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IEEE Guide for the Design, Construction, and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility

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Abstract: Significant community acceptance and environmental compatibility items to be considered during the planning and design phases, the construction period, and the operation of electric supply substations are identified, and ways to address these concerns to obtain community acceptance and environmental compatibility are documented. On-site generation and telecommunication facilities are not considered.
Keywords: A-weighted sound level, commercial zone, hazardous material, industrial zone, noise, permitting process, residential zone, wetlands

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Introduction

(This introduction is not part of IEEE Std 1127-1998, IEEE Guide for the Design, Construction, and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility.)

This guide was revised by members of Working Group G2—Design and Location of Substations for Community Acceptance, and is under the sponsorship of the Substations Environmental Subcommittee of the Substations Committee of the IEEE Power Engineering Society.

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CLAUSE PAGE

IEEE Guide for the Design, Construction, and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility

1. Overview

1.1 Scope

This guide identifies significant community acceptance and environmental compatibility items to be considered during the planning and design phases, the construction period, and the operation of electric supply substations, and documents ways to address these concerns to obtain community acceptance and environmental compatibility. On-site generation and telecommunications facilities are not considered.

1.2 Purpose

Approvals for new substations or even expansions of existing facilities can be subjected to extensive review for community acceptance and environmental compatibility. A variety of permits are often required by the governing bodies before construction of a substation may begin. Concerns are being voiced by governmental agencies and community groups in areas not considered necessary heretofore in the permitting process. In some instances, land acquired for substations years in advance of construction is deemed impossible to build on under present expectations and requirements.

This guide has been divided into three major parts with the goal of providing guidance on acceptable practices for

a) Planning and design (Clause 4.);
b) Construction (Clause 6.); and
c) Operation of safe and reliable substations (Clause 7.).

For community acceptance and environmental compatibility, several considerations should be satisfactorily addressed, including the following:

— Noise;
— Site preparation;
— Aesthetics;
— Fire protection;
— Potable water and sewage;
— Hazardous materials;
— Electric and magnetic fields;
— Safety and security.

2. References

This guide shall be used in conjunction with the following publications.

Accredited Standards Committee C2-1997, National Electrical Safety Code® (NESC®) (ANSI).[1]

IEEE Std 80-1986 (Reaff 1991), IEEE Guide for Safety in AC Substation Grounding.[2]

IEEE Std 100-1996 , The IEEE Standard Dictionary of Electrical and Electronics Terms.

IEEE Std 644-1994 , IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines.

IEEE Std 979-1994, IEEE Guide for Substation Fire Protection.

IEEE Std 980-1994 , IEEE Guide for Containment and Control of Oil Spills in Substations.

IEEEP1402/D8 , DRAFT Guide for Electric Power Substation Physical and Electronic Security, dated April 1997.[3]

IEEE Std C37.123-1996 , IEEE Guide to Specifications for Gas-Insulated, Electric Power Substation Equipment.

3. Definitions

Definitions of terms pertinent to the subject matter are listed here. Definitions as given herein apply specifically to the application of this guide. For additional definitions, see IEEE Std 100-1996 .

3.1 A-weighted sound level: The representation of the sound pressure level that has as much as 40 dB of the sound below 100 Hz and a similar amount above 10 000 Hz filtered out. This level best approximates the response of the average young ear when listening to most ordinary, everyday sounds. Generally designated as dBA.

3.2 commercial zone: A zone that includes offices, shops, hotels, motels, service establishments, or other retail/ commercial facilities as defined by local ordinances.

[1]The NESC is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.
[2]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.
[3]This IEEE standards project was not approved by the IEEE Standards Board at the time this publication went to press. For information about obtaining a draft, contact the IEEE.

3.3 hazardous material: Any material that has been so designated by governmental agencies or adversely impacts human health or the environment.

3.4 industrial zone: A zone that includes manufacturing plants where fabrication or original manufacturing is done, as defined by local ordinances.

3.5 noise: Undesirable sound emissions or undesirable electromagnetic signals/emissions.

3.6 residential zone: A zone that includes single-family and multi-family residential units, as defined by local ordinances.

3.7 wetlands: Any land that has been so designated by governmental agencies. Characteristically, such land contains vegetation associated with saturated types of soil.

4. Planning strategies and design

A project to successfully design, construct, and operate a substation begins with proper planning. The substation's location and proximity to wetlands, other sensitive areas, and contaminated soils; its aesthetic impact; and the concerns of nearby residents over noise and electric and magnetic fields (EMF) can significantly impact the ability to achieve community acceptance and environmental compatibility. Public perceptions and attitudes toward both real and perceived issues can affect the ability to obtain all necessary approvals and permits.

These issues can be addressed through presentations to the governmental officials and the public. Deciding on the location of the site and where to place equipment on that site, inspections of the proposed site for potential environmental problems, and measurement of ambient noise and EMF levels are some of the steps that can be initiated early in the project. Failure to obtain community acceptance can delay the schedule or, in the extreme, stop a project completely.

4.1 Site location, selection, and preparation

4.1.1 Site location and selection

The station location (especially for new substations) has increasingly become a key factor in determining the success of any substation project. Initially, the site location will be selected based on developing electrical loads, the proximity of nearby electric transmission and distribution lines, costs, accessibility, and consultation with governmental agencies. In recent years, a number of major projects have been delayed or blocked by public opposition. In some instances, substations have been built but never used.

The final site location may ultimately depend upon the ability of the user to successfully satisfy the public and resolve potential community acceptance and environmental compatibility concerns. If the user determines it is prudent to involve the public in the decision-making process of site selection, a proactive public involvement program should be developed and implemented. The best site location, and placement of the substation on that site are influenced by several factors, including but not limited to the following:

a) Community attitudes and perceptions;
b) Location of nearby wetlands or bodies of water or environmentally sensitive areas;
c) Site contamination (obvious or hidden);
d) Commercial, industrial, and residential neighbors, including airports;
e) Permit requirements and ordinances;
f) Substation layout (including future expansions) and placement of noise sources;
g) Levels of electric and magnetic fields;
h) Availability and site clearing requirements for construction staging;
i) Access to water and sewer;

j) Drainage patterns and storm water management;
k) Potential interference with radio, television, and other communication installations;
l) Disturbance of archaeological, historical, or culturally significant sites;
m) Underground services and geology;
n) Accessibility;
o) Aesthetic and screening considerations.

4.1.1.1 Wetlands

The design of any new substation should protect wetlands and ground water from sedimentation runoff, oil spills, and changes in storm water discharge flows. Mapping wetland boundaries and designing a facility that will minimize construction activities within or adjacent to designated wetlands should be a priority. Use of an alternative site where available should be strongly considered, as government agencies may prohibit any disturbance to a designated wetland area. If no alternative exists to utilizing a wetland location, design consideration should be given to preserving and improving surrounding wetlands as a compromise for community acceptance.

A site-development plan is necessary for a substation project that borders wetlands. Such a plan for the site and its immediate surroundings should include the following:

a) Land-use description;
b) Grades and contours;
c) Location of any wetland boundaries and stream-channel encroachment lines;
d) Indication of flood-prone areas and vertical distance or access to ground water;
e) Indication of existing wildlife habitats and migratory patterns.

The plan should describe how site preparation will modify or otherwise impact these areas and what permanent control measures will be employed, including ground water protection.

4.1.1.2 Site contamination

There are many substances that if found on or under a substation site would make the site unusable or require excessive funds to remediate the site before it would be usable. Some of the substances under consideration are as follows:

a) Polychlorinated biphenyls (PCBs);
b) Asbestos;
c) Lead and other heavy metals;
d) Pesticides and herbicides;
e) Radioactive materials;
f) Petrochemicals;
g) Dioxin;
h) Oil.

In addition to the above, any substance that a government agency has determined to be a hazardous material should be considered. Governmental guidelines for the levels of these substances should be used to determine if the substance is present in large enough quantities to be of concern.

As a minimum, all potential sites should be visited by personnel trained to spot potential contamination sources at the site and from nearby areas. Soil samples from a substation site, as well as samples of the materials used in the construction of any existing buildings or structures should be tested before acquiring or developing the site to determine if any substance listed above is present in large enough concentration to require removal. It should be recognized that substantial excavation and soil removal and disposal are normally required due to the installation of foundations for new equipment and structures.

The cost of this removal and disposal should be considered before acquiring or developing the site. If a cleanup is needed, the acquisition of another site should be considered as governmental regulations can hold the current owner or user of a site responsible for cleanup of any contamination present, even if substances were deposited prior to acquisition. If a cleanup is initiated, all applicable governmental guidelines and procedures should be followed.

4.1.1.3 Potable water and sewage

The substation site may need potable water and sewage disposal facilities.

Water may be obtained from municipal or cooperative water utilities or from private wells. The quality of water supplied by municipal or cooperative water utilities is beyond the control of the substation owner. The quality of water from private wells, however, can be controlled by location, depth, and treatment. The limits on contaminants in well water should be in compliance with any applicable governmental agency regulations before the well water is used.

Sewage may be disposed of by municipal services or septic systems, or the site could be routinely serviced by portable toilet facilities, which are often used during construction. Where municipal services are used for either water or sewer service, the requirements of that municipality must be met. The municipality may consider the substation owner as a developer and apply the same requirements for water or sewer main extensions that would be required of a typical developer before service taps can be made.

