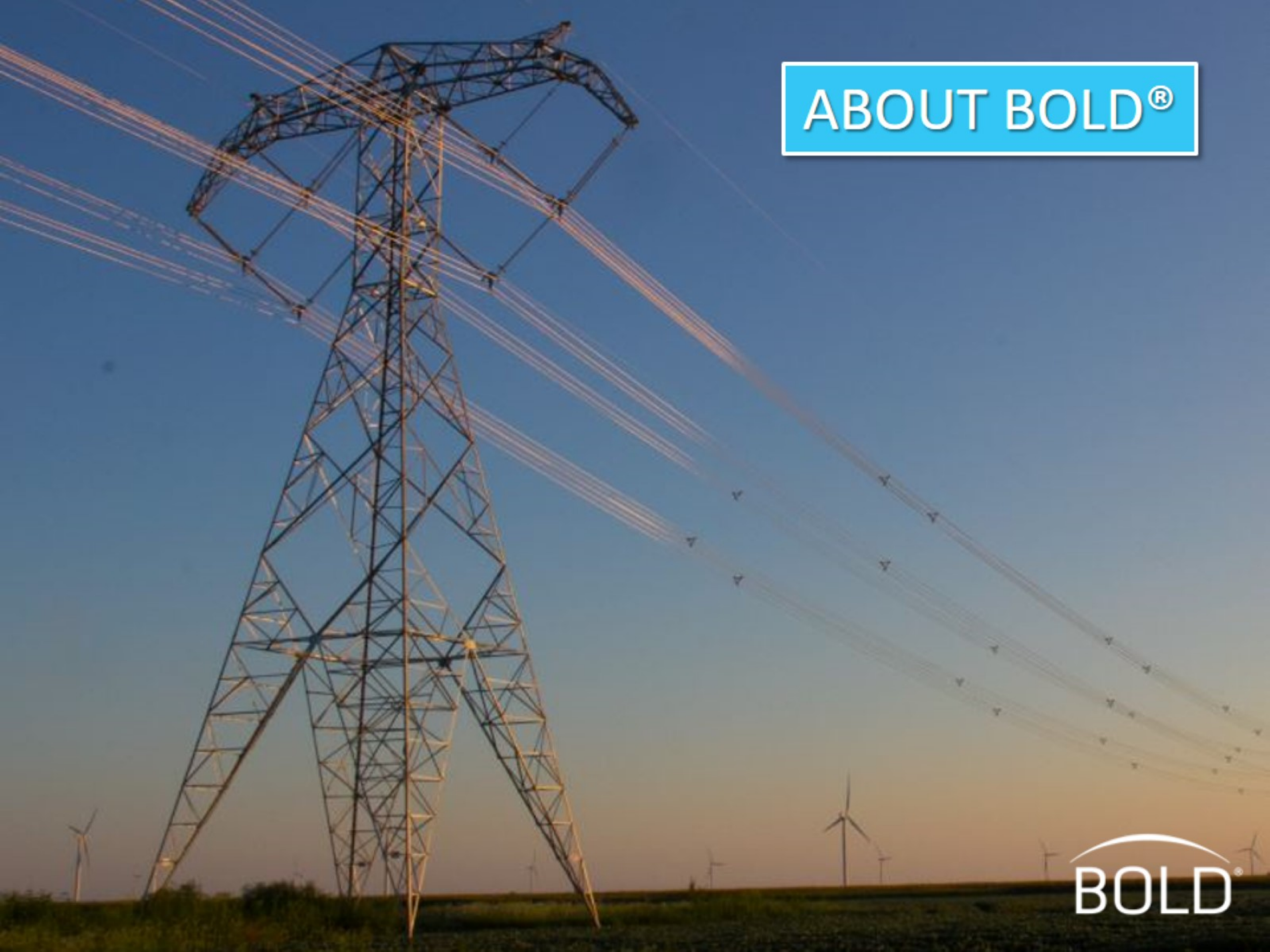
BOLD® Low Impedance Line Design

BOLD®

Efficiency never looked so good®


ABOUT BOLD®
BOLD®

BOLD Delivers

- **Higher Capacity & Efficiency**
  - Significantly increases capacity (up to 60%)
  - Avoids complexity and cost of compensation
  - Reduces Line Losses (up to 33%)

- **Environmentally Friendly**
  - Mitigates electromagnetic field effects (up to 50%)
  - Reduces structure heights (as much as 30%)
  - Provides simple, elegant, low-profile design
  - Built-in avian protection features

- **Regulatory Answers**
  - Addresses need for Advanced Transmission Technology
  - More rapidly brings new and replacement circuits into service
  - Maximizes right-of-way utilization

- **BOLD is Cost Competitive**
  - BOLD competes on a first-cost basis
  - BOLD excels on a $/MW basis

BOLD Delivers

Concept – December 2012

Reality – July 2016

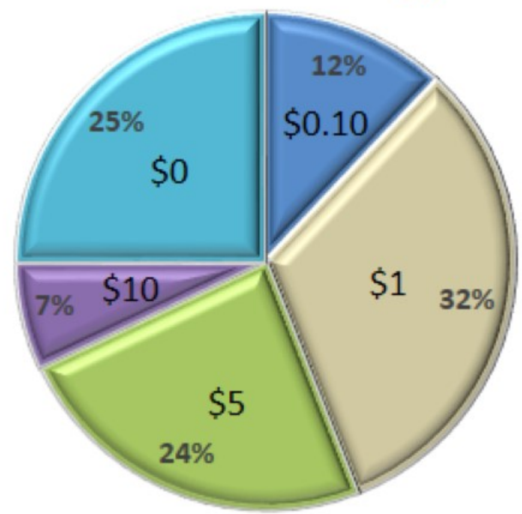
BOLD

BOLD Survey Summary

Public concerns regarding transmission include property value, health impacts, visual impacts

- **79%** value advanced technology
- **75%** would pay more for advanced technology
- **70%** preferred **BOLD** structures versus traditional double-circuit design

