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Draft Zambian Standard

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

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The preparation of this Zambian Standard was entrusted upon the Electrical Construction Standard Formulation Technical Committee, upon which the following organisations were represented: -

Copperbelt Energy Corporation Plc
Energy Regulation Board
Engineering Institution of Zambia
Ministry of Health
Ministry of Local Government and Housing
Ministry of Mines and Minerals Development
National Council for Construction
The University of Zambia, School of Engineering
Zambia Association of Manufacturers
Zambia Bureau of Standards
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FOREWORD

This standard is based on IEEE std 1127-1998(R2004) and has been developed as a guide in the construction of electricity supply substations in Zambia. It is noted that environmental issues have increasingly become of concern in any construction activity. This standard addresses issues required for the substations to be accepted by the community (who may or may not necessarily be electricity consumers) as well as those of environmental compatibility.

The standard points out the considerations to be made starting from the design stage through the construction stage to the operational stage of an electricity supply substation.

Recommendations for corrections, additions or deletions shall be addressed to the ERB Electrical Construction standard formulation Technical Committee Chairman, c/o ERB, 8th Floor Premium House, Nasser Road, P.O. Box 37631, Lusaka 10101, Zambia.

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CONTENT PAGE

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DRAFT ZAMBIAN STANDARD DZS 690:2006

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

1. SCOPE AND PURPOSE

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 included.

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 regulatory bodies before construction of a substation may begin. Concerns are being voiced by regulatory bodies 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 strategies 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:

(a) Noise;
(b) Site preparation;
(c) Aesthetics;
(d) Fire protection;
(e) Potable water and sewage;
(f) Hazardous materials;
(g) Electric and magnetic fields;
(h) Safety and security.

2. REFERENCES

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

Environmental Protection and Pollution Control Act, Cap 204

Factories Act, Cap 441

ZS691, Guide for Safety in AC Substation Grounding.

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

ZS692, Guide for Substation Fire Protection.

ZS418 Electrical Safety Code

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 Town and Country Planning Act.

3.3 Electrical substation

An enclosed assemblage of equipment, e.g. switches, circuit breakers, buses and transformers, under the control of authorised persons, through which electric energy is passed for the purpose of switching or modifying its characteristics.

3.4 Hazardous material

Any material that has been so designated by Environmental Council of Zambia or adversely impacts human health or the environment.

3.5 Industrial zone

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

3.6 Noise

Undesirable sound emissions or undesirable electromagnetic signals/emissions.

3.7 Residential zone

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

3.8 Wetlands

Any land that has been so designated by the Ministry of Tourism, Environment and Natural Resources. Characteristically, such land contains vegetation associated with saturated types of soil.

3.9 Zoning

Assigning as to a particular area having particular features, properties, purpose or use.

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 regulatory bodies 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) is 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 regulatory bodies. It is possible that major projects can be delayed or blocked by public opposition. In some instances, substations may be 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 neighbours, including airports;
e) Permit requirements and regulations;
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 minimise construction activities within or adjacent to designated wetlands should be a priority. Use of an alternative site where available should be strongly considered, as governmental regulatory bodies may prohibit any disturbance to a designated wetland area. If no alternative exists to utilising 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 the Environmental Council of Zambia (ECZ) has determined to be a hazardous material should be considered. ECZ 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 recognised 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 ECZ 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 ECZ 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 water utilities or communal water sources or from private wells. The quality of water supplied by utility or communal water sources 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 National Water and Sanitation Council (NWASCO) regulations before the well water is used.
Sewage may be disposed of by sewerage utilities or septic systems, or the site could be routinely serviced by portable toilet facilities, which are often used during construction. Where utilities are used for water or sewer services, the requirements of that utility must be met. The utility 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 and national regulations.

4.1.2 Site preparation

4.1.2.1 Gradient

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 (projection) to be excavated and removed, or if there is a flooding potential at the lower elevation. The finished gradient of the substation should be designed to minimise 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 will also lessen the extent to which side-sloped or retaining walls are required to provide yard transition to the existing gradient. 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 silt, and sites that have side slopes. A layer of medium to coarse sand or geo-textile fabric beneath a crushed stone surface can minimise 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 minimising 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.

Substation design should comply with erosion and sedimentation-control guidelines of the Ministry of Tourism, Environment and Natural Resources (MTENR).

4.1.2.3 Oil-spill containment and control

The detection, control and containment of oil spills should comply with the requirements of the Environmental Council of Zambia. Where local government regulations exist, the substation design must also 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 lay-by at intervals from 60 m to 120 m 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 are 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 neighbouring entryways is important;
b) Required by local regulations;
c) On a steep gradient 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. 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 erosion 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, minimise 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 regulatory requirements.

4.1.3.1 Upstream considerations

It is necessary to consider stream floodways where construction may be discouraged, prohibited or where it is subject to approval by a regulatory authority. Information about flooding may be available from local authorities. If the substation site is outside a floodway zone, 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 gradient, 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 which are 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 channelisation, elimination of natural hills by smooth gradients, 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 allows, open ditch storm-water systems are generally preferable to pipe systems because they are less costly, minimise 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. This 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 harmonises 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 colour, 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, modelling, 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 Landscaping and topography

4.2.2.1 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. Trees that give excellent coverage and colour, and can be used in clusters, in hedges, or spaced apart should be considered. 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.

4.2.2.2 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 moulded 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 realised by utilising cut material spoil on the site for earth forms rather than removing it from the site.

4.2.3 Fences and walls

The Electrical Safety Code ZS 418 requires that fences, screens, partitions, or walls be employed to keep unauthorised persons away from substation equipment.

4.2.3.1 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 galvanised or painted in dark colours to minimise their visibility, or they can be obtained with vinyl cladding. They can also be installed with wooden slats or coloured plastic strips woven into the fence fabric. Earthing or grounding and maintenance considerations should be reviewed before selecting such options.

4.2.3.2 Wood fences

This type of fence should be constructed using naturally rot-resistant or pressure-treated wood, in natural colour 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.

4.2.3.3 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 colours, and can be used in combination for an attractive architectural appearance. Brick and pre-cast 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 neighbouring facilities. Walls can be subject to graffiti, and this should be part of the consideration of their use.

