Circuits and Systems for Power Management and Conversion

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Outline

- Current trends on power conversion and management
- Activities and projects

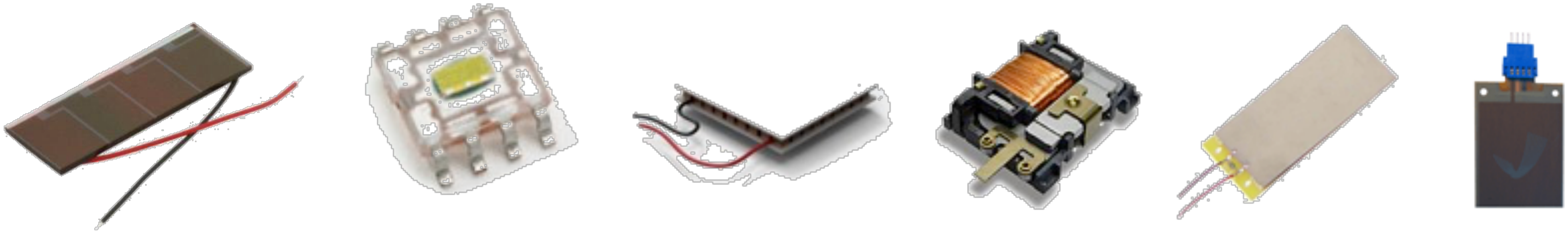
Current trends on power conversion and management

Main Drivers

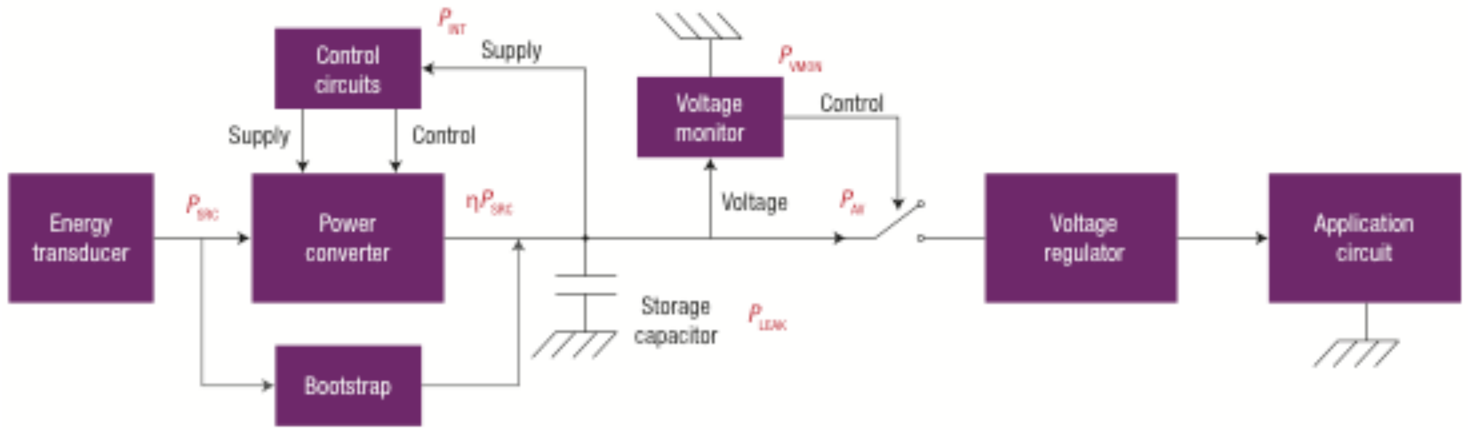
- Long-lasting battery-powered devices
- Pervasive and miniaturized electronics
- Sustainability and carbon neutrality
- Microgrids and Renewables
- Electric mobility
- Data Centers
- …

Energy Harvesting

- Power is scavenged by the environment by using specific transducers exploiting different physical effects



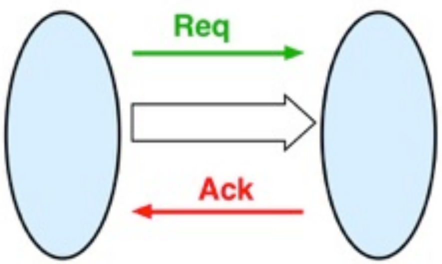
- Typical power levels ranging from µW to mW: need for trade-offs in power conversion, management and delivery

