

# **ELECTRICAL ENERGY EFFICIENCY**

## **TECHNOLOGIES AND APPLICATIONS**

**Andreas Sumper**

*BarcelonaTech (UPC), Institute for Energy Research (IREC), Spain*

**Angelo Bagгинi**

*University of Bergamo, Italy*



A John Wiley & Sons, Ltd., Publication

# Contents

<b>List of Contributors</b>	<b>xi</b>
<b>Preface</b>	<b>xiii</b>
<b>Foreword</b>	<b>xv</b>
<b>1 Overview of Standardization of Energy Efficiency</b>	<b>1</b>
<i>Franco Bua and Angelo Baggini</i>	
1.1 Standardization	3
1.1.1 ISO	4
1.1.2 IEC	5
1.1.3 CEN and CENELEC	6
Further Readings	8
<b>2 Cables and Lines</b>	<b>9</b>
<i>Paola Pezzini and Andreas Sumper</i>	
2.1 Theory of Heat Transfer	10
2.1.1 Conduction	10
2.1.2 Convection	10
2.1.3 Radiation	11
2.2 Current Rating of Cables Installed in Free Air	12
2.3 Economic Aspects	15
2.4 Calculation of the Current Rating: Total Costs	16
2.4.1 Evaluation of $CJ$	16
2.5 Determination of Economic Conductor Sizes	18
2.5.1 Economic Current Range for Each Conductor in a Series of Sizes	18
2.5.2 Economic Conductor Size for a Given Load	18
2.6 Summary	19
References	19
<b>3 Power Transformers</b>	<b>21</b>
<i>Roman Targosz, Stefan Fassbinder and Angelo Baggini</i>	
3.1 Losses in Transformers	23
3.1.1 No-Load Losses	23
3.1.2 Load Losses	24

3.1.3	<i>Auxiliary Losses</i>	24
3.1.4	<i>Extra Losses due to Harmonics, Unbalance and Reactive Power</i>	25
3.2	Efficiency and Load Factor	30
3.3	Losses and Cooling System	31
3.4	Energy Efficiency Standards and Regulations	32
3.4.1	<i>MEPS</i>	37
3.4.2	<i>Mandatory Labelling</i>	37
3.4.3	<i>Voluntary Programmes</i>	37
3.5	Life Cycle Costing	39
3.5.1	<i>Life Cycle Cost of Transformers</i>	40
3.5.2	<i>Detailed Considerations</i>	44
3.6	Design, Material and Manufacturing	47
3.6.1	<i>Core</i>	47
3.6.2	<i>Windings</i>	52
3.6.3	<i>Other Developments</i>	54
3.7	Case Study – Evaluation TOC of an Industrial Transformer	54
3.7.1	<i>Method</i>	55
3.7.2	<i>Results</i>	56
	References	59
	Further Readings	59
3.A	Annex	60
3.A.1	<i>Selected MEPS</i>	60
<b>4</b>	<b>Building Automation, Control and Management Systems</b>	<b>71</b>
	<i>Angelo Baggini and Annalisa Marra</i>	
4.1	Automation Functions for Energy Savings	72
4.1.1	<i>Temperature Control</i>	72
4.1.2	<i>Lighting</i>	74
4.1.3	<i>Drives and Motors</i>	74
4.1.4	<i>Technical Alarms and Management</i>	75
4.1.5	<i>Remote Control</i>	76
4.2	Automation Systems	76
4.2.1	<i>KNX Systems</i>	77
4.2.2	<i>Scada Systems</i>	82
4.3	Automation Device Own Consumption	86
4.4	Basic Schemes	86
4.4.1	<i>Heating and Cooling</i>	86
4.4.2	<i>Ventilation and Air Conditioning</i>	95
4.4.3	<i>Lighting</i>	107
4.4.4	<i>Sunscreens</i>	109
4.4.5	<i>Technical Building Management</i>	110
4.4.6	<i>Technical Installations in the Building</i>	111
4.5	The Estimate of Building Energy Performance	113
4.5.1	<i>European Standard EN 15232</i>	113
4.5.2	<i>Comparison of Methods: Detailed Calculations and BAC Factors</i>	115
	Further Readings	124