4.2.4 Colour

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

Above the skyline, the function of colour 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 colour can soften the appearance of substation structures in the course of changing daylight.

Below the skyline, colour can be used in three aesthetic capacities. Drab colouring, 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 colouring should have very limited variation in hues, but contrast by varying paint saturation is often more effective than a monotone coating. Colours and screening can often be used synergistically. A second technique is to use colour 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 colour equipment and structures for intense visual impact.

4.2.5 Lighting

When attractive landscaping, decorative fences, enclosures, and colours 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 neighbouring 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.

4.2.6 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 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.

4.2.7 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 areas 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, colour, materials, shape) to match neighbouring 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 coloured blocks may be selected to achieve a desired architectural effect. Brick, architectural metal panels, and pre-cast 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.

4.2.8 Bus design

Substations can be constructed partly or entirely within above-ground or below-ground 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 sub-clause is limited to exposed above-ground substations.

4.2.8.1 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.

4.2.8.2 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.

4.2.8.3 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.

4.2.8.4 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 favour 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 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 neighbours, 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 may be typically received concerning substations with transformers of less than 10 MVA capacity, except in urban areas with little or no buffers. Complaints may be more common at substations with transformer sizes of 20–150 MVA, especially within the first 170–200 m. However, in very quiet rural areas where the night time ambient can reach 20–25 dBA, the noise from the transformers of this size can be audible at distances of 305 m or more. In urban areas, substations at 330 kV and above may not often result 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 on the following page.

Table 1 — Common outdoor noise levels

Type	Noise level (dBA)
Jet flyover at 305 m	110
Gasoline lawn mower at 0.9 m	100
Diesel truck at 15 m	90
Noisy urban daytime	80
Gasoline lawn mower at 30.5 m	70
Commercial area heavy traffic at 90 m	60
Quiet urban daytime	50
Quiet urban night time	40
Quiet suburban night time	30
Quiet rural night time	20
Threshold of hearing	10
Source: Fundamental and Abatement of Highway Traffic Noise, 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. A substation could benefit from the shielding effect of highway noise if it is located less than 3 km 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 non uniform 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.

$$N \ ? \ ?4.4 \ ? \ dBT \ ? \ 20 \log \frac{D}{\sqrt{WH}} \qquad (1)$$

or

$$N \ ? \ ?6.2 \ ? \ dBT \ ? \ 2.08 \log ?(kV)(kVA)? ? \ 20 \log D \qquad (2)$$

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 (m);
H is height of main tank (m);
D is distance from the transformer to the point of interest (m).

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 on page 20 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.

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 enacted by the Environmental Council of Zambia (ECZ) where limited buffer zones 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 neighbours may be initially successful. However, development of the area during the life of the substation could result in additional neighbours. In general, the existence of a substation prior to the arrival of new neighbours 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.

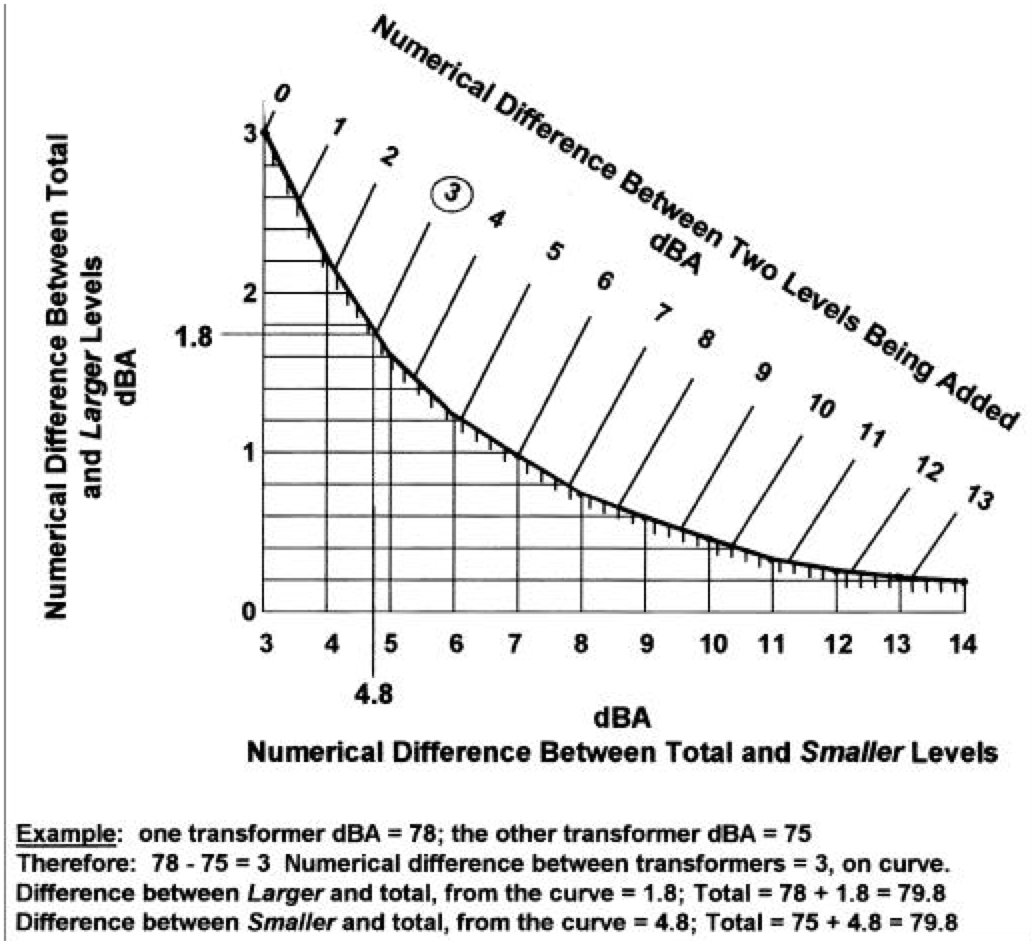

Figure 1— Nomograph for determining combination sound levels [*from IEEE std 1127-1998(R2004)*]

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 132 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 neighbours will minimise 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, minimising the likelihood of a complaint. Placement of substations near backdrop hills may redirect the radiant sound as might substations set below gradient 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 centre of the property, rather than at the edges, will lessen the effect on the neighbours.