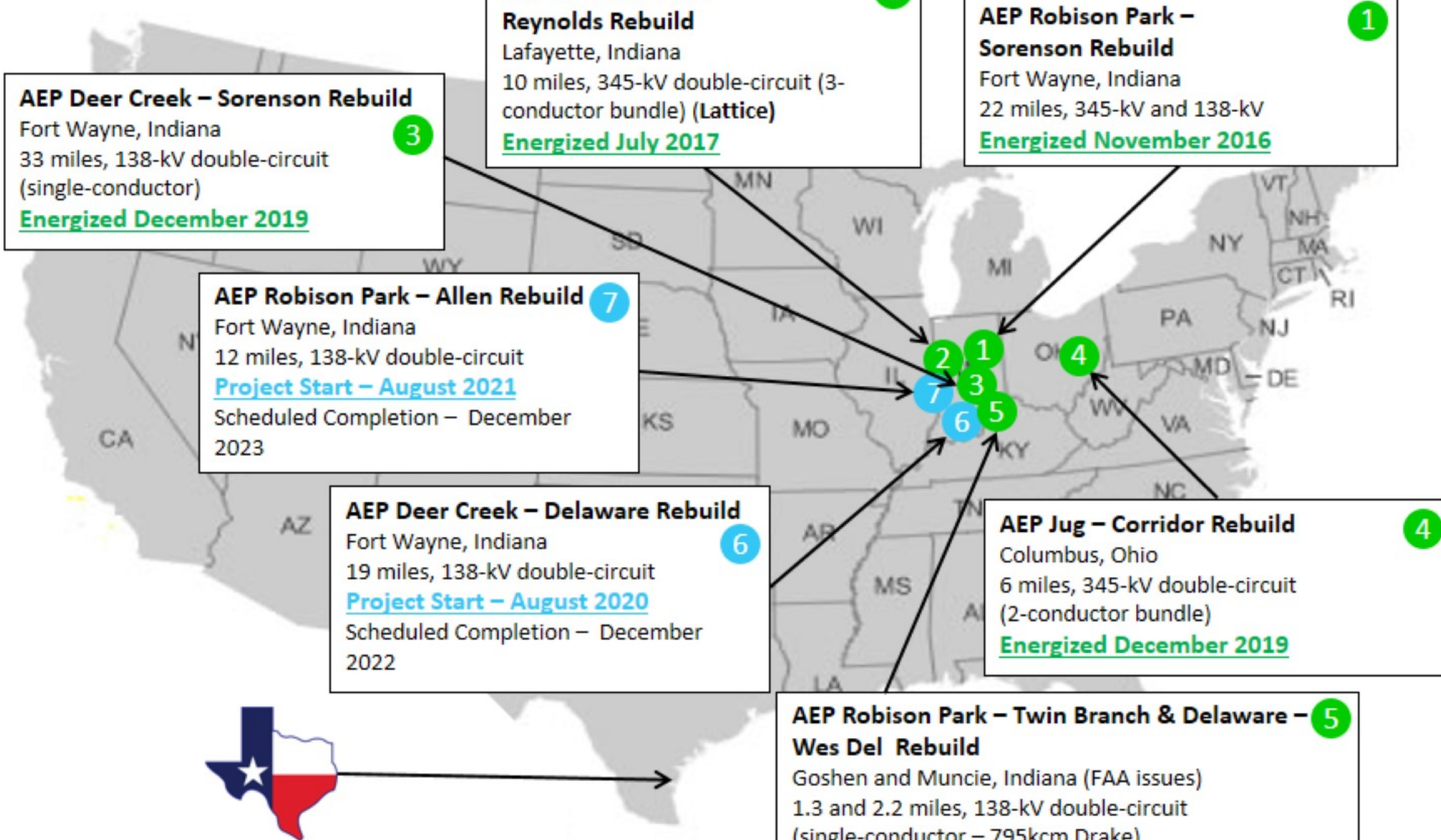
Acceptable monthly premium for advanced technology:



Survey conducted with 1,000 U.S. customers and 500 European customers.

BOLD® Project Deployment

as of Sept. 2021



AEP Robison Park – Sorenson Rebuild (1)
Fort Wayne, Indiana
22 miles, 345-kV and 138-kV
Energized November 2016

AEP Meadow Lake – Reynolds Rebuild (2)
Lafayette, Indiana
10 miles, 345-kV double-circuit (3-conductor bundle) (**Lattice**)
Energized July 2017

AEP Deer Creek – Sorenson Rebuild (3)
Fort Wayne, Indiana
33 miles, 138-kV double-circuit (single-conductor)
Energized December 2019

AEP Jug – Corridor Rebuild (4)
Columbus, Ohio
6 miles, 345-kV double-circuit (2-conductor bundle)
Energized December 2019

AEP Robison Park – Twin Branch & Delaware – Wes Del Rebuild (5)
Goshen and Muncie, Indiana (FAA issues)
1.3 and 2.2 miles, 138-kV double-circuit (single-conductor – 795kcm Drake)
Energized December 2019

AEP Deer Creek – Delaware Rebuild (6)
Fort Wayne, Indiana
19 miles, 138-kV double-circuit
Project Start – August 2020
Scheduled Completion – December 2022

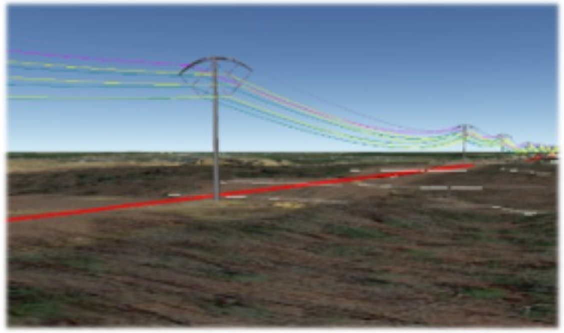
AEP Robison Park – Allen Rebuild (7)
Fort Wayne, Indiana
12 miles, 138-kV double-circuit
Project Start – August 2021
Scheduled Completion – December 2023


