Contents

xvii

Preface

1	Intr	roduction, review of electric circuits	1	
	Objectives and abstract			
	1.1 Introduction, power system structure, brief history of power sys			
	1.2	Electric circuit review		
		1.2.1 Linearity and superposition	6	
		1.2.2 DC vs AC power systems	7	
		1.2.3 Resistive, inductive, and capacitive circuit elements	10	
		1.2.4 Effective or RMS value	12	
	1.3	Phasor representation	13	
	1.4	Power in single-phase AC circuits	17	
	1.5	Power factor correction—brief introduction	22	
	1.6	Electrical energy	23	
	1.7	Measurement units used in energy systems	25	
	1.8 Chapter summary			
	Further readings			
	Que	estions and problems	28	
2	Power system basics			
	Objectives and abstract			
	2.1	Introduction, power system basics	33	
	2.2	Sources of energy	38	
	2.3	Power system structure and components	40	
	2.4	Three-phase systems	41	
		2.4.1 Balanced loads	46	
		2.4.2 Mixed connection circuits, wye-delta connection	48	
	2.5	Power relationships in three-phase circuits	49	
	2.6	6 Per-unit system		
	2.7	Voltage and frequency characteristics	56	
	2.8	Chapter summary	59	
	Further readings			
	Questions and problems			

3			ers and electrical motors	65 65		
			and abstract			
	3.1		uction	65		
		3.1.1	Transformers in electrical systems	66		
	2.2		Electromechanical energy conversion systems	67		
	3.2		former theory, construction, and design	68		
		3.2.1	Polarity of transformer windings	75		
			Practical (non-ideal) transformers	76		
			Voltage regulation	79		
		3.2.4	6	81		
		3.2.5		82		
			Transformer connections	85		
	2.2		Transformer efficiency	87		
	3.3		ectrical motors	88		
			Electric motor fundamentals	89		
			Synchronous motors	89		
	~ .		Induction motors	95		
	3.4	-	achines	102		
	3.5	-	er summary	110		
		her read	•	110		
	Que	stions a	nd problems	111		
4	Loa	d chara	acteristics, wiring, and power cables	115		
	Objectives and abstract					
	4.1 Introduction, building energy analysis, and electrical					
		design	n procedure	116		
		4.1.1	Electrical design procedure and building energy analysis	117		
		4.1.2	Branch circuits and feeders	118		
	4.2	Load	estimate and calculations	120		
		4.2.1	Convenience power, connected and demand loads	121		
		4.2.2	Lighting load estimate methods	127		
		4.2.3	Dedicated and general-purpose receptacle load estimates	131		
		4.2.4	Equipment, auxiliary, industrial, and motor load calculations	134		
		4.2.5	Heating, cooling, electric cooking, and laundry equipment	136		
		4.2.6	Load and correction factors estimate applications	141		
	4.3	Condu	actors and cables	144		
		4.3.1	Conductor types and sizes	144		
		4.3.2	Cable impedance calculations	149		
		4.3.3	Conductor ampacity	151		
		4.3.4	Cable corrections factors	152		
		4.3.5	Voltage drop calculation	156		
		4.3.6	Cable construction	157		
	4.4		g devices	162		
		4.4.1	Switches	162		
		4.4.2	Receptacles	164		
		4.4.3		166		

	4.5 Summary of the load computation procedure and cable siz	ing 167		
	4.6 Chapter summary	169		
	References and further readings	170		
	Questions and problems	171		
5	Power distribution, load, and motor centers			
	Outline and abstract			
	5.1 Introduction, power distribution, and electrical services	174		
	5.1.1 Electrical services and industrial power distribution			
	5.2 Power distribution networks	178		
	5.2.1 Power distribution configurations	179		
	5.2.2 Feeder voltage drops, electric distribution losses,			
	and power factor control	180		
	5.3 Power distribution system characteristics and components	186		
	5.3.1 Power distribution equipment and components5.3.2 Three-phase power distribution, grounded,	191		
	and ungrounded systems	192		
	5.3.3 Power distribution transformers and devices	196		
	5.4 Industrial power distribution and building power			
	supply systems	198		
	5.4.1 Switchgears, load, and motor centers	199		
	5.4.2 Switchgear and motor control center ratings	201		
	5.5 Chapter summary	203		
	References and further readings Questions and problems	204 205		
	Questions and problems	203		
6	g · · · · · · · · · · · · · · · · · · ·			
	Outline and abstract	207		
	6.1 Introduction, facility power supply calculations, and design			
	6.2 Building electrical system characteristics	210		
	6.3 Branch circuits and feeders	213		
	6.4 Cable installations, raceways, and conduits	217		
	6.5 Panel-boards and industrial power distribution	227		
	6.5.1 Panel-board and switchboards calculations and ratio6.5.2 Load and motor centers	ngs 227 229		
	6.5.3 Load center, switchgear and motor control center	229		
	ratings	231		
	6.6 Chapter summary	231		
	Further readings			
	Questions and problems			
	Questions and problems	234		
7		237		
	Objectives and abstract	237		
	7.1 Introduction, lighting basics	238		
	7.2 Lighting in engineering, architecture, industrial process,			
	and building operation	240		

