EMERGING POWER CONVERTERS TOPOLOGIES FOR DC BUILDINGS APPLICATION

Tutorial 3

Centre of Excellence in Energy Efficiency

International Conference on DC Microgrids

TUTORIAL 3: INSTRUCTORS

International Conference on DC Microgrids

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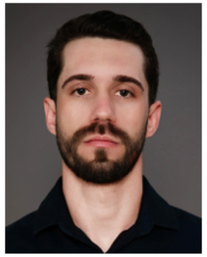
Neelesh Yadav (Member, IEEE) received the B. Tech.-M.Tech. dual degree from Lovely Professional University, Punjab, India, in 2016, and the Ph.D. degree in electrical engineering from the Indian Institute of Technology Mandi, Mandi, India, in 2022. He is currently a Postdoctoral Researcher with the Power Electronics Group, Tallinn University of Technology, Tallinn, Estonia. His research interests include control and power management in DC microgrids, fault detection, and AC-DC/DC-DC converters.



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i³ DC
Accelerates Energy Transition

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INTRODUCTION, STANDARDS, AND REQUIREMENTS FOR RESIDENTIAL DC ELECTRICAL INSTALLATIONS

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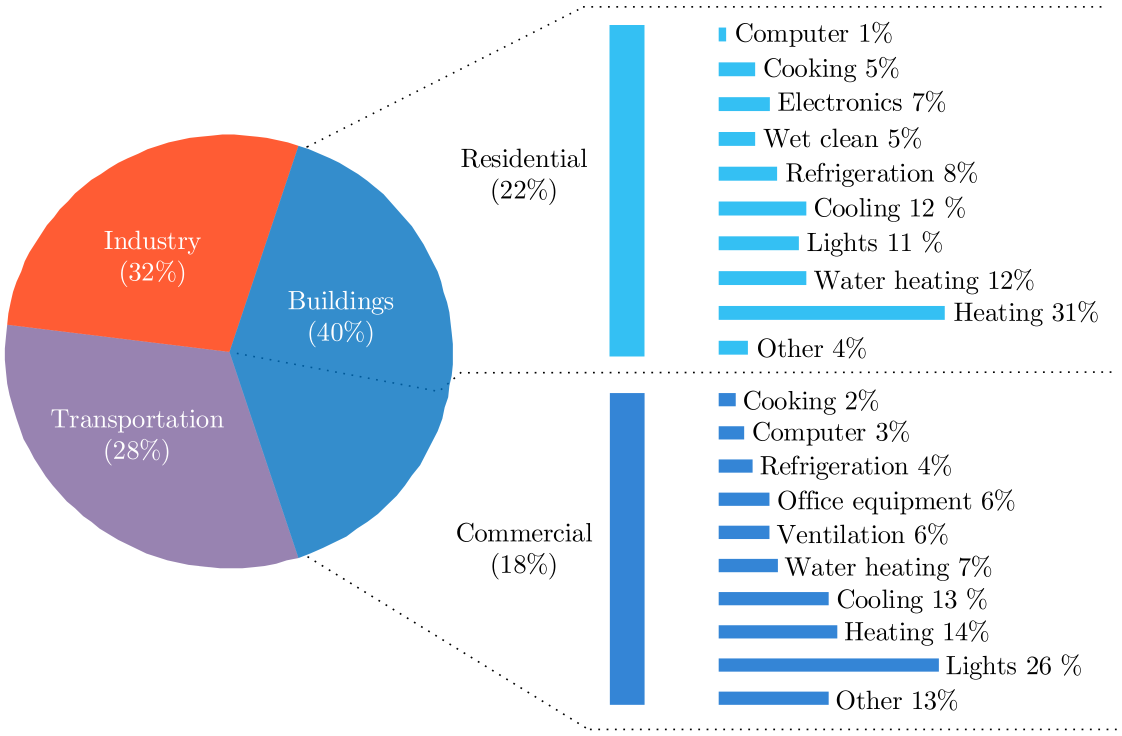
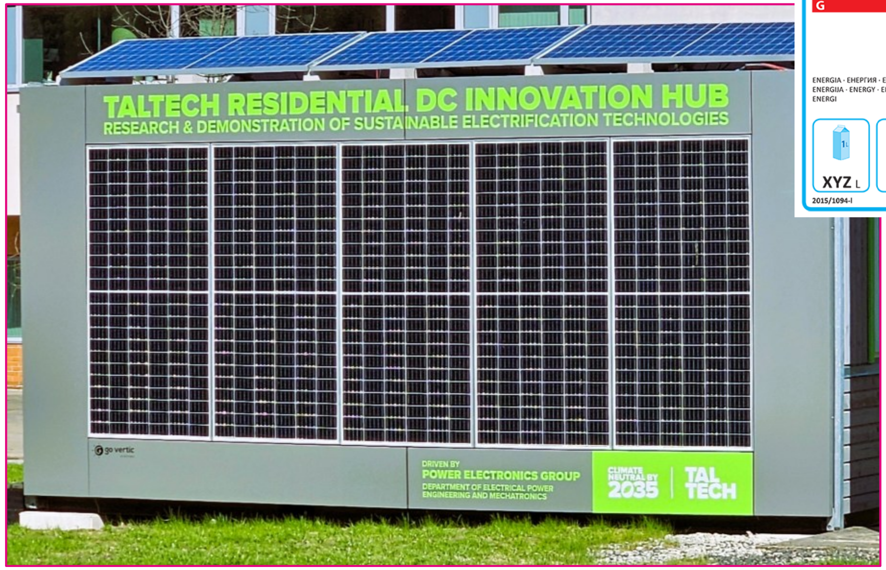
ENERGY EFFICIENCY OF BUILDINGS: AN ISSUE

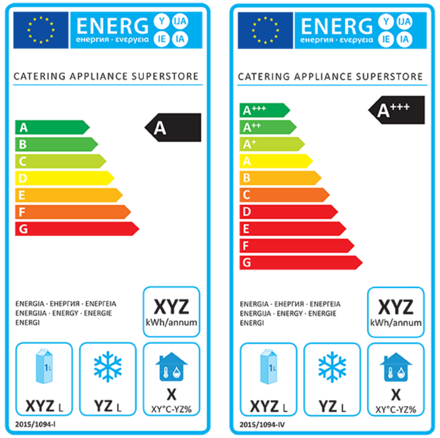
- Buildings consume (and waste!!!) too much energy:
  - Annual energy consumption in Estonia $33...34\ \mathrm{TWh/y}$
  - Share of buildings 50% (w/o industrial buildings)
  - EU average 40%
- Currently, roughly 75% of buildings in the EU are not energy efficient:
  - $85–95\%$ of today's buildings will still be in use in 2050
- To boost decarbonization the EU requires all new buildings from 2021 to be nearly zero-energy buildings (NZEB)
- NZEB (or class A building) :
  - fully covered by energy from renewable sources and without on-site carbon emissions from fossil fuels

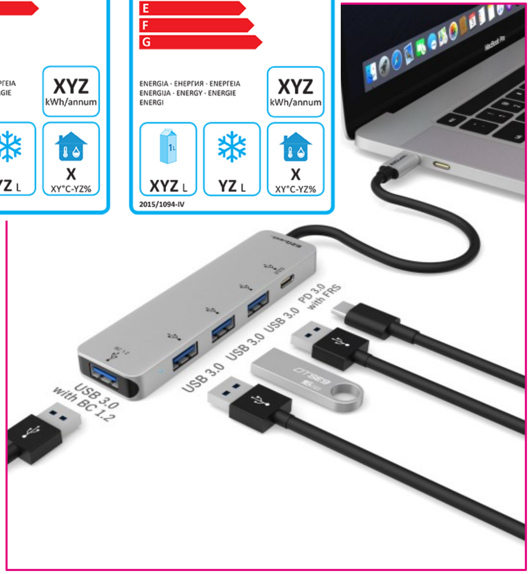


NEARLY ZERO-ENERGY BUILDINGS TODAY

- In practice, NZEB consumes up to 4 times less energy than the traditional ones
- Energy efficiency is the main feature of ZEB - PV installation (backed up with energy storage), heat pump, heat recovery ventilation, energy-efficient appliances and lighting, smart control of loads
- NZEB:
  - High energy performance (low energy consumption)
  - Local renewable generation
  - Most of energy saving technologies are based on power electronics

