6. TRANSMISSION LINE OPERATING CHARACTERISTICS

Chapter 6: Transmission Line Operating Characteristics: provides information regarding the operating characteristics of the proposed 345 kV transmission lines and associated substations. This includes information regarding electric and magnetic fields, noise, ozone and nitrogen oxide emissions, and potential radio and television interference.

Key Terms:

- ***Conductor*** – a wire made up of multiple strands, most often aluminum but can also include steel and sometimes copper, that together carry electricity. A bundled conductor is two or more of these "wires" connected together in parallel to increase the electrical capacity of a transmission line.
- ***Corona discharge*** – the breakdown or ionization of air within a few centimeters or less immediately surrounding conductors and can produce ozone and oxides of nitrogen in the air surrounding the conductor. While transmission lines are designed to limit this effect, imperfection on a conductor such as a scratch on the wire, or a protrusion on hardware, can cause this corona discharge to be noticeable from ground level.
- ***Electric fields*** – are created by the electric charge (i.e., voltage) on a conductor. Electric fields are solely dependent upon the voltage of a conductor. Electric field strength is measured in kV per meter (kV/m). The strength of an electric field decreases rapidly as the distance from the source increases. Electric fields are created anytime electricity is present even when current is not flowing or the electric device is not turned on.
- ***Extremely Low Frequency*** – this term is used to identify electric and magnetic fields within the range of 1 to 300 Hertz. Transmission lines in the United States operate at 60 Hertz.
- ***Magnetic Fields*** – are created by and are solely dependent upon the electric current in the conductor. Magnetic field strength is measured in milliGauss (mG). The strength of a magnetic field decreases rapidly as the distance from the source increases. Any device that uses electric current creates a magnetic

field. Magnetic fields generated by electric lines are in the extremely-low-frequency (ELF) range of electromagnetic spectrum.

6.1 Transmission Line Operating Characteristics Overview

The major components of an overhead transmission line include: (1) an above ground structure typically made from wood or steel, often referred to as a pole or tower; (2) the wires attached to the structure and carrying the electricity, called conductors; (3) insulators connecting the conductors to the structures to provide structural support and electrical insulation; (4) shield wires which protect the line from direct lightning strikes; and (5) ground rods located below ground and connected at each structure.

During operation, transmission lines are, for the most part, passive elements of the environment as they are stationary in nature with few, if any, moving parts. Their primary impact is aesthetic, i.e., a man-made structure in the landscape. Due to the physics of how electricity works, some chemical reactions occur around conductors in the air: noise can occur in some circumstances; interference with electromagnetic signals can occur; and electrical and magnetic fields are created around the conductors. All of these operating characteristics are considered when designing the transmission line to prevent any significant impacts to its operation and to the overall environment.

6.2 Ozone and Nitrogen Oxide Emissions

Corona consists of the breakdown or ionization of air within a few centimeters of conductors. Usually some imperfection such as a scratch on the conductor or a water droplet is necessary to induce corona discharge because transmission lines are designed to be corona free under typical operating conditions. Corona can produce ozone and oxides of nitrogen in the air surrounding the conductor. Ozone also forms in the lower atmosphere from lightning discharges and from reactions between solar ultraviolet radiation and air pollutants, such as hydrocarbons from auto emissions. The natural production rate of ozone is directly proportional to temperature and sunlight, and inversely proportional to humidity. Thus, humidity or moisture, the same factor that increases corona discharges from transmission lines, inhibits the production of ozone. Ozone is a very reactive form of oxygen molecule and combines readily with other elements and compounds in the atmosphere. Because of its reactivity, it is relatively short-lived.

Currently, both state and federal governments have regulations regarding permissible concentrations of ozone and oxides of nitrogen (NO_x). The state and national ambient air quality standards for ozone are similarly restrictive. The national standard is 0.07 parts per million (ppm) on an eight-hour averaging period. The state standard is 0.08 ppm based on the fourth highest eight-hour daily maximum average in one year. Both averages must be compared to the national and state standards because of the different averaging periods. Calculations done for a 345 kV project showed that the maximum one-hour concentration during foul weather (worst case) would be 0.0007 ppm. This is well below both federal and state standards. Most calculations of the production and concentration of ozone assume high humidity or rain, with no reduction in the amount of ozone due to oxidation or air movement. These calculations would therefore overestimate the amount of ozone that is produced and concentrated at ground level. Studies designed to monitor the production of ozone under transmission lines have generally been unable to detect any increase due to the transmission line facility.