	7.3	Lighti	ng theory and illumination calculation methods	242		
		7.3.1	Basic parameters used in lighting physics	243		
		7.3.2	The visible spectrum and color	251		
		7.3.3	Color specifications and characteristics	254		
		7.3.4	Light control and basic concepts in optics	257		
	7.4	Lighti	ng equipment and systems	260		
		7.4.1	Light sources and systems	261		
		7.4.2	Lamp efficiencies, control, and electrical requirements	269		
		7.4.3	Common lamp luminances and luminaires	273		
	7.5	Indoo	r and outdoor lighting design	278		
		7.5.1	Factors affecting the selection of the light sources			
			and equipment	279		
		7.5.2	Lighting design project structure and criteria	283		
		7.5.3	Indoor lighting design methods	284		
		7.5.4	Outdoor lighting design	292		
	7.6	Chapt	er summary	294		
	Refe	erences	and further readings	295		
	Que	stions a	nd problems	296		
8	Motor control and protection, drives, and applications					
	Obje	ectives	and abstract	299		
	8.1	Introd	uction	300		
	8.2	Poly-p	bhase induction motor control schemes and methods	302		
		8.2.1	Induction motor starting methods	304		
		8.2.2	Voltage drop during the start-up of induction motors	311		
		8.2.3	Induction motor speed control	313		
	8.3	Startir	ng and speed control of synchronous motors	318		
	8.4		otor protection methods	322		
		8.4.1	Unbalanced phase motor protection	324		
		8.4.2	Low voltage, undervoltage, voltage drop,			
			and break motor protection	325		
	8.5	Single	e-phase motor control	328		
	8.6	DC m	otor protection and control methods	330		
	8.7	Electr	ic drives	332		
	8.8	Summ	nary	335		
	Refe	erences	and further readings	336		
	Que	stions a	nd problems	337		
9	Wind and solar energy					
	Obje	Objectives and abstract				
	9.1	Introd	uction	339		
	9.2	Wind	energy	342		
		9.2.1	Wind energy resources	345		
		9.2.2				
			stability effects	348		

			Wind shear, wind profile, wind gust, and other	
			meteorological effects	350
			Wind velocity statistics	354
			Wind statistical models	356
			Rayleigh probability distribution	359
	9.3		lirection	360
	9.4		energy estimation	362
	9.5		nergy conversion systems	364
			Wind energy conversion system components	368
	9.6	Solar e		370
			Solar resources	373
	9.7	Photov		383
			PV cell manufacturing technologies	391
			PV modules and arrays	393
			PV system configuration and sizing	396
	9.8	-	r summary	397
			nd further readings	399
	Ques	tions an	d problems	400
10	Geot	hermal	energy, small hydropower, and bioenergy	405
			nd abstract	405
		Introd		406
	10.2	Geoth	ermal energy	407
			Geothermal energy origins and resources	410
		10.2.2		
			characteristics	415
		10.2.3	Direct use of geothermal energy	417
			Geothermal heat pumps	426
			Electricity from geothermal energy sources	430
	10.3		hydropower	434
			Small and mini hydropower	442
			2 Small hydroelectric power technology	448
			Generators and control	454
	10.4	Bioen	ergy, biofuel, biomass, and waste energy	457
	10.5		er summary	459
	Further readings			
			d problems	460 461
11	Fno	av etor	age systems	465
11			nd abstract	465
	11.1		uction and energy storage importance	405
	11.1		y storage functions and applications	400
	11.2	11.2.1		470
	11.3		y storage system types	473
	11.3	Energ 11.3.1		475
		11.3.1	Pumped hydroelectric energy storage (PHES)	4/0

		11.3.2 Compressed air energy storage (CAES)	479
		11.3.3 Electrochemical energy storage	483
		11.3.4 Battery operation principles and battery types	486
		11.3.5 Battery fundamentals, parameters, and electric circuit	
		models	492
		11.3.6 Flow batteries and special battery types	500
		11.3.7 Fuel cells and hydrogen energy	504
		11.3.8 Flywheel energy storage (FES)	512
		11.3.9 Superconducting magnetic energy storage	515
		11.3.10 Supercapacitors	519
	11.4	Chapter summary	521
	Refer	ences and further readings	522
	Quest	tions and problems	522
12	Distr	ibuted generation, microgrids, thermal energy storage,	
	and 1	micro-combine heat and power generation	527
	Objec	ctives and abstract	527
	12.1	Introduction, distributed, and dispersed generation	528
		12.1.1 Thermal engineering basics	531
	12.2	Energy conservation and efficiency in building	
		and industrial energy systems	539
	12.3	Thermal energy storage systems	543
	12.4	Microgrids and building integrated renewable	
		energy systems	549
		12.4.1 Microgrid concepts and architecture	550
		12.4.2 Building thermal energy storage applications	555
	12.5	Micro-combined heat and power generation	557
		12.5.1 Micro-combined heat and power system structure	
		and configurations	558
		12.5.2 Micro-CHP economics	561
	12.6	Chapter summary and discussions	562
		ences and further readings	563
	Quest	tions and problems	564
13	Ener	gy management, RES, and distributed generation economics	567
		ctives and abstract	567
		Introduction, DG, and RES economical aspects	568
	13.2	EMS in manufacturing, industrial, and commercial sectors	569
		13.2.1 Identification of energy usage factors and parameters	572
	13.3	Energy management principles and methods	576
	13.4	Energy audit and energy conservation	577
		13.4.1 Types and structure of energy audits	580
		13.4.2 Energy audit structure and phases	581
	13.5	Renewable energy economics	584

13.6 Cha	pter summary	586			
References	References				
Questions	and problems	588			
14 Post-face	and pedagogical suggestions	589			
14.1 Boo	ok overview	589			
14.2 Ped	agogical approaches and suggestions for instructors	590			
Appendix A	Common parameters, units, and conversion factors	593			
Appendix B	Design parameters, values, and data	599			
Appendix C	Design parameters, conversion factors, and data				
	for renewable energy conversion systems	609			
Index		613			