OVERHEAD DESIGN AND CONSTRUCTION FUNDAMENTALS

Presenter:

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TOPICS TO COVER

• AS/NZS7000 Overhead Line Design Standard
• Overhead Line Ratings
• Transmission vs Distribution
• Distribution Design Aspects
• Major line components (structures, conductors)
• Structural design (working stress and limit state)
• Impacts of Embedded Generation
• New Technology on Distribution Networks
  • Statcom LV Regulator
  • Ground Fault Neutraliser
  • Sparkless Fuses
  • S&C Intellirupter
AS/NZS 7000 OVERHEAD LINE STANDARD

• Developed by Aust Stds EL052-05 Committee
• Published 26 November 2010
• Supercedes C(b) 1 and AS/NZS4676
• Sets minimum prescriptive standards
• Suite comprises 3 parts:
  • Part 1 – Detailed Procedures
  • Part 2 – Handbook
  • Part 3 – ENA Guideline for Construction and Maintenance
AS/NZS 7000 OVERHEAD LINE STANDARD

• Limit state design principles for various line components
• Security classes and design working life
• More detailed coverage on Electrical Design and Earthing (using EG0 Risk based earthing approach)
• Covers steel lattice, steel poles, concrete poles, wood poles and crossarms
• Handbook HB331 published April 2012
• Amendments to AS/NZS7000 – due to be published in the next few months
OVERHEAD LINE RATINGS

• One of first decisions to be made – what line would you construct to supply a customer load or embedded generator of 20 MW?

• Typical ratings across range of voltages
  • 11 kV – 4 to 8 MVA
  • 33 kV – 30 to 40 MVA
  • 132 kV – 100 to 300 MVA
  • 275 kV – 300 to 1000 MVA (twin conductors)
  • 500 kV – 1000 to 2000 MVA (quad conductors)

• Bundled conductors needed to comply with environmental requirements
TRANSMISSION DESIGN

Voltages above 33 kV

• One off designs from substation to substation
• Suite of structures
• Long spans (typically 300 metres and longer)
• Steel towers, steel poles, concrete poles
• Special foundation designs
DISTRIBUTION DESIGN

Voltages up to 33 kV

• Standard Constructions
• Standard Conductors (meet MVA rating required for line)
• Timber, Concrete or Steel Poles
• Stays
• Earthing (HV and LV)
• Range of Insulator Types (pin, posts, disc, long rods)
• Pole Mounted Plant (transformers, reclosers)
The line design process is an iterative process, taking into account the various design factors.
Steel Transmission Structures

Double cct 230 kV – upgradable to Single cct 500 kV

765 kV Horizontal (Vee Insulators)
Unique Transmission Structures from Finland
Other Innovative Structures
Distribution Conductors

Conductor Types are:

- **HDC** - Hard Drawn Copper (7/.064, 7/.080, 7/.104), installed on early overhead lines, but superseded by the lower cost aluminium conductors since the 1960’s.
- **AAC** - All Aluminium Conductor (Libra 7/3.0, Mars 7/3.75, Moon 7/4.75, Pluto 19/3.75), which are installed in short span applications typical for an urban area.
- **AAAC** – All Aluminium Alloyed Conductor (Iodine 7/4.75, Neon 19/3.75) installed in long span applications in typical rural area.
- **ACSR** - Aluminium Conductor Steel Reinforced (Apple 6/1/3.0, Banana 6/1/3.75, Cherry 6/4.75 7/1.6, Raisin 3/4/2.5), installed in long span applications in a typical rural area.
- **SC/GZ** – Galvanised Steel, remote rural and SWER lines.
- **CCT** – Covered Conductor Thick, used in vegetated areas to improve reliability.
- **Hendrix Covered Conductor System**
- **HVABC and LVABC covered conductors**
Insulated conductors

- **low voltage**
  - *aerial bundled conductor* (aluminium, xlpe)

- **high voltage**
  - *aerial bundled conductor metallic screen*
  - *aerial bundled non metallic screen* (aluminium, semicond screen, xlpe, semicond screen, copper metallic screen, support catenary sc/gz)

- **covered conductor**
  - *standard*
  - *thick*
Hendrix Spacer Cable System
Damage from Cyclone Larry

Can or should we design lines for these wind conditions?
Damage from Brisbane Floods 2011

Moggill Ferry – caught up in o/h conductors

11 kV line – Postmans Ridge

Or for flood conditions?
SECURITY LEVELS

In the Overhead Line Standard Security levels are distinguished as follows:

**Level I**
Applicable to overhead lines where collapse of the line may be tolerable with respect to social and economic consequences.