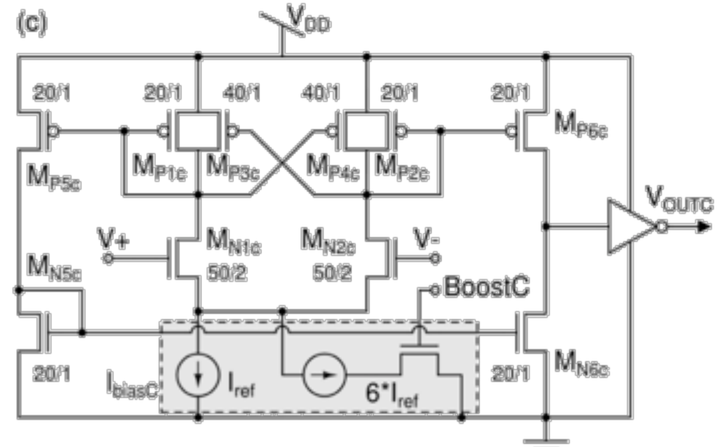


Energy Harvesting

- Open challenges
  - managing μW and below

asynchronous control logic



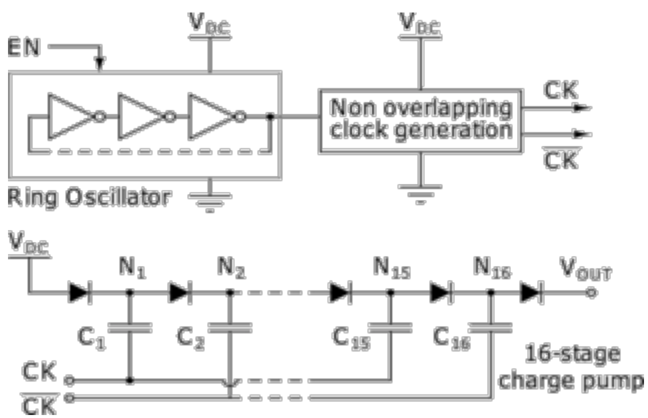


nano-current dynamically boosted bias currents

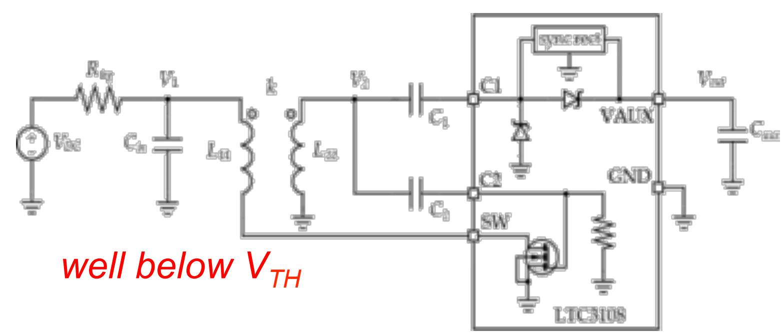
  - battery-less operation with ultra-low voltages down to few mV

slightly below V_{TH}:

an oscillator starts driving a charge pump



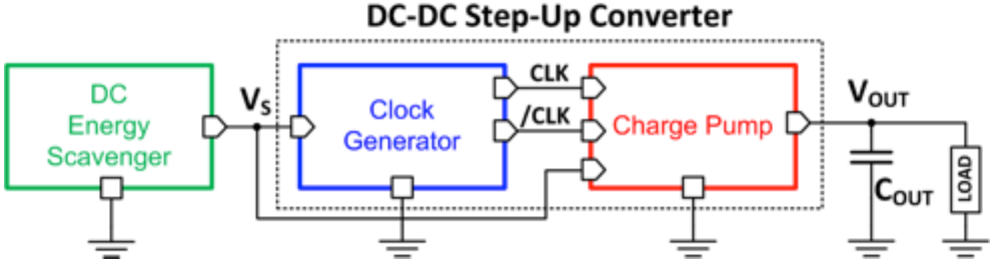
well below V_{TH}

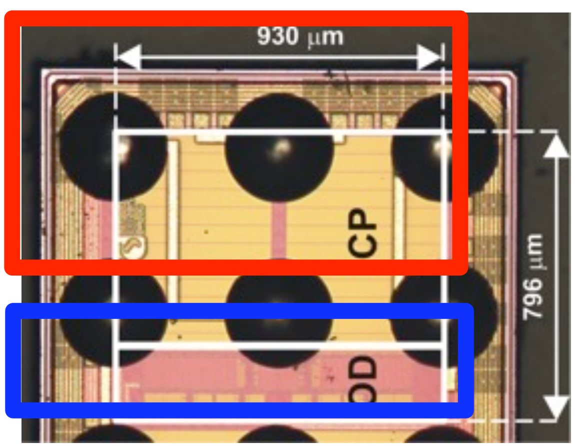


step-up oscillators exploiting magnetic or piezoelectric transformers

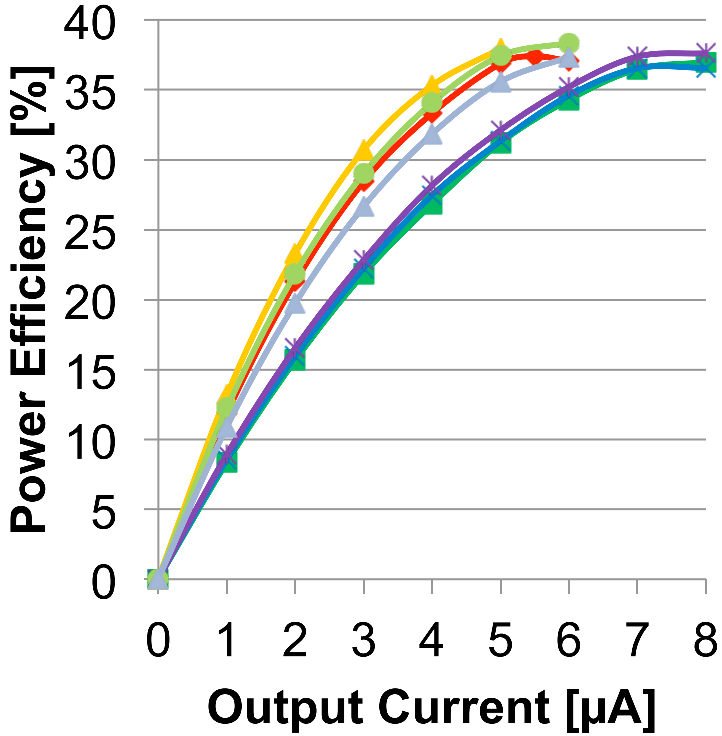
Energy Harvesting

- Open challenges
  - Inductorless implementations: switched-capacitor DC/DC converters are expected to play a significant role in several micro-power applications



