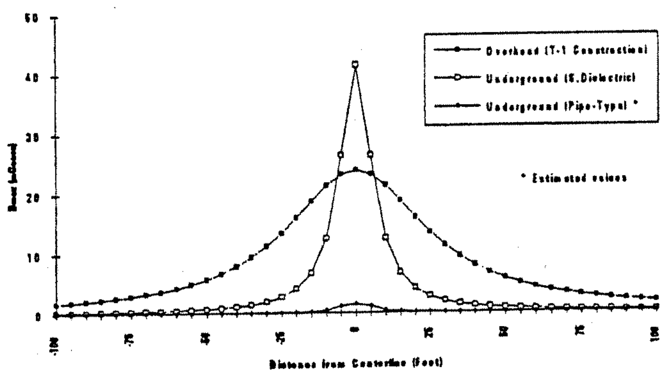
TRANSMISSION LINE

EMF DESIGN

GUIDELINES

Example EMF Comparison Between Overhead & Underground Lines



Pacific Gas and Electric Company
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I. INTRODUCTION

The electric and magnetic field (EMF) issue has become an area of increasing public concern. There is a heightened sensitivity among the public to the siting and construction of new, and the upgrading of existing electric facilities. Much of this concern centers on the exposure to magnetic fields. For field reduction and exposure discussions in this document, the abbreviation, EMF, is synonymous with magnetic fields.

There is substantial scientific uncertainty and no widespread agreement among scientists as to how the presently available information regarding the possible health effects of magnetic fields should be interpreted. Agencies such as California Department of Health Services (CDHS) and Federal Environmental Protection Agency (EPA) have been reviewing the studies conducted thus far to determine if adverse health effects are associated with EMF, and have found no basis for setting health standards. Some laboratory research has identified biological effects from exposure to magnetic fields. Animal and epidemiological studies are inconclusive on whether exposure to EMF can cause human health effects. It is also not clear as to what aspect, if any, of the magnetic field might be of significance. Those aspects currently being examined include the average magnetic field strength, peak field strength, switching of fields, transients, time spent in field, and frequency of field.

There are many references available that provide an in-depth examination of the EMF issue. The literature discusses a wide range of technical, biological, health, communication, and policy issues. Many of these references can be obtained through division EMF coordinators at the PG&E local offices. Publications dealing with EMF are available to interested customers by these coordinators.

II. PURPOSE OF DESIGN GUIDELINES

The Transmission Line EMF Design Guidelines describe various PG&E transmission line design categories, practices and procedures for implementing programs to manage magnetic field strength levels. Using the procedures as described will help identify those design options that minimize the magnetic field levels associated with transmission line facilities. Because science has not determined the health effect, if any, of exposure to EMF, PG&E cannot and does not claim that any steps it takes to reduce fields will benefit human health. The field reduction techniques described in the design guidelines are proven methods, and new techniques will be incorporated as they become available and field tested with the following considerations: percentage field reduction, maintenance, and operational reliability.

This document is intended to provide the PG&E personnel who are involved in the planning, design, construction, or reconstruction of electric transmission facilities with information concerning the options that may be available to reduce the magnetic field strength magnitudes. The information presented includes siting and land issues, technical details of engineering designs, and comparisons of various PG&E approved designs and construction methods.

Minimizing the magnetic field strength is one of the many factors to consider in the planning and design of a transmission system. It must be considered along with other issues such as safety, environmental concerns, reliability, insulation and electrical clearance requirements, aesthetics, cost, operations, and maintenance. These other factors are essential to the design and must continue to be addressed.

In some cases, transmission facilities occupy the same structure as distribution facilities (i.e. transmission pole with distribution underbuilt), the "**Distribution Line EMF Design Guidelines**" should be referred to for distribution facility information. If substations are included in the project, "**Substation EMF Design Guidelines**" should be used as a reference.

III. OVERVIEW OF ELECTRIC AND MAGNETIC FIELDS

EMF is an expression used to refer to the "Electric and Magnetic Fields" emanating from sources such as electric power facilities, wiring, and electrical appliances in the home and the work place. These power frequency electric and magnetic fields are a natural consequence of electrical circuits. They can be either calculated using data relating to the electric facilities or can be directly measured using the appropriate measuring instruments.

