TUTORIAL ON THERMAL RATING OF LINES (TB 207)

Prepared by Study Committee B2

Advisory Group 4 – Electrical Effects

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CONTENTS

- Calculation of conductor temperature
  - Steady State
  - Transient
  - Abiabatic

HEAT GAIN =HEAT LOSS

$$P_j + P_M + P_S + P_i = P_c + P_r + P_w \qquad (1)$$

where

P_j = joule heating
P_M = magnetic heating
P_S = solar heating
P_i = corona heating
P_c = convective cooling
P_r = radiative cooling
P_w = evaporative cooling

Ohmic Heating

$$P_i = k_i I^2 R_{dc}[1+\alpha(T_{av}-20)]$$

Radial Temperature Difference

$$T_c - T_s = \frac{P_T}{2\pi\lambda}\left[\frac{1}{2} - \frac{D_2^2}{D^2 - D_2^2}\left(\ln\frac{D}{D_2}\right)\right]$$

P_T	= the total heat gain per unit length
D	= the external conductor diameter, i.e. the outer diameter
D_2	= the internal diameter which is the diameter of the steel core
T_s	= surface temperature
T_c	= core temperature
λ	= effective radial thermal conductivity

Forced Convective Cooling

$$P_c = \pi\lambda_f(T_s - T_a)Nu$$

$$Nu = B_1(Re)^n$$

$$Re = \rho_r vD/\nu,$$

Effect of wind angle

$$Nu_\delta = Nu_{90}\left[A_1 + B_2(\sin\delta)^{m_1}\right]$$

$A_1 = 0.42$, $B_2 = 0.68$ and $m_1 = 1.08$ for $0° < \delta < 24°$

$A_1 = 0.42$, $B_2 = 0.58$ and $m_1 = 0.90$ for $24° < \delta < 90°$

IMPORTANT FORMULAE – Low Convection < 0.5 mps

When the wind blows parallel to the conductor axis the Nusselt number with a wind angle of 0° drops to around 0.42 Nu_{90}. This is due to swirling of the flow due to the stranding of the conductor.

With low wind velocity ($V < 0.5$ m/s), however, it has been found that there is no preferred wind direction and the Nusselt number is unlikely to go below (refer section 3.1.3 for calculation of cooling at low wind speeds):

