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DRAFT STANDARD FOR PUBLIC COMMENTS

Draft Zambian Standard

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

ZAMBIA BUREAU OF STANDARDS

DRAFT STANDARD FOR PUBLIC COMMENTS

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FOREWORD

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The preparation of this Zambian Standard was undertaken by the Technical Committee TC 5/7: Electricity Supply which is responsible for the development of standards for electrical generation, transmission and distribution systems.

The standard is technically equivalent to the IEEE Std 1127-2013, Guide for the Design, Construction, and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility

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ZAMBIA BUREAU OF STANDARDS

DRAFT ZAMBIAN STANDARD

GUIDE FOR THE DESIGN, CONSTRUCTION AND OPERATION OF ELECTRIC POWER SUBSTATIONS FOR COMMUNITY ACCEPTANCE AND ENVIRONMENTAL COMPATIBILITY

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1 OVERVIEW

1.1 Scope

This guide identifies significant community acceptance and environmental compatibility items to be considered during the planning and design phases, the construction period, and the operation of electric supply substations, and documents ways to address these concerns to obtain community acceptance and environmental compatibility. On-site generation and telecommunications facilities are included.

1.2 Purpose

This guide provides guidance on community acceptance and environmental compatibility for new substations or substation expansions. It has been divided into four major parts arranged chronologically with the goal of providing guidance on acceptable practices for:

a) Site Selection (Clause 4.);
b) Design (Clause 6.);
c) Construction (Clause 7.); and
d) Operation and Maintenance (Clause 8.).

However, many of the activities discussed under the different parts may overlap. For example, the permitting activities in Clause 5 occur throughout the process with some permit considerations occurring at the beginning of site selection and others taking place during construction. Also, many design considerations require more of an iterative process rather than a chronological one. Therefore, users of this guide should be aware that some overlap of information exists between clauses.

2 NORMATIVE REFERENCES

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ZS 418 Electrical Safety Code
ZS 691 Safety in AC Substation Grounding.
ZS 692 Substation Fire Protection.
Environmental Management Act, No. 12 of 2011
Factories Act, Cap 441 of the Laws of Zambia
IEEE Standards Dictionary Online
ZS IEEE 980 Guide for Containment and Control of Oil Spills in Substations
ZS IEEE 1402 Guide for Physical Security of Electric Power Substations

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3 DEFINITIONS

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause

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

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

3.3. Community: local authority, regulatory agencies, project affected persons.

3.4. 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.

3.5. Hazardous material: Any material that has been so designated by the Environmental Management Act, No. 12 of 2011 or adversely impacts human health or the environment.

3.6. Industrial zone: A zone that includes manufacturing plants where fabrication or original manufacturing is done, as defined by local regulations.

3.7. Noise: Undesirable sound emissions or undesirable electromagnetic signals/emissions.

3.8. Residential zone: A zone that includes single-family and multi-family residential units, as defined by local regulations.

3.9. Wetlands: Any land that has been so designated by the relevant government agency. Characteristically, such land contains vegetation associated with saturated types of soil.

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

3.11. Zone of Influence: An area of engineering soils likely to be affected by loading due to engineering or building development**.**

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4 SITE SELECTION

4.1 General

A project to successfully design, construct, and operate a substation begins with proper planning. Site selection 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 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 impacts, and measurement of ambient noise and electromagnetic field (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, ultimately, stop a project completely.

4.1.1 Site location and selection

The best site location and placement of the substation on a project site are influenced by several factors, each of which can affect the time and cost required in constructing the substation project, including but not limited to the following:

a) Proximity to electric load or generation
b) Proximity to transmission and distribution lines and availability of access for future lines
c) Substation size requirements - initial and ultimate layout (future expansion)
d) Availability of adequate property and willing seller
e) Vegetation - clearing requirements
f) Community attitudes and perceptions
g) Location of nearby wetlands or bodies of water or environmentally sensitive areas
h) Topography and soil conditions
i) Site contamination (obvious or hidden)
j) Seismic considerations
k) Proximity to airports
l) Local zoning, commercial, industrial, and residential neighbours
m) Permit requirements and regulations
n) Proximity to other utilities - phone, water, and sewer
o) Drainage patterns and storm-water management
p) Disturbance of archaeological, historical, or culturally significant sites
q) Site accessibility - proximity to roads and railways
r) Aesthetic and screening considerations

4.1.1.1 Proximity to electric load or generation

There are benefits to both community acceptance and the electrical system in locating substations near the electrical load or generation site due to shorter lines required. Typically the overhead lines (both transmission and distribution) provide more concerns to the public than the substation. However, location of the substation dictates some line routing considerations.

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4.1.1.2 Proximity to transmission and distribution lines and availability of access for future lines

The substation site selection affects the line routing for both transmission and distribution lines. The line routing and right-of-way (ROW)/wayleave requirements typically have a significantly larger impact on the public than the substation as the wayleave is adjacent to much more area. Siting a new substation in an area where all the lines enter and leave the substation in the same direction can create a new transmission corridor with several lines constructed in the same area. This not only impacts the public with the corridor area with many lines, but it may have system reliability issues as well.

