Minnesota's Evolving Power Grid: A Planner's Perspective of the Past, Present and Future

David Kempf

Manager, Transmission Planning Engineering

Great River Energy

Overview

- History of the planned grid
- Today's new challenges
- Transmission grid of the future

Objectives of transmission planning

Planning Coordination

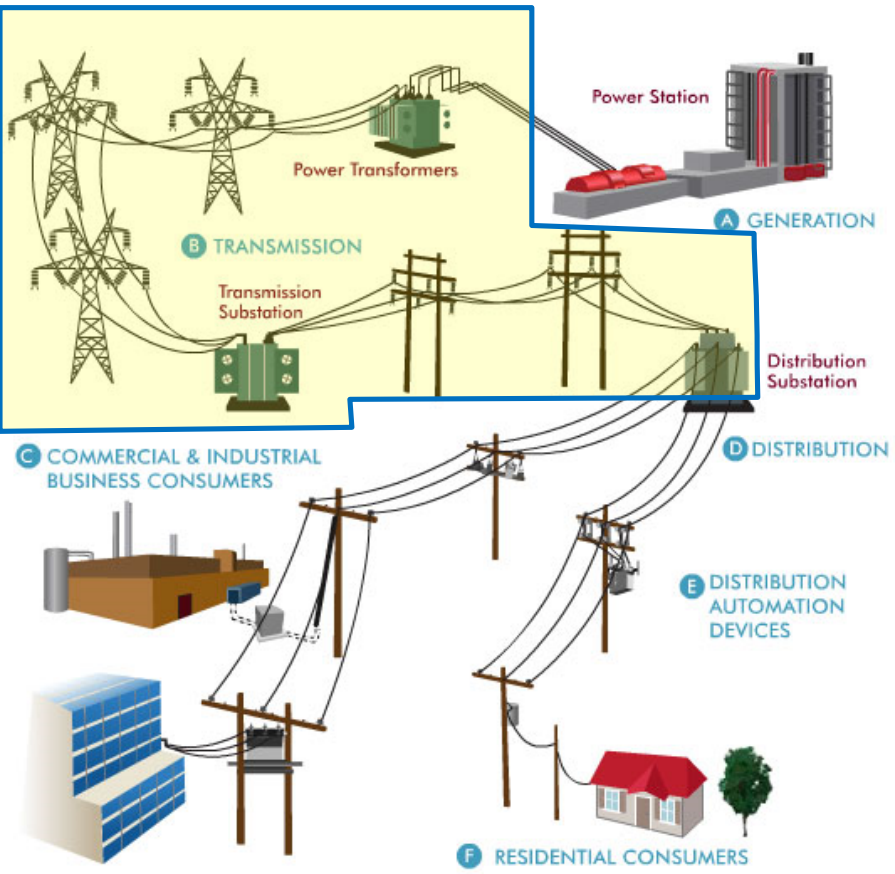
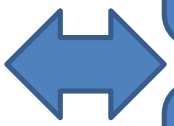


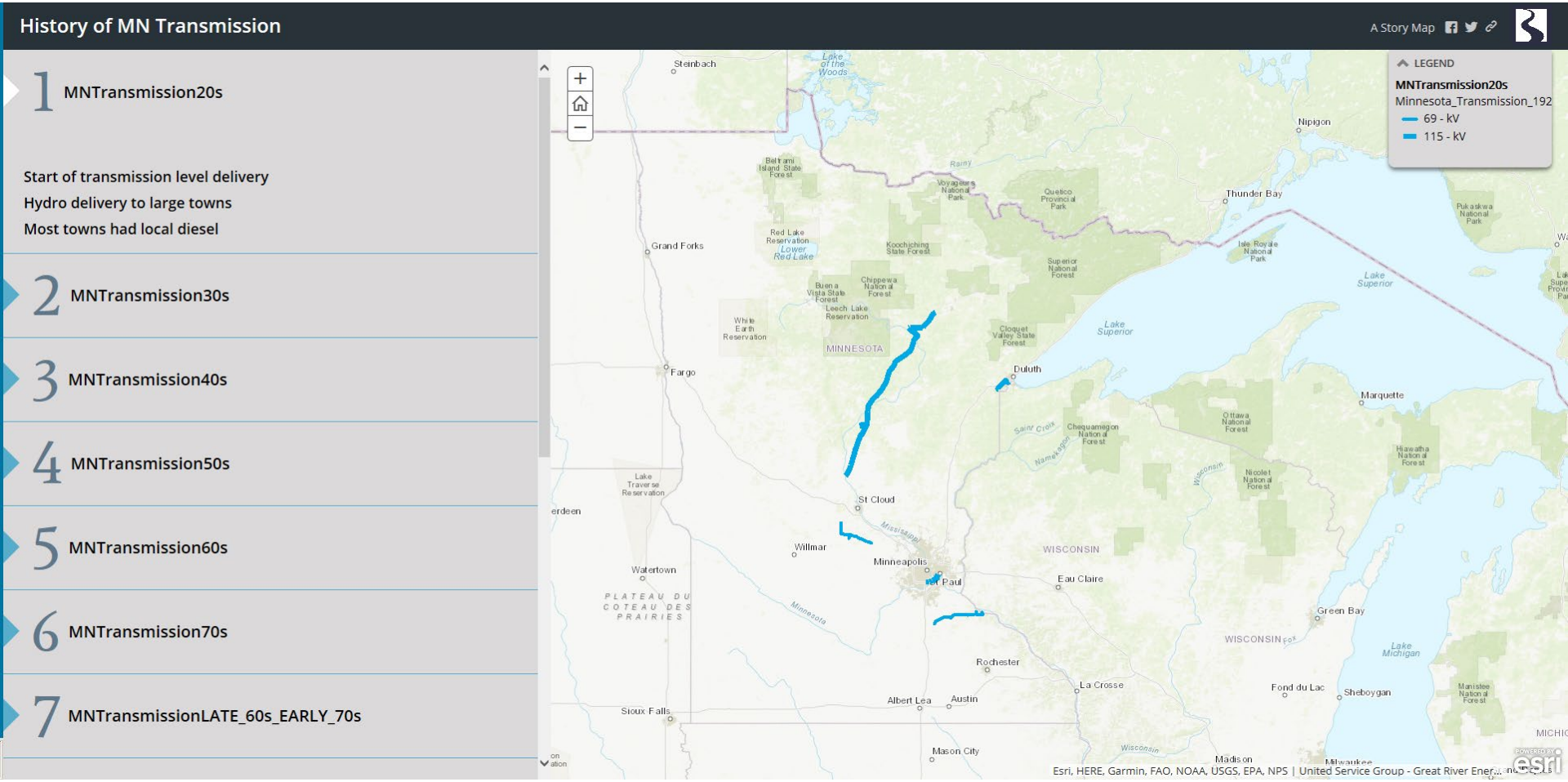
Image by protectpowersystem.blogspot.com

- Transmission assessments
- NERC requirements
- Generation
- Consumer Load
- Model building



- Inter-connection customers
- Adjoining utilities
- Midwest ISO
- Midwest Reliability Organization

1920s



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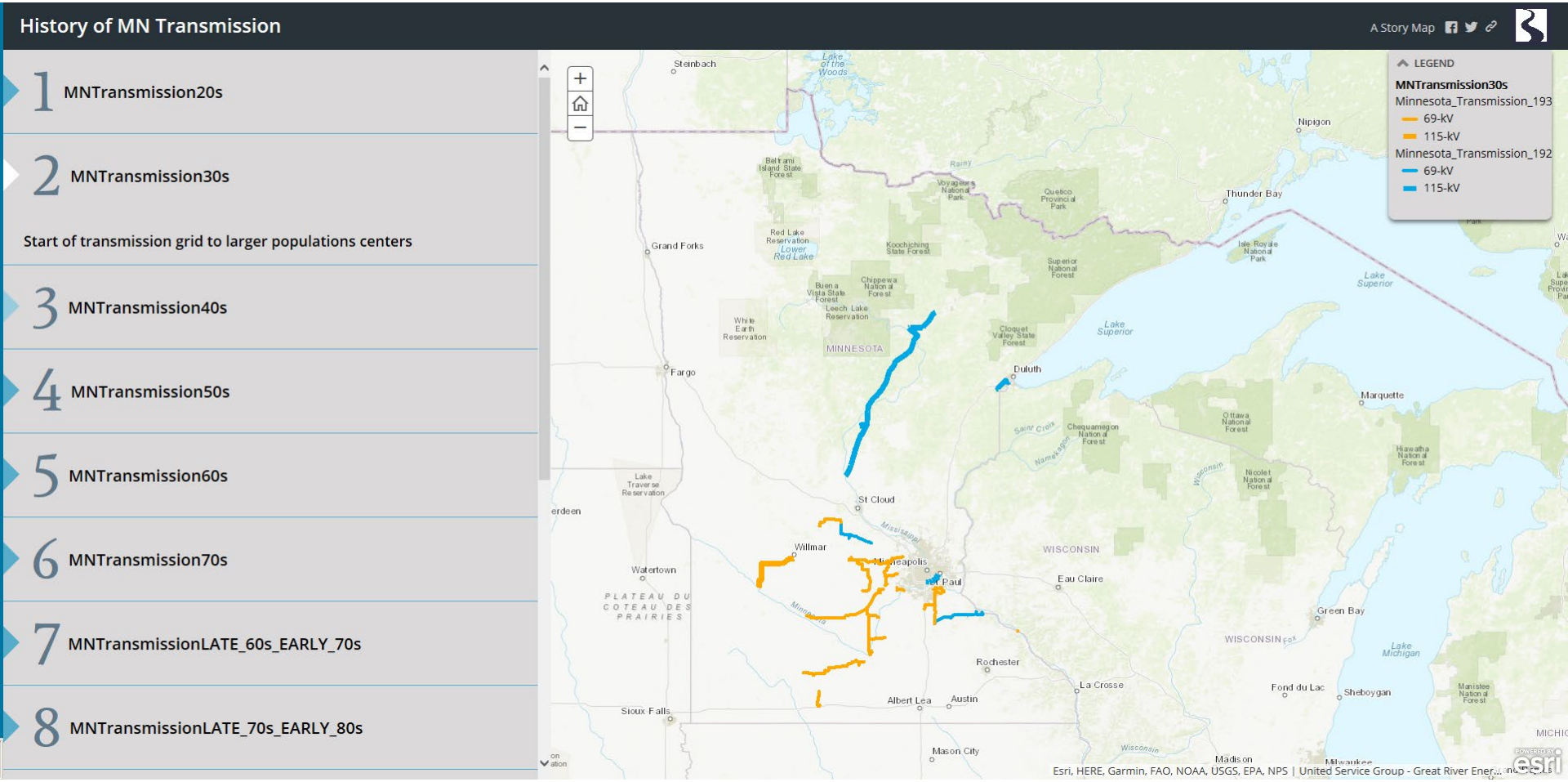
1930s