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-gradient 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 at 120 Hz] above, as well as beyond the line of sight from the transformer centre 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.

$$dB_{120\ Hz} \; ? \; 9.5\log\left(\sqrt{R^2 \; ? \; h^2} \; ? \; R\right) ? \; 8.7 \qquad (3)$$

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

Where

R is the distance (m) from the geometric centre of the transformer tank to the inside surface of the wall;

h is both the height (m) of the wall above the line drawn from the observer to the geometric centre, and the horizontal length of the wall in both directions from a point opposite to the geometric centre at distance *R*.

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

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.

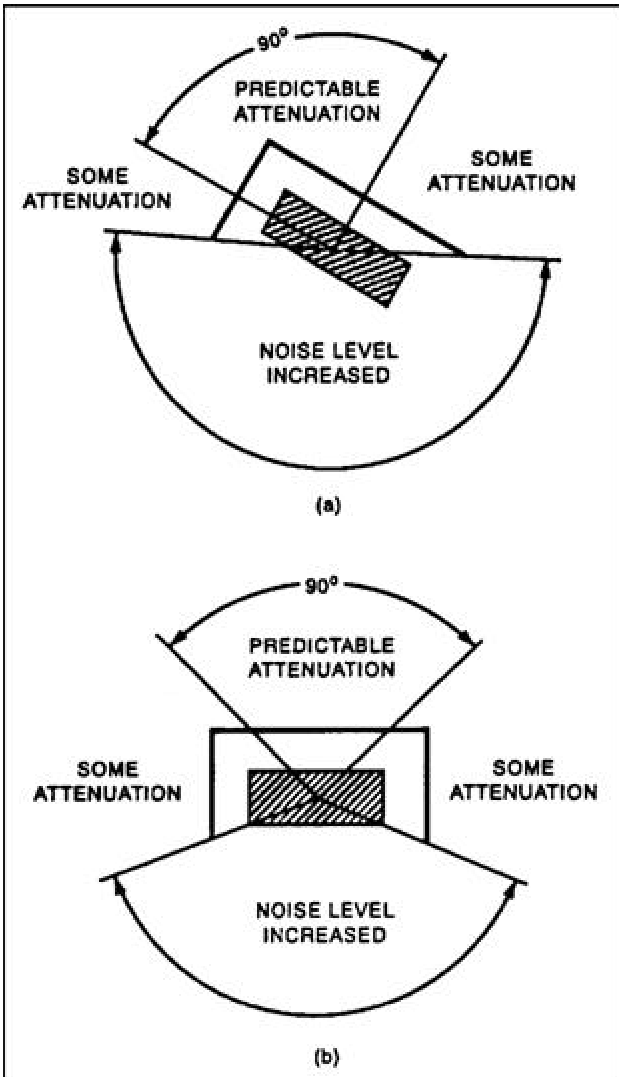

Figure 2— Regions of sound attenuation and sound increase around (a) L-shaped barrier (two-sided) and (b) U-shaped barrier (three-sided) [*from IEEE std 1127-1998(R2004)*]

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 or more. In quiet rural areas, and some suburban areas, low night time 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 night time 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 (night time) can be offset by the closer proximity of nearby residents [in some cases less that 30 m]. 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) Bus work;
c) Transformers;
d) Air core reactors;
e) Switchgear and cabling;
f) Line traps;
g) Circuit breakers;
h) Earth mesh or Ground grid;
i) Capacitors;
j) Battery chargers;
k) Computers;
l) Generators;

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 earthed or 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, it decreases significantly toward the fence line. At the fence line, 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

The Electrical Safety code ZS 418 specifies guidelines for safe distances from live conductors for different voltage levels at 50 Hz.

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 phase 1-2-3 on one circuit and phase 3-2-1 on the other circuit, will result in increasing the field level because the fields of the adjacent number 3 phases add together.

c) *Lower operating system voltage.* The effects of electric field depends on how high the system voltage is.

d) *Optimise substation layout.* The presence of nearby buses, either earthed (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 (ground), or most metals, have little shielding effect on magnetic fields.

Magnetic fields are measured in Webers per square metre (Wb/m^2) or Tesla. 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:

? S*napshot.* 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 recognised that this could be complex and it is recommended that commercially available computer programs be used. Several computer programs are available that utilise 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 recognised 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 earth or 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 modelled.

In evaluating the results, modifications should be considered when the substation designer has specific regulation criteria or governmental guidelines for magnetic field reduction. Utilities may be directed by the Energy Regulation Board to take EMF reduction steps on transmission, substation, and distribution facilities to reduce exposure to magnetic fields. This criterion 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

There are no governmental regulations specifically for power frequency magnetic fields in substations in Zambia

Magnetic field levels at substations are lower at the substation fence than at the edge of the right-of-way. 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) Minimise currents by increasing operating system voltages, minimising power transfers, providing reactive load compensation, and/or providing alternate transmission line power flow paths.

d) Balance currents on transmission/distribution lines.

e) Optimise 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 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 the Energy Regulation Board 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 electrical safety code.

Recommended clearances from substation live parts to the fence and security methods are specified in the Electrical Safety Code ZS 418.

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 Earthing or grounding

Earthing or grounding should meet the requirements of ZS691 to ensure the design of a safe and adequate earthing or grounding system. All non-current-carrying metal objects in or exiting from substations should be earthed (grounded), generally to a buried metallic grid (mesh), 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 substations. 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 ZS692 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 governmental regulatory 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;
h) EMF; and
i) Information and communication technologies (ICT).

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 neighbour.

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, organisations, 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 programme 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 regulatory bodies may 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 organisations 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 upfront public involvement, and where no strong opposition exist in the project area. The organised 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, archaeological 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—non toxic 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 stabilisation (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

Problems associated with an undeveloped property can occur during the construction stage of a substation and should be considered. In fact, the presence of construction materials and equipment can create additional attractive nuisances. New hazards such as excavations, uncompleted structures, and construction equipment now are on site that could cause injury to unauthorised personnel or even passers by.

