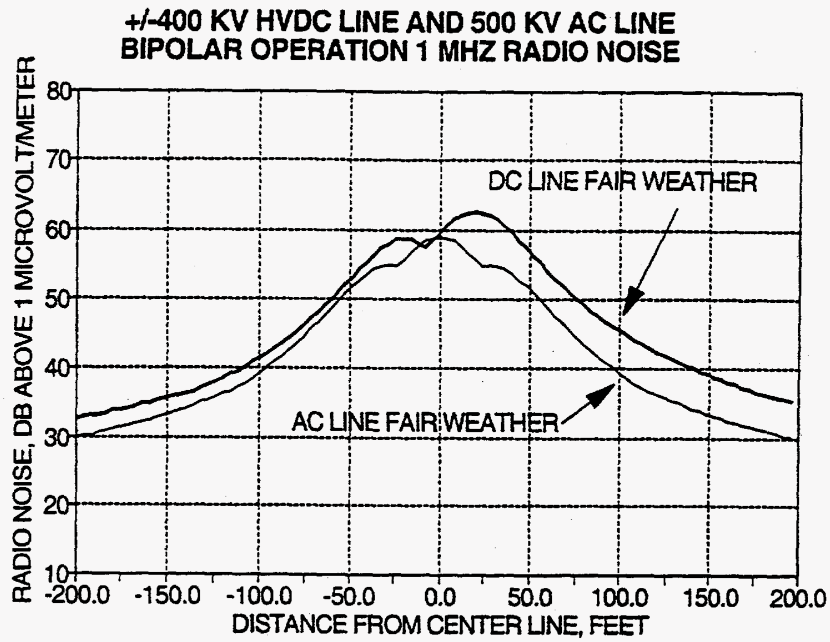

Figure 10.3 RN Comparison of DC and AC Lines in Fair Weather

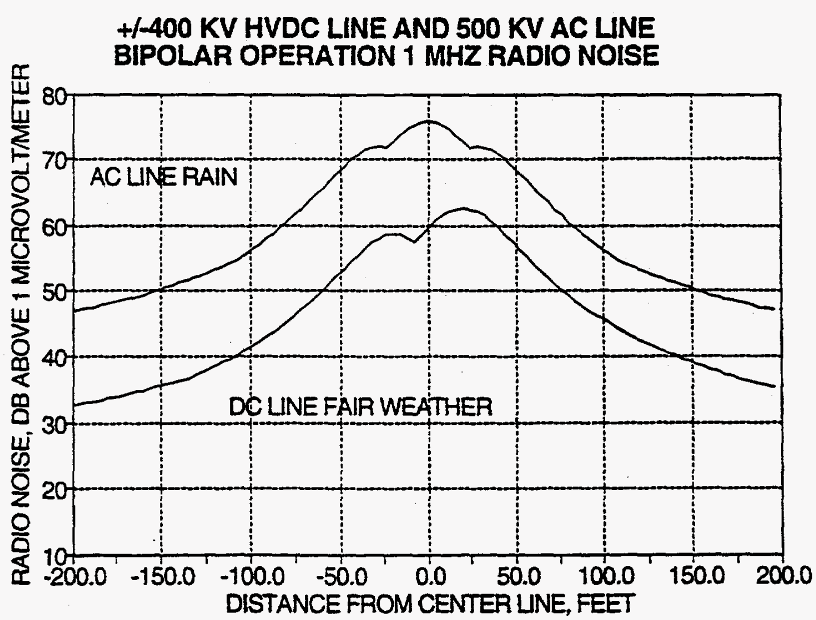

Figure 10.4 RN Comparison of DC Line in Fair Weather and AC Line in Rain

10.2.2 Audible Noise

Audible noise first appeared as a problem when 765 kV ac transmission lines were first introduced. Audible noise, like radio noise, is produced by corona on transmission line conductors. For ac lines, it takes on two forms: a sizzling or crackling sound called random noise and a single pitch tone called hum. Only the random noise component is present for dc lines. Transmission line random audible noise is rich in high frequency components, which gives it a distinctive sound. Both dc and ac lines have similar corona noise frequency spectra.

Random noise results from a multitude of small snapping sounds at corona points on the conductor. Sound propagates through air at approximately 1100 feet per second. The path length, and hence the phase shift, is different from each corona point to the listener. Each sound arrives with a different phase delay and results in the distinctive random noise sound rich in high frequency components.

Audible noise from insulator corona is rarely evaluated. In densely populated countries attention has been given to aeolian noise resulting from wind passing over the conductors, but this is an entirely different subject from electrically-caused corona noise and is entirely independent of whether the line operates dc or ac.

The human ear does not have a linear frequency response. As a result, it is necessary to adjust measured noise levels, given in decibels (dB), to obtain correlation with human ear sensitivity. The correlation is provided by frequency response "weighting" curves. The "A" weighting curve is used for most community noise evaluation studies. Noise calculated or measured with a particular weighting curve is identified with the letter of the curve in parentheses, for example 50 dB(A) for A weighting.

The noise profiles predicted by computer programs assume no obstructions between the line and listener. This is equivalent to saying that the operator has a clear view of the line from horizon to horizon. In practice, however, the farther one moves from the line, the more sound-absorbing trees and vegetation come between the listener and line. The effect of this sound absorption is that measured sound profiles tend to decrease with distance faster than do predicted profiles.

Audible noise from ac transmission lines is generally of concern only in wet conditions. Fair weather audible noise can be sometimes heard, but rarely is it able to be measured because of the presence of background noise. On the other hand, the highest noise levels occur during rain, which can itself mask the noise. Audible noise can be characterized by exceedence levels, typically L_5 and L_{50} foul weather, referred to as "heavy rain" and "wet conductor" conditions, respectively. Other references call these "maximum" and "average" foul weather conditions. The L_{50}, wet conductor, or average foul weather value is the number most commonly used for audible noise evaluation of ac transmission lines. In contrast, audible noise from dc transmission lines is generally greater during fair weather than for rain.

Many jurisdictions have noise abatement ordinances which specify noise at the property line. These ordinances take a number of forms. Some are maximum A-weighted levels. Some have different levels for day and night. Some are equivalent values averaged over a period of time L_{eq} to allow for variations of noise with weather. Others are day-night limits L_{dn} where nighttime noise is more heavily weighted than daytime noise to represent the greater annoyance potential of noise at night. When equivalent averaged values are used for evaluation of audible noise, it is necessary to take into account the relative number of hours for foul weather audible noise (ac lines) versus the number of hours for fair weather audible noise (dc lines).

Figures 10.5-10.7 present the following calculated audible noise lateral profiles for the example dc and ac transmission lines:

10.5 DC line bipolar operation in fair weather and rain
10.6 DC line monopolar and bipolar operation
10.7 Comparison of dc line in fair weather and ac line in rain

Observations from these figures:

- As with radio noise, fair weather audible noise from a dc line exceeds the audible noise during rain.

- Likewise, noise during bipolar operation is greater than noise during monopolar operation.