The national standard for nitrogen dioxide (NO_2), one of several oxides of nitrogen, is 100 parts per billion (ppb) and the annual standard is 53 ppb. The State of Minnesota is currently in compliance with the national standards for NO_2. The operation of the proposed transmission lines would not create any potential for the concentration of these pollutants to exceed the nearby (ambient) air standards.

6.3 Noise

6.3.1 Transmission Line Noise

Generally, activity-related noise levels during the operation and maintenance of substations and transmission lines is minimal.

Transmission conductors can produce noise under certain conditions. The level of noise depends on conductor conditions, voltage level, and weather conditions. Noise emission from a transmission line occurs during certain weather conditions. In foggy, damp, or rainy weather, power lines can create a crackling sound due to the small amount of electricity ionizing the moist air near the wires. During heavy rain, the background noise level of the rain is usually greater than the noise from the transmission line. As a result, people do not normally hear noise from a transmission line during heavy rain. During light rain, dense fog, snow, and other times when there is moisture in the air, transmission lines will produce audible noise equal to approximately household background levels. During dry weather, audible noise from transmission lines is barely perceptible by humans.

6.3.2 Substation Noise

Substations may also contribute noise. Transformer or shunt reactor "hum" is the dominant noise source at substations if such equipment exists. At substations without transformers or shunt reactors, only infrequent noise sources would exist such as the opening and closing of circuit breakers or the operation of an emergency generator. All of the substation modifications required for the Project will comply with the Minnesota Pollution Control Agency (MPCA) Noise Area Classification noise standards as set forth in Minnesota Rule 7030.0040.

6.4 Radio, Television, and GPS Interference

Overhead transmission lines are designed to not cause radio or television interference under typical operating conditions. Corona, as well as spark discharge, from transmission line conductors can generate electromagnetic "noise" at the same frequencies that some radio and analog television signals are transmitted. This noise can cause interference with the reception of these signals depending on the frequency and strength of the radio and television signal. Interference from a spark discharge source can be found and corrected.

If radio interference from transmission line corona does occur, satisfactory reception from AM radio stations previously providing good reception can be restored by appropriate modification of (or addition to) the receiving antenna system. AM radio frequency interference typically occurs immediately under a transmission line and dissipates rapidly within the right-of-way to either side.

FM radio receivers usually do not pick up interference from transmission lines because:

- Corona-generated radio frequency noise currents decrease in magnitude with increasing frequency and are quite small in the FM broadcast band (88-108 Megahertz); and
- The excellent interference rejection properties inherent in FM radio systems make them virtually immune to amplitude-type disturbances.

A two-way mobile radio located immediately adjacent to and behind a large metallic structure (such as a steel tower) may experience interference because of signal-blocking effects. Movement of either mobile unit so that the metallic structure is not immediately between the two units should restore communications. This would generally require a movement of less than 50 feet by the mobile unit adjacent to a metallic tower.

Television interference is rare but may occur when a large transmission structure is aligned very close to the receiver and between the receiver and a weak distant signal, creating a shadow effect. If television or radio interference is caused by or from the operation of the proposed facilities in those areas where good reception is presently obtained, Applicants will take necessary action to restore reception to the present level, including the appropriate modification of receiving antenna systems if deemed necessary.

6.5 Safety

The Project will be designed in compliance with local, state, and NESC standards regarding clearance to ground, clearance to crossing utilities, clearance to buildings, strength of materials, and right-of-way widths. Appropriate standards will be met for construction and installation, and all applicable safety procedures will be followed during and after installation.

The proposed transmission lines will be equipped with protective devices to safeguard the public from the transmission lines if an accident occurs, such as a structure or conductor falling to the ground. The protective devices include breakers and relays located where the line connects to the substation(s). The protective equipment will de-energize the line should such an event occur. Proper signage will be posted warning the public of the risk of coming into contact with the energized equipment.