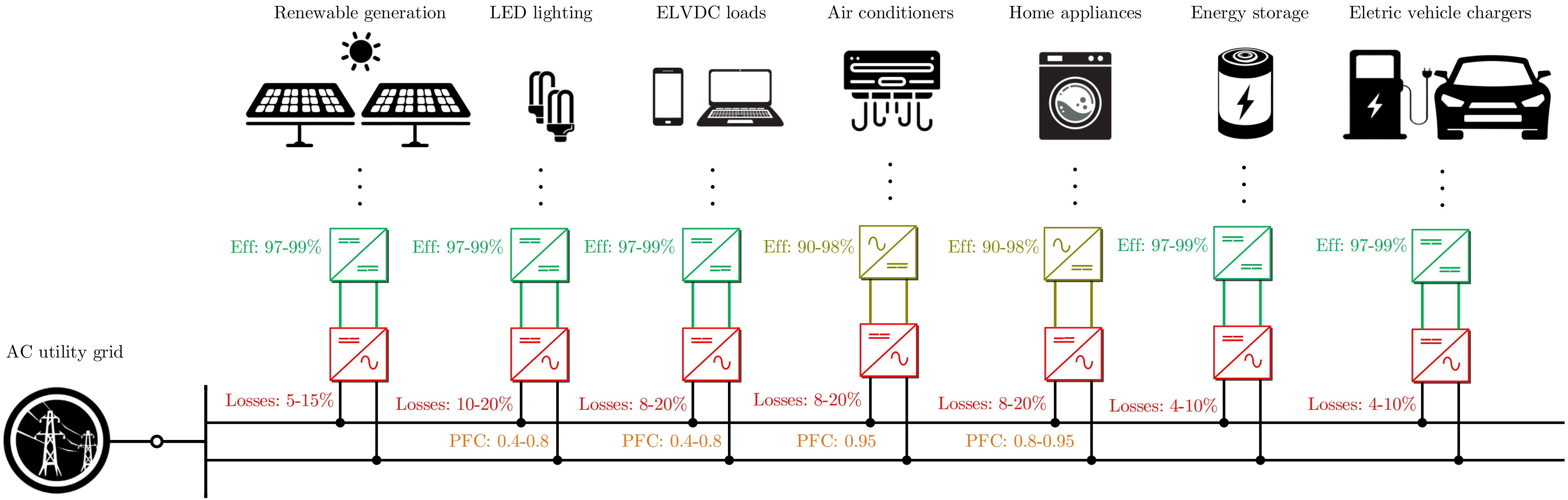






POWER ELECTRONICS FOR AC-BASED NZEB TODAY

- AC is rectified in every appliance, reducing efficiency, reliability, and power factor
- Power factor is an issue



E. L Carvalho, A. Blinov, A. Chub, P. Emiliani, G. de Carne and D. Vinnikov, "**Grid Integration of DC Buildings: Standards, Requirements, and Power Converter Topologies**," in IEEE Open Journal of Power Electronics, 2022.

POWER ELECTRONICS FOR AC-BASED NZEB TODAY

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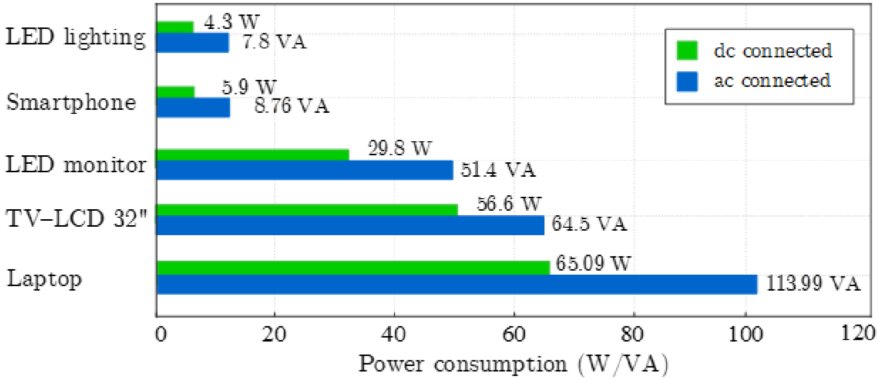
- Power Factor Correction (PFC) is required only above $75\ \mathrm{W}$, and the energy efficiency is further affected by a non-unity power factor
- Cumulative energy waste could become significant, even in installations where low-power devices are dominant

1	Urms	232.37	V
2	Irms	0.5766	A
3	P	65.09	W
4	S	133.99	VA
5	Q	117.12	var
6	Uthd	1.122	%
7	Ithd	86.841	%
8	PF	0.4858	
9	Udc	19.243	V
10	Idc	-3.022	A
11	P	-58.16	W

MEASURED POWER FACTOR FOR DIFFERENT HOME APPLIANCES

Appliance	Measured power factor	Power consumption
LED light bulb	0.5534	7.82 VA
Smartphone charger	0.5814	8.76 VA
LED monitor	0.5797	51.4 VA
TV – LCD 32"	0.8775	64.5 VA
Laptop Charger	0.4858	113.99 VA



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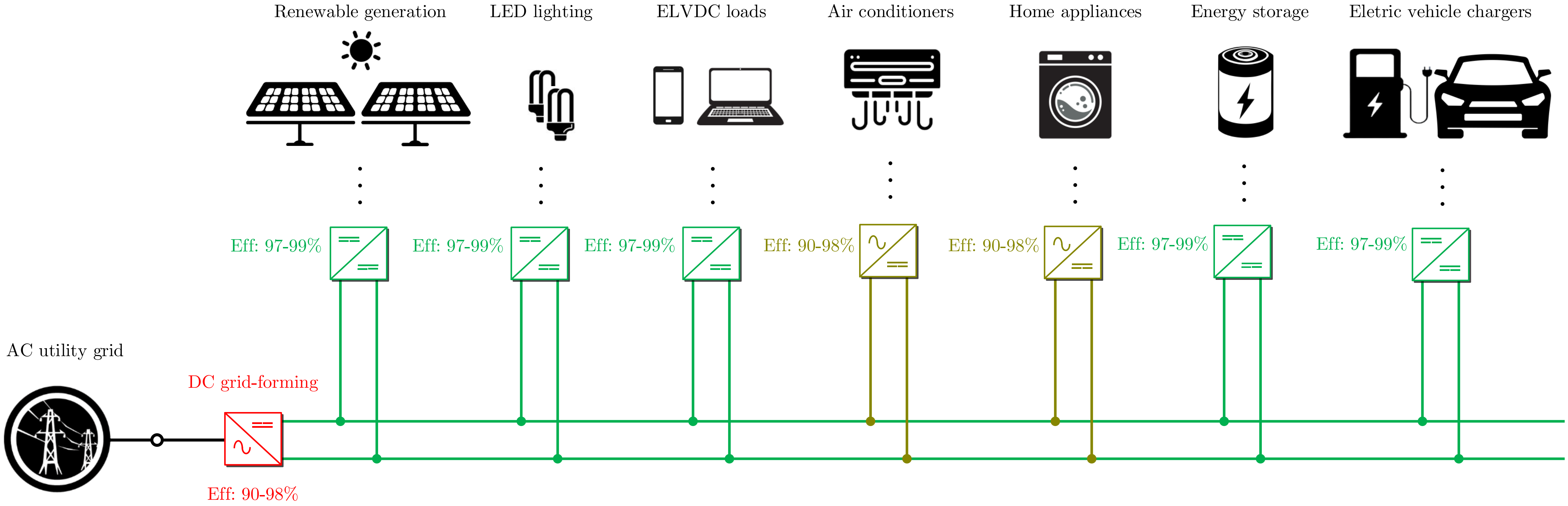
E. L. Carvalho, R. Mandriolli, A. Chub, D. Vinnikov, "**Power Factor Correction for DC-Powered Buildings Using an Isolated AC-DC Interlinking Converter: Experimental Validation and Comparative Analysis**" in 9th International Conference on Clean Electrical Power, Sardinia, Italy, 2025.

DC-POWERED BUILDINGS: THE NEXT-GENERATION OF NZEB

- Increased efficiency and maximized self-consumption of renewable energy due to the less energy conversion stages (DC can save up to $30\ \%$ of energy waste)
- No reactive power – only active energy is delivered
- Simple coordination and control, better resilience, and energy security (droop control based)



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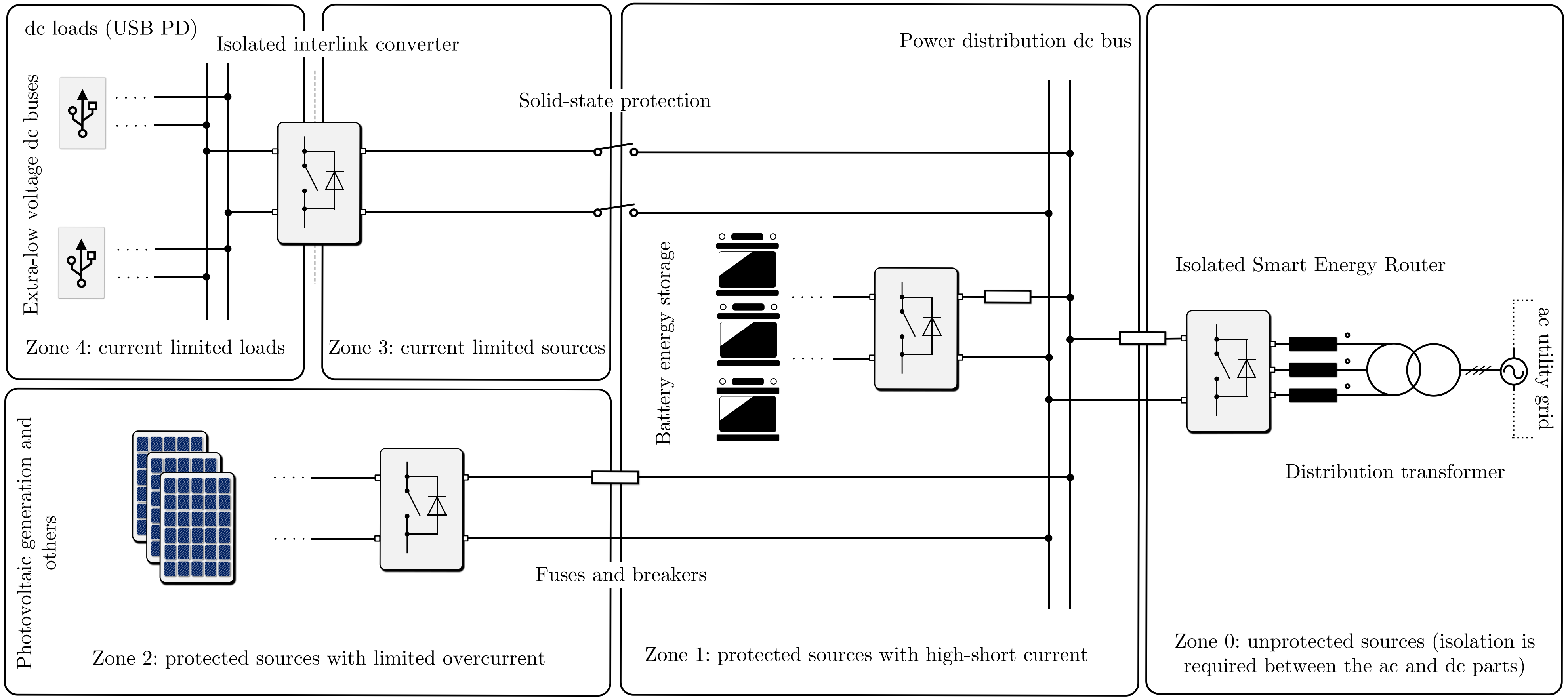
MAIN INITIATIVES TOWARDS DC

