Interconnection and Transmission for Wind Generation

WEATS 2006

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Boulder, Colorado

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Topics I Will Cover

- Examples of distributed wind generation projects
- How wind turbines are interconnected to the distribution system
- How do wind turbines affect the distribution system
- Connecting to the Transmission Grid

Single 900 kW Wind Turbine
Connected to Distribution Line
For Waverly Power & Light

Examples of Distributed Wind Generation

- Small wind turbines in Wisconsin
  - One serving a farm
  - One simply interconnected to rural distribution feeder

Three 35 kW Wind Turbines Near Lynd, Minnesota

65 kW Wind Turbine Powering a Radio Station at Sioux City, Iowa

65 kW Wind Turbine at Boondocks Truck Stop near Williams, Iowa

How Are Small Wind Turbines Interconnected?

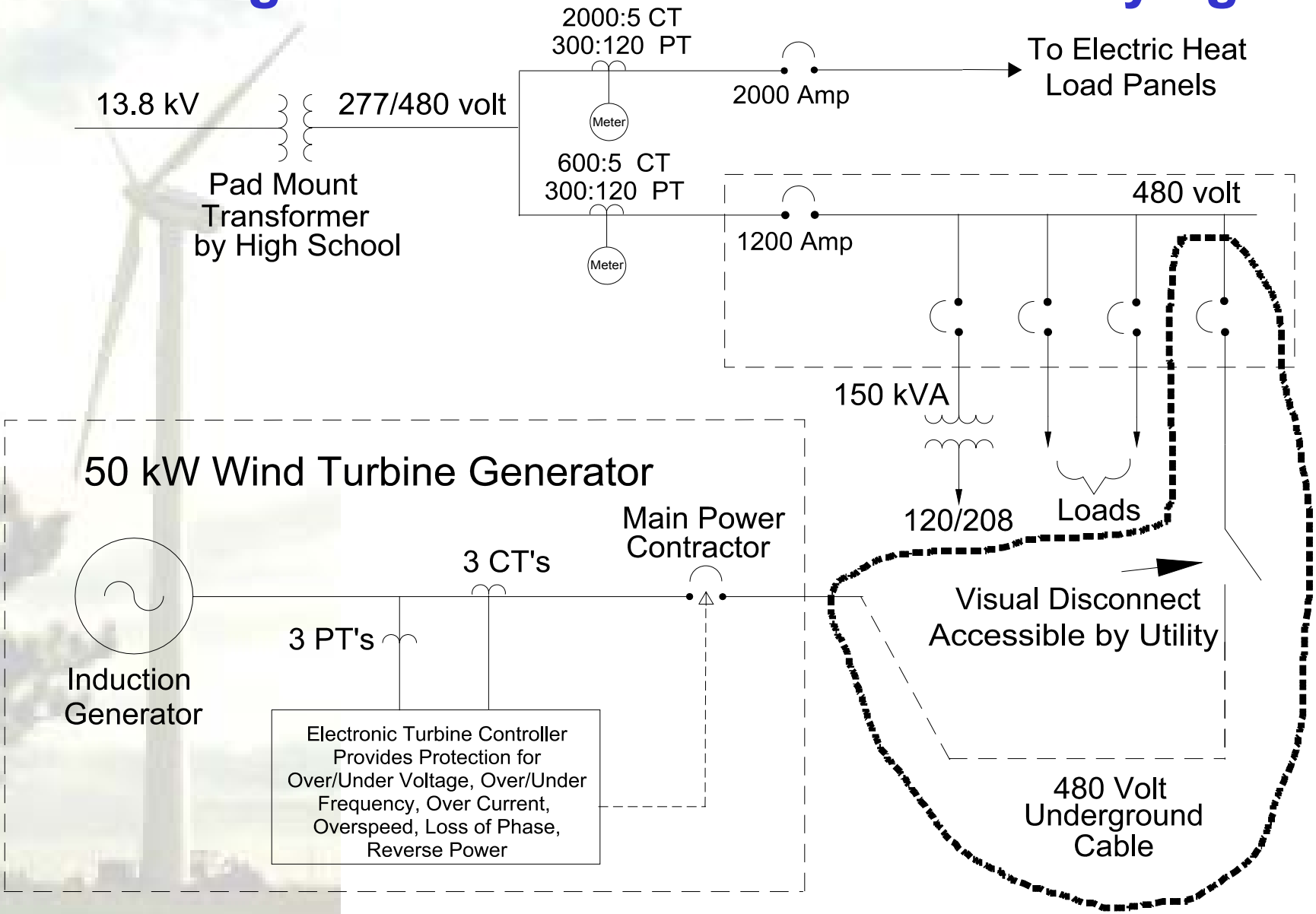
- Typically, turbines up to 10 kW are connected to customer's 120/240 volt service entrance panel through an inverter.
  - Inverter needed because small wind turbines aren't constant speed
- Turbines from 20 kW to 40 kW are usually induction generators, which may be single or three phase for net billing applications
  - One or two speed, essentially synchronized to to 240 or 480 volt service
- Turbines larger than 40 kW are three-phase induction generators, usually tied directly to 480 volt. New Bergey 50 kW unit will use an inverter.

65 kW Wind Turbine Near Livingston, Montana

Three 65 kW Wind Turbines at Britt, Iowa

65 kW Wind Turbine for Sentral Schools at Fenton, Iowa

Interconnection of a 50 kW Wind Turbine Using Self Contained Protective Relaying



New Bergey 50 kW Wind Turbine

- Latest technology
- Designed to be less expensive per kW
- 22’ long blades
- More efficient in low wind speeds
- Very simple design – three moving parts
- Uses slightly modified ABB variable speed motor controller as inverter interface to 480 v. electric service

Midsize Wind Turbines (100-250 kW)

225 kW at Lac Qui Parle School in Minnesota

225 kW Wind Turbine Powering Waste Water Treatment Plant at Nevada, Iowa

How Are Midsize Wind Turbines Interconnected?

- If the turbine is close to a customer's load center, then the turbine can be connected to customer's 240/480 volt main service panel
  - This allows easy netting of load and generation
- Turbine may have a step up transformer at the base of the wind turbine to connect directly to distribution grid
  - More difficult to connect wind turbine "behind the meter" for netting unless the customer has primary metering
- Midsize Turbines usually have sophisticated protective relaying system built into turbine controller, which should preclude the need for separate relays and breaker

250 kW Wind Turbine on Rural 13.8 kV Line

Large Wind Turbines (250-2,000 kW)

600 kW Turbine at School in Akron, Iowa

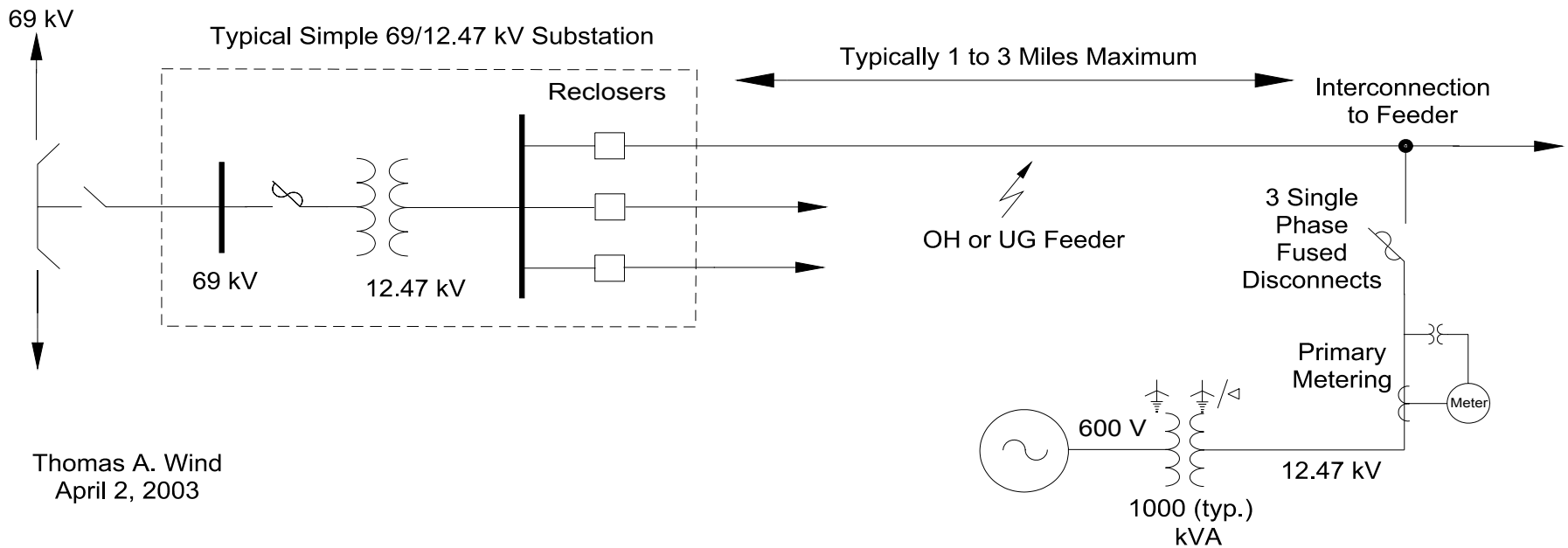
600 kW Turbine at School in Forest City, Iowa

Connected by Fuses to Distribution System

How Are Larger Wind Turbines Interconnected?

- Larger wind turbines have step-up transformer at base of the wind turbine to boost voltage to distribution level, then interconnection is made to the primary. This could be either before or after a customer's meter or directly to the distribution feeder.

Single Line Diagram of Basic Interconnection



Thomas A. Wind
April 2, 2003

What Type of Interconnection Equipment is Used for Larger Wind Turbines?

- The type of equipment will vary depending upon what the utility requires
  - This depends upon the need for control and information
    - Can be very simple
    - Can be more complex and costly
- Based on my experience, if utility owns wind turbines, then installation is typically simpler and less costly

A 750 kW & 250 kW Wind Turbine at Spirit Lake Schools

Two 750 kW Wind Turbines for the City of Moorhead, Minnesota

Two 750 kW Turbines Owned by the Kas Brothers at Woodstock, Minnesota

MinWind 1 & 2 Wind Farms
Four 950 kW Turbines at LuVerne, Minnesota

Two Farmer-Owned
Cooperatives, each owns
Two 950 kW wind turbines
Tom Arends, Mark Willers
are the two presidents

Two 900 kW Farmer-Owned Wind Turbines Near Woodstock, Minnesota

What is the Electrical Impact of a Large Wind Turbine on a Distribution Feeder

- Will reduce the power flow from the substation
  - May cause back-feed into substation
  - Need to make sure substation voltage regulator will work for reverse power
- May increase or decrease distribution line losses over the course of a year, depending upon the relative level and location of the wind generation and load
- Will reduce transmission system losses
- Will usually increase the voltage level out on the feeder during normal operation.

Coordination of Feeder Protection

- Must ensure that the addition of a wind turbine won't significantly impact feeder reliability
- Wind turbine should readily trip off on its own for any disturbance, such as faults and for over or under voltages
- Wind turbines also trip for phase unbalance, and over/under frequency
- Don't want extra unnecessary substation or line recloser operations because of wind turbine

Two 950 kW Wind Turbines for the City of Fairmont, Minnesota

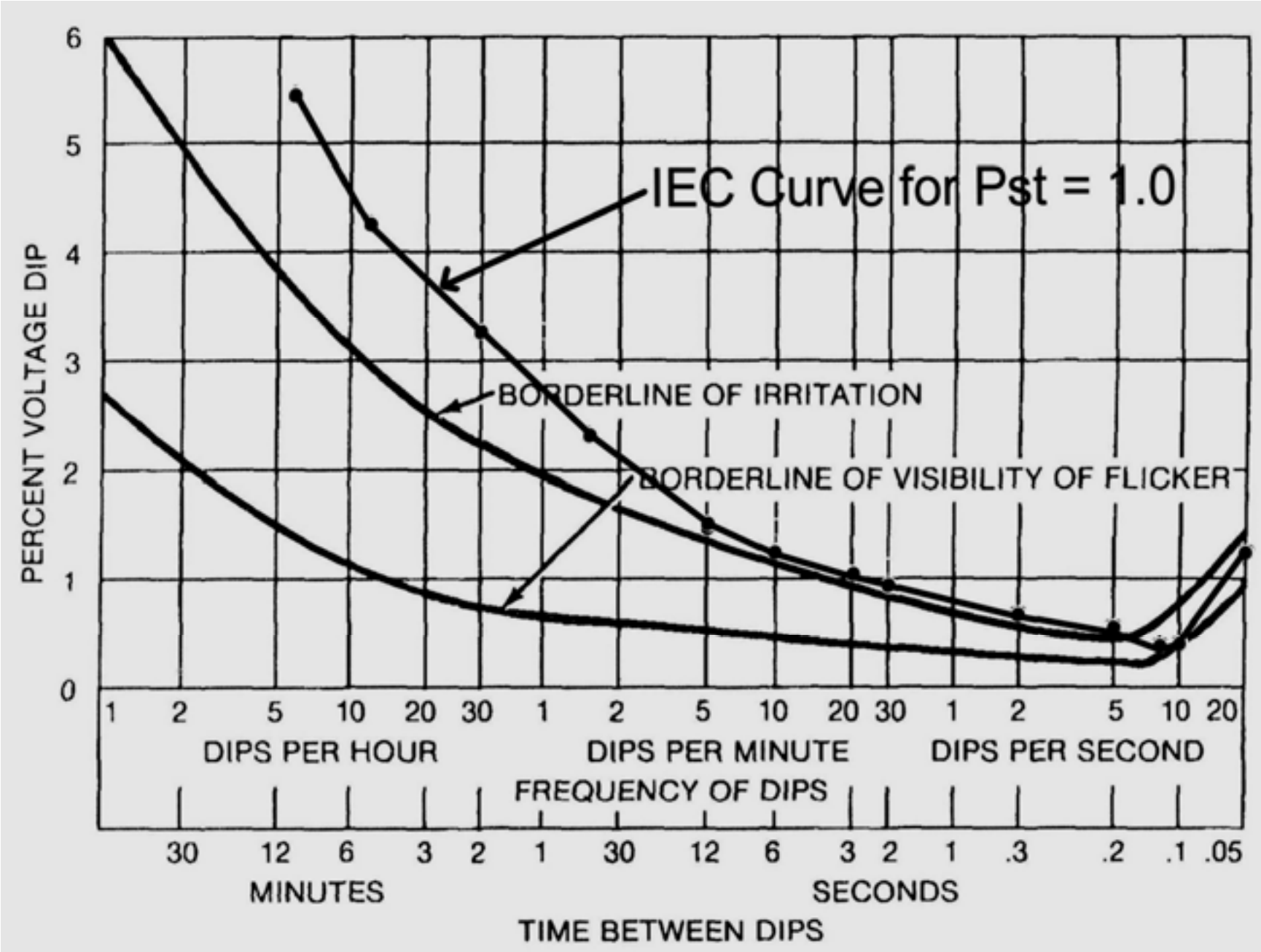
Reclosers Moved Downstream from Turbines

