Technical Memorandum

White Paper on High-Voltage Direct Current Transmission Lines and Electronic Devices

Prepared for

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Introduction

Exponent was retained by Clean Line Energy to provide a high-level technical assessment of the potential for the performance of electronic devices to be affected by its proposed high-voltage direct current (HVDC) transmission lines.[1]

HVDC is a well-established technology with over half a century of safe and reliable operation across the world and is particularly well-suited to transport large amounts of renewable power generated in remote areas over long distances to demand centers. Some landowners have asked for information about potential effects of HVDC transmission lines on various communication devices and implanted medical devices. Information about television and radio reception, cell phones, wireless internet, and global positioning system (GPS) satellite receivers is discussed in the section on electric fields. The section on magnetic fields discusses standards throughout the world and research regarding potential effects on implanted medical devices.

[1] This report summarizes work performed to date and presents the findings resulting from that work. For this report we reviewed information about proposed Clean Line HVDC lines and the technical literature. Exponent has exercised usual and customary care in the conduct of this review and the findings presented herein are made to a reasonable degree of engineering and scientific certainty. Exponent reserves the right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available, through any additional work, or review of additional work performed by others. The scope of services performed during this investigation may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented herein are at the sole risk of the user. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

Electric Fields

Many people are familiar with static electricity, experienced commonly as a shock after walking across a carpet and then touching a doorknob. What may be less familiar is the importance of actually reaching for the doorknob. The electric field, which is created by the accumulated static electricity, is concentrated at the ends of outstretched fingers when reaching for the doorknob. It is this concentrated electric field which causes an electrical breakdown of the air and results in a small shock. A similar process occurs at the surface of high-voltage power-line conductors such as those used on HVDC transmission lines. The electric field surrounding a transmission line becomes concentrated on surface irregularities such as nicks or debris and causes the electrical breakdown of air, just like in the example of the doorknob. When this happens on a transmission line, a tiny amount of energy is released. This energy is called corona. One of the effects of corona is radio noise which has the potential to affect television and radio reception.

This is illustrated by the dark blue curve in Figure 1, which represents the magnitude of corona-generated radio noise. The radio noise from the HVDC line decreases rapidly with frequency so that devices operating at higher frequencies (such as GPS, cell phones, and wireless internet) are far less likely to be affected by radio noise than devices which operate at lower frequencies (such as amplitude-modulated [AM] radio stations). This source of radio noise is most intense directly beneath transmission lines and decreases rapidly with distance away from the lines.

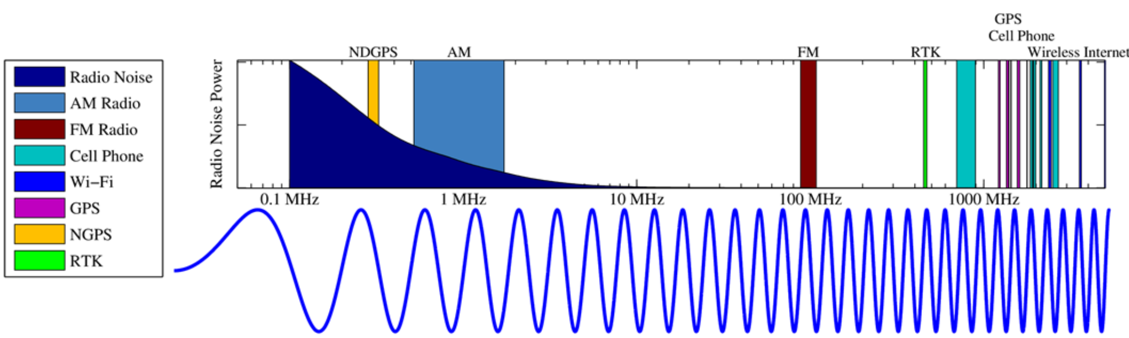

Figure 1. Magnitude of corona-generated radio noise and frequency range of various technology

Television and Radio Reception

The radio noise produced by corona associated with overhead transmission lines can occur at frequencies that are used for the transmission of radio signals; however the power of radio noise from a transmission line decreases rapidly with increasing frequency as shown in Figure 1. While radio noise from a transmission line may exist at any frequency between 0.5 megahertz (MHz) and 1,000 MHz, it more strongly affects devices operating at lower frequencies such as AM radio signals (520 to 1,720 kilohertz [kHz]). Frequency modulated (FM) radio stations (transmitting at a frequency between 88 and 108 MHz) generally are not affected by radio noise from transmission lines because their frequency of operation is much higher and because their mode of operation is different. In the past, radio noise was also a concern for the video portion of analog television signals; however, this is no longer the case in the United States because broadcast television stations have switched to digital broadcasting and no longer transmit older analog AM video signals.