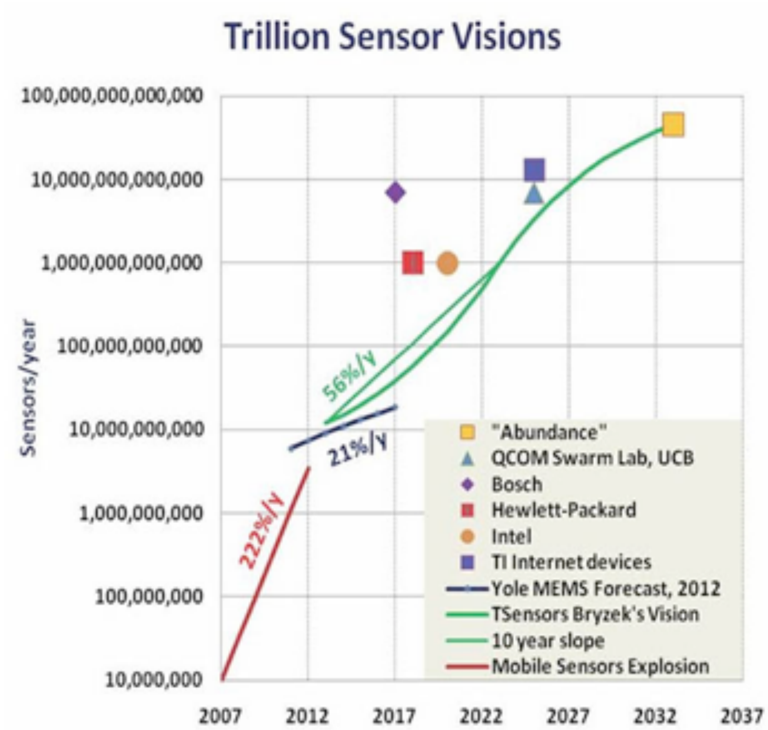


55 nm CMOS TSMC



Power Management for IoT

- The vision
  - integration (heterogeneous modules with different and highly variable current demands)
  - pervasivity



J. Bryzek, Emergence of Trillion Sensors Movement, IEEE MEMS, 2014

Power Management for IoT

- Open challenges
  - increased time between recharges
    → conversion efficiency, reduced consumptions
  - low stand-by currents
    →reduce impact of AC/DC in stand-by, quiescent currents from batteries
  - long-term reliability
    → shaping battery currents, fault prevention/protection
  - integration of heterogeneous modules with different and highly variable current demands
    → dynamic modulation of bias currents and control loops, light load efficiency, voltage scaling

Power management for data centers

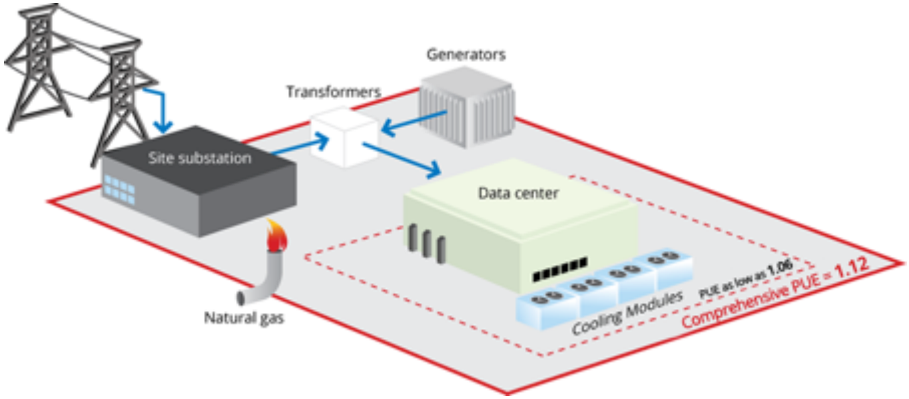
Internet is responsible of the consumption of the 2% of the world use of energy*.

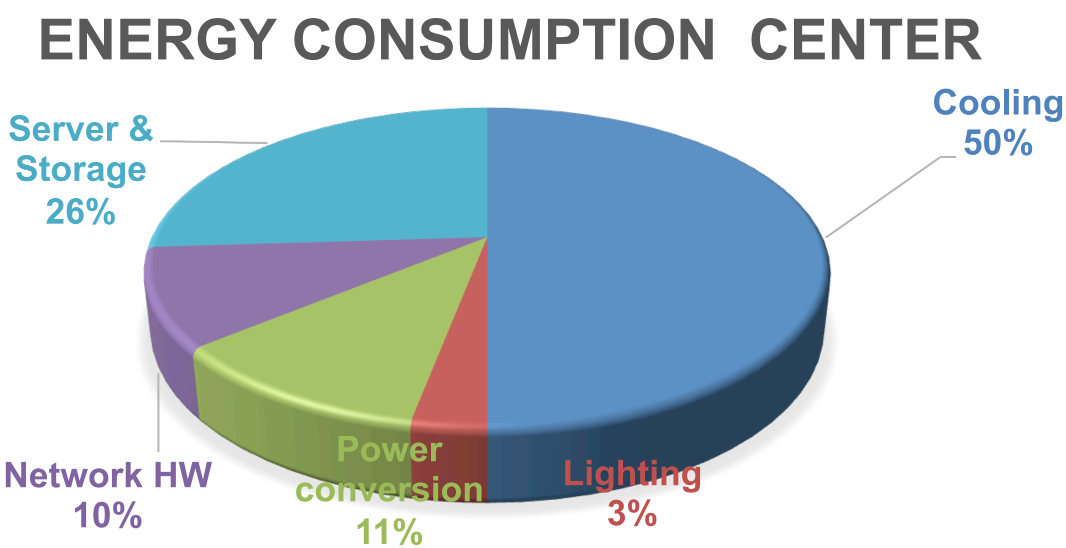
** The Energy and Emergy of the Internet*
Barath Raghavan and Justin Ma,Proceedings of the ACM Workshop on Hot Topics in Networks (HotNets), November 2011.