- Current/OS Foundation: protocols under development
- NPR9090: first national practice guidelines for DC (2018)



Zone 0: High current sources, with unlimited overcurrent, e.g., battery banks, 5 MW generators, utility grid:
V ≤ 1.5 kV
I > 500 A

Zone 1: dc-dc converters with limited current and high short-circuit currents, e.g., renewable sources protected by fuses. ELV sources:
V ≤ 1.5 kV
I ≤ 500 A

Zone 2: dc sources with low short-circuit current. Residual current devices (RCD) are required:
V ≤ 120 V dc (dry env.)
V ≤ 60 V dc (humid env.)
V ≤ 30 V dc (wet env.)
I ≤ 50 A

Zone 3: Electronic protection without short-circuit current. Only RCD is required. Sources up to 1 kW.

Zone 4: Consumer dc buses with very limited overcurrent. USB-C and other devices.

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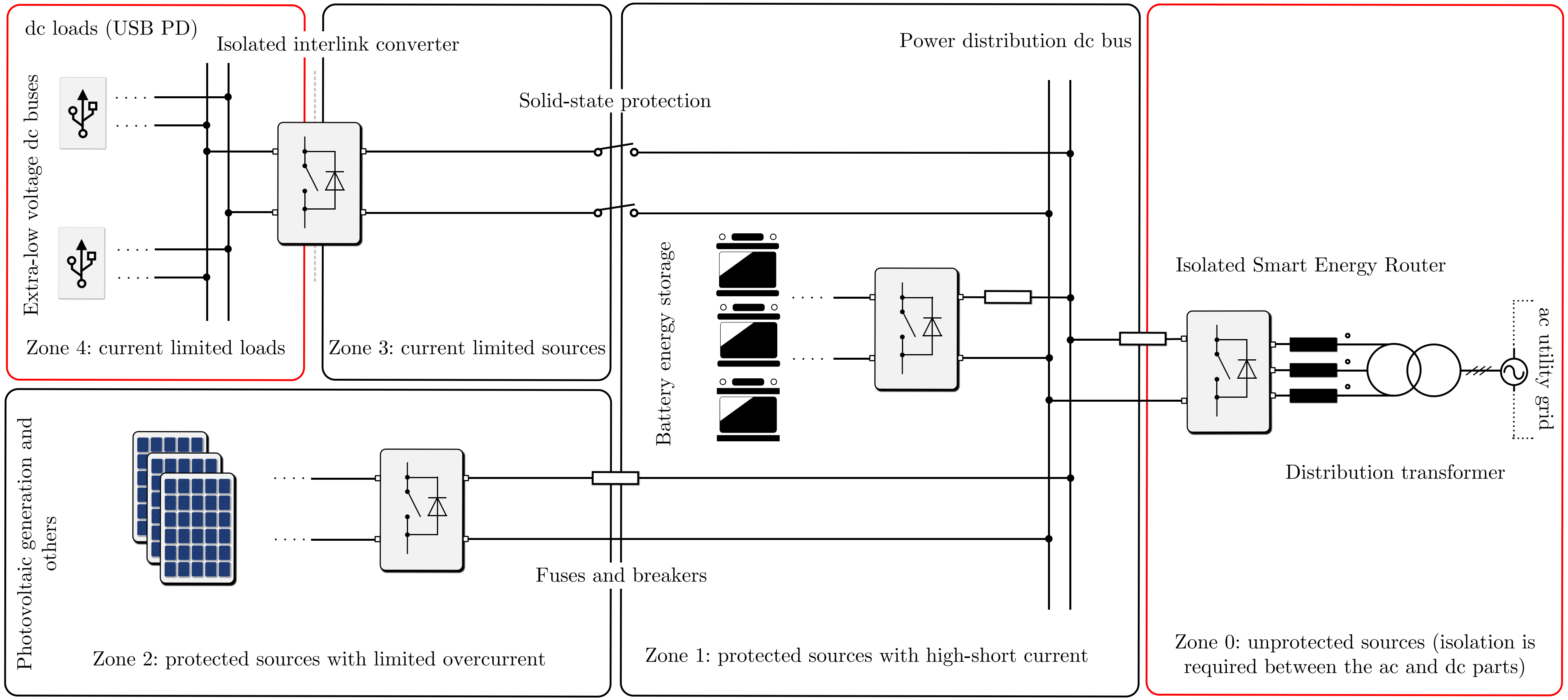

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VOLTAGE LEVELS ACCORDING TO CURRENT/OS

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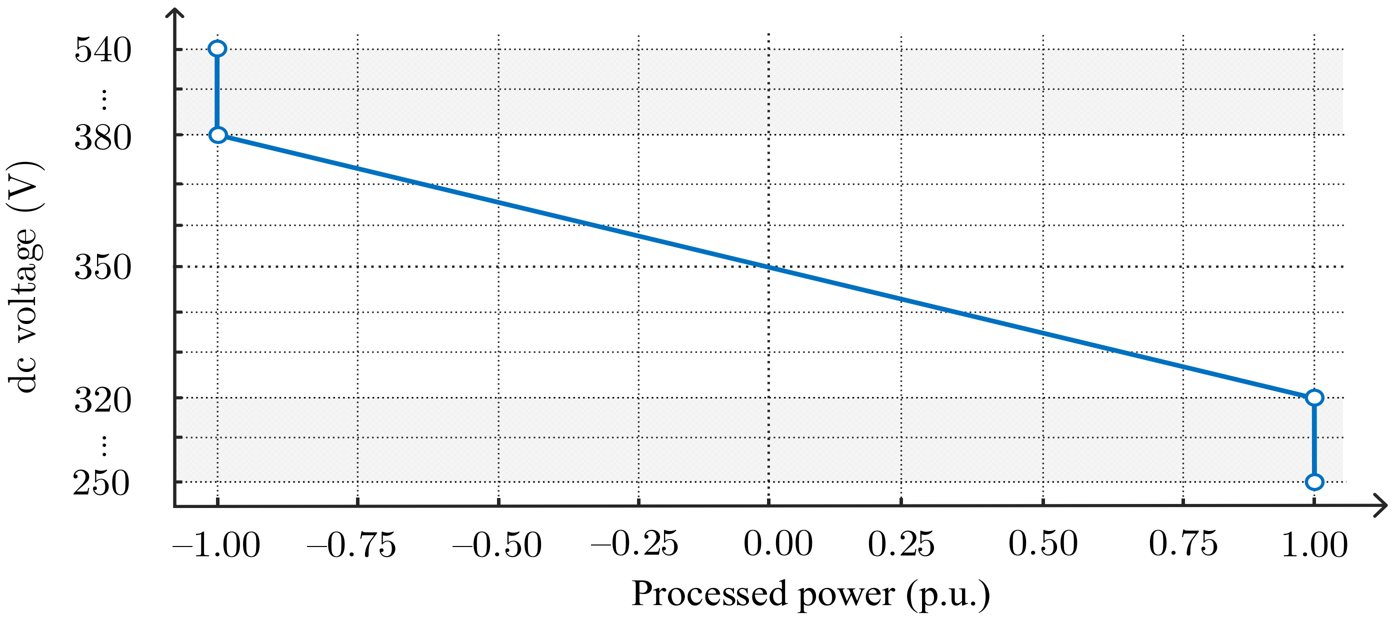
- Voltage levels and bands are selected according to the application
  - Industrial-scale: $640 - 760 \ V_{dc}$
  - Building scale: $320 - 380 \ V_{dc}$
  - ELVDC: $24 - 57 \ V_{dc}$
- Droop control is essential to ensure compatibility between different sources and loads



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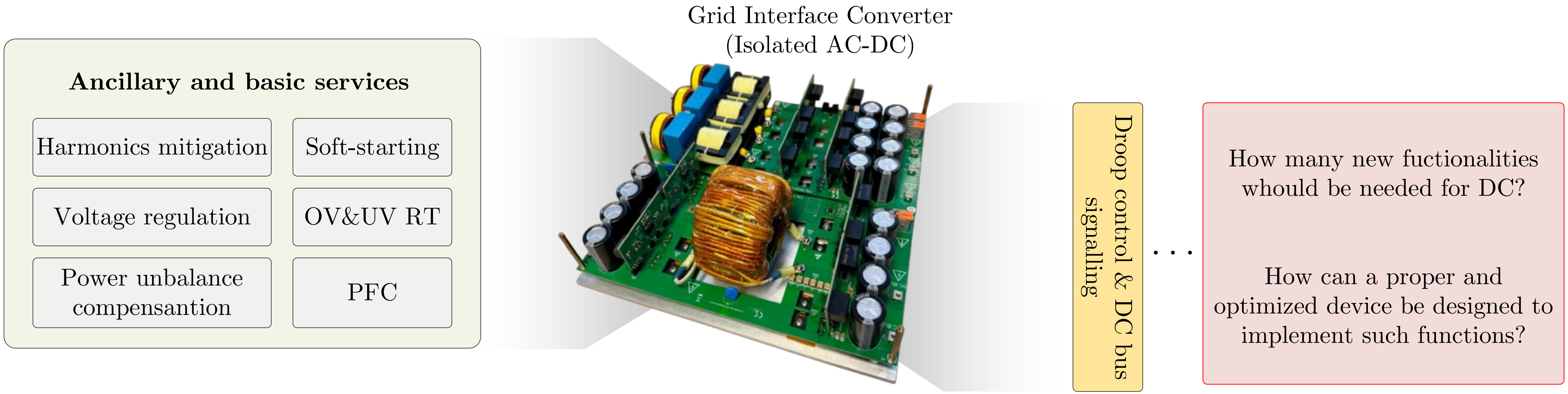
E. L Carvalho, A. Blinov, A. Chub, P. Emiliani, G. de Carne and D. Vinnikov, "**Grid Integration of DC Buildings: Standards, Requirements, and Power Converter Topologies**," in IEEE Open Journal of Power Electronics, 2022.

