

# A Cascaded Power Electronics Architecture for Transformerless Medium-voltage PV Systems

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My project partners are below and UT students are Rahul Mallik and Soham Dutta.



Dragan Maksimovic

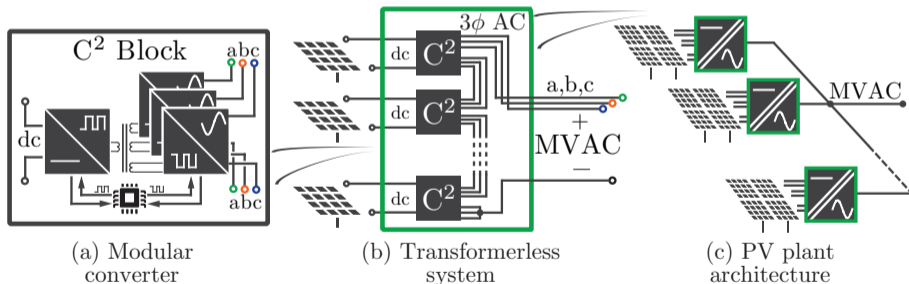
Students: Branko Majmunovic, Satyaki Mukherjee



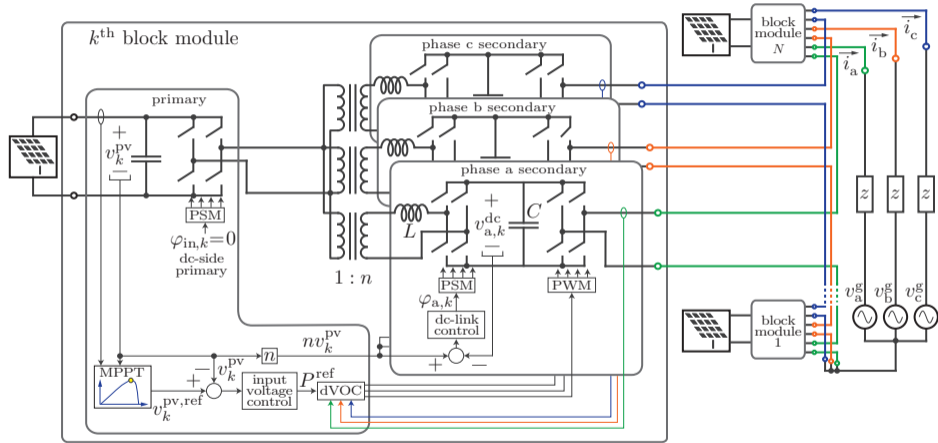
Gab-Su Seo  
**NREL**  
NATIONAL RENEWABLE ENERGY LABORATORY

# The Main Idea: A Circuits to Systems Approach

- A dc to three-phase ac converter + control building block is proposed
- Each block performs string-level PV maximum power point tracking
- The ac sides of each block are cascaded to obtain transformerless utility-scale inverters



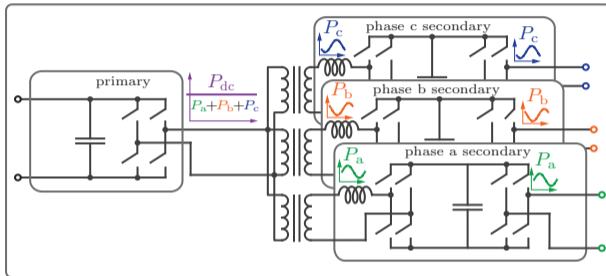
Cascaded power stages with control loops.



<sup>1</sup>Achanta, Johnson, Maksimovic, "A multilevel DC to three-phase AC architecture for photovoltaic power plants," TEC, 2019.

# The Power Stage

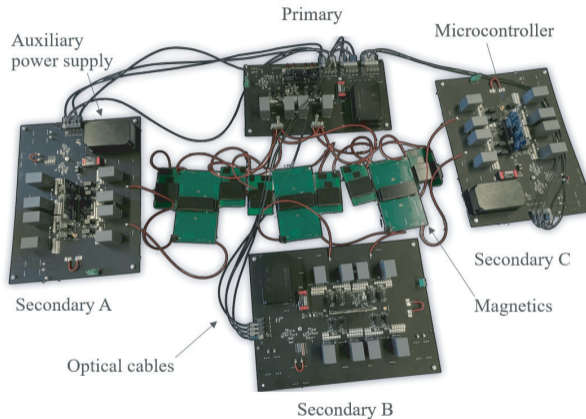
Smooth power delivery minimizes energy storage requirements.



