Solutions Manual

Principles of Electric Machines and Power Electronics

Second Edition

P. C. Sen

Solutions Manual to Accompany

PRINCIPLES OF ELECTRIC MACHINES AND POWER ELECTRONICS

SECOND EDITION

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PREFACE

This text book can be used for either a single semester length course or for a two-semester course sequence. The instructor should feel free to choose the topics for the course. The selection would be guided by the objectives of the course and the curriculum. The flexible organization of the material allows sections and entire chapters to be skipped without loosing continuity. The instructor may also choose the sequence of coverage - for example, some may prefer to discuss synchronous machines before induction machines.

It is also possible to offer a short course in power electronics based on Chapter 10 on Power Semiconductor Converters and sections on motor speed control in Chapters 4, 5, 6 and 7.

The Second Edition incorporates nearly twice as many problems as the First Edition. When assigning problems, the instructor may select some from this text book, while others can be freshly formulated or selected from another book. Students may be critical if all problems are assigned from the same text book.

P.C. Sen

September, 1996

CONTENTS

CHAPTER 1

1.1 (a) $H = \frac{Ni}{l} = \frac{250 \times 100}{0.5} = 50{,}000 \text{ At/m.}$

$B = \mu_0 H = 4\pi 10^{-7} \times 50{,}000 = 0.062832 \text{ T}$

(b) $L = \frac{N\phi}{i} = \frac{NB\pi r^2}{i} = \frac{N\pi r^2}{i}\mu_0\frac{Ni}{l} = \frac{N^2\mu_0\pi r^2}{l}$

$= \frac{250^2 \times 4\pi 10^{-7} \times 3.1416 \times (2.5 \times 10^{-2})^2}{0.5} \text{ H}$

$= 308.43 \ \mu\text{H}$

1.2 (a) $\mathcal{R}_{Thick} = \frac{70 \times 10^{-2}}{2000 . 4\pi . 10^{-7} \times 15 \times 10 \times 10^{-4}}$

$= 18568.03$

$\mathcal{R}_{Thin} = \frac{80 \times 10^{-2}}{2000 . 4\pi . 10^{-7} \times 10 \times 10 \times 10^{-4}}$