INTERLINKING CONVERTERS (GRID-INTERFACE)

- Enabling technology for DC microgrids: operates as a DC grid-forming converter
- Provides galvanic isolation (between AC and DC parts)
- Bidirectional power transfer – improved management to increase self-consumption
- Droop control operation – easy compatibility with DERs and loads
- Ancillary services for both, AC and DC grids



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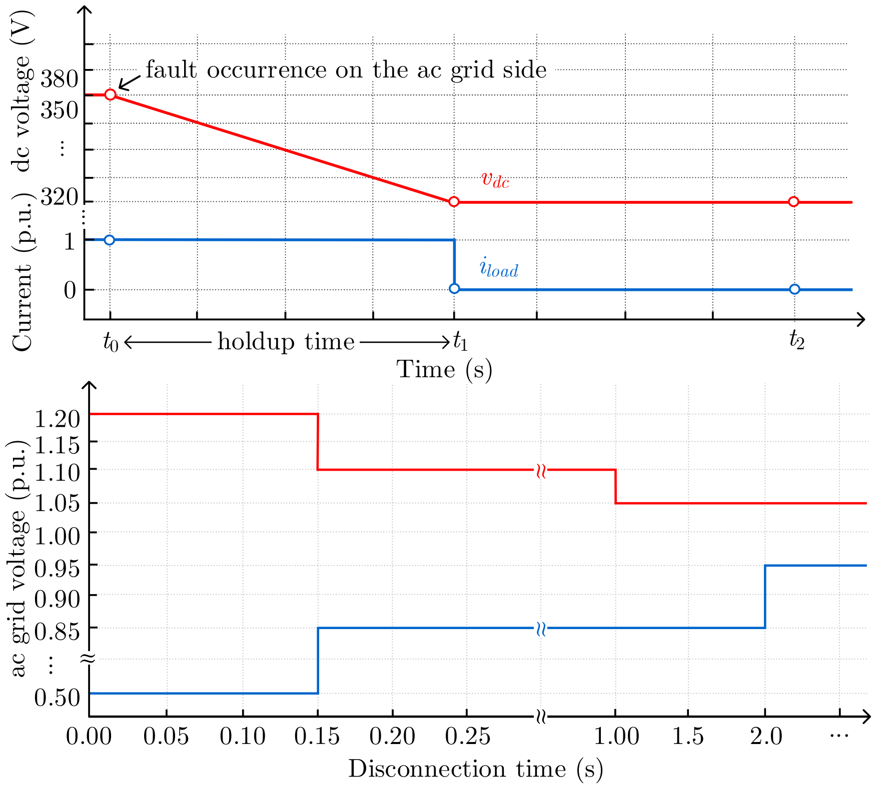
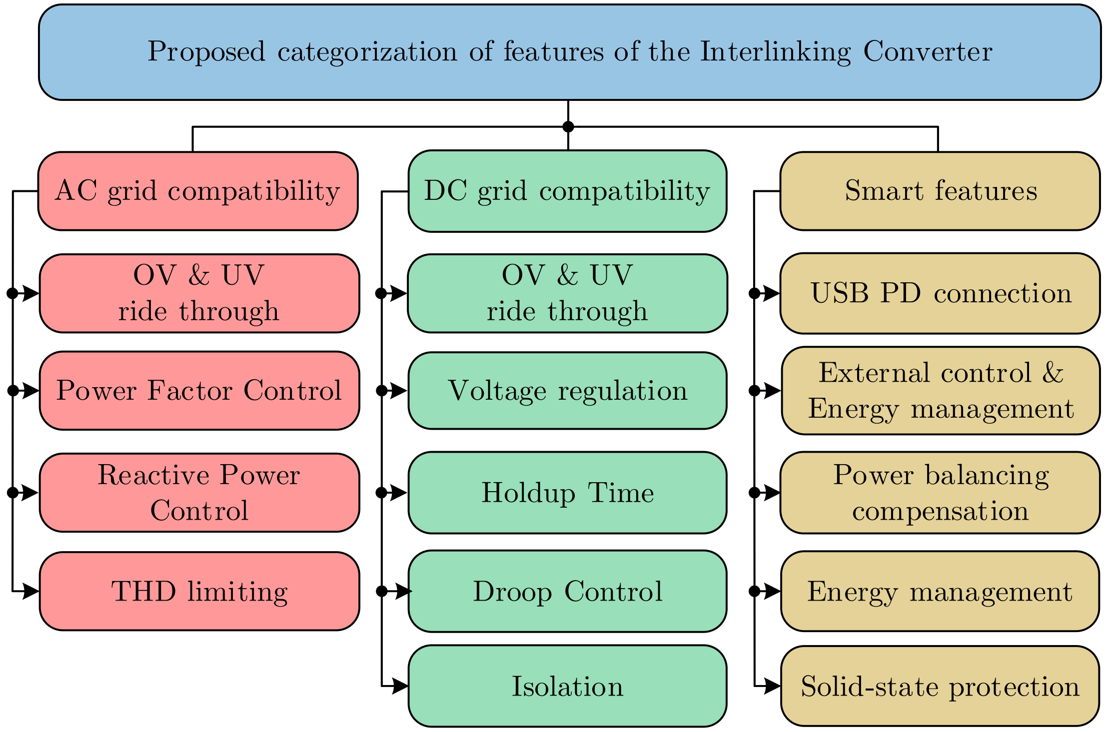
STANDARTIZATION RELATED TO INTERLINKING CONVERTERS

- Grid-interface/interlinking converters are multifunctional devices
- Main functions should acomplish with both
- Standartization/certification procedures for GIC are complex topic and still an open to be discussed





S. Ali, E. L. Carvalho, D. Vinnikov, "**An Overview of Smart and Essential Features in AC-DC Interlinking Converters for DC Buildings**" to be published.

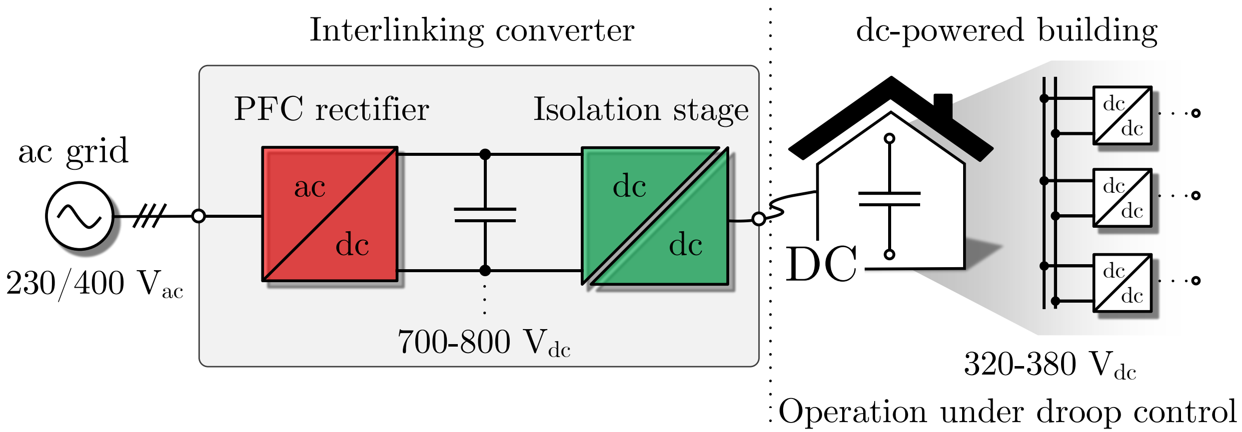
POWER CONVERTER TOPOLOGIES FOR AC-GRID INTEGRATION
THE ENABLING TECHNOLOGY FOR DC-POWERED BUILDINGS

