TUTORIAL TITLE:

Ultra-Capacitors in Power Conversion

-Applications, Analysis and Design from Theory to Practice-

NAME AND AFFILIATION OF THE AUTHOR:

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SCOPE AND BENEFITS:

This tutorial is about ultra-capacitors short term energy storage and applications in power conversion. The tutorial is particularly focused on analysis, modeling and design of ultra-capacitor modules and interface dc-dc power converters in general.

Why power conversion and energy storage are important?

Power conversion systems and power electronics play significant role in our everyday life. It would be difficult to imagine a power conversion application such as industrial controlled electric drives, renewable sources, power generation and transmission devices, home appliance, mobile diesel-electric gen-sets, earth moving machines and equipment, transportation, etc., etc without power electronics and static power converters. In most of these applications, we are facing stronger and stronger demand for a device that is able to store and re-store certain amount of energy during short period. The energy storage device should be able to quickly store and restore energy at very high power rate. Charging and discharging time is from few seconds up to few tens of seconds. The charging power density is in order of 5 to 10kW/kg. Today, two energy storage technologies fit well into such requirements: 1) Flywheel energy storage and 2) Electrochemical double layer capacitors (EDLC), well known as the ultra-capacitors. In this tutorial, the ultra-capacitors are addressed only.

THE TUTORIAL CONTENT:

I. Energy Storage Technologies & Devices

Fundamentals and history of energy storage technologies and devices will be presented in the first part of the tutorial. State of the art energy storage technologies and devices will be briefly described.

II. Ultra-capacitor Energy Storage Device

Background theory of ultra-capacitors will be given in the second part of the tutorial. The ultra-capacitor modeling with attention to the application oriented model will be given. Method to compute the ultra-capacitor current stress and power losses for different conditions will be discussed. We will see how the ultra-capacitor losses depend on the charge/discharge frequency

and how the losses can be computed when the charge/discharge current frequency is in range of mHz (very low frequency) and in range of couple of Hz (low frequency). Thermal modeling and analysis of ultra-capacitor cells and modules will also be discussed in details.

III. Fundamentals of Power Conversion & Ultra-capacitor Applications

Fundamentals and history of static power converters and applications will be given in the third part of the tutorial. The need for short term energy storage in today's power conversion application sis then addressed and discussed. A structure of a typical power conversion system with ultra-capacitor energy storage will be presented. Different power conversion systems such as Variable speed drives, Renewable sources (wind for example), RTGC, Earth moving equipment, Mobile diesel-electric gen-sets, STATCOM and other power transmission devices with short term active power capability, UPS and Traction drives will be discussed in some details. Main application issues and possible solutions will be discuses in details. Simplified control scheme for each application will be addressed too.

IV. Design and Selection of Ultra-capacitor Modules

In the fourth part the tutorial, we will discuss selection and design of the ultra-capacitor module. We will see how the ultra-capacitor rated voltage and capacitance should be selected according to the application requirement. Then, losses and efficiency of the ultra-capacitor module versus size and cost will be discussed. Couple of application examples such as variable speed drives will be given. Finally, some aspects of the ultra-capacitor module design will be presented. Series connection of elementary ultra-capacitor cells and voltage balancing issue will be discussed. The module thermal design and thermal management will be considered too. The analysis and design guidelines will be covered by several examples from real applications such as low and medium power variable speed drives, high power UPS and special low power STATCOM applications.

V. Interface dc-dc converters for energy storage applications: Analysis & Design

The interface dc-dc converters will be discussed in the fifth part of the tutorial. Firstly, we will clearly explain the need for the interface power converter in ultra-capacitor applications. Then, state of the art topologies will be briefly compared according to the applications requirement. Two-level multi-cell interleaved dc-dc converter is one of the best candidates for high power applications. This topology will be analyzed in details. Design of the inter-cell transformer, filter inductor, dc bus capacitor and power semiconductors will be addressed in details. Modeling & control of two-level multi-cell interleaved converters will also be discussed. The analysis and design guidelines will be covered by couple of real examples such as low and medium power variable speed drives, high power UPS and specific low power STATCOM applications.