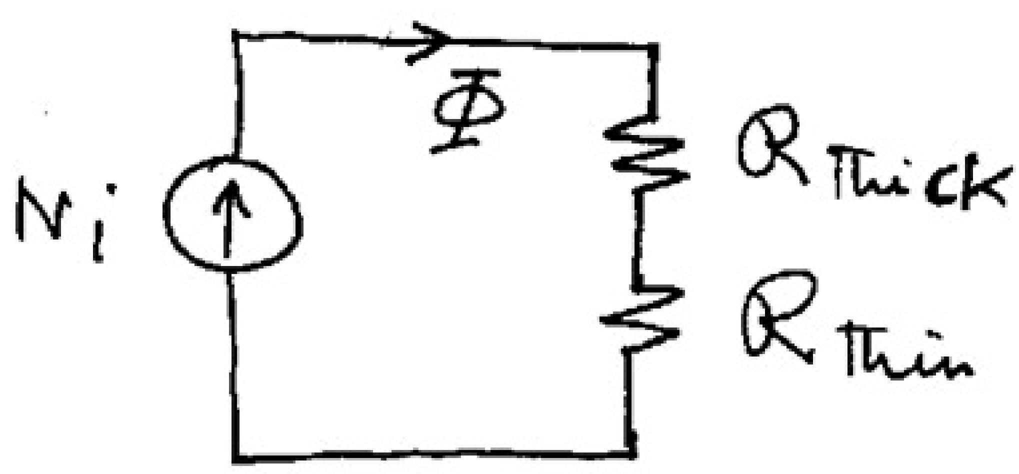
$= 31830.91$

$\mathcal{R}_{Thick} + \mathcal{R}_{Thin} = 50398.94$

$\Phi = \frac{500 \times 1}{50398.94} = 0.009921 \text{ Wb.}$

(b) $B_{Thick} = \frac{0.009921}{150 \times 10^{-4}} = 0.6614 \text{ T.}$

$B_{Thin} = \frac{0.009921}{100 \times 10^{-4}} = 0.9921 \text{ T}$



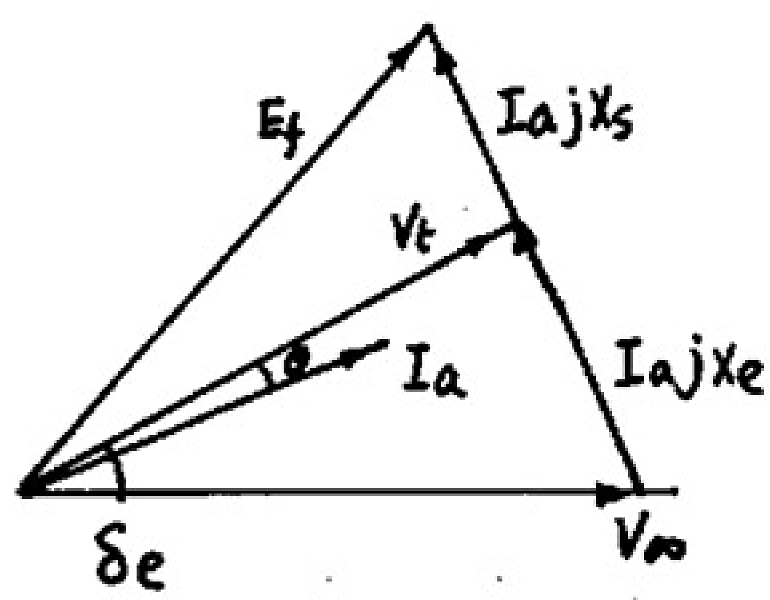
(b) $I_a = \dfrac{10,000}{\sqrt{3} \times 208} = 27.76 \text{ A}$

$E_f = 120\angle 0^\circ + 27.76\angle 0^\circ \cdot 1.5\angle 90^\circ$

$= 127\angle 19.1^\circ$

$\dfrac{I_f(b)}{I_f(a)} = \dfrac{127}{156.86} \times 100 = 80.96\ \%$

6.13 (a)



$V_t = V_\infty + I_a jX_e \longrightarrow$ Take V_∞ as ref. $\rightarrow V_t$ leads V_∞

$E_f = V_t + I_a jX_s = V_\infty + I_a j(X_s + X_e) \longrightarrow E_f$ leads V_t

(b) $P = 0.8 \text{ p.u.} = \dfrac{V_\infty V_t}{X_e} \sin\delta_e = \dfrac{1\times 1}{0.25}\sin\delta_e \qquad \delta_e = 11.537^\circ$

Alli $\qquad PF = \cos\theta = \cos\frac{\delta}{2} = 0.9949$ (lag)

$I_a = \dfrac{P}{V_t\cos\theta} = \dfrac{0.8}{1\times 0.9949} = 0.8041 \text{ P.U.}$

(c) $E_f = V_\infty + I_a j(X_s + X_e) = 1 + 0.8041\angle 5.7685^\circ \times 1.75\angle 90^\circ = 1.6424\angle 58.5^\circ$

6.14 (a) $P_{max} = \dfrac{V_t V_\infty}{X_e}\sin 90^\circ = \dfrac{1\times 1}{0.25} = 4 \text{ P.U} = 4\times 500 = 2000 \text{ MW}$

(b) $P_{max} = \dfrac{E_f V_\infty}{X_s + X_e}\sin 90^\circ = \dfrac{1\times 1}{1.5+0.25} = 0.5714 \text{ p.u.} = 0.5714\times 500 = 285.714 \text{ MW}$

6.15 (a) $1800 = \dfrac{1200\times 60}{P} \longrightarrow P = 4$

(b) $V_b = \dfrac{6600}{\sqrt{3}} = 3810.6 \text{ V/ph} \quad I_b = 1500\text{A} \quad Z_b = \dfrac{3810.6}{1500} = 2.54\Omega$

$X_s = 0.95 \times 2.54 = 2.4134\Omega \qquad R_a = 0.012 \times 2.54 = 0.0305\ \Omega$

(c) (i) $T = \dfrac{2000 \times 746}{1800 \times 2\pi/60} = 79,152.87 \text{ N.m}$

(ii) $P_{in} = \sqrt{3} \times 6600 \times 1350 \times 1 = 15.432 \text{ MW}$

$P_{out} = 20000 \times 746 = 14.92 \text{ MW} \quad Eff = \dfrac{14.92}{15.32} = 96.68\%$

