OVERHEAD DESIGN MANUAL

Section 1 – Line Design Overview

Approved by: F. Zaini
OVERHEAD DESIGN MANUAL

SECTION 1 LINE DESIGN OVERVIEW

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DESIGN CONSIDERATIONS AND LOAD CASES

At distribution voltages, overhead line design tends to consist of both simple structural engineering and electrical engineering. The two main technical aspects to the design of overhead distribution lines are:

1. ensuring that the mechanical load forces do not exceed the strength of the structures or other components, and

2. ensuring that there are adequate clearances—between the conductors and the ground or from other objects in the vicinity of the line, as well as between the various phase conductors and circuits themselves so that clashing does not occur.

The line must comply with these requirements over the full design range of weather and load conditions that could be reasonably encountered—when the line is cold and taut, when at its maximum design temperature and consequently when conductor sag is at a maximum, and under maximum wind conditions. The load conditions to be considered for Energex lines are set out in the following sections, where applicable wind pressures, temperatures and load factors are listed.

LIMIT STATES

For structural integrity to be maintained the structure strength must always exceed the applied mechanical load, otherwise the line passes beyond the limit of its intact state to a damaged state or failed state. Also, the loads should not cause the line to become unserviceable in some way, e.g. if loads caused excessive deflection of a structure, causing clearances to be reduced below their design limits, or conductors are deformed by excessive loading though not actually broken.

<table>
<thead>
<tr>
<th>INTACT STATE</th>
<th>DAMAGED STATE</th>
<th>FAILED STATE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Serviceability Limit</strong></td>
<td><strong>Ultimate Strength Limit</strong></td>
<td></td>
</tr>
</tbody>
</table>

This may be expressed by the following general limit state equation:

\[ \phi R_n > \text{effect of loads} (\gamma, W_n + \sum \gamma, X) \]

(i.e. strength > applied loading)

where:

- \( \phi \) = the strength factor, which takes into account variability of the material, workmanship, maintenance regime etc.
- \( R_n \) = the nominal strength of the component
- \( \gamma_x \) = the load factor, taking into account the variability of the load, importance of structure, dynamics etc.
- \( W_n \) = wind load
- \( X \) = the applied loads pertinent to each loading condition

In limit state design, strength factors and load factors take into account statistical variations in loads and material properties to achieve a desired level of reliability.
Thus, the **Strength Limit** equation used within Energex, which pertains to loading under short-term (3s) wind gusts, with the appropriate load factors applied, may be expressed as follows:

\[ \phi R_n > 1.0 W_n + 1.1 G_s + 1.25 G_c + 1.25F_{tw} \]

where:

\[ \begin{align*}
W_n &= \text{effect of wind load on structure} \\
G_s &= \text{vertical downloads due to the self weight of structure + fittings} \\
G_c &= \text{vertical downloads due to conductors} \\
F_{tw} &= \text{conductor tension loads under maximum wind conditions}
\end{align*} \]

(G indicates loads due to action of gravity; \( W \) indicates loads due to action of wind.)

Note that the limit state equation is not a simple arithmetic equation. The loads include various vector components—vertical, horizontal longitudinal and horizontal transverse. However, for simple distribution lines, downloads are often relatively minor and are not a significant contribution to an overturning moment on the pole, so are often ignored. Note, too, that the structure components have different strengths in different directions and under different actions, e.g. compression, tension, shear or torsion.

Apart from the Maximum Wind Strength Limit, Energex commonly also requires checking of the **Everyday Limit**, which addresses the effect of sustained (no wind) loading, primarily due to conductor everyday tension. This is particularly appropriate with timber and composite fibre components, which may deflect or deform under a sustained load. This limit state, with appropriate load factors applied, may be expressed as:

\[ \phi R_n > 1.1 G_s + 1.25 G_c + 1.1F_{te} \]

where:

\[ F_{te} = \text{conductor tension loads under everyday (no wind) conditions} \]

This limit state approach to overhead design has been used widely in Australia since 1999. It is a rationalisation of the earlier working stress method, which applied a general factor of safety that was somewhat arbitrary in its derivation. Limit state design uses higher, more realistic wind loads (aligned with AS/NZS 1170 wind code), and material strength factors more closely aligned with reliability of performance. It takes a reliability-based (acceptable risk of failure) approach. Based on this approach, Energex applies an Average Recurrence Interval (ARI) of 50 years to determine design wind pressures for normal distribution lines.

The following sections present design wind loads, load factors, strength factors and design temperatures to be used for various situations and load cases.

**AS/NZS 7000:2010** also sets out other limit states that designers may need to check where relevant, such as:

- failure containment or broken wire condition (where one phase conductor breaks on one side of a strain point, so that the loads applied are then out of balance)
- maintenance and construction loading
- snow and ice loading
- seismic loading
- torsional loading
- maximum wind uplift.

**PRACTICAL APPLICATION OF LIMIT STATE EQUATIONS**

This manual presents tables of pole strengths in section 2. Mechanical loads applied by conductors are presented in section 6. These tables already incorporate the various load and component strength factors. This allows designers to easily compare loads with strength in order to check pole sizing and the need for stays.
LOAD FACTORS

<table>
<thead>
<tr>
<th>LOAD CASE</th>
<th>HORIZONTAL CONDUCTOR FORCES</th>
<th>WIND LOAD ON STRUCTURE</th>
<th>VERTICAL LOADS</th>
<th>CONDUCTORS</th>
<th>STRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Wind</td>
<td>$F_t$</td>
<td>$W_n$</td>
<td>$G_c$</td>
<td>1.25</td>
<td>1.1</td>
</tr>
<tr>
<td>Wind</td>
<td>1.25</td>
<td>1.0</td>
<td>1.25</td>
<td>1.1</td>
<td></td>
</tr>
</tbody>
</table>

Refer AS/NZS 7000:2010 Table 7.3 for additional details.