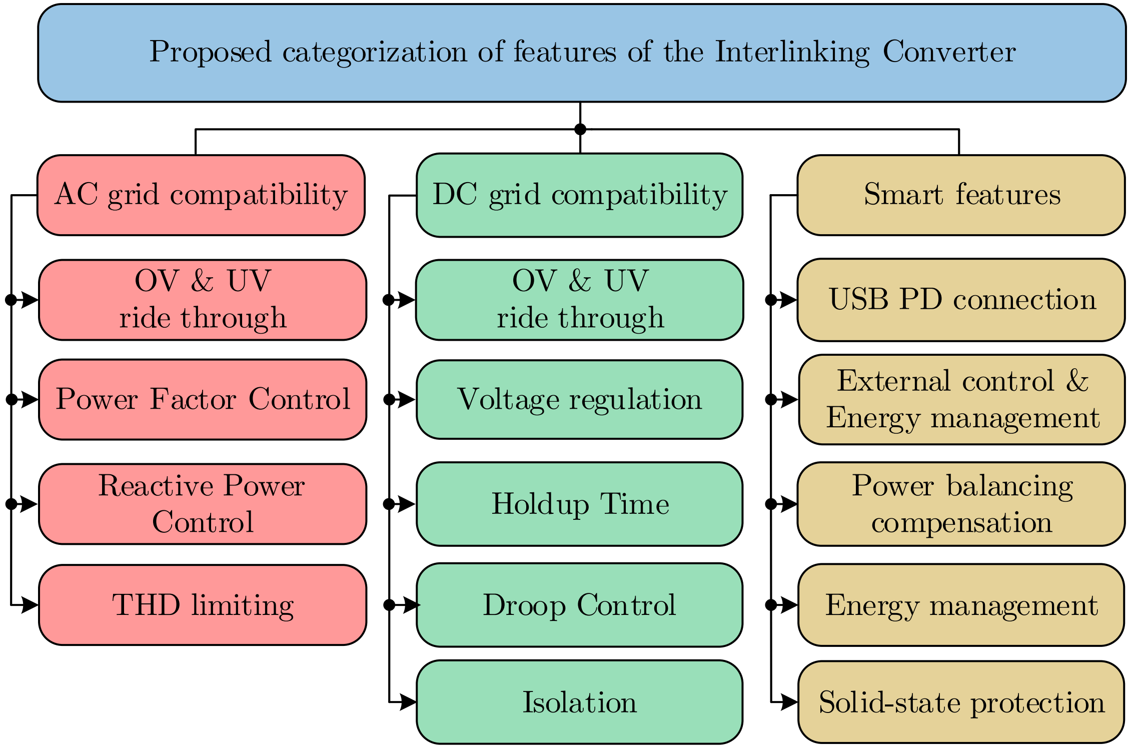
Dr. Edivan Laercio Carvalho

International Conference on DC Microgrids

POWER CONVERTERS SOLUTIONS FOR GIC

- Isolated active front-end converter (i-AFE)
- Main function: interlink between AC and DC grids
- Basic topology: AC-DC + DC-DC
- Well-defined roles according to each power processing stage
- Efficiency is the main challenge





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POWER CONVERTERS SOLUTIONS FOR GIC

SINGLE-STAGE / MATRIX-BASED CONVERTERS

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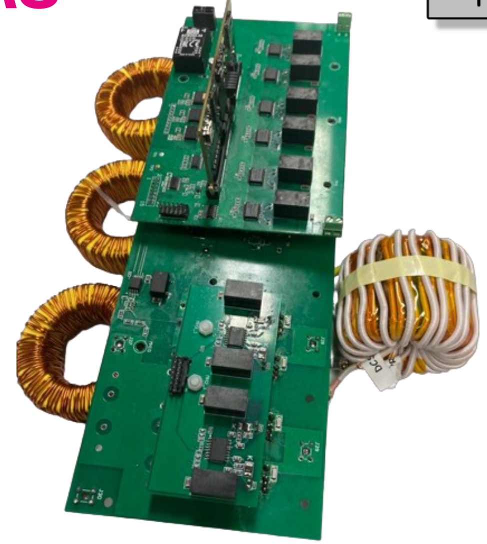
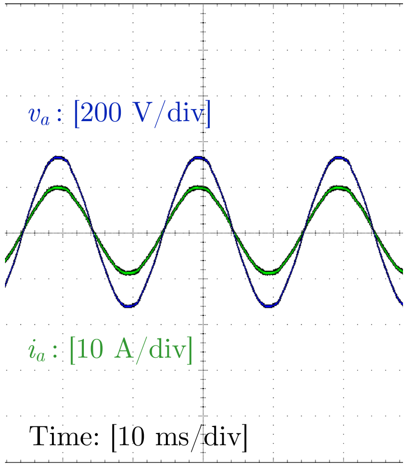
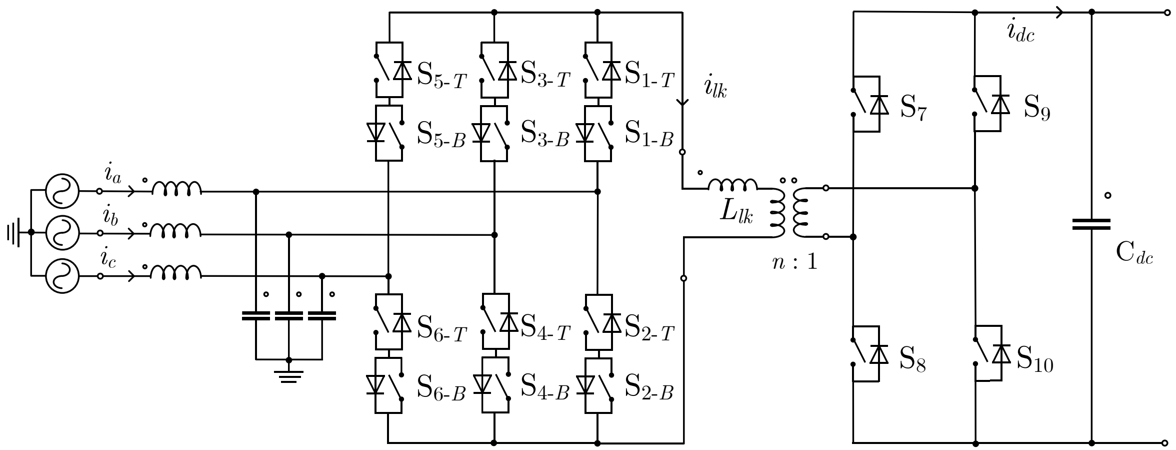
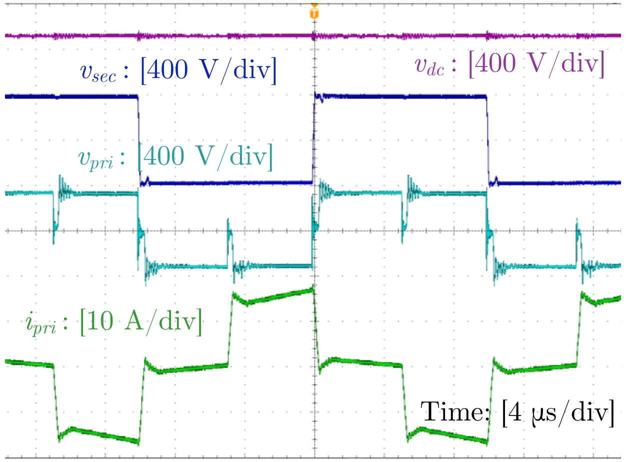
- Lower number of sensors/feedback loops
- No intermediate dc link
- Complex modulation strategy
- Higher THD (for voltage-fed topologies)
- High efficiency: $96.7\ \%$ peak $(3.5\ \mathrm{kW})$









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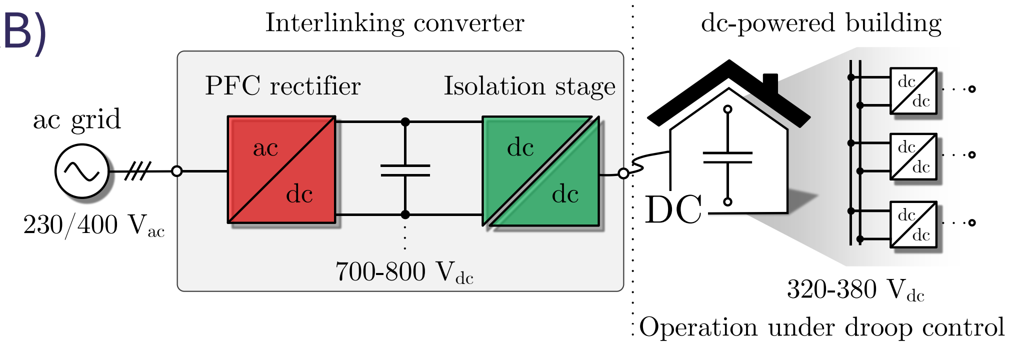
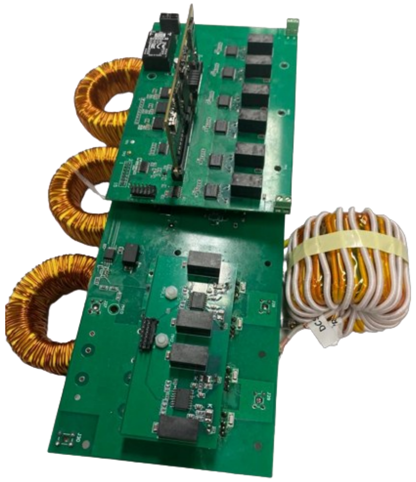
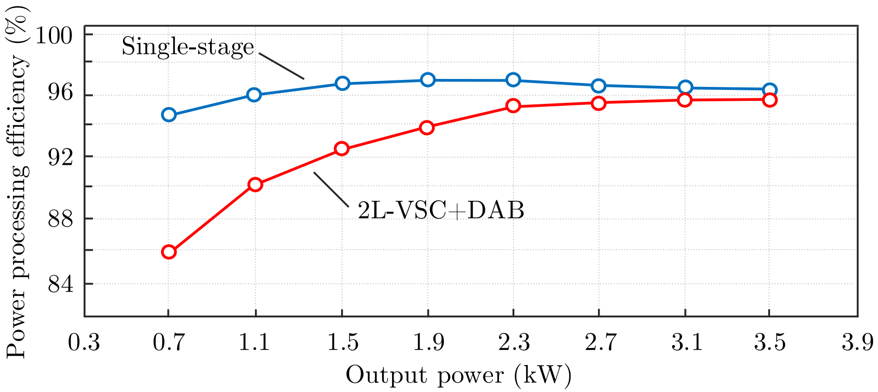
E. L. Carvalho, A. Blinov, A. Chub, D. Vinnikov, "**Three-Phase Bidirectional Isolated AC-DC Matrix-Converter with Full Soft-Switching Range**", in IEEE ACCESS