Substation layout considerations also may have an impact on line routing. Space limitations inside the substation can limit where specific lines enter the substation and the substation layout may require unwanted line crossings or additional wayleave requirements outside the substation.

Some transmission line designs utilise double-circuit structures to carry two transmission lines on the same structure. This can have permit approval and system reliability implications. Some government agencies are aware of the reliability issues and limit the amount of double-circuit installation on high-voltage transmission lines. This can create the need for wider transmission corridors to accommodate the number of lines entering a substation.

4.1.1.3 Substation size requirements

It is important to consider the initial substation construction requirements as well as future substation expansion per the ultimate design in order to determine the substation size requirements. The ultimate substation may require more area than what is inside the initial fenced area. It is important to be aware of the number of existing and future transmission and distribution lines and associated wayleave requirements. There may be storm-water runoff requirements to consider such as construction of a retention pond based on permitting. Accessibility to and from the site location with respect to access roads is also a key factor. The transmission or distribution lines may require additional wayleave. There are benefits for substation design engineers to have more space to accommodate different layouts or configurations to reduce wayleave requirements from line routing.

4.1.1.4 Availability of adequate property and willing seller

The availability of adequately sized property with a willing seller can be an important aspect in site selection. This may provide the utility with a partner in the community and may be a crucial aspect of the ability to obtain permit approval to construct the substation on a preferred site. This will also provide a communication point for developing community acceptance at any public hearings.

4.1.1.5 Site vegetation

Proposed sites with heavy vegetation or a large number of trees should be evaluated for several issues other than the cost of clearing. If the site is large enough to retain the vegetation as screening around the site, consideration should also be given to the concern for security of a site that is not readily visible for observation. An evaluation of the fire hazard created by the retention of such vegetation should also be included. Permitting requirements and mitigation methods for the removal of the vegetation or trees may be required. Water runoff considerations and the possible need to permit the creation of wetlands should also be considered if clearing is required. In initial site evaluation, the abundance of heavy vegetation may hinder the ability to provide a valid assessment of the acceptability of the site due to the unknown topography behind or under the vegetation. In cases where vegetation is left to screen the substation, transmission and/or distribution line wayleave clearing requirements should be considered to avoid future conflicts.

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4.1.1.6 Community attitudes and perceptions

Consulting local community representatives helps develop a sense of their values and concerns, providing important information for the site selection team to consider. In addition this assists in developing a good working relationship with the community.

4.1.1.7 Wetlands

The design of any new substation should consider the protection of wetlands and groundwater from sedimentation runoff, insulating fluid, 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, when available, may be considered, as government agencies (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. The development of wetland delineation maps for the area may require field inspection during the growing season.

A site-development plan is necessary for a substation project that borders wetlands. Such a plan for the site and its immediate surroundings may include but is not limited to 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 groundwater
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 groundwater protection.

4.1.1.8 Topography

The selection of an elevation for a substation yard should include consideration of environmental factors in addition to accessibility, construction, and cost factors. A lower elevation in relation to surrounding terrain and vegetation may improve concealment. This, however, can significantly increase the impact on construction if the water table is high, if there is a ledge to be excavated and removed, or if there is a flooding potential at the lower elevation. Also consideration should be given to balancing cut and fill quantities, to minimise export and/or import of soil.

A flat substation yard is most desirable when considering substation design and operability. When steep slopes are encountered, a stepped substation of two or more levels can be designed to achieve flat areas within the yard. The slope of a substation yard should be designed to minimise erosion and sedimentation potentials and should retard oil-spill containment in the more impermeable soils. A sloped yard or swale will also lessen the extent to which side-sloped or retaining walls are required to provide yard transition to the existing grade. Minimised slopes allow easier access of vehicles and maintenance equipment required for effective operation and maintenance of facilities.

The soil conditions can have significant effects on the substation construction and resulting grading design requirements. If there is a large amount of topsoil to be removed to provide adequate support for the substation equipment, there may be benefits to purchasing adequate property to spread the unusable topsoil, or foundation spoils, outside the substation graded area.

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Sedimentation potential is likely to exist on sites. 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 topsoil. This solution also assists in reducing the amount of moisture that could facilitate the growth of unwanted vegetation.

4.1.1.9 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 preceding list, any substance that the environmental management regulatory agency has determined to be a hazardous material should be considered. The regulatory 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.

All potential sites should have a historical review completed to review prior landowners and prior use. In addition, all potential sites should be visited by personnel trained to identify 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 clean-up is needed, the acquisition of another site should be considered since the environmental management regulations can hold the current owner or user of a site responsible for clean-up of any contamination present, even if substances were deposited prior to acquisition. If a clean-up is initiated, all applicable environmental regulatory guidelines and procedures should be followed.

4.1.1.10 Seismic considerations

Although the risk for seismic activity will likely be the same for the general area requiring a substation, soil type and distance from the fault line are two key considerations to reduce the response impact from an event.

