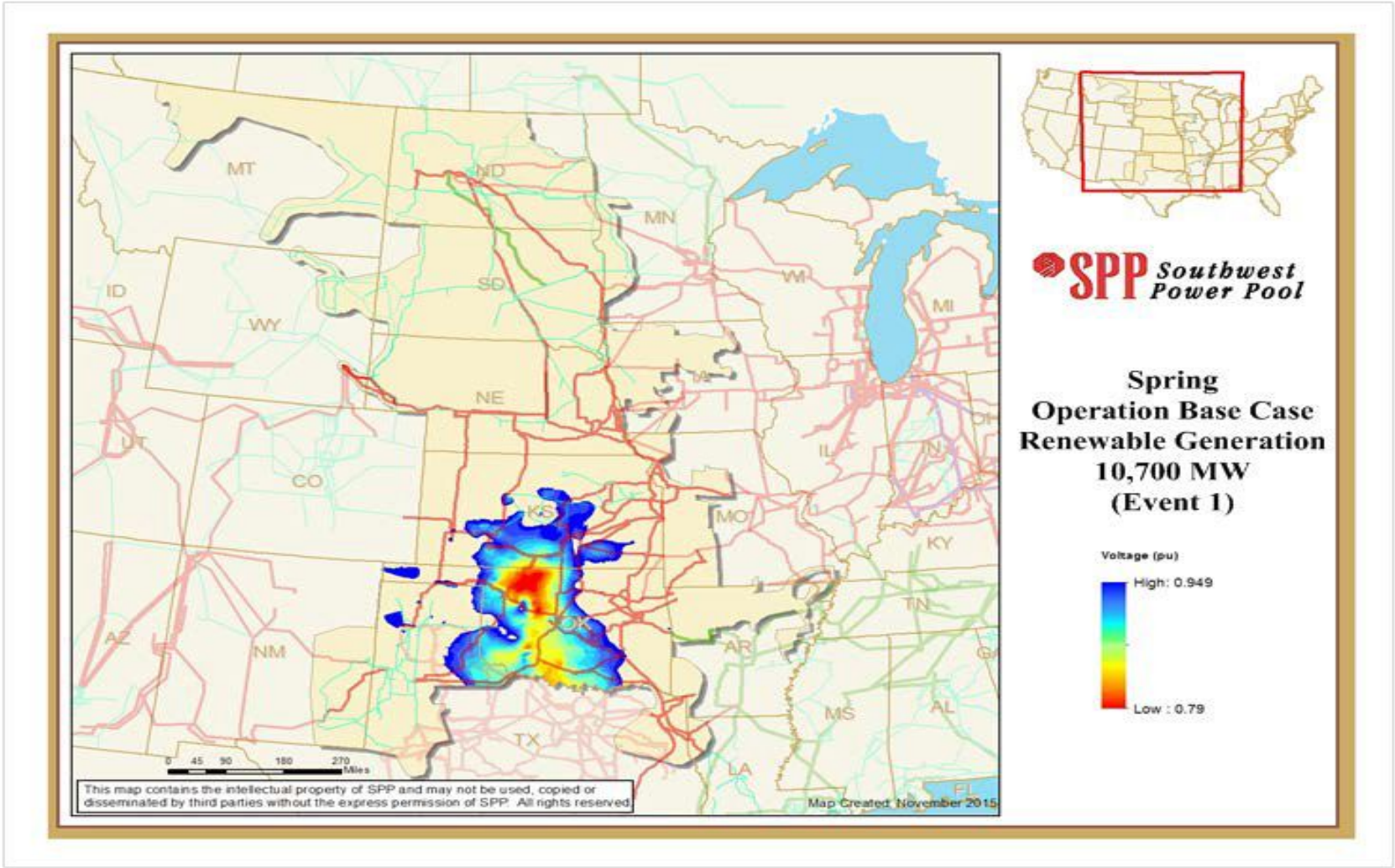
SVC[3] locations are Washita, Spearville, Thistle, Tatonga, Smokey Hills. (VC) Voltage Collapse.

