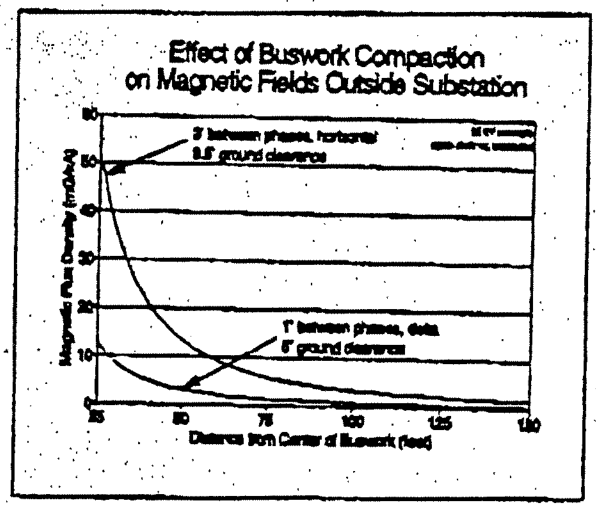
SUBSTATION

EMF DESIGN

GUIDELINES



Pacific Gas & Electric Company
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I. INTRODUCTION

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

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

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

II. PURPOSE OF DESIGN GUIDELINES

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

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

Minimizing the magnetic field strength is one of the many factors to consider in the planning and design of a substation. It must be considered along with other issues such as safety, environmental concerns, reliability, insulation and electrical clearance requirements, aesthetics, cost, operations, and maintenance. These other factors are essential to the design and must continue to be addressed. In all cases, transmission line facilities and/or distribution line facilities interact with the substation facility at the fence line. The **"Transmission Line EMF Design Guidelines"** and **"Distribution Line EMF Design Guidelines"** should be referred to for mitigating magnetic fields for those facilities beyond the fence line.

III. OVERVIEW OF ELECTRIC AND MAGNETIC FIELDS

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

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

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

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

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

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

While both electric and magnetic fields exist near electric transmission facilities, the remainder of the discussion in this document relates only to magnetic fields. This is the area of public concerns and the focus of health research. Although a number of characteristics of magnetic fields are being studied (such as average strength, peak strength, transients and harmonics), it is the 60 hertz (rms) magnetic field strengths that are the subject of these field reduction guidelines.

Magnetic fields for transmission, distribution, and substation facilities can be calculated for specific installations using computer programs and knowing the voltage, current, and construction type and configuration. The computer programs provide accurate results to the extent that the appropriate bus currents and physical arrangement data are used. The difficulties encountered in the computer model usually stem from the constantly changing complexity in the operation of the power system being modeled.

Please refer to **Appendix A** for a Reference of resource information and **Appendix B** for a Glossary of commonly used terms.

IV. PG&E CORPORATE EMF POLICY

PG&E's Corporate EMF Policy is to address concerns about EMF. Until definite scientific conclusions are reached, PG&E will:

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

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

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

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

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

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

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

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

V. NO/LOW COST FIELD REDUCTION

Definition

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

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

- **No cost** measures are those steps taken in the design stage, including changes in standard practices, which will not increase the project cost but will reduce the magnetic field strength. Any % field reduction at the fence line is desirable given that fields are not increased to the public elsewhere.

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

V. NO/LOW COST FIELD REDUCTION (cont.)

Applications

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

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

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

1. NO COST vs LOW COST

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

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

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

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

reduce the cost to implement known measures. For upgraded projects, the benchmark should apply to that portion of the project for which the utility is seeking authorization."

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

2. MINIMUM FIELD REDUCTION

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

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

3. AREA PRIORITIZATION

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

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

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

PRIORITIZED AREAS
(based on public concern)

HIGHEST Priority

1. Schools, Licensed day care
2. Residential
3. Commercial/Industrial
4. Recreational
5. Rural
6. Undeveloped land, zoned for residential
7. Undeveloped land, zoned for commercial/industrial

LOWEST Priority

4. APPLICATION OF LOW COST MEASURES

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

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

5. FIELD MANAGEMENT PLAN

It is the project lead's (project manager or project engineer for smaller projects) responsibility to prepare a field management plan for project authorization on all projects and the plan's written summary shall include the following (see **Appendix C** for the Field Management Plan):

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

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

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

VI. DESCRIPTION OF PG&E FACILITIES

PG&E's current substation system consists of 1,100 transmission and distribution facilities within the service territory of Northern and Central California. For 1993 there was a total approximate installed capacity of 34,000 MVA for transmission substations and 22,000 MVA for distribution substations to deliver a combined energy use of 75,000 million kWh.

