IECON 2022 Tutorial Proposal Form

- **Title of the Proposal:**
  Utilizing Medium Voltage SiC MOSFETs in Power Conversion Applications: State of the art, Challanges, and Future perspective
- **Presenter(s):**
  Professor, Stig Munk-Nielsen, Aalborg University
  Associate Professor, Michael Møller Bech, Aalborg University
  Research Assistant and Work package leader, Jannick Kjær Jørgensen, Aalborg University
  Postdoc, Dipen Narendra Dalal, Aalborg University
  Postdoc, Hongbo Zhao, Aalborg University
  Senior Specialist and work package leader, Bjørn Rannestad, KK Wind Solutions
- **Brief description:**
  As one of the newest actions to achieve neutral CO_2 emissions by 2050, Germany, Denmark, Netherlands, and Belgium are aiming to build 150 gigawatts offshore wind farms in the North Sea (35 times larger than the electricity consumption in Denmark today), to produce more green electricity.

  Inside the wind turbines, power electronics converters equipped with 1200V-1700V IGBTs are the state-of-the-art solution. The renewable industry shows us, that the lGBT-based converter topologies require approximately 1000 A per megawatts of power. Hence in order to achieve larger-scale electric energy conversion, it will require a single power electronic unit to convert up to 15 MW power from the offshore turbine. It implies that the currents will be in the range of 15 kA using the conventional low voltage power electronic solution, where significant losses are caused by both switching and conduction. For a commercial power electronics converter system based on IGBTs, the efficiency is around 97%, which means about 4.5 gigawatts (double consumption of Denmark @2021) of electricity in future north sea wind farms will be wasted by undesired losses using the conventional IGBT-based solutions, where the economic loss is billions of euros every year in the future north sea wind farm, as well as other renewable energy farms.

  The medium-voltage SiC MOSFETs, one of the advanced wide-bandgap power semiconductors, is still in the engineering phase. At Aalborg University, we are funded and supported by three world-leading wind industry companies to conduct research on the use of advanced power semiconductors for two-level medium-voltage power converters. A 50 kVA MV converter using advanced power semiconductors has been designed and tested, where the efficiency is above 99% with hard switching and a 5 kHz switching frequency. In the demonstrated system, we have studied special considerations on power module packagings, gate drivers, coolings, and magnetic filters with ultra-low capacitive couplings, where such capacitive couplings are the bottlenecks for the demonstrated medium-voltage system.

  With the successful implementation of medium-voltage SiC MOSFETs, the future high-power wind turbines, e.g., in the north sea wind farm, can still use a simple two-level topology but operate at a higher voltage with higher power and efficiency. We estimate the overall efficiency of the power electronic units in turbines using medium-voltage SiC MOSFETs to be around 98%-99%, with 1%-2% loss reductions. Just using the future north sea wind farm as an example, by applying the new medium-voltage technology, 1.5-3 gigawatts can be saved, which corresponds to billions of euros per year or the total electricity consumption of Denmark.

During the perspective tutorial, we would like to share our current outcomes, challenges, and future perspectives on the power electronic converters using the advanced medium-voltage SiC MOSFETs. The application is not limited to wind energy generation only, the technology can be extended to applications such as: ultra-fast EV chargers, electrical onboard ship systems, and applications with high demand for efficient energy conversion.

Acknowledgment: Innovation Fund Denmark grant for the project: MVolt 'Medium voltage power electronics for wind systems'. Three industrial partners support the project, including Vestas A/S, Siemens Gamesa, and KK wind solutions.

- **Duration:** 180 mins
- **Outline:**

Slot 1:
Part 1: Background and Introduction to power electronics in future energy system
Presenter: Stig Munk-Nielsen
Duration: 30 mins + 5 mins Q&A
Abstract: The background and state-of-the-art power electronics technology will be introduced in Part 1. Conventional energy systems are using traditional power electronics semiconductors, e.g., diodes, thysistors, or IGBTs, which implies more loss or less control freedoms. Mordern power electronics components enabled by wide-bandgap components brings several significant advantages, but at the same time, results in design challenges. The gains and pains of power electronics in future energy system will be introduced. The novel medium voltage SiC MOSFETs will be introduced and compared with other compoments.

Part 2: Medium-voltage or low-voltage? Insights from industrial applications.
Presenter: Bjørn Rannestad
Duration: 20 mins + 5 mins Q&A
AbstractMotivation and hypothesis for using 10 kV SiC MOSFETs will be introduced. A comparison between conventional power semiconductors and wide-bandgap semiconductors will be presented. The unique characteristics of medium-voltage SiC power semiconductors will be introduced. The demonstrated power electronics converter system enabled by 10 kV SiC MOSFETs will be introduced.