1 Turn on and scale Spring 45% wind generation not in Spring 30% model.

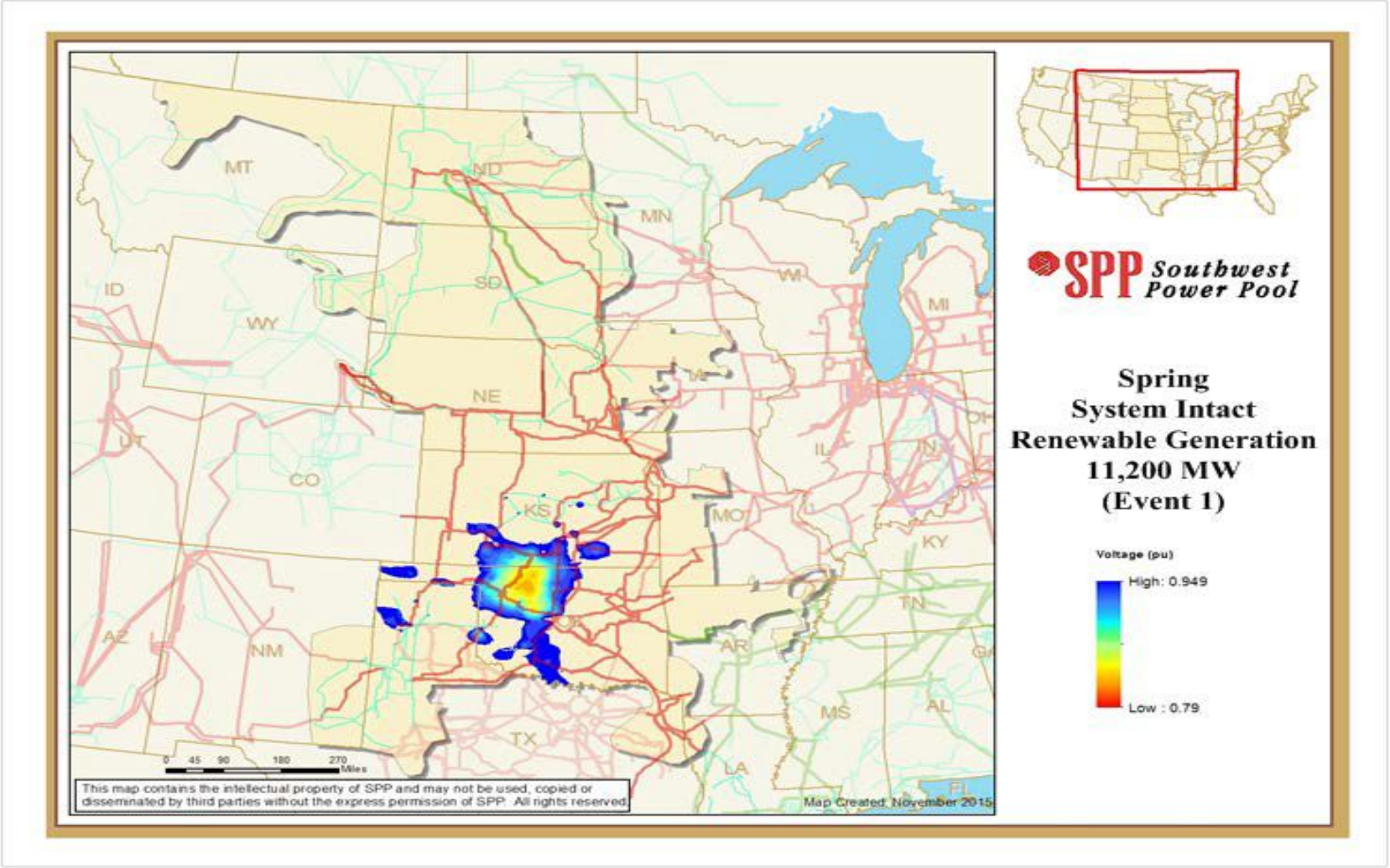
2 Turn on and scale Spring 60% wind generation not in Spring 45% model.