Electric fields are present whenever **voltage** exists on a conductor, and are not dependent on current. The magnitude of the electric field is primarily a function of the operating voltage of the line and decreases with the distance from the source (line). The electric field can be shielded (the strength can be reduced) by any conducting surface; such as trees, fences, walls, buildings, and most structures. The strength of an electric field is measured in volts per meter.

Magnetic fields are present whenever **current** flows in a conductor, and are not dependent on the voltage present on the conductor. The strength of these fields also decrease with distance from the source. However, unlike electric fields, conducting materials, such as the earth, living organisms, or non-ferromagnetic metals, have little shielding effect on magnetic fields.

They can sometimes be shielded through the use of specially engineered enclosures designed from magnetic field shielding material. Presently, the application of these shielding techniques in a power system environment is minimal because of the substantial costs involved, and the difficulty of obtaining practical designs

The magnetic field strength is a function of both the current on the conductor and the design of the system. Magnetic fields are measured in Gauss or Tesla (1 Tesla = 10,000 Gauss). However, for the current levels normally encountered in power systems, the field strength is in the milligauss range (1 mGauss = 0.001 Gauss = 0.1 μT).

There are two methods of interpreting magnetic fields: the maximum field vector (Bmax) and the square root of the sum of the squares of the three x, y, and z field vectors, or resultant field (Bresultant). Refer to Figure 1. The maximum field vector can be measured with a single-axis meter, rotated until the meter reads a maximum field in a particular direction. The resultant field can be measured with a three-axis meter which calculates the square root of the sum of the squares of the three orthogonal fields. Single-axis meter can also be used to find the resultant field by hand calculations after obtaining the orthogonal fields. The Bresultant can be greater than the

Bmax at the same location by up to 41% (due to field polarization), for certain conductor geometries. Bmax is used for all magnetic field values in this design guideline, and fields are measured or calculated at three feet above the ground, unless otherwise noted.

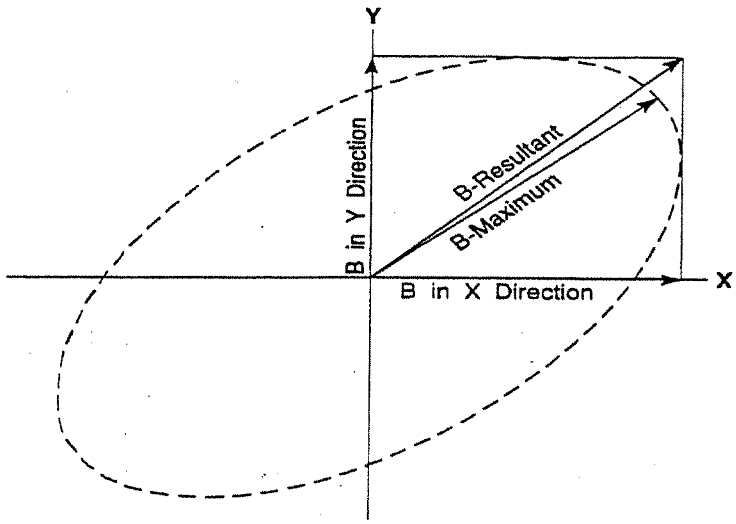

FIGURE 1 - Bmax vs. Bresultant (Field Polarization)

Magnetic field strengths diminish with distance. Fields from compact sources (i.e., those containing coils or magnets such as small appliances and transformers) drop off with distance (r) from the source by a factor of $1/r^3$. For three phase power lines with balanced currents, the magnetic field strength drops off at a rate of $1/r^2$. Fields from unbalanced currents, which flow in paths such as neutral or ground conductors, fall off inversely proportional to distance from the wire, 1/r. Thus, there are other factors besides just distance, such as conductor spacing and phase balance, that have a large effect on the magnetic field strength because they control the rate at which the fields decrease.

While both electric and magnetic fields exist near electric transmission facilities, the remainder of the discussion in this document relates only to magnetic fields. This is the area of public concern and the focus of health research. Magnetic fields for transmission, distribution, and substation facilities can be calculated for specific installations using computer programs and knowing the current, construction type, configuration and phase rotations. The computer programs provide accurate results to the extent that the appropriate line current and physical arrangement data are used. The difficulties encountered in the computer modeling usually stem from the time variant characteristics of the power system input parameters (current, phase angles, unbalanced, etc.).