Safety and security procedures should be implemented at the outset of the construction process to protect the public and prevent unauthorised access to the site. These procedures should be developed in conformance with regulations such as the Factories Act Cap 441; Refer to appendix 1. The safety and security programme 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 minimise the impact on the substation neighbourhood, 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 only be done in an approved manner. In open areas this activity is prohibited by the Environmental Protection and Pollution Control Act Cap 204.

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 neighbourhood. 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 Environmental Council of Zambia 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 utilised 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. The colour can be maintained by taking the steps outlined in section 4.2.4

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) Fertilisation;
c) Approved chemical application;
d) Pruning and vegetation control;
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 minimise Radio Frequency (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 minimised 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 Appendix 1.
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) Earthing or grounding systems;
i) Fire protection equipment;
j) All oil-filled equipment;
k) Spill-containment systems.
1) Gas -filled and vacuum equipment

7.4 Fire protection

Refer to ZS 692 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 ECZ requirements. For general guidance involving other materials see ECZ guidelines.

APPENDIX 1: Guide for Electric Power Substation Physical and Electronic Security

This appendix is based on IEEE Std 1402-2000.

1. SCOPE AND PURPOSE

1.1 Scope

This appendix identifies and discusses security issues related to human intervention during the construction, operation (except for natural disasters), and maintenance of electric power supply substations. It also documents methods and designs to mitigate intrusions.

1.2 Purpose

Access to electric supply substations by unauthorised personnel is an increasing problem for the electric industry. These intrusions may result in loss, damage, and maloperation of equipment and facilities and may create potential safety and environmental liabilities. This appendix presents various methods and techniques presently being used to mitigate human intrusions, as identified in an industry survey. In 1994, an IEEE Substation Security Guide Survey questionnaire was sent to utilities internationally; the responses from this survey are presented in Clause 7 of this appendix..

3. Definitions

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

3.1 construction stage:

The time related to the installation or modification of fixtures or structures, including services, foundations, steel, conductors, buildings, and earthing or grounding.

3.2 intrusion:

Unauthorised access to the substation property through physical presence or external influence.

3.3 operational stage:

The time following commissioning of the facility.

3.4 undeveloped stage:

The time prior to the installation of permanent structures, site preparation, preliminary surveying, surface stripping, fence erection, road building, equipment and material staging, furnishing construction power, etc.

4. Intrusions

4.1 Types of intrusions

Intrusions can be classified into the following categories:

a) *Pedestrian*: A person walking onto the substation property or into the substation proper, either accidentally or for the purpose of vandalism, robbery, theft, dumping, or other illicit activities.
b) *Vehicular:* A vehicle driven into a substation, either through an open gate or through the perimeter fence or wall. This intrusion may be for the same purposes listed in item a), or may be the result of an accident.

c) *Projectile:* Foreign objects thrown or propelled into the substation area that may damage substation equipment or the control room (e.g., rocks, kites, bottles, missiles, explosives, and bullets).
d) *Electronic:* Entry into the substation via telephone lines or other electronic-based media for the manipulation or disturbance of electronic devices. These devices include digital relays, fault recorders, equipment diagnostic packages, automation equipment, computers, programmable logic controllers, and communication interfaces.

4.2 Parameters and events that influence intrusions

4.2.1 Economic

In some areas, theft of copper, aluminum, or other components from a substation may be prevalent.

4.2.2 Location

Higher levels of crime, vandalism, and graffiti may be common behaviours in certain neighbourhoods. School properties or other public areas adjacent to or near a substation or substations located in remote areas may also present additional opportunities for intrusions.

4.2.3 Aesthetics

Walls, plantings, or screening treatments may make substations an attractive and secluded meeting spot for various recreational or illicit activities.

4.2.4 Labour conflicts

Strikes, slowdowns, personnel reductions, or other labour conflicts by utility or contract workers can be a significant factor influencing intrusions as the substation can be an attractive target.

4.2.5 Use of adjacent property

Uses of adjacent property may lead to intrusions onto substation property. Commercial activities, building, storage, equipment and material locations, and building structures can facilitate intrusions onto substation property.

4.2.6 Curiosity and ignorance

Many items in a substation may attract curious individuals who are unaware of the hazards that exist within the substation fence.

4.2.7 Civil/political unrest

Terrorism, war, riots, civil disobedience, and public events provide increased opportunity for intrusions.

4.2.8 Joint-use facilities

Establishment of a substation on or adjacent to a facility that is shared, owned, or used by others could provide additional opportunity for intrusions as the potential for legitimate access by unqualified personnel increases.

4.2.9 Natural and/or catastrophic disasters

The effects of natural and/or catastrophic disasters may render security systems ineffective.

4.3 Problems caused by intrusions

Human intrusions onto substation sites can create many problems and can occur during any of the following three stages of substation development:

a) The undeveloped stage
b) The construction stage
c) The operational stage

These problems, which can be unique to only one stage or can be common to one or more of the three stages, are discussed in clauses 4.3.1, 4.3.2, and 4.3.3 of this appendix.

4.3.1 Undeveloped stage

This appendix assumes that at the time a substation property is obtained, it is free of any hazardous materials.

The problems associated with an undeveloped substation property can generally be classified as attractive nuisances, dumping, vandalism, illicit activities, and sabotage.

Attractive nuisances are any items that, by their mere presence, may draw people's attention for use or play without recognising their dangerous qualities. These may include, but are not limited to, old wells, septic systems, caves, trees, rock formations, and ponds. These items may attract people onto the property, where they may be injured or killed. Civil lawsuits could result from these occurrences.

An unsecured substation property is an attractive place for the dumping of trash or hazardous materials. This dumping can cause public complaints or legal citations. The removal of these materials may be quite expensive.

Vandalism on the property can create problems similar to those caused by dumping.

A vacant property may also provide a place for various unwanted or illicit activities to occur. These activities may also cause public complaints and possible civil actions.

Finally, sabotage can be caused by disgruntled or striking employees, other personnel (e.g., construction crews, contracted services, customer utility manpower), or groups opposed to the development of a substation at the site.

4.3.2 Construction stage

Each problem associated with an undeveloped property and described above can occur during the construction stage of a substation and should be considered. In fact, the presence of construction materials and equipment can create additional attractive nuisances. New hazards such as excavations, uncompleted structures, and construction equipment now are on site that could cause injury to unauthorised personnel.

