LIFE CYCLE 2006 – Connecticut Siting Council Investigation into the Life Cycle Costs of Electric Transmission Lines

FINAL REPORT

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8. Cost Effects of EMF Mitigation

EMFs are invisible lines of electrical and magnetic force that surround any electrical conductor with a current flowing along its length. For EMF at 60 Hz the electric field and the magnetic field may be treated separately. Both types of fields are present in the immediate vicinity of most power transmission lines, and in general:

- The electric field level (measured in kilovolts/meter, kV/m) increases in direct proportion to line voltage.
- The magnetic field level (measured in milligauss, mG) increases in direct proportion to the current flow in the line.

The levels of the both the electric field and the magnetic field are much higher in close proximity to a transmission line than they are at some distance from the line.

Transmission line EMF has been discussed at some length over the last 20 years, because there is concern that these fields may present health risks to those who are exposed to them on a regular basis. However, as stated previously by Acres (1):

> The biological effects from extremely low frequency fields are difficult to detect and define. At the present time, many studies on the subject of health risk and EMF have been conducted worldwide. To date, the scientific evidence is inconclusive, and a direct link between adverse health and EMF associated with electric power frequency (60 Hz in North America) cannot be confirmed or denied.

Despite this lack of proof, standards have been adopted by some governmental agencies as a safeguard for public health. Because there often are additional costs associated with mitigating EMF, this chapter addresses the field levels associated with the types of lines anticipated for Connecticut and discusses the costs needed to reduce them. These field levels were not explicitly modeled for the exact line designs illustrated in Section 3. Instead, field profiles from other studies for similar line types and voltages are presented in this section to show the relative magnitudes of such fields, some alternatives for reducing the field levels, and the approximate cost of doing so.

8.1 Overhead Construction

Both electric and magnetic fields are present in the area surrounding any overhead a.c. transmission line. The levels of these fields vary with line voltage and current, line design, and distance from the three phase conductors. These effects are illustrated in this section for typical 345 kV and 115 kV lines. Background on the assumed line configurations is provided in Appendix B.

8.1.1 Effects of line configuration and voltage

The arrangements and spacing of conductors on an overhead line significantly influence the EMF levels under the line. For example, Table 8-1 shows the magnetic and electric fields for both horizontal and delta conductor configurations at 345 kV. Magnetic fields for the delta configuration are 64% of those for the horizontal configuration directly under the line. However, delta configuration magnetic fields are approximately half of those for the horizontal configuration at distances of 20-100 ft from the centerline. Maximum electric fields for the delta configuration are only 15% lower than those for the horizontal configuration, but they are 50% lower at distances from 40 to 100 feet from the centerline. These reduced magnetic and electric fields for lines with a delta configuration must be balanced against first costs that are approximately 80% higher.

Line voltage also is an important factor in determining EMF levels near an overhead transmission line. Table 8-2 shows various magnetic and electric field levels for both horizontal and delta conductor configurations at 115 kV. When compared with similar EMF levels in Table 8-1 for 345 kV lines, the Table 8-2 data confirm that electric fields are impacted most by changes in line voltages. The line voltages in Table 8-2 are approximately one-third of those for Table 8-1, but the maximum electric fields are reduced by almost a factor of four. In this case, the reductions are due not only to changes in voltage but also to changes in conductor height and spacing. Because the assumed current flows for the 115 kV lines are 1000 Amperes per phase, as was the case for the comparable 345 kV lines, magnetic field levels changed for less between Tables 8-1 and 8-2. Once again, the changes are primarily due to differences in conductor configuration and spacing.

8.1.2 Effects of split-phasing

Split-phasing is a line design concept that reduces EMF by canceling the fields using additional phase conductors on the transmission towers. The most typical arrangements use two conductors per phase, for a total of six conductors. However, the towers must be comparable to those required for a double-circuit line, with the associated additional cost. Table 8-1 (part C) shows the very significant reduction in the magnetic field that result from split-phasing, especially at distances of 20 to 100 ft. from the right-of-way (ROW) centerline. Electric fields with split phasing are only incrementally lower than those for a delta configuration. First costs associated with split-phasing at 345 kV are, typically 40% higher than those for a single-circuit, wood H-Frame design (R.I. Study). Table 8-2 (part C) shows similar reductions for a split-phasing arrangement at 115 kV.