Event 1: Operation Model Transfer to Voltage Collapse



Spring 30% Penetration Event 1 plus 3,600 MW - Voltage Contour.

Event 1: Planning Model Transfer to Voltage Collapse



Spring System Intact 45% Penetration Event 1 plus 500 MW - Voltage Contour.

Dynamic Reactive Reserve (MVAR) - Spring

Model Type	Season & Renewable Penetration	Renewable Start (MW)	Renewable Stop (MW)	Delta Transfer (MW)	DRR [1] (MVAR)	SVC (MVAR)	Source (MVAR)	Sink (MVAR)	State
Operation Outages	Spring 30%	7,100	10,700	3,600	446	0	278	168	Stable
Operation Outages	Spring 45%	10,700	11,700	1,000	1,148	0	514	634	VC
Operation Outages	Spring 45% + (SVC2)	10,700	14,300	3,600	3,239	2,000	380	858	Stable
Operation Outages	Spring 60% + (SVC2)	14,300	15,200	900	2,365	2,000	37	328	VC
Operation Outages	Spring 60% + (SVC3)	14,300	15,400	1,100	3,046	2,100	620	325	Stable
Planning	Spring 30%	7,100	10,700	3,600	277	0	213	64	Stable
Planning	Spring 45%	10,700	13,100	2,400	1,722	0	692	1,030	VC
Planning	Spring 45% + (SVC1)	10,700	14,300	3,600	2,780	1,300	536	944	Stable
Planning	Spring 60% + (SVC1)	14,300	15,400	1,100	2,039	1,400	449	190	Stable

Dynamic Reactive Reserve (MVAR) - Fall

Model Type	Season & Renewable Penetration	Renewable Start (MW)	Renewable Stop (MW)	Delta Transfer (MW)	DRR [1] (MVAR)	SVC (MVAR)	Source (MVAR)	Sink (MVAR)	State
Operation Outages	Fall 30%	7,200	10,800	3,600	287	0	260	27	Stable
Operation Outages	Fall 45%	10,800	13,000	2,200	934	0	-102	1,035	VC
Operation Outages	Fall 45% + (SVC1)	10,800	14,400	3,600	2,361	1,700	-240	900	Stable
Operation Outages	Fall 60% + (SVC1)	14,400	15,400	1,000	2,141	1,500	455	186	Stable
Planning	Fall 30%	7,200	10,800	3,600	257	0	232	25	Stable
Planning	Fall 45%	10,800	13,100	2,300	922	0	-115	1,037	VC
Planning	Fall 45% + (SVC1)	10,800	14,400	3,600	1,976	1,400	-23	599	Stable
Planning	Fall 60% + (SVC1)	14,400	15,400	1,000	1,976	1,500	319	157	Stable

Renewable generation real power (MW) limits

Model	% Reserve	Operations (N-0)	Operations (N-1)	System Intact (N-0)	System Intact (N-1)
Spring	0	11,700	10,700	13,100	11,200
Spring	5	11,100	10,100	12,400	10,600
Fall	0	13,000	10,900	13,100	10,900
Fall	5	12,300	10,300	12,400	10,300