Additional problems that can occur during the construction stage are theft and increased vandalism. Construction materials that contain copper and aluminum are very attractive since they can easily be sold for scrap. The use of copper-clad or galvanised steel wire or stranded wire may be a theft deterrent due to its negligible scrap value compared to solid copper wire or strand. During the construction stage, these items are often packaged for convenient removal and may be stored in unsecured areas. Construction equipment, such as pickup trucks and excavation equipment, is motorised and can be easily removed from the site. The removal or vandalism of materials and equipment will increase the cost of the project. In addition, many of the items required for the construction of a substation have long delivery times and are not easily replaced. The loss of these items may also drastically delay the completion of the project and increase cost.

4.3.3 Operational stage

Although the substation is normally energised during the operational stage, nearly all of the potential problems described above, as well as the removal of gauges and copper ground materials, meter damage, and the opening of transformer valves, can occur. The fact that a substation is energised does not deter these problems.

An additional concern during the operational stage arises from the fact that the substation is normally energised and often unattended. At this stage, intrusions can affect the integrity of the electric power supply and the reliability of the transmission and distribution grid, if the intrusion results in power interruptions. Examples include projectiles, poles, or kites that come in contact with energised parts, and electronic interference with relaying and control circuits. Intruders have been known to open valves, push buttons, and operate circuit breakers, reclosers, and switches.

Another area of concern comes from employees and other authorised personnel with legitimate access to a substation. Their actions can defeat the security aspects of the station design in order to facilitate their functions, such as removal of a vehicle gate centre stay to allow easier removal of waste. Such actions may allow a locked gate to move beyond its design limits and permit unauthorised access.

Sabotage becomes more of a concern in the operational stage. Sabotage can be done by those who normally have legitimate access to the substation, such as construction crews, contracted services, customer or utility manpower, or by those with no legitimate access, such as criminals, activists, and extremists.

Safety concerns increase significantly because of the potential for accidental human contact with energised equipment or removal of earthing or grounding material that could cause hazardous conditions for personnel. Some examples include persons under the influence of alcohol or drugs, teenagers on a dare, and unsuspecting children. All have been known to come in contact with energised conductors or equipment.

Substations located on slopes can be subject to erosion and wash out, which can create openings under the fence and compromise security. In addition, electronic intrusion becomes a concern. Electronic interference, whether accidental or intentional, can disrupt communications, protective relaying, control, supervisory control and data acquisition (SCADA), and other instrumentation. Security systems can also be defeated or jeopardised. Substations may contain microprocessor-based relays and programmable logic controllers (PLCs), as well as other intelligent electric devices (IEDs). In addition, many utilities are including local area network (LAN) systems within the substation environment. These LAN systems will allow IEDs and relays to share information as well as transmit important system data directly to the control centre of various utilities. However, the introduction of computer systems with on-line access to substation information is significant in that substation relay protection, control, and data collection systems may be exposed to the same vulnerabilities as all other computer systems. As the use of computer equipment within the substation environment increases, the need for security systems to prevent electronic intrusions may become even more important.

Electronic computer intrusion in its broadest definition can cover all acts that change, delete, or otherwise interfere with the data and program mes stored in computer files. This includes deliberate acts to steal, alter, or destroy information.

5. Criteria for substation security

A mitigation program me should be put in place either during the initial design or after experiencing substation intrusions. Typical criteria for implementing substation security programmes are based on an assessment of probability, frequency, duration and cost of occurrences, safety hazards, severity of damage, equipment type, number and type of customers served, substation location, design type, criticality of load, and quality of service at existing substations. Also, weather conditions in the area of the substation should be considered, since they can impact response time to an intrusion.

The point at which cost of occurrences and safety hazards justify implementing deterrent programmes is often difficult to establish. However, the security survey results indicate that the most common parameters for implementing corrective actions are physical injuries, criticality of load, and extent of damage. These issues should also be considered in new designs.

6. Security methods

Security requirements should be identified in the early design stages of the substation project. Generally, it may be more economical to anticipate and incorporate security measures into the initial design rather than retrofit substations at a later date.

This clause identifies the use of barriers, electronics, and other methods of providing substation security.

6.1 Barriers

6.1.1 Fences

Fences of various materials provide primary security to limit access to substation property; refer to the Electrical Safety Code ZS 418 for fence requirements. In addition, adding top and bottom rails on fence sections, closed track roller systems to sliding gates, and methods such as welding to prevent hinge pins and bolts from being easily removed, may improve the overall integrity of the fencing system. Also, the extension of materials above and below grade, such as concrete curbing, has been used to reduce the possibility of erosion and dig-ins under the fence.

Double-fencing (enclaving), increased fence height, and smaller-dimension mesh fabric that impedes climbing may also be considered to avoid access over the fence. Areas that experience large snow accumulations should consider use of higher fences.

The material utilized for the fence should be commensurate with the evaluated security risk of the area. A standard chain-link fence is easily cut and most purposeful intruders use this method to gain access. Chain link fences are therefore of little value against this type of intruder.

6.1.2 Walls

Solid masonry or metal walls may provide an additional degree of security. Solid walls are generally more difficult to breach and also prevent direct line-of-sight access to equipment inside the substation. Solid walls may prevent external vandalism, such as gunshot damage, depending on the height of the wall, surrounding terrain, and elevation of equipment inside the substation.

6.1.3 Entrance/equipment locks

All entrances to substations should be locked. All equipment located outdoors within the substation fence should have a provision for locking cabinets and operating handles where unauthorized access could cause a problem. Padlocks should be of a type that can utilize a non-reproducible key. Similar locking devices should be used on gates and doors to any buildings within the substation fence. Maintenance of equipment alignment is important to ensure proper installation of locks. In places where it is difficult to keep equipment in alignment, the use of a chain and lock is a practical method to secure the gate. However, avoid the substitution of chains where possible, since they may compromise the security of a locking system.

6.1.4 Other barriers

Access to energized equipment and bus may be of concern if the perimeter security measures are breached. Polycarbonate or other barriers on ladders and structure legs should be considered in order to prevent inadvertent access. Refer to the NESC and Occupational Safety and Health Administration (OSHA) requirements.

Driveway barriers (gates, guard rails, ditches, etc.) at the property line for long driveways can help limit vehicular access to the substation property.

