

**ELECTRIC TRANSMISSION LINE ROUTING USING
A DECISION LANDSCAPE BASED METHODOLOGY**

A Thesis by

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I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in Electrical Engineering.

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ABSTRACT

Transmission line construction is one of the most complex engineering projects. Routing a transmission line is much more difficult than routing any other public infrastructure. The present system used by utilities is time consuming and does not produce satisfactory results. Actual construction of a large transmission line can be completed in a year or two, but due to complexities involved in the approval procedure, and opposition from various groups it can take years to build a line, and in some cases projects are stopped altogether.

The Geographic Information System is used in several ways by transmission line designers but its use in routing is limited. A new method, analytical minimum impedance surface (AMIS), developed by the University of Kentucky Transportation Research Center for routing highways is being adapted to routing transmission lines. This method will enhance the public involvement in the routing process, reduce opposition from stakeholders, and increase the probability of acceptance of the project.

This thesis contains the preliminary work required to apply AMIS to transmission line routing. Landscape features that affect the route of the line are the most significant part of this research. These features are incorporated into raster based GIS, and using information gathered from stakeholders, the route with minimum opposition is developed between two substations. Routing a line is also affected by the rules and regulations in a particular state. In this thesis a brief introduction is given to the main legal requirements involved in line routing. Non-point impacts that are independent of terrain are also given in detail. Potential stakeholders and their importance in the routing process is also explained in this thesis.

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LIST OF ABBREVIATIONS / NOMENCLATURE

GIS	Geographic Information System
AMIS	Analytical Minimum Impedance Surface
EMF	Electro Magnetic Force
NESC	National Electric Safety Code

LIST OF SYMBOLS

ε

Electric permittivity

μ

Magnetic permeability

Chapter-1

INTRODUCTION

1.1 Background

The US power transmission system is the one of largest electrical interconnected systems in this world. Transmission lines delivers and processes bulk electrical power on its way from generating stations to distribution, which completes the processing and delivers it to consumers. Demand for electricity continuously also increases over time. In order to meet this demand new generators are built. The power from these generators will overload existing lines, so new lines are needed.

Electricity was a regulated industry but Federal Energy Regulatory Commission (FERC) Order 888 [1] requires wholesale electric power trade in open markets. As a result of this deregulation, electric power is sold to the highest bidder. This open market is intended to allow utilities to sell and buy energy from other utilities irrespective of distance. The transmission grid is expected to carry out such transactions within the utilities. These transactions are for financial reasons, not for the traditional transmission function of reliability.

Load growth and open markets reduce the reliability and security of the power system. Utility investment in new technologies like line upgrades, dynamic allocation and real time monitoring is not enough to meet the required reliability standards. These technologies are not sufficient to improve reliability in a deregulated environment. New transmission lines are required to meet the reliability needs of the system.

In the US 10,126.8 line miles of transmission were planned for 1994 to 2004. These are in different stages of planning and construction [1]. Many of these lines may be delayed or may

not be constructed at all. The main reason for this is that it is very difficult, uncertain and expensive to route lines in US.

Transmission line routing is a complex process which involves local, state and federal agencies. The route of the line is first approved by the state, usually a state commission, and then it goes to federal agencies like the Department of Energy (DOE) and FERC for approval. Depending upon the line route, approval may be required from several federal and state agencies. The transmission line routing process is highly complex, as transmission lines are not aesthetically pleasing, and people are concerned about health issues like EMF. This may create a high level of public opposition towards a line. Projects may face legal litigation from various stakeholders involved in the project if their concerns are not properly addressed. Such legal litigation further delays the project. This results in an increase in the budget of the project and a stage may come at which the utility finds the project to be financially unfeasible.

This thesis is a part of a multidisciplinary National Science Foundation funded project to modify and develop a geographic information system (GIS) based methodology for routing highways [2]. The methodology, analytical minimum impedance surface (AMIS), was developed by the Kentucky Transportation Research Center, and was successfully applied to highway routing. AMIS is an analytical tool which facilitates the choice of route corridor. AMIS is built by specifying multi-criteria priority model developed from the inputs of its participants and weighting its factors and then integrating this data into the GIS to create the impedance surface.

Ideally, this tool is sufficiently well-designed that it would also be capable of improving the corridor planning process generally. Highway and transmission line routing are similar processes and this technique allows line planners to solicit, gather and document information from stakeholders. This introduces transparency and satisfaction for both the public and planners.

GIS is already used in transmission line routing as a technical tool. This research applies GIS to increase the public involvement in the routing process and which further results in reductions in time involved in approval of the line. This technique reduces the public resistance during the planning and design process and allows more people to participate in the complex infrastructure planning and design problems.

1.2 Objective

The main objective of this thesis to develop a technique to simplify the complex routing process in which concerns and issues of the stakeholders are addressed in a fair and transparent manner. This research will apply a GIS based technique developed for routing highways, to the transmission line routing problem. All the necessary work required to apply this technique to transmission line routing is presented in this thesis.

1.3 Thesis Organization

This document is organized into six chapters. Chapter two provides the landscape features for transmission line routing. Chapter three is about the judicial requirements for transmission line routing. Chapter four highlights the main stakeholders involved in the routing process. Chapter five presents non-point impact features for line routing. Chapter six presents conclusions and future work.

CHAPTER-2

LANDSCAPE FEATURES FOR LINE ROUTING

2.1 Introduction to landscape Features

The most significant task of this research is to determine the landscape features for transmission line routing. Landscape features for a transmission line are all those parameters that can affect the route of a transmission line at any stage during the project. These parameters may affect the route directly or indirectly and may be visible or not. For this research the landscape features are used as parameters which will determine the route of the transmission line. The landscape features are used in AMIS logic, which is a decision support methodology developed for routing highways. The data collected from AMIS is further integrated into GIS software to develop a route for a transmission line between the sending end substation and the receiving end substation.

Many landscape features for routing highways are also landscape features for routing transmission lines as the two routing processes are very similar to each other. In routing transmission lines, landscape features are more related to engineering and safety requirements. Another major difference is the height of the transmission line towers. The height of the tower makes the transmission line more viewable from a distance than highways, and this result in more concerns among the local community. The landscape features are explained and categorized into socio-economic features, environmental features, health and safety features and engineering features. All features listed in these categories must be considered during line routing.

2.2 Socio-Economic Features

2.2.1 Visual Effect

The socio-economic effects of the power transmission line are the main reasons for the reluctance of the general public towards a power transmission line project. As mentioned earlier the height of the transmission line towers makes the line more viewable from a distance, and this result in altering the scenery of an area. The visual impact of transmission line is an issue of concern for the public. The criteria used in assessment of visual impacts categorize impacts into high, moderate and low impact categories.

The impacts are considered high when a transmission line is the dominant feature in the view, and most viewers see the line in foreground or middle-ground. When the line is within 0.25 to 0.5 miles of the viewer it is in foreground, and middle-ground starts from the foreground to 5 miles from the viewer. The view is considered background when the line is more than 5 miles from the viewer [3]. The impacts are moderate when the line is clearly visible to the viewer but not a focal point in its view, and most viewers see the line in the middle-ground. The impacts are low when a line is visible but are not apparent to the viewer and to most viewers the line is primarily seen in middle-ground and background.

The visual effects of a line can be simulated using software. A simulated transmission line in a scenic area shows its affect on the scenery of the area. These affects are more prominent if the lines are in a wilderness area. Fig 2.1 shows a mountain range and Fig 2.2 shows the same range with simulated transmission line towers.



Fig 2.1 North view of Saddle Mountains.

After analyzing the pictures we can see that how a transmission line affects the scenery of an area. The location of transmission line towers affects the view also, for instance as shown in this picture if the towers are built on the top of the mountain then the line will have a higher visual impact on the area.



Fig 2.2 North view of Saddle Mountains with a simulated power transmission line.

2.2.2 Land Values

Construction of new buildings or structures has a direct or indirect impact on the land value of an area. Buildings and infrastructure influence the land value of an area, for instance a shopping mall in an area tends to increase the land value of that area whereas a chemical manufacturing plant tends to reduce the land value of that area. Studies have shown that transmission lines have a variable and erratic impact on property values [3]. Short term adverse impacts may occur but lines do not usually cause any long-term adverse impacts on the property adjacent to the right-of-way (ROW) of the transmission line.

2.2.3 Relocation

During the route selection for a transmission line a straight route with minimal curves is desirable as it gives the best engineering and economic solution. In order to achieve this route the

line may have to pass through certain places which are already inhabited by people. Depending upon the population density and other factors either the community is relocated or the route of the transmission line is changed. In some cases it is necessary to relocate houses, farms, etc., from ROW to another site. For this relocation the company that owns the transmission line is responsible for the relocation, settlement and income restoration of the affected families. It can be concluded that such relocations along the route increase the cost of the transmission line.

2.2.4 Employment

Power transmission lines have both positive and negative impacts in a particular area. During the construction phase the project requires skilled workers for construction of the line. If the labor is available from the area then it reduces unemployment in that area, and then line has a temporary positive impact. But in case of a labor shortage, if the project introduces large numbers of new employees and requires higher salaries to be paid to those non-resident employees, then line can have an adverse impact. Employment impacts are intermittent and they are limited to construction phase only [4].

2.2.5 Native American land

In the US there are some areas that belong to Native American tribal communities and their laws and regulations are different from usual state laws. Most of these areas have cultural, religious or other sentimental importance to a particular community, and as far as possible such areas should be avoided by transmission line routes. Any construction in such areas requires permission from the Native American tribes which can further delay the process.

2.2.6 Linear Developments

Construction of a new gas pipeline, railroad, or power transmission line may create barriers for other projects. For instance if there is a transmission line between two areas then it

affects linear developments such as construction of roads, subways, bridges, etc., between the two areas. During the initial stages of route selection, the linear developments and other proposed and approved projects should be considered. If such proposed projects are not considered in an early stage then they could cause problems later. It may also be possible to route a line along an existing route of a highway or other linear development.

2.2.7 Land Clearing

Most routes for transmission line go through rural and undeveloped areas, and it is often required to clear the land in order to maintain proper clearances [5]. In erodible areas and areas of critical wildlife habitat utilities have to carry out revegetation and land restoration programs. Land clearing and restoration makes a project more expensive, so during selection of a route these factors must be considered in determining the most economical route.

2.2.8 Industrial Development

The demand for energy is increased with industrial development of an area, and in order to meet this demand the grid must have enough transmission capacity to supply the required power. In areas where the economy is mostly industrial, transmission lines are a limiting factor on the population. The population will not grow in an area where there is insufficient supply of energy to support the local industry [6].

2.2.9 Population Density

In general, transmission lines are routed through rural and less populated areas. In high population areas transmission line projects face higher reluctance due to aesthetic, health hazards, and other reasons. High population density areas must be avoided. When there is no alternative or alternatives are not technically feasible, then underground cable should be

considered. But underground cable use in transmission line is rare, as it is not economically feasible.

2.3 Environmental features

2.3.1 Construction

The construction, operation and maintenance of a transmission line have both short term and long term effects on the environment. Most of the environment impacts are results of construction and maintenance activities. Poor construction practices in access roads, ROW clearing, and site preparation have direct effects on the geology of an area.

The construction and maintenance activities alone or in combination with natural factors could result in landslides. Improper construction activities like poor construction of roads, improperly placed fills, poorly designed cut slopes; poor drainage and logging degrade the environment. A deep-seated landslide has a great impact on the line alignment, but its occurrence is rare [7]. But these activities disturb the soil surface and result in increases in soil erosion, runoff and sedimentation of water bodies.

Soil erosion is a short term effect of the transmission line construction process. Along the route some sections may require excavation for access roads, and tower footing requires blasting of the hard rock. Blasting requires temporary displacement of residents and wildlife from the area. These excavations in the soil create spoils and slopes which are more prone to soil erosion than bedrock spoil and slopes [7]. Soil erosion is reduced once cuts and fills along the roads and areas cleared for tower construction are revegetated.

Another problem is that if towers foundations are built improperly on settlement prone soil then they settle differentially, and are not functioning as they are designed to function. This

result of improper construction requires additional maintenance work which could result in indirect environmental impacts.

2.3.2 Seismology

The seismology of an area plays an important role in the selection of a route. Earthquake prone areas must be avoided as far as possible, since an earthquake can force reconstruction of a power transmission line and could significantly affect its operation if line towers foundations are damaged. If the towers are constructed on soft ground then they have to withstand strong amplified motions, which may result in damage to the structure [7]. An unidentified active fault at a tower location causes tower damage if that fault ruptures. These factors must be considered and studied in route selection and also during final tower location.

2.3.3 Water Quality

The Federal Clean Water Act requires states to preserve the water quality of the rivers, streams, lakes and estuaries and develop programs to reduce pollution in water bodies that do not meet required standards. Power transmission lines often cross streams, lakes and other water bodies in their route, and construction and maintenance activities could affect water quality in these bodies.

Line construction can directly affect flood plains by creating obstructions in the paths of floodwater channels, which increases the potential for flooding. In general, controlled activities of construction and operation and maintenance activities have no affect on ground water, but uncontrolled activities like accidental spills of lubricant and fuels can result in contamination of ground water [7].