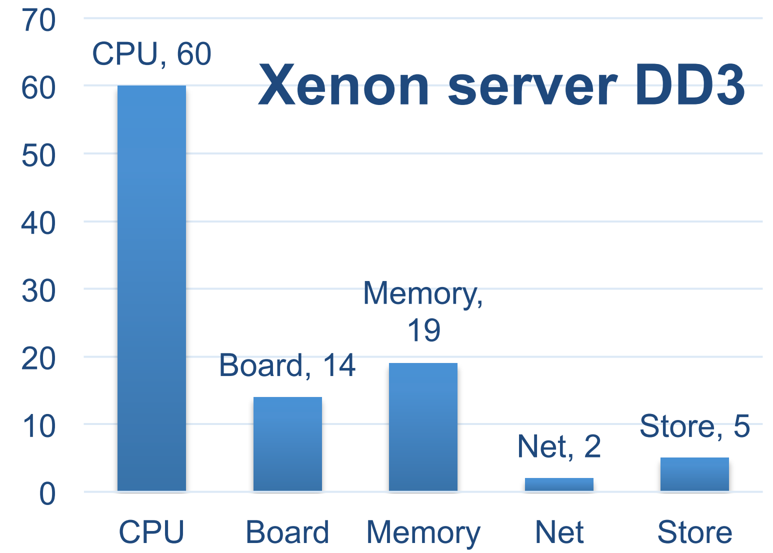
Power Management for Data Centers

- PUE is the metric used (power usage effectiveness)

$PUE = P_T / P_{IT}$
P_T = total power
P_{IT} = power information technology
Usually is 1.8 but there are examples of data centers with 1.05