Section 4

Preliminary 2017 Variable generation Integration Study (VIS) Results

Power Tech Labs/SPP Load pocket critical generator outages

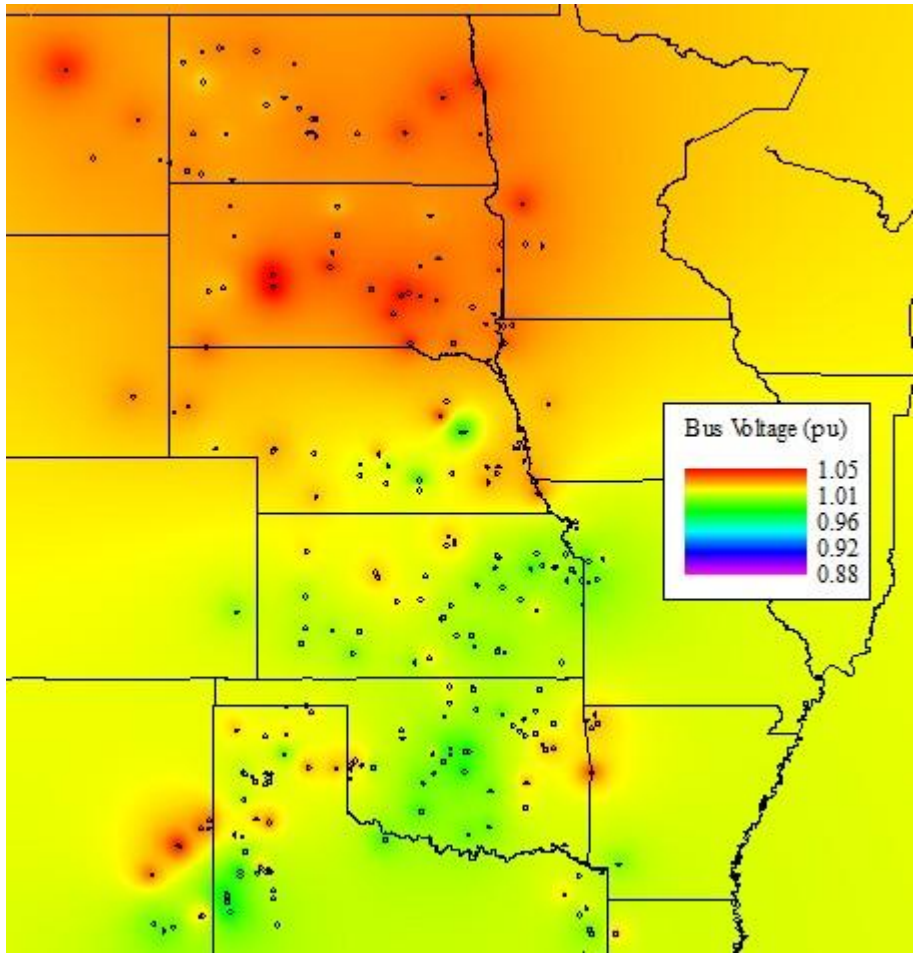
Area	Critical Ctg	Load Inc. MW
Area 1 - East Nebraska	"NEBCTY2G 23.0" | Pgen= 497.6MW	1220
Area 2 - SouthOK	"ARBWND11 34.5" | Pgen= 79.4MW	640
Area 3 - SPS South	"HOBBS_PLT3 118.0" | Pgen= 199.4MW	420
Area 4 - Woodward	"SLEEPING 138." | Pgen= 73.9MW	760
Area 5 - Wichita	"WCGS U1 25.0" | Pgen= 1189.6MW	240
Area 6 - KansasCityMetro	"IAT G2 1 25.0" | Pgen= 900.0MW	580
Area 7 - Oklahoma City	"KNGFSR12 34.5" | Pgen= 158.7MW	1080
Area 8 - Williston	“LINDAHLWNDGW0.69" | Pgen= 34.9MW	840

Power Tech Labs/SPP Load pocket critical transmission outages

Area	Critical Contingency	Load Inc. MW
Area 1 - East Nebraska	"TATONGA7345." to "MATHWSN7 345."	300
Area 2 - SouthOK	"TATONGA7345." to "MATHWSN7 345."	60
Area 3 - SPS South	*"SUNDOWN6230." to "AMOCO_SS 6230."*	400
Area 4 - Woodward	"O.K.U.-7 345." to "L.E.S.-7 345."	700
Area 5 - Wichita	"TATONGA7345." to "MATHWSN7 345."	260
Area 6 - KansasCityMetro	"TATONGA7345." to "MATHWSN7 345."	300
Area 7 - Oklahoma City	"TATONGA7345." to "MATHWSN7 345."	100
Area 8 - Williston	"BELDEN -MW7115." to "RBNSNLAK-MW7115."	180

