SWAT Southwest Area Transmission

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AZ CORP COMMISSION
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ORIGINAL

July 8, 2009

Arizona Corporation Commission
DOCKETED
JUL - 8 2009
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Docket Control
Arizona Corporation Commission
1200 W. Washington Street
Phoenix, Arizona 85007

RE: SWAT White Paper on Structure Separation for Transmission Lines in Common Corridors; Docket No. E-00000D-09-0020

Dear Sir/Madam:

The Southwest Area Transmission (SWAT) Sub-Regional Transmission Planning Group is comprised of transmission regulators/governmental entities, transmission users, transmission owners, transmission providers, transmission operators and environmental entities. The group was formed to promote regional planning across the entire Southwest area of the Western Electricity Coordinating Council. A key goal of SWAT is to maximize use and benefits of the existing and future regional transmission system. SWAT operates in a public forum and is open to any entity or persons interested in the development and future of the electric transmission system. SWAT encourages collaborative efforts and joint participation to address issues.

In May 2008 the SWAT Oversight Committee approved the formation of a new task force to address issues associated with the determination of the separation distance for EHV/HV transmission lines that are parallel in a common corridor. SWAT members identified this as a key issue requiring more study as the issue has been raised in recent siting matters before the Arizona Corporation Commission and will likely be a recurring issue as new transmission lines are sited in common corridors. The Common Corridor Task Force considered Western Electricity Coordinating Council, North American Electric Reliability Corporation, Federal Energy Regulatory Commission standards and criteria, system reliability, environmental impacts (visual and others), EMF impacts, land use, property values and severance, federal land issues, maintenance requirements, best practices, and project cost in its evaluation of such line separation. The task force prepared a white paper that addresses the group's findings. The conclusions included in the White Paper suggest that there is not a universal solution that can be applied to every evaluation of corridor separation. However, the White Paper describes the issues that should be weighed in evaluating the addition of a circuit with existing circuits or new common corridors. The attached White Paper entitled "White Paper on Structure Separation for Transmission Lines in Common Corridors" dated May 2009, was approved by the SWAT Oversight Committee at its May 19-20, 2009 meeting. SWAT offers this White Paper for the Commission's consideration in developing policy direction.

Sincerely,

Robert E. Kondziolka

Robert E. Kondziolka
Chairman of the SWAT Sub-Regional Transmission Planning Group

REK:JKB

Enclosure

cc: Janice Alward
Ernest Johnson
Prem Bahl
SWAT Oversight Committee
SWAT Common Corridor Task Force

Original and 13 copies of the foregoing filed with Docket Control.

SWAT
Southwest Area Transmission

SWAT

Common Corridor Task Force

White Paper on Structure Separation for Transmission Lines in Common Corridors

FINAL

May 2009

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EXECUTIVE SUMMARY

This White Paper addresses the issues between the reliability benefits of increasing the separation of circuits versus the increased cost and potential land disturbance necessary for increased separation distances for transmission lines in common corridors.

The separation of circuits can be varied between the minimum electrical safety separation distances to beyond the height of the structures for transmission lines in common corridor, i.e., falling separation. The costs of separating lines in a common corridor must be weighed against the risk of these typical common outage incidents and the consequences to the system if the outage were to occur. However, increasing separation does not guarantee increased reliability as there are still common outage events that can occur even if the separation is greater than the structure height, such as fires, airplanes, etc. The NERC Standards only require study of circuits on a common structure. WECC criteria have performance requirements for adjacent circuits in a corridor. Hence, only the WECC region has the added performance requirements for multiple circuits in a corridor. These additional requirements in WECC could result in significant reduction in path ratings and render the project uneconomical.

There is not a universal solution that can be applied to every evaluation of corridor separation, However, this White Paper describes the issues that are to be weighed whenever evaluating the addition of a circuit with existing circuits or new common corridors; reliability versus cost comparison for each project. These issues are weighed in the evaluation but the relevance of particular issues needs to be determined as it applies to the specific corridor being evaluated, i.e., evaluations are done on a case by case basis.

General Conclusions

Separation May Not Measurably Improve System Reliability or Operational Limits

A way to insure that one circuit in a corridor cannot physically impact an adjacent circuit is to build it beyond the physical boundaries of the adjacent circuit. However, this adds the cost of increased corridor costs. As the separation distance is increased from the safety minimum, some potential outage cause probabilities are reduced. However, building circuits beyond the physical limit does not eliminate the common exposure to some outage causes.

Separation Requires Additional Cost

The effort to minimize easement requirements is to minimize the cost to rate payers. Separation increases easement width requirements and the total cost of easements for the transmission line.

Increased Separation May Increase Land Use Restrictions

Transmission line easements create land use limitations on the underlying landowner. A transmission line easement typically precludes any development directly under the facilities; however, adjacent land uses such as commercial or industrial typically are more compatible than residential. Residential uses are typically not as compatible with a transmission line right-of-way for various concerns. Recreational trails have shared right-of-way with transmission lines due to existing access and open linear path.

Separation Limits Transmission Line Siting Opportunities

Separation would increase easement widths which may preclude and eliminate some route opportunities. Increased separation may reduce opportunities in line siting options.

Separation Could Cause Creation of Additional Transmission Line Corridors

Because there are usually increased costs associated with greater easement width when paralleling an existing line, the owner of the new line may have financial motivation to site new lines along new routes.

Separation Creates Additional Difficulties Siting Transmission Corridor across Public Lands

Majority of federal and state agencies have adopted management guidelines within their respective land management plans to consolidate linear infrastructure to the extent possible. The siting of a transmission line across public land requires environmental analysis to comply with the guidelines adopted in the respective management plan. Locating transmission lines outside of designated corridors may extend the permitting schedule several years and require additional environmental analysis.

TASK FORCE MEMBERS

The SWAT Common Corridor Task Force was developed out of members of SWAT in the summer of 2008 to discuss and write a White Paper about common corridor issues. The Mission of this Task Force was: *to address and establish principles associated with the determination of the separation distance of linear circuits that are in parallel in the same corridor.*

This White Paper was to address and describe common corridor structure separation issues; system reliability, EMF impacts, land use, aesthetics, potential increase with severance, federal land issues, cost differences, WECC/NERC/FERC standards, best practices and trade–offs.

The Task Force Members were:

Brian Keel – SRP - Chair
Michael Voda – SRP
Tom Wray – SWPG, SunZia
Cindy Bailey – SWPG, SunZia
Jaime Wood – EPG
Baj Agrawal – APS
Javi Munoz – SRP
Ken Bagley – Genesee Consulting
Mark Etherton – PDS, SunZia
Ron Belval – TEP
Prem Bahl – ACC
Doug Selin – APS

The Task Force met once with presentations from all members of the Task Force about the topic on which the member was deemed to be the expert. The presentations and the messages of the presentations were converted into this document.

POSITION OF STATE LAND DEPARTMENTS

In an effort to ascertain the position of regional state land departments on the siting of transmission facilities, discussions were held with representatives of the Arizona and New Mexico state land departments. Through these discussions it became apparent that both states' respective land departments held similar positions on the siting of transmission facilities on state land. Their principal concern is with maximizing the value of trust land.

Neither state has explicit principles which need to be followed when evaluating such requests. All requests to utilize state trust land, for the purpose of siting transmission facilities, will be evaluated on a case-by-case basis. Electric system reliability is not an explicit concern when evaluating a request, but the implications of siting facilities on the value of adjoining property is an explicit concern. As such, preference was implied to locating transmission facilities along the path of existing facilities or section lines.

State Guide for Siting

This portion discusses state siting laws, regulations, and guidelines governing the construction of transmission facilities in the U.S. Transmission siting regulations were researched to identify structure separation distance standards for parallel lines in a common corridor. Research was based on states within the Western Electricity Coordinating Council including: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

The following table outlines each state's regulatory authority responsible for approving the construction of transmission facilities; the citations covering transmission facility siting regulation; and the certificate awarded to an applicant by the regulatory authority that permits construction.

State	Regulatory Authority	Regulatory Citations	Certificate Allowing Construction
Arizona	Arizona Corporation Commission; Power Plant and Transmission Line Siting Committee	Arizona Revised Statutes 40-360	Certificate of Environmental Compatibility
California	California Public Utility Commission	California Public Utility Code Section 8026-8038; General Order No 130-D	Certificate of Public Convenience and Need; Lines under 200 kV require a Permit to Construct
California	California Energy Commission; Energy Facilities Siting Division	California Public Resources Code Section 25300-25324	Application for Certification

Colorado	Colorado Public Utilities Commission	Colorado Revised Statutes 40-2-126; 4 Code of Colorado Regulations 723	Certificate of Public Convenience and Necessity
Idaho	Idaho Public Utilities Commission	Idaho Code Chapter 61 Sections 526-528	Certificate of Convenience and Necessity
Montana	Montana Department of Environmental Quality (DEQ)	Montana Major Facility Siting Act, 75-20-101 et seq. MCA	Certificate of Environmental Compatibility
Nevada	Public Utilities Commission of Nevada; Reviewed by the Department of Conservation and Natural Resources	Utility Environmental Protection Act state statute 704.820-704.900 and/or Nevada Administrative Code 703.415-703.427	Utility Environmental Protection Act Permit
New Mexico	New Mexico Public Regulation Commission	New Mexico Statutes and Court Rules Chapter 62	Certificate of Convenience and Necessity
Oregon	Oregon Energy Facility Siting Council	Siting requirements: ORS 469.320; Conditions: ORS 469.401, 469.442; Standards: ORS 469.490, 469.501; EFSC Rules: ORS Chapter 345, Division 1-29	Site Certificate
Utah	Public Service Commission of Utah	Utah Code – Statutes Title 54	Certificate of Convenience and Necessity
Washington	Washington Energy Facility Site Evaluation Council	Energy Facilities Site Location Chapter 80.50 of the Revised Code of Washington	Site Certification Agreement
Wyoming	Wyoming Public Service Commission; Department of Quality has siting jurisdiction over lines built by any entity other than a public utility	Wyoming Public Service Commission Title 37 PSC Rules 202, 204, 205	Certificate of Public Convenience and Necessity

Review of the regulatory citations for each of these states confirmed there are no guidelines specifying separation distances between transmission facilities in a common corridor for Arizona, California, Colorado, Montana, Nevada, New Mexico, Oregon, Utah, Washington, or Wyoming. These results were further confirmed by speaking with representatives from each of the public utilities or designated siting authority. There was a general consensus that engineering judgment and electrical construction codes will determine structure separation distances for parallel lines in a common corridor.

The Idaho Public Utilities Commission detailed construction standards in the Idaho Code Title 61, Chapter 17 (61-1706) that states, "*Each transmitting utility will construct,* *install, operate, and maintain its transmission facility in compliance with the current edition of the National Electrical Safety Code published by the Institute of Electrical and Electronics Engineers.*

Sources

State-Level Electric Transmission Line Siting Regulation Directory: Edison Electric Institute: Prepared by Resource Strategies, Inc.

Washington Energy Facility Site Evaluation Council
http://efsec.wa.gov/lawrule.shtml
Oregon State Website
http://oregon.gov/ENERGY/SITING/index.shtml
Oregon Revised Statutes
http://www.leg.state.or.us/ors/469.html
Montana Department of Environmental Quality
http://deq.mt.gov/MFS/index.asp
Montana Code Annotated
http://data.opi.state.mt.us/bills/mca/75/20/75-20-101.htm
Wyoming Public Service Commission
http://psc.state.wy.us/htdocs/electric_new.htm
Idaho Public Utilities Commission
www.puc.state.id.us
Idaho Code Chapter 17, Title 61 (61-1706)
http://www3.state.id.us/cgi-bin/newidst?sctid=610050038.K
Arizona Corporation Commission
www.azcc.gov/
Arizona Revised Statutes
www.azleg.state.az.us/ArizonaRevisedStatutes.asp
California Energy Commission
www.energy.ca.gov/
California Public Utility Commission
www.cpuc.ca.gov/puc/
California Public Resource Code and Public Utilities Code
www.leginfo.ca.gov/calaw.html
Colorado Public Utilities Commission
www.dora.state.co.us/PUC/
Colorado Revised Statutes
www.state.co.us/gov_dir/leg_dir/olls/colorado_revised_statutes.htm
New Mexico Public Regulatory Commission
www.nmprc.state.nm.us/
New Mexico Statutes and Court Rules
www.conwaygreene.com/NewMexico.htm
Public Utilities Commission of Nevada
http://pucweb1.state.nv.us/pucn/PUCHome.aspx

Nevada Revised Statutes
www.leg.state.nv.us/law1.cfm
Nevada Administrative Code
www.leg.state.nv.us/NAC/NAC-703.html
Public Service Commission of Utah
www.psc.utah.gov/index.html
Utah Code Public Utility
http://www.le.state.ut.us/~code/TITLE54/TITLE54.htm
Utah Division of Public Utilities
http://publicutilities.utah.gov/utilitylaws.html

PERMITTING AND CONSTRUCTION IMPLICATIONS ON FEDERAL LANDS

Siting of a high voltage (HV) or extra-high voltage (EHV) transmission line across the Western states could cross several hundred miles of lands managed privately, by the state, and/or federal government, each with its own set of rules and procedures for granting rights-of-way. The federal land management plans typically designate utility corridors, or in some cases exclusion or avoidance areas where development (e.g., overhead transmission lines) cannot occur. Management plans typically identify the width of the utility corridor and may specify the type of utility allowed within a corridor (e.g., overhead transmission line versus an underground pipeline). Permitting requirements are subject to regional or site-specific agency procedures.

There are several areas where potential jurisdictional constraints such as crossing Indian reservations, national monuments, national forests, national recreation areas, etc. are present. These jurisdictional constraints present potential issues and may limit the ability to connect areas of major energy sources with major load centers. Agencies' (federal, state, and local) utility corridors vary in width from several hundred feet to over 5 miles, and length may be influenced by physical planning boundaries, land uses, and environmental resources present in a given area. These widths may allow the siting of utility lines in existing corridors to avoid environmentally sensitive areas, jurisdictional constraints, and meet WECC criteria for separation of lines.

If a utility proposes to construct and operate a transmission line on federally managed lands outside of the designated corridor, the proponent may be required to amend the adopted management plan. Existing transmission lines located on federal, state, or private land generally presents options immediately adjacent to the facility to site an additional transmission line. The ability to share right-of-way and access roads minimizes potential environmental impact, and has been identified as opportunity areas in past transmission line siting projects throughout the western United States.

Potential environmental impacts to siting transmission lines in separate corridors require each project to be evaluated independently. In addition, each project would include analysis of cumulative effects for all past, present, and future projects. The permitting risk is dependent upon the level of potential environmental impact for siting the transmission line. Each project area may have different jurisdictions with various policies or regulations, environmental resource concerns, or linear features considered opportunities throughout the area. Therefore, potential environmental impacts for separation of corridors cannot be specifically addressed in this White Paper. In general, the potential for increased environmental impacts resulting from corridor separation would likely occur to environmental resources including, but not limited to, visual, land use, biology, cultural, socioeconomics, etc. For example, corridor separation could result in increased disturbance from new access roads and could potentially locate a new corridor near populated areas or dispersed residences increasing environmental impacts.

The intent of this section of the White Paper is to discuss the potential permitting and construction implications of increased separation distance between new and/or existing HV/EHV transmission lines.

Department of Energy Final Programmatic Environmental Impact Statement

The purpose of the Final Programmatic Environmental Impact Statement (PEIS) is to implement Section 368 of the Energy Policy Act of 2005. The Final PEIS designates corridors for the preferred location of linear facilities in agency land use and resource management plans on federal lands. However, Section 368 does not require the agencies to consider or approve specific projects, right-of-way applications, or other permits within designated energy corridors. The corridor widths in the Final PEIS range from 200 feet to 5.5 miles, depending on federal agency and adopted management plan. The Final PEIS does not provide guidelines for siting transmission lines.

WECC Separation Criteria

The separation criteria is being driven by WECC in the process of developing a new deterministic criterion for adjacent transmission lines to be considered as independent for rating purposes. The adopted WECC separation criteria applied for current and for future HV/EHV transmission lines may be as much as 500 feet or one span distance, whichever is greater. Many utility system planners have identified typical HV/EHV transmission line spans ranging between 800 feet up to 1,800 feet (average of 1,500 feet) with a right-of-way width of 175 feet up to 300 feet. For example, transmission lines rights-of-way (up to 300 feet in width) would be required to have a distance of 1,500 feet separation.

Transmission Line Siting and Separation

Agencies and environmental communities agree that one of the most effective ways to reduce environmental impacts can be through consolidation of facilities and/or placement of facilities in proximity to one another. Some of the advantages can include (1) the use of "common access" resulting in reduced levels of ground disturbance, (2) placement of facilities within an area that has been previously modified (reduced impacts on habitat [fragmentation], existing and planned land use, visual resources, etc.) and (3) potential cumulative effects. This could affect the level of NEPA analysis required, and whether or not an amendment to agencies' land-use plans would be required, both of which have implications on schedule and costs (e.g., approval, appeals, etc.).

On private lands, utilities in existing rights-of-way can be considered an opportunity area for future transmission lines. However, when separation such as up to 1,800 feet is established, the opportunities associated in proximity to the existing line(s) may not be present. Examples of these conditions can include areas used for agricultural purposes (e.g., farmland) and developed areas where offsetting the new line can increase the effect on environmental conditions and, consequently, public opposition. In addition, perceptions often are influenced by other existing corridors that are seen as examples. For instance, in Arizona there are numerous transmission lines in proximity to one another in corridors leading into the Phoenix area (e.g., Mead to Phoenix, south of Page, south of Tucson) that are highly visible to the public. Individuals in both developed and rural settings have and will continue to identify these examples and question the need for additional separation between transmission lines.

Federal Land Policy Management Act of 1976 (FLPMA) Section 503

By virtue of the almost one-half billion acres of public and forest lands that it governs, the FLPMA is the most significant of the laws authorizing federal agencies to grant easements and other rights-of-way. FLPMA requires that each right-of-way grant contain terms and conditions that will, among other things, 'minimize damage to scenic and esthetic values and fish and wildlife habitat and otherwise protect the environment.' Congress addressed the issue of rights-of-way utility corridors in Section 503 of the FLPMA. Section 503 states that the Secretary of the Interior shall designate corridors to minimize adverse environmental impacts and the Order 13213 requires BLM to emphasize rights-of-way planning and corridor designations. The overall objective is to continue to make federally administered lands available for needed rights-of-way where consistent with national, state, and local plans, and use common rights-of-way to minimize environmental impacts and proliferation of separate rights-of-way.

FLPMA further states that to the extent possible and with consideration of safety conditions, it is required that use of rights-of-way are to be common and use of designated corridors for new rights-of-way. A designated corridor is a preferred location for the placement of rights-of-way.

Section 368 of the Energy Policy Act of 2005 requires the federal land agencies to anticipate and plan for the energy infrastructure needs of the nation. Section 368 is based on FLPMA Section 503 and designed to encourage closer cooperation among federal jurisdictions involved in the siting of linear energy facilities to identify appropriate corridors that could be available for siting energy facilities and be consistent with the management priorities established for the affected federal lands. Siting transmission facilities across federal lands is among the most difficult siting challenges faced. The need to cross a parcel of federal land entails an established process that generally requires a lengthy timeframe.

Potential Scenarios Resulting from Implementation of WECC Separation Criteria

There are three scenarios that could potentially occur as a result of increased separation distances based upon WECC separation criteria. The separation criteria would apply to existing and proposed HV/EHV transmission lines. The scenarios are described below.

The first scenario is likely the most restrictive, with consideration for constructing new transmission lines in corridors with existing transmission lines. There are likely very few corridors containing one or more existing transmission lines that would allow construction of proposed transmission lines, while maintaining a separation distance average of 1,500 feet between rights-of-way.

In the second scenario, two proposed transmission lines could be separated from each other using geographically unique corridors paralleling existing transmission lines. Although the conditions described for the first scenario could apply, it is potentially more feasible to construct a single proposed transmission line adjacent to an existing transmission line, while maintaining a separation distance average of 1,500 feet between rights-of-way.