- For the example lines, audible noise produced by the dc line during fair weather is approximately 15 dB below that produced by the ac line during rain. Thus, the highest sound levels from the dc line should be less of an effect than those from an ac line. For especially quiet locations the impact of the relative number of hours of fair weather versus rain should be factored into an overall assessment of the relative noise. There is also some indication that audible noise from a dc line may be more irritating to people than ac line noise of the same magnitude. This may also be a factor in especially quiet locations.

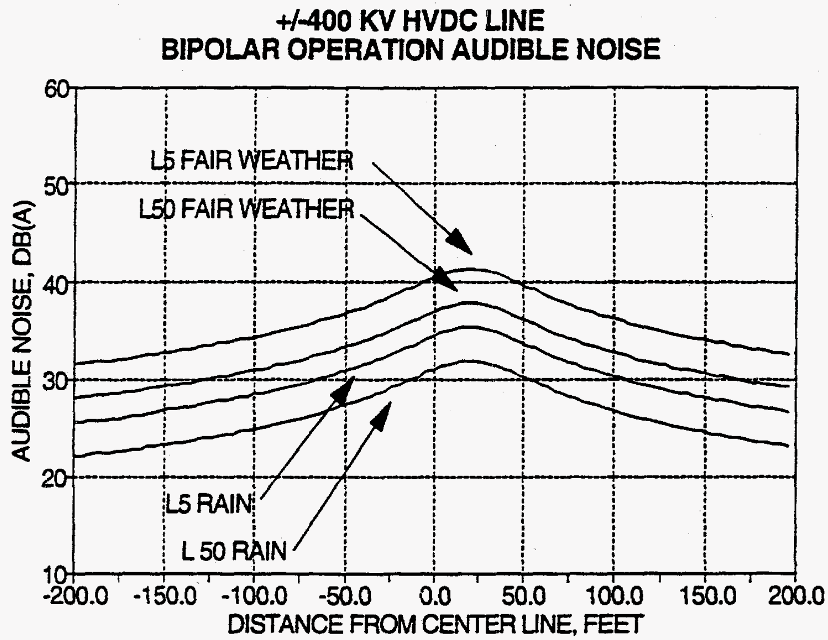

Figure 10.5 AN DC Line Bipolar Operation in Fair Weather and Rain

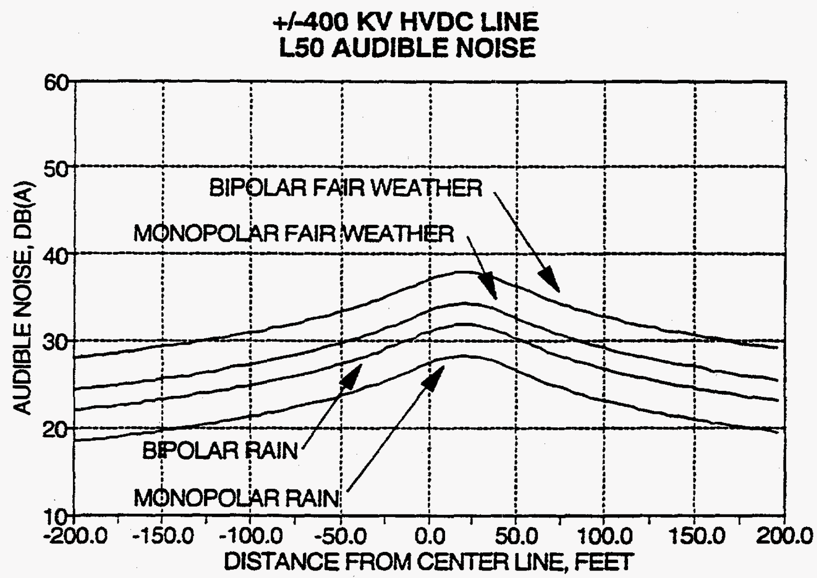

Figure 10.6 AN DC Line Monopolar and Bipolar Operation

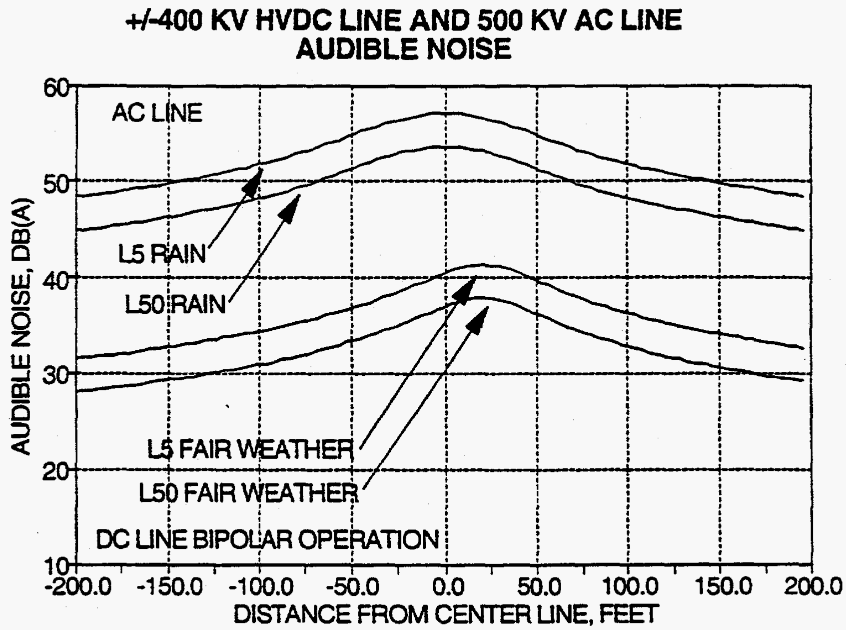

Figure 10.7 RN Comparison of DC Line In Fair Weather and AC Line in Rain

10.2.3 Air Ions

Air ions are natural components of the atmosphere. Ions are molecules with extra electrons (negative ion) or missing electrons (positive ion). They may be produced by such activities as storms, sunlight, blowing dust, and corona. High voltage dc lines typically operate in constant corona and produce air ions by the breakdown of the air molecules adjacent to the conductor (corona). The flow of air ion current equals the corona loss current.

Because of the non-alternating nature of direct current transmission, the air ions migrate away from a dc line instead of being trapped near the line conductors as with an ac line. Because both conductors of a dc line have an electric field, both can produce corona and therefore air ions. Most air ions are attracted to the conductor opposite to the one that generated them. Neutralization occurs when air ions combine with those of opposite polarity. Most air ions from HVDC lines are neutralized. Approximately 10% of the ions escape and migrate away from the transmission line, filling the space between line conductors and ground. A unipolar space charge region exists under each of the conductors, and a bipolar space charge region between the conductors. Migration of ions is a function of ion mobility as well as atmospheric conditions. The migrating air ions are carried away by wind, much like dust particles or pollen. Therefore, few air ions produced by the dc line are present on the upwind side of the line. Downwind air ion concentrations have been measured up to ½ mile from a dc line, although only for a small fraction of time.

