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A Practical Guide and Commentary on NEC and IEC 60364

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Preface

For the design, calculation, dimensioning, and evaluation of an electrical power system, the electrical engineer and technician need not only comprehensive theoretical knowledge but also a reference book to make his work easier. This book is intended to fulfill this task.

This book is a follow-up to "Analysis and Design of Low-Voltage Power Systems", published in 2004, and contains didactical improvements and new topics such as power flow, generators, earthing in electrical networks, and relays. Each topic has been written in such a way that the readers can accomplish their tasks with the help of this book without much effort.

Many practical examples, tables, diagrams, and a comprehensive collection of literature make the compendium a complete tool. Planning values and equations required for the calculation process can be extracted from the numerous tables and diagrams. The book is well suited for teaching as well as for practical use. Special emphasis has been placed on deepening the theory, practice, and standards.

For this reason, the present book, intended as a help for the planning engineer in the solution of problems in electrical networks, also presents a detailed discussion of the current situation in regard to standards.

Following the theoretical part and the discussion of regulations and standards, a wide range of examples taken largely from practice is worked out fully.

The readers will be systematically familiarized with the structure, design, behavior, protection, calculation, planning, and design of electrical networks and switchgear. The following questions are covered in this book:

- How can I design the electrical system?
- Which regulations do I have to observe?
- Which calculations do I have to perform?
- Which methods/CAD can I use?
- Which protective measures do I have to consider?
- Which requirements and conditions apply for project planning?
- How can persons and animals be protected against electrical shock?
- Which operational components shall I select?
- Are there special problems with regard to planning?

For calculation, dimensioning, and evaluation of a system, in addition to extensive professional knowledge the planning engineer requires above all CAD experience and a knowledge of all relevant standards and regulations. Due to the great number of standards and their revision in regular intervals and also due to their increasing international harmonization, maintaining this knowledge is becoming more and more difficult.

This book will give engineers, technicians, master electricians, industry professionals, students convincing insights into the immense complexity of electrical power systems and networks and the breadth and depth of power engineering.

It is not possible to present all topics in one book with theory, practice, and standards. Individual topics can still be deepened with the literature given at the end of the book.

I wish you much success and enjoy reading this book.

Weinheim
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Ismail Kasikci

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I would like to thank the companies Siemens and ABB for their figures, pictures, and technical documentation. In particular, as a member, I am also indebted to the VDE (Association for Electrical, Electronic and Information Technologies) for their support and release of different kind of tables and data.

Furthermore, I welcome every suggestion, criticism, and idea regarding the use of this book from those who read the book.

Finally, I appreciate the feedbacks from designers, planners, and readers for their useful recommendations and critics.

This book describes the most important theory, practical terms, and definitions with respect to IEC or EN standards and useful examples. This book is structured as follows:

Chapter 1	is an introduction into the power system today.
Chapter 2	gives an overview of electrical power systems.
Chapter 3	describes the scope of DC current installations.
Chapter 4	gives a small introduction into smart grids.
Chapter 5	explains planning and project management briefly.
Chapter 5	deals with three phase alternating current.
Chapter 6	gives an overview of the network forms for low and medium voltage.
Chapter 7	describes the method of symmetrical components.
Chapter 8	explains the type of short-circuit currents in three-phase networks and the meaning, tasks, and origin of DIN EN 60909-0.
Chapter 9	describes the relays in electrical power systems generally.

Chapter 10	explains the load flow calculation.
Chapter 11	explains the type of neutral point treatment and substation earthing in high-voltage power installations.
Chapter 12	presents the protection against electric shock.
Chapter 13	deals with the most important overcurrent protection devices with the time–current characteristics.
Chapter 14	discusses the current carrying capacity of conductors and cables.
Chapter 15	gives an overview of the selectivity and back-up protection.
Chapter 16	presents the voltage drop calculations.
Chapter 17	gives a brief overview of the switchgear combinations.
Chapter 18	explains the compensation for reactive power.
Chapter 19	describes lightning protection systems.
Chapter 20	gives a brief overview of lighting systems.
Chapter 21	explains generators briefly.
Chapter 22	describes transformers.
Chapter 23	presents low voltage motors.
Chapter 24	asks some questions of each topic.

Symbols

a	center-to-center distance between bus bars, costs of electrical energy, room length, center-to-center distance between conductors, near-to-generator short-circuit
a_i	utilization factor for motors
$A_{W,D}$	surface area of walls and ceiling
A	acquisition price, floor area of room, air intake, and exhaust opening, initial value of DC component
A_2	area of circle
A_e	effective cooling area of housing, equivalent collecting area of stand-alone structure
A_0	individual surface areas of external side of housing
c_max	voltage factor
c	voltage factor, temperature distribution factor, specific heat capacity of conducting material, smallest power step
C_str	phase capacitance
C_e	Environmental coefficient
C'_E	ground capacitance
C	capacitor power
C_p	rated power
D	separation distance
E	light intensity
E_m	average light intensity
E_n	rated light intensity
f_1	stator frequency
f_2	rotor frequency
f_n	network frequency
F	electrodynamic force between conductors
g_i	coincidence factor
GD	moment of inertia

