SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL℠ Company

EMF Design Guidelines For Electrical Facilities

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Acknowledgements

Southern California Edison Company has prepared these “EMF Design Guidelines” to focus the dialogue on the EMF Issue and magnetic field reduction measures.

Many Southern California Edison employees have contributed to the formulation of this booklet, including Dr. Jack Sahl of Environmental Health & Safety, Richard Tom of the Law Department, Tom Burhenn of Regulatory Policy & Affairs, and Jon Sirugo, Charles Kim, Glenn Sias, Brian Thorson, and Ann Almonte of the EMF Research & Education Department.

Disclaimer

The primary purpose of EMF Design Guidelines is to give SCE personnel who are responsible for implementing the "no-cost" and "low-cost" measures the knowledge and tools necessary to assist in determining the most appropriate design for each application in a consistent manner. The EMF Design Guidelines are intended for new construction or major reconstruction of electric utility transmission, substation, and distribution facilities. They are not applied to changes made in connection with routine maintenance, emergency repairs, or minor changes to existing facilities.

The justification for California's EMF Program is the desire to be appropriately cautious in the face of scientific uncertainty about potential public health impacts. SCE is committed to taking appropriate actions to respond to EMF issue. While California's EMF Program may, or may not, have any actual public health benefits, it is justified as long as the costs are reasonable, and it does not adversely affect electric system reliability and safety.

The magnetic field values in these guidelines are for comparison of construction methods only and cannot be assumed to represent actual milliGauss (mG) levels found near SCE electrical facilities. These magnetic field values are provided to help SCE personnel in selection of "no-cost and low-cost" option(s) that best meet the appropriate design requirements. SCE cannot guarantee that once built, the selected option will achieve those exact magnetic fields, or that the actual magnetic field levels will remain constant over time. Changes in line loading and other electric utility system changes could cause the magnetic fields to go up or down.

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1 Policy and Regulatory History

An integrated action plan has been developed in California in response to public and scientific concerns about potential health impacts from power frequency electric and magnetic fields (EMF) from electricity utility facilities. California's EMF program includes initiatives by the California Public Utilities Commission, California Department of Education, California Department of Health Services, and the electric utility industry.

In combination, this includes employee and customer education, and support of research to address the remaining scientific question and internal policies for siting new electric utility transmission and distribution facilities. The "EMF Design Guidelines" are part of California's comprehensive response. EMFs have not been established to have either worker or community health impacts. Nor is there sufficient scientific information available for the relevant state or national public health and environmental regulatory agencies to establish specific numeric public health exposure standards. This is because a health hazard has not been established, and there is no operational definition of exposure in the context of "safe" or "not safe."

These conclusions are consistent with the following recently published reports: The National Institute of Environmental Health Sciences (NIEHS) of 2000, the International Agency for Research on Cancer (IARC) 2001, the National Radiological Protection Board (NRPB) 2001, the International Commission on non-Ionizing Radiation Protection (ICNIRP) 2001, and the California Department of Health Services (CDHS) 2002. The justification for California's EMF Program is the desire to be appropriately cautious in the face of scientific uncertainty about potential public health impacts. SCE is committed to taking appropriate actions to respond to the EMF issue. Southern California Edison (SCE) also encourages the meaningful participation of people interested in our decision making process for siting and designing new electrical facilities. While these actions may, or may not, have any actual public health benefits, they are justified as long as the costs are reasonable and they do not adversely affect electric system reliability and safety.

On November 2, 1993, the California Public Utilities Commission (CPUC) issued decision 93-11-013. The purpose of this decision was to establish rules and procedures for addressing the potential health effects of electric and magnetic fields of utility electrical facilities.

"The CPUC decision is based upon a regulatory strategy that:

- Sets the foundation for obtaining answers to key questions;
- Provides for public education and information;
- Takes public concerns into account;
- Allows for appropriate interim responses;
- Is consistent with existing knowledge;
- Does not disproportionately allocate public resources;
- Can be updated as new information becomes available; and
- Allows for an open decision-making process which includes public participation."

Decision 93-11-013 specifically requires the state's investor owned electric utility companies to implement:

- No-cost and low-cost steps to reduce EMF levels;
- Workshops to develop EMF design guidelines[1];
- Uniform residential and workplace EMF measurement programs;
- Support of various health research programs[2].

Additional information about the CPUC and CDHS EMF programs can be found at:

- California Public Utilities Commission
  www.cpuc.ca.gov/divisions/energy/environmental/emf/emfopen.htm

- California Department of Health Services
  www.dhs.ca.gov/ps/deode/ehid/emf

Information on the US Federal Government's and The World Health Organization's EMF Programs can be found at the following websites:

- Federal Government's National Institute of Environmental Health Sciences
  www.niehs.nih.gov/emf/rapid

- World Health Organization
  www.who.int/peh-emf

1.1 Southern California Edison EMF Policy

There are many sources of power frequency electric and magnetic fields, including internal household or building wiring, electrical appliances, and electric power transmission and distribution facilities. There have been numerous scientific studies about the potential health effects of EMF. Interest in a potential link between long-term exposures to EMF and certain diseases is based on the combination of this scientific research and public concern.

After 30 years of research, a health hazard has not been established to exist. Many of the questions about specific diseases have been successfully resolved due to an aggressive international research program. Potentially important public health questions remain about whether there is a link between EMF exposures in homes or work and some diseases, including childhood leukemia and a variety of adult diseases (e.g., adult cancers and miscarriages). Because of this research, some health authorities have identified magnetic field exposures as a possible human carcinogen.

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[1] These workshops were held in 1994 and included the participation of a wide range of stakeholders. Refer to Section 3.0 "Purpose of EMF Design Guidelines" for additional information.
[2] For further information about these research efforts, contact Southern California Edison's EMF Research and Education Center at (800) 200-4723.

While scientific research is continuing on a wide range of questions relating to exposures at both work and in our communities, a quick resolution of the remaining scientific uncertainties is not expected.

SCE is aware that there is concern about the potential health effects of power-frequency electric and magnetic fields. Notwithstanding the health, safety, and economic benefits of electricity, SCE recognizes and takes seriously its responsibility to help address these EMF concerns. In order to better understand EMF and to respond to the current uncertainty, SCE will continue to:

- Assist the California Public Utilities Commission (CPUC) and other appropriate local, state, and federal governmental agencies in the development and implementation of reasonable, uniform regulatory guidance;

- Provide balanced, accurate information to our employees, customers, and public agencies, including EMF measurements and consultation to our customers upon request;

- Take appropriate "no-cost and low-cost" steps to minimize field exposures from new facilities, and continue to consult and advise our customers with respect to existing facilities, subject to CPUC guidance;

- Support appropriate research programs to resolve the key scientific questions about EMF; and,

- Research and evaluate occupational health implications, and provide employees who work near energized facilities with timely, accurate information about field exposures in their work environment.

2 Introduction to EMF

"EMF" is the expression commonly used when talking about "power-frequency electric and magnetic fields." Power-frequency electric and magnetic fields are a natural consequence of the flow of electricity. The strength of electric and magnetic fields can either be measured using a gaussmeter or estimated using formulas factoring in voltages, currents, and system designs.

Electric fields are produced by the voltage on a conductor and rapidly decrease with the distance from the source. The electric field can easily be shielded by trees, fences, buildings, and most other structures. The strength of the electric field is a function of system design and the magnitude of the voltage level. Electric fields are measured in units of kiloVolts per meter (kV/m).

Magnetic fields are produced by the current in a conductor. They also rapidly decrease with distance from the source. Magnetic fields are much more difficult to shield than electric fields. The strength of the magnetic field is a function of system design and the magnitude of the current. Magnetic fields are measured in units called milliGauss (mG).

Although the term EMF includes both electric and magnetic fields, the focus of the California EMF Consensus Group and the California Public Utilities Commission in Decision 93-11-013 has been on magnetic fields. SCE's Design Guidelines are exclusively applied to consideration of magnetic fields. While the fields from each power line will vary depending on load, design and other factors, examples of possible magnetic field levels that could be found near different voltages of power lines are shown in Table 2.1.

Table 2-1 Example of Power Frequency Magnetic Fields from Electric Power Lines

Source of Magnetic Fields	Distance from Source or Location	Magnetic Fields (mG)
500 kiloVolt Transmission Line	Edge of Right-of-Way	30
230 kiloVolt Transmission Line	Edge of Right-of-Way	14
66 kiloVolt Transmission Line	Under the Line	13
12 kiloVolt Distribution Line	Under the Line	7

Figure 2.1 shows examples of sources of magnetic fields in and around a residence. These sources also exist in and around other buildings, such as schools, offices, stores, and businesses. Electric and magnetic fields can be detected and measured near internal wiring, electrical appliances, water pipes, and wherever electrical voltages and currents are present.

Figure 2-1 Sources of Magnetic Fields

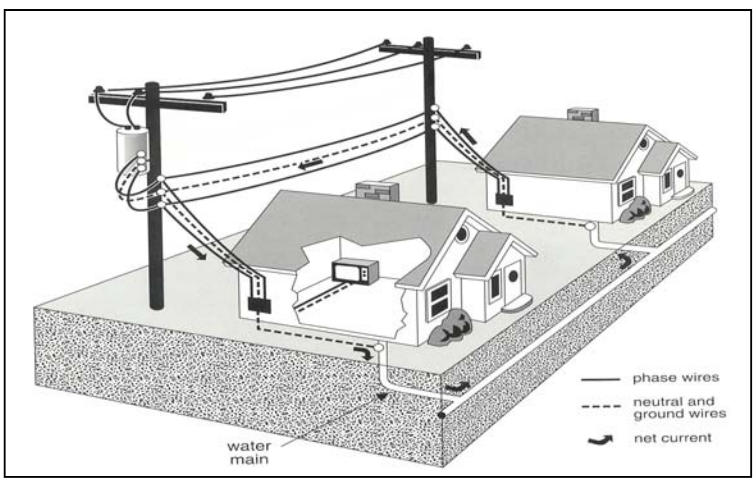


Table 2-2 shows magnetic field strength levels for various household and business appliances, ranging from 1500 mG for a can opener to nearly non-existent amounts as one moves away from the source. Magnetic field strength levels decrease quickly as the distance from these appliances increases. Figures represented in the table are provided by the National Institute of Environmental Health Sciences and the U.S. Department of Energy[3].

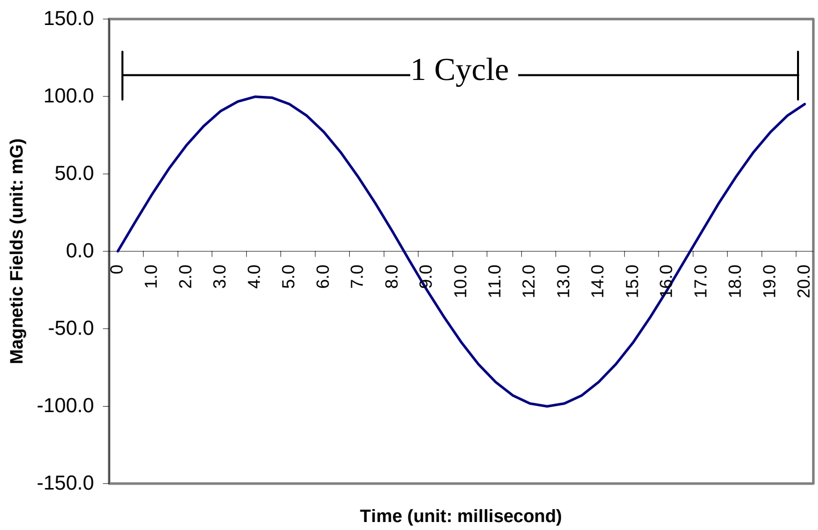
Table 2-2 Magnetic Fields from Electrical Appliances[3]

Appliances	Magnetic Fields (milliGauss)			
	6 inches	**1 foot**	**2 feet**	**4 feet**
Hair Dryers	700	70	10	1
Electric Shavers	600	100	10	1
Blenders	100	20	3	-
Can Openers	1500	300	30	4
Microwave Ovens	300	200	30	20
Refrigerators	40	20	10	10
Washing Machines	100	30	6	-
Vacuum Cleaners	700	200	50	10
Power Saws	1000	300	40	4
Drills	200	40	6	-
Copy Machines	200	40	13	4
Fax Machines	9	2	-	-
Video Display Terminals	20	6	3	-
Electric Pencil Sharpeners	300	90	30	30

The magnetic fields produced by power lines have properties similar to those of the Earth's magnetic field (the Earth's magnetic field ranges from 380 mG to 560 mG). The field has direction, polarity (+ or -) and magnitude (strength). However, unlike the earth's magnetic field, power line magnetic fields change magnitude and polarity with time, as illustrated in Figure 2-2.

The "power-frequency" magnetic field, just like the AC electric current that produced it, makes one complete positive polarity/negative polarity cycle in 16.67 milliseconds, or 60 complete cycles per second. The field thus has a frequency of 60 cycles per second, or 60 "Hertz."

Figure 2-2 "Power Frequency (60 Hz)" Magnetic Fields



[3] Source: _Questions and Answers About EMF: Electric and Magnetic Fields Associated with the Use of Electric Power_, National Institute of Environmental Health Sciences and U.S. Dept. Of Energy: Pages 33-35. June 2002

Power frequency magnetic fields can be measured by simple hand-held instruments or calculated using one of several available computer software programs. SCE uses EMDEX meters to measure magnetic fields. These instruments read the combination of the three axis of the magnetic field, or the "resultant", also known as "$\mathbf{B}_{Resultant}$". SCE also uses "**Fields**," and "**3D Fields**" programs for calculating magnetic fields. The "Fields" program gives both "B_{max}[4]" and "$B_{Resultant}$." SCE uses $B_{resultant}$ for evaluating "no-cost and low-cost" magnetic field reduction measures for electric power lines. When "3D Fields" are being used for substation projects, it calculates $B_{Resultant}$ only. In the EMF Design Guidelines, both B_{max} and $B_{resultant}$ have been used to demonstrate the intensity of magnetic fields.

[4] "Bmax" is the maximum phasor component of the magnetic field in a point in space and is represented by the magnitude and direction of the major semi-axis of the field ellipse. The ellipse axes correspond to the zero rate of change of the field magnitude with respect to the angle in space or with respect to time.