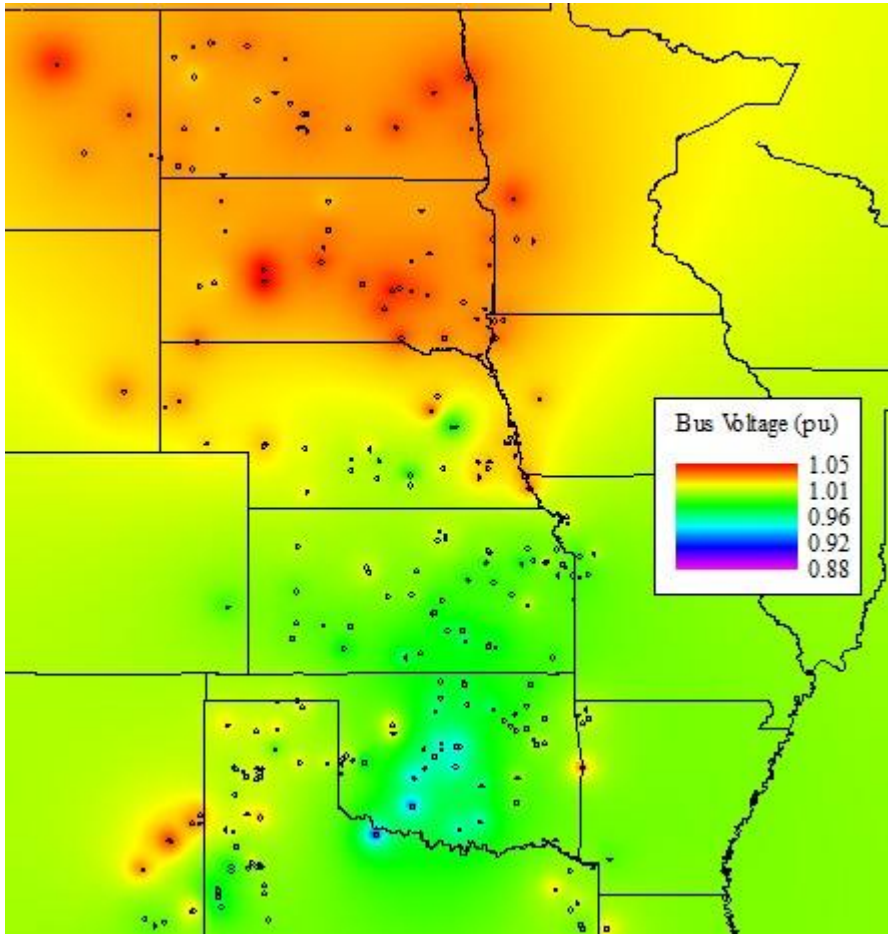
Power Tech Labs/SPP Contour map – bus voltages

