Appendix G

EMF Reports for Single Circuit Transmission Lines

- **Transmission Line EMF Report – Single Circuit – 414 MW**
- **Transmission Line EMF Report – Single Circuit – 207 MW**

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Transmission Line
EMF Report – Single Circuit

PLUM CREEK WIND PROJECT 414 MW

PREPARED BY
ULTEIG ENGINEERS, INC.
PROJECT NO. 19.00499

REV. C
DATE: 10/11/19

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Executive Summary

This report focuses on the Electric and Magnetic Field (EMF) studies performed for the Plum Creek Wind 345kV Transmission Line, located in Redwood and Cottonwood Counties, MN. The purpose of the EMF analysis is to determine the maximum electric and magnetic field intensities that will be produced by the proposed transmission line. The electric field is a function of the overall operating voltage of the proposed transmission line and increases in intensity as voltage increases. Alternatively, magnetic field is a function of the maximum operating current and increases with increasing current. Both electric and magnetic field values are dependent on line geometry and distance from the energized conductor.

Electric and magnetic field calculations in this report are based on the use of a single circuit bundled 954 kcmil 54/7 "Cardinal" ACSR conductor with two conductors per phase or 1272 kcmil 45/7 "Bittern" ACSR conductor with two conductors per phase. Wire attachment heights are based on typical tangent structure geometry determined in preliminary route design. Structure geometry is determined using a minimum ground clearance value of 27'-3". Single circuit calculations are performed using a single pole braced post structure for the typical tangent geometry. The structure provides 15'-0" vertical phase spacing with braced post insulators that extend horizontally approximately 12'-0" from the pole centerline. The right-of-way width being studied is 150 feet. The Plum Creek Wind Farm turbine output will be 414MW, which equates to approximately 815 amps at 345kV.

For the proposed single circuit transmission line, the calculated maximum electric field for either conductor option has an intensity of 6.89 kV/m occurring at 15 feet from the centerline and 0.93 kV/m at the edge of the right-of-way. The calculated maximum magnetic field intensity is 129.6 MilliGauss at 10 feet from the centerline and 25.19 MilliGauss at the edge of the right-of-way.

Additional Information

Magnetic Field Background

Magnetic fields are present around any electrical conductor and electrical device, including household wiring, electrical distribution lines, substation equipment, and household appliances. The magnetic field intensity, or magnetic flux density, is measured in MilliGauss, and is proportional to the current flow on the transmission line. It is calculated at one meter (3.28 feet) above the ground, with maximum turbine output and at the lowest point of sag. Measurable magnetic field will only occur in the immediate vicinity of transmission lines, as it decreases in strength the further away from the energized conductors. Some examples of common sources of magnetic fields, and their intensities, measured in MilliGauss (mG), are listed below.

Appliance	Distance from Source		
	6 inches	1 foot	2 feet
Hair Drier	300	1	--
Electric Shaver	100	20	--
Can Opener	600	150	20
Electric Stove	30	8	2
Television	NA	7	2
Portable Heater	100	20	4
Vacuum Cleaner	300	60	10
Copy Machine	90	20	7
Computer	14	5	2

Source: *EMF In Your Environment* (EPA 1992).

Electric Field Background

Electric fields, like magnetic fields, generally only occur within the immediate vicinity of transmission lines and are present around any electrical device. The further away from the energized conductors (or device), the weaker the electric field strength. However, unlike magnetic fields, electric fields increase intensity with voltage, rather than current. Electric fields can induce current on nearby conductor objects, such as metal shovels, metal tanks, metal fences, etc. It is also possible for humans to also become electrically charged when underneath a transmission line. This normally goes unnoticed, and is generally harmless.

The electric field is measured in kilovolts per meter (kV/m) and is proportional to the voltage on the transmission line. It is calculated at one meter (3.28 feet) above the ground, with maximum line voltage, and at lowest point of sag. Maximum conductor voltage is defined as the phase-to-ground operating voltage plus 5% to account for potential overvoltage situations. (5% overvoltage is an industry standard value used as voltage can vary slightly depending on system conditions). This equates to 210 kV when considering a transmission line with phase-to-phase voltage of 345kV.

Health and Biological Background

Concerns about health effects of EMF from power lines were first raised in the late 1970s. Since then, considerable research has been conducted to determine if exposure to magnetic fields, such as those from high-voltage power lines, causes biological responses and health effects. Initial epidemiological studies completed in the late 1970s showed a weak correlation between surrogate indicators of magnetic field exposure (such as wiring codes or distance from roads) and increased rates of childhood leukemia (Wertheimer et. al, 1979). Toxicological and laboratory studies have not shown a biological mechanism between EMF and cancer or other adverse health effects. In 2007, the World Health Organization ("WHO") concluded a review of health implications from magnetic fields and concluded, "virtually all of the laboratory evidence and the mechanistic evidence fail to support a relationship between low-level ELF magnetic fields and changes in biological function or disease status" (WHO, 2007). Natural and human-made electromagnetic fields are present everywhere in our environment. Natural electric fields in the atmosphere range from background static levels of 10 to 120 volts per meter ("V/m") to well over several kilovolts per meter ("kV/m") produced by the build-up of electric charges in thunderstorms. The Earth itself has a magnetic field that ranges from approximately 300 to 700 milligauss ("mG"). In addition to the presence of the earth's steady state electric field, an average home experiences additional magnetic fields of 0.5 mG to 4 mG which arise from the general wiring and appliances located in a typical home (National Cancer Institute, 2009).