<b>5</b>	<b>Power Quality Phenomena and Indicators</b>	<b>125</b>
	<i>Andrei Cziker, Zbigniew Hanzelka and Ireana Wasiak</i>	
5.1	RMS Voltage Level	126
5.1.1	<i>Sources</i>	127
5.1.2	<i>Effects on Energy Efficiency</i>	128
5.1.3	<i>Mitigation Methods</i>	130
5.2	Voltage Fluctuations	132
5.2.1	<i>Disturbance Description</i>	132
5.2.2	<i>Sources of Voltage Fluctuations</i>	134
5.2.3	<i>Effects and Cost</i>	135
5.2.4	<i>Mitigation Methods</i>	138
5.3	Voltage and Current Unbalance	138
5.3.1	<i>Disturbance Description</i>	139
5.3.2	<i>Sources</i>	140
5.3.3	<i>Effect and Cost</i>	140
5.3.4	<i>Mitigation Methods</i>	143
5.4	Voltage and Current Distortion	145
5.4.1	<i>Disturbance Description</i>	145
5.4.2	<i>Sources</i>	146
5.4.3	<i>Effects and Cost</i>	147
5.4.4	<i>Mitigation Methods</i>	153
	References	162
	Further Readings	162
<b>6</b>	<b>On Site Generation and Microgrids</b>	<b>165</b>
	<i>Irena Wasiak and Zbigniew Hanzelka</i>	
6.1	Technologies of Distributed Energy Resources	166
6.1.1	<i>Energy Sources</i>	166
6.1.2	<i>Energy Storage</i>	170
6.2	Impact of DG on Power Losses in Distribution Networks	175
6.3	Microgrids	178
6.3.1	<i>Concept</i>	178
6.3.2	<i>Energy Storage Applications</i>	180
6.3.3	<i>Management and Control</i>	182
6.3.4	<i>Power Quality and Reliability in Microgrids</i>	184
	References	186
	Further Readings	187
<b>7</b>	<b>Electric Motors</b>	<b>189</b>
	<i>Joris Lemmens and Wim Deprez</i>	
7.1	Losses in Electric Motors	190
7.1.1	<i>Power Balance and Energy Efficiency</i>	191
7.1.2	<i>Loss Components Classification</i>	193
7.1.3	<i>Influence Factors</i>	195
7.2	Motor Efficiency Standards	199
7.2.1	<i>Efficiency Classification Standards</i>	199

7.2.2	<i>Efficiency Measurement Standards</i>	200
7.2.3	<i>Future Standard for Variable Speed Drives</i>	207
7.3	High Efficiency Motor Technology	208
7.3.1	<i>Motor Materials</i>	210
7.3.2	<i>Motor Design</i>	218
7.3.3	<i>Motor Manufacturing</i>	224
	References	226
<b>8</b>	<b>Lighting</b>	<b>229</b>
	<i>Mircea Chindris and Antoni Sudria-Andreu</i>	
8.1	Energy and Lighting Systems	230
8.1.1	<i>Energy Consumption in Lighting Systems</i>	230
8.1.2	<i>Energy Efficiency in Lighting Systems</i>	231
8.2	Regulations	233
8.3	Technological Advances in Lighting Systems	234
8.3.1	<i>Efficient Light Sources</i>	234
8.3.2	<i>Efficient Ballasts</i>	239
8.3.3	<i>Efficient Luminaries</i>	241
8.4	Energy Efficiency in Indoor Lighting Systems	242
8.4.1	<i>Policy Actions to Support Energy Efficiency</i>	242
8.4.2	<i>Retrofit or Redesign?</i>	245
8.4.3	<i>Lighting Controls</i>	247
8.4.4	<i>Daylighting</i>	251
8.5	Energy Efficiency in Outdoor Lighting Systems	252
8.5.1	<i>Efficient Lamps and Luminaires</i>	253
8.5.2	<i>Outdoor Lighting Controls</i>	256
8.6	Maintenance of Lighting Systems	259
	References	260
	Further Readings	261
<b>9</b>	<b>Electrical Drives and Power Electronics</b>	<b>263</b>
	<i>Daniel Montesinos-Miracle, Joan Bergas-Jané and Edris Pouresmaeil</i>	
9.1	Control Methods for Induction Motors and PMSM	266
9.1.1	<i>V/f Control</i>	266
9.1.2	<i>Vector Control</i>	271
9.1.3	<i>DTC</i>	272
9.2	Energy Optimal Control Methods	274
9.2.1	<i>Converter Losses</i>	275
9.2.2	<i>Motor Losses</i>	276
9.2.3	<i>Energy Optimal Control Strategies</i>	276
9.3	Topology of the Variable Speed Drive	276
9.3.1	<i>Input Stage</i>	277
9.3.2	<i>DC Bus</i>	278
9.3.3	<i>The Inverter</i>	279
9.4	New Trends on Power Semiconductors	280