h	height difference, distance between lighting elements and evaluation level
H	magnetic field strength, height of housing
i_{DC}	decaying DC current component
i_{p}	peak short-circuit current
I	current, light intensity
I_0	no-load current
I_{thr}	rated short time current
I_{an}	starting current of motor
I_{rM}	rated current for motors in a group
I''_{kQ}	initial symmetrical short-circuit current
I_a	cutoff current of overcurrent protective equipment
I_A	starting current
I_d	leakage current
$I_{\Delta n}$	rated differential current of RCD
I_{f}	fault current (smallest short-circuit current)
I_{an}/I_{rM}	ratio of starting current to rated current for motor
I_{n}	nominal current
I_e	current setting
I_{rm}	magnetic current setting
I''_{k1}	single-pole short-circuit current
I''_{k2}	two-pole short-circuit current
I''_{k3}	three-pole short-circuit current
I''_{k2E}	two-pole short-circuit with contact to ground
I''_{kEE}	double ground fault short-circuit current
I_k	steady state short-circuit current
I_{th}	thermal short-circuit current
I_B	load current
I_n	rated current of protective equipment
I_z	permissible current loading of cable or conductor
I_r	rated current
I_{Δ}	current for delta connection
I_{Y}	current for star connection
I_2	large test current
I''_k	initial symmetrical short-circuit current
J_L	mass moment of inertia of load
J_{thr}	rated short-time current density
k	housing constant, material factor, or specific conductivity factor, transformation ratio of transformer, material coefficient, correction factor for operating conditions

k	1.06 for oil transformers, 1.2 for resin-encapsulated transformer
k_a	costs of work
k_c	current distribution coefficient, dependent on geometrical arrangement
k_L	power costs
k_m	depends on material of isolation path
k_i	depends on lightning protection class
K_1	costs of a light fixture, capacity costs for amortization and interest
K_2	costs of installation and installation material
K_3	price of a lamp
K_4	costs of replacing a lamp
K_J	annual costs
K_A	proportionate acquisition costs
$K(P_0/P_k)$	operating costs resulting from no-load and short-circuit losses
K_u	maintenance costs
$K_{W,D}$	heat transfer coefficient
l	length
l_h	length of horizontal grounding electrode
l_v	length of vertical grounding electrode
l_1	minimum length of grounding electrode
m	decaying DC component, thermal effect of DC component with three-phase AC current and single-phase AC current
M_M	motor torque
$M_{M\Delta}$	motor torque for direct startup
$M_{M\mathrm{Y}}$	motor torque for star-delta startup
M_L	load torque (counter-torque)
M_{L0}	load breakaway torque
M_N	rated torque
M_A	pull-up torque
M_acc	accelerating torque
M_S	pull-up torque
M_K	breakdown torque
$M_L(M)$	load moment relative to motor shaft
n	speed of rotation, calculated number of lighting elements, thermal effect of AC current component with three-pole short-circuit, number of internal horizontal partitions, number of transformers in parallel, decaying AC current component, amortization time in years, number of loads

n_1	total number of lamps
n_2	number of lamps per lighting element
n_S	synchronous speed of rotation
n_M	speed of rotation of motor
n_L	speed of rotation of load
N	number of windings
N_c	permissible number of critical lightning strikes
N_d	strike frequency of the structural installation
N_g	lightning density
p	rate of interest
P_n	rated power
P_v	transformer power loss, control gear power loss
P	effective power, effective power loss of operational equipment installed in housing, power consumption of one lamp + control gear
P_L	lamp power
P_k	Short-circuit losses
$P_{\max}$	power requirement
P_i	installed power
P_{input}	power input
P_{output}	power output
P_d	output
P_0	no-load losses
P_{Vr}	equipment power losses
P_{Fe}	core losses
P_{Cu}	load losses
P_{rM}	rated power of motor
q	factor for the calculation of breaking currents of asynchronous motors
Q	reactive power
Q_v	dissipated losses
$Q_{W,D}$	losses dissipated through walls and ceiling
Q_{v1}	proportion in natural air stream
Q_{v2}	proportion through walls and ceiling
Q_{v3}	proportion in forced air stream
Q_T	no-load reactive power of transformer
r	average radius, percent capital costs from interest and amortization
R_A	sum of resistances of grounding electrode and protective conductor