6.2 Electronic

A variety of commercially available systems can be employed to provide varying levels of security in the substation. Caution should be used when employing sensing devices that are subject to erroneous activation due to movements caused by animals, wind, seismic events, or vibrations. All wiring for electronic security systems should be installed in a manner that will ensure operational integrity and resistance to tampering.

6.2.1 Photoelectric/motion sensing

Perimeter systems using photoelectric or laser sensing may be utilized to provide perimeter security. Overall area security may be provided by motion-sensing devices; however, great attention should be shown in the placement of these devices since animal intrusion alarms may become a nuisance and sensors may be deemed ineffective.

6.2.2 Video surveillance systems

Video systems can be deployed to monitor the perimeter of the substation, the entire substation area, or the building interiors. Systems of this type require 24 h monitoring, which can be a costly alternative. Video systems are available that utilize microwave and infrared to activate a slow-scan video camera. This can be alarmed and monitored remotely and automatically videotaped.

6.2.3 Building systems

One of the more common methods utilized is an intrusion alarm on control buildings. These systems include, at a minimum, magnetic contacts on all the doors, and have the provisions to communicate through the existing telephone network or SCADA systems. A local siren and strobe light may be located on the outside of the building to indicate the alarm condition. The system should be capable of being activated or deactivated using an alphanumeric keypad, key switch, or a card reader system located inside the building. All siren boxes and telephone connections should have contacts to initiate an alarm if they are tampered with.

6.2.4 Computer security systems

Computer security systems can be subdivided into three major components: identification, authentication, and auditing. Identification is simply a login name or user identification (user id) to determine who wants access to the information. Authentication is the process of verifying that the person logging in is who they say they are. Finally, the audit is an attempt to verify that only authorized personnel are accessing the data through the use of separate reporting and logging systems. Some typical security methods are discussed in 6.2.4.1 through 6.2.4.5.

6.2.4.1 Passwords

Probably the most widely used and most common form of protection is the user ID and password. All security systems, regardless of their sophistication, begin with a user ID and password protection system. However, working alone, they are also the easiest to break. Keep in mind the following points:

a) Do not use personal information, such as birthdays, names, etc.
b) Do not use common words or names.
c) Use at least four characters and preferably more.
d) Memorize them.
e) Mix symbols, numbers, and both upper and lower case letters.
f) Change the password periodically.
g) Limit the number of attempts to enter a password.

6.2.4.2 Dial-back verification

This technique provides one of the best methods of protecting a system from external access. The system is based on the intended user first calling the equipment via modem, which initiates a dial-back response by the equipment using a predetermined telephone number. Although this technique provides increased protection from external intrusion, it provides little protection from electronic intrusion by those within the organization.

6.2.4.3 Selective access

This technique allows access for information purposes to a large group while restricting authorization for modification of files to a smaller group through the use of an additional password.

6.2.4.4 Virus scans

A computer virus is another form of electronic intrusion. With the increased use of desktop and laptop equipment to access substation equipment, it is possible that an infected computer could spread a virus to the substation equipment. The introduction of computer viruses can be limited by the following:

a) Employing virus scanning software.
b) Scanning all floppy discs prior to use on any computer system.
c) Destroying all discs suspected of infect ion.

6.2.4.5 Encrypting and encoding

Where it is suspected that intruders may be able to defeat the identification and authentication security measures and gain unauthorized access to the computer, further protection may be warranted. The program or its critical data can be encoded or encrypted to block access, even after access to the computer has been gained. This method also can be used to block access by unauthorized personnel with legitimate access to the area housing the computer, especially when the computer may be routinely left on-line.

6.3 Other methods

6.3.1 Lighting

The entire interior of the substation may be provided with dusk -to- dawn lighting to provide a minimum light level of 21.52 Lux (2 footcandles). Placement of lighting posts should be such as not to assist an intruder who may climb the posts to enter the substation. All wiring to the lighting posts should be in conduit or concealed to minimize tampering by an intruder. In addition, areas outside the substation, but within the facility property, should also be considered for lighting to deter loitering near the substation.

Zoning and other local regulations may restrict or prohibit lighting.

6.3.2 Landscaping

Any landscaping treatment around substations should be carefully designed so as not to create potential security problems.

6.3.3 Building

In general, most building materials provide adequate security protection. Selection of the type of building construction should be suitable for the level of security risk. Typically, features that should be included are steel doors with tamper-proof hinges and roof-mounted heating/air conditioning units. Any wall openings (i.e., wall air conditioners) should have security bars over and around the unit. A building that is part of the perimeter fence line should be at least as secure as the fence. Construction of a building to enclose the substation or exposed equipment and materials can provide an additional layer of protection against intruders. For example, using trailers or buildings to enclose material stored at construction sites may deter theft.

6.3.4 Patrols

In areas where vandalism has been a chronic problem and at critical substations, judicious use of security patrol services should be considered. A partnership should be established with local law-enforcement agencies to facilitate the need for local patrols of selected substation facilities to deter vandalism and unauthorized entry. Security procedures should be established that specifically identify who handles security alarms and what the notification procedure is within the company and local law enforcement agencies.

Furthermore, during special or unusual occasions, such as labor disputes, the Olympics, or a presidential visit, security procedures at critical substations may include identification checks by security patrols and limited access to the substation.

6.3.5 Special precautions for natural and/or catastrophic disaster

During a disaster, responding security or law-enforcement personnel may not be able to respond within an acceptable time due to transportation restrictions or higher priority emergencies. However, proper planning for disasters that might occur in a given location can help to protect a substation and preclude the need to deploy personnel during the event.

Failure to recognize the impact of the following events and to institute precautions could result in numerous false alarms:

a) *Wind*. Do not use security measures that might be activated by high winds.
b) *Seismic activity*. Do not use devices that could be triggered by earth tremors.
c) *Vehicular, rail, or aircraft intrusion.* While prudent siting methods can reduce the likelihood of such an event, substations at times must be contiguous to these modes of transportation as a matter of necessity. Alternate means of accessing the site can be helpful when the normal access is blocked by an intrusion. In addition, prudent planning for emergency response to the above should include the availability of items such as emergency lighting and temporary fencing materials.