- Pre-contingenc y base case



Power Tech Labs/SPP Contour map – bus voltages

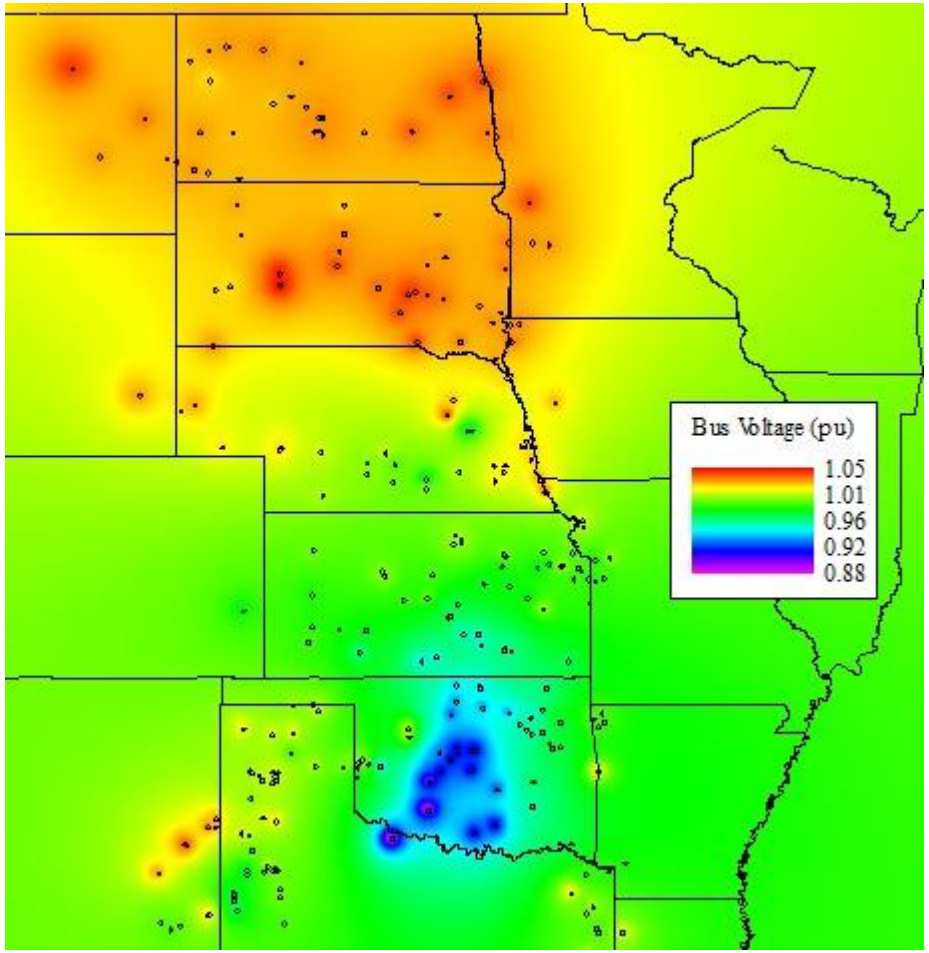
- Post-contingency *base case* Tatonga-Matthewson



Power Tech Labs/SPP Contour map – bus voltages

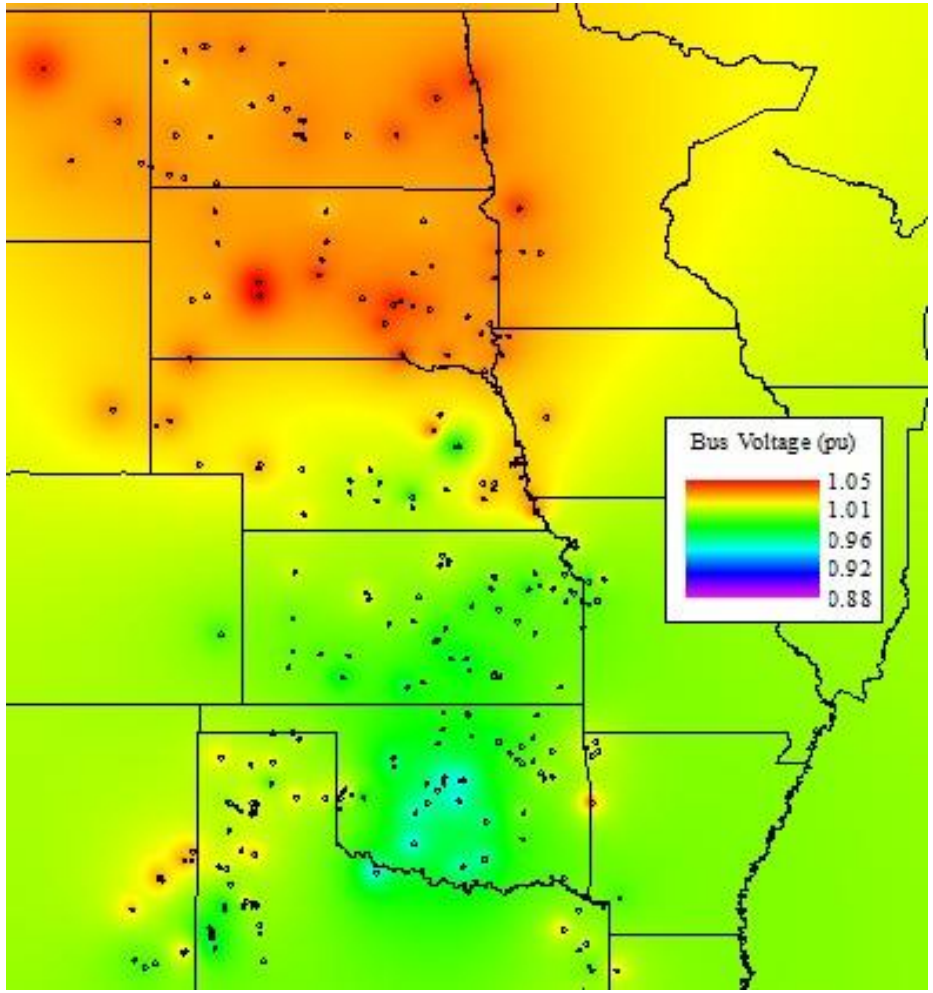
- Post-contingency *limiting point*
  Tatonga-Matthewson