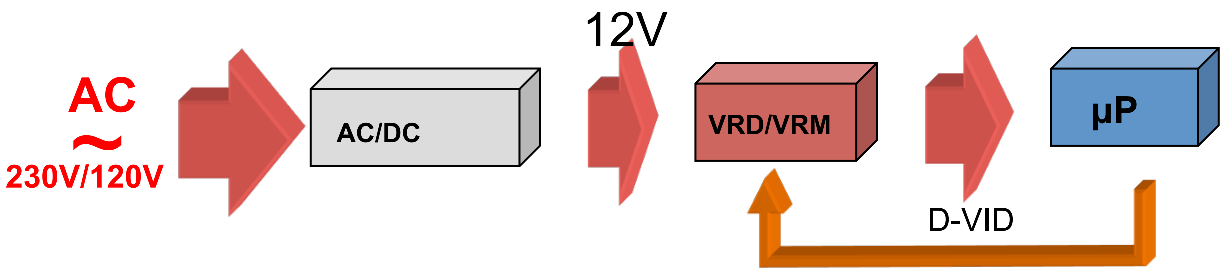




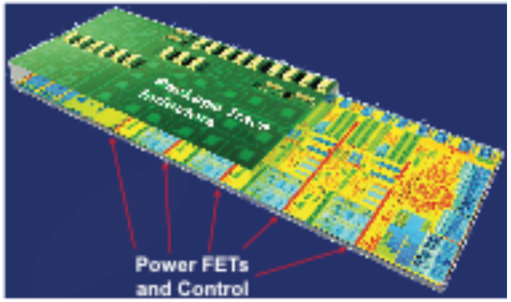


Power distribution in data centers

- State of the art



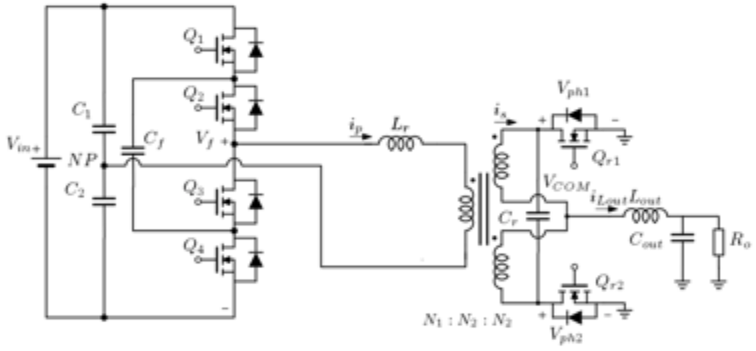
Conversion on Package



- Alternative solutions

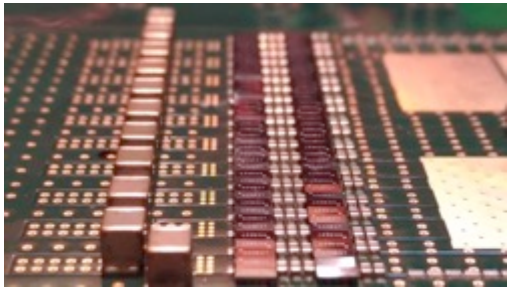
48V Direct conversion
1.8V 240A

400V Direct conversion
1.8V 240A



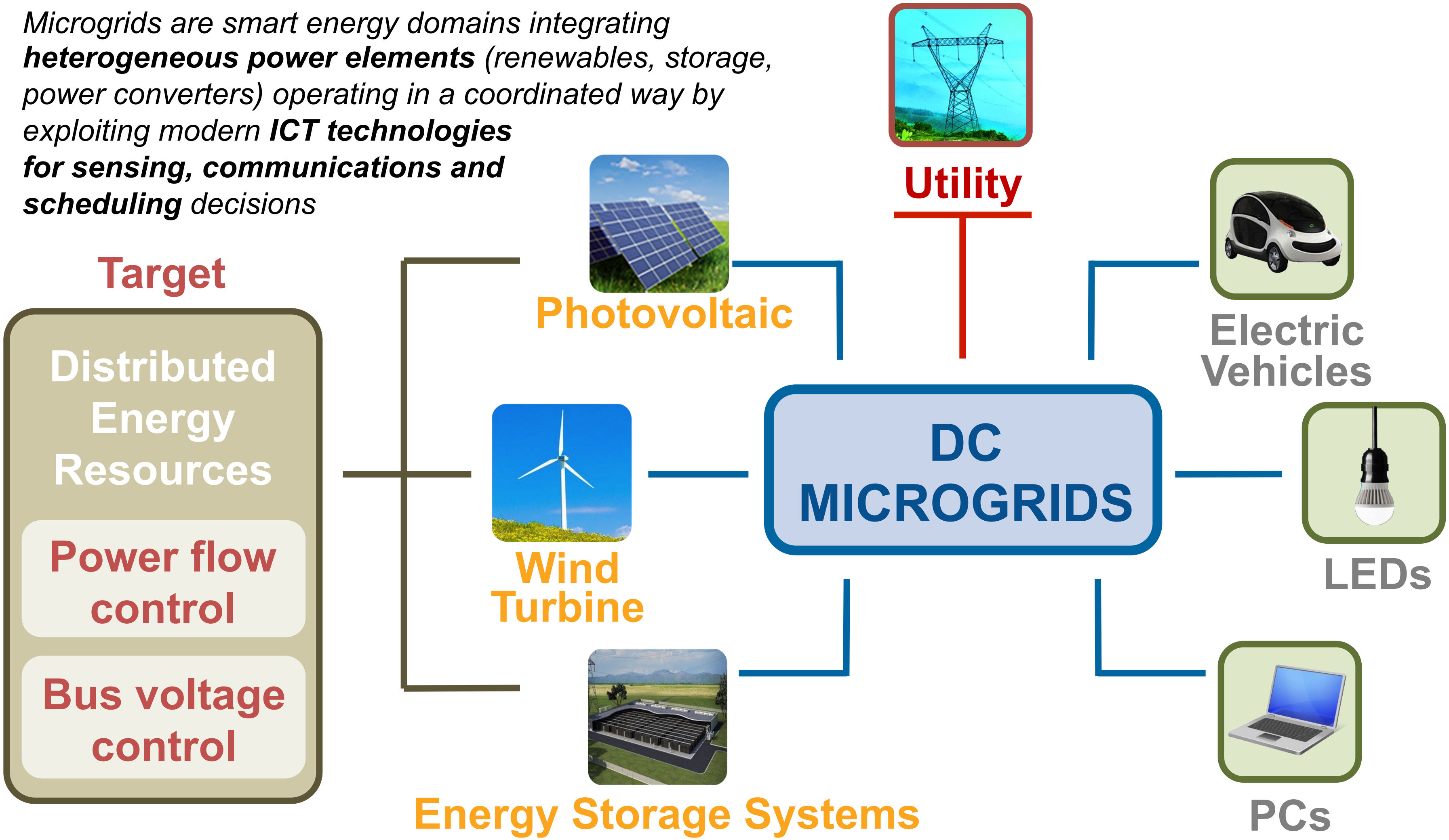
New topologies on package

2cmX5cm 400A 0.8V



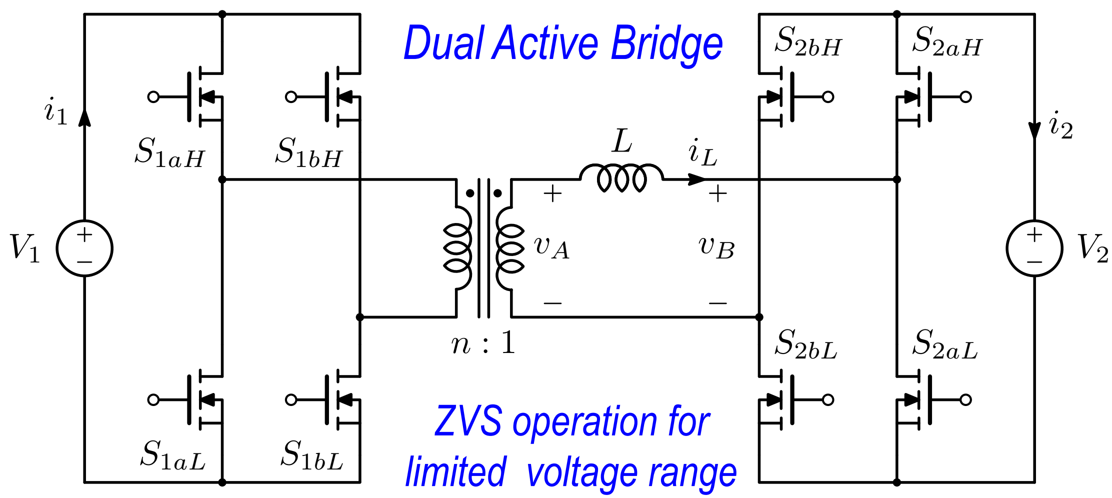
DC Microgrids

*Microgrids are smart energy domains integrating **heterogeneous power elements** (renewables, storage, power converters) operating in a coordinated way by exploiting modern **ICT technologies for sensing, communications and scheduling** decisions*

