16.0 CORONA AND INDUCED CURRENT EFFECTS

16.1 INTRODUCTION AND METHODOLOGY

This chapter considers issues related to corona and induced current effects, including the potential for shock, fuel ignition, fires, lightning and effects on cardiac pacemakers. It also considers corona "noise" that can create potential interference with radio, television and computer monitors. Additional information about scientific research related to public health concerns about electric and magnetic fields (EMF) is provided in Appendix H.

16.2 REGULATORY FRAMEWORK

Health and safety guidelines and regulations related to high-voltage transmission lines are provided in a number of sources, including the National Electrical Safety Code, American National Standards Institute, American Medical Association Council on Scientific Affairs, American Conference of Governmental Industrial Hygienists, various state regulations and other organizations, as discussed below and in Appendix H.

The National Electric Safety Code (NESC) has set an induced current limit of 5 mA for objects under transmission lines (ANSI 2002). Transmission lines in California must comply with General Order No. 95 which does not have a limitation on induced currents similar to the NESC. The American Conference of Governmental Industrial Hygienists recommends not exceeding an electric field of 1 kV/m or magnetic field level of 1,000 mG for occupational exposure of workers wearing cardiac pacemakers (ACGIH 2001). Reception guidelines are published by the Federal Communications Commission (FCC).

16.3 EXISTING CONDITIONS

16.3.1 Induced Currents, Shock, Fuel Ignition, Fires, Lightning, and Cardiac Pacemakers

Electric currents can be induced by electric and magnetic fields in conductive objects near to transmission lines. For magnetic fields, the concern is for very long objects parallel and close to the line. However, the majority of concern is related to the potential for small electric currents to be induced by electric fields in metallic objects close to transmission lines. Metallic roofs, vehicles, vineyard trellises, and fences are examples of objects that can develop a small electric charge in proximity to high voltage transmission lines.

Object characteristics, degree of grounding, and electric field strength affect the amount of induced charge. An electric current can flow when an object has an induced charge and a path to ground is presented. The amount of current flow is determined by the impedance of the object to ground and the voltage induced between the object and ground. The amount of induced current that can flow is important to evaluate because of the potential for nuisance shocks to people and the possibility of other effects such as accidental ignition of fuel.

The amount of induced current can be used to evaluate the potential for harmful or other effects. Previous work on appliance leakage current can provide some insight into this issue. Leakage (and induced) current is commonly measured in units of milliamperes, mA (i.e. one mA is 0.001 amperes of electric current). Most appliances have a leakage current that flows through the body of the user. Usually the amount of current is very small and is below the threshold of perception. Many factors affect how much current flows. In addition to appliance design and age, contact resistance and insulation from ground affect the magnitude of current that flows through the user. Appliance leakage currents have been measured for a variety of appliances and levels ranged from 0.002 mA to tens of mA (Kahn 1966, Stevenson 1973).

There is a U.S. standard for the leakage current from appliances that was developed to minimize the potential for electric shock hazards and sudden involuntary movements that might result in an accident (ANSI 1992). The standard limits appliance leakage current to 0.5 mA for portable appliances and 0.75 mA for stationary or fixed appliances. The standard was developed with consideration of the variable threshold of human perception of electric current.

Different people and different situations produce a range of current perception values. As an example, when an average person grips an energized conductor, the median (50-percentile) threshold for perception of an AC electric current is 0.7 mA for women and 1.1 mA for men (Dalziel 1972, EPRI 1982). If the current is gradually increased beyond a person's perception threshold, it becomes bothersome, and possibly startling. With sufficiently large currents, the muscles of the hand and arm involuntarily contract and a person cannot release the gripped object.

The reasonably safe value at which 99.5 percent can let go (0.5 percent cannot) is 9 mA for men and 6 mA for women (Bridges 1985). An equivalent let-go value of 5 mA has been estimated for children (EPRI 1982). However, before the current flows in a shock situation, contact must be made, and in the process of establishing contact a small arc occurs. This causes a withdrawal reaction that, in some cases, may be a hazard if the involuntary nature of the reaction causes a fall or other accident. Consideration of let-go currents was the basis for the National Electric Safety Code (NESC) to set an induced current limit of 5 mA for objects under transmission lines (ANSI 2002). Transmission lines in California must comply with General Order No. 95 which does not have a limitation on induced currents similar to the NESC.