Early research on laboratory lines indicated that positive pole ion activity is greater than negative pole ion activity, much as positive pole radio and audible noise is greater than negative pole radio and audible noise. Measurements on operating lines have found negative pole ion activity as anticipated, but positive pole ion activity suppressed. The difference in ion production between laboratory lines and operating lines is caused by the effect of elevated air temperature near the conductors resulting from resistive heating of the conductors from the load current. Passage of load current raises the conductor temperature, and therefore decreases the relative air density of the air surrounding the conductor. Ion production is a function of relative air density, so by this means line current has an influence on ion production.

The electric field from a dc line is a random variable. In foul weather a charge sheath forms around the conductor, which decreases the electric field near the conductor (reducing audible and radio noise), but increases the ground level field. The electrical environment surrounding a dc transmission line is therefore composed of three parts:

- The electric field which exists in the absence of ions in kV/m, frequently called the electrostatic field.
- Ion current density in Amperes per square meter (A/m^2).
- Space charge density (small air ions and charged aerosols) in ions/cm^3 or charge density in Coulombs/m^3.

The total electric field measured near a dc line is the sum of that produced by charge on the line conductors in the absence of ions, plus the effect of the space charge. Migration of the space charge because of the force caused by the electric field causes an ion current density in the space surrounding the line.

Even under stable weather conditions, the total ground level electric field and ion current density vary over a wide range, making prediction difficult. During fair weather, the effect of the space charge is rarely to decrease the electric field below that expected from line conductor charge alone, and may increase the electric field to a maximum strength 2 to 4 times that due to the line conductors alone. Ion activity generally increases during rain for dc lines, although the maximum electric field and ion current density in rain may not be greater than those in fair weather. The maximum value of ground level electric field including the effect of the space charge is the value of the uniform field given by line voltage divided by conductor height.

The magnitude of ion current is on the order of hundreds of nanoamperes per square meter. The current intercepted by a person standing under a dc line is on the order of a few microamperes, several orders of magnitude below that needed to perceive a shock. The ion current density deposits charge on nearby objects, causing a surface voltage build-up if the object is well insulated from ground. The amount of charge accumulated depends on the size of the object, its location with respect to the line, and its resistance to ground. As a practical matter, people and other objects normally have a sufficiently low resistance to ground to limit the charge accumulation to very low levels. If a sufficiently high resistance exists, a large object may store enough energy to deliver a shock similar to that experienced by walking on a carpet in winter and touching a door knob. This charge is on the order of 5-10 millijoules. There is insufficient current density to sustain a steady current shock. This is in contrast to ac transmission lines, where electric field induction can result in both transient spark and steady state current effects.

DC electric fields induce a static charge on the surface of conducting objects near the line. This may result in discharges similar to insulated objects charged by ion deposition. Perceptible spark discharges may thus occur from both insulated and conducting objects in the field of a dc line.

Hair stimulation and other sensations experienced by the skin may result in human perception of the field. The same phenomenon holds for ac transmission lines. The threshold of perception for the electric field from a dc line is greater than the threshold of perception from an ac line. Thus, a dc electric field is generally less bothersome to work or be in than an ac electric field of the same level.

While not an environmental effect to the public, electric field and ion current induction are factors for safe live-line maintenance of an energized dc line. Tests have shown that a helicopter-airborne platform can be safely used to perform live-line work.

10.2.4 Corona loss

Corona loss is the electrical energy loss resulting from corona activity on the conductors. This loss is proportional to corona current, which can be measured when corona is the only electrical load on the conductors. Corona loss varies with weather conditions. It is a function of wind speed, rain, snow, and fog. There is also a slight dependence on relative humidity. Corona loss typically increases by a factor of 2 to 5 in precipitation, with a maximum factor of 10. Corona loss may be a factor in the economic choice of conductor bundles, but is not an environmental concern.

10.2.5 Ozone

Conductor corona activity produces small amounts of ozone. Ozone production rates depend on the corona loss, and thus correlates to the same weather conditions as corona loss. Wind tunnel tests indicate ozone production rates about three times larger for the negative pole than for the positive pole for the same corona current. Tests indicate these wind tunnel tests are indicative of ozone production on operating lines.

During fair weather, ozone production from an HVDC line is not detectable in the variability in natural ozone. Under certain precipitation conditions, it is rarely possible to detect corona-produced ozone downwind from a +/- 500 kV HVDC line at the height of the conductors on the order of less than 2 parts per billion. The difficulty of making this small measurement indicates that ozone is not a factor in environmental assessment of HVDC lines.

10.3 ELECTRIC FIELD EFFECTS

The electric field of an ac transmission line induces voltages on nearby objects by the capacitive voltage divider between line, object, and ground. These objects are typically vehicles, people, animals, sheds, and similar sized bodies. Evaluation of electric field effects of ac lines involves human perception, annoyance, and safety with respect to voltages and currents induced on these nearby objects. The electric field of a dc transmission line is static and therefore unable to induce voltages on nearby bodies by capacitive coupling. Deposition of charge and induction of voltage and current by ion phenomena from dc lines have been addressed in the section on air ions.

The electric field of a dc line in the absence of space charge (the electrostatic field) is a useful benchmark for comparing dc and ac lines. Figures 8-9 present the following calculated electric field lateral profiles for the example dc and ac transmission lines:

10.8 DC line monopolar and bipolar operation
10.9 Comparison of dc line and ac line

The maximum electric field under the line during monopolar operation is greater than that during bipolar operation. The maximum electric field under the dc line for bipolar operation is greater than that for the ac line. DC lines typically operate at higher ground level electric fields than ac lines, because dc lines are not subject to the same capacitive induction that ac lines experience.

