Line Separation

Background

While it is generally desirable to build lines on the same corridor side by side for environmental and land use reasons, the likelihood and consequences of outage of two or more lines due to a common event must be considered by transmission planners. The loss of multiple circuits into a load area will result in increased demand over the remaining circuits and can result in area blackout unless load and/or generation (sometimes a sizable amount) is tripped off to balance flow with remaining transmission capacity. Transmission planning is done on the basis of *not* interrupting customer load for the more common system transmission line outage events since high voltage grid interruptions have the potential to affect a large number of customers and critical load such as hospitals, emergency services, and other essential or sensitive loads.

The Western Electricity Coordinating Council (WECC), formerly the Western Systems Coordinating Council (WSCC), is the organization that sets transmission system reliability standards for the Western U.S. The WECC, of which BPA is a member, has established performance criteria applicable to loss of multiple lines. In the case of the more likely multi-contingency events (loss of two lines or all lines in a corridor) standards exist related to allowed electrical performance as well as admissible countermeasures such as load or generator tripping. Successive loss of transmission lines and attendant load and generation, like falling dominoes (called "cascading") is not allowed. In the case of even less likely events (sometimes called unplanned or extreme events), reliance is placed on containment measures such as load shedding, system islanding (separating areas of the system from one another), and other means to limit cascading.

Simultaneous loss of two adjacent lines is considered to be a likely (credible) event and therefore must be planned for in outage studies. Simultaneous loss of two or more lines built on separate rights-of-way is generally considered to be a non-credible event. Provision has been made for specific cases to classify loss of two lines on the same right-of-way as a non-credible event based on line design; length; location, e.g., whether forested, agricultural, mountainous, etc; outage history; operational guidelines; and separation between circuits. This is understood by referring to the North American Electric Reliability Council (NERC)/WSCC Planning Standard WSCC-S2 on the following page.

WSCC-S2 The NERC Category C.5 initiating event of a non-three phase fault with normal clearing shall also apply to the credible common mode contingency of two adjacent circuits on separate towers. The credibility of such an outage depends upon the credibility of the common mode failure. The credible outrage of two circuits could result from a lightning storm or forest fire. Considerations in the determination of credibility should include line design; length; location, whether forested, agricultural, mountainous, etc.; outage history; operational guidelines; and separation between circuits.[1]

A process has been established to evaluate situations on a case-by-case basis to determine if a higher or lower standard is applicable. Contingencies with an estimated Mean Time Between Failure (MTBF) of greater than 300 years are not held to the standard of "no cascading." These provisions are covered in standards WSCC-S5 and WSCC-S6.

WSCC-S5 For contingencies involving existing or planned facilities, the Table W-1 performance category can be adjusted based on actual or expected performance (e.g. event outage frequency and consideration of impact) after going through the WSCC Phase I Probabilistic Based Reliability Criteria (PBRC) Performance Category Evaluation (PEC) Process.[1]

WSCC-S6 Any contingency adjusted to Category D must not result in a cascading outage unless the MTBF is greater than 300 years (frequency less than 0.0033 outages/year) or the initiating disturbances and corresponding impacts are confined to either a radial system or a local network.[1]

Line Spacing Requirements

There is not any single criteria or rule that establishes minimum circuit spacing requirements to qualify as very low likelihood (not credible) because the importance of various risk factors is not the same in all cases. However, cases within WSCC of minimum separation of 2,000 feet have been accepted as not credible. The following list represents risks that are mitigated by line separation. To the extent that these can be mitigated by design or maintenance measures, the need for separation may be reduced.

1. One tower falling into an adjacent line;
2. A snagged shield wire from one line being dragged into the adjacent line (span length);
3. An aircraft flying into more than one circuit;

4. Fire on the right-of-way or smoke (ionized particles) enveloping more than one circuit causing temporary failure; and
5. Lightning strokes affecting more than one line.

The risk of lightning-caused events can be mitigated by the use of shield wires (a target instead of the energized conductors), and by modifying protective control circuits (relaying).

Risks 1 through 3 are generally mitigated by increased spacing between lines. Some organizations use separation by more than the span length as adequate to designate the circuits as being in separate corridors.[2,3] Span lengths for 500-kV lines are typically 1,000 to 1,500 feet, depending on terrain.

The risk of fire or smoke affecting two lines can be managed by right-of-way maintenance practices and notification procedures. Increased spacing reduces the risk that multiple circuits will be affected and increases time for notification and corrective dispatcher action. Terrain is important in terms of the amount and volatility of combustible materials.

When Is Corridor Separation Needed?