<sup>1</sup>Achanta, Johnson, Maksimovic, "A multilevel DC to three-phase AC architecture for photovoltaic power plants," TEC, 2019.

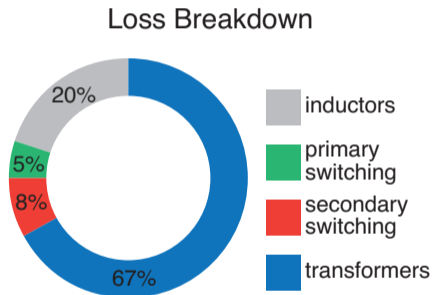
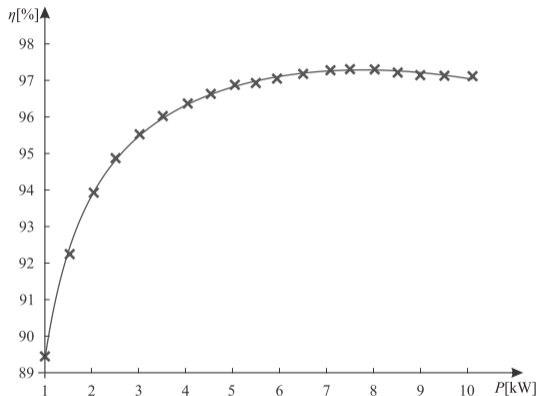
# The Power Stage

Fully PCB-based hardware build of 10 kW block below.



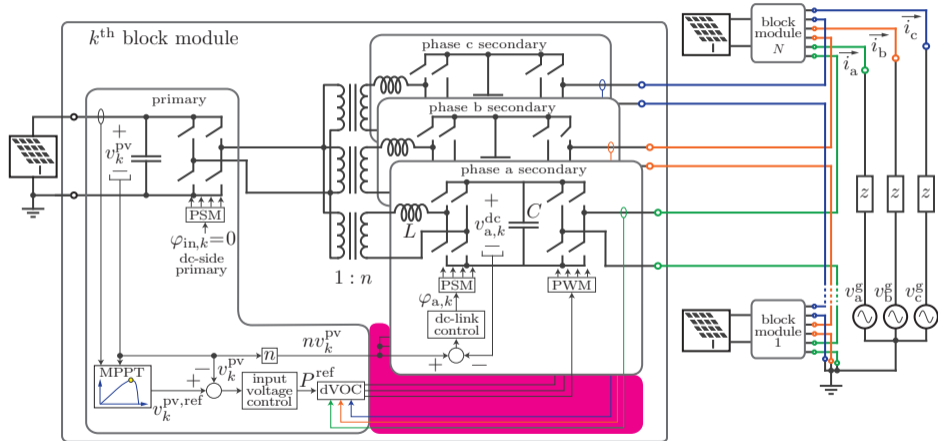
<sup>1</sup>Majmunović, Mukherjee, Martin, Mallik, Dutta, Seo, Johnson, Maksimović, "1 kV, 10-kW SiC-based quadruple active bridge DCX stage in a DC to three-phase AC module for medium-voltage grid integration," TPEL, 2022.

Novel magnetics design facilitates zero voltage switching across the full ac cycle.



<sup>1</sup>Majmunović., Mukherjee, Mallik, Dutta, Seo, Johnson, Maksimović, "Soft-switching over the entire line cycle in a quadruple active bridge-based DC to three-phase AC module," APEC, 2020.

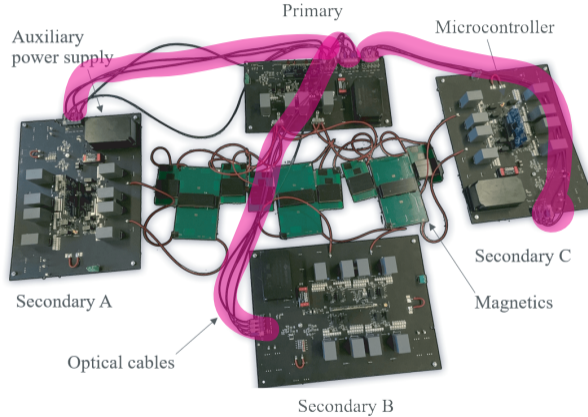
Control signals are exchanged between grounded primary and floating secondaries.