DESIGN WIND PRESSURES

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>DESIGN PRESSURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductors</td>
<td>900Pa</td>
</tr>
<tr>
<td>Round Poles</td>
<td>1300Pa</td>
</tr>
<tr>
<td>Flat Surfaces (Projected Area)</td>
<td>1500Pa</td>
</tr>
</tbody>
</table>

Notes

1. Wind pressures are generally based upon synoptic wind events since the entire Energex franchise area lies within 'coastal' zone - Refer AS/NZS 7000:2010 Appendix B and AS/NZS 1170.2 for additional details. Refer also Handbook to AS/NZS 7000 HB 331:2012 Table 7.1.
2. In general, span reduction factors are not used within Energex distribution design for the sake of simplicity. However, their use may be warranted for very large spans, say in excess of 200m.
3. The above wind pressures correspond to a wind speed of 139km/h. The various pressures listed are due to the different drag coefficients of the various components.
## COMPONENT STRENGTH FACTORS

### PART OF OVERHEAD LINE

#### COMPONENT

<table>
<thead>
<tr>
<th>PART OF OVERHEAD LINE</th>
<th>COMPONENT</th>
<th>LIMIT STATE</th>
<th>STRENGTH FACTOR ( \phi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood structures preserved by full length treatment</td>
<td>Pole</td>
<td>Strength</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>Serviceability</td>
<td>0.4*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crossarm</td>
<td>Strength</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>Serviceability</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Wood structures not preserved by full length treatment</td>
<td>Pole</td>
<td>Strength</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Serviceability</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crossarm</td>
<td>Strength</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Serviceability</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Concrete structures</td>
<td>Pole</td>
<td>Strength</td>
<td>0.9 (1.0*)</td>
</tr>
<tr>
<td>Steel structures</td>
<td>Pole or crossarm</td>
<td>Strength</td>
<td>0.9</td>
</tr>
<tr>
<td>Composite Fibre Structures</td>
<td>Pole or crossarm</td>
<td>Strength</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Serviceability</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Stays</td>
<td>Cable</td>
<td>Strength</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>Cable members</td>
<td>Strength</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>Anchors</td>
<td>Strength</td>
<td>0.50</td>
</tr>
<tr>
<td>Conductors</td>
<td></td>
<td>Strength</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td>Serviceability</td>
<td>0.50</td>
<td></td>
</tr>
</tbody>
</table>

* 1.0 can be used for the Energex standard range of Rocla Reinforced poles
* 0.4* Refer Sheet 2-12-1 for more detail on Pole Serviceability factors used in Energex

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### PART OF OVERHEAD LINE

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>LIMIT STATE</th>
<th>STRENGTH FACTOR ( \phi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fittings and pins—forged or fabricated</td>
<td>Strength</td>
<td>0.95</td>
</tr>
<tr>
<td>Fittings—cast</td>
<td>Strength</td>
<td>0.90</td>
</tr>
<tr>
<td>Fasteners</td>
<td>Bolts, nuts, washers</td>
<td>Strength</td>
</tr>
<tr>
<td>Porcelain or glass insulators</td>
<td>Strength</td>
<td>0.95</td>
</tr>
<tr>
<td>Synthetic composite suspension or strain insulators</td>
<td>Strength</td>
<td>0.5</td>
</tr>
<tr>
<td>Synthetic composite line post insulators</td>
<td>Strength</td>
<td>0.9 (max. design cantilever load)</td>
</tr>
<tr>
<td>Foundations relying on strength of soil—conventional soil testing</td>
<td>Strength</td>
<td>0.6</td>
</tr>
<tr>
<td>Foundations relying on strength of soil—empirical assessment of soil</td>
<td>Strength</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Notes**

1. Refer AS/NZS7000:2010 Table 6.2 for additional details.
2. Serviceability limit – 'No Wind' Condition.
   Strength limit – 'Wind' Condition.
**LINE TEMPERATURE CASES**

<table>
<thead>
<tr>
<th>SITUATION</th>
<th>TEMP</th>
<th>WHEN USED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard (Reference) Temperature</td>
<td>15°C</td>
<td>Reference temperature for conductor stringing tables</td>
</tr>
<tr>
<td>Max. Design Temp. (Hot)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Bare Mains (see Note 1)</td>
<td>75°C</td>
<td>Checking clearance from ground or objects below the line</td>
</tr>
<tr>
<td>LVABC, CCT</td>
<td>80°C</td>
<td></td>
</tr>
<tr>
<td>HVABC (catenary)</td>
<td>50°C</td>
<td></td>
</tr>
<tr>
<td>New 33kV Line</td>
<td>110°C</td>
<td></td>
</tr>
<tr>
<td>OHEW, OPGW</td>
<td>40°C</td>
<td></td>
</tr>
<tr>
<td>PILOT, ADSS, BBCC</td>
<td>40°C</td>
<td></td>
</tr>
<tr>
<td>Min. Temp. (Cold)</td>
<td>5°C</td>
<td>Checking clearance from objects above the line</td>
</tr>
<tr>
<td>Uplift</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard</td>
<td>5°C</td>
<td>Checking for uplift forces, esp. on intermediate structures</td>
</tr>
<tr>
<td>Western Areas</td>
<td>0°C</td>
<td></td>
</tr>
<tr>
<td>Subcircuit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below standard bare or insulated mains (Winter Night Rating)</td>
<td>15°C</td>
<td>Checking intercircuit clearance—hot supercircuit above and cool subcircuit below</td>
</tr>
<tr>
<td>Below new 33kV line designed for 110°C operation (Summer Day Rating)</td>
<td>35°C</td>
<td></td>
</tr>
</tbody>
</table>