Interconnected with Fuses

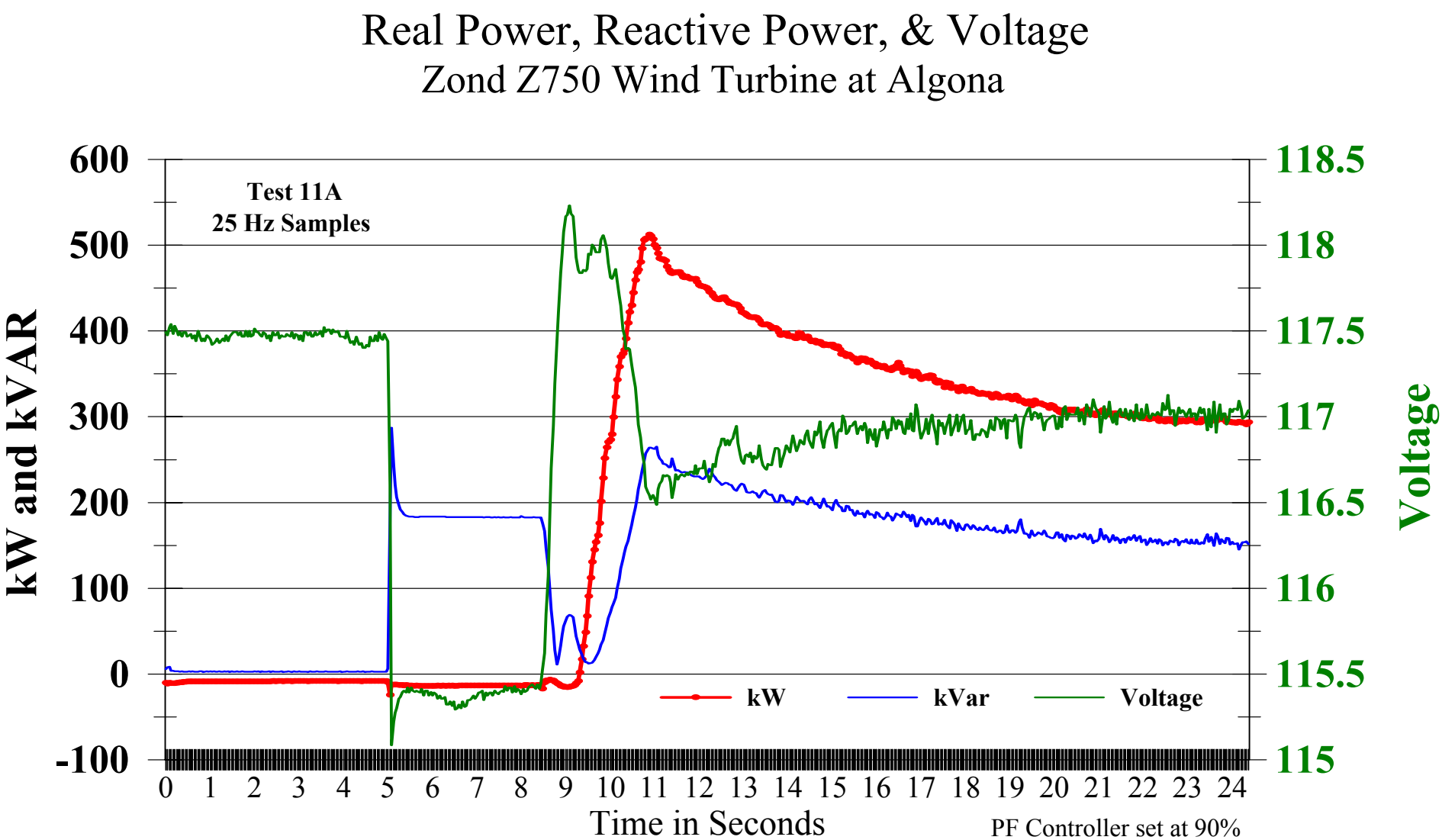
Transient Electrical Impacts

- During startup and generator switching, there will be inrush currents which will cause the voltage to dip or flicker
- Voltage flicker may or may not be noticeable or objectionable
  - Depends upon magnitude and how often it occurs
  - See IEEE Flicker Curve
  - Magnitude of flicker depends upon the stiffness of the line
    - Voltage level (4.16 kV, 12.5 kV, etc.)
    - Distance from substation
    - Size of substation transformer
    - Wind turbine electrical design.

IEEE & IEC Flicker Curves



Wind Turbine Startup at Algona, Iowa



Wind Turbine Transient Currents

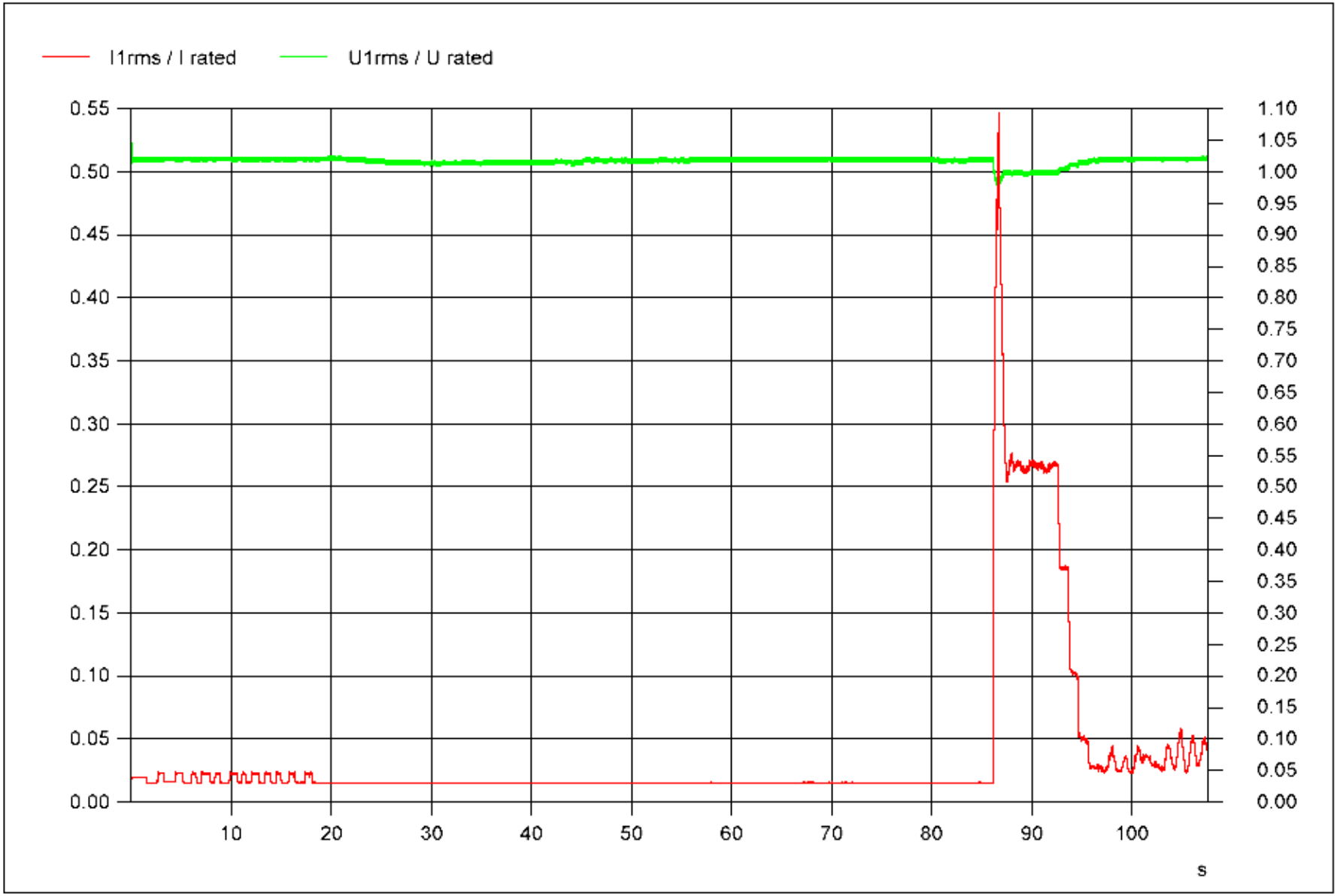


Figure 3.2.5 : Normalised rms-values for current and voltage against time for phase L1

Wind Turbine Transient Power

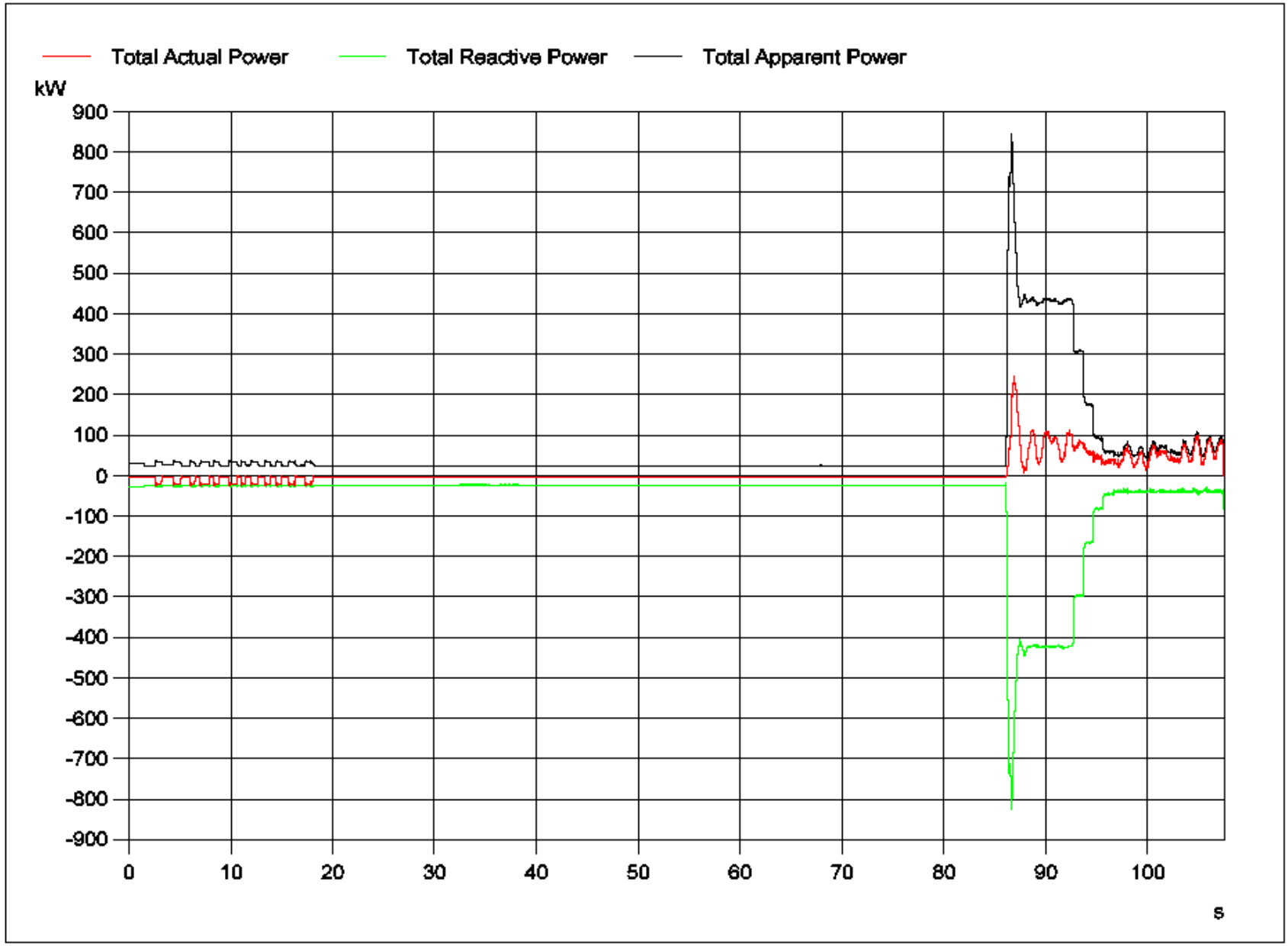
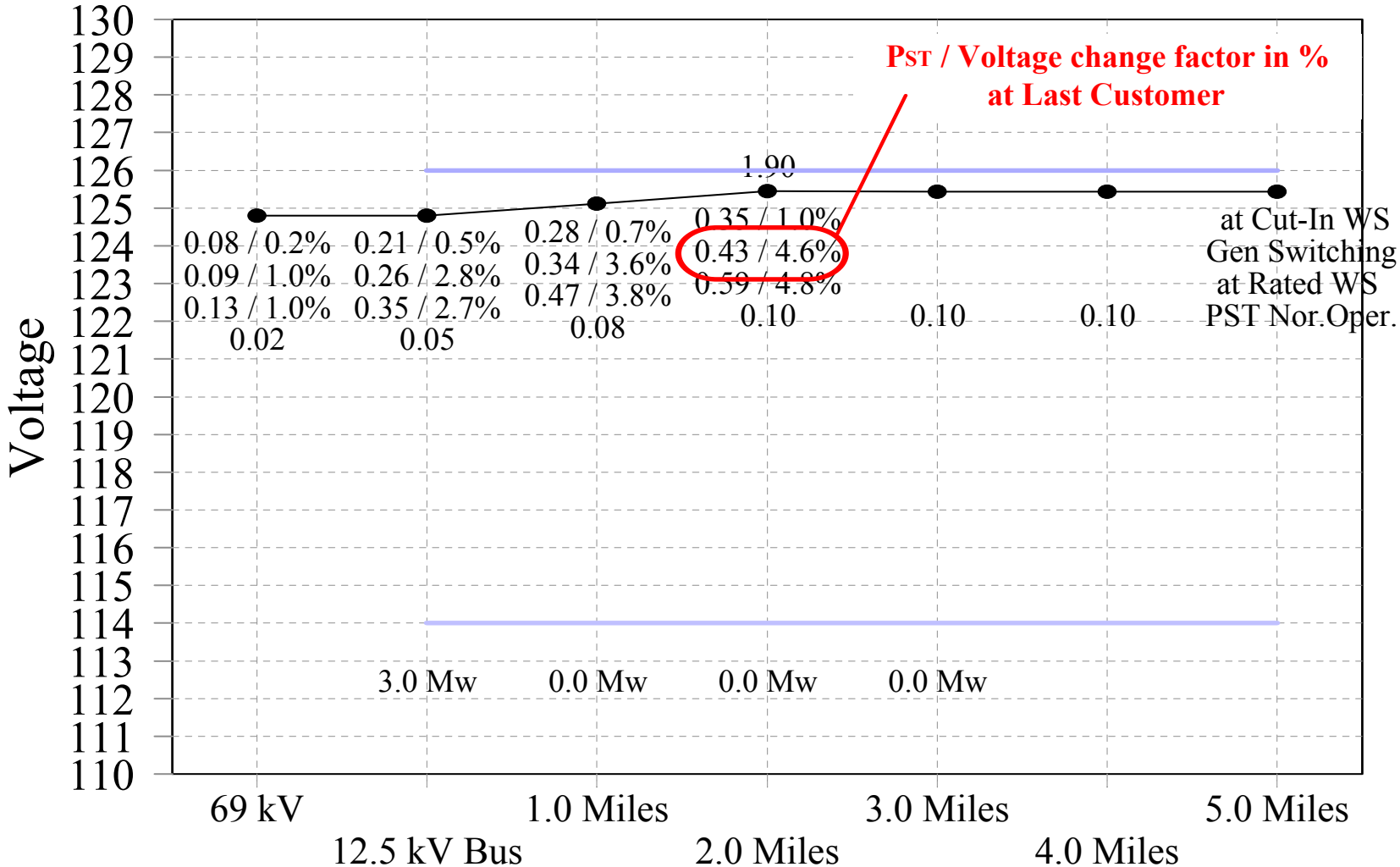


