Differential-mode converter: A universal topology for energy storage

Invited Lecture

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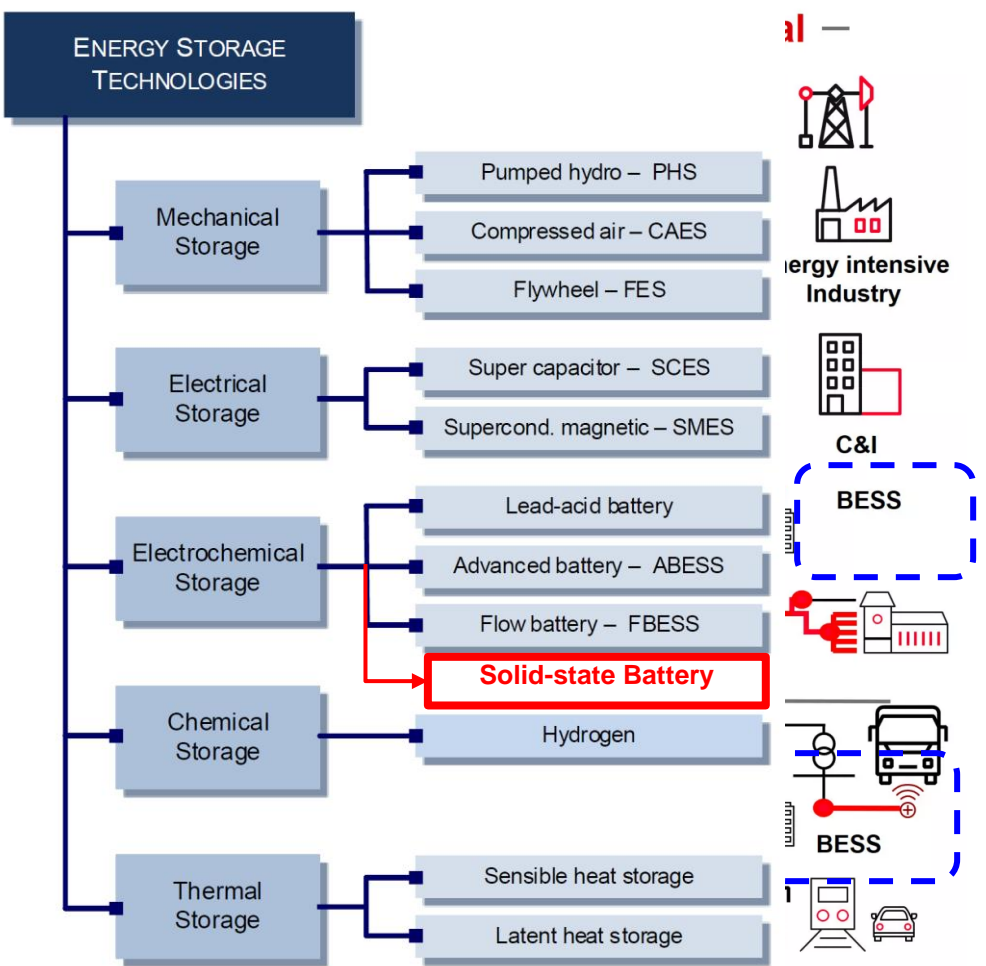General Co-Chair, IEEE ECCE'24