3 Purpose of EMF Design Guidelines

The California Public Utilities Commission adopted a policy where investor-owned electric utilities operating within the state agree to incorporate various “no-cost and low-cost” measures into the construction of new or upgraded power lines and substations (Decision 93-11-013). This decision also authorized each utility to develop and publish a set of “EMF Design Guidelines” implementing this policy. SCE periodically updates the EMF Design Guidelines to reflect current information. This update was done to capture the information that has resulted from the California Department of Health Services, Federal NIEHS EMF RAPID, World Heath Organization, IARC review, and U.K. NRPB EMF research reviews.

These EMF Design Guidelines are intended for new construction or major reconstruction of electric utility transmission, substation, and distribution facilities. They describe the methodology for evaluating “no-cost and low-cost” measures to reduce magnetic fields in new construction or major reconstruction. Their purpose is to give the designer the tools and knowledge necessary to assist in determining the most appropriate design for each application in a consistent manner. These guidelines are not applied to changes made in connection with routine maintenance, emergency repairs, or minor changes to existing facilities[5].

In summary:

- SCE is taking reasonable “no-cost and low-cost[6]” steps to build new electric utility lines and substations in ways that reduce magnetic fields in accordance with CPUC Decision 93-11-013[7];
- These guidelines have been updated to reflect new information from the CDHS, NIEHS, WHO, and NRPB EMF Program.

When applying these guidelines, the proposed electrical facility will be designed and routed consistently with existing SCE design, siting, construction, operation, and maintenance criteria. Design criteria may include aesthetic considerations where required by local code or to be consistent with existing electrical facilities in that geographic area. Certain magnetic field reduction measures such as line phasing, line routing, pole height, pole-head configuration, and location of substation equipment may be included in the preliminary design[8.] Some of these measures can be considered “no-cost” magnetic field reduction measures. This preliminary design can serve as the basis for the four percent (4%) cost benchmark used in the evaluation of further “low-cost” measures. The calculated field for the preliminary design can be served as the basis for the fifteen percent (15%) magnetic field reduction used to determine “noticeable reduction.”

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[5] The specific criteria for application of these guidelines are included in the respective Transmission and Subtransmission, Substation, and Distribution sections of this document.

[6] CPUC 93-11-013: “We direct the utilities to use 4 percent *(of the total cost of a budgeted project)* as a benchmark in developing their magnetic fields mitigation guidelines. We will not establish a 4 percent cap at this time because we don’t 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.” (Section 3.3.2)

[7] California Public Utilities Commission, Order Instituting Investigation (OII) Decision 93-11-013, Dated November 2, 1993.

[8] Some magnetic field reduction measures could be “low-cost” measures depending upon the scope of the project.

Over the years, many "no- and low-cost" measures have become standard design practice for SCE, especially for 66 kV and 115 kV electrical systems. Therefore, the preliminary designs submitted for review under the EMF Design Guidelines may already incorporate "no- and low-cost" magnetic field reduction measures and no further selection of "no- and low-cost" measures is needed.

SCE's first priority in the design of any electrical facility is public and employee safety. Without exception, design and construction of electric power system facilities must comply with all federal, state, and local regulations, applicable safety codes, and SCE construction standards. Furthermore, power lines and substations must be constructed so that they can operate reliably at their design capacity. Their design must be compatible with other lines in the area. They must result in reasonable costs to operate and maintain. These, and other requirements, are included in the existing CPUC regulations[9] and under SCE's construction standards. Any possible "no-cost and low-cost" magnetic field mitigation measures, therefore, must meet these requirements.

In summary:

- The use of these "no-cost and low-cost" methods will be governed by employee and public safety, good engineering practices, future system requirements, local conditions, economics, and reliability considerations; and

- SCE will revise the EMF Design Guidelines as more information becomes available.

[9] California's General Order 95, for example, establishes rules and specifications for the construction of overhead transmission and distribution lines in California.

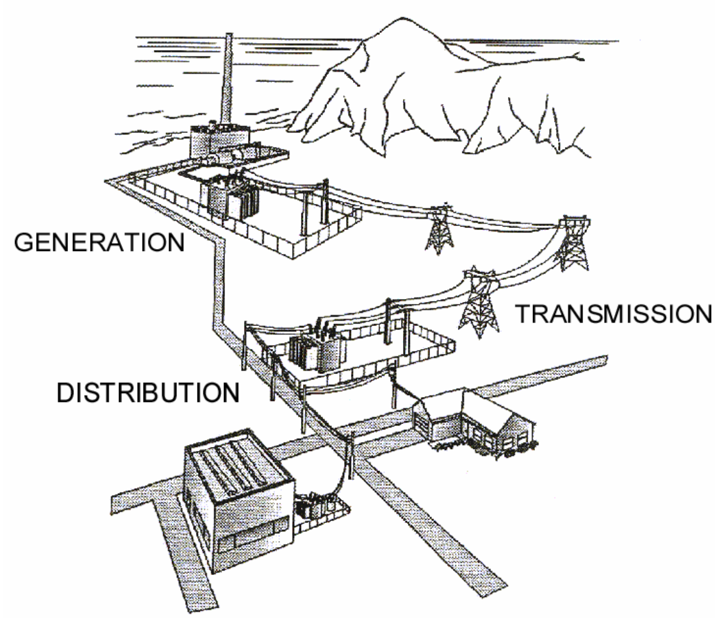
4 Understanding SCE's Transmission, Subtransmission, Substation, and Distribution Systems

4.1 SCE's Electric Power Lines

SCE classifies its electric power lines as transmission, subtransmission, and distribution, depending upon the line voltage. The transmission system generally includes lines where the voltage ranges from 161 to 500 kilovolts (kV); the subtransmission system includes lines from 50 kV through 161 kV; and distribution lines are those with voltages less than 50 kV.

SCE's electricity delivery system starts at a generating station. Transmission lines bring electricity to transmission substations. High-voltage power is carried from the generating station, using high-capacity transmission lines supported by above ground metal structures, with an exception of less than 2 miles of underground structure. The interconnection of transmission lines forms the major part of the power system network. Transmission lines in British Columbia (Canada), Alberta (Canada), Washington State, Oregon, Idaho, Montana, Wyoming, Nevada, Utah, Colorado, New Mexico, Arizona, and California are interconnected to deliver more reliable and stable electric power. At transmission substations, the voltage is reduced and routed in multiple directions by subtransmission lines. Subtransmission lines are constructed on wood poles or steel poles, or placed in underground structures. Subtransmission lines end at the facilities of large power users or at distribution substations. At distribution substations, the voltage is further reduced and delivered to homes and offices on wires supported by wooden poles or in underground structures. All components of the transmission, subtransmission, distribution, and substation systems that are "energized" (carrying electricity) create electric and magnetic fields. The system is shown graphically in Figure 4-1.

Figure 4-1 The Electrical Power System



4.2 Transmission and Subtransmission Right-of-Way[10]

The minimum width of most overhead right-of-way (or franchise) for power lines of 220 kV and below is determined by swing characteristics of the line and minimum clearances as required by CPUC General Order 95. Within the SCE system, this has usually resulted in a centerline-to-edge of right-of-way widths of 12.5 feet for overhead 66 kV lines, 15 feet for overhead 115 kV, 50 feet for overhead double-circuit 220 kV lines, and 75 feet for overhead single-circuit 220 kV lines. Widths may, at times, exceed or be less than these values, depending upon local conditions or other considerations.

The minimum centerline-to-edge of right-of-way width of 100 feet was established for overhead 500 kV lines through radio interference studies conducted in the early 1960's. This 100-foot distance is about 20 feet greater than would be needed for swing considerations. Smaller than 100-foot right-of-way widths for 500kV lines are found on lands under the US Forest Service and Bureau of Land Management (BLM) jurisdictions, due to the lack of development adjacent to the right-of-way.

4.3 SCE's Substation Systems

Substations receive power from generating stations and/or other substations of the same type. They are interconnected with other transmission substations through transmission lines and to distribution substations through subtransmission lines. A single substation facility can have both transmission and distribution components.

Substations increase the voltage for long distance transmission or decrease it for distribution and use by the customer. In addition, substations provide switchgear to direct the electricity to individual lines and to circuit breakers to clear lines in the event of an electric system failure.

Distribution substations receive power from transmission substations through the radial or looped subtransmission lines. After the power is transformed to a lower voltage, they distribute the power into a relatively large number of radial distribution circuits. These circuits, in turn, deliver the power to the individual customers after further transformation at locations throughout the distribution network.

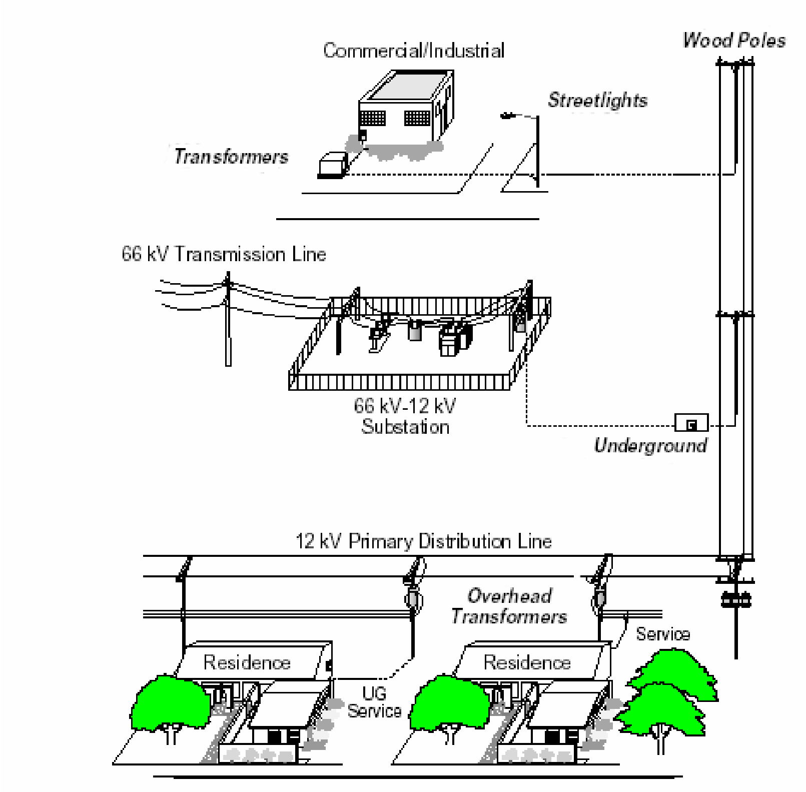
Distribution substations must be located close to, and generally central to the load served due to high loses and voltage drops present in distribution lines. This is the reason why most distribution substations are located in populated areas.

4.4 SCE's Distribution System

SCE's distribution system of 50kV and lower lines begins at the distribution substations and delivers power to each of the company's over four million customers and many streetlights. The types of distribution system equipment required to provide electrical service in SCE's service territory are illustrated in Figure 4-2.

[10] SCE also has power lines on franchise, fee-owned, and easement property.

Figure 4-2 Distribution System



4.5 Loading Variations

The electrical loads of all power lines (transmission, subtransmission, and distribution) and all substations are constantly changing based on the electric power usage of all customers. This is called "demand" or "load". As the demand changes in a particular neighborhood, the current on the distribution circuit serving that neighborhood changes. Changes on distribution circuits cause a change in the demand at the distribution substation. This, in turn, changes the load on the subtransmission lines, the transmission substation, transmission lines, and generating stations.

Generally, demand or loads are cyclical on a hourly, daily, monthly, and annual basis. For example, Figure 4-3 represents the daily cycle of a transmission line (normalized MVA) and Figure 4-4 and Figure 4-5 represent the weekly and monthly cycle of the substation (normalized MVA).