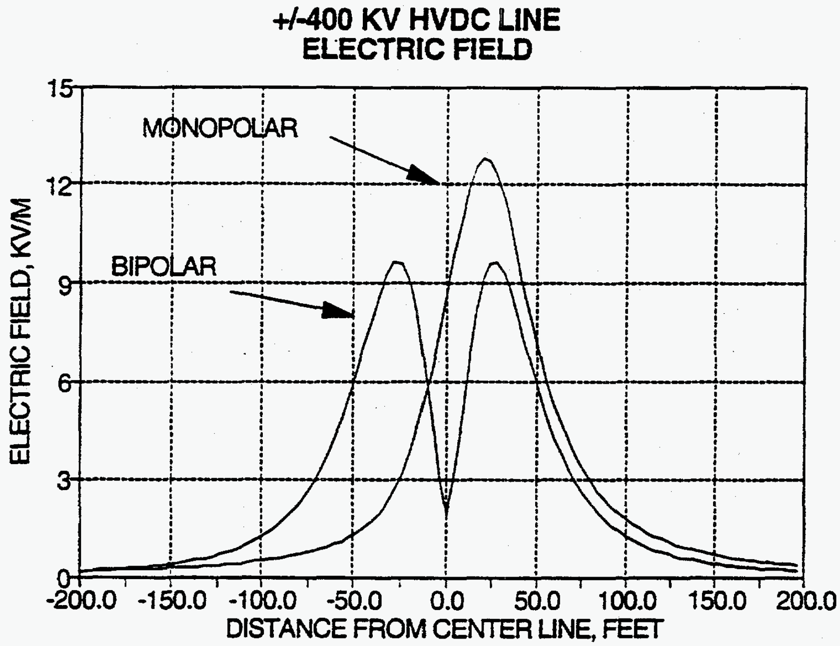

Figure 10.8 EF DC Line Monopolar and Bipolar Operation

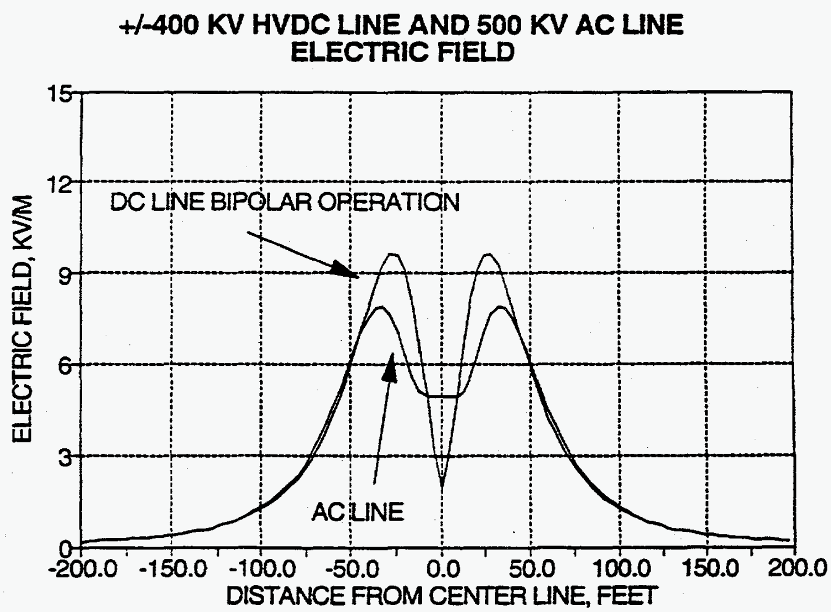

Figure 10.9 EF Comparison of DC Line With AC Line

10.4 MAGNETIC FIELD EFFECTS

The magnetic field of an ac transmission line induces voltages on nearby objects by inductive coupling between the line and nearby parallel objects such as pipelines, long fences, telephone lines, and railroads. As with electric fields, evaluation of magnetic field effects of ac lines involves human perception, annoyance, and safety with respect to voltages and currents induced on these nearby objects. In addition to human safety, inductive effects of ac lines include possible interference to railroad signals, noise in telephone circuits, and possible impairment of pipeline cathodic protection systems. The magnetic field of a dc transmission line is static, and therefore unable to induce voltages on nearby bodies by inductive coupling.

Figures 10.10-10.11 present the following calculated magnetic field lateral profiles for the example dc and ac transmission lines:

10.10 DC line monopolar and bipolar operation for three line loading levels
10.11 Comparison of dc and ac lines at 1000 MW each

Monopolar operation of the dc line results in larger magnetic field than bipolar operation at the same pole current. For the same circuit loading, the magnetic field profiles of the example dc and ac lines are similar.

An effect of magnetic field of a dc line which is not present for an ac line is deflection of a compass needle near the line. This is potentially significant for a dc line crossing or near a navigational channel. Figures 10.12-10.14 present calculated compass needle deflection at 3 feet above ground level for the example dc transmission line under the following conditions:

10.12 Bipolar operation at 1000 MW loading
10.13 Monopolar and bipolar operation for three line loading levels
10.14 Monopolar and bipolar operation at greater distances from the line

Within 50 feet of the center of the line the compass needle deflects as much as 33 degrees from magnetic north. Maximum deflection is greater for monopolar operation than it is for bipolar operation. For monopolar operation the deflection is only in one direction, rather than swinging about zero as is the case for bipolar operation. Beyond about 300 feet from the line the deflection is less than 1 degree, even for maximum current and monopolar operation. Concern is sometimes expressed about a possible effect of dc lines on migratory birds, because they use the earth's magnetic field for navigation during migration. The effect of the dc line would be at most a few degrees course error for a few feet of flight, less than would be expected from wind currents.

A magnetic field influence common to both ac and dc lines is their effect on the display of video display terminals. AC power frequency magnetic field beyond 10 mG can cause jitter of the display, depending on the particular terminal. DC magnetic field can cause deflection of the image and color distortion. Jitter from ac magnetic fields is visible at lower field strengths than deflection or color distortion from dc magnetic fields. The comparable field profiles between dc and ac lines indicated in Figure 10.12 indicates that computer monitor interference is less of a concern for dc lines than for ac lines of comparable loading.