GPS interference is also not anticipated. Applicants use GPS-based survey equipment directly under transmission lines and have not experienced any problems.

6.6 Electric and Magnetic Fields

"EMF" is an acronym for the terms electric and magnetic fields. For the lower frequencies associated with power lines (referred to as ELF), EMF should be considered separately – electric fields and magnetic fields, measured in kV/m and mG, respectively. Electric fields are dependent on the voltage of a transmission line and magnetic fields are dependent on the current carried by a transmission line. The strength of the electric field is proportional to the voltage of the line, and the intensity of the magnetic field is proportional to the current flow through the conductors. Transmission lines operate at a power frequency of 60 Hertz (cycles per second).

6.6.1 Electric Fields

There is no federal standard for transmission line electric fields. The Commission, however, has imposed a maximum electric field limit of 8 kV/m measured at one meter above the ground.[83] The standard was designed to prevent serious hazards from shocks when touching large objects parked under AC transmission lines of 500 kV or greater. **Figure 29** provides the electric fields at maximum conductor voltage for the proposed 345 kV transmission line. Maximum conductor voltage is defined as the nominal voltage plus five percent. The maximum electric field, measured at one meter (3.28 feet) above ground, associated with the Project is calculated to be 5.19 kV/m. As shown in **Figure 29**, the strength of electric fields diminishes rapidly as the distance from the conductor increases. The electric field values of all of the design options at the edge of the transmission line right-of-way and sample points beyond are shown in **Table 28**.

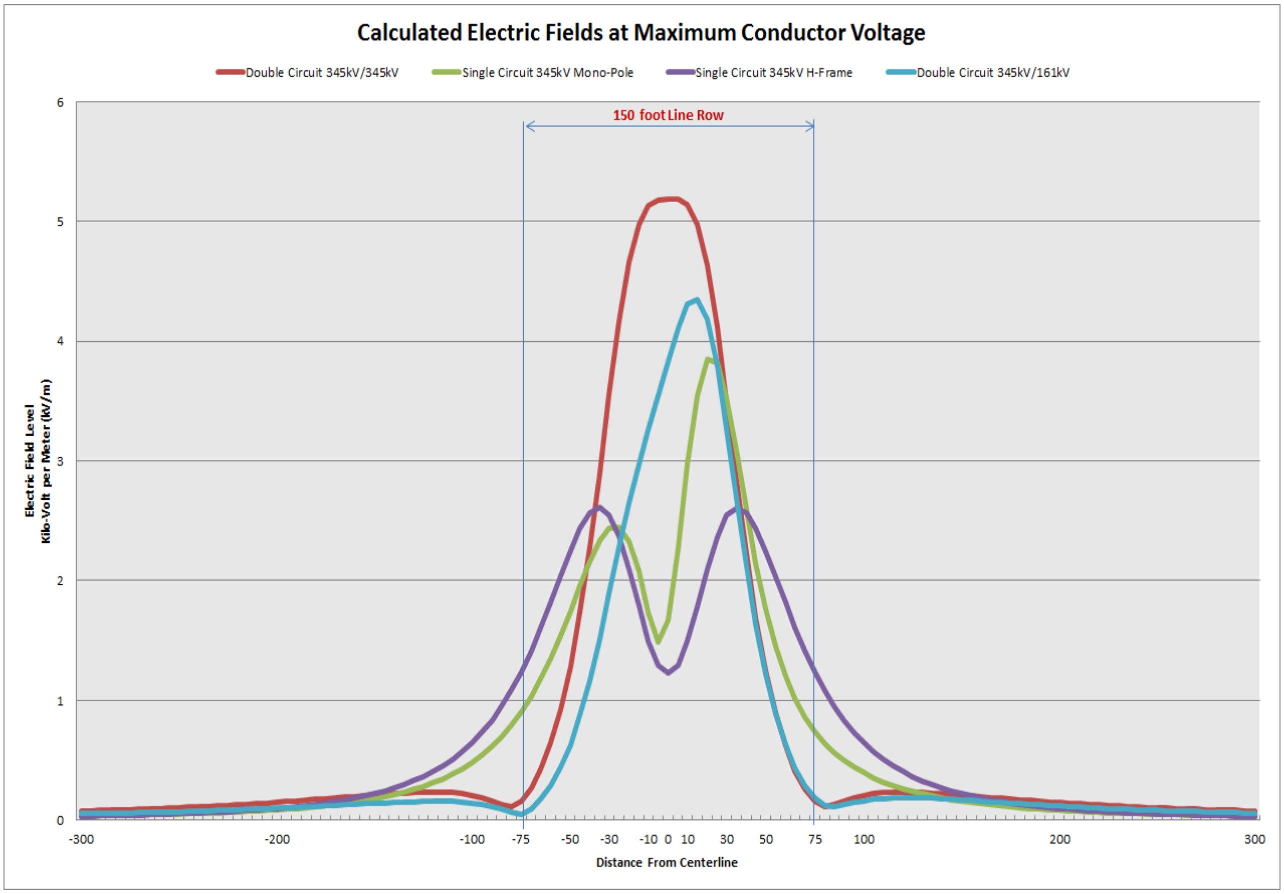
[83] *In the Matter of the Route Permit Application for a 345 kV Transmission Line from Brookings County, S.D. to Hampton, Minn.,* Docket No. ET2/TL-08-1474, ORDER GRANTING ROUTE PERMIT (Sept. 14, 2010) (adopting the Administrative Law Judge's Findings of Fact, Conclusions, and Recommendation at Finding 194).