**Notes**

1. Many older lines were designed to lower temperatures, commonly 55°C.
2. See also Section 1.6 sheet 7.

**SITUATION** | **TEMP** | **WHEN USED** |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Blowout</td>
<td>30°C</td>
<td>Checking horizontal line displacement (sideways ‘sag’) under 500Pa wind force</td>
</tr>
<tr>
<td>No Wind’ Load Condition</td>
<td>15°C</td>
<td>Calculating sustained loads</td>
</tr>
<tr>
<td>’Wind’ Load Condition</td>
<td>15°C</td>
<td>Calculating loads under maximum wind condition</td>
</tr>
<tr>
<td>Midspan Conductor Clearances</td>
<td>50°C</td>
<td>Checking interphase conductor spacing to avoid clashing</td>
</tr>
</tbody>
</table>

**Notes**

1. Many older lines were designed to lower temperatures, commonly 55°C.
2. See also Section 1.6 sheet 7.
OVERVIEW OF DISTRIBUTION LINE DESIGN PROCESS

In general, design of an overhead line follows the steps shown opposite (with variations as necessary to suit the design).

It should be noted that the process is iterative, i.e. the designer may make some initial assumptions, e.g. as to pole height and size, which may later need to be amended as the design is checked and gradually refined. Various options will be tried until a final optimum arrangement is formulated.
1. **DETERMINE DESIGN INPUTS/PARAMETERS**

Assemble all relevant requirements, constraints and background information, such as:

- customer requirements
- planning requirements
- existing and proposed schematics
- future development
- statutory authority (e.g., local authority, main roads, railways, waterways, environmental) requirements regarding alignments, types of construction and clearances
- coordination with other services
- integration with lighting design
- survey/site information
- maps.

This information should be placed on file or documented in an appropriate manner.

2. **SELECT ROUTE**

When selecting the route of the overhead line, factors to be considered include:

- cost – generally the shorter the route the cheaper it will be
- access to line and poles
- servicing lots/properties, present and future
- disruption to environment, vegetation or other services
- community acceptance
- obtaining approvals
- requirement for easements – lines on public lands are preferred
- ease of excavation for pole foundations.

3. **SELECT CONDUCTOR**

Conductor selection should be carried out in accordance with Section 9.2 'Cable Selection Guidelines', planning requirements and any other applicable ENERGEX standards. Factors to be considered include:

- voltage
- whether the line is a main 'trunk' or a 'spur'
- load (present and future) – current-carrying capacity, voltage drop, losses
- fault levels and protection
- local conditions – pollution, fires, vegetation
- line design temperature
- stringing tension.

4. **SURVEY & DRAW GROUND LINE PROFILE**

Line profiling is often necessary for lines traversing uneven ground. Where ground is flat or evenly sloping, profiling may not be necessary. The designer may be able to check ground clearances by simply deducting the sag in the longest span from the average height of the supports at either end.

Other reasons for line profiling include:

- checking clearances from structures such as ‘skip’ poles or street lights
- checking ground clearances where the heights of the two supports for a conductor span differ markedly
- determining inter-circuit clearances on long multi-circuit spans (king bolt spacings may need to be adjusted), typically >100m
- checking for uplift forces on structures
- determining vegetation clearing requirements.
The ground line profile is plotted from survey data for the line route, typically using the following scales:

- Horizontal: 1:1000 (1mm = 1m)
- Vertical: 1:200 (5mm = 1m)

The survey data may consist of distance and slope measurements for various segments of ground, between which the ground is assumed to slope evenly. These should be converted to distance (chainage) and RL (reduced level) measurements, to facilitate plotting.

\[
HD = SD \cos \theta \\
\approx SD \quad \text{if} \quad \theta < 10^\circ \\
VD = SD \sin \theta
\]

where:
- \(SD\) = Slope Distance
- \(VD\) = Vertical Distance
- \(HD\) = Horizontal Distance

The GL Offset allows the designer to check that conductors do not sag below the minimum vertical clearance. (An alternative approach is to reduce pole heights by the required vertical ground clearance.)

5. SELECT STRUCTURE & POLE-TOP CONSTRUCTION TYPE

Refer to ‘Pole Selection Guidelines’ and ‘Poletop Constructions’, Selection Guidelines’.

Factors to be considered include:
- voltage(s)
- number of circuits
- requirement for an overhead earth wire
- subcircuits such as pilot cable or BBCC
- vegetation and other local conditions
- magnitude of mechanical loads – depends on span lengths and stringing tensions
- required spanning capability.