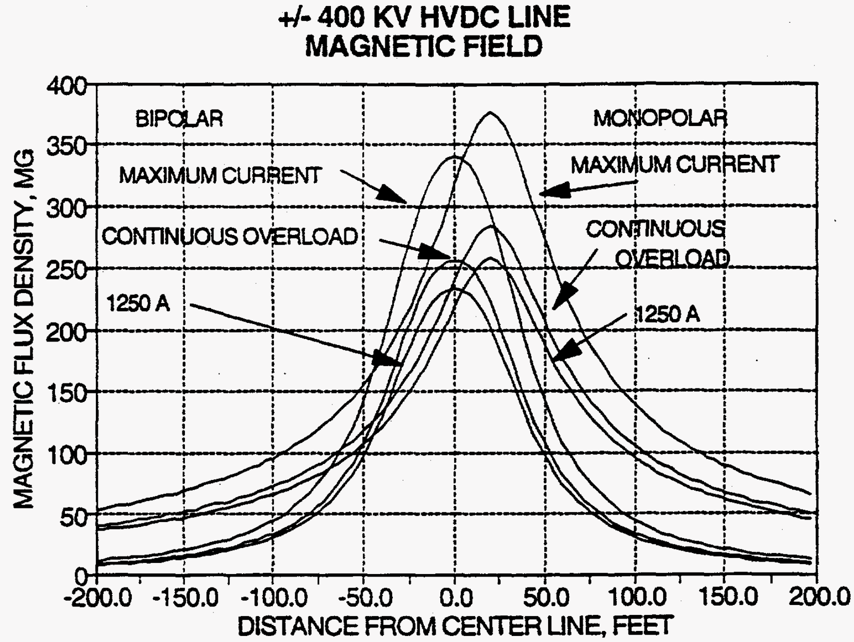

Figure 10.10 MF DC Line Monopolar and Bipolar Operation

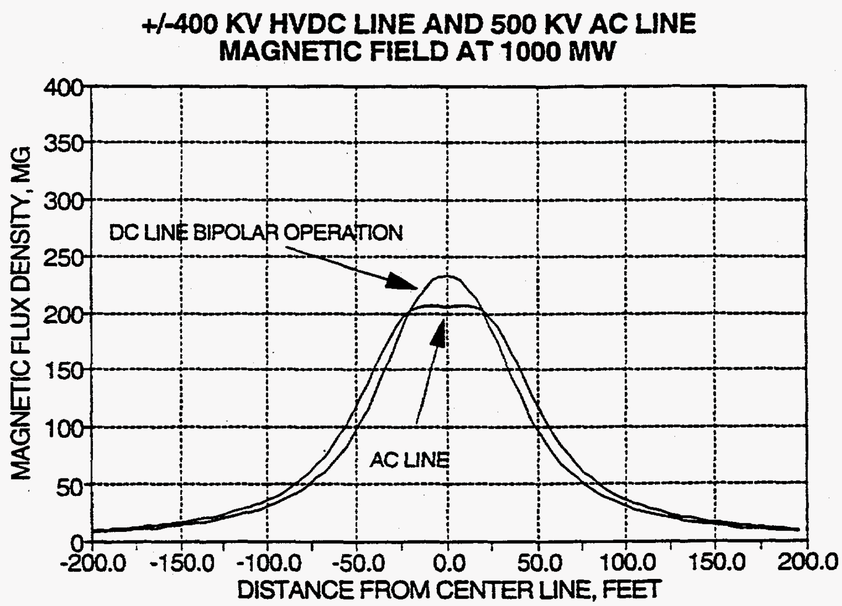

Figure 10.11 MF Comparison of DC and AC Lines at the Same Loading

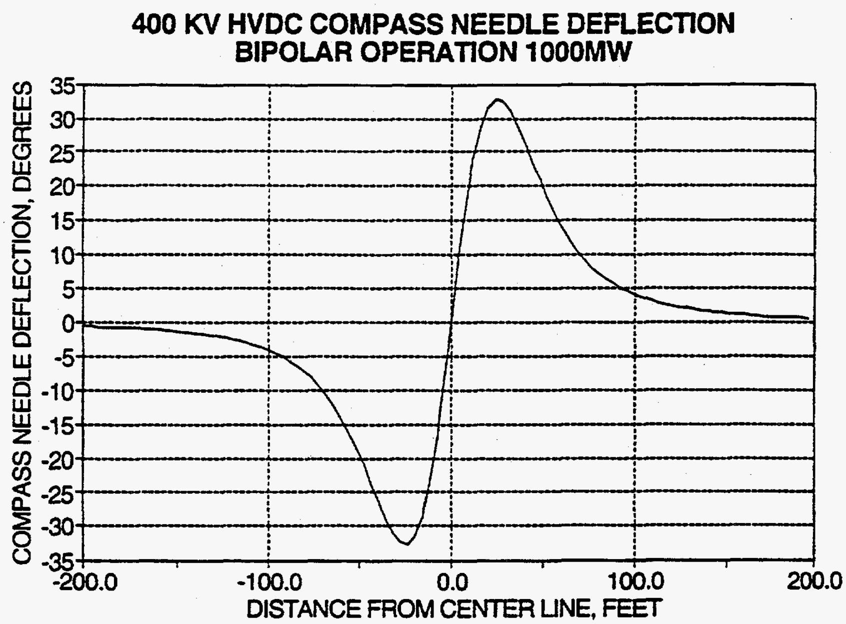

Figure 10.12 Bipolar Operation Compass Needle Deflection

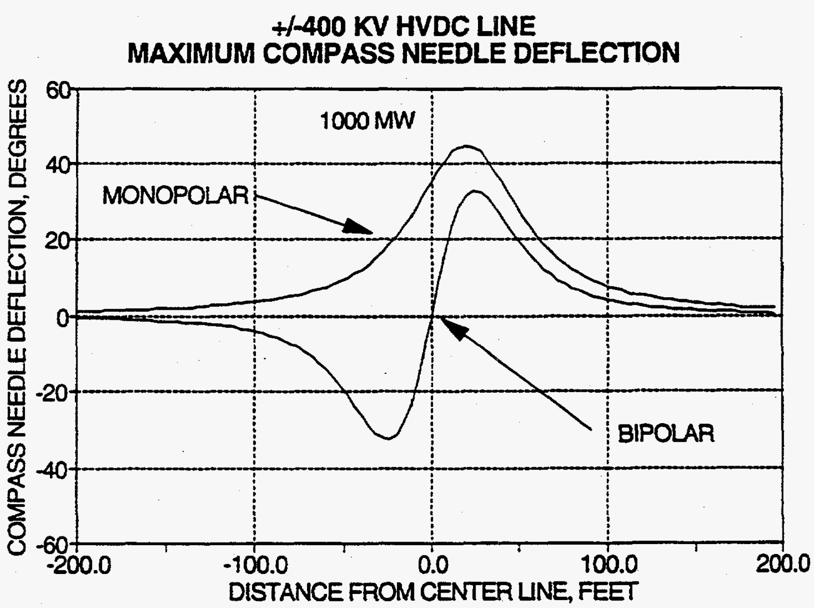

Figure 10.13 Compass Needle Deflection Monopolar and Bipolar Operation

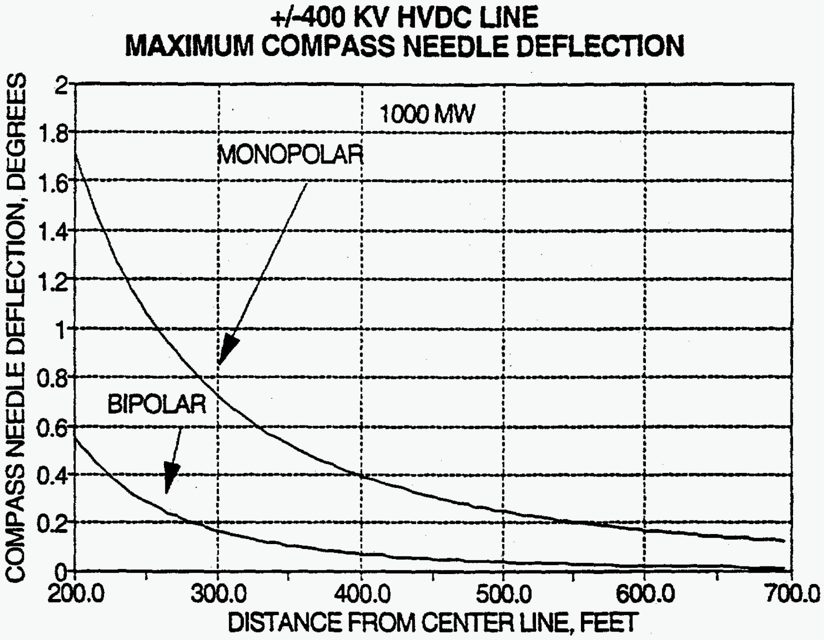

Figure 10.14 Compass Needle Deflection Far From DC Line

10.5 COORDINATION WITH PARALLEL FACILITIES

Possible interference to power line and open wire carrier installations caused by HVDC converter stations was addressed in the section on radio interference. Inductive coordination of ac power lines and telephone lines is virtually as old as the utility industry. Inductive coupling from power frequency and harmonic currents into parallel telephone lines have been extensively studied. The steady current in a dc transmission line does not induce voltage in parallel facilities, but harmonic frequency currents do exist on both the dc and ac side of converter stations. Induced noise voltage is highest for monopolar earth return, less for monopolar metallic return, and lowest for bipolar operation. Filters designed into the converter stations are very effective in reducing induced noise voltage.