  East Nebraska
  Load Pocket



Power Tech Labs/SPP Contour map – bus voltages

- Post-contingency *base case* Wolf Creek outage

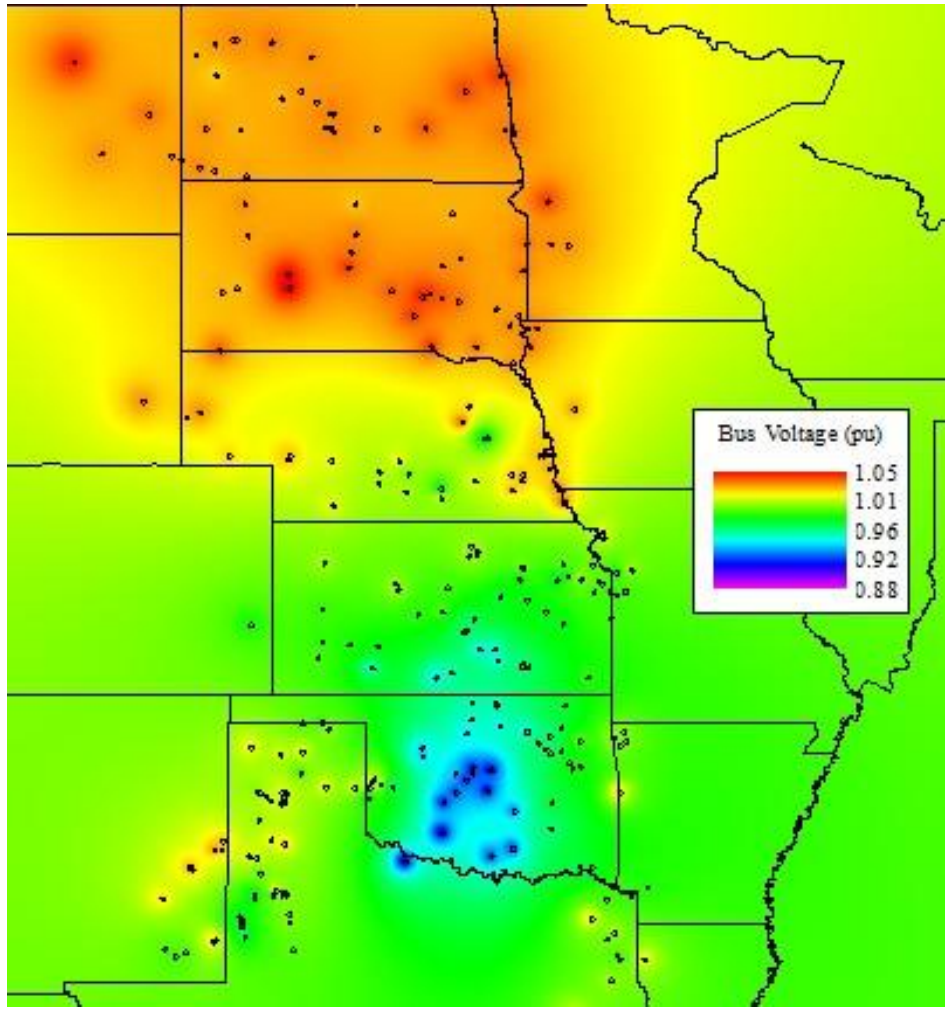


Power Tech Labs/SPP Contour map – bus voltages

- Post-contingency *limiting point*

  Wolf Creek outage

  Wichita load pocket