Considerable research has been conducted throughout the past three decades to determine whether exposure to power-frequency (60 hertz) EMF causes biological responses and health effects. Epidemiological and toxicological studies have shown no statistically significant association or weak associations between EMF exposure and health risks. In 1999, the National Institute of Environmental Health Sciences ("NIEHS") issued its final report on "Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields" in response to the Energy Policy Act of 1992. NIEHS concluded that the scientific evidence linking EMF exposures with health risks is weak and that this finding does not warrant aggressive regulatory concern. However, because of the weak scientific evidence that supports some association between EMF and health effects, and the common exposure to electricity in the United States, passive regulatory action, such as providing public education on reducing exposures, is warranted.

Minnesota, California and Wisconsin have all conducted literature reviews or research to examine this issue. In 2002, Minnesota formed an Interagency Working Group to evaluate the body of research and develop policy recommendations to protect the public health from any potential problems resulting from high voltage transmission line EMF effects. The Working Group consisted of staff from various state agencies. The Working Group published its findings in a White Paper on EMF Policy and Mitigation Options in September 2002 (Minnesota Interagency Working Group, 2002). The findings of the Working Group are summarized in the following paragraph: "Research on the health effects of EMF has been carried out since the 1970s. Epidemiological studies have mixed results — some have shown no statistically significant association between exposure to EMF and health effects, some have shown a weak association. More recently, laboratory studies have failed to show such an association, or to establish a biological mechanism for how magnetic fields may cause cancer. A number of scientific panels convened by national and international health agencies and the United States Congress have reviewed the research carried out to date. Most researchers concluded that there is insufficient evidence to prove an association between EMF and health effects; however, many of them also concluded that there is insufficient evidence to prove that EMF exposure is safe."

The State of Minnesota's Public Utilities Commission and before them, the Minnesota Environmental Quality Board ("EQB") have recently addressed the matter of EMF with respect to new transmission lines in a number of separate dockets over the past few years. For the Brookings County – Hampton 345 kV Route Permit proceeding, after extensive testimony on the issue, the Commission adopted the administrative law judge's findings that "there are no demonstrated impact on human health and 21 safety that is not adequately addressed by the existing State standards for [electric fields or magnetic fields] exposure." In the Matter of the Route Permit Application by Great River Energy and Xcel Energy for a 345 kV Transmission Line from Brookings County, South Dakota to Hampton, Minnesota, Docket No. ET2/TL-08-1474, ALJ Findings of Fact, Conclusions and Recommendation at Finding 216 (April, 22, 2010 and amended April 30, 2010; adopted by the Commission in its Order Granting Route Permit, at 12 (September 14, 2010)

Study Criteria

Software Used

The software used for both electric and magnetic field calculations was developed by Bonneville Power Administration (BPA). Two different programs were used; MF CALC (for the magnetic field), and EF CALC (for the electric field). The BPA method for calculating electric and magnetic fields is an empirical method developed from long-term measurements on a number of full-scale operating or test lines. It is specifically designed to calculate electric and magnetic fields based on phase configuration, conductor size, number of conductors, voltage (electric field), and current flow (magnetic field).

Assumptions

- Conductor is 954 kcmil 54/7 “Cardinal” ACSR with two conductors per phase (Diameter is 1.196”) OR 1272 45/7 “Bittern” ACSR (Diameter is 1.345”) with two conductors per phase.
- Minimum ground clearance of 27’-3” when conductor is at max sag conditions
- Typical single circuit direct-embed steel poles in delta configuration:
    - 15’-0” vertical spacing between phases with braced post insulators extending 12’-0” horizontally from structure centerline
- Minimum ground clearance of 27’-3” when conductor is at max sag conditions
- Right-of-way width is 150 feet (75 ft each side of centerline)

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Transmission Line

EMF Report – Single Circuit

PLUM CREEK WIND PROJECT 207 MW

PREPARED BY

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For the proposed single circuit transmission line, the calculated maximum electric field for either conductor option has an intensity of 6.89 kV/m occurring at 15 feet from the centerline and 0.93 kV/m at the edge of the right-of-way. The calculated maximum magnetic field intensity is 64.8 MilliGauss at 10 feet from the centerline and 12.6 MilliGauss at the edge of the right-of-way.

Additional Information

Magnetic Field Background

Magnetic fields are present around any electrical conductor and electrical device, including household wiring, electrical distribution lines, substation equipment, and household appliances. The magnetic field intensity, or magnetic flux density, is measured in MilliGauss, and is proportional to the current flow on the transmission line. It is calculated at one meter (3.28 feet) above the ground, with maximum turbine output and at the lowest point of sag. Measurable magnetic field will only occur in the immediate vicinity of transmission lines, as it decreases in strength the further away from the energized conductors. Some examples of common sources of magnetic fields, and their intensities, measured in MilliGauss (mG), are listed below.

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- Minimum ground clearance of 27'-3" when conductor is at max sag conditions
- Typical single circuit direct-embed steel poles in delta configuration:
  - 15'-0" vertical spacing between phases with braced post insulators extending 12'-0" horizontally from structure centerline
- Minimum ground clearance of 27'-3" when conductor is at max sag conditions
- Right-of-way width is 150 feet (75 ft each side of centerline)

Results

Single Circuit - Magnetic Field

The calculated peak magnetic field from the transmission line is 64.8 mG and occurs at a distance approximately 10 feet from the proposed centerline. At 75 feet from the proposed centerline (the edge of the right-of-way), the calculated peak magnetic field is 12.60 mG. Peak magnetic field intensities occur at the maximum turbine output from the Plum Creek Wind farm, which is approximately 407.5 amps at 345kV. Maximum field levels occur under the conductors on the side of the structure with two phases. Magnetic field values will not change based on conductor selection, thus only one set of results is provided.

Normal magnetic field strengths when the Plum Creek Wind project is in operation will be of much weaker intensity than the reported maximum values. Actual current flow and associated magnetic fields will vary throughout the day as wind speed changes, and turbine output varies. It is anticipated that peak output of the wind farm will occur a limited number of times throughout a given year.