As noted, the NERC/WSCC Planning Standards make allowance for mitigating action for multi-contingency outages affecting lines on the same right-of-way. However, it is BPA and general utility practice that two-line outages should *not* rely on interruption of customer load except for very unusual operating conditions such as adverse cold weather or a weakened transmission system. Generator tripping may be used as a countermeasure in some cases for two-line outages but it also becomes objectionable if the requirements are excessive or impractical.

Summary - As a matter of practice, construction on separate rights-of-way is necessary when a multi-circuit outage on a common corridor must be considered a credible event and corrective action for this outage would require excessive or impractical countermeasures.

Risk Considerations

Historical data over a 15-year period for the BPA system has been analyzed according to cause for overlapping outages of lines on the same corridor. This information for 125 events across 6,636 corridor miles is illustrated in Table 1.

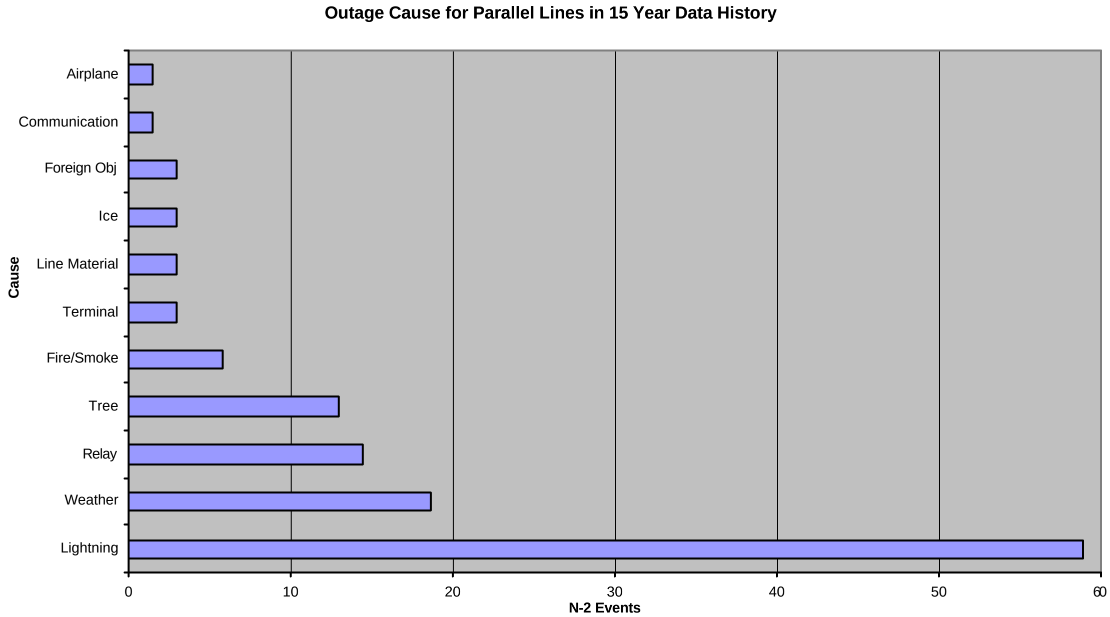

Table 1. Summary of overlapping outages on common corridor by cause. Unknown events are distributed pro-rata to other causes.

The line proximity-related risk elements are: airplane, foreign object, ice, line material, fire/smoke, tree, weather, and lightning. The outage rate of a two-line outage between Schultz and Vantage may be estimated by normalizing the line-related outage components to 35 miles and normalizing the terminal-related components to one terminal pair (Schultz) relative to just over 1,000 terminal pairs in the database. This results in an expected outage Mean Time Between Failure (MTBF) of about 28 years, which is insufficient to meet the WECC standard of 300 years.

While there is not a sufficient database to accurately quantify the effect of separation distance on the outage rate of two parallel lines, separation of lines by a distance corresponding to the average span length or more significantly reduces the risk factors due to a common mode event. In such cases it is assumed that the outage risk is limited to that of terminal-related causes. WECC has not required planning for outage of both lines when separated except on an exploratory basis.

Experience has borne out the benefit of separation in the case of the 148-mile Captain Jack – Olinda 500-kV line, which was built with a separation of more than one span length from the Malin-Round Mountain 1&2 500-kV lines, which had in the past experienced numerous two-line outage events, some with serious system consequences. Since energization of the Captain Jack-Olinda line in 1993 there has not been a single case of simultaneous outage of all three lines, notwithstanding a number of outages of the 95-mile Malin-Round Mountain 1&2 500-kV lines.

Cases considered in applying separation to the Captain Jack – Olinda line [2] include:

- Aircraft causing simultaneous outage of two 500-kV circuits, three 230-kV circuits, and a 66-kV circuit on September 13, 1973;
- Sabotage and/or vandalism incidents involving the bulk power system;
- Numerous simultaneous overlapping outages of adjacent lines caused by smoke or fire;
- Lightning strike on one line creating voltage fluctuations on the adjacent line to cause sympathetic arc-over of adjacent circuits (example of May 1, 1979 on the Malin-Round Mountain lines); and
- Wind and ice events occurring in various situations.