2024 Power Electronics and Energy Conversion Workshop
Sponsored By: Sandia National Lab/, Albuquerque, NM, USA
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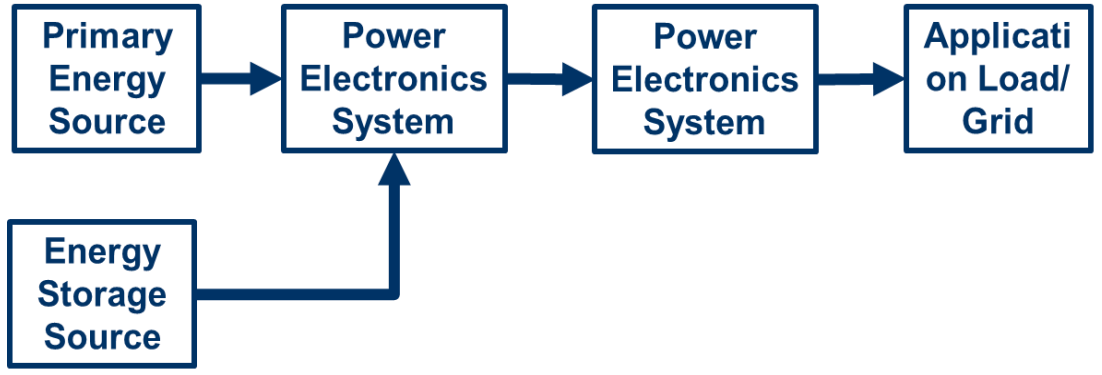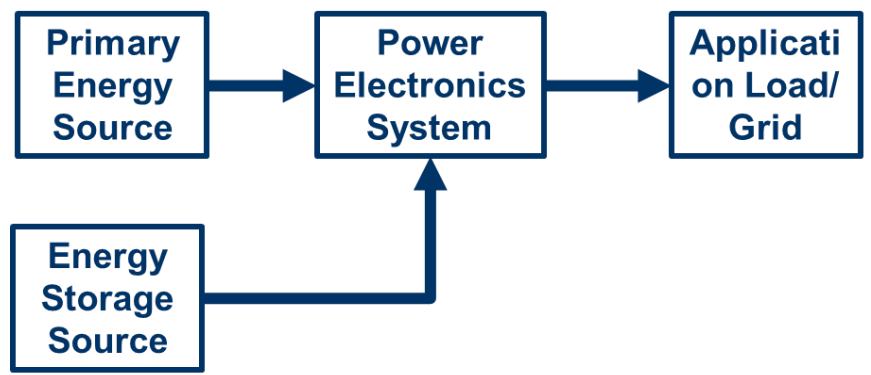