Note: The tutorial material is based on the book "**Ultra-Capacitors in Power Conversion: Applications, Analysis and Design from Theory to Practice**" which will be published in Q3/2013, the publisher IEEE & John Wiley and Sons, Ltd.

SCHEDULE :

Monday, September 2nd - Tutorial day (Location: University of Lille)

08:00 - 09:30	Registration for **Tutorials**
09:30 - 11:00	**1. Energy Storage Technologies and Devices** 1.1. Introduction 1.2. Direct Electrical Energy Storage Devices 1.3. Indirect Electrical Energy Storage Technologies and Devices 1.4. Applications and Comparison **2. Ultra-Capacitor Energy Storage Device** 2.1. Background of Ultra-Capacitors 2.2. Electric Double Layer Capacitors -EDLC 2.3. Macro (Electric Circuit) Model 2.4. Energy and Power 2.5. Charge/Discharge Methods 2.6. Frequency Related Losses 2.7. The Ultra-capacitor Thermal Aspects 2.8. Ultra-capacitor High Power Modules 2.9. The Ultra-capacitors Trends and Future Development
11:00 - 11:30	**Coffee break & Discussion**
11.30 - 13:00	**3. Fundamentals of Power Conversion & Ultra-capacitor Applications** 3.1. Static Power Converters: From Yestarday to Tomorow 3.2. Interest of Power Conversion with Energy Storage 3.3. Controlled Electric Drive Applications 3.4. Renewable Energy Sources Applications 3.5. Autonomous Power Generators and Applications 3.6. Energy Transmission and Distribution Applications 3.7. Uninterruptible Power Supplies (UPS) Applications 3.8. Electric Traction Applications 3.9. Generalization & Applications Summary
13:00 - 14:00	**Lunch break**
14:00 - 15:30	**4. Ultra-capacitor Module Selection and Design** 4.1. Introduction 4.2. The Module Voltage Rating and Voltage Levels Selection 4.3. The Capacitance Determination 4.4. Ultra-capacitor Module Design 4.5. Ultra-capacitor Modules Thermal Management 4.6. Testing of Ultra-capacitor Cells & Modules
15:30 - 16:00	**Coffee break & Discussion**

16:00 - 17:30	**5. Interface DC-DC Converters: Analysis & Design** 5.1. Introduction 5.2. Background & Classification of Interface DC-DC Converters 5.3. State of the Art Interface dc-dc Converters 5.4. The Ultra-capacitor Current and Voltage Definition 5.5. Multi-cell Interleaved DC-DC Converters 5.6. Design of Two-level N-cell Interleaved dc-dc Converters 5.7. Modeling and Control of Two-level N-cell Interleaved dc-dc Converters 5.8. Conversion Power Losses: A General Case Analysis 5.9. Power Converters Thermal Management: A General Case Analysis

WHO SHOULD ATTEND?

This full day tutorial is mainly aimed at power electronics engineers and professionals who want to improve their knowledge and understanding of advanced ultra-capacitor energy storage devices and their application in power conversion, nowadays as well as in near future. Moreover, a part of the tutorial can be useful for students and engineers who want to improve knowledge of advanced dc-dc converters for energy storage applications in general.

Technical Level: The tutorial attendees are expected to have basic knowledge in math, theory of electric circuits and systems, electromagnetic, power electronics and control systems.

FEW WORDS ABOUT THE INSTRUCTOR:

Dr. Petar J. Grbović received the Dipl. Eng. (B. Sc) and M.Sc. 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 he is with HUAWEI Technologies, Europe Energy Competence Center in Munich/Nuremberg, Germany, where he works as a Senior Expert in the area of power electronics and power conversion.

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

Dr. Grbović holds four US and European patents, nine US and European patent applications and five US patent applications in filing process. He is *IEEE* Senior Member of Power Electronics and Industrial Electronics society and PCIM Conference Advisory Committee Member.