HOW IT WORKS
BOLD

BOLD Development

Surge Impedance changes with $\sqrt{L^+/C^+}$ (ohm)

- $L^+ \approx \frac{\mu_0}{2\pi} \ln\left(\frac{d_{eq}}{R_{eq}}\right) = 0.3219 \ln\left(\frac{d_{eq}}{R_{eq}}\right) mH/mi$
- $C^+ \approx {}^{2\pi\varepsilon_0}/_{\ln\left(\frac{d_{eq}}{R_{eq}}\right)} = {}^{89.41}/_{\ln\left(\frac{d_{eq}}{R_{eq}}\right)} nF/mi$
- $Z^+ \approx 60 \ln\left(\frac{d_{eq}}{R_{eq}}\right) \Omega$
- Where:
  - $d_{eq} = \sqrt[3]{d_{ab} d_{bc} d_{ca}}$ ***Eq. Phase Spacing (ft)***
  - $R_{eq} = \sqrt[N]{N r R^{N-1}}$ ***Eq. Bundle Radius (ft)***
  - $d_{ab}, d_{bc}, d_{ca} =$ *Phase spacings (ft)*
  - $N =$ *Number of subconductors per phase*
  - $r =$ *Subconductor radius (ft)*
  - $R -$ *Subconductor bundle radius (ft)*



Theory → **Modeling** → **Testing** → **Field Validation**

Structural

Electrical

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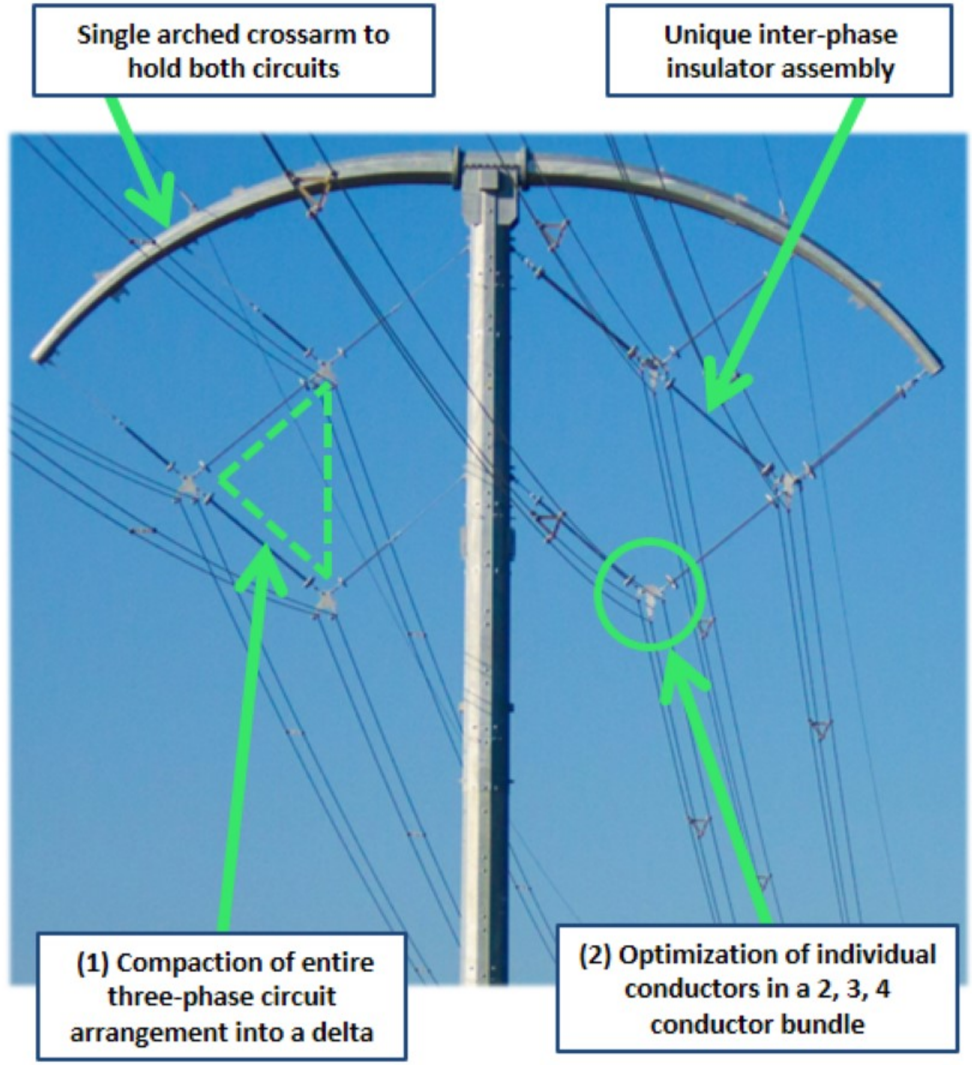
How **BOLD** Works

- **Leverage physics to maximize electrical performance:**
  (1) Reduce phase separation into a "delta" configuration
  (2) Optimize conductor size and bundle diameter
- **Reduces inductance (L) and impedance (Z) and increases capacitance (C)**
- **Higher degree of intrinsic "self-compensation"**
- **Arched cross arm and inter-phase insulators**



BOLD

BOLD ADVANTAGE – THE MATH

- Surge Impedance changes with $\sqrt{L^+/C^+}$ (ohm)
  - $L^+ \approx \frac{\mu_o}{2\pi} \ln\left(\frac{d_{eq}}{R_{eq}}\right) = 0.3219 \ln\left(\frac{d_{eq}}{R_{eq}}\right) mH/mi$
  - $C^+ \approx {2\pi\epsilon_o}\Big/{\ln\left(\frac{d_{eq}}{R_{eq}}\right)} = {89.41}\Big/{\ln\left(\frac{d_{eq}}{R_{eq}}\right)} nF/mi$
  - $Z^+ \approx 60 \ln\left(\frac{d_{eq}}{R_{eq}}\right) \Omega$
  - Where:
    - $d_{eq} = \sqrt[3]{d_{ab} d_{bc} d_{ca}}$ ***Eq. Phase Spacing (ft)***
    - $R_{eq} = \sqrt[N]{NrR^{N-1}}$ ***Eq. Bundle Radius (ft)***
    - $d_{ab}, d_{bc}, d_{ca} = Phase\ spacings\ (ft)$
    - $N =\ Number\ of\ subconductors\ per\ phase$
    - $r =\ Subconductor\ radius\ (ft)$
    - $R = Subconductor\ bundle\ radius\ (ft)$