4.1.1.11 Proximity to airports

The proximity of a substation and associated overhead lines can be negatively affected by their proximity to airports. The airport location will require height limitations on both substation and overhead line structures. These

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limitations can impact the number and height of transmission line structures and the line route. Consideration should be given to potential interference with air navigation system facilities.

4.1.1.12 Local zoning

Local zoning regulations may place limitations on property usage or require zoning revisions to property prior to obtaining approval to construct substation facilities. Other area property zoning or property usage may also affect the permit approval process. For more information on permitting refer to Clause 5.

The number of residences or other buildings and structures within a certain distance of the proposed substation may have an impact on site selection. Where several sites are selected as may be required by permit requirements, government agencies may require documentation of affected commercial properties, industrial properties, and residential properties as well as environmental areas affected by the different solutions in order to select a site for permit approval.

4.1.1.13 Permit requirements and regulations

There are local and national permit requirements that vary greatly. It is very important for the site selection team to include someone familiar with the permit requirements for the area to be considered prior to selecting a substation site. Refer to Clause 5 for further permitting details.

4.1.1.14 Proximity to other utilities

The substation site may need phone service, potable water, or sewage disposal facilities.

The proximity of a substation to local phone lines or access to communications systems can impact obtaining service, and providing the Zone of Influence for isolation.

Water may be obtained from water utilities or communal water sources or from private wells. The quality of water supplied by the utility or communal 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 water and sanitation 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 service, the requirements of that utility should 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.

4.1.1.15 Environmentally sensitive and protected areas

Substation site selection should consider the impacts of sites near any navigable waterways or other environmentally sensitive and/or protected areas and may need special considerations to control water runoff and contain oil spills from existing waterways.

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4.1.1.16 Archaeological, historical, or culturally significant sites

Substation site selection should attempt to avoid disturbance to identified archaeological, historical or culturally significant areas. If unavoidable, permits may require documentation and mitigation of these areas.

4.1.1.17 Site accessibility

Site selection should consider the existing roads and new access 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.

It is important that substation access for construction, operation, and maintenance equipment minimises the effects on the local traffic flow. Blind road access can create traffic issues. The provision of off-road parking for operations and maintenance vehicles can facilitate community acceptance by promoting considerations of safety for both the public as well as the maintenance and operations personnel who travel to the substation worksite.

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

4.1.1.18 Aesthetic and screening considerations

Some substation site requirements require special considerations to provide screening from the public for new substations. This may be a permit requirement.

There are many aesthetic considerations that may benefit the site selection team to provide a priority or preference rating on one site over another.

The aesthetic considerations are covered in detail in 6.1.

4.1.2 Storm-water management

Where rapid scour by storm-water flow entering or leaving a substation yard is not a problem, sedimentation-control features of substation design will be adequate by themselves. Where this is a potential problem, site design should, to the extent possible, 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 should conform to regulatory requirements.

4.1.2.1 Upstream considerations

Most, if not all, communities have flood maps prepared under the auspices of the local authorities or government agencies. These maps indicate stream flood ways where construction is discouraged or prohibited and floodway fringes where construction is limited and subject to the approval of a regulatory authority. If the substation site is outside of these floodway zones, the most frequent source of concern is when the site includes stream control measures for a wetland that should 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 should 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

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permitted to remain in the general area of the control if it is situated exactly at existing grade and any stream crossing is made with a bridge. For wetland preservation, such a bridge and its abutments need to be outside of the watercourse during normal flows, but not necessarily outside of the stream's floodway. This same bridge concept can be used to help preserve existing conditions downstream.

4.1.2.2 Downstream considerations

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

4.1.2.3 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 and ice hazards. Both of these consequences can be mitigated by applying additional crushed stone to problem areas. Underground storage systems may be a cost-effective alternative when space is a concern.

4.2 Community considerations

Consider the optimal timing for meeting with local government and community officials to inform them of the community need or electrical system need. These meetings are an excellent method of soliciting feedback to determine critical issues regarding substation site selection, and help strengthen working relationships with the local community.

If appropriate or necessary, public open houses may be beneficial. The open house process should be well planned and the team attending or presenting information should be well informed on the project needs and requirements prior to the event.

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5 PERMITS

5.1 General

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

a) Site location
b) Level of groundwater
c) Proximity of wetlands and other bodies of water
d) Potential of existing hazardous materials
e) Need for potable water and sewage
f) Noise sound level
g) Proximity to airports
h) Aesthetics
i) EMF

Additional factors influencing the number of permits required and complexity of the permitting process for a project include:

a) If the project is a new substation,
b) If it is an addition to an existing facility,
c) If the substation is to be built within existing property boundaries, and
d) If the substation is associated with a larger project, such as a transmission line, generating plant, or other facility.

For new substations, part of the site selection process should be to find, when possible, a location where substations fall within acceptable land uses based on local zoning codes.