The third scenario would result in the construction of proposed transmission lines in entirely new corridors for the whole length of the project. The proposed transmission lines could be collocated or in geographically unique corridors. This scenario would be very difficult to permit due to jurisdictional approvals, management plans directives/restrictions, public opposition, and environmental constraints (e.g., land use, biology, cultural, and visual resources).

Section Summary

If the increased separation distance pushes a proposed transmission line outside of a designated federal utility corridor, this would require a management plan amendment, thus increasing the permitting risks. This is due to additional environmental impacts resulting from new construction (e.g., access roads, structure clearing, and staging areas) predominantly beyond areas previously disturbed for existing projects. This would be a primary concern throughout federal lands, especially those managed by the Bureau of Land Management and Forest Service. However, it is important to note that this could also have an effect on state, municipal, and private lands as well since those agencies typically share similar concern for planning resources for lands they own/manage.

In combination with the separation, requirements or preferences for placement of facilities (e.g., transmission line on one side or another of an existing line, and substation locations in relation to the transmission lines being sited) may further constrain the ability to site the facilities in ways that are compatible with existing physical conditions (terrain and other features) and in coordination with agency land-use plans.

Given the potential consequences of this separation, justification and clear definition of the need for and the extent of separation will be critical during the siting and permitting of future HV/EHV transmission lines.

CONSIDERATIONS IN SELECTING WIDTH OF TRANSMISSION LINE EASEMENTS

The following is a brief summary of the considerations in determining the width of a transmission line easement. The width of the easement is influenced by the type of structure, the arrangements of the electrical conductors (wires) on the structure, the types of insulators used to attach the wire, distance between transmission structures and the space required to construct and maintain the line.

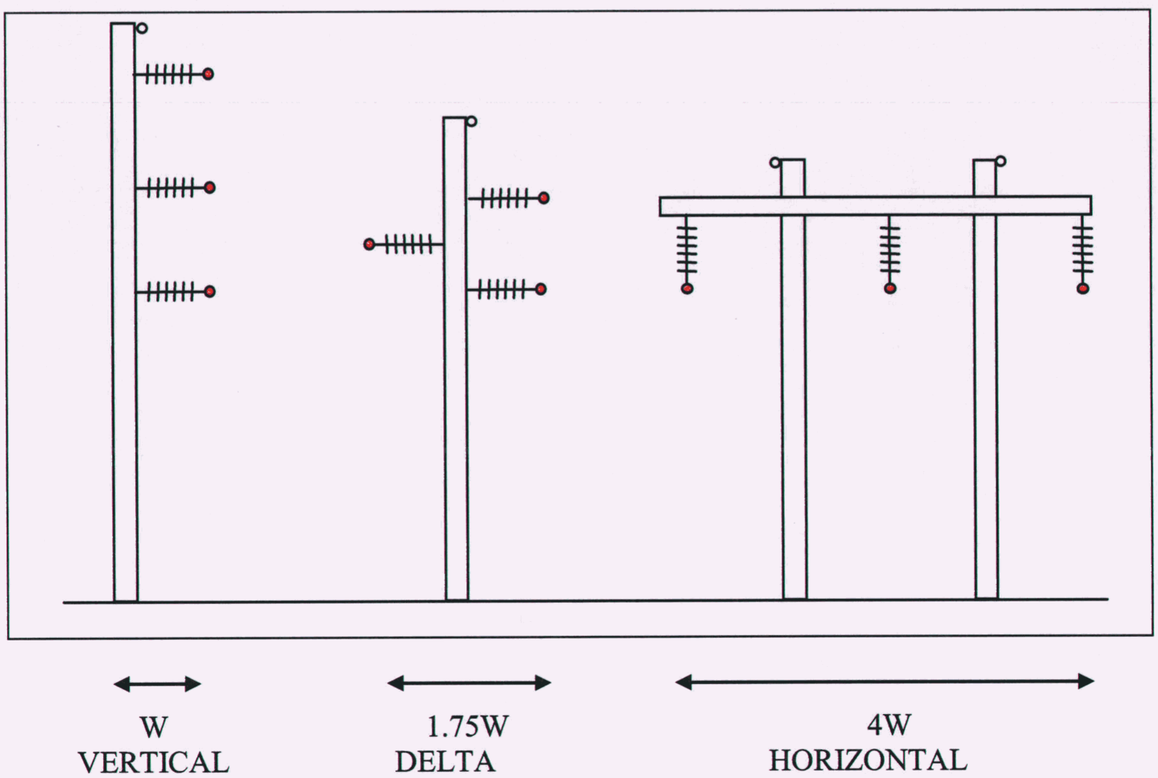
Structure Framing

The arrangement of the electric conductors on a structure (framing) selected for a given structure or line is dependent upon several factors including; cost, limitation in available easement width, the number of circuits, clearance requirements, structural capacity and aesthetics.

Single Circuit Framing Configuration

Single circuit structures are typically framed vertically, in a delta configuration, or horizontally and increase in width respectively.

FIGURE 1 – Single Circuit Structures



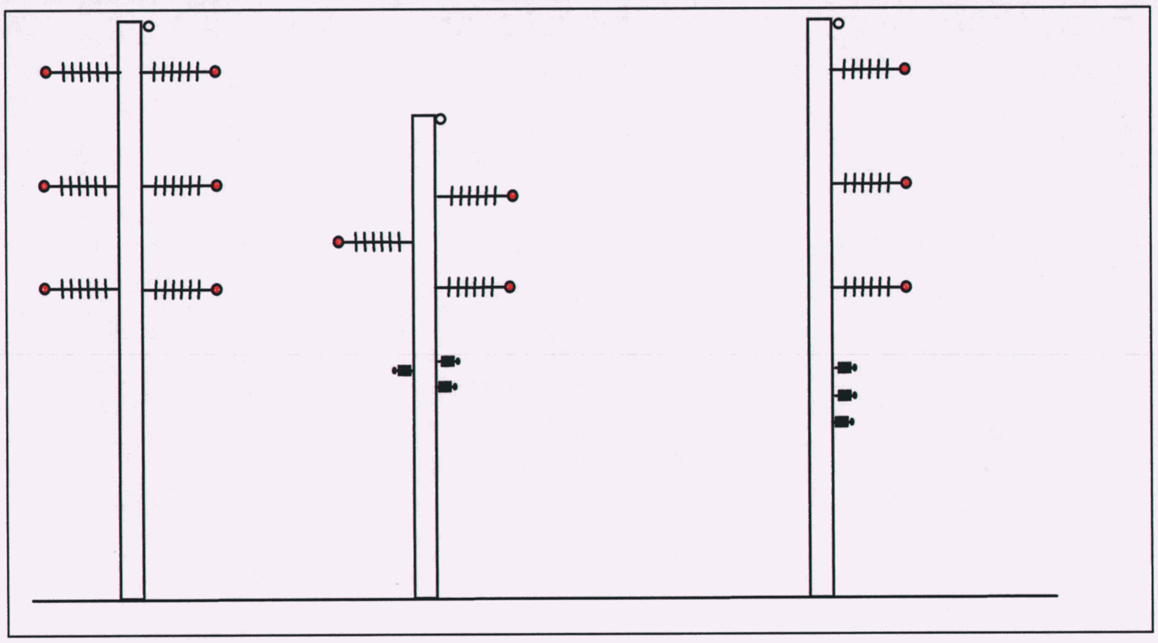
Note that this depiction is schematic. Insulators can vary from Post, braced posts (horizontal vee), Suspension insulator strings on arms or Vee strings.

The horizontal framing configuration will be around four times the width of a vertically framed structure using insulator post framing. If the vertically framed pole is configured with arms and suspension insulators (or V strings), the difference in width is reduced slightly (horizontally framed structure will be ~3.5 W).

Double Circuit Framing Configuration

Generally, two circuits of similar voltage will be framed vertically in a side by side configuration. If there is a large difference in voltage levels between the two circuits, the lower voltage may be framed entirely below the circuit of greater voltage as shown below.

FIGURE 2 – Double Circuit Framing



Double Circuit Vertical Framing	Double Circuit Delta Framing Underbuilt	Double Circuit Vertical Framing Underbuilt

Horizontal framing on double circuit structures is not common. Therefore, variation in width amongst double circuit structures is less than that of single circuit structures.

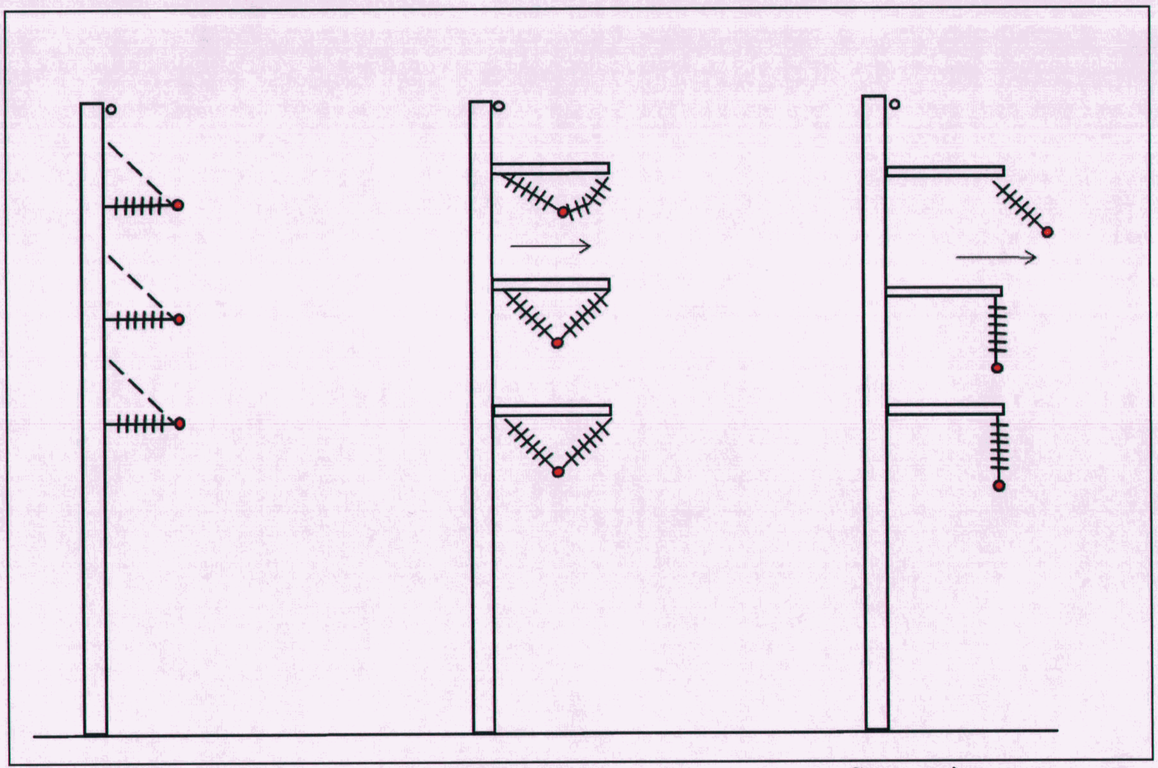
Triple and Quad Circuit Structures

When the number of circuits on a structure is three or more, typically there are one or two larger circuits on the upper portion of the pole with one or two circuits framed in the underbuilt position.

Insulators

The insulator is the non-conducting structural element that attaches the conductor to a structure. Insulators may be attached to a structure in several configurations which either restrict or permit the movement of the conductor attachment point relative to the structure. Rigidly mounted insulators such a Post or Braced Post will not permit the movement of the conductor attachment while V-Strings allow small amounts and Suspension Insulators permit free motion as shown below.

FIGURE 3 – Insulator Swing



Post or Braced Post
No insulator swing

V-Strings
Very slight insulator swing

Suspension
Very large Insulator swing

The greater the range of motion in the swing of an insulator under high wind conditions, the greater the required width of a transmission line easement.

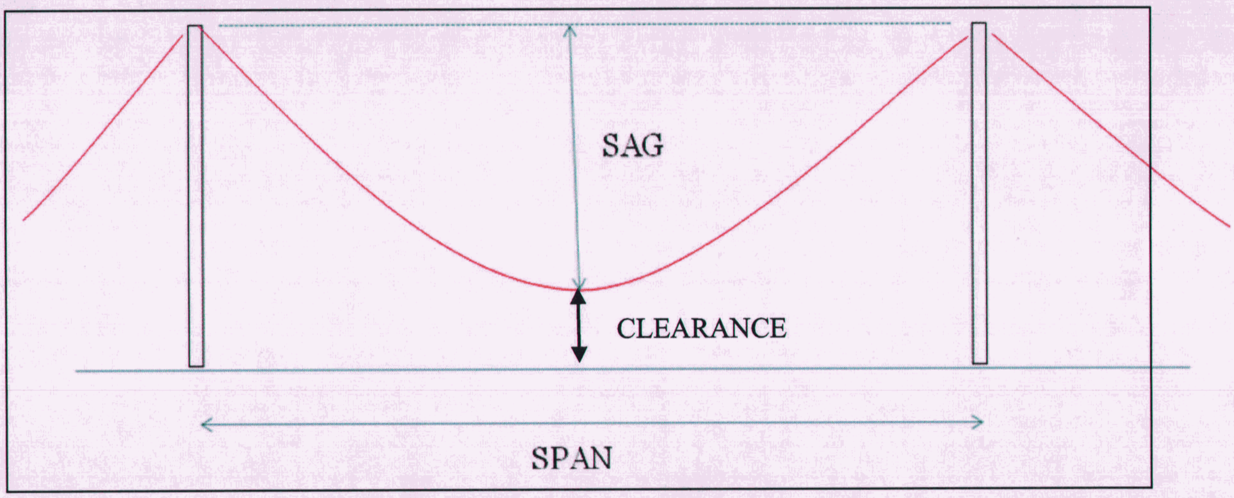
Sag and Blowout

A conductor suspended between two structures forms a catenary (a mathematical shape). This complex mathematical shape is often simplified to a parabola so that parabolic equations may be used to estimate the position and shape the conductor forms.

The amount the conductor droops down below the ***average*** height of the two ends of its support is called SAG. The amount of sag is dependent on the distance (span) between supports, weight of the wire and the tension at which the conductor is installed. Since conductors are made up of aluminum, a material which expands and contracts with temperature, sag is also highly dependent on the temperature of the conductor.

FIGURE 4 – Sag

$$SAG = \frac{SPAN^2 * Weight/Ft}{8 * Tension}$$

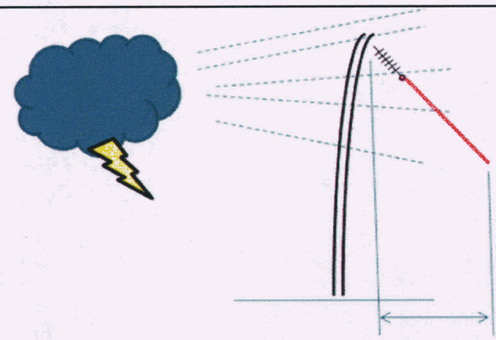


Sag is a function of the square of the span (modeled by a parabolic equation). A parabolic shape has sides that slope at an increasing rate at greater distance from the center. Therefore, as the span increases, pole heights increase at a greater rate at greater distances from the center of the span. Pole heights will increase at the rate of [Clearance + SAG] for any span.

Note in the equation that sag is a function of the square of the span. Therefore, as the conductor span increases, sag increases at a much greater rate. Conductor sag may be reduced by increasing tension, However, the higher the tension, the stronger (more expensive) the support structures resisting that tension. The National Electric Safety Code limits tensions of conductors to insure adequate strength margins exist at temperature and wind extremes. Another negative aspect of high tension is vibration control; the tighter the wire, the more it vibrates in wind. Vibration can lead to breaking of the strands in the wire and eventually failure of the conductor.When wind blows transversely (perpendicularly to the span), the conductor will deflect and "blow out".

When viewed from above, the shape of blowout is similar to the shape of the sag and increases with the velocity of the wind

FIGURE 5 - Blowout



$$\text{Blowout} = \sin\left[\tan^{-1}\left[\frac{\text{Dia x Force}}{12\ \text{Wgt/ Ft}}\right]\right] * \text{SAG}$$

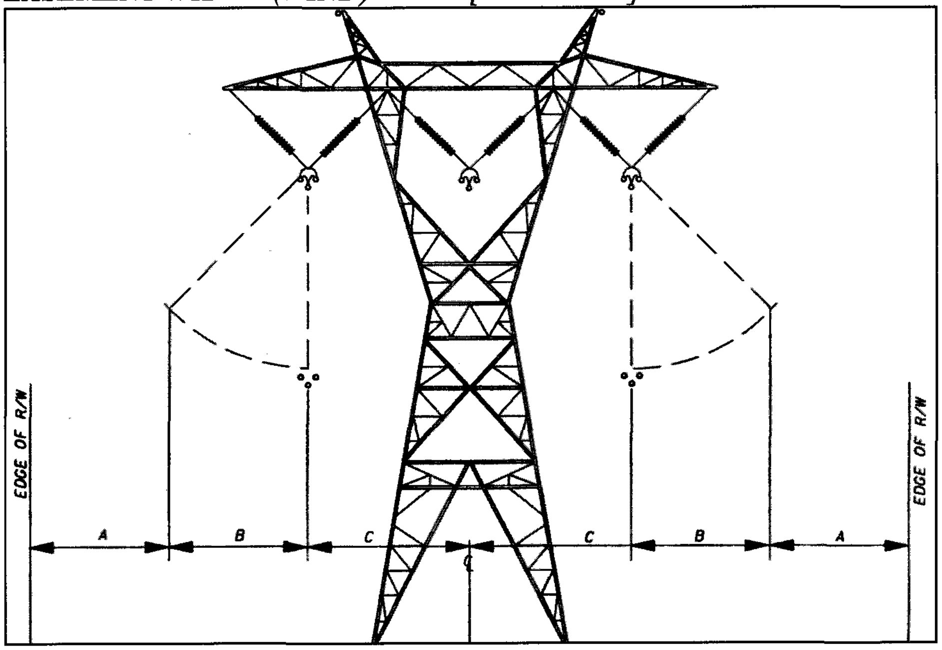
Blowout is directly proportional to the sag of the conductor and the wind pressure. The longer the span, the greater the sag and the greater the resulting blow out.