6. SELECT STRINGING TENSION AND BASIC SPAN LENGTH

In general, the number of poles should be kept to a minimum. When span lengths are long, greater conductor stringing tensions must be used so that adequate ground clearance is maintained, or additional pole height is required.

However, if the spans are too long, mechanical forces on the structures will be excessive, and there may be inadequate spacing between phase conductors.
Gaining the balance between these two requirements is the art of optimal line design, as illustrated below:

(a) TENSION TOO TIGHT (High mechanical forces)

(b) TENSION TOO SLACK (Too many structures)

(c) TENSION JUST RIGHT

Lines in rural locations tend to use longer spans, typically over 100m.

However, in urban areas, shorter spans tend to be used due to:
- the requirement to service smaller lots – poles need to be positioned at points from which services will emanate
- the requirement to support public lighting
- the need to keep structures compact and less visually obtrusive
- the need to keep stays on poles to a minimum
- use of larger conductor sizes to supply higher load density
- increased number of circuits, including communications cables.

As a general guide, the table below shows basic span lengths for various standard stringing tables.

<table>
<thead>
<tr>
<th>Stringing Table</th>
<th>Typical Basic Span Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>T42</td>
<td>250m</td>
</tr>
<tr>
<td>T65</td>
<td>200m</td>
</tr>
<tr>
<td>T110</td>
<td>150m</td>
</tr>
<tr>
<td>T220</td>
<td>100m</td>
</tr>
<tr>
<td>T440</td>
<td>70m</td>
</tr>
<tr>
<td>T660</td>
<td>50m</td>
</tr>
<tr>
<td>T880</td>
<td>35m</td>
</tr>
</tbody>
</table>

The span lengths and tensions used will need to suit the pole-top constructions used – refer ‘Poletop Constructions’ Layout Guides.

Subcircuits should not be strung tighter than supercircuits.

2:1 Rule

In general, the longest span within a strain section should not be more than double the length of the shortest span. This rule can be relaxed where:
- conductors are strung at T440 or slacker, or
- suspension structures of 11SU, 11SUA or 11SUAAH are used.

Nonetheless, no span in the strain section should be longer than double the MES or shorter than half the MES.

7. NOMINATE POLE POSITIONS

In urban areas, poles are generally positioned on the roadway in line with alternate lot boundaries in order to service each property without service lines crossing adjacent properties.

Positioning poles close to gates, driveways, large trees or in a way that obstructs views from houses should be avoided.
It is often preferable to position the poles on the side of the road with the greatest number of lots so as to keep the number of cross-road services to a minimum.

Public lighting requirements may also influence pole positions.

In general, straight lines are preferable to lines with numerous deviation angles, both aesthetically and due to minimising forces on structures. Avoid switching sides of the road more often than is necessary, as phase transpositions on LV lines will be required (if there are two or more successive poles on the opposite side).

Span lengths should be similar within a strain section. Remember the 2:1 rule mentioned on the previous page. All span lengths should be compatible with the stringing tension and pole-top constructions employed (refer ‘PoleTop Constructions’ and ‘Stringing Tables’).

Where practical poles should not be located where they are likely to impede the vision of motorists or where they are likely to be struck by errant vehicles, e.g. on a sharp corner, or the outside radius of a curve.

Adequate space should be available for stays fitted to poles.

Avoid locations where:
- access is difficult (eg steep embankments, heavily-vegetated areas, or down narrow laneways)
- pole foundations will be poor (eg swampy ground, open drains, irrigation or flood-prone areas, loose sand)
- excavation is difficult (eg rocky ridges, bedrock or shale close to surface, numerous or sensitive underground services).

For a line over undulating ground, avoid placing poles at the bottom of a dip, as uplift will likely occur. Poles are best placed on the shoulders either side of a gully.

Whenever pole positions are altered, you will need to recalculate the MES.

8. NOMINATE STRAIN POINTS, POLE HEIGHTS AND CIRCUIT ATTACHMENT HEIGHTS

Strain points, or shackles are placed in a line at typically every 5th to 10th pole. Factors influencing the placement of shackles include:
- creating manageable sections of line for construction or repair crews – strain sections should not be longer than can be erected and tensioned by an average crew in a day.
- length of cable on drum – typ. 1200m for bare mains
- keeping all spans within the strain section of similar length
- isolating critical spans, eg across a highway, railway, or creek, or spans that are prone to damage, from the rest of the line
- providing points for electrical isolation (by breaking bridges, or where temporary ABSs may be installed by live line crews)
- accommodating large deviation angles
- avoiding uplift.

For general guidelines on pole sizing, refer ‘Poles’; concrete and wood pole data.

The heights nominated for poles will depend upon factors such as:
- the number of circuits supported
- the area traversed – clearances vary for road crossings, footpaths, non-trafficable areas etc
- mounting heights of public lighting, pole-mounted plant or other attachments.

For standard king bolt spacing refer ‘Clearances’ and ‘PoleTop Constructions’. Increased spacings may be required for long spans, as determined by profiling of the line.

Remember that conductor heights may be different from kingbolt heights. On pin constructions, the conductors are above the king bolt; on suspension constructions, they are below. The mimic diagrams in Section 4 ‘Poletop Constructions’ provide dimensions.
9. **DRAW CIRCUIT PROFILE**

The conductor profile may be drawn manually by using a boomerang-shaped template, or by plotting points on the catenary curve.