While there is no steady-state induction of voltages or currents to pipes and fences parallel to a dc transmission line, there is the possibility of voltages and currents due to transient line current during fault conditions or line switching. There normally is insufficient energy coupled during a single fault transient to be of concern for safety for facilities adequately grounded for lightning protection.

10.6 HYBRID AC/DC TRANSMISSION LINES

There is increasing probability as use of dc power transmission increases that ac and dc lines will share the same right-of-way, or even be constructed as double circuit lines. The phrase "hybrid" ac/dc transmission lines refers to ac and dc circuits sharing common support structures or right-of-way. In such situations it is necessary to consider field and ion interactions between the two circuits. These interactions have both environmental and system operation consequences. System operation concerns include:

- Relay misoperation due to zero sequence currents induced in the ac lines by transients in the dc lines.
- Consequences of faults involving both the dc and ac circuits.
- Effects on dc converter station operation caused by induction from the ac line.
- Transformer saturation on the ac system resulting from dc currents coupled from the dc line.

The presence of the dc line causes a dc component of electric field at the surface of the conductors of the ac line. Likewise, the presence of the ac line causes an ac component of electric field at the surface of the conductors of the dc line. Because conductor corona radio and audible noise are functions of the maximum electric field at the conductor surface, this additional field component has an effect on radio and audible noise of the hybrid configuration.

Positive corona is the major contributor to radio and audible noise, whether the transmission line is dc or ac. Negative dc fields enhance positive ac transmission line corona activity, increasing radio and audible noise from the ac line. Positive dc fields suppress positive ac transmission line corona activity, decreasing radio and audible noise from the ac line. The relative arrangement of the circuits thus may increase or decrease the overall noise. In foul weather the ac conductors are the predominant source of audible noise, the level being increased if the ac conductors are near the negative dc conductor.

For dc and ac circuits on adjacent towers, the ground level electric field, ion density and ion current density are approximately the same as they would be for both circuits calculated separately. When the dc and ac circuits are constructed on the same structure, there can be an appreciable interaction between them, the details of which depend on the relative layout of the circuits on the structure. If the ac circuit is constructed beneath the dc circuit, there is a shielding of the dc line electric field, ion density, and ion current density at ground level. Increased electric field at the surface of the conductors of the ac line, however, results in increased radio and audible noise from the ac line. In general, the ac conductors behave as active shield wires for the dc circuit by emitting a compensating dc corona which reduces the dc electric field and ion densities. If the dc circuit is constructed beneath the ac circuit, the dc poles act as shield wires for the ac line, reducing the ac electric field at ground level.

One truly interactive effect is human perception of the electric field from a hybrid line. The stimulation of a person by a dc and an ac electric field acting together is considerably greater than for either field acting alone. For example, a typical person in a 15 kV/m ac electric field would experience perceptible, but not annoying sensation. A typical person in a 15 kV/m dc electric would not be able to perceive the existence of the field. However, in a combined 15 kV/m ac and 15 kV/m dc electric field, a typical person would find it intolerable. This is a true interaction, and must be considered when ac and dc lines are installed in close proximity to each other.

The magnetic field environment of hybrid ac/dc transmission lines is the sum of the fields of each line individually, and no special considerations need to be taken for installation of hybrid lines from a magnetic field standpoint.

Corona and field effects of hybrid ac/dc lines are slightly more complicated to analyze than for either type alone, but the mutual interactions from an environmental standpoint are not sufficient to incur a practical hindrance to their use.

10.7 EXAMPLE: CONVERSION OF AC LINE TO DC

Chapter 5 of the Task 1 report discusses conversion of existing ac overhead transmission lines to dc as a means of making optimum use of limited corridors. An example is presented for conversion of an existing double circuit 230 kV ac line to 188 kV dc. In addition to the insulation requirements which must be met for successful dc operation, it is prudent to make an assessment of electrical environmental effects.

Figure 10.15 shows lateral profiles for fair weather radio noise for both ac and dc operation for the same structure and conductors. Fair weather is frequently assumed for a radio noise evaluation because it is generally the most prevalent weather condition. Radio noise is plotted for the following three conditions:

- Double circuit ac line at 230 kV with superbundle phasing (identical phasing for both circuits). Superbundle phasing is the most common arrangement for older circuits. It has lower conductor surface electric field and smaller corona effects, but higher ground level electric and magnetic fields than low reactance phasing.

- Triple circuit dc line operating at 190 kV with the same polarity on all three circuits (positive pole on the left side of the structure).

- Triple circuit dc line operating at 190 kV with the positive pole on the right side of the structure on the center circuit.

The dc configuration with the same polarity on all three circuits has the lower radio noise profile, comparable with that of the existing ac line. Which polarity is chosen would be based on a complete analysis as described in the earlier sections of this chapter.

Figure 10.16 shows lateral profiles for L_{50} fair weather audible noise for dc operation and L_{50} rain audible noise for ac operation for the same structure and conductors. These conditions correspond to those most likely to produce complaints from nearby people. With either relative polarity the dc line audible noise is at least 10 dB below that of the ac line.

Figure 10.17 shows lateral profiles of electric field for the same dc and ac comparison. Electrostatic field magnitude is given for the two dc line polarities, ignoring the effect of air ions on the field profiles. Reversing the polarity of the center circuit reduces the ground level electric field profile. Reversing the polarity of the center circuit will also probably trap a larger percentage of air ions and reduce the ion concentration at ground level.

Figures 10.18 and 10.19 show lateral profiles of magnetic field for the same dc and ac comparison. As with electric field, reversing the polarity of the center circuit reduces the ground level magnetic field profile. Figure 10.18 shows magnetic field profiles for the same total megawatts for dc and ac operation, and Figure 10.19 shows profiles for all conductors at 1000 amperes for all cases. For both electric and magnetic fields the profile for ac operation lies between the profiles for the two relative polarities for dc operation.

A full analysis requires establishment of criteria and evaluation of the predicted values. A preliminary examination of Figures 10.15 through 10.19 indicates that conversion of the example double circuit 230 kV ac line to triple circuit 190 kV dc is feasible from an electrical environmental standpoint.