IV. PG&E CORPORATE EMF POLICY

PG&E's Corporate EMF Policy is to address concerns about EMF and the company is committed to do following:

1. Establish procedures to explicitly consider EMF exposure in the design of, planning for, and communication about new and upgraded facilities.

2. Take steps to reduce EMF exposure in the design of new and upgraded facilities.

3. Encourage a multi-industry effort to share responsibility for effectively addressing public concern of EMF exposure resulting from their products and services, while increasing overall energy efficiency. This effort should include the building industry, manufacturers of appliances, electronic equipment, heavy machinery, and other appropriate industries.

4. Work closely with employees and union leadership to continue to review and implement EMF policies and procedures, provide employees with up-to-date information, and conduct measurements on request.

5. Provide customers with up-to-date information on EMF, conduct measurements on request, and continue supporting the establishment of EMF Public Information Centers.

6. Fund and actively participate in EMF research, and work closely with government officials to resolve EMF issues.

Given the status of research on EMF at the present time, PG&E will continue to work closely with government agencies, citizen groups, research organizations, and other appropriate bodies to ensure that our policies and practices continue to reflect up-to-date information.

These guidelines address PG&E policy statement numbers 1 and 2 above as they relate to electric transmission facilities.

V. NO/LOW COST FIELD REDUCTION

Definition

On November 2, 1993, the California Public Utilities Commission directed all investor owned utilities in the state to take "no cost and low cost" EMF reduction steps on transmission, substation and distribution facilities to reduce exposure to magnetic fields (EMF OII - Decision 93-11-013). The Company's definition of "no cost and low cost" for **transmission facilities** is as follows:

- No cost and low cost measures should be taken to reduce magnetic fields on **new and upgraded** facilities.

- **No cost** measures are those steps taken in the design stage, including changes in standard practices, which will not increase the project cost but will reduce the magnetic field strength.

- **Low cost** measures are those steps that will cost about 4% or less of the total project cost and will reduce the magnetic field strength in an area (e.g., by a school, near residences, etc.) by approximately 15% or more at the edge of the right of way. The total project cost is defined as all costs associated with the siting, design and construction of those specific new or upgraded transmission, substation, or distribution project facilities. The total project cost figure used, as a basis of low cost determination, is only that particular component of the project being evaluated for magnetic field reduction steps. As an example, when a substation and a transmission line are being designed, 4% of the total cost for the transmission line will be considered for magnetic field reduction from the line and 4% of the total substation cost will be considered for reduction from the substation. The 15% reduction in magnetic field strength in an area can be achieved by a combination of reduction techniques. This project cost increase will be provided by the project funding sponsor.

Application

In the California Public Utility Commission (CPUC) Decision 93-11-013, dated November 2, 1993, there is direction on how no and low cost measures should be adopted for transmission facilities:

> "For new and upgraded facilities (facilities requiring certification as contemplated in General Order (G.O.) 131*), we direct that low-cost options shall be implemented to the extent approved through the project certification process; no-cost mitigation measures should be undertaken until further notice."

It is PG&E's policy to take reasonable no and low cost steps on new and upgraded facilities to reduce EMF exposure, whether or not G.O. 131 certification is required. If a project is requested and funded by a customer, agency or other organization, the no and low cost measures would be paid for by the same party.

1. NO COST vs LOW COST

In keeping with its policy and the CPUC decision, no cost measures should always be used to reduce EMF on new, upgraded and retrofitted projects, as long as they are not in conflict with other design and siting options as described in the Section IV -- "Purpose of Design Guidelines".

Low cost measures will also be considered on these projects. The CPUC Decision defined low cost as the following:

> "We direct the utilities to use 4 percent as a benchmark in developing their EMF mitigation guidelines. We will not establish 4 percent as an absolute cap at this time because we do not want to arbitrarily eliminate a potential measure that might be available but costs more than the 4 percent figure. Conversely, the utilities are encouraged to use effective measures that cost less than 4 percent. Given the evolving body of research on EMF mitigation measures, we feel that 4 percent provides the utilities with sufficient guidance without hindering their ability to seek out or develop innovative measures and to reduce the cost to implement known measures. For upgraded

* General Order 131 is the Commission's rule governing construction of transmission lines and power plants above 200 kV. In Order Instituting Investigation (OII) 83-04-03, we (the CPUC) are revising G.O. 131. Under the proposed revisions, our authority over new transmission lines would extend to lines 50 kV and above.

projects, the benchmark should apply to that portion of the project for which the utility is seeking authorization."