Figure 3.2.6 : Active, reactive and apparent power against time

Example of Flicker Evaluation

Proposed Site With 2 NEG-M 950 WTG
NEG-Micon 950 kW with 4/0 ACSR

Voltage Profile, Voltage Change & Flicker Disturbance Factors

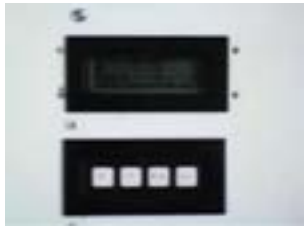


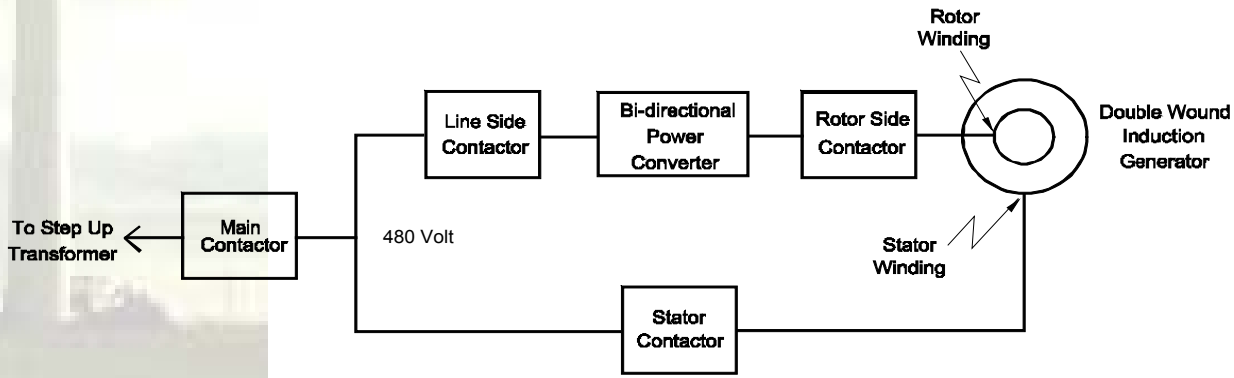
For IEC 61400-21 Data Format

Electrical Impacts (continued)

- During normal operation, changes in kW generation will change the voltage level on the feeder
- Its possible, but very unlikely, that gusty wind could change the kW output enough that it would cause the voltage level to change enough to be noticeable. To be noticeable, the following conditions would be needed:
  - Very weak grid, such as a 2.4 kV system, or a long distance from the substation
  - A combination of wire size and distance from substation
  - A wind turbine with a high flicker characteristic

Three 750 kW Wind Turbines Designed to Regulate Power Factor Connected to 13.8 kV 1/0 ACSR Rural Feeder at Algona

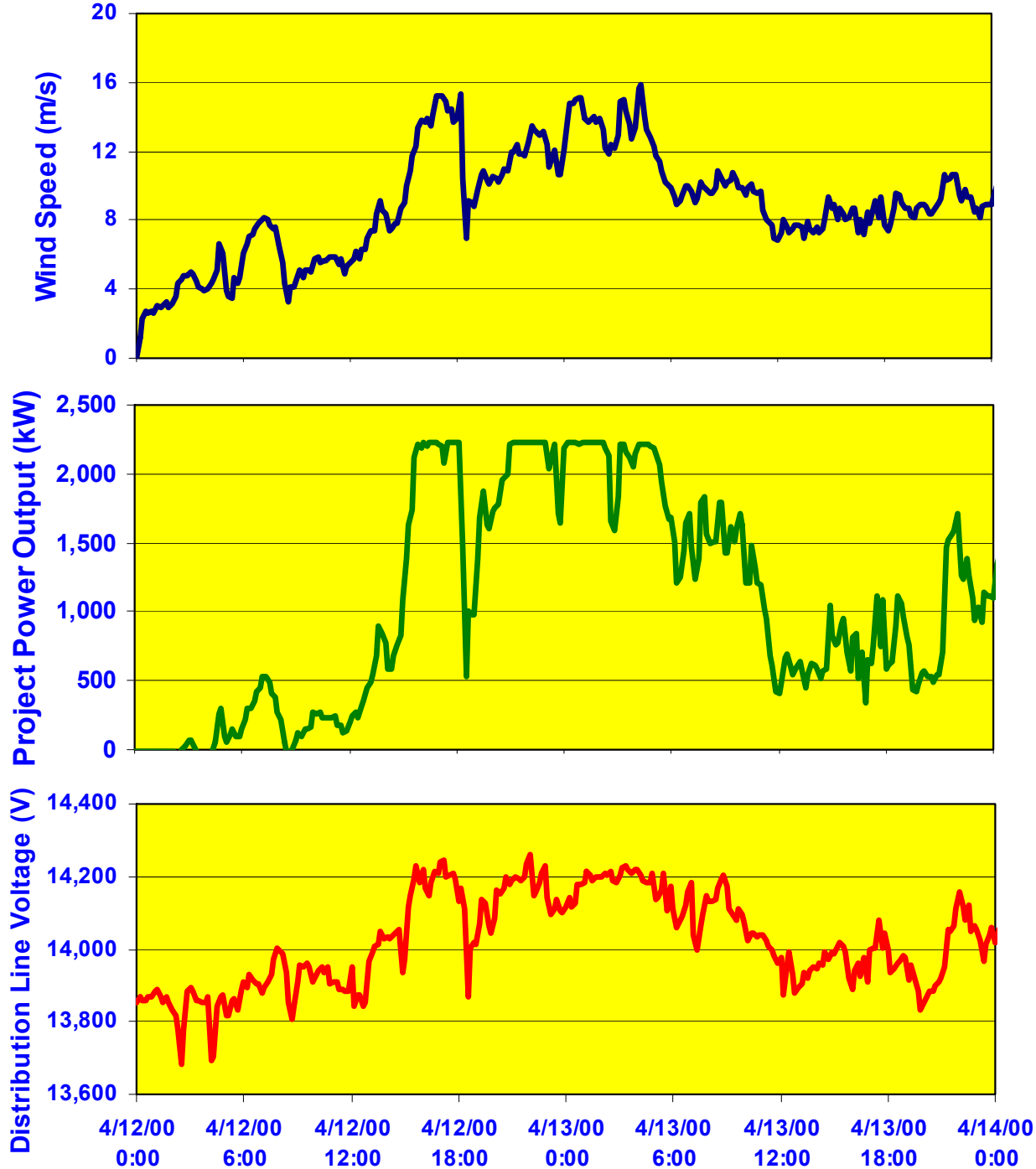




Wind Speed

Power Output

Distribution Line Voltage



Summary of Interconnection Issues

- Wind turbines are relatively easy to interconnect to the distribution system
- Modern large wind turbines have very sensitive controls that trip the wind turbine off line for any disturbances
- Coordination of relay settings and fuses should be checked when a large wind turbine is added
- Since large wind turbines can cause noticeable voltage flicker in some cases, an evaluation should be made for each installation
- Large wind turbines can potentially cause above normal voltage levels on feeders