There are no federal or Minnesota state regulations on maximum magnetic field intensity, however, Florida and New York both limit the magnetic fields on new transmission lines to 200 MilliGauss at the edge of the right of way. The peak magnetic field intensity on the Plum Creek Wind project is below this level.

Table 1.A: Single Circuit Magnetic Field Input Data

Bundle	Bundle Description	X-Position [ft]	Y-Position [ft]	Current [A]	Phase Orientation Angle
1	"Cardinal" Or "Bittern"	12	27.25	407.5	0
2	"Cardinal" Or "Bittern"	-12	42.25	407.5	120
3	"Cardinal" Or "Bittern"	12	57.25	407.5	240

Table 1.B: Single Circuit Calculated Magnetic Field Results

Negative X-Direction From Centerline											
Distance From Centerline [ft]	-75	-65	-55	-45	-35	-25	-20	-15	-10	-5	0
Magnetic Field Strength [mG]	9.93	12.49	16.01	20.87	27.50	36.18	41.21	46.56	52.00	57.21	61.63
Positive X-Direction From Centerline											
Distance From Centerline [ft]	0	5	10	15	20	25	35	45	55	65	75
Magnetic Field Strength [mG]	61.63	64.46	64.80	62.21	57.16	50.77	38.03	28.08	21.03	16.10	12.60

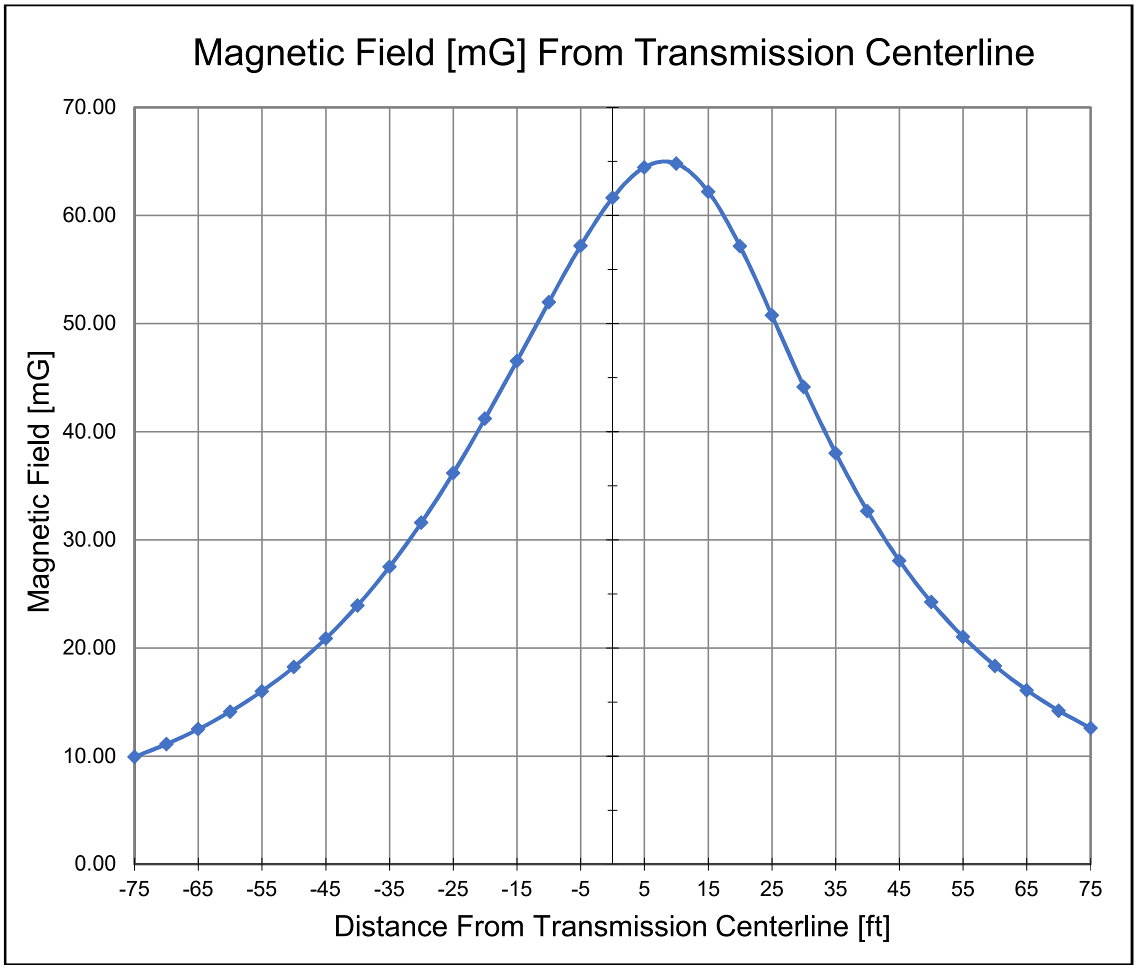

Figure 1: Single Circuit Maximum Magnetic Field Strength in milliGauss
(one meter above ground, at distances in feet from the transmission centerline, single pole)

Single Circuit - Electric Field

The maximum calculated electric field for the single circuit "Cardinal" configuration is 6.80 kV/m at 15 feet from the proposed transmission centerline. At 75 feet from the proposed transmission centerline (the edge of the proposed right-of-way), the calculated electric field is 0.92 kV/m. The maximum calculated electric field for the single circuit "Bittern" configuration is 6.89 kV/m at 15 feet from the proposed transmission line centerline and 0.93 kV/M at 75 feet from the proposed centerline (edge of proposed right of way). The maximum electric field for both options occurs 15 feet offset from the transmission centerline due to the delta phase configuration of the single circuit transmission line structures (two phase conductors on one side of the pole, and a single on the opposite side of the pole). Maximum field levels occur directly under the phase conductor on the side of the structure with two phases. Figure 2 & 3 below illustrate the electric field intensity as compared to the proposed transmission centerline.