The intent is not to spend a specified amount on every project. In fact, the CPUC encourages utilities "to use effective measures that cost less than 4 percent." The intent behind using no and low cost measures is to look at the design of a specific new line or upgrade, take no cost measures to reduce EMF, and then, consider if there are other ways to reduce EMF for a low cost.

2. MINIMUM FIELD REDUCTION

The Decision discusses that a "noticeable reduction" should be achievable before implementing a single or combination of measures, but declined to adopt a specific number. 15% or more reduction is used as the criteria for application within any one area. Also consider the guidance in the decision:

" If the design guidelines identify a particular EMF reduction measure as appropriate and justified in a given situation, then that measure should be available for a utility to implement in that situation."

3. AREA PRIORITIZATION

The 15% or more reduction is not meant to restrict choices of EMF reduction measures, but to guide the design engineer on when a selection or combination is "appropriate and justified in a given situation."

In determining how to apply low cost measures to the project, the entire project team should be consulted. This will ensure a variety of views (engineering, division, operations, communication, environmental, permitting, and public affairs, etc.) are considered to provide optimum choices. The basis of taking low cost measures is public concern, and it is criteria based on public concern that will determine where these measures will be applied. Instead of using **exemptions** which would require a number of explanations of when they would and would not apply, it is clearer to use criteria prioritized on public concern.

Low priority are those areas with little or no public exposure such as unpopulated, forested and/or government owned land, such as national parks. Highest priority are schools (public and private) and day care centers, where public concern has been most intense. In between these high and low priorities, are areas of varying concern: agricultural/rural, planned/zoned but undeveloped land, recreational, commercial/industrial and residential. (See chart below.)

PRIORITIZED AREAS
(based on public concern)

HIGHEST Priority

1. Schools, licensed day care
2. Residential
3. Commercial/Industrial
4. Recreational
5. Agricultural, rural
6. Undeveloped land, zoned for residential
7. Undeveloped land, zoned for commercial/industrial
8. Unpopulated, forested, government owned land

↓

LOWEST Priority

4. APPLICATION OF LOW COST MEASURES

When selecting where low cost measures should be applied, high priority areas must be considered first. In addressing the high priority areas, a series of questions must be answered, such as:

i. Are these areas located near enough to the facility to be of public concern?
ii. Are there measures which can be taken to reduce magnetic fields at edge of right-of-way by 15% or more?
iii. Is the cost of reducing fields at all areas about 4% or less of the total project budget?
iv. Have all areas of equal priority been considered? (Unless all areas within a priority group can receive equivalent* treatment, no single area in this or a lower priority group will receive low cost measures. It is the project team's responsibility to search for opportunities for low cost measures, yet ensure fair solutions.)

* Equivalent can be defined in this circumstance as applying some type of low cost measures to all areas in a priority group. The measures may not necessarily be the same in every area, and reductions may not necessarily be equal to have treated areas equivalently.

5. FIELD MANAGEMENT PLAN

It is the project lead's (project manager or project engineer for smaller projects) responsibility to prepare a Field Management Plan for project authorization on all projects. The plan should be reviewed by the Transmission Lines Engineering Group in G. O. before the authorization process. The plan's written summary shall include the following (see Appendix-C for the Field Management Plan form):

i. General description of the project (cost, design, length, location, etc.).
ii. General description of the surrounding land uses, using priority criteria classifications.
iii. No cost options to be implemented.
iv. Priority areas where low cost measures are to be applied.
v. Measures considered for magnetic field reduction, percent reduction and cost.
vi. Conclusion - which options were selected and how areas were treated equivalently or why low cost measures cannot be applied to this project due to cost, percent reduction, equivalence or some other reason.

These plans will also be used in the following ways: If a project is scheduled for G.O. 131 certification, the final low cost measures will be approved through the certification process. It will be the team's job to prepare a field management plan for submittal as part of that project documentation. Whether or not a certification is required, the project team will use the field management plan by making it available to the public through the communication program for that project.