9.1 **Supports**

Poles are drawn to scale on the profile, with marks placed at the support points for each circuit.

The conductor profile is drawn for each circuit, linking the two support points.

9.2 **Conductor Temperatures for Profiling**

Conductor sag depends upon conductor temperature. Various temperatures are used for different purposes, as tabulated to the right.

For a standard new HV super circuit + LV subcircuit open-wire line, we would draw profiles for both Winter Night and Summer Day conditions:

For HV feeders with an overhead earthwire, intercircuit spacing should be checked with both circuits at 40°C.

See in Section 5 for required design clearances.

**Old Design Ratings.**

For reference only to determine thermal ratings of existing circuits. All new construction is to be designed to the standards on the table to the right.

- 55"A" Superct / Subcct 55/15°C
- 75"A" Superct / Subcct 75/15°C
- 55"B" Superct / Subcct - Winter night 55/15°C, Summer Day 90/35°C
- 75"B" Superct / Subcct - Winter night 75/15°C, Summer Day 110/35°C

**Check for Uplift**

| Western Areas | 0°C |

**Check for Clearance to Ground and Fixed Objects**

| 33kV Open Wire | 110°C |
| 11kV & LV Open Wire | 75°C |
| LVABC & 11kV CCT | 80°C |
| Communications Cables (Pilot, BBCC etc) | 55°C |
| HVABC (catenary) | 50°C |

**Check for both Winter Night and Summer Day conditions**

**Winter Night Supercircuit**

| 33kV Open Wire | 75°C |
| 11kV Open Wire | 75°C |
| 11kV CCT | 60°C |
| HVABC (catenary) | 25°C |

**Winter Night Subcircuit**

| 15°C |

**Summer Day Supercircuit**

| 33kV Open Wire | 110°C |
| 11kV Open Wire | 75°C |
| 11kV CCT | 80°C |
| HVABC (catenary) | 50°C |

**Summer Day Subcircuit**

| 35°C |
9.3 Drawing a Circuit Profile Using a Sag Template

Although profiling is generally done with computer software nowadays, the approach shown below is one using a sag template and well illustrates design principles. A sag template is made from a transparent material and is designed to overlay the ground line profile already drawn. The template is positioned to link the two support points for the circuit.

The top edge is used for drawing a cold (or cool) condition curve and the bottom edge for the hot condition.

The template is asymmetrical to allow for undulating terrain or dissimilar heights at the ends of the span. Being transparent, it is reversible and may be oriented with the high side to either the left or the right.

The template has horizontal and vertical scales that must match those used to draw the ground profile. The datum lines or scales on the template must be aligned with the grid of the graph paper, i.e. tilting the template will produce error.

The vertical datum or scale must lie between the two support points. If this is not the case, then an uplift condition may exist.

Be sure that you have selected the correct template, one that:
- applies to the type of conductor being profiled – different templates should be used for AAC, Copper, LVABC etc.
- has the correct stringing table
- has the correct MES range for the line – i.e. the strain section MES should not be significantly below or above the template MES
- has scales that match the ground profile
- has the correct hot and cold/cool temperatures.

For constructions in which the phase conductors are at different heights, e.g. vertical delta, vertical or wishbone, it may be necessary to profile both upper and lower phases within the circuit.

Templates may be constructed using the procedure used for plotting a circuit profile, as described in the next sub-section. The plot may be photocopied onto an acetate sheet, which is then cut to produce a template. Be sure to mark/label the template with:
- type/class of conductor, e.g. AAC
- stringing table, e.g. T220
- datum lines
- scales, e.g. 1:1000 hor. & 1:200 vert.
- curve temperatures e.g. 5°C and 75°C
- MES used for calculation, project name, if applicable.
9.4 **Plotting a Circuit Profile**

The profile of an overhead conductor span is the shape of a catenary. For practical purposes on distribution lines, this shape may be approximated by a parabola. (For sags less than 9% of span length, the difference between the catenary and the parabola is less than 1%.)

The relationship between span and sag is illustrated below.

![Diagram showing support at same level and different level with sag and span percentages](image)

Where the difference between support point heights is not too great, the circuit profile may be plotted directly onto the ground profile using this technique. However, where significant height difference exists between the ends of the span, a template should be constructed and used as described in subsection 9.3.

10. **CHECK VERTICAL CLEARANCES**

The profile is checked (refer 'Clearances'), to ensure that:
- the circuit profile does not cross below the GL Offset line
- that adequate clearances are maintained between supercircuits and sub-circuits
- all vertical clearances are maintained from structures and other services.

Where ground clearances are inadequate, the designer may need to consider:
- increasing pole height, or
- reducing span lengths, or
- increasing stringing tension.

Where intercircuit clearances are inadequate, the designer may need to:
- increase king bolt spacing, or
- alter type of construction, or
- reduce span lengths, or
- increase tension in top circuit, or
- decrease tension in bottom circuit.
11. CHECK FOR UPLIFT

An upward force may be exerted on a structure under cold conditions when mains are tight. While this may be tolerable for a strain (shackle) construction, it is unacceptable for pin, angle or suspension constructions.

The check for uplift is made by ensuring that the low point of the 5°C circuit profile is always between the support structures, as illustrated below.

![Diagram of uplift check](image)

Uplift problems can also be avoided by:
- selection of suitable pole positions
- selective use of increased height poles
- use of moderate stringing tensions
- shackling the mains where uplift is unavoidable.