Table 8-1. 345-kV EMF Levels from the Rhode Island Study

	Configuration and Field	Maximum Field	Distance from Centerline of Structure (ft)						
			0	20	40	60	80	100	200
A.	Horizontal								
	Magnetic field (mG)	210 at 0 ft	210	208	141	77.1	45.4	29.4	7.39
	Electric field (kV/m)	4.32 at 30 ft	2.73	3.67	3.75	1.89	0.92	0.5	0.07
B.	Davit (Delta)								
	Magnetic field (mG)	135 at -10 ft	132	95.7	58.7	35.6	22.8	15.6	4.23
	Electric field (kV/m)	3.64 at -20 ft	2.54	1.90	1.61	0.99	0.58	0.36	0.07
C.	Split-phase (Vertical)								
	Magnetic field (mG)	67.4 at 0 ft	67.4	52.8	29.2	15.5	8.69	5.2	0.83
	Electric field (kV/m)	3.00 at 10 ft	2.45	2.99	1.36	0.7	0.46	0.3	0.05

Table 8-2. Calculated 115-kV EMF Levels for Various Conductor Configurations

Configuration and Field	Maximum Field	Distance from Centerline of Structure (ft)						
		0	20	40	60	80	100	200
A. Horizontal								
Magnetic field (mG)	181 at 0 ft.	181	141	77.3	37.0	22.9	16.9	3.20
Electric field (kV/m)	1.16 at 0 ft.	0.40	1.14	0.76	0.34	0.16	0.095	0.015
B. Davit (Delta)								
Magnetic field (mG)	109 at 1 ft.	108	82.3	43.4	22.9	13.3	10.1	1.83
Electric field (kV/m)	0.945 at 12 ft.	0.72	0.90	0.46	0.20	0.11	0.069	0.015
C. Split-phase (Vertical)								
Magnetic field (mG)	43.4 at 0 ft.	43.4	29.7	13.7	6.40	2.97	1.83	0
Electric field (kV/m)	0.72 at 12 ft.	0.58	0.65	0.23	0.057	0.019	0.011	0

Table 8-3. Calculated EMF Levels for Single- and Double-Circuit 115 kV Overhead Lines

Configuration and Field	Maximum Field	Distance from Centerline of Structure (ft)						
		0	20	40	60	80	100	200
A. Single-circuit (vertical)								
Magnetic field (mG)	102 at 8ft	93.9	90.1	53.5	31.3	19.9	13.7	5.3
Electric field (kV/m)	1.18 at 8ft	1.02	0.87	0.26	0.03	0.04	0.05	0.02
B. Double-circuit (vertical)								

Magnetic field (mG)	171 at 0ft	171	139	87.8	51.9	34.4	24.4	6.1
Electric field (kV/m)	1.99 at 0ft	1.99	1.21	0.32	0.04	0.05	0.06	0.02

8.1.3 Single vs. Double-Circuit Lines

Table 8-3 lists EMF levels at various distances from the center-line of a single-circuit and a double-circuit 115 kV overhead line. The conductors for each circuit are arranged vertically, and a nominal loading level of 1000 Amperes per phase was assumed for both lines. Even though the power flow is doubled under these loading assumptions, EMF levels for the double-circuit line increase by less than a factor of two. This is due to some cancellation in the fields from the two circuits. A comparison of EMF levels for the single-circuit line in Table 8-3 that has a vertical conductor configuration with those for the single-circuit line in Table 8-2 that has a delta configuration shows quite similar field levels. Greater EMF level reductions are possible with more compact delta configurations that have less space between the conductors for each phase.

8.2 Underground construction

EMF from underground lines differs from EMF from overhead lines in two major respects:

1) Electric fields are zero above an underground line because the ground is at zero potential, and it is an excellent conductor of electricity.

   Magnetic fields above an underground line can be higher than those beneath an overhead line because the conductors are much closer to the ground level, where most human contact would take place.

Because of the first consideration, only the magnetic field associated with underground lines need to be examined. This section discusses how these magnetic fields vary with cable configuration and examines the effectiveness of metallic shielding in mitigating these fields.

8.2.1 Effects of cable configuration

As is true with overhead transmission lines, the magnetic fields associated with underground lines vary considerably with the configuration of the cables for each of the three phases. Horizontal and delta configurations are both very common, and the magnetic fields for both are highest in the center of the ROW. As Figure 8-1 shows, the maximum magnetic field for the assumed 115 kV XLPE line with cables in a horizontal configuration and a loading level of 1000 Amperes per phase is approximately 200 mG, but it is less than 60 mG only 20 ft from the center of the ROW. For a 115 kV XLPE line with similar cables in a delta configuration and similar loading, the maximum field is approximately 95 mG and the field is less than 25 mG only 20 ft from the ROW centerline (See Figure 8-2). Magnetic field levels for three different line loadings are presented in Figures 8-1 and 8-2. Conductor sizes and physical arrangements are shown in Appendix B.