Figure 4-3 Example of Transmission Hourly Loading Variation

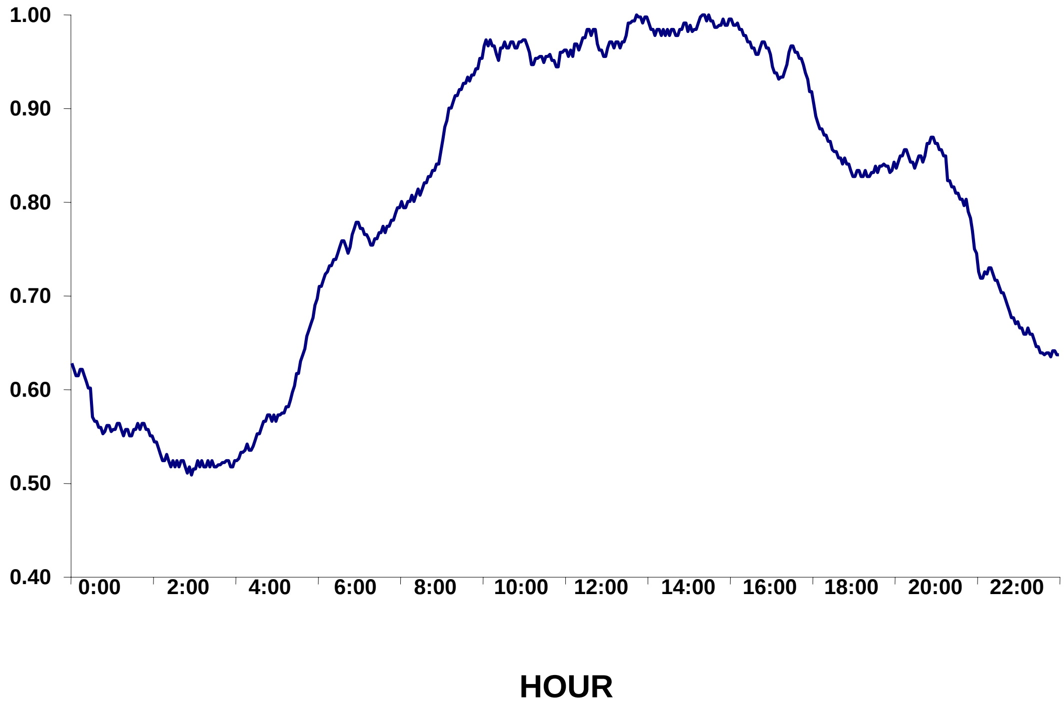


Figure 4-4 Example of Substation Daily Loading Variation

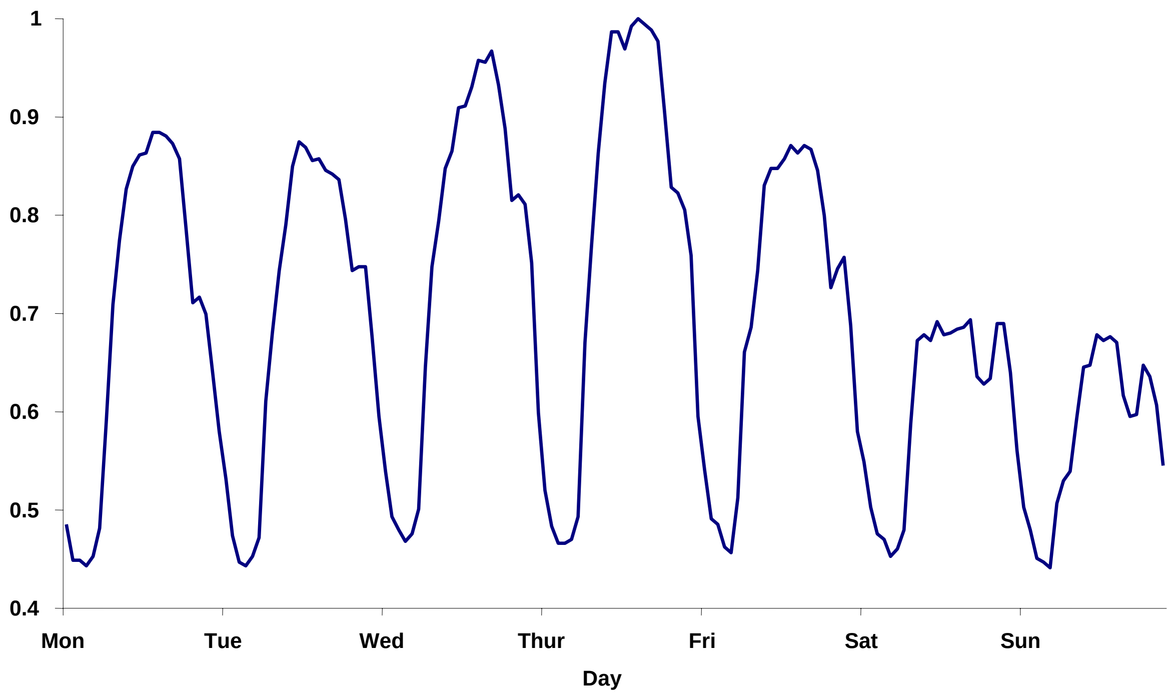
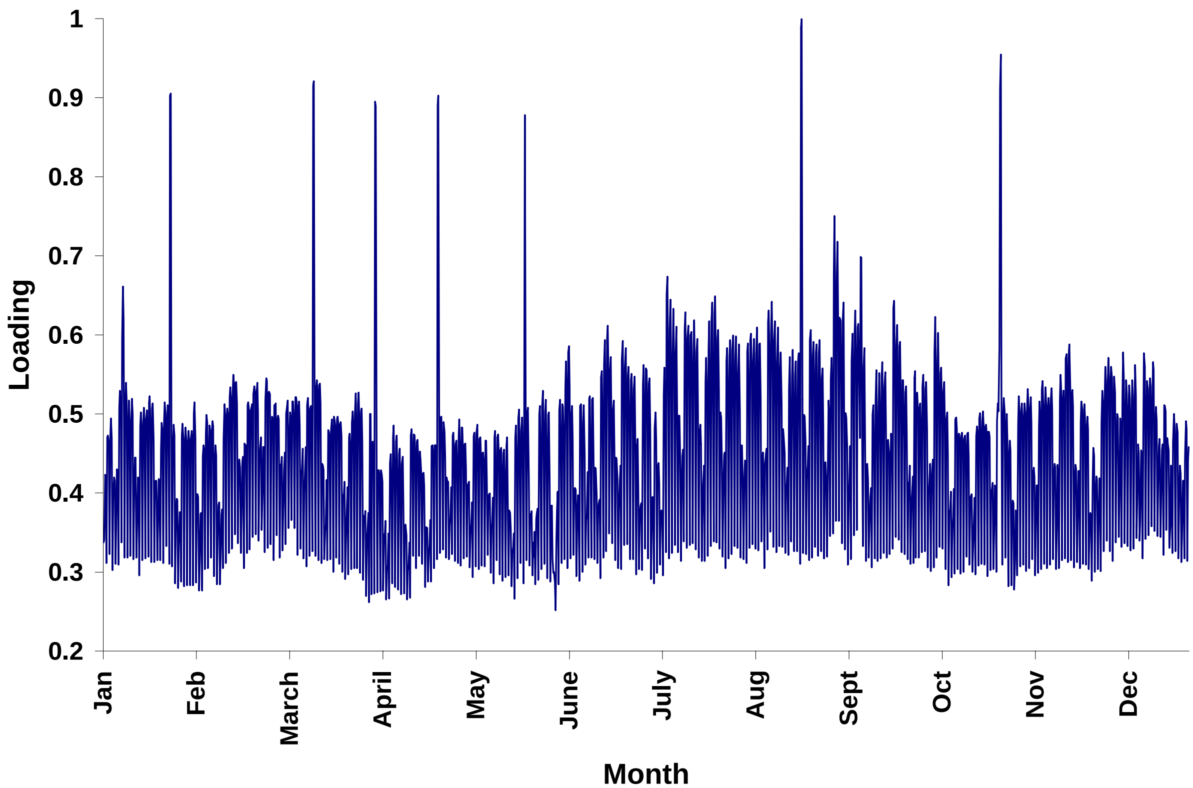


Figure 4-5 Example of Substation Monthly Loading Variation



5 "No-Cost and Low-Cost" Magnetic Field Reduction Measures

5.1 CPUC Decision

Design and construction of all transmission and subtransmission lines, and substations must comply with all federal, state, and local regulations, applicable safety codes, and SCE design standards. Any possible EMF mitigation measures, therefore, must meet these requirements. As supplement to this, the California Public Utilities Commission directed all investor-owned utilities in the state to take "no-cost and low-cost" magnetic field reduction measures for new and upgraded electrical facilities (CPUC Decision 93-11-013).

SCE defines "no-cost and low-cost" as:

- "No-cost" measures include any design changes that reduces the magnetic field in public areas without increasing the overall project cost;
- "Low-cost" measures are those steps taken to reduce magnetic field levels at reasonable cost. The CPUC Decision (93-11-013) states,

  "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."

The CPUC agreed that a "low-cost" measure should achieve some noticeable reduction, but declined to specify any numeric value. SCE uses a minimum fifteen percent (15%) reduction as the criteria for the application of "low-cost" measures.

5.2 Methods for Reducing Magnetic Fields

This section discusses methods that can be applied to reduce the magnetic fields from SCE's new electrical facilities. The cost of magnetic field reduction measures compared to SCE's standard construction practices for a particular project normally should not exceed four percent (4%) of the total cost of the project. The total project cost is based on all of the individual components of the entire project. For example, if the construction of transmission lines also involves the construction of a sub-station then the total project cost is the sum of both the transmission line and sub-station elements. The following methods for reducing magnetic fields apply to new electrical facilities:

1. Increasing the distance from the lines:
   - Increasing pole (structure) height,
   - Increasing the width of right-of-way, and/or
   - Locating power lines closer to the centerline of the corridor.
2. Reducing conductor (phase) spacing.
3. Optimizing phasing in a multi-circuit corridor.

4. Converting single-phase to split-phase circuits.
5. Placing facilities underground.

5.2.1 Increasing the Distance from Electrical Facilities

Reducing field strength by increasing the distance from the source can be accomplished either by increasing the width of the right-of-way or by increasing the height of the conductor above ground, or doing both. For substations, placing major electrical equipment, such as switch-racks and power transformers, near the center of the substation can minimize the magnetic fields outside of the property line as well.

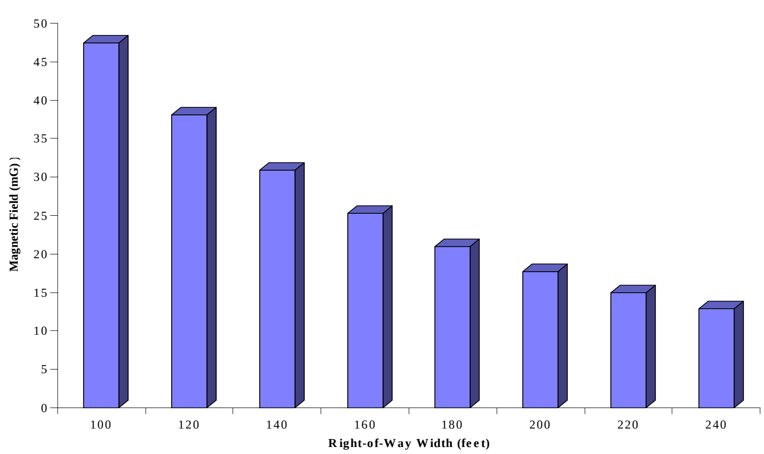
Right-of-Way Width

The minimum width of most overhead right-of-way for power lines of 220 kV and below is determined by swing characteristics of the line and minimum clearances as required by CPUC General Order 95. This has resulted in a centerline-to-edge of right-of-way width of 12.5 feet for overhead 66 kV lines, 15 feet for overhead 115 kV, 50 feet for most overhead double-circuit 220 kV lines, and 75 feet for most overhead single-circuit 220 kV lines. Widths may, at times, exceed or be less than these values, depending upon specific local conditions or other considerations.

For overhead 500kV lines, the minimum right-of-way width is generally 100 feet. It was established through radio interference studies conducted in the early 1960's and is about 20 feet greater than would be needed for swing considerations alone. Exceptions to the 100-foot right-of-way width are found in lands under the US Forest Service and Bureau of Land Management (BLM) jurisdictions, due to the lack of development adjacent to the right-of-way.

While consideration can be given to increasing the width of the right-of-way to reduce magnetic fields in adjacent areas, the high cost of this measure usually limits this technique to small portions of a line. Figure 5-1 demonstrates how the field is reduced as one moves away from the line. In this example, which is based on a double-circuit 220 kV line with a 30 foot ground clearance and a load of 500 amps, a 20-foot increase in right-of-way width is required to achieve a 19 percent reduction in the field at the edge of the right-of-way.

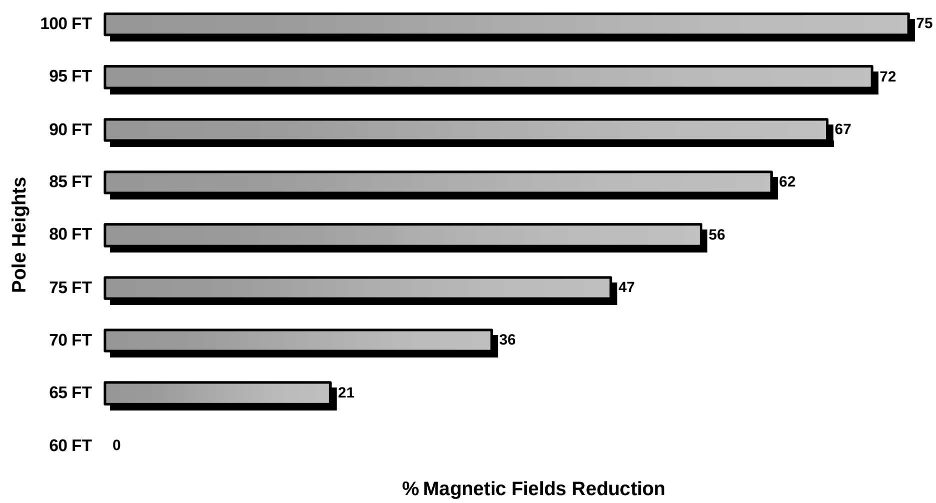
Figure 5-1 Magnetic Fields vs. Distance



5.2.2 Raising Conductor Height

Raising the height of the structures, and thus the height of the conductor, can reduce the fields underneath the line, as can be seen in Figure 5-2[11]. For the example shown in Figure 5-2, an increase in pole height from 60 to 65 feet reduces the magnetic field by 21 percent, while an increase from 80 to 85 feet reduces the field by only an additional 6 percent. This approach will be more practical for wood pole lines than for steel tower lines due to the higher costs associated with steel poles.

Figure 5-2 Percentage Magnetic Field Reduction vs. Pole Height



5.2.3 Reducing Conductor (Phase) Spacing

The magnetic field produced by overhead and underground power lines is approximately inversely proportional to the distance between the phase conductors. Thus, reducing the spacing between conductors by 50 percent generally reduces the magnetic field at ground level by approximately 50 percent. In theory, as the distance between conductors approaches zero, the field would approach zero. However, a power line with zero distance between the conductors cannot operate. Thus, the minimum distance between conductors is established by the amount of insulation required to prevent arc over. In addition, in the case of overhead lines, sufficient distance must also be maintained to allow linemen to safely climb the towers for routine maintenance and repairs.

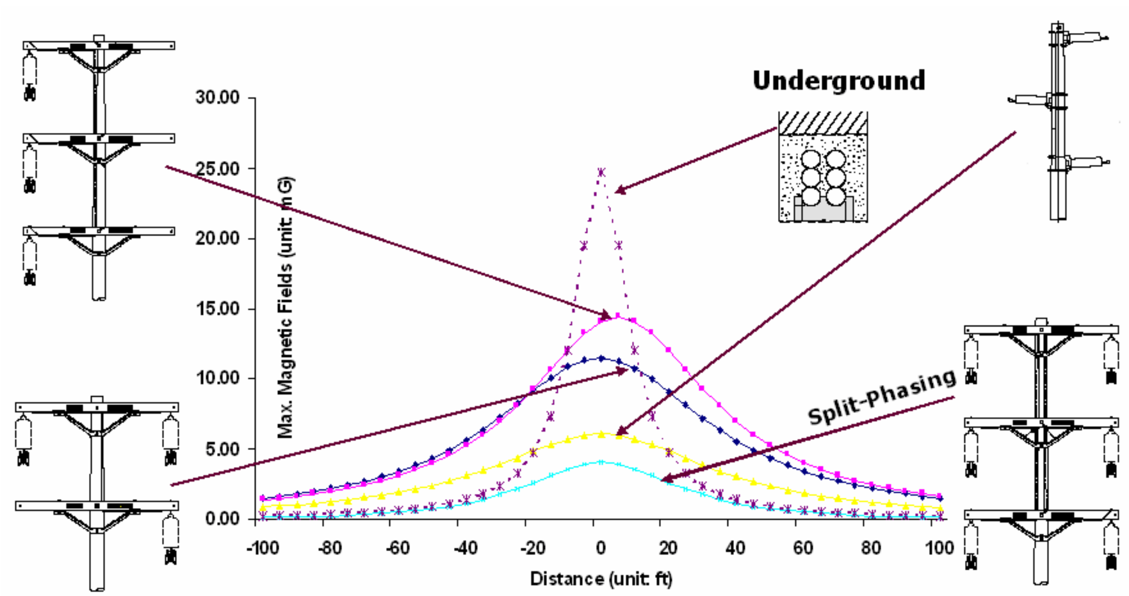
The minimum distance between overhead conductors for power lines built in California is established by CPUC General Order (GO) 95. Utilities may establish minimum clearances greater than those allowed in GO 95 if required for safe working conditions or to prevent flash over. In most cases, insulation levels will be established based on lightning, switching surge, or insulator contamination considerations.