L, Z decrease; C increases with:

- Closer phase spacing
- More sub-conductors
- Larger bundle diameter
- Larger conductor diameter

BOLD leverages these principles

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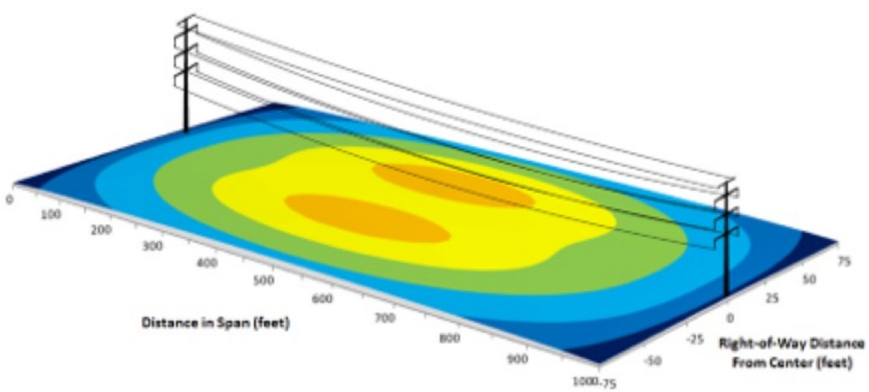
Magnetic Field Mitigation

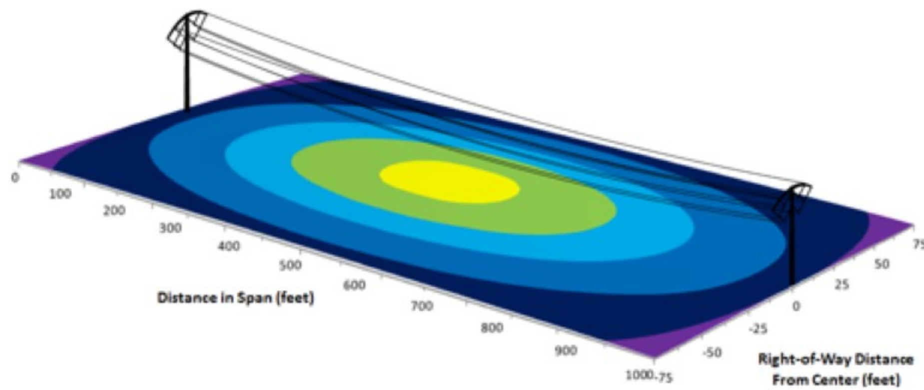
Traditional 345-kV	**BOLD** 345-kV

Magnetic Field Profile @1000MVA Per Circuit
Traditional 345-kV 2-Falcon 25.5ft Phase Spacing 18" Bundle Diameter
Super Bundle Arrangement (A-B-C / A-B-C)



Min = 34.5 mG
Max = 193.4 mG

Magnetic Field Profile @1000MVA Per Circuit
BOLD 345-kV 3-Cardinal 15ft Phase Spacing 29" Bundle Diameter
Super Bundle Arrangement (A-B-C / A-B-C)



Min = 16.2 mG
Max = 157.6 mG

Magnetic Field Intensity (mG)

0-30 | 30-60 | 60-90 | 90-120 | 120-150 | 150-180 | 180-210 | 210-240 | 240-270 | 270-300

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1000' Span Lengths

BOLD Reduces Avian Interaction*

- **Nesting**
  - **BOLD** eliminates cavity nests and should minimize corvid and raptor stick nests due to the unique arch-shaped cross member.
- **Collision**
  - **BOLD** has design elements to reduce collision risk
- **Feces**
  - **BOLD** should reduce pollution outages by limiting perching and creating a barrier; it may also reduce streamer outages.
- **Predation Management**
  - **BOLD** may minimize avian predation on sensitive species by reducing nesting on transmission structures.
- **Electrocution**
  - **BOLD** can be implemented as eagle friendly

* Source: EDM International, Inc. study (2018)

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BOLD STRUCTURE FAMILY
BOLD

Better Use of RoW

BOLD allows you to deliver **more** power in a given right-of-way when compared to traditional transmission line designs. That means less land is needed to fulfill capacity needs.

One **BOLD** 345-kV double-circuit line can deliver the same power carrying capacity as three traditional 345-kV single- circuit lines creating a smaller environmental footprint of roughly 1/3 by comparison