VI. MAGNETIC FIELD MODELING TOOL

There are several programs available at PG&E to perform the computer modeling of the magnetic field environment of electric transmission lines. The program recommended for use on standard transmission line configurations is the "FIELDS" program, a public domain program created by Southern California Edison Company. This program is available from Transmission System Engineering, who also provide documentation and support to users of this program. Other programs are used by Engineering to model more complex environments. By utilizing computer programs, the designer can determine the phasing, phase configurations, and construction options that provide the lowest levels of magnetic field strength.

The magnetic field strength of a transmission line is dependent upon the point along the line at which the magnetic field is calculated. Because the height of the conductors varies along the line, the magnetic field strength also varies along the line. The maximum magnetic field is obtained at the minimum conductor clearance point, which is normally at midspan. Therefore, the minimum clearance height should be used when calculating the field strength of the line. However, if the strength at a particular location is desired, the characteristics at that location, including conductor height, should be used.

Magnetic field strength of a transmission line is typically calculated, for field reduction comparison, at three feet above the ground and at the edge of the right of way.

VII. MAGNETIC FIELD REDUCTION TECHNIQUES

In general, there are four techniques which may be available to reduce the magnetic field strength levels from electric power transmission facilities. They are:

- Increase Distance from Conductors
- Reduce Conductor Spacing
- Minimize Current
- Optimize Phase Configuration

This section contains a detailed discussion of each option and how these techniques can be applied to PG&E transmission lines. The intent of this section is to define the options that may be available. However, the practicality of any particular option must be addressed in each specific case.

Increase Distance from Conductors

The strength of the magnetic field decreases as the distance from the conductors increases. Therefore, one method of reducing the magnetic field strength at a particular location is to increase the distance of the conductors from the location of interest. The rate of decrease is dependent on several factors, including line design and the current unbalance in the circuit.

The areas of interest, where field minimization is desired, are those that are accessible to the public. For electric transmission lines, this location most commonly is the edge of the right of way. Magnetic field reduction may be accomplished in a variety of ways, including:

- Siting- taking into account the types of land uses adjacent to transmission lines.
- Access- minimizing public usage of the line rights of way.
- Rights of Way- increasing the rights of way width.
- Height- increasing the height of overhead lines.
- Depth- increasing the depth of underground lines.

Siting

In the siting of new transmission lines or rerouting of existing lines, the alternative route analysis will consider potential land use impacts. A study of the existing and projected magnetic field environments should be performed to investigate how siting considerations may be affected by magnetic field strengths. Included in the study should be an analysis of present magnetic field strengths, computer generated field strengths for the proposed alternatives and a discussion of how land uses may be impacted. This may cause a longer route to be analyzed than would normally be considered and any resulting environmental problems or costs must be balanced against the EMF issue.

<u>Access</u>

It has been a common practice for PG&E to allow access by third parties to transmission rights of way for various uses: including jogging, hiking, and bicycle paths; parking lots; nurseries; parks and activity fields; and other similar uses.

With existing rights of way, limiting access may or may not be an option depending on the rights that PG&E possesses on the route and the existing land uses that are already permitted. There may be some possibilities to improve or expand the restrictions on existing rights of way when local developments necessitate that the line be relocated. Where PG&E can not regulate land use, PG&E will provide EMF information to the requesting third party for their consideration prior to their decision concerning the prospective use of the property.

<u>Rights of Way</u>

For transmission lines 230 kV and below, the minimum rights of way widths are determined by the swing characteristics of the line plus minimum clearances specified in G. O. 95. For 500 kV lines, the minimum width is based on radio interference studies conducted in the 1960s, which resulted in rights of way width 40 feet wider than needed for swing considerations.

Increasing the widths of rights of way will increase the distance from the conductors to the edge of the right of way, thereby reducing the magnetic field strength level at the edge of the right of way. Land availability for acquisition and the costs associated with the purchase of the additional property rights must be taken into consideration when examining this option. In addition, this action will only provide the desired result if the uses of the right of way are also controlled.

The following table provides a list of "typical" right of way widths used for new transmission lines. Right of way widths for existing lines or when special circumstances require, will differ from the values below. In addition, the actual right of way required will depend on the topography, structure type, span length, and other factors.