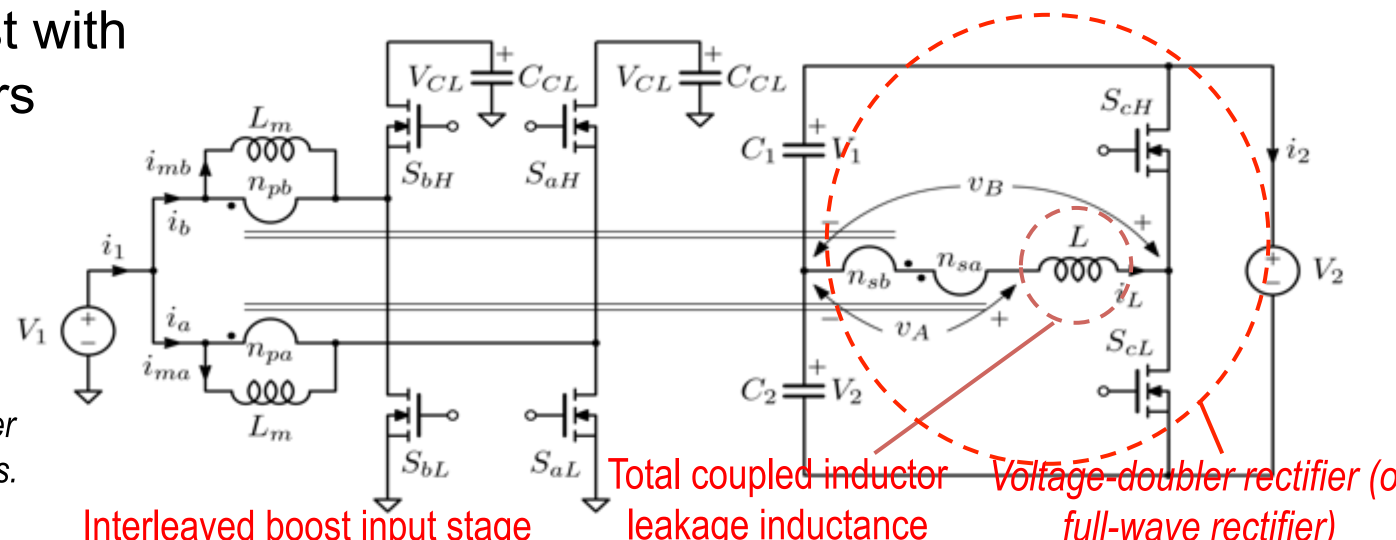


Power Conversion in DC Microgrids

- Need of interfacing low voltage energy sources (i.e. 48V) to a higher DC voltage bus (i.e. 400V)



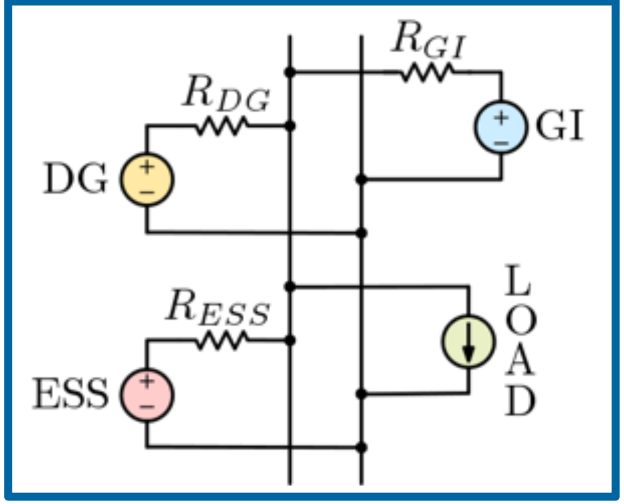
- Interleaved Boost with Coupled Inductors (IBCI)



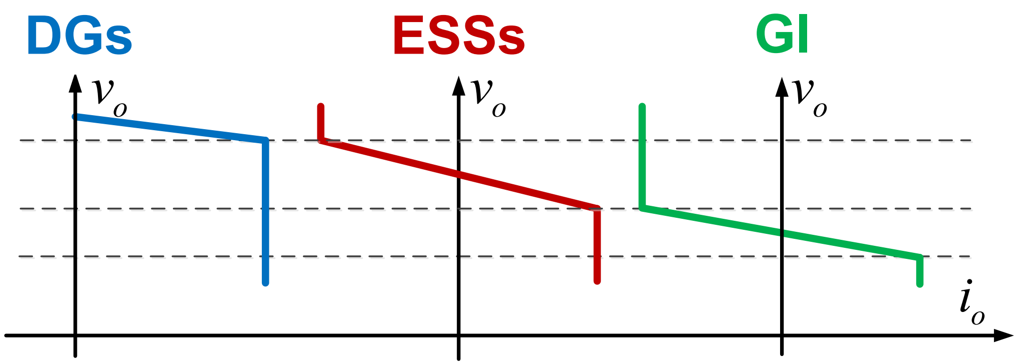
[1] G. Spiazzi et al: "Analysis of the Interleaved Isolated Boost Converter With Coupled Inductors" IEEE Trans. Ind. Elect., 2015