Specific permitting requirements may vary widely based on the location of the facility. While national permitting requirements generally apply, provincial and local jurisdictions will also have permitting requirements. Engagement of a local environmental permitting specialist, consultant or the energy regulatory body early in the project development process is an important step toward a successful project. The local specialist will be familiar with the myriad permitting requirements of the area impacted by the development of the substation project.

The current national laws make it a requirement for any person intending to construct an energy facility (which includes a substation) to apply for a permit from the energy regulatory body. The energy regulatory body provides information on the permitting requirements for developers of substations and a construction permit is issued to a developer who meets these requirements.

Further, the energy regulatory body issues a licence to operate the substation once construction has been successfully completed.

5.2 Public involvement

Timing for the permit application is a critical factor because permit applications may trigger public opposition. 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

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those affected by the project, identify political and community concerns, obtain an informed consensus from project stakeholders, and provide a basis to increase credibility and reputation as a good neighbour.

Public participation can be defined as the process of communicating with interested or affected individuals, organisations, and government entities before permit applications are filed. 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 constructing entity by providing two-way communication and collaborative problem solving with the goal of achieving better and more acceptable decisions. Every effective public participation program does, however, include a public information component. Public participation is mutual problem solving between the community and the constructing entity in an effort to reach a decision that achieves public acceptance.

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
g) Developing relationships with the community

The government agencies have enacted laws that require public participation prior to the permit application.

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6 DESIGN

6.1 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 the following:

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 and landscaping, if required
e) Site access that harmonises with the community

6.1.1 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 at the completion of the project. Also, in recent years with the satellite and aerial imagery, in addition to the substation itself, an entire area has been driven or flown by in computer generated videos.

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.

The level of the effort to provide visual simulation depends on the extent of detail that is requested for permitting or public meetings.

6.1.2 Landscaping and topography

6.1.2.1 Landscaping

Landscaping, as a supplement to natural vegetation screening, may be a very effective aesthetic treatment where buffer spacing exists on site to provide vegetation concealment of a substation site. 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 may be employed informally and with variety. Low ground cover and grasses are effective on berms and in ditches. When planted on top of a berm, the impact of the landscaping plantings can be immediate for screening purposes. Coniferous trees give excellent coverage and colour, and can be used in clusters, in hedges, or spaced apart. Size should be sufficient for the screening purpose but not so large as to impact clearances of overhead lines. Species selection may avoid animal or bird attractant types that create a hazard to the function and operation of equipment or personnel.

All plantings may be locally available and compatible types, and may require minimum maintenance. Ongoing maintenance needs, such as irrigation and trimming, may also be considered.

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Landscape locations near walls and fences should not compromise substation grounding/earthing, maintenance access, or security.

6.1.2.2 Topography

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

The initial 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 may consider the effect of screening, horizontal setback, and the background screen on the primary observation. Aesthetically, the land form within the site may reflect or blend with the topography of its environment. The use of land form may be evaluated in combination with plant materials. The 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.

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. The design of earth forms should incorporate the water patterns to allow the water flow to leave the property within acceptable parameters. Appreciable cost savings can be realised by utilising cut material spoil on the site for earth forms rather than removing it from the site. A layer of medium to coarse sand or geotextile fabric beneath a crushed stone surface can minimise the potential for sedimentation potential within a substation yard area that is long and steeply sloped. A satisfactory surfacing material is a well-graded, crushed aggregate. Roads can be hard paved if:

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

Roads should be provided with appropriate surface drainage control.

6.1.3 Fences and walls

The primary means of limiting public access to substations is by the erection of a suitable barrier, such as a fence or a wall with warning signs. The ZS 418: Electrical Safety Code requires that fences, screens, partitions, or walls be employed to keep unauthorised persons away from substation equipment.[1] At a minimum, the barrier should meet the requirements of ZS 691 and other applicable electrical safety codes and standards.

Recommended clearances from substation live parts to the fence are specified in the ZS 418 and other applicable electrical safety codes, and security methods are described in ZS IEEE 1402.

[1] Information on references can be found in Clause 2

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

6.1.3.2 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 or security breaches than masonry or metal.

6.1.3.3 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. Concrete or masonry walls also provide the benefit of noise suppression for urban locations. 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 precast concrete can also be used in solid walls, but these materials can be far more expensive. These materials may be considered where necessary for architectural compatibility with neighbouring facilities. Walls can be subject to graffiti, and this may be part of the consideration of their use. Access to substation equipment should be considered carefully.

6.1.4 Colour

When substations are not well screened from the community, colouring may 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, as follows:

a) 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 may 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.
b) Using 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 may be avoided.
c) Brightly coloured equipment and structures can provide for an intensive visual impact.

Use of non-industry standard colour can be more expensive and may create maintenance issues in case of failure.

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6.1.5 Lighting

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. Local jurisdictions may have additional lighting requirements.

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

6.1.6 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 aboveground. Transmission line termination structures are usually the tallest and most obvious. Use of underground line exits may 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 may be reduced if a low-profile design is used. Often the substation with low-profile structures can be brought below the nearby tree line profile. However, low- profile structures may impact the space requirements.