Table 2.A: Single Circuit Electric Field Input Data – "Cardinal"

Bundle	Bundle Description	X-Position [ft]	Y-Position [ft]	# Cond.	Cond. Dia [in]	Cond. Spacing [in]	Line to Neutral Voltage [kV]	Phase Orientation Angle
1	"Cardinal"	12	27.25	2	1.196	18	209.15	0
2	"Cardinal"	-12	42.25	2	1.196	18	209.15	120
3	"Cardinal"	12	57.25	2	1.196	18	209.15	240
4	OPGW	7	80.25	1	0.528	0	0	0
5	EHS	-7	80.25	1	0.375	0	0	0

Table 2.B: Single Circuit Calculated Electric Field Results – "Cardinal"

Negative X-Direction From Centerline											
Distance From Centerline [ft]	-75	-65	-55	-45	-35	-25	-20	-15	-10	-5	0
Electric Field Strength [kV/M]	0.92	1.20	1.58	2.04	2.51	2.80	2.82	2.82	3.01	3.65	4.72
Positive X-Direction From Centerline											
Distance From Centerline [ft]	0	5	10	15	20	25	35	45	55	65	75
Electric Field Strength [kV/M]	4.72	5.86	6.66	6.80	6.29	5.37	3.39	2.04	1.31	0.94	0.73

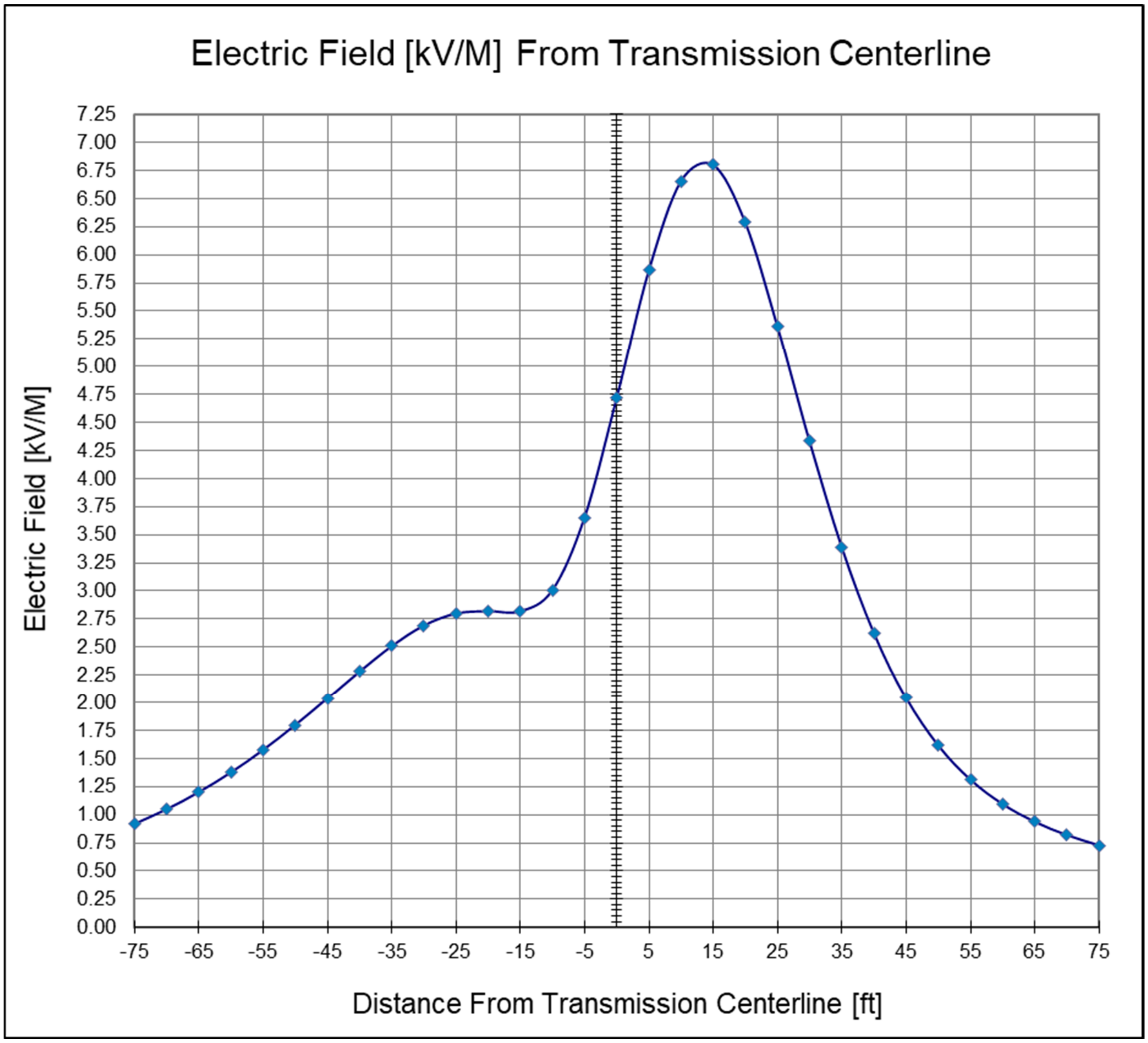

Figure 2: Single Circuit Maximum Electric Field Strength in kV/M – "Cardinal"
(one meter above ground, at distances in feet from the transmission centerline, single pole, delta configuration)