[11] Figure uses a 60 foot pole as the base pole height, single circuit.

Because underground cables are insulated, they may be placed within inches of each other. This results in more cancellation of the magnetic fields between an underground circuit's phases compared with an overhead circuit. Therefore, the fields from an underground circuit will generally be lower than a comparably loaded overhead circuit at most places except directly above the underground line. Directly above the underground line, the cancellation effect of the underground conductors is offset by their proximity to the surface. On the other hand, overhead conductors will be much further away and will generally create a lower field directly under the line.

Figure 5-3 shows differences in magnetic fields produced by four types of pole-head configurations commonly used for 66 kV subtransmission line; see Appendix 14 for various pole-head configurations.

Figure 5-3 Magnetic Fields vs. Pole-head Configuration

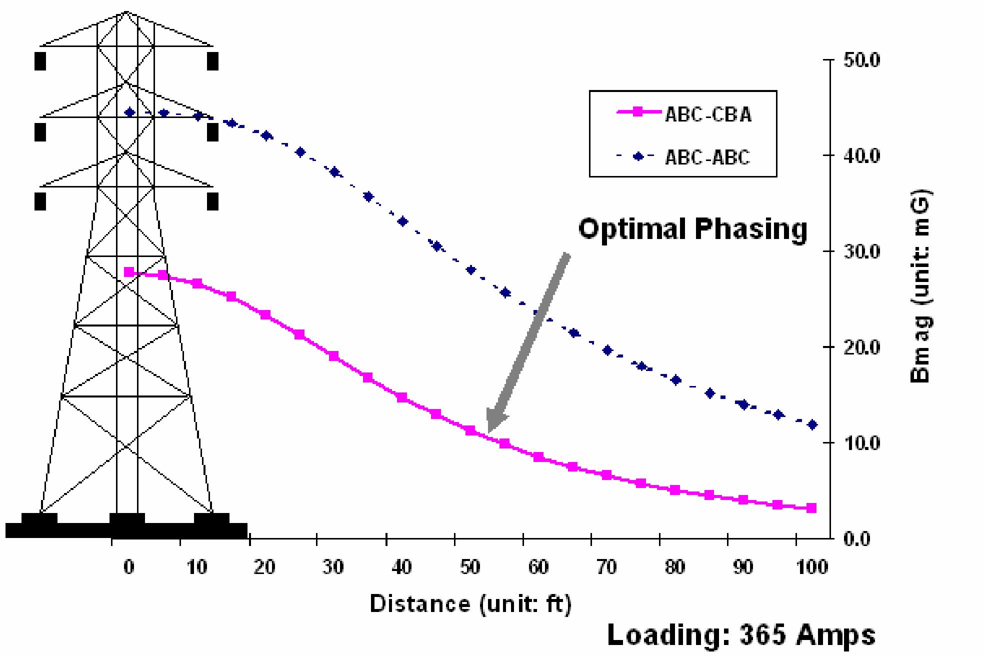


5.2.4 Optimizing Phasing in Multi-Circuit Rights-of-Way

When two or more circuits share a structure, the resultant magnetic field will be the vector sum of the individual conductor fields on the structure. By using proper phasing techniques, the field from one circuit can reduce the field from another circuit, thereby minimizing the level of magnetic field at ground level. Many of SCE's transmission right-of-ways include circuits of different voltages. Often the phasing of circuits 50 kV and above within a single corridor can be coordinated to reduce magnetic field.

Figure 5-4 shows an example of double-circuit 220 kV transmission lines. Optimal "ABC-CBA" phasing provides a 60 percent reduction relative to the ABC-ABC phasing.

Figure 5-4 Optimal Phasing of 220 kV Transmission Line



5.2.5 Converting Single Phase Lines to Split Phase Lines

In split phase power lines, currents in the three phases are split among six conductors, two per phase. The simplest case consists of splitting the current equally between two parallel circuits using double-circuit cross-arms. Physically, the line looks like a conventional double-circuit subtransmission line where each circuit carries 50 percent of the current. By optimal phasing, magnetic field reductions of 50 percent or more can be achieved. Figure 5-3 shows the magnetic field under a 66 kV power line using a conventional TO 306 pole-head and a split phase design using a double-circuit TO 335 configuration. In this case, a reduction of almost 60 percent was achieved. This technique, however, is usually not a "low-cost" magnetic field reduction measure due to the higher construction costs.

5.2.6 Placing Facilities Underground

All techniques previously discussed for overhead field reduction also apply to underground circuits. The magnetic field from underground circuits will decrease more rapidly as one moves away from the circuit than it will with comparably loaded overhead circuits. This is due to the closer spacing of the underground conductors (refer to Figure 5-3). However, the magnetic field directly above the underground line section can be higher than under the equivalent overhead line section due to closer proximity to the underground conductor (e.g. 66 kV underground cables are located 3 to 4 feet below the ground level whereas overhead conductors are located 40 feet above the ground). In addition, changing facilities overhead to underground are usually not a "low-cost" magnetic field reduction measure due to the higher costs associated with undergrounding of facilities.

5.3 Process of Selecting and Implementing “No- and Low-Cost” Magnetic Field Reduction Measures

Design and construction of electric power systems must comply with all applicable federal, state, and local regulations, safety codes, and SCE standards. Additional EMF mitigation options based on CPUC Decision 93-11-013 must be consistent with these requirements. We utilize a four-stage process to select and implement “no-cost and low-cost” magnetic field reduction measures. The measures are implemented in the following order:

1. “No-Cost” option(s) that can be uniformly applied to the entire project. “Phasing” will almost always be a selected option.

2. Existing public schools, or those under development (if known) should be the next priority for mitigation after “No-Cost”. Measures should be applied equitably along the project route if multiple schools are involved. It is possible that all the “low-cost’ funds available to the project (i.e., below 4% of the sum of the cost of all project elements) will be expended upon measures near schools--leaving little or no funds available for other “low cost” measures in other areas.

3. Residential, Public Parks, Commercial, and Industrial developments should be considered for “low-cost” mitigation techniques only if the “low-cost” measures can be applied equitably to ensure fairness.

4. Land that is not expected to be developed need not have any “low cost” measures applied.

   For example:

   a. State Parks.

   b. U.S. Forest Service.

   c. U.S. Bureau of Land Management.

   d. Formally designated “open space”.

6 The Field Management Plan Process

6.1 Field Management Plan

The Field Management Plan (FMP) is the primary means by which SCE systematically assesses and documents its consideration of "no-cost and low-cost" magnetic field reduction measures for new or major reconstructed transmission lines, subtransmission lines and substations rated 50 kV and above (refer to Section 6.4 for exceptions).

FMPs will be prepared by the principal designer[12] for relevant projects and will be retained with the work order. For any project requiring General Order (GO) 131D filling, the FMP will be incorporated as a part of the GO 131D filing. Where alternative transmission routes and/or substation sites are included in the GO 131D filing, the FMP will include the evaluation of "no-cost and low-cost" magnetic field reduction measures for each alternative.

Although the CPUC does not require a project specific field management plan for electrical facilities rated 50 kV and below, utilities are required to incorporate magnetic field reduction measures into their standard designs for distribution circuits. Therefore, SCE has incorporated magnetic field reduction measures into its Distribution Design Standards (DDS); refer to Chapter 11 of DDS and Section 9 of this document for more information.

Basic elements of the Field Management Plan include a project description, an evaluation of both "no-cost and low-cost" magnetic field reduction measures, and specific recommendations regarding magnetic field reduction measures to be incorporated into the final transmission line, subtransmission line, or substation design (refer to Section 7 and 8 for more information on FMP content).

6.2 Types of FMP

There are two types of FMP, a Detailed FMP (or simply called "FMP") and a "Basic FMP."

The Detailed FMP consists of a brief summary of the EMF issue, project description, evaluation of "no-cost and low-cost" magnetic field reduction measures, magnetic field models (if necessary), and recommendations (refer to Table 6-1 to determine what types of projects require a Detailed FMP).

For some projects with limited work scope, a Basic FMP is sufficient to document "no-cost and low-cost" magnetic field reduction measures. The Basic FMP consists of a project description, applicable "no-cost and low-cost" magnetic field reduction measures without magnetic field model(s), and recommendations.

[12] In most cases, the principal designer is the estimator (50-161 kV), the line-designer (above 161 kV), the engineer, or the project manager who is directly responsible for designing transmission lines, subtransmission lines, or substations rated 50 kV and above.

6.3 How to Determine If a FMP (or Basic FMP) Is Needed

The CPUC in Decision 93-11-013 states, "Utility management should have reasonable latitude to deviate and modify their guidelines as conditions warrant and as new magnetic fields information is received." Table 6-1 provides criteria by which the principal designer can determine if the project requires a Detailed FMP, a Basic FMP, or no FMP. Preparation of Detailed FMPs and Basic FMPs by the principal designers will be coordinated with the EMF Education Center to ensure consistency across all SCE departments.

Table 6-1 Criteria to Determine Whether A Field Management Plan is Required

FMP Type	Type of Work	Criteria
Transmission Lines (rated 50 kV and above)		
Detailed FMP Note: A Detailed FMP will be used for projects requiring certification under GO 131-D.	New Transmission Line: The construction of a new transmission line having a rated voltage of 50 kV or above. Major Reconstruction: Major reconstruction of an existing transmission line (>50 kV), if the reconstruction requires certification under GO 131-D.	All newly constructed transmission lines will incorporate "no- and low-cost" magnetic field reduction measures. All major reconstruction of existing transmission lines will require "no- and low-cost" magnetic field reduction measures unless otherwise exempted under section 6.4 or in Table 6-1. A Basic FMP may be used if certification under GO 131-D is not required.
Basic FMP Note: A BASIC FMP will be used unless the project requires certification under GO 131-D.	Rule 20 Conversions: Direct replacement of overhead subtransmission and transmission lines with underground circuits under Rule 20. Relocation: Relocation of poles & towers involving more than 2000 feet of circuit.	The circuit route is pre-established for rule 20 conversions. Phase spacing and depth are set by SCE construction standards. Thus optimal phasing is the only magnetic field reduction measure available to the designer. The Basic FMP will be restricted to an evaluation of optimal phasing. Modeling is not required. Relocation of existing circuits generally does not provide for alternative line routes. Available options are typically limited to minor changes in pole tower height, or minor changes in pole-head configuration, or optimal phasing. The Basic FMP will normally cover these options only. Modeling is not required.

Table 6-1 Criteria to Determine Whether A Field Management Plan is Required cont.

FMP Type	Type of Work	Criteria
Basic FMP Note: A BASIC FMP will be used unless the project requires certification under GO 131-D.	Pole-head Reconfiguration: Pole-head reconstruction involving more than 2000 feet of transmission circuit. The complete replacement of an existing pole-head configuration with a new design. For example, the replacement of a TO309 66kV pole-head configuration with a TO325 configuration.	Pole-head replacement is limited in scope; thus, field management options are generally restricted to selecting the pole-head configuration and optimal phasing which results in the lowest field consistent with good engineering practice. In most cases, the new pole-head configuration must be consistent with the remainder of the line and/or local standards. The Basic FMP will be limited to an assessment of alternative pole-head configurations and will not require modeling.
	Reconductor > 2000 ft.: Replacement only of existing conductors and/or insulators with new conductors / insulators.	In most cases, replacement of existing transmission or subtransmission line conductors is limited in scope; therefore, Basic FMP will be limited to an assessment of optimal phasing for reconductor activity involving more than 2000 circuit feet.
None	Relocation: Relocation of poles & towers involving less than 2000 feet of circuit.	Minor relocation of facilities is limited in scope and does not provide significant opportunity to implement magnetic field reduction measures.
	Reconductor < 2000 ft.: Replacement only of existing conductors and/or insulators with new conductors / insulators.	Replacement of existing transmission circuit conductors is limited in scope and does not provide significant opportunity to implement magnetic field reduction measures.
	Pole-head Re-Configuration < 2000 ft.: Pole-head reconstruction involving 2000 feet or less of a transmission circuit will not require a field management plan.	Pole-head reconstruction involving 2000 feet or less of a transmission circuit will not require a field management plan.
	Maintenance: All maintenance work that does not materially change the design or overall capacity of the transmission line, including the one-for-one replacement of hardware, equipment, poles or towers.	Maintenance work is limited in scope and does not provide significant opportunity to implement magnetic field reduction measures.

Table 6-1 Criteria to Determine Whether A Field Management Plan is Required cont.		
FMP Type	**Type of Work**	**Criteria**
None	Safety and Protective Devices: The addition of current transformers, potential transformers, switches, power factor correction, fuses, etc. to existing overhead, pad-mount, or underground circuits.	The addition of protective equipment or power factor correction to existing transmission circuits is limited in scope and does not provide significant opportunity to implement magnetic field reduction measures.
	Emergency Repairs: All emergency work required to restore service or prevent danger to life and property.	This work is performed on existing facilities under emergency conditions and does not involve redesign.
Substation (rated 50 kV and above)		
Detailed FMP Note: A Detailed FMP will be used for projects requiring certification under GO 131-D.	New Substations: The construction of a new substation having a rated high side voltage of 50kV or above. Major Reconstruction/ GO 131-D: Major reconstruction of an existing substation that involves the installation of additional transformers to achieve an increased rated capacity and that requires certification under GO 131-D.	All newly constructed substations will incorporate "no- and low-cost" magnetic field reduction measures. All major reconstruction of existing substations will require "no- and low-cost" magnetic field reduction measures unless otherwise exempted under Section 6.4 or in Table 6-1. A Basic FMP may be used if certification under GO 131-D is not required.
Basic FMP Note: A BASIC FMP will be used unless the project requires certification under GO 131-D.	Major Reconstruction / without GO 131-D: Major reconstruction of an existing substation that involves the installation of additional transformers to achieve an increased rated capacity and that does not require certification under GO 131-D.	Major substation reconstruction projects involving the addition of new transformers but not requiring GO 131-D certification may use a Basic FMP. The Basic FMP will be limited to an evaluation of magnetic field reduction measures applicable to the transmission get-away[13] and to the location of the new transformers so as to maximize the distance from the transformers to the substation fence. Modeling is not required for the Basic FMP.