Table 28
Electric Field Calculations

Structure Type	Nominal Voltage	Distance to Proposed Centerline (feet)												
		-300	-200	-100	-75	-50	-25	0	25	50	75	100	200	300
345 kV Single-Circuit Monopole	362 kV	0.03	0.09	0.48	0.91	1.75	2.45	1.67	3.82	1.76	0.74	0.39	0.08	0.03
345 kV/345 kV Double-Circuit Monopole	362 kV	0.08	0.15	0.21	0.16	1.29	4.16	5.19	4.11	1.25	0.15	0.21	0.15	0.08
345 kV Single-Circuit H-frame	362 kV	0.03	0.10	0.65	1.24	2.25	2.37	1.23	2.37	2.25	1.24	0.65	0.10	0.03
345 kV/161 kV Double-Circuit Monopole[84]	362 kV - 169 kV	0.05	0.10	0.14	0.05	0.63	2.28	3.83	3.79	1.22	0.18	0.16	0.12	0.06

[84] The 345/115 kV structure design will have similar (although slightly lower) electric field calculations as the 345/161 kV structure design.

Figure 29
Calculated Electric Fields (kV/m) for Proposed 345 Kilovolt Transmission Line Designs (3.28 feet above ground)*



*The colors in the figure represent different design options and do not represent route alternatives.

6.6.2 Magnetic Fields

The projected magnetic fields for different structure and conductor configurations for the Project are provided in **Figure 30**, **Figure 31,** and **Table 29**. Since magnetic fields are dependent on the current flowing on the line, magnetic fields were calculated for two different typical system conditions during the Project's first-year in service (2022). These two scenarios are: (1) System Peak Energy Demand and (2) High Wind Utilization. The assumed current for each scenario is provided in amps or MVA.

The "System Peak Energy Demand" current flow (estimated loading of 50 MVA), represents the current flow on the line during the peak hour of system-wide energy demand and is shown in **Figure 30** and **Table 29**. Typically, the peak hour of system-wide energy demand on the NSP system is characterized by a summer day with high temperatures and low levels of wind generation.

Magnetic fields were also calculated for "High Wind Utilization" current flow (estimated loading of 375 MVA), as shown in **Figure 31** and **Table 29**. This scenario represents the current flow on the line during a non-peak time (winter months) when there is high levels of wind generation and the transmission system is intact (i.e., no outages).