Table 3.A: Single Circuit Electric Field Input Data – "Bittern"								
Bundle	**Bundle Description**	**X-Position [ft]**	**Y-Position [ft]**	**# Cond.**	**Cond. Dia [in]**	**Cond. Spacing [in]**	**Line to Neutral Voltage [kV]**	**Phase Orientation Angle**
1	"Bittern"	12	27.25	2	1.345	18	209.15	0
2	"Bittern"	-12	42.25	2	1.345	18	209.15	120
3	"Bittern"	12	57.25	2	1.345	18	209.15	240
4	OPGW	7	80.25	1	0.528	0	0	0
5	EHS	-7	80.25	1	0.375	0	0	0

Table 3.B: Single Circuit Calculated Electric Field Results – "Bittern"											
Negative X-Direction From Centerline											
Distance From Centerline [ft]	-75	-65	-55	-45	-40	-30	-20	-15	-10	-5	0
Electric Field Strength [kV/M]	0.93	1.22	1.60	2.06	2.31	2.73	2.86	2.86	3.05	3.70	4.78
Positive X-Direction From Centerline											
Distance From Centerline [ft]	0	5	10	15	20	30	40	45	55	65	75
Electric Field Strength [kV/M]	4.78	5.94	6.75	6.89	6.37	4.39	2.66	2.07	1.33	0.95	0.74

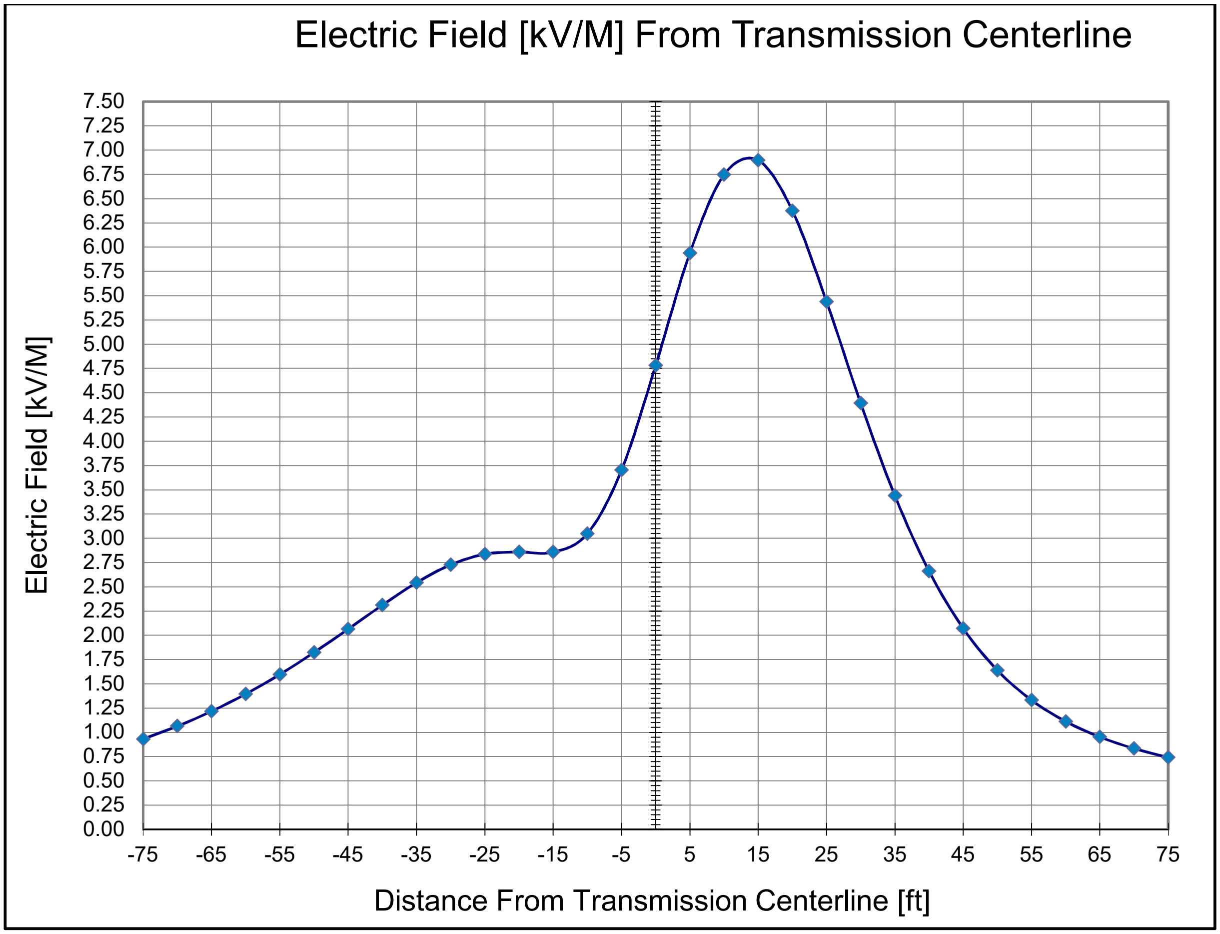

Figure 3: Single Circuit Maximum Electric Field Strength in kV/M – "Bittern"
(one meter above ground, at distances in feet from the transmission centerline, single pole, delta configuration)

Conclusions

It is considered acceptable in Minnesota for new transmission line designs to limit maximum electric fields to 8 kV/m anywhere within the right-of-way. The Plum Creek Wind project electric field levels will be below this threshold for the single circuit transmission structures.

The electric and magnetic field levels are within industry and state acceptable limits for the 954 kcmil 54/7 "Cardinal" ACSR and 1272 45/7 "Bittern" conductor considered. No adverse impacts are anticipated based on the study results, therefore no mitigation is required at this time.