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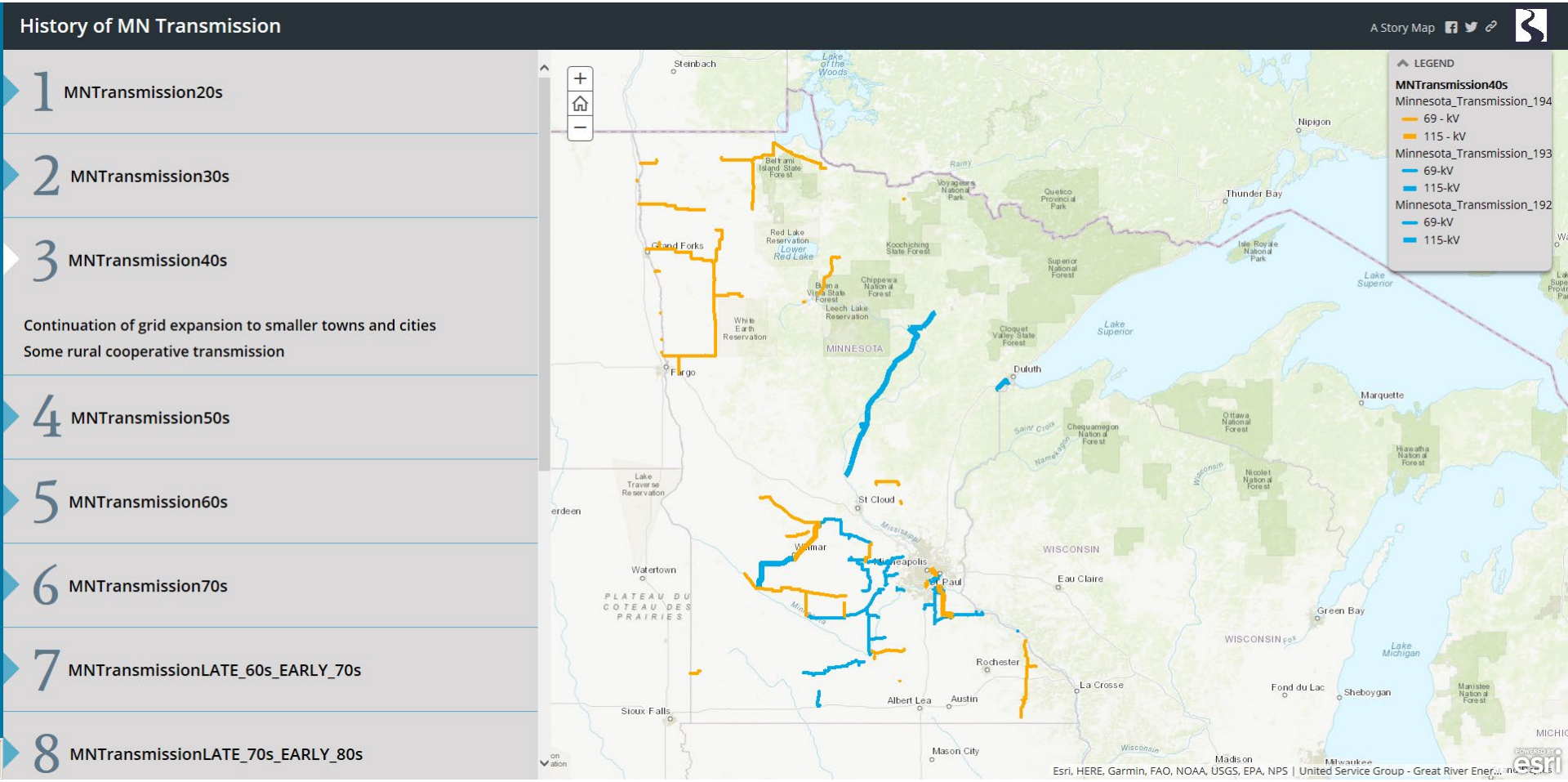
1940s



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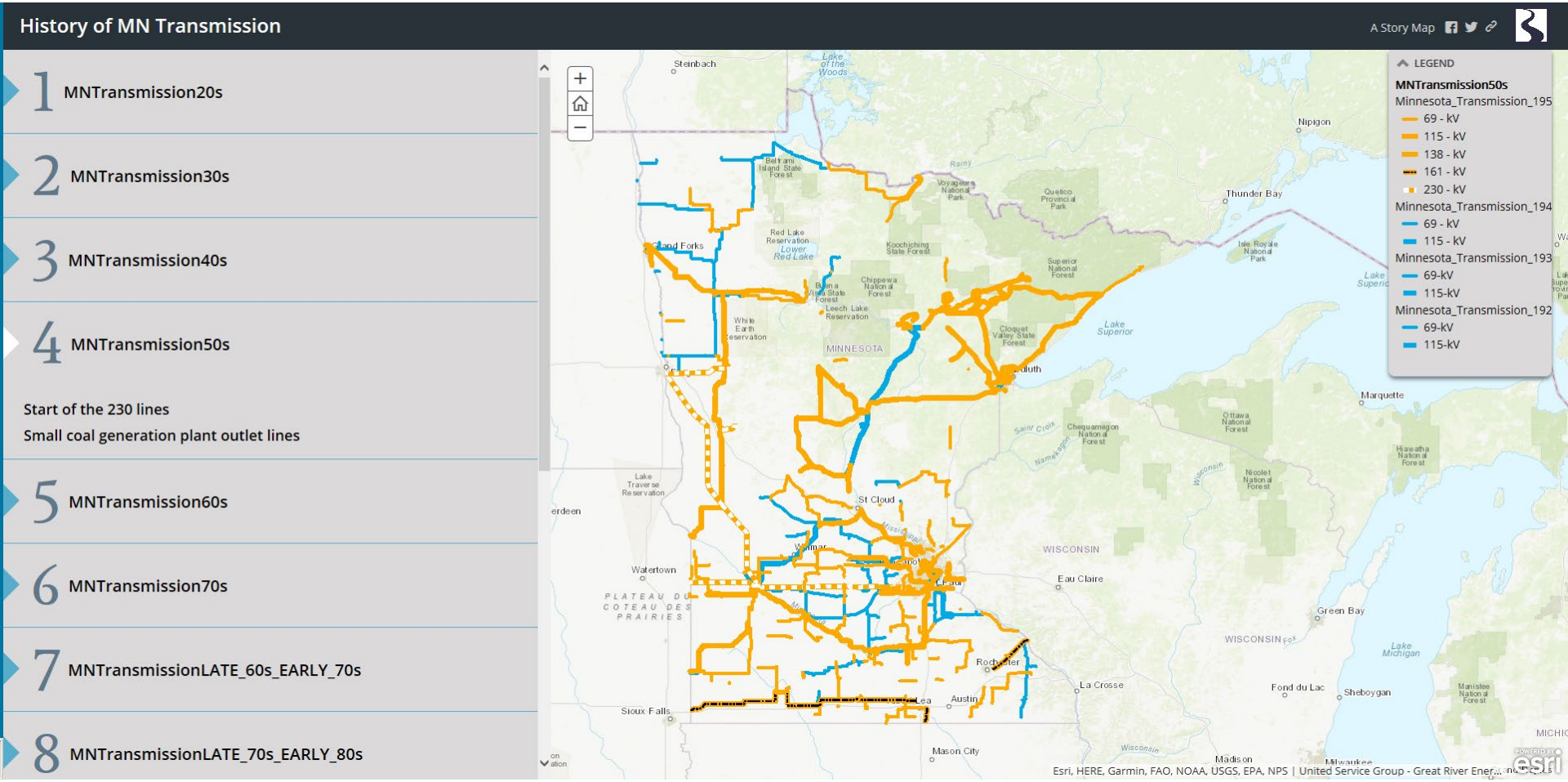
1950s


History of MN Transmission
A Story Map
1 MNTransmission20s
2 MNTransmission30s
3 MNTransmission40s
4 MNTransmission50s
Start of the 230 lines
Small coal generation plant outlet lines
5 MNTransmission60s
6 MNTransmission70s
7 MNTransmissionLATE_60s_EARLY_70s
8 MNTransmissionLATE_70s_EARLY_80s
LEGEND
MNTransmission50s
Minnesota_Transmission_195
69 - kV
115 - kV
138 - kV
161 - kV
230 - kV
Minnesota_Transmission_194
69 - kV
115 - kV
Minnesota_Transmission_193
69-kV
115-kV
Minnesota_Transmission_192
69-kV
115-kV
MINNESOTA
WISCONSIN
Duluth
St Cloud
Eau Claire
Green Bay
La Crosse
Rochester
Austin
Sioux Falls
Mason City
Madison
Watertown
Thunder Bay
Nipigon
Marquette
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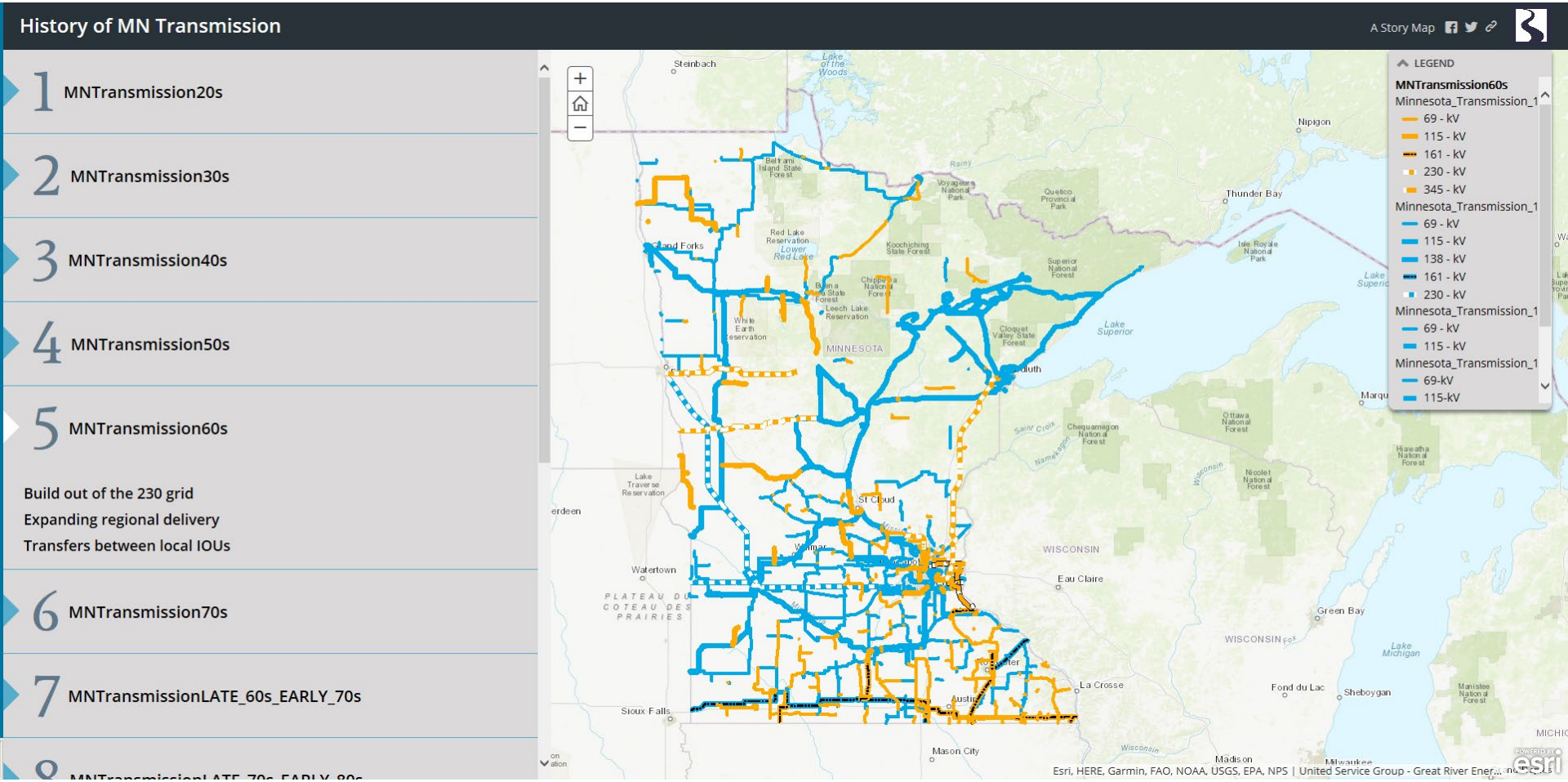
1960s



