Peter Zacharias (Editor)

Use of Electronic-Based Power Conversion for Distributed and Renewable Energy Sources

20 Years of Research on Power Conversion Systems

ISET

1 Technical Innovations for Sustainable Energy Supply 1
by J. Schmid

1.1 Requirements and Strategy 1
1.2 Integrated Supply Systems 1
1.3 Carbon Capture and Storage (CCS) 2
1.4 Power Grids with Distributed Sources 2
1.5 The Role of Renewable Energy Sources 3
1.6 Bibliography 7

2 Common Information and Requirements to Power Conversion Components and Systems for Utilization of Distributed Energy Resources (DER) 9
by P. Zacharias

2.1 General Aspects of Utilization of DER and Distributed Power Supply Systems 9
2.2 Components of DER Systems with Basic Requirements of Power Conditioning 12
2.3 Stand Alone and Grid Connected Applications and their Characteristics 24

3 Power Electronic Converters for Utilization of Distributed Energy Resources 27
by S. Araújo, T. Bülo, B. Sahan, P. Zacharias

3.1 General Definitions 27
3.2 Method to Compare Different Circuitries 29
3.3 Basic DC/DC Converters with Unipolar Output 36
3.4 Basic DC/DC Converters with Bipolar Output 42
3.5 Basic Hard Switching DC/DC Converters with Isolating Transformer 46
3.6 Basic Soft Switching DC/DC Converters with Isolating Transformers 56
3.7 Basic DC/AC Converter Circuits for Single-Phase Systems with PWM 65

4 Basics on DC/AC Converters 79
4.1 Development and Basic Function of an Inverter 79
by J. M. A. Myrzik
4.2 Introduction into Synthesis of Output Voltage at Switch Mode DC/AC Converters 89
by P. Zacharias
4.3 Multilevel Inverter Topologies with Staircase Output Voltage, ... 100
by S. Daher
4.4 Topological Development of Power Converter Systems 133
by J. M. A. Myrzik

5 Systems for DC/AC Conversions 147
5.1 Use of Power Converters for Decentralised Energy Supply*[B1] 147
by B. Burger, W. Kleinkauf, P. Zacharias
5.2 The Multi-String Converter Concept for PV Systems*[B2] 158
by M. Meinhardt, G. Cramer, B. Burger, P. Zacharias
5.3 Inverters for Modular and Extendable Electric Energy Supply Systems*[B3] 168
by B. Burger, P. Zacharias, G. Cramer, W. Kleinkauf
5.4 Design and Benchmark of a Multilevel Converter for Large-Scale Wind Power Systems*[B4] .. 176
by B. Sahan, S. V. Araújo, A. Engler, F. L. M. Antunes
5.5 Development of a Single-Stage Three-Phase PV Module Integrated Converter*[B5] 187
by B. Sahan, A. Notholt-Vergara, A. Engler, P. Zacharias, N. Henze
5.6 Performance of a Novel Three-Phase Photovoltaic Inverter for Module Integration*[B6] 201
by N. Henze, A. Engler, B. Sahan

6. Common Design Approaches of Highly Efficient Electronic Power Conversion Systems **211**
by P. Zacharias

6.1 Power Dissipation in Semiconductor Devices 211
6.2 The DC Link for Voltage Source Inverters 230
6.3 Electrical Connections and Lines – Layout of Conductors for the Power Connections 243
6.4 Overvoltage Protection 255
6.5 Service Life Duration of Power-Electronic Component Parts 258

7 Microgrids and Hybrid Systems **267**
7.1 Analysis of Inverter-Controlled Island Grids – Transient Simulations with ATP-EMTP and PowerFactory*[B7] 267
by M. Braun, T. Degner, A. Engler

7.2 Microgrid Management with a High Share of Renewable Energy Sources*[B8] 272
by M. Vandenbergh, A. Engler, R. Geipel, M. Landau, Ph. Strauss

7.3 Using Minigrids for Stabilizing the Main Grid*[B9] 280
by D. Coll-Mayor, A. Notholt, A. Engler and E. García-Moreno

7.4 10 Years Hybrid System 'Starkenburger Hütte' (Starkenburg Lodge) – Operating Experience with an Innovative System Concept*[B10] 287
by M. Landau, H. Deubler

7.5 Experiences with the Electrification of a Gambian Village*[B8] 296
by R. Geipel, P. Isfort, M. Landau, J. Schmid, P. Schweizer-Ries, P. Strauß, M. Vandenbergh