Determining Total Easement Width for Blow Out

As discussed, the elements making up the width of a transmission line easement are structure configuration, insulator and conductor movement due to wind (the magnitude of which is influenced by span) and the electrical clearance required at the edges of the easement for safety. When combining all those elements, the calculation of the easement width will be a sum of the component parts:

FIGURE 6 – Easement Width

EASEMENT WIDTH (WIND) = 2 [A + B + C]



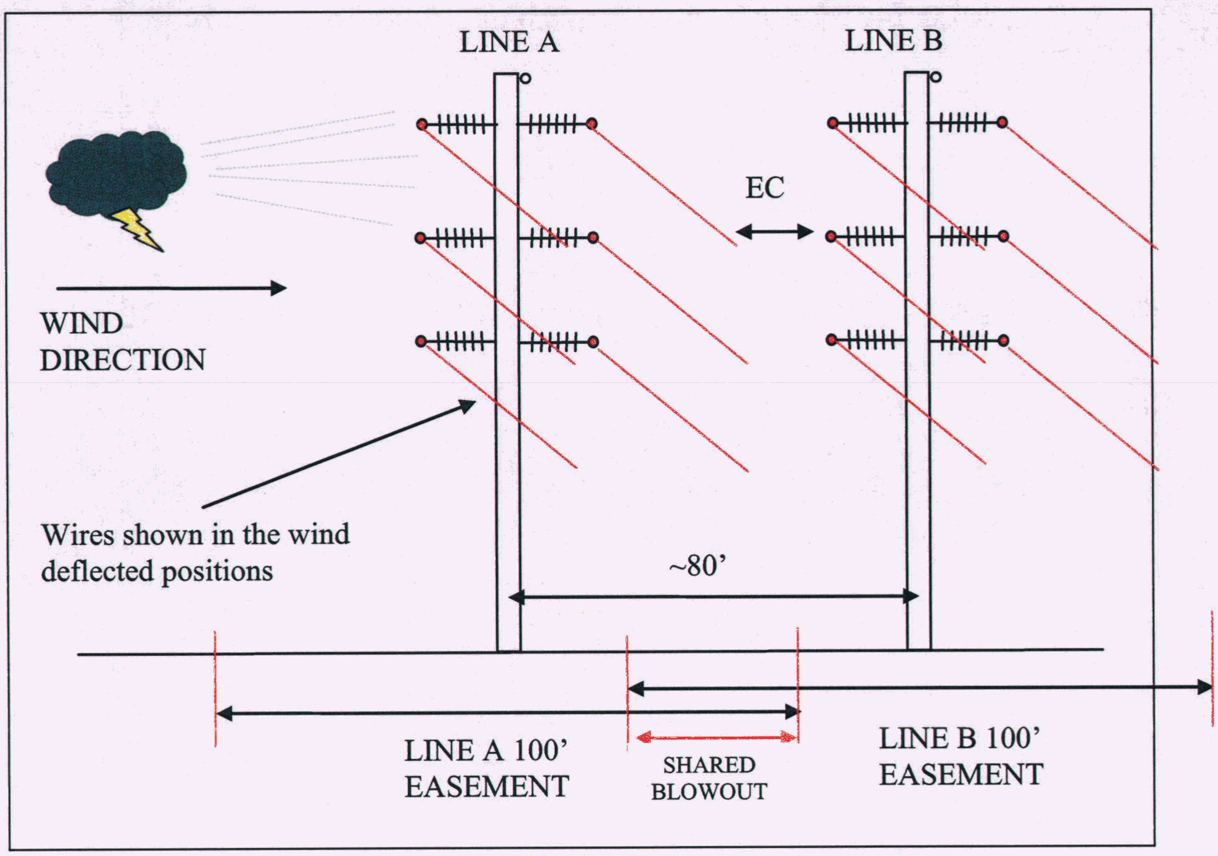
- A = N.E.S.C. Horizontal Clearance to Buildings (14' at 500 kV)
- B = Conductor Blowout due to wind (includes insulator swing and deflection of the structure)
- C = Distance from center of structure to outer conductor

Shared Easements between Parallel Transmission Lines

When parallel transmission lines occupy a common corridor, it is possible to "share" blow out space in the area between the lines. This sharing of space is possible because the wind deflects the wires together in the same direction.

For example: LINE A, a double circuit 230 kV transmission line might normally occupy a 100ft wide easement with the structures centered in the 100ft. When LINE B is constructed adjacent to LINE A, the combined easement widths may be less than 100' + 100' because the space between the lines may be reduced if the two lines have similar spans and adjacent structures. As the wind blows, the wires on each line will be deflected in the same direction. The pressure of the wind would not allow the wires to swing in one direction on one line and in the opposite direction on the other. Therefore, the wires of one line may crossover or "share" the blowout zone of the adjacent line.

FIGURE 7 – Common Corridor



NOTE: All dimensions shown are approximate and for demonstration purposes only
EC = Electrical Clearance

IMPORTANT NOTE: Other requirements for easement width may prevent sharing of space between transmission lines. This example only discusses space required for blowout. Other factors such as clearances required for maintenance of the line may demand greater distances between adjacent transmission lines.

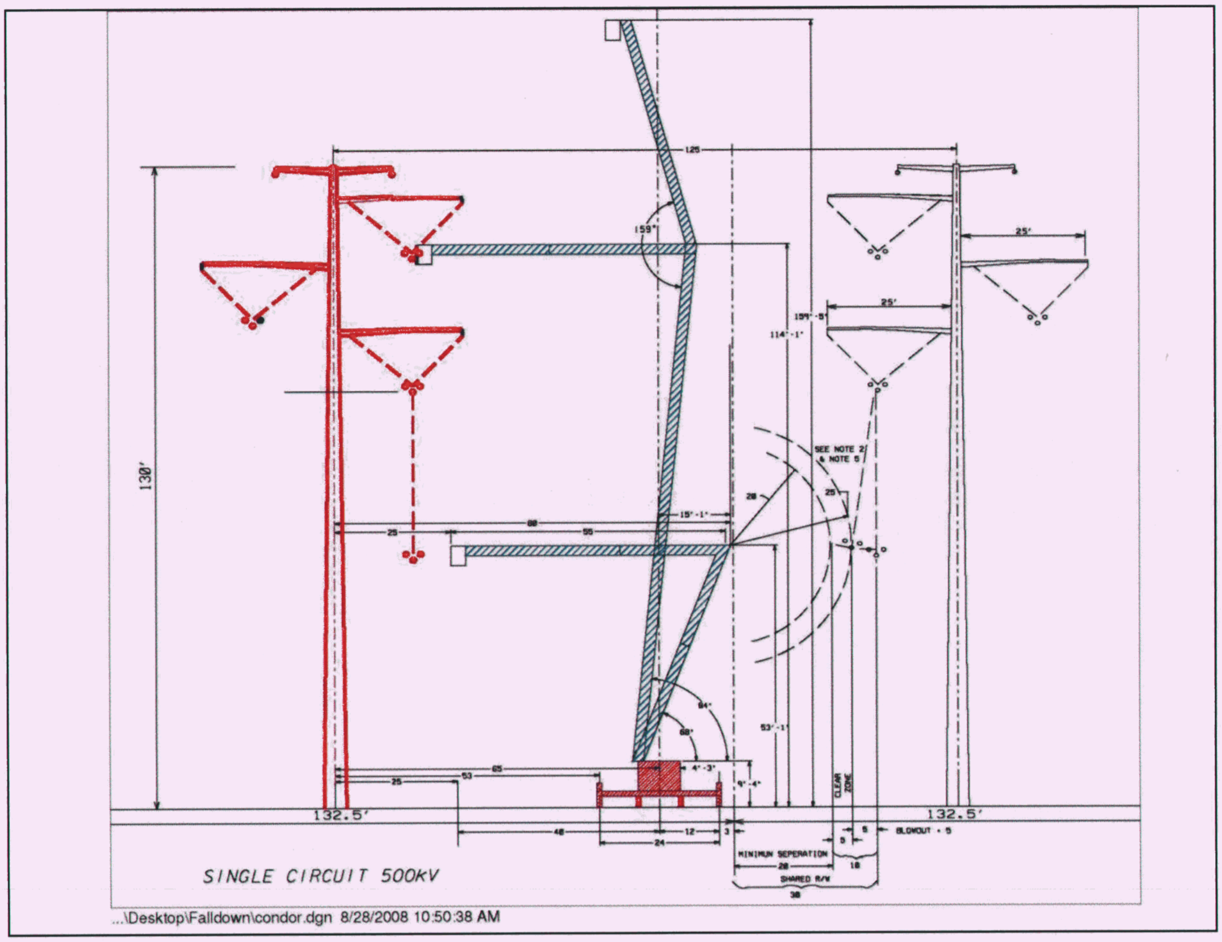
Easement Width Requirements for Maintenance

Maintenance activities on transmission line structures typically require the use of cranes and high reach bucket trucks. To accommodate the use of this equipment, easements must be sized to allow for their operation at a safe distance from the transmission line

It may be extremely difficult or expensive to get an electrical outage on a transmission line; therefore, work is often done in the presence of energized lines, commonly referred to as "live line maintenance." Safe working clearances between the energized wire and the cranes or bucket trucks must be maintained. Working clearances are established by the NESC and OSHA. The operating space required will be a function of the line voltage and the operational range of the equipment.

Figure 8 illustrates an example of the dimensional requirements considered from working on an energized line with a high-reach manlift. This illustration assumes a parallel circuit adjacent to line; electrical clearance must be watch on both sides of the man lift.

FIGURE 8 – Manlift Reach Requirements



Total Cost Optimization Using Easement Width

The major cost components of a transmission line are:

Easement Acquisition: Easements are purchased for the right to construct and maintain the transmission line. The easement has stringent limitations on how the land owner may use the underlying land and therefore, the cost of acquisition approaches the salable value of the land

In areas of high land value (urban areas), easement may exceed $100,000 per acre. In rural and desert areas, values are currently $30,000 to $40,000 per acre. For a 500 kV transmission line in a 130 feet wide easement, in an area with an average of $50,000 per acre, easement costs would be $790,000 per mile

Conductor: Selection of the conductor is outside of the topic of easement width and will not be discussed.

Structures and Foundations: The cost of steel structures is relatively straightforward; as it may be estimated on a cost per pound basis. Lattice towers are made up of hot rolled shapes and have a current cost of approximately $1.30 per pound. Tapered tubular steel poles are custom fabricated shapes and currently cost $2.20 per pound. The weight of the structures supporting a similar load is relatively similar with steel poles being slightly heavier than an equivalent lattice tower.

However, foundation costs for steel poles are significantly higher. Lattice towers require four simple "push-pull" foundations to resist vertical loads and are relatively inexpensive. Steel poles require larger diameter piers heavily reinforced to resist overturning. A single steel pole foundation may cost 2 to 5 times more than the four foundations required for an equivalent lattice tower.

Optimization: The goal in transmission line design is to optimize the total installed cost:

Total installed cost = $LAND + $MATERIALS + $CONSTRUCTION

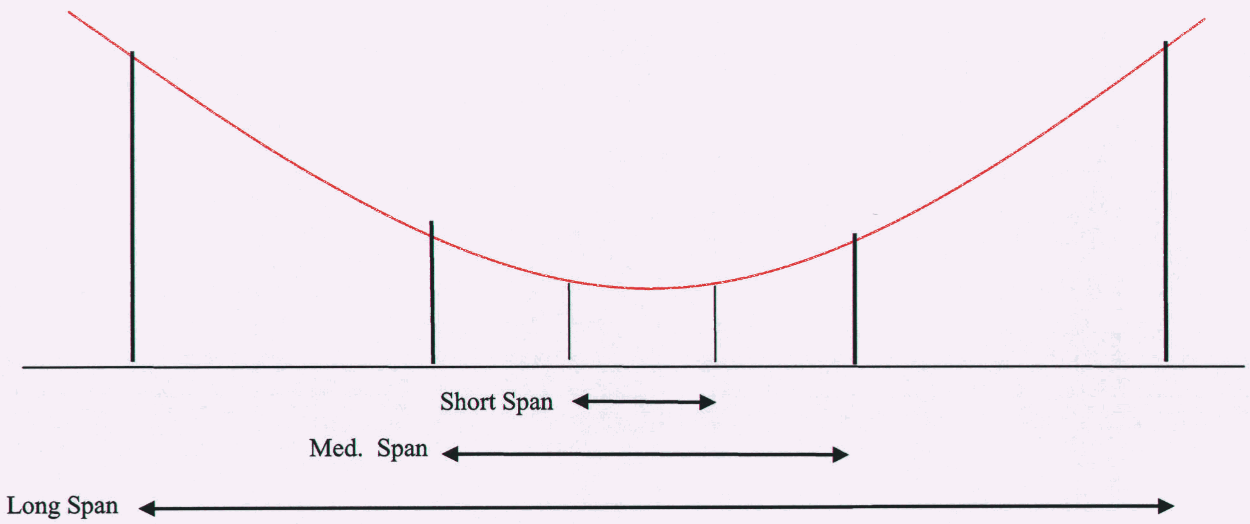
Cost trends may be illustrated by looking at relative changes in easement widths. This comparison assumes that the easement width is fully utilized for conductor blowout (narrow easements = short spans, wider easements = greater spans):

Narrow Easement: Land costs are relatively low with the narrow easement. However, easement width restricts the allowable conductor blowout requiring shorter spans and more structures. Structures are closely spaced and not utilized very well due to short spans. Structures have a basic minimum height to provide the electrical clearances. Construction costs are relatively high because there are more structures per mile and more wire attachments to construct: *Total cost is relatively high.*

Medium width Easement: As easement gets wider, land costs increase. However, with the wider easement, the allowable conductor blowout may increase and poles may be spaced further apart. With the increasing spans, pole heights increase only slightly (wire is shaped like a parabola and in medium spans, the rate of increase in sag does not increase significantly) due to the shape of the wire catenary, so overall, structure and foundations cost decrease. Construction costs decrease because of fewer pole and few wire connections per mile. *Total cost is lower than the narrow easement cost.*

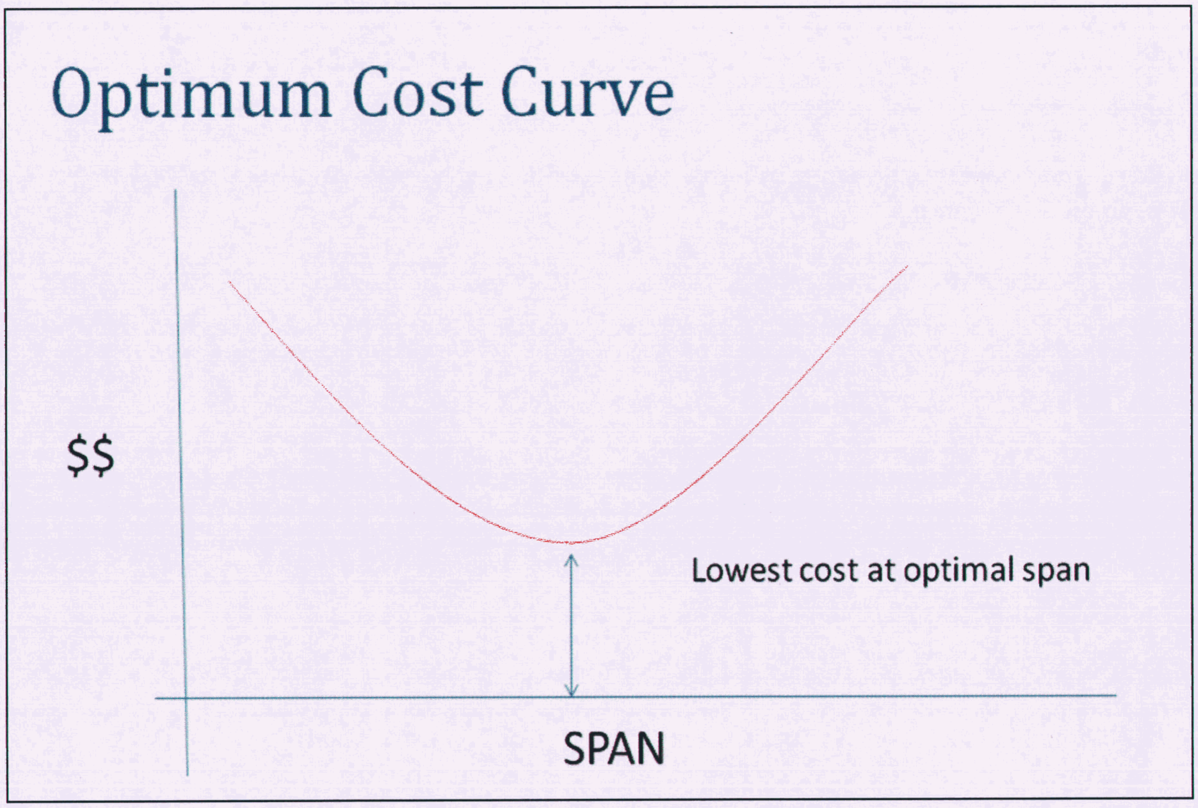
Wide Easement Width: The wider the easement, the greater the land cost. With a wider easement, there is more space for the conductor to blow out and poles may be spaced further apart. As the spans increase, the pole heights have to increase significantly (larger spans are further from the center of the wire parabola and the rate of sag starts to increase at a greater rate). Pole weights increase significantly along with the foundation cost. Construction cost increase due to the very large structure weights and heights and large foundation piers. *Total cost is relatively high.*

EFFECT OF SPAN DISTANCE ON RELATIVE HEIGHT OF POLES



The cost variables in the discussion above may be easily quantified. If plotted, total costs based on span (a function of easement width due to blowout) is illustrated by Figure 9. From this curve, the optimum easement width and average span may be determined. This will result in the lowest possible cost of the transmission line.

FIGURE 9 – Optimum Cost Curve



STRUCTURAL DESIGN OF TRANSMISSION LINE STRUCTURES

The basic function of a transmission line structure is to hold wires up in the air. While this seems like a relatively simple concept, different forces imposed on the structure can be complex due to widely varying environmental conditions. Wind forces act on the wires and structures, aluminum wires are subject to wide ranges of tension due to change in temperature and conductor creep (stretching) and in some parts of the country, ice and snow may build up on the wires creating tremendous weight loads.

The various potential combinations of forces are broken down into "Load Cases". A 'load' is the set of forces imposed on the wire or structure. A load case is a defined set of environmental conditions (including the age of the wire) to establish a set of forces imposed on the wires and structures. Load cases may also consider special situations that only occur during construction of the transmission line. Other load cases may consider extreme conditions such as when one of the wires breaks which changes the load configuration on a structure.

Defining Loads on Transmission Lines

Load Cases may be defined in three primary categories:

a) Statutory Loads – Loads based on weather conditions; various combinations of Temperature, Wind and Ice. These loads are defined in a regulatory standard.
b) Safety Loads – Unbalanced load combinations to improve the structural reliability of individual structures and the integrity of the transmission line in general.
c) Maintenance and Construction Loads – Load configurations that occur only during construction and maintenance of the transmission line. Emphasis on safety for workers on structures during construction.

Statutory loads are the only types of loads used industry wide with specific definitions on how loads are applied to wires and structures. Safety and Construction loads are defined and used at the prerogative of the transmission line owner/designer.

Statutory Loads

Statutory Loads are typically required by the governing jurisdiction. Most states use the National Electric Safety Code (NESC) by reference. California has developed its own code in lieu of the NESC.

Section 25 of the NESC defines loads applied to wires and structures that are weather related loads. Weather related loads can be two types:

Deterministic Loads - Weather related loads that have values that were established based on experience. NESC Rule 250B and the Light, Medium and Heavy Load District load are deterministic loads. Figure 10 is the excerpt from the NESC defining Rule 250B loads. Note the three combinations of wind speed and ice thickness on wires for the three load districts.

Reliability Based Loads - Weather related loads based on statistical analysis of recorded weather data. American Society of Civil Engineers Standard No. 7 "Minimum Design Loads for Buildings and Other Structures" provides the source data for reliability based loads established in NESC Rule 250 C Extreme Wind and Rule 250D Extreme Winds and Ice. Wind speeds and ice thickness are quantified based on a 50 year Return Period; there is a 1 in 50 probability in any year that the wind or ice will exceed that magnitude. Figure 11 is the excerpt from NESC showing the wind map for Rule 250 C.