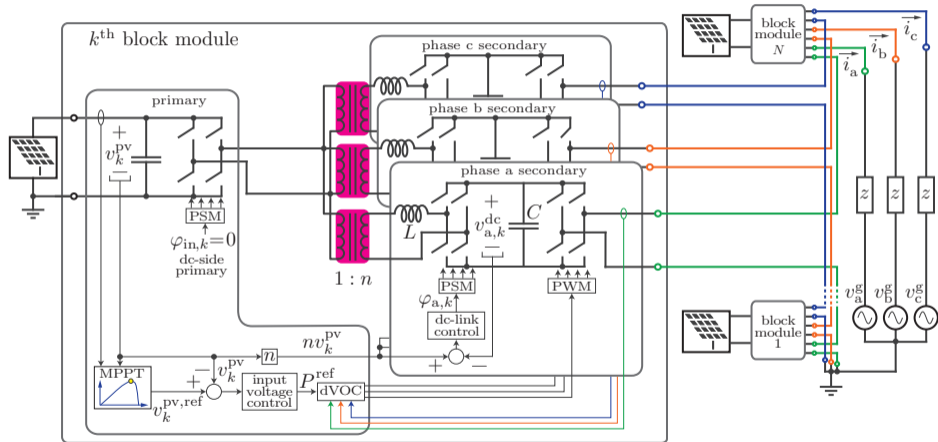


# Medium-voltage Isolation

Optical cables exchange signals between both sides.

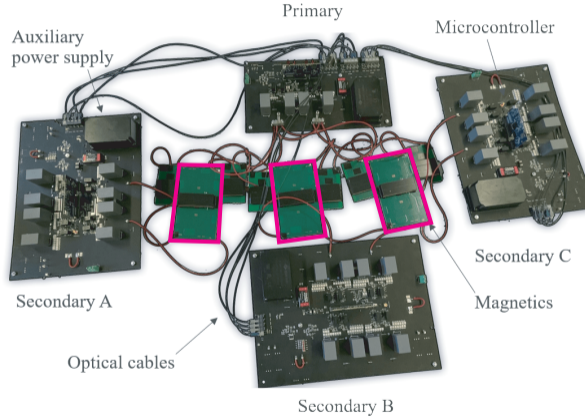


Planar PCB-based high-frequency transformers withstand medium voltages.



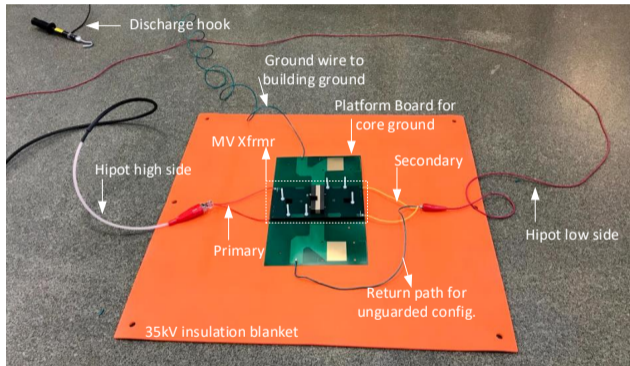
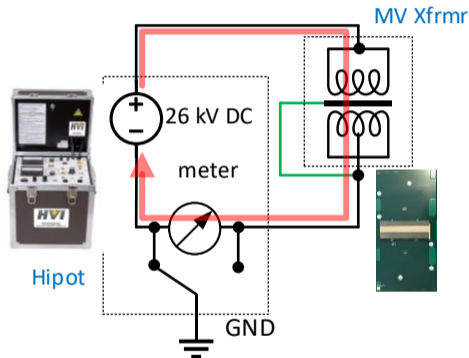
# Medium-voltage Isolation

A novel PCB with Kapton dielectric between adjacent layers was built.