16.3.1.1 Lightning

Concern is sometimes expressed that transmission lines are unsafe in electrical storms or somehow attract lightning. However, transmission lines do not "attract" lightning. Atmospheric electricity strikes the earth at locations where localized charge in a cloud and surface conditions cause a lightning stroke to occur. A lightning stroke usually hits the tallest object within the immediate area; therefore, a transmission line actually protects the land near it from lightning much as a lightning rod on top of a school protects the building beneath it. Concern about lightning is also mitigated by the fact that the San Francisco Bay Area has an extremely low incidence of lightning.

16.3.1.2 Corona, Radio and Television Interference, and Computer Monitor Interference

One of the phenomena associated with energized high voltage transmission lines is corona. Under certain conditions, the localized electric field near an energized conductor can be sufficiently concentrated to produce a tiny electric discharge that can ionize air close to the conductors (EPRI 1982). This partial discharge of electrical energy is called corona discharge, or corona. Several factors, including conductor voltage, shape and diameter, and surface irregularities such as scratches, nicks, dust, or water drops can affect a conductor's electrical surface gradient and its corona performance. Corona is the physical manifestation of energy loss, and can transform discharge energy into very small amounts of sound, radio noise, heat, and chemical reactions of the air components. Because power loss is uneconomical and noise is undesirable, corona on transmission lines has been studied by engineers since the early part of this century.

The phenomenon of corona is associated with high voltage transmission line conductors along any section or location. Many excellent references exist on the subject of transmission line corona (e.g. EPRI 1982). Consequently, corona is well understood by engineers and steps to minimize it are one of the major factors in transmission line design. Corona is usually not a design problem for transmission lines rated at 230 kV and lower.

Overhead transmission lines do not, as a general rule, interfere with normal radio or TV reception. There are two potential sources for interference: corona (described above) and gap discharges. Gap discharges are different from corona and can occur on low voltage distribution lines. Gap discharges can take place at locations where tiny electrical separations (gaps) develop between mechanically connected metal parts (for example, on broken or poorly fitting line hardware, such as insulators, clamps, or brackets). A small electric spark discharge across the gap can create unwanted electrical noise. Gap discharge noise sources can be located and repaired.

Typically, corona interference to radio and television reception is usually not a design problem, and interference levels both in fair weather and in rain are extremely low at the right-of-way edge for 230 kV and lower transmission lines and will usually meet or exceed reception guidelines of the

Federal Communications Commission (FCC). Generally, interference due to gap discharges is less frequent for high voltage transmission lines than lower voltage lines. The large majority of interference complaints have been found to be attributable to sources other than power lines.

Personal computer monitors using cathode ray tubes (CRTs) can be susceptible to magnetic field interference. Magnetic field interference results in disturbances to the image displayed on the CRT monitor, often described as screen distortion, "jitter," or other visual defects. The extent of interference depends on 60 Hz magnetic field intensity, monitor orientation, monitor design, and the monitor's vertical refresh rate for the image. Possible solutions to computer monitor interference issues include: relocation of the monitor, use of magnetic shield enclosures, software programs to adjust the monitor's vertical refresh rate, and replacement of cathode ray tube monitors with liquid crystal displays (LCD's). It is important to note that use of flat screen LCD computer displays (immune to 60 Hz magnetic fields) has grown significantly in the past couple of years as unit prices have declined and image quality has improved.

16.4 POTENTIAL IMPACTS AND MITIGATION MEASURES

16.4.1 Significance Criteria

Project construction and operation activities would be considered to have a significant impact relative to corona and induce current effects if they would:

- Create a new fire hazard.
- Create a substantial public health hazard.
- Interfere with or prevent nearby businesses, farmers, and residents from using radios, televisions, or computers.

16.4.2 Construction Impacts

Public health impacts related to corona and induced current are not anticipated during construction, as the existing line will be taken out of service (electricity will be shut off) before the old conductors are removed. The new conductors for both circuits will be energized only after pole construction, conductor stringing and tensioning are complete.

16.4.3 Operation Impacts

16.4.3.1 Induced Currents, Shock, Fuel Ignition, Fires, Lightning, and Cardiac Pacemakers

Impact 16.1 Shock Potential.

Electric currents can be induced by electric and magnetic fields in conductive objects near to transmission lines. The amount of induced current that can flow is important to evaluate because of the potential for nuisance shocks to people and the possibility of other effects such as accidental ignition of fuel. Typically, calculated induced currents for common objects under a 230 kV or lower transmission line are below the threshold of perception and are far below hazardous levels.

Agricultural operations can occur on or near a transmission line right-of-way. Irrigation systems often incorporate long runs of metallic pipes which can be subject to magnetic field induction when located parallel and close to transmission lines. Operation of irrigation systems beneath transmission lines presents another safety concern. If the system uses a high-pressure nozzle to project a stream of water, the water may make contact with the energized transmission line conductor.