Septic systems, when used, should meet all applicable local, state, and federal regulations.

4.1.2 Site preparation

4.1.2.1 Grade

The selection of a design elevation for a substation yard should include consideration of environmental factors in addition to construction and cost factors. A lower elevation in relation to surrounding terrain and vegetation may improve concealment. This, however, can significantly increase the impact on construction if the water table is high, if there is a ledge to be excavated and removed, or if there is a flooding potential at the lower elevation. The finished grade of the substation should be designed to minimize flooding and presence of standing water on the substation site. The slope of a substation yard should be designed to lessen erosion and sedimentation potentials and should retard oil-spill containment in the more impermeable soils. A sloped yard or swale will also lessen the extent to which side-sloped or retaining walls are required to provide yard transition to the existing grade. The slope of the substation should not be excessive to allow easy access of vehicle and maintenance equipment required for safe operation and maintenance of facilities.

4.1.2.2 Sediment control

Sedimentation potential is more likely to exist on sites consisting of fine sand or silty soil, and sites that have side slopes. A layer of medium to coarse sand or geotextile fabric beneath a crushed stone surface can minimize this potential within a substation yard area that is long and steeply sloped. For exterior side slopes, the erosion potential increases with both the length and the steepness of the slope. Because slope length decreases as the steepness increases, a common solution for overall economy and minimal environmental impact is to provide the steepest structurally-stable slope, thus minimizing slope length. This is especially the case where existing tree screening is important. Secondary measures to curb slope erosion include the installation of top-slope diversion channels and intermediate benches cut into the slopes. Both of these measures require additional cleared space. A solution that does not take space is the placement of a layer of medium to coarse sand over the finer materials and beneath the top soil. This solution also assists in reducing the amount of moisture that could facilitate the growth of unwanted vegetation.

Many governmental agencies have published erosion and sedimentation-control guidelines that should be followed in substation design.

4.1.2.3 Oil-spill containment and control

IEEE Std 980-1994 provides guidance for the detection, containment, and control of non-PCB insulating-oil spills in substations. Where federal, state, and/or local government regulations exist, the substation design must comply.

4.1.2.4 Access roads

For environmental compatibility, access roads can be designed to be unobtrusive. Width can be limited to one lane except for turnouts at intervals from 60 m to 120 m (200 ft to 400 ft), and widened to two lanes at vertical and horizontal curves with short sight distances. Design shall consider requirements for the installation and removal of the longest piece of equipment including maximum slope and turning radius for the transporting equipment. An equipment removal plan should be prepared for all major equipment in the substation prior to deciding upon appropriate access roads.

Where tree screening is available, horizontal curves can be provided to block the view of the substation from the street. Long access roads have been known to become meeting sites for illegal activities and dumping of solid or hazardous wastes. These activities can be a concern to the nearby residents. The installation of locked gates and fencing or vehicular barriers at access road entrances may be helpful in this situation.

A satisfactory surfacing material is a well graded crushed stone. Roads can be hard paved if

a) Matching the appearance of neighboring entryways is important;
b) Required by local ordinance;
c) On a steep grade subject to erosion;
d) Required for equipment transportation.

Roads should be provided with appropriate surface drainage control.

4.1.2.5 Potable water and sewage

These facilities should be designed using good engineering practices and constructed to avoid freezing. The design should consider local climate and soil conditions and provide systems that will not adversely affect ground water, adjacent land owners, or inhabitants. Care should be taken during the design of the substation to prevent the possibility of hazardous discharges, when present, from entering ground water, drains, or the substation's sewer system. Septic tank design should not interfere with buried ground and power distribution during installation and maintenance.

4.1.3 Storm-water management

Where rapid scour by storm-water flow entering or leaving a substation yard is not a problem, sedimentation-control features of substation design will be adequate by themselves. Where this is a potential problem, site design should, to the extent possible, minimize changes to the natural flow of storm water entering and leaving the site. Open storm-water flows across the substation yard should be avoided. Drainage should be designed to route water runoff from the substation to designated places to avoid flooding of access roads and nearby areas. Storm-water management must conform to governmental agency requirements.

4.1.3.1 Upstream considerations

Most, if not all, communities have flood maps prepared under the auspices of governmental agencies. These maps indicate stream floodways where construction is discouraged or prohibited, and floodway fringes where construction is limited and subject to the approval of some governing agency. If the substation site is outside of these floodway zones, the most frequent source of concern is when the site includes stream control measures for a wetland that must be maintained. Lowering or raising the elevation of this control affects the water level in the wetland. Since the position of the control may, in the future, vary with the quantity of flow, the control must be located, and its position preserved, throughout the entire range of stream flows. A substation yard should not be situated where control would be affected. However, the access road may sometimes be permitted to remain in the general area of the control if it is situated exactly at existing grade, and any stream crossing is made with a bridge. For wetland preservation, such a bridge and its abutments need to be outside of the watercourse during normal flows, but not necessarily outside of the stream's floodway. This same bridge concept can be used to help preserve existing conditions downstream.

4.1.3.2 Downstream considerations

It is often necessary to select those aspects of drainage changes least likely to adversely affect critical downstream activities. The design should hold changes to a minimum at the point of these activities, even at the expense of greater changes for less sensitive areas. The most common problem is the acceleration of runoff due to pipe flow channelization, elimination of natural hills by smooth grading, and hard paving. Corrective flow-retarding measures include providing rough channel bottoms, usually in the form of large angular rocks, lengthening channels and thereby decreasing slopes, and retention basins. Excessive retention will rarely cause a downstream problem except in extremely arid areas where evaporation is significant.

4.1.3.3 General design considerations

Where space permits, open ditch storm-water systems are generally preferable to pipe systems because they are less costly, minimize blockage problems, and usually provide better retardation of runoff. The possibility of oil spills or the contribution of degreasers or solvents should be considered in storm-water system designs. The consequences of not having adequate storm drainage within a working area are usually limited to temporary shallow flooding and ice hazards. Both of these consequences can be mitigated by applying additional crushed stone to problem areas. Underground storage systems may be a cost-effective alternative when space is a concern.

4.2 Aesthetics

It is helpful to develop an aesthetic image of the substation so that it can be accepted by the community. Sites can be selected that fit into the context of present and future community patterns.

Community acceptability of a site is influenced by

a) Concerns about compatibility with present and future land uses;
b) Building styles in the surrounding environment;
c) Landscape of the site terrain;
d) Allowance for buffer zones for effective blending, landscaping, and safety;
e) Site access that harmonizes with the community.

In addition, the site may need to be large enough to accommodate mobile emergency units and future expansions without becoming congested and therefore be perceived as untidy and displeasing.

4.2.1 Visual simulation

Traditionally, site rendering was an artist's sketch, drawing, painting, or photomontage with airbrush retouching, preferably in color, as accurate and realistic as possible. In recent years, these traditional techniques, although still employed, have given way to two- and three-dimensional computer-generated images, photorealism, modeling, and animation to simulate and predict the impact of proposed developments.

This has led to increased accuracy and speed of image generation in the portrayal of new facilities for multiple-viewing (observer) positions, allowing changes to be made early in the decision-making process while avoiding costly alterations that sometimes occur later during construction.

4.2.2 Slide library

A slide library of several hundred slides of aesthetic design choices is available from the IEEE. It is a compilation of landscaping, decorative walls and enclosures, plantings, and site location choices that have been used by various utilities worldwide to ensure community acceptance and environmental compatibility. It is assembled and maintained by Working Group G1 of the Environmental Subcommittee of the IEEE/PES Substations Committee. Various formats (slides, VHS videotape, and CD-ROM) are being investigated as a vehicle for making this library available at a reasonable cost to many users. Contact the IEEE for the latest format.

4.2.3 Landscaping and topography

4.2.3.1 Landscaping

Where buffer space exists on site to provide vegetative concealment of a substation, landscaping, especially as a supplement to natural vegetative screening, is a very effective aesthetic treatment. On a site with little natural screening, plantings can be used in concert with architectural features to complement and soften the visual effect.

Shrubs, hedges, and other small plantings are useful for low coverage, fill-in, and accent. These should be employed informally and with variety. Low-ground cover and grasses are effective on berms and in ditches. When planted on top of berms, the impact of the landscaping plantings can be immediate for screening purposes. Coniferous trees give excellent coverage and color, and can be used in clusters, in hedges, or spaced apart. Size should be sufficient for the screening purpose but not so large as to endanger overhead lines. Species selection should avoid animal or bird attractant types that create a hazard to the function and safety of equipment or personnel.

All plantings should be locally available and compatible types, and should require minimum maintenance. Their location near walls and fences should not compromise either substation grounding or the security against trespass by people or animals.

4.2.3.2 Topography

Topography or land form, whether shaped by nature or by man, can be one of the most useful elements of the site to solve aesthetic and functional site development problems.

The first and foremost consideration is to carefully examine the immediate environment of the substation site to discover natural land forms that can influence how the site itself is molded and landscaped. For example, some sites may have a hillside backdrop that would absorb the skyline view or foreground slopes that influence the primary observation zone. Environmental topography design should consider the effect of screening, horizontal setback, and the background screen on the primary observation zone.