**Level II**
Applicable to overhead lines where collapse of the line would cause negligible danger to life and property and alternative arrangements can be provided if loss of support services occurs.

**Level III**
Applicable to overhead lines where collapse of the line would cause unacceptable danger to life or significant economic loss to the community and sever vital post disaster services.
# RELIABILITY AND DESIGN SERVICE LIFE

## Table 6.1

<table>
<thead>
<tr>
<th>Design Working Life</th>
<th>Level I</th>
<th>Level II</th>
<th>Level III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporary construction and construction equipment, e.g. hurdles and temporary line diversions with design life of less than 6 months</td>
<td>5</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>&lt;10 years</td>
<td>10</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>25 years</td>
<td>25</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>50 years</td>
<td>50</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>100 years</td>
<td>100</td>
<td>200</td>
<td>400</td>
</tr>
</tbody>
</table>

Return period winds given in AS1170 for different regions
LOADING ON STRUCTURES

Wind pressure \( (P_z) = 0.6 \times V_z^2 \times \text{Drag Factors} \)

The design site wind speed is taken as—

\[
V_z = V_{RP} M_d M_{z,\text{cat}} M_s M_t
\]

where

- \( M_{z,\text{cat}} \) = gust winds speed multiplier for terrain category at height \( z \). Refer AS/NZS 1170.2 for all regions use Table 4.1(A).
- \( M_d \) = wind direction multiplier.
- \( M_s \) = shielding multiplier.
- \( M_t \) = topographic multiplier for gust wind speed.
- \( V_{RP} \) = basic regional wind velocity for the region
LOADING ON STRUCTURES

\[ F_T = P_Z \times D \times W_d + 2 \times T_X \times \sin \frac{\theta}{2} \]

- \( F_T \) = force on the conductor
- \( P_Z \) = wind pressure
- \( D \) = conductor diameter
- \( W_d \) = wind span
- \( T_X \) = horizontal tension
- \( \theta \) = structure deviation angle
TIP LOAD CALCULATIONS

$$\text{Tip Load} = \left[ F_1 \times d_1 + F_2 \times d_2 + F_3 \times d_3 + F_4 \times d_4 + F_{\text{wind}} \times \frac{d_1}{2} \right] \frac{1}{d_1}$$
Pole height = 17.4m
Earth wire = Libra AAC (T_x = 2700N)
Conductors = Pluto AAC (T_x = 9000N)
Line deviation = 20°
Wind span = 180m
Average pole OD = 0.4m
Wind pressure = 500 Pa on conductor/OHEW, and 750 Pa on pole

\[ F_1 = P_w \times OD \times W_d + 2T_x \sin \frac{\theta}{2} \]

\[ = 500 \times 0.009 \times 180 + 2 \times 2700 \times \sin 10 \]

\[ = 1747.7 \text{ N} \]

\[ F_2, F_3, F_4 = 500 \times 0.0188 \times 180 + 2 \times 9000 \times \sin 10 \]

\[ = 4817.7 \text{ N} \]

\[ F_{w\phi} = P_{w\phi} \times OD \times d_1 \]

\[ = 750 \times 0.4 \times 17.4 \]

\[ = 5220 \text{ N} \]

Tip Load = \[ F_1 + F_{2,3,4} \left( \frac{d_2 + d_3 + d_4}{d_1} \right) + \frac{F_{w\phi}}{2} \]
Tip Load = \( F_1 + \frac{F_{2,3,4}}{d_1} \left( \frac{d_2 + d_3 + d_4}{d_1} \right) \) + \( \frac{F_{w\phi}}{2} \)

= 1747.7 + 4817.7 \left( \frac{15 + 13.5 + 12}{17.4} \right) + \frac{5220}{2}

= 1747.7 + 11213.6 + 2610

= 15.6 kN

Select Pole with a Maximum Working Load of 15.6 kN – Standard range of wood poles is 12 kN and 20 kN, concrete poles can be procured at 16 kN
Limit State Design
**limit state**  
state at which the overhead line or component no longer satisfies the design performance requirement