Type of Line	Typical R/W Width
Single/Double Circuit Wood Pole Line	40'
Double Circuit 115kV Tower Line, Tubular Steel Pole Line	80'
Double Circuit 230kV Tower Line, Tubular Steel Pole Line	100'
Bundled Double Circuit 230kV Tower Line	120'
Single Circuit 500kV Tower Line	200'
Underground	Normally in franchised rights

TABLE 1 - Typical Right of Way Widths

Height

Another possible technique to reduce the magnetic field strength at ground level is to increase the distance of the conductors from ground. There are two primary methods in which this may be accomplished:

- Raise the height of the transmission structures used.
- Reduce the sag of the conductors by:
  - Adding additional structures to reduce the span length.
  - Increasing the conductor tension. This technique may be limited by the strength of the structures, insulators, and/or conductors. In addition, conductor vibration tendencies at high tensions must be addressed.
  - Using a lighter weight conductor. This technique may be limited by the strength of the conductor, conductor vibration at high tensions, and by the minimum conductor size allowable for a voltage level due to radio interference criteria.

The above options to reduce the sag increase the height of the conductor at midspan but do not change the conductor height at the structure. Therefore, the significant magnetic field reduction only occurs at midspan when reducing the sag.

Figure 2 below illustrates the affect of increased conductor height on the magnetic field strength as calculated at a distance of 3 feet above ground level. The figure uses a conductor base height of 30' and provides reduction percentages at the centerline, 40' from the centerline (edge of an 80' right of way), 100' and 150' from the centerline for various increases in conductor height. This figure shows the percentage reduction decreases as one goes away from the centerline of the tower.

The figure shown is based on a "typical" 115kV double circuit tower line (DCTL) design; however, the general relationship between increased conductor height and magnetic field at ground level generally holds true for all other voltage levels and configurations. The field reduction percentages are independent of the actual current magnitudes. Once again, whether this option of increasing the conductor height is practical will depend upon environmental and economic constraints.

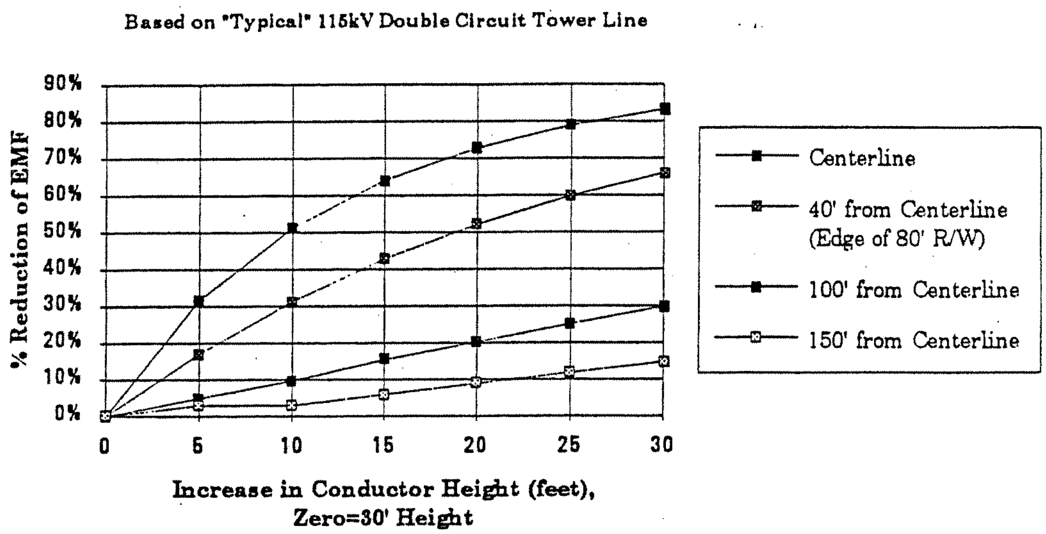

FIGURE 2 - Example of Magnetic Field Reduction as a Function of Conductor Height

Figure 3 compares magnetic field strength vs. distance from the centerline of a typical double-circuit 230kV, cross phased configuration, for two different conductor heights. This figure illustrates that increasing the height of a line can be very effective at reducing the magnetic field strength directly under a line, but the effectiveness rapidly falls off as one moves away from the line.