$$Nu_{cor} = 0.55 Nu_{90} \quad (15)$$

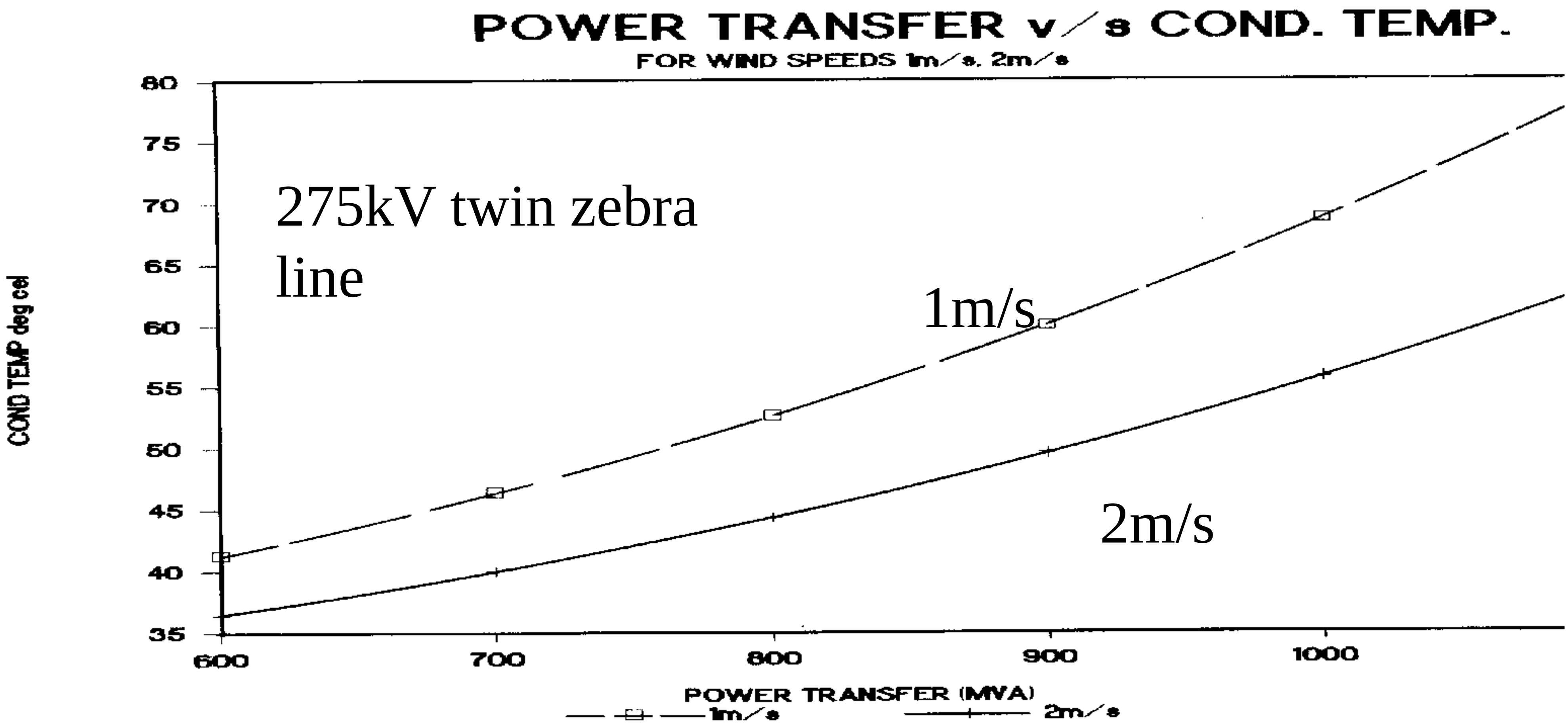
Nu_{cor} is the corrected Nusselt number.

Also note that there is no preferred direction so the low wind speed is assumed to be at 45 deg.