FIGURE 10 - Map for NESC Rule 250B

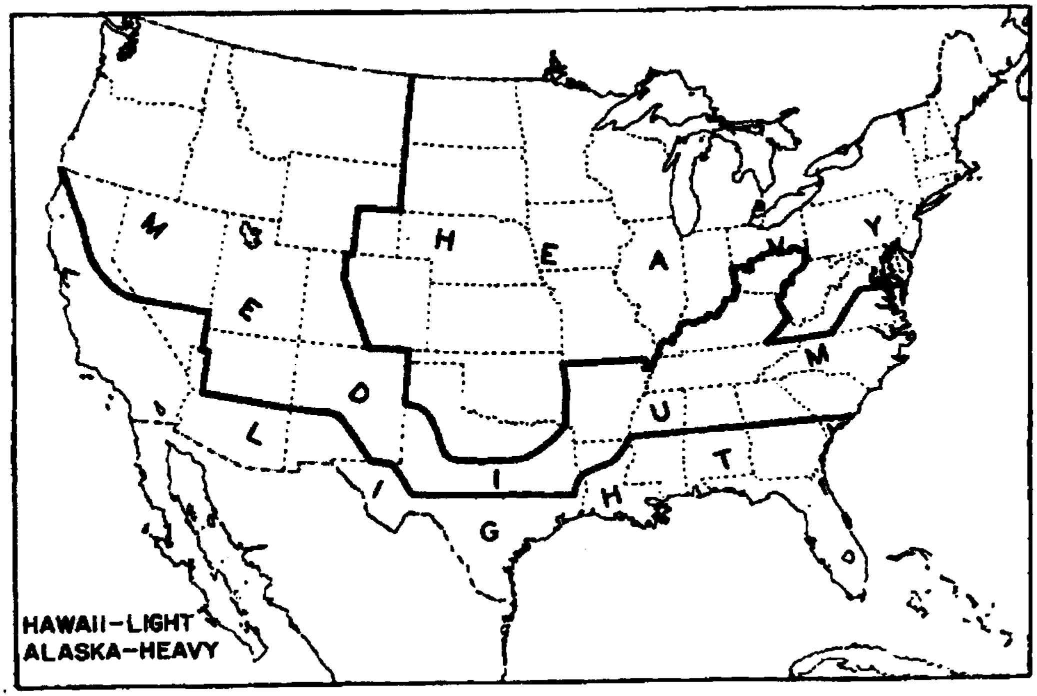


Fig 250-1
General Loading Map of United States
with Respect to Loading of Overhead Lines

Table 250-1
Ice, Wind, and Temperature

	Loading districts (For use with Rule 250B)			Extreme wind loading (For use with Rule 250C)
	Heavy	Medium	Light	
Radial thickness of ice (mm)	12.5	6.5	0	0
(in)	0.50	0.25	0	0
Horizontal wind pressure (Pa)	190	190	430	See Fig 250-2
(lb/ft²)	4	4	9	See Fig 250-2
Temperature (°C)	–20	–10	–1	+15
(°F)	0	+15	+30	+60

FIGURE 11 - Maps for NESC Rule 250C

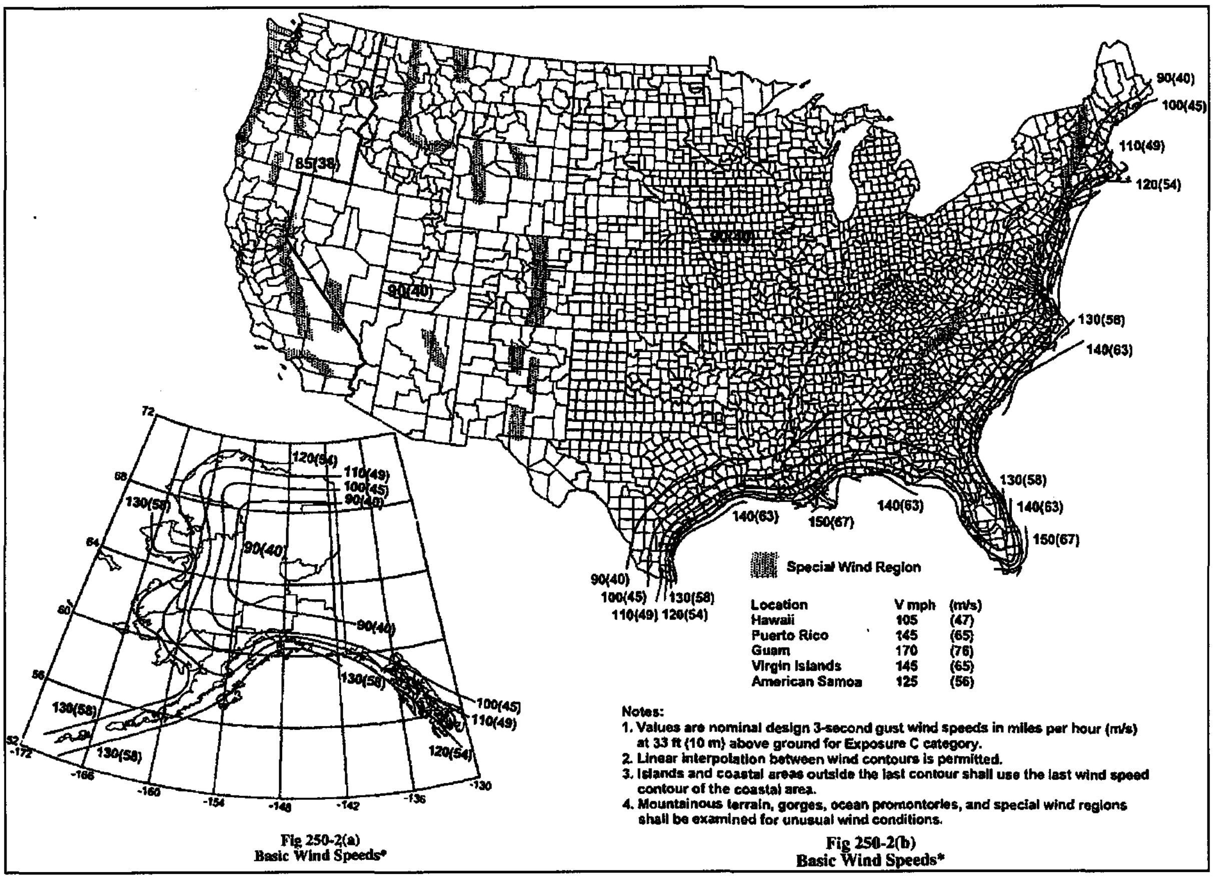


Fig 250-2(a)
Basic Wind Speeds*

Fig 250-2(b)
Basic Wind Speeds*

Safety Loads

Safety related load cases are designed to prevent catastrophic or cascading structure failures in a transmission line. There are historical examples of transmission lines that were designed with only marginal longitudinal load resistance. A failure of a single structure caused a cascading failure which brought down many miles of structures. By considering loads that might occur when some wires are not intact, structures may be designed to resist unusual load configurations that occur during atypical events. Examples of safety related load cases are:

- Broken Conductors: When a wire breaks in a span, the structure no longer has balanced tensions at a point where the wire is attached to the structure. The structure now has to resist the full tension of the wire in one direction. This is a large load for a structure designed primarily to hold up the wire and resist wind loads only.
- Broken Insulator: When a suspension insulator string breaks and the wire remains intact, the adjoining two structures now have to carry the weight of the wire. This additional load can sometimes double the weight load and create an unbalanced

longitudinal load on a structure if the wire does not sag to the ground to relieve the load.

- One-Way Deadend: A structure that is at a large angle in the line (say at a 50 degree turn) is constructed with the wires attached "dead ended" to the structure. This attachment method transfers the full tension of the wires to the structure. With the wires intact in both directions, the total forces on the structure are lower than when the wires were intact in one direction only. The absence of the wires in one direction could occur during construction (one side was built prior to the other) or the wires in one span could be lost due to some catastrophic event. The result would be 'dead end' loads in one direction only which would be a more severe load on the structure than with all wires intact.

- Regional Weather Conditions: Some areas of the country are subjected to intense weather patterns that occur in limited regional areas. Some examples might be strong winds in a river valley or gorge, a location in mountains that has unusually high snow and ice or intense seasonal storms such as microburst downdrafts in thunderstorms. The NESC does not define these regional events and it is the prerogative of a utility whether to develop special load cases to resist locally occurring events that might exceed statutory loads.

Additional Safety Related Loads may be developed for special structures that are placed in a line in order to improve the structural reliability of the line. For example; a very long transmission line that had no changes in direction might be constructed entirely of structures designed only to hold the weight and wind loads from the wires. If the structures have a relatively small resistance to longitudinal loads, the line designer might wish to provide a more robust design to improve the structural performance of the line by inserting stronger structures placed at intervals (say 2, 5 or 10 miles) as a safety device to stop a cascade failure. This is a technique applicable for non-symmetrical structures such as an H-frame.

Maintenance and Construction

Some extremely high loads on a structure may occur only at the time of construction. Examples are:

Unbalanced Loads on Structures: Lattice towers in particular are somewhat sensitive to unbalanced loading on the structure which might cause the entire structure to twist. This loading may only occur during construction when some but not all the wires are attached to the tower. A single circuit, horizontally framed tower at an angle in the line may have one side (all phases) constructed and intact. As wires are attached to the ends of the arms on other side of the tower, the tower will start to twist under the unbalanced loads. Different combinations of the wire loads might be considered for construction load cases to insure the structure is not susceptible to failure during times when not all wires are attached.

Snubbing loads: In a long straight transmission line, wire can be pulled a finite distance (say 20,000 feet). The wire will then be pulled in the next 20,000 feet in a separate operation. These two pulls must be jointed with splices in the wires. After the first pull is complete, the wires must be held at tension; they are brought down to ground level and attached to anchors (or large pieces of equipment) and thus temporarily "snubbed" to the ground. The downward angle of the wire at the first structure from the snub point creates a very large vertical load on that structure. This very large snubbing load would only occur during construction.

Safety of Workers: During construction of the transmission line, construction workers typically work on or suspended from elements of a structure. Any structural failures at this period of construction have high risk of injury or fatality. The loads of the workers and applied loads from the wires and equipment during the period of construction may have special design considerations through the use of higher 'load factors' to increase structural reliability and improve safety for workers. (A discussion of load factors is in the following sections of this paper).

Determining the "Ultimate Loads" Applied to the Structure

The NESC uses a *Load and Resistance Factor Design* (LRFD) analysis method when determining the necessary strength of structures. A load is defined and quantified by the forces from weight, wind pressures and wire tensions. These loads are increased by a load factor. The sum of these factored loads on a structure must be less than the strength (resistance) of the structure. (Although by theory it is something different, a load factor might be thought as a factor of safety. A load factor and a factor of safety are both similar in that they increase the required strength by a set amount.)

LRFD equations take the form:

$\Theta R \geq \delta Q$

Where:
Θ - Resistance or Strength Factor - Used to reduce the nominal value of strength of a material to a standard or uniform definition of strength for wood, steel and concrete structures. Strength factors might be ~.67 for a wood pole structure, 0.9 for a concrete pole structure and 1.0 for a steel structure.

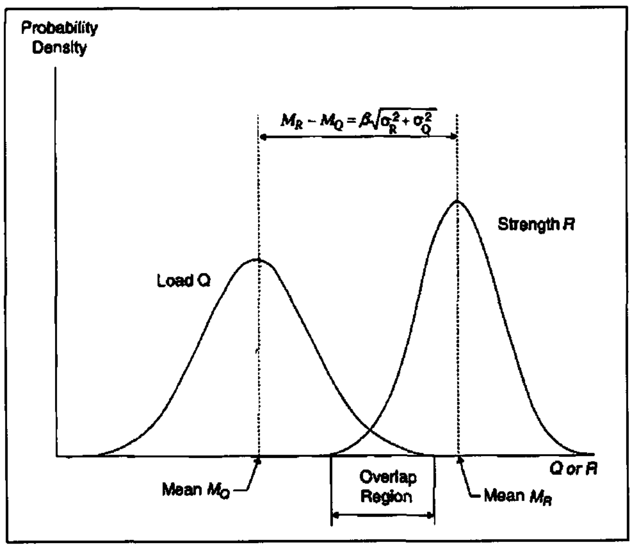
R - Resistance or Strength. The calculated theoretical nominal strength for that type of structure and material. The nominal strength of wood poles is defined at the average breaking strength of the wood. The nominal strength of steel structures is approximately 1% Lower Exclusion Limit (LEL) of the steel yield strength.

Δ - Load factor: Always 1.0 or greater. Used to adjust the reliability of a structure by increasing or decreasing the necessary strength relative to a defined load. Generally, it is also dependant on the variability, type or importance of the load. "Live" loads such as wind tend to have higher load factors (2.5). For more consistent and very definable loads (such as weight,) the load factor is lower (1.5). For an extreme load case (such as hurricanes or tornados) the load itself is extreme and there little need to increase it with the load factors are near 1.0 (1.0 to 1.1).

Q - Load: weight, wind pressures, tensions, etc.

Structural Reliability: Structural reliability is measureable as a function of degree of separation between the mean of the strength and the mean of the load. Figure 12 illustrates probability density functions (PDF) for an applied load and the strength of a structure. The variability of the load might be thought of as wind speed. The variability in strength might be the small variations in the strength of various pieces of steel making up the structure. The area where the curves overlap defines the probability of failure. The relative measure of reliability is a function of the distance between the mean value of the load and strength.

FIGURE 12 – Probability Density Function



The relative reliability of a structure may be influenced by changing the load factors applied to the load. By increasing the load factor, the requirement for strength is increased. As depicted in Figure 12, the PDF for strength would shift to the right and be pushed further away from the PDF of the load. The greater the load factor, the greater the separation between mean strength and mean load and the higher the structural reliability. As the strength curve is pushed to the right, the overlapping areas of the curves decrease which illustrates the reduction in the probability of failure. The magnitude of a load factor may be adjusted depending on the targeted relative level of structural reliability.

(For a more detailed discussion of definition of loads, strengths of materials and LRFD, please refer to ***Reliability Based Design of Utility Pole Structures*** , ASCE Manuals and Reports on Engineering Practice No 111.)

NESC Grades of Construction

NESC defines two levels of reliability using "Grades of Construction". Grade C is a lower level of structural reliability. Grade B is a higher level of structural reliability. The load factors are used with the determinist loads in Rule 250B. Because Rule 250B uses deterministic loads, there is not an established interval for a Return Period (probability of failure). The equivalent return period may be calculated when Rule 250B loads are compared to regional data from probability based loads such as the maps used for Rule 250C.Load Factors are based on Grade of Construction:

LOAD FACTORS for Rule 250B			
Grade Of Construction	WIND	WEIGHT	TENSION
NESC Grade B	LF = 2.5	1.5	1.65
NESC Grade C	LF = 1.75	1.5	1.3

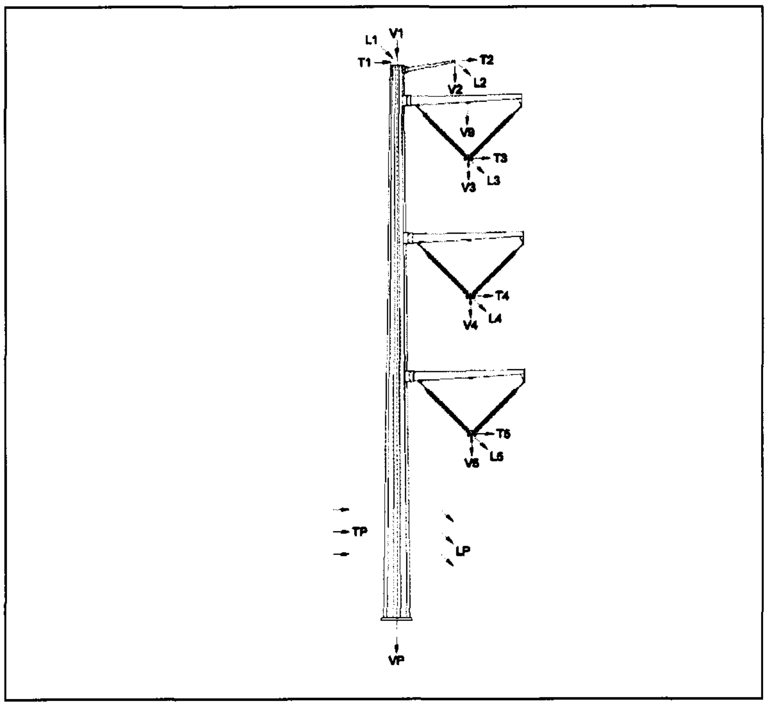
The NESC does not require a specific Grade of Construction by voltage level. The NESC does require Grade B construction when lines cross critical infrastructure such as railroads or controlled access highways. Due to their importance, it is common practice to use Grade B Construction in the design of EHV Transmission Lines.

Load cases for Transmission Line Structures

Transmission structures are typically designed for various types of load cases as described above. For each load case, a set of assumptions define the climatic conditions, wire conditions and any work or unusual condition on the wires or tower. It is common practice for a transmission line designer to have an established set of guidelines for defining load cases. One example of design guideline is attached as Appendix A, ***Load Cases for Transmission Line Structures***.

The assumptions defined in each load case allow the calculation of the forces on the wires and structures. Depending on the type of load case, the line designer selects the appropriate load factors to use for the load case. Loads are calculated for each point a wire is attached to a structure. The load points are communicated to a pole designer by a schematic depiction of the structure called a 'Load tree' (See Figure 13).

FIGURE 13 – Load Tree



There are three load vectors at each load point: V= Vertical, T = Transverse, L = Longitudinal.

Figure 14 is one example of how a list of load cases and individual point loads associated with each load case might be summarized for a pole designer.

FIGURE 14 – Load Points

LOAD TABLE: STRUCTURE TYPE SUSPENSION — 1 degree

V=VERTICAL T=TANGENTIAL L=LONGITUDINAL ON AXIS OF POLE

ALL LOADS INCLUED OVERLOAD CAPACTIY FACTORS (OCF)

POSITIVE VERTICAL LOAD IS DOWNWARD

WIND SPAN = [illegible] FT
WEIGHT SPAN = 1400 FT

OHSW TENSION = 2100 LBS
OPGW TENSION = 3700 LBS
525kV TENSION = 10000 LBS PER CONDUCTOR

POLE LOADING POINTS

LOAD CASE	1 V1	1 T1	1 L1	2 V2	2 T2	2 L2	3 V3	3 T3	3 L3	4 V4	4 T4	4 L4	5 V5	5 T5	5 L5
1	1.04	1.18	-	1.04	1.18	-	12.79	8.48	-	12.79	8.48	-	12.79	8.48	-
4	0.76	1.31	-	0.76	1.31	-	9.38	9.31	-	9.38	9.31	-	9.38	9.31	-
7	0.76	0.06	-	0.76	0.06	-	40.06	-	-	9.38	0.90	-	9.38	0.90	-
8	0.76	0.06	-	0.76	0.06	-	8.00	0.42	9.67	9.38	0.50	-	9.38	0.50	-
9	0.39	0.34	3.82	0.76	0.54	-	9.38	3.88	-	9.38	3.88	-	9.38	3.88	-
11	0.76	0.06	-	0.76	0.06	-	9.93	0.50	5.73	9.38	0.50	-	9.38	0.50	-
12	4.66	-	0.11	4.66	-	0.11	29.48	-	1.01	29.48	-	1.01	29.48	-	1.01
13	0.39	0.03	0.04	0.76	0.06	-	-	-	-	-	-	-	-	-	-
14	1.38	0.10	-	1.38	0.10	-	-	-	-	17.06	0.91	-	17.06	0.91	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	0.69	0.04	-	0.69	0.04	-	8.53	0.36	-	8.53	0.36	-	8.53	0.36	-

LOAD CASE	6 V6	6 T6	6 L6	7 V7	7 T7	7 L7	8 V8	8 T8	8 L8	9 V9	9 T9	9 L9	10 V10	10 T10	10 L10	11 V11	11 T11	11 L11
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	32.11	0.91	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

LOAD CASE	12 V12	12 T12	12 L12	13 V13	13 T13	13 L13	14 V14	14 T14	14 L14	15 V15	15 T15	15 L15	16 V16	16 T16	16 L16	WIND ON POLE/ARMS (psf) Tp	WIND ON POLE/ARMS (psf) Lp	OVERLOAD CAPACITY FACTOR FOR WT. OF POLE OCF * Vpole
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22.5	0	1.50
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29	0	1.10
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1.10
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1.10
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	0	1.10
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1.10
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1.10
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1.10
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1.10
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1.10
17A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1.50
17B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1.10
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1.00

BLACK & VEATCH CORPORATION

500kV Transmission Construction Standards

SRP

PROPRIETARY MATERIAL

PALO VERDE - BROWNING TRANSMISSION LINE PROJECT

PWT - SRA 500kV SC VERTICAL TANGENT (5SCT)

LOADING TABLE

REV. NO.	0
ISSUE DATE:	02/26/07
REV. DATE:	00/00/00
APPROVAL:	
1133-3012	

Design of a Transmission Line Structure

The transmission line designer develops the necessary geometry for the transmission structure (height, arm lengths, attachment points) and loads and attachment points. The structure designer takes that geometry and loads and creates a design capable of supporting the loads. For taper tubular poles, that includes deciding on steel plate thicknesses and diameter of the pole shaft and arms. Design software is used to find a lowest weight optimal solution in order to create a pole at the lowest possible cost.

How Structures Fail?

Wood pole Structures

Wood is a brittle material. Failures occur suddenly with dramatic separation of wood fibers and complete loss in the structural capacity of the cross section of the pole. Wood poles normally fail in shear which causes the splintery lengthwise separation of the wood fibers. Wood may also have "brash" failures when the fibers separate cleanly across the cross section of the pole. This type of failure results in complete separation of the pole at the failure.