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Results

Single Circuit - Magnetic Field

The calculated peak magnetic field from the transmission line is 129.62 mG and occurs at a distance approximately 10 feet from the proposed centerline. At 75 feet from the proposed centerline (the edge of the right-of-way), the calculated peak magnetic field is 25.19 mG. Peak magnetic field intensities occur at the maximum turbine output from the Plum Creek Wind farm, which is approximately 815amps at 345kV. Maximum field levels occur under the conductors on the side of the structure with two phases. Magnetic field values will not change based on conductor selection, thus only one set of results is provided.

Normal magnetic field strengths when the Plum Creek Wind project is in operation will be of much weaker intensity than the reported maximum values. Actual current flow and associated magnetic fields will vary throughout the day as wind speed changes, and turbine output varies. It is anticipated that peak output of the wind farm will occur a limited number of times throughout a given year.

There are no federal or Minnesota state regulations on maximum magnetic field intensity, however, Florida and New York both limit the magnetic fields on new transmission lines to 200 MilliGauss at the edge of the right of way. The peak magnetic field intensity on the Plum Creek Wind project is below this level.

Table 1.A: Single Circuit Magnetic Field Input Data

Bundle	Bundle Description	X-Position [ft]	Y-Position [ft]	Current [A]	Phase Orientation Angle
1	"Cardinal" Or “Bittern”	12	27.25	815.1	0
2	"Cardinal" Or “Bittern”	-12	42.25	815.1	120
3	"Cardinal" Or “Bittern”	12	57.25	815.1	240

Table 1.B: Single Circuit Calculated Magnetic Field Results											
Negative X-Direction From Centerline											
Distance From Centerline [ft]	-75	-65	-55	-45	-35	-25	-20	-15	-10	-5	0
Magnetic Field Strength [mG]	19.86	24.99	32.02	41.74	55.01	72.36	82.43	93.12	104.01	114.43	123.27
Positive X-Direction From Centerline											
Distance From Centerline [ft]	0	5	10	15	20	25	35	45	55	65	75
Magnetic Field Strength [mG]	123.27	128.94	129.62	124.44	114.32	101.54	76.07	56.18	42.07	32.20	25.19

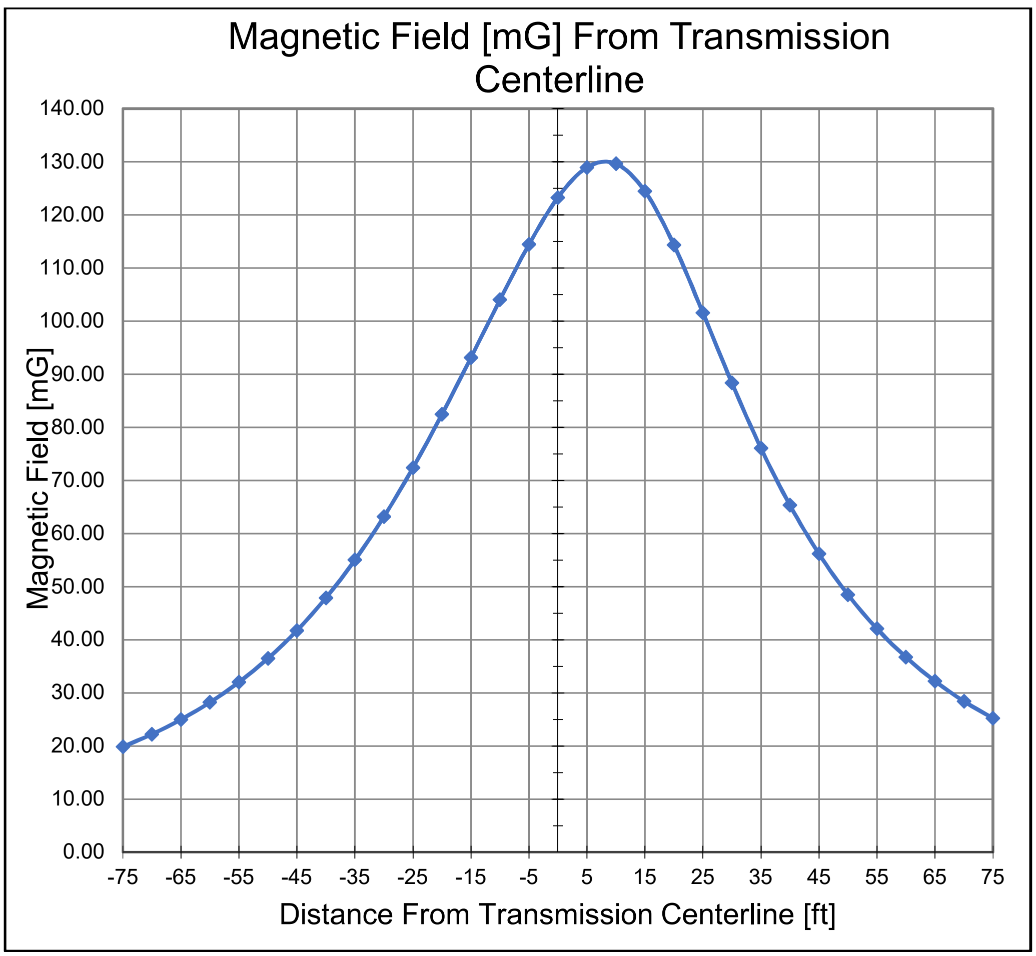

Figure 1: Single Circuit Maximum Magnetic Field Strength in milliGauss
(one meter above ground, at distances in feet from the transmission centerline, single pole)

Single Circuit - Electric Field

The maximum calculated electric field for the single circuit “Cardinal” configuration is 6.80 kV/m at 15 feet from the proposed transmission centerline. At 75 feet from the proposed transmission centerline (the edge of the proposed right-of-way), the calculated electric field is 0.92 kV/m. The maximum calculated electric field for the single circuit “Bittern” configuration is 6.89 kV/m at 15 feet from the proposed transmission line centerline and 0.93 kV/M at 75 feet from the proposed centerline (edge of proposed right of way). The maximum electric field for both options occurs 15 feet offset from the transmission centerline due to the delta phase configuration of the single circuit transmission line structures (two phase conductors on one side of the pole, and a single on the opposite side of the pole). Maximum field levels occur directly under the phase conductor on the side of the structure with two phases. Figure 2 & 3 below illustrate the electric field intensity as compared to the proposed transmission centerline.