Cell Phones

Also shown in Figure 1 is the frequency band of cell phones that receive and transmit radiofrequency (RF) signals ranging from 850 MHz to 2,150 MHz. While transmission lines can produce measurable radio noise in the AM RF band, the radio noise from a HVDC transmission line is so weak at the high frequencies used by cell phones it does not interfere with a cell phone's functioning even when nearby a HVDC transmission line.

Wireless Internet

Most wireless internet operates at a frequency of 2.4, 3.6, or 5 gigahertz (GHz). As shown in Figure 1, the level of radio noise from a HVDC transmission line is so small at these frequencies that it effectively does not overlap with wireless internet signals and, therefore, does not affect wireless internet function.

Global Positioning System

GPS is a space-based navigation system that relies on signals from orbiting satellites above Earth to establish the position of a GPS receiver on the ground. This concept is illustrated in Figure 2, in which satellites are synchronized to simultaneously transmit a signal containing information about the time and location of each satellite. A receiver on the ground collects the signals from three or more of these satellites and uses the information to determine its location.

Figure 2. Orbiting satellites

Under ideal conditions, the information that reaches the GPS receiver is exactly the same as the information sent by the satellite and the receiver can calculate a precise and accurate location. Errors in the calculated location can occur, however, if the quality of the signal is degraded somewhere between the satellite and the receiver. This can occur if another RF signal interferes with the reception of the GPS signal—a phenomenon comparable to listening to someone speak across a noisy room. Their voice (signal) may be drowned out by all the other “noise” in the room. Another source of GPS signal degradation is distortion of the signal itself—comparable to listening to someone speak on a windy day or listening to a conversation through a thick wall. In these cases, the message is “blown away” or “blocked” before it reaches you.

A well-known limitation of GPS is that buildings and trees can physically block the signal. This blocking effect theoretically also can be caused by transmission line towers, although they present a very much smaller cross section. Naturally-occurring sources of RF (e.g., geomagnetic storms) and man-made sources of RF (e.g., television transmitters) sometimes are reported to interfere with GPS signals because these sources produce interference *in the same frequency range as GPS signals.* GPS signals are transmitted at a far higher frequency, however, than the radio noise of a HVDC transmission line as shown in Figure 1. Measurements taken beneath HVDC transmission lines have shown no significant signal degradation from radio noise or signal blocking by towers and no effect on the proper function of a GPS receiver [1].

A more common problem for GPS receivers is the distortion of the signal as it passes through random fluctuations in the ionosphere. Like spoken words on a windy day, sometimes some of the GPS message gets through, but it is often distorted and in need of clarification or correction. To address this problem, modern GPS receivers can receive corrections from a number of satellite-based systems with frequencies above 1 GHz to improve the accuracy of positional location [1-4, 6-10]; this is called differential GPS (DGPS).

Some GPS systems also make use of real-time kinematic (RTK) technique to improve the accuracy of the GPS location information by making use of the ultra high frequency (UHF) range [2, 10]. Since the frequency bands of these systems are far higher than the primary radio noise frequencies produced by a HVDC transmission line [4, 11], signal interference is unlikely to occur [1]. One scenario where an HVDC transmission line may have some effect on GPS performance is on a system using Nationwide Differential GPS (NDGPS), which is a land-based GPS correction system used in the United States and formerly along the southern border of Canada that was developed to improve GPS accuracy when GPS first became available [2]. NDGPS uses lower frequencies to send correction signals and can sometimes overlap with the primary radio noise frequencies discharged from a HVDC transmission line [5, 11]. The likelihood of interference in each situation will depend on the GPS receiver's distance to the line, as well as its distance to the closest NDGPS antenna. A momentary loss of NDGPS signal, however, should not substantially affect the accuracy of the overall positioning system. Though there is a potential for NDGPS interference by HVDC transmission lines in some locations, NDGPS has been mostly supplanted by newer technologies, and has been eliminated in most land locations in Canada [12].

GPS Use in Agriculture

Extensive measurements made with two agricultural/survey grade GPS receivers around two HVDC transmission lines did not show signal reception or degradation, tower signal blocking, or interference to the reception of RTK positional correction signals above 450 MHz used for farming operations [1]. In addition, since RTK correction signals are transmitted from antennas that are typically only a few meters high, HVDC transmission line towers are not likely to block line-of-sight signals from these sources. In cases where such an event was to occur, repositioning the RTK base station antenna should resolve the issue. Signal degradation can occur due to other unrelated signal reflections and the overall performance of a GPS guidance system in agriculture depends upon a high-quality receiver, installed properly, with good positional correction from an independent source.