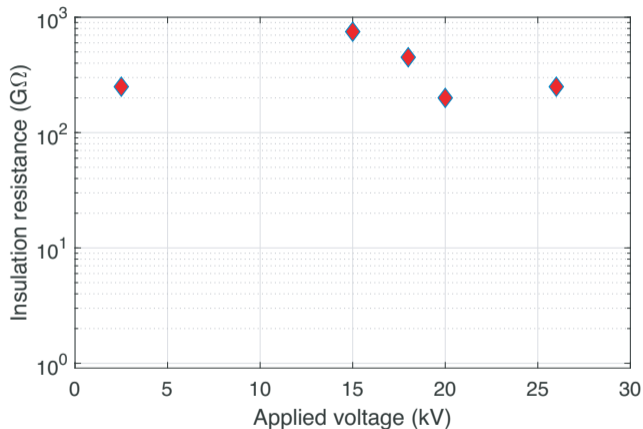
# Medium-voltage Isolation

Medium-voltage transformer has an ELP102 core, 5 layers/winding, 5 turns/layer, 2 oz copper.



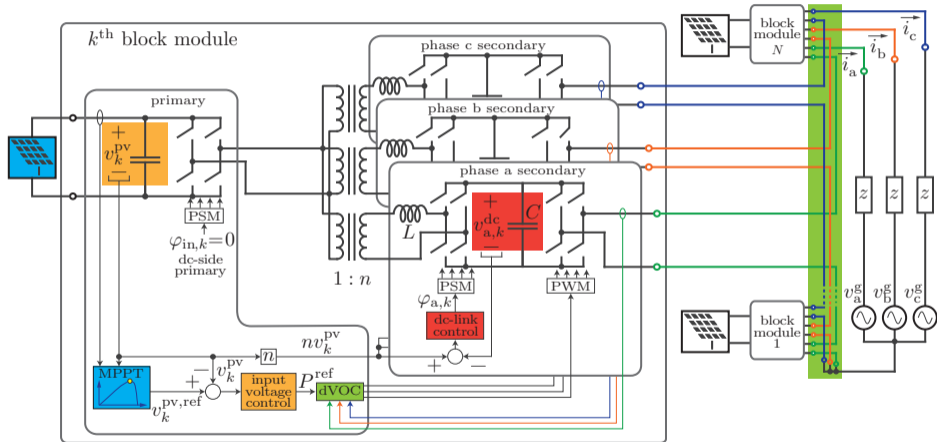
<sup>1</sup>Mukherjee, Majmunović, Seo, Dutta, Mallik, Johnson, Maksimović, "A high-frequency planar transformer with medium-voltage isolation," APEC, 2021.

High-potential experimental measurements show isolation  $>25$  kV.

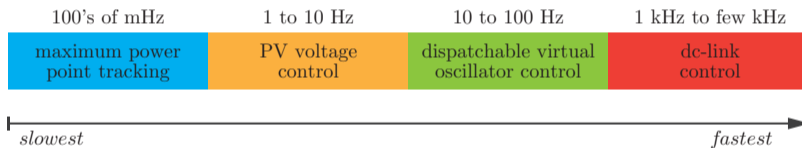


<sup>1</sup>Mukherjee, Majmunović, Seo, Dutta, Mallik, Johnson, Maksimović, "A high-frequency planar transformer with medium-voltage isolation," APEC, 2021.

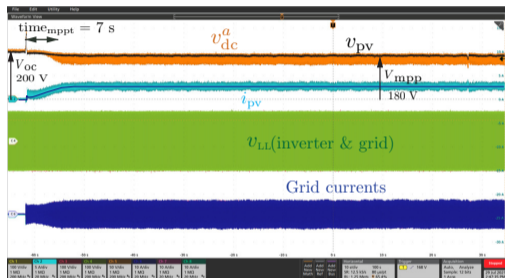
Each particular controller and its plant are designed to operate at distinct timescales.



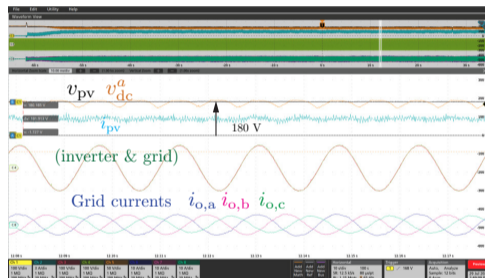
Timescale separation facilitates decoupled design of each loop & ensures stability.



Measurements showing all four control loops working in concert within a block.