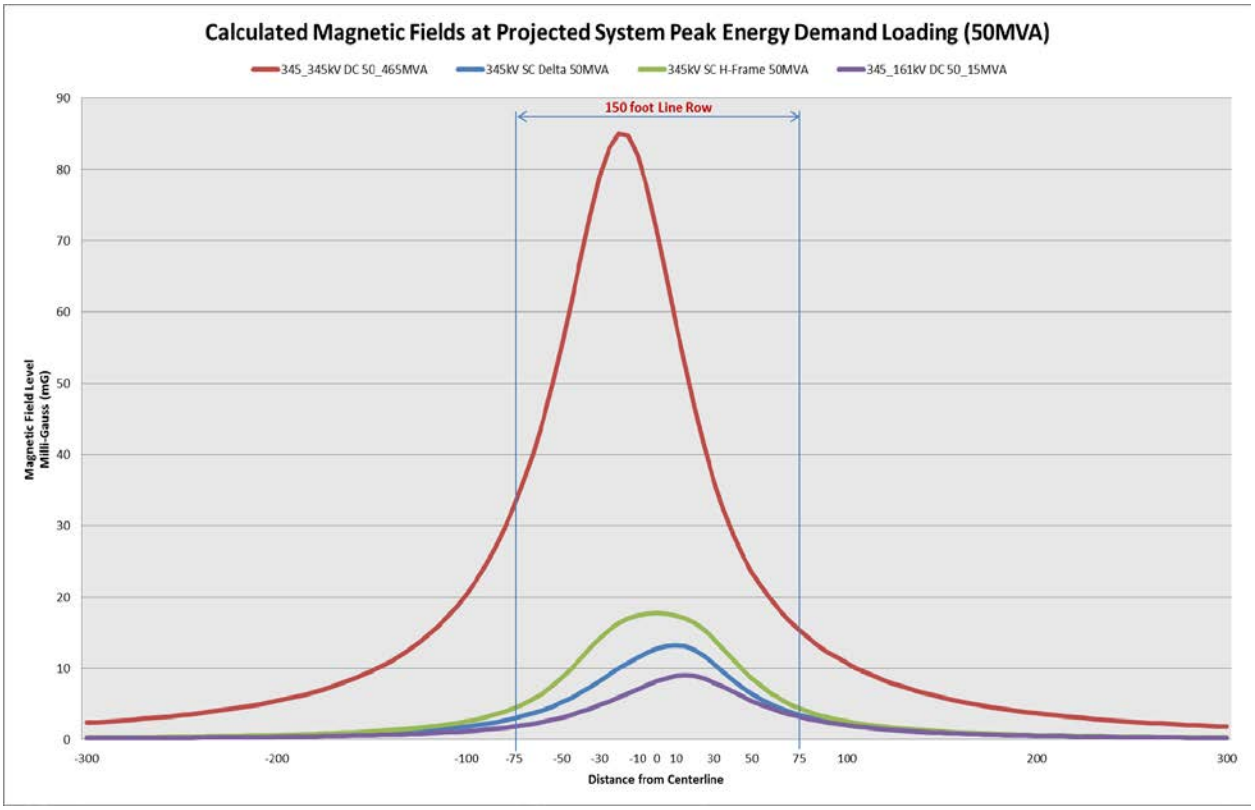
The magnetic field values for the two scenarios were calculated at a point where the conductor is closest to the ground. The magnetic field data shows that magnetic field levels decrease rapidly as the distance from the centerline increases (proportional to the inverse square of the distance from source). In addition, since the magnetic field produced by the transmission line is dependent on the current flow, the actual magnetic fields when the Project is placed in service will vary as the current flow on the line changes throughout the day.