9.12 (a) From pre-fault condition

$$E_i'' = V_t + I_a jX_d'' = 1 + 1\angle 0^\circ \cdot 0.3\angle 90^\circ = 1.044 \text{ p.u.}$$

$$I_{ac}\Big|_{max} = \frac{E_i''}{X_d''} = \frac{1.044}{0.3} = 3.48 \text{ p.u.}$$

(b) $$I_{dc}\Big|_{max} = \sqrt{2} \times 3.48 = 4.921 \text{ p.u.}$$

(c) $$I_{sc}\Big|_{max} = \sqrt{3.48^2 + 4.921^2} = 6.027 \text{ p.u.}$$

(d) From pre-fault condition

$$E_i = V_t + I_a jX_d = 1 + 1\angle 0^\circ \, 1\angle 90^\circ = 1.414 \text{ p.u.}$$

$$E_i' = 1 + 1\angle 0 \cdot 0.4\angle 90^\circ = 1.077 \text{ p.u.}$$

$$i_{sc}(t) = \sqrt{2}\left[\frac{1.414}{1} + \left(\frac{1.077}{0.4} - \frac{1.414}{1}\right)e^{-t/1.5} + \left(\frac{1.044}{0.3} - \frac{1.077}{0.4}\right)e^{-t/0.03}\right]\sin\omega t + 4.921e^{-t/0.2}$$

$$= \sqrt{2}\left[1.414 + 1.2785e^{-0.6667t} + 0.7875e^{-33.3t}\right] \cdot \sin\omega t + 4.921e^{-5t}$$

$$i_{sc}\Big|_{t=0.5} = \sqrt{2}\left[1.414 + 1.2785 \times 0.716 + 0.7875 \times 0\right] \times \sin\omega t + 4.921 \times 0.0821$$

$$= \sqrt{2}\,(2.3294) + 0.404$$

$$I_{sc}\Big|_{t=0.5} = \sqrt{2.3294^2 + 0.404^2} = 2.364 \text{ p.u.}$$

9.13 (a) Prefault conditions ; $V_t = 1.0$ p.u. $I_a = 1\angle 0^\circ$ p.u.

$$E_i = V_t + I_a jX_d = 1 + (1)(1.2)\angle 90^\circ = 1.562\angle 50.2^\circ$$

$$E_i' = 1.0 + (1)(0.4)\angle 90^\circ = 1.077\angle 21.8^\circ$$

$$E_i'' = 1.0 + (1)(0.25)\angle 90^\circ = 1.0308\angle 14^\circ$$

APPENDIX A

A.1

$n = \frac{36}{4\times 3} = 3$ slots/pole/phase

$\alpha = \frac{180}{3\times 3} = 20$, $\gamma = 180 - 140 = 40$

$\therefore$ distribution factors are

$$K_{d1} = \frac{\sin(3\times 20/2)}{3\sin(20/2)} = 0.9598$$

$$K_{d3} = \frac{\sin(3\times 3\times 20/2)}{3\sin(3\times 20/2)} = 0.6667$$

$$K_{d5} = \frac{\sin(3\times 5\times 20/2)}{3\sin(5\times 20/2)} = 0.2176$$

The pitch factors are:

$K_{p1} = \cos(40/2) = 0.9397$

$K_{p3} = \cos(3\times 40/2) = 0.5$

$K_{p5} = \cos(5\times 40/2) = 0.1736$

The winding factors are:

$K_{w1} = K_{d1}K_{p1} = 0.9598\times 0.9397 = 0.9019$

$K_{w3} = K_{d3}K_{p3} = 0.6667\times 0.5 = 0.3333$

$K_{w5} = 0.2176\times 0.1736 = 0.0378$

From eq. A.27, the rms fundamental voltage is

$E_1 \propto B_{1(max)}K_{w1} = K\times 1\times 0.9019 = 0.9019K$

The 3rd + 5th harmonic voltages are

$E_3 = K B_{3max} K_{w3} = K\times 0.4\times 0.3333 = 0.13332K$

$E_5 = K B_{5max} K_{w5} = K\times 0.2\times 0.0378 = 0.0076K$

Phase voltage is

$$E_{LN} = (E_1^2 + E_3^2 + E_5^2 + \cdots)^{1/2}$$
$$= K(0.9019^2 + 0.13332^2 + 0.0076^2 + \cdots)^{1/2}$$
$$\simeq 0.9118K$$