Control of DC Microgrids

$$v_{ref} = V_0 - R_d \times i_o$$



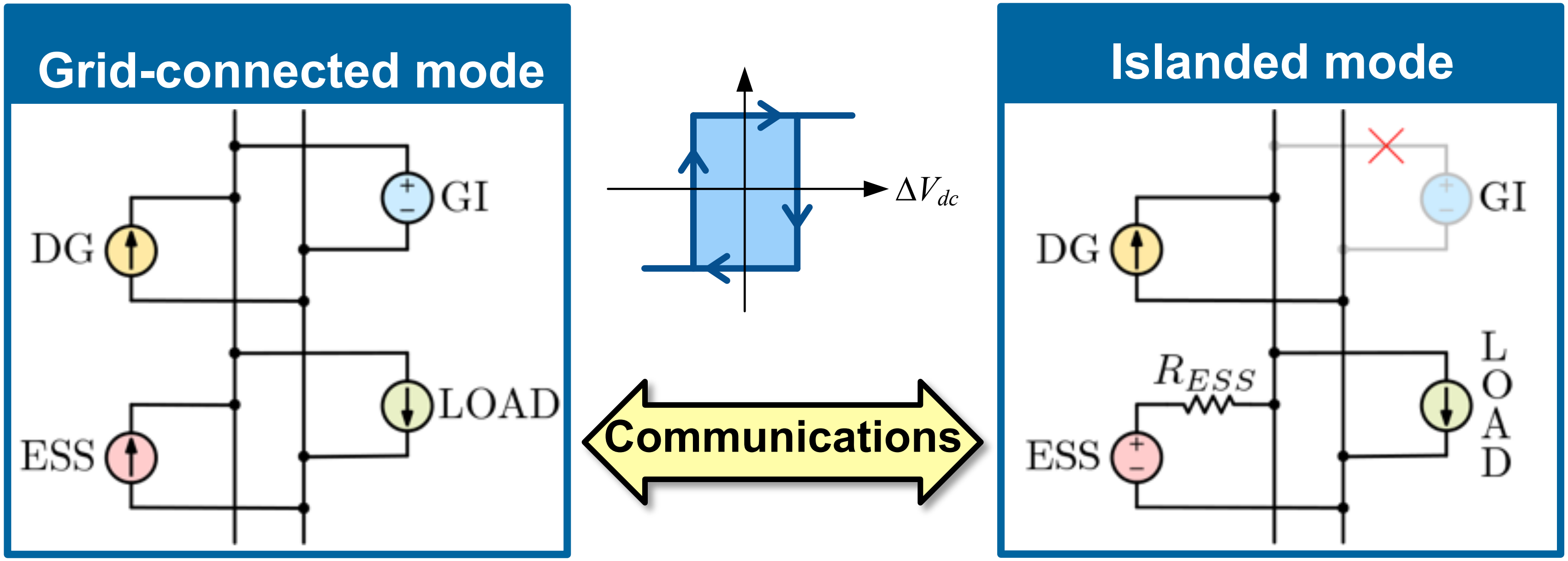
- Droop control



- **Autonomous operation with parallel converters**
- **Seamless disconnection from utility**
- **Power sharing is affected by bus impedance**
- **Operation point is fixed with particular loads having limited control flexibility**

Yunjie Gu. "Mode-Adaptive Decentralized Control for Renewable DC Microgrid With Enhanced Reliability and Flexibility". TPE

Control of DC microgrids



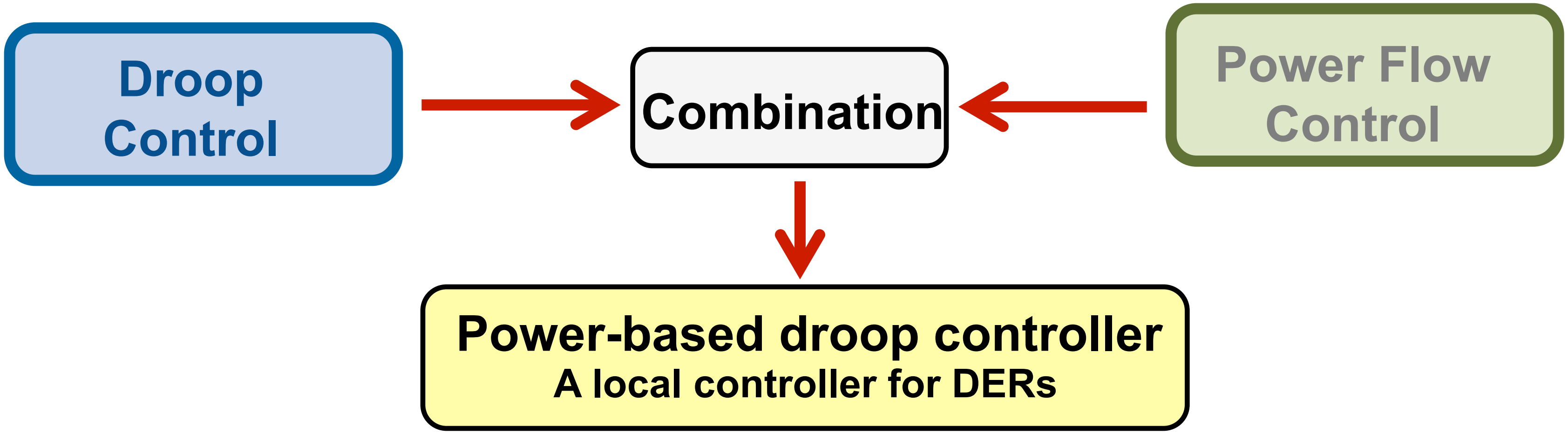
- Power flow control in grid-connected mode
- Enhanced power sharing precision in grid-connected mode