2.3.4 Air Quality

Transmission line construction activities cause low or moderate impacts on the air quality of an area. Vehicles and other heavy machinery used in the construction emit pollutants from fuel ignition like carbon monoxide, carbon dioxide, sulphur oxide, nitrogen oxides, particulate matter, volatile and semi-volatile compounds. Dust is also generated due to movement of vehicles and land clearing activities. All these emission and pollutants have short terms effects and they have low level or no impacts on the air quality.

The corona phenomenon of high voltage transmission lines, discussed in detail later in this thesis, has a potential impact on air quality during operation of the transmission line. Transmissions lines operating at 115 kV or above have high electric field strength which causes the breakdown of the air on the surface of the conductor. This breakdown of the air results in the production of ozone and oxides of nitrogen. This effect is more prominent in inclement weather condition like a rainy day [6].

2.3.5 Vegetation

Construction of power transmission lines affects the vegetation of an area. Transmission line routes are hundreds of miles in length and most parts of the route are in undeveloped areas, which have various plant species along and within the ROW. Line construction activities have short term impacts, whereas maintenance activities could result in long term impacts. Road, tower construction and clearing land for the ROW results in removal of plants. In some cases the topsoil and root systems of native plants species are completely destroyed or removed from the area.

Soil distributed in a ROW, and a lack of competing species, can result in the growth of noxious weeds due to construction and maintenance activities [6]. This depends upon number of

factors like elevation, slope and direction of slope face, soil type, and amount of moisture present in the soil [3]. Federal or state listed endangered plant species must be protected from construction and other maintenance activities. During the selection of the route, the vegetation of that area must be studied well in advance of construction. Impacts can be avoided by planning construction in a season when most of these species are in dormancy [3].

2.3.6 Wildlife

Wildlife conservation is equally as important as that of vegetation. In the US there are several federal and state laws that enforce protection of wildlife. Transmission line construction requires clearing of the land, specially in forested and rural areas. Forest land must be cleared in and along the ROW for construction. This clearing of land results in loss of forest and impacts animal species in the forest habitat. The construction of new roads encourages the recreational use of the area, and species like deer, elk become more vulnerable to humans [6].

Line construction and maintenance activity in areas which are close to wetlands and open water adversely affects the habitat of riparian and other wetland species. The most visible affect of transmission line is the electrocution of the birds, when transmission lines fall in the path of the migratory birds. Utilities can adopt design changes for towers, insulators and conductors which reduce the electrocution of these birds by power transmission lines [3].

2.3.7 Fish Habitat

Transmission lines often cross streams, wetlands, and other water bodies, and may have an adverse impact on the fish. Construction results in sediment deposition in streams and other water bodies from excavation, stockpiles, land clearing and soil from roads. Dumping and concrete washing also cause increase sediment loads in wetlands and streams. Movement of heavy machinery and noise from construction equipment also causes sediment release,

mechanical disturbances, vibrations, and shocks, which can cause fish to move to other areas from their native habitats. This movement results in loss of various fish species from an area.

Construction and maintenance require clearing, which results in removal or reduction of shady areas and woods, which in turn reduces the buffer capacity, i.e. the ability of vegetation to grow along the streams and protect them from sediment deposition [6]. Clearing of vegetation leads to high flood flows, which in turn causes more deposition and sedimentation and affects the fish habitat and can also cause gill abrasion to fish. In some cases low base temperatures result in warmer water temperatures which may be lethal for fish [3].

During the planning stages of transmission line projects, when the route for the line is selected, it is a good practice to contact fish conservation societies to identify fish habitats in the region. All these affects must be considered when the route of a line is selected and it must be ensured that construction and maintenance activities are not going to cause any adverse affects to the fish habitat.

2.4 Health and Safety features

Transmission lines are designed to transfer large amount of energy at high voltages and high currents, and such flow of high currents and voltages on these lines results in various health and safety problems in and around the ROW.

2.4.1 Electric Fields

Economics dictates that transmission lines transmit power at high voltages. Electric fields around lines are the result of the high voltage gradient on the surface of the conductor. Electric fields are strongest at the surface of the conductor, and lose intensity away from the conductor.

Much of the route of a transmission line goes through rural and undeveloped areas where there are more plants and animals than humans, so exposure of plants and animals to electric

fields must be considered. Animals are shielded from electric fields by vegetation, and exposure is greatest when they are passing beneath transmission lines. Various studies have been done on effects of electric fields on animal behavior, melatonin production and immune function, and impacts found were low [7]. Similar results were found in studies on plants.

Electric field exposure is an issue of concern in urban areas, but electric fields are shielded by conducting objects like fences, walls and trees. In buildings and houses around 90-95% of electric field is shielded [8]. Electric field exposure depends upon the way transmission lines are designed. Utilities can alter the electric field exposure by changing the vertical and horizontal clearances and arrangement of conductors.

2.4.2 Magnetic fields

Magnetic fields around transmission lines are due to the flow of the current in the line. Unlike electric fields, magnetic fields increase and decrease depending on the electric load on the line. Intensity of the magnetic field is dependent upon the distance from the transmission line [8].

Electrical appliances like ovens or heaters produce magnetic fields of less than 2 mG and in buildings or houses close to transmission lines the major source of magnetic fields is the transmission line. Magnetic field exposure from a line is higher in comparison to the electric field. Magnetic fields are not shielded by trees, fences, or structures, as in the case of electric fields.

Both electric and magnetic fields induce currents, and certain unusual circumstances, like contact of a grounded person with an ungrounded object under a high electric field, can result in nuisance shock or spark discharge. Research on electric and magnetic fields shows no evidence that supports a relation between electric or magnetic fields and adverse health affects

like cancer and other diseases. Statistical investigations are still going on between child leukemia and magnetic field exposure [3].

2.4.3 Audible Noise

Construction activities like movement of heavy machinery, erection of towers and conductors result in noise around the ROW. The noise levels may be objectionable if construction is too close to a populated area.

Another source of noise from transmission lines is corona, for lines 345 kV and above. This is more prominent in foul weather conditions and meteorological data shows that these conditions exist 7% of the time in a year. For a new line after construction, grease or oil on the surface of conductor are sources of corona. A new line has audible noise of 50 dBA around the ROW in foul weather conditions [3].

Power transmission lines have substations at the start, end and in between. Audible noise effects of substations depend upon the level of background noise existing around the substation. Switching and protection equipment installed in substation produces noise in the form of low frequency hum. This noise depends upon the operating mode of the equipment installed [5].

2.4.4 Hazardous Materials

Hazardous material use and disposal is always issue of a concern for any construction project. In the case of a transmission line, use of hazardous materials is minimum. Polychlorinated biphenyl (PCB) is prohibited for transformer and power circuit breakers. Disposal of the concrete, paints and wood preservatives and petroleum products like fuels, hydraulic fluids, etc., must follow strict disposal procedures. Accidental flow of such materials could cause lethal damage to flora and fauna along the ROW [6]. Utilities must control disposal of hazardous material during the construction and maintenance of a transmission line.

2.4.5 Fire

Fire hazard is another threat posed by transmission lines to crops, vegetation and other combustible material. The accidental fall to the ground of a loaded transmission line creates an arc sufficient to burn the combustible material and this could result in crop, grass, or forest fires [4]. In routing transmission line through rural areas and forests, adequate clearance should be maintained to reduce the chance of fires. In general, trees are not allowed to grow more than 20 feet high in ROW [6].

2.4.6 Induced Currents

Electromagnetic fields from transmission lines induce currents on objects in the proximity of the line. Certain circumstances, like contact of a grounded person with an ungrounded object under a high voltage line, can result in a nuisance shock or spark discharge. The magnitude of the induced current depends upon the electric field strength, size of the object and insulation between object and ground. Magnetic fields also induce currents when objects like fences, pipelines and wires are in parallel with lines [4].

The National Electrical Safety Code requires that for voltages more than 98 kV ac to ground the induced currents not be more than 5 mA [9]. Transmission line designers must design with enough clearances throughout the route of the line so that line can meet these requirements.

If the line route is near pipelines, the line fields will induce currents in the pipeline, and this can result in shocks to maintenance personnel working on those pipelines. The magnitude of inductive interference depends upon the grounding resistance of line towers, distance between pipeline and transmission line, and size of the structure grounding system, soil characteristics along the pipeline and transmission line, and the pipeline coating resistance. Under faulted conditions like single line to ground faults the induced potential on an unprotected pipeline could

reach thousands of volts and in extreme cases this could puncture a pipeline [4]. Inductive interference with pipelines must be considered during line design and route selection for a transmission line.

2.5 Engineering Features

Most of the factors that are affected by power transmission line routing have been discussed previously in this chapter. But transmission line routing not only depends upon non-technical factors like environmental and socio-economic, but also on engineering factors. Line designers have to carefully study and design the line to give the best engineering solution for various problems like corona, interference and natural factors like wind and ice.

2.5.1 Electromagnetic Interference

Electromagnetic interference is one of the major problems that designers face during the design process. Corona and gap discharges are the main sources of electromagnetic interference. Corona is generally seen in 345 kV and higher voltage transmission lines. Electromagnetic radiation from corona discharges affects am radios, whereas gap discharges affect both television and radio reception. Radio frequency emissions from corona occur between the ranges of 100 kHz to 2 MHz, and most communication systems like police, fire, commercial radios and cellular phones operate above 2 MHz. Broadcast am radio, however, operates between 535 and 1604 kHz, and is thus often affected [3].

Signal reflections from power transmission lines may cause ghosting in weak television signals. Electrical discharges between broken and loose hardware like insulators, clamps and brackets are transmitters of frequencies that can cause interference with some radio and television signals. Interference depends upon the strength & quality of the transmitting signal, the distance of the source to the receiver and the quality of the radio or TV system [4].

Interference with railroad communication is another major issue of concern. In routing transmission lines it must be considered that in extreme conditions, the transmission line may cause disturbances to railroad communication. This interference must be reduced by increasing the vertical and horizontal clearances of the power transmission line from the railroad.

2.5.2 Lightning

The operation and performance of a transmission line is affected by lightning strikes. The route of a transmission line plays a vital role in the lighting performance of the line. Studies shows that lines have more outages in severe weather conditions. An area which is more prone to flashes will have more outages irrespective of soil characteristics. Exposure to lighting strikes is much higher on a mountain top or ridge, which should be avoided as far as possible [10].

Soil resistivity and structure height are the two important factors that affect the lighting performance of the line. The designer should reduce the structure height in open fields and as far as possible try to share the ROW with another line. This practice helps in reduction of lighting outages.

2.5.3 Wind

The environment around a line, including wind, affects various electrical properties of the line. High velocity winds not only increase mechanical loading but also reduce the vertical and horizontal clearances. Low velocity wind of a sufficient amplitude results in conductor fatigue by Aeolian vibration. In regions where ice storms occur oscillations are produced near the fundamental or at second or third harmonics, and this result in amplitudes as large as conductor sag. These two phenomena are found in both bundled as well as single conductor lines.

Wake-induced oscillations are aerodynamic forces produced when a conductor moves in and out of the wake of the upstream conductor. Such forces are found in bundled conductors

[11]. During planning stages line designers have to study the wind conditions of route that the line is going to follow before selection of the final route. For lines with structures more than 60 feet above ground, NESC extreme wind loading conditions apply and wind pressure calculated in this manner assumes no ice load [9]. Calculations must be adjusted accordingly if ice loading is possible.

2.5.4 Ice Loading

Ice accumulation on conductors during winter affects the operation of the power transmission line. In long-span lines with conductors in the same vertical plane, outages may occur due to a sudden jump of the conductors when ice drops from the conductor. Ice jumps occur when no wind is blowing, so all forces and reactions are in the vertical direction [11]. NESC has established ice loading districts which are used to estimate the expected thickness of ice that will accumulate on conductors [9].

2.5.5 Forest Fire

Forest fires cause great damage to transmission lines. Most transmission line conductors are aluminum (ACSR), and they lose their mechanical strength in the environment of high temperature, humidity, smoke, dust and flames of a forest fire. Utilities must gather data on the vegetation around the ROW and determine the risk of forest fires during selection of the route [12].

Forest fires are not only a problem for conductors but for line insulators also. The accumulation of soot and dust results in contamination of the insulators and reduces the breakdown strength of the insulator. Line designers should avoid routes near agricultural fields like sugarcane, since a fire in a sugarcane field reduces air insulation, which can reduce flashover voltage to 0.5 kVrms/cm [13].

2.5.6 Compact Line

In the US, state and federal commissions and laws and regulations can make it extremely difficult to get permits and acquisitions for ROWs for power transmission lines [14]. In such cases utilities may select a compact line design as its best engineering solution to problems like aesthetic impacts, economics and ROW restrictions.

These compact lines can sometimes be constructed along existing distribution and transmission line ROWs. Compact line design offers various choices in configurations and it had been found that ROW requirements and costs for these lines are low in comparison to conventional designs.