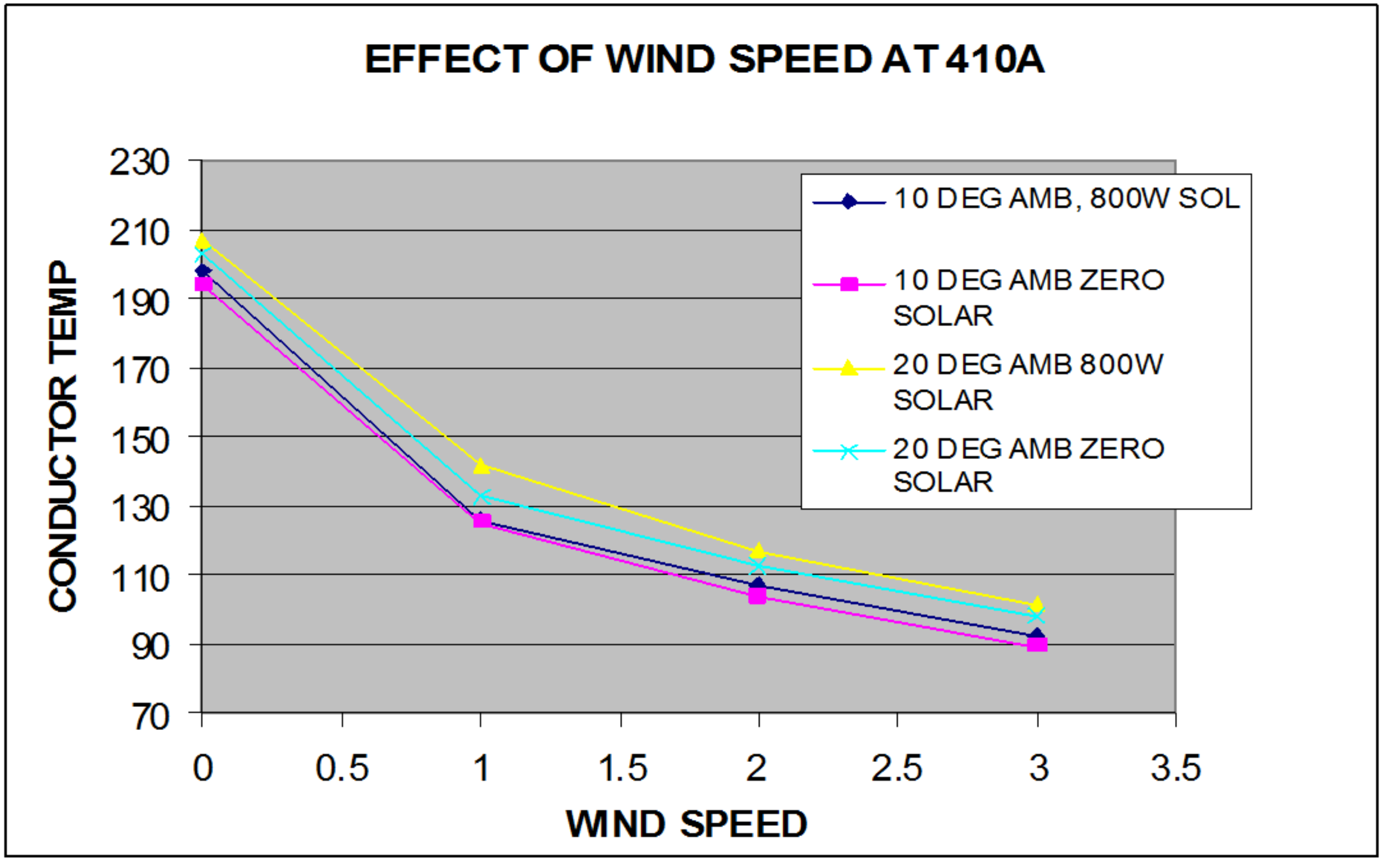
Solar Heating

- Dependent on the diameter of conductor
- Absorptivity and emissivity
  - How dark or how shiny is the conductor?
  - Shiny conductors run hotter at high current levels.
    - Be careful on new lines with immediate high loadings
    - Conductor inserts.
- Dependent on solar radiation.
  - Global depending on direct and diffuse.
- Solar radiation less impact on high templating temperature lines with high current densities.

Effect of templating temperature and wind



EFFECT OF WIND SPEED



Use of Steady State Formulae

- Determine the long term steady state rating for conductors.
- Determine the optimum templating temperature for new lines or uprating of old lines.

Unsteady state evaluation

$$\frac{\partial T}{\partial t} = \frac{\lambda}{\gamma c}\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) + \frac{q(T,r,t)}{\gamma c}$$

$$T_{av} = \frac{T_c + T_s}{2}$$

Since the mass per unit length $m = \gamma A$ and $q = P/A$, where A is the cross-sectional area and P is the power per unit length,

$$mc\frac{dT_{av}}{dt} = P_J + P_M + P_S - P_r - P_c$$

$$t = \frac{-mc\,\theta_m}{I^2 R_{ac} + P_S} \ln\left(\frac{\theta_m - \theta}{\theta_m - \theta_1}\right)$$