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1970s

History of MN Transmission

A Story Map

1 MNTransmission20s

2 MNTransmission30s

3 MNTransmission40s

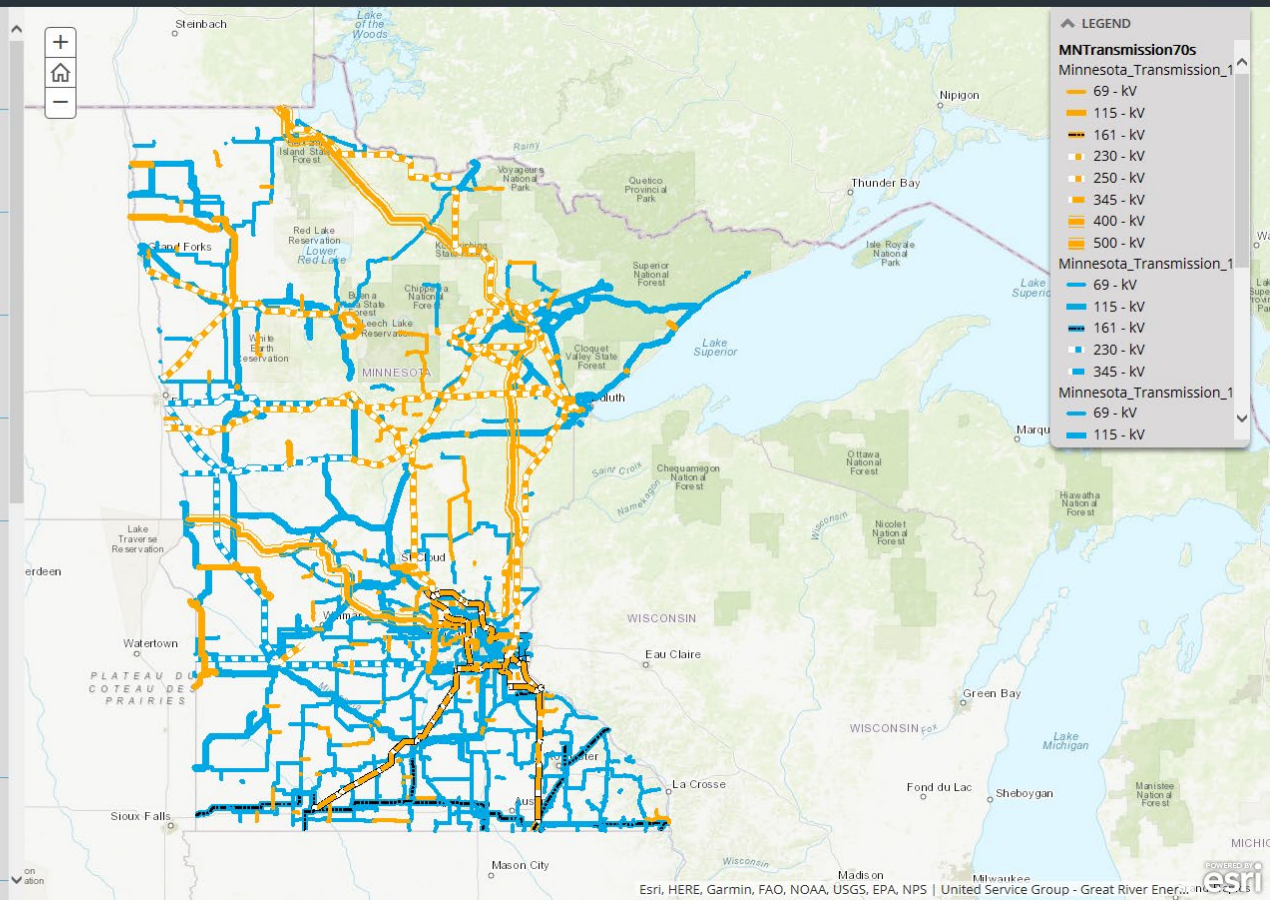
4 MNTransmission50s

5 MNTransmission60s

6 MNTransmission70s

Energy crisis
Major expansion of the transmission grid including EHV level
Electricity is becoming king
Large generation plants within Minnesota

7 MNTransmissionLATE_60s_EARLY_70s



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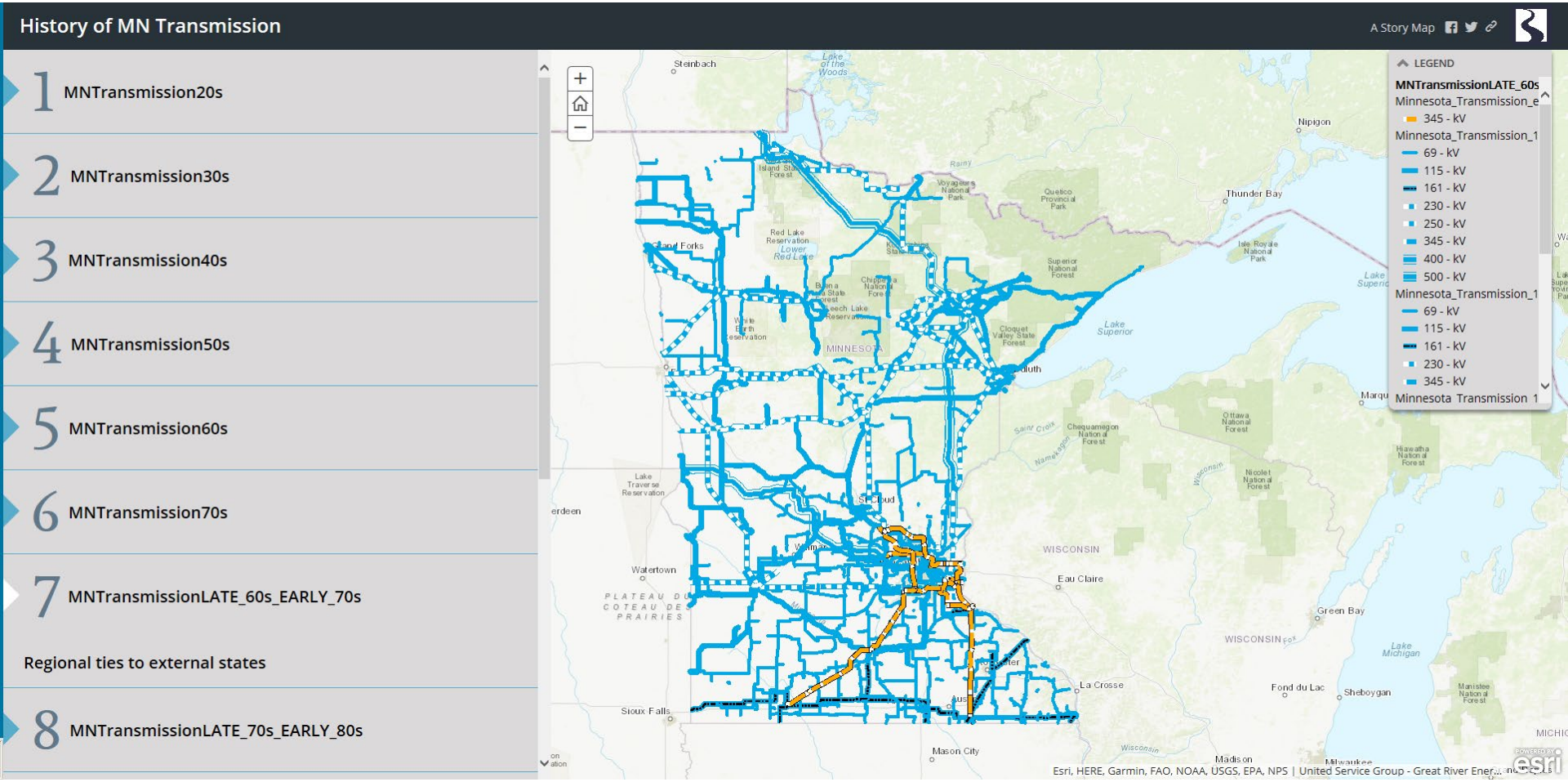
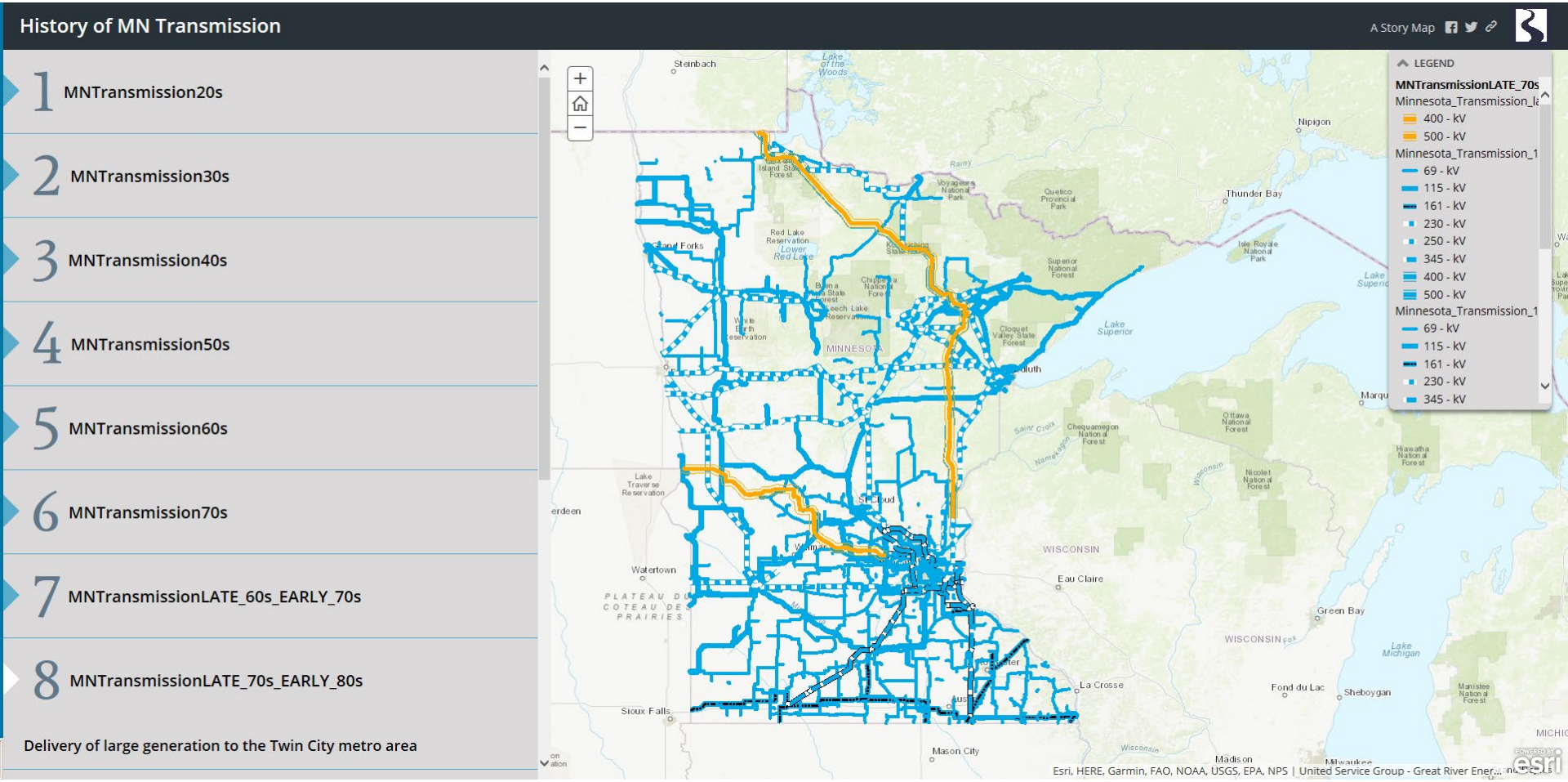
Regional Ties – Export/Import