12. CHECK HORIZONTAL CLEARANCES

A check should be made to ensure that there are adequate horizontal clearances between the line and buildings, streetlight columns, embankments, etc, (refer ‘Clearances’).

Also, the designer should ensure that the easement or footpath has sufficient width to avoid the line entering private property under wind conditions.

Blowout is essentially horizontal sag in a conductor due to wind forces. It is sometimes greater than sag in a span, since wind forces on the conductor may be greater than gravitational force. Values of blowout for different conductors under various stringing tensions are tabulated in section 7.

The blowout at any point along a span may be calculated using the values for a parabola given in subsection 9.4 above.
A plan view of the circuit may be drawn. At the midpoint of each span, a line equal to the blowout for the span is drawn at right angles to the centreline. A parabola may be then be plotted for the span, as illustrated below.

Where horizontal clearances are inadequate, the designer may need to consider:
- increasing stringing tension, or
- altering type of construction, e.g., vertical instead of flat, or
- using insulated conductors
- reducing span length
- relocating poles.

13. CHECK STRUCTURE CAPACITY MATCHES MECHANICAL LOADS

The mechanical forces on each pole should be checked and compared with pole strengths (refer ‘Poles’ and ‘Mechanical Loads’). Special attention should be paid to deviation angle and termination poles. For in-line intermediate poles, it is normally only necessary to check the pole with the greatest wind span.

Where the mechanical load exceeds pole strength the designer should consider:
- increasing pole strength rating, or
- backstaying the pole, or
- reducing stringing tension, or
- using a concrete pole.

14. NOMINATE FITTINGS AND OTHER REQUIREMENTS

The designer needs to nominate appropriate:
- shackle (strain point) locations
- bridging (refer ‘Poletop Constructions’)
- clamps and connectors (sized to suit conductor and bridging wire sizes, correct metal to avoid corrosion between dissimilar metals) – Refer Overhead Construction Manual Section 8
- sleeves, splices, helical terminations as applicable – Refer Overhead Construction Manual Section 8
- insulator types (refer ‘Poletop Constructions’)
- anti-vibration and vibration protection measures (refer ‘Poletop Constructions’)
- lightning protection, as applicable
- earthing (refer ‘Earthing’)
- vegetation clearing requirements (refer WCS 1.6).

15. MODIFY DESIGN AS REQUIRED

Frequently it will be necessary to modify the design as it progresses so as to:
- meet engineering requirements such as clearances, structural soundness etc
- to optimise the design, keeping costs to a minimum.

Keeping the number of structures to a minimum is important in minimising costs.
When optimising the design, ‘whole-of-life’ costs should be considered, taking into account:
- initial cost of materials
- initial cost of construction
- the expected life of the components
- operational costs
- maintenance costs
- reliability.

Consult planning staff for assistance to assess any design options equitably.

The design should be practical to construct and maintain. It should make adequate provision for future development (e.g., fitting of street lights, servicing, addition or uprating of circuit). However, designers should not make excessive provision for developments that are uncertain, many years in the future, or may be paid for at a future time by some other party.

16. DOCUMENT DESIGN

This final stage involves documenting the design as a works plan, complete with schedules.

The conductor schedule should make due allowance for inelastic stretch when nominating construction sags.

The design should be thoroughly checked using a checklist.

All relevant documentation must be placed on the design file for the project.

At this stage there will be numerous other tasks to complete, such as:
- obtaining approvals from stakeholders and relevant authorities
- establishing easements
- preparation of resource estimates
- ordering materials.
MEASURING SAG ON AN EXISTING CIRCUIT

Using a Height Stick

1. Measure conductor height at each end of the span.
2. Measure conductor height at mid-point of span (not necessarily the point where the mains are closest to the ground). Do not pull down on the conductor being measured.
3. If the ground is not level or evenly sloping, then take a sight line correction to compensate for any mid-span dip or hump, as described in steps 4 – 6.
4. Place a mark on each pole at eye level, say 1.65m.
5. From one end, sight from one eye line to the other.
6. Have an assistant stand at the midpoint of the span holding the height stick. Signal to the assistant as to the position of the sight line, and record the height.
7. The sag in the span is given by the formula:

\[
Sag = \frac{(h_1 + h_2)}{2} - h_m + (SL - 1.65)
\]

Using A Multifunction Laser EDM with Internal Inclinometer

1. Stand at a point from which the entire span can be viewed.
2. Set the instrument to read VD (vertical distance relative to instrument or eye height).
3. Measure conductor heights (relative to instrument) at supports at each end of the span.
4. Measure conductor height mid-span (relative to instrument).
5. Calculate sag by subtracting midspan height from the average of the two support heights:

\[
Sag = \frac{(VD_1 + VD_2)}{2} - VD_m
\]
A new commercial development at 107 Irvine Rd is to be supplied by a 500kV.A padmounted transformer on the consumer’s property, as shown below.

The new transformer is to be fed via an overhead extension emanating from Pole 9973 in Pearl Rd. The project planners have specified that MOON Conductor (7/4.75 AAC) be used for the 11kV extension. A 95mm² LVABC tie is also to be established between the external network and the new transformer.

Irvine Rd slopes downward from west to east, with a bridge across a small non-navigable creek.

The route of the new line has been profiled using a clinometer and trundle wheel, with distances and slopes measured shown below.