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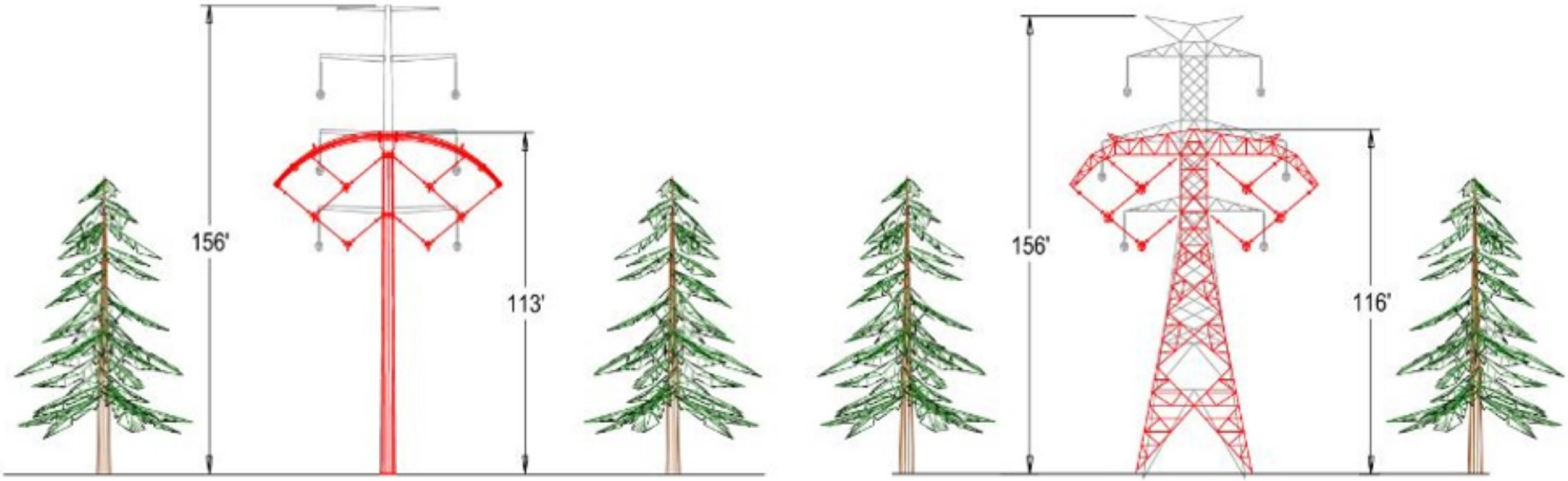
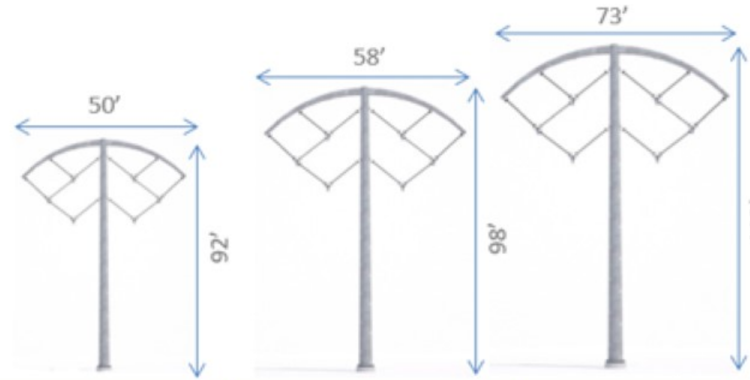
Structure Comparison – 345 kV

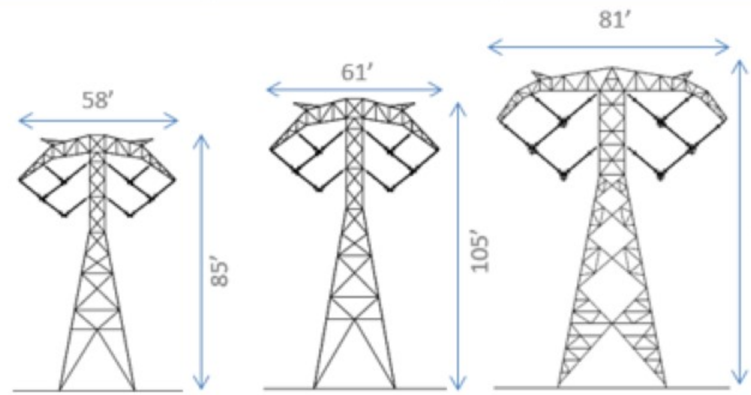


1000' Span Lengths

BOLD Structure Families



OPTIONS	115/138-kV	230-kV	345-kV
Single Circuit	✓	✓	✓
Double Circuit	✓	✓	✓
Various Conductor Options	✓	✓	✓



1000′ Span Lengths

BOLD Structure Family

Running Corner

Dead-End

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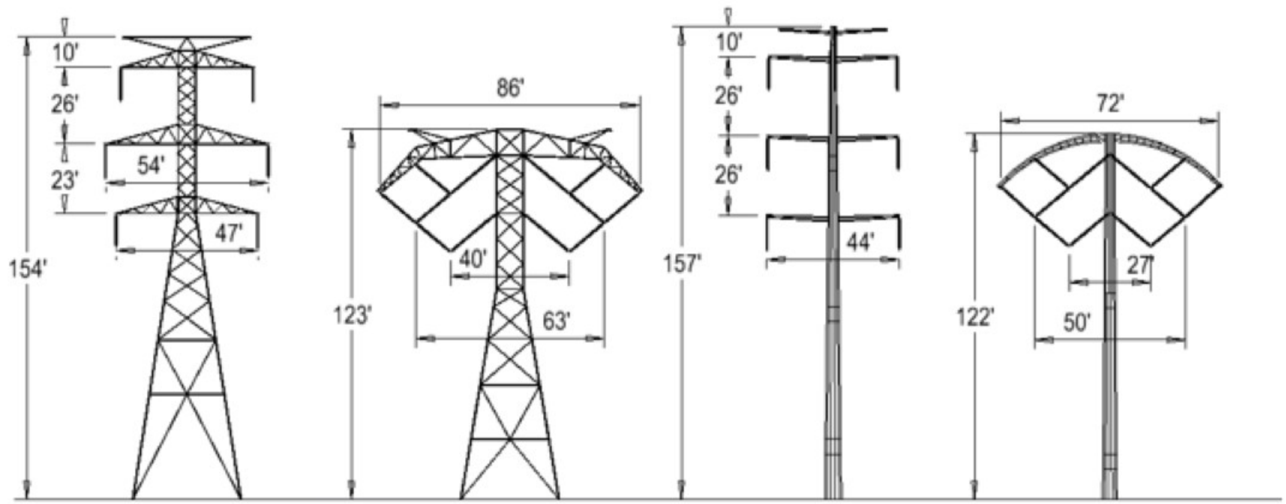
345-kV **BOLD** vs. Traditional