The potential for induced currents can be reduced by phase configuration, higher conductor clearance above ground, and the use of cross-phasing on double circuit lines. Typically, calculated induced currents for common objects under a 230 kV or lower transmission line (using a set of worst-case theoretical assumptions: the object is perfectly insulated from ground, located in the highest field, and touched by a perfectly grounded person) are below the threshold of perception and are far below hazardous levels.

Because agricultural irrigation pipes contact moist soil, electric field induction is generally negligible, but annoying currents could still be experienced from magnetic field coupling to the pipe. Pipe runs laid at right angles to the transmission line will minimize magnetically induced currents, although such a layout may not always be feasible. If there are induction problems, they can be mitigated by grounding and/or isolating the pipe runs.

For operation of high-pressure nozzles on irrigation systems, generally the water stream consists of solid and broken portions. If the solid stream contacts an energized conductor, an electric current could flow down the water stream to someone contacting the high-pressure nozzle. Transmission line contact by the broken-up part of the water stream is unlikely to present any hazard.

Mitigation Measure 16.1. PG&E will examine properties along the transmission line corridor and talk to property owners as necessary to identify fences or pipes (e.g., agricultural irrigation pipes) that could pose an induction problem or be incompatible with the power line. If there are induction problems, they can be mitigated by grounding and/or isolating the fence, pipe run, etc. For example, PG&E will need to replace about a 20-foot long section of an existing wire mesh fence around pole 82 with a fiberglass fence section (pers. comm. Mike Neer, PG&E Construction Manager, July 6, 2004).

Lightning

Transmission lines do not attract lightning. However, lightning does tend to strike taller objects more frequently. For objects less than 600 feet tall, the strike probability is directly related to height (i.e., an object twice as tall as another object will generally have twice as many strikes) although object shape can be a factor too. For objects over about 600 feet tall, the likelihood of lightning strikes increases exponentially (Veimeister 1972).

A transmission line passing above the earth can be said to cast an "electrical shadow" on the land beneath it (EPRI 1982). Lightning strokes that would generally terminate on the land inside the shadow will strike the transmission line instead and strokes outside this shadow will miss the line entirely. Therefore, a transmission line actually protects the land near it from lightning strikes.

Cardiac Pacemakers

Another area of concern related to the electric and magnetic fields of transmission lines has been the possibility of interference with cardiac pacemakers. There are two general types of pacemakers: asynchronous and synchronous. The asynchronous pacemaker pluses at a predetermined rate and is practically immune to interference because it has no sensing circuitry and is not exceptionally complex. The synchronous pacemaker, on the other hand, pulses only when its sensing circuitry determines that pacing is necessary.

The concern is that interference could result from transmission line electric or magnetic fields, and cause a spurious signal in the pacemaker's sensing circuitry (Sastre 1997). However, when these pacemakers detect a spurious signal, such as an induced 60 Hz current, they are programmed to revert to an asynchronous or fixed pacing mode of operation and return to synchronous operation within a specified time after the signal is no longer detected. The issue for pacemakers is if power line fields could adversely affect their operation.

The potential for cardiac pacemaker interference is associated with high voltage transmission lines along any section or location. Higher voltage transmission lines and lower conductor ground clearances generally produce higher electric fields, which is related to the potential for pacemaker interference.

The potential for pacemaker interference from power line fields depends on the manufacturer, model, and implantation method, among other factors. Studies have determined thresholds for interference of the most sensitive units to be about 2,000 to 12,000 mG for magnetic fields and about 1.5 to 2.0 kV/m for electric fields (University of Rochester 1985). Electric and magnetic fields at the edge of power line rights-of-way are generally below these values, but on the right-of-way the electric field threshold can be exceeded in some cases. The American Conference of Governmental Industrial Hygienists recommends not exceeding an electric field of 1 kV/m or magnetic field level of 1,000 mG for occupational exposure on workers wearing cardiac pacemakers (ACGIH 2001).

It is unclear that reversion to a fixed pacing mode is harmful since pacemakers are routinely put into reversion with a magnet to test operation and battery life. Some new pacemaker models are dual chamber devices that can be more sensitive to external interference. Some of these dual chamber units may experience inappropriate pacing behavior (prior to reversion to fixed pacing mode) in electric fields as low as 1.5-2 kV/m, while other models appear unaffected in fields up to 20 kV/m. The biological consequences of brief, reversible pacemaker malfunction are mostly benign. An exception would be an individual who has a sensitive pacer and is completely dependent on it for maintaining all cardiac rhythms. For such an individual, a malfunction that compromised pacemaker output or prevented the unit from reverting to the fixed pacing mode, even brief periods of interference, could be life-threatening (Sastre 1997). The precise coincidence of events (i.e. pacer model, field characteristics, biological need for full function pacing) would generally appear to be a rare event.