2.6 GIS Features.

All the features explained above are crucial for transmission line routing, but not all can be incorporated into GIS. Those that can be used in GIS are listed in Table 2.1. National Electric Safety Code required clearances for some of the features are given in Appendix-A.

Table 2.1

Landscape Features for GIS

<i>Man-made Constructability</i>	<i>Natural Constructability</i>	<i>Proximity Effects to Buffer for: EMF, Noise, Sight</i>	<i>Environmental or Cultural Damage</i>
Oil and gas wells	15-25% Slope	Habitation	Wildlife management area
Water Tower	10-15% Slope	School	Threatened and End. Habitat
Strip or Shaft Mines	5-10% Slope	National properties eligible (106)	National forest
Public Water Supply	Rock base	Hospital	Superfund site
Airport	Mixed/unknown base	Church	Wetland
Sewage treatment	Soil base	State park	EPA project sites
Quarry	Soil Resistance	Wild and scenic river	Archaeological feature
Pumping station	Floodplain	Public campground	Prime farmland
Cemetery	Forested	National park	Springs
Pipeline	Land Value	Picnic area	Streams
Golf course	Seismic zones	Indian Tribe Land	Sink holes
Fish hatchery	Lightning Risk	Radio or TV tower	Known caves
Armory	Wind Loading		High probability of caves
Railroad			
Far from roads			
Water filtration			
Dams			
Power Line			
Tire dump			
Hazmat Site			
Landfills			
Military installation			
Underground fuel tank			

CHAPTER-3

JUDICIAL REQUIREMENTS FOR TRANSMISSION LINES

3.1 Introduction to routing laws

This section of the thesis is primarily aimed at regulations and requirements of local and state authorities for a transmission line project. In most states in the US, transmission line construction projects need approval from state agencies first, and then by federal agencies if required. Most US states have laws or rules which are directly or indirectly related to transmission line construction. These laws and rules must be followed for any construction of new or upgraded transmission lines.

The involvement of the federal agencies like DOE and FERC makes sure that transmission line projects are in compliance with the National Environmental Policy Act (NEPA). NEPA makes sure that projects like construction of transmission lines and gas pipelines etc., are environment friendly, and that construction of these projects is not going to cause any adverse changes in the environment. Generally, the NEPA compliance requirement is applicable to federal agencies and in areas under federal jurisdiction, but some state authorities has also adopted environment impact assessment laws.

3.2 State Commission

State utility commissions play an important role in the approval of transmission line projects, and in about 80 % of the states in the US, the state utility commission is the primary authority for issuing permits for transmission line construction. In most of the cases the state commission acts as a facilitator in resolving disputes among utilities, the public and various other utilities and entities.

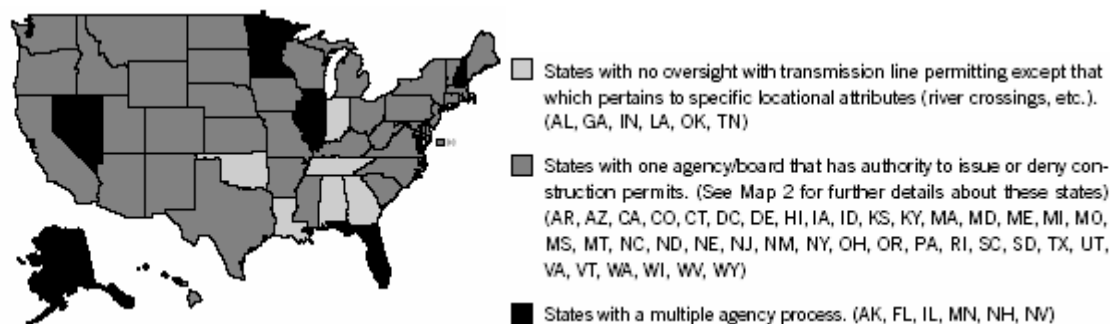


Fig 3.1 – Permitting categories by state [15].

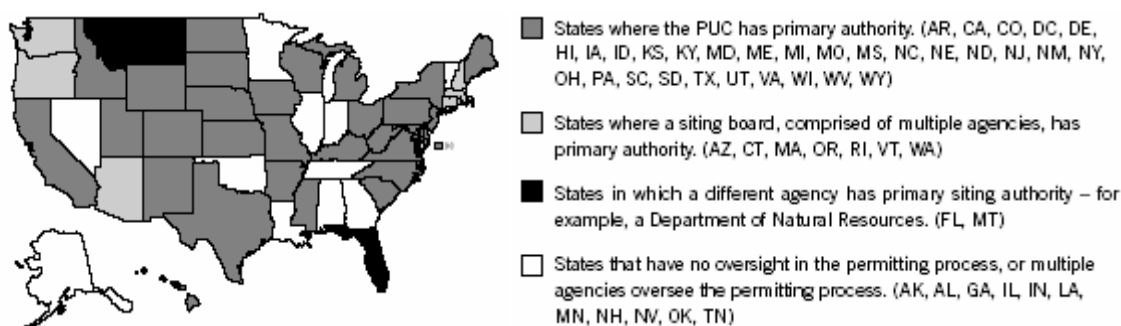


Fig 3.2 - States with one agency authorization [15].

In recent times with the establishment of transmission independent service operators (ISO) in various states, the state utility commission plays a vital role in power transmission related issues. When it comes to reviewing transmission line projects the voltage of the transmission line is important. Transmission line voltage is a critical component of the line construction process, with increasing voltage resulting in increased clearance requirements from the ground and from other objects. Magnetic coordination with other utilities also increases with higher voltage. Transmission line rated voltage is a design constraint, because at higher voltages,

the adverse environmental impacts, like corona which produces ozone and audible noise, are more prominent.

Another critical issue associated with line voltage is cost, which increases as voltage increases. Larger conductors and towers are required, and more protective equipment is required in substations. About thirty-three percent of the states require review of projects rated below 100 kV, and about twenty-four percent review only projects greater than 100 kV, and nineteen percent of states review only when voltage is more than 200 kV. [15]

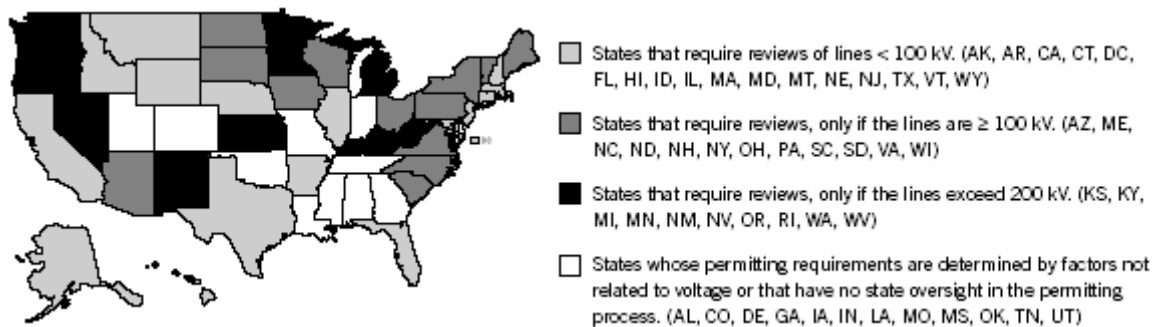


Fig 3.3- States in which Power transmission line are permitted by line voltages [15]

3.3 Certificate of Public Convenience & Necessity

Utilities or transmission companies in states which require state approval must notify in writing the state commission or any other agency with authority over the review and approval of power transmission line projects. The most common certificate or approval document in various US states is a “Certificate of Public Convenience and Necessity”. As the name implies, the state wants to know the necessity of a new line for state and how it is going to be beneficial for residents of state. Utilities have to present the necessity of the new transmission line in a report

format to the commission, along with the initial application. In some states like Arizona the utility must also obtain a certificate of environmental compatibility from the state [16].

3.3.1 Need for Transmission Line

In most of the states in the US utilities have to explain to the state why their project is a necessity for the state. This necessity may be due to various reasons; it may, for example, be due to outage studies conducted by the utility which show the line is needed to prevent blackouts or load shedding. Such a line improves reliability of service in the state. Other reasons include increased demand due to population increases, and market considerations that will result in savings for state customers.

In most of states the commission or the other agencies that have authority over issuing permits to transmission lines require detailed information about upcoming projects. The application should explain where the proposed transmission line is going to be built. Commissions also want to know about the proposed route, and they need maps that show the proposed route [17].

The route explains where the actual line is going to be built, and describes the area, community and people affected by the transmission line. The utility must notify all the landowners in advance who are going to be affected by their proposed project. In order to build a transmission line utilities purchase as easement from the landowners who fall in the ROW of the line [18].

3.3.2 Interference

The construction and operation of the transmission line may cause interference with other utilities, including railroad, telecommunications and other electric utilities. States require utilities to notify railroad companies and other utilities about there project in advance.

Kansas statutes states that the utilities have to utilize the public and private roads in a most efficient way, and when there is an inductive interference between the two utilities then both utilities have to determine an efficient and economical solution. The solutions should be the best engineering solution at least cost [19].

3.3.3 Project Cost

Cost is a critical component of line design and construction, not only to the utilities but also to the state, because ultimately the utility is going to extract the cost of the transmission line from its customers. In most states the commission requires the utility to give an estimated cost for the transmission line project when filing the application for permit [20]. State commission's applications also require utilities to specify their methods of financing for the projects. Power transmission line construction takes years, and sometimes the estimated cost at beginning of the project is much less than the actual cost because of unforeseen legal delays. The state commission needs assurance that the utility has the ability to finish the project within the expected period, and that the projects will not be deferred during construction due to lack of finances [21].

3.3.4 Land Easement

Transmission line projects require land on which to build structures or towers to support transmission line conductors. In general, utilities do not purchase the land, but instead an easement is secured from the landowner in which the landowner grants rights to construct and operate the line. The state requires state approval of the project before any easements and acquisitions by utilities [22].

The state will assure that landowners receive an appropriate market price for the land that they are losing for a transmission line project. Relocation of some landowners is part of land

acquisitions in most large projects. In most states compensation for relocation and re-establishment of the owners will be paid by the utility. For example, in Connecticut if the landowners incur reasonable expenses in moving more than two hundred miles away from its property then utility will pay the relocation expenses [22].

3.3.5 Environment Impact

Transmission line projects affect the environment around the line. As discussed in Chapter 2, these affects are of a wide variety ranging from socio-economic to ecological imbalance. Utilities have to give an environmental assessment report to the state for a permit or “Certificate of Environment Compatibility” to construct a transmission line in most states. This environmental impact statement includes assessment of the impacts of the transmission line on the habitat of animals and plants, air and water quality, socio-economics, etc., posed by transmission line.

A utility must prove that the adverse environmental impacts are minimized by available technology and other factors like economics, in comparison to the other alternatives to the transmission lines [23]. Power transmission lines go through a wide variety of areas and some of them may be in wilderness or areas that have historic importance to the state. The state makes sure that the transmission line project is not going cause any adverse impacts or any threat to the areas of scenic and historic importance.

Approval or denial of a project depends upon on all the various factors. The state commission considers why the utility requires new or upgraded lines and whether the need can be met by other alternatives [24]. The commission will also consider the impacts of the proposed line on consumer rates and may not approve a project that is going to increase the energy cost to the consumer.

The commission also evaluates the managerial and financial abilities of the utility which is going to build the proposed transmission project in the state. They also evaluate the environmental impacts of the power transmission project and if the project is going to cause an adverse impact to the state's environment then its chances of approval are jeopardized.

3.4 National Environmental Policy Act

In the US the act that is enforced and accepted by various federal and state agencies is "The National Environmental Policy Act of 1969". The purpose of this act is to encourage harmony between people and their environment and to present a national policy that reduces damage to the environment and biosphere and also encourages human health and welfare.

The act recognizes the deep impact of various activities on the population growth, high density urbanization, industrial expansion and exploitation of natural resources. Beginning from the 1st July 1970, the president shall convey an "Environment Quality Report" to congress which includes the status and condition of manmade and natural altered environmental classes of the nation, present and future trends in the quality, management and utilization of those environments, adequate availability of natural resources to compensate the human and economic requirements of the nation, review of government and non-government projects and their effect on the environment and development and utilization of natural resources [25].

Environmental impact statements are documents that review and explain the impacts of the transmission line on the environment. Most of the high voltage transmission lines must comply with NEPA requirements, and federal agencies like DOE evaluate such projects and determine compliance with NEPA. For planning and decision making environmental assessment is used and depending upon the environmental assessment, the federal agency determines whether a formal environmental impact statement is required for the project [26].

CHAPTER 4

STAKEHOLDERS IN TRANSMISSION LINE ROUTING

4.1 Introduction

A large transmission line project is the one of the most complex engineering projects, often taking years before actual structures are built. One of the reasons for delays is the involvement of stakeholders in the process. In the US all major transmission line projects have stakeholders involved. This may be at the state level with the state commission or at the federal level with DOE or other federal agency. Rules and regulations in the US for transmission line projects give equal rights to all stakeholders to express their concerns and views about the project.