Distributed Wind Generation Case Study

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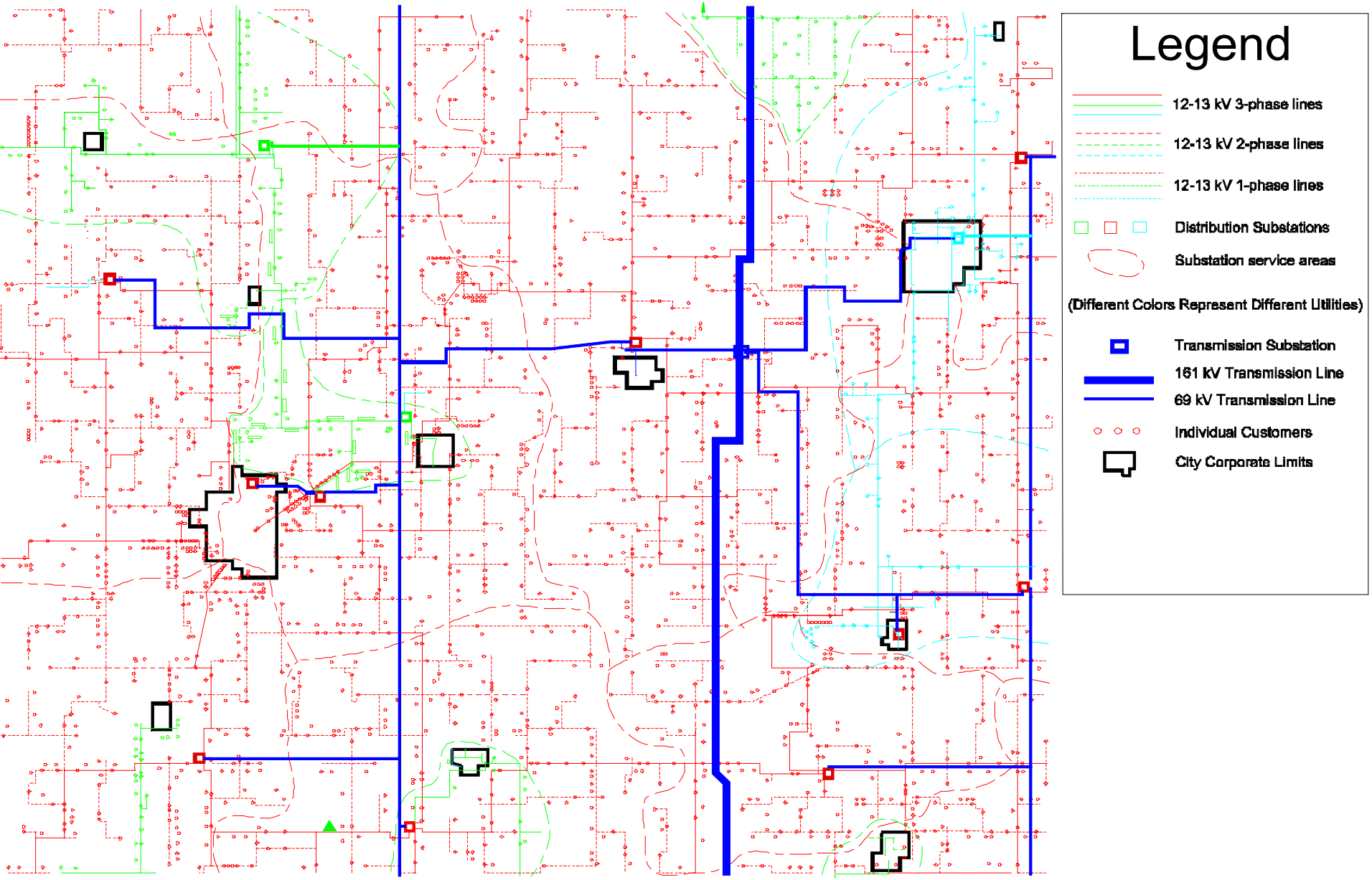
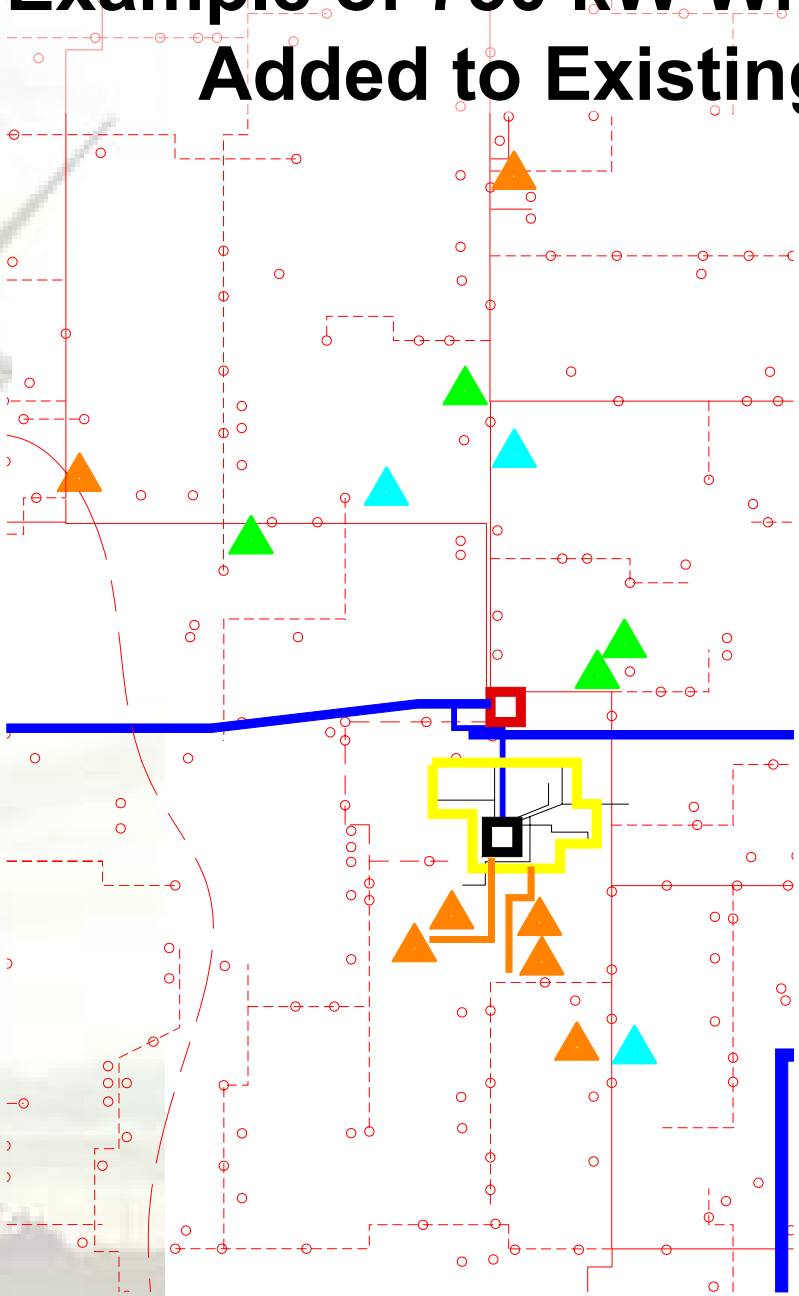
Case Study in Iowa

- Distributed Wind Power Assessment
- Sponsored by the National Wind Coordinating Committee
  - Princeton Energy Resources International
  - Wind Utility Consulting
- Case study in Iowa to determine how many wind turbines could be connected to the existing distribution system in an area
- 750 square mile area in Iowa