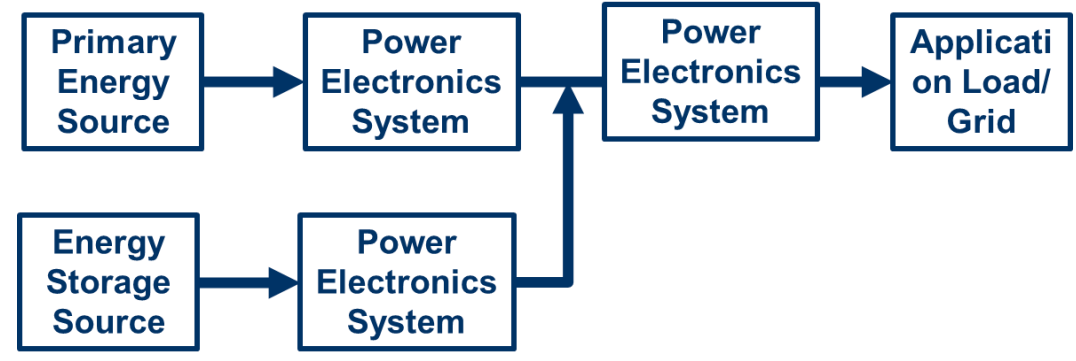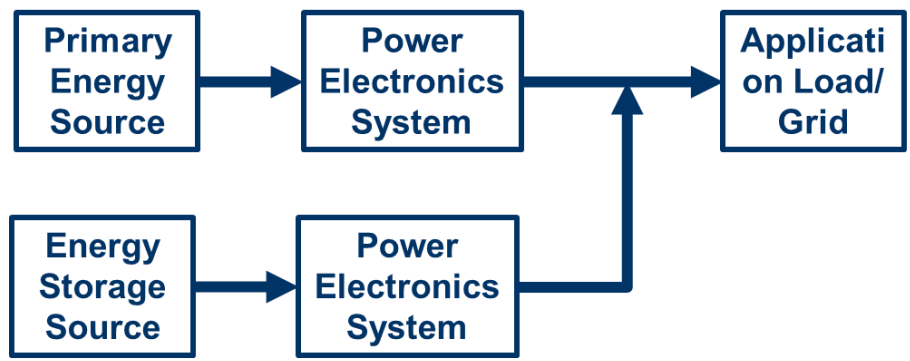
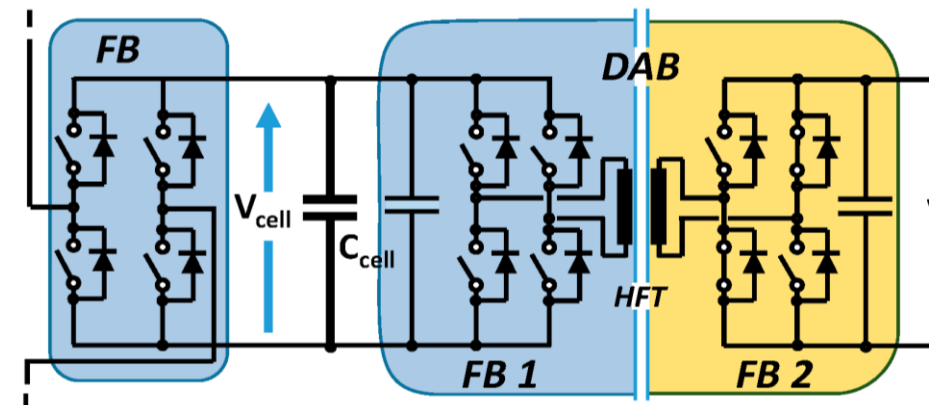# Why do we need energy storage (ES)?
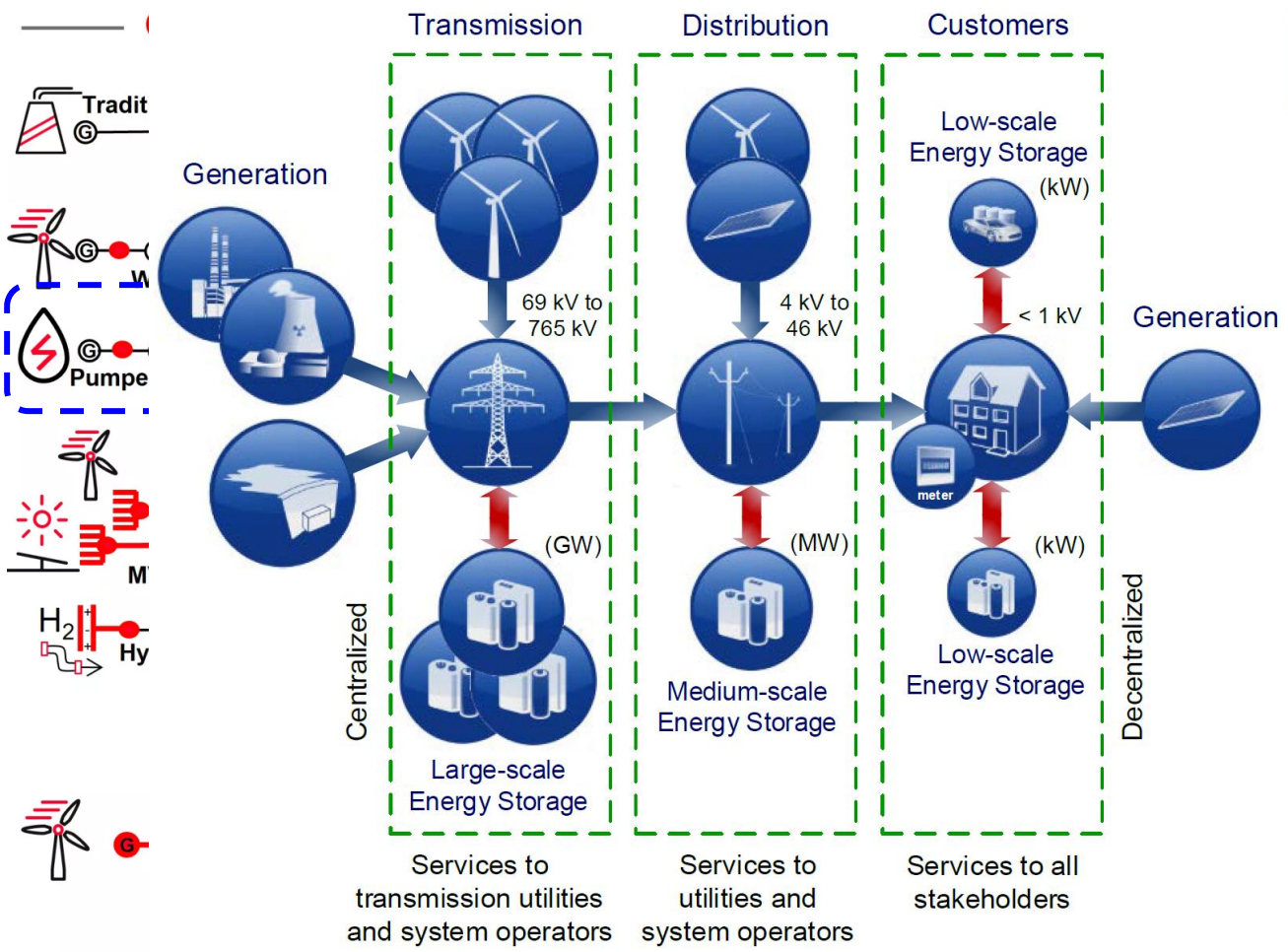
Source: M. G. Molina