Aesthetically, the land form within the site should reflect or blend with the topography of its environment. The use of land form should be carefully evaluated in combination with plant materials. The careful and sensitive blending of these two important elements can result in a meaningful site development. Trees and shrubs can be less massive and numerous when combined with ground forms of various shapes.

The shape of topography will vary with each situation. The gentle soft forms might be entirely fitting for the wide open countryside, whereas more tailored, sculptured forms might be compatible with an urban setting.

Use of topography as a visual screen is often overlooked. Functionally, earth forms can be permanent, visual screens constructed from normal on-site excavating operations. When combined with plantings of grass, bushes, or evergreens and a planned setback of the substation, berms can effectively shield the substation from nearby roads and residents. Appreciable cost savings can be realized by utilizing cut material spoil on the site for earth forms rather than removing it from the site.

4.2.4 Fences and walls

The National Electrical Safety Code® (NESC®) (Accredited Standards Committee C2-1997) requires that fences, screens, partitions, or walls be employed to keep unauthorized persons away from substation equipment.

4.2.4.1 Chain-link fences

This type of fence is the least vulnerable to graffiti and is generally the lowest-cost option. Chain-link fences can be galvanized or painted in dark colors to minimize their visibility, or they can be obtained with vinyl cladding. They can also be installed with wooden slats or colored plastic strips woven into the fence fabric. Grounding and maintenance considerations should be reviewed before selecting such options.

4.2.4.2 Wood fences

This type of fence should be constructed using naturally rot-resistant or pressure-treated wood, in natural color or stained for durability and appearance. A wood fence can be visually overpowering in some settings. Wood fences should be applied with caution because wood is more susceptible to deterioration than masonry or metal.

4.2.4.3 Walls

Although metal panel and concrete block masonry walls cost considerably more than chain-link and wood fences, they deserve consideration where natural or landscaped screening does not provide a sufficient aesthetic treatment. Each of these options is available in a range of types, shapes, and colors, and can be used in combination for an attractive architectural appearance. Brick and precast concrete can also be used in solid walls, but these materials can be far more expensive. These materials should be considered where necessary for architectural compatibility with neighboring facilities. Walls can be subject to graffiti, and this should be part of the consideration of their use.

4.2.5 Color

When substations are not well screened from the community, coloring should be considered to improve the visual effects.

Above the skyline, the function of color is usually confined to eliminating reflective glare from bright metal surfaces. Because the sun’s direction and the brightness of the background sky vary, no one color can soften the appearance of substation structures in the course of changing daylight.

Below the skyline, color can be used in three aesthetic capacities. Drab coloring, using earth tones and achromatic hues, is a technique that masks the metallic sheen of such objects as chain-link fences and steel structures, and reduces visual contrast with the surrounding landscape. Such coloring should have very limited variation in hues, but contrast by varying paint saturation is often more effective than a monotone coating. Colors and screening can often be used synergistically. A second technique is to use color to direct visual attention to more aesthetically pleasing items, such as decorative walls and enclosures. In this use, some brightness is warranted, but highly saturated or contrasting hues should be avoided. A third technique is to brightly color equipment and structures for intense visual impact.

4.2.6 Lighting

When attractive landscaping, decorative fences, enclosures, and colors have been used to enhance the appearance of a highly visible substation, it may also be appropriate to use lighting to highlight some of these features at night. Lighting of such exterior features may be accomplished with ornamental lighting, garden lighting, floodlights, or architectural lighting. Generally, such lighting is more appropriate for larger substations in commercial-industrial areas. In a residential area, lighting that differs from the lighting used on neighboring residential properties or unnecessarily focuses attention on the substation is likely to be unwelcome. Although all-night lighting can enhance substation security and access at night, it should be applied with due concern for nearby residences.

4.2.7 Structures

The importance of aesthetic structure design increases for structures that extend into the skyline. The skyline profile typically ranges from 6 m to 10 m (20 ft to 35 ft) above ground. Transmission line termination structures are usually the tallest and most obvious. Use of underground line exits will have the greatest impact on the substation's skyline profile. Where underground exits are not feasible, low-profile station designs should be considered. The visual impact of the structures is reduced if a low-profile design is used. Often the substation with low-profile structures can be brought below the nearby tree line profile.

For additional cost, the most efficient structure design can be modified to improve its appearance. The following design ideas may be used to improve the appearance of structures:

a) Tubular construction;
b) Climbing devices not visible in profile;
c) No splices in the skyline zone;
d) Limiting member aspect ratio for slimmer appearance;
e) Use splices other than pipe-flange type;
f) Use of gusset plates with right angle corners not visible in profile;
g) Tapering ends of cantilevers;
h) Equal length of truss panel;
i) Making truss diagonals with an approximate 60° angle to chords;
j) Use of short knee braces or moment-resistant connections instead of full-height diagonal braces;
k) Use of lap splice plates only on the insides of H-section flanges.

4.2.8 Enclosures

Total enclosure of a substation, within a building that may serve other non-utility needs, is an option in urban settings where underground cables are used as supply and feeder lines. Enclosure by high walls, however, may be preferred if enclosure-type concealment is necessary for community acceptance.

A less costly design alternative in non-urban locales that are served by overhead power lines is to take advantage of equipment enclosures to modify visual impacts. Relay and control equipment, station batteries, and indoor power switchgear all require enclosures. These enclosures can be aesthetically designed and strategically located to supplement landscape concealment of other substation equipment. The exterior appearance of these enclosures can also be designed (size, color, materials, shape) to match neighboring homes or buildings.

Industrial-type, pre-engineered metal enclosures are a versatile and economic choice for substation equipment enclosures. Concrete block construction is also a common choice, for which special shaped and colored blocks may be selected to achieve a desired architectural effect. Brick, architectural metal panels, and precast concrete can also be used.

Substation equipment enclosures usually are not exempt from local building codes. Community acceptance, therefore, requires enclosure design, approval, and inspection in accordance with local regulation.

4.2.9 Bus design

Substations can be constructed partly or entirely within aboveground or belowground enclosures. However, cost is high and complexity is increased by fire-protection and heat-removal needs. Bus design for such facilities is not a community aesthetic concern, so this subclause is limited to exposed aboveground substations.

4.2.9.1 Air-insulated substations

The bus and associated substation equipment are exposed and directly visible. An outdoor bus may be multi-tiered or spread out at one level. Metal or wood structures and insulators support such bus and power line terminations. Space permitting, a low-profile bus layout is generally best for aesthetics and is the easiest to conceal with landscaping, walls, and enclosures. Overhead transmission line terminating structures are taller and more difficult to conceal in such a layout. In dry climates, a low-profile bus can be achieved by excavating the earth area, within which outdoor bus facilities are then located, for an even lower profile.

4.2.9.2 Switchgear

Metal-enclosed or metal-clad switchgear designs that employ either air or other insulation systems house the bus and associated equipment in a metal enclosure are an alternative design for distribution voltages. These designs provide a compact low-profile installation that may be aesthetically acceptable.

4.2.9.3 Gas-insulated substations (GIS)

Bus and associated equipment can be housed within pipe-type enclosures using sulphur hexafluoride or another similar gas for insulation. Not only can this achieve considerable compactness and reduced site preparation for higher voltages, but it can also be installed lower to the ground. A GIS can be an economically attractive design where space is at a premium, especially if a building-type enclosure will be used to house substation equipment (see IEEE Std C37.123-1996).

4.2.9.4 Cable bus

Short sections of overhead or underground cables can be used at substations, although this use is normally limited to distribution voltages (e.g., for feeder getaways or transformer-to-switchgear connections). At higher voltages, underground cable can be used for line-entries or to resolve a specific connection problem.

4.3 Noise

Audible noise, particularly continuously radiated discrete tones (e.g., from power transformers), is the type of noise that the community may find unacceptable. Community guidelines to ensure that acceptable noise levels are maintained can take the form of governmental regulations or individual/community reaction (permit denial, threat of complaint to utility regulators, etc.). Where noise is a potential concern, field measurements of the area ambient noise levels, and computer simulations predicting the impact of the substation may be required. The cost implications of the mitigation methods (low-noise equipment, barriers or walls, noise cancellation techniques, etc.) may become a significant factor when a site is selected.

Noise can be transmitted as a pressure wave either through the air or through solids. The majority of cases involving the observation and measurement of noise have dealt with noise being propagated through the air. However, there are reported cases of audible transformer noise appearing at distant observation points by propagating through the transformer foundation and underground solid rock formations. Since the occurrence of this is rare, there is no technical analysis or empirical data available to predict the likelihood of occurrence. It is best to avoid the situation by isolating the foundation from bedrock where the conditions are thought to favor transmission of vibrations.

4.3.1 Noise sources

4.3.1.1 Continuous audible sources

The most noticeable audible noise generated by normal substation operation consists of continuously radiated audible discrete tones. Noise of this type is generated primarily by power transformers. Regulating transformers, reactors, and emergency generators, however, could also be sources. This noise is the type most likely to be subject to governmental regulation. Another source of audible noise in substations, in particular extra high voltage (EHV) substations, is corona from the bus and conductors.