All Electric Lines and Rural Consumers in Study Area



Example of 750 kW Wind Turbines Added to Existing Lines

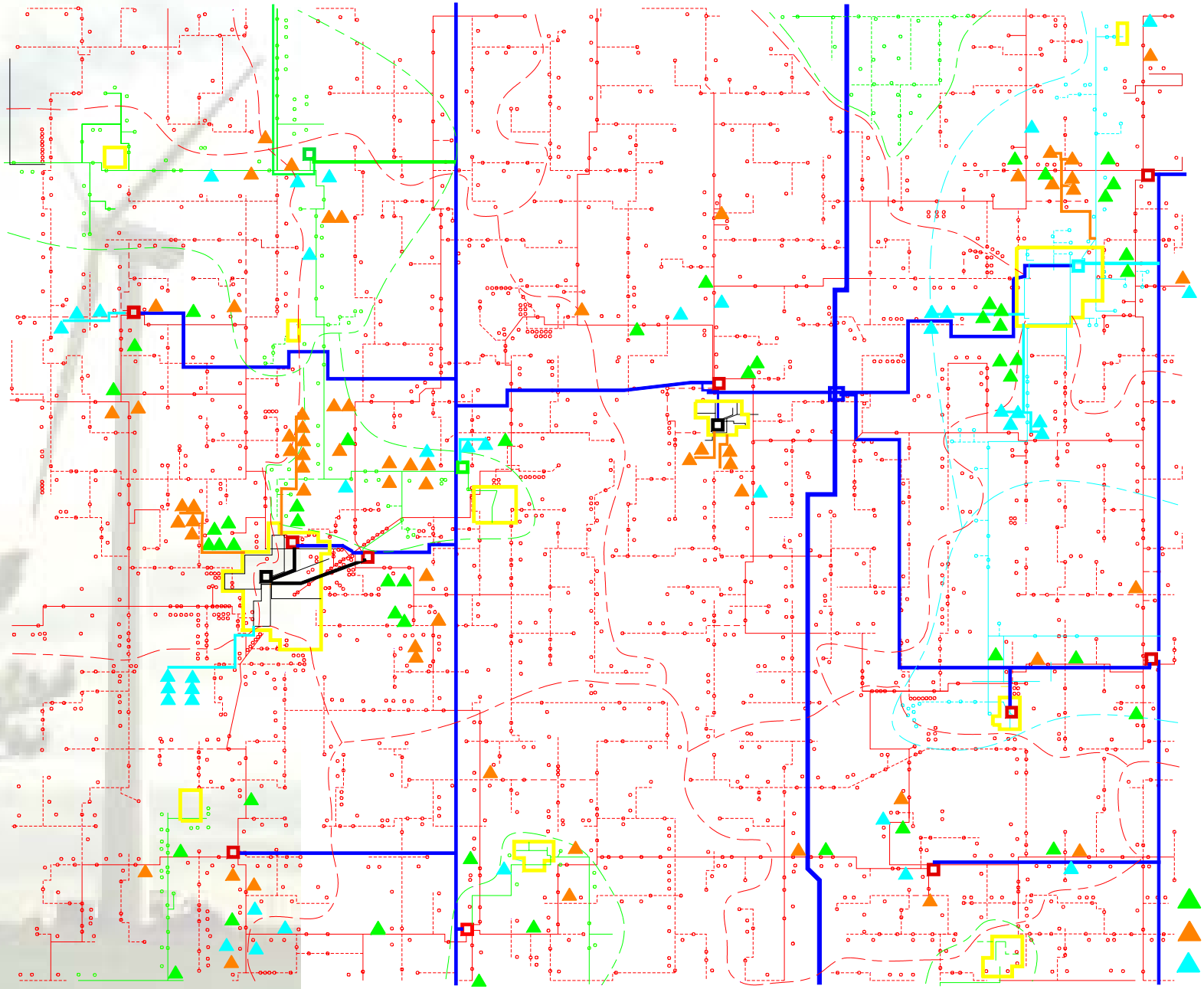


Level 1

Level 2

Level 3

750 kW Wind Turbines Added in Entire Area

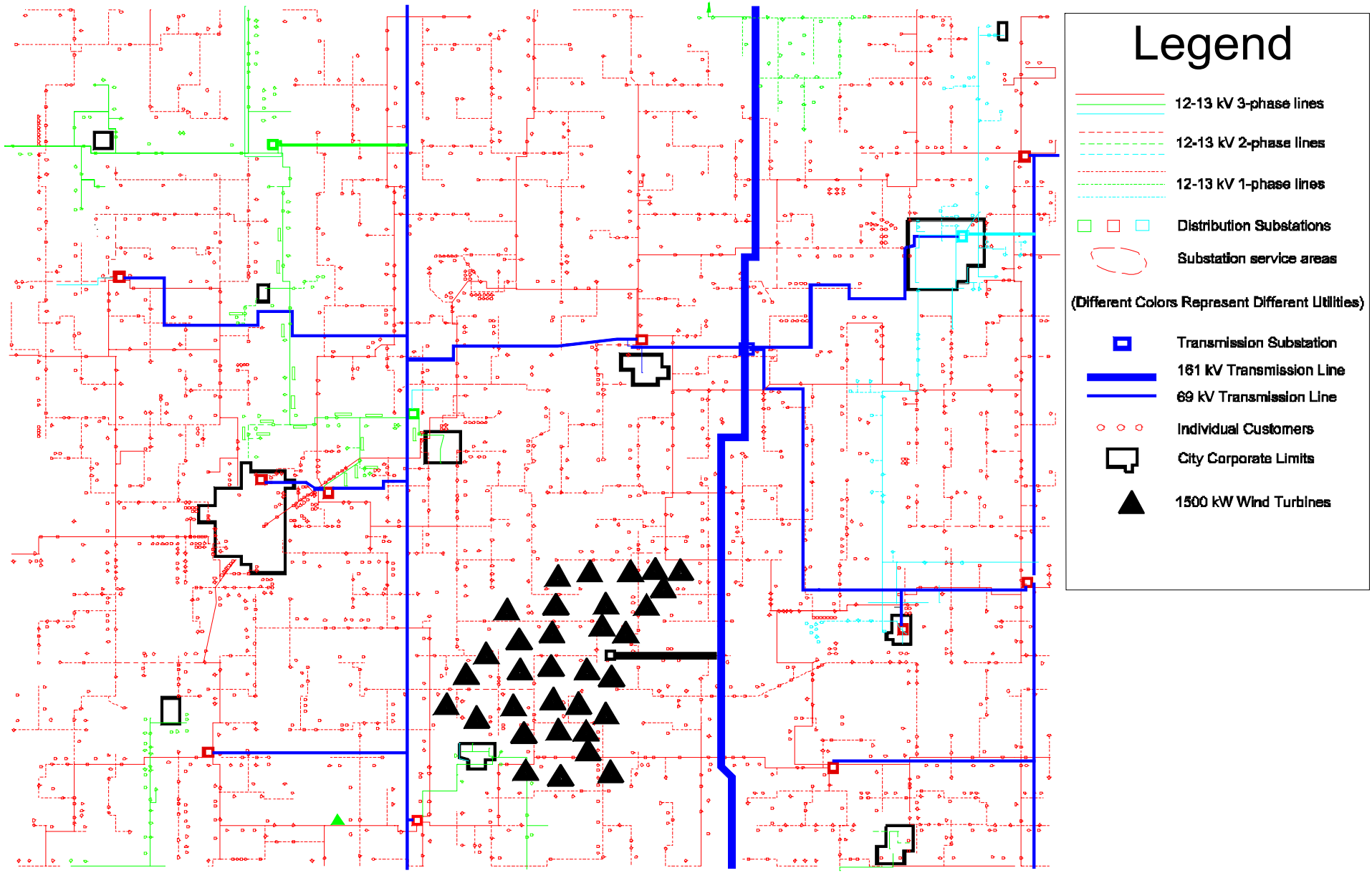


Summary of Number of Wind Turbines Added and the Cost of Interconnection

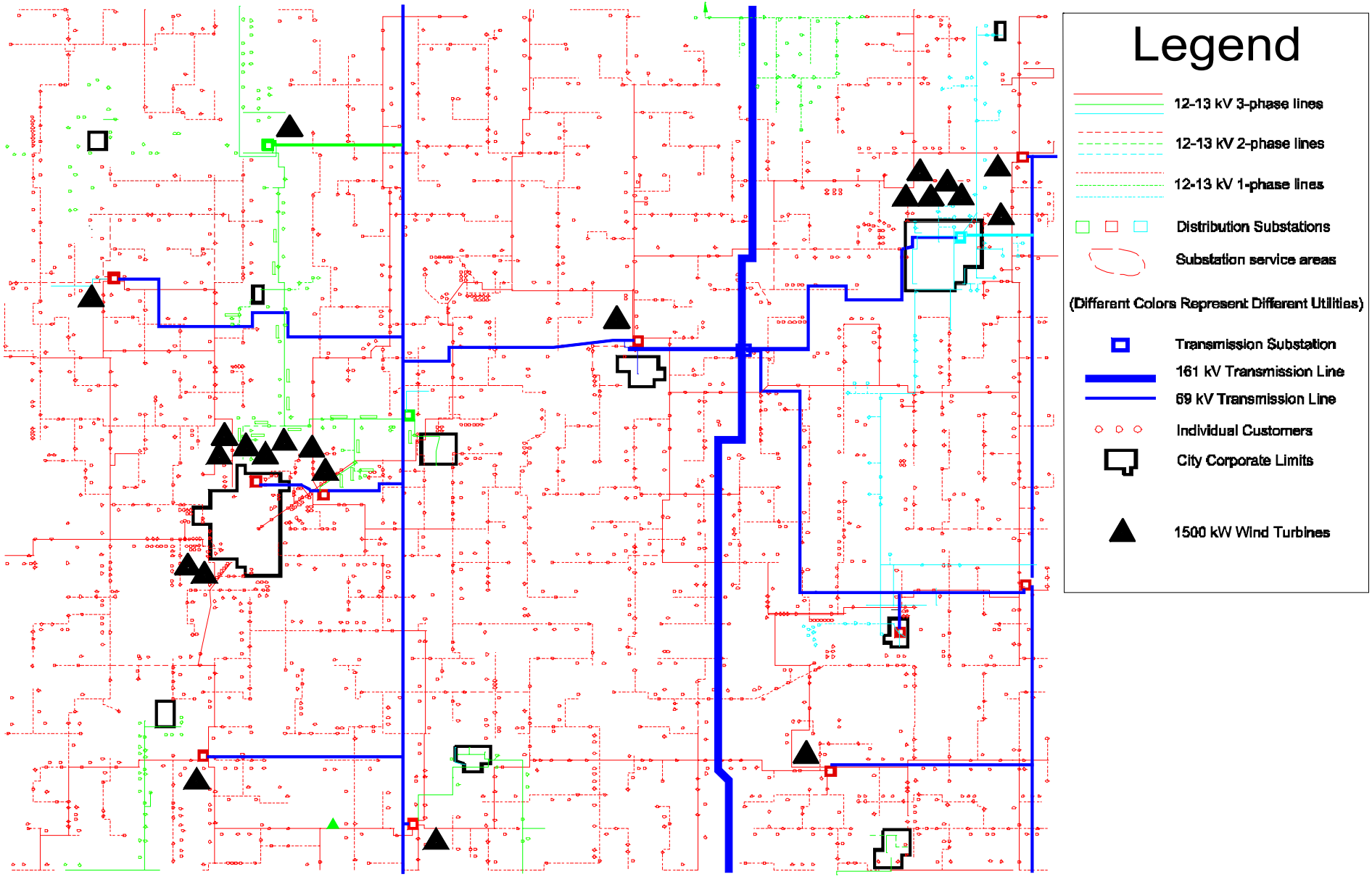
Cost of Distribution System Reinforcements for Added Wind Generation						
Penetration Level	750 kW Turbines Added		Range of Reinforcement Costs in $/kW			Cumulative Average Cost
	Number	MW	Minimum	Maximum	Average	
Level I	48	36.00	$2	$20	$5	$5
Level II	62	46.50	$27	$105	$61	$36
Level III	41	30.75	$38	$178	$115	$58
Totals	151	113.25				

This amount of wind generation will produce on average twice as much electricity as the study area uses over the year

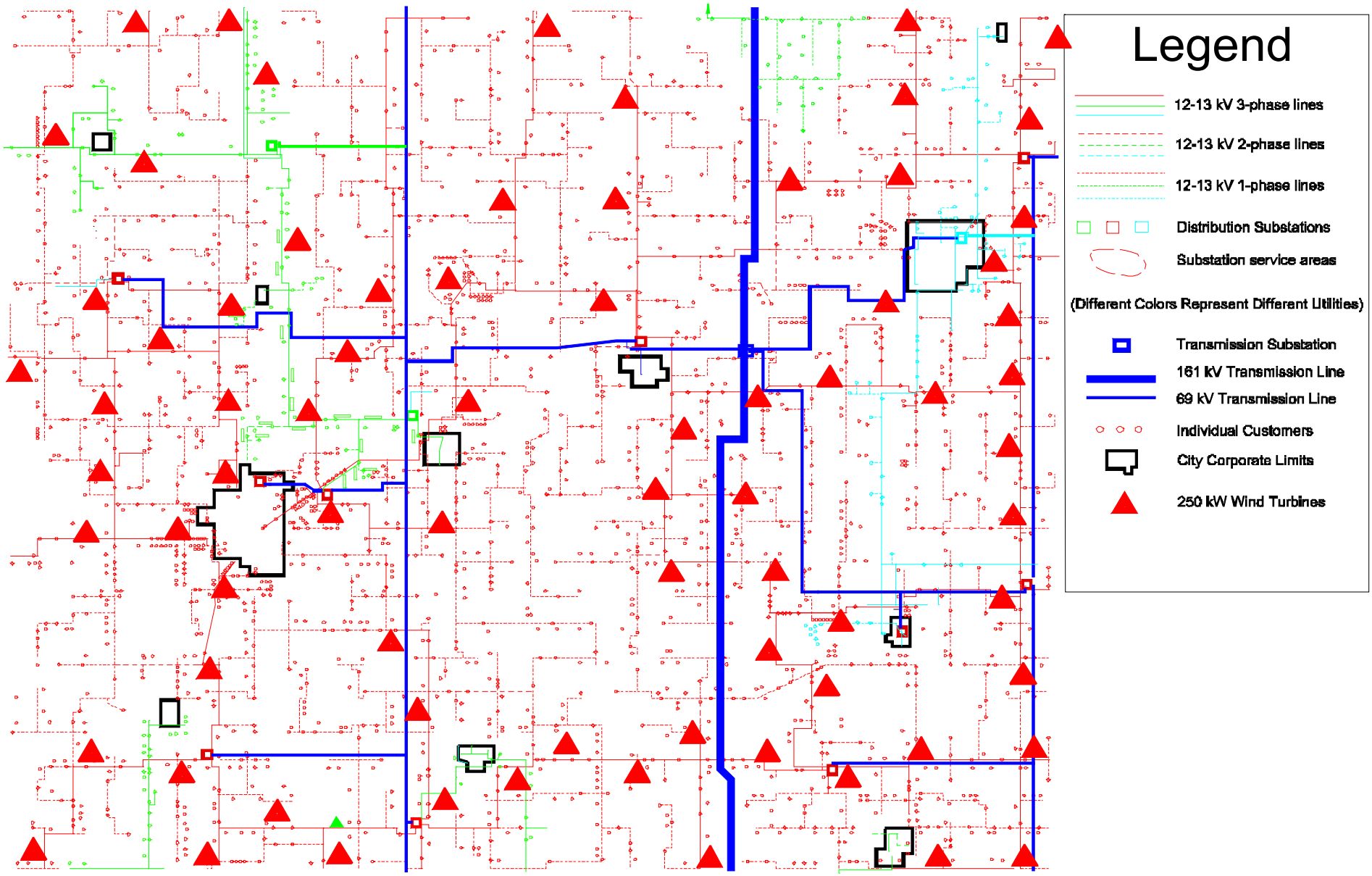
Potential 50 MW Wind Farm Using 33 1,500 kW Wind Turbines



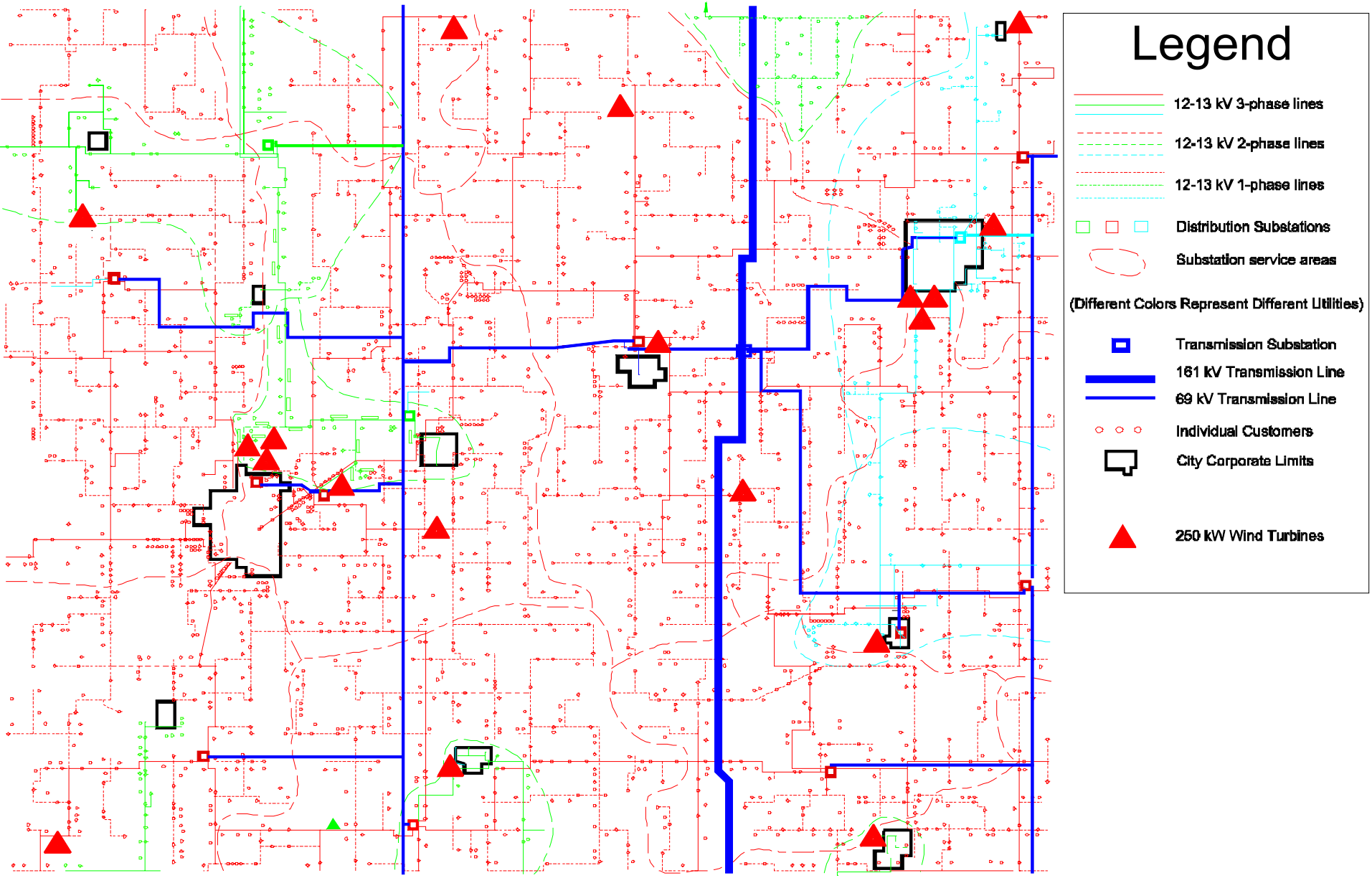
General Locations Where 1,500 kW Wind Turbines Can be Connected to the Existing Distribution System



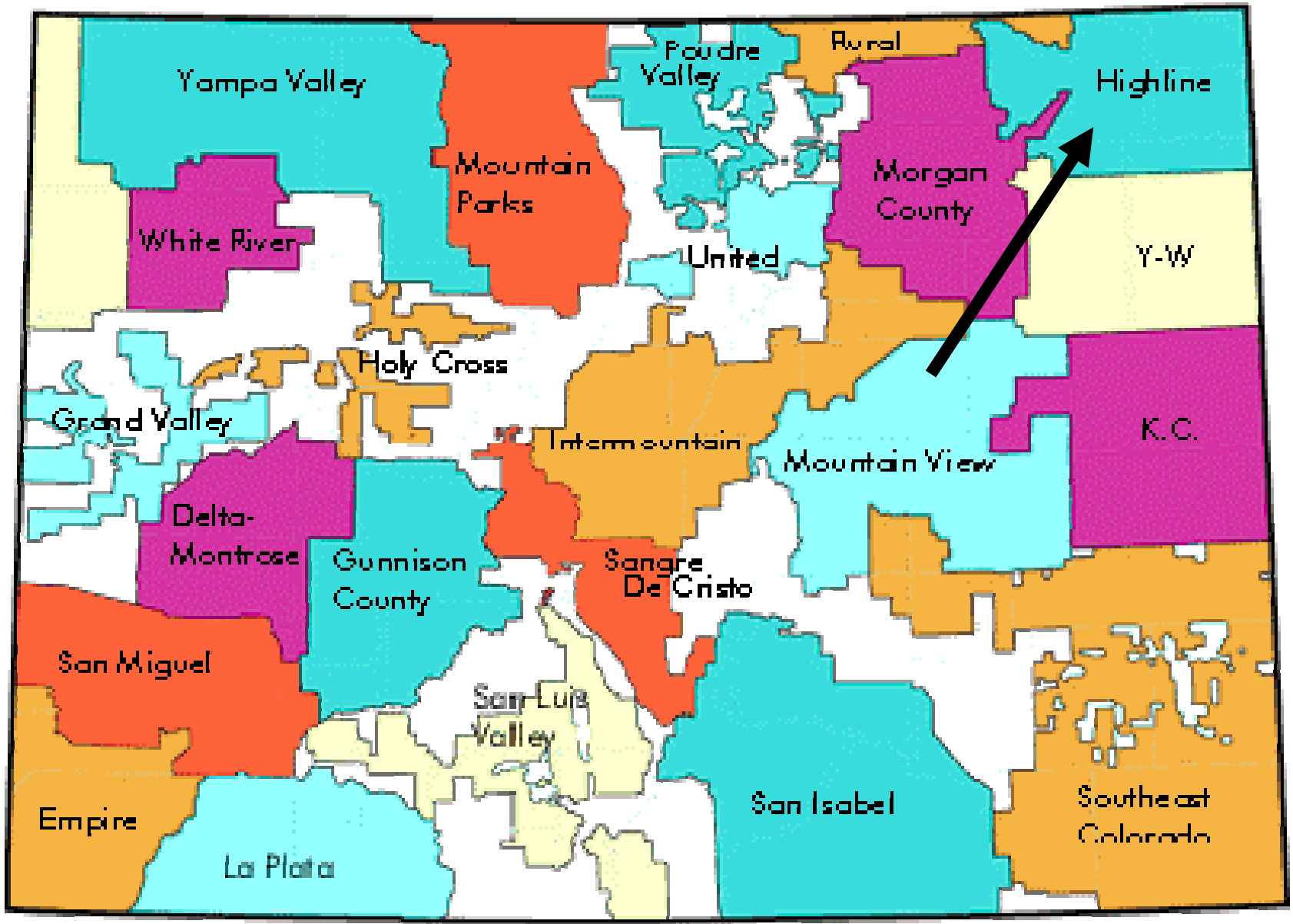
General Locations Where 250 kW Wind Turbines Can be Connected to the Existing Distribution System