STRUCTURE TYPE	Traditional Lattice Tower	BOLD Lattice	Traditional Tubular	BOLD Tubular
Phase Configuration:	3-954 kCM ACSR (Cardinal)	3-954 kCM ACSR (Cardinal)	3-954 kCM ACSR (Cardinal)	3-954 kCM ACSR (Cardinal)
Structure Height (AGH):	154 ft	123 ft	157 ft	122 ft
Groundline Moment:	10,300 ft-kips	7,000 ft-kips (-32%)	10,420 ft-kips (+1%)	7700 ft-kips (-25%)
Structure Weights:	29,500 lbs	25,000 lbs (-15%)	60,000 lbs (+103%)	47,000 lbs (+59%)

1200' Span Lengths
NESC Light Zone

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BOLD Conductor Options

	3-954 BOLD Lattice	3-954 Traditional Lattice	2-1590 BOLD Lattice	2-1590 Traditional Lattice	2-954 BOLD Lattice	2-954 Traditional Lattice
Average Line Cost* ($/mile)	100%	105%	97%	102%	87%	92%
Tangent Structure Weight (lbs.)	100%	118%	95%	108%	85%	97%
Foundation (cu. yd)	100%	106%	97%	103%	91%	97%
Impedance (Ω)	100%	+127%	+122%	+136%	+130%	+145%

*Indicative cost comparison, using common assumptions and unit pricing.

Baseline

BOLD is the optimal design for cost and impedance.

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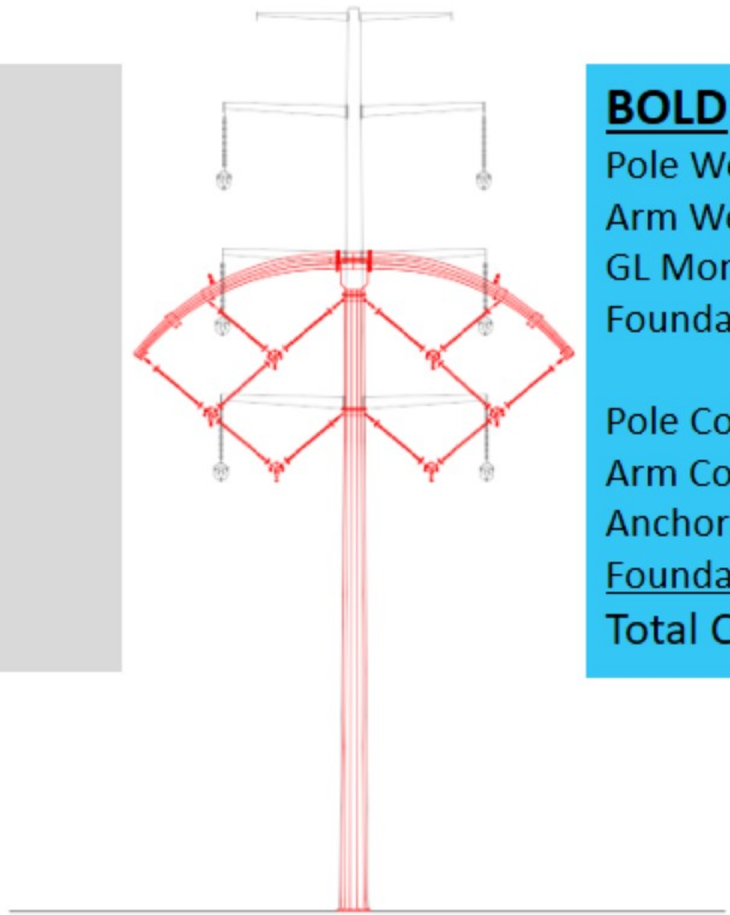
A Cost Competitive **BOLD** Solution

Traditional	
Pole Weight	38,100 lbs
Arm Weight	10,378 lbs
GL Moment	7,400 ft-K
Foundation Size	6.5 ft x 28ft
Pole Cost	100%
Arm Cost	100%
Anchor B Cost	100%
Foundation Cost	100%
Total Cost	100%



BOLD	
Pole Weight	33,100 lbs
Arm Weight	11,070 lbs
GL Moment	5,600 ft-K
Foundation Size	6 ft x 24 ft
Pole Cost	87%
Arm Cost	157%
Anchor B Cost	70%
Foundation Cost	74%
Total Cost	99%

Typical 345-kV Tangent Structure

2-1590 ACSR Falcon

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BENEFITS
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BOLD Benefits Summary

Higher Capacity
- Up to 60%
- Can avoid costly and complex compensation

Increased Efficiency
- **Reduces Line Losses** (up to 33%)

Mitigates EMF Effects
- Up to 50%

Aesthetically Pleasing for Customers
- 70% preferred

Reduces Avian Interaction
- Nesting
- Collision
- Contamination
- Electrocution

Reduces Structure Heights
- By nearly 30%

Maximizes Right-of-Way Utilization

Regulatory
- Addresses desire for Advanced Transmission Technology

Cost Competitive!

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Efficiency never looked so good.®

Meeting w/ ERCOT RPG
September 15, 2021

Thank You!