4.3.1.2 Continuous radio frequency (RF) sources

Another type of continuously radiated noise that can be generated during normal operation is RF noise. These emissions can be broadband and can cause interference to radio and television signal reception on properties adjacent to the substation site. Objectionable RF noise is generally a product of unintended sparking, but can also be produced by corona.

4.3.1.3 Impulse sources

While continuously radiated noise is generally the most noticeable to substation neighbors, significant values of impulse noise can also accompany normal operation. Switching operations will cause both impulse audible and RF noise with the magnitude varying with voltage, load, and operation speed. Circuit-breaker operations will cause audible noise, particularly operation of air-blast breakers.

4.3.2 Typical noise levels

4.3.2.1 Equipment noise levels

Equipment noise levels may be obtained from manufacturers, equipment tendering documents, or test results.

Transformer noise will “transmit” and attenuate at different rates depending on the transformer size, voltage rating, and design. Few complaints from nearby residents are typically received concerning substations with transformers of less than 10 MVA capacity, except in urban areas with little or no buffers. Complaints are more common at substations with transformer sizes of 20–150 MVA, especially within the first 170–200 m (500–600 ft). However, in very quiet rural areas where the nighttime ambient can reach 20–25 dBA, the noise from the transformers of this size can be audible at distances of 305 m (1000 ft) or more. In urban areas, substations at 345 kV and above often have not resulted in many complaints because of the large parcels of land on which they are usually constructed.

4.3.2.2 Ambient noise levels

The degree of annoyance with continuous audible noise is dependent in a large part upon the relative level of the ambient noise. The human ear will normally only notice the dominant of several noises.

Sources of ambient noise in the community include vehicular or railway traffic, factories, aircraft, animals, and appliances such as attic fans, air conditioners, and lawn mowers. If ambient noise is very low, even a small amount of wind can override the other noise sources and become the dominant ambient noise.

The human ear distinguishes a particular sound source and establishes whether it is objectionable or not by comparing it to the general background or ambient noise to which it has become accustomed. Ambient noise is generally a broadband noise that covers a large range of frequencies, with no pronounced or outstanding tones. The addition of another broadband noise source, such as a fan, would not likely be distinguishable by the human ear. Car horns, gun shots, and transformer noise, being more or less of a pure tone, can readily be distinguished by the human ear if loud enough.

Common outdoor noise levels are shown in Table 1.

Table 1— Common outdoor noise levels

Type	Noise level (dBA)
Jet flyover at 305 m (1000 ft)	110
Gasoline lawn mower at 0.9 m (3 ft)	100
Diesel truck at 15 m (50 ft)	90
Noisy urban daytime	80
Gasoline lawn mower at 30.5 m (100 ft)	70
Commercial area heavy traffic at 90 m (300 ft)	60
Quiet urban daytime	50
Quiet urban nighttime	40
Quiet suburban nighttime	30
Quiet rural nighttime	20
Threshold of hearing	10
Source: Fundamental and Abatement of Highway Traffic Noise. By permission of BBN Corporation.	

Highway traffic can provide a base ambient noise that can help to shield substation noise. While it is easy to measure traffic noises near the highway, it becomes increasingly difficult to measure them at distances of 1.5–3 km (1–2 mi). A substation could benefit from the shielding effect of highway noise if it is located less than 3 km (2 mi) from a highway.

4.3.2.3 Attenuation of noise with distance

The rate of attenuation of noise varies with distance for different types of sound sources depending on their characteristics. Point sound sources that radiate equally in all directions will decrease at a rate of 6 dB for each doubling of distance. Cylindrical sources vibrating uniformly in a radial direction will act like long source lines and the sound pressure will drop 3 dB for each doubling of distance. Flat planar surfaces will produce a sound wave with all parts of the wave tracking in the same direction (zero divergence). Hence, there will be no decay of the pressure level due to distance only. To determine the effect distance will have requires the designer to first identify the characteristics of the source before proceeding with the design.

A transformer will exhibit combinations of all of the above sound sources depending on the distance and location of the observation point. Because of its height and width, which can be one or more wavelengths, and its nonuniform configuration, the sound pressure waves will have directional characteristics with very complex patterns. Close to the transformer (near field), these vibrations will result in lobes with variable pressure levels. Hence the attenuation of the noise level will be very small. If the width (W) and height (H) of the transformer are known then the near field is defined, from observation, as any distance less than $2\sqrt{WH}$ from the transformer.

Further from the transformer (far field), the noise will attenuate in a manner similar to the noise emitted from a point source. The attenuation is approximately equal to 6 dB for every doubling of the distance. It never becomes a true point source since it retains some directional planar and cylindrical wave characteristics. Consequently, the noise level will still vary with direction (i.e., full side view versus an edge view) even if distance remains constant. Studies have shown that the sound pressure in a given direction can deviate as much as 4 dB above or below the average noise level. The deviation will occur over less than 10% of the circumference of the transformer. For overexcited transformers, the noise at the tank and hence any observation point can be significantly higher than the noise level at rated voltage.

For far field effect, an equation has been developed to represent the attenuation of sound for transformers as a function of the height and width of the main transformer tank. Since height and width are generally proportional to the transformer voltage and capacity ratings, the equation has been further modified to relate attenuation to these transformer ratings. Both equations can be readily plotted graphically for comparison to ambient noise levels.

$$N = -4.4 + dBT - 20\ \log\frac{D}{\sqrt{WH}} \tag{1}$$

or

$$N = 4.1 + dBT + 2.08\ \log[(\mathrm{kV})(\mathrm{kVA})] - 20\ \log D \tag{2}$$

In both cases, far field is defined as

$$D > 2\sqrt{WH}$$

where

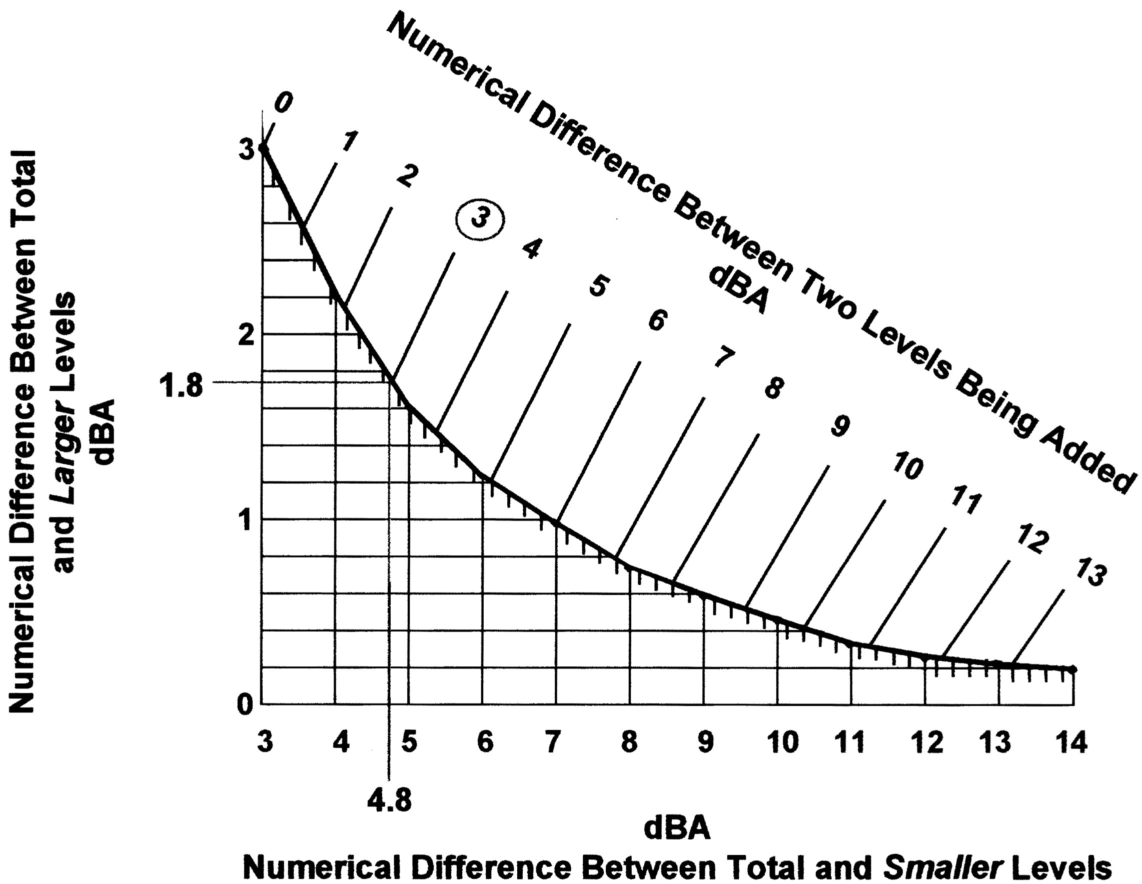
N	is	noise (dBA) at a point distance *D* from the transformer;
dBT	is	specified noise level at the transformer (dBA);
kVA	is	transformer size (self-cooled rating);
kV	is	high-voltage winding (phase-to-phase);
W	is	width of main tank (ft);
H	is	height of main tank (ft);
D	is	distance from the transformer to the point of interest (ft).