Table 29
Magnetic Field Calculations

Structure Type	System Condition	Current (Amps)	Distance to Proposed Centerline (feet)												
			-300	-200	-100	-75	-50	-25	0	25	50	75	100	200	300
345 kV Single-Circuit Monopole	System Peak Energy Demand (50 MVA)	84	0.24	0.52	1.86	2.99	5.22	9.11	12.73	11.76	6.46	3.49	2.10	0.56	0.25
	High Wind Utilization (375 MVA)	628	1.78	3.90	13.92	22.31	38.92	67.94	94.86	87.58	48.21	26.06	15.70	4.16	1.86
345 kV/345 kV Double-Circuit Monopole	Peak System Energy Demand (50 MVA/465 MVA)	84/778	2.37	5.43	20.45	32.73	55.17	82.98	71.58	41.11	23.62	15.38	10.73	3.72	1.83
	High Wind Utilization (375 MVA/940 MVA)	682/1573	4.44	10.24	39.62	64.36	110.58	170.30	154.94	90.68	46.90	29.29	20.26	6.96	3.40
345 kV Single-Circuit H-frame	Peak System Energy Demand (50 MVA)	84	0.29	0.65	2.57	4.43	8.65	15.40	17.75	15.40	8.64	4.42	2.57	0.65	0.29
	High Wind Utilization (375 MVA)	628	2.17	4.90	19.52	34.13	69.16	129.36	148.73	129.32	69.12	34.11	19.51	4.89	2.17
345 kV/161 kV Double-Circuit Monopole[85]	Peak System Energy Demand (50 MVA/15 MVA)	84/54	0.19	0.38	1.21	1.86	3.12	5.39	8.16	8.59	5.48	3.24	2.03	0.55	0.24
	High Wind Utilization (375 MVA/45 MVA)	682/162	1.48	3.03	9.08	13.42	21.38	36.33	59.11	65.63	42.74	25.40	15.97	4.30	1.89

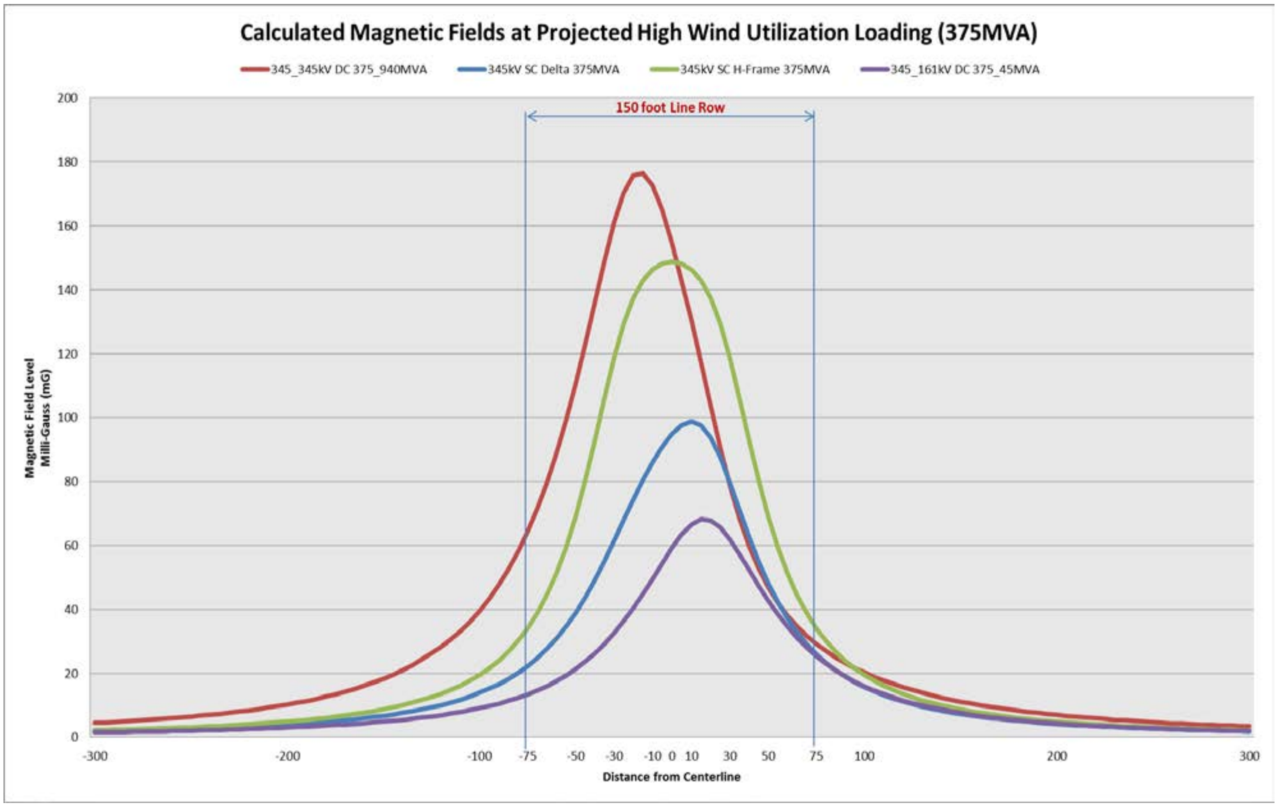
[85] The 345 kV/115 kV structure design will have similar magnetic field calculations to the 345 kV/161 kV structure design.