Source: Hitachi Energy

What is the role of power electronics (PE) in ES?

Primary Energy Source	→	Power Electronics System	→	Application Load/ Grid
Energy Storage Source	→	Power Electronics System	↗	

Primary Energy Source	→	Power Electronics System	→	Power Electronics System	→	Application Load/ Grid
Energy Storage Source	→	Power Electronics System	↗			

Primary Energy Source	→	Power Electronics System	→	Application Load/ Grid
Energy Storage Source	↗			

Primary Energy Source	→	Power Electronics System	→	Power Electronics System	→	Application Load/ Grid
Energy Storage Source	↗					

> ➢ **Power electronics "processes" the power of ES and feeds the (DC or AC) application load / grid, as necessary, to compensate for any "shortfall" in the energy provided by the primary energy source (e.g., renewable and intermittent DERs)**
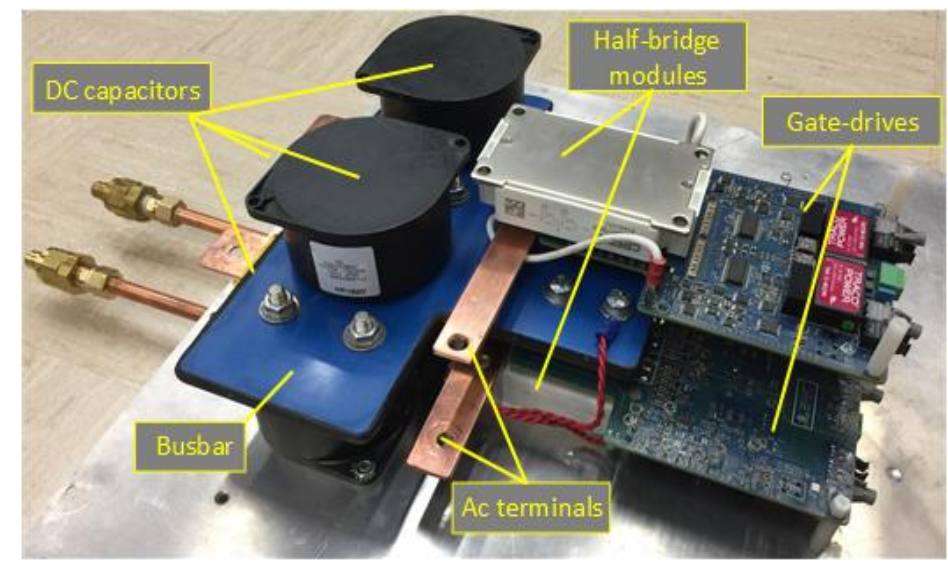
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How does universality of PE help?

