Partial Power Processing Converters:

The Myth, Reality and Proper Implementation of a Groundbreaking Concept

Abstract— Power electronics and power conversion in general is today part of every segment of our life. Any piece of electric equipment we have today is somehow based on power electronics and converters; home appliance, industrial equipment, renewable energy, automotive, avionic, etc., etc. Conversion efficiency, specific power, power density and converter cost are today the most critical requirements for new converters. One way to increase the efficiency and reduce cost/size/weight is to deploy multi-level and/or multi-cell converters and partial power processing power converters. A novel solution to ultra-high efficiency and specific power dc/dc converters has been proposed and theoretically investigated in this tutorial. The solution is based on the fact that in most of application we do not need to process entire dc bus voltage and output current. We can process a fraction of the dc bus voltage and/or the load current. In other words, we do not need to process the converter total rated power; we would process just a fraction of the rated power. This is so-called concept of Partial Power Rated Converters (PPRC). Typical target applications are PV boost converters, energy storage (batteries and ultra-capacitors) interface converters, isolated ac/dc power supplies, electric drives, etc., etc.

Advantages of the PPRC concept, such as significant reduction of the input/output filter size & weight, voltage rating of power devices and conduction/switching losses are theoretically investigated and discussed in the tutorial. Various applications such as energy storage interface converters, isolated ac-dc converters and double feed electric machines are also discussed.

Several case studies and design examples are given in concluding part of the tutorial. One particular design example presented in the tutorial is 25kW battery interface dc/dc converter. An extraordinary efficiency of 99.5%, specific power of 30kW/kg and power density of 50kW/dm^3 have been achieved.

This tutorial is aimed at power electronics engineers, professionals and graduate students who want to improve their knowledge and understanding of advanced concepts of power conversion, such as Partial Power Rated Converters and applications.

CONTENT

I. Fundamentals of Solid-State Power Converters (5min)

Fundamentals and history of solid-state power conversion will be briefly presented in the first part of the tutorial. Perspectives and future development of power converters will be addressed too.

II. Concept of Asymmetrical Partial Power Rated Converters (45 min)

Motivation and background of Partial Power Rated Converters (PPRC) concept is given in this part of the tutorial. Then, the PPRC is analyzed in details.

III. Voltage Balancing (15 min)

The problem of partial dc bus voltage balancing issue is discussed in this part of the tutorial. Possible arrangements of the voltage balancing device and power rating versus the input-to-the output voltage ratio are presented and analyzed in details.

IV. Series Resonant Converter as the Voltage Balancing Device (15min)

One way to balance partial dc bus voltages is to deploy Series Resonant Converter (SRC) as the Voltage Balancing Circuit (VBC). Detailed analysis of SRC VBC is given in this part of the tutorial. Steady state operation as well as transient analysis and modelling of the SRC operating in DCM will be discussed.

Different control modes of SRC such as Resonant Mode and Quantum Mode will be analyzed and discussed in details. By operating the SRC in Quantum Mode (i.e. DCM2), the voltages across dc bus capacitors can be regulated. Modelling of SRC in this mode of operation will be discussed, and design example will be given.

The benefits of multi-cell interleaved SRC as an active VBC will be presented and discussed in details.

V. Input Series Output Parallel (ISOP) Connected Converters as the PPRC (10min)

In this part of the tutorial, we will discuss the Input Series Output Parallel (ISOP) and the Input Parallel Output Series (IPOS) connected converters. The ISOP & IPOS are Multi-Cell & Multi-Level converters that combine the advantages of parallel and series interleaving. This concept can also be used as a part of the PPRC where the dc bus partial voltage is automatically balanced without additional balancing devices and converters.

VI. Concept of Symmetrical Partial Power Rated Converters (45 min)

Motivation and background of Symmetrical Partial Power Rated Converters (S-PPRC) concept is given in this part of the tutorial. Then, the S-PPRC is analyzed in deep details.