The heights of the existing pin crossarms on P9973 are 10.1m (11kV) and 8.3m (LV). The mains heights mid-span, either side of P9973, are 9.3m (11kV) and 7.2m (LV).

The pole alignment in the footpath specified by the local authority is 3.65m from the real property boundary. The soil is hard clay, except in the swampy region in the immediate vicinity of the creek.

Design the new section of overhead line.
DESIGN SOLUTION

The total route length is 155m. This is too far to cover with a single span, since LVABC has a practical spanning limit of 100m (refer 'Poletop Constructions'). Consequently, we will aim to use two spans to cover the distance. As a general rule LVABC is limited to T440. We recognize that the spans will be rather long for T440 stringing, but hope that we can use the terrain in our favour.

We need to select a position for the intermediate pole. The two possible locations are:
- in line with the western (upper) lot boundaries of Lot 105, or
- in line with the eastern (lower) lot boundary of Lot 105.

The top location seems best since:
- it is generally good practice to place poles on ridge shoulders and use a longer span over a gully
- the level of attachment of the LVABC on existing pole P9973 will be low, so we will need the shorter span on the western side.

Thus, our new extension will appear as shown below in plan view.
At station 1, ie P9973, we will need to fit terminations for the new circuits, viz 11T and LVABC/T. In order to meet the required spacings between circuits (refer ‘Clearances’) the existing LV crossarm on P9973 will require lowering. The spacings will change as shown below.

The lowering of the LV crossarm by 1.05m does not present any problems for the line in Pearl Rd. The mid-span height of the LV mains will be reduced from 7.2m to (8.3-1.05/2) = 6.675m. Note as the height is modified 1.05m at one end, only ½ of 1.05m will be achieved mid-span. The resulting mid-span height of 6.675m exceeds minimum height requirement of 5.5m. (Refer ‘Clearances’). Note that in this example KingBolt spacings have been used for profiling while in practice actual conductor heights shall be used (variations result from type of construction used refer Overhead Construction Manual).

A ground line profile is now required. Using trigonometry, we convert the measured distances and slope angles to chainage and level values, as tabulated below.

<table>
<thead>
<tr>
<th>Description</th>
<th>Distance</th>
<th>Slope</th>
<th>HD</th>
<th>VD</th>
<th>Chainage</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stn 1 P9973</td>
<td>0</td>
<td>0</td>
<td>51</td>
<td>0</td>
<td>51</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>-3°</td>
<td>40</td>
<td>-2.09</td>
<td>91</td>
<td>-2.09</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>-1°</td>
<td>18</td>
<td>-0.31</td>
<td>109</td>
<td>-2.40</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>-3°</td>
<td>21</td>
<td>-1.10</td>
<td>130</td>
<td>-3.50</td>
<td></td>
</tr>
<tr>
<td>Creek</td>
<td>11</td>
<td>0°</td>
<td>11</td>
<td>0</td>
<td>141</td>
<td>-3.50</td>
</tr>
<tr>
<td>Stn 3</td>
<td>14</td>
<td>+3°</td>
<td>25</td>
<td>+0.73</td>
<td>155</td>
<td>-2.77</td>
</tr>
</tbody>
</table>

These may be used to plot a profile with a horizontal scale of 1:1000 and a vertical scale of 1:200, as shown below.

We will draw a minimum ground clearance line parallel with the ground line. For the most part, this line shall be 5.5m above the ground line. However, near the creek where the ground is not trafficable we may reduce the clearance to 4.5m.

The existing and proposed terminations are shown below.
We shall now add the poles to the profile. We already have measured heights for station 1.

Initially, we will select a 12.5/8-14L pole for station 2. The pole at station 3 will need to be taller, and heavier since it is a termination pole with 11kV and LV underground cables terminating on it, say 14/12-22L. (Incidentally, we may need to revise these heights later if there is insufficient clearance.)

We now refer to ‘Poles’ and select suitable pole foundations and sinking depths. The soil is well-drained hard clay and provides a good foundation. Our selections are as follows:

<table>
<thead>
<tr>
<th>Station</th>
<th>Sink Depth</th>
<th>Foundation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stn 2</td>
<td>2.05m</td>
<td>NAEF (natural earth fill foundation)</td>
</tr>
<tr>
<td>Stn 3</td>
<td>2.30m</td>
<td>NAEF (natural earth fill foundation)</td>
</tr>
</tbody>
</table>

The heights of the poles out of ground shall be:

<table>
<thead>
<tr>
<th>Station</th>
<th>Height Out of Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stn 2</td>
<td>10.45m</td>
</tr>
<tr>
<td>Stn 3</td>
<td>11.70m</td>
</tr>
</tbody>
</table>

We now need to nominate constructions and calculate the heights of circuit attachment points on the poles at stations 2 and 3.

The mains may be run in a single strain section, since the two spans are not greatly dissimilar in length (cf 2:1 guideline). The MES in the new strain section is calculated as follows:

\[
MES = \sqrt{\frac{(90^3 + 65^3)}{(90 + 65)}} = 80.5m
\]

(Refer ‘Stringing Tables’)

By reference to ‘Clearances’, we obtain the values tabulated below.