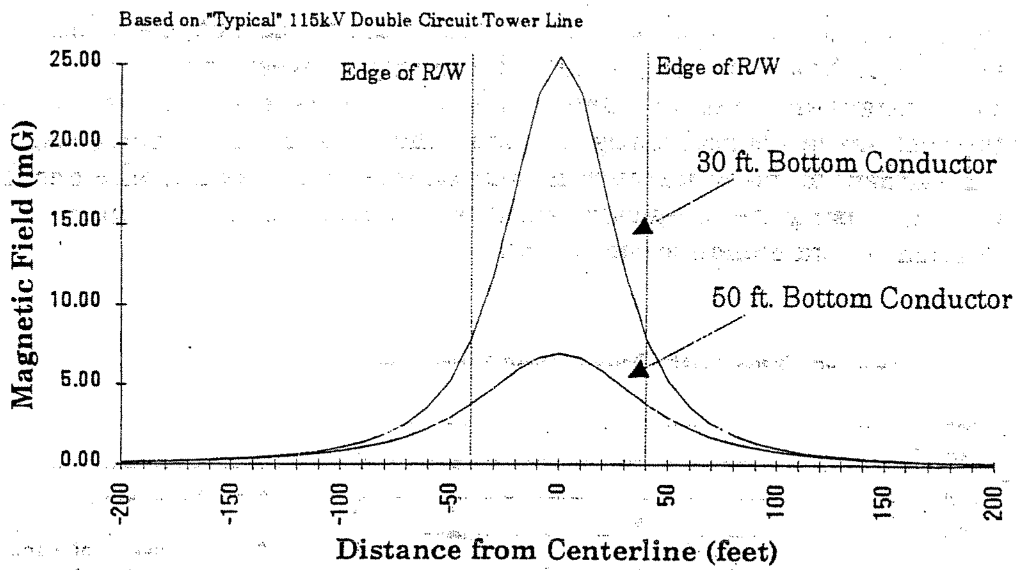

FIGURE 3 - Magnetic Field vs. Distance from Centerline

Depth

The magnetic field strength of underground transmission lines can be reduced by increasing the depths at which the lines are buried. Increasing the depth of an underground line from 3 feet to 4 feet lowers the magnetic field strength by approximately 25%. A reduction in the field strength of approximately 40% can be obtained by increasing the depth from 3 feet to 5 feet. It should be noted that any increase in the depth could have a significant impact on the cost and the current carrying capacity of the underground facilities.

Reduce Conductor Spacing

The magnetic field strength at ground level is a result of the addition of the magnetic field vectors of the various current carrying conductors. As the phases are moved closer together, there is increased phase-to-phase cancellation of the magnetic field and the total resultant field strength decreases. Therefore, compact spacing designs can result in a lower magnetic field strength than larger, more spread out designs.

For overhead lines, horizontal or vertical configurations typically have a larger phase spacing and hence, produce higher fields under the line than triangular or delta configurations. For underground lines, self contained systems, where each phase is placed in a separate duct, generally produce greater fields than pipe-type systems, where all three phases are contained in a single duct.

Due to flashover and reliability considerations for the circuit, there is a practical limit to the reduction in spacing that can be achieved (minimum spacings can be found in PG&E Design Standards and CPUC G. O. 95). A reduction in the phase spacing may also impact live line work procedures used to maintain the line. In addition, a reduction in phase spacing changes the impedance of the line which may require modifications in the switching and protection systems to ensure proper fault clearing.

Minimize Current

As mentioned in the Section II (Overview of EMF), the magnetic field strength is directly proportional to the magnitude of the current flowing in the conductor. The higher the current, the greater the field strength. This is true for both the phase conductor current or the unbalanced neutral current. This section will discuss both.

For phase currents, the amount of power a line transports is proportional to the product of voltage and current, $P=V*I$. From this equation, it can be seen that the power flow and the voltage of the line are two factors that can be manipulated to reduce the current.

Higher voltage transmission lines can transport the same amount of power with less current than a lower voltage line. As a result, a line operating at the higher voltage will produce a lower magnetic field strength for the same power transfer than a line operating at a lower voltage. It should be noted that an increase in the line voltage will also allow additional power to be transferred without increasing the magnetic field. This alternative is often not practical due to the additional cost of higher voltage terminal equipment.