(a)



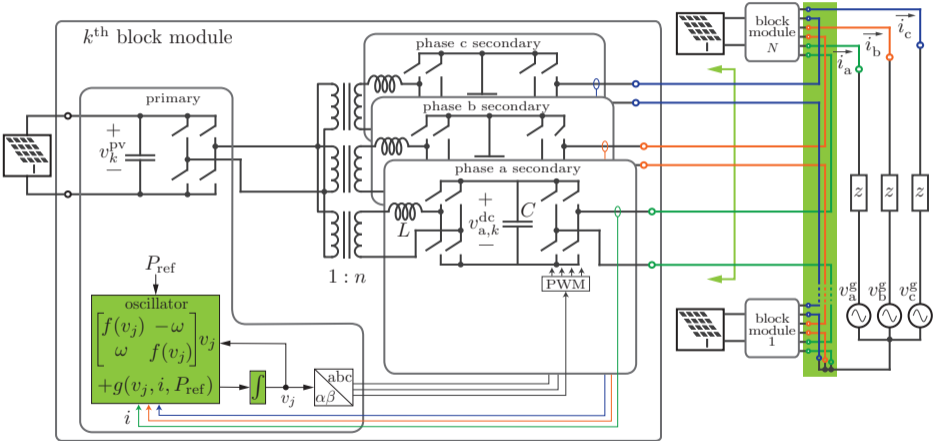
(b)

<sup>1</sup>Mallik, Majmunović, Dutta, Seo, Maksimović, Johnson, "Control design of series-connected PV-powered grid-forming converters via singular perturbation," TPEL, 2023.

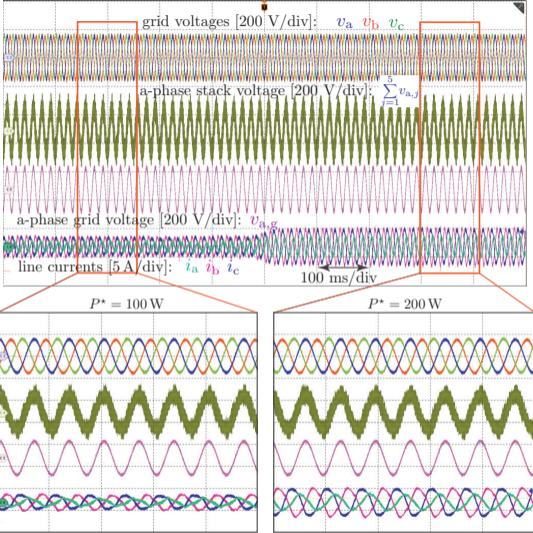
<sup>2</sup>Lu, Mallik, Dhople, Johnson, "Dispatchable virtual oscillator controlled inverters with current-limiting and MPPT capabilities," ECCE, 2021.



Fully decentralized PLL-free ac-side controls use dispatchable virtual oscillator control.



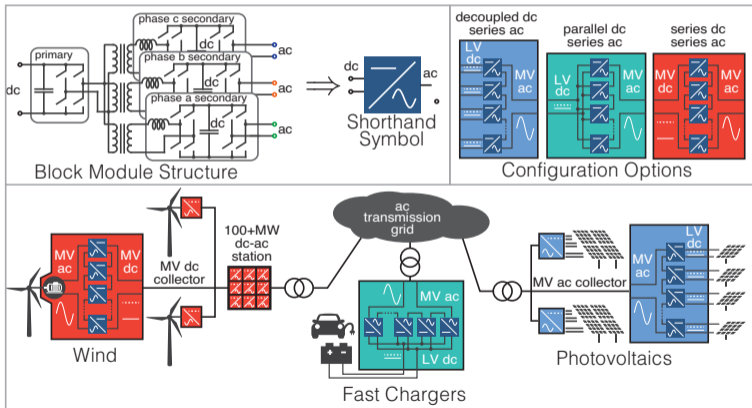
Measurements across five cascaded grid-connected blocks:



<sup>1</sup>Dutta, Lu, Mallik, Majmunović, Mukherjee, Seo, Maksimović, Johnson, "Decentralized control of cascaded H-bridge inverters for medium-voltage grid integration," COMPEL, 2020.

# Looking Ahead to the Future

- Validation at medium voltage will happen when next big project arrives.
- Extending to SSTs, Extreme Fast EV Chargers, and various applications.



**Thanks for your attention!**

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