Large Generation to Twin Cities



1980s

History of MN Transmission

A Story Map

3 MNTransmission40s

4 MNTransmission50s

5 MNTransmission60s

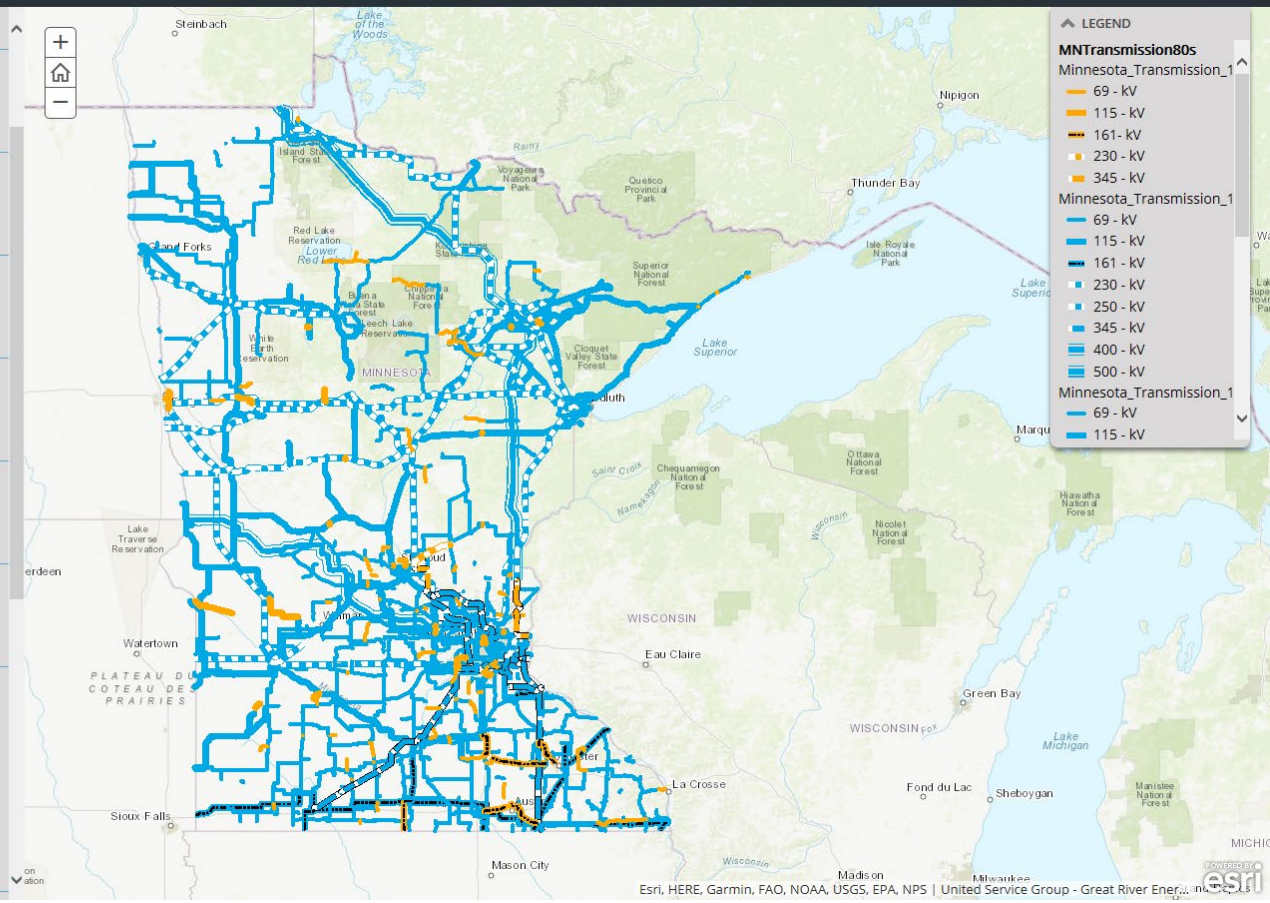
6 MNTransmission70s

7 MNTransmissionLATE_60s_EARLY_70s

8 MNTransmissionLATE_70s_EARLY_80s

9 MNTransmission80s

Capacity available on transmission grid
Largely load serving and reliability
No incentive to build



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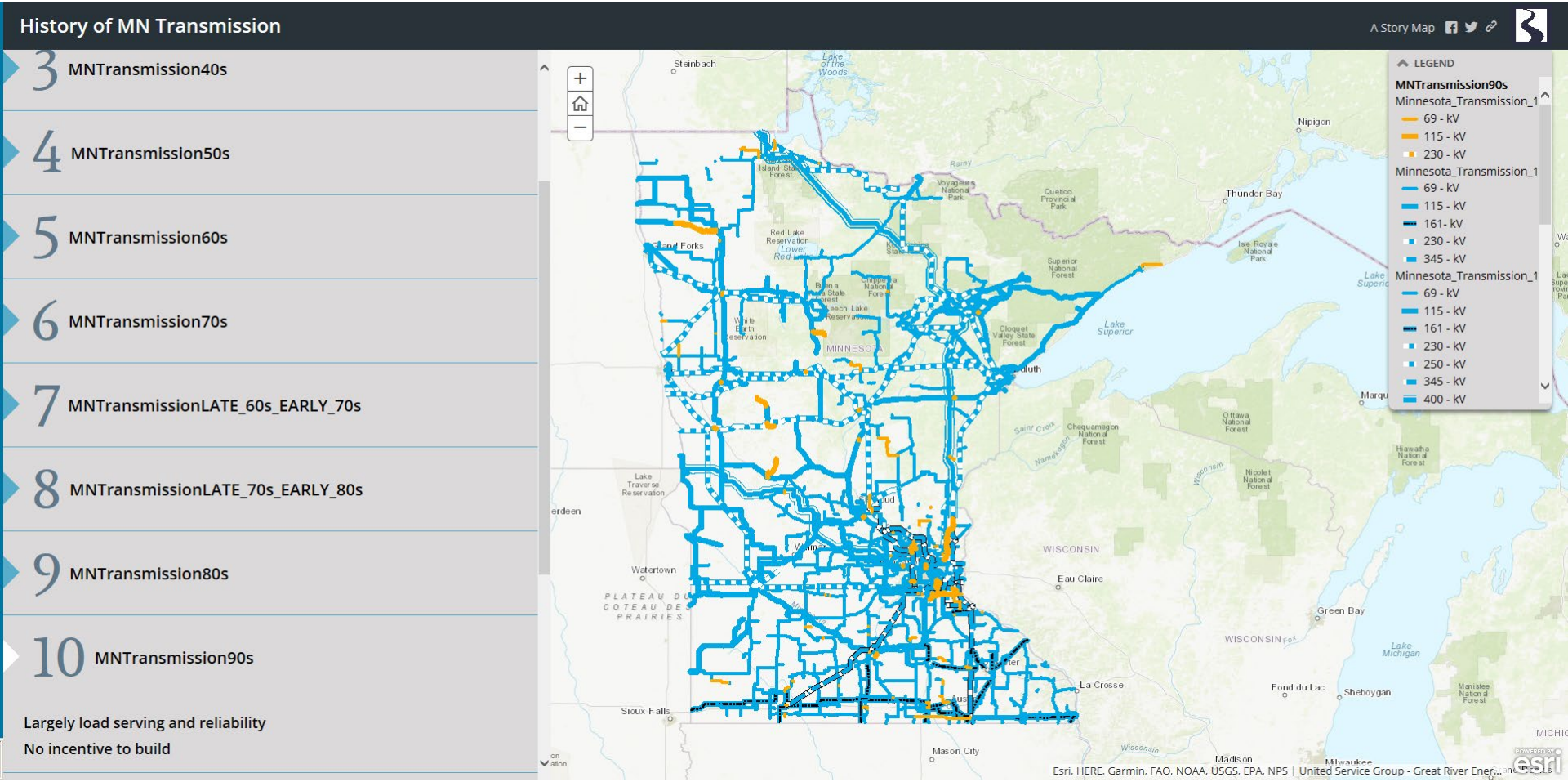
1990s


History of MN Transmission
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3 MNTransmission40s
4 MNTransmission50s
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6 MNTransmission70s
7 MNTransmissionLATE_60s_EARLY_70s
8 MNTransmissionLATE_70s_EARLY_80s
9 MNTransmission80s
10 MNTransmission90s
Largely load serving and reliability
No incentive to build
LEGEND
MNTransmission90s
Minnesota_Transmission_1
69 - kV
115 - kV
230 - kV
Minnesota_Transmission_1
69 - kV
115 - kV
161 - kV
230 - kV
345 - kV
Minnesota_Transmission_1
69 - kV
115 - kV
161 - kV
230 - kV
250 - kV
345 - kV
400 - kV
MINNESOTA
WISCONSIN
Thunder Bay
Nipigon
Duluth
Eau Claire
Green Bay
La Crosse
Sioux Falls
Watertown
Mason City
Madison
Fond du Lac
Sheboygan
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2000s

History of MN Transmission

A Story Map

5 MNTransmission60s

6 MNTransmission70s

7 MNTransmissionLATE_60s_EARLY_70s

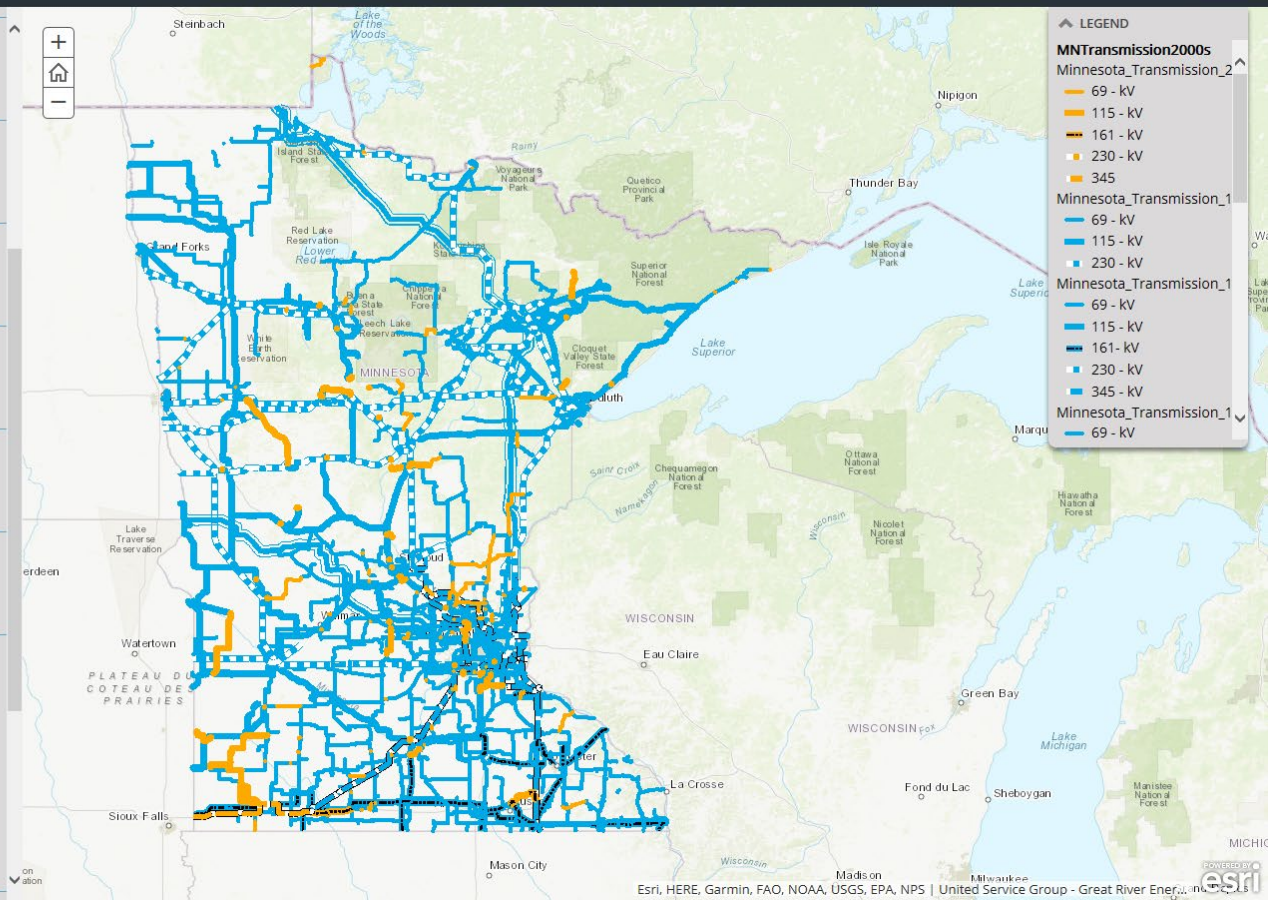
8 MNTransmissionLATE_70s_EARLY_80s

9 MNTransmission80s

10 MNTransmission90s

11 MNTransmission2000s

Largely load serving 115kV expansion
NERC standards established as requirements after 2003 blackout
Renewable Energy Standards
MISO market