❑ Commonality of building blocks

❑ Design cycle time reduction

❑ Interoperability

❑ Supply chain

❑ Rapid scalability

❑ Cost reduction

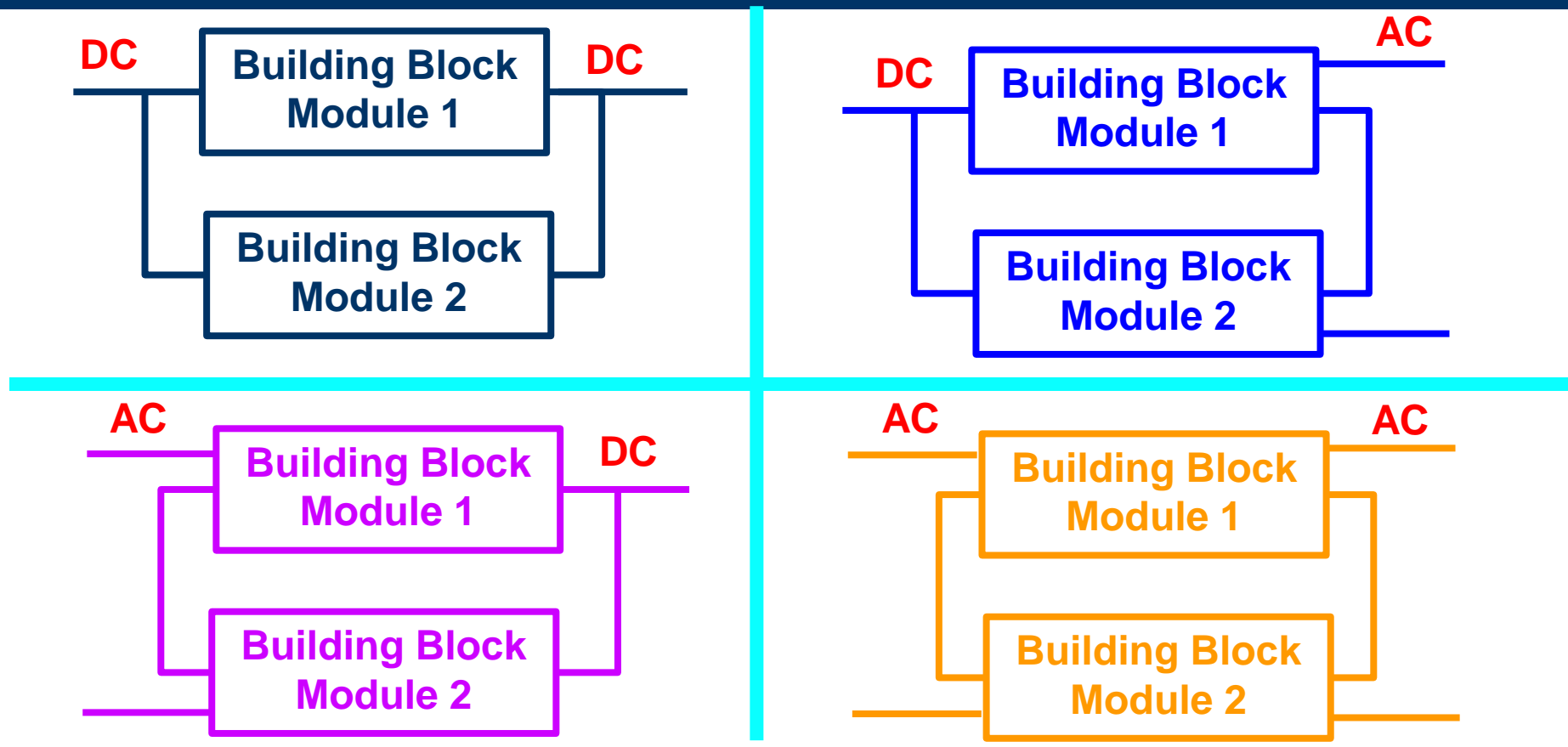T. Ericsen, Y. Khersonsky, P. Schugart and P. Steimer, "PEBB - Power Electronics Building Blocks, from Concept to Reality," 2006 3rd IET International Conference on Power Electronics, Machines and Drives - PEMD 2006, Dublin, Ireland, 2006, pp. 12-16.

Source: Google

Source: ABB

Source: CPES, Virginia Tech

Differential-mode (DM) PE architecture

DC **Building Block Module 1** DC

Building Block Module 2

DC **Building Block Module 1** AC

Building Block Module 2

AC **Building Block Module 1** DC

Building Block Module 2

AC **Building Block Module 1** AC

Building Block Module 2

- ➢ **Universal**
- ➢ **Modular approach**
- ➢ **Noise mitigation**

- ➢ **Scalable**
- ➢ **Power decoupling**
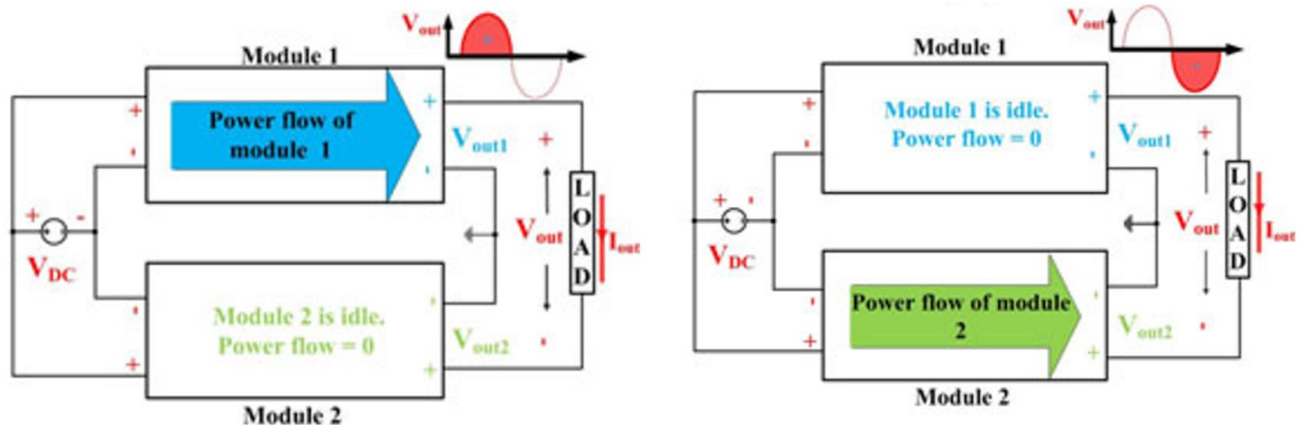- ➢ **B/block: dc/dc with ES**