For additional cost, the most efficient structure design can be modified to change the appearance of the steel for aesthetic purposes. Some ideas include the following:

a) Low-profile 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 of 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
l) Use of weathered or painted steel

6.1.7 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 locales that are served by overhead power lines is to take advantage of equipment enclosures to modify visual impacts. Relay and control equipment, station batteries, and indoor power switchgear all require enclosures. These enclosures can be aesthetically designed and strategically located to supplement landscape concealment of other substation equipment. The exterior appearance of these enclosures can also be designed (size, colour, materials, shape, etc.) to match neighbouring homes or buildings.

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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 precast concrete can also be used.

6.1.8 Bus design

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

6.1.8.1 Air-insulated substations

When chain-link fencing is used, 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, wood, or concrete structures with 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 to install outdoor bus facilities. In substation sites with limited space it may be more acceptable to consider a high-profile design in order to limit the area required for the substation. This can provide benefits to customers who need a substation to accommodate new load but want to limit the substation footprint.

6.1.8.2 Switchgear

Metal-enclosed or metal-clad switchgear designs that employ either air or other insulation systems and enclose 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.

6.1.8.3 Gas-insulated substations (GIS)

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

6.1.8.4 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.

6.2 Noise

Audible noise, particularly continuously radiated discrete tones (e.g., from power transformers), is the type of noise the community may find unacceptable. Community guidelines that establish acceptable noise levels can take the form of national 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

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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.

6.2.1 Noise sources

6.2.1.1 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, can also be sources. This noise is the type most likely to be subject to national regulation. Another source of audible noise in substations, in particular extra high voltage (EHV) substations, is corona from the bus and conductors.

6.2.1.2 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.

6.2.1.3 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.

6.2.2 Typical noise levels

6.2.2.1 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, loading, and design. Few complaints from nearby residents are typically received concerning substations with small transformers (e.g., less than 10 MVA), except in urban areas with little or no buffers. Complaints are more common as transformer size increases, especially within the first 170 m to 200 m. However, in very quiet rural areas where the night time ambient can reach 20 dBA to 25 dBA, the noise from the transformers of this size can be audible at distances of 305 m or more. Substations constructed on large parcels of land often have not resulted in many noise complaints because the transformer is further away from the public.

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6.2.2.2 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 more 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. Some jurisdictions may have additional requirements related to pure tones.

Common outdoor noise levels are shown in Table 1.

Table 1: Common outdoor noise levels

Type	Noise level (dBA)
Jet flyover at 305 m	110
Petrol lawn mower at 0.9 m	100
Diesel truck at 15 m	90
Noisy urban daytime	80
Petrol 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: IEEE std 1127 - 2013 (Table 2) (*Fundamental and Abatement of Highway Traffic Noise. By permission of BBN Corporation*)

Highway traffic can provide a base ambient noise that can help 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 km to 3 km. A substation could benefit from the shielding effect of highway noise if it is located less than 3 km from a highway.

6.2.2.3 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

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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, Equation 1 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, Equation 2 has been further modified to relate attenuation to these transformer ratings. Both equations can be readily plotted graphically for comparison to ambient noise levels.

$$N = -4.4 + dBT - 20\log\left(\frac{D}{\sqrt{WH}}\right) \qquad \text{Equation 1}$$

Or

$$N = -6.2 + dBT + 2.08\log[(kV)(kVA)] - 20\log D \qquad \text{Equation 2}$$

In both cases, far field is defined as follows:

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

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)

If *W*, *H*, and *D* are expressed in feet (ft.), Equation 1 remains unchanged as it is dimensionless. Equation 2 becomes Equation 3:

$$N = 4.1 + dBT + 2.08\log\{(kV)(kVA)\} - 20\log D \qquad \text{Equation 3}$$

With respect to more than one transformer, the contribution of each source at the point of observation should be calculated separately. The value of each is combined as the logarithmic sum of the two. **Error! Reference source not found.** 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.

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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.