6.3.6 Communications

A key element of theft or loss control is communication, both internal and external to the company. Notification of a loss and the monetary or safety implications increase problem awareness and vigilance.

6.3.6.1 Internal

Companies should ensure that employees are advised of their security responsibilities. Employees responsible for the resources under their care or control should take reasonable precautions against loss, theft, or damage. Operational and inspection procedures can be utilized to reduce the potential for intrusions. These procedures should include inspection of the perimeter for breaks in the security measures, including padlocks, electronic security systems and alarms, the condition of all warning signs, and the integrity of the fence. Alertness, vigilance, and reporting of incidents will contribute to improved security.

Awareness can be improved by

a) Providing tutorial information to employees.
b) Using posters on-site.
c) Circulating information on reported incidents.
d) Using a site security checklist.
e) Encouraging suggestions for improvement.
f) Marking tools with company identification.
g) Encouraging customers and property owners to report suspicious activity around facilities.

Identification of all losses is essential to determine the security measures required on a future project. Losses can be the result of employees or non-employees identifying and exploiting an opportunity. The purpose of the internal communication is to identify the problem to all levels of management on an internal company basis. Details of an incident include date, time, location, value, loss description, impacts, and contributing factors/suspects. All are important data to identify. Suspect names or very specific data regarding a particular incident should be carefully screened to prevent adverse impacts on further legal action or prosecution. As an example of a proposed format, see Figure 1. Once a format is developed, a common database program can sort incidents and may help identify patterns.

6.3.6.2 External

Another important element in reducing theft is communication with groups outside the company, including neighbors adjacent to the substation. If a loss occurs, quickly disseminating information on a regional basis may help identify the parties involved and may potentially deter future acts. Facsimile, e-mail, or phone notification networks to possible outlets for stolen goods, such as local companies, scrap or recycle dealers, and law enforcement can provide an expeditious vehicle for loss notification.

Suspicious conductor scrap sales, vehicle thefts, and regional loss problems can be better investigated through coordinated and cooperative industry and law-enforcement efforts.

In addition, once intruders are apprehended and convicted, information concerning the intrusion and individuals involved could be made public in an effort to deter future attempts.

6.3.7 Additional security measures

The following additional security measures should be considered:

a) Structures and poles should be kept a sufficient distance from the fence perimeter to minimize the potential use of the structure itself to scale the fence.
b) All sewer and storm drains that are located inside the substation perimeter, with access from the outside, should be spiked or fitted with vertical grillwork to prevent entry.
c) Manhole covers or openings should be located on the inside of the substation perimeter fence.
d) Driveway barriers (gates, guardrails, ditches, etc.) at the property line for long driveways can help limit vehicular access to the substation property.
e) Signs should be installed on the perimeter fence to warn the public that:
    1) Alarm systems are providing security for the substation.
    2) Entry is not permitted.
    3) There is a danger of shock inside.
f) Most of the security measures described in this clause can be utilized in a retrofit application at an existing substation.

INCIDENT ALERT

Issued in the interest of incident prevention by the Security Department

Issue Number 001

Date: June 1, 1996 Time: 12:25 p.m.
Location: ACB Company, Inc.
Value of material involved: $500 + (estimated)
Loss: Approximately 500 lb, 100 mcm, 15 kV scrap copper cable stored in backyard.
Impact: Monetary/potential hazard to employees and visitors — suspect almost ran over employee while exiting facility after being approached.
Contributing factors/suspects: Vehicle – yellow, full size, 1983 station wagon, driven by white male, 30s, 6’1”, 180 lbs, blonde hair. Other similar incidents past few years. Facility has interior security system. Yard not covered presently.
Note: Copies of actual Loss Report which provides more detail may be obtained by contacting Mr. Smith at (800) 555-1234, extension 567.

Figure 1—Example form

7. Effectiveness of security methods

Table 1 through Table 4 contain a summary tabulation of responses to the security survey. The tabulation provides an indication of the effectiveness of security methods used by the respondents in four types of substations: urban, suburban, rural, and industrial/commercial. Regardless of the substation type, some general observations are possible. Use of lights, signs, and special locks are by far the most common security methods employed. Although generally effective according to the majority of the respondents, these methods were not found to be completely effective and can be defeated.

The remaining methods surveyed apparently are not often utilized, based on the limited number of respondents employing the specific methods. This is probably the result of increased cost, complexity, and/or inconvenience. When employed, these methods have been found to be generally more effective than lights, signs, and special locks. Those methods (alarm systems, motion detectors, and electronic protection) used least often were reported to be completely effective.

Other methods reported in the survey included portable video cameras, sirens activated by motion, silent alarms, private security companies, and laser alarms. These methods were not widely used and there was no report as to their effectiveness.

Table 1—Effectiveness of security methods—urban substations

Method	Number of respondents reporting to survey	Respondents reporting method not effective (%)	Respondents reporting method somewhat effective to effective (%)	Respondents reporting method very effective to completely effective (%)
Lights	31	7	77	16
Signs	27	7	78	15
Special locks	18	1	66	33
Solid wall	7	0	57	43
Security guard	5	0	60	40
Manned station	4	0	100	0
Optical alarms	4	0	75	25
Fence	4	0	75	25
Video camera	3	0	100	0
Special equipment (metal-clad, polymer)	3	0	67	33
Door alarm (to SCADA)	2	0	0	100
Alarm system	2	0	0	100
Motion detectors	1	0	0	100
Electronic protection	1	0	0	100

Table 2—Effectiveness of security methods—suburban substations

Method	Number of respondents reporting to survey	Respondents reporting method not effective (%)	Respondents reporting method somewhat effective to effective (%)	Respondents reporting method very effective to completely effective (%)
Lights	31	6	78	16
Signs	27	11	81	8
Special locks	19	5	69	26
Solid wall	4	0	60	40
Security guard	6	0	100	0
Manned station	4	0	100	0
Optical alarms	4	0	100	0
Fence	5	0	60	40
Video camera	3	0	100	0
Special equipment(metal-clad, polymer)	3	0	67	33
Door alarm (to SCADA)	2	0	0	100
Alarm system				
Motion detectors	1	0	0	100
Electronic protection	2	0	0	100