If *W*, *H*, and *D* are expressed in meters, the first equation remains unchanged as it is dimensionless. The second equation becomes:

$$N = -6.2 + dBT + 2.08\ \log[(\mathrm{kV})(\mathrm{kVA})] - 20\ \log D(m) \tag{3}$$

With respect to more than one transformer, the contribution of each source at the point of observation should be calculated separately. The value of each is combined as the logarithmic sum of the two. Figure 1 may be used to approximate this logarithmic sum. If a transformer has a fan array, the noise contribution of the fans can be calculated using the same equation where *W* and *H* are the fan array dimensions. A designer should determine the need to add design margin to the layout of a new station if transformer noise will be a concern.

For a distance less than $2\sqrt{WH}$, these equations will not apply as the sound pressure attenuation is influenced by factors other than logarithmic reduction.



Example: one transformer dBA = 78; the other transformer dBA = 75
Therefore: 78 - 75 = 3 Numerical difference between transformers = 3, on curve.
Difference between *Larger* and total, from the curve = 1.8; Total = 78 + 1.8 = 79.8
Difference between *Smaller* and total, from the curve = 4.8; Total = 75 + 4.8 = 79.8

Figure 1— Nomograph for determining combination sound levels

4.3.3 Governmental regulations

Governmental regulations may impose absolute limits on emissions, usually varying the limits with the zoning of the adjacent properties. Such limits are often enacted by cities, villages, and other incorporated urban areas where limited buffer zones often exist between property owners. Typical noise limits at the substation property line used within the industry are as follows:

— Industrial zone < 75 dBA
— Commercial zone < 65 dBA
— Residential zone < 55 dBA

Additional governmental noise regulations address noise levels by limiting the increase above the existing ambient to less than 10 dB. Other regulations could limit prominent discrete tones, or set specific limits by octave bands.

4.3.4 Noise abatement methods

It is beyond the scope of this guide to make recommendations as to which method of noise abatement is best suited for specific applications due to the wide range of cost implications and site variables that can exist. However, as an aid to those engaged in the design of noise abatement systems, several examples of various types that have been used successfully are described in 4.3.4.1 through 4.3.4.8.

The likelihood of a noise complaint is dependent on several factors, mostly related to human perceptions. As a result, the preferred noise abatement method is time dependent as well as site specific. Placement of the substation in an isolated area with few neighbors may be initially successful. However, development of the area during the life of the substation could result in additional neighbors. In general, the existence of a substation prior to the arrival of new neighbors may not prevent a noise complaint. On the other hand, increased development will probably bring with it an associated increase in the background ambient, which may help to reduce the likelihood of a complaint.

In addition, the concept of change is important. When a new substation is built in a previously quiet residential or rural area, the transformer noise will represent a noticeable change, with an increased likelihood of being perceived as being an annoyance. Given enough time, its effect will become less noticeable. People may become accustomed to continuous background noise such as airplanes landing and taking off from nearby airports, and effectively tune out the background noise. A similar psychological reaction to transformer noise can occur, which is one reason the addition of a second transformer at an existing station may not generate community reaction to the increased noise.

If a second adjacent transformer produces an identical noise level to the existing transformer (e.g., 75 dBA), the total sound will be 78 dBA for a net increase of only 3 dB. This is due to the logarithmic effect associated with a combination of noise sources. The graph shown in Figure 1 can be used to determine the resultant noise level of two noise sources. Most people cannot perceive changes in noise levels of 3 dB or less.

4.3.4.1 Reduced transformer sound levels

Since power transformers, voltage regulators, and reactors are the primary sources of continuously radiated discrete tones in a substation, careful attention to equipment design can have a significant effect on controlling noise emissions at the substation property line. This equipment can be specified with noise emissions below manufacturer's standard levels, with values as much as 10 dB below those levels being typical.

In severely restrictive cases, transformers can be specified with noise emissions 20 dB less than the manufacturers' standard levels, but usually at a significant increase in cost. Also, inclusion of bid evaluation factor(s) for reduced losses in the specification can impact the noise level of the transformer. Low-loss transformers are generally quieter than standard designs.

4.3.4.2 Low-impulse noise equipment

Outdoor-type switching equipment is the cause of most impulse noise. Switchgear construction and the use of vacuum or puffer circuit breakers, where possible, are the most effective means of controlling impulse emissions. The use of circuit switchers or air-break switches with whips and/or vacuum bottles, for transformer and line switching, may also provide impulse-emission reductions over standard air-break switches.

4.3.4.3 RF noise and corona-induced audible noise control

Continuously radiated RF noise and corona-induced audible noise can be controlled by the use of corona-free hardware and shielding for high-voltage conductors and equipment connections, and attention to conductor shapes to avoid sharp corners. Angle and bar conductors have been used successfully up to 138 kV without objectionable corona if corners are rounded at the ends of the conductors and bolts are kept as short as possible.

Tubular shapes are typically required above this voltage. Pronounced edges, extended bolts, and abrupt ends on the conductors can cause significant RF noise to be radiated. The diameter of the conductor also has an effect on the generation of corona, particularly in wet weather when water droplets disturb the smooth surface of conductors. Increasing the size of single grading rings or conductor diameter may not necessarily solve the problem. In some cases it may be better to use multiple, smaller diameter, grading rings.

4.3.4.4 Site location

For new substations to be placed in an area known to be sensitive to noise levels, proper choice of the site location can be effective as a noise abatement strategy. Obviously, a location isolated from all neighbors will minimize the likelihood of a noise complaint. Where this is not possible, the advantage of sites in high ambient noise level areas should be considered. Locations in industrial parks or near airports, expressways, or commercial zones can provide almost continuous ambient noise levels of 50 dB or higher, minimizing the likelihood of a complaint. Placement of substations near backdrop hills may redirect the radiant sound as might substations set below grade and surrounded by berms.

4.3.4.5 Larger yard area

Noise intensity varies inversely with distance. An effective strategy for controlling noise of all types involves increasing the size of the parcel of real estate on which to locate the substation.

4.3.4.6 Equipment placement

Within a given yard size, the effect of noise sources on the surroundings can be mitigated by careful siting of the noise sources within the confines of the substation property. In addition, making provisions for the installation of mobile transformers, emergency generators, etc., near the center of the property, rather than at the edges, will lessen the effect on the neighbors.

4.3.4.7 Barriers or walls

If adequate space is not available to dissipate the noise energy before reaching the property line, structural elements might be required. These can consist of walls, sound-absorbing panels, or deflectors. In addition, earth berms or below-grade installation may be effective. It may be possible to deflect audible noises, especially the continuously radiated tones most noticeable to the public, to areas not expected to be troublesome. Foliage, in spite of the potential aesthetic benefit and psychological effect, is not particularly effective for noise reduction purposes.

Properly constructed sound barriers can provide several decibels of reduction in the noise level. An effective barrier involves a proper application of the basic physics of

a) Transmission loss through masses;
b) Sound diffraction around obstacles;
c) Standing waves behind reflectors; and
d) Absorption at surfaces.

In general, materials with a high mass have a good transmission loss. As a general rule, it can be said that if a barrier of sufficient height to shield the noise is constructed of a material that can support itself and resist the wind load imposed upon it simultaneously, it will meet the transmission loss requirements. Due to the sound diffraction around the barrier, materials and transmission losses greater than 25 dB will not affect the new attenuation produced by the wall at large distances.

The height of the wall is determined primarily by the diffraction of sound around the wall. A significant reduction in sound is obtained when the barrier extends approximately one wave length [about 3.0 m (9.5 ft) at 120 Hz] above, as well as beyond the line of sight from the transformer center to the listener. Where a specific decibel reduction is desired or known, a more precise determination of the height and length of walls necessary to alleviate the noise problem can be made. The formula for calculating the necessary height and length of the walls is based on the Fresnel theory of the diffraction of a point source of light over a knife edge. Wells and Fehr converted the Fresnel formula to express it in terms of sound waves rather than light waves. In turn, sound engineers have transformed the Wells-Fehr theorem into the formula below.

$$dB_{120\ \mathrm{Hz}} = 9.5\ \log[\sqrt{R^2 + h^2} - R] + 3.8 \quad (4)$$

(For 240 Hz, add 2.8 to result of 120 Hz calculation; for 360 Hz, add 4.5 to result of 120 Hz calculation.)

where

R is the distance (ft) from the geometric center of the transformer tank to the inside surface of the wall;
h is both the height of the wall above the line drawn from the observer to the geometric center, and the horizontal length of the wall in both directions from a point opposite to the geometric center at distance *R*.

With known values for *R* and the decibel reduction desired, a specific value of *h* can be calculated.

If *R* and *h* are expressed in meters, the above formula becomes

$$dB_{120\ \mathrm{Hz}} = 9.5\ \log[\sqrt{R^2 + h^2} - R] + 8.7 \quad (5)$$

(For 240 Hz, add 7.7 to result of 120 Hz calculation; for 360 Hz, add 9.4 to result of 120 Hz calculation.)

