

Electrical Machines and Power Electronics

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Van Nostrand Reinhold

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Van Nostrand Reinhold (UK) Co. Ltd.

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**Published by Van Nostrand Reinhold (UK) Co. Ltd.
Molly Millars Lane, Wokingham, Berkshire, England**

Library of Congress Cataloging in Publication Data

Steven, R. E. (Robert Edgar)

Electrical machines and power electronics.

Includes bibliographical references and index.

1. Electric machines. 2. Electric transformers.

3. Power electronics. I. Title.

TK2000.S77 1983 621.31'042 82-20033

ISBN 0-442-30547-8

ISBN 0-442-30548-6 (pbk.)

Printed and bound in Hong Kong

Electrical Machines and Power Electronics

'It is as impossible to learn science from hearsay as to gain wisdom from proverbs. Ah, it is so easy to follow a line of argument and so difficult to grasp the facts that underlie it.

Our popular lecturers on physics present us with chains of deductions so highly polished that it is a luxury to let them slip from end to end through our fingers. But they leave nothing behind but a vague memory of the sensation they afforded.'

G. B. Shaw

Preface

This textbook presents a complete and up-to-date study of this subject for electrical, control, electronic and mechanical engineers. It is based on the author's earlier successful book, *Electromechanics and Machines*, published by Chapman & Hall, London, 1970. Notable revisions and additions include the transformer, induction motors, including single phase types, and additional design principles. The importance of power electronics in modern practice is recognized in the text and by a chapter describing the basic performance of these devices and systems.

The treatment reflects the modern interest in machines and systems, embracing principles of dynamic circuit theory, transient performance and related power electronics. It also embraces fundamental aspects of design necessary to an understanding of the more sophisticated analyses, which have been made possible by new materials and important computing facilities, and provides the basis of popular assumptions employed to permit linear analyses. Some traditional methods of analysis are retained on merit and the temptation to proceed too rapidly to the generalized machine theory has been resisted. An elementary knowledge of d.c. and a.c. circuit theory is assumed, as well as some knowledge of electromagnetism and differential calculus. Elementary or advanced courses may be selected from the text, the remaining material providing ample background reading.

It is intended as a student textbook but should appeal also to practising engineers who wish to up-date their knowledge. Various selected references are given where particular topics may be examined in wider context. Well established notation is used and demonstrative examples with solutions are provided.

The author wishes to acknowledge with thanks the guidance he has obtained from various papers and books wherein notation and important fundamental concepts have been established. These are recommended in chapter references for further studies.

Units and Symbols

The adoption of a standard system of units and symbols has many advantages. But it does not protect the student from variations which occur in contemporary and near-contemporary literature and practice. In this textbook rationalized m.k.s. (SI) units are implied, except where specifically stated otherwise.

Attempts to provide a 'standard' notation of symbols becomes a pedantic exercise. The symbols used in this book are of common conventional usage, but the same symbol can find usage in two different contexts. The following list is provided for general guidance, in addition to local definitions within the text.

A	amplifier gain
A	amperes (unit of current)
A	area (metres ²)
A	armature
AT	ampere-turns
a	coordinate axis
a	a phase axis
a	real part of complex root and damping factor
a	slot pitch
a	parallel paths of a winding
a	area
a	armature
\overline{ac}	specific electric loading
B	flux density (webers/m ² = tesla)
\bar{B}	specific magnetic loading
C	capacitance (farads)
C	transformation matrix
C_p	specific heat at constant pressure
c	a phase axis
c	spring compliance; a numeric
D	diameter; delta connection
D	damping coefficient
D_e	effective damping
d	direct axis

d	distance
d	differential
E	r.m.s. and d.c. voltage
e	instantaneous voltage
e	pertaining to eddy currents
e	electrical
F	force (newtons)
$F(s)$	Laplace function
\mathcal{F}	magnetomotive force
F_v	viscous friction (\propto velocity)
f	frequency (cycles/second = hertz)
f	instantaneous force
f	function of
f	field quantity
G	output coefficient
G	coefficient of rotational inductance
G	goodness factor
g	generator; airgap
g	damper winding on q -axis
H	magnetizing force (ampere turns)
H	henries (unit of inductance)
H	inertia constant
Hz	hertz
h	pertaining to hysteresis; rectifier transformer leakage inductance; heat transfer coefficient
I	r.m.s. current, d.c. current
i	instantaneous current
J	polar moment of inertia; current density
j	mathematical operator = $(-1)^{1/2}$
K	a constant; thermal conductivity
k	kilo = 10^3 unit
k	coefficient of coupling
k	a constant
L	inductance (henries)
L	length
L_{mt}	length of mean turn
L	line value
l	length
\ln	natural logarithm
M	mass (kilograms)

M	angular momentum
M	mutual inductance
m	phases
m	milli = 10^{-3} unit
m	metres
m	coils/phase
m	motor
m	mechanical
m_{\max}	maximum value
N	magnetizing turns
N	r.p.m.
N	North polarity
n	general numeric, (e.g. n th harmonic)
n	speed r.p.s.
n	natural (frequency)
O	origin of a graph
o	subscript for no load
o	unity p.f.
o	resonant value
P	power (watts)
\mathcal{P}	permeance
p	differential operator d/dt
p	pairs of poles
p	phase value
p	pole pitch
p.u.	per unit
Q	kilovolt-amperes (reactive) = kVAR
q	quadrature axis
q	magnetic neutral axis
q	charge (coulombs); rate of heat developed
R	ohmic resistance
\mathcal{R}	reluctance
r	radius
r	ohmic resistance
r	rotor
S	South polarity; kilovolt-amperes ($= P + jQ$)
ss	steady state
s	complex frequency
s	synchronous
s	fractional slip

s	stator
T	time-constant (seconds)
T	time
Ⓓ	torque (newton-metres)
t	time (seconds)
t	thickness
t	terminal value; tooth
t	Thévenin value
t	transpose of a matrix
V	r.m.s. or d.c. voltage (usually applied)
V	unit of voltage; volume
VTA	volt-time area
v	velocity (metres/second)
v	instantaneous voltage
W	energy (joules or watt. seconds)
W	power in watts
Wb	webers
X	reactance
x	displacement
x	dimension
x	Steinmetz index
x	algebraic term
Y	admittance; wye or star connection (3 phase)
Y	pole-pitch
y	coil-span or pitch
Z	electrical impedance
Z	number of conductors
z_m	impedance in mechanical units

Greek:

α	impedance angle = $\tan^{-1} R/X$; rectifier firing angle
β	a constant index; inverter angle of advance; cut-off angle; rectifier extinction angle
δ	misalignment and load angle, (electrical degrees); inverter extinction angle
∂	partial differential
Δ	elemental change, delta connection
ϵ	exponential, base of natural logarithms
ζ	damping ratio
η	efficiency
x	

θ	an angle; a quantity; temperature difference
λ	flux linkages; impedance angle = $\tan^{-1} X/R$
μ	permeability; micro = 10^{-6} unit; rectifier overlap angle
μ_0	magnetic space constant ($= 4\pi \cdot 10^{-7}$ H/m)
ξ	electric field strength (volts/metre = newtons/coulomb)
π	mathematical constant
ρ	resistivity, (electrical); density
σ	leakage coefficient; real axis co-ordinate in complex plane; winding space factor
Σ	summation
ϕ	instantaneous magnetic flux; phase angle
Φ	magnetic flux (webers = tesla m ²)
ψ	mechanical angle; angular displacement
ω	angular frequency; speed, rads/second
γ	ripple factor (rectifiers); internal phase angle
τ	time period

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