VII. Protection and Fault Management (15min)

Last but not lease, protection and fault management of partial power rated converters will be address

VIII. Case Studies (45 min)

Several real-life application examples and design cases will be given and discussed at the end the tutorial:

a) 25kW Ultra-Efficient and Compact dc/dc Converter for Energy Storage Grid Connected Applications,
b) 20kVA 5-Level E-Type Converter for LV Power Quality Applications,
c) High-Power Density DC-DC Converters for High-Power LED Applications,
d) Voltage Balancing Device for High Power Ultra-Capacitor Cells and Modules…
e) 30kW Ultra-Efficient and Compact dc/dc Converter for PV Applications,
f) Ultra-Dense & Efficient AC-DC Converter for Portable Welding Tools (16kW, 40V @ 400A),

The Tutorial Presenter 1:

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Univ.-Prof. Dr. Petar J. Grbović received the Dipl. Ing. (B. Sc.) and the Magister degrees from the School of Electrical Engineering, University of Belgrade, Serbia, in 1999 and 2005, and the Doctor (Ph.D) degree from the Laboratoire 'Électrotechnique et d'Électronique de Puissance de Lille, l'Ecole Centrale de Lille, France in 2010.

From March 1999 to February 2003, he was an R/D Engineer with RDA Co, Belgrade. From November 2000 to June 2001, he was a Consulting Engineer with CESET Italy (a division of Emerson Appliance Motors Europe). From March 2003 to April 2005, he was with the R&D Department, PDL Electronics, Ltd., Napier, New Zealand. Since April 2005 until July 2010, he was working with Schneider Toshiba Inverter Europe, Pacy-Sur-Eure, France, as Power Electronics Group Expert. Since September 2010 until August 2011, he was with General Electric Global Research, Munich, Germany. Since September 2011 until September 2018, he was with HUAWEI Technologies, Europe Energy Competence Centre in Munich/Nuremberg, Germany, where he worked as a Senior Expert in the area of power electronics and power conversion. In March 2016 he was appointed to position of the scientific committee of Centre of Power Electronics and Drives, C-PED Lab., Roma TRE University, Italy. In June 2018 he was appointed to position of Full Professor at Innsbruck Power Electronics Laboratory (the i-PEL), the University of Innsbruck, Austria.

The focus of his research is on application of advanced energy storage devices, active gate driving for high power IGBTs and SiC MOSFETs, power converter topologies, advanced power semiconductor devices and control of power converters and semiconductor switches.

Prof. Grbović published 30 IEEE journal papers, 60 IEEE conference papers, 29 IEEE tutorials and a book "Ultra-capacitors in power Conversion Systems: Analysis, Modelling and Design in Theory and Practice". He has 17 US & EP patents granted and 9 international patent applications pending.

The Tutorial Presenter 2:

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Prof. Dr. Thierry A. Meynard graduated from the Ecole Nationale Supérieure d'Electrotechnique, d'Electronique, d'Hydraulique de Toulouse in 1985, became a Doctor of the Institut National Polytechnique de Toulouse, France, in 1988 and was then an invited researcher at the Université du Québec à Trois Rivières, Canada, in 1989. He joined the CNRS (Centre National de la Recherche Scientifique) as a full-time researcher in 1990, was Head of the Static Converter Group from 1994 to 2001. From 2010 to 2018 he has been associate director of the national program 3DPHI (3-Dimensional Power Hybrid Integration). He is now Directeur de Recherches CNRS at the LAPLACE(*), but in parallel he has been also involved in several industry-related activities.

Thierry A. Meynard has been part-time consultant with Cirtem from 2000 to 2016. In 2016 he co-founded and became scientific advisor at the company Power Design Technologies that develops PowerForge, the software for design of 2- and multi-level power converters later acquired by Gamma Technologies. Since January 2020, he is also acting as an independent consultant to transfer more innovation into industrial products.

His main research interests are related to series and parallel multicell converters, magnetic components and the development of design tools for power electronics.