Wood pole diameter (and resulting taper) is specified in ANSI 05.1 Specifications and Dimensions for Wood Pole. Because the geometry of poles resulting from this standard, single wood pole generally fail approximately 1/3 the height from the ground when loaded to the breaking point. Wood poles are susceptible to termite attack and decay below ground level. Poles weakened in the groundline zone will typically fail at the groundline if overloaded.

More complex structures such as H-Frames have high stress levels at the cross bracing. If the cross bracing fails first, the poles may fail near ground line. If the poles fail prior to the cross bracing, the poles will break higher up in the area of the cross bracing. However, failure of these structures is a more complex mechanism and it is difficult to generalize.

Steel Pole Structures

Steel is an elastic material up to its yield point. After the yield point is reached, steel becomes plastic. If the stress is maintained on the steel, it will continue to stretch with permanent deformation. The stress required to continue this deformation is around 75% of the yield strength. Therefore, a steel structure, after is starts to yield, retains a significant portion of its original strength if the cross section of the steel shape remains intact. The loss of the structural cross section (such as the buckled shape at a hinge) is the greater contribution for loss of strength than the fact the steel has yielded.

When a single steel pole is loaded to the point of failure, it is difficult to generalize where the buckling will occur. The point in any steel pole most susceptible to buckling is at a point of high stresses and where the ratio of diameter to thickness of the plate (shell thickness) is highest. Because poles may be designed at any diameter using a wide variety of steel plate thicknesses, this critical point varies widely on poles of different designs. In general, it will occur near the groundline or just above a point where the shell thickness changes (which could occur almost anywhere on the pole).

Lattice Towers

Lattice towers are also made up of ductile steel. However, the structural form is a truss which is very rigid and does not allow for significant deformation. Once the yield point or buckling point of a member is reached, the change in length of that member will cause a collapse in that portion of the tower.

It is very common in an overloaded lattice tower to have the initiating failure occur at a bolted connection. This failure tends to be sudden and cause a local collapse of the shapes in the area. It is typical that a local collapse of members anywhere in a tower will distort and overload adjacent portions of the tower until the tower collapses completely. Failures are more common in the lower portion of the tower. As failures occur in the lower portion of the tower, the weight of the wires and the upper part of the tower tend to crush and compress the tower as it collapses. It is rare that a tower would fail transversely and remain intact for the full height of the tower unless there was a failure of the uplift foundations.

Transmission line Failures

It is not practical to consider how a single transmission line structure will fail without considering the influence of the restraining action of the wires and the resistance of adjacent structures. Transmission line conductors are typically at tensions where the movement of a single structure would significantly increase the wire tensions. The loads would be transmitted to the adjacent structures and those adjoining structures would assist in resisting a simple overturning failure of a single structure.

If the failing pole has a hinge near the groundline, the restraining action of the wires will resist the failing pole from falling down intact in the transverse direction. If the failing structure is a lattice tower, this will tend to cause the tower buckle and crumple inward as it rotates. A steel pole will typically fail at a hinge. The combination of the restraining action of the wires in addition to the remaining plastic capacity of the steel will hold the pole in the air at some buckled shape.

Failure in a wood pole line is more variable. Because wood pole structures are shorter with smaller spans, the initiating event (such as high wind) is likely overloading a series of poles. The restraining action of adjacent poles is not as effective (the adjacent poles are near failure also) and it is more common to see a cascade event of pole lying on the ground, full length intact.

FIGURE 15 – Structure Height vs. Separation

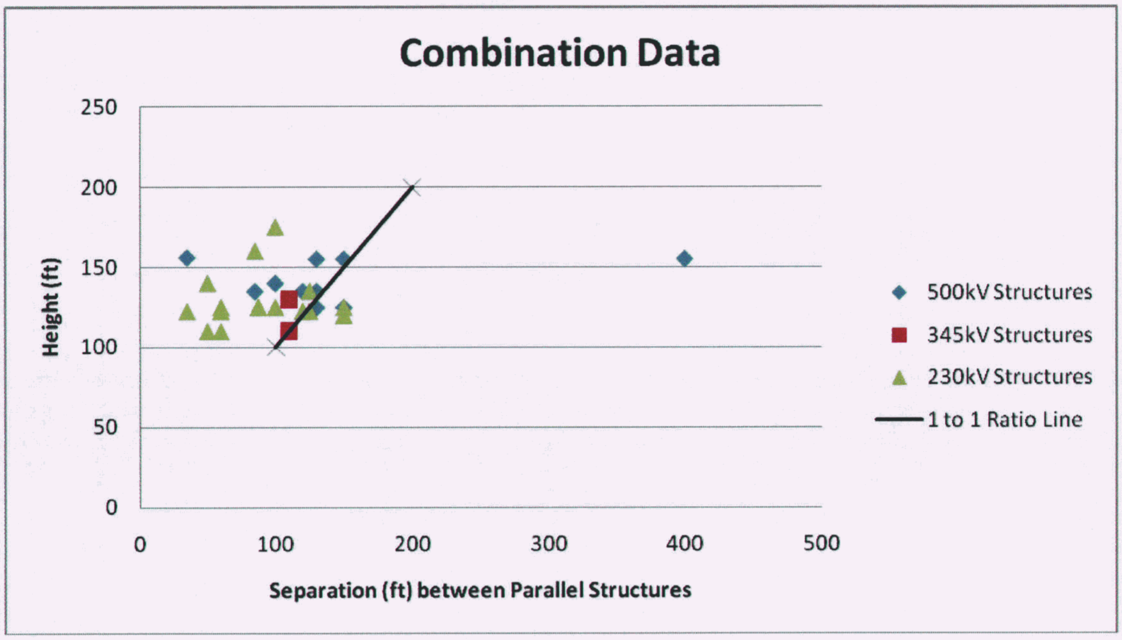


Figure 15 shows combination data of 5 WECC utilities depicting typical results of 2 circuit corridors height versus separation of the structures. 500, 345 and 230kV circuits data are plotted in Figure 15. Figure 15 generally shows that the height of structures is greater than the separation. This is evident because the majority of the data points in Figure 15 are on the left side of the 1 to 1 Ratio Line. This means that during the design of these corridor circuits the assumption was that the structures are not expected to fail by rotating on the base of the structure to fall into the adjacent structures, transmission line and related appurtenances. The easement width is defined by the clearances needed for safe operation and maintenance of the line.

Conclusion

Transmission lines are designed for environmental and operating conditions that are common and statistically valid for the geographic area. Structural failures are rare enough that a lateral collapse of a structure is not an event that is technically or economically valid consideration. In the pursuit of system reliability and public safety, the intent of the design is for structures remain intact.

EASEMENT VALUATION AND ACQUISITION PROCESS

Prior to acquisition, the easement is appraised by an independent appraiser. The appraiser first identifies and establishes the value of the larger subject parcel that the easement will cross. The appraiser also examines recent sales of similar properties and then he compares them to the subject property. He will consider such factors as parcel size, zoning, location and the time of the sale. The appraiser may make adjustments to the comparable sales if they are slightly dissimilar to the subject property to arrive at his opinion of value of the larger subject parcel.

Once the value of the larger parcel has been established, the appraiser will then value the easement within that parcel. The easement is valued as a part of the whole property because the owner retains the use of the underlying fee land. The land under the easement still has value and use to the owner. He may use the easement area for any purpose whatsoever so long as that use doesn't interfere with the safe operation and maintenance of the line. Because the owner retains rights to use the land in the easement area, the easement is valued as a percentage of the full fee value. The value of the easement is determined by the appraiser based on the rights being acquired specified in the easement verbiage.

In some situations, severance damages may be incurred as a result of the easement acquisition. Severance damages are defined as the difference in value of the original parcel and the remainder parcel after the acquisition of the easement. In general, if an easement bisected a parcel as opposed to traversing the perimeter, one would expect to see a reduction in value to the larger parcel. The amount of severance damages is determined by the independent appraiser based on the diminished use of the parcel in the after condition.

Severance damages may result if the easement being acquired across the larger parcel diminishes the size of the remainder parcel in such a way that it is unusable for development or if it changes the highest and best use of the property in the after condition to a lesser use than in the before condition. For this reason, the minimum necessary easement is acquired to reduce the impacts on remainder parcels. Wider easements result in greater numbers of parcels that have severance damages due to the decreased size of the remainder parcels.

In order to leave the owners of land the most usable amount of property and with the goal of reduction of severance, easements are acquired as close to any existing transmission lines as possible based on industry-wide acceptable line separation standards and maintenance requirements. It is common practice to share space between the lines for line blow out. If utility companies didn't cooperate to share blow-out, a wider easement would be required across the larger parcel that would leave the owner with less unencumbered property. Based on the parcel size, this could also have an impact on and possibly increase the amount of severance damages that may occur.

In some situations, an easement must be acquired across parcels of raw land that are currently being platted, or already are platted, for development. Additional costs may be incurred associated with reengineering the subdivision and submitting the plat for additional approvals with the various jurisdictions. Additional severance may be incurred if the easement creates loss of saleable lots. The greater the easement width, the greater the potential to leave the developer less developable property. Not only would severance damages be claimed by the developer, acquisition would include additional costs associated with reengineering and replatting.

In the acquisition process, the utility sends an offer to purchase the easement and a copy of the appraisal the property owner. If the owner disagrees with the value, he may elect to obtain his own appraisal. The utility and the owner would try to agree on a value. If no agreement can be reached, the utility would most likely have to complete the acquisition using the eminent domain process. Wider easements generate claims of greater severance on the part of property owners. This would make it even more difficult for the utility and the owner to come to an agreement on the value of the easement and the severance damage, if any, on compensation. Inability to agree on values leads to the eminent domain process and the associated additional legal costs.

SWAT TRANSMISSION CORRIDOR WORK GROUP

Section 368 of the Energy Policy Act of 2005 (EPAct) *"directs the Secretaries of Agriculture, Commerce, Defense, Energy, and the Interior (the Agencies) to designate under their respective authorities corridors on Federal land in the 11 western States for oil, gas and hydrogen pipelines and electricity transmission and distribution facilities (energy transport corridors)."* To achieve this goal, the Bureau of Land Management led a multi-agency initiative throughout the Western United States to develop a Programmatic Environmental Impact Statement (PEIS) to identify and designate these corridors. The Final PEIS was issued in November 2008 and identified more than 6,000 miles of transmission corridors on federal land.

Concurrent to this process, utilities in Arizona and throughout the Southwest are constantly evaluating their generation and transmission needs based on their load or customer serving needs, the availability of specific generation resources, and the location of available electrical transmission capacity. This effort represents a level of specific detail not contemplated by the federal EPAct initiative and involves the identification of corridors in broader areas than those defined by the PEIS.

Understanding that the planning and permitting of new transmission facilities, in particular, typically requires coordination with multiple agencies and jurisdictions, it is advantageous to work in advance to the extent possible, to identify the specific locations where these facilities will be located. The planning process associated with the National Environmental Policy Act (NEPA) required when a project involves federally-managed land can take many years to complete. Federal land managing agencies have frequently commented that energy projects present complex issues and decision making and that staffing constraints make the processing of requests for right-of-way or easement a challenging process. This can be compounded by the schedule demands resulting from financial, construction scheduling, and customer needs. It is therefore advisable for utilities to conduct advance planning activities with these agencies in order to allow for a longer lead time in resource impact assessment and permitting decisions.

Establishment of the SWAT Transmission Corridor Work Group

To accomplish the objective of improving long-range transmission project planning with federal and other agencies, the member utilities of the SWAT organization have developed a Transmission Corridor Work Group. This group will include representatives of utilities in the Southwest that will identify federal, state, and local planning efforts that are underway or planned for the future. This will include identifying the schedule and process for the update of specific planning documents such as Resource Management Plans, Forest Plans, and County Plans, among others. The purpose of this effort will be to provide information and comment during the plan development processes about electrical infrastructure projects that may affect the respective jurisdiction. It has been communicated to utility representatives that advance planning for major infrastructure projects may improve the process by which agencies and the public evaluate these projects. This communication can also potentially reduce the costs and schedule associated with the permitting of electric infrastructure.

Case Study – Forest Plan Revisions in Arizona

In 2006, the six National Forests in Arizona (Apache-Sitgreaves, Coconino, Coronado, Kaibab, Prescott, and Tonto) began the process of updating their Forest Plans with a public scoping process in advance of the preparation of an Environmental Impact Assessment required by NEPA. Arizona Public Service (APS), in coordination with SWAT, provided a letter to each of the six forests requesting to be added to the public information distribution lists. This allows APS an opportunity to comment on future documents. The letter also suggested that the planning for new transmission line corridors across federally-managed Forests should be included in the Plan Revision process. The letter highlighted the needs utilities have to provide reliable power and to meet new renewable energy standards as factors for consideration in the planning process.

After the filing of the letters, APS prepared a presentation for the Leadership Team of each of the six forests that highlighted and illustrated the reasons utilities need to not only preserve existing utility corridors on Forest land but the need to study new corridors as well. Some of the factors that were presented supporting these recommendations included the following key points:

- Identifying new utility corridors will potentially increase reliability and reduce operational concerns for utilities and the customers they serve
    - Arizona forests have been impacted from drought and insect infestation and are susceptible to annual forest fires
    - The peak forest fire season corresponds nearly exactly to the highest demand the state's utilities have for electricity
    - A significant amount of transmission capacity is located on federally managed forests in Arizona

- New transmission lines will be necessary to transport bulk energy from sources throughout the west and will need to cross USFS land in Arizona
    - Arizona's population growth rate is one of the highest in the country, which results in a high demand for electrical energy
    - The Arizona Corporation Commission requires that 15% of the power generated in Arizona come from renewable resources by 2025
    - Utilities foresee the need for future transmission lines to access generation resources throughout Arizona and beyond
    - Existing lines that transport bulk electrical energy through USFS land are scheduled at or near capacity

- Federal and state regulatory requirements for utilities require that additional emphasis be placed on the location and management of electrical transmission corridors.
    - The Federal Energy Regulatory Council (FERC) has implemented tighter guidelines on the management of vegetation in and around transmission corridors as part of the Energy Policy Act of 2005.
    - The Western Energy Coordinating Council is currently performing studies to determine standards for line separation to ensure maximum transmission line rating
    - The Arizona Corporation Commission supports projects that improve reliability and do not negatively impact load-serving capability in the event of a common corridor outage

APS has subsequently been monitoring, providing feedback, and maintaining active communication with USFS representatives as part of the Forest Plan Revision process. The next steps in this process will include a series of activities that allow for SWAT member utilities to provide input into each of the Plan Revision documents with the overall goal of accommodating existing and new transmission corridors in the revised Forest Plans as appropriate. These steps will include the following:

- Initiate environmental/siting studies to determine location of new utility corridors

- Provide environmental/siting studies, maps, and corridor recommendations to USFS for inclusion in the forest plan revisions

- Seek adoption of new utility corridor designations in each of the plan revisions for USFS-managed forests in Arizona

It is anticipated that these goals and objectives can be undertaken with the broader support and participation of the SWAT Transmission Corridor Work Group.

<u>Next Steps of the SWAT Transmission Corridor Work Group</u>

Member utilities of the SWAT organization will be asked to identify those representatives that are interested in participating in the Transmission Corridor Work Group. Once this group is assembled, the Work Group will develop a list of objectives and assign specific work tasks to its participant members. The overall goal of the Work Group will be **to identify and coordinate with federal, state, and local agencies regarding future infrastructure planning.** This will be accomplished through the identification of those planning processes that are underway or that will be undertaken in the near future and to establish a dialogue with the planning representatives of each effort. In some cases, it will be appropriate to conduct educational briefings similar to those held with the leadership of the Arizona national forests to highlight utility needs, issues, and the benefits of advance planning for utility corridors.

Summary

There are a number of factors, including federal, state, and industry policies that are influencing the need for sound and long-term planning for electric transmission corridors in the Southwest. The pressures on public land and the reliability and resource diversity issues facing utilities will require that more coordination take place between representatives of both interests. Initiatives underway in Arizona show the need for a meaningful dialogue and engagement in activities that support advance utility corridor planning.

The SWAT Transmission Corridor Work Group will focus on identifying opportunities to integrate utility infrastructure planning into federal, state, and local planning initiatives with the goal of streamlining the process by which projects can be permitted and developed while improving the public's knowledge and input into the planning process. The Work Group will closely monitor the evaluations and recommendations put forth by the SWAT Common Corridor Work Group, providing input and exchanging information as both initiatives are advanced.

NERC/WECC STANDARDS APPLIED TO COMMON CORRIDOR STRUCTURE SEPARATION

This section of the paper describes the applicable National or Regional standards applied to transmission lines in a common corridor.

NERC – North American Electric Corporation

The NERC Standards are applicable to NERC members, which covers the power transmission systems of the United States and the provinces of Canada. The applicable and current NERC Standard applied to transmission lines in a common corridor is from the NERC Table I. Transmission System Standards — Normal and Emergency Conditions from the TPL (Transmission Planning Standards) Standard Contingency,

> C.5: Events Resulting in the Normal Clearing of Any Two Circuits of a Multiple Circuit Tower Line.

The C.5 planning event or outage means that the system performance of the NERC Category C is applied to the system response to the outage of two adjacent circuits that are on the same towerline or same structures.

The performance requirements for NERC Category C are:

• Thermal and Voltage Limits Within Applicable Ratings:	YES
• Loss of Demand or Curtailed Firm Transfers:	Planned/Controlled
• Cascading Outages:	No

The system response to a Category C outage can result in planned load curtailments or controlled curtailment of firm transfers to keep the elements of the network within their thermal and voltage limits. These outages are not allowed to cascade.

The simultaneous outage of 3 or more circuits on the same towerline or structures or the outage of two or more or all of the circuits in a common right-of-way, the performance requirements of Category D are applied;

The performance requirements for NERC Category D are to evaluate for risks and consequences:

- May involve substantial loss of customer Demand and generation in a widespread area or areas.
- Portions or all of the interconnected systems may or may not achieve a new stable operating point.
- Evaluations of these events may require joint studies with neighboring systems.

The system response to a Category D outage is quite less stringent than the Category C outage. Category D outages may allow loss of customer Demand to widespread areas nor is the settlement of the system to a stable operating point required for Category D outages.

Given the above difference of the Category C and Category D requirements, there is no difference in application of the performance requirements whether a circuit is placed directly adjacent to an existing structure line or 500 feet or 3000 feet away. According to the NERC Standards, there is no difference unless the circuits are on the same structures and then the simultaneous outage of the two circuits is evaluated versus Category C requirements.

FERC – Federal Electricity Regulatory Council

There are currently no FERC Standards or criteria put forth by the Federal regulatory body.

WECC – Western Electricity Coordinating Council

Because WECC is a member of NERC, the NERC Standards are applied to all WECC Members. However, there is a more stringent WECC criteria applied to transmission circuits in a common corridor. This is a WECC criterion, not a standard. The difference between a Standard and a criterion is that a Standard is subject to audit and monetary sanctions. The performance expectations of a WECC criteria is expected to be observed by WECC members. However, WECC member peer pressure can be used against a WECC member to comply with a criteria, but a WECC member does not have to comply with the criteria. The WECC criterion is not audited and not subject to sanction.

WECC Criteria WRS1.1: The NERC C.5 (event resulting in the loss of two or more (multiple) elements; any two circuits of a multiple circuit tower-line) initiating event of a non-three phase fault with normal clearing shall also apply to the common mode contingency of two Adjacent Transmission Circuits on separate towers unless the frequency is determined to be less than one in thirty years.

The WECC criteria is stated that; in addition to the NERC Standard C.5, the additional planning requirements of two Adjacent Transmission Circuits on separate towers, but only if the frequency of this outage is less than one in thirty years. This statement adds the probability of the outage to the determination of the applicability of this outage.

Common Corridor Definition: Contiguous right-of-way or two parallel rights-of-way with centerline separation less than the longest span length of the transmission circuits at the point of separation or 500 feet, whichever is greater, between the transmission circuits. This separation requirement does not apply to the last five spans of the transmission circuits entering into a substation.