Stakeholder involvement is crucial, as it can delay a project, or in some cases stop it altogether. The whole process is very complex due to clearances needed from various agencies, each of whom is a stakeholder. Any delay in the project affects utilities involved in the project as the cost for building the line keeps on increasing due to delays, and in the worst cases utilities may completely lose interest in construction of transmission lines. The critical issue is to identify the stakeholders who have an interest in the transmission line projects so they can be involved from the start. The important stakeholders for a transmission line project are listed, and their importance is explained in the following paragraphs. A detailed list of stakeholders is in Appendix B.

4.2 Electric Utilities

A utility or a company which is going to build a transmission line must give notice in advance to other electric utilities that are along the ROW or cross the ROW of the proposed project. Utilities have to maintain proper clearance from other transmission or distribution lines

as required by the NESC and standards followed within the utility or specified in state legislature. A line should not effect the operation and maintenance of other utilities' transmission or distribution lines.

4.3 Telecommunication Utilities

To avoid interference with telecommunications, a line must maintain proper clearances from communication lines. The line owner must give notice in advance to all the telecom utilities along the ROW or which cross the ROW.

4.4 Railroad Companies

In the US, railroad companies are often paralleled or crossed by overhead transmission and distribution lines. Proper horizontal and vertical clearances must be maintained from the transmission lines in accordance with the NESC. Communication signals used by the railroad may be affected by electromagnetic fields produced by the transmission lines and as far as possible this interference should be avoided.

4.5 Highway authorities

There are several manmade features that may cross or parallel the route of a line and one of them is highways. Utilities have to maintain proper vertical and horizontal clearance from highways so that the transmission lines do not pose an undue risk to the safety of the traffic moving on the highways. Highway authorities must be notified before the final route for a transmission line has been planned.

4.6 Radio and Television companies

A common problem that utilities face is interference with broadcast communication signals and this problem is worse if the receiver or transmitter of the signal is in close proximity to transmission line. Utilities have to make sure that magnetic interference from a line is not

going to cause excessive noise to radio or tv signals. During the selection of the route, such interference its affects on the communication signal should be considered.

4.7 Landowners

The group most affected by the construction of a transmission line is nearby landowners. Transmission lines or any other construction projects need land to build structures. In the US, especially in rural areas where a ROW crosses a farm, farmers agricultural practices are affected by the line and in most cases the utilities have to secure an easement for land with the landowner. In urban areas transmission lines face even greater reluctance from landowners as they pose not only intermittent problems like dust and noise during construction but permanent problems like aesthetic impacts on the scenery of an area.

4.8 Native American tribes

In the US some lands are reserved for Native American tribes. These areas have their own laws and regulations irrespective of the state laws in which they fall. Utilities have to obtain permission from that particular tribe to pursue construction in the tribal region. It must insure that construction, operation and maintenance activities of do not disturb any values and beliefs of the tribe in which transmission line route falls.

4.9 Airport authorities

Tower height depends upon the clearance requirements of the line from ground, which in turn depend upon the voltage level of the line. High towers near an airport or airfield have to obtain permission from the airport or authorities before construction of transmission line towers. In some cases construction and maintenance permits must also be obtained from airport authorities before construction.

4.10 Chemical Industries

Production of chemicals and chemical products results in emissions of toxic pollutants in the air. If a transmission line is in close proximity to a chemical industry then fumes or minute dust particles accumulate over the insulators and form a conducting path over the surface, causing line outages. In some cases utilities alter the route of a line, and in other cases chemical industries have to install special equipment to reduce the chemical fumes to the surrounding air.

4.11 Archeological & historic conservation agencies

In the US there are sites that have importance in the history and culture of the country, and notice must be provided of any action that could affect the site to the agency that has authority over the conservation of that site. Transmission line construction and maintenance practices can disturb the site to a great extent and cause some of the cultural importance of a site to be lost.

4.12 Cultural & religious bodies

In the US there are sites where land is owned by religious and church bodies who are working for the wellbeing of the people in the community. During the preliminary routing of the line, especially in urban areas, where such groups are present utilities have to consider the importance of such bodies to the community. They must satisfy the demands and needs of all religious and cultural bodies along the route of the transmission line.

4.13 Military Installations

Military installations are secured and fortified and access is limited. Construction and maintenance activities could cause a threat to the security of the installations. Military installations have their own communication system to communicate with other military installations and electromagnetic interference from a transmission line with communication

signal introduces a noise in the signal and results in poor communication. Such interference could result in loss of valuable information, so utilities must notify any military installation before construction of any transmission line within or near to the periphery of the installation.

CHAPTER-5

NON-POINT IMPACT FEATURES

5.1 Introduction to Non-point Impact features

The routing process is not only affected by topography-dependent landscape features but also by features that are independent of the topography of the region. Such features are called non-point impact features.

GIS is raster based software that incorporates information about a particular area, and such information can be used to see potential barriers in the route of a line. All such information is related to a particular location. For example, GIS can map the location of all rivers or wetlands in a particular region. Even though non-point impacts do not have a specific location, they can still be integrated into a GIS based platform.

Electric fields, magnetic fields, radio frequency interference, and audible noise are the important non-point impact features for a transmission line. All these features affect the route of the line irrespective of the topography of the land. One common factor among all these features is distance decay; the effects decrease with distance from the line. For instance, magnetic field intensity is very high within the ROW but as we move away from the line the field decreases. Non-point impact features can create objections among the people who have property within or near the ROW. This can affect the transmission line construction project at any stage so it is helpful to calculate the level of these features and include them in the routing process.

In this section calculation procedure for electric fields, magnetic fields, audible noise and radio frequency noise are explained. Equations to calculate these quantities are applied to example data from the El Segundo transmission line project [8]. Conductor geometry and line data for this project is shown in the Fig 5.1.

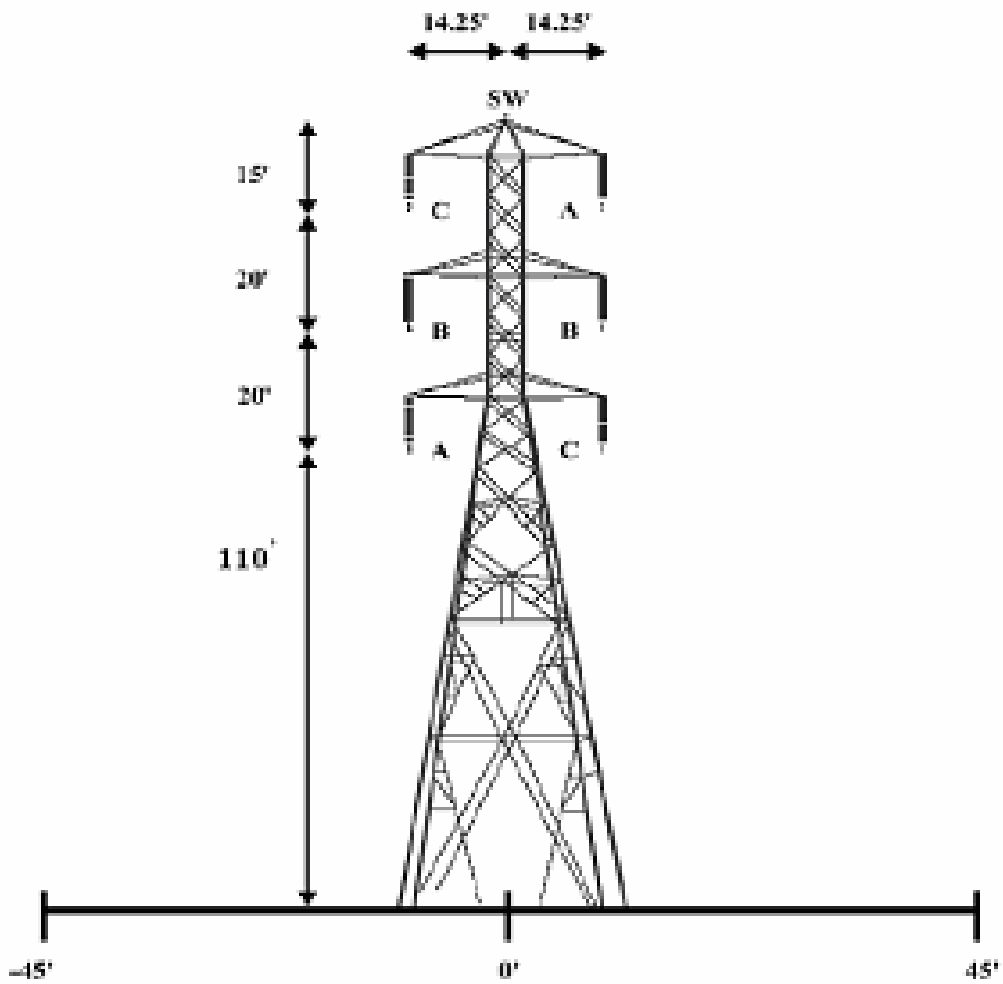


Fig 5.1 Transmission line geometry of El Segundo Transmission Line [8].

5.2 Electric Fields

Superposition of the three fields from the phase conductors produces a resultant electric field. In calculations the effect of the conducting earth is represented by image charges located below the conductors at a depth below the earth which is same as the height of the conductor above the earth. At 60 Hz the time required for charges to redistribute themselves due to an externally applied field is very small in comparison to the power frequency wave, so it appears as if earth is a perfect conductor.

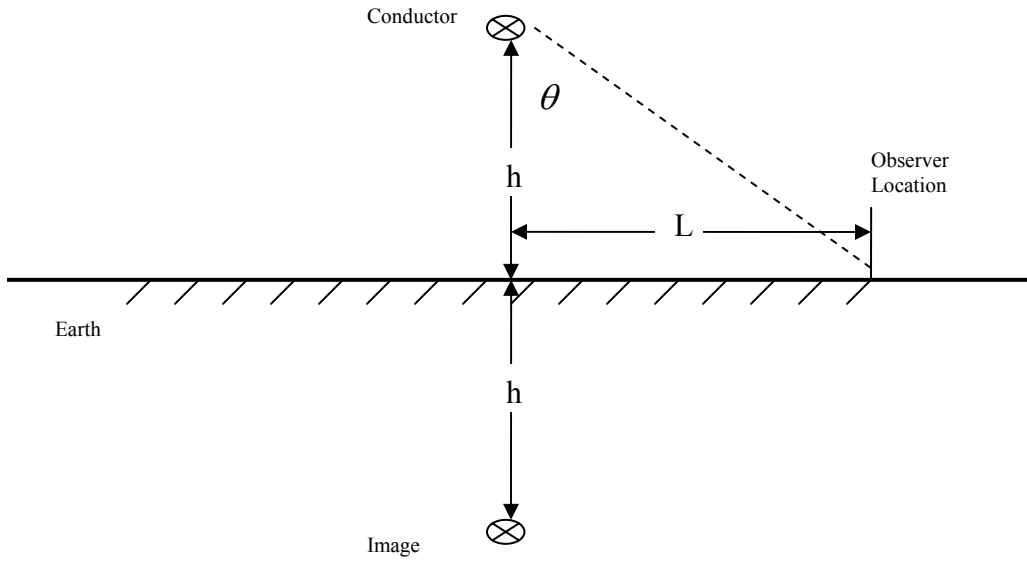


Fig 5.2 Single conductor profile [11].

For a single of conductor of radius r and a height h above the earth, shown in Fig. 5.2, the ground level electric field can be calculated:

$$E = \frac{Q_l}{2\pi\epsilon r} \quad (5-1)$$

Where distance from the conductor to the observer is

$$r = \sqrt{h^2 + L^2} \quad (5-2)$$

Hence

$$E = \frac{Q_l}{2\pi\epsilon\sqrt{h^2 + L^2}} \quad (5-3)$$

Where Q must be $[Q] = [C][V]$ and for a single conductor the equation reduces to

$$Q_l = P^{-1}V = \frac{1}{(1/2\pi\epsilon)\ln(2h/r)}V \quad (5-4)$$

E is radially directed from the line charge and its vertical component is

$$|E| \cos \theta = \frac{Q_l}{2\pi\epsilon\sqrt{h^2 + L^2}} \frac{h}{\sqrt{h^2 + L^2}} = \frac{Q_l}{2\pi\epsilon} \frac{h}{h^2 + L^2} \quad (5-5)$$

Thus, the total ground-level field is given by

$$E = \frac{Q_l}{\pi\epsilon} \frac{h}{h^2 + L^2} \quad (5-6)$$

And at ground level horizontal components of the conductor and its image cancel each other and the resultant field is only vertical [11]. The above ground electric field is for a single conductor and for a three phase line fields from all the three conductor fields are calculated separately and added. If the transmission line has bundled conductors then, for a bundle diameter D of n conductors of radius r , the GMR is given by

$$\text{GMR} = \frac{D}{2} \sqrt{\frac{2nr}{D}} \quad (5-7)$$

Replacing conductor radius with GMR gives an approximate representation of electric field as shown in the Fig 5.3.