<table>
<thead>
<tr>
<th>Station</th>
<th>Construction</th>
<th>KBS</th>
<th>King Bolt Height</th>
<th>Conductor Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>11TDA</td>
<td>0.15</td>
<td>10.30</td>
<td>10.30 (A, C ph)</td>
</tr>
<tr>
<td></td>
<td>LVABC/SU3</td>
<td>1.60</td>
<td>8.70</td>
<td>8.50</td>
</tr>
<tr>
<td>3</td>
<td>11T</td>
<td>0.15</td>
<td>11.55</td>
<td>11.55</td>
</tr>
<tr>
<td></td>
<td>11 UG Term.</td>
<td>1.40</td>
<td>10.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LVABC/T</td>
<td>1.80</td>
<td>8.35</td>
<td>8.35</td>
</tr>
<tr>
<td></td>
<td>LV UG Term.</td>
<td>0.15</td>
<td>8.20</td>
<td></td>
</tr>
</tbody>
</table>

We also verify that the distances and angles are within the capability of the nominated constructions by reference to layout guides in ‘Poletop Constructions’. (Note that the line deviation angle at station 2 is 4°.)

We will need to plot the circuits for the following conditions:

- 11kV 75°C Intercircuit clearance
- LV 15°C Intercircuit clearance
- LV 80°C Ground clearance-Hot condition for LVABC

Uplift is not a concern in this instance and there is no need to plot profiles at 5°C.
To plot the circuits, we will either need to:
- obtain a suitable sag template, or
- determine the sag in each span by reference to sag tables.

Assuming that we take the latter course, we are able to calculate sags as tabulated below (refer ‘Stringing Tables’).

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Stringing</th>
<th>Temperature</th>
<th>Sag 1 – 2 (65m span)</th>
<th>Sag 2 – 3 (90m span)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11kV T440</td>
<td>75°C</td>
<td>2.21m</td>
<td>4.24m</td>
<td></td>
</tr>
<tr>
<td>LV T440</td>
<td>15°C</td>
<td>1.86m</td>
<td>3.56m</td>
<td></td>
</tr>
<tr>
<td>LV T440</td>
<td>80°C</td>
<td>2.23m</td>
<td>4.29m</td>
<td></td>
</tr>
</tbody>
</table>

We are now able to draw our profile, as shown below.

Notice that the 80°C catenary curve for the LVABC falls below the ground offset clearance line. Our design is therefore unsatisfactory.

We have two options here:
- Increase pole height at station 2, or
- Increase stringing tension.

We will select the first option, as T220 is only to be used on LVABC if <150A load. Let us increase the size of the intermediate pole to 14m.

Its new sinking depth will be 2.1m, giving a tip height of 11.9m. The circuit attachment heights will increase to 11.75m (11kV) and 10.15m (LV). The revised profile is shown below.

The increase in pole height at station 2 has corrected the ground clearance problem.

We also note that intercircuit clearances are satisfactory. (The intercircuit clearances were unlikely to be a problem on such short spans, since we are using standard king bolt spacings and a lower tension on the subcircuit than the supercircuit.)
We now check horizontal clearances and blowout. We need only consider the longer span. By reference to ‘Stringing Tables’ we find blowout to be as follows:

11kV MOON T220 2.01m + 0.6m trident constr. width from centre  
LVABC95 T440 3.18m + 0.2m half pole width

We note that even with allowances for pole/construction width, the blowout is satisfactory, ie less than the 3.65m that the pole is away from the real property boundary, although there is not a lot of margin. In this case, the design is acceptable, since there are no buildings or structures in proximity to the middle of the 90m span.

We now check the tip loads on the poles, with results as shown below. (Refer to section 2.11 for information on tip load calculation)

<table>
<thead>
<tr>
<th>Station</th>
<th>No Wind</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.00kN</td>
<td>22.33kN</td>
</tr>
<tr>
<td>2</td>
<td>0.46kN</td>
<td>6.37kN</td>
</tr>
<tr>
<td>3</td>
<td>6.14kN</td>
<td>22.77kN</td>
</tr>
</tbody>
</table>

We now compare these loads with the pole strengths given in section 2.3. At station 1, the ‘Wind’ condition tip load exceeds that of the pole and staying is required. Station 2 is not overloaded. At station 3, we can manage the load if we use a 14/20-36L pole.

Since ground space is limited at station 1 by the property boundary, we will opt for a sidewalk type stay. Reference to ‘Stays’ section 3.3 indicates that with a 5° angle on the stay wire relative to vertical the stay will have a strength of 31.5kN, well above the 22.3kN load. The stay anchor will be installed 3050mm from the pole, which will be 600mm from the RP boundary, which is sufficient.

Screw anchor will be (refer ‘Stays’):
- Station 1 - single screw 200mm blade diameter, installed @ 140 bar

Since we are able to interconnect to the external LV network, and we do not anticipate any problems with earthing, we shall specify CMEN earthing for the cable termination. A common cable guard may be used for the HV and LV cables, affixed to the eastern side of the pole at station 3 opposite the direction of oncoming traffic. (The HV cable will twist around the pole for the termination on the west side.)

We will also need to specify bridging between the existing line and the new line at station 1. Referring to the Overhead Construction Manual page section 8, page 33 & 34, we specify the following bridging arrangements:

11kV: 6m x 20279 CCT, 6 x 5893 clamps  
LV: 4 x 14090 clamps

Note in both cases the mains are extended to act as bridging cables. This is a preferred practice that minimises the number of joints (which is a good thing for increased network reliability).

We are now ready to document the design as a works plan.