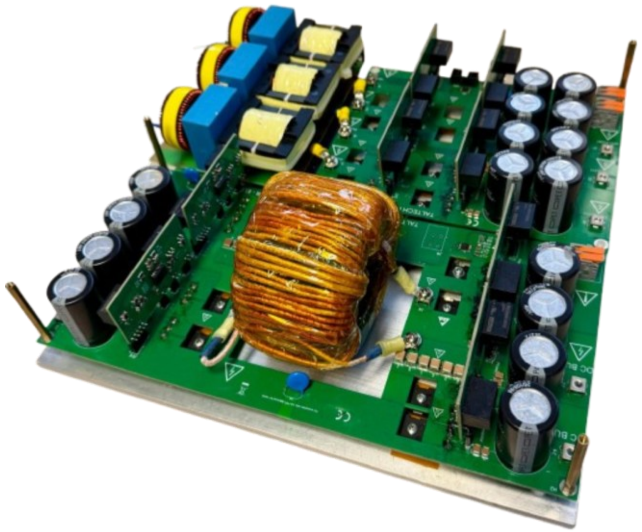
POWER CONVERTERS SOLUTIONS FOR GIC
TWO-STAGE AC-DC CONVERTERS

- Based on voltage source (2L-VSC) + Dual Active Bridge (DAB)
- Bulking intermediate DC bus for decoupling both stages
- Flexible solution – allows to develop different functions for grid interaction
- Flat efficiency is the main challenge









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POWER CONVERTERS SOLUTIONS FOR GIC

TWO-STAGE AC-DC CONVERTERS

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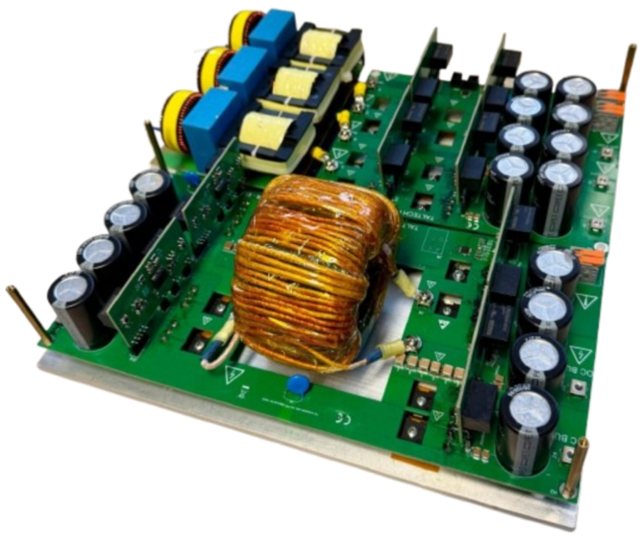
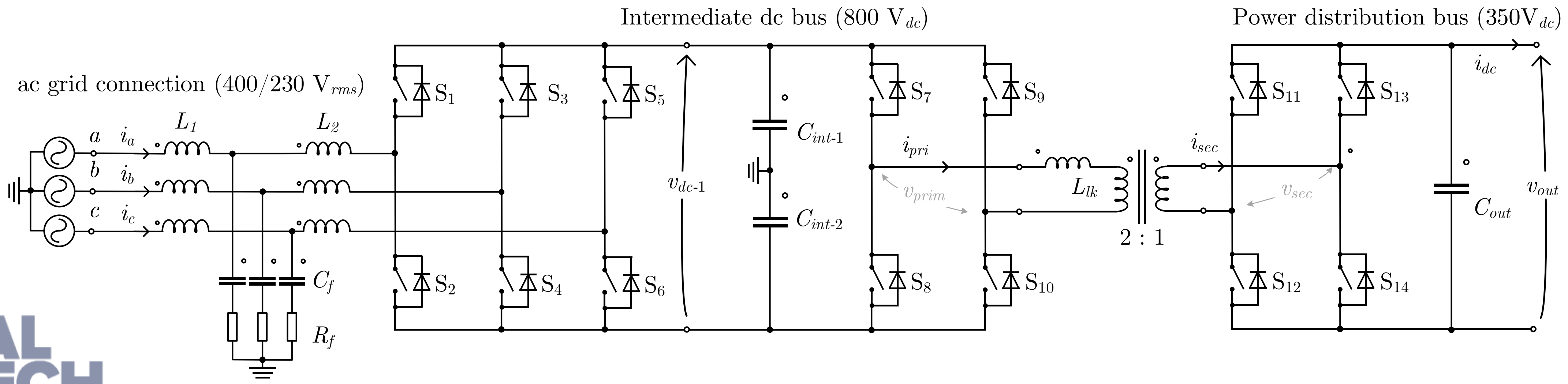


- Bidirectional power router for prosumer DC buildings
- High-frequency galvanic isolation
- Input $230/400\ V_{ac}$, output $350\ V_{dc}$, $5 \ldots 10$ kW
- Droop control according to Current/OS protocol
- Efficiency curve optimized for part-load operation based on statistical data $(> 97\ \%)$
- Possible multi-port configuration with USB-PD output



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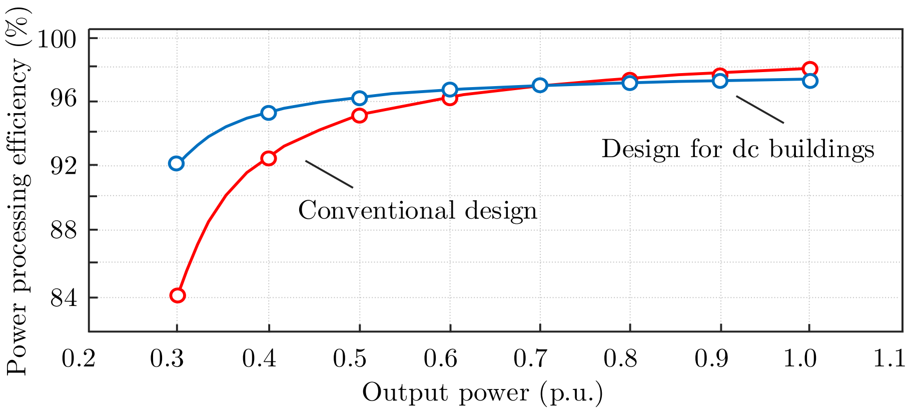
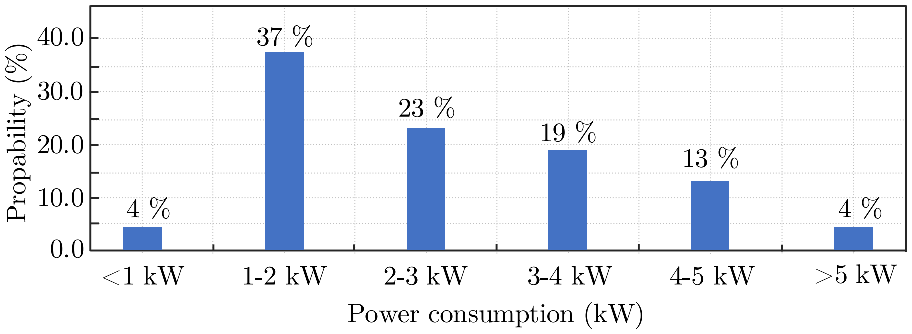
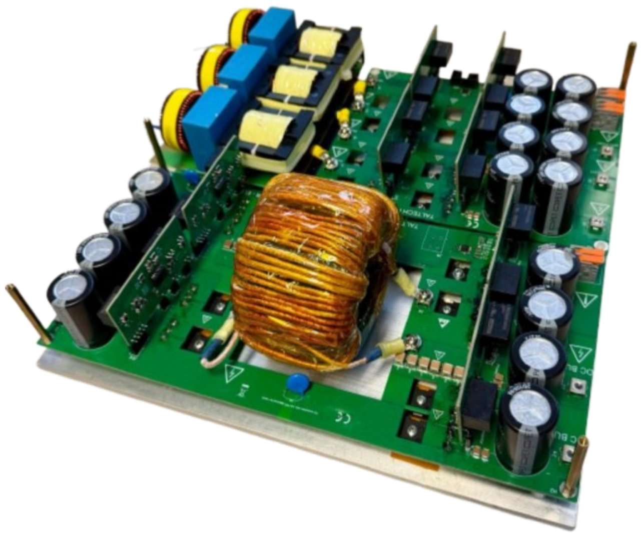
E. L. Carvalho, A. Blinov, A. Chub, D. Vinnikov, "**Design Considerations of Dual-Active Bridge DC Grid-Forming Converter for DC Buildings**", in Trans. on Industrial Electronics