Table 3—Effectiveness of security methods—rural substations

Method	Number of respondents reporting to survey	Respondents reporting method not effective (%)	Respondents reporting method somewhat effective to effective (%)	Respondents reporting method very effective to completely effective (%)
Lights	31	13	74	13
Signs	22	11	77	12
Special locks	17	6	65	29
Solid wall	1	0	100	0
Security guard	4	25	50	25
Manned station	3	0	100	0
Optical alarms	5	0	100	0
Fence	5	0	60	40
Video camera	3	0	66	34
Special equipment (metal-clad, polymer)	3	0	100	0
Door alarm (to SCADA)	1	0	0	100
Alarm system	2	0	0	100
Motion detectors				
Electronic protection	1	0	0	100
Passive and microwave systems	4	0	0	100

Table 4—Effectiveness of security methods—industrial/commercial substations

Method	Number of respondents reporting to survey	Respondents reporting method not effective (%)	Respondents reporting method somewhat effective to effective (%)	Respondents reporting method very effective to completely effective (%)
Lights	28	4	82	14
Signs	25	8	84	8
Special locks	15	7	73	20
Solid wall	3	0	34	66
Security guard	5	0	40	60
Manned station	3	0	100	0
Optical alarms	2	0	100	0
Fence	3	0	66	34
Video camera	2	0	100	0
Special equipment (metal-clad, polymer)	2	0	50	50
Door alarm (to SCADA)	1	0	0	100
Alarm system	1	0	0	100
Motion detectors				

8. Substation security plan

The preparation of a security plan shall require answering the following:

a) Why is the plan needed?
b) Who will administer the plan?
c) What security measures are required by the individual facility?

These questions need to be addressed before a comprehensive and cost-effective security plan can be created.

8.1 Objective of the security plan

For any plan to be successful, it must have a clearly stated objective. Using historical operating data, demographics information, and industry experience, each company can determine the level and type of security required. Defining the objective will help focus attention on those security methods most appropriate to the company's needs. The objective should state the present and primary concerns, such as vandalism and theft in existing stations, or theft and injury during substation construction.

8.2 Responsibility for security

Identification of the person or persons responsible for security implementation and administration is critical to the effectiveness of the plan. Therefore, defined levels of responsibility and specific tasks are required for each level. Each company should have someone in charge of facilities security. This individual should be responsible for assuring that a security plan is developed, implemented, regularly reviewed, and updated. Regular inspection of facilities to assure that security measures are in effect should be part of the security plan, along with employee training and methods that enable employees to report irregularities or breaches of security.

8.3 Basic security requirements

All existing and new substations have a basic minimum level of security required. This includes fences with locked gates, control buildings with locked doors, a special type of grounding system if copper theft is prevalent, and minimum clearance distances between perimeter fences and energized equipment. Basic security requirements should list these measures as required in all cases, regardless of location or age of the station. In addition, some types of security breach may require special or immediate action by operations staff. For example, damage to the ground system of an energized station should be treated with care in case of the unlikely event of a dangerous touch potential. These types of security breaches should be noted in the security plan. At construction and material storage sites, or vacant land, minimum security levels may either not exist, or may be inadequately described. Therefore, it is important to define the security measures required by type of facility or site, especially if the measures required are different from other basic measures normally required. For instance, vacant land should be inspected on a regular basis for evidence of use for illicit activities, unauthorized dumping, and existence of holes that could cause injury due to falls. Security methods at active construction sites can include moving all construction equipment inside of fenced areas at night and check in/check-out of personnel through a security gate.

8.4 Additional security measures

Additional security measures, over and above the basic requirements, may be determined to be necessary based on the security survey results. The increased security measures required should be based on restricted access or high-risk areas. The types of security used in these instances could include motion detectors, perimeter/area detection systems, security cameras, jersey barriers, and posted guards.

8.5 Sample security assessment

A plan for evaluating the effectiveness of any mitigating measures should be initiated. Records should be kept for each substation to document the security option used, date of application, type of intrusion and problem the option is intended to mitigate, and the history of intrusion problems. This record is necessary to monitor the performance of the applied option in order to evaluate the feasibility of future applications. The form shown in Figure 2 is a sample format for security assessment and includes a summary of the items addressed in this guide.

Security Assessment

Assessment completed by: ________________________
Date: ________________________
I. SUBSTATION LOCATION: ____
II. SUBSTATION CLASSIFICATION:
A. Type:
? Rural ? New facility ? Permanent facility
? Urban ? Existing facility ? Temporary facility
? Construction site ? Land bank
1. Construction type____________________________________
2. Location____
3. Distance to nearest occupied facility_______________________
4. Type of access road__________________________________
5. Visibility/screening from view__________________________
6. Distance to regularly traveled road________________________
7. Topography____
8. Environmental consideration___________________________
B. Planned activity:
? Vacant ? Construction
? Pre-construction ? Operational
C. Equipment involved:
? None (unoccupied) ? Construction equipment
? Storage ? Energized facility
III. SITE RISK EVALUATION:
Local demography Labor conflicts/disputes
Local economics Adjacent landowners (uninhabited)
Local crime rate/reported incidents Adjacent landowners (inhabited)
Local building/construction aesthetics Substation value
IV. SITE MAINTENANCE:
Yes No
A. General observation:
Evidence of use ? ?
Bottles and/or cans ? ?
Refuse ? ?
Standing water ? ?
Comments/explanation: ____
____
____

Figure 2—Security assessment

Yes No
B.Walls and fences:
Damage ? ?
Graffiti ? ?
Broken strands or holes ? ?
Rust to galvanizing ? ?
Undermining ? ?
Evidence of attempted entry ? ?
Damage to locks or hinges ? ?
Comments/explanation:____

Yes No
C. Station yard:
Refuse ? ?
Disturbed grading ? ?
Damage to grounding conductor
or hardware ? ?
Graffiti on walls or equipment ? ?
Loose valves or evidence of tampering ? ?
Evidence of vandalism ? ?
Broken or chipped porcelain ? ?
Comments/explanation:____

Yes No
D.Control building:
Attempted entry ? ?
Stolen or missing maintenance equipment ? ?
Evidence of occupancy ? ?
Tampered control equipment ? ?
Comments/explanation:____

Comments/other:____

Recommendations: ____

Figure 2—Security assessment (continued)