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2010s

History of MN Transmission

A Story Map

5 MNTransmission60s

6 MNTransmission70s

7 MNTransmissionLATE_60s_EARLY_70s

8 MNTransmissionLATE_70s_EARLY_80s

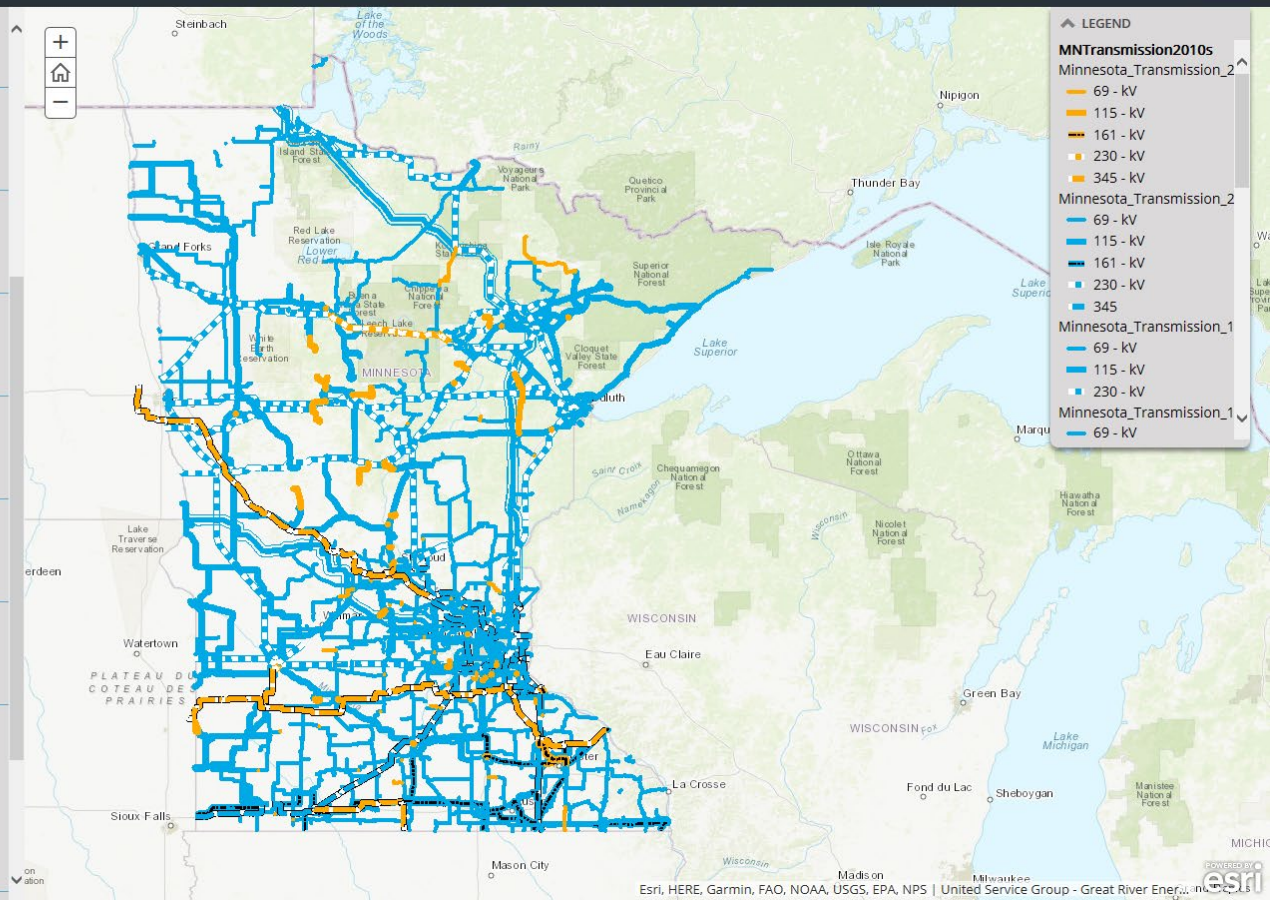
9 MNTransmission80s

10 MNTransmission90s

11 MNTransmission2000s

12 MNTransmission2010s

Regional build out for wind outlet and regional reliability concerns resulting in further EHV construction



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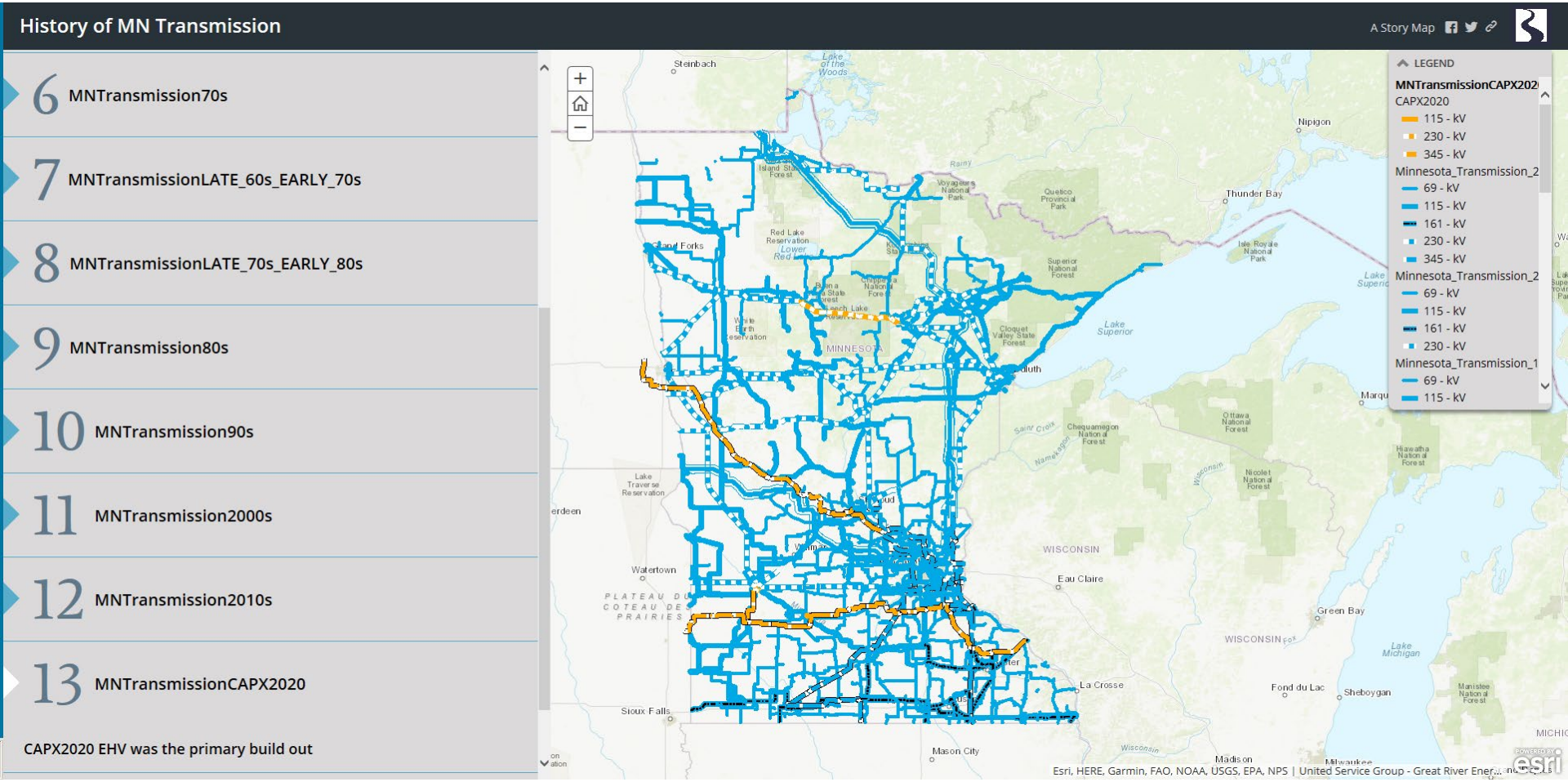
CapX 2020



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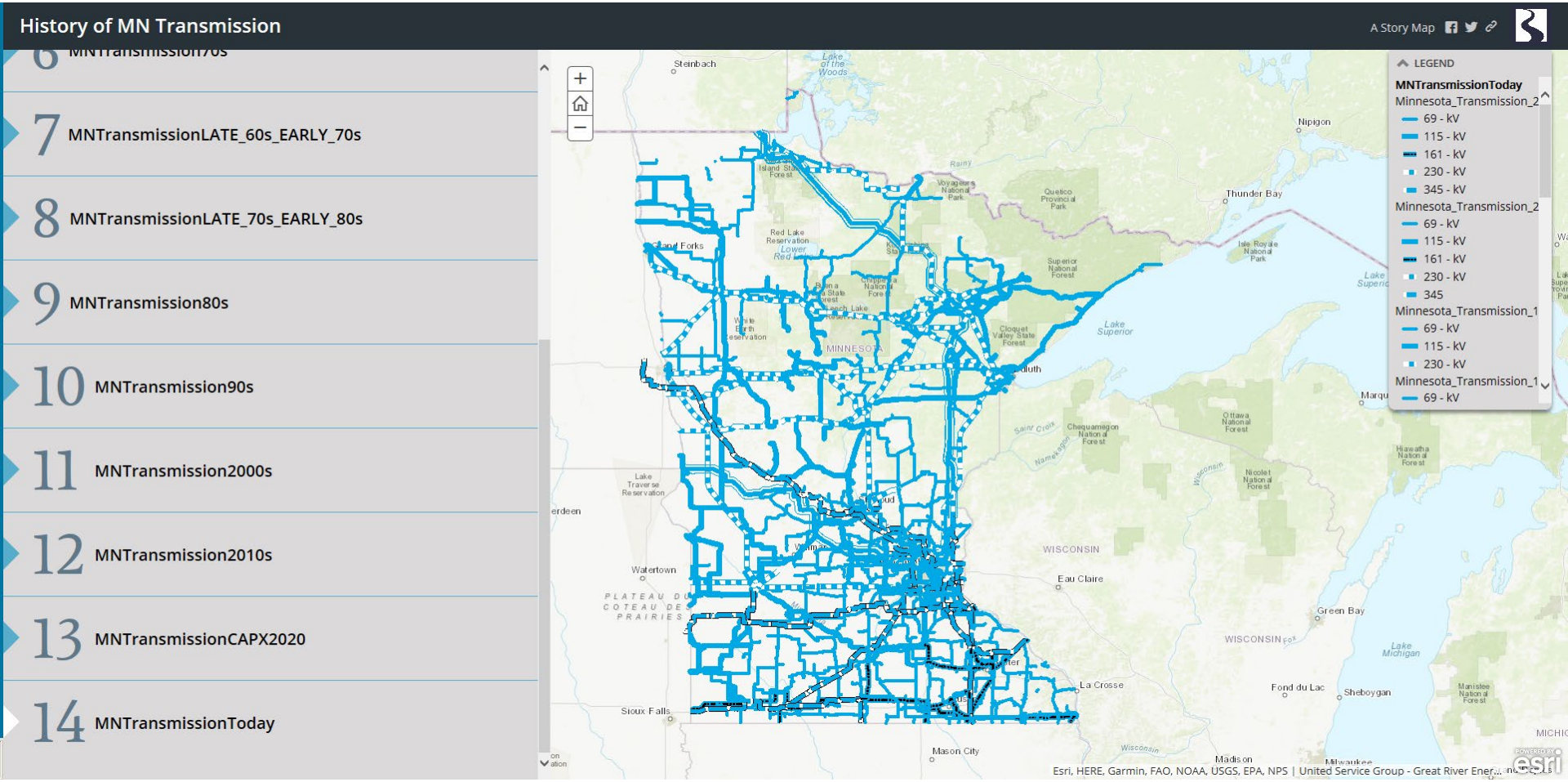
Today


History of MN Transmission
A Story Map
6 MNTransmission70s
7 MNTransmissionLATE_60s_EARLY_70s
8 MNTransmissionLATE_70s_EARLY_80s
9 MNTransmission80s
10 MNTransmission90s
11 MNTransmission2000s
12 MNTransmission2010s
13 MNTransmissionCAPX2020
14 MNTransmissionToday
LEGEND
MNTransmissionToday
Minnesota_Transmission_2
69 - kV
115 - kV
161 - kV
230 - kV
345 - kV
Minnesota_Transmission_2
69 - kV
115 - kV
161 - kV
230 - kV
345
Minnesota_Transmission_1
69 - kV
115 - kV
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Steinbach
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Sioux Falls
Mason City
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Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS | United Service Group - Great River Ener...