- Transition between modes:
  Critical communications
  Islanding detection

- **Master-slave control**

Farzam. "Overview of Power Management Strategies of Hybrid AC/DC Microgrid". TPE

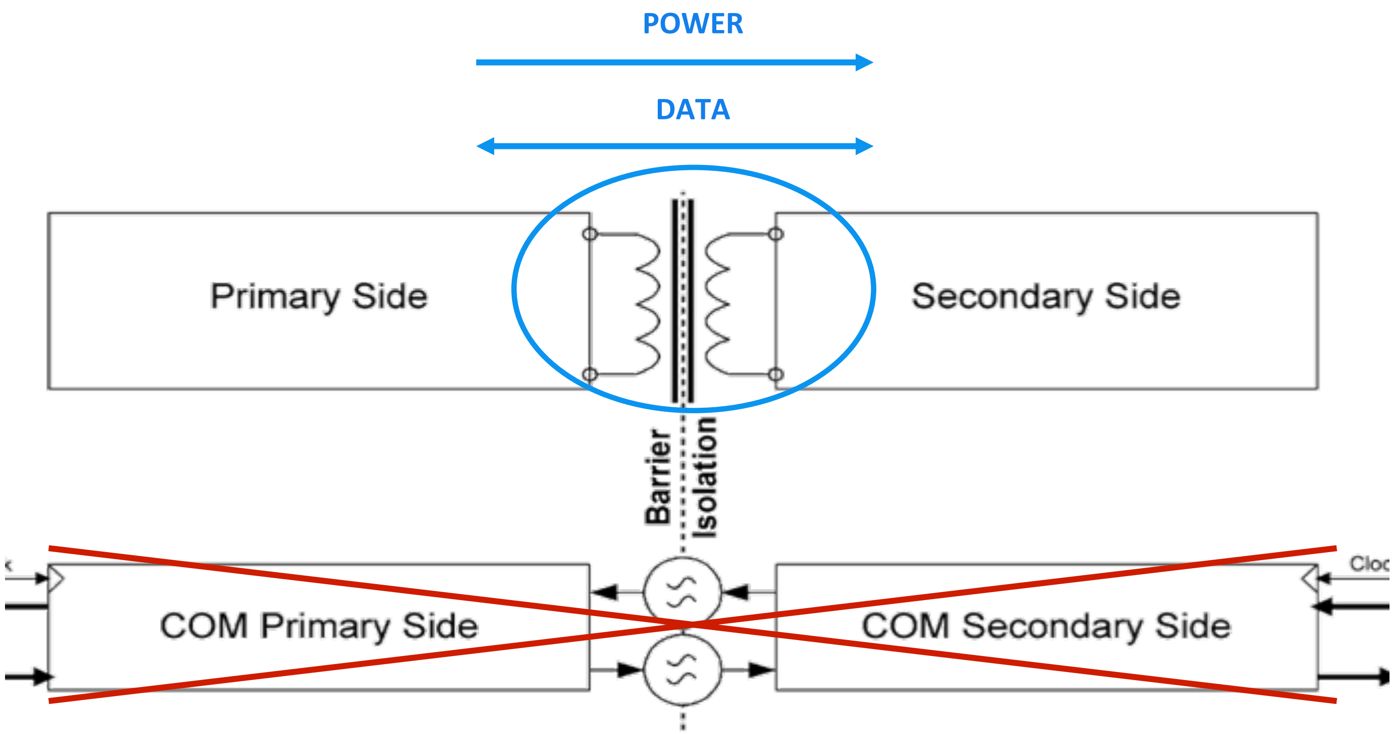
Control of DC Microgrids



- **Power flow control** when grid-interface (GI) converter imposes the bus, with improved power sharing accuracy and control flexibility
- **Droop control** if GI converter loses capability of regulating bus
- **Seamless transition** between these two modes, without communications or bus voltage variation detection

Communications in Microgrids

- Open challenges
  - implementation of efficient communication on the DC bus
    - DC/DC converters with embedded communication capabilities



Activities and Projects

IUNET Energy-related Projects

IUNET was and is participating to several projects involving energy conversion and management at different levels

ENIAC ERG	*Focus on more efficient energy management from high performance PV cells to power conversion, intelligent drive control, power delivery and interface to smart-grid.*
ENIAC E2SG	*Energy management policies, modeling and simulation of smart grids, DC/DC converters with embedded communication capabilities*
ENIAC END	*Energy harvesting and power management for self-powered sensor nodes*
ENIAC LAB4MEMS	*Energy harvesting and power management for MEMS and miniature energy transducers*

These projects were funded by the European Commission through the ENIAC and ECSEL Joint Undertakings

IUNET Energy-related Projects

IUNET was and is participating to several projects involving energy conversion and management at different levels

ECSEL R2POWER300 — *Reliability of integrated power devices and design of reliability-aware DC/DC converters*

H2020 NEREID — *Benchmarking and roadmapping for micropower management circuits*

FLAG-ERA CONVERGENCE — *Integrated nano-power energy harvesting and power management for wearable IoT nodes*

ECSEL CONNECT — *Microgrids as smart energy domains, DC/DC converters and control for microgrids, DC/DC converters with embedded communications, more efficient SiC/GaN-based DC/DC converters, switched capacitor converters, nanopower energy harvesting circuits*

The CONNECT experience

- **CONNECT**: Innovative smart components, modules and appliances for a truly connected, efficient and secure smart grid
  - Funded by the European Commission through the ECSEL JU grant agreeement no. 737434
  - 4 IUNET universities involved + 18 EU partners
  - 1.366.000 EUR total costs for IUNET
  - Ranked first in the ECSEL call, now at M6
  - Born from the E2SG (and ERG) consortium

*Microgrids are smart energy domains integrating **heterogeneous power elements** (renewables, storage, power converters) operating in a coordinated way by exploiting modern **ICT technologies for sensing, communications and scheduling** decisions*

The CONNECT experience

- Microgrids represented an amazing backgroud to integrate heterogeneous research activity in many fields, from **IoT** and **energy harvesting** to **advanced power electronics** and **electric grid control**
- Power electronics activities IUNET is contributing to:
  - Nano-/micro-power harvesting circuits (UNIBO)
  - More efficient 100W DC/DC converters based in SiC/GaN power devices
  - Switched-cap DC/DC converters
  - DC/DC level shifting converters
  - Control techniques for DC/DC converters for DC microgrids
  - DC/DC with embedded communication capabilities
- Not counting other topics:
  - smart WSNs and IoT, sensors, algorithms, etc.

Conclusions

- IUNET university teams carried out many and notable scientific and industrial achievements in their respective areas of expertise in the last years
- Considering power electronics as a transversal topic in projects with wider global objectives proved to be a successful approach
  - Enforcing collaborations and teaming
  - Funding research opportunity
  - Excellence of Science, Societal Challenges, and LEIT

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