APPENDIXII

i) $I^2R$ Loss

The Influence of Temperature on Resistance:

\[ R_2 = R_1 [1 + \alpha (T_2 - T_1)] \]

\( R_1, R_2 \) = Resistance of conductor.
\( T_1, T_2 \) = Temperature of the conductor.
\( \alpha \) = Temperature co-efficient in \((K^{-1})\)

- 0.0005 for Aluminum conductor
- 0.00392 for hard copper conductor
- 0.004 for soft copper conductor

Skin Effect Ratio:

With increase in frequency (or harmonics), the effective current density produces an increase in effective resistance (which is further required to be corrected for the operating temperature value) and a decrease in effective internal resistance.

Aluminum / Copper conductor at commercial power frequency & harmonic loss evaluation.

All conductors at carrier and radio frequencies.

\[ R^1 = KR \]
\[ R^1 = \text{effective resistance of a linear cylindrical conductor to sinusoidal alternating current at a given frequency.} \]
\[ R = \text{True DC resistance with continuous current.} \]
\[ K = \text{A factor determined from table in terms of } x. \text{ The value of } x \text{ is given by} \]

\[ X = 2\pi a \sqrt{2f \mu / \rho} \]
\( a \) = radius of conductor on cm.
\( f \) = frequency in cycles / sec.
\( \mu \) = magnetic permeability of conductor
Row = resistivity in abohm-cm (abohm = $10^{-9}$ ohm)

X = $0.063598 \sqrt{\mu/R}$

$\mu$ = it’s value for non-magnetic materials (like aluminium, copper etc.) is 1.

R = dc resistance of conductor at operating temperature in ohm/miles.

Manufacturers normally give the value of R20, which is actual dc resistance at 20°C for example,

For 400mm$^2$ cables, R20 = 0.0778
For 300mm$^2$ cables, R20 = 0.1000

After correcting those above values, for actual cable operating temperature i.e. 65°C, the revised values of R65 are calculated and indexed with skin effect ratio for loss evaluation.

ii) Transformer Loss

1. Transformer parameters

$P_{BP}$ = Bid price

$P_{EL}$ = Excitation/non-load loss.

$= P_h + P_e$

Where,

$P_h = K_h \times Vol. \times f x B_{max}^n$

$P_e = K_e \times Vol. \times f^2 \times T^2 \times B_{max}^n$

Vol. = Volume of iron.

T = Lamination thickness
\[ N = \text{Steinmetz co-efficient.} \]
\[ P_h = \text{Hysteresis loss} \]
\[ P_e = \text{Eddy current loss.} \]
\[ K_h = \text{Hysteresis constant.} \]
\[ K_e = \text{eddy current constant.} \]
\[ F = \text{Harmonic nos.} \]
\[ B_{\text{max}} = \text{maximum flux density} \]
\[ B_{\text{max}} = \frac{\Phi_{\text{max}}}{\text{area.}} \]
\[ \Phi_{\text{max}} = V/4.44 \times f \times K_w \times N \]
\[ V = \text{Voltage} \]
\[ K_w = \text{Winding factor} \]
\[ N = \text{Number of turns.} \]
\[ B_{\text{max}} = \text{Promotional to } K \times V/f. \]
\[ P_e = \text{Proportional to } K \times V^2. \]
\[ P_h = \text{Proportional to } K \times V^n / f^{(n-1)} \]

The above is on the assumption that eddy-current loss in the core is independent of frequency and hysteresis loss in the core is inversely proportion to frequency.

However the above analysis is workable/accurate only upto 10\textsuperscript{th} harmonic. However, beyond 10\textsuperscript{th} harmonic, the skin effect is considerable enough to be neglected and hence eddy current core loss component begin to increase, which is accounted for.
\( P_{\text{LL}} = \) Load loss.
\( = P_{\text{DC}} + P_{\text{EC}} + P_{\text{OSL}} \)
\( P_{\text{DC}} = \) dc resistance losses.
\( P_{\text{EC}} = \) winding stray losses due to skin & proximity effects.
\( P_{\text{OSL}} = \) other stray losses.
\( P_{\text{DC}} = \frac{P_0}{P_{1\text{pu}}} \)
\( \text{i.e.} \ (I_1^2 \times R_{\text{DC}}) / P_{1\text{pu}}. \)
\( P_{\text{EC}} = \left[ \frac{(P_1 - P_0)}{P_{1\text{pu}}} \times W \right] \times I_n^2 \times n^q \times \text{pu} \)
\( P_{\text{OSL}} = \left[ \frac{(P_1 - P_0)}{P_{1\text{pu}}} \times (1-\text{w}) \right] \times ((I_n^2 \times n^q) \times \text{pu} \)
\( P_1 = \) Fundamental load losses
\( P_0 = \) DC winding losses.
\( R_{\text{DC}} = \) Equivalent DC resistance.
\( W = \) winding stray loss as a fraction of total stray losses.
\( 1-\text{w} = \) other stray loss as a fraction of total stray losses.
\( q = \) rate of increase of winding stray loss with harmonics.
\( R = \) rate of increases of other stray loss with harmonics.
\( N = \) harmonics.
\( I_1 = \) fundamental component of rms current.
\( I_n = \) pu harmonics current.
## Appendix III
### Arc Furnace Parameters Data Sheet

Transformer rating: 40 MVA, Short Circuit Reactance: 2.460 mΩ, Rated Voltage: 407 V, Nominal Current: 56.74 kA

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Appendix IV

EAF Model Simulation in Pscadfor Furnace