[13] This is a part of Transmission/Subtransmission FMP.

Substation (rated 50 kV and above) cont.		
None	Reconstruction without installation of additional transformers: This includes, for example, the installation of additional switchgear, line or bank positions, power factor correction capacitors, underground circuits and overhead circuits.	The addition of switchgear or other apparatus is limited in scope and does not provide significant opportunity to implement magnetic field reduction measures.
	Direct Replacement: The direct replacement of substation equipment, even if the new equipment has a different capacity rating.	The direct replacement of substation equipment is limited in scope and does not provide significant opportunity to implement magnetic field reduction measures.
	Maintenance: All maintenance work that does not materially change the design of the substation.	Maintenance work is limited in scope and does not provide significant opportunity to implement magnetic field reduction measures.
	Emergency Repairs: All emergency work required to restore service or prevent danger to life and property.	This work is performed on existing facilities under emergency conditions and does not involve redesign.
Distribution (less than 50 kV)		
None	Construction or reconstruction of distribution circuits with voltages less than 50 kV.	SCE's DDS incorporates magnetic field reduction measures for distribution lines.

6.4 Exemption Criteria

The California Public Utilities Commission, in Decision 93-11-013, recognized that some flexibility was required in the EMF Design Guidelines. In section 3.4.2 of the decision, the CPUC stated: "Electric utility management should have flexibility to modify the guidelines and to incorporate additional concepts and criteria as new magnetic fields information becomes available. However, if the EMF Design Guidelines are to be truly used as guidelines, the utilities should incorporate criteria which justify exempting specific types of projects from the guidelines."

SCE has adopted the following criteria to determine those projects exempted from the requirement for consideration of "no-cost and low-cost" magnetic field reduction measures:

1. Emergency
   - All work required to restore service or remove an unsafe condition.
2. Operation & Maintenance
   - Washing and switching operations.
   - Replacing cross-arms, insulators, or line hardware.
   - Replacing deteriorated poles.
   - Maintaining underground cable and vaults.
   - Replacing line and substation equipment with equipment serving the same purpose and with similar ratings.
   - Repairing line and substation equipment.
3. Relocations
   - Line relocation of less than 2000 feet.
   - Installation of guy poles or trenching poles only.
4. Minor Improvements
   - Addition of safety devices.
   - Reconductoring less than 2000 feet, where changing pole-head configuration is not required.
5. Projects located on land under the jurisdiction of the National Park Service, the State Department of Parks and Recreation, U.S. Forest Service, or Bureau of Land Management (BLM).

The EMF Engineers are available to provide any assistance necessary.

7 Field Management Plans for Transmission or Subtransmission Line

Construction of a new transmission (or subtransmission) line, the major upgrade of an existing transmission (or subtransmission) line that requires GO 131D certification, or the relocation of 2000 feet or more of an existing transmission (or subtransmission) line or any relocation or modification of existing transmission (or subtransmission line) near an existing or proposed school[14] will require the preparation of a Field Management Plan; refer to Table 6-1 to determine if a Detailed FMP (or Basic FMP) is needed; refer to Section 6.4 for exemption criteria.

Design and construction of all transmission and subtransmission lines must comply with all federal, state, and local regulations, applicable safety codes, and SCE design standards. Evaluation of "no- and low-cost" magnetic field reduction measures, therefore, is limited to existing and approved SCE standards and practices. The magnetic field reduction measures applicable to a transmission and subtransmission line are as follows:

- Selecting line route;
- Purchasing additional right-of-way, if necessary;
- Choosing an alternative design:
    - Increasing pole/tower height;
    - Choosing pole (or tower) head configuration;
    - Choosing to phase optimally, if applicable;
    - Underground.

Table 6-1 should be used to determine whether a Basic FMP or a Detailed FMP is needed for the transmission (or subtransmission) project. Transmission (or subtransmission) Field Management Plans should include the following sections; refer to Section 7.1 to 7.5 for more information.

- Project Description;
- Evaluation of "No-Cost" Magnetic Field Reduction Measures;
- Evaluation of "Low-Cost" Magnetic Field Reduction Measures;
- 2D Magnetic Field Model, may be required for a Detailed FMP;
- Recommendations.

If any school is involved with the project; refer to Section 10 for more information.

7.1 Project Description

The project description portion of the Transmission (or subtransmission) Field Management Plan will include the following:

[14] Refer to Section 10, "California Department of Education's (CDE) Standards for Siting New Schools Adjacent to Electric Power Lines Rated 50 kV and Above," for more information regarding FMP requirements for projects near schools.

- Information for a proposed line route for a Detailed FMP, attach a project map showing the transmission (or subtransmission) line route, alternative line route (if applicable), edge of right-of-way or easement, and major streets and highways. For a Basic FMP, briefly describe the scope of work including line route;
- Description of land use adjacent to the line route for both Basic and Detailed FMP;
- Circuit name and rated voltage, circuit rating, and circuit phasing if more than one circuit is present in the same corridor for both Basic and Detailed FMP (rated 50 kV and above);
- Description of proposed design for a Detailed FMP, include pole height, pole-head configuration, maximum sag at rated load, and minimum ground clearance for overhead design. For a Basic FMP, include pole height, pole-head configuration. For underground facilities (for both Detailed FMP or Basic FMP), show the depth and location of each duct;
- Include estimated total project costs for preferred design and for each alternative design, if applicable (for a Detailed FMP).

7.2 Preferred Design with Magnetic Field Reduction Measures Added

The preferred designs with magnetic field reduction options incorporated for transmission and subtransmission line voltage classes are as follows:

500 kV & 220 kV Transmission Lines

In general, transmission lines go through many cities and counties. Therefore, engineering requirements may vary greatly within the scope of the project. For example, "minimum clearance" requirements vary depending upon areas (i.e. rural area vs. urban area). Therefore, the primary transmission designer should work with the EMF engineer early in the design phase to determine all available options[15] for reducing magnetic fields at the edge of the right-of-way. The design with selected "no- and low-cost" magnetic measures may serve as the "preferred" design and can be used for examining all alternative designs.

66 kV & 115 kV Subtransmission Lines

The preferred design[16] for 66 and 115 kV subtransmission lines are constructed with the following features.

Table 7-1 Preferred Design with Most Effective Magnetic Field Reduction Options Incorporated

	66 kV Overhead Construction		115 kV Overhead Construction	
	Single Circuit	Double Circuit	Single Circuit	Double Circuit
Base Pole Height[17]	70 feet	75 feet	70 feet	75 feet
Base Pole-head Configuration	TO 306, 325 or equivalent	TO 335, 352 or equivalent	TO 362, 380 or equivalent	TO 390 or equivalent
Minimum Clearance	35 feet	35 feet	35 feet	35 feet

[15] This option includes, but is not limited to, selection of alternate routes and different types of structures.
[16] Following preferred designs for 66 & 115 kV subtransmission lines already have magnetic field reduction measures implemented, such as pole-head configuration selection and/or structure (pole) height.

On any project involving a corridor, magnetic fields are calculated at the edge of the corridor. Magnetic fields are calculated directly under the line if the power line is on a franchise property.

7.3 Project Cost

The basis for applying "low-cost" magnetic field reduction measures will be determined by direct project cost associated with engineering, design work, procurement, and construction (excluding licensing, permitting, and right-of-way acquisition costs). The direct cost of the project (excluding licensing, permitting and right-of-way acquisition costs) for the purpose of determining "low-cost" magnetic field reduction measures will be based on the sum of the costs of all transmission, substation, and distribution components of the project. That is, the direct cost of the transmission line component of the project will be combined with any substation or distribution direct costs to determine "low-cost" measures. This cost pricing system will be used for all preferred project costs as well as for all SCE and customer projects. There are no exceptions.

7.4 "No-Cost and Low-Cost" Magnetic Field Reduction Measures

Depending upon the rated line voltage, Table 7-2 or Table 7-3 (or equivalent list of magnetic reduction measures) will be used to determine "No-Cost and Low-Cost" magnetic field reduction measures applicable to the project.

The table will list all "no-and low-cost" measures considered, identify those measures included in the final design and provide reasons why those measures not included in the final design were rejected.

Table 7-2 "No-Cost and Low-Cost" Magnetic Field Reduction Measures for New, Major Upgrade, and Relocation of Electric Power Line Projects 66 kV or 115 kV

"Low-Cost" Magnetic Field Reduction Measures	% Reduction (High[18] or Low)	Cost (High[19] or Low)	Priority Rank[20] (High or Low)	Adopt in Final Design
Select pole-head configuration for the lowest magnetic field.				
Locate circuit additional distance away from the property line.				
Increase pole height (Note: Preferred Design as shown on Table 7-1 already has this option incorporated.)				
Optimize phasing, if applicable. This option applies to the new construction and within a multiple circuit corridor.				

[17] Exceptions to the "preferred design" are determined by the primary designer for allowing design variances based on engineering & safety requirements. For example, if the proposed line needs to cross underneath existing power lines, the pole height and pole-head configuration can be changed from the "preferred design."
[18] "High" means the magnetic field reduction is equal or greater than 15% by itself or when combined with other measures.
[19] "High" means the implementing cost of this option is greater than 4% of the total project cost.
[20] The option that gives the highest percent magnetic field reduction and lowest cost has the highest priority rank.

Table 7-3 "No-Cost and Low-Cost" Magnetic Field Reduction Measures for New, Major Upgrade, and Relocation of Electric Power Line Projects 66 kV or 115 kV (continued)				
"Low-Cost" Magnetic Field Reduction Measures	**% Reduction (High[21] or Low)**	**Cost (High[22] or Low)**	**Priority Rank[23] (High or Low)**	**Adopt in Final Design**
Converting single phase lines to split-phase lines. (It is usually not a "low-cost" option.)				
Underground (It may not be a "low-cost" option.)				
Selecting alternate route.				
Other, if any.				

Table 7-4 "No-Cost and Low-Cost" Magnetic Field Reduction Measures for New, Major Upgrade, and Relocation of Electric Power Line Projects 220 kV or 500 kV				
"Low-Cost" Magnetic Field Reduction Measures	**% Reduction (High[24] or Low)**	**Cost (High[25] or Low)**	**Priority Rank (High[26] or Low)**	**Adopt in Final Design**
Select tower (or structure) with pole-head configuration for the lowest magnetic field.				
Increase width of right-of-way. (It may not be a "low-cost" option.)				
Increase tower (or structure) height.				
Optimize phasing for multiple circuits in a single corridor[27].				
Converting single phase lines to split-phase lines. (It is usually not a "low-cost" option.)				
Underground. (It is not "low-cost" option in most cases.)				
Selecting alternate route. (It may not be a "low-cost" option.)				
Other, if any.				

[21] "High" means the magnetic field reduction is equal or greater than 15% by itself or when combined with other measures.
[22] "High" means the implementing cost of this option is greater than 4% of the total project cost.
[23] The option that gives the highest percent magnetic field reduction and lowest cost has the highest priority rank.
[24] "High" means the magnetic field reduction is equal or greater than 15% by itself or when combined with other measures.
[25] "High" means the implementing cost of this option is greater than 4% of the total project cost.
[26] The option that gives the highest percent magnetic field reduction and lowest cost has the highest priority rank.
[27] Notify "Protection Engineering" for proposed phasing prior to construction.

7.5 Two Dimensional Magnetic Field Modeling for Transmission (or Subtransmission) Line

Southern California Edison has developed the "2D Fields" program to evaluate the magnetic field characteristics of the proposed construction and various magnetic field reduction alternatives. It is important to remember that estimates of magnetic field levels are calculated based on a specific set of line loading conditions. Therefore, it is important to make logical assumptions as to what these loads and resultant currents will be and to keep these assumptions consistent when comparing two or more different cases.

SCE commonly uses the following assumptions in the modeling of transmission or subtransmission lines.

- The line will be considered loaded at 75% of forecasted load;
- Magnetic field strength is calculated at a height of three feet above ground (assuming flat terrain);
- Resultant magnetic fields ($B_{Resultant}$) are being used;
- All line loadings are considered as balanced (i.e. neutral or ground currents are not considered);
- The line is considered working under normal operating conditions;
- Dominant power flow directions are being used.

A 2D Model should reflect all transmission lines and subtransmission lines within the corridor.

7.6 Recommendations

The final plan will list the "no-cost and low-cost" measures adopted into the transmission (or subtransmission) line design, the aggregate costs to implement these measures expressed as a percentage of the total project cost, and a discussion of the expected relative field reduction to be achieved. Any measures that do not, in aggregate, result in a fifteen percent or more reduction in the magnetic field will not be implemented.

The most common recommendations requested on past projects were to:

- Increase pole height for overhead design;
- Use compact pole-head configuration for overhead design;
- Optimally phase all transmission and subtransmission lines within the corridor.

7.7 Basic Field Management Plan Form for 66 kV and 115 kV Subtransmission Lines

Circuit Name: ____
Work Order No: ______________________ Date: ______________
Designer Name: ______________________ Telephone No: ______________

I. Preliminary Check List

		Yes	No
1	Does this project require a GO 131D Certification?	[ ]	[ ]
2	Is the line route in conflict with the CDE's EMF setback requirement? (Refer to Section 10)	[ ]	[ ]

If the answers to the above questions are "No," a Basic FMP is sufficient to document "no-cost and low-cost" EMF options. If any of answers above is "Yes," a Detailed FMP is required.