Another way to minimize the load current is to minimize the power transferred. This may be feasible in selected sites, but it may not be a practical proposition to achieve large scale reductions in load current because the magnitude of power transferred is controlled primarily by the level of customer demand for the electrical power.

It is possible to achieve some reduction in current through Customer Energy Efficiency programs. Adequate reactive load compensation (i.e. capacitors) can be provided to bring the power factor closer to unity at the distribution level, thereby minimizing the reactive power flow on transmission lines. In addition, the current on a particular transmission line may be reduced by providing an alternative path for the power to flow. This may be accomplished through the switching or reconfiguration of existing facilities or the construction of additional transmission lines.

The magnetic field strength from lines with unbalanced currents decreases less rapidly than the fields from lines with balanced currents. In some cases, the ground level component of the magnetic field strength due to the unbalance is greater than the component due to the phase currents. Therefore, balancing an existing unbalanced line will have a large effect on the ground level field strength.

Generally, distribution line currents are much more unbalanced than transmission line currents, due to single phase loads and operational conditions on distribution lines. However, specific conditions (i.e. long radial feeds) may also cause significant unbalance on transmission line currents.

Phase Configuration

Selective use of some phase configurations can be used as a field cancellation technique. Since the resultant magnetic field strength at any one point in space is the vector sum of the individual fields of the three phases of the line, the phases from one circuit of a multi-circuit line can be used to reduce the field from another circuit, thereby reducing the total magnetic field strength. For this reason, multi-circuit lines may have lower magnetic fields than single circuit lines.

Typically, double circuit tower lines, where the individual circuits are "cross phased," produce lower ground level magnetic fields than other phasing options. A cross phase configuration is obtained when one circuit on a multi-circuit structure is phased in the opposite phase order of the other circuit, e.g., circuit #1= ABC and circuit #2= CBA (as shown in Figure 4).

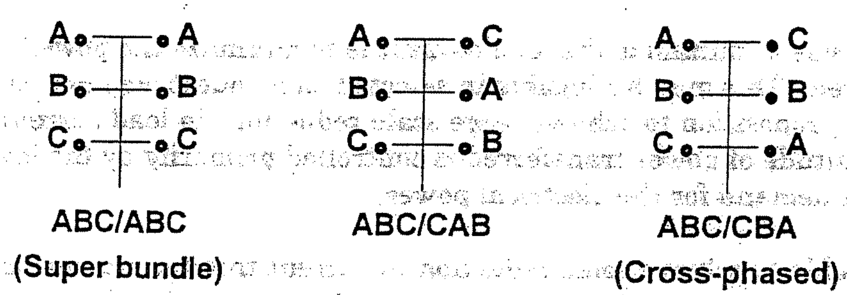

FIGURE 4 - Phase Configurations

Using a cross phased configuration on a new line is usually easy and can be achieved at no additional cost. Changing existing lines to a cross phased configuration is also possible, but does result in an additional cost.

There are also situations where a transmission line is overbuilt onto a distribution circuit pole line. Depending on the loading (both current magnitude and balance of phases), direction of current flow, and phase configuration; the addition of the transmission line may actually result in a lower magnetic field strength than the case with the distribution line alone. It should be noted that some distribution primary and secondary circuits may have 30 degree phase shifts from the rest of the system, due to wye-delta transformer connections. A computer study must be performed to adequately assess the interaction of the magnetic fields from the multiple sources.

Another common situation is where multiple transmission lines are in a common corridor. The phasing relationship between all circuits in the corridor must be evaluated to determine the optimum phasing for the lines that results in the lowest combined field strength. It should be kept in mind when doing this evaluation that the loading and direction of current flow on each circuit may vary with time. Therefore, there may not be one single "optimum" low field phasing combination for the corridor. It is recommended that in this case the phasing configuration that results in the lowest average field strength when people are in the environment, should be used.

Another application of field cancellation through phase configuration is "split phasing", where a single circuit is constructed as two parallel circuits. For maximum field cancellation, current is evenly splitted between the two circuits and conductors are arranged in the cross phased configuration. Although PG&E has not applied this technique at the present time, it may be considered keeping in mind costs and system reliability.