What has history built us

- Multiple voltage levels
- Multiple conductor sizes
- Longevity
  - Substations-swap out equipment
  - Lines-?
- Northeast Blackout of 2003: “We are a major superpower with a third-world electrical grid,” Bill Richardson, former secretary of energy in the Clinton Administration
- Ouch that hurt, but we can definitely do better

Conductor Average	Age	X/R	Amps	kV and Miles									
				24	34.5	41.6	69	115	161	230	345	400	500
7#6 CW CU	66	0.9	248				1.0						
SPARATE 2 7/1 ACSR	63	0.6	126				11.0						
RAVEN 1/0 6/1 ACSR	58	0.8	227		17.4	6.7	211.0						
PIGEON 3/0 6/1 ACSR	54	1.2	268			31.6	84.1	4.1					
PARTRIDGE 266 26/7 ACSS	53	2.0	711				10.6						
WAXWING 266 18/1 ACSR	52	1.8	280				13.5						
TERN 795 45/7 @ 160 Deg F ACSR	48	5.9	662							54.1			
FLICKER 477 24/7 ACSR	48	3.5	711					33.4					
QUAIL 2/0 6/1 ACSR	48	1.0	245			21.9	130.4						
Merlin 336 18/1 ACSR	48	2.4	561		16.8		1.4						
PARTRIDGE 266 26/7 ACSR	47	1.9	451			4.7	677.1	70.1					
HAWK T2-477 26/7 ACSR	44	7.3	1155					5.2					
TERN 795 45/7 ACSR	42	5.8	894				0.2	56.3		172.7			
PENGUIN 4/0 6/1 ACSR	42	1.5	345	1.0	77.8	132.3	691.0						
4A CWC	40	0.5	152				9.5						
RAIL 2-954 45/7 ACSR	40	10.2	891								54.0		
BUNTING 1192.5 45/7 ACSR	39	21.1	3717										69.8
LAPWING 1590 45/7 DC ACSR	39	DC	1422									871.7	
BITTERN 1272 45/7 ACSR	37	8.7	1209							9.0			
LAPWING 1590 45/7 ACSR	37	10.4	1342					4.3					
IBIS 397 26/7 ACSR	37	2.8	625				130.6	0.7					
ROOK 636 24/7 ACSR	36	4.6	848				1.0	2.7	24.3				
BUNTING 1192 45/7 ACSR	35	16.5	1411								21.4		
RAIL 954 45/7 ACSR	34	7.1	1125					0.6		284.2			
DRAKE 795 26/7-Bundle ACSR	31	9.4	1964					3.6					
LINNET 336 26/7 ACSR	27	2.4	549		14.9	43.6	188.1	12.7					
PIEGON T2-3/0 6/1 ACSR	23	2.4	538			1.5	5.7	9.8					
TERN 795 45/7 ACSS	20	5.7	1551					17.0					
RAVEN T2-1/0 6/1 ACSR	20	1.5	423	8.3			15.7						
HEN 477 OVAL 23/7 ACSR	19	3.4	732				11.8						
DRAKE 795 26/7 ACSR	17	6.0	956				7.2	76.3					
LINNET T2-336 26/7 ACSR	16	4.4	747					27.2					
IBIS 397 26/7 ACSS	15	2.7	1006				2.5						
PENGUIN T2-4/0 6/1 ACSR	12	2.6	627	22.6			43.2						
HAWK 477 26/7 ACSR	12	3.5	702				86.7	97.1					
HAWK 477 26/7 ACSS	11	3.3	1114				209.6	39.9					
LINNET 336 26/7 ACSS	11	2.3	903				31.2						
DRAKE 795 26/7 ACSS	10	5.6	1562				41.8	73.5	21.4	51.5			
CARDINAL 954 54/7 - ND ACSS	5	7.2	1834							3.2			
CARDINAL 954 20/7 TW-BUNDLED ACSS	4	11.0	3608							5.1	513.9		

ps	kV and Miles									
	24	34.5	41.6	69	115	161	230	345	400	500
3				1.0						
6				11.0						
7		17.4	6.7	211.0						
3			31.6	84.1	4.1					
				10.6						
0				13.5						
2							54.1			
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5			21.9	130.4						
		16.8		1.4						
			4.7	677.1	70.1					
5					5.2					
4				0.2	56.3		172.7			
5	1.0	77.8	132.3	691.0						
2				9.5						
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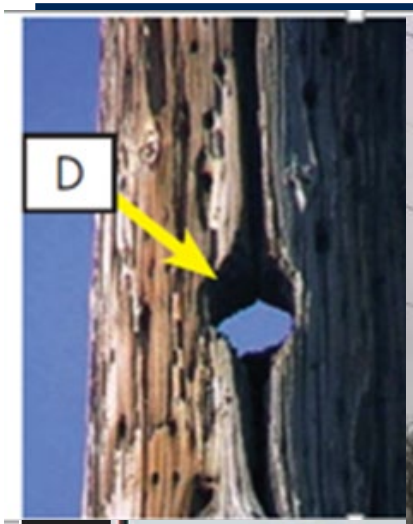
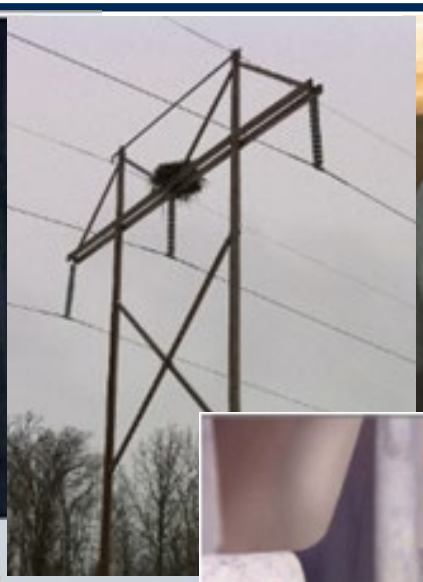
IBIS 397 26/7 ACSR	37	2.8	625	

Age and condition

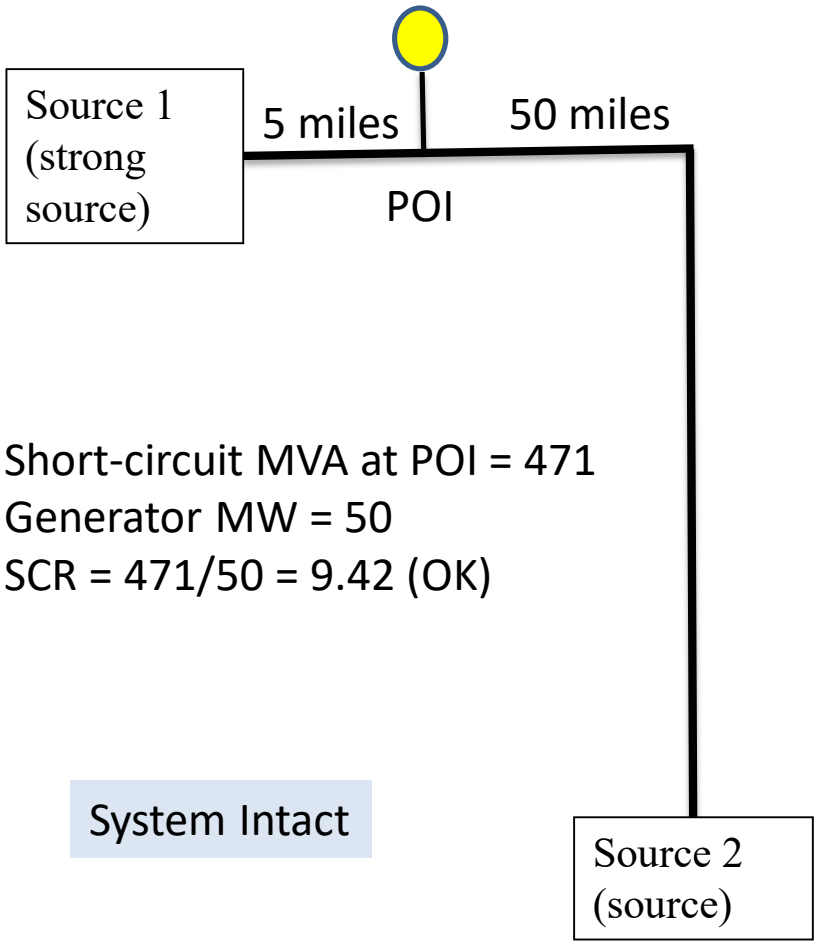




New challenges today

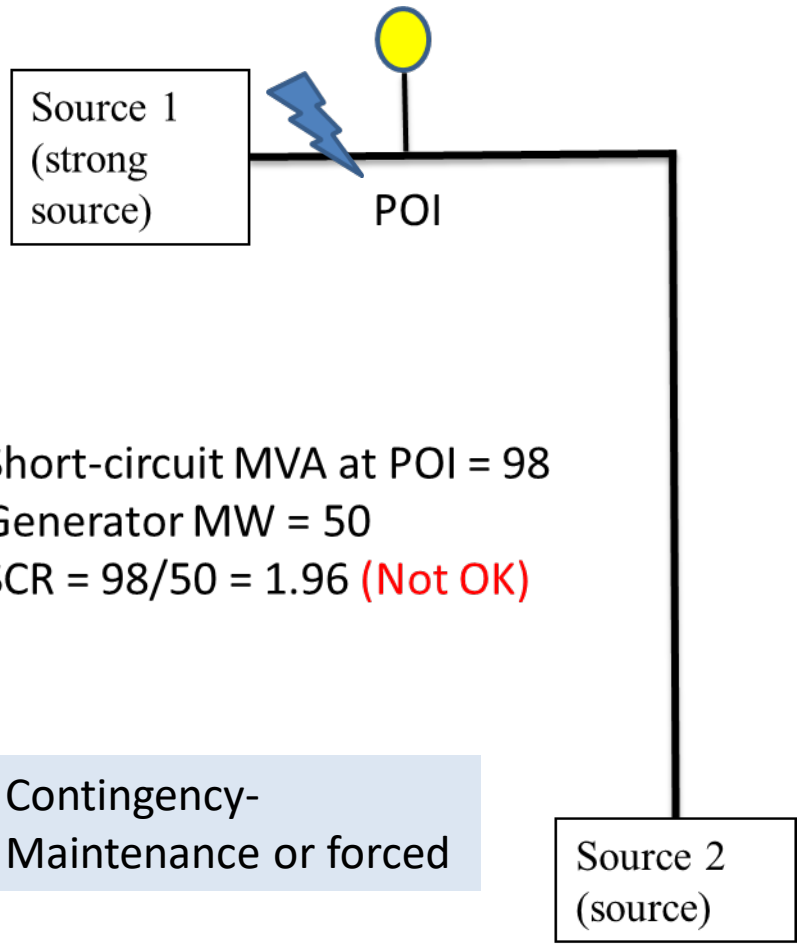
- Lack of load growth
  - Economic collapse of late 2000s
  - Efficiency
- Regional lines
  - Generation driven, who pays
  - State siting requirements
- Renewables
  - Inverter based concerns
- Generation retirements
- Stability concerns arising
  - Inertia?
- Market congestion
  - Difficulty taking out lines for maintenance

Inverter based generation and SCR



Short-circuit MVA at POI = 471
Generator MW = 50
SCR = 471/50 = 9.42 (OK)

System Intact



Short-circuit MVA at POI = 98
Generator MW = 50
SCR = 98/50 = 1.96 (Not OK)