This definition was recently adopted by WECC. Examples: if the longest span length of 2 circuits is 600 feet apart then the corridor is defined as 600 feet, if the longest span of two circuits is 450 feet then the corridor is defined as 500 feet.

Adjacent Transmission Circuits: Transmission circuits within a Common Corridor with no other transmission circuits between them. Transmission Lines that cross but are otherwise on separate corridors are not Adjacent Transmission Circuits.

The definition of Adjacent Circuits is that the circuits only have to be adjacent to each other without crossing lines. This definition eliminates the uncertainty of what lines to consider for study for the example of a corridor with more than 3 lines, i.e., only need study the combinations of adjacent circuits.

The WECC Criteria is more stringent than the NERC Standard in the following aspects:

- "a non-three phase fault with normal clearing"
  - which means that need to cover all faults except for the 3 Phase Fault

- common mode contingency of two Adjacent Transmission Circuits on separate towers
  - any circuits that are adjacent to each other in a corridor not just on the same structures

The last statement of the WECC Criteria, WRS1.1, which discuses the probability of outage, set the task of the Planner to determine and convince that the corridor outage rate is greater than once in 30 years. The addition of the outage rate of the circuits is a result of the PBRC, the Probabilistic Based Reliability Criteria. The PBRC results were adopted by WECC in 1998.

There exists a process within WECC, as part of the Reliability Performance Evaluation Work Group or RPEWG, that has evaluation criteria and a process to determine if two transmission circuits can be exempted from the more stringent WECC Criteria, WRS1.1. To date there have been four applications and successful results that the RPEWWG has evaluated and determined that the corridor circuits are not to be held to the more stringent WECC WRS1.1 Criteria.

The more stringent criteria of WECC are applied to NERC Table I and to voltage dip and frequency dip limits which are listed in the following WECC Table W-1

During the evaluation of adding a new line to an existing corridor, the added separation distance costs will be evaluated against placing the new line beyond the WECC Common Corridor Definition. The addition of the new line wider than the Common Corridor means the performance requirements are not as stringent as if placing the new line within the Common Corridor. Achieving a needed Path Rating or new line capability may demand that the new line be placed outside the Common Corridor. Power flow and other studies will be used to evaluate and compare the resulting Path Rating or new line benefit to the system within or without the Common Corridor.

WECC TABLE W – 1

WECC DISTURBANCE-PERFORMANCE TABLE OF ALLOWABLE EFFECTS ON OTHER SYSTEMS

NERC and WECC Categories	Outage Frequency Associated with the Performance Category (outage/year)	Transient Voltage Dip Standard	Minimum Transient Frequency Standard	Post Transient Voltage Deviation Standard (See Note 2)
A	Not Applicable	Nothing in addition to NERC		
B	≥ 0.33	Not to exceed **25%** at load buses or **30%** at non-load buses. Not to exceed **20% for more than 20 cycles** at load buses.	Not below **59.6** Hz for 6 cycles or more at a load bus.	Not to exceed **5%** at any bus.
C	0.033 – 0.33	Not to exceed **30%** at any bus. Not to exceed **20% for more than 40 cycles** at load buses.	Not below **59.0** Hz for 6 cycles or more at a load bus.	Not to exceed **10%** at any bus.
D	< 0.033	Nothing in addition to NERC		

Conclusions

There are NERC Planning Standards applied to the outage of two circuits on a common structure and WECC criteria applied to the outage of two circuits of a common corridor. The NERC Standard compliance is audited and subject to sanctions from NERC. The WECC criteria, even though more stringent than the NERC Standard, is not subject to sanctions from WECC or NERC. However, all WECC members comply with the WECC criteria. Even though there are no sanctions involved, no additional path ratings will be approved by WECC unless the criteria are met. This could make the project economically unacceptable.

If a circuit is constructed within WECC and it is placed in the Common Corridor with an existing circuit, then the WECC Table W - 1 Transient Voltage Dip, Minimum Transient Frequency and Post Transient Voltage Deviation Requirements are applied to this outage. Therefore, the placement of a new circuit within the same Common Corridor of an existing circuit does not change the outage performance status according to NERC Standards. However, the placement of a new circuit within the Common Corridor of an existing circuit does change the performance status according to WECC criteria. Placing a new circuit within the boundaries given by the definition of a Common Corridor of an existing circuit adds more stringent performance requirements. Placing a new circuit outside of the defined WECC Common Corridor will not add the extra burden of meeting the additional WECC performance criteria.

EFFECT OF LINE SEPARATION DISTANCE ON ELECTRIC AND MAGNETIC FIELDS

The effect of separation distance between two parallel EHV transmission lines on the electric and magnetic fields associated with the lines is discussed in this section. Electric and magnetic fields are naturally occurring phenomenon associated with transmission lines. When multiple transmission lines are in the same corridor, the electric and magnetic fields from each line combine and can add or subtract from each other to create higher or lower field levels. Thus, the separation distance between parallel transmission lines in a common corridor can affect the magnitude of the resulting electric and magnetic fields. To study the effect of separation distance on EHV lines, two parallel EHV line configurations were modeled using some basic assumptions as follows:

Configuration 1: Parallel 500kV lines on lattice towers
- Horizontal phase configuration assumed
- Separation distance varied from 100 to 200 feet in 25 foot increments
- Optimal phasing employed to reduce fields
- Assume 525kV voltages on lines for electric field calculations
- Assume 1000A current flows for magnetic field calculations
- Right-of-way width allows for 100 feet from middle of structure

Configuration 2: Parallel Double Circuit 230kV lines on steel poles (4 parallel lines)
- Vertical phase configuration for each circuit
- Separation distance varied from 50 to 200 feet in 25 foot increments
- Optimal phasing employed to reduce fields
- Assume 230kV voltages for electric field calculations
- Assume 500A current flows for magnetic field calculations
- Right-of-way width allows for 50 feet from middle of structure

Summary of Results – Electric Field

To determine the effect of separation distance on the electric and magnetic fields, calculated field quantities were compared for the different separation distances inside and outside the right-of-way (ROW). Tables 1 and 2 summarize the findings for the electric field calculations while Figures 16 and 17 graphically show plots of the electric fields for the 500kV and 230kV configurations respectively. Note the following summary points from these tables and figures.

- The peak electric field both inside and outside the ROW decreases as separation distance increases for both the 500kV and 230kV line models.
- In terms of actual field quantities, the differences with separation are not significant for the 500kV lines.
- For the 230 kV line model, the percent differences in electric field magnitude can reach 12% outside the ROW and 30% inside the ROW. However, the

actual magnitude quantities are fairly low to start with so the percent difference is not significant from a total electric field standpoint.

- As separation distances increase, the electric fields for the parallel lines no longer interact between the parallel lines and start behaving like independent lines. This is seen at distances of approximately 175 feet for the 500kV lines and 125 feet for the 230kV lines.

Table 1: 500kV Line Electric Field Results

Measurement	Separation Distance				
	100'	125'	150'	175'	200'
Peak Field Outside ROW (kV/m)	1.64	1.65	1.60	1.60	1.59
Percent Field Change	0	1.00%	-2.08%	-2.56%	-2.99%
Peak Field Inside ROW (kV/m)	6.02	5.94	5.90	5.88	5.87
Percent Field Change	0	-1.26%	-1.89%	-2.29%	-2.51%

FIGURE 16 - 500kV Line Electric Field Plots

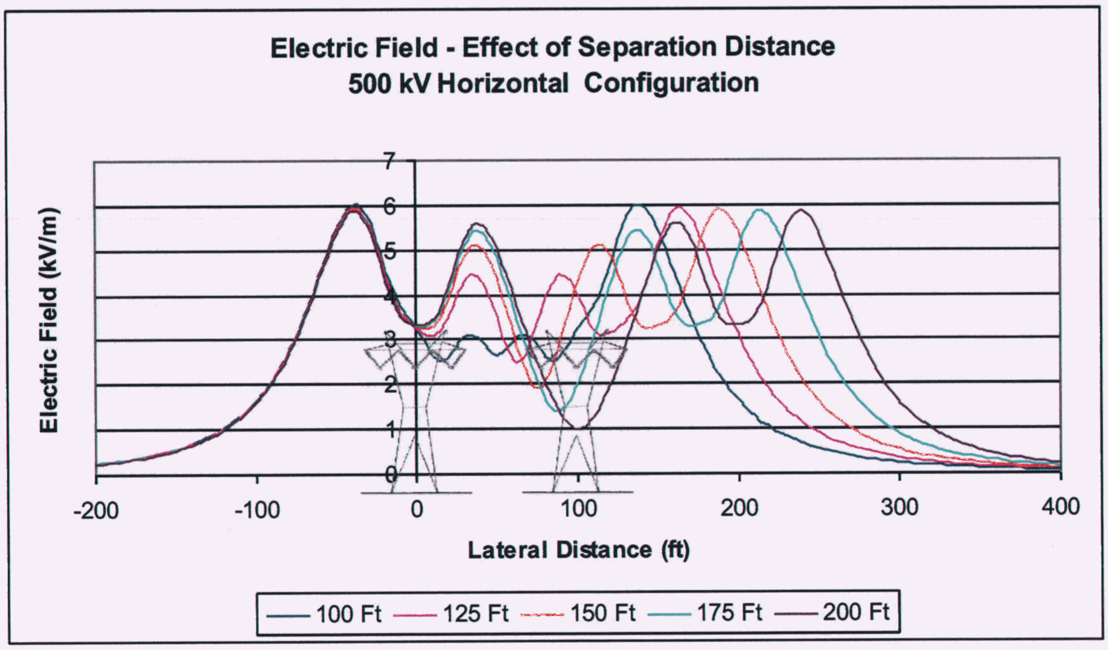
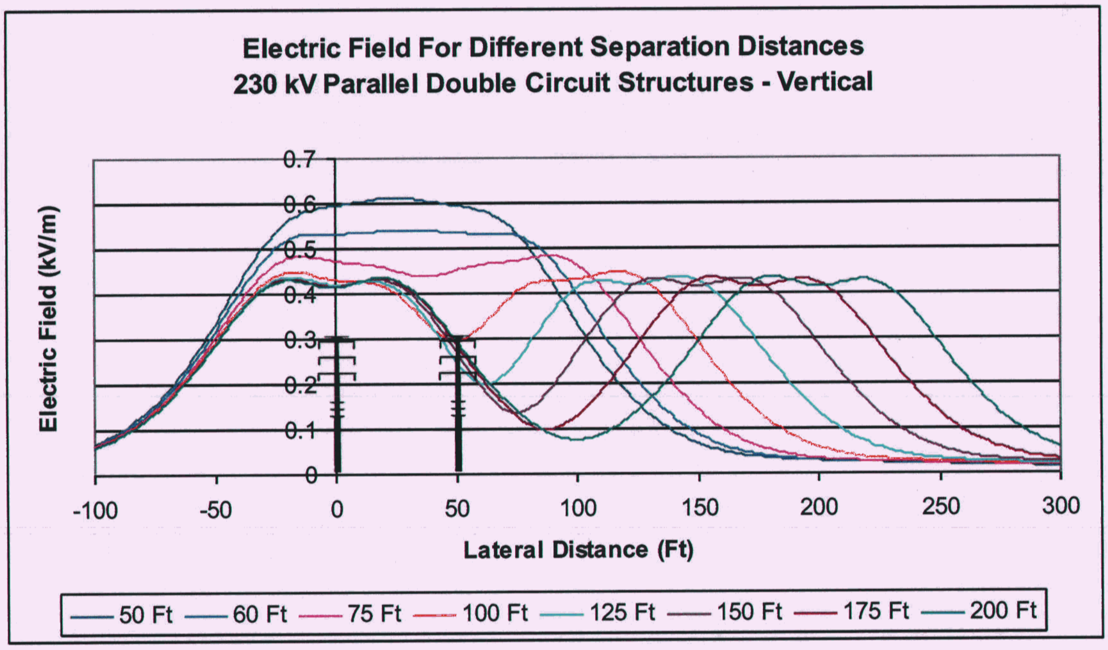


Table 2: 230kV Line Electric Field Results							
Measurement	Separation Distance						
	50'	75'	100'	125'	150'	175'	200'
Peak Field Outside ROW (kV/m)	0.33	0.31	0.29	0.30	0.29	0.30	0.29
Percent Field Change	0	-6.06%	-12.1%	-9.09%	-12.1%	-9.09%	-12.1%
Peak Field Inside ROW (kV/m)	0.61	0.48	0.45	0.44	0.43	0.44	0.44
Percent Field Change	0	-21.3%	-26.2%	-27.9%	-29.5%	-27.9%	-27.9%

FIGURE 17 - 230kV Line Electric Field Plots



Summary of Results – Magnetic Field

Magnetic field results are evaluated similarly to the electric field results. Peak calculated magnetic field inside and outside the ROW are determined and compared for different separation distances. Tables 3 and 4 and Figures 18 and 19 give the 500kV and 230kV model results respectively. Note the following summary points:

- The 500kV parallel line model shows that as separation distance increases, peak magnetic field outside the ROW decreases slightly and peak magnetic field inside the ROW increases slightly. Percentage changes are on the order of a few percent inside the ROW and up to 11% outside the ROW.
- The 230kV parallel line model shows that as separation distance increases, peak magnetic field values decrease both inside and outside the ROW. Percentage

decreases are on the order of 20% for both inside and outside the ROW depending on the separation distance.

- As separation distance increases, the resulting magnetic fields begin emulating those of independent lines. This begins to be apparent with 75 foot separations distances for the 230kV lines. Since the 500kV lines have a minimum separation distance of 100 feet, this property is visible for all of the 500 kV separation distances modeled.
- In terms of actual quantities, the decreases in magnetic field strength are not significant with the variation in separation distance. The 230kV results show up to 20% differences but the base magnitude is lower due to the lower current modeled in the study than in the 500kV line model.

Table 3: 500kV Line Magnetic Field Results

Measurement	Separation Distance				
	100'	125'	150'	175'	200'
Peak Field Outside ROW (mG)	42.27	41.04	39.07	38.11	37.39
Percent Field Change	0	-2.91%	-7.57%	-9.84%	-11.5%
Peak Field Inside ROW	139.6	140.1	142.0	144.0	145.7
Percent Field Change	0	0.37%	1.77%	3.20%	4.41%

FIGURE 18 - 500kV Line Magnetic Field Plots

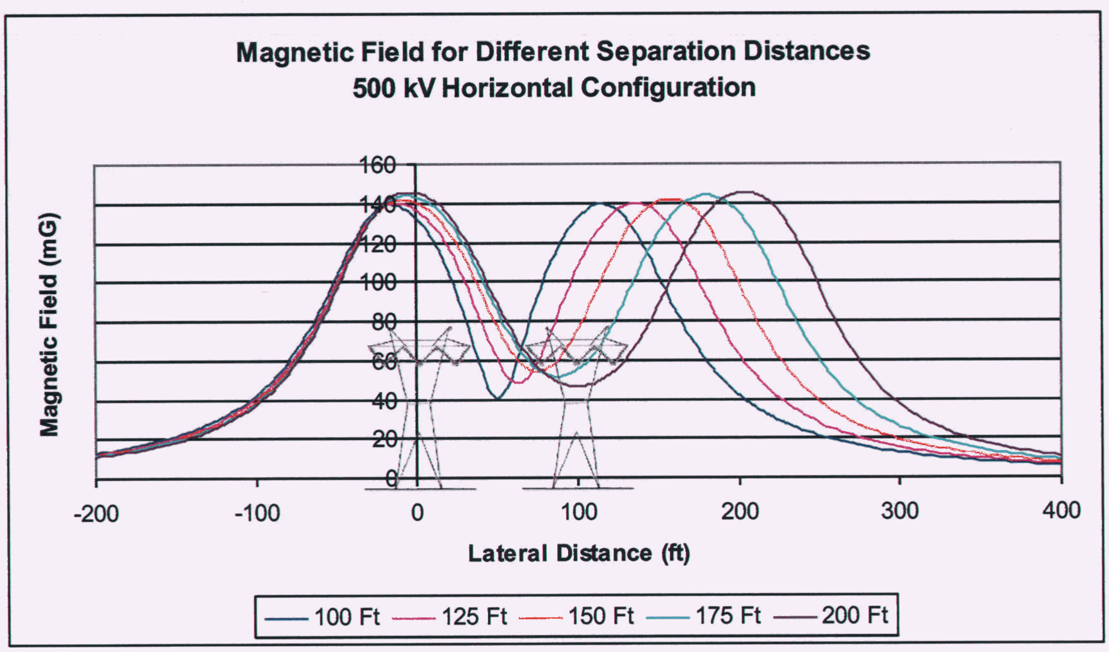
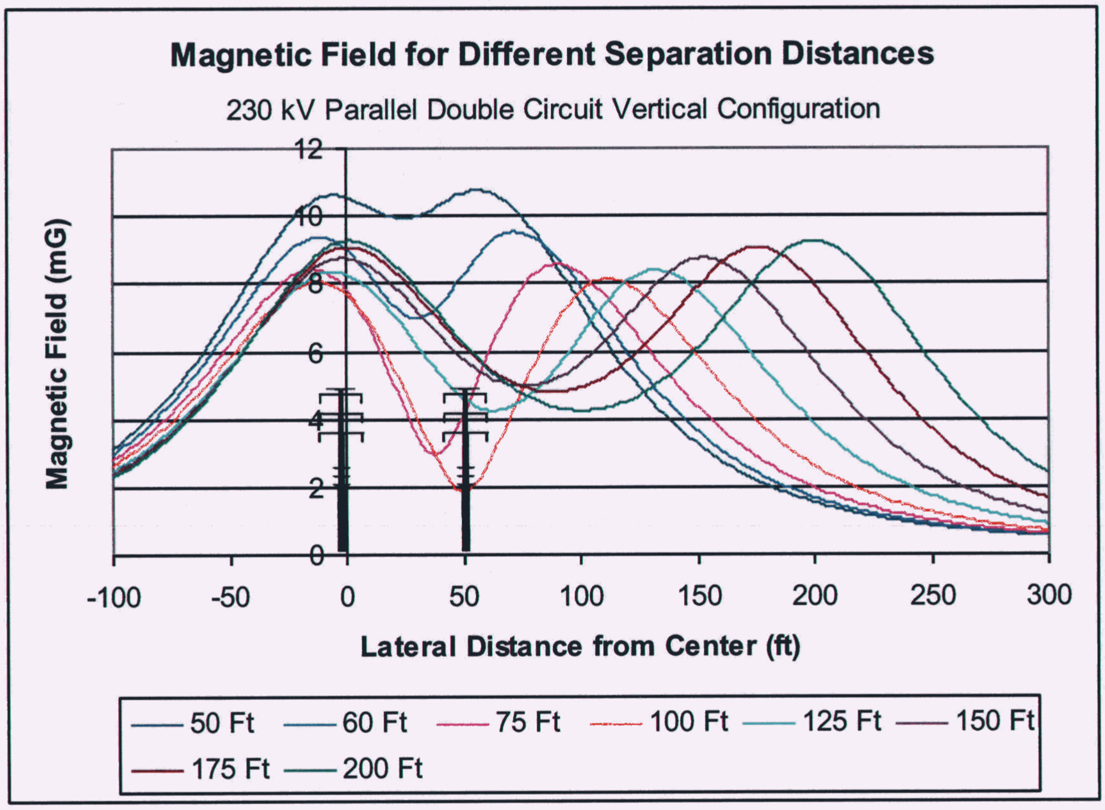


Table 4: 230 kV Line Magnetic Field Results							
Measurement	**Separation Distance**						
	50’	75’	100’	125’	150’	175’	200’
Peak Field Outside ROW (mG)	7.39	6.50	5.87	5.85	5.69	5.73	5.67
Percent Field Change	0	-12.0%	-20.6%	-20.8%	-23.0%	-22.1%	-23.3%
Peak Field Inside ROW (mG)	10.7	8.57	8.15	8.40	8.76	9.07	9.28
Percent Field Change	0	-20.4%	-24.3%	-21.9%	-18.6%	-15.7%	-13.8%

FIGURE 19 - 230kV Line Magnetic Field Plots



SYSTEM RELIABILITY IMPACTS

Objective

To evaluate the physical requirements and potential reliability impacts associated with more stringent criteria increasing separation for new transmission lines. The ACC wishes to investigate potential reliability benefits associated with line separation such that structure failures would not cause outages on adjacent lines. The goal is to gain insights into possible cost-effective reliability improvement that may be realized by increased line separation on a case-by-case basis. This is to be accomplished by assessment and discussion of generic examples of an EHV corridor wherein there are existing transmission facilities and additional two circuits would be needed. This analysis should be considered a template wherein individual transmission providers may include their respective ROW requirements, line design standards and structure characteristics. For example, structures may be robust enough that separation by full tower height may not be necessary. Hence tradeoff between investments in physical structures versus increased separation with associated land impact may be better understood.