Whenever sound is reflected by a wall, the original wave and its reflection combine to form standing waves. In order to limit the increased sound level that can result from these standing waves, the wall should be placed at odd multiples of a quarter wavelength of the 120 Hz sound being attenuated away from the transformer tank wall. Wall placements at multiples of a half wavelength should be avoided. In addition to selecting the proper spacing to eliminate standing waves, it is necessary to absorb the sound at the inner surface of the barrier to obtain the best results. Tests have shown that even with proper wall spacing, a hard surfaced wall can result in a noise increase of 1–3 dB. Specially designed sound absorbing masonry blocks with cavities resonant at 120 Hz can also be effective.

If it is desired to control the sound in one direction, a two- or three-sided barrier can be used. Model tests have shown that predictable attenuation can be obtained over a 90° sector (see Figure 2). Outside the 90° sector, attenuation is somewhat lower, and the noise radiated to the unshielded regions can increase. Two- or three-sided barriers can be used when there is little chance of a complaint coming from the open side of the barrier. The location of nearby control houses and other large surfaces should also be noted as they can act as a reflective surface and increase the sound level in the opposite direction. Four-sided barriers can be used with predictable results only if the inside surfaces are lined with a good absorbing material to prevent multiple reflections. If greater attenuation is required, a partial roof can be constructed. As the barrier becomes more complete, however, transformer cooling can become a problem. This may make it necessary to derate or modify the transformer to add more fans, or admit air through the bottom of the wall through sound-absorbing ducts. Another alternative for forced oil and air (FOA) transformers is to mount coolers with low-noise fans outside the sound enclosure using extended piping and vibration isolators.

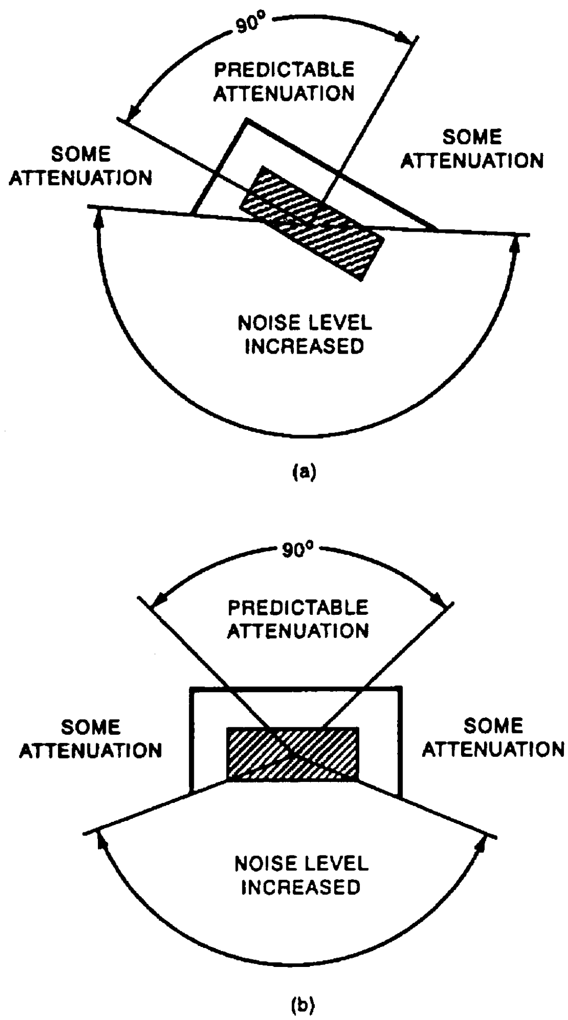


Figure 2— Regions of sound attenuation and sound increase around (a) L-shaped barrier (two-sided) and (b) U-shaped barrier (three-sided)

4.3.4.8 Active noise cancellation techniques

Another solution to the problem of transformer noise involves use of active noise control technology to cancel unwanted noise at the source, and is based on advances in digital controller computer technology. Active noise cancellation systems can be tuned to specific problem frequencies or bands of frequencies achieving noise reduction of up to 20 dB.

4.3.5 Community acceptance

The noise level at which transformers become an annoyance is not necessarily dependent upon the level of the transformer noise but may depend upon the differential between ambient and added noise. If the transformer can be heard, it can be an annoyance. Information from the noise profile study may be used for a presentation to obtain community acceptance.

Noise attenuation with distance is logarithmic, and even where large buffer zones exist, the noise levels from larger transformers can exceed 25–30 dBA at 300 m (1000 ft) or more. In quiet rural areas, and some suburban areas, low nighttime ambient sound levels of 30 dBA or less are possible. The higher background ambient noise levels resulting from high traffic volume, business and industrial activity, and the normal household activities such as children playing, dogs barking, lawn mowing, etc., will be missing during the evening and nighttime hours. On warm summer nights, nearby residents can find the transformer noise level to be annoying (for sleeping with open windows, sitting outside, etc.). As a result, sound levels well below the ones imposed by governmental regulations may have to be considered to lessen complaints.

Objections to substation noise levels below those set by governmental regulations can also occur in urban areas. However, the benefit resulting from higher ambient background levels of 35–45 dBA or more (nighttime) can be offset by the closer proximity of nearby residents [in some cases less that 30 m (100 ft)]. Community acceptance of noise levels may not always have a technical basis. Residents who are annoyed simply by the presence of the substation may find perceived excessive noise levels to be a tangible factor upon which to base a complaint.

4.4 Electric and magnetic fields

Electric substations produce electric and magnetic fields. 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 or directly measured. Governmental regulations concerning levels may exist, and where they do, the substation design must comply.

In a substation, the strongest fields around the perimeter fence come from the transmission and distribution lines entering and leaving the substation. The strength of fields from equipment inside the fence decreases rapidly with distance, reaching very low levels at relatively short distances beyond substation fences.

There has been substantial interest by the public and the scientific community in the question of whether the exposure to these fields involves a risk to humans or the environment. Worldwide, the many epidemiological, engineering, and biological studies of the effects and risks of EMF on people have been inconclusive in their results and for many the questions on the health risks remain unanswered.

In response to the public concerns with respect to EMF levels, whether perceived or real, and to governmental regulations, the substation designer may consider design measures to lower EMF levels or public exposure to fields while maintaining safe and reliable electric service.

4.4.1 Electric and magnetic field sources in a substation

Typical sources of electric and magnetic fields in substations include the following:

a) Transmission and distribution lines entering and exiting the substation;
b) Buswork;
c) Transformers;
d) Air core reactors;
e) Switchgear and cabling;
f) Line traps;
g) Circuit breakers;
h) Ground grid;
i) Capacitors;
j) Battery chargers;
k) Computers.

4.4.2 Electric fields

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

In substations, the electric field is extremely variable due to the screening effect provided by the presence of the grounded steel structures used for electric bus and equipment support.

Although the level of the electric fields could reach magnitudes of approximately 13 kV/m in the immediate vicinity of high-voltage apparatus, such as near 500 kV circuit breakers, the level of the electric field decreases significantly toward the fence line. At the fence line, which is at least 6.4 m (21 ft) from the nearest live 500 kV conductor (reference the NESC), the level of the electric field approaches zero kV/m. If the incoming or outgoing lines are underground, the level of the electric field at the point of crossing the fence is negligible. Since the scope of this guide is community acceptance, this guide does not cover occupational guidelines.

4.4.2.1 Governmental regulations

For the US and Canada, there are no governmental standards specifically for 60 Hz electric fields in substations (at the property line). The standards and guidelines that do exist are applicable to transmission line electric field levels, as shown in Table 2.

Table 2— Transmission line electric field standards

Location	Electric field		
	On right-of-way (kV/m)		Edge of right-of-way (kV/m)
Florida	8 10	(for lines of 69—230 kV) (for 500 kV lines)	2 —
Minnesota	8		—
Montana	7	(maximum for highway crossings)	1
New Jersey	—		3
New York	11.8 11 7	 (maximum for private road crossings) (maximum for highway crossings)	1.6 — —
Oregon	9		—
Canada	7 10	(maximum for highway crossings)	3 —

4.4.2.2 Reduction methods

Reduction techniques that may be available to the substation designers are as follows:

a) *Increase the height of the buses.* If the height of buses doubles, the level of electric field directly underneath the bus decreases by more than 50%; however, this may cause only a negligible decrease of the electric field strength at the substation property line.
b) *Decrease the phase spacing and bus diameter.* Theoretically, a decrease of 50% of either phase spacing or bus diameter could cause a reduction in the electric field level by approximately 10%. Allowable phase spacing reduction may be limited by other factors such as electrical clearances and short-circuit forces. Some phasing arrangement on parallel circuits, such as ABC on one circuit and CBA on the other circuit, will result in increasing the field level because the fields of the adjacent C phases add together.
c) *Lower operating system voltage.*
d) *Optimize substation layout.* The presence of nearby buses, either grounded or at lower voltages, acts as a shield and reduces the electric field in the immediate area.
e) *Use natural shielding.* Trees, and other vegetation along the property line may reduce the electric field level there.

4.4.2.3 Community acceptance

Community acceptance of a project's electric field levels can be improved by open, direct, and honest communication of the electric field design to the affected public. By clearly and plainly demonstrating the definition and design levels of electric fields, an informed consensus can be reached.

4.4.3 Magnetic fields

Magnetic fields are present whenever current flows in a conductor, and are not voltage dependent. The level of these fields also decreases with distance from the source but these fields are not easily shielded. Unlike electric fields, conducting materials such as the earth, or most metals, have little shielding effect on magnetic fields.