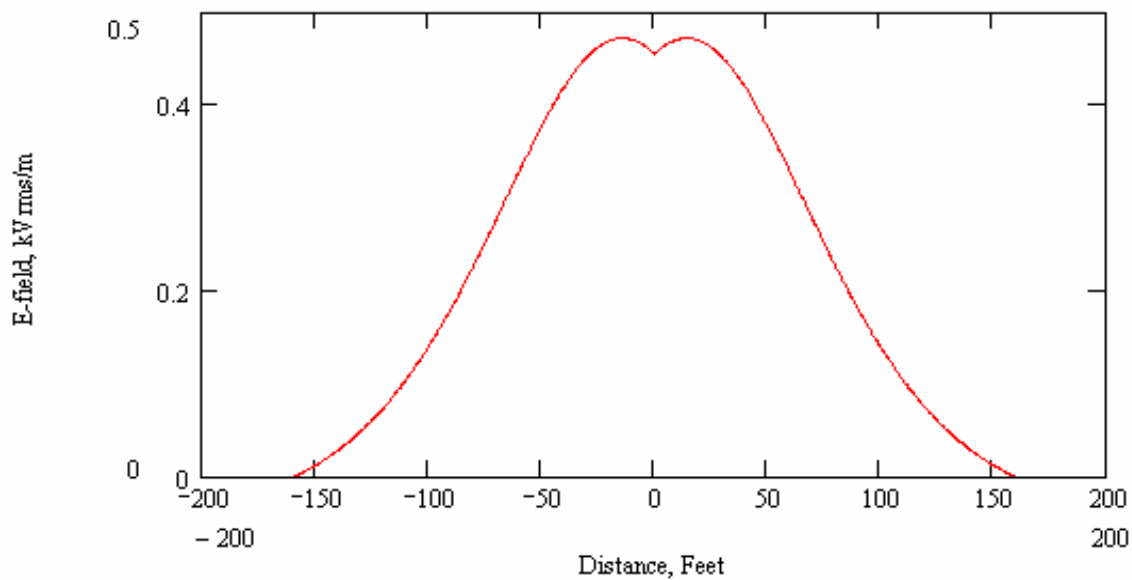


Fig 5.3 Electric field profile for transmission line.

5.3 Magnetic Fields

Magnetic fields are produced by transmission lines due to the flow of current in phase conductors. Unlike electric fields, magnetic fields change with respect to the change in the flow of current in the phase conductors. Magnetic fields also decay with distance, as distance from the line increases the magnitude of the magnetic field decreases. Magnetic field coupling affects objects parallel to the line, like fences and pipelines, and are generally negligible for vehicle or building sized objects. Magnetic field coupling is modeled as a low voltage and low impedance source with relatively high short-circuit currents.

Single grounds are ineffective in preventing magnetically coupled voltages; multiple low resistance grounds are required. Images are also used for calculating magnetic fields [11], but the assumption of a transmission line with no earth at all gives a closer approximation to the ground level magnetic fields than assuming a perfectly conducting earth. This effect is frequently modeled as an image of the conductor located at greater depth in the earth than conductors above the earth.

Distances of several hundred meters are frequently used for this image depth, which is given by $D = 660\sqrt{\rho/f}$, where ρ is the soil resistivity in ohm-meters and f is the frequency. It is usually adequate to consider conductor in free space images.

$$B = \frac{\mu I}{2\pi r} = \frac{\mu I}{2\pi\sqrt{h^2 + L^2}} \quad (5-8)$$

The above equation, 5-8, is then separated into horizontal and vertical components by multiplying by $\sin \theta$ and $\cos \theta$. The horizontal and vertical components of B must be combined individually as vectors. This results in different angles from combining horizontal and vertical components and causes their resultant to trace an ellipse in time.

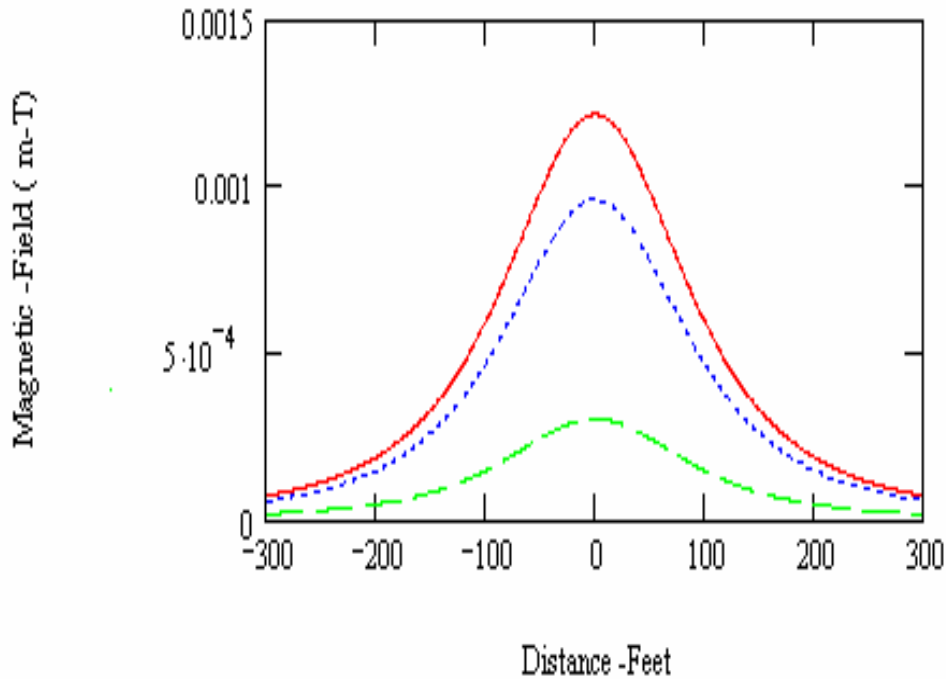


Fig 5.4 Magnetic field profile for Transmission line.

The same method can be used for image currents at some depth, for computations with image fields included. The ground wires and bundled conductors can also be included by using matrix equations. Fig 5.4 gives the resulting approximate representation of the magnetic field for the example transmission line.

5.4 Radio Noise

Electrical discharges across small gaps (micro-sparks) and partial electrical discharges (corona) are two phenomena that cause electromagnetic interference from an overhead transmission line. Corona-generated radio noise decreases with distance and also decreases with higher frequencies. This usually affects am radio, and higher frequencies such as tv and fm radio signals are not affected.

Gap-type sources are found at insulators, line hardware and defective equipment. Gap-type sources for radio interference are not a design problem; they occur during construction and maintenance of transmission lines, and 90% of the noise complaints are removed and eliminated by repairing the damaged equipment [11]. In the design phase, conductor and hardware corona is considered. Properly designed conductors produce rare complaints except in weak signal fringe areas. Lines constructed with reduced conductor spacing have resulting higher electric fields on hardware, so “corona free” hardware is important to eliminating electromagnetic interference.

Radio and television noise for ac transmission lines are a function of weather. Fair weather noise may be significant and varies with season, wind velocity and barometric pressure. A comparison method for calculating radio noise is useful for conventional geometries and designs.

$$RI = -150.4 + 120 \log g + 40 \log d + 20 \log (h/D^2) + 10[1 - (\log 10f)^2] \quad (5-9)$$

Where

g = average maximum surface gradient of conductor.

d = sub-conductor diameter, mm

D = radial distance to observer, m

h = height of phase, m

RI = fair-weather radio noise, dB

RI is calculated for each phase and the maximum value is used as the RI for the line. The average foul-weather levels are 17 dB above fair weather and heavy-rain averages RI 24 dB above fair weather. There are no acceptable RI limits in the US because of difficulties in setting universal criteria for all land use and local conditions. To set criteria for evaluation of radio-noise, two quantities are used: level of signal strength in the line vicinity, and signal/noise ratio.

The signal to noise ratio on the edge of the ROW averages 24 to 26 dB. Primary signal strengths may be 54 dB above 1 μ V in rural areas and 88 dB or more in cities.

Due to limited number of cases of conductor corona-induced tv interference, prediction of TV noise is not as advanced as that of radio noise. Most tv interference complaints result from micro-sparks which can be eliminated as they occur, and these are not generally design considerations. In a few cases corona-caused tv noise occurs in foul weather. Fig 5.5 shows an approximate representation of radio interference for the example transmission line.

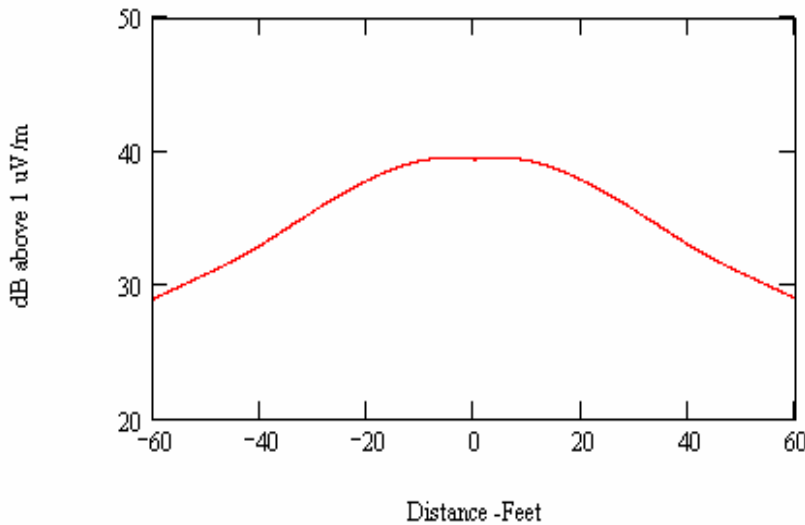


Fig 5.5 Radio noise profile for transmission line.

5.5 Audible Noise

Substation and transmission lines are sources of audible noise. Audible noise from a transmission line during fair weather conditions is unnoticeable. During wet weather, rain droplets collect on the conductor and cause a crackling or humming sound which can be heard near the line. Audible noise decreases with distance from the line. Ambient or background noise is a composite of sounds from many near and far sources. Average ambient daytime and nighttime noise levels are listed in the Table 5.1. Outdoor average nighttime ambient noise level is lower than daytime ambient levels by approximately 5 dB [8].

Audible noise from corona during foul weather is a critical design parameter for ac transmission lines. Audible noise consists of a random component and low frequency hum, and each is caused by a different physical mechanism. Only hum is closely related to corona loss, while the most frequent cause of annoyance is random noise.

Table 5.1

AVERAGE AMBIENT SOUND LEVELS

Type of Neighborhood	A-Weighted Ambient Sound level (dBA)	
	Day	Night
Rural	35	35
Residential Suburban	40	35
Residential Urban	45	40
Commercial	50	45
Industrial	55	50

Consider A -weighted sound level, $[dB(A)]$ during the rain.

L_{50} is the level exceeded 50% of the time during rain.

L_5 is the level, exceeded 5% of the time during rain.

Average is the average level of noise expected during rain.

Heavy rain is the level of noise expected in heavy rain.

The formula developed for L_{50} and L_5 values developed at Project UHV [11] is given by

g Average- maximum surface gradient of conductor or conductor bundle, kV/cm

n Number of sub conductors in a phase bundle.

d Diameters of sub-conductors, cm

D Distance from line to point at which noise level is to be calculated, m.

SL A -weighted sound level of the noise produced by the line, dB(A)

AN A -weighted sound level of the noise produced by one phase of the line, dB(A).

AN₀ Reference A -weighted sound level, dB(A)

K_1, K_2, K_3, K_4 , Constant coefficients

Application All line geometries.

Noise measure: $L_{50, \text{rain}}$ and $L_5 \text{ rain}$

Range of validity 230-1500 kV, $1 \leq n \leq 16$, $2 \leq d \leq 6$

For each phase, the L_5 noise level is given by

$$AN_5 = -665/g + 20 \log n + 44 \log d - 10 \log D - 0.02D + AN_0 + K_1 + K_2 \quad (5-10)$$

With

$$AN_0 = 75.2 \text{ for } n < 3$$

$$= 67.9 \text{ for } n \geq 3$$

$$K_1 = 7.5 \text{ for } n = 1$$

$$= 2.6 \text{ for } n = 2$$

$$= 0 \text{ for } n \geq 3$$

$$K_2 = 0 \text{ for } n < 3$$

$$= [22.9(n-1)d/B] \text{ for } n \geq 3$$

Where B is the bundle diameter, cm.

The L_{50} level for each phase is obtained from

$$AN_{50} = AN_5 - \Delta A \quad (5-11)$$

Where $\Delta A = 14.2 \text{ g}_c/g - 8.2$ for $n < 3$

$$= [14.2 \text{ g}_c/g - 10.4 - 8[(n-1) d/B]] \quad \text{for } n \geq 3$$

And $\text{g}_c = 24.4(d^{0.24})$ for $n \leq 8$

$$= 24.4(d^{0.24}) - 0.25(n-8) \quad \text{for } n > 8$$

$$SL = 10 \log \sum_{i=1}^P 10^{A_{Ni}/10} \quad (5-12)$$

This method helps in analyzing the maximum expected noise levels as well as the effect of the width of the ROW. Similarly, design variables such as conductor size, spacing and configuration; height of conductors; weather variations, etc., can be considered. Most audible noise complaints occur during wet-conductor conditions and low ambient noise occurs in conditions after rain or fog. During heavy rain the rain noise covers the transmission line noise, and other factors such as closed windows result in fewer complaints even though the noise is louder. Figs. 5.6 and 5.7 show the audible noise profile for the example transmission line for levels exceeding 5% and 50% of time during rain.