Contingency-
Maintenance or forced

Inverter concerns with new generation

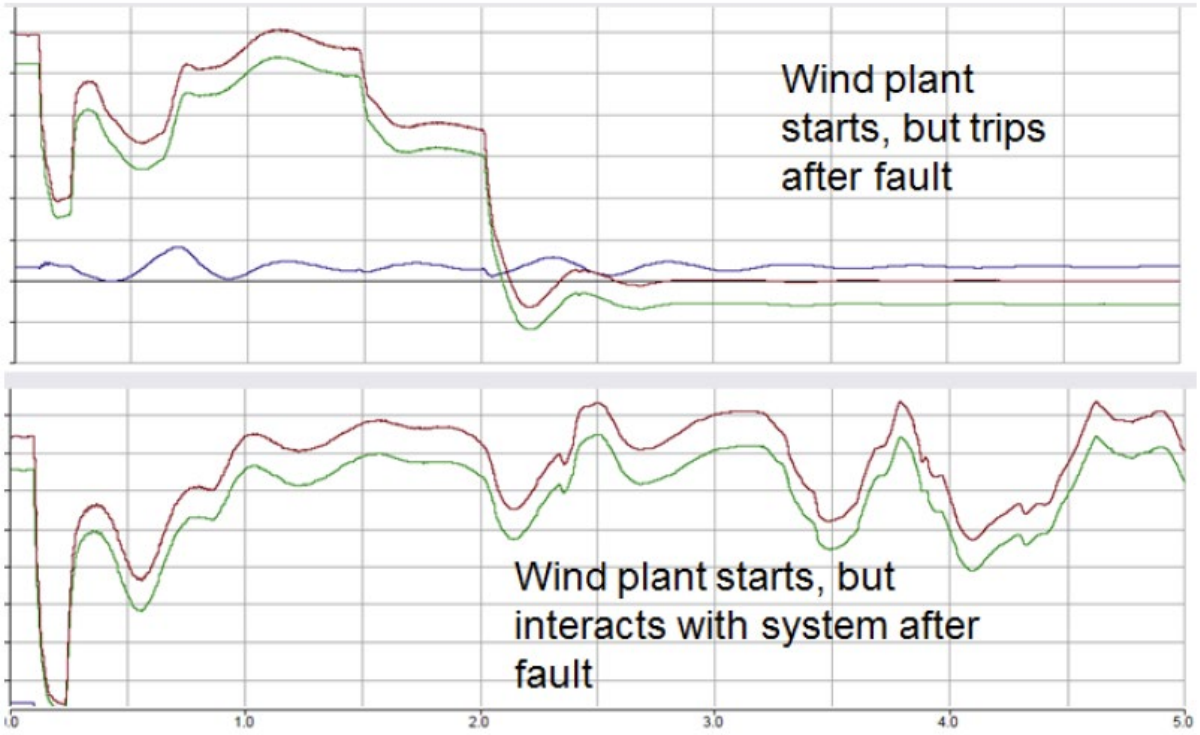
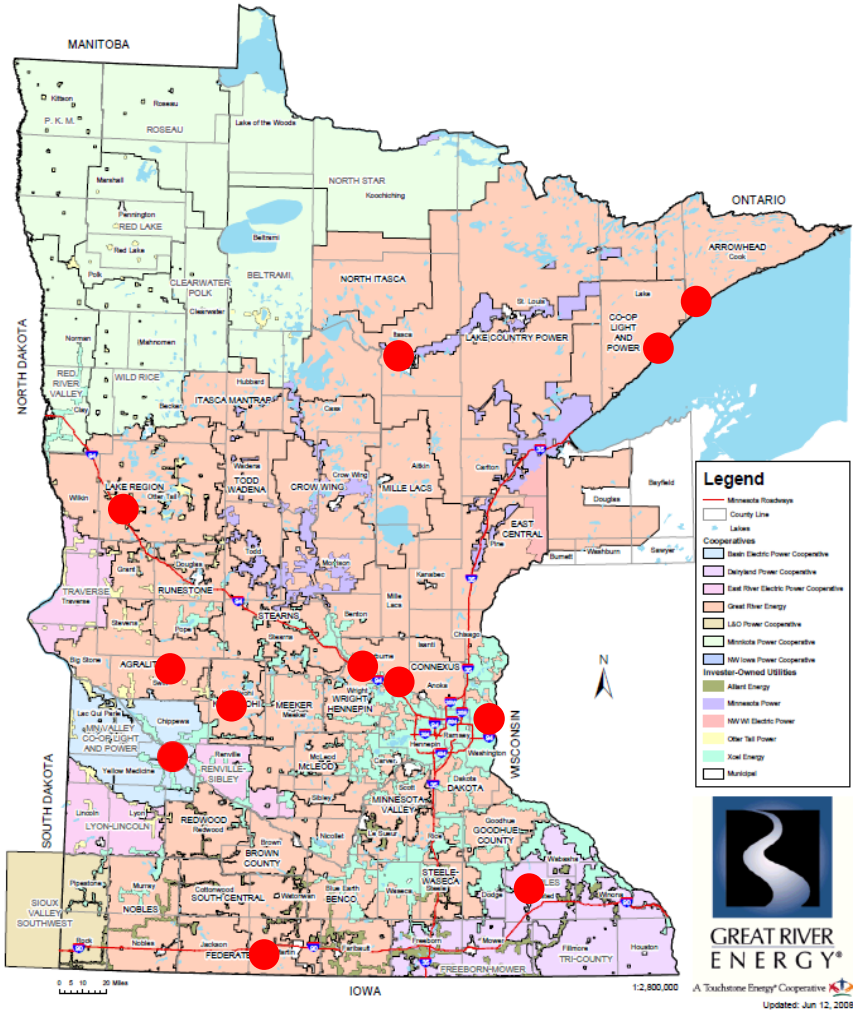


Figure 3.4: Example of Control Instability at Wind Plant Connected to Weak Grid [Source: Electranix]

From NERC Reliability Guideline:
Integrating Inverter-Based Resources into Weak Power Systems

Generation idling

- Maintained voltage
- Delivered power out of a region-not any more
- Long distance delivery of power
- Reliability and stability concerns
- Variability of replacement generation



Maintaining stability

- $P = \frac{V_s V_r \sin(\varsigma)}{X_{eq}}$

- Equal Area Criterion
- Acceleration equal to deceleration
- Power will be traveling greater distances
- Voltage is dropping in load areas

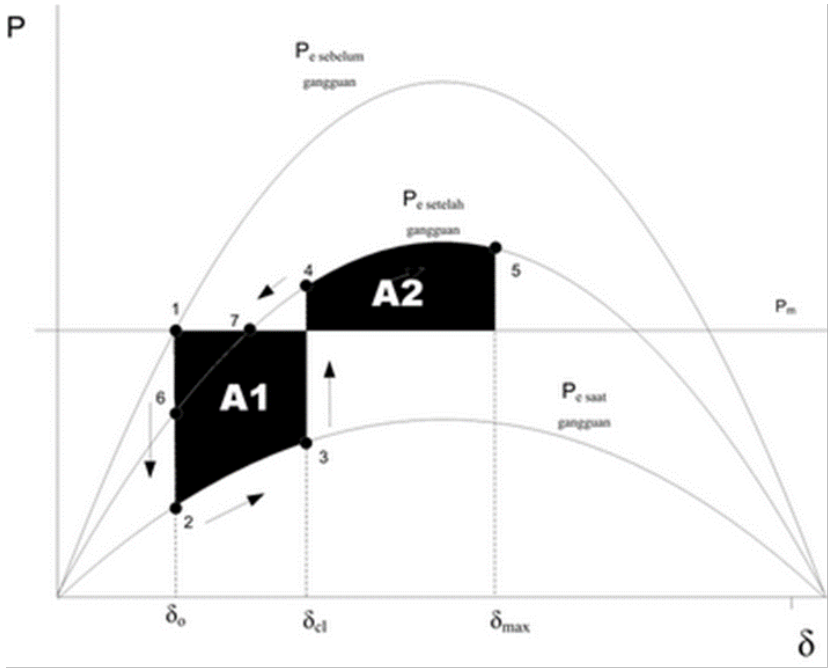
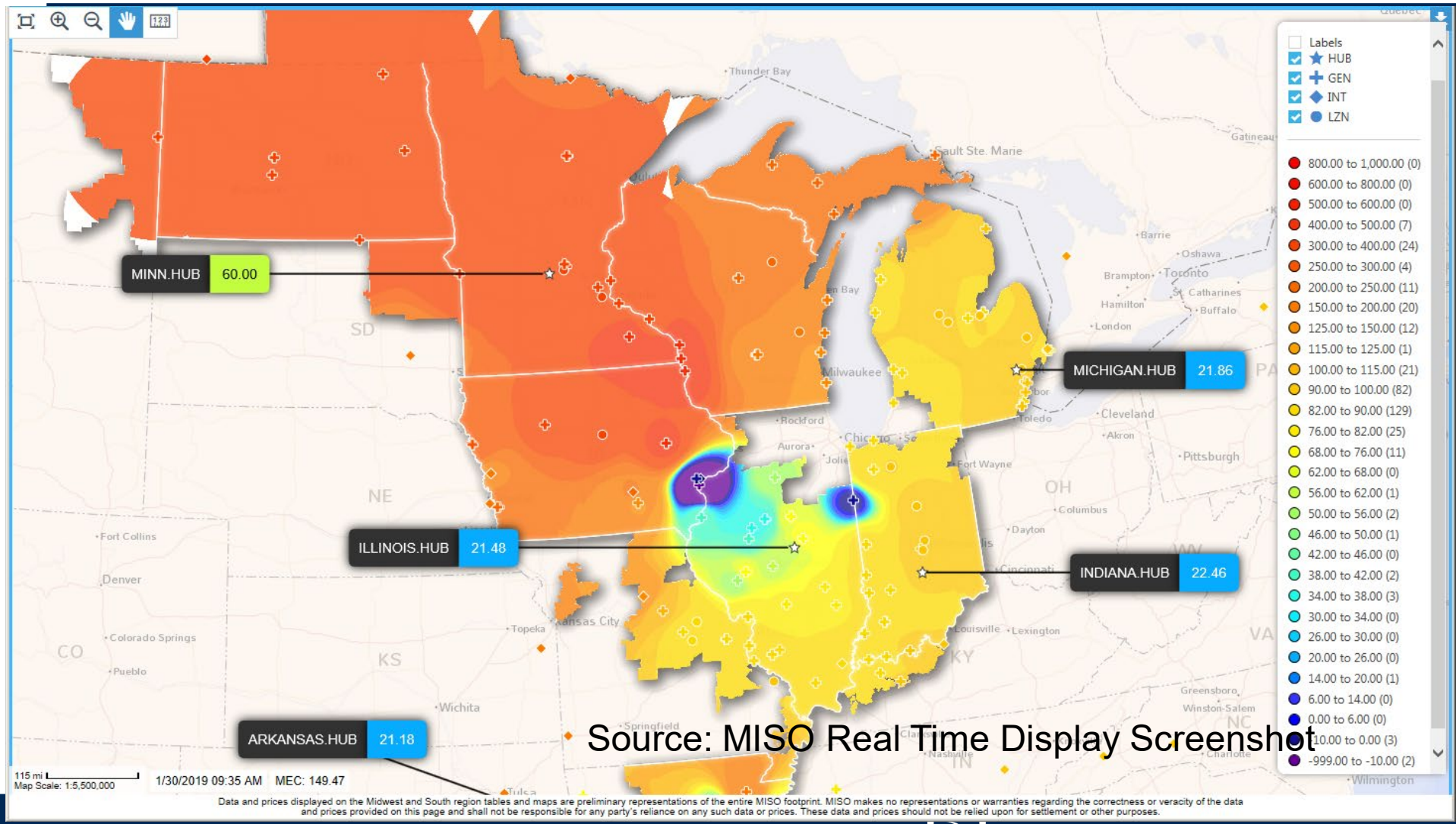