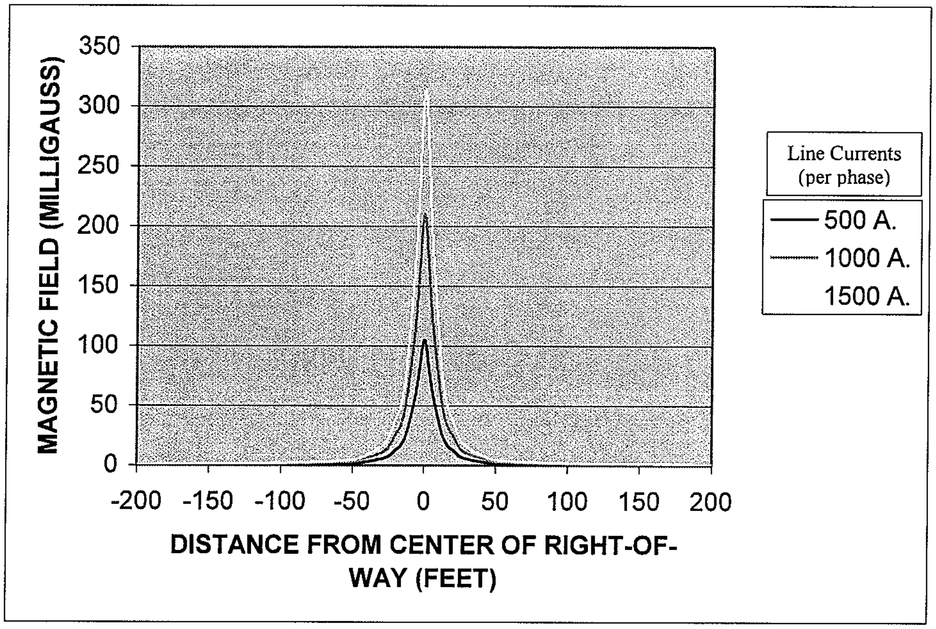

Figure 8-1 Magnetic Field Profiles for 115 kV XLPE Line with Horizontal Cable Arrangement

Source: Connecticut Siting Council and Acres International Corp., "Life Cycle Cost Studies for Overhead and Underground Electric Transmission Lines," pp. 106-111.

8.2.2 Effects of cable type

Magnetic fields are much lower for pipe-type underground lines, because the cables are compactly configured within a metal pipe. Also, a steel pipe provides the maximum shielding effect on magnetic fields, compared to a flat steel plate. As Figure 8-3 shows, the maximum field for a 115 kV HPFF cable, at an assumed loading level of 1000 Amperes per phase, is only 30 mG, and field levels at 20 ft or more from the ROW centerline are negligible.

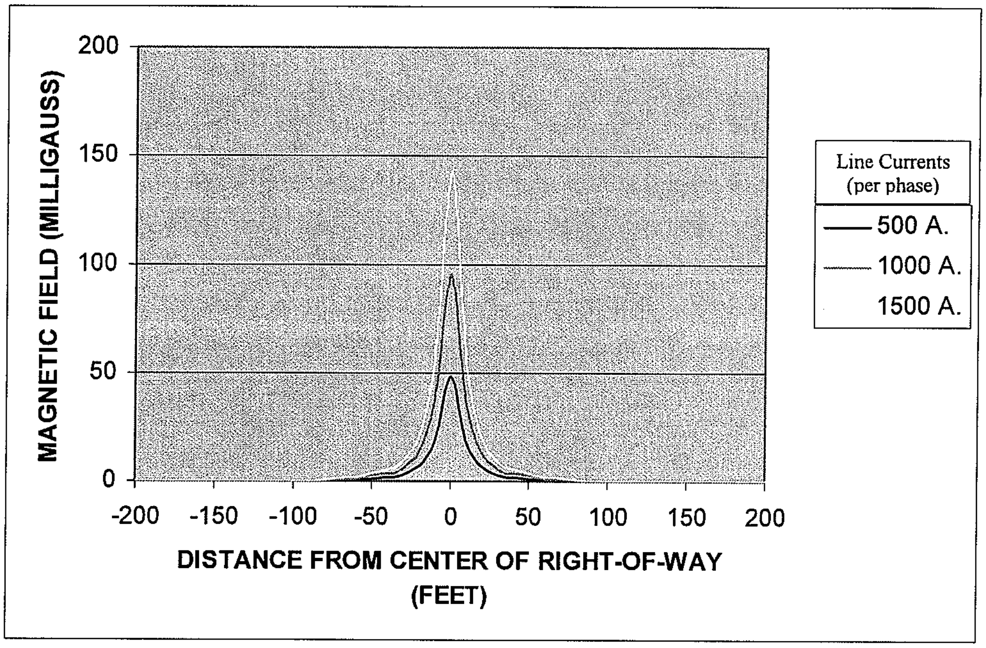

Figure 8-2 Magnetic Field Profiles for 115 kV XLPE Line with Delta Cable Arrangement

Source: Connecticut Siting Council and Acres International Corp., "Life Cycle Cost Studies for Overhead and Underground Electric Transmission Lines," pp. 112-115.