PG&E's **transmission** substations are those facilities with two or more operating voltages above 60kV (there are some transmission facilities, known as switching stations, that have only one transmission operating voltage, yet differ from distribution substations because there are no distribution operating voltages). Transmission substations are interconnected through transmission lines with other transmission substations and generation facilities across PG&E's service territory to transmit bulk power across the grid to meet customers' loading needs. They are not typically located in highly populated area.

PG&E's **distribution** substations are those facilities with operating transmission voltages of 230kV, 115kV, 69kV, or 60kV and distribution operating voltages of 4kV to 34.5kV. The large number of different voltages is due to PG&E's incorporation of other smaller utilities in previous years. Some stations have more than one distribution operating voltage. Some stations only have distribution operating voltages and are known as Unit Subs, such as 21/4 kV or 12/4 kV. In some cases a distribution station is contained within the same perimeter security fence of a transmission substation facility.

Distribution substations are connected radially or looped to transmission lines to receive some of the bulk power. The distribution substation transforms power to a lower voltage for distribution along circuits to customers in communities. Figure VI-1 shows a typical distribution substation single line diagram for this purpose. Voltage drop along the distribution circuits limits the practical length of the circuit, therefore, distribution substations need to be located relatively closely to the loads they serve.

PG&E's typical distribution substation design (115/12kV) as shown in Figure VI-2, is a plan view of low-profile, tubular steel construction, with rigid aluminum tubing for bus conductors. PG&E is aggressively developing a new design standard (nicknamed Bantam Sub) to "compact" the area required for these facilities and reduce the overall cost. Figure VI-3 shows a single line diagram and plan view of the new conceptual design. Figure VI-4 depicts the fenced area savings from the new design when compared to the current design.

