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Electric and Magnetic Field Best Management Practices For the Construction of Electric Transmission Lines in Connecticut

January 2006 DRAFT

I. Introduction

The Connecticut Siting Council (Council) recognizes that the potential for health effects from exposure to power-line electric and magnetic fields (EMF) remains a concern among some members of the public. Studies conducted from the late 1970's to date have presented a range of conclusions regarding health risks from exposure to EMF from electric transmission lines. To address this concern, the Council (in accordance with Public Act 04-246) issues this policy document "*Best Management Practices for the Construction of Electric Transmission Lines in Connecticut*," which provides the latest information to the public regarding both scientific-research consensus on EMF health concerns and technological changes in transmission-line siting and construction that affect public exposure to power-line EMF.

Electric fields are proportional to line voltage, decrease rapidly with distance from the source, and are interrupted by conductive materials. Magnetic fields (MF) are proportional to electric current, also decrease with distance from the source, but are unaffected by most materials. Concerns regarding EMF and health effects arise in the context of electric transmission and distribution lines, which produce time-varying EMF, sometimes called extra-low frequency electric and magnetic fields, or ELF-EMF. In the U.S., EMF associated with electric-power have a frequency of 60 cycles per second (or 60 Hz). In addition to power lines, common sources of EMF include substations, transformers, household electrical wiring, electrical tools, and household appliances such as hair dryers, televisions, and electric ovens. Health concerns have focused on magnetic fields rather than electric fields. Average background levels of 60-Hz magnetic fields in most homes, away from appliances and electrical panels, range from 0.5 to 5 milligauss (mG) (NIEHS, 2002). MF near operating appliances such as ovens, fans, hair dryers, *etc.* can range from 10's to 100's of mG. As a point of comparison, the steady magnetic field of the earth is about 550 mG, which we experience as a time-varying field as we move about.

MF levels under transmission lines vary greatly, increasing and decreasing throughout the day as the demand for electric current in the lines increases and decreases. MF levels in the vicinity of transmission lines can range from about 5 to 150 mG, depending on electric-current load, height of the conductors, separation of the conductors, and how far away the lines are. For a given power loading and type of line, the size of the MF produced by a transmission line drops off with distance from the conductors, becoming indistinguishable from levels found inside or outside homes at distances beyond approximately 150 to 200 feet (NIEHS, 2002).

In Connecticut, existing and proposed transmission lines are designed to carry electric power at voltages of 69, 115, or 345 kilovolts (kV). Distribution lines typically operate at voltages below 69 kV and may produce levels of MF similar to those of transmission lines. The purpose of this document is to address MF guidelines and engineering practices for proposed electric transmission lines, but not other sources of MF.

II. Health Effects from Power-Line MF

The Connecticut Department of Public Health (DPH) has produced an EMF Health Concerns Fact Sheet (January 2004) that incorporated scientific research and conclusions from national and international health panels. The DPH concluded there is no definitive scientific evidence that demonstrates an association between EMF exposure and an increase in health risks. [http://www.dph.state.ct.us/Publications/brs/eoha/emf_2004.pdf]

Numerous public health agencies have provided conclusions similar to those of DPH, namely that there is no established link between adverse health effects and EMF exposure. For example, the American Cancer Society does not recognize EMF as a risk factor for cancer. The American Medical Association characterizes the EMF health-effect literature as "inconsistent as to whether a risk exists." The National Institute of Environmental Health Sciences (NIEHS) concluded in 1999 that EMF exposure couldn't be recognized as "*entirely safe*" due to some statistical evidence of a link with childhood leukemia. However, the NIEHS recommended "continued education on ways of reducing exposures," rather than regulatory guidelines (NIEHS, 1999). Among reviews by other study groups, including the International Agency for Research on Cancer (IARC) (2002), the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (2003), the British National Radiation Protection Board (NRPB) (2004), and the Health Council of the Netherlands ELF Electromagnetic Fields Committee (2003), the general conclusion is that there is no consistent evidence regarding exposures to typical power-line MF causing adverse health effects. IARC classified MF as "possibly carcinogenic to humans" based upon pooling of the results from several epidemiologic associations. IARC further stated that the evidence suggesting an association between childhood leukemia and residential MF strengths is "limited," with "inadequate" support for any other cancer effects. Among those agencies that provide guidelines for acceptable, continuous-exposure, general-public MF levels, the values range from 800 to 9,000 mG.