Background

Assume that a major load center is served from multiple EHV interconnections. One of the interconnections is supplied by a 50 mile long double circuit 345kV transmission line that is integrated with a network that imports power to the load center. The existing 50 mile double circuit has reached the point at which, based on WECC contingency standards for multiple contingencies, it limits the load serving capability of the load center. In the example, the solution is to add two new 345kV circuits in parallel with the existing double circuit line. Note that this type of analysis may be transferable and applied to 230kV or 500kV lines.

Two alternatives are considered to ensure that a full range of options are encompassed. The first, "Conservative Alternative" assumes relatively large ROW widths are required. The second, characterized as "Constrained Alternative", assumes that ROW is constrained. All alternatives assumed that structures would be lined up to minimize blow out requirements. The former implies relatively large land impact caused by the need to acquire more ROW due to increased structure separation requirements. The latter suggests a lesser land impact resulting from line design consistent with the goal of maintaining reliable system operation within a narrower ROW.

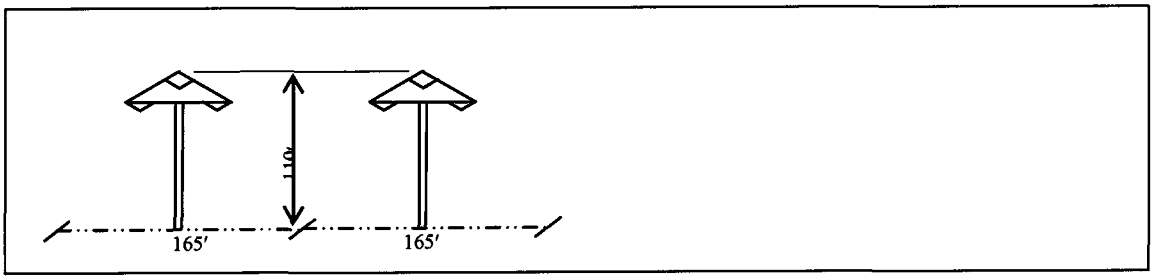
Conservative Alternative

The Conservative Alternative assumes relatively wide hypothetical ROW requirements for the existing system will apply to future construction.

Existing 345kV Structures and ROW

Assume the applicable standards require 165' of ROW with the line centered on the ROW as shown in Figure 20.

FIGURE 20 - Existing 345kV Structures

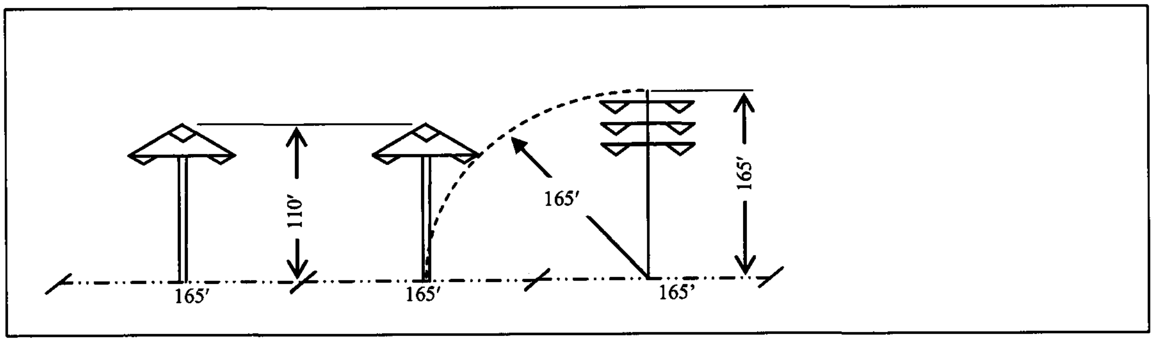


Assume the contingency analysis findings are that loss of both circuits results in overload of other parallel facilities, thereby limiting the amount of load served within the subject load pocket. Also, assume a worst case scenario under which addition of a single new 345kV line is not adequate due to loss of any combination of two of the three parallel lines overloads the remaining line. Hence two additional lines will be included in the reliability evaluation.

Scenario A - New 345kV Double Circuit / Conservative Alternative

Assume the Transmission Provider (TP) standard requires 165' of ROW with the line centered on the ROW and the standard for new lines is monopole designed to accommodate double circuits whether single or double circuits are to be installed. The new double circuit would be centered on an additional 165' of ROW as shown in Figure 21.

FIGURE 21 - New 345kV Double Circuit / Conservative Alternative



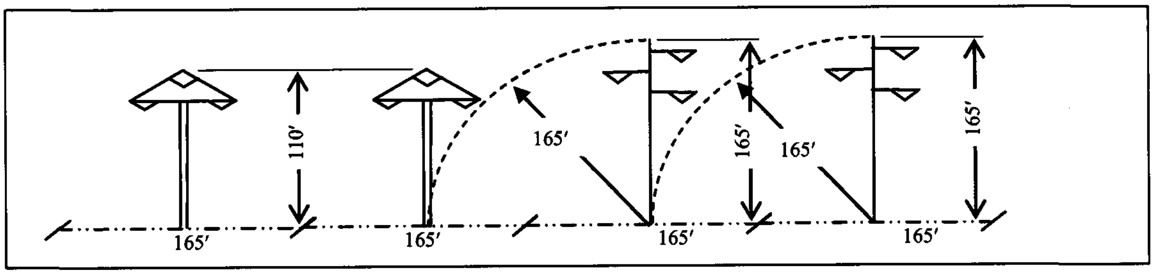
WECC planning standards require analysis of any two adjacent circuits in a common ROW as a Category C contingency. Hence the contingencies would consist of outages on both of the existing circuits, outages of the center existing circuit with the inside circuit of the new double circuit, and finally outage of both circuits on the new double circuit line.

Assume the separation is not adequate to prevent the new double circuit from contacting the inside existing circuit and results in the loss of three of the four lines. This would be considered a Category D contingency with the consequence of overload of the remaining line. The TP providing service would evaluate for consequences considering the relatively low probability of such an event[1] and determine a course of action. Note that damage from adjacent structure contact may be minimized to the extent that no line outage may occur if the towers are designed to withstand an impact to the lower quarter or third of the structure.

Scenario B - Two New 345kV Single Circuits / Conservative Alternative

Assume the TP standards require 165' of ROW with the line centered on the ROW. Each of the new single circuits would be centered on separate additional 165' ROWs, requiring an additional total of 330' of ROW as shown in Figure 22.

FIGURE 22 - Two New 345kV Single Circuits / Conservative Alternative

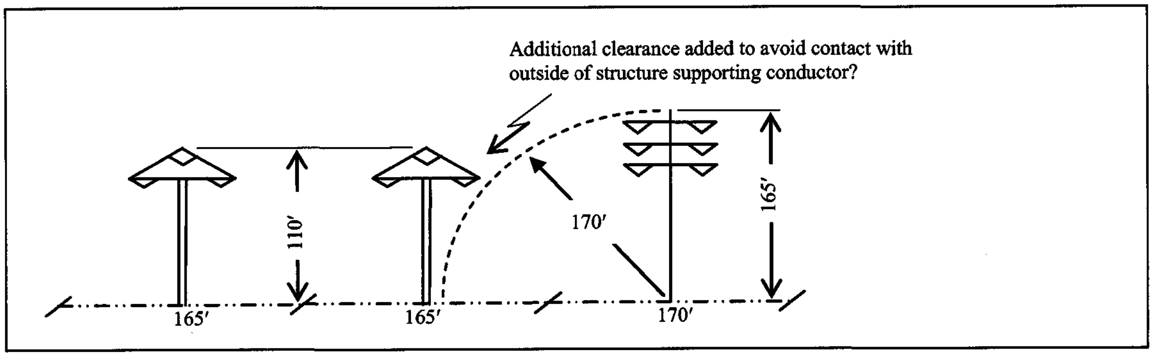


Category C contingencies would consist of loss of existing circuits, loss of the center existing circuit with the adjacent new single circuit, and loss of both new circuits. There should be no Category D issues attributed solely to inadequate separation to avoid adjacent circuit contact, since no more than two circuits would be involved for any given event involving contact from the adjacent line.

Relatively modest increase to ROW width would be needed to the "Conservative Alternative" to achieve separation such that structure failures would not make contact with adjacent lines. In the case of the addition of a double circuit line, the increase would be on the order of 5' as shown in Figure 23 New 345kV Double Circuit / Proposed Guideline.

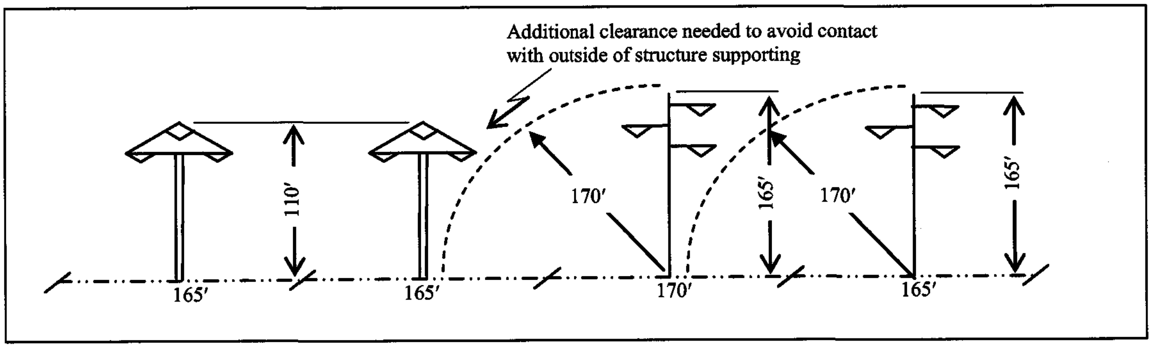
[1] The Task Force observed that the likelihood of structures falling into the adjacent circuit is very low because the conductors and shield wires would prevent the broken structure(s) from falling to the ground.

FIGURE 23 - New 345kV Double Circuit / Proposed Guideline



Only 5' additional ROW would be needed assuming separate single circuits on separate ROWs to meet the proposed guideline as well. Refer to Figure 24. Note that 335' would be required for the separate circuits versus 170' for the double circuit.

FIGURE 24 - Two New 345kV Single Circuits / Proposed Guidelines



Observations regarding the Conservative Alternative

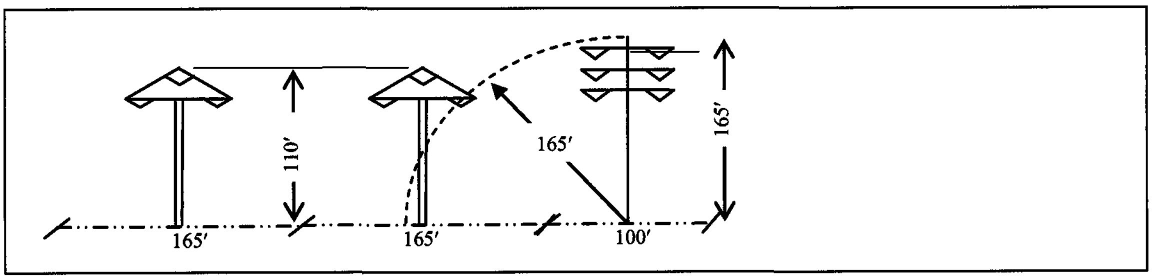
1. Generally the *incremental* ROW requirements, based on the assumed TP standards in the example are relatively small. In other words, the Conservative Alternative example may serve as the benchmark defining the ROW width that would be needed to meet the proposed ACC guideline.
2. Maintaining separation to avoid structure related contact with adjacent facilities has the potential to reduce the likelihood of Category C and D contingencies that would be caused by one line falling into the other. However such events are relatively unlikely.
3. Addition of multiple lines on separate single circuit structures with each on relatively wide separate ROWs results in fewer Category C and D contingency issues than double circuit lines on single structures. However land requirements and associated impacts are much less for multiple circuit structures.

Constrained Alternative
The Constrained Alternative assumes that relatively narrow ROW requirements will apply to future construction. TPs typically face physical or economic constraints depending on terrain, economic development, land use restrictions or other factors that may influence line siting. Therefore "Constrained Alternative" scenarios were developed to assess these potential conditions.

Scenario C - New 345kV Double Circuit / Constrained Alternative

The new double circuit is assumed to be spaced such that failure of the new double circuit could possibly result in contact with the adjacent existing line. Separation between the new line and the adjacent circuit is assumed to be less than the new tower height such that contact with the outside phase of the adjacent structure could conceivably occur. Refer to Figure 25.

FIGURE 25 - New 345kV Double Circuit / Constrained Alternative

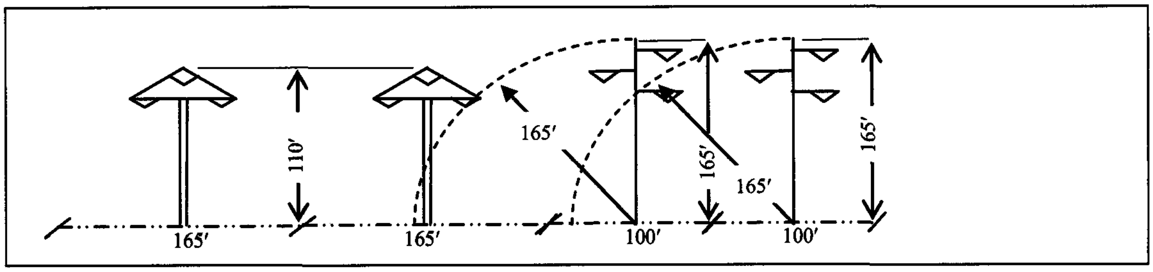


Scenario C analysis is very similar to Scenario A in that separation is not adequate to prevent the new double circuit from contacting the inside existing circuit and results in the loss of three of the four lines. This would be considered a Category D contingency. However, depending upon the proximity of the two sets of structures, the probability of this type of event could be higher than for the Conservative Alternative.

Scenario D - Two New 345kV Single Circuit / Constrained Alternative

The two new single circuits are assumed to be spaced such that failure of either new circuit could result in contact with the adjacent existing or new lines. Detailed line design analysis would have to be done to determine optimal spacing considering the ability of the conductors to prevent failed structures from leaning far enough to contact adjacent lines.

FIGURE 26 - Two New 345kV Single Circuits / Constrained Alternative



Category C analysis is identical to Scenario B. There should be no Category D issues attributed solely to insufficient separation to avoid adjacent circuit contact, since no more than two circuits would be involved for any single event.

Section Summary

Achieving line separation contemplated in the proposed guideline could improve reliability, but would require significant additional land investment. Depending upon the individual transmission provider's standards, ROW widths could be increased by a range of 1.5 to 2 times existing requirements. Therefore, consideration of the proposed guidelines should be considered on a case-by-case basis.

GENERAL CONCLUSIONS

The Paper has described different decision variables in the determination of and the consequences in putting circuits in proximity to each other in common corridors.

The extremes of placing transmission lines in corridors are from having many lines in a corridor to having no lines in a corridor or all lines in separate corridors. The variables affected by the extremes are land use or cost and the potential impact to power system reliability by the outage of all the circuits in a corridor. This is a balance of cost and reliability.

It is a reasonable expectation that the reliability of the electric transmission system could be improved if separation distance between parallel transmission lines in a common corridor were increased to the width such that the failure of one line could not physically impact the adjacent line, the physical limit.

Typical common corridors have as residents EHV circuits which, if outaged at the same time, may lead to widespread customer outages or even to blackouts in the power system. As corridor line additions are speculated, system studies will be performed to determine the system impacts, if indeed the corridor does suffer an outage of all elements in the corridor. A mitigating aspect of lines in a common corridor is whether there is a divergence of terminations. This may allow the outage of the corridor without system impact.

The costs of separating lines in a common corridor must be weighed against the risk of these typical common outage incidents and the consequences to the system if the outage were to occur.

There are various causes of multiple circuit outages in a common corridor, fire, flooding, aircraft contact, adverse weather, lightning, equipment failure, human error, sabotage, etc.

Fires raging across forest fire susceptible areas can take transmission lines out for hours as the fire goes past and to clean potential damage. Aircraft damage has happened where a plane catches and drags a conductor from one circuit to another causing multiple circuit outages. Adverse weather, hard winds, may cause the failure of one tower failing into the adjacent circuit. Lightning typically causes the outage of one circuit at a time. Structures typically fail with downward pressure because of the weight of the conductor but have failed into adjacent circuits in the past. Sabotage has more potential because of the proximity of more structures in a common corridor and more damage.

The following points highlight the fight between increased transmission circuit separations in common corridors versus the added land cost of the added separation.

Separation May Not Measurably Improve System Reliability or Operational Limits

A way to insure that one circuit in a corridor cannot physically impact an adjacent circuit is to build it beyond the physical boundaries of the adjacent circuit. However, this adds the cost of the increased corridor costs.

If two circuits are at the safety limit of separation, the minimum separation, what are the benefits of adding separation between the circuits in the corridor out to the physical limits of the circuits?

As the separation distance is increased from the safety minimum, some potential outage cause probabilities are reduced. But as this distance is increased, the cost to the utility is increased because of increased land use. There are common outage causes that are still at the same level of common exposure as the corridor width expands from the safety limit to the physical limit. The outage type that may influence the width of separation is the possibility of structures falling down into adjacent circuits or parts of an existing circuit being dragged into another circuit.

However, building circuits beyond the physical limit does not eliminate the common exposure to some outage causes, For example, if circuits in a corridor are in a high fire danger area, the width of the corridor is almost meaningless as the fire exposes all circuits in the fire area to outage.

Separation Requires Additional Cost

Minimum width of easements is established by the minimum space required for safe electrical clearances during high winds and/or the minimum required space for constructing and maintaining the transmission line. This determination is part of a cost optimizing process to reduce the total cost of the transmission line. The effort to minimize easement requirements is in order to minimize the cost to rate payers. Separation increases easement width requirements and the total cost of easements for the transmission line.

Increased separation of easements may also result in additional costs to comply with environmental policies and regulations because of the increased amount of new disturbance to the landscape. An extensive environmental study could potentially be required if a new easement is proposed outside of an existing corridor.

Increased Separation May Increase Land Use Restrictions

Transmission line easements create stringent land use limitations on the underlying landowner. Existence of a transmission line typically precludes development of commercial or residential structures of any type. Development limitations are necessary to insure future access is possible for maintenance of wires and structures. Separation increases the 'unusable' space between parallel transmission lines and increases the total land with restrictions for use of the land owner.

Separation Limits Transmission Line Siting Opportunities

In developing potential transmission line routes, it is common for a potential route to have a "pinch point"; an area which has a restricted width that the line must pass through. Restrictions may be geographic, created by existing structures or by limits of legal boundaries. Separation would increase easement widths which may preclude and eliminate some route opportunities. Increased separation may reduce opportunities in line siting options.

Separation Could Cause Creation of Additional Transmission Line Corridors

It is common practice to consider route options paralleling existing transmission lines. Increased additional separation could preclude this route option because easement costs and potential environmental impacts would increase where the new line does not parallel existing lines. Because there is usually increased cost associated with greater easement width when paralleling an existing line, the owner of the new line has financial motivation to site new lines along new routes. Existing transmission lines generally have an access road and have previously disturbed landscape. Locating proposed facilities adjacent to existing facilities minimizes new disturbance to an area and minimizes environmental impact.