R'_L	relative effective resistance of a conductor
R_E	grounding resistance
R_l	conductor resistance
R	pure resistance, equivalent resistance, costs of cleaning per light and per year
R_Q, X_Q	ohmic, inductive resistance of control gear network
R_T, X_T	ohmic, inductive resistance of transformer
R_L, X_L	ohmic, inductive resistance of network
R_{0T}, X_{0T}	ohmic, inductive no-load resistance of transformer
R_{0L}, X_{0L}	ohmic, inductive no-load resistance of network
R_{G}	resistance of generator
s	slip, protection ratio
S	apparent power, cross section of conductor
S''_k	short-circuit power
S_{rT}	rated power of individual transformer
S_{st}	load starting capability
$\sum P_{\mathrm{rM}}$	sum of rated effective powers
$\sum S_{\mathrm{rT}}$	sum of rated apparent powers
S''_{kQ}	initial symmetrical short-circuit apparent power
S_0	no-load apparent power of transformer
t	time
t_{ab}	cutoff time of overcurrent protection equipment
t_{zu}	permissible cutoff time
t_L	economic life of lamp
t_B	yearly time in use
t_a	cutoff time
T_B	operating time in years
T_a	starting temperature
T_e	end temperature
T_B	operating time
Δt	overtemperature of air in housing, general
$\Delta t_{0,5}$	overtemperature of air, internal, at half height of housing
$\Delta t_{0,75}$	overtemperature of air, internal, at three-quarters height of housing
$\Delta t_{1,0}$	overtemperature of air, internal, at upper edge of housing
Δu	percent voltage drop
ΔP	power loss
ΔU	voltage drop
U_E	ground potential rise

U_{T1}	touch voltage without potential grading (on concrete-footing grounding electrode)
U_{T2}	touch voltage without potential control (on concrete-footing grounding electrode + potential grading grounding electrode)
U_0	line-to-ground voltage
U_T	touch voltage
U_S	step voltage
U_{nQ}	rated voltage of network at connecting point Q
U	rated AC voltage between external lines, charging voltage
U_n	rated voltage of network
U_{rG}	rated voltage of generator
U_{rM}	rated voltage of motor
$''u$	transformation ratio
$''u_f$	fictitious transformation ratio
$''u_r$	rated value of transformation ratio for transformer with step switch at principal tapping
v	depreciation factor
V_L	amount of air
x	exponent
X	reactance, distance from concrete-footing grounding electrode
X''_d	subtransient reactance
X'_L	relative reactance of a conductor
Z	impedance
Z_1	positive-sequence impedance
Z_2	negative-sequence impedance
Z_0	zero-sequence impedance
Z_E	impedance of grounding electrode system
Z_Q	impedance of control network
Z_{PE}	impedance of protective conductor
Z_T	impedance of transformer
Z_v	source impedance
Z'	relative impedance
Z_F	fault impedance
Z_k	body impedance
Z_{st}	site impedance
Z_S	ground fault loop impedance
Z'_S	ground fault loop impedance, consisting of neutral conductor and protective conductor of circuit

Z_{TLV}	impedance of transformer (low voltage side)
Z_{THV}	impedance of transformer (high voltage side)
Z_{KW}	Corrected impedance of power plant block, relative to high voltage side
Z_G	impedance of generator
Z_M	short-circuit impedance of a motor
Z_{GK}	corrected impedance of generator
α	temperature coefficient
δ	loss factor
η	efficiency of gear system
η_b	lighting utilization factor
η_i	utilization factor
η_B	lighting utilization factor according to data sheet
ϑ	temperature
$\Delta\vartheta$	temperature rise
θ	conductor temperature
Θ	current linkage
$\Theta_{\max}$	highest temperature attained
κ	conductivity
ρ_m	density of conductor material
φ_{rG}	Phase angle between $U_{\mathrm{rG}}/\sqrt{3}$ and I_{rG}
$\cos\varphi$	power factor
$\sin\varphi$	reactive factor
Φ_n	lumens per lamp per lighting element $\times$ 0.95 correction factor
μ	factor for the calculation of the symmetrical short-circuit current

Abbreviations

A	aluminum conductor
AC1	non-inductive or weakly inductive load, resistance furnace
AC2	slipring motors: starting, switching off
AC3	squirrel cage motors: starting, switching off while running
AC4	squirrel cage motors: switching on, breaking by plugging, jogging
ASM	asynchronous motor
B	mine-type installations
BHKW	block heating power plant
CENELEC	European Committee for Electrotechnical Standards
CW	wave-shaped concentric conductor
DIN	German Standards Institute
DKE	German Electrotechnical Commission
ED	ON period
EN	European Norm
EPR	ethylene–propylene–rubber insulation
FE	concrete-footing grounding electrode
G	rubber insulation or generator
HKS	heating, climate, sanitary
HV	high voltage
IEC	International Electrotechnical Commission
L_1, L_2, L_3	external conductor
LEMP	lightning electromagnetic pulse
LV	low voltage
LVMD	main low voltage distribution panel
M	motor, switchgear
MDP	main distribution panel
MGT	main grounding terminal
MV	medium voltage
N	neutral conductor
OPE	overcurrent protection equipment
PE	protective conductor
PV	primary voltage (transformer) or harmonics
PVC	polyvinyl chloride insulation

R	semiconductor
RCD	residual current protective device
SEMP	switching electromagnetic pulse
SE	grading grounding electrode
SV	secondary voltage (transformer)
T	transformer
TAB	technical conditions for connection
UMZ	independent maximum time relays or independent maximum current protection (UMZ relays)
UVV	accident prevention regulations
VBG	accident prevention regulations of the BG
VDE	Union of Electrotechnical, Electronics and Information Technology
VdS	union of property insurers
VPE	cross-linked polyethylene insulation
Y	PVC insulation