There are no state or federal health-based exposure standards for 60-Hz MF, although several states have established standards that serve to maintain EMF at levels comparable to those that have always existed along transmission-line right-of-ways (ROWs). Worldwide, aside from the guideline levels mentioned above, no strict, health-based exposure standards have been set. This reflects the weight of scientific evidence supporting an absence of plausible, causal relationships between MF exposure and adverse health effects.

III. Policy of the Connecticut Siting Council

The Council recognizes that a causal link between power-line MF exposure and adverse health effects has not been established, even after much investigative effort in the U.S. and abroad. Furthermore, the CSC recognizes that additional research is not likely to prove the safety of power-line EMF to the satisfaction of all. Although the Council is uncertain of the public health benefit of any specific MF guideline, it will consider the MF value, derived below, as a screening level applicable to the right-of-way (ROW) edge, below which health benefits are very unlikely to accrue. For the interim, the Council will continue its policy to mitigate MF when feasible with little or no cost. Mitigation measures may not be appropriate or applicable in all cases.

The CSC MF screening level is based, in part, on the Council's recognition of and agreement with the conclusions of a wide range of public health consensus groups, and in part, on a review that was commissioned by the Council on scientific research bearing on whether plausible causal links exist between typical MF levels and adverse health effects.

The usual approach used by regulatory bodies in the face of missing or less-than-satisfactory dose-response data is to use the highest "no-effect" level identified in careful, lifetime-exposure laboratory animal experiments, and then apply several "safety factors" or "uncertainty factors" to ensure the absence of adverse health effects. The CSC MF screening level is based on a "no-effect" level in lifetime-exposure, animal-carcinogenicity experiments undertaken by the National Toxicology Program (NTP), [1] as well as by other researchers. Even at the highest MF exposure levels, no increase in tumors was seen, and hence a no-effect level in lifetime animal exposures was identified at approximately 10,000 mG.

As discussed in a USEPA guidance document, [2] animal data are typically extrapolated to human risk assessment using uncertainty factors of 1, 3, or 10. Likewise, within-human variability is accounted for by assigning an additional uncertainty factor of 1, 3, or 10. In developing the MF screening value, the maximum uncertainty factors are used.

Incorporating one safety factor of 10 for animal-to-human extrapolation, and a 2^{nd} safety factor of 10 for the potential range of susceptibility within the human population, yields a screening level of 100 mG. An additional implicit safety factor derives from applying this screening level to the ROW edge, because MF levels beyond the ROW edge are anticipated to be lower. A further safety factor derives from applying this screening level to the 24-hour-average MF anticipated during summer or winter peak loading conditions, because the annual average MF levels will be considerably lower.

IV. MF Best Management Practices

The Connecticut Siting Council has adopted the following Best Management Practices relating to the construction of new electric transmission lines in the State. These practices are intended for use by public service utilities and the Council, when considering the installation of new electric transmission lines. Such practices are based on the CSC policy of mitigating ROW edge MF levels with low-cost and practical engineering approaches that reduce MF levels without compromising system reliability. The ROW-edge screening level of 100 mG identifies a range, above which more attention would be paid to mitigation strategies. The Council's Policy includes periodically requesting an update on changes in public-health consensus-group positions on EMF, and an update on those aspects of MF bioeffects research that identify adverse health effects from exposure to power-line fields. Finally, the Council requires calculation of post-construction, in-operation MF, with MF being projected at the seasonal maximum 24-hr-average current load on the line anticipated within 5-years after the line is placed into operation.

A. Public Health Consensus Groups and MF-Exposure Health-Effects Research

The Council recognizes on the one hand, a degree of uncertainty surrounding the long-term health effects from exposure to power-line MF. On the other hand, a considerable weight of existing scientific evidence supports the conclusion that biological effects, and certainly adverse health effects, are very unlikely below the screening level of 100 mG. Nonetheless, to ensure the Council is apprised of new developments in MF research, the Council will request (of the CT DPH or other qualified party), periodic updates on public-health consensus-group positions, as well as updates on scientific research relevant to anticipating potential health effects from EMF that may occur in the power-line environment.