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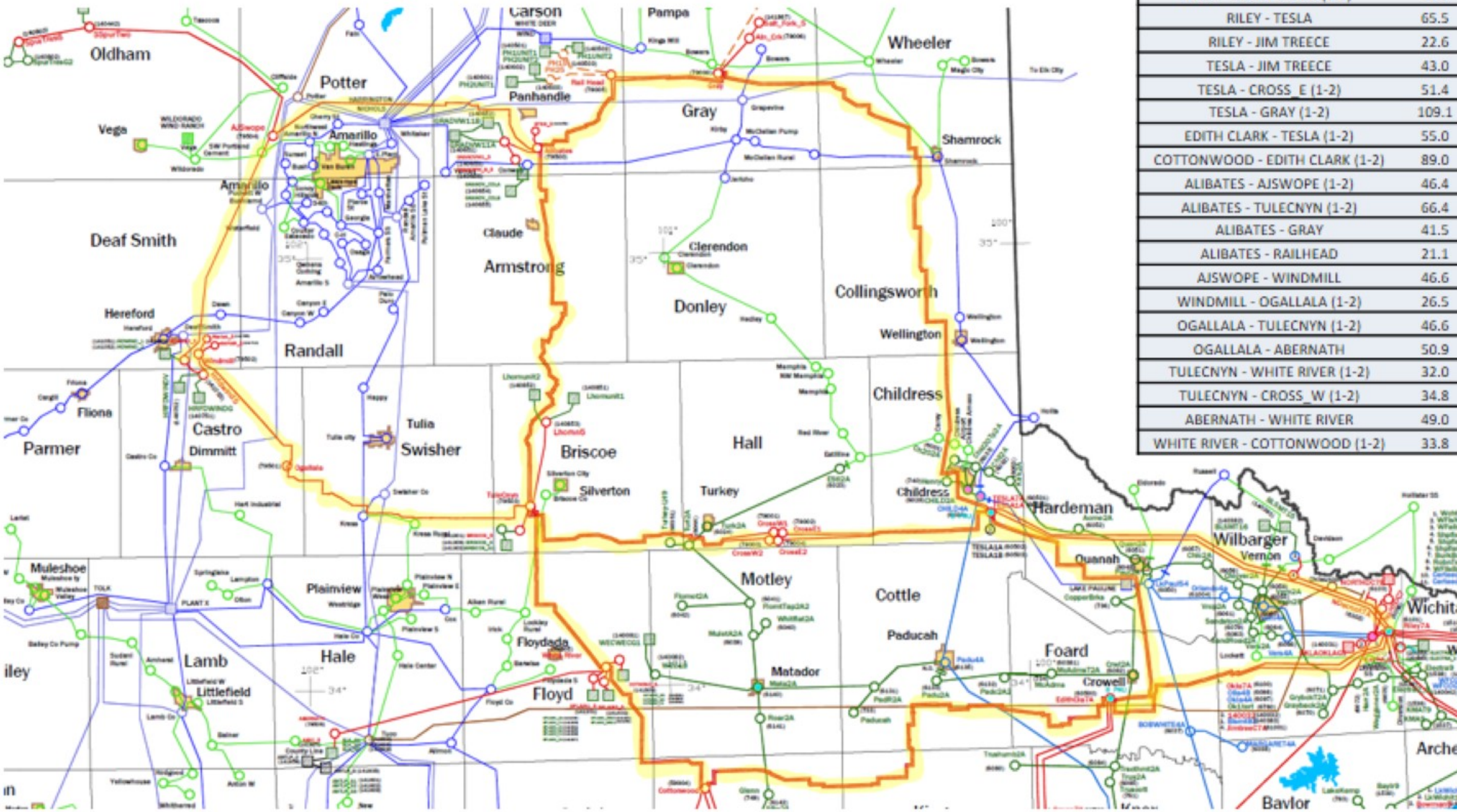
APPENDIX

ERCOT **BOLD** Study*

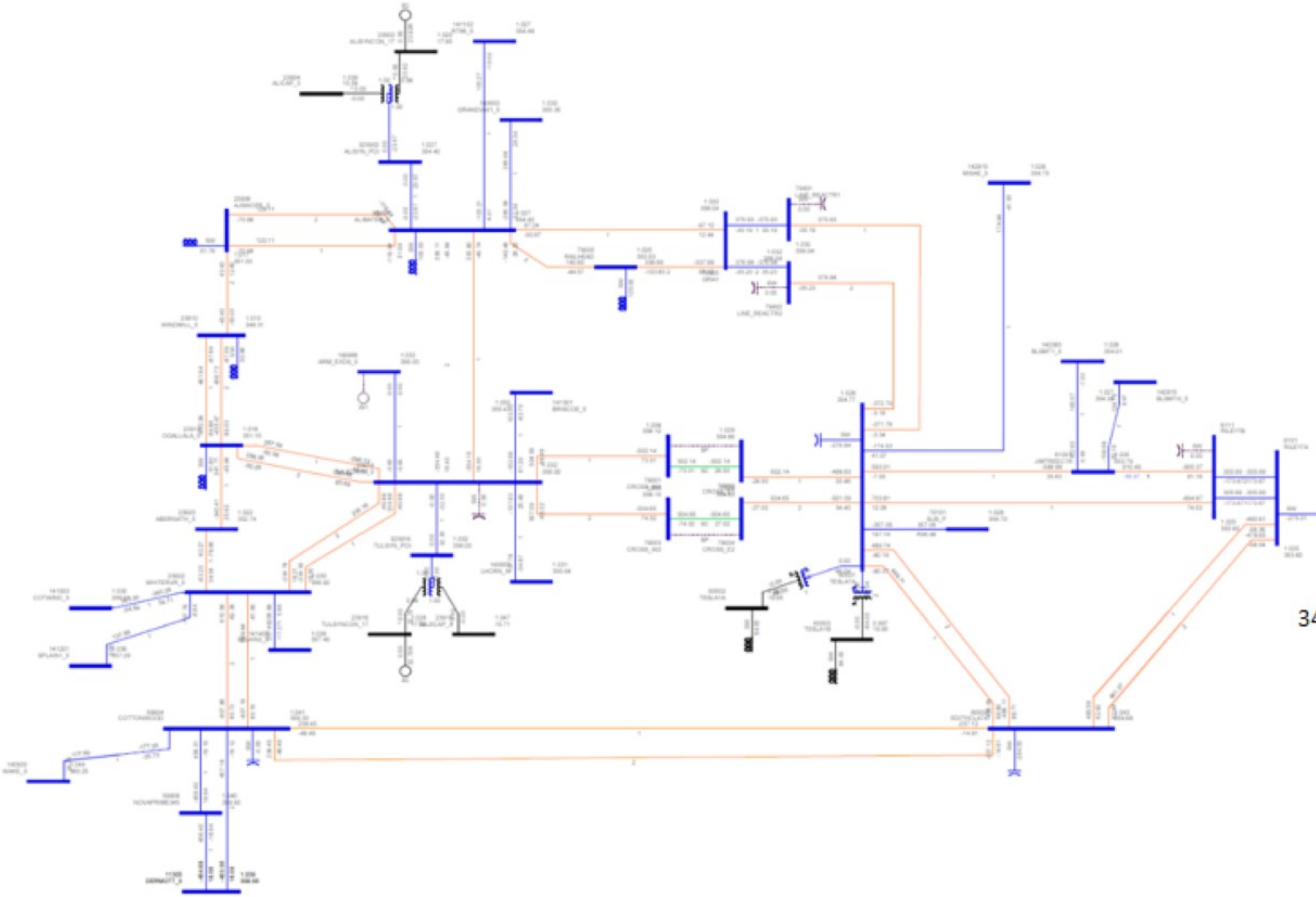
LINE NAME	LENGTH
RILEY - EDITH CLARK (1-2)	41.7
RILEY - TESLA	65.5
RILEY - JIM TREECE	22.6
TESLA - JIM TREECE	43.0
TESLA - CROSS_E (1-2)	51.4
TESLA - GRAY (1-2)	109.1
EDITH CLARK - TESLA (1-2)	55.0
COTTONWOOD - EDITH CLARK (1-2)	89.0
ALIBATES - AJSWOPE (1-2)	46.4
ALIBATES - TULECNYN (1-2)	66.4
ALIBATES - GRAY	41.5
ALIBATES - RAILHEAD	21.1
AJSWOPE - WINDMILL	46.6
WINDMILL - OGALLALA (1-2)	26.5
OGALLALA - TULECNYN (1-2)	46.6
OGALLALA - ABERNATH	50.9
TULECNYN - WHITE RIVER (1-2)	32.0
TULECNYN - CROSS_W (1-2)	34.8
ABERNATH - WHITE RIVER	49.0
WHITE RIVER - COTTONWOOD (1-2)	33.8