II. Project Description *(Refer to EMF Design Guide Section 7.1 for more information)*

III. "No-Cost and Low-Cost" Magnetic Field Reduction Measures Check Lists

	For Overhead "No-Cost and Low-Cost" Magnetic Field Reduction Measures	**Yes**	**No**
1	Is the height of the majority of poles the same or taller than under the preferred design? (Refer to Section 7.2)	[ ]	[ ]
2	Are the majority of pole-head configurations the same (or equivalent) to that under the preferred design? (Refer to Section 7.2)	[ ]	[ ]
3	Will all overhead transmission / subtransmission lines within the corridor be phased optimally (if applicable)? If applicable, attach a diagram (or a statement) with proposed phasing identifications associated with each circuit names. Contact an EMF Engineer to determine optimal phasing if necessary.	[ ]	[ ]
	For Underground "No-Cost and Low-Cost" Magnetic Field Reduction Measures		
4	Will all underground transmission / subtransmission lines within the corridor be phased optimally (if applicable)? If applicable, attach a diagram (or a statement) with phasing identifications associated with each circuit name.	[ ]	[ ]

Note: Question 1 above is applicable only to a new proposed subtransmission line. If any of the answers above is "NO," a Detailed FMP may be required. Contact EMF Engineer for more information.

Designer's Signature ______________________________________

EMF Engineer's Name & Signature ______________________________________

Keep this basic subtransmission field management plan with the work order and send a copy to EMF Research & Education Group.

8 Substation[28] Field Management Plan

Construction of a new substation or the major upgrade of an existing substation will require the preparation of a Substation Field Management Plan. A major upgrade means the expansion of an existing substation through the addition of transformer bank(s) or new power line(s) rated 50 kV or above. "One-for-one" replacement of substation transformers, circuit breakers, or other apparatus does not constitute an upgrade, even if that replacement results in an increase in rated capacity. The addition of instrumentation, control, or protection equipment does not constitute a major upgrade. Refer to Table 6-1 to determine if a Detailed FMP (or Basic FMP) is needed (refer to Section 6.4 for exemption criteria).

Generally, magnetic field values along the substation perimeter are low compared to the substation interior because of the distance to the energized equipment. Normally, the highest values of magnetic fields around the perimeter of a substation are caused by overhead lines and underground duct banks entering and leaving the substation, and not by substation equipment. Therefore, the magnetic field reduction measures generally applicable to a substation project are as follows:

- Site Selection for a new substation;
- Selection of structures & equipment;
- Setback of structures & equipment;
- Location of Operating & Transfer Bus;
- Lines entering and exiting the substation (this will be a part of Transmission/Subtransmission Line FMP).

Table 8-1 Preliminary Questions for "No- and Low-Cost" Magnetic Field Reduction Measures for Substations		**Yes**	**No**
1	Does the substation site meet CDE's EMF Setback Requirement[29]?		
2	Are transformers and air core reactors > "X" feet from substation property line? "X" = 15 feet for 66 kV and 115 kV substation = 50 feet for 220 kV and 500 kV substation		
3	Are switchracks, capacitor banks & bus > "Y" feet from substation property line? "Y" = 8 feet for 66 kV and 115 kV substation = 40 feet for 220 kV and 500 kV substation		
4	Are underground cable duct banks > 12 feet from side of property line? Note: Question 4 is applicable for 66 kV and 115 kV substations only.		
5	Are the transfer & operating bus configured with the transfer bus facing the nearest property/fence line? Note: Question 5 is applicable for 66 kV, and 115 kV substations only.		

Note: Question 1 is applicable only to a new proposed substation.

[28] Any substation whose primary voltage is 50 kV and above.
[29] If answer to this question is 'No,' Refer to Section 10 for additional requirements for preparing a Detailed FMP.

If all answers to above questions are "Yes," a "Substation Field Management Plan Form" is sufficient to document "no-cost and low-cost" EMF options. Refer to Section 8.5 for "Substation Field Management Plan Form." For a Basic Substation FMP, use "Substation Field Management Form" as well. If any answers to the questions above are "No," consult with an EMF engineer about listed options in Section 8.2 to determine whether a Detailed Substation FMP is required.

A Substation Field Management Plan should include the following (refer to Section 8.1 to 8.5 for more information);

- Project Description;
- Evaluation of "No-Cost and Low-Cost" Magnetic Field Reduction Measures;
- Substation 3D Magnetic Field Model for a Detailed FMP, if needed;
- Recommendations;
- Refer to Section 10 if any school is nearby the proposed substation.

8.1 Project Description

The project description portion of the Substation Field Management Plan will include the following sections:

- A site map showing the substation property perimeter, transmission and subtransmission lines entering and exiting the substation, streets, and adjacent property use (for a Detailed FMP);
- A diagram showing the approximate location of transformers, switch racks, operating and transfer bus, capacitor banks, and reactors (for a Detailed FMP);
- Description of land use adjacent to the substation and scope of the project (for both Basic and Detailed FMP);
- Description of voltage and MVA rating for the substation and for all proposed circuits entering and exiting the substation (for both Basic FMP and Detailed FMP); and
- Include the estimated total project cost (for a Detailed FMP).

8.2 "No- and Low-Cost" Magnetic Field Reduction Measures

A substation Field Management Plan will include Table 8-1, or equivalent list of magnetic field reduction measures applicable to the project. If any of those measures listed on Table 8-1 are not incorporated into the preliminary substation design, complete Table 8-2 for the FMP. Table 8-1 and Table 8-2 will list all "no- and low-cost" magnetic field reduction measures considered, and identify those measures included in the final design and provide reasons why those measures not included in the final design were rejected.

Table 8-2 Additional "No- and Low-Cost" Magnetic Field Reduction Measures for Substation Projects 50 kV and Above

"Low-Cost" Magnetic Field Reduction Measures	% Reduction (High[30] or Low)	Cost (High[31] or Low)	Priority Rank (High[32] or Low)	Adopt in Final Design
Redesign substation to maximize clearance to the substation property line or to meet the setback requirement; refer to Table 8-1.				
Purchase additional property to increase clearance to fence or to meet the setback requirement; refer to Table 8-1.				
Consult the transmission engineer (or estimator) if increasing get-away pole height or depth of underground duct bank would further reduce the magnetic fields.				

8.3 3D Magnetic Field Modeling for a Detailed Substation Field Management Plan

3D magnetic field modeling is required when the only viable magnetic field reduction option is to modify power lines (50 kV and above) entering and leaving the substation. Normally, the highest values of magnetic fields around the perimeter of a substation are caused by overhead lines and underground duct banks entering and leaving the substation and by underground duct banks running parallel to the perimeter. Therefore, only get-away power lines are considered for 3D magnetic field modeling. All other conductors (such as connecting a bus to a circuit breaker) are not included in the model because they are not the major source once the switchracks have been located to the center of the substation.

When modeling a substation, it is important to keep in mind that all the resultant magnetic fields are being calculated based on a specific loading condition. Therefore, it is important to make some logical assumptions as to what these loads and consequent currents will be and to keep these assumptions constant when comparing two or more different cases.

SCE commonly uses the following assumptions in the modeling of substations.

- The substation will be considered loaded at its nameplate capacity with the load equally balanced among the available transformer banks and electric circuits (unless a different loading condition is specified);
- All transmission and subtransmission lines as well as distribution circuits are assumed to have balanced loads. Neutral or ground currents are not considered;
- The substation is considered working under normal operating conditions;
- All distribution circuits located in underground duct banks are assumed to be phased in a fixed pattern, which is kept constant throughout the calculations.

[30] "High" means the magnetic field reduction is equal or greater than 15% by itself or when combined with other measures.
[31] "High" means the implementing cost of this option is greater than 4% of the total project cost.
[32] "High" means the implementing cost of this option is greater than 4% of the total project cost.

3D Field model should show the substation property line (or fence line) and power line rated 50 kV and above entering and exiting the substation.

8.4 Recommendations

After the magnetic field reduction measures are identified using Table 8-1, Table 8-2, or by 3D Field calculations, the results will be reviewed and analyzed. The substation design will then be reviewed to determine what changes may be recommended to reduce the magnetic fields.

The most common recommendations requested on past SCE projects were to:

- Relocate underground distribution circuit duct banks further inside the substation to increase their separation from the substation fences (virtually a "no-cost" alternative);
- Relocate one fence and expand the substation to one side to increase the distance to energized equipment ("low-cost" alternative);
- Change the two initial transformer banks of a substation designed for an ultimate capacity of four banks, from bank positions Nos. 1 and 2 (near one end of the substation) to bank positions Nos. 2 and 3 (near the center of the substation);
- Optimally phase all circuits entering/exiting the substation; this will be a part of Transmission/Subtransmission Line FMP;
- Increase getaway pole heights; this will be a part of Transmission/Subtransmission Line FMP.

These recommendations are consistent with the following recently published reports: The National Institute of Environmental Health Sciences (NIEHS) of 2000, the International Agency for Research on Cancer (IARC) 2001, the National Radiological Protection Board (NRPB) 2001, the International Commission on non-Ionizing Radiation Protection (ICNIRP) 2001, and the California Department of Health Services (CDHS) 2002.

8.5 Substation Field Management Plan Form

Check One: New Substation [ ] Major Upgrade [ ]

Substation Name: ____________________

Work Order No: ____________________ Date: ____________

Designer Name: ____________________ Telephone No: ____________

I. Project Description *(Refer to EMF Design Guide Section 8-1 for more information)*

II. Magnetic Field Reduction Measures Check List

	"No-Cost and Low-Cost" Magnetic Field Reduction Measures	**Yes**	**No**
1	Does the substation site meet CDE's EMF Setback Requirement? (Applicable only to a new proposed substation; Refer to Section 10)	[ ]	[ ]
2	Are transformers and air core reactors > "X" feet from substation property line? "X" = 15 ft. for 66 kV and 115 kV substations = 50 ft. for 220 kV and 500 kV substations	[ ]	[ ]
3	Are switchracks, capacitor banks & bus > "Y" feet from substation property line? "Y" = 8 ft. for 66 kV and 115 kV substations = 40 ft. for 220 kV and 500 kV substations	[ ]	[ ]
4	Are underground cable duct banks > 12 feet from side property line? Note: This is applicable to 66 kV and 115 kV substations only.	[ ]	[ ]
5	Are transfer & operating buses configured with the transfer bus facing the nearest property/fence line? Note: This is applicable to 66 kV and 115 kV substations only.	[ ]	[ ]

If any of the answers above is 'No,' consult with an EMF engineer as to whether a Detailed FMP is required. *Please notify the subtransmission primary designer for consideration of optimally phasing subtransmission line(s) entering and exiting the substation.*

Name of Transmission Engineer/Estimator,
if applicable to this project ____________________

Substation Designer's Signature ____________________

EMF Engineer's Name & Signature ____________________

Keep this basic substation field management plan with the work order and send a copy to EMF Research & Education Group.

9 Magnetic Field Management for Distribution Projects

Magnetic field reduction measures have been incorporated into Southern California Edison's "Distribution Design Standards Manual" (DDS) and will be implemented in new construction or major reconstruction of SCE's distribution circuits. Therefore, a Field Management Plan (FMP) is not required for any distribution project less than 50 kV.

9.1 Recommended Magnetic Field Reduction Measures for Distribution

This section offers a description of "no-cost and low-cost" practices and procedures designed to reduce magnetic field exposures from various distribution equipment and facilities. The magnetic fields practices and procedures are categorized into the following sections:

1. Electric Meters and Panels
2. Low-Voltage Services
   a. Overhead Residential
   b. Overhead Commercial/Industrial
   c. Underground Residential
   d. Underground Commercial/Industrial
3. Low-Voltage Secondaries
   a. Overhead
   b. Open-Wire Close to Buildings
   c. Open-Wire Above Pedestrian Walkways
   d. Underground
4. Padmount and Buried Underground Residential Distribution (BURD) Equipment
   a. Padmount Transformers
   b. BURD Transformers
   c. Switches and Capacitor Banks
5. Primary Conductors
   a. Overhead Distribution Circuits with Transmission Overbuilds
   b. Single Overhead Circuits
   c. Double Overhead Circuits
   d. Single Underground Circuits
   e. Multiple Underground Circuits

9.1.1 Electric Meters and Panels

Table 9-1 shows magnetic field levels measured with the EMDEX meter at distances of one and three feet from residential and commercial/industrial meter panels. High current values of 100A for residential and 250A for Commercial/Industrial customers were chosen as typical "worst case" peak demands at the panel.

Table 9-1 Magnetic Fields and Meters & Panels

Service Type	Measured Magnetic Fields		% Reductions
	Parameters	Bmax (unit: mG)	
Residential	@ 100A, 1 ft. @ 100A, 3 ft.	96 12	87
Commercial/Industrial	@ 250A, 1 ft. @ 250A, 3 ft.	128 15	88

Based on the magnetic fields findings shown in Table 9-1, the following design recommendations for residential and Commercial/Industrial meter panels will be used:

- When practical, locate meters, panels, and service wires near storage rooms or normally unoccupied spaces (such as garages);
- Consider the access needs for FSR/Meter Reader, from a safety, servicing, and reliability perspective.

9.1.2 Low-Voltage Services

9.1.2.1 Overhead Residential Services

The following design recommendations will be used for overhead residential services:

Table 9-2 Design Recommendations for Overhead Residential Services

Design Category	Design Recommendations
New Construction	Use only triplex services.
Rewire	• Replace residential open-wire services with triplex services in accordance with the ongoing open-wire replacement program. • Replace all open-wire services with triplex services for customers completing rewire.

By replacing residential open-wire services with triplex services, a reduction of 75 percent in magnetic field levels at three feet can be achieved at "low-cost."

9.1.2.2 Overhead Commercial/Industrial Services

The following design recommendations for overhead commercial/industrial services will be used:

Table 9-3 Design Recommendations for Overhead Commercial/Industrial Services

Design Category	Design Recommendations
New Construction	• Use only multiplex services. • Whenever practical, avoid "high use" areas.
Rewire	• Replace Commercial/Industrial open-wire services with multiplex services for customers completing rewire.

By replacing commercial/industrial open-wire services with multiplex services, a reduction of 60 percent in milliGauss levels at three feet can be achieved. Additional magnetic fields level reduction can be achieved by locating the multiplex services further away from occupied areas or structures (e.g., move from 3 to 5 feet).

9.1.2.3 Underground Residential Services

Magnetic field levels over underground service are expected to be very low; thus, it is recommended that no changes to be made.

9.1.2.4 Underground Commercial/Industrial Services

Where practical, parallel service cables and conduits (to the buildings) should be routed away normally occupied rooms.

9.1.3 Low-Voltage Secondaries

9.1.3.1 Overhead Secondaries

Multiplex secondaries are recommended for new overhead secondary installations. When rebuilding or rewiring an overhead secondary, change open-wire secondaries to multiplex conductors when existing open wire is not sufficient to meet capacity and voltage-drop standards.