Magnetic fields are measured in Webers per square meter (Tesla) or Maxwells per square centimeter (Gauss). One Gauss = 10^{-4} Tesla. The most common unit for this application is milliGauss (10^{-3} Gauss).

Various factors affect the levels of the fields, including the following:

a) Current magnitude;
b) Phase spacing;
c) Bus height;
d) Phase configurations;
e) Distance from the source;
f) Phase unbalance (magnitude and angle).

Magnetic fields decrease with increasing distance (r) from the source. The rate is an inverse function and is dependent on the type of source. For point sources such as motors and reactors, the function is $1/r^3$; for three-phase, balanced conductors the function is $1/r^2$; and for single-phase sources such as neutral or ground conductors the function is $1/r$. Besides distance, conductor spacing and phase balance have the largest effect on the magnetic field level because they control the rate at which the field changes.

Magnetic fields can sometimes be shielded by specially engineered enclosures. 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.

4.4.3.1 Magnetic field measurements

Measurements can be made using a commercially available, three-axis recording magnetic field meter. Measurements should be made as a minimum at the property line. Additional measurements could be taken at appropriate locations such as the substation fence line. The two basic measurement types are as follows:

- *Snapshot.* Survey of magnetic field levels made at one instant in time;
- *Timed.* Snapshots made over a daily or weekly load cycle.

Measurements should be made to establish ambient levels at new sites, determine baseline levels at existing sites, or to verify calculated values. Results can be presented as follows:

a) Line graphs showing magnetic field levels versus linear distance along fence or property lines. Sources of peak field levels should be identified where possible. These are usually due to overhead and/or underground power lines into or out of the substation.
b) Contour plots showing magnetic field levels as contour lines on a site plan. The location of major site facilities such as buses, transformers, control house, fence, roads, and overhead and/or underground lines should be shown.
c) Three-dimensional plot of magnetic field levels on a site plan.

4.4.3.2 Magnetic field calculation methods

Should it be necessary to calculate the field levels within the station, it should be recognized that this could be complex and it is recommended that commercially available computer programs be used. Several computer programs are available that utilize a simplified representation of the substation to model and vary the magnetic field levels in and around a substation. The model typically includes the high-voltage buses and conductors and the last one or two spans of the transmission and distribution lines into or out of the substation. It is important to accurately model the phase relationship of the substation conductors and the lines. It is recognized that the relative position of the phase conductors may not be known when all three conductors are installed in a common duct. The phase arrangement assumed in this circumstance shall be chosen by analyzing many possible combinations of conductors in the duct bank and selecting one that results in magnetic field levels greater than the median field levels of the combinations evaluated.

The following are some common assumptions that could be considered; however, actual conditions may change the results:

a) Loads include peak loads or transformer nameplate loads.
b) Transmission and distribution circuits have balanced loads. Neutral and ground currents are usually not considered.
c) Substation is in its normal operating state with regard to breaker and switch positions and equipment in service.
d) Equipment such as high-voltage circuit breakers, switches, transformers, switchgear, control cables, and low-voltage power cables are typically not modeled.

In evaluating the results, modifications should be considered when the substation designer has specific regulation criteria or governmental guidelines for magnetic field reduction. Some utilities have been directed by government agencies to take EMF reduction steps on transmission, substation, and distribution facilities to reduce exposure to magnetic fields. This criteria is generally intended to be applied to new construction where design changes can be made with little or no increase in the cost of the substation.

4.4.3.3 Governmental regulation

In the US and Canada, there are no governmental regulations specifically for power frequency magnetic fields in substations. The states of Florida and New York have set magnetic field level limits; these limits are applicable only to transmission lines at the edge of right-of-ways, as shown in Table 3.

Table 3— Transmission line magnetic field limits

State	Magnetic field for edge of right-of-way (mG) (maximum load)
Florida	150 (for lines of 69–230 kV) 200 (for 500 kV lines) 250 (for 500 kV lines on certain existing right-of-ways)
New York	200

These limits are designed to maintain the status quo by limiting fields to existing maximum levels produced under maximum continuous-load-carrying conditions. There is no scientific basis to set limits based on health concerns.

Magnetic field levels at substations are typically much lower at the substation fence than those shown in Table 3. The highest magnetic field levels will most often be found directly underneath the overhead lines or above the underground lines entering or exiting the substations. The magnetic field levels produced by the substation itself are lower because of the buffer zone present between the substation equipment and the fence line.

4.4.3.4 Reduction methods

Reduction techniques that may be available to the substation designer include the following:

a) Increase the distance from the sources. The substation designer shall choose the area of interest for reduction and the distance to be increased. One method is to consider the areas that are accessible to the public. Limiting public access to the areas with the lowest fields may involve moving the substation security fence, increasing the height of incoming transmission lines, or moving the outgoing distribution lines or duct banks to another location inside the substation. Another method of increasing distance is locating substations close to or on existing transmission corridors.
b) Reduce conductor spacing to increase the phase-to-phase cancellation of the magnetic fields, resulting in a reduction of the total magnetic field strength. Installing substation feeder outlets in underground ducts allows the phases to be placed in a single duct, thus reducing the overall magnetic field strength.
c) Minimize currents by increasing operating system voltages, minimizing power transfers, providing reactive load compensation, and/or providing alternate transmission line power flow paths.
d) Balance currents on transmission/distribution lines.
e) Optimize phase configuration to achieve magnetic field cancellation by choosing a bus design with phase configuration of vertical, delta, or a combination of both rather than a horizontal design.
f) Shield the source by surrounding the conductors, primarily buses, with a shield structure.

4.4.3.5 Community acceptance

In recent years, concerns for public health and a safe environment have generated many concerns over EMF. Community acceptance of magnetic fields from substations located in areas near their residences can result in heated debate. EMF has developed into a socio-political issue that is not just a not-in-my-back-yard (NIMBY) issue. In many communities EMF is perceived as an unacceptable risk affecting the health, property values, and the environment of the community. Unsatisfactory resolution of these concerns by the project team or the utility can evolve into project delays or changes, legal issues, and the possibility of the project being stopped or cancelled.

To obtain permits, the project team may be required to involve the community and provide the public and governmental bodies with data explaining the design and levels of magnetic fields created by the project. If project management determines to resolve EMF concerns in the community by involving the public, it is important to work openly and honestly with the community. Great care must be taken not to mislead the community regarding magnetic field levels.

To obtain a community's consensus and acceptance, the project team should prepare a plan for involving the community and strive to develop a positive relationship of trust and credibility within the community by listening and acknowledging their right to be concerned about matters that affect them.

Community acceptance of EMF levels may not always have a technical basis. Residents who are annoyed simply by the presence of the substation may find perceived excessive EMF levels to be a tangible factor upon which to base a complaint.

4.5 Safety and security

4.5.1 Fences and walls

The primary means of ensuring public safety at substations is by the erection of a suitable barrier, such as a fence or a wall with warning signs. As a minimum, the barrier should meet the requirements of the NESC and other applicable electrical safety codes.

Recommended clearances from substation live parts to the fence are specified in the NESC, and security methods are described in IEEE P1402/D8 .

4.5.2 Lighting

Yard lighting may be used to enhance security and allow equipment status inspections. A yard-lighting system should provide adequate ground-level lighting intensity around equipment and the control-house area for security purposes without disruption to the surrounding community. High levels of nightly illumination will often result in complaints.

4.5.3 Grounding

Grounding should meet the requirements of IEEE Std 80-1986 to ensure the design of a safe and adequate grounding system. All non-current-carrying metal objects in or exiting from substations should be grounded (generally to a buried metallic grid) to eliminate the possibility of unsafe touch or step potentials, which the general public might experience during fault conditions.

4.5.4 Fire protection

The potential for fires exists throughout all stations. Although not a common occurrence, substation fires are an important concern because of potential for long-term outages, personnel injury or death, extensive property and environmental damage, and rapid uncontrolled spreading. Refer to IEEE Std 979-1994 for detailed guidance and identification of accepted substation fire-protection design practices and applicable industry standards.

5. Permitting process

A variety of permits may be required by the governing bodies before construction of a substation may begin. For the permitting process to be successful, the impact on the community and the environment of the following factors may have to be considered:

a) Site location;
b) Level of ground water;
c) Location of wetlands;
d) Possibility of existing hazardous materials;
e) Need for potable water and sewage;
f) Possible noise;
g) Aesthetics; and
h) EMF.

Timing for the permit application is a critical factor because the permit application may trigger opposition involvement. If it is determined that the situation requires public involvement, the preparation and implementation of a detailed plan using public participation can reduce the delays and costs associated with political controversy and litigation. In these situations, public involvement prior to permit application can help to build a positive relationship with those affected by the project, identify political and community concerns, obtain an informed consensus from project stakeholders, and provide a basis for the utility to increase its credibility and reputation as a good neighbor.

Examples of approaches that have been used with success are described in 5.1 and 5.2 to aid those responsible for cost efficiency and on-time completion and those who secure the various construction permits.

5.1 Active community involvement

Public participation can be defined as the process by which a utility consults with interested or affected individuals, organizations, and government entities before permit applications are filed. Active community involvement is often based on the premise that if the community is presented with the facts and given the opportunity to have their questions answered, informed consensus will be reached and opposition (based on the fear of the unknown) to the project will fade. This approach seeks out the public's thoughts, concerns, fears, and opinions before decisions are made.