Table 2.A: Single Circuit Electric Field Input Data – “Cardinal”

Bundle	Bundle Description	X-Position [ft]	Y-Position [ft]	# Cond.	Cond. Dia [in]	Cond. Spacing [in]	Line to Neutral Voltage [kV]	Phase Orientation Angle
1	"Cardinal"	12	27.25	2	1.196	18	209.15	0
2	"Cardinal"	-12	42.25	2	1.196	18	209.15	120
3	"Cardinal"	12	57.25	2	1.196	18	209.15	240
4	OPGW	7	80.25	1	0.528	0	0	0
5	EHS	-7	80.25	1	0.375	0	0	0

Table 2.B: Single Circuit Calculated Electric Field Results – “Cardinal”

Negative X-Direction From Centerline											
Distance From Centerline [ft]	-75	-65	-55	-45	-35	-25	-20	-15	-10	-5	0
Electric Field Strength [kV/M]	0.92	1.20	1.58	2.04	2.51	2.80	2.82	2.82	3.01	3.65	4.72
Positive X-Direction From Centerline											
Distance From Centerline [ft]	0	5	10	15	20	25	35	45	55	65	75
Electric Field Strength [kV/M]	4.72	5.86	6.66	6.80	6.29	5.37	3.39	2.04	1.31	0.94	0.73

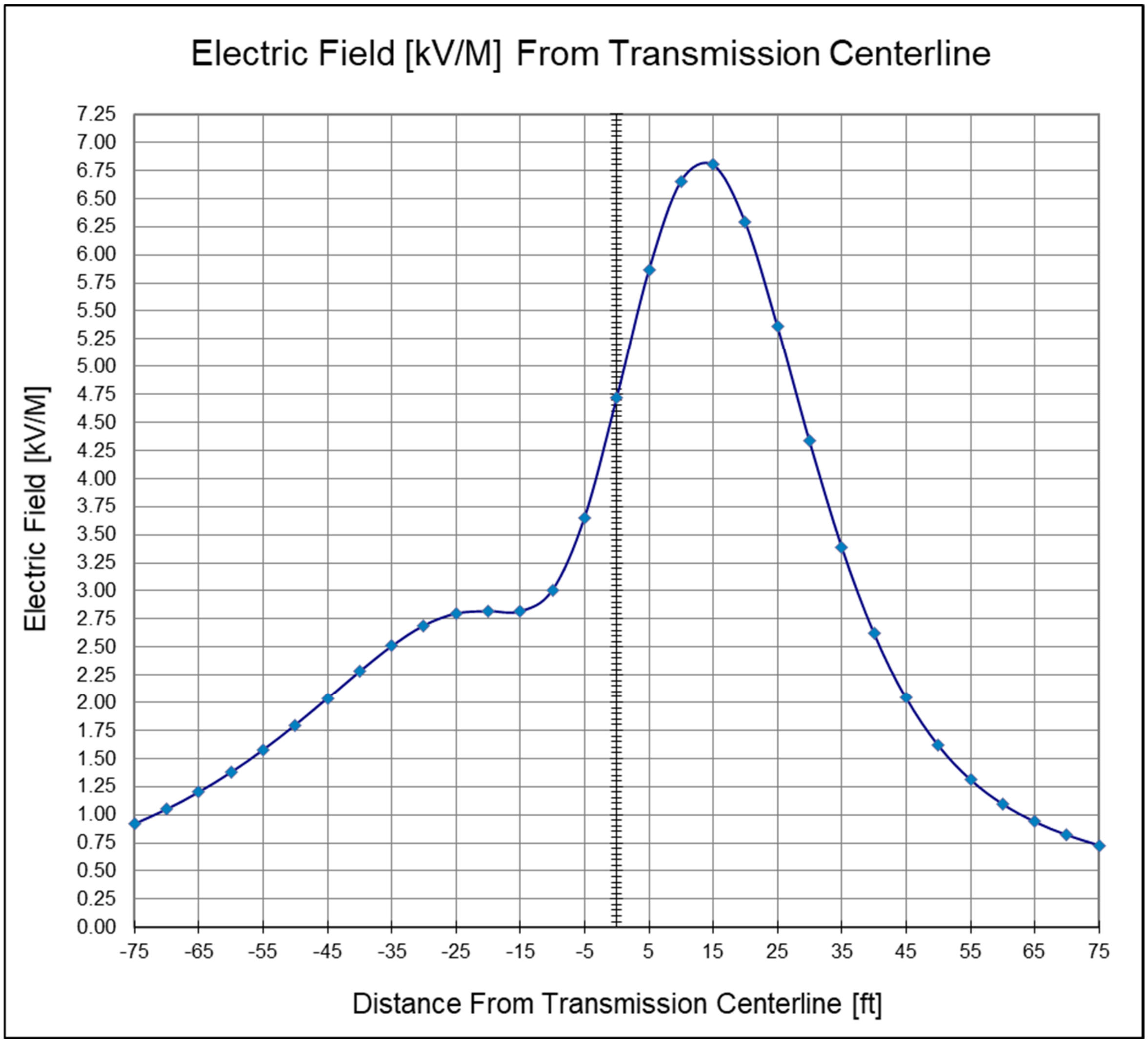

Figure 2: Single Circuit Maximum Electric Field Strength in kV/M – "Cardinal"
(one meter above ground, at distances in feet from the transmission centerline, single pole, delta configuration)