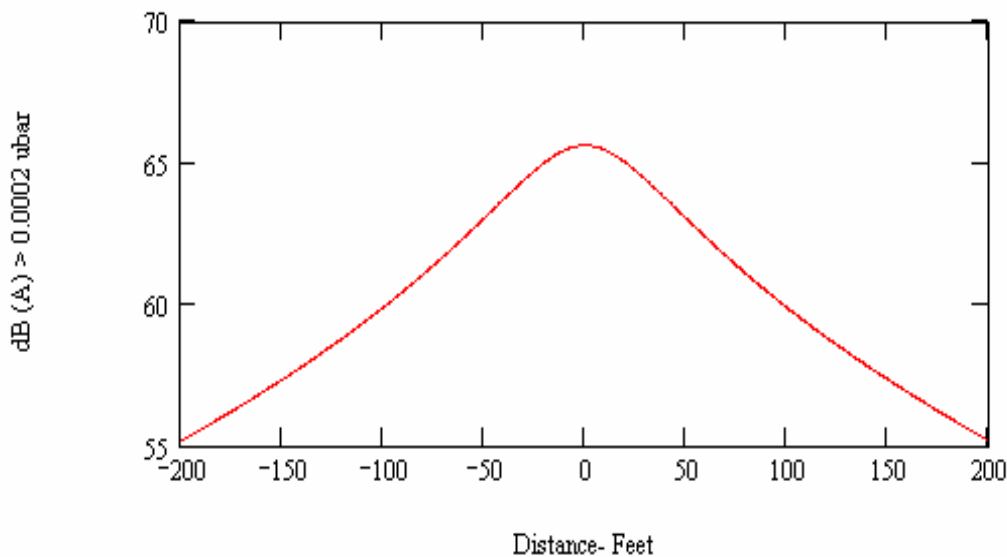


Fig 5.6 Audible noise profile for level exceeding 5% of time.

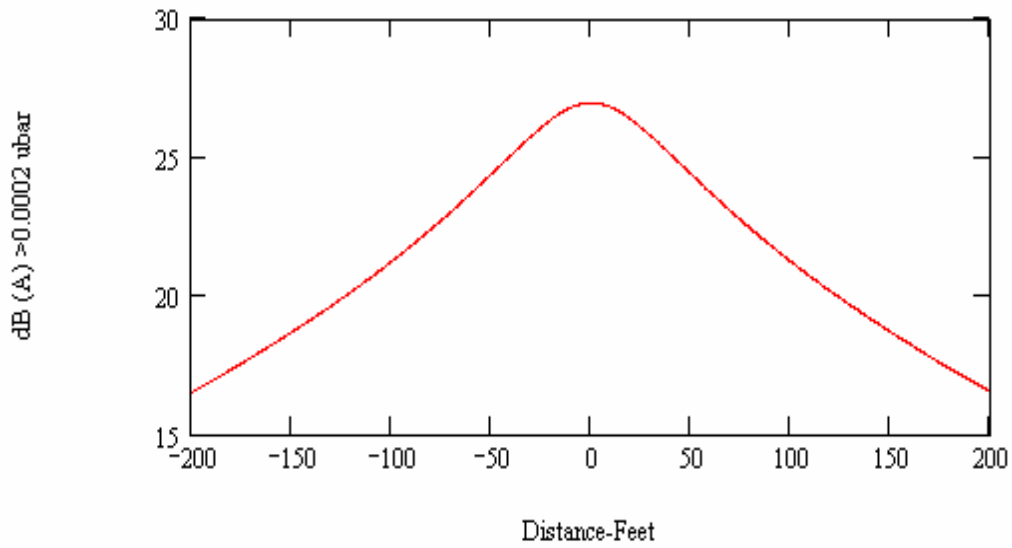


Fig 5.7 Audible noise profile for level exceeding 50% of time.

The detailed calculations for electric fields, magnetic fields, radio noise and audible noise to obtain the curves of Figs. 5.3 to 5.7 are given in Appendix C.

CHAPTER-6

CONCLUSIONS & RECOMMENDATIONS

The transmission line routing process can be made simpler and less time consuming by using the GIS based AMIS technique. Landscape features are incorporated into AMIS software, and then it can be applied to any transmission routing project. This research shows that routing a transmission line is not only an engineering problem but also includes socio-economic, environmental and safety issues.

The utilities must know all the legal obligations required for a new transmission line well ahead of construction. State rules and laws must be followed and implemented. The state commission responsible for issuing permits must be consulted before filing an application for a permit. Federal agencies are involved in projects in which a line is routed through federal property, and also in extra high voltage and international transmission line projects.

Stakeholders are the most critical groups in the whole transmission line routing process. When a project is in the planning stage all the stakeholders must be identified and their concerns must be properly addressed. This avoids later litigation, and reduces unnecessary delays in a project. The AMIS technique gives transparency, an analytical mechanism for comparing values, rapid assessment and results, and above all, less opposition from stakeholders during polling in meetings with stakeholders.

Objections to transmission lines mainly come from the electric fields, magnetic fields, audible noise and radio noise produced by the line. All these features decay with distance, and as we go away from the line, their effects decrease.

6.1 Future Work

The AMIS technique for routing highways can be applied to line routing to determine the least cost route between two substations. But the objective is to find a route with minimum opposition; the route developed by the above technique may or may not be the lowest cost solution. In the future there may be rules and laws about the levels of electric and magnetic fields around transmission line. The effects of electric fields, magnetic fields, radio noise and audible noise can be integrated in GIS to see their effects in the area around a transmission line.

This research work can be further extended from the transmission level to distribution. The AMIS technique can be applied and tested for routing overhead and underground distribution. The routing technique can be integrated into commercial line design software like PLS-Cad to route lines while considering the other engineering design requirements of a line.

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APPENDICES

APPENDIX-A

A.1 Vertical Clearances

A.1.1 Vertical clearance above road

For 161 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 18.5 \text{ ft} + 0.4 \frac{\left(\frac{161}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 20.865 \text{ ft}$$

RUS recommended clearance = NESC vertical clearance + RUS Adder

$$RVC := NVC + 2.5 \text{ ft}$$

$$RVC = 23.365 \text{ ft}$$

For 230 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 18.5 \text{ ft} + 0.4 \frac{\left(\frac{230}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 22.193 \text{ ft}$$

RUS recommended clearance = NESC vertical clearance + RUS Adder

$$RVC := NVC + 2.5 \text{ ft}$$

$$RVC = 24.693 \text{ ft}$$

For 345 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 18.5 \text{ ft} + 0.4 \frac{\left(\frac{345}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 24.406\text{ft}$$

RUS recommended clearance= NESC vertical clearance + RUS Adder

$$RVC := NVC + 2.5\text{-ft}$$

$$RVC = 26.906\text{ft}$$

A.1.2 Vertical clearance above railroad

For 161 kV line

NESC vertical clearance =NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 26.5\text{ft} + 0.4 \frac{\left(\frac{161}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 28.865\text{ft}$$

RUS recommended clearance= NESC vertical clearance + RUS Adder

$$RVC := NVC + 2.5\text{-ft}$$

$$RVC = 31.365\text{ft}$$

For 230 kV line

NESC vertical clearance =NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 26.5\text{ft} + 0.4 \frac{\left(\frac{230}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 30.193\text{ft}$$

RUS recommended clearance= NESC vertical clearance + RUS Adder

$$RVC := NVC + 2.5\text{-ft}$$

$$RVC = 32.693\text{ft}$$

For 345 kV line

NESC vertical clearance =NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$\text{NVC} := 26.5 \text{ ft} + 0.4 \frac{\left(\frac{345}{\sqrt{3}} - 22 \right)}{12} \cdot \text{ft}$$

$$\text{NVC} = 32.406 \text{ ft}$$

RUS recommended clearance = NESC vertical clearance + RUS Adder

$$\text{RVC} := \text{NVC} + 2.5 \text{ ft}$$

$$\text{RVC} = 34.906 \text{ ft}$$

A.1.3 Vertical clearance above farmland

For 161 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$\text{NVC} := 18.5 \text{ ft} + 0.4 \frac{\left(\frac{161}{\sqrt{3}} - 22 \right)}{12} \cdot \text{ft}$$

$$\text{NVC} = 20.865 \text{ ft}$$

RUS recommended clearance = NESC vertical clearance + RUS Adder

$$\text{RVC} := \text{NVC} + 2.5 \text{ ft}$$

$$\text{RVC} = 23.365 \text{ ft}$$

For 230 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$\text{NVC} := 18.5 \text{ ft} + 0.4 \frac{\left(\frac{230}{\sqrt{3}} - 22 \right)}{12} \cdot \text{ft}$$

$$\text{NVC} = 22.193 \text{ ft}$$

RUS recommended clearance = NESC vertical clearance + RUS Adder

$$\text{RVC} := \text{NVC} + 2.5 \text{ ft}$$

$$\text{RVC} = 24.693 \text{ ft}$$

For 345 kV line

NESC vertical clearance =NESC basic vertical clearance + 0.4(kV_{L-G}-22)/12

$$NVC:= 18.5\text{ ft} + 0.4 \frac{\left(\frac{345}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 24.406\text{ft}$$

RUS recommended clearance= NESC vertical clearance + RUS Adder

$$RVC:= NVC + 2.5\text{ ft}$$

$$RVC = 26.906\text{ft}$$

A.1.4 Vertical clearance above rivers & streams

For 161 kV line

NESC vertical clearance =NESC basic vertical clearance + 0.4(kV_{L-G}-22)/12

$$NVC:= 17\text{ ft} + 0.4 \frac{\left(\frac{161}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 19.365\text{ft}$$

RUS recommended clearance= NESC vertical clearance + RUS Adder

$$RVC:= NVC + 2.5\text{ ft}$$

$$RVC = 21.865\text{ft}$$

For 230 kV line

NESC vertical clearance =NESC basic vertical clearance + 0.4(kV_{L-G}-22)/12

$$NVC:= 17\text{ ft} + 0.4 \frac{\left(\frac{230}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 20.693\text{ft}$$

RUS recommended clearance= NESC vertical clearance + RUS Adder

$$RVC:= NVC + 2.5\text{-ft}$$

$$RVC = 23.193\text{ft}$$

For 345 kV line

NESC vertical clearance =NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC:= 17\text{-ft} + 0.4 \frac{\left(\frac{345}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 22.906\text{ft}$$

RUS recommended clearance= NESC vertical clearance + RUS Adder

$$RVC:= NVC + 2.5\text{-ft}$$

$$RVC = 25.406\text{ft}$$

A.1.5 Vertical clearance above lakes 200 -2000 acres

For 161 kV line

NESC vertical clearance =NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC:= 34.5\text{-ft} + 0.4 \frac{\left(\frac{161}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 36.865\text{ft}$$

RUS recommended clearance= NESC vertical clearance + RUS Adder

$$RVC:= NVC + 2.5\text{-ft}$$

$$RVC = 39.365\text{ft}$$

For 230 kV line

NESC vertical clearance =NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 34.5 \text{ ft} + 0.4 \frac{\left(\frac{230}{\sqrt{3}} - 22 \right)}{12} \cdot \text{ft}$$

$$NVC = 38.193 \text{ ft}$$

RUS recommended clearance = NESC vertical clearance + RUS Adder

$$RVC := NVC + 2.5 \text{ ft}$$

$$RVC = 40.693 \text{ ft}$$

For 345 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 34.5 \text{ ft} + 0.4 \frac{\left(\frac{345}{\sqrt{3}} - 22 \right)}{12} \cdot \text{ft}$$

$$NVC = 40.406 \text{ ft}$$

RUS recommended clearance = NESC vertical clearance + RUS Adder

$$RVC := NVC + 2.5 \text{ ft}$$

$$RVC = 42.906 \text{ ft}$$

A.1.6 Vertical clearance above buildings.

For 161 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 12.5 \text{ ft} + 0.4 \frac{\left(\frac{161}{\sqrt{3}} - 22 \right)}{12} \cdot \text{ft}$$

$$NVC = 14.865 \text{ ft}$$

RUS recommended clearance = NESC vertical clearance + RUS Adder

$$RVC := NVC + 2 \cdot \text{ft}$$

$$RVC = 16.865\text{ft}$$

For 230 kV line

$$\text{NESC vertical clearance} = \text{NESC basic vertical clearance} + 0.4(kV_{L-G} - 22)/12$$

$$NVC := 12.5\text{ ft} + 0.4 \frac{\left(\frac{230}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 16.193\text{ft}$$

$$\text{RUS recommended clearance} = \text{NESC vertical clearance} + \text{RUS Adder}$$

$$RVC := NVC + 2 \cdot \text{ft}$$

$$RVC = 18.193\text{ft}$$

For 345 kV line

$$\text{NESC vertical clearance} = \text{NESC basic vertical clearance} + 0.4(kV_{L-G} - 22)/12$$

$$NVC := 12.5\text{ ft} + 0.4 \frac{\left(\frac{345}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 18.406\text{ft}$$

$$\text{RUS recommended clearance} = \text{NESC vertical clearance} + \text{RUS Adder}$$

$$RVC := NVC + 2 \cdot \text{ft}$$

$$RVC = 20.406\text{ft}$$

A.1.7 Vertical clearance above Distribution power line.