- ➢ **B/block with optimal topology**

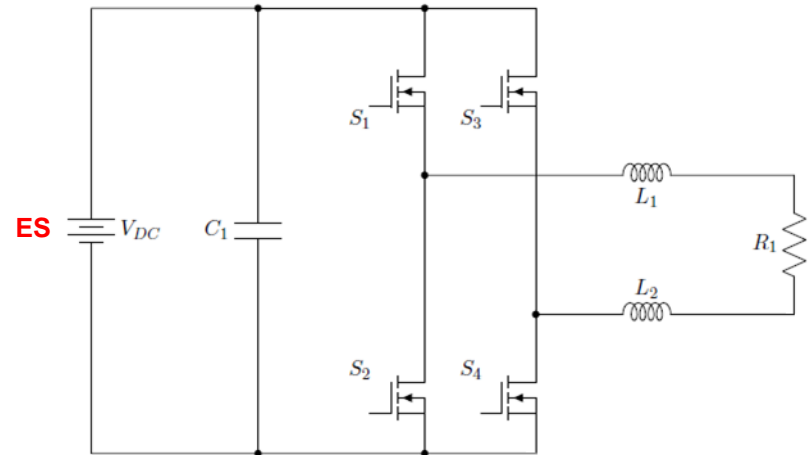# How does DM PE achieve universality?
DM single-phase inverter
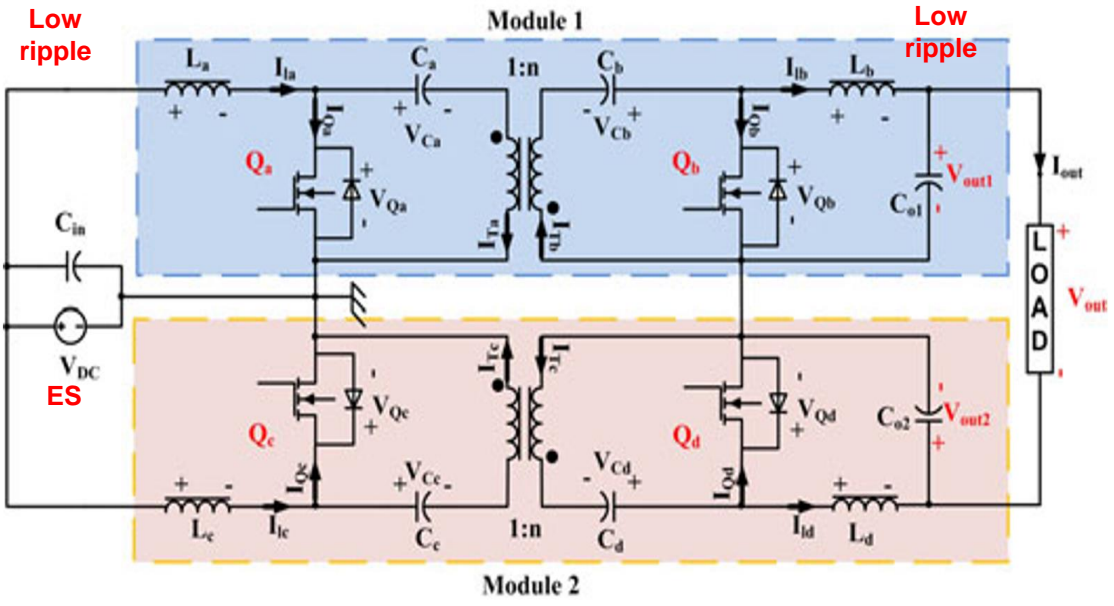
S.K. Mazumder, "Scalable single-stage differential power converter," USPTO Patent# 9379640, June 28, 2016.
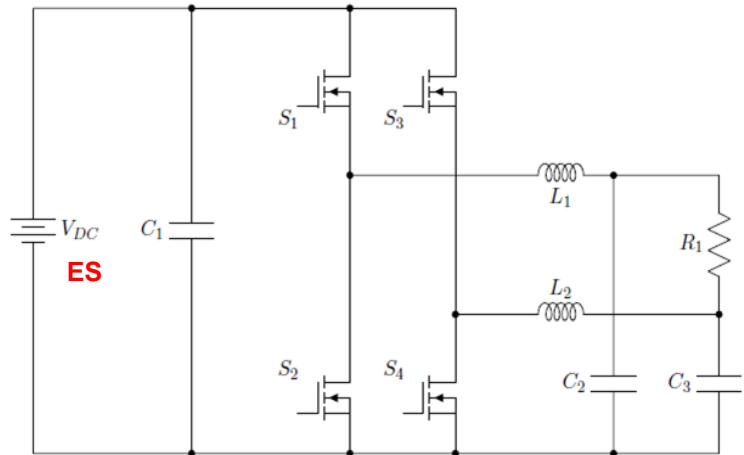
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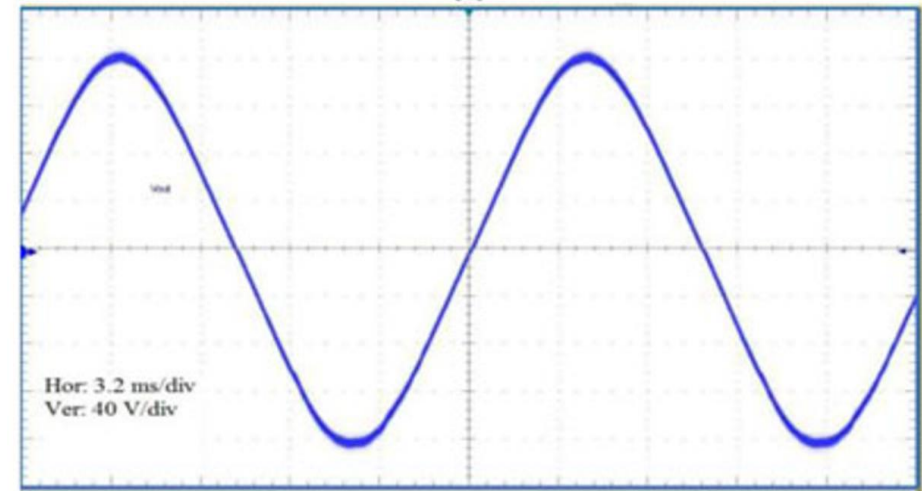
How does DM PE achieve universality?
## DM inverter with integrated power decoupling