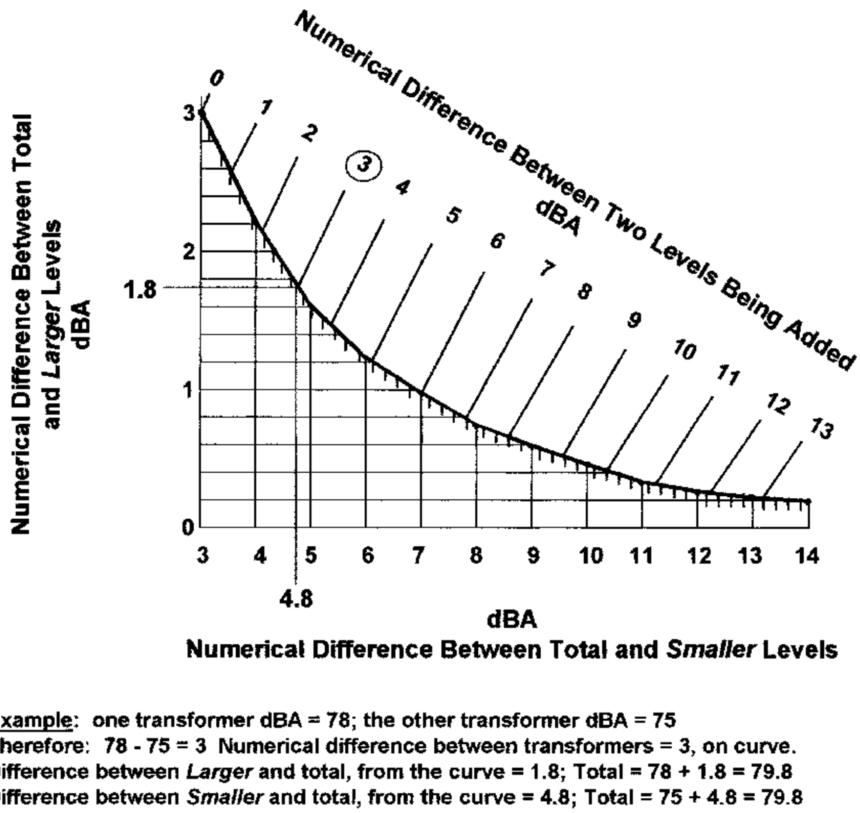

Figure 1: Nomograph for determining combination sound levels
[from IEEE Std 1127 – 2013 (Figure 1)]

6.2.2.4 National regulations

National 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 management regulatory agency where limited buffer zones often exist between property owners.

Additional national noise regulations address noise levels by limiting the increase above the existing ambient. Other regulations could limit prominent discrete tones or set specific limits by octave bands.

6.2.3 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 6.2.3.1 through 6.2.3.7.

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

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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 **Error! Reference source not found.** 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.

6.2.3.1 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 and manufactured at an additional cost 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.

6.2.3.2 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.

6.2.3.3 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 high voltages without objectionable corona if corners are rounded at the ends of the conductors and bolts are kept as short as possible.

Tubular shapes may be required at extra high voltages. 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.

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6.2.3.4 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 may 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 grade and surrounded by berms.

6.2.3.5 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.

6.2.3.6 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.

6.2.3.7 Barriers or walls

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

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

a) Transmission loss through masses
b) Sound diffraction around obstacles
c) Standing waves behind reflectors
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 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 Equation 4

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$$dB_{120Hz} = 9.5\log\left[\sqrt{(R^2 + h^2} - R\right] + 8.7 \qquad \text{Equation 4}$$

(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 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 atdistance R

With known values for R and the decibel reduction desired, a specific value of h can be calculated. If R and h are expressed in feet, Equation 4 becomes Equation 5:

$$dB_{120Hz} = 9.5\log\left[\sqrt{(R^2 + h^2} - R\right] + 3.8 \qquad \text{Equation 5}$$

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

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

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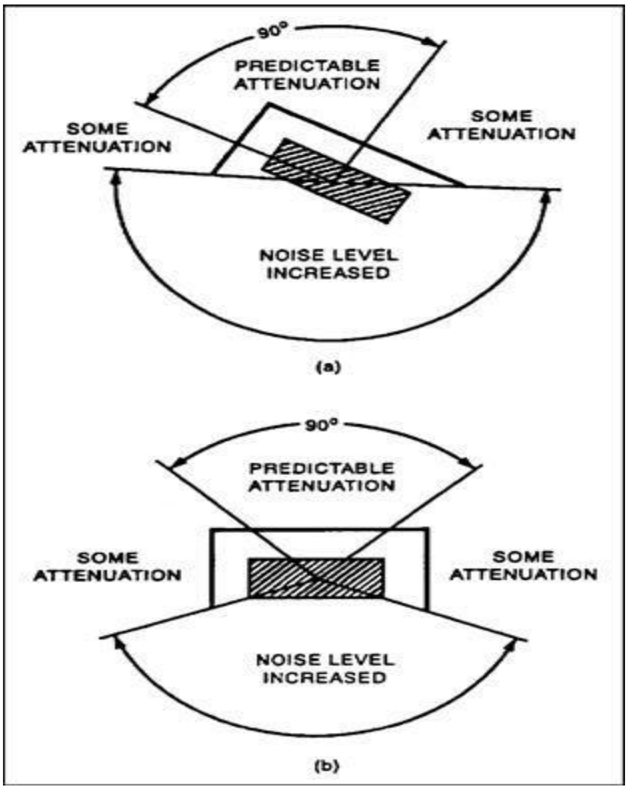

Figure 2: Regions of sound attenuation and sound increase around (a) L-shaped barrier (two- sided) and (b) U-shaped barrier (three-sided) [*from IEEE std 1127 – 2013 (Figure 2)*]

6.2.4 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.

6.2.5 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 dBA to 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 national regulations may have to be considered to lessen complaints.