8.2.3 Mitigation alternatives

The most common method for mitigating the magnetic fields of solid dielectric cables is cable reconfiguration.. One type of cable reconfiguration is the arrangement of cables in a delta configuration, as previously illustrated by the reduced fields in Figure 8-2. However, cable reconfiguration can also be used to reduce magnetic fields by cancellation among the three phases in a manner similar to the split-phasing of overhead transmission lines. In this case, it is common to use two cables per phase and to arrange one set of three cables with phase ordering A-B-C, while arranging the other set of three cables in a B-C-A phase order. The two sets of cables are configured in parallel, either horizontally or vertically. When configured as a double circuit line such alternate phasing schemes can reduce magnetic fields by up to 50% with little additional cost above that for a standard double circuit line. When used as an alternative to a three-cable, single circuit line, however, there is a cost penalty because the total required length of cable is doubled.

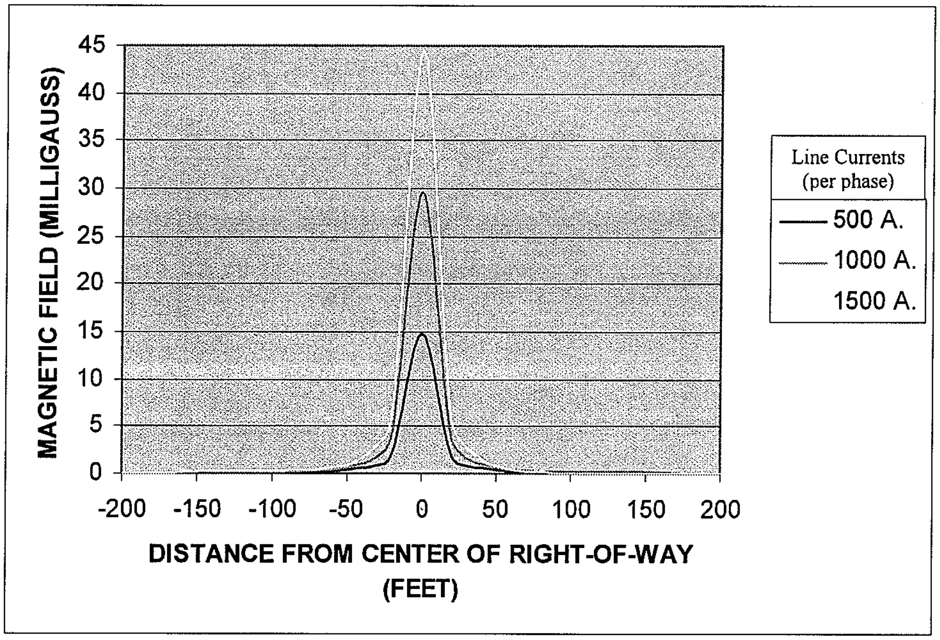

Figure 8-3 Magnetic Field Profiles for Typical 115 kV HPFF Line

Source: Connecticut Siting Council and Acres International Corp., "Life Cycle Cost Studies for Overhead and Underground Electric Transmission Lines," pp. 96-99.

Another mitigation method for XLPE lines is the use of metallic shielding. Such shielding, which typically involves the insertion of steel plates between the cables and the ground level, has not been used previously in Connecticut. Shielding methods were considered during the Docket 272 proceedings, however. Specifically, the Docket 272 Findings of Fact conclude that steel plates installed over the top of a 345 kV cable trench could reduce magnetic fields directly over the trench by a factor of two to five. However, such steel plates also cause a "wing effect" to either side of the trench where the magnetic fields would increase somewhat. When the location of interest is a short distance away from the cable trench, therefore, such plates are generally not an effective tool for mitigating magnetic field levels.

The costs of these metallic shields vary with cable size and trench (or duct) size. However, they would most likely be used only in certain sensitive areas where human exposure to the field was a concern.

9. Environmental Considerations and Costs

The State of Connecticut has a diverse and unique environment that is greatly valued by it's citizens. Accordingly, it is appropriate that the benefits of protecting and enhancing that environment are weighed against the associated costs. While electric power delivery enhances the lives of citizens in many ways, it also has impacts that can affect almost every aspect of their environment. This chapter identifies and