Cochlear Implants

In addition to causing radio noise, the electric fields and related corona phenomena of HVDC transmission lines can also lead to a small accumulation of charge on nearby objects. Since there have been reports of damage to cochlear devices caused by the buildup of far larger amounts of static charge, such as from children sliding down plastic gym slides, this possibility has been considered for HVDC transmission lines. Cochlear implants are devices with a small external microphone and a surgically implanted receiver in the auditory portion of the inner ear, which can provide partial hearing to some persons with severe hearing loss. Provided the cochlear implants have been tested for electromagnetic immunity as set forth in the International Electrotechnical Commission's (IEC) medical electrical equipment standards 60601-1-2 and 60601-4-2 [13], the device should also provide immunity to such effects for HVDC transmission lines.

Magnetic Fields

Static (i.e., direct current) magnetic fields are produced by a number of man-made sources, as well as many natural phenomena. The most prevalent static magnetic field is produced by the Earth as a result of the constant flow of current deep within its core—called the geomagnetic field. It is this field that is used for compass navigation. The geomagnetic field ranges in intensity from 300 to 700 milligauss (mG), varying with latitude. It is highest at the magnetic poles and lowest at the equator. In the northern United States, the strength of the geomagnetic field is approximately 550 mG [14].

HVDC transmission lines are also a source of static magnetic fields and, depending on the transmission line's orientation with respect to the geomagnetic field, the magnetic field from an HVDC transmission line can either add to or subtract from the strength of the Earth's geomagnetic field. The static magnetic field levels below overhead HVDC transmission lines are similar to or less than the static magnetic field of the Earth. Unlike electric fields and magnetic fields from power systems that transmit *alternating current*, neither the electric fields nor the magnetic fields of HVDC transmission lines induce significant voltages in objects or nearby persons. Hence, for a HVDC transmission line, only the direct effects of the magnetic field exposure is of interest with respect to implanted medical devices such as cardiac pacemakers, implantable cardioverter defibrillators (ICDs), and pressure shunts since no significant, indirect effects of induced currents and voltages occur.

Pacemakers and Implantable Cardioverter Defibrillators

Pacemakers and ICDs are small, battery-powered devices that are implanted inside patients at risk for various heart conditions. These devices generate an electrical impulse either to regulate the beating of the heart (pacemaker) or to shock the heart back into a normal rhythm (ICDs), when necessary. The magnetic fields of HVDC transmission lines are too weak to affect these devices as explained below.

The Association for the Advancement of Medical Instrumentation (AAMI) has reviewed important parameters and developed recommendations and standards for pacemakers and ICDs that are designed to ensure their safe and proper operation. The AAMI standard states that pacemakers and ICDs shall not be affected by static magnetic fields of up to 1 millitesla (mT) (equivalent to 10,000 mG) and shall not remain functionally affected after exposure to static magnetic fields of up to 50 mT (500,000 mG) [15]. The background level of the geomagnetic field in the northern United States is approximately 550 mG and the increase from a Clean Line transmission project is estimated to be 300 to 600 mG. *Therefore, the exposure of a person with an implanted pacemaker or ICD, even directly under the transmission line, will be approximately 10 times below the lower AAMI recommended limit of 10,000 mG.* If a patient does have a concern about the compatibility of their device with any source, they should consult their physician.

Pressure Shunts

Several medical conditions can lead to increased pressure on the brain from the accumulation of excess fluid, which can occur if fluid flow out of the skull is blocked, if fluid cannot be absorbed properly back into the blood, or if too much fluid is produced by the brain. This condition is treated by a shunt that regulates the amount, flow, and pressure of fluid within the brain and opens to allow excess fluid to drain from the skull. Since these shunts are inaccessible after their implantation, their settings cannot be changed by standard methods and powerful magnets are often used to change the valve settings on the shunts. Current research indicates that the valve setting of some hydrocephalus shunts can be altered by static magnetic fields with a minimum strength of 3 mT (30,000 mG), but there is no reported effect on hydrocephalus shunts below this level [16, 17, 18]. As described above, even directly under the transmission line, where the magnetic field from a Clean Line transmission project is highest, the magnetic-field level will be approximately 30 times below that shown to possibly alter the operation of shunts.

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