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Objections to substation noise levels below those set by national regulations can also occur in urban areas. However, the benefit resulting from higher ambient background levels of 35 dBA to 45 dBA or more (night time) can be offset by the closer proximity of nearby residents (in some cases less than 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.

6.3 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. National regulations concerning levels may exist, and where they do, the substation design should comply.

In a substation, the strongest fields near 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 national regulations, the substation designer may consider design measures to lower EMF levels or public exposure to fields while maintaining reliable electric service.

6.3.1 Electric and magnetic field sources in a substation

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

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

6.3.2 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.

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

Although the level of the electric fields could reach levels of approximately 13 kV/m in the immediate vicinity of high-voltage apparatus, such as near 500 kV equipment, the level of the electric field decreases significantly toward the perimeter fence. At the fence, which is at least 6.4 m from the nearest live 500 kV conductor, 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.

There may be national standards specifically for electric fields in substations (at the property line). It is recommended that any national standards and guidelines be reviewed. The ZS 418: Electrical Safety Code and the Wayleave Code of Practice specify guidelines for safe distances from live conductors for different voltage levels at 50 Hz.

6.3.2.1 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 a factor of four.
b) Modifying phase spacing and bus diameter. Theoretically, a decrease of 50% of either phase spacing or bus diameter could cause a reduction in the electric field level by approximately 10%. Allowable phase spacing reduction may be limited by other factors such as electrical clearances and short-circuit forces. Some phasing arrangement on parallel circuits, such as ABC on one circuit and CBA on the other circuit, will result in increasing the field level because the fields of the adjacent C phases add together.
c) 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.
d) Use natural shielding. Trees and other vegetation along the property line might reduce the electric field level there.

6.3.2.2 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 public. By clearly and plainly demonstrating the definition and design levels of electric fields, informed consent can be reached.

6.3.3 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 meter (Tesla) or Maxwells per square centimetre (Gauss). One Gauss = 10^{-4} Tesla. The most common unit for this application is milli-Gauss (10^{-3} Gauss). Various factors affect the levels of the fields, including the following:

a) Current magnitude
b) Phase spacing
c) Bus height

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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 $1/r^2$. 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.

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.

There may be other standards specifically for magnetic fields in substations (at the property line). It is recommended that any relevant standards and guidelines be reviewed.

6.3.3.1 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:

a) Snapshot - Survey of magnetic field levels made at one instant in time
b) 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:

1) 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.
2) Contour plots showing magnetic field levels as contour lines on a site plan. The location of major site facilities such as buses, transformers, control building, fence, roads, and overhead and/or underground lines should be shown.
3) Three-dimensional plot of magnetic field levels on a site plan.

6.3.3.2 Magnetic field calculation methods

If it is 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 should be chosen by analysing many possible combinations of

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conductors in the duct bank and selecting one that results in magnetic field levels greater than the median field levels of the combinations evaluated.

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

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

In evaluating the results, modifications should be considered when the substation designer has specific regulation criteria or national guidelines for magnetic field reduction. Utilities are required to adhere to national standards, regulations and codes by taking 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.

6.3.3.3 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 should 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 feeders 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.

6.3.3.4 Community acceptance

In recent years, concerns of public impact have generated much discussion over EMF. Community acceptance of electromagnetic fields from substations located in areas near their residences can result in heated debate. EMF has developed into a socio-political issue that is not just a not-in-my-back-yard (NIMBY) issue. In many communities EMF is perceived as an unacceptable risk affecting the health, property values, and the environment of the community. Unsatisfactory resolution of these concerns by the project team 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 relevant regulatory agencies with data explaining the design and levels of magnetic fields created by the project.

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If the project team 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 should be taken not to mislead the community regarding magnetic field levels.

To obtain a community's consensus and acceptance, the project team may 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.

6.4 Environmental considerations

6.4.1 Oil spill containment and control

The detection, control and containment of oil spills should comply with the requirements of the environmental management regulatory agency. Where other government regulations exist, the substation design must also comply. ZS IEEE 980 provides guidance for methods used for the containment and control of non-PCB insulating-oil spills in substation. Spill Prevention Control and Countermeasure (SPCC) Plans are typically created for substation sites.

6.4.2 Sulphur hexafluoride gas considerations

Sulphur hexafluoride (SF_6) gas is used extensively in circuit breakers, gas insulated substations, and switchgear because of its effective inertness and dielectric properties. Emissions of SF_6 gas have become a concern as it relates to greenhouse gasses.

Concern about SF_6 emissions will vary among regulating agencies, yet it may be pertinent from a permitting perspective that planned equipment meets certain emission rates, for example 0.5% per year or less, depending upon the latest industry capabilities.

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7 CONSTRUCTION

7.1 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.

7.1.1 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 may be considered. Protective measures established during the design phase or committed to through the permitting process for groundwater, wetlands, flood plains, streams, archaeological sites, and endangered flora and fauna should be implemented during this period.