Panhandle Geographic View

*Study of ERCOT area, performed by BOLD.

ERCOT **BOLD** Study*



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345 kV Lines Converted to BOLD
(4x795 ACSR Drake)
are Orange

Panhandle One-Line Diagram and Assumed BOLD Substitution

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*Study of ERCOT area, performed by BOLD.

ERCOT **BOLD** Study*

Table 1 – Contingency simulation results															
Contingency	80% (6206.26 MW)			85% (6594.15 MW)			90% (6982.04 MW)			95% (7369.93 MW)			100% (7757.82 MW)		
	Case 0	Case 1	Case 2	Case 0	Case 1	Case 2	Case 0	Case 1	Case 2	Case 0	Case 1	Case 2	Case 0	Case 1	Case 2
Event 1	Stable	Stable	Stable	Marginally stable[1]	Stable	Stable	Unstable	Stable	Stable	Unstable	Stable	Stable	Unstable	Marginally stable[2]	Marginally stable[5]
Event 2	Stable	Stable	Stable	Unstable	Stable	Stable	Unstable	Stable	Stable	Unstable	Stable	Stable	Unstable	Marginally stable[3]	Stable
Event 3	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Unstable	Stable	Stable	Unstable	Stable	Stable
Event 4	Stable	Stable	Stable	Stable	Stable	Stable	Unstable	Stable	Stable	Unstable	Stable	Stable	Unstable	Stable	Stable
Event 5	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Unstable	Stable	Stable	Unstable	Marginally stable[4]	Marginally stable[6]
Event 6	Stable	Stable	Stable	Unstable	Stable	Stable	Unstable	Stable	Stable	Unstable	Stable	Stable	Unstable	Stable	Unstable

- Case 0 is the base case(DWG 2023HWLL). By default, one Gauss series capacitor is bypassed. The rest (two at Cross, two at Kirchhoff, one at Gauss) are in service.
- Case1 is Case 0 + BOLD substitutions
- Case2 is Case 1 + two series caps at Cross bypassed

With series capacitors in service, BOLD technology could increase 1103MW transfer capability (from 80% to 95%) while maintaining stability

Performance When Series Capacitors Are In Service

*Study of ERCOT area, performed by BOLD.

ERCOT **BOLD** Study*

Table 2 – Contingency simulation results-without series capacitor																
Contingency	65% (5042.58 MW)		70%(5430.47 MW)		75% (5818.37 MW)		80% (6206.26 MW)		85% (6594.15 MW)		90% (6982.04 MW)		95% (7369.93 MW)		100% (7757.82 MW)	
	Case 3	Case 4	Case 3	Case 4	Case 3	Case 4	Case 3	Case 4	Case 3	Case 4	Case 3	Case 4	Case 3	Case 4	Case 3	Case 4
Event 1	Stable	Stable	Stable	Stable	Stable	Stable	Marginally stable[a]	Stable	Marginally stable[a]	Stable	Unstable	Stable	Unstable	Unstable	Unstable	Unstable
Event 2	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Unstable	Stable	Unstable	Stable	Unstable	Stable	Unstable	Unstable
Event 3	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Unstable	Stable	Unstable	Stable	Unstable	Marginally stable[b]
Event 4	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Marginally stable	Stable	Unstable	Stable	Unstable	Stable	Unstable	Marginally stable[c]
Event 5	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Unstable	Stable	Unstable	Stable	Unstable	Unstable
Event 6	Stable	Stable	Unstable	Stable	Unstable	Stable	Unstable	Stable	Unstable	Stable	Unstable	Stable	Unstable	Unstable	Unstable	Unstable

- Case3 is Case 0 + series caps at Cross, Gauss and Kirchhoff bypassed
- Case4 is Case 3 + BOLD substitutions

Without series capacitors, BOLD technology could increase 1940 MW transfer capability (from 65% to 90%) while maintaining stability

Performance When Series Capacitors Are Bypassed

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*Study of ERCOT area, performed by BOLD.