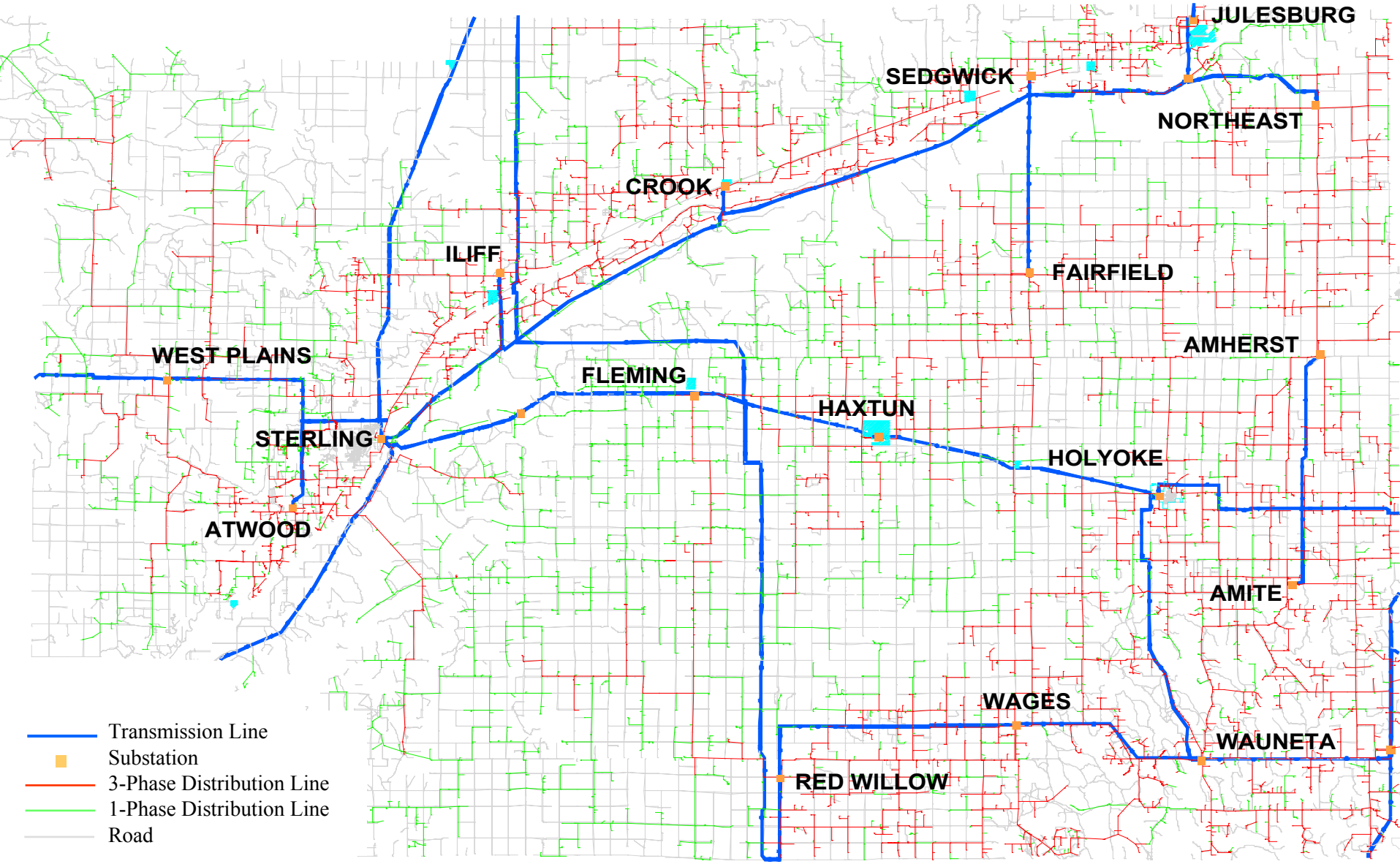
Potential Locations Where 250 kW Wind Turbines Can be Connected and Used to Serve Customers' Own Needs



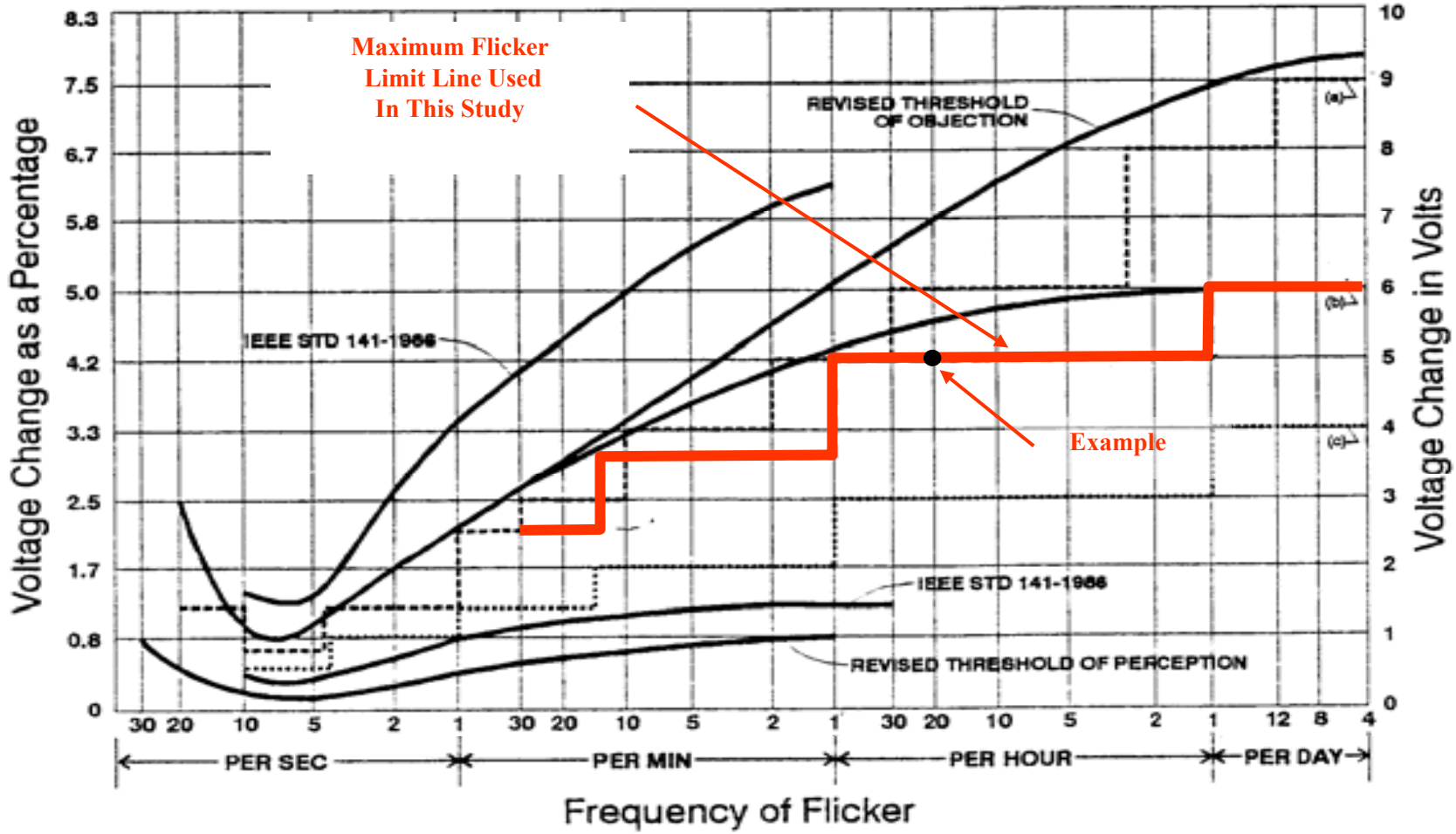
A Similar Study Was Completed for a Cooperative in Colorado
Highline Electric Association Electric Cooperatives



Map of HEA Facilities in Colorado with Names of Substations Evaluated in CO Study