For 161 kV line

$$\text{NESC vertical clearance} = \text{NESC basic vertical clearance} + 0.4(kV_{L-G} - 22)/12$$

$$NVC := 2 \cdot \text{ft} + 0.4 \frac{\left(\frac{161}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 4.365\text{ft}$$

RUS recommended clearance= NESC vertical clearance + RUS Adder

$$RVC := NVC + 1.5\text{-ft}$$

$$RVC = 5.865\text{ft}$$

For 230 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G} - 22)/12$

$$NVC := 2\text{-ft} + 0.4 \frac{\left(\frac{230}{\sqrt{3}} - 22\right)}{12} \text{-ft}$$

$$NVC = 5.693\text{ft}$$

RUS recommended clearance= NESC vertical clearance + RUS Adder

$$RVC := NVC + 1.5\text{-ft}$$

$$RVC = 7.193\text{ft}$$

For 345 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G} - 22)/12$

$$NVC := 2\text{-ft} + 0.4 \frac{\left(\frac{345}{\sqrt{3}} - 22\right)}{12} \text{-ft}$$

$$NVC = 7.906\text{ft}$$

RUS recommended clearance= NESC vertical clearance + RUS Adder

$$RVC := NVC + 1.5\text{-ft}$$

$$RVC = 9.406\text{ft}$$

A.1.8 Vertical clearance above Communication line.

For 161 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 5 \cdot \text{ft} + 0.4 \frac{\left(\frac{161}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 7.365 \text{ft}$$

RUS recommended clearance = NESC vertical clearance + RUS Adder

$$RVC := NVC + 1.5 \cdot \text{ft}$$

$$RVC = 8.865 \text{ft}$$

For 230 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 5 \cdot \text{ft} + 0.4 \frac{\left(\frac{230}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 8.693 \text{ft}$$

RUS recommended clearance = NESC vertical clearance + RUS Adder

$$RVC := NVC + 1.5 \cdot \text{ft}$$

$$RVC = 10.193 \text{ft}$$

For 345 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 5 \cdot \text{ft} + 0.4 \frac{\left(\frac{345}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 10.906 \text{ft}$$

RUS recommended clearance = NESC vertical clearance + RUS Adder

$$RVC := NVC + 1.5 \cdot \text{ft}$$

$$RVC = 12.406 \text{ft}$$

A.2 HORIZONTAL CLEARANCE

A.2.1 Horizontal Clearance from buildings wind at rest

For 161 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 7.5\text{-ft} + 0.4 \frac{\left(\frac{161}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 9.865\text{ft}$$

RUS recommended clearance = NESC vertical clearance + RUS Adder

$$RVC := NVC + 1.5\text{-ft}$$

$$RVC = 11.365\text{ft}$$

For 230 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 7.5\text{-ft} + 0.4 \frac{\left(\frac{230}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 11.193\text{ft}$$

RUS recommended clearance = NESC vertical clearance + RUS Adder

$$RVC := NVC + 1.5\text{-ft}$$

$$RVC = 12.693\text{ft}$$

For 345 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 7.5\text{-ft} + 0.4 \frac{\left(\frac{345}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 13.406\text{ft}$$

RUS recommended clearance= NESC vertical clearance + RUS Adder

$$RVC := NVC + 1.5\text{-ft}$$

$$RVC = 14.906\text{ft}$$

Horizontal Clearance from buildings wind when wind is blowing

For 161 kV line

NESC vertical clearance =NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 4.5\text{-ft} + 0.4 \frac{\left(\frac{161}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 6.865\text{ft}$$

RUS recommended clearance= NESC vertical clearance + RUS Adder

$$RVC := NVC + 1.5\text{-ft}$$

$$RVC = 8.365\text{ft}$$

For 230 kV line

NESC vertical clearance =NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 4.5\text{-ft} + 0.4 \frac{\left(\frac{230}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 8.193\text{ft}$$

RUS recommended clearance= NESC vertical clearance + RUS Adder

$$RVC := NVC + 1.5\text{-ft}$$

$$RVC = 9.693\text{ft}$$

For 345 kV line

NESC vertical clearance = NESC basic vertical clearance + $0.4(kV_{L-G}-22)/12$

$$NVC := 4.5 \text{ ft} + 0.4 \frac{\left(\frac{345}{\sqrt{3}} - 22\right)}{12} \cdot \text{ft}$$

$$NVC = 10.406 \text{ ft}$$

RUS recommended clearance = NESC vertical clearance + RUS Adder

$$RVC := NVC + 1.5 \text{ ft}$$

$$RVC = 11.906 \text{ ft}$$

APPENDIX-B

List of Stakeholders for Transmission Line Routing

Federal Agencies

Advisory Council on Historic Preservation

Agency for International Development

Appalachian Regional Commission
Defense Nuclear Facilities Safety Board

Delaware River Basin Commission

Denali Commission

Department of Agriculture

Department of Commerce

Department of Defense

Department of Energy Advisory Boards

Department of Health and Human Services

Department of Homeland Security

Department of Housing and Urban Development

Department of the Interior

Department of Justice

Department of Labor

Department of State

Department of Transportation

Department of the Treasury

Department of Veterans Affairs

Environmental Protection Agency

Federal Energy Regulatory Commission

Federal Maritime Commission

Federal Trade Commission

General Services Administration

International Boundary and Water Commission

International Trade Commission

Marine Mammal Commission

National Aeronautics and Space Administration

National Capital Planning Commission

National Science Foundation

Nuclear Regulatory Commission

Office of Science and Technology Policy

Overseas Private Investment Corporation

Small Business Administration

Susquehanna River Basin Commission

Tennessee Valley Authority

State and Local government authorities

National Association of Attorneys General

National Governors' Association

Rocky Flats Coalition of Local Governments

Southern States Energy Board

Western Governors' Association

Western Interstate Energy Board

Western Regional Air Partnership

American Indian Tribal Issues agencies

Civilian Radioactive Waste Management

Congressional and Intergovernmental Affairs

Economic Impact and Diversity

Energy Efficiency and Renewable Energy

Energy Information Administration

Environment, Safety and Health

Environmental Management

Fossil Energy

General Counsel

National Nuclear Security Administration/Defense Nuclear Nonproliferation

National Nuclear Security Administration/Defense Programs

Nuclear Energy

Policy and International Affairs

Science

Bonneville Power Administration

Carlsbad Field Office

Denver Regional Office

Golden Field Office

Idaho Operations Office

Lawrence Livermore National Laboratory/Diné College

Los Alamos National Laboratory

Los Alamos Site Office

National Energy Technology Laboratory

National Nuclear Security Administration Service Center

National Renewable Energy Laboratory

Naval Petroleum and Oil Shale Reserves in Colorado, Utah, Wyoming

Nevada Site Office

Oak Ridge Operations Office

Office of Repository Development

Richland Operations Office

Sandia National Laboratories

Sandia Site Office

Savannah River Operations Office

Southeastern Power Administration

Southwestern Power Administration

West Valley Demonstration Project

Western Area Power Administration

Non-Governmental Organizations

Academic Institutions, Communities and Agencies Network (ACA-Net)

Advocates for the Oak Ridge Reservation

AFL-CIO

Alliance for Nuclear Accountability

Alliance to Save Energy

American Association of Blacks in Energy
American Boiler Manufacturers Association
American Coal Ash Association
American Gas Association
American Petroleum Institute
American Public Power Association
American Recreation Coalition
Blue Ridge Environmental Defense League
Border Ecology Project
Carolina Peace Resource Center
Center for Applied Research
Center for Biological Diversity
Center for Community Action
Center for Health, Environment and Justice
Citizen Alert
Citizens for Alternatives to Radioactive Dumping (CARD)
Citizens for Environmental Justice
Clark Atlanta University
Clean Water Action
Coal Exporters Association of the US
Coalition for Health Concern
Coastal Conservation Association
Committee to Bridge the Gap

Concerned Citizens for Nuclear Safety

Deep South Center for Environmental Justice

Diné CARE (Citizens Against Ruining Our Environment)

Ducks Unlimited, Inc.

Economists Allied for Arms Reduction

Edison Electric Institute

Electric Power Research Institute

Electric Power Supply Association

Energy Communities Alliance

Environmental Defense

Environmental Defense Institute

Environmental Justice Resource Center

Environmental Poverty Law Program

Fernald Residents for Environmental Safety and Health (FRESH), Inc.

Friends of the Earth

Gas Technology Institute

Global Resource Action Center for the Environment

Government Accountability Project

Great Lakes United

Greenpeace International

Heart of America Northwest

Independent Terminal Operators Association

Indigenous Environmental Network

Institute for Energy and Environmental Research
Institute for Science and International Security
Interhemispheric Resource Center
Keep Yellowstone Nuclear Free
Legal Aid of North Carolina Pembroke Office
Los Alamos Study Group
Miamisburg Environmental Safety and Health, Inc. (MESH)
The Minnesota Project
National Audubon Society
National Coal Council
National Community Action Foundation
National Congress of American Indians
National Fish and Wildlife Foundation
National Hispanic Environmental Council
National Mining Association
National Parks Conservation Association
National Petrochemical and Refiners Association
National Petroleum Council
National Rural Electric Cooperative Association
National Tribal Environmental Council
National Trust for Historic Preservation
National Water Resources Association
National Wildlife Federation

Native Action

Natural Resources Defense Council

The Nature Conservancy

New England Wild Flower Society, Inc.

New York City Environmental Justice Alliance

Nuclear Control Institute

Nuclear Energy Institute

Nuclear Watch of New Mexico

Oak Ridge Environmental Peace Alliance

Panhandle Area Neighbors and Landowners (PANAL)

Peace Action Education Fund

Peace Farm

Physicians for Social Responsibility

Portsmouth/Pikeon Residents for Environmental Safety and Security

Prairie Rivers Network

Responsible Environmental Action League (REAL)

Rocky Mountain Peace and Justice Center

Sierra Club

Snake River Alliance

Southern Organizing Committee for Economic and Social Justice

Southwest Network for Environmental and Economic Justice

Southwest Research and Information Center

STAND (Serious Texans Against Nuclear Dumping), Inc.

The Tennessee Conservation League

Tri-Valley CAREs (Communities Against a Radioactive Environment)

Trout Unlimited

U.S. Public Interest Research Group

UCC Commission for Racial Justice

Union of Concerned Scientists

US Energy Association

Western Resource Advocates

Western States Legal Foundation

The Wilderness Society

Women's Action for New Directions

APPENDIX-C

Non-point Impact Calculations

Electric Field Calculations

$$V := 230 \cdot \text{V}$$

GMR

$$x := \frac{1.246}{2} \cdot \sqrt{\frac{2 \cdot 2 \cdot 0.042}{1.246}} \cdot \text{ft}$$

$$x = 0.229 \text{ft}$$

$$h := 110 \cdot \text{ft}$$

$$h = 33.528 \text{m}$$

$$E1(d, t) := \frac{2}{\ln\left(2 \cdot \frac{110}{0.229}\right)} \cdot \frac{110 \cdot V \cdot \cos(2 \cdot \pi \cdot 60 \cdot t)}{\left[110^2 + (14.25 - d)^2\right]}$$

$$h := 130 \cdot \text{ft}$$

$$h = 39.624 \text{m}$$

$$E2(d, t) := \frac{2}{\ln\left(2 \cdot \frac{130}{0.229}\right)} \cdot \frac{130 \cdot V \cdot \cos(2 \cdot \pi \cdot 60 \cdot t + 120 \cdot \text{deg})}{\left[130^2 + (14.25 - d)^2\right]}$$

$$h := 150 \cdot \text{ft}$$

$$h = 45.72 \text{m}$$

$$E3(d, t) := \frac{2}{\ln\left(2 \cdot \frac{150}{0.229}\right)} \cdot \frac{150 \cdot V \cdot \cos(2 \cdot \pi \cdot 60 \cdot t + 240 \cdot \text{deg})}{\left[150^2 + (14.25 - d)^2\right]}$$

$$ECl(d, t) := E1(d, t) + E2(d, t) + E3(d, t)$$

$$h := 110 \cdot \text{ft}$$

$$h = 33.528 \text{m}$$

$$E4(d,t) := \frac{2}{\ln\left(2 \cdot \frac{110}{0.229}\right)} \cdot \frac{110 \cdot V \cdot \cos(2 \cdot \pi \cdot 60 \cdot t)}{\left[110^2 + (14.25 + d)^2\right]}$$