7.6 Interconnection of Solar Powered Mini-Grids – A Case Study for Kythnos Island*[B11] 302
by T. Degner, P. Taylor, D. Rollinson, A. Neris, S. Tselepis

7.7 Expandable Hybrid Systems for Multi-User Mini-Grids*[B12] 311
by M. Vandenbergh, S. Beverungen, B. Buchholz, H. Colin, N. Ketjoy, F. Kininger, D. Mayer, J. Merten, J. Reekers, Ph. Strauss, T. Suwannakum, X.Vallvé

8 Ancillary Services and Grid Integration of Distributed Power *Sources* **321**
8.1 Technological Control Capabilities *of DER* to Provide Future Ancillary Services*[B13,B23] 321
by M. Braun

8.2 Reactive Power Supplied by PV Inverters – Cost-Benefit-Analysis*[B6] 333
by M. Braun

8.3 Reactive Power Supplied by Wind Energy Converters – Cost-Benefit-Analysis*[B14] 346
by M. Braun

8.4 Simulation Model Based Control Development of a Multifunctional PV-Inverter*[B5] 362
by D. Geibel, J. Jahn, R. Juchem

8.5 An Overview on the Integration of Large-Scale Wind Power into the Electric Power System*[B15] 375
by R. P. S. Leão, T. Degner, F. L. M. Antunes

8.6 Extended Operation Control to Integrate German (Offshore) Wind Farms*[B16] 391
by M. Wolff, R. Mackensen, G. Füller, B. Lange, K. Rohrig, F. Fischer, L. Hofmann, S. Heier, B. Valov

8.7 Wind Power Prediction in Germany – Recent Advances and Future Challenges*[B17] 398
by B. Lange, K. Rohrig, B. Ernst, F. Schlögl, Ü. Cali, R. Jursa, J. Moradi

8.8 Condition Monitoring and Maintenance Strategies for the Next Generation of Large Offshore Wind Turbines*[B16] 407
P. Caselitz, J. Giebhardt

8.9 Cold Climate Wind Energy Co-Operation Under the IEA*[B17] 413
by T. Laakso, L. Tallhaug, R. Horbaty, I. Baring-Gould, A. Lacroix, E. Peltola, M. Durstewitz, L. Battisti

8.10 +15 Years Practical Experiences with Wind Power in Germany*[B17] 421
by M. Durstewitz, C. Ensslin, B. Hahn, K. Rohrig

9 Power Management with Distributed Sources in Public Grids 431

9.1 Decentrally Organized Energy Management in the Electric Distribution Grid – Integration of the Low Voltage Level into Grid Communication and Control 431
by C. Bendel, D. Nestle, J. Ringelstein

9.2 Trends in Intelligent Systems, the Web, and e-Services in Energy*[B18] 444
by J. M. (Hans) Akkermans

10 Control Technology for Systems with Network Interconnection and in Isolated Operation 451

10.1 Modeling of Power Converter Systems 451
by J. M. A. Myrzik

10.2 Fast Signal Conditioning in Single Phase Systems*[B12,B19] 461
by B. Burger, A. Engler

10.3 Applicability of Droops in Low Voltage Grids*[B7,B24] 473
by A. Engler

11 Safety Aspects for Decentralised Grid Connected Power Supply Systems 485

11.1 Analysis of the Safety and Reliability of Decentralised Grid-Connected Energy Generating Plants 485
by S. Malcher

11.2 Examination of the Performance of Decentralised Energy Generating Plants under Different Grid Connection Conditions 495
by C. Bendel, G. Klein, D. Nestle, M. Ries, M. Viotto

11.3 Investigation of PV Inverters on the Direct Voltage Side – Line and non-Line Conducted 547
by C. Bendel, P. Funtan, J. Kirchhof, G. Klein

11.4 Testing for Design of Safe PV Inverters 610
by C. Bendel, P. Funtan

11.5 Technical Solutions and Trial Results 632
by C. Bendel, H. Faßhauer, J. Kirchhof, D. Nestle, M. Viotto

11.6 Investigations on Mains System Reactions of Photovoltaic Inverters in the Example of the Olympic Village in Sydney*[B20] 666
by P. Zacharias, E. D. Spooner

11.7 Reactive Energy in Case of Megawatt PV Systems*[B21] 675
by T. Degner, A. Shustov, B. Decker, C. Hennig

Annex

A Alphabetical Index of the Authors 679

B Table of Conferences 682

C Acknowledgement 684

* *Indices refer to Annex B*