<table>
<thead>
<tr>
<th>state of system</th>
<th>intact state</th>
<th>damage state</th>
<th>failure state</th>
</tr>
</thead>
</table>

**degradations mechanisms**

- annealing, fatigue damage or permanent elongation (recoverable damage)
- corrosion, annealing, fatigue damage, or UTS (non recoverable damage)

**for example**

IEC 60826

- lowest of
  1. vibration limit; or
  2. clearance infringement; or
  3. 75% of CBL

**ultimate tensile stress** (rupture)
**Working Stress Design**

The equation used in the WSD method to calculate the required component strength is:

\[
\frac{\text{Component strength}}{F \text{ of } S} \geq \text{load}
\]

It was quite common to transpose the factor of safety figure to the right hand side of the equation and thus the equation became:

\[
\text{Component strength} \geq \text{Factor of Safety} \times \text{load}
\]
Limit State Design

In LRF design the following equation must be satisfied:

$$\text{Design resistance} \geq \text{design action effect}$$

or

$$\phi R_n \geq S$$

• Is a more logical method for dealing with structural designs
• The international community has moved to limit state design
• Considers the performance of the system under different loading conditions (servicability and failure)
Maximum Wind Load
LSD Equation

\[ \phi R_n > W_n + 1.1 G_s + 1.25 G_c + 1.25 F_t \]

Where
- \( \phi \) capacity factor or strength factor
- \( R_n \) ultimate strength of structural component
- \( W_n \) wind load
- \( G_s \) vertical dead load (non conductor loads)
- \( G_c \) vertical dead load (conductor loads)
- \( F_t \) intact conductor tension loads @appropriate wind load
# TABLE 6.2
STRENGTH REDUCTION FACTOR $\phi$ FOR COMPONENT STRENGTH

<table>
<thead>
<tr>
<th>Description</th>
<th>Component</th>
<th>Strength</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood structures, poles or members (preserved by full length treatment)</td>
<td>Poles</td>
<td>0.5 to 0.8</td>
<td>AS 1720&lt;br&gt;AS 2209</td>
</tr>
<tr>
<td>(see Note 3 and Appendix F)</td>
<td>Cross-arms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood structures, poles or members (preserved by full length treatment)</td>
<td>Poles</td>
<td>0.4 (see Note 3)</td>
<td>AS 1720&lt;br&gt;AS 2209</td>
</tr>
<tr>
<td>(see Note 3 and Appendix F)</td>
<td>Cross-arms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fibre reinforced composite poles. Design based primarily on testing</td>
<td>Poles</td>
<td>0.75</td>
<td>EUROCOMP Design Code and Handbook</td>
</tr>
<tr>
<td>(see Note 7 and Appendix J)</td>
<td>Cross-arms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fittings and pins, forged or fabricated</td>
<td></td>
<td>0.95 (verified from statistical testing)</td>
<td>AS 1154</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8 (unverified)</td>
<td></td>
</tr>
<tr>
<td>Fittings, cast</td>
<td></td>
<td>0.9 (verified from statistical testing)</td>
<td>AS 1154</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.75 (unverified)</td>
<td></td>
</tr>
<tr>
<td>Porcelain or glass cap and pin string insulator units</td>
<td></td>
<td>0.8 (unverified)</td>
<td>AS 3608</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(electro-mechanical strength)</td>
<td></td>
</tr>
<tr>
<td>Parameter</td>
<td>Value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------</td>
<td>------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pole height</td>
<td>17.4m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earth wire</td>
<td>Libra AAC ($T_x = 5000N$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conductors</td>
<td>Pluto AAC ($T_x = 13000N$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line deviation</td>
<td>20°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind span</td>
<td>180m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average pole OD</td>
<td>0.4m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind pressure</td>
<td>900 Pa on conductor/OHEW, and 1300 Pa on pole</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
F_1 = P_w \times OD \times W_d + 2T_x \sin \frac{\theta}{2}
\]

\[
= 900 \times 0.009 \times 180 + 2 \times 1.25 \times 5000 \times \sin 10
\]

\[
= 3627.5 \text{ N}
\]