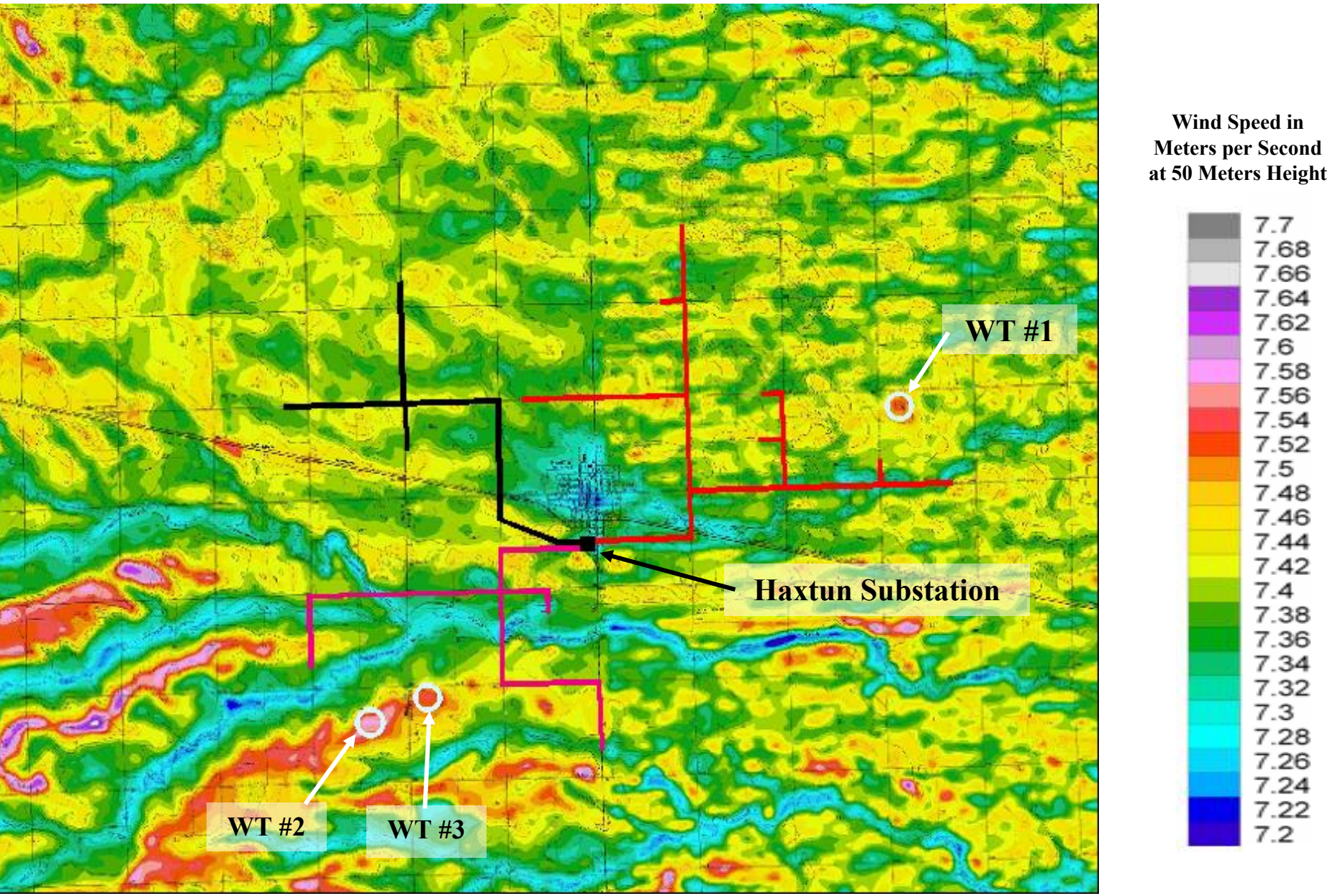


Flicker Guidelines Used by Highline Electric Association in CO

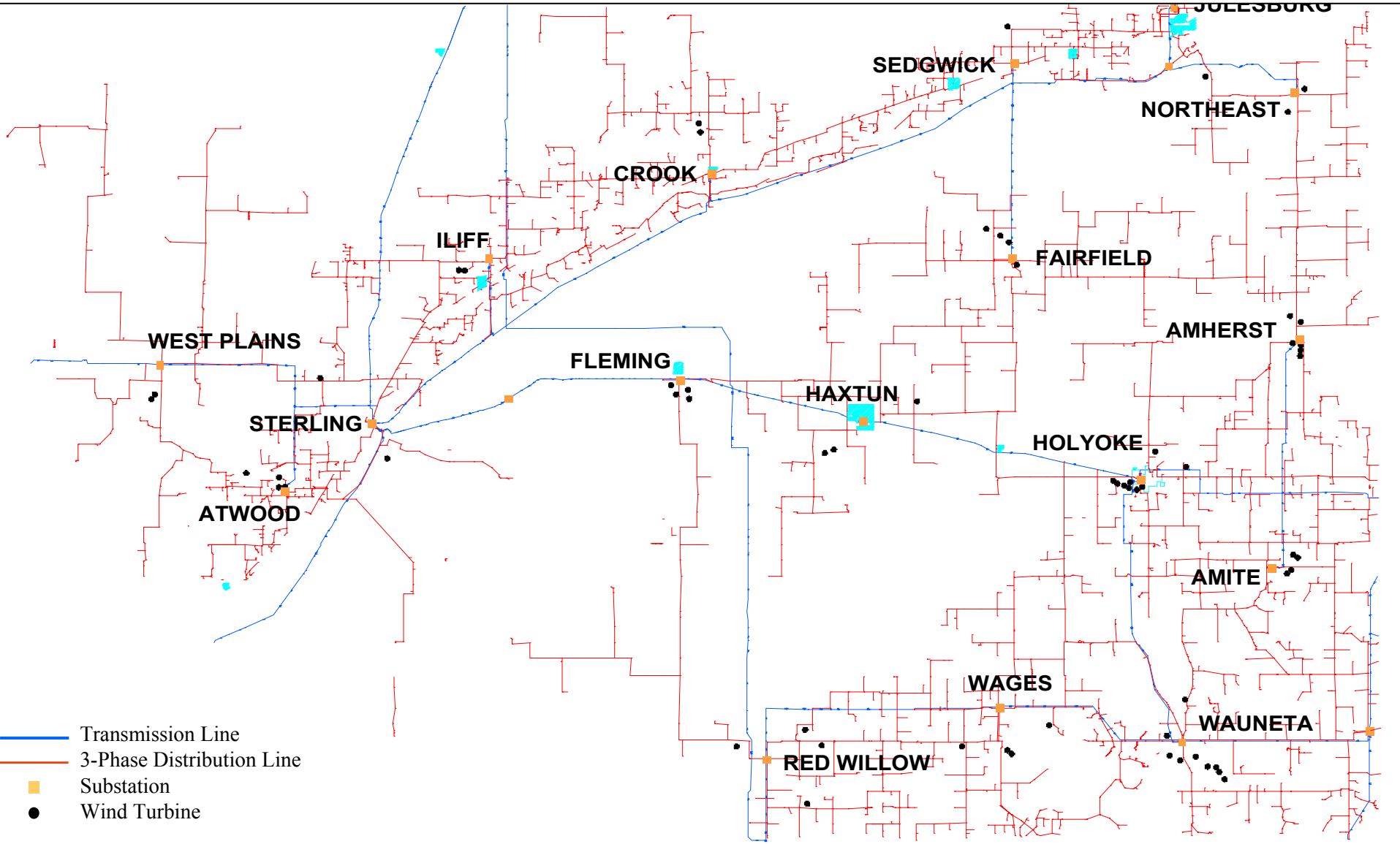


(a) REVISED FLICKER LIMITS FOR INSTALLATIONS (1-PH LINE OR INDIVIDUAL SERVICE)
(b) FLICKER LIMITS FOR INSTALLATIONS SERVING FEW CUSTOMERS
(c) FLICKER LIMITS FOR INSTALLATIONS SERVING MANY CUSTOMERS

Wind Speed Map Showing Turbine Locations that Can Be Connected to the Haxtun Substation Grid



Map showing HEA Substations, 3-Phase Feeders, and Potential Locations of the Maximum Number of Wind Turbines That Can be Interconnected Without System Reinforcements



Summary of Results from Distributed Generation Study for Highline Electric Cooperative in Colorado

		Scenario 1	Scenario 2		Scenario 3
Substation Name	Substation Transformer MVA Rating	Farthest Distance in Miles from Substation	Most Number of Turbines	Limiting Factor	Potential Distribution System Reinforcement Options to Allow More Wind Turbines to be Connected to the Existing Distribution System
Amherst	14.0	5.4	6	Flicker	Dedicated collection line to a windy area
Amitie	14.0	5.5	4	Flicker	Dedicated collection line to a windy area
Atwood	7.0	4.2	4	Transformer	Larger transformer
Crook	7.0	5.1	2	Poor Wind	Two 1-mile Line extensions to windier sites would allow 2 more turbines
Fairfield	14.0	5.0	4	Flicker	Dedicated collection line to a windy area
Fleming	7.0	4.0	4	Transformer	Larger transformer
Haxtun	7.0	4.8	3	Flicker	Dedicated collection line to a windy area
Holyoke	14.0	6.6	9	Transformer	Larger transformer and dedicated collection line
Iliff	7.0	5.2	2	Poor Wind	Two 1-mile Line extensions to windier sites would allow 2 more turbines
Julesburg	10.5	4.3	0	Poor Wind 1	A line extension would allow 2 turbines to be added.
Northeast	10.5	5.8	3	Flicker	Dedicated collection line to a windy area
Red Willow	14.0	5.5	4	Flicker	Dedicated collection line to a windy area
Sedgwick	5.3	2.8	1	Flicker	Dedicated collection line to a windy area
Sterling	7.0	6.5	2	Flicker	Dedicated collection line to a windy area
Wages	22.4	6.4	4	Flicker	Dedicated collection line to a windy area
Wauneta	22.4	7.0	9	Flicker	Dedicated collection line to a windy area
West Plains	3.8	3.3	2	Transformer	Larger transformer
Total Number of 1.5 Mw Turbines Added …..			63		

Notes: 1 - Since wind speeds are so much better on the higher ridges beyond the exsiting distribution lines, it was assumed no wind turbines would be connected to the existing distribution grid at Julesburg unless line extensions of at least one mile in length were constructed. This length exceeded the 1/2 mile limit set in the study.

Connecting Wind Generation to the Transmission Grid

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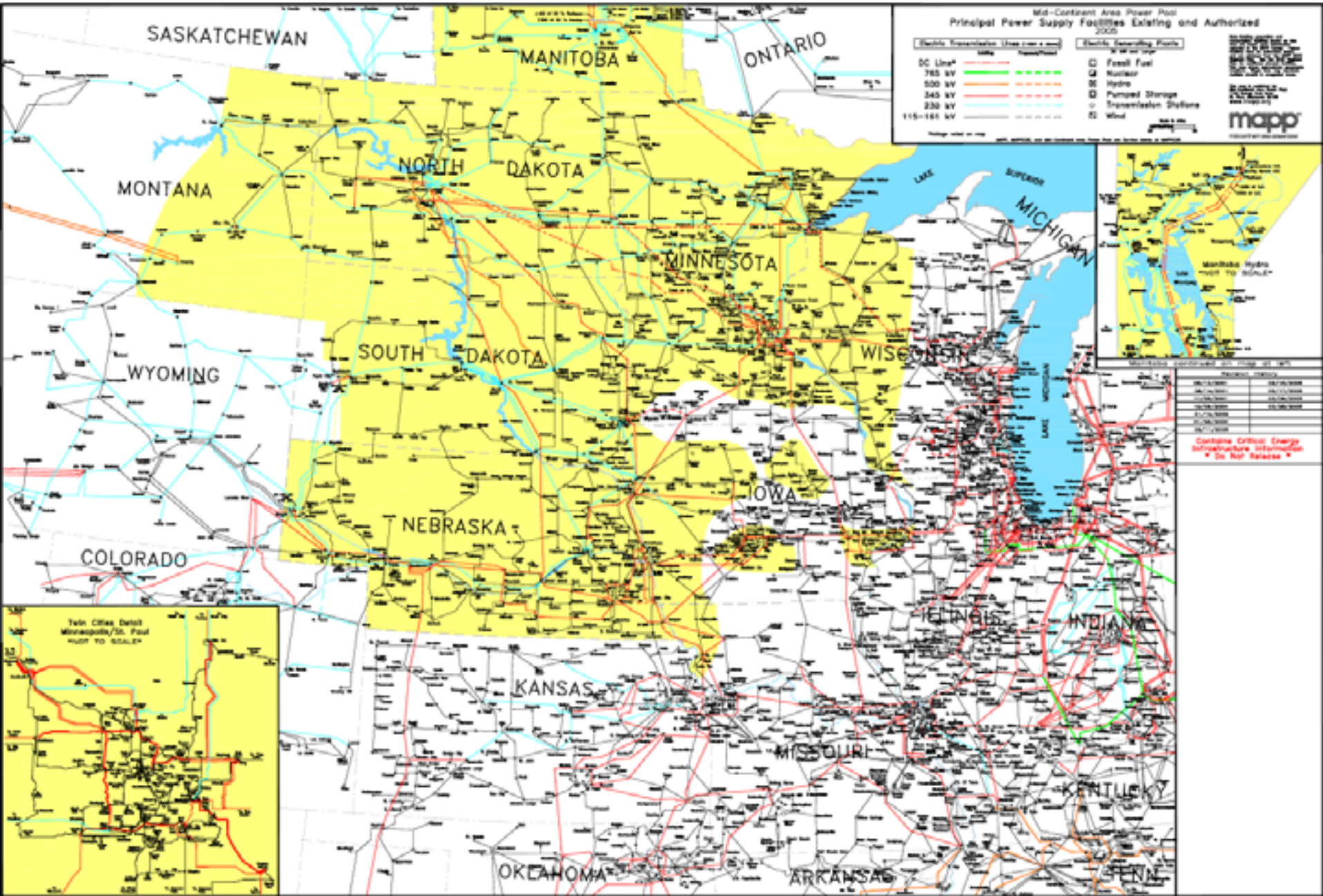
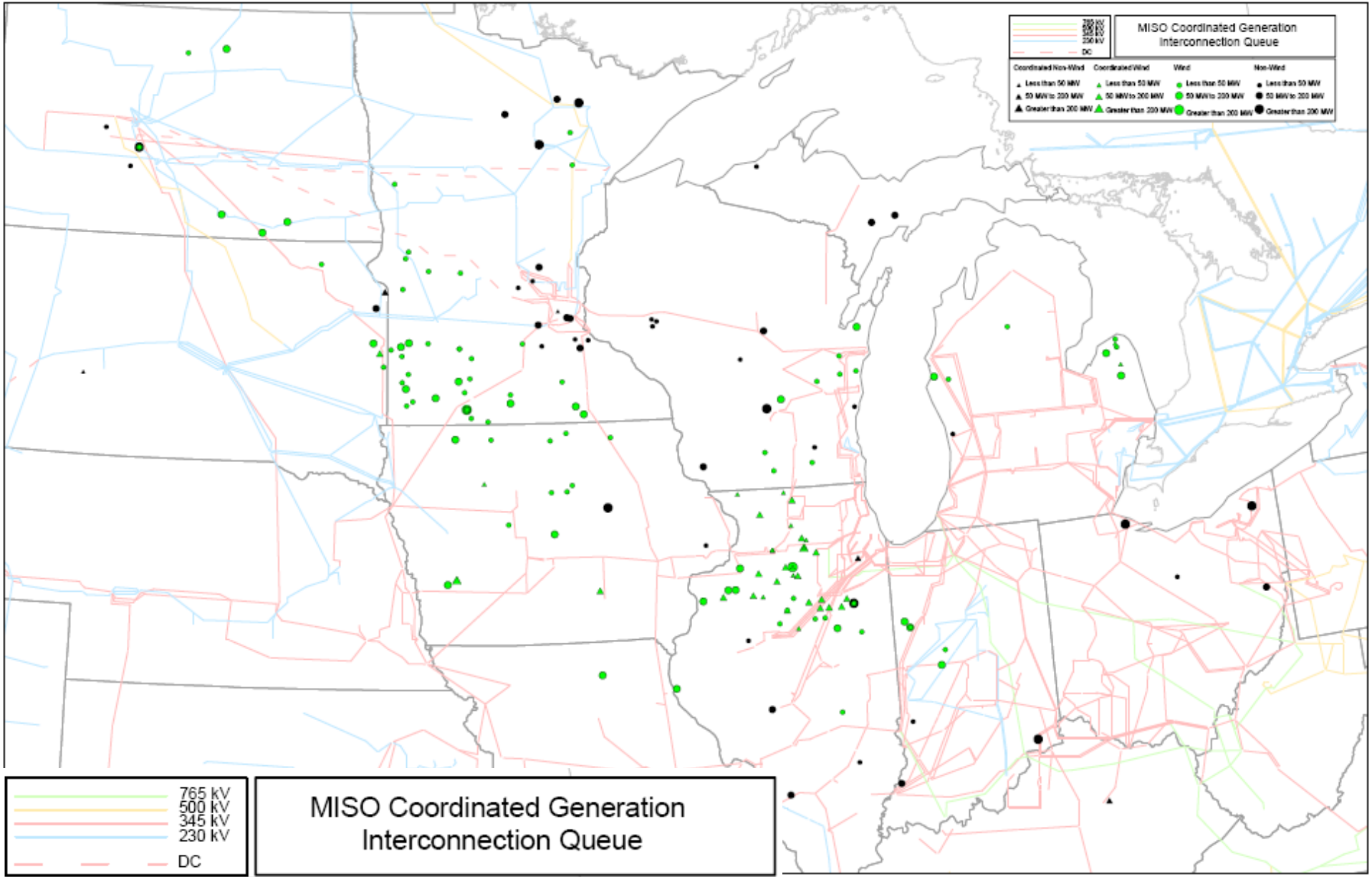
The Transmission Grid is a Complex Web