Similar justification was used as a basis for plans to construct the Los Banos – Gates 500-kV line (also in California) with separation of approximately 2000 feet from the existing 500 kV lines [3]. This reference cites a case where more than 5 million customers in five western and southwestern states were affected by outages associated with gale force winds when a 500-kV tower fell laterally into a tower on an adjacent 500-kV line.

Attachment 1 identifies risk factors, design variables, and mitigation that can be considered to increase system reliability.

References:

[1] NERC/WSCC Planning Standards, Board of Trustees Approved April 18, 2002, available from the WECC web page at: www.wecc.biz/documents/standards/recently_approved_standards.html

[2] Corridor Separation for the California-Oregon Transmission Project, California Oregon Transmission Project Power System Studies Committee Report, October 1985, pages 10-12.

[3] Los Banos – Gates Environmental Report and Technical Appendices, September 1996, page 2-3 through 2-5.

Attachment 1 Robust Line Design Features

Background

With more demands for use of land there is increasing difficulty in opening up new rights-of-way (ROW) for transmission. At the same time it is essential that the transmission system be developed from the standpoint of ensuring adequate system reliability. Accordingly, objective guidelines are needed for making decisions affecting these factors. This policy addresses design and planning considerations in relationship to risk of common mode multiple-line outages with the goal of improving expectations of what can be expected in terms of line outage performance and complementing probabilistic methods.

Risk Factors

The following is a list of risk factors to be considered in ROW planning for cases where it is the goal that the N-2 outage be of very low probability. Generally risk increases with common ROW distance.

R1 Risk of fire affecting both lines
R2 Risk of one tower falling into another line
R3 Risk of a conductor from one line being dragged into another line
R4 Risk of lightning strikes tripping both lines
R5 Risk of an aircraft flying into both lines
R6 Risk of station-related problems resulting in loss of two lines for a single event
R7 Risk of snow or earth slides
R8 Risk of loss of two lines due to an overhead crossing

Design Variables

The following are design variables that affect the credibility of each of the above Risk Factors:

V1 Substation breaker configuration (R6)
V2 Circuit centerline spacing (R1, R2, R3, R8)
V3 Span length (R3)
V4 Tower design (R2, R7, R8)
V5 Use of shield wires for lightning (R4)
V6 Conductor support systems (R8)
V7 Use of deadend versus suspension towers (R3)
V8 Use of single pole reclosing (R4)
V9 Vegetation management (R1)

V10 Fire watch curtailments (R1)
V11 Shortening of line on common ROW (R1 through R8)
V12 Tower grounding (R4)
V13 Protective relaying design and settings (R6)

Example Mitigation

The following guidelines are based on either eliminating the risk of each factor or reducing its risk such that the combined MTBF is maximized, enabling upgrading of case classification.

Centerline Spacing (elimination of risk)
Lines separated by more than the height of the adjacent tower structure where fire exposure risk is minimal and the ROW is not in an area of expected air traffic. Wider separation of 1,000 to 2,000 feet in areas where dry fuels would be present to support a fire affecting both lines before it could be detected and loading reduced.

Line Crossings (elimination of risk)
Use of robust tower and conductor support systems of overhead line.
Spacing of lines by more than one span length in cases where dropping of a conductor is a credible risk.
Overhead line cannot cascade into crossing.

Substation Configuration (elimination of risk)
Substations configured such that a fault on one line followed by breaker failure will not result in a loss of the parallel line.

Locational Hazards (elimination of risk)
In areas where risk is increased due to locational hazards, the centerline spacing is increased.
Proximity to flight traffic pattern (increase centerline spacing to not less than one span length).
Proximity to slide areas (increase centerline spacing to be clear of slide area).

Vegetation Management (elimination of risk)
Procedures in place for increased vegetation management in areas where accumulation of combustible fuel could result in line tripping in less than 30 minutes from initiation of a fire.
Operational procedures in place which can allow reporting of fire and reduction of transfer levels within 30 minutes.

Lightning Mitigation (reduction of risk)
Use of overhead shield wires to minimize risk of loss of two lines due to lightning.
Single-pole reclosing to minimize risk of loss of both lines due to a strike affecting both circuits.
Estimate MTBF from typical area statistics:

- Probability of common mode lightning event/year/mile with and without shield wire.
- Probability of common mode event resulting in three-pole trip of both circuits with/without SPR.

Protective Relaying (elimination of risk)
Certification that settings and design are such that a single-fault condition will not result in loss of more than one parallel line.

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