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1 NTP results on EMF: http://ntp.niehs.nih.gov/index.cfm?objectid=0715F186-0A93-D872-71107B2800AFFF20 and http://ntp.niehs.nih.gov/index.cfm?objectid=070AD5C6-C1D7-707E-98D995AD5F7018E1 and http://ntp.niehs.nih.gov/index.cfm?objectid=03F4E009-F65D-D9A2-00695566614BE30E and http://ntp.niehs.nih.gov/index.cfm?objectid=070ADFA9-0312-B818-5E35D0CFA503A7DD

2 USEPA. 2002. "A Review of the Reference Dose and Reference Concentration Processes." EPA/630/P-02/002F, December 2002. http://www.epa.gov/IRIS/RFD_FINAL[1].pdf

The Council will continue to seek guidance from the Connecticut DPH regarding the potential for adverse health effects from exposure to transmission-line EMF. As stated in the DPH's 2004 Fact Sheet on EMF, there is no current scientific evidence clearly demonstrating an increased health risk associated with exposure to EMF, but uncertainties warrant continued vigilance. The Council recognizes the DPH as the Connecticut agency in charge of protecting the health and safety of the public. The Council notes that the DPH has not set any guidelines or standards limiting exposure of the public to MF from transmission lines.

B. Pre and Post Construction MF Calculations

When preparing a transmission line project, an applicant shall provide design alternatives and pre-construction calculations of MF resulting from each alternative, under normal system peak load conditions, and under projected seasonal maximum 24-hr-average current load on the line anticipated within 5-years after the line is placed into operation. MF values should be calculated perpendicular to the corridor containing the proposed transmission lines, from the ROW centerline out to a distance of 300 feet, at intervals of 25 feet. Typically, this would be done at the location of maximum line sag.

As part of this determination, the applicant will provide the Council with information regarding land use within 300 feet of the proposed transmission-line, for example, commercial, industrial, farmland, recreational areas, residential areas, public and private schools, licensed youth camps, public playgrounds, licensed day care facilities, hospitals, and licensed nursing homes.

The applicant should calculate future MF levels at the edge of the ROW under various practical design options that reduce MF values through low-cost and reliable methods. MF values should also be provided for each of the design options at 25-foot intervals perpendicular from the proposed transmission line. This will allow for an evaluation of how MF levels differ between alternative power line configurations. The intent of presenting various design options is to achieve reduced MF levels when possible through practical design changes. Factors in selecting a specific design are related to effects on MF exposure levels, effects on line reliability, cost of the design, and other practical factors such as visual impact.

C. Buffer Zones

As enacted by the General Assembly in Section 4 of Public Act No. 04-246, a buffer zone in the context of transmission line siting is deemed to minimally be the distance between the proposed transmission line and the edge of the utility ROW. Buffer zone distances may also be guided by the standards presented in the National Electrical Safety Code (NESC) published by the Institute of Electrical and Electronic Engineers (IEEE). These electrical engineering standards provide for the safe installation, operation, and maintenance of electrical utility lines, including clearance requirements from vegetation, buildings, and other natural and man-made objects that may arise in the ROW area. The safety of power line workers and the general public are considered in the NESC standards. None of these standards include magnetic field limits.

In 1991, the New York Public Service Commission established an interim policy that requires new high voltage transmission lines be designed so that the maximum magnetic fields at the edge of the ROW, one meter above ground, do not exceed 200 mG if the line were to operate at its highest continuous current rating. This 200 mG level represents the maximum calculated magnetic field level for 345 kV lines now in operation in New York State.

The Florida Environmental Regulation Commission established a maximum magnetic field limit for transmission lines and substations in 1989. The MF limits established ranged from 150 mG to 250 mG, depending on the voltage of the transmission line. These limits were based on the MF produced by existing transmission lines. The Council will continue to monitor how these and other states determine EMF limits on new transmission lines.

In its reviews of proposed transmission-line facilities, the Massachusetts Energy Facilities Siting Board has used an edge-of-ROW level of 85 mG as a benchmark for comparing different design alternatives and different projects. Although a ROW-edge level in excess of this value is not prohibited, such an excess may trigger a more in-depth review of environmental impacts.

D. Engineering Controls that Modify EMF Levels

When considering an electric-transmission-line application, the Council will expect the utility applicant to examine the following Engineering Controls that determine MF levels in publicly accessible areas: distance, height, conductor separation, vertical configuration, optimum phasing, underground installation, and higher voltage. Any change in power-line design may also affect the line impedance, corona performance, mechanical behavior, system performance, cost of the line, and aesthetics. The Council will consider all of these factors in relation to the MF levels achieved *via* any particular Engineering Control.