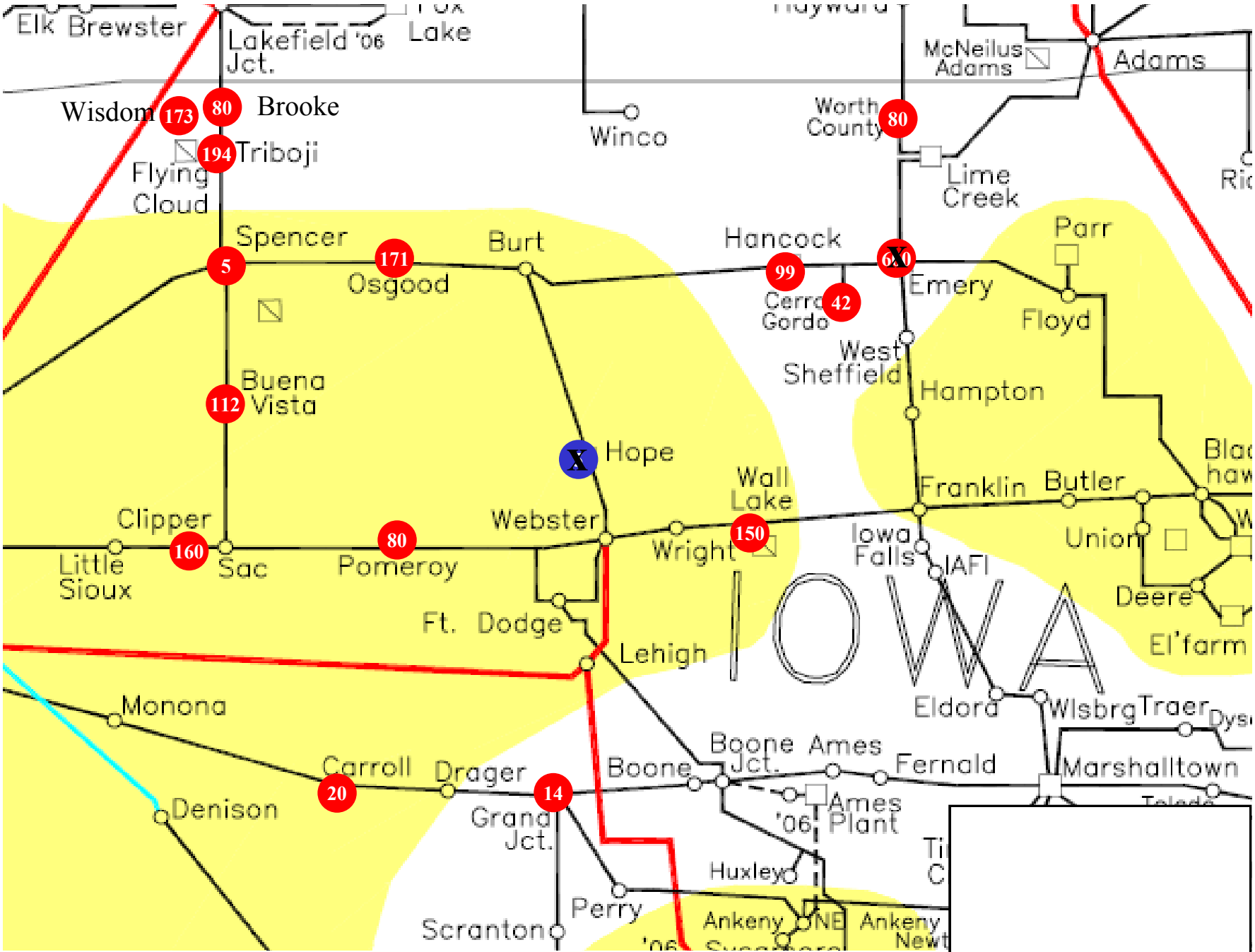


765 kV
500 kV
345 kV
230 kV
DC

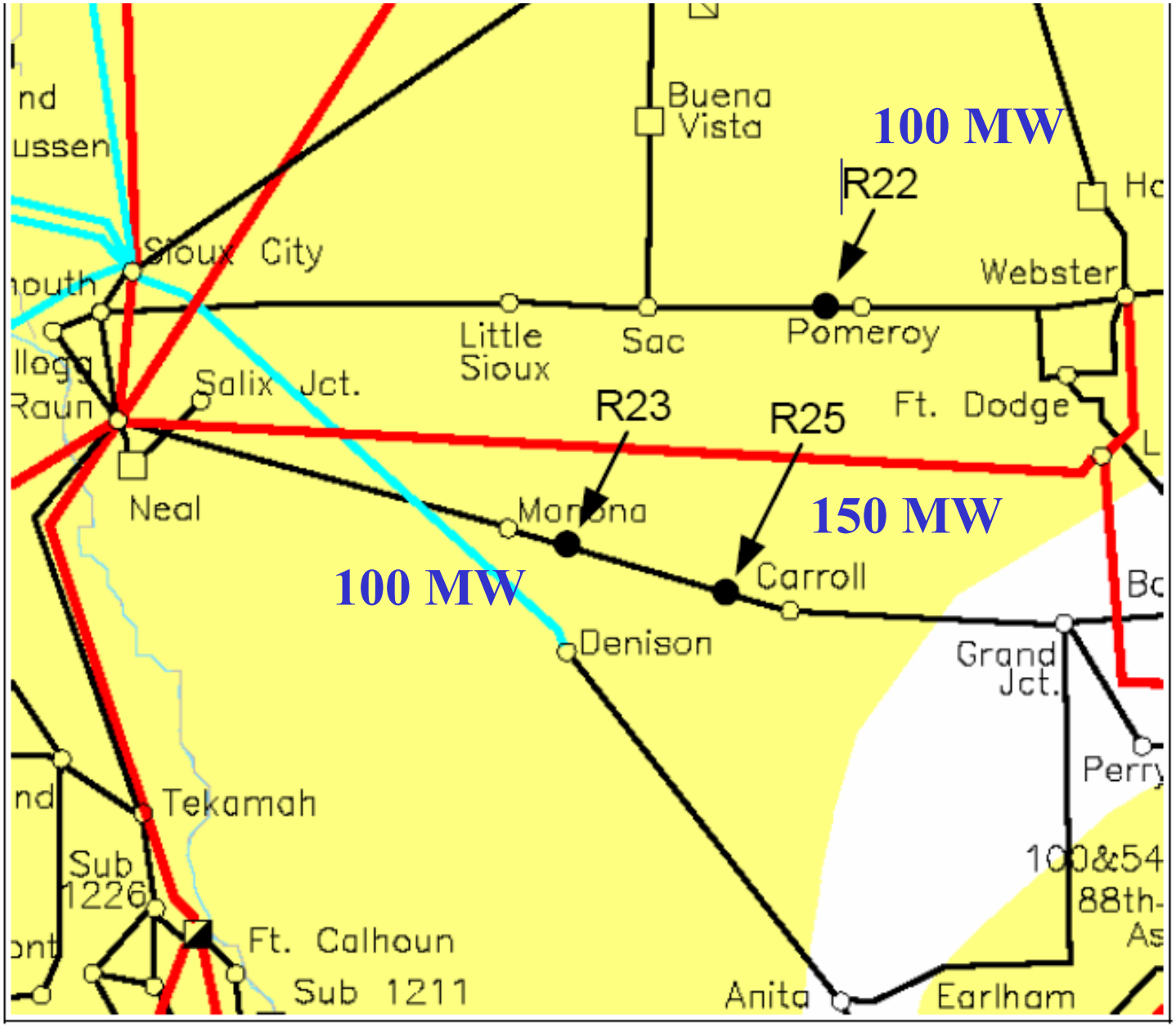
MISO Coordinated Generation Interconnection Queue

Coordinated Non-Wind	Coordinated Wind	Wind	Non-Wind
Less than 50 MW	Less than 50 MW	Less than 50 MW	Less than 50 MW
50 MW to 200 MW	50 MW to 200 MW	50 MW to 200 MW	50 MW to 200 MW
Greater than 200 MW	Greater than 200 MW	Greater than 200 MW	Greater than 200 MW

Wind Generation in Iowa



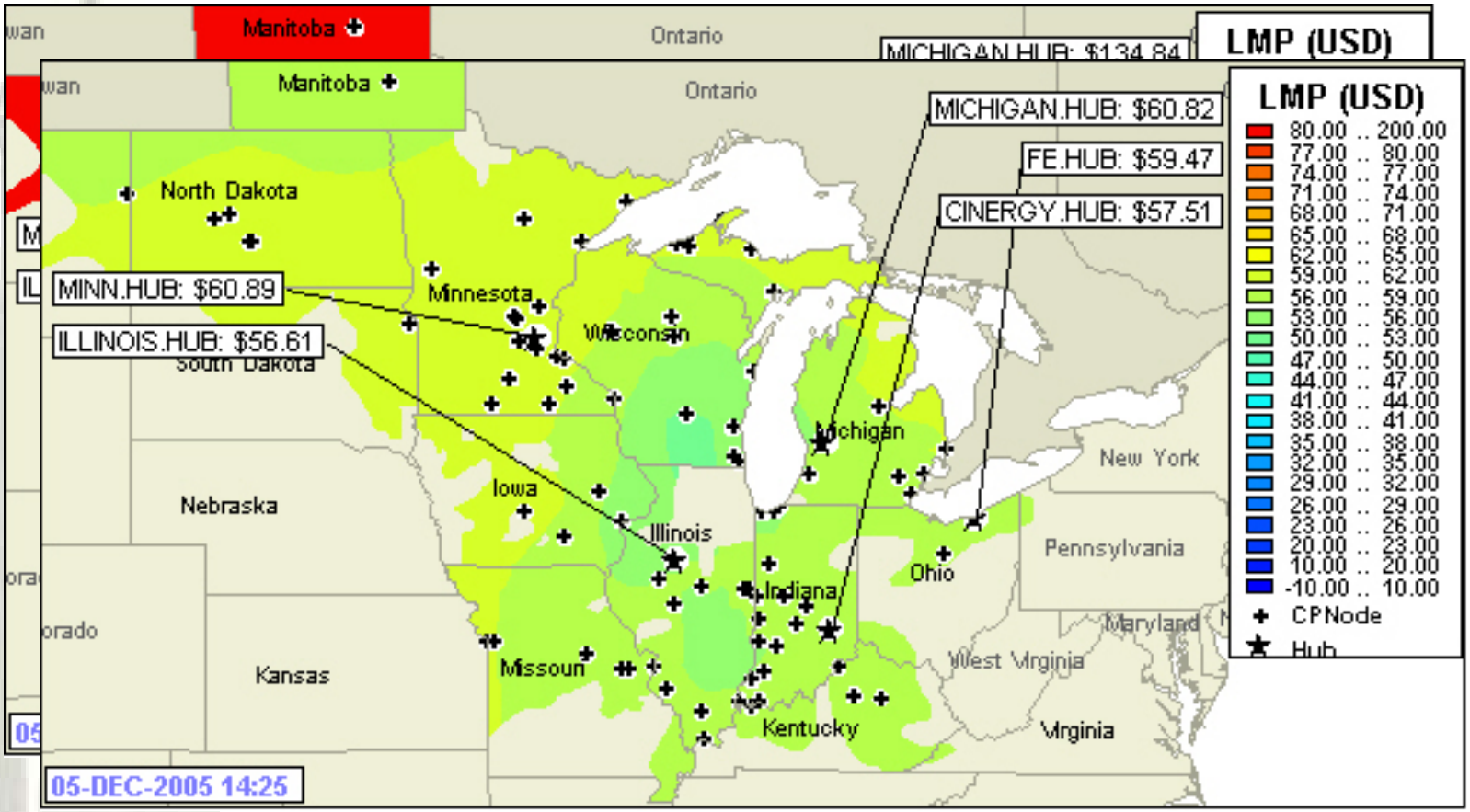
Recent Proposal by MidAmerican Energy in Iowa to Add 350 MW of New Wind Generation in Western Iowa to the Existing 161 kV Grid



Network Upgrades Required to Accommodate 350 MW of New Wind Generation in Iowa Connected to Existing 161 kV Grid

2.4 WIGG Network Upgrades

Based on preliminary analysis of the WIGG projects the study group identified the network upgrades listed below. Power flow cases that include the WIGG projects include the following network upgrades:

- Carroll-Drager 161 kV: raise structures to achieve 245 MVA rating
- Monona-R23 161 kV: raise structures to achieve 260 MVA rating
- Hinners-Carroll 161 kV: raise structures to achieve 260 MVA rating
- Pomeroy-Hayes 161 kV: raise structures to achieve 224 MVA rating
- Franklin-Butler raise 161 kV: raise structures to achieve 195 MVA rating
- Wall Lake-Franklin 161 kV: raise structures to achieve 200 MVA rating
- Butler-Union 161 kV: raise structures to achieve 185 MVA rating
- Little Sioux-Sac Wind 161 kV: raise structures to achieve to 205 MVA
- Replace Monona 161-69 kV Xfmr with 83.3 MVA unit with a 69 kV series reactor
- Add 2nd Carroll 161-69 kV Xfmr
- Add Monona 69 kV 20 Mvar shunt capacitor
- Rebuild Carroll-Carroll S 69 kV: 5.1 miles of T2-4/0 ACSR to achieve 125 MVA rating
- Rebuild Carroll S-Toyne 69 kV: 9 miles of T2-4/0 ACSR to achieve 125 MVA rating
- Drager-Grand Junction 161 kV: raise structures to achieve 180 MVA rating
- Neal-Monona 161 kV: raise structures to achieve 240 MVA rating
- Little Sioux – Sac Wind 161 kV: raise structures to achieve 224 MVA rating
- Buena Vista – Sac 161 kV: replace current transformer to achieve a 223 MVA rating
- Sub KFD – Hayes 69 kV: Re-conductor 1 mile of line to achieve 143 MVA rating

Wholesale Electric Market Prices on the Grid Have Been High Recently This is Driven New Wind Projects