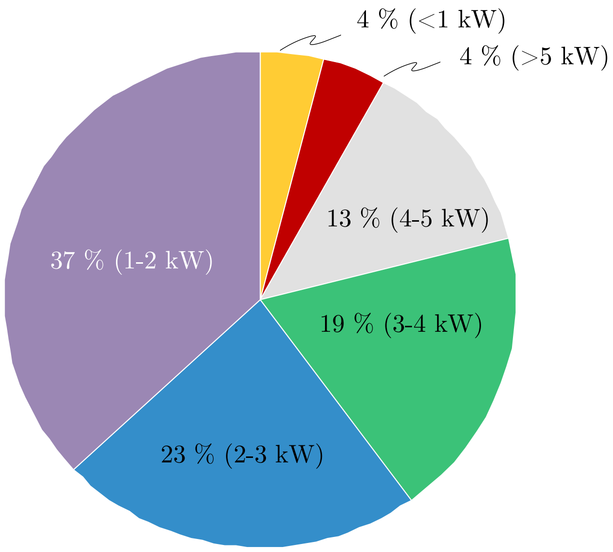
DESIGN TARGETS AND PRIORITIES



- Application oriented design
- Investigate actual operational profile
- Indicate most probable working conditions
- Optimized design considering the droop curve







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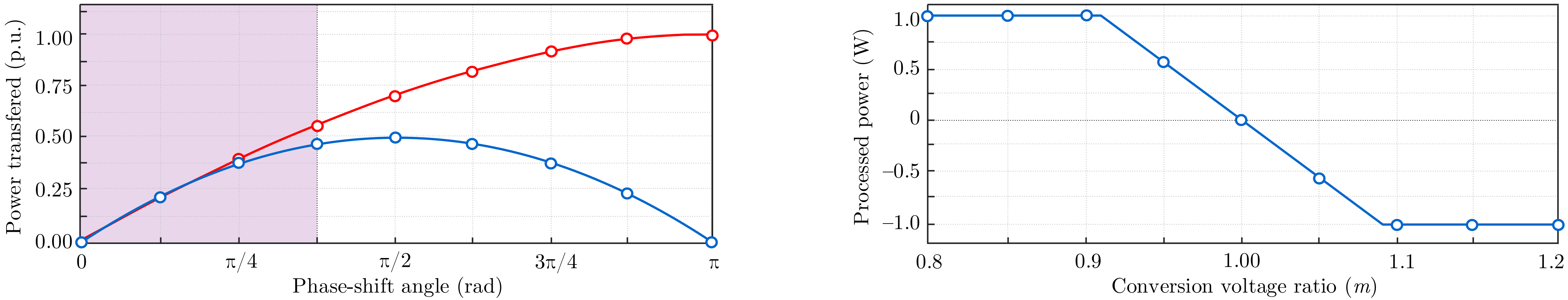
DROOP CONTROL IMPACT ON CONVERTER EFFICIENCY

- **Conventional design**: designed to operate within a predefined region
- **Operation under droop control**: the processed power is constrained to follow a specific line, which is determined by the droop control
- Effective operation area should be considered



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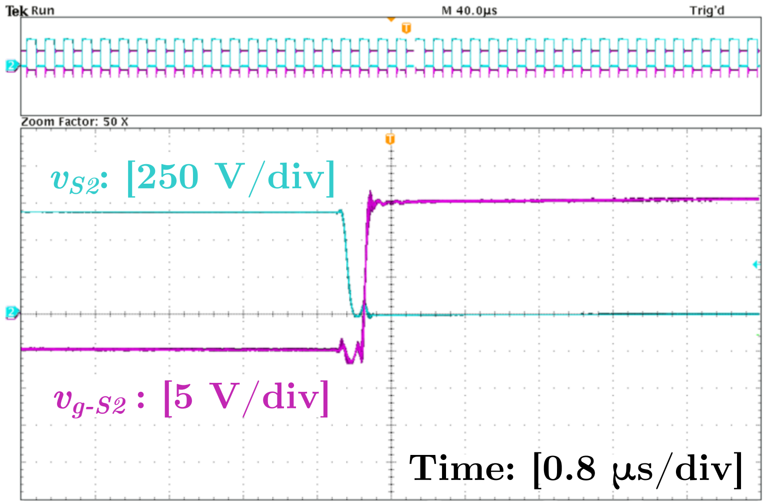
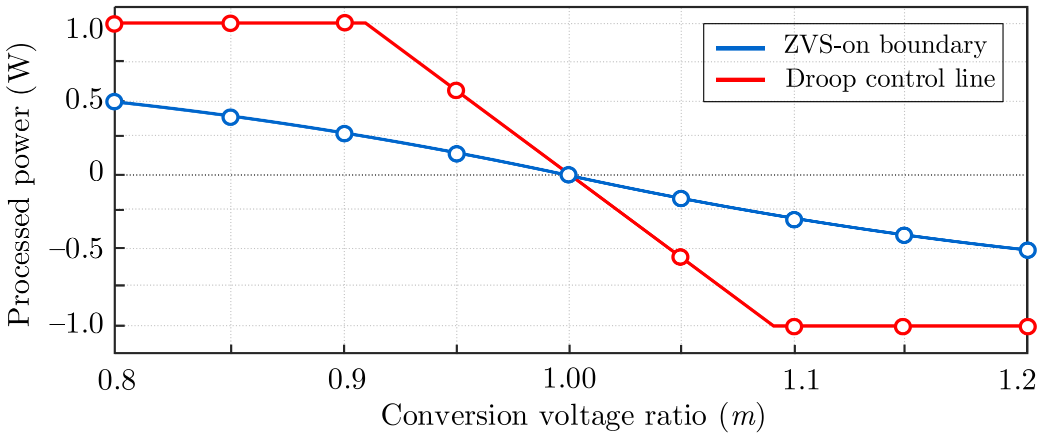
DROOP CONTROL IMPACT ON CONVERTER EFFICIENCY

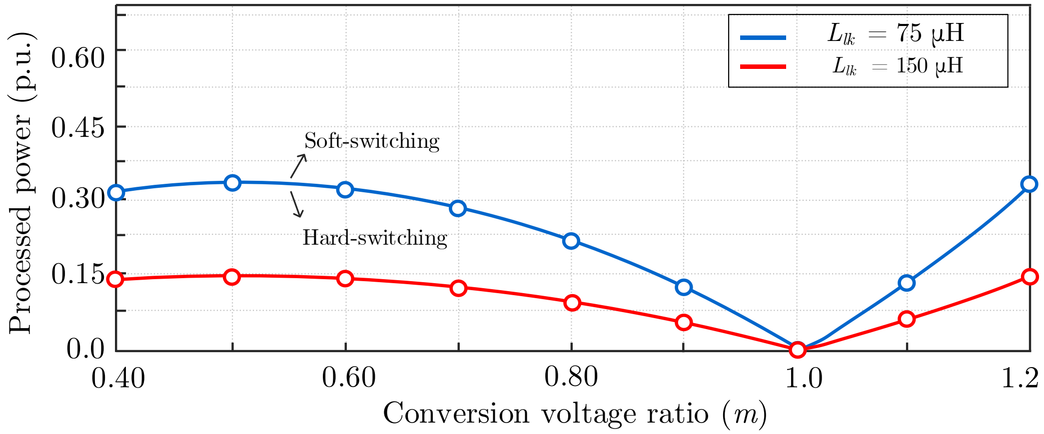
- Dual Active bridge operation
- How does droop control affect the soft-switching operation?
- Under droop control is possible to ensure wide soft-switching range