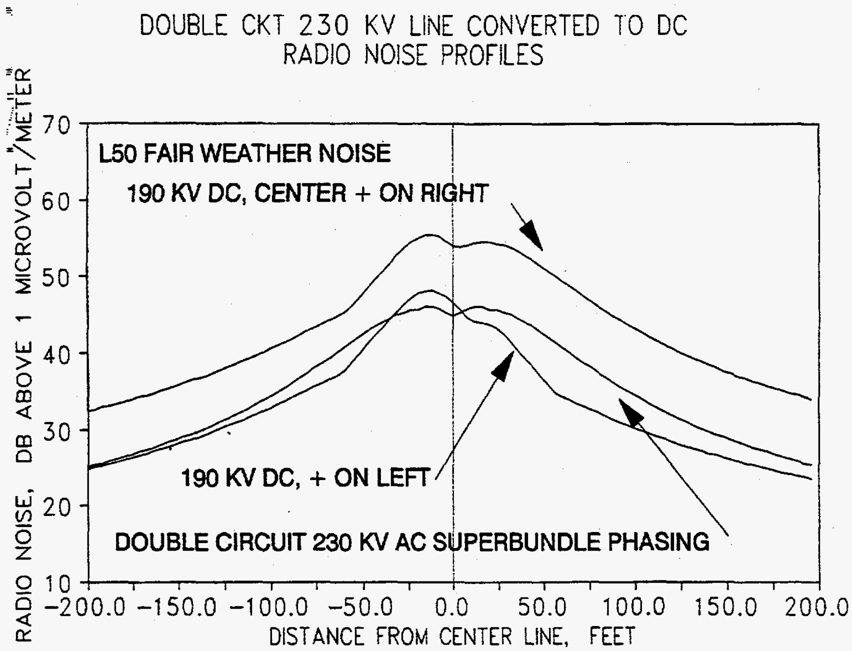

Figure 10.15 Radio Noise for AC Line Converted to DC

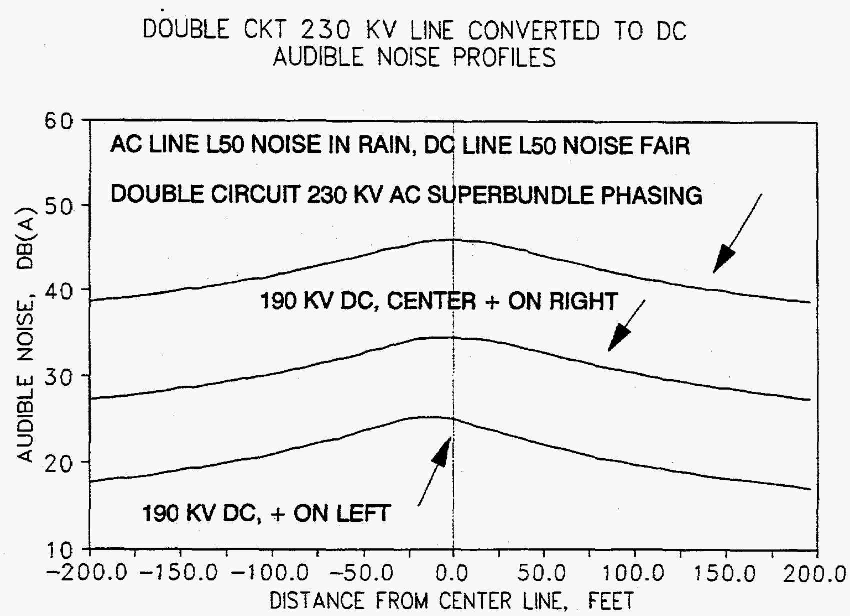

Figure 10.16 Audible Noise for AC Line Converted to DC

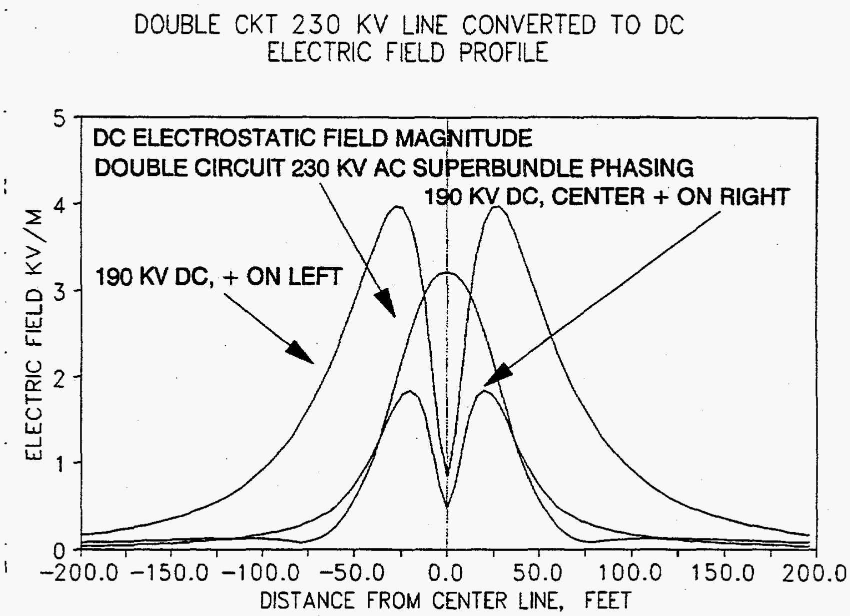

Figure 10.17 Absolute Value of Electric Field for AC Line Converted to DC

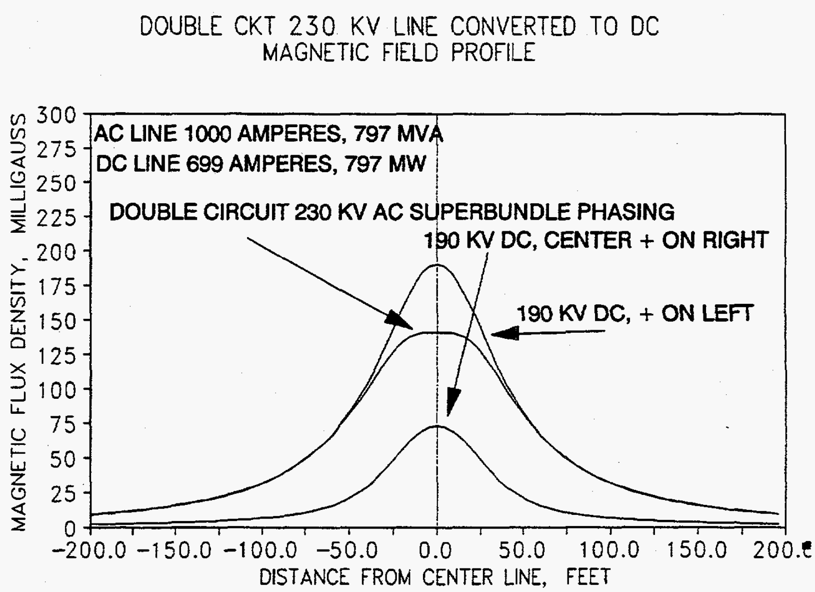

Figure 10.18 Magnetic Field for AC Line Converted to DC, Same MW

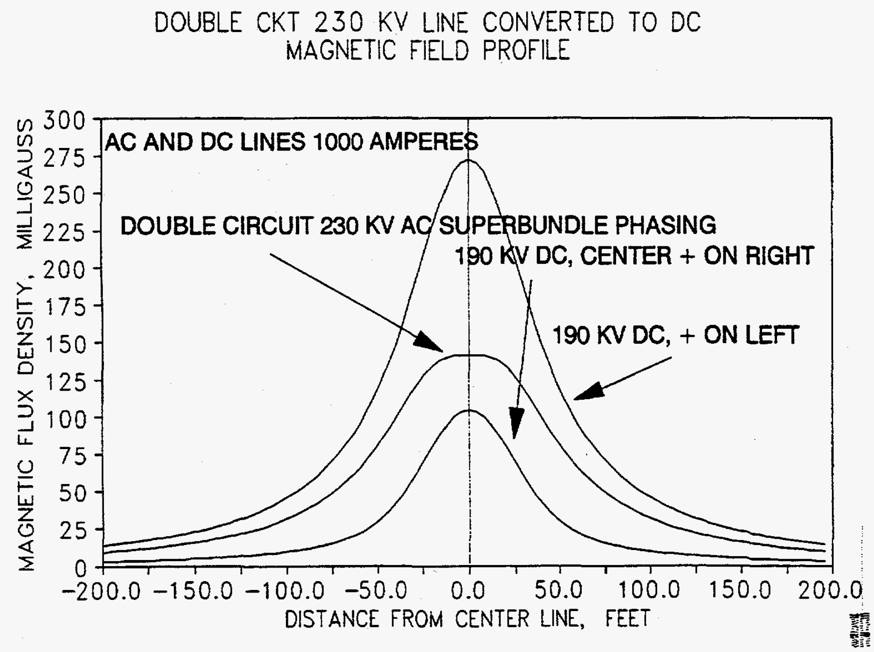

Figure 10.19 Magnetic Field for AC Line Converted to DC, Same Current

10.8 SUMMARY

HVDC systems environmentally are often more compatible than comparable ac systems. HVDC lines produce static electric and magnetic fields which are incapable of inducing voltages and currents on nearby objects by capacitive and inductive coupling. In contrast, capacitively and inductively coupled voltages and currents are primary effects from ac lines.

One environmental factor from dc lines that is not present from ac lines is the migration of air ions away from the line. While dc lines can induce voltage and current as a result of the ion flow in the air surrounding the line, they are incapable of sustaining sufficient steady current to be perceived by a person.

When dc and ac transmission lines are installed on the same structure or right-of-way, consideration must be given to possible human perception of the combined dc and ac electric fields, as human sensitivity to combined fields is greater than to either alone.

Audible and radio noise from a dc line are generally greatest during fair weather, as opposed to audible and radio noise from ac lines which are greatest during foul weather. The maximum noise from a dc line in fair weather is less than the maximum noise from an ac line during foul weather. Audible and radio noise thus may have less of an overall impact from dc transmission lines than from ac lines.

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APPENDIX: ALTERNATING CURRENT MAGNETIC FIELDS

Electric and magnetic fields are found everywhere electricity is used. The 60-Hz magnetic field levels in homes, for example, measured near electrical appliances, range from a fraction of a milligauss to several hundreds of milligauss. The intensity of electric and magnetic fields associated with sources relate to the voltages and currents on power lines and other conductors that respectively produce them. Because residential wiring and power delivery systems carry electricity that alternates with a frequency of 60 Hz, the EMF from these facilities also oscillates at 60 Hz.

Potential Health Implications of AC Magnetic Field Exposures

Questions have been raised as to whether exposure to electric and magnetic fields in the extremely-low-frequency (ELF) range (30-300-Hz) could adversely affect human health. While there has been more than 100 years of biological research on magnetic fields, largely for basic science and potential therapeutic purposes, the speculation that magnetic fields at ELF frequencies could have adverse effects, particularly relating to cancer, has arisen mainly from epidemiologic studies reported over the past 14 years. Only magnetic field exposures are discussed because the electric field levels are attenuated and shielded by any conductive materials including buildings, fences and trees. Thus, largely precluding opportunities for significant contributions to long-term exposures from sources external to buildings. In addition, there is considerably more scientific and public concern about magnetic rather than electric field exposures because of some recent epidemiology studies.