Distance

MF levels from transmission lines (or any electrical source) fall off with distance, with increasing distance resulting in lower MF levels. This can be achieved by purchase of wider rights-of-way where available, by using vertical designs as discussed below, and by replacing two side-by-side single circuit towers with a double circuit tower.

Height of Support Towers

Another method of reducing MF levels at the edge of a ROW is by increasing the height of the towers supporting the conductors. The main drawbacks of this approach are an increase in the cost of supporting structures, the potential detrimental visual effects, and the modest reductions achieved (unless the ROW width is unusually narrow).

Conductor Separation

Decreasing the distances separating the individual phase conductors can reduce MF. Because the individual phase conductors carry currents in opposite directions, the MF produced by the closer conductors add and subtract in such a way as to result in partial cancellation. However, placing the conductors closer together has practical limits. The distance between the conductors must be sufficient to maintain adequate electrical clearance at all times, and to assure utility worker safety when working on energized lines. One drawback of a close conductor installation is the need for more support structures per mile (to reduce conductor sway in the wind), resulting in a higher installation cost and increased visual impact.

Vertical Configuration

The arrangement of conductors on the support towers influences MF. Conductors arranged in a flat, horizontal pattern at allowable clearances would generally have greater MF levels than conductors arranged in a vertical configuration. This is due both to the wider spacing between the conductors typical of H-frame designs, as well as to all 3 conductors being closer to the ground. For single-circuit lines, a compact triangular configuration, called a “delta configuration” generally offers the lowest MF levels. A vertical configuration may cost more and may have increased visual impact.

Optimum Phasing

Optimum phasing applies in a situation where more than one circuit exists in a transmission-line ROW. Electric transmission circuits utilize a three-phase system with each phase carried by one conductor, or a bundle of conductors. Utilities use the letters A, B, and C to denote each of the three phases, with each letter representing the phase of one conductor. A double-circuit design places two circuits on one structure, with the three conductors in an A-B-C and C-B-A vertical configuration. Optimum phasing reduces MF through partial cancellation. For a ROW with more than two circuits, the phase relationships of the conductors can generally be optimized to reduce MF levels. The amount of magnetic field cancellation will vary depending upon the relative loading of each circuit. For existing transmission lines on the same ROW, this is usually the least cost method of reducing magnetic fields.

MF can be reduced for a single circuit line by constructing it as a double-circuit line, and arranging the conductor placement and phasing for optimum cancellation. The utility may refer to this as a split-phase design. Disadvantages of the split-phase design include higher cost and increased visual impact.

Underground Lines

Underground transmission lines place the phase conductors in close proximity, because solid insulating material is used between the conductors instead of air. The close proximity of the phase currents increases the degree of MF cancellation, but does not eliminate MF. Underground transmission lines are typically three to five feet below ground, which places them in closer proximity to someone crossing the ROW, and magnetic fields can be quite high directly over the line. The MF on either side of the line, however, decreases more rapidly with increased distance, compared to overhead transmission lines.

The greatest reduction in magnetic field can be achieved with “pipe-type” cable. This type of cable has all three phases installed inside a steel pipe and uses a dielectric fluid circulated inside the pipe for electrical insulation and cooling. This achieves low magnetic field because of the close proximity of the three phase conductors and the magnetic shielding provided by the steel pipe.

Lengthy high-voltage underground transmission lines can be problematic due to the operational limits posed by the inherent design. The insulating materials do not allow for efficient cooling of the conductors. The capacity of the line can also be reduced because of the high capacitive charging current of such systems. This, in turn, may have a significant impact on the electrical behavior of a transmission system and its operational reliability. Underground lines are costly and difficult to repair, leading to longer outages than an overhead design. The cost to install underground lines can be anywhere from two to ten times the cost of installing an overhead transmission line. There can also be significantly greater ecological impacts, although visual impact is reduced.

The Council recognizes the operational issues and other concerns regarding the reliability of lengthy underground transmission lines and further understands that engineering research regarding the feasibility of operating underground transmission lines is ongoing. Thus, the Council may require information on the latest technological and feasibility information regarding underground transmission lines in any new application. New developments in underground technology will be incorporated into these Best Management Practices as they occur.

Increased Voltage

MF are proportional to current, and, for example, replacing a 69 kV line with a 138 kV line (that delivers the same power at half the current) will result in lower MF. This may be an expensive solution in cases where transformers and substation equipment need to be replaced.

V. References

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