Proposed transmission lines are designed in accordance with CPUC General Order 95 guidelines for safe ground clearances established to protect the public from electric shock caused by induced currents. Electric fields are also shielded by common objects, such as trees, bushes, walls, fences, etc. and therefore electric fields may be reduced outside of the right-of-way. Since electric and magnetic fields decrease with distance from the power line conductors, increasing the right-of-way width will also mitigate the potential for pacemaker interference beyond the right-of-way.

Fire

The potential for fires can be produced by transmission line electrical conductors of any voltage, configuration, or location. Transmission lines may pose a threat of fire if a conducting object were to come into close proximity to the transmission line (resulting in a flashover to ground), or if an energized phase conductor were to fall to the earth. If an energized conductor were to remain in contact with combustible material for too long it might heat this material and cause a fire. It is typical practice for the constructing utility to clear tall objects, such as trees, from the right-of-way during construction, and to continue to clear such hazards over time. In addition, the proposed transmission line would be designed to comply with the minimum ground clearances set forth in California's General Order No. 95, and this should provide adequate distance from objects below the line. If, for some reason, an energized phase conductor does fall to the ground and create a line-ground fault, high-speed relay equipment is designed to sense that condition and actuate circuit breakers that can de-energize the line in less than about one-tenth of a second. This procedure has proven to be a reliable safety measure and reduces the risk of fire from high voltage transmission lines to a low level.

Fuel Ignition

Induced currents related to fuel ignition can be produced by the electric field of transmission lines along any section or location. If a vehicle were to be refueled in the under a high voltage transmission line, a possible safety concern could be the potential for accidental fuel ignition. The source of fuel ignition could be a spark discharge into fuel vapors collected in the filling tube near the top of the gas tank. The spark discharge would be due to current induced in a vehicle (insulated from ground) by the electric field of the transmission line and discharged to ground through a metallic refueling container held by a well-grounded person. One additional consideration would be gasoline stations located near the right-of-way edge.

Theoretical calculations indicate that if a number of unlikely conditions exist simultaneously, a spark could release enough energy to ignite gasoline vapors (EPRI 1982). This could not occur if a vehicle were simply driven or parked under a transmission line. Rather, several specific conditions need to be satisfied: A large gasoline-powered vehicle would have to be parked in an electric field of about 5 kV/m or greater (Deno 1985). A person would have to be refueling the vehicle while standing on damp earth and while the vehicle is on dry asphalt or gravel. The fuel vapors and air would have to mix in an optimum proportion. Finally, the pouring spout must be metallic. The chances of having all the conditions necessary for fuel ignition present at the same time are extremely small. Very large vehicles (necessary to collect larger amounts of electric charge) are often diesel-powered, and diesel fuel is less volatile and more difficult to ignite. Typically for 230 kV and lower transmission lines, electric field levels within the right-of-way are far too low for the minimum energy necessary for fuel ignition under any practical circumstances. Therefore, fuel ignition does not pose a significant hazard. For gasoline stations located near the right-of-way edge, the already low electric fields of the transmission lines in this project would be further reduced to almost zero due to shielding by typical metallic coverings over the refueling area and by the presence of any nearby light poles or trees (Deno 1987). A typical tractor-trailer gasoline truck used to replenish the underground fuel storage tanks is commonly grounded during fuel handling operations, and this is done to eliminate electric discharges. Therefore, fuel ignition does not pose a significant hazard.

16.4.3.2 Corona, Radio and Television Interference, and Computer Monitor Interference

Radio and Television Interference

Overhead transmission lines do not, as a general rule, interfere with normal radio or TV reception. There are two potential sources for interference: corona and gap discharges. Corona occurs very close to high voltage electrical conductors, where the localized electric field can be sufficiently concentrated to ionize air close to the conductors. This can result in a partial discharge of electrical energy called a corona discharge, or corona, and can sometimes generate unwanted radio frequency electrical noise. Several factors, including conductor voltage, shape and diameter, and surface irregularities such as scratches, nicks, dust, or water drops can affect a conductor's electrical surface gradient and its corona performance.