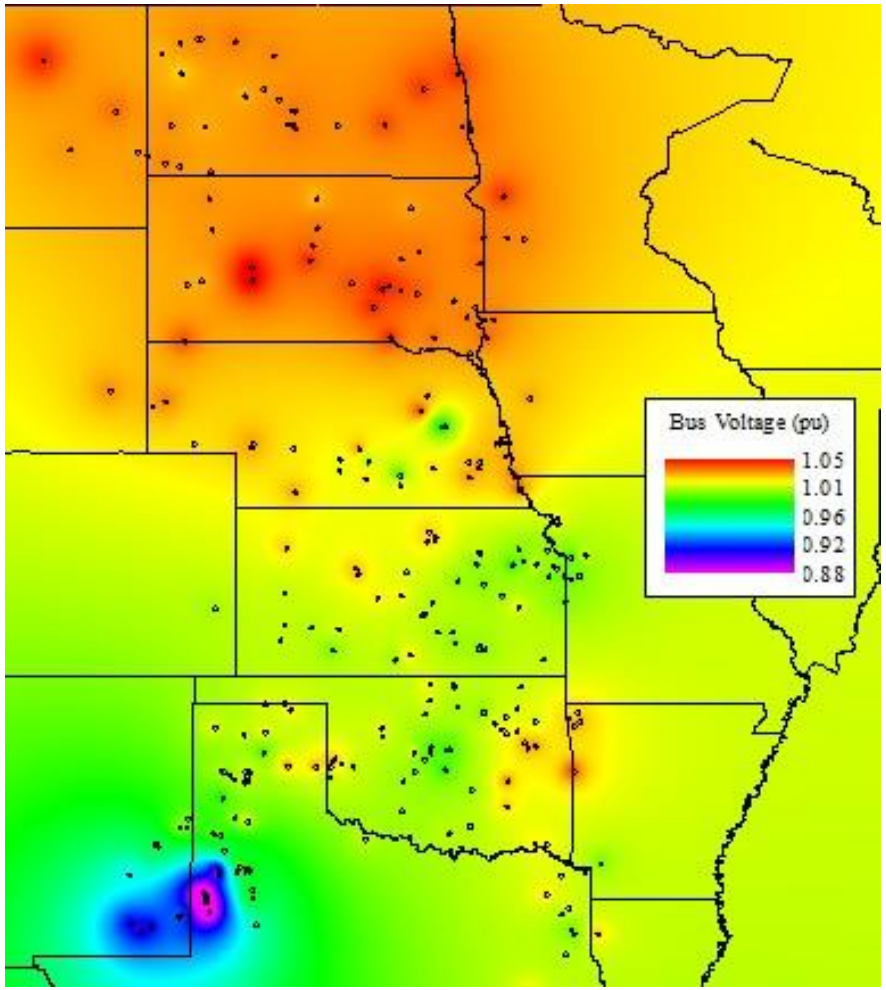


Power Tech Labs/SPP Contour map – bus voltages

- Post-contingency *limiting point*

  Hobbs 3 gen. outage

  SPS South load pocket

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SEVENTY-FIVE YEARS OF
RELIABILITY THROUGH RELATIONSHIPS