Figure 30*
Calculated Magnetic Flux density (mG) for Proposed 345 Kilovolt Transmission Line Designs at System Peak Energy Demand Loading (3.28 feet above ground)



* The colors in the figure represent different design options and do not represent route alternatives.

Figure 31*
Calculated Magnetic Flux density (mG) for Proposed 345 Kilovolt Transmission Line Designs at High Wind Utilization Loading (3.28 feet above ground)



* The colors in the figure represent different design options and do not represent route alternatives.

Applicants acknowledge that it is possible that the current flow on the proposed 345 kV line may, under certain system contingencies (i.e., lines are out of service), be higher than what is projected under these two scenarios. However, such system contingencies are rare and the high current flow will only persist for a limited time (i.e., no more than five minutes). The above two scenarios illustrate the typical current flow for the proposed 345 kV line.

There are presently no Minnesota regulations pertaining to magnetic field exposure. Applicants provide information to the public, interested customers, and employees so they can make informed decisions about magnetic fields. Such information includes the availability for measurements to be conducted for customers and employees upon request.

Considerable research has been conducted since the 1970s to determine whether exposure to power-frequency (60 hertz) magnetic fields causes biological responses and health effects. Public health professionals have also investigated the possible impact of exposure to EMF on human health for the past several decades. While the general consensus is that electric fields pose no risk to humans, the question of whether exposure to magnetic fields can cause biological responses or health effects continues to be debated.

Since the 1970s, a large amount of scientific research has been conducted on EMF and health. This large body of research has been reviewed by many leading public health agencies such as the U.S. National Cancer Institute, the U.S. National Institute of Environmental Health Sciences, and the World Health Organization (WHO), among others. These reviews do not show that exposure to electric power EMF causes or contributes to adverse health effects.

For example, in 2016, the U.S. National Cancer Institute summarized the research as follows:

> Numerous epidemiologic studies and comprehensive reviews of the scientific literature have evaluated possible associations between exposure to non-ionizing EMFs and risk of cancer in children (12–14). (Magnetic fields are the component of non-ionizing EMFs that are usually studied in relation to their possible health effects.) Most of the research has focused on leukemia and brain tumors, the two most common cancers in children. Studies have examined associations of these cancers with living near power lines, with magnetic fields in the home, and with exposure of parents to high levels of magnetic fields in the workplace. No consistent evidence for an association between any source of non-ionizing EMF and cancer has been found.[86]

[86] NAT'L CANCER INSTITUTE, *Electromagnetic Fields and Cancer* (updated May 27, 2016), *available at* https://www.cancer.gov/about-cancer/causes-prevention/risk/radiation/electromagnetic-fields-fact-sheet.

Wisconsin, Minnesota, and California have all conducted literature reviews or research to examine this issue. In 2002, Minnesota formed an Interagency Working Group (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 and published its findings in a White Paper on Electric and Magnetic Field (EMF) Policy and Mitigation Options in September 2002, (Minnesota Department of Health, 2002). The report summarized the findings of the Working Group as follows:

> Research on the health effects of [MF] has been carried out since the 1970s. Epidemiological studies have mixed results – some have shown no statistically significant association between exposure to [MF] 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 [MF] and health effects; however, many of them also concluded that there is insufficient evidence to prove that [MF] exposure is safe. (*Id.* at p. 1.)