$$h := 130 \cdot \text{ft}$$

$$h = 39.624\text{m}$$

$$E5(d,t) := \frac{2}{\ln\left(2 \cdot \frac{130}{0.229}\right)} \cdot \frac{130 \cdot V \cdot \cos(2 \cdot \pi \cdot 60 \cdot t + 120 \cdot \text{deg})}{\left[130^2 + (14.25 + d)^2\right]}$$

$$h := 150 \cdot \text{ft}$$

$$h = 45.72\text{m}$$

$$E6(d,t) := \frac{2}{\ln\left(2 \cdot \frac{150}{0.229}\right)} \cdot \frac{150 \cdot V \cdot \cos(2 \cdot \pi \cdot 60 \cdot t + 240 \cdot \text{deg})}{\left[150^2 + (14.25 + d)^2\right]}$$

$$EC2(d,t) := E4(d,t) + E5(d,t) + E6(d,t)$$

Magnetic Field Calculations

A) For Proposed Load

$$I := 1620$$

$$\mu := 4 \cdot \pi \cdot 10^{-7}$$

For circuit-1

$$B1(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t)}{2 \cdot \pi \cdot \sqrt{110^2 + (14.25 - d)^2}}$$

$$B2(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t + 120 \cdot \text{deg})}{2 \cdot \pi \cdot \sqrt{130^2 + (14.25 - d)^2}}$$

$$B3(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t + 240 \cdot \text{deg})}{2 \cdot \pi \cdot \sqrt{150^2 + (14.25 - d)^2}}$$

$$BC1(d,t) := B1(d,t) + B2(d,t) + B3(d,t)$$

For circuit-2

$$B4(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t)}{2 \cdot \pi \cdot \sqrt{110^2 + (14.25 + d)^2}}$$

$$B5(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t + 120 \cdot \text{deg})}{2 \cdot \pi \cdot \sqrt{130^2 + (14.25 + d)^2}}$$

$$B6(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t + 240 \cdot \text{deg})}{2 \cdot \pi \cdot \sqrt{150^2 + (14.25 + d)^2}}$$

$$BC2(d,t) := B4(d,t) + B5(d,t) + B6(d,t)$$

$$BCP(d,t) := (BC1(d,t) + BC2(d,t)) \cdot 10^3 \quad \text{mT}$$

B) For Existing Load

$$I := 1280$$

$$\mu := 4 \cdot \pi \cdot 10^{-7}$$

For circuit-1

$$B1(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t)}{2 \cdot \pi \cdot \sqrt{110^2 + (14.25 - d)^2}}$$

$$B2(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t + 120 \cdot \text{deg})}{2 \cdot \pi \cdot \sqrt{130^2 + (14.25 - d)^2}}$$

$$B3(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t + 240 \cdot \text{deg})}{2 \cdot \pi \cdot \sqrt{150^2 + (14.25 - d)^2}}$$

$$BC1(d,t) := B1(d,t) + B2(d,t) + B3(d,t)$$

For circuit-2

$$B4(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t)}{2 \cdot \pi \cdot \sqrt{110^2 + (14.25 + d)^2}}$$

$$B5(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t + 120 \cdot \text{deg})}{2 \cdot \pi \cdot \sqrt{130^2 + (14.25 + d)^2}}$$

$$B6(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t + 240 \cdot \text{deg})}{2 \cdot \pi \cdot \sqrt{150^2 + (14.25 + d)^2}}$$

$$BC2(d,t) := B4(d,t) + B5(d,t) + B6(d,t)$$

$$BC\mathcal{H}(d,t) := (BC1(d,t) + BC2(d,t)) \cdot 10^3 \text{ mT}$$

C) For Measured Load

$$I := 40z$$

$$\mu := 4 \cdot \pi \cdot 10^{-7}$$

For circuit-1

$$B1(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t)}{2 \cdot \pi \cdot \sqrt{110^2 + (14.25 - d)^2}}$$

$$B2(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t + 120 \cdot \text{deg})}{2 \cdot \pi \cdot \sqrt{130^2 + (14.25 - d)^2}}$$

$$B3(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t + 240 \cdot \text{deg})}{2 \cdot \pi \cdot \sqrt{150^2 + (14.25 - d)^2}}$$

$$BC1(d,t) := B1(d,t) + B2(d,t) + B3(d,t)$$

For circuit-2

$$B4(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t)}{2 \cdot \pi \cdot \sqrt{110^2 + (14.25 + d)^2}}$$

$$B5(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t + 120 \cdot \text{deg})}{2 \cdot \pi \cdot \sqrt{130^2 + (14.25 + d)^2}}$$

$$B6(d,t) := \frac{\mu \cdot I \cdot \cos(2 \cdot \pi \cdot t + 240 \cdot \text{deg})}{2 \cdot \pi \cdot \sqrt{150^2 + (14.25 + d)^2}}$$

$$BC2(d,t) := B4(d,t) + B5(d,t) + B6(d,t)$$

$$BC(d,t) := (BC1(d,t) + BC2(d,t)) \cdot 10^3 \text{ mT}$$

Fair Weather Radio Noise Calculations

$$E := \frac{230\sqrt{3} \cdot \left(1 + \frac{2 \cdot 1.582}{30.48}\right)}{2 \cdot \sqrt{3} \cdot 1.582 \cdot \ln\left(\frac{609.6}{\sqrt{1.582 \cdot 30.48}}\right)}$$

$$E = 17.931$$

Conductor radius -1.582 cm, Bundle spacing-30.48 cm, GMD 609.6 cm,

$$dd := 1.246 \cdot \text{in}$$

$$dd = 31.648\text{mm}$$

$$h := 45.72 \cdot \text{m}$$

$$f := 1$$

$$h := 110 \cdot \text{ft}$$

$$h = 33.528\text{m}$$

$$D1(d) := \sqrt{(4.343 - d)^2 + 33.528^2}$$

$$RI1(d) := -150.4 + 120 \cdot \log(E) + 40 \cdot \log(31.648) + 20 \cdot \log\left[\frac{33.528}{(D1(d))^2}\right] + 10 \cdot [1 - (\log(f))^2]$$

$$h := 130 \cdot \text{ft}$$

$$h = 39.624\text{m}$$

$$D2(d) := \sqrt{(4.343 - d)^2 + 39.624^2}$$

$$RI2(d) := -150.4 + 120 \cdot \log(E) + 40 \cdot \log(31.648) + 20 \cdot \log\left[\frac{39.624}{(D2(d))^2}\right] + 10 \cdot [1 - (\log(f))^2]$$

$$h := 150 \cdot \text{ft}$$

$$h = 45.72\text{m}$$

$$D3(d) := \sqrt{(4.343 - d)^2 + 45.72^2}$$

$$RI3(d) := -150.4 + 120 \cdot \log(E) + 40 \cdot \log(31.648) + 20 \cdot \log\left[\frac{45.72}{(D3(d))^2}\right] + 10 \cdot [1 - (\log(f))^2]$$

$$h := 110 \cdot \text{ft}$$

$$h = 33.528\text{m}$$

$$D4(d) := \sqrt{(4.343 + d)^2 + 33.528^2}$$

$$RI4(d) := -150.4 + 120 \cdot \log(E) + 40 \cdot \log(31.648) + 20 \cdot \log\left[\frac{33.528}{(D4(d))^2}\right] + 10 \cdot [1 - (\log(f))^2]$$

$$h := 130 \cdot \text{ft}$$

$$h = 39.624\text{m}$$

$$D5(d) := \sqrt{(4.343 + d)^2 + 39.624^2}$$

$$RI5(d) := -150.4 + 120 \cdot \log(E) + 40 \cdot \log(31.648) + 20 \cdot \log\left[\frac{39.624}{(D5(d))^2}\right] + 10 \cdot [1 - (\log(f))^2]$$

$$h := 150 \cdot \text{ft}$$

$$h = 45.72\text{m}$$

$$D6(d) := \sqrt{(4.343 + d)^2 + 45.72^2}$$

$$RI6(d) := -150.4 + 120 \cdot \log(E) + 40 \cdot \log(31.648) + 20 \cdot \log\left[\frac{45.72}{(D6(d))^2}\right] + 10 \cdot [1 - (\log(f))^2]$$

Audible Noise Calculations

Level exceeding 5% of the time

$$n := 2$$

$$AN_0 := 75.2$$

$$K_1 := 2.6$$

$$K_2 := 0$$

$$g_c := 24.4 \cdot 3.165^{-0.24}$$

$$x := 1 \cdot \pi$$

$$E := \frac{230\sqrt{3} \cdot \left(1 + \frac{2 \cdot 1.28}{30.48}\right)}{2 \cdot \sqrt{3} \cdot 1.28 \cdot \ln\left(\frac{609.6}{\sqrt{1.28 \cdot 30.48}}\right)}$$

$$E = 21.26$$

$$x = 3.281\text{ft}$$

$$h := 110 \cdot \text{ft}$$

$$h = 33.528\text{m}$$

$$AN_{15}(d) := \frac{-665}{E} + 20 \cdot \log(2) + 44 \cdot \log(3.165) - 10 \cdot \log\left[\sqrt{(4.343 - d)^2 + 33.528^2}\right] - 0.02 \cdot \left[\sqrt{(4.343 - d)^2 + 33.528^2}\right] + AN_0 + K_1 + K_2$$

$$h := 130 \cdot \text{ft}$$

$$h = 39.624\text{m}$$

$$AN_{25}(d) := \frac{-665}{E} + 20 \cdot \log(2) + 44 \cdot \log(3.165) - 10 \cdot \log\left[\sqrt{(4.343 - d)^2 + 39.624^2}\right] - 0.02 \cdot \left[\sqrt{(4.343 - d)^2 + 39.624^2}\right] + AN_0 + K_1 + K_2$$

$$h := 150 \cdot \text{ft}$$

$$h = 45.72\text{m}$$

$$AN_{35}(d) := \frac{-665}{E} + 20 \cdot \log(2) + 44 \cdot \log(3.165) - 10 \cdot \log\left[\sqrt{(4.343 - d)^2 + 45.72^2}\right] - 0.02 \cdot \left[\sqrt{(4.343 - d)^2 + 45.72^2}\right] + AN_0 + K_1 + K_2$$

$$h := 110 \cdot \text{ft}$$

$$h = 33.528\text{m}$$

$$AN_{45}(d) := \frac{-665}{E} + 20 \cdot \log(2) + 44 \cdot \log(3.165) - 10 \cdot \log\left[\sqrt{(4.343 + d)^2 + 33.528^2}\right] - 0.02 \cdot \left[\sqrt{(4.343 + d)^2 + 33.528^2}\right] + AN_0 + K_1 + K_2$$

$$h := 130 \cdot \text{ft}$$

$$h = 39.624\text{m}$$

$$AN_{55}(d) := \frac{-665}{E} + 20 \cdot \log(2) + 44 \cdot \log(3.165) - 10 \cdot \log\left[\sqrt{(4.343 + d)^2 + 39.624^2}\right] - 0.02 \cdot \left[\sqrt{(4.343 + d)^2 + 39.624^2}\right] + AN_0 + K_1 + K_2$$

$$h := 150 \cdot \text{ft}$$

$$h = 45.72\text{m}$$

$$AN_{65}(d) := \frac{-665}{E} + 20 \cdot \log(2) + 44 \cdot \log(3.165) - 10 \cdot \log\left[\sqrt{(4.343 + d)^2 + 45.72^2}\right] - 0.02 \cdot \left[\sqrt{(4.343 + d)^2 + 45.72^2}\right] + AN_0 + K_1 + K_2$$

$$AN_5(d) := \frac{AN_{15}(d) + AN_{25}(d) + AN_{35}(d) + AN_{45}(d) + AN_{55}(d) + AN_{65}(d)}{10}$$

$$SL_5(d) := 10 \cdot \log\left(10^{\frac{AN_{15}(d)}{10}} + 10^{\frac{AN_{25}(d)}{10}} + 10^{\frac{AN_{35}(d)}{10}} + 10^{\frac{AN_{45}(d)}{10}} + 10^{\frac{AN_{55}(d)}{10}} + 10^{\frac{AN_{65}(d)}{10}}\right)$$

Level exceeding 50% of the time

$$\Delta A := 14.2 \cdot \frac{g_c}{5.609} - 8.2$$

$$\Delta A = 38.649$$

$$AN_{150}(d) := AN_{15}(d) - \Delta A$$

$$AN_{250}(d) := AN_{25}(d) - \Delta A$$

$$AN_{350}(d) := AN_{35}(d) - \Delta A$$

$$AN_{450}(d) := AN_{45}(d) - \Delta A$$

$$AN_{550}(d) := AN_{55}(d) - \Delta A$$

$$AN_{650}(d) := AN_{65}(d) - \Delta A$$

$$SL_{50}(d) := 10 \cdot \log \left(10^{\frac{AN_{150}(d)}{10}} + 10^{\frac{AN_{250}(d)}{10}} + 10^{\frac{AN_{350}(d)}{10}} + 10^{\frac{AN_{450}(d)}{10}} + 10^{\frac{AN_{550}(d)}{10}} + 10^{\frac{AN_{650}(d)}{10}} \right)$$