Public participation differs from public relations or public information programs where information flows only outward from the utility by providing two-way communication and collaborative problem solving with the goal of achieving better and more acceptable decisions. Every effective public participation program does however, include a public information component. Public participation is mutual problem solving between the community and the utility in an effort to reach a decision that achieves public acceptance. An exchange of information takes place, but, beyond that, public participation is an effort to find an acceptable solution. In order to reach an informed consensus, the information presented to the public must be complete and objective.

Common goals of a public participation plan are as follows:

a) Informing the public;
b) Information gathering;
c) Identifying public concerns and values;
d) Developing a consensus;
e) Achieving acceptance;
f) Developing and maintaining credibility.

Some governmental agencies have enacted laws that require public participation prior to the permit application.

5.2 Low-key community involvement

Low-key community involvement can be defined as the process by which a utility consults with interested or affected individuals and public organizations only after permit applications are filed. In this situation, the project's plan for public participation would indicate that a low-key community involvement approach will be successful where communication is limited initially to the immediate governmental officials and decision makers. Extensive involvement of the public would be pursued only as requested during the permitting process as the need develops.

This approach can be successful in situations where there are no governmental regulations or guidelines requiring up-front public involvement, and where no strong opposition exist in the project area. The organized opposition that can arise from public involvement can override any attempt at open communications. This may be especially true where the real focus of the media and/or opposition has little direct correlation with the specific substation project, but rather uses the project simply as a convenient rallying point for some other agenda.

6. Construction

6.1 Site preparation

The site preparation process includes a number of activities that could have potential impact on the community acceptance and the environment. The following is a listing of these activities, the problems presented, and the control methods available. All construction work should be done in accordance with the pre-agreed project plan.

6.1.1 Clearing, grubbing, excavation, and grading

Concerns include the creation of dust, mud, water runoff, erosion, degraded water quality, and sedimentation. The stockpiling of excavated material and the disposal of excess soil, timber, brush, etc., are additional items that should be considered. Protective measures established during the design phase or committed to through the permitting process for ground water, wetlands, flood plains, streams, archeological sites, and endangered flora and fauna should be implemented during this period.

6.1.2 Site access roads

The preparation and usage of site access roads create concerns that include construction equipment traffic, dust, mud, water runoff, erosion, degraded water quality, and sedimentation. Access roads can also have an impact on agriculture, archaeological features, forest resources, wildlife, and vegetation.

6.1.3 Water drainage

Runoff control is especially important during the construction process. Potential problems include flooding, erosion, sedimentation, and waste and trash carried off site.

6.1.4 Control methods

The following is a listing of methods that can be used to prevent or control problems:

a) Dust and mud control:
   1) Water sprinkling trucks and spray hoses;
   2) Chemical—nontoxic dust retarders;
   3) Timely operation—in cases of moving equipment;
   4) Covered haulers;
   5) Crushed stone access road;

    6) Vehicle washing;
    7) Routine road cleanup.
- b) Erosion and sedimentation control:
    1) Silt fences and hay bales;
    2) Sediment basins and ponds;
    3) Terracing, benching, and serrated slope areas;
    4) Stone and soil dikes;
    5) Drainage ditches;
    6) Diversion structures;
    7) Vegetation buffers;
    8) Soil stabilization (seeding, netting, vegetation binders, wood chip cover, mulching, sodding, hay or straw matting, shrubbery, and creeper planting);
    9) Site access roads should follow natural site contours where possible.

6.2 Noise

Noise control is important during construction in areas sensitive to this type of disturbance. An evaluation should be made prior to the start of construction to determine noise restrictions that may be imposed at the construction site. Typical areas where noise mitigation controls may be required include residential, hospital, convalescent home, office, school, and wildlife sanctuary.

The following are suggested methods that can be used to reduce noise during the construction process:

- a) Equipment mufflers;
- b) Barrier walls;
- c) Blasting mats;
- d) Sound-absorbent materials;
- e) Selective and timely use of equipment (e.g., avoid weekend, late evening, and early morning hours).

6.3 Safety and security

Safety and security procedures should be implemented at the outset of the construction process to protect the public and prevent unauthorized access to the site. These procedures should be developed in conformance with governmental agencies. See IEEE P1402/D8 for detailed descriptions of the security methods that can be employed. The safety and security program should be monitored continuously to ensure that it is functioning properly.

The following are suggestions for safety and security at the site:

- a) Temporary or permanent fencing;
- b) Security guards;
- c) Security monitoring systems;
- d) Traffic control;
- e) Warning signs;
- f) Construction safety procedures;
- g) Temporary lighting.

6.4 Traffic control

The use of various types of construction vehicles and greater presence and flow of personal vehicles are experienced during the construction period than when the substation is in normal operation.

To minimize the impact on the substation neighborhood, the following should be considered:

a) Police assistance and manual traffic control;
b) Traffic signal installations;
c) Reduce traffic at peak hours of commercial or community use;
d) Coordinate movement with industries, schools, or other activities in the area;
e) Move oversized vehicle loads over roadways during minimum traffic periods;
f) Provide adequate parking on site.

6.5 Site housekeeping

During construction, debris and refuse should not be allowed to accumulate. Efforts should be made to properly store, remove, and prevent these materials from migrating beyond the construction site.

Burning of refuse should be avoided. In many areas this activity is prohibited by law.

Portable toilets that are routinely serviced should be provided.

6.6 Hazardous material

The spillage of transformer and pipe cable insulating oils, paints, solvents, acids, fuels, and other similar materials can be detrimental to the environment as well as a disturbance to the neighborhood. Proper care should be taken in the storage and handling of such materials during construction.

There are many substances which, if found on a substation site during construction, will require stoppage of work and notification of governmental agencies before the site can become usable. Some such substances are PCBs, asbestos, dioxin, lead and other heavy metals, and radioactive materials. Equipment containing unacceptable chemicals should not be utilized in new constructions. Disposal of hazardous materials should be done with care, avoiding spills and adhering to appropriate guidelines, procedures, and governmental regulations.

7. Operations

7.1 Site housekeeping

7.1.1 Water and sediment control

Routine inspection of controls for water flows is important to maintain proper sediment control measures. Inspection should be made for basin failure and for gullies in all slopes. Inspection of all control measures is necessary to be sure that problems are corrected as they develop, and should be made a part of regular substation inspection and maintenance.

7.1.2 Yard surface maintenance

Yard surfacing should be maintained as designed, to prevent water runoffs and control dust. If unwanted vegetation is observed on the substation site, approved herbicides may be used with caution to prevent runoff from damaging surrounding vegetation. If runoffs occur, the affected area should be covered with stone to retard water runoff and to control dust.

7.1.3 Paint

When material surfaces are protected by paint, a regular inspection and repainting should be performed to maintain a neat appearance and to prevent corrosion damage.

7.1.4 Landscaping

Landscaping should be maintained to ensure perpetuation of design integrity and intent. Successful accomplishment of this goal will be enhanced by

a) Watering;
b) Fertilization;
c) Approved chemical application;
d) Pruning;
e) Lawn maintenance;
f) Plant replacement as needed.

7.1.5 Storage

In some areas, zoning will not permit storage in substations. The local zoning must therefore be reviewed before storing equipment, supplies, etc. The appearance of the substation site should be considered so it will not become visually offensive to the surrounding community.

7.2 Noise

Inspection of all attributes of equipment designed to limit noise should be performed periodically.

7.2.1 Continuous audible sources

Periodic maintenance and inspection of station equipment and systems should be performed to ensure that they are functioning in accordance with their design. Any loose attachments resulting from vibration could add to continuous noise levels produced by the substation and should be corrected.

Inspections of connector hardware and bus for proper installation and follow-up removal of rough edges, projections, and rough surfaces might be required to ensure continuous corona-free performance, and to minimize RF noise. It is also important to maintain good electrical contact in all metallic parts to eliminate gap sparking by ensuring proper contact pressures.

7.2.2 Impulse source

Community disturbances from circuit-breaker (especially air-blast type) and switch operations can be minimized by proper scheduling of equipment maintenance and testing.

7.3 Safety and security

All substations should be inspected regularly, following established and written procedures to ensure the safety and security of the station. Safe and secure operation of the substation requires adequate knowledge and proper use of each company's accident prevention manual. See IEEE P1402/D8 for detailed descriptions of the security methods that can be employed.

Routine inspections of the substation should be performed and recorded, and may include the following:

a) Fences;
b) Gates;
c) Padlocks;
d) Signs;
e) Access detection systems;
f) Alarm systems;

g) Lighting systems;
h) Grounding systems;
i) Fire protection equipment;
j) All oil-filled equipment;
k) Spill-containment systems.

7.4 Fire protection

Refer to IEEE Std 979-1994 for detailed guidance and identification of accepted substation fire-protection practices and applicable industry standards. Any fire-protection prevention system installed in the substation should be properly maintained.

7.5 Hazardous material

A spill-prevention control and counter-measures plan should be in place for the substation site and should meet governmental requirements. For general guidance, see IEEE Std 980-1994 .

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