The potential health implications of magnetic field exposures like those produced by utility distribution and transmission lines are assessed by weighing data obtained from both epidemiology studies of human populations and laboratory studies of biological responses to magnetic fields in living animals or in isolated cells and tissues.

Epidemiological Studies

Epidemiologic studies provide information directly about people and their illnesses. However, investigators have very limited control over the ascertainment of exposures, genetic make-up, and habits of people who are studied. In contrast, strict control over exposure, diet and individual characteristics is obtained only in laboratory studies, where exposures and responses can be manipulated to investigate their relationships and the mechanisms involved.

Some residential studies of magnetic field exposures to power lines report a weak association between childhood cancer and a rough, surrogate (or substitute) estimate of magnetic field exposure. For example, it has been reported that childhood leukemia is associated with magnetic field exposures estimated from power lines capable of carrying high currents (Wertheimer and Leeper, 1979; Savitz et al, 1988; London et al, 1991), or calculated annual magnetic fields from power lines (Feychting and Ahlbom, 1992). Yet, methods of estimating magnetic field exposure based upon the levels actually measured at the child's residence have not yielded any reliable associations with leukemia of children (Savitz et al, 1988; London et al, 1991; Feychting and Ahlbom, 1992). Still other studies report no associations with leukemia (Olsen et al, 1993; Verkasalo et al, 1993). Although the short-comings of these and other similar studies preclude any definitive interpretation of their significance for human health at this time, these studies have prompted interest in continuing research to determine whether chronic exposure to power frequency magnetic fields of more than 2-3 milligauss could influence cancer risks.

Other epidemiological studies have looked for associations between the occupations of people with cancer and occupations presumed to have exposures to magnetic fields. However, in the vast majority of these studies, the exposures of individuals to electric or magnetic fields have not been measured, and these workers also are likely to have been exposed to various chemicals on the job, some of which are potentially carcinogenic. Although some recent studies have attempted to characterize past exposures with measurements and evaluated chemical exposures, the findings of these studies have not been consistent.

Laboratory Research

Laboratory studies have been conducted over a wide range of magnetic field intensities at 60 Hz and similar frequencies to elicit biological responses and identify the conditions and mechanisms under which they can be produced. However, from perhaps thousands of studies in the literature, relatively few biological responses are reported to occur with exposure to 60-Hz magnetic fields at intensities less than one Gauss, and those that have been reported are not adverse. Many findings are reported not to be confirmed by other investigators. Although there is considerable interest in determining whether there is any biological basis for an association between ELF fields and cancer, the available data has not provided any substantive support for a role for magnetic fields to influence tumorigenic processes.

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