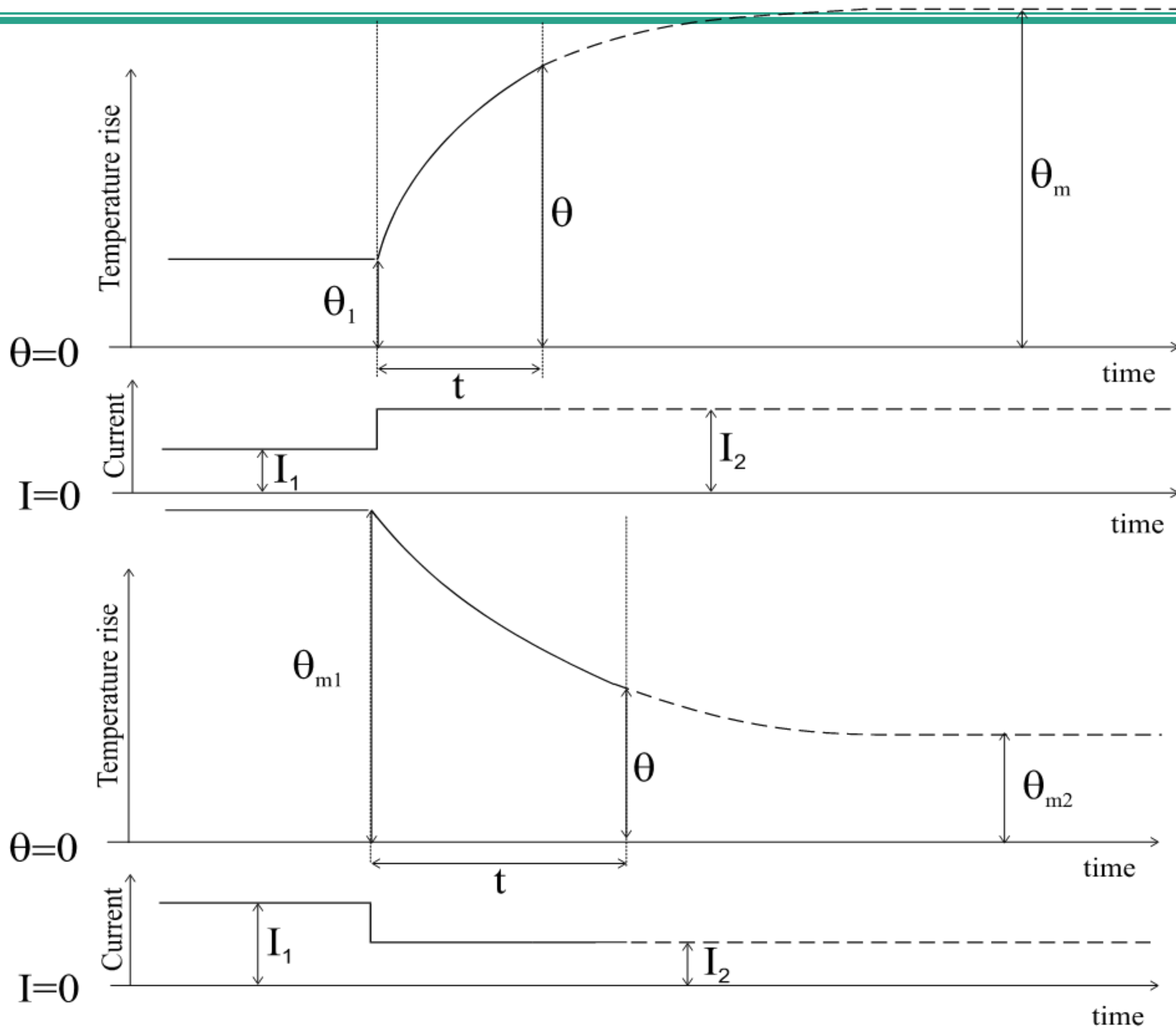
R_{ac} = ac resistance per unit length at ambient temperature

θ = T_{av}-T_a = average temperature rise of conductor

θ_1 = T_{av1}-T_a = initial average temperature rise of conductor at time t_1

θ_m = T_{avm}-T_a = asymptotic average temperature rise of conductor

Heating and Cooling



Making use of dynamic behaviour

- The time constant is around 20 minutes.
- Wind has major effect on conductor temperature.
- Wind is variable within the time constant.
- Load is variable.
- This allows for increased real time rating to be determined.

The interval of time is calculated using equation (21):

$$dt_i = \frac{mc(\theta_i)\cdot d\theta}{P_J(\theta_i)+P_M(\theta_i)+P_S-P_c(\theta_i)-P_r(\theta_i)}$$

where θ_i is the temperature rise at step i.

POINTS TO REMEMBER

- At high templating temperatures solar radiation has minimal effect.
  - Highest temperatures occur at night.
- Steady state used for deterministic ratings and certain probabilistic ratings - templating temperature.
- Unsteady state used for Real time monitoring and certain probabilistic ratings - operational benefits.