7.1.2 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. Some form of future access should be maintained for emergency replacement of equipment.

7.1.3 Water drainage

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

7.1.4 Control methods

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

a) Dust and mud control
   1) Water sprinkling trucks and spray hoses
   2) Chemical - nontoxic dust retarders
   3) Timely operation - in cases of moving equipment
   4) Covered haulers
   5) Crushed stone access road
   6) Vehicle washing
   7) Routine road clean-up

b) Erosion and sedimentation control
   1) Silt fences and hay bales
   2) Sediment basins and ponds
   3) Terracing, benching, and serrated slope areas
   4) Riprap and soil dikes
   5) Drainage ditches
   6) Diversion structures
   7) Vegetation buffers

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8) Soil stabilisation (seeding, netting, vegetation binders, wood chip cover, mulching, sodding, geotextile fabrics, hay or straw matting, shrubbery, and creeper planting)
9) Site access roads may follow natural site contours where possible
10) Dewatering of site and trenches
11) Concrete truck washout pit

7.2 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, preferably during the design and permitting stage 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)

7.3 Physical site security

Security procedures may be implemented during 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 of the Laws of Zambia (or subsequent versions of it). Refer to ZS IEEE 1402 for detailed descriptions of the security methods that can be employed. The security program may be monitored continuously to check that it is functioning properly.

The following are suggestions for site security:

a) Temporary or permanent fencing
b) Security guards
c) Security monitoring systems
d) Traffic control
e) Warning signs
f) Appropriate construction procedures
g) Temporary lighting
h) Tailgate meeting
i) Secure lock-ups for expensive equipment, copper wire, etc.

7.4 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 may be considered:

a) Traffic access, flow, and control as part of site development plan
b) Police assistance and manual traffic control
c) Traffic signal installations

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d) Reduce traffic at peak hours of commercial or community use
e) Coordinate movement with industries, schools, or other activities in the area
f) Move oversized vehicle loads over roadways during minimum traffic periods
g) Provide adequate parking on site

7.5 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. Material recycling may be considered and followed where possible.

Burning of refuse should be avoided and in many areas is prohibited by law. In open areas this activity is prohibited by the environmental management regulations.

Portable toilets should be provided during the entire construction period and routinely serviced.

7.6 Hazardous material

The spillage or leakage of 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 transportation, storage and handling of such materials during construction.

There are many substances that, if found on a substation site during construction, will require stoppage of work and notification of the environmental management regulatory agency before the site can become usable. Some of such substances are PCBs, asbestos, dioxin, lead and other heavy metals, and radioactive materials. Disposal of hazardous materials should adhere to appropriate guidelines, procedures, and national regulations.

7.7 Oil containment

Refer to ZS IEEE 980 for detailed guidance and identification of accepted substation oil containment practices and applicable industry standards.

7.8 Community involvement

Communicate the construction activities and impacts to the community throughout the project construction phase. Address community inquiries and concerns regarding the construction activities. Consideration may be given to developing a communications plan for initial and staged construction/development as well as for special operational or maintenance activities well into the life of the substation.

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8 OPERATIONS AND MAINTENANCE

8.1 Site housekeeping

8.1.1 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 identify problems so they can be corrected as they develop and should be made a part of regular substation inspection and maintenance.

8.1.2 Yard surface maintenance

Yard surfacing should be maintained as designed, to prevent water runoffs and to control dust. If unwanted vegetation is observed on the substation site, approved herbicides should be used with caution to prevent airborne and liquid runoff from damaging surrounding vegetation. If the possibility of runoffs could occur, then the affected area may be covered with stone to retard water runoff and to control dust. To help prevent airborne contamination, herbicides should be applied on a calm day.

8.1.3 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.

8.1.4 Landscaping

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

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

8.1.5 Storage

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

8.2 Noise

Inspection and maintenance of all attributes of equipment designed to limit noise should be performed periodically (as per Original Equipment Manufacturers (OEM) guide).

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8.2.1 Continuous audible sources

Periodic maintenance and inspection of station equipment and systems are recommended. 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 may reduce corona and minimise RF noise. It is also important to maintain good electrical contact in all metallic parts to eliminate gap sparking by improving contact pressures.

8.2.2 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.

8.3 Physical site security

All substations should be inspected periodically, following established and written procedures to maintain the security of the station. Refer to ZS IEEE 1402 for detailed descriptions of the security methods that can be employed.

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

a) Fences
b) Gates
c) Padlocks
d) Signs
e) Access detection systems
f) Alarm systems
g) Lighting systems
h) Earthing or Grounding systems
i) Fire protection equipment
j) All oil-filled equipment
k) Spill-containment systems

8.4 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.

8.5 Hazardous material

A spill-prevention control and counter-measures plan should be in place for the substation site and should meet environmental management agency requirements. For general guidance involving other materials see relevant environmental management guidelines.

A SPCC Plan should be in place for the substation site and should meet the prescribed national environmental requirements. For general guidance involving other materials see the environmental management agency guidelines and ZS IEEE 980.

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