9.1.3.2 Open-Wire Secondaries Close to Buildings

GO 95 allows a minimum three foot horizontal clearance between the overhead secondaries and the building structures. When rebuilding or upgrading open wire overhead secondaries located close to occupied rooms in buildings, the following "no-cost and low-cost" options may be used to reduce magnetic fields:

- Reduce the pin-spacing of the open-wire conductors to a minimum.

- Increase the conductor clearance of the open-wire secondaries with respect to the building.

- Replace open-wire secondaries with multiplex conductors.

Figure 9-1 Proximity to Building - Magnetic Fields

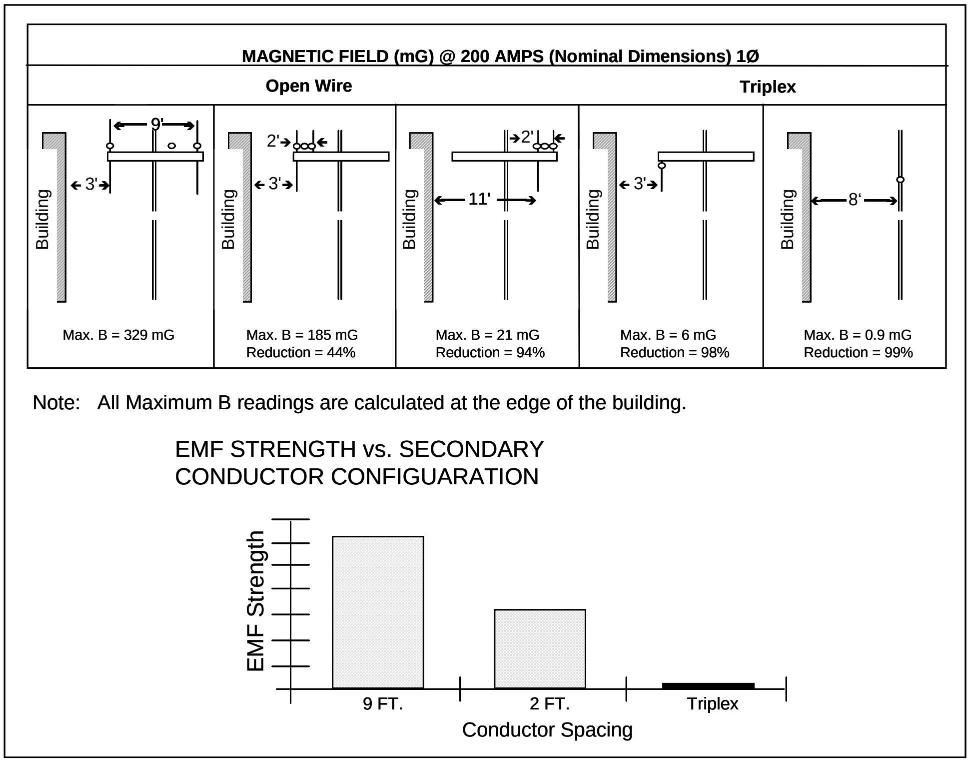


Figure 9-1 shows, for example, how the open-wire secondaries can be arranged on the ten foot cross-arms to reduce magnetic fields. It also shows how open-wire secondaries can be converted to triplex. Depending on the location of the triplex, either at the close end of the cross-arm or on the pole itself, the magnetic field levels are reduced accordingly.

9.1.3.3 Open-Wire Secondaries Above Pedestrian Walkways

Figure 9-2 shows the magnetic field levels calculated for 20 feet and 25 feet ground clearance and various open-wire secondary configurations. These calculated values show that installing the open wires closer together or using taller poles will reduce the magnetic field levels.

Figure 9-2 Magnetic Field - Distance from Secondary Wires

MAGNETIC FIELD (mG) @ 200 AMPS (Nominal Dimensions) 1Ø

Conductor Height	Open Wire (Nominal Dimensions)				Triplex
	9 ft.	7 ft.	3 ft.	2 ft.	
20 FT.	S N S Max. B = 38.6 mG Reduction = N/A	S N S Max. B = 31.4 mG Reduction = 19%	S N S Max. B = 15.0 mG Reduction = 61%	S N S Max. B = 10.0 mG Reduction = 74%	Max. B = 0.1 mG Reduction = 99%
25 ft.	S N S Max. B = 23.7 mG Reduction = N/A	S N S Max. B = 19.1 mG Reduction = 19%	S N S Max. B = 9.0 mG Reduction = 62%	S N S Max. B = 6.0 mG Reduction = 75%	Max. B = 0.1 mG Reduction = 99%

Note: All Maximum B readings are calculated at a three foot elevation.

9.1.3.4 Underground Secondaries

Since the magnetic field levels over underground secondaries are expected to be relatively low, no further reduction techniques are recommended.

9.1.4 Padmount and BURD Equipment

Padmount transformers, switches, and capacitors are common distribution equipment that are installed above ground level and are normally located in open spaces near customers' residences and businesses.

9.1.4.1 Padmount Transformers

Padmount transformers are installed above ground and located in open yards or parking areas, normally exposed to residences and the public. Magnetic field levels adjacent to the secondary side of the transformer are normally the highest. Levels fall rapidly with greater distance from the transformers. Therefore, when installing a new padmount transformer, position the secondary side of the transformer, when practical, so barriers such as landscaping, fencing, or block walls will discourage people from approaching the secondary side of the transformer.

9.1.4.2 BURD Transformers

Buried Underground Residential Distribution (BURD) transformers are installed below ground level. The magnetic field levels measured at three feet above ground are relatively low. Thus, changes in existing design practices are not recommended.

9.1.4.3 Switches and Capacitor Banks

The magnetic field levels measured around switches and capacitor banks are relatively low. Thus, changes in existing design practices are not recommended.

9.1.5 Primary Conductors

9.1.5.1 Distribution Circuits with Transmission Overbuild

Unlike the transmission or subtransmission lines, distribution line currents are not generally well balanced. When circuits are not well balanced, the magnetic cancellation effect from optimal phasing decreases. In many cases, using taller poles may reduce magnetic fields more than optimal phasing, especially for subtransmission lines with a lateral distribution circuit underbuild. Therefore, consider using taller poles when planning a new or rebuilt overhead distribution circuit with subtransmission overbuild.

9.1.5.2 Single Overhead Circuit

The following guidelines are recommended to reduce magnetic fields for installing single overhead circuits:

- Whenever practical, use horizontal cross-arm design (Construction Standard DC 510.1) for all new single overhead circuit construction. The single cross-arm and the conductors can be positioned higher compared to the vertical design (DC 540); thus, horizontal design reduces magnetic fields levels. Whenever practical, place the neutral wire at the outmost position on the cross-arm so that all phase wires are positioned close together.

- For circuits using 1/0 or smaller conductors, no change in existing practices is recommended.

- For circuits using 336 kcmil or larger conductors, a minimum of 45-foot long poles will be used.

9.1.5.3 Double Overhead Circuits

The following guidelines for double overhead circuits are recommended to reduce magnetic fields and control costs:

- Whenever practical, use vertical design (Construction Standard DC 540) for new double overhead circuit construction because there is more clearance between the two vertical circuits for operation and maintenance.

- Use minimum 50-foot poles for new constructions. Using taller poles, in many cases, may reduce magnetic fields more than optimal phasing due to current unbalance.

- At getaways, use optimal phasing, ABC/CBA, if practical, to take advantage of field cancellation from currents in adjacent circuits, for new construction and with other significant work.

9.1.5.4 Single Underground Circuit

The magnetic fields directly above the underground circuit can be higher than the magnetic fields directly below an overhead circuit carrying the same currents. The field is stronger because the underground circuit is much closer to ground level than the overhead circuit; however, magnetic fields from underground circuits will drop off more rapidly than comparably loaded overhead circuits due to the closer spacing of the underground cables.

The following guidelines are recommended to reduce magnetic fields for installing a single underground circuit:

- Locate the conduit away from heavy foot traffic or normally occupied area, where practical.

- Install a heavily loaded circuit in the bottom conduit of a duct bank, where practical.

9.1.5.5 Multiple Underground Circuits

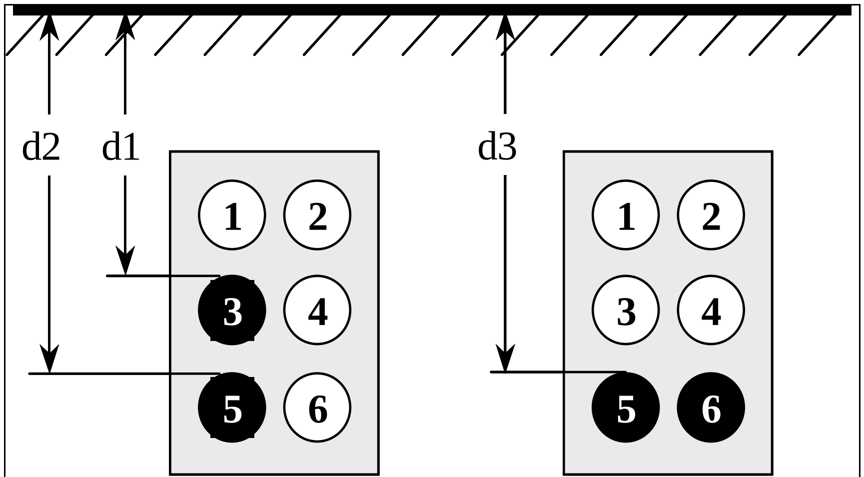
Figure 9-3 shows the magnetic field levels calculated at three feet above ground level over two underground primary circuits installed in various conduit positions. Since the underground conductors twist and roll as they are installed in the duct, the phase relationship and field cancellation may vary over a wide range.

The following guidelines are recommended to reduce magnetic fields for double and multiple underground circuits installed in duct banks:

- Locate the conduits away from heavy foot traffic and normally occupied areas, where practical.

- Install heavily loaded circuits in bottom ducts first, where practical.

Figure 9-3 Magnetic Field - Multiple Underground Primary Circuits



Construction Standard (UGS-120)	
Cable Depth "d" (inch)	Max. B (mG) @ 3 ft
d1 = 35 d2 = 40	6.1 ~ 12.1
Average B	6.6

Construction Standard (UGS-120)	
Cable Depth "d" (inch)	Max. B (mG) @ 3 ft
d3 = 40	5.2 ~ 15.2
Average B	11.4

Note: Average B is a weighted calculation of various phase conductor orientations in duct.

10 California Department of Education's (CDE) Standards for Siting New Schools[33] Adjacent to Electric Power Lines Rated 50 kV and Above

The California Department of Education (CDE) evaluates potential school sites under a range of criteria, including environmental and safety issues. Exposures to power-frequency electric and magnetic fields (EMF) are one of the criteria.

CDE has established the following "setback[34]" limits for locating any part of a school site property line near the edge of easements for any electrical power lines rated 50 kV and above:

- 100 Feet for 50 – 133 kV Power Lines
- 150 Feet for 220 – 230 kV Power Lines
- 350 Feet for 500 – 550 kV Power Lines

School districts that have sites which do not meet the California Department of Education setbacks may still obtain construction approval from the state by submitting an EMF mitigation plan. The mitigation plan should consider possible reductions of EMF from all potential sources, including power lines, internal wiring, office equipment and mechanical equipment. Generally, school districts hire independent consultants who are familiar with the process to complete these plans. SCE's EMF Research and Education Department will provide the school district's consultant with the information necessary to develop the mitigation plan and assist in the coordination of other company resources to assist the process. For further details, contact the EMF Research and Education Department at (800) 200-4723.

10.1 School District's Request to Modify Existing Electrical Facilities

When any school, school district, or CDE requests SCE to modify SCE's existing electrical facilities, SCE may accommodate the request based upon the following conditions:

- The school or the school district must pay all costs[35] for modifying SCE's existing electrical facilities.

[33] School is defined as public and accredited private schools K through 12th Grade under the California Department of Education's jurisdiction.
[34] "School Site Selection and Approval Guide" *by* School Facilities Planning Division of the California Department of Education
[35] The costs include (but are not limited to) detailed estimation, design, construction, and easement (or right-of-way) acquisition costs.

- The school or the school district must have a communication plan to notify customers, property owners, and other affected parties in writing of the proposed change. It is the primary responsibility of the school district to resolve objections raised by nearby property owners.

- Design and construction of all electric power systems must comply with all federal, state, and local regulations, applicable safety codes, and SCE standards. Any possible magnetic field mitigation measures, therefore, must meet these requirements.

- SCE will notify the customer that it does not provide guarantees that any proposed mitigation measures will eliminate EMF exposure, nor that any reduction in EMF level is beneficial to human health. In addition, SCE does not guarantee that the electric load on any facility will remain constant, but may at some future time be increased or reduced, as circumstances require. The reality is that increasing demand for electricity will most likely result in future increased magnetic field exposure.

11 Appendix A - Assumptions Used in The Calculation of Magnetic Fields

Unless otherwise noted, the following assumptions are made for the calculation of magnetic fields shown in the tables and figures of the EMF Design Guidelines.

Table 11-1 Assumptions Used in Magnetic Field Calculations

Voltage Class	Phase Current	Phase Angles	Pole Length	Ground Clearance	Depth of Underground	Location of mG Measure
4 kV	100 Amps	a: 30 b: 150 c: 270	30'		3'	3' Height Under Line
12 kV 16 kV	100 Amps	a: 60 b: 180 c: 300	30'		3'	3' Height Under Line
66 kV	250 Amps	a: 30 b: 150 c: 270	Single = 60’ Double = 60'		4'	3' Height Under Line
115 kV	250 Amps	a: 0 b: 120 c: 240		40'	4'	3' Height Under Line
161 kV	250 Amps	a: 0 b: 120 c: 240		40'		3' Height Under Line or Edge of ROW
220 kV	500 Amps	a: 0 b: 120 c: 240		50'		3' Height Edge of ROW
500 kV	1000 Amps	a: 0 b: 120 c: 240		50'		3' Height Edge of ROW

12 Appendix B - SCE's Phasing Sequence

When more than one circuit is on the structure or right-of-way, the phase-angle relationships between the circuits must be determined. The phase angle in degrees gives the electrical location for all phases in relationship to each other. The different phase relationships of voltage and current for all SCE system voltages with power flow in the same direction in all cases is shown in Table 12.1.