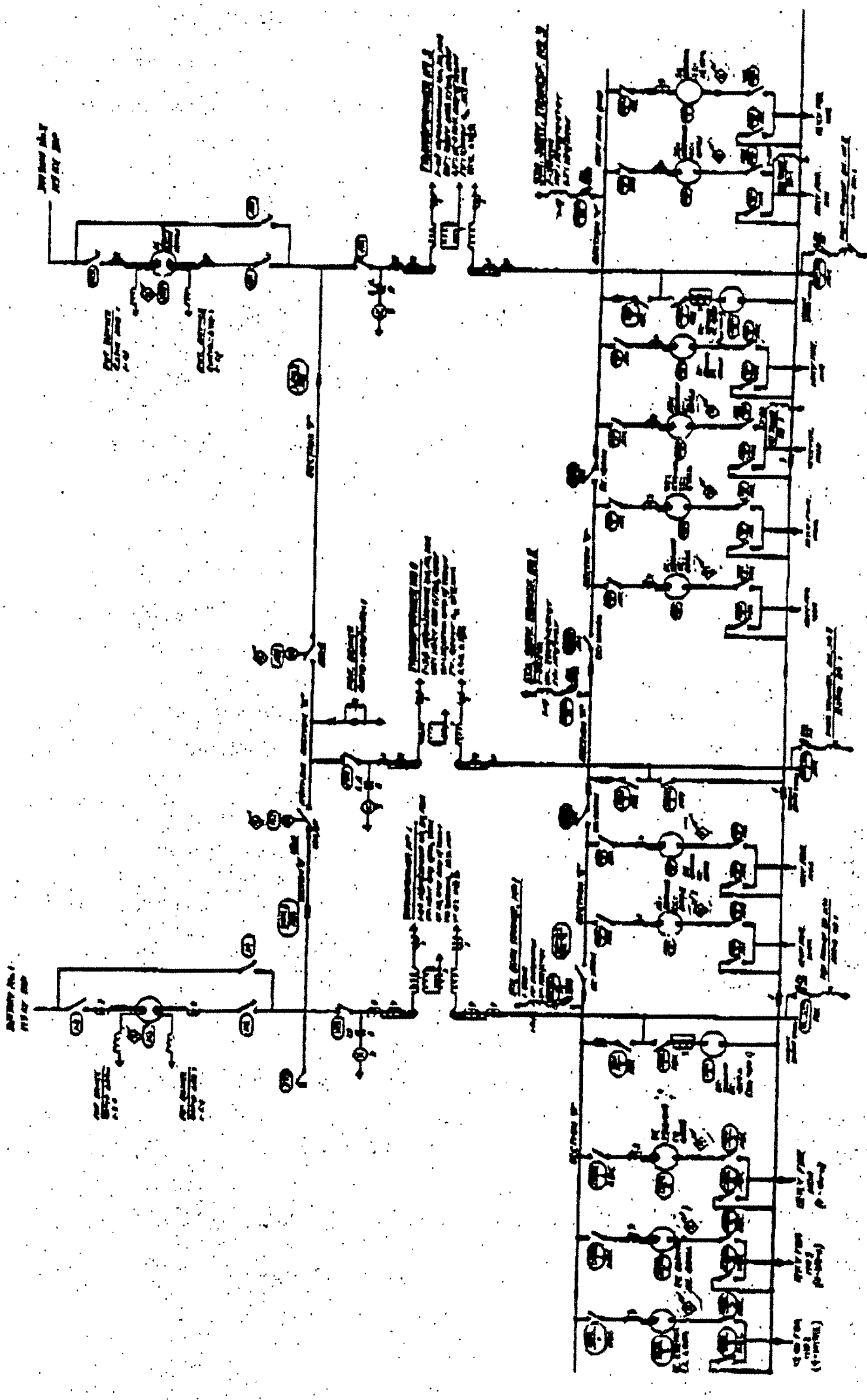

FIGURE VI-1 TYPICAL DISTRIBUTION SUBSTATION SINGLE LINE DIAGRAM

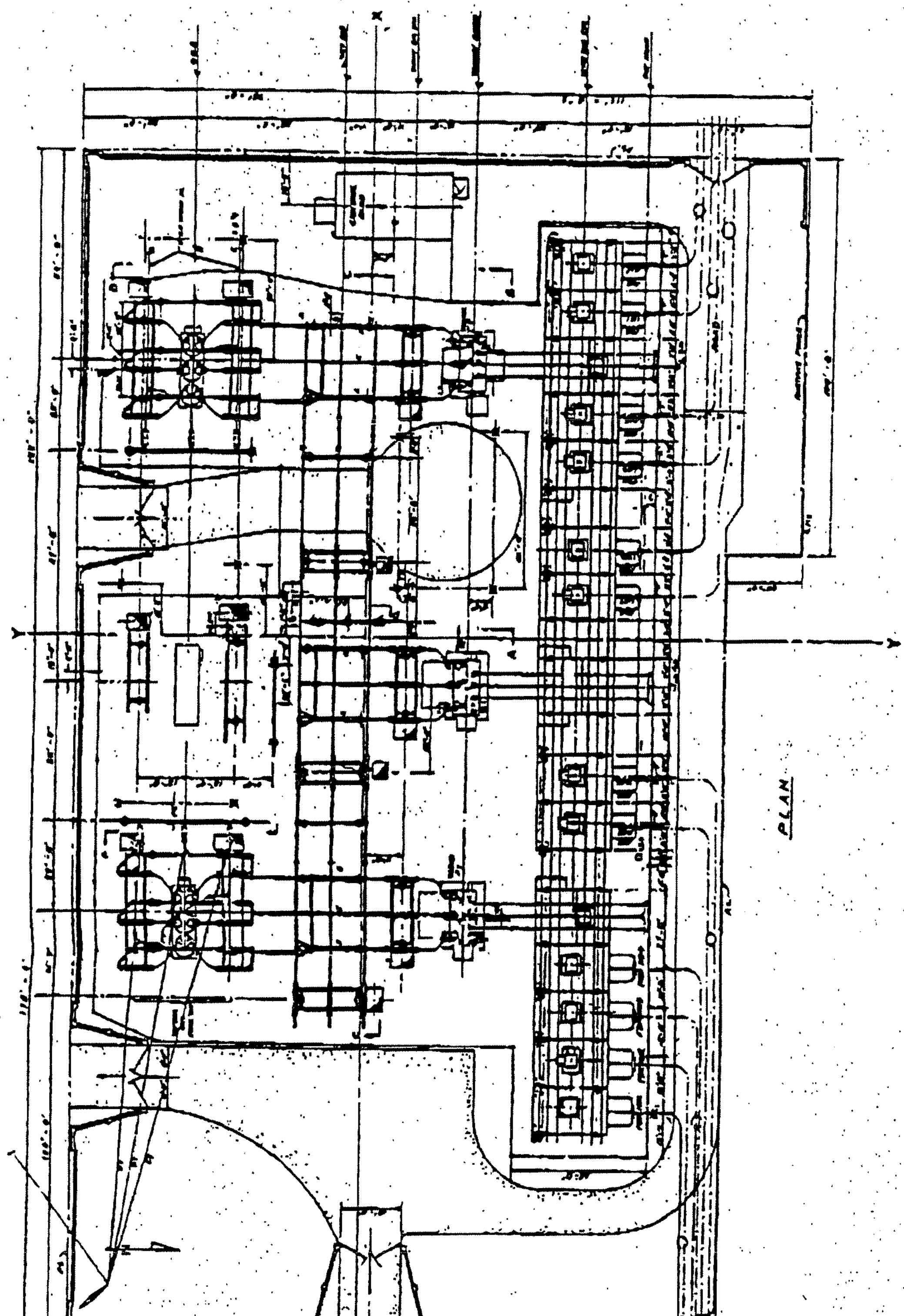

FIGURE VI-2 TYPICAL DISTRIBUTION SUBSTATION PLAN VIEW

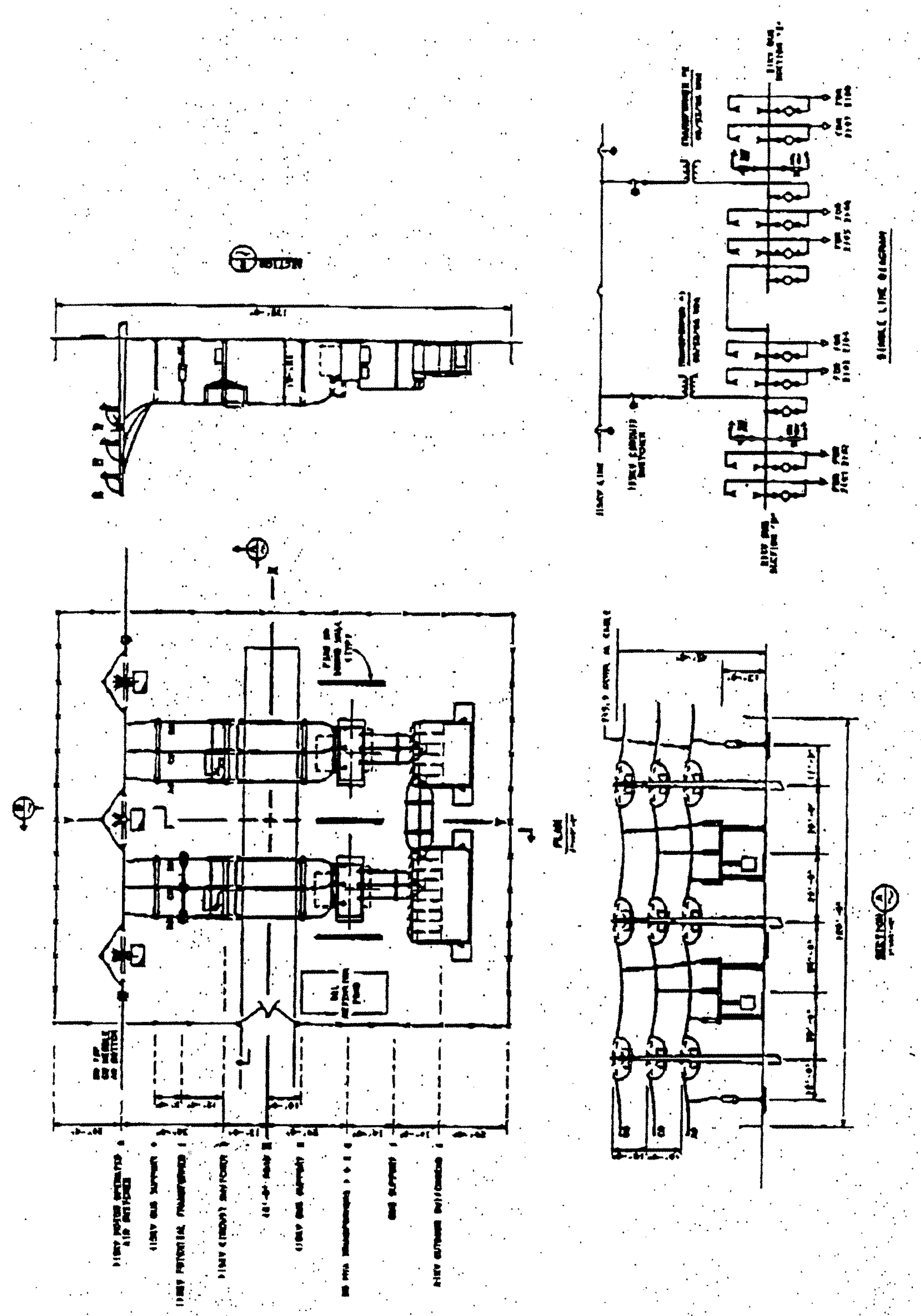

FIGURE VI - 3 "COMPACT" DESIGN OF DISTRIBUTION SUBSTATION

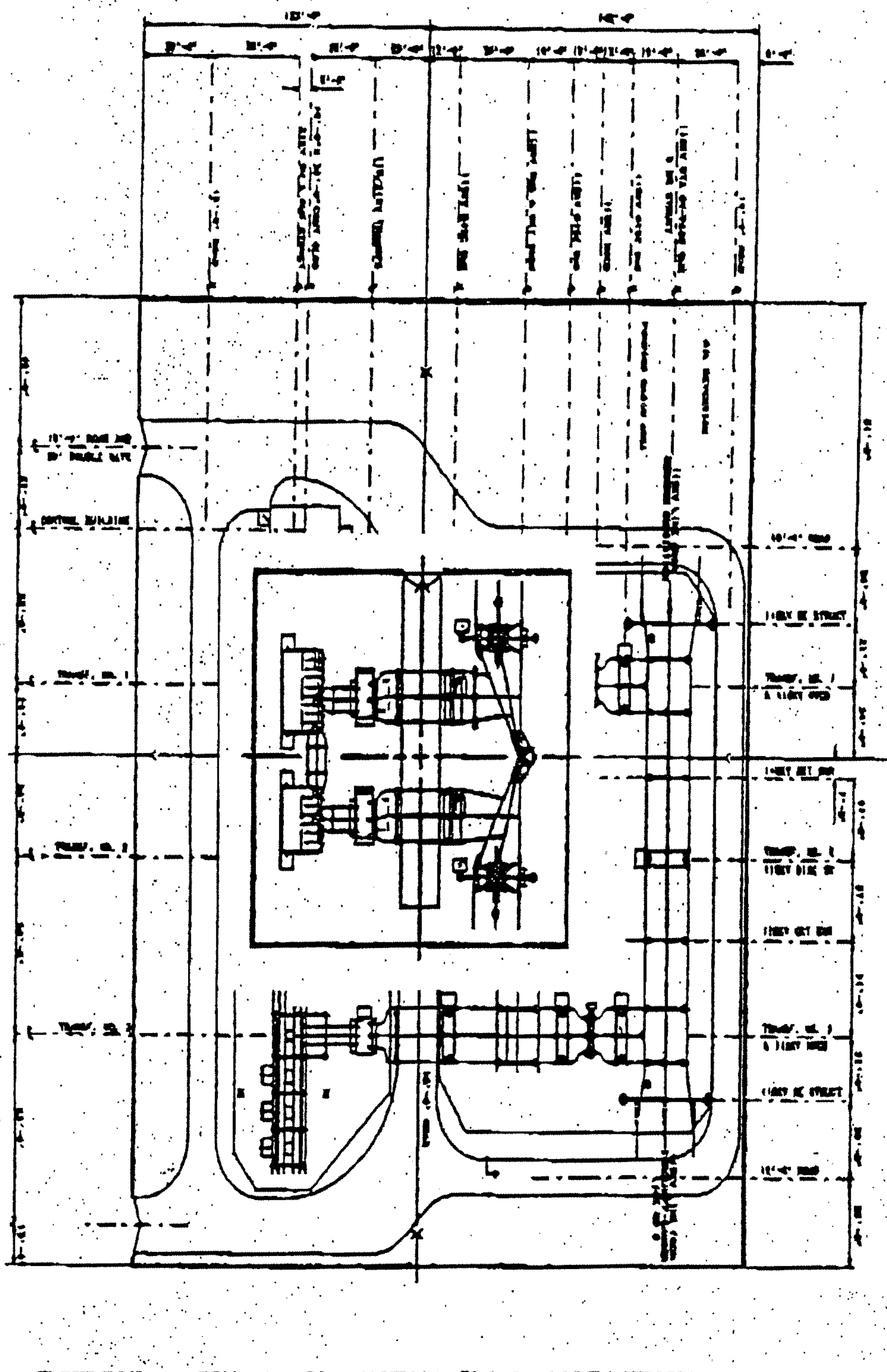

FIGURE VI-4 . FENCED AREA SAVINGS FROM "COMPACTION"

Other utility purposes for substations are:

- λ Controlling the power flow of interconnected grid system during normal and disturbance periods
- λ Voltage control
- λ Redundancy of equipment for maintenance and failure back-up

It is important to understand that the load at a typical substation varies daily and seasonally as the customer load changes (see Figure VI-5). The average annual loading at a substation is typically only 40% of the maximum load on the annual peak day.

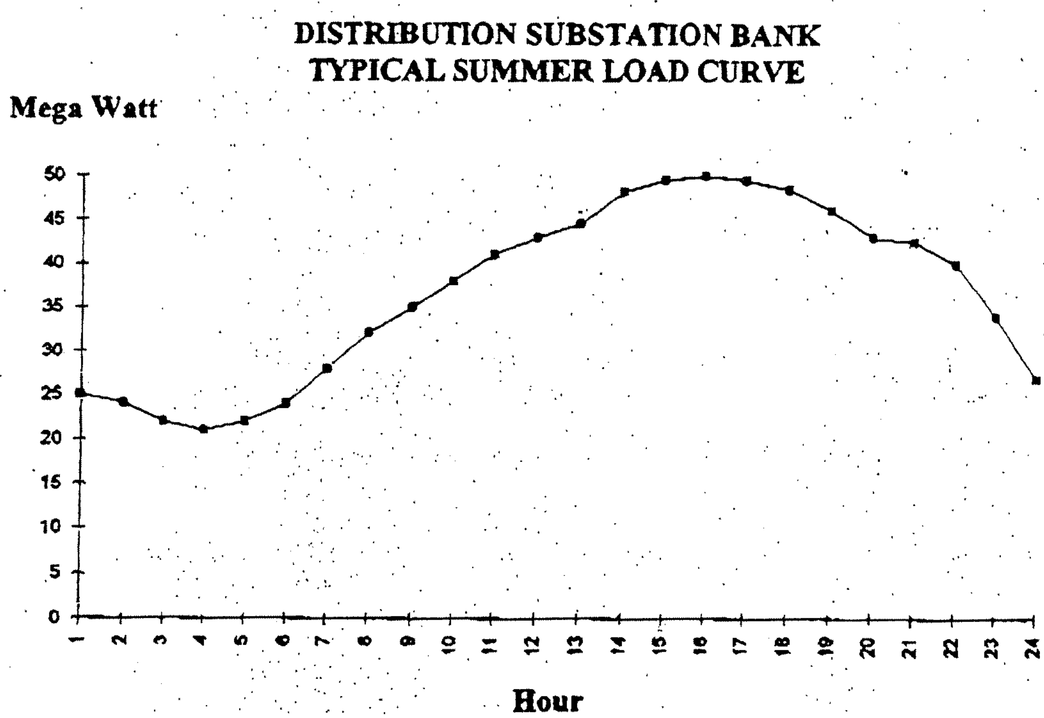

Figure VI-5 Substation Typical Daily Load Curve

Table 1 below summarizes the general purposes and location for various types of substation facilities.

Types	Location	Purpose
Transmission, Switching	Rural	Bulk Power
Distribution	Urban/Suburban	Transform bulk load
Unit Subs	Suburban	Transform local loads
Industrial	Industrial site	Dedicated Service

Table 1 – Substation General Purpose and Location

Equipment that can be installed within a substation varies but can be generalized as follows:

Magnetic field sources --Busses, Transformer, Circuit Breaker, Potheads, Reactors, Capacitors, Battery Charger

Other types--Battery, Lighting, Station Service, Building, Switches, Connectors, Insulators, Structures, Relays, Alarms, Conduits, Grounds, Control Cable, Fence/Wall