Separation Creates Additional Difficulties Siting Transmission Corridor across Public Lands

Majority of federal and state agencies have adopted management guidelines within their respective land management plans to consolidate linear infrastructure to the extent possible. The siting of a transmission line across public land requires environmental analysis to comply with the guidelines adopted in the respective management plan. Locating transmission lines outside of designated corridors may extend the permitting schedule several years and require additional environmental analysis.

APPENDIX A: LOAD CASES FOR TRANSMISSION LINE STRUCTURES

NOTE: This is an example of a load case document used by a utility company. It is not proposed for wide use or implementation. It is an example of how various load cases may defined and quantified for designing transmission line structures.

LOADING CASES
FOR TRANSMISSION LINE STEEL STRUCTURES

1.0 GENERAL

The purpose of this design guideline is to provide information for developing loads on steel structures for transmission lines. This guideline covers definition and development of loads, loading combinations (load cases) and other related data for the design of steel transmission line structures.

2.0 ABBREVIATIONS, CODES, AND STANDARDS

Reference to standard specifications herein shall be interpreted to mean the latest revision. The following abbreviations when used herein mean:

ACI - American Concrete Institute

AISC - American Institute of Steel Construction

AISI - American Iron and Steel Institute

ANSI - American National Standards Institute

ASCE - American Society of Civil Engineers

ASTM - American Society for Testing and Materials

EPRI - Electric Power Research Institute

IEEE - Institute of Electrical and Electronic Engineers

NESC - National Electric Safety Code

3.0 LOADS

3.1 General

Structures shall be designed for the loads described herein. All working loads are to be multiplied by the appropriate Overload Factors (OLF). The working loads, multiplied by the OLF, will be defined as the Factored Design Load (FDL). Loadings shall not be less than those specified in the NESC (Rules 250-252). Extreme wind loads shall be in accordance with NESC Rule 250C wind gust with 100 year return period. If a transmission line is located in an area subject to high winds and special gust conditions, special studies may be required.

Calculations for the different loading cases, that are project specific, are included in Appendix A to this document.

The structure loading drawings shall indicate the wires sizes, physical wire characteristics, controlling tensions, wind spans, weight spans and overload capacity factors. The information shall be such to allow the design loads to be recalculated at a future time.

3.2 General Loading Requirements

3.2.1 Three general loading districts as defined by the NESC are used in establishing the working loads on wires and structures due to weather. The districts are designated as Heavy, Medium, and Light loading as shown in the NESC. For structures located below 2,500 feet elevation, the Light loading district shall be used. For structures located between 2,500 feet and 5,000 feet elevation, both the Light and Medium loading criteria shall be used. Above 5,000 feet elevation, or where meteorological records indicate large ice accumulation, the Heavy loading criteria shall also be used.

3.2.2 Extreme wind loading, as shown in the NESC, on wires and structures shall also be checked in all cases.

3.3 Wire Loadings

Loads on wires shall be per NESC Rule 251 (As a point of clarification, the constant in Rule 251B3 is used for determining the total wire tension only and does not apply to horizontal wind or vertical loads on wires applied to the structure.).

3.4 Loads On Supporting Structure

The loads on the structure shall consist of all wire loads, the self-weight of the structure, the weight of the insulators and hardware, wind loads, and ice loads.

3.5 Vertical Loads

3.5.1 The vertical loads on supporting structures shall consist of their own weight plus the superimposed weight, which they support, including all wires and vertical component of tension, insulators, workmen, and hardware.

The following values may be used for insulator and hardware assemblies:

OPGW & OHSW Suspension 25 pounds

OPGW & OHSW Deadend	50 pounds
230 kV Suspension Vee-string (polymer)	100 pounds
230 kV Deadend with jumper (polymer)	250 pounds
230 kV Suspension I-String (polymer)	50 pounds
500 kV Suspension Vee-string (porcelain)	900 pounds
500 kV Deadend with jumper (porcelain)	3,500 pounds
500 kV Suspension I-String (porcelain)	700 pounds

3.5.2 The vertical load contributed by the wires is determined using the effective vertical (weight) span. The weight span is the horizontal distance between the minimums on the sag curve as shown on the plan-and-profile sheets. The weight span shall be determined with proper consideration of the effect of support at different elevations and the prevailing temperature.

3.5.3 The weight of ice shall be assumed to be 57 pounds per cubic foot. The weight of ice upon supports may normally be ignored on the completed structure; but if the coating of ice on crossarms or long horizontal members can create stresses that require 25% or more of the capacity of the member, the ice load should be included in the design of the member.

3.5.4 Allowance shall be made for vertical loads on the structure due to wire stringing operations or maintenance techniques. When the tensioner is located between two towers or if the wire is snubbed, the line tension adds a vertical component to the loads. This vertical component shall be determined using an angle of 1 Vertical: 5 Horizontal.

3.5.5 On lattice towers, all bracing members oriented less than 30° from the horizontal should be designed to safely support the weight of a 300 lb. man.

3.6 <u>Transverse Loads</u>

3.6.1 The transverse loads on a structure shall be determined by the effect of wind on projected surfaces of the structure and wires and any line tension caused by a change in line alignment.

3.6.2 Extreme Wind loads shall be the greater of NESC Rule 250C or ASCE with a return period of 100 years. Wind pressure varies with height above ground. For wind loads other than

NESC Rule 250B, wind pressure shall be adjusted for elevation.

3.6.3 In general, basic wind pressures may be determined by:

$P_w = 0.00256 C_d V^2 k_z G_{RF} I C_d$

Where P_w = pressure on projected area (psf)
V = design wind speed, 3 second gust (mph)
C_d= shape factor
k_z = velocity pressure exposure coefficient
G_{RF} = gust response factor
I = importance factor = 1.0

Common Shape Factors:

Cylindrical/Wires	1.0
Flat	1.6

The gust response factor is different for wires and structures which causes the wind pressure to be greater on structures.

3.6.4 Wind loads on lattice structures constructed of angles shall be computed from the basic wind pressures applied to the sum of the projected areas of the members of the front face, and shall be increased by 3.20 (to allow for the pressure on the opposite face and a shape factor of 1.6). The total load need not exceed the load which would occur on a solid structure of the same outside dimensions.

3.6.5 The effective horizontal (wind) span for determining the wind on wires shall be equal to one-half the sum of the adjacent spans between supporting structures.

3.6.6 Where NESC loading conditions are specified, the wind velocity is applied horizontally at right angles to the direction of the line.

3.6.7 Where a change in direction of wires occurs, the transverse loading upon the supporting structure shall be the resultant load equal to the vector sum of the maximum transverse wind load and the resultant load imposed by the wires due to their change in direction. In obtaining these loadings, a wind direction shall be used which will give the maximum resultant load.

3.6.8 The structure shall have sufficient strength, when standing without wires, to withstand the wind pressure specified under the maximum wind loading. The wind load shall be calculated using NESC Rule 250C with a 100 year return period. The structure shall be capable of withstanding this load from any direction.

3.7 Longitudinal Loads

3.7.1 Structure shall be designed to withstand longitudinal loads due to a local perturbation such as a broken conductor (at single conductor per phase), a broken sub-conductor (at two or more conductors per phase), a broken shield wire or a dropped insulator assembly on an adjacent structure (the greatest loading from whichever cases are deemed applicable).

For suspension insulators, the swing of the insulator due a broken conductor should taken into be account. This results in a lower load than simply considering full differential tensions.

On structures with line post insulators, effects of broken conductor loads should be evaluated on a project by project basis. Other types of attachments (post insulators on conductors or short linkages on shield wires) may result in a minor reduction of the full differential tension.

3.7.2 Longitudinal loads due to differential ice loading or ice shedding in one span shall be considered in areas where ice accumulation occurs. Static approximations may be used since the loads seldom occur simultaneously and due to the flexibility of the tower and line system.

3.7.3 The longitudinal loading upon supporting structures at dead-ends for line terminations shall equal the tensions of all wires under the wire load conditions specified, except that with spans in each direction from the dead-end structure the longitudinal loading shall be taken as the difference in tensions. (Applicable to all load cases except XVII)

3.7.4 Where longitudinal loads can be created by the difference in tensions in the wires in adjacent spans caused by unequal vertical loading and/or unequal spans, the structure should be capable of supporting this longitudinal loading. Because these forces are indeterminate, the tension imbalance may be approximated for design. For design, the longitudinal load will be the difference in tensions in spans (within the Ruling Span) of –50% and +200% of the Ruling Span at 0°F. The Ruling Span is defined as follows:

$$RS = (\Sigma S_i^3 / \Sigma S_i)^{0.5}$$

Where: RS = Ruling Span
S_i = actual spans for line segment between dead-ends.

3.7.5 Allowance shall be made for longitudinal loads that may be produced on the structure by wire stringing operations or construction techniques. An example would be the jamming of the running board into the stringing sheave, causing the insulator assembly (and the non-sagged conductor) to swing, thus adding a longitudinal imbalance. These loads are indeterminate, but may be calculated by approximating the swing angle of the insulator assembly as 30°, which is based on past experience. The longitudinal load for the 30^0 swing angle is equal to the vertical load times the tangent of 30^0.

3.8 Overload Factors

3.8.1 For transmission lines, NESC OLF for Grade B construction shall be used for all NESC required load cases. These overload factors from the 2002 NESC are:

Type of Load	OLF
Vertical	1.50
Transverse Wind	2.50
Transverse Wire Tension	1.65
Longitudinal at Dead-Ends	1.65
Longitudinal in General	1.10

3.8.2 For loading conditions other than NESC (refer to IEEE papers A-77-228-0, 83-WM-152-6, and C-73-378-7), smaller OLF are used since maximum loads are applied. The OLF provides a buffer for uncertainty with the loads, variation of the material (estimated to be 5-10% for steel towers), risk to human life, the recurrence interval of load, and the probability that the load will occur. Also, the precision of calculating internal stresses, possible material deterioration due to weathering, deviation in calculated loads, and the consequence of failure should be considered in selecting the OLF. The minimum OLF to use would be 1.1 where no risk to human life is involved and up to 2.0 or more where human life is involved.

3.9 Structure Types

3.9.1 Loading conditions on structures depend on the geometry of the wires (angles, spans heights) and the sequence and manner in which the line is constructed. In general, structures types are as follows:

3.9.1.1 Tangent: Primarily resists wind and weight loads. Tangents are also typically designed to resist nominal transverse loads from small line angles up to 2 degrees. Insulators are typically suspension in an I-string or V-string configuration.

3.9.1.2 Angle (suspension): Primarily resists wind and weight loads and some transverse loads due to line angles of up to 30 degrees. Insulators are typically suspension with I-string, V-string, or pull off configurations. Conductor supports, arms and orientation of attachment points will have provisions to account for the line angle.

3.9.1.3 Strain: Resists weight, wind, transverse loads due to angles greater than 30 degrees and differential longitudinal tensions in the line. The structures are not designed to withstand a full one way dead end load. Lattice strain structures may also be designed for use in a tangent configuration when longitudinal loads are unequal due to significant changes in elevations, spans or conductor tensions. Strain structures are framed with dead end insulator strings.

3.9.1.4 Dead End: Resists weight, wind and transverse loads due to medium to large line angles between 60 – 90 degrees in an intact condition and under a full dead end in one direction.

Lattice structures may also be designed for use as a full dead end at line angles less than the maximum design angle, such as an in-line, tangent dead end.

4.0 LOADING COMBINATIONS

4.1 General

4.1.1 The following combinations of loading conditions shall be investigated in the design and analysis of all structures and structural components. Sizing shall be based on the most critical loading combinations. Different members are usually sized by different loading cases.

4.1.2 The number and type of load cases to use are dependent on the location, design, and size of project. (See Section 4.2.2 for the minimum number of load cases to be considered.)

4.1.3 Where a line angle is specified, the structure is oriented such that the centerline of the crossarm will bisect the angle formed by the conductors in the adjacent spans. The structure shall withstand loads imposed at line angles up to and including the line angle specified.

Structures may be used for larger wind and /or weight spans than the maximum specified (e.g., a 10 degree angle tower can be used for a longer weight span at a lower line angle; however, because application is limited, care should be taken to keep these load cases from controlling tower member sizes).

4.1.4 Lattice structure loading combinations should consider the simultaneous application of the maximum wind and weight span, and also consider other combinations of maximum and minimum weight spans. The selection of various span combinations is dictated by the project terrain and structure applications. Uplift loads should also be considered.

4.1.5 Lattice towers shall be designed and analyzed for every combination of shortest and longest leg extensions connected to the tower body or a body extension.

4.1.6 Construction sequence patterns should be followed when determining the order in which construction loads are applied to the tower.

4.2 Load Cases

4.2.1 Load Cases should be selected based on the type of structure and function in the transmission line. Typical minimum load combinations for elevations below 2,500 feet include:

Type	All Structures	Towers	Poles
Tangent	I, IV,VII, VIII, IX, XI, XII, XIII, XIV	V, VI	
Angle (Suspension)	I, IV, VII, VIII, IX, XI, XII, XIII, XIV	V,VI	XVIII
Strain	I, IV, XVI	V,VI, XV, XIX	XI, XII, XIII, XVIII
Dead End	I, IV, XVII	V,VI, XV, XX	XI, XII, XIII, XVIII

4.2.2 For load cases on lattice towers identified thus (*), all members (members oriented less than 30° from the horizontal) to be used for support of personnel during construction or maintenance are to be designed for the specified loads plus a 300 lb. vertical load applied to produce maximum bending stress in member (OLF = 1.0 in bending).

4.2.3 Initial tensions for the following load cases shall be defined as the tensions using the normal modulus of elasticity of the cable material before any creep effects have occurred.

4.2.4 Case I: NESC Light Loading Condition. 60 mph wind (9 psf), 30°F, no ice, and initial tensions. All wires intact. (OLF's per NESC)

4.2.5 Case II: NESC Medium Loading Condition. 40 mph wind (4 psf), 15°F, ¼" radial ice, and initial tensions. All wires intact. (OLF's per NESC)

4.2.6 Case III: NESC Heavy Loading Condition. 40 mph wind (4 psf), 0°F, ½" radial ice, and initial tensions. All wires intact. (OLF's per NESC)

4.2.7 Case IV: NESC Extreme Wind (NESC Rule 250C), or ASCE 100 year return period wind gust. Minimum 96.3 mph wind, 30°F, no ice, and initial tensions. All wires intact. (OLF = 1.10)

4.2.8 Case V: Diagonal Extreme Wind, NESC Rule 250C, 100 year return period wind gust. Minimum 96.3 mph wind acting at 45° to the centerline of the crossarms, 30°F, no ice, and initial tensions. (OLF = 1.10)

4.2.9 Case VI: Extreme Wind Gust on Tower without wires. NESC Rule 250C, 100 year return period wind gust. Minimum 96.3 mph wind (see 3.6.8) acting parallel, perpendicular, and at 45° to the centerline of the crossarms, and no ice. (OLF = 1.10)

4.2.10 Case VII: Loads resulting from an Insulator Assembly Failure on Adjacent Tower Causing the Conductor(s) to drop. Use impact factor of 3 on vertical loads (unless otherwise determined), no wind, 30°F, no ice, and initial tensions. (OLF = 1.10)

4.2.11 Case VIII: Loads resulting from one broken conductor or subconductor in One Phase. No wind, 30°F, no ice and initial tensions. (OLF = 1.10)

4.2.12 Case IX: Loading from one broken OHSW (overhead shield wire). 60 mph (9 psf wind) uniform wind, 60°F, and initial tensions. (OLF = 1.10)

4.2.13 Case X: Loads due to differential ice loading or to ice shedding. No wind, 30°F, ice as calculated, and initial tensions. (OLF = 1.10)

4.2.14 *Case XI: Stringing conditions. Vertical loads due to weight of conductors, OHSW, insulators and hardware assemblies, and travelers. Transverse load imposed by line angle tension. Longitudinal load at any conductor position due to a 30° swing of the insulator assembly and traveler. No wind, 30°F, no ice, and initial tensions for OHSW and stringing tensions for conductors. (OLF = 1.10) The longitudinal load for the 30^0 swing angle is equal to the vertical load times the tangent of 30^0.

4.2.15 *Case XII: Stringing condition (One way snub). Vertical loads due to weight of conductors, OHSW, insulator and hardware assemblies, travelers, and two (2) 300 lb. men. Additional vertical load due to the component of line tension caused by the vertical angle between the tower crossarm and the tensioner (maximum 1 vertical: 5 horizontal). Transverse load imposed by the line angle tension. No wind, 30°F, no ice, and initial tensions. (OLF = 1.10 for structure weight & 2.00 for all applied loads).

4.2.16 *Case XIII: Stringing condition. Longitudinal load on any one OHSW equal to 20% of the RTS (Rated Tensile Strength), together with the normal vertical and transverse loads on that OHSW. The other OHSW may be installed. No conductors on the tower. No wind, 30°F, no ice, and initial tensions. (OLF = 1.10 for structure weight & 2.00 for all applied loads).

4.2.17 *Case XIV: Maintenance condition. Vertical load on the crossarm above the apex of the V-string assembly (or to an attachment plate located elsewhere) equal to twice the weight of the bare conductors. Other conductor positions and OHSW have normal vertical loads. Transverse load imposed by the line angle tension. No winds, 30°F, no ice, and initial tension. (OLF = 1.10 for structure weight & 2.00 for all applied loads)

4.2.18 *Case XV: Strain Tower Stringing Conditions (Two way snub). Vertical load due to weight of conductors, OHSW, insulators and hardware, travelers, and two (2) 300 lb. men. Additional vertical load due to the component of line tension caused by the vertical angle between the tower crossarm and the tensioner (maximum 1 vertical: 5 horizontal). Tower snubbed in two directions. No wind, 30°F, no ice, and initial conditions. (Note: The OHSW may be designed for full dead-ending.) (OLF = 1.10 for structure weight & 2.00 for all applied loads)

4.2.19 *Case XVI: Strain Structure, One Side Intact Only. All conductors and OHSW installed on one face of the structure only at the design line angle. For the NESC light loading district, the stringing wire tension is at no wind, no ice, 30°F, initial. For the NESC Medium and Heavy loading districts the wire tension is at no wind, no ice, 0°F, initial. (OLF = 1.10)

(Note: Older lattice towers may not be designed for this load case as written. Refer to the original tower designs for unbalanced load case.)

4.2.20 Case XVII: Dead-End Structure, One Side Intact Only. Design for the greater of NESC District Loading or NESC Extreme Wind condition. All conductors and OHSW installed on one face of the structure only at the design line angle. (OLF either in accordance with NESC or 1.10 for extreme wind loads.)

(Note: Older lattice towers may not be designed for this load case as written. Refer to the original tower designs for dead end load case.)

4.2.21 Case XVIII: Camber. All conductors and OHSW installed. No wind, 60°F, no ice, and final tensions. (OLF = 1.00)

4.2.22 Case XIX: Construction and Maintenance – Strain Tower Torsion. Longitudinal and transverse load due to dead ending one outside phase on one side of tower with both OHSW's and other two phases installed. For the NESC light loading district, the wire tension is at no wind, no ice, 30°F, initial. For the NESC Medium and Heavy loading districts the wire tension is at no wind, no ice, 0°F, initial. (OLF = 1.25)

4.2.23 Case XX: Construction and Maintenance – Dead End Tower Torsion. Longitudinal and transverse loads due to dead ending center phase in both directions and dead ending both outside phases in opposite directions to produce a maximum torsion. Dead end both OHSW's, simultaneously with conductors, in opposite directions to produce maximum torsion. For the NESC light loading district, the wire tension is at no wind, no ice, 30°F, initial. For the NESC Medium and Heavy loading districts the wire tension is at no wind, no ice, 0°F, initial. (OLF = 1.25.)

5.0 DEFLECTIONS

The minimum electrical clearance distances, as specified in the Design Criteria, shall be maintained under all conditions. The only exception would be during the construction loading cases.

6.0 CAMBER (POLE STRUCTURES)

If the structure deflection is greater than ½ the diameter of the pole top, the pole shall be cambered. Load condition shall include all circuits and subconductors installed at 60° F, no wind and final tensions.