Without power decoupling

With power decoupling

In discontinuous modulation

	Without decoupling	With power decoupling
Input Voltage	450 V	450 V
Output Voltage$_{(RMS)}$	219.4 V	219.3 V
Power	994.6 W	994.4 W
Switch Frequency	20 kHz	20 kHz
DC Link Capacitor	150µF	50µF
AC Link Capacitor	NO	15µF x 2
I$_{S1\ (RMS)}$	2.407 A	3.345 A
I$_{S2\ (RMS)}$	3.852 A	3.729 A
I$_{Peak}$ (Switches)	7.458 A	11.45 A
THD Output Current	1.51%	1.02 %

L. F. M. Arruda, S. Esmaeilirad, S. Gupta, and S. K. Mazumder, "Ripple mitigation in augmented discontinuous modulation scheme based differential mode inverter," accepted, IEEE Industrial Electronics Conference, 2024.

How does DM PE achieve universality?
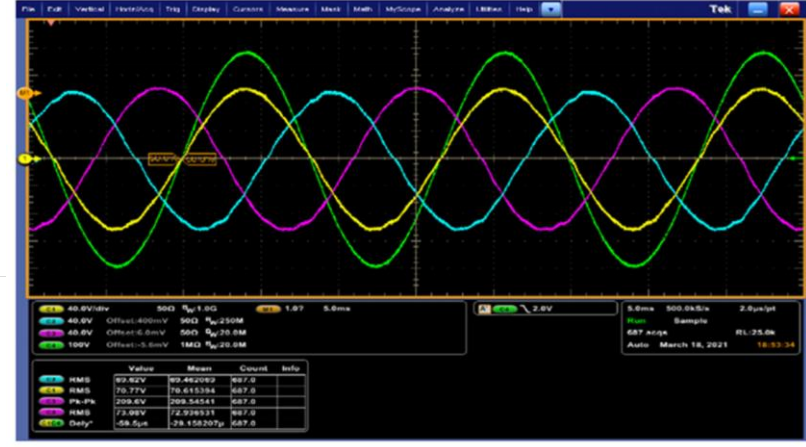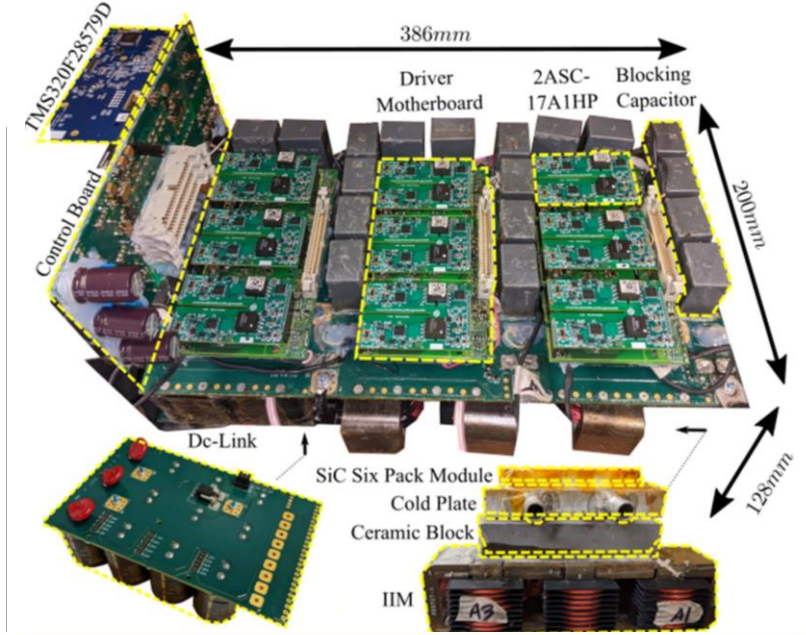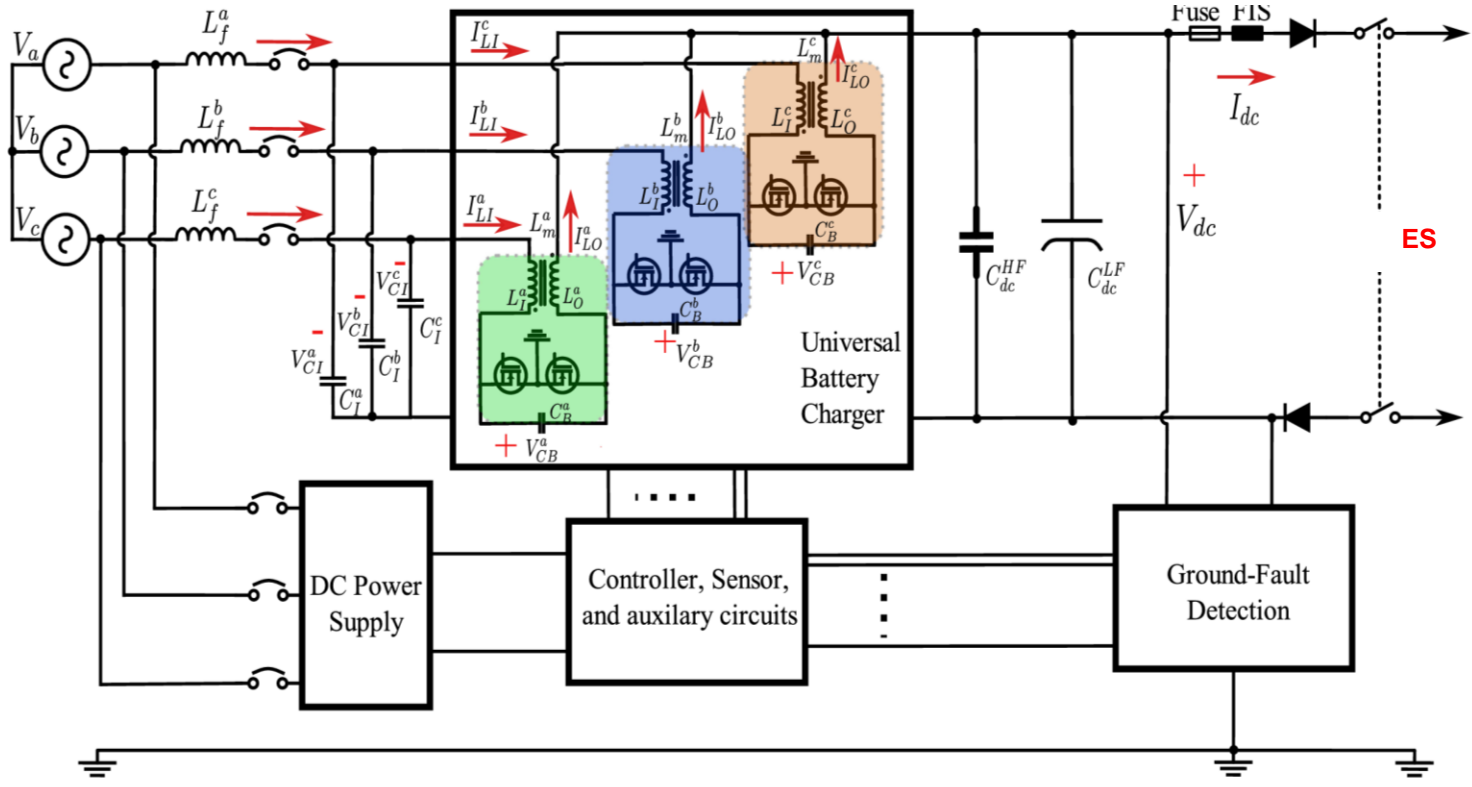## DM three-phase inverter
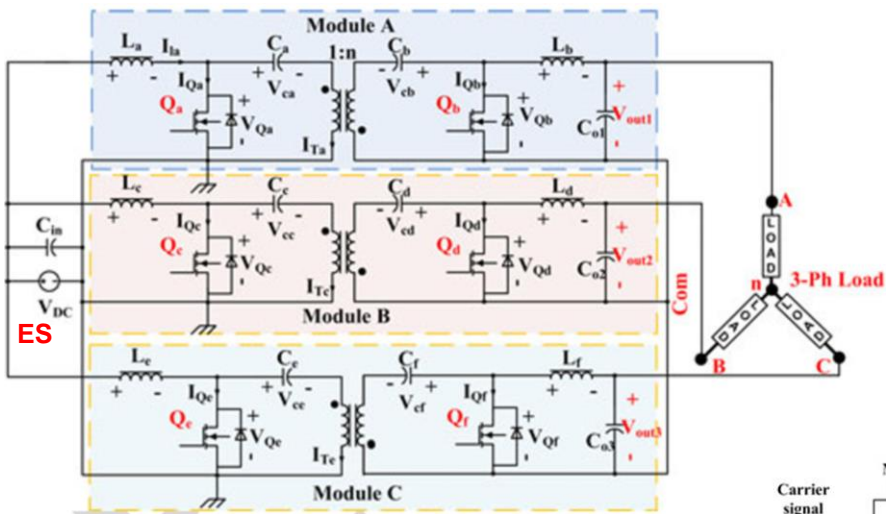
S.K. Mazumder, "Scalable single-stage differential power converter," USPTO Patent# 9379640, June 28, 2016.