The Commission, based on the Working Group and WHO findings, has repeatedly found that "there is insufficient evidence to demonstrate a causal relationship between EMF exposure and any adverse human health effects."[87]

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[87] *In the Matter of the Application of Xcel Energy for a Route Permit for the Lake Yankton to Marshall Transmission Line Project in Lyon County*, Docket No. E002/TL-07-1407, FINDINGS OF FACT, CONCLUSIONS OF LAW AND ORDER ISSUING A ROUTE PERMIT TO XCEL ENERGY FOR THE LAKE YANKTON TO MARSHALL TRANSMISSION PROJECT at 7-8 (Aug. 29, 2008); *see also In the Matter of the Application for a HVTL Route Permit for the Tower Transmission Line Project*, Docket No. ET2, E015/TL-06-1624, FINDINGS OF FACT, CONCLUSIONS OF LAW AND ORDER ISSUING A ROUTE PERMIT TO MINNESOTA POWER AND GREAT RIVER ENERGY FOR THE TOWER TRANSMISSION LINE PROJECT AND ASSOCIATED FACILITIES at

6.7 Stray Voltage and Induced Voltage

"Stray voltage" is a condition that can potentially occur on a property or on the electric service entrances to structures from distribution lines connected to these structures-not transmission lines as proposed here. The term generally describes a voltage between two objects where no voltage difference should exist. More precisely, stray voltage is a voltage that exists between the neutral wire of either the service entrance or of premise wiring and grounded objects in buildings such as barns and milking parlors. The source of stray voltage is a voltage that is developed on the grounded neutral wiring network of a building and/or the electric power distribution system.

Transmission lines do not, by themselves, create stray voltage because they do not connect directly to businesses or residences. Transmission lines, however, can induce voltage on a distribution circuit that is parallel and immediately under the transmission line. If the proposed transmission lines parallel or cross distribution lines, appropriate mitigation measures can be taken to address any induced voltages. For additional information regarding stray voltage, please see the Minnesota Stray Voltage Guide that is available online at: www.minnesotastrayvoltageguide.com or contact your electrical utility provider.

6.8 Farming Operations, Vehicle Use, and Metal Buildings near Power Lines

The power lines will be designed to meet or exceed minimum clearance requirements with respect to electric fencing as specified by the NESC. Nonetheless, insulated electric fences used in livestock operations can be instantly charged with an induced voltage from transmission lines. The induced charge may continuously drain to ground when the charger unit is connected to the fence. When the charger is disconnected either for maintenance or when the fence is being built, shocks may result. The local electrical utility can provide site specific information about how to prevent possible shocks when the charger is disconnected.

23 (Aug. 1, 2007) ("Currently, there is insufficient evidence to demonstrate a causal relationship between EMF exposure and any adverse human health effects.").

Farm equipment, passenger vehicles, and trucks may be safely used under and near power lines. The power lines will be designed to meet or exceed minimum clearance requirements with respect to roads, driveways, cultivated fields, and grazing lands as specified by the NESC. Recommended clearances within the NESC are designed to accommodate a relative vehicle height of 14 feet.

Vehicles, or any conductive body, under high voltage transmission lines will be immediately charged with an electric charge. Without a continuous grounding path, this charge can provide a nuisance shock. Such nuisance shocks are a rare event because generally vehicles are effectively grounded through tires. Modern tires provide an electrical path to ground because carbon black, a good conductor of electricity, is added when they are produced. Metal parts of farming equipment are frequently in contact with the ground when plowing or engaging in various other activities. Therefore, the induced charge on vehicles will normally be continually flowing to ground unless they have unusually old tires or are parked on dry rock, plastic, or other surfaces that insulate them from the ground. Applicants can provide additional vehicle-specific methods for reducing the risk of nuisance shocks in vehicles.

Buildings are permitted near transmission lines but are generally discouraged within the right-of-way itself because a structure under a line may interfere with safe operation of the transmission facilities. For example, a fire in a building within the right-of-way could damage a transmission line. The NESC establishes minimum electrical clearance zones from power lines for the safety of the general public and utilities often acquire easement rights that require clear areas in excess of these established zones. Utilities may permit encroachment into that easement for buildings and other activities when they can be deemed safe and still meet the NESC minimum requirements. Metal buildings may have unique issues due to induction concerns. For example, conductive buildings near power lines of 200 kV or greater must be properly grounded. Any person with questions about a new or existing metal structure can contact the Applicants for further information about proper grounding requirements.