\[
F_2, F_3, F_4 = 900 \times 0.0188 \times 180 + 2 \times 1.25 \times 13000 \times \sin 10
\]

\[
= 8686.3 \text{ N}
\]

\[
F_{w\phi} = P_{w\phi} \times OD \times d_1
\]

\[
= 1300 \times 0.4 \times 17.4
\]

\[
= 9048 \text{ N}
\]

\[
\text{Tip Load} = F_1 + F_{2,3,4} \left( \frac{d_2 + d_3 + d_4}{d_1} \right) + \frac{F_{w\phi}}{2}
\]
Ultimate Tip Load = \( F_1 + F_{2,3,4} \left( \frac{d_2 + d_3 + d_4}{d_1} \right) + \frac{F_{w\phi}}{2} \)

\[
= 3627.5 + 8686.3 \left( \frac{15 + 13.5 + 12}{17.4} \right) + \frac{9048}{2}
\]

\[
= 3627.5 + 20218 + 4524
\]

\[
= 28.37 \text{ kN}
\]

To select pole:

1. Take into account component strength factor, e.g., 0.72 for preserved wood pole, 1.0 for steel pole
2. Ultimate strength for pole is 39 kN for wood pole and 30 kN for steel pole
IMPACTS OF EMBEDDED GENERATION ON DISTRIBUTION NETWORKS

Solar PV Impacts in Energex

- 302,000 residential PV systems
- 1,044 MW of generation
- 1000 transformers with penetration levels above 30%
- High voltage on the LV network (outside regulations)
- Reverse power flow on 11 kV feeders
- High neutral currents (100 Amps)
- 100 voltage enquiries per month
- Appliance damage claims
IMPACTS OF EMBEDDED GENERATION ON DISTRIBUTION NETWORKS

Measures to address high voltage

1. Balance of the PV load (generally for the larger sizes only)
2. Change of transformer tap (this will reduce the voltage be around 6 volts)
3. Re-conductoring of LV mains
4. Install additional transformer to reduce size of LV area
5. Disconnect inverter or adjust maximum inverter cut-off voltage
6. Low voltage regulators

33,000 solar panels, 8.1 MW Germany
NEW TECHNOLOGY ON DISTRIBUTION NETWORKS

Statcom LV Regulator

• 4 Quadrant Inverter
• Regulates low voltage
• 20 kVAr reactive (inductive and capacitive)
• 20 kW Battery Storage

Tyree - RegFormer

Technical Specification

Ratings
  • 100kVA Rating

Voltage Regulation
  • +10/-5% Off circuit tap range
  • ± 10% Voltage regulation via power electronics
  • Setpoint and Voltage Adjustment Interval settings
  • Regulates phase voltages individually.

Other Features
  • Pole Mounted
  • Data logging of load current, voltage and temperature
Varentec - Engo-V10

Technical Specifications

Ratings:
- 10kVA single phase units

Voltage Regulation:
- Regulation based on VAr injection
- 1 kVA steps
- Voltage setpoint and bandwidth settings.
- Can only boost voltage

Other Information:
- 10 year life expectancy
- Communication capabilities

Wilson - Hybrid OLTC Distribution Transformer

Technical Specifications

Ratings:
- 315kVA

Voltage Regulation:
- 2.5% tap steps
- +10/-5% Voltage Range

Other Information:
- 3,000 tap operations between services.
- Pole Mounted
- Communication capabilities
NEW TECHNOLOGY ON DISTRIBUTION NETWORKS

Bushfire/Reliability Initiatives

• Ground Fault Neutraliser
  • Petersen coil in transformer neutral
  • Virtually eliminates fault current
  • Jemena has installed one in Victoria
  • PBST recommendation in Victoria
NEW TECHNOLOGY ON DISTRIBUTION NETWORKS

Bushfire/Reliability Initiatives

• Sparkless Fuses (FaultTamer and Boric Acid fuses)
• FuseSaver Device (Kaon)
  • Installed downstream of MDO fuse
  • Operates before fuse
  • Reclose time around 9 seconds
NEW TECHNOLOGY ON DISTRIBUTION NETWORKS

Bushfire/Reliability Initiatives

• S&C IntelliRupter
  • Unique pulse closing scheme
  • Addresses conductor burn down
  • Do not need to revise protection settings at substation
New Overhead Line Markers
Questions?