9.4.1	<i>Modulation Techniques</i>	281
9.4.2	<i>Review of Different Modulation Methods</i>	283
	References	291
	Further Readings	193
<b>10</b>	<b>Industrial Heating Processes</b>	<b>295</b>
	<i>Mircea Chindris and Andreas Sumper</i>	
10.1	General Aspects Regarding Electroheating in Industry	298
10.2	Main Electroheating Technologies	302
10.2.1	<i>Resistance Heating</i>	302
10.2.2	<i>Infrared Heating</i>	309
10.2.3	<i>Induction Heating</i>	314
10.2.4	<i>Dielectric Heating</i>	318
10.2.5	<i>Arc Furnaces</i>	325
10.3	Specific Aspects Regarding the Increase of Energy Efficiency in Industrial Heating Processes	326
10.3.1	<i>Replacement of Traditional Heating Technologies</i>	327
10.3.2	<i>Selection of the Most Suitable Electrotechnology</i>	329
10.3.3	<i>Increasing the Efficiency of the Existing Electroheating Equipment</i>	330
	References	333
	Further Readings	334
<b>11</b>	<b>Heat, Ventilation and Air Conditioning (HVAC)</b>	<b>335</b>
	<i>Roberto Villafáfila-Robles and Jaume Salom</i>	
11.1	Basic Concepts	336
11.2	Environmental Thermal Comfort	338
11.3	HVAC Systems	342
11.3.1	<i>Energy Conversion</i>	344
11.3.2	<i>Energy Balance</i>	346
11.3.3	<i>Energy Efficiency</i>	347
11.4	Energy Measures in HVAC Systems	348
11.4.1	<i>Final Service</i>	348
11.4.2	<i>Passive Methods</i>	348
11.4.3	<i>Conversion Device</i>	351
11.4.4	<i>Energy Sources</i>	353
	References	354
	Further Readings	355
<b>12</b>	<b>Data Centres</b>	<b>357</b>
	<i>Angelo Baggini and Franco Bua</i>	
12.1	Standards	357
12.2	Consumption Profile	358
12.2.1	<i>Energy Performance Index</i>	360
12.3	IT Infrastructure and Equipment	360
12.3.1	<i>Blade Server</i>	360
12.3.2	<i>Storage</i>	361

12.3.3	<i>Network Equipment</i>	361
12.3.4	<i>Consolidation</i>	362
12.3.5	<i>Virtualization</i>	362
12.3.6	<i>Software</i>	363
12.4	Facility Infrastructure	363
12.4.1	<i>Electrical Infrastructure</i>	363
12.4.2	<i>HVAC Infrastructure</i>	365
12.5	DG and CHP for Data Centres	368
12.6	Organizing for Energy Efficiency	369
	Further Readings	370
<b>13</b>	<b>Reactive Power Compensation</b>	<b>371</b>
	<i>Zbigniew Hanzelka, Waldemar Szpyra, Andrei Czikar and Krzysztof Piątek</i>	
13.1	Reactive Power Compensation in an Electric Utility Network	373
13.1.1	<i>Economic Efficiency of Reactive Power Compensation</i>	377
13.2	Reactive Power Compensation in an Industrial Network	380
13.2.1	<i>Linear Loads</i>	381
13.2.2	<i>Group Compensation</i>	383
13.2.3	<i>Nonlinear Loads</i>	387
13.3	Var Compensation	391
13.3.1	<i>A Synchronous Condenser</i>	391
13.3.2	<i>Capacitor Banks</i>	392
13.3.3	<i>Power Electronic Compensators/Stabilizers</i>	393
	References	398
	Further Readings	398
<b>Index</b>		<b>399</b>