Gap discharges are different from corona. They can develop on power lines at any voltage and are more frequently found on smaller low voltage distribution lines. Gap discharges can take place at locations where tiny electrical separations (gaps) develop between mechanically connected metal parts (for example, on broken or poorly fitting line hardware, such as insulators, clamps, or brackets). A small electric spark discharge across the gap can create unwanted electrical noise. In addition, tiny electrical arcs can develop on the surface of dirty or contaminated insulators, but this interference source is less significant than gap discharge. Hardware is designed to be problem-free, but corrosion, wind motion, gunshot damage and insufficient maintenance contribute to gap formation.

A working group of the Radio Noise Subcommittee of the Institute of Electrical and Electronics Engineers has developed a Radio Noise Design Guide for High-Voltage Transmission Lines (IEEE 1971). This guide is useful for evaluating the performance of a high-voltage transmission line before it is built. The design guide is applicable to overhead ac transmission lines in the voltage range of 115 kV to 800 kV. This design guide is a valuable tool in the design of overhead high-voltage transmission lines because it gives guidelines for acceptable electrical parameters (i.e. conductor surface gradients) that engineers can use to evaluate design options. The IEEE guide is based on many years of research and practical experience. This document provides a range of maximum conductor surface gradients that have been shown to be acceptable in terms of corona performance. The concept is to design high-voltage transmission lines with conductor surface gradients equal to or less than the maximum recommended values. Lower gradients mean less corona activity and noise. Engineers can control the conductor gradients by selection of conductor size (larger conductors equals lower gradients), phase spacing and arrangement, and sometimes by bundling (use of multiple conductors per phase lowers the surface gradient).

The potential for radio and television interference is associated with transmission and distribution line electrical conductors of any voltage, configuration, or location. There has been a significant amount of work done to quantify radio and TV noise and provide design methods to mitigate this phenomenon during design (e.g. EPRI 1982, IEEE 1971, 1972, 1976). Corona generated electrical noise decreases with distance from a transmission line and also decreases with higher frequencies (when it is a problem, it is usually for AM radio and not the higher frequencies associated with TV signals). Corona interference to radio and television reception is usually not a design problem for transmission lines rated at 230 kV and lower. Typically, radio and TV interference levels both in fair weather and in rain are extremely low at the right-of-way edge for 230 kV and lower transmission lines and will usually meet or exceed reception guidelines of the Federal Communications Commission (FCC).

The severity of gap discharge interference depends on the strength and quality of the transmitted radio or TV signal, the quality of the radio or TV set and antenna system, and the distance between the receiver and power line. The large majority of interference complaints are found to be attributable to sources other than power lines: poor signal quality, poor antenna, door bells and appliances such as heating pads, sewing machines, freezers, ignition systems, aquarium thermostat, fluorescent lights, etc. (IEEE 1976).

Generally, interference due to gap discharges is less frequent for high voltage transmission lines than lower voltage distribution lines. The reasons that transmission lines have fewer problems include: predominate use of steel structures, fewer structures, greater mechanical load on hardware, and different design and maintenance standards. Gap discharge interference can be avoided or minimized by proper design of the transmission line hardware parts, use of electrical bonding where necessary, and by careful tightening of fastenings during construction. Individual sources of gap discharge noise can be located and corrected. Arcing on contaminated insulators can be prevented by increasing the insulation in high contamination areas and with periodic washing of insulator strings.

Computer Monitor Interference

Personal computer monitors using cathode ray tubes (CRTs) can be susceptible to magnetic field interference. Magnetic field interference results in disturbances to the image displayed on the CRT monitor, often described as screen distortion, "jitter," or other visual defects (Banfi 2000). In most cases it can be annoying, and at its worst, it can prevent use of the monitor. The extent of interference depends on 60 Hz magnetic field intensity, monitor orientation, monitor design, and the monitor's vertical refresh rate.

The potential for computer monitor interference is associated with transmission and distribution lines of any voltage, configuration, or location. Heavily loaded transmission lines and lower conductor ground clearances generally produce higher magnetic fields, which is related to the potential for computer monitor interference.

Computer monitors that use cathode ray tubes, or CRTs, could potentially experience image jitter due to magnetic fields of about 10 mG or less, depending upon factors such as the size and type of monitor. This image distortion does not occur on liquid crystal display (LCD) monitors common on most portable computers (ESAA 1996). Computer monitor interference is a recognized problem in the video monitor industry. As a result, there are manufacturers who specialize in monitor interference solutions and shielding enclosures. Possible solutions to computer monitor interference issues include: relocation of the monitor, use of magnetic shield enclosures, software programs to adjust the monitor's vertical refresh rate, and replacement of cathode ray tube monitors with liquid crystal displays. It is important to note that use of flat screen LCD computer displays (immune to 60 Hz magnetic fields) has grown significantly in the past couple of years as unit prices have declined and image quality has improved.

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