Part 3: Packaging techniques, challenges, and opportunities for 10 kV SiC MOSFETs
Presenter: Jannick Kjær Jørgensen
Duration: 25 mins + 5 mins Q&A
Abstract: Power modules made with SiC MOSFETs shows new challenges compared with conventional technology. We must understand the new constraints we face and realize the design paradigm may have to change for the new achievable voltage levels. With a focus on understanding "where does the energy go" we will use this guiding principle to challenge conventional design strategies and talk about opportunities that can come when we move away from these.

Slot 2:

Part 4: Challages in utilizing MV SiC MOSFET in MV Power Converstion applications
Presenter: Dipen Narendra Dalal
Duration: 25 mins + 5 mins Q&A
Abstract: In this part, the challenges with regards to utilizing MV SiC devices in the practical power conversion applications will be discussed with focus on: power modules, gate drivers, measurement circuits.

Part 5: Integrate magnetic components to 10 kV SiC MOSFETs
Presenter: Hongbo Zhao
Duration: 25 mins + 5 mins Q&A
Abstract: The challenges for integrating magnetic components with 10 kV SiC MOSFETs will be introduced first. The importance of parasitic capacitance in magnetic components will be highlighted. Two different modeling methods, including physics-based modeling method and behavioral-based modeling method, will be introduced to characterize the parasitic capacitive couplings. Methods for reducing parasitic capacitance in filter inductors will also be shared.

Part 6: A power cycling test setup for converters enabled by medium voltage SiC MOSFETs
Presenter: Michael Møller Bech
Duration: 25 mins + 5 mins Q&A
Abstract: The power cycling test platform for evaluating the medium voltage power electronic converters will be introduced and the approaches for the power loss estimation will be presented.

- **Motivation and Focus:** Briefly explain why this topic is important for IES community and outline the learning outcome (No more than 600 words)

Reliable and sustainable green energy is one of the most important action to combat climate change. The perspective contents shared in this tutorial can introduce a novel and efficient solution for the industry to convert and distribute megawatt renewable energy in the future power conversion applications.

The advanced 10 kV SiC MOSFETs is not commercial yet. However, according to our ongoing research project at Aalborg University, we already see promising features of utilizing in future high-power (MW-level) energy conversion applications with increased 1-2% system-level efficiency, which can save hundreds of gigawatts electricity for the world in the future.

However, utilizing the MV SiC MOSFETs in practical applications imposes challagnes for power electronic converter designer. One of the most significant challenges is how to deal with the fast switching transitions, which is a double-edged sword in using advanced technology. On the one hand, the fast switching behaviors can help to increase the system-level efficiency with reduced switching loss. On the other hand, the fast switching behaviors introduce side-effects to the system, where the high-frequency capacitive current can be generated and further result in electromagnetic interface issues and saturation of switching devices.

Using the advanced 10 kV SiC MOSFETs can also attract interest from other shareholders of electrical systems. The switching frequency of future large-scale power electronics in the system can be increased, where the IES members with a background of control and system optimizations may utilize the superior characteristics. The voltage level of future large-scale power electronics can also be increased, where the IES members of the electric system architect can design the future electric system with more efficient but simpler topologies.

During the presentation, besides introducing the outcomes of our research, we will also highlight the remaining challenges and our perspectives on using this advanced technology. The challenges on material for better dielectric and thermal characteristics may also inspire the IES members with more ideas. The vision of the advanced technology and future high-power electric energy system can also motivate relevant IES members to expand the technology to more applications, e.g., power-to-X applications, ultra-fast EV charger stations, solid-state transformers, and more.

- **Brief CV:** Photo, name, email, and a short CV (relevant to the proposal).

Stig Munk-Nielsen

Email: smn@energy.aau.dk

Stig Munk-Nielsen is currently Professor at the Department of Energy Technology, Aalborg University, Denmark. Since 2008 Stig worked with circuits for monitoring of high power IGBT voltage drop for failure analysis purpose and the team managed to install monitoring systems in off-shore wind turbine in 2018. Since 2013 we secured funding for a die packaging team and laboratory facilities for 10 kV SiC devices and later on we did numerous application designs with GaN, Si and other SiC devices. The packaging facilities inaugurated in 2017 is a key enabler to the goal of extending the team experience with digital design framework, where the team initially included the L, C parasitic of power module layouts. In current projects, we want to extend our experience from electric, thermal design framework to include mechanical wear out. The application examples include medium voltage Wind Turbine converters and low voltage pump motor drive systems technology.