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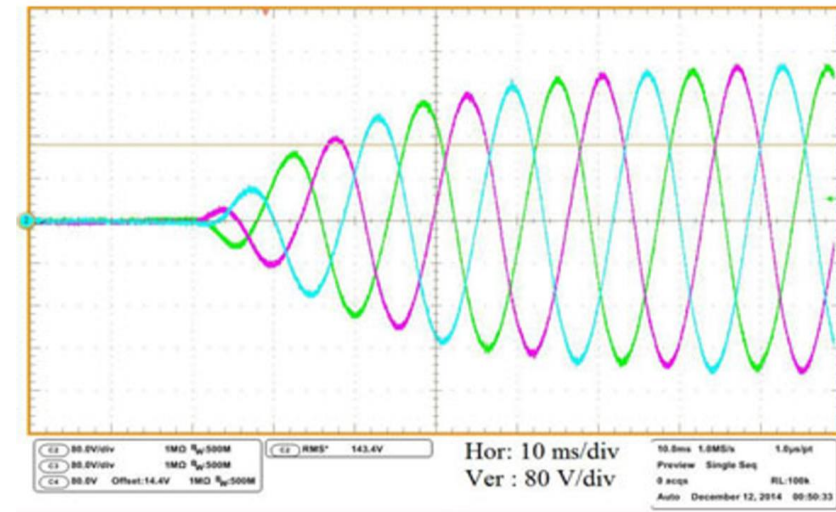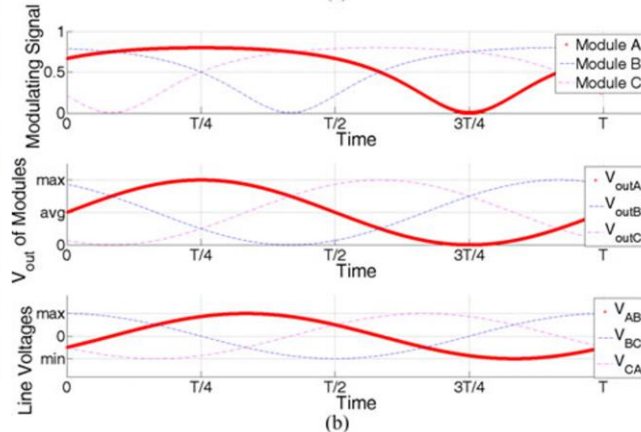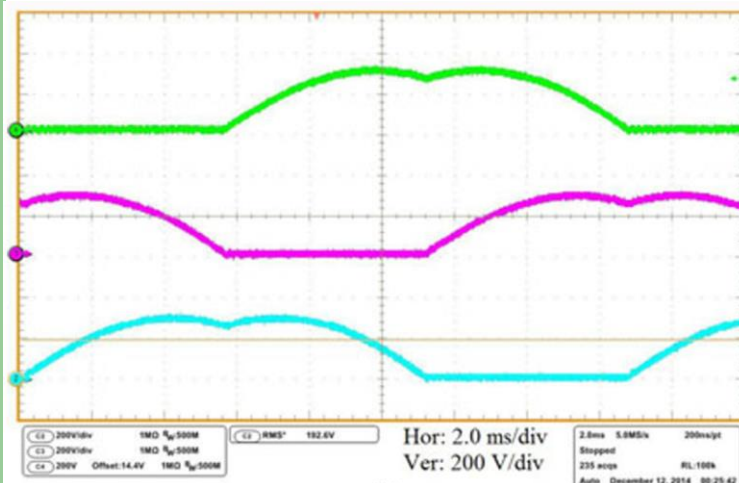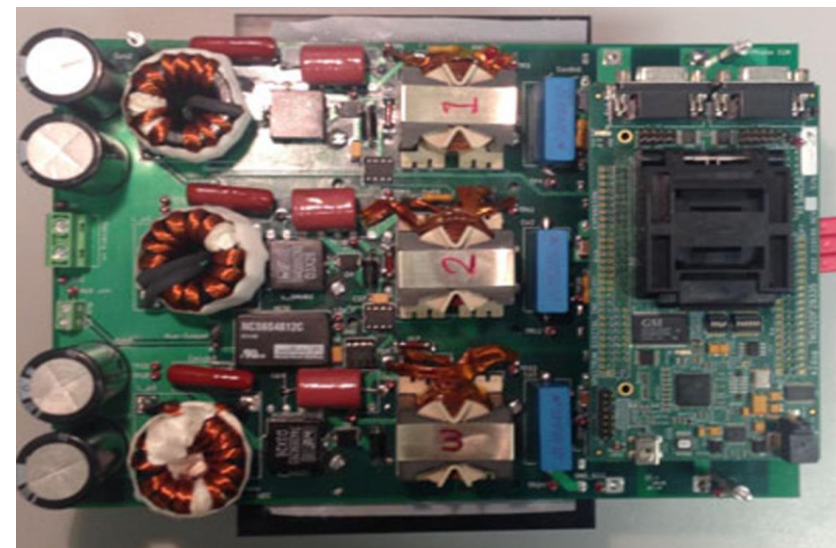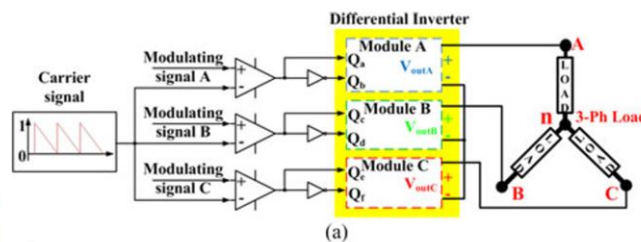
How does DM PE achieve universality?
DM ES charger

• S.K. Mazumder, M. Mohamadi, and N. Kumar, "Three-phase differential mode converter", USPTO Patent# US 11,502,596 B2, Nov 15, 2022.

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How does DM PE achieve universality?
DM solid-state transformer (SST)

Summary

1. Differential-mode converter is modularly scalable solution that provides universal mechanism for energy storage at different voltage and power levels, with single and multiphase embodiments, with power decoupling, and with four-quadrant (i.e., dc/dc, dc/ac, ac/dc, and ac/ac) functionalities.

2. Unlike dual active bridge (DAB), a differential-mode architecture can incorporate application-specific topological optimality in the building block and may yield lower device count.

Thank You!

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