Finite Element Method : Future Distribution Grids

Contents

Chapter 1

STEDIN Transformer Parameters

This chapter contains transformer parameters as given in [1].

1.1 Power Rating

Power rating = 400 kVA

1.2 Line to Line Parameters

Primary voltage, $V_{pri,line,rms}$ = 10750 V
Secondary voltage, $V_{sec,line,rms}$ = 420 V
Primary current, $I_{pri,line,rms}$ = 21.48 A
Secondary current, $I_{sec,line,rms}$ = 549.86 A

1.3 Phase to Phase Parameters

Considering a delta-wye connected transformer,
Primary voltage, $V_{pri,phase,rms}$ = 10750 V
Secondary voltage, $V_{sec,phase,rms}$ = 242.49 V
Primary current, $I_{pri,phase,rms}$ = 12.40 A
Secondary current, $I_{sec,phase,rms}$ = 549.86 A

Corresponding peak values will be,
Primary voltage, $V_{pri,phase,peak}$ = 15202.40 V
Secondary voltage, $V_{sec,phase,peak}$ = 342.93 V
Primary current, $I_{pri,phase,peak}$ = 17.54 A
Secondary current, $I_{sec,phase,peak}$ = 777.62 A

1.4 Turns Ratio

Primary turns, N_{pri} = 266
Secondary turns, N_{sec} = 6

1.5 Core Parameters

The values are as given in Section 2.3.2 of [2] for grain-oriented silicon steel (Fe-(3 wt%)Si alloys).
Electrical Resistivity = 45×10^{-8} Ωm
Electrical Conductivity = 2.22×10^6 $\Omega^{-1}\text{m}^{-1}$
Saturation Polarization = 2.03 T

Maximum Relative Permeability = 8×10^4
Density = 7.65×10^3 kg/m^3
50 Hz Power Loss at 1.4 T = 0.6 W/kg
50 Hz Power Loss at 1.7 T = 1.21 W/kg

Chapter 2

Magnetic Field Simulations

2.1 General Expression for FEM

$$\nabla \times \left[\frac{1}{\mu}\nabla \times A\right] = J_0 + J_c \qquad (2.1)$$

where,

J_0 = source current density,

J_c = conduction current density.

Since, current flows along the z-axis and the geometry is in xy plane,

$$-\nabla \cdot \left[\frac{1}{\mu}\nabla A_z\right] = J_0 + J_c \qquad (2.2)$$

In frequency domain,

$$-\nabla \cdot \left[\frac{1}{\mu}\nabla A_z\right] + j\omega\sigma A_z = J_0 \qquad (2.3)$$

In time domain,

$$-\nabla \cdot \left[\frac{1}{\mu}\nabla A_z\right] + \frac{\partial A_z}{\partial t} = J_0 \qquad (2.4)$$

2.2 Without Eddy Currents

$$-\nabla \cdot \left[\frac{1}{\mu}\nabla A_z\right] = J_0 \qquad (2.5)$$

2.3 With Eddy Currents

$$-\nabla \cdot \left[\frac{1}{\mu}\nabla A_z\right] + j\omega\sigma A_z = J_0 \qquad (2.6)$$

2.4 Non-Linear Characteristics of Core

The nonlinear magnetic characteristic with hysteresis neglected can be approximated as given in [3].

$$\frac{1}{\mu} = k_1 e^{k_2 B^2} + k_3 \qquad (2.7)$$

where, K_1, k_2 and k_3 are constants equal to 3.8, 2.17, and 396.2, respectively.

References

[1] M. van Dijk, "A theoretical approach towards digital twins: A balance between an empirical and a fundamental model for distribution transformers," *Delft University of Technology*, 2022.

[2] F. Fiorillo, *Characterization and measurement of magnetic materials*. Academic Press, 2004.

[3] J. Brauer, "Simple equations for the magnetization and reluctivity curves of steel," *IEEE Transactions on Magnetics*, vol. 11, no. 1, pp. 81–81, 1975.