Table 3.A: Single Circuit Electric Field Input Data – "Bittern"								
Bundle	**Bundle Description**	**X-Position [ft]**	**Y-Position [ft]**	**# Cond.**	**Cond. Dia [in]**	**Cond. Spacing [in]**	**Line to Neutral Voltage [kV]**	**Phase Orientation Angle**
1	"Bittern"	12	27.25	2	1.345	18	209.15	0
2	"Bittern"	-12	42.25	2	1.345	18	209.15	120
3	"Bittern"	12	57.25	2	1.345	18	209.15	240
4	OPGW	7	80.25	1	0.528	0	0	0
5	EHS	-7	80.25	1	0.375	0	0	0

Table 3.B: Single Circuit Calculated Electric Field Results – "Bittern"											
Negative X-Direction From Centerline											
Distance From Centerline [ft]	-75	-65	-55	-45	-40	-30	-20	-15	-10	-5	0
Electric Field Strength [kV/M]	0.93	1.22	1.60	2.06	2.31	2.73	2.86	2.86	3.05	3.70	4.78
Positive X-Direction From Centerline											
Distance From Centerline [ft]	0	5	10	15	20	30	40	45	55	65	75
Electric Field Strength [kV/M]	4.78	5.94	6.75	6.89	6.37	4.39	2.66	2.07	1.33	0.95	0.74

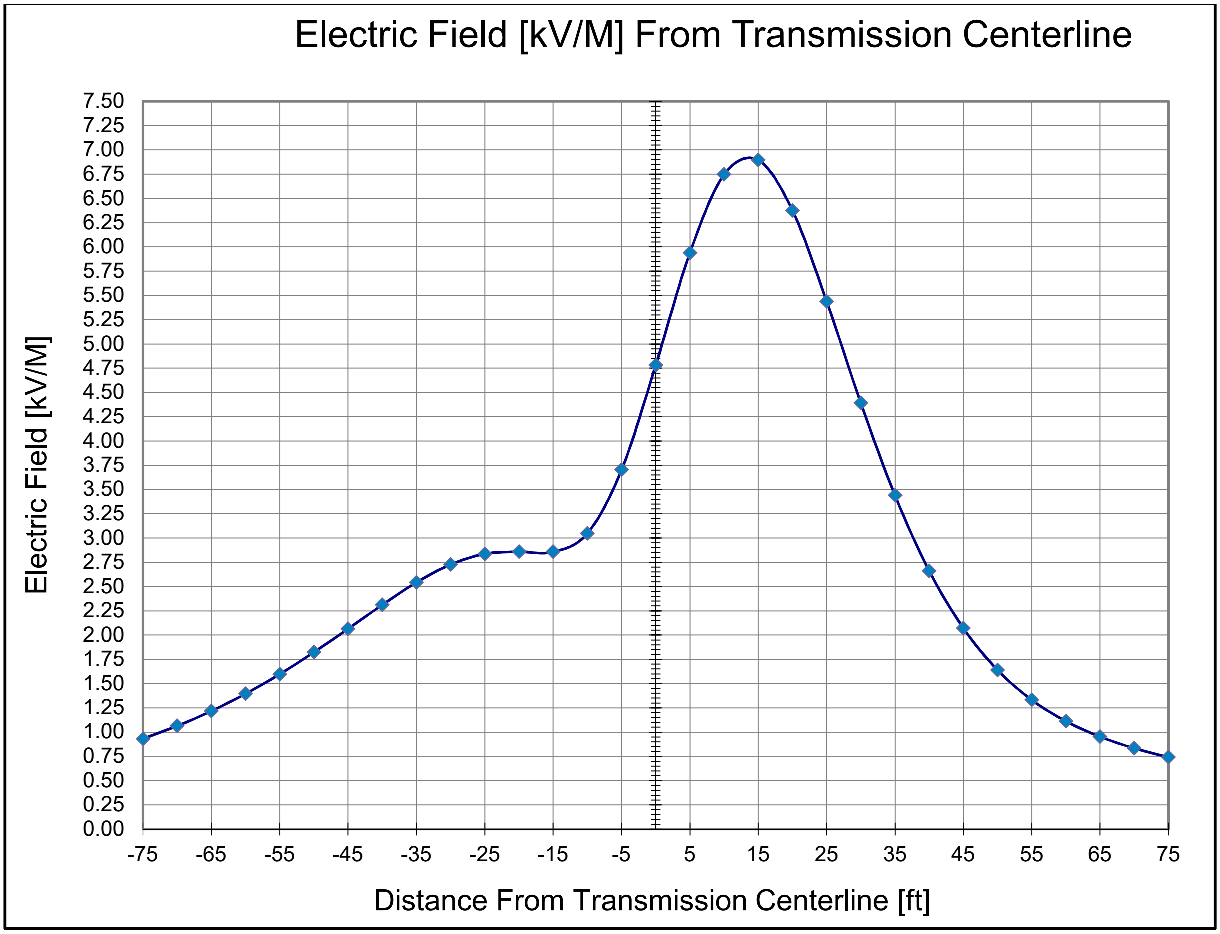

Figure 3: Single Circuit Maximum Electric Field Strength in kV/M – "Bittern"
(one meter above ground, at distances in feet from the transmission centerline, single pole, delta configuration)

Conclusions

It is considered acceptable in Minnesota for new transmission line designs to limit maximum electric fields to 8 kV/m anywhere within the right-of-way. The Plum Creek Wind project electric field levels will be below this threshold for the single circuit transmission structures.

The electric and magnetic field levels are within industry and state acceptable limits for the 954 kcmil 54/7 "Cardinal" ACSR and 1272 45/7 "Bittern" conductor considered. No adverse impacts are anticipated based on the study results, therefore no mitigation is required at this time.

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