Bjørn Rannestad

Email: bjran@kkwindsolutions.com

Bjørn Rannestad is currently the senior specialist for Power Converters, Global Technology & Innovation at KK Wind Solutions, Denmark. He has 14 years of experience in the development and research for wind turbine power electronic converters. Since 1999, he has been involved in power electronics design and manufacturing. In 2019, he finished the industrial Ph.D. program at Aalborg University, with a focus on megawatt power electronics converters for wind turbines. He has published more than 20 patent applications and academic papers on various power electronic topics.

Jannick Kjær Jørgensen

Email: jkj@energy.aau.dk

Jannick Kjær Jørgensen is currently a research assistant at the Department of Energy Technology, Aalborg University, Denmark. He got his Master's in Nanomaterials and Nanophysics from Aalborg university in 2018. He has been working on design and manufacture of medium voltage SiC-based power modules since 2018, with a particular focus on challenges with scaling power of these. His research interests include parasitics in medium voltage systems, and manufacturing and design constraints of SiC power modules.

Dipen Narendra Dalal
Email: dnd@energy.aau.dk

Dipen N. Dalal received the M.Sc. degree in Energy Engineering with specialization in Power Electronics and Drives, PhD degree from Department of Energy, Aalborg University, Denmark in 2016 and 2021, respectively. He is currently working as a Postdoctoral researcher with Department of Energy, Aalborg University. His research interests include wide band-gap power semiconductor devices and medium voltage high power converters.

Hongbo Zhao

Email: hzh@energy.aau.dk

Hongbo Zhao received the Ph.D. degree in Power Electronics from Aalborg University, Denmark, in 2021. Currently, he is a Postdoc Researcher with Aalborg University, Aalborg, Denmark. His research interests include high-frequency modeling and analysis of high-power magnetics and filters, as well as medium-voltage converters enabled by wide band-gap power devices. He has published 1 international patent and more than 20 papers.

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Michael Møller Bech

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Michael M. Bech earned the Ph.D. degree in Power Electronics and Drives in 2000 from Aalborg University, Energy Department. He is currently an Associate Professor in Mechatronics and Power Electronics at the same university. He has 27 years of experience with research and development and he works a part-time consultant to Danish companies. His interests include power electronic converters, motor drives and their control, system design optimization and experimental work in these fields.

- **Relevant publications:** Maximally 5 publications including edited books

[1] B. Rannestad, K. Fischer, P. Nielsen, K. Gadgaard and S. Munk-Nielsen, "Virtual Temperature Detection of Semiconductors in a Megawatt Field Converter," in IEEE Transactions on Industrial Electronics, vol. 67, no. 2, pp. 1305-1315, Feb. 2020, doi: 10.1109/TIE.2019.2901662.

[2] D. N. Dalal, H. Zhao, J. K. Jorgensen, N. Christensen, A. B. Jorgensen, S. Beczkowski, C. Uhrenfeldt, and S.M. Nielsen, "Demonstration of a 10 kV SiC MOSFET based Medium Voltage Power Stack," 2020 IEEE Applied Power Electronics Conference and Exposition (APEC), 2020, pp. 2751-2757, doi: 10.1109/APEC39645.2020.9124441.

[3] H. Zhao et al., "Parasitic Capacitance Modeling of Inductors Without Using the Floating Voltage Potential of Core," in IEEE Transactions on Industrial Electronics, vol. 69, no. 3, pp. 3214-3222, March 2022, doi: 10.1109/TIE.2021.3068677.

[4] J. K. Jorgensen, D. N. Dalal, S. Beczkowski, S. Munk-Nielsen and C. Uhrenfeldt, "Multi-chip Medium Voltage SiC MOSFET Power Module with Focus on Low Parasitic Capacitance," CIPS 2020; 11th International Conference on Integrated Power Electronics Systems, 2020, pp. 1-6.

[5] J. Jacobsen, B. Kjærsgaard, D. N. Dalal, H. Zhao, Z. Yan, M. M. Bech, S. Munk-Nielsen, B. Rannestad, "Test Platform for Comparative Evaluation of 690 V – 4160 V Power Electronic Converters,"2022 IEEE 13th International Symposium on Power Electronics for Distributed Generation Systems, accepted.