Image from askramadhan.wordpress.com

LMP markets

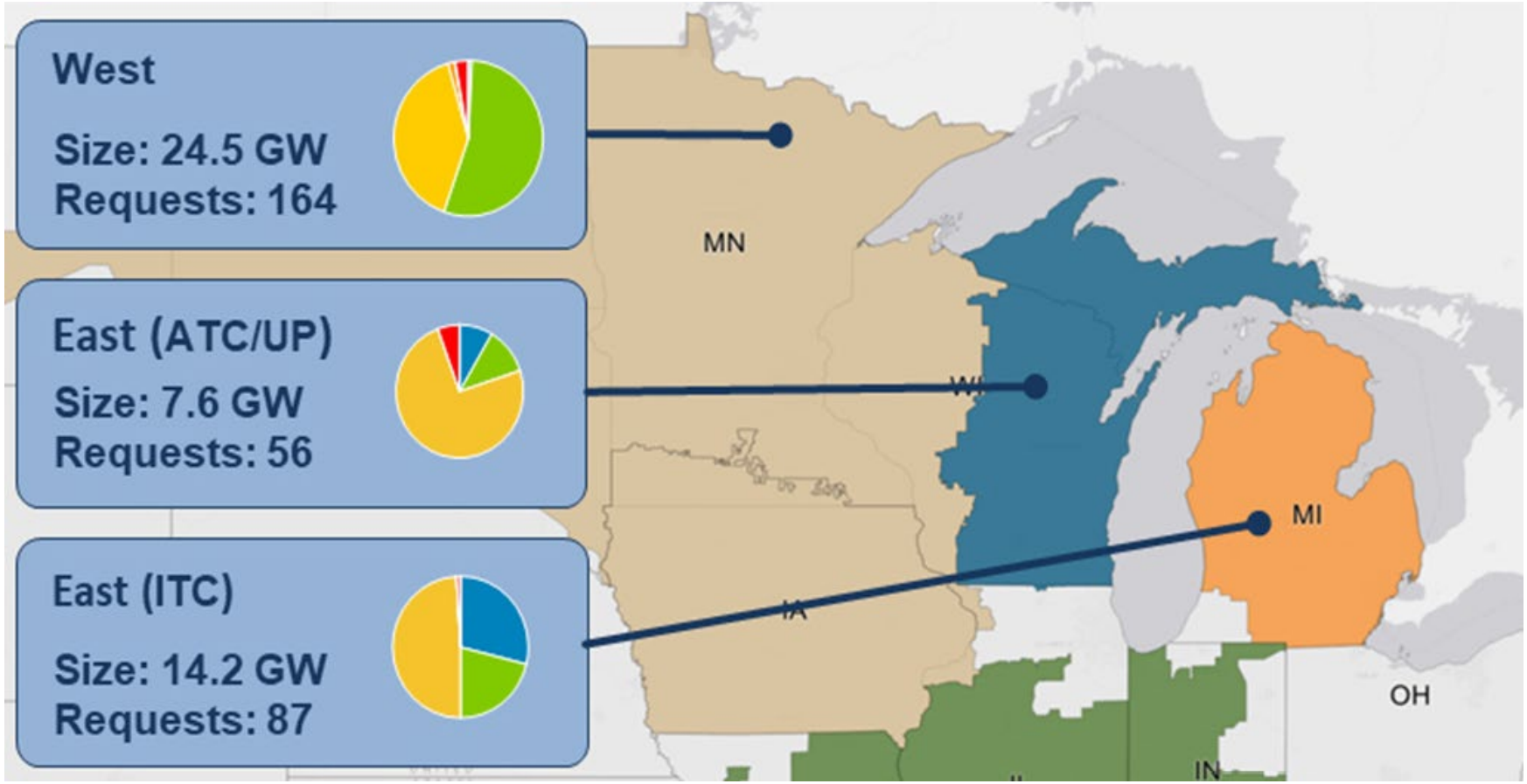


Source: MISO Real Time Display Screenshot

Transmission grid of the future

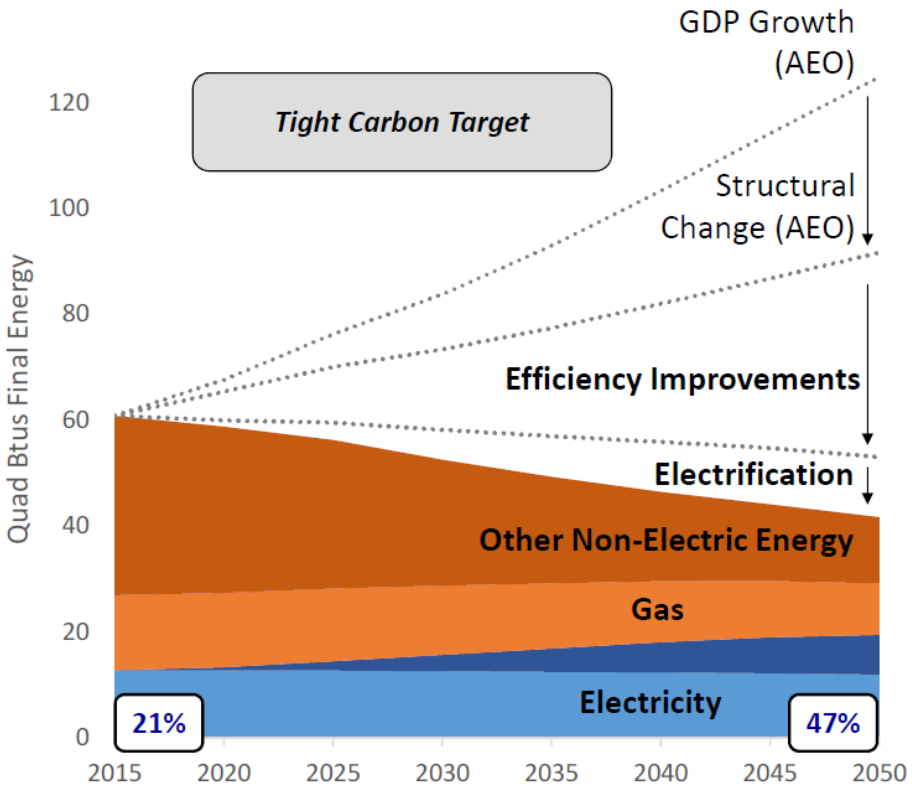
- Affordability to the consumers
  - Large renewable generation with transmission buildout
  - Distributed energy resources
  - Is transmission worth the investment?
- New technology
  - STATCOM, automated switching, inverters
  - Dynamic ratings
- Renewables
  - Integrating where power is needed
  - Regional transmission - DC lines
- Electrification of load
- Non-wire alternatives

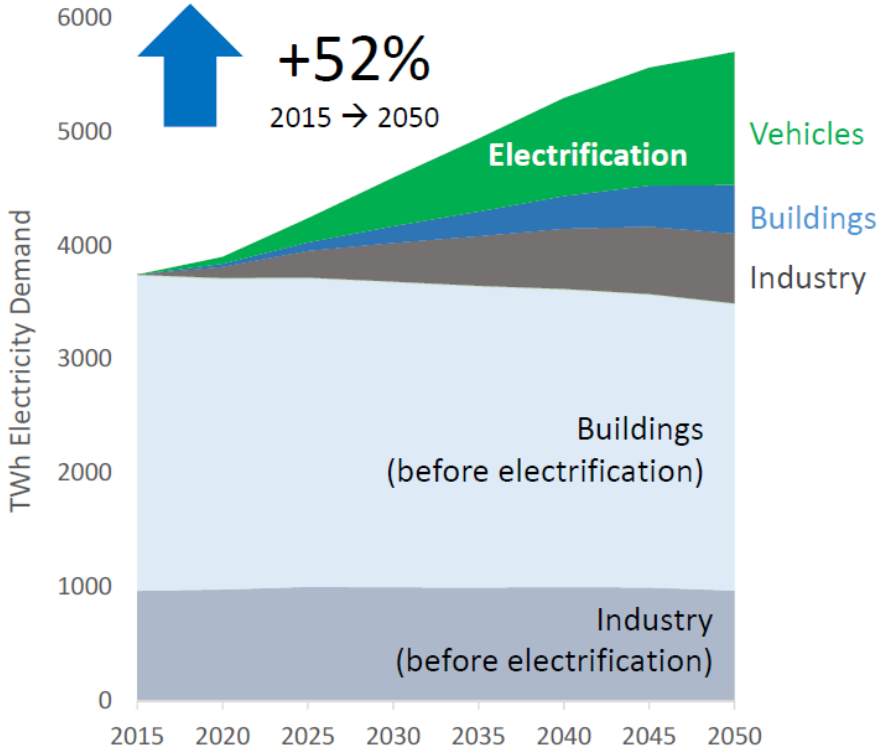
Generator interconnection: West area



Source: MISO Transmission Planning Department

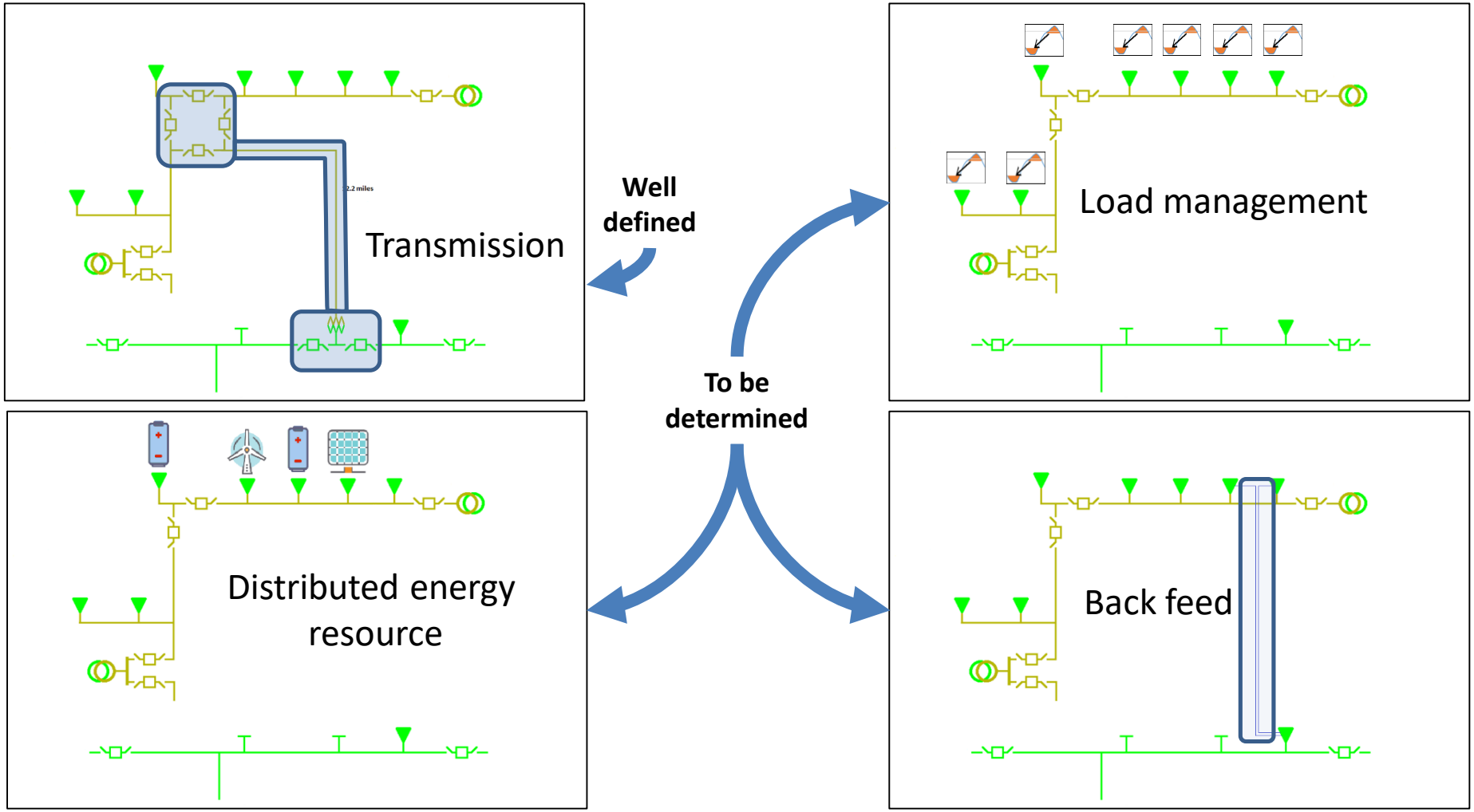
Electrification transformation





Source: EPRI National Electrification Assessment

Transmission non-wire alternatives



Conclusion

- More transmission lines and storage will be needed as variable resources become more prevalent.
- Accessible corridors need to be available.
- Maintain affordable power to the consumer