Table 12-1 Phase Relationship for Various SCE Voltages

kV	Area	Phase (Degree)		
		A	B	C
500	System	0	120	240
220	System	0	120	240
161	System	0	120	240
115	System	0	120	240
66	System	30	150	270
66	Havasu	0	120	240
55	Lee Vining	0	120	240
55	Control	30	150	270
33	System	30	150	270
33	Death Valley	330	210	90
16	System	60	180	300
16	Havasu	30	150	270
12	Baker	0	240	120
12	Blythe	300	60	180
12	System	60	180	300
4	Porterville	60	180	300
4	Tulare	0	120	240
4	Eastern System	60	180	300
4	System	30	150	270
2.4	Houston	30	150	270

If more than one circuit is on the structure or on an adjacent structure, the magnetic fields will interact with each other. The first circuit will establish a direction of current flow by using angles from Tables B.1. All other circuits' phase angles will be based on the direction of current flow relative to the first circuit. If current flow of the circuit under consideration is in the same direction as circuit No. 1, use the angles in **Table 12.1** according to the circuit voltage. If current flow of the circuit under consideration is in the opposite direction compared to the circuit No. 1, use the angles in **Table 12-2** according to the circuit voltage.

Table 12-2 Phase Relationship for Various SCE Voltages (Power Flow is in Opposite Direction to Table 12-1)

kV	Area	Phase (Degree)		
		A	B	C
500	System	180	300	60
220	System	180	300	60
161	System	180	300	60
115	System	180	300	60
66	System	210	330	90
66	Havasu	180	300	60
55	Lee Vining	180	300	60
55	Control	210	330	90
33	System	210	330	90
33	Death Valley	150	30	30
16	System	240	0	120
16	Havasu	210	330	90
12	Baker	180	60	300
12	Blythe	120	240	0
12	System	240	0	120
4	Porterville	240	0	120
4	Tulare	180	300	60
4	Eastern System	210	330	90
4	System	180	300	60
2.4	Houston	180	300	60

13 Reference

The information contained in this section is derived from, and is consistent with the following scientific literature:

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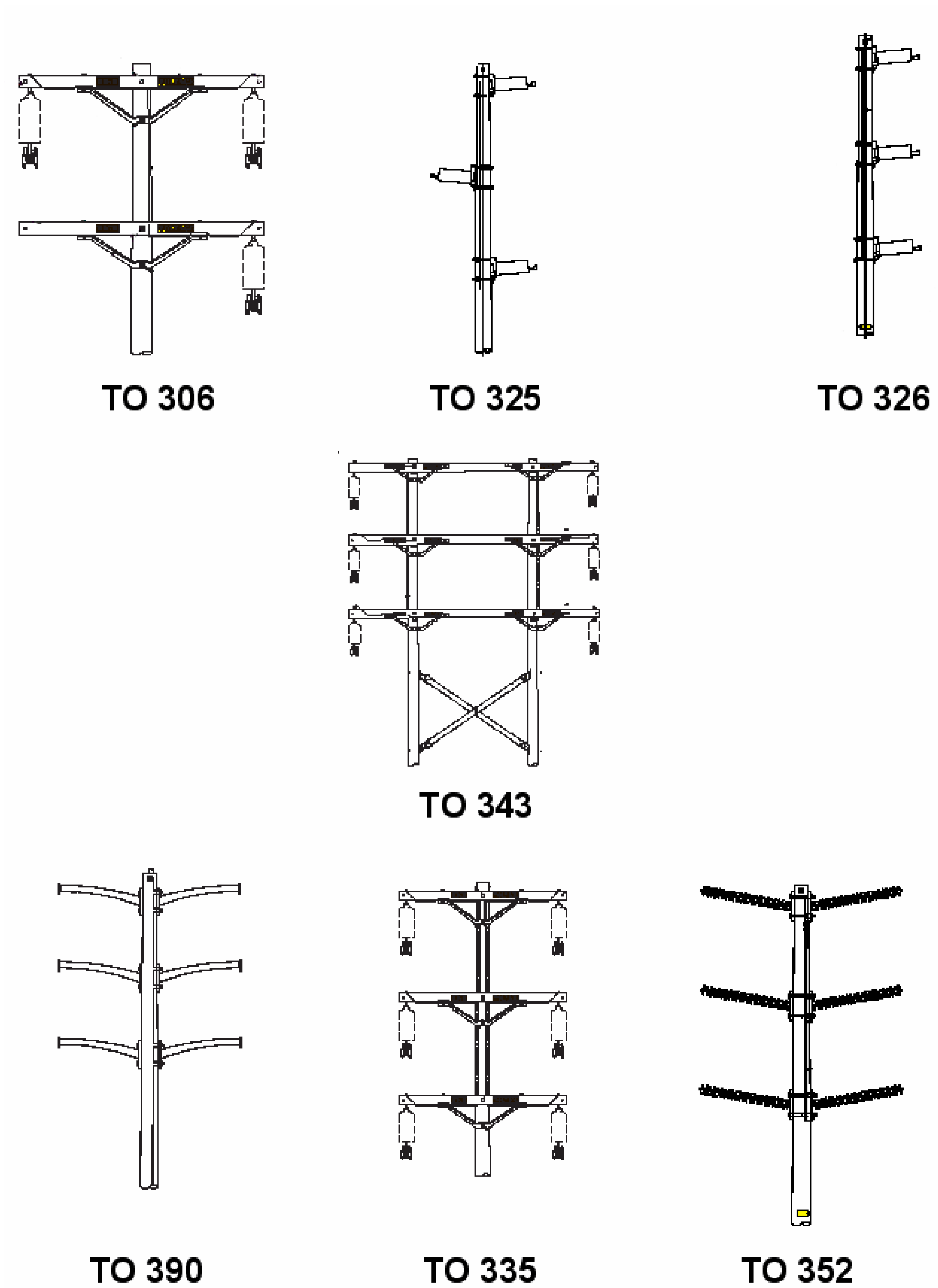
14 Various Pole-head Configurations for Subtransmission Lines



15 Glossary

3D Fields	A Computer program called 3D-FIELDS has been developed by SCE that models magnetic fields resulting from combinations of conductors typically found at substations.
Ampere (A)	The standard unit for measuring electric current. One ampere represents a charge flow of one coulomb per second.
Access Right	The right of an owner to have ingress and egress to an from his/her property.
Alternating Current (AC)	A current with a magnitude that oscillates above and below zero (i.e., reverses direction) in a periodic manner.
B	Magnetic flux density, measured in Gauss (G) or milliGauss (mG), also known as the magnetic field.
Balance	Refers to the degree that each circuit phase carries equal amounts of current.
BURD	Buried Underground Residential Distributions. Equipment and conductors located entirely below ground.
Bus	A conductor or group of conductors that serve as a common connection between two or more circuits.
Bus Tie	A switchrack position which connects the transfer bus to the operating bus.
Charge	The quantity of electrons or ions that is stored on a conductor. Analogous to a quantity of water stored in a vessel. To store electrical charges in a device.
CIC	Conductor-in-Conduit. Flexible underground conduit containing current-carrying conductor.
Concentric	A series of small wires at ground potential designed to carry neutral current, helically wound over the surface of underground insulated phase conductors.
Condemnation	The exercise of the power of eminent domain: that is, the taking of private property for public use.
Conductor	A substance that passes electric current. Good conductors are generally made of metal, although other substances, such as the earth or the human body, can be relatively good conductors.
Contiguous	In actual or close contact, touching, adjacent, near.

Commercial/Industrial (C/I)	Commercial/Industrial refers to a customer class.
Coulomb (C)	The standard unit for measuring electric charge. One coulomb contains 6.24 x 10^{18} elemental charges.
Current	The flow of electric charge measured in root mean square amps for magnetic field calculations.
CPUC	The California Public Utilities Commission.
Dedication	An appropriation of land by its owner for some public use accepted for such use by authorized public officials on behalf of the public.
Distribution	Power delivery system below 50,000 volts (50 kV).
Duty	The amount of electric energy at a particular location under a short circuit condition, also called “short circuit duty.”
Easement	A right or interest in the land of another which entities the holder to some use, privilege, or benefit (such as to place pole lines or roads, thereon, or travel over, etc.) out of, or over, said land.
Electric Field	Field resulting from presence of voltage. Measured in volts per meter (V/m). Electric fields can be shielded by conducting material. Electric fields are not the primary focus of the EMF Design Guidelines.
Electromagnetic Field	A condition of space containing both electric and magnetic fields.
EMF	Electric and Magnetic Fields. For purposes of this guide, only power frequency (60 Hz) fields are discussed.
Eminent Domain	The right or power of the government to take private property with just compensation for public use.
Encroachment	Trespass; the building of a structure or construction of any improvements, partly or wholly, on the property of another.
Energy	The capacity for doing work or producing heat.
Field	A space within which magnetic or electric forces are active.
FIELDS	A computer program developed by SCE that models transmission, subtransmission, and distribution lines. This program calculates the electric and magnetic fields for long parallel conductors, both overhead and underground. Utilization of this program allows the designer to calculate expected electric and magnetic fields for various design configurations, loadings, and voltages.

Franchise	Permission granted by a municipality to install electrical facilities along public streets or thoroughfares.
Frequency	The number of cycles per second (Hertz) of an alternating current or voltage. The frequency of power equipment in the United Stated is 60 Hertz. In many other countries, a frequency of 50 Hertz is used.
Gauss (G)	A common unit for measuring magnetic fields.
GO	General Order. A decision and policy put into effect by the California Public Utilities Commission.
Hertz (Hz)	Measurement of frequency of an alternating electric source in cycles per second.
Impedance	The quality of a substance or device that resists the flow of current. Even good conductors have a certain amount of impedance. For the non-specialist, impedance and resistance may be thought to express a similar phenomenon, although there are technical differences between these two terms.
Insulation	A substance that conducts current poorly, such as plastic or rubber.
kcmil	1,000 circular mills, the size of a conductor, cross-sectional area.
Kilo (k)	Prefix indicating one thousand.
KVA	KiloVolt Amps, a measure of electrical power.
License	Formal or legal permission to do something specified.
Loop feeder	A number of tie feeders in series, forming a closed loop for distribution circuits.
Magnetic Field	A region of influence around a moving charge or current. The intensity is measured by the magnetic flux density B, in milliGauss (mG). Magnetic fields are flat, readily shielded by the ground, buildings, or the human body.
Maximum B	The range of magnetic flux density, B, varies through a minimum and maximum over a period of 1 cycle. Magnetic fields calculated in this guide will show the maximum magnetic field.
Mega (M)	Prefix meaning one million.
Micro (μ)	Prefix indicating one one-millionth.

Milli (m)	Prefix indicating one one-thousandth.
Multiplex	A section of conductors consisting of two (duplex), three (triplex), or four (quadruplex) individual conductors twisted around each other. These are generally used as services or secondary wiring.
Net-through Unbalance	A balanced network is one where there currents are equal in magnitude and separated in phase by 120 degrees. If the currents are not equal in magnitude or not separated by 120 degrees, they are said to be unbalanced. In the case of parallel circuits, unbalanced currents can circulate in a loop between the parallel circuits (circulating unbalance) or they can flow through the network (through unbalance). In single circuit or non-parallel multiple circuit transmission lines, only through unbalance is possible. By careful arrangement of the phase in parallel transmission lines, both through and circulating unbalance can be minimized.
Neutral	Current or conductor carrying current returning to the source. Neutrals are at ground potential and not considered a 'phase' of the circuit. Earth may be a neutral path back to the source.
Occupied Space	Rooms, buildings, playgrounds, and other areas where people may spend extended periods of time.
Open-Wire	Secondary voltage conductors on separate insulators and not twisted together.
Operating Bus	A bus which is always energized under normal operating conditions.
Overhead (OH)	Overhead refers to electrical conductors and equipment mounted on poles.
Padmount	Equipment (transformers, switches, etc.) which sits on the ground on concrete-like “pads” fed by underground conductors.
Phase	Electric current, voltage, or conductors carrying electricity greater than ground potential. Each 'phase' of a circuit will have unique electrical values at any point in time compared to other ‘phases’ of the same circuit.
Phase Conductor	One of the three current-carrying wires in a three-phase alternating current power line.
Optimal Phasing	The physical positioning of each phase of the circuit(s) on a pole line with respect to each other.
Prescription	Title obtained in law by long possession. Occupancy for the period described by the Code of Civil Procedures as sufficient to bar an action for the recovery of the property gives title by prescription.
Primary	Voltages greater than 600 volts. Also refers to the “high side” voltage on a transformer.

Radial feeder	A feeder supplying electric energy to a substation or feeding point that receives energy by no other means. The normal flow of energy in such a feeder is in one direction only.
Resistance	The quality of a substance or device that resists the flow of current. Even good conductors have a certain amount of resistance.
Right-of-Way	In its strict meaning, an easement or the right of passage over another person's ground. Through usage at SCE, any right (fee, license, or easement) secured to permit the construction, maintenance, reconstruction, or removal of company facilities.
Secondary	Voltage or conductors carrying voltage less than 600 volts on the distribution system. Also refers to the "low side" voltage on a transformer.
Services	Conductors carrying power to customer meter panels, generally at secondary voltages.
Shielding	A substance or device that blocks electric or magnetic fields.
Short Circuit	An abnormal connection (including an arc) of relatively low impedance between two points of different potentials.
Subtransmission	Power delivery system at voltages between 50,000 and 161,000 volts (50 kV - 161 kV).
Swing	The movement of conductors, or amount of, due to wind blowing on the conductor.
Switchrack	The portion of a substation that contains all the elements (buses, circuit breakers, switches) corresponding to one voltage (i.e., 66 kV switchrack).
Transfer Bus	A bus which is used when the operating bus or any elements connected to it are out for maintenance.
Transmission	Power delivery system above 161,000 volts (161 kV).
Transmission System	An interconnected group of electric transmission lines and associated equipment which transfer electric energy, in bulk, between points of supply and points of delivery.
Transposed Line	The phase conductors of the circuit that have interchanged positions on the structure between successive lengths of line so as to minimize electrical unbalances.

Unbalance	Different amounts of current carried on each phase of the circuit.
Underbuild	The lower voltage circuits that are constructed underneath a higher voltage circuit on the same pole line.
Underground (UG)	Electrical conductors and equipment which are located beneath the street grade.
Volt (V)	The standard unit for measuring voltage.
Volts per Meter (V/m)	A standard unit for measuring the strength of an electrical field.
Voltage	The electrical force that propels current in a conductor. Analogous to the pressure in a water hose.