ZVS-on boundary / droop control line



Soft-switching boundaries



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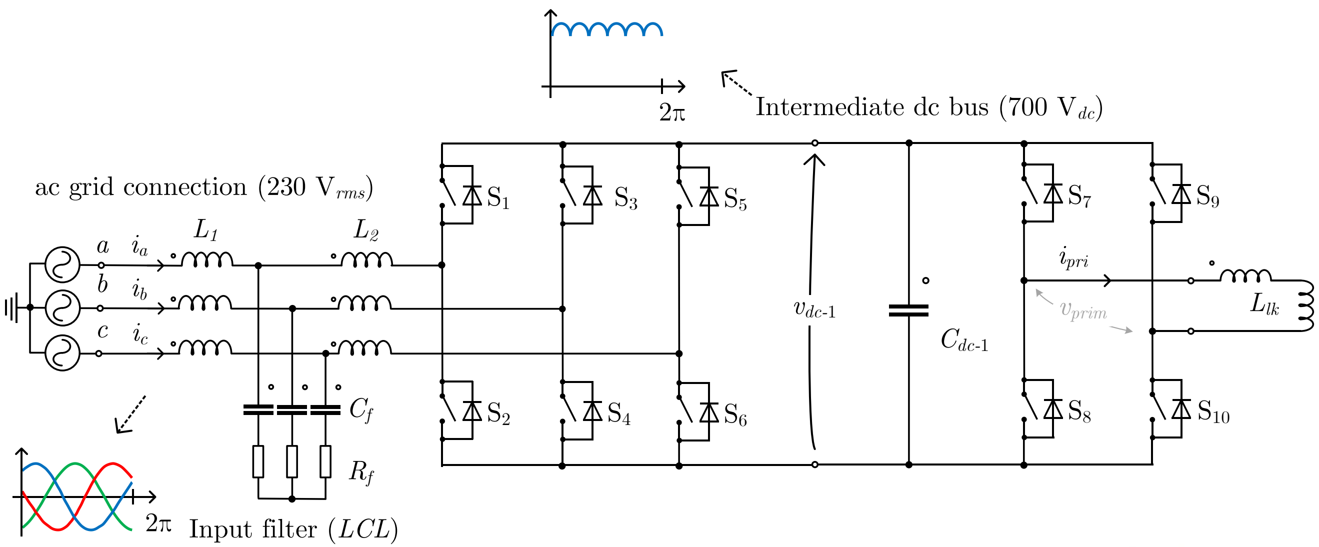
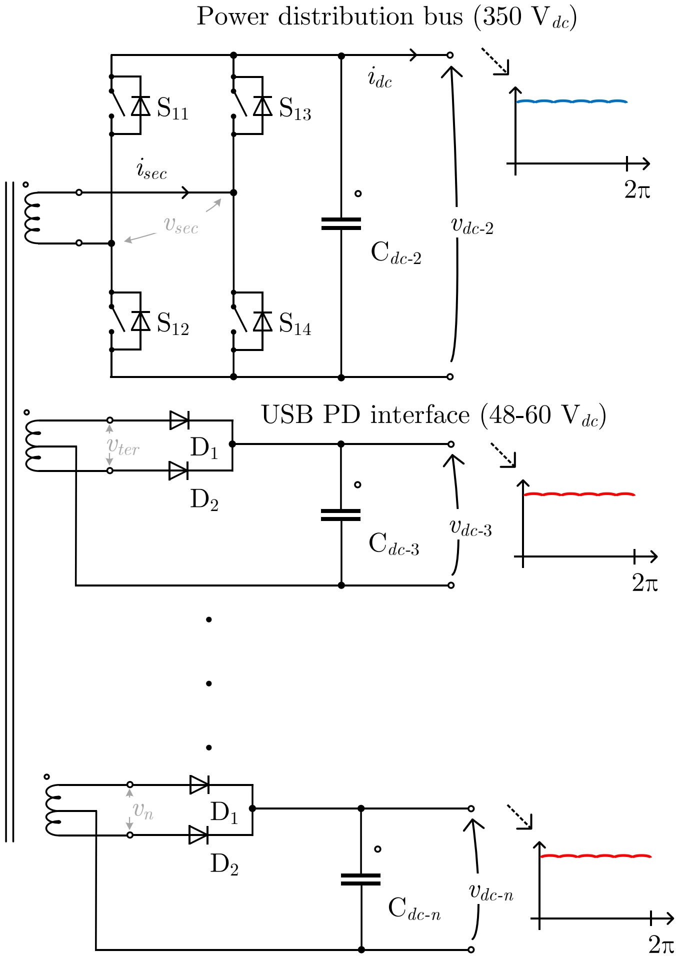
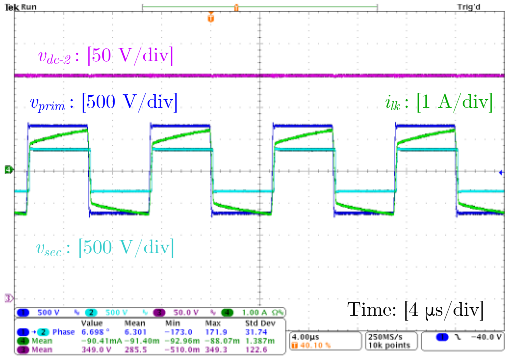
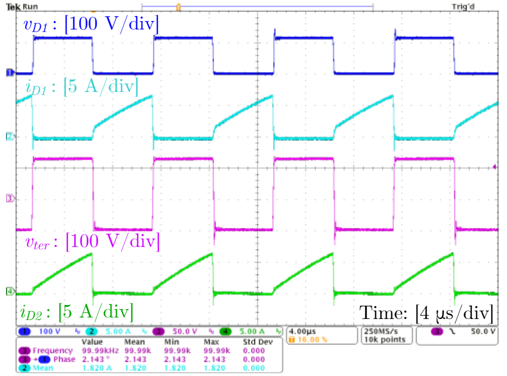
EMERGING TOPOLOGIES FOR GIC

- Multiport converter with USB PD interface, according to Current/OS protocols





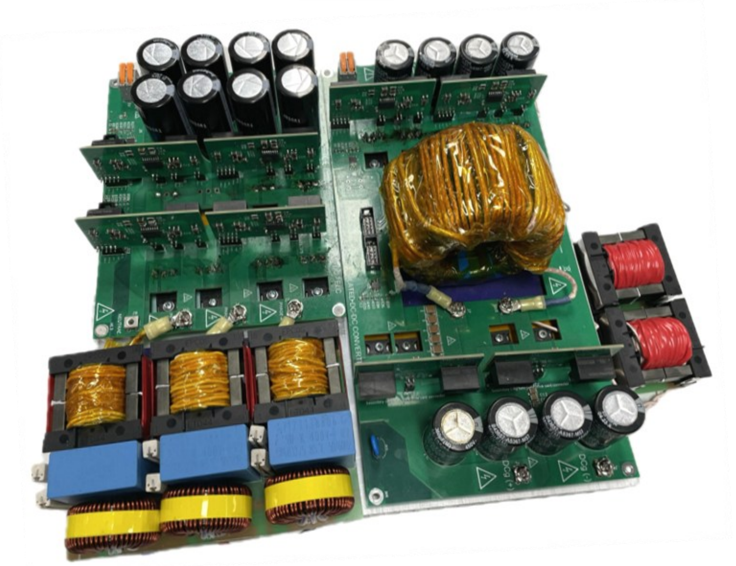


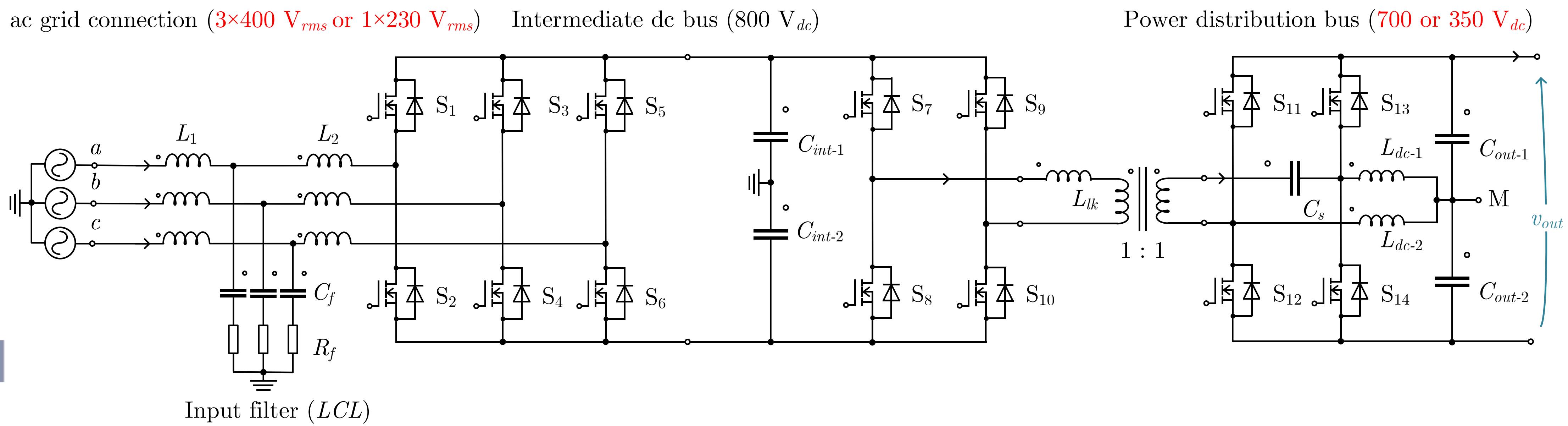


E. L. Carvalho, A. Blinov, A. Chub, D. Vinnikov, "**Magnetically Integrated Multiport Converter for Energy Management in DC-Powered Buildings**", in Eletronica de Potencia (SOBRAEP)

EMERGING TOPOLOGIES FOR GIC

- **Universal interlinking converter:**
  - Proposed to cover different types of DC grids (bipolar and unipolar)
  - Self-balanced configuration (additional service for the dc grid)
  - Reduced number of semiconductors
  - Either single- or three-phase connection with AC grid
  - Better resilience and flexibility





EMERGING TOPOLOGIES FOR GIC

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- **High flexibility for the AC grid connection:**
  - Individual phase control enables connection to both single-phase and three-phase systems
  - Under fault conditions, the converter can continue operating with derated power

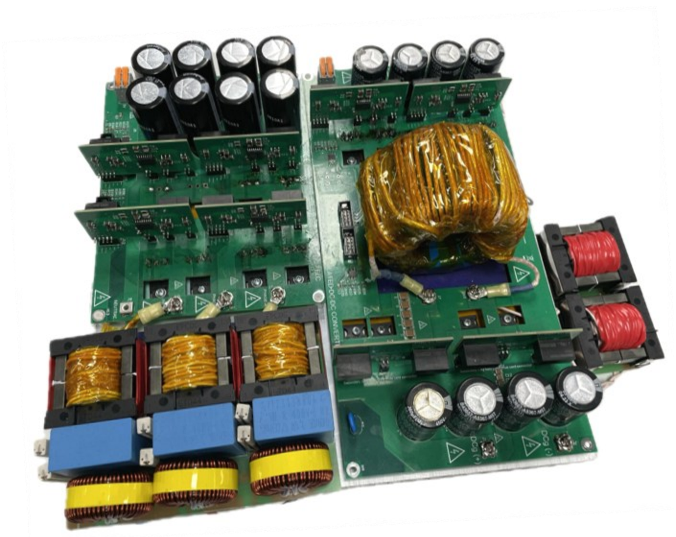


TABLE I
VOLTAGE, CURRENT, AND POWER RATINGS ACCORDING TO THE CONVERTER OPERATION MODES

	Mode	ac voltage	ac current	Power rate
3-ph	Normal	*3 × 400 V_{rms}	7.25 A_{rms}	5.00 kW
1-ph	Normal	230 V_{rms}	7.25 A_{rms}	1.67 kW
2-ph	Abnormal	230 V_{rms}	7.25 A_{rms}	3.34 kW
1-ph	Abnormal	*1 × 400 V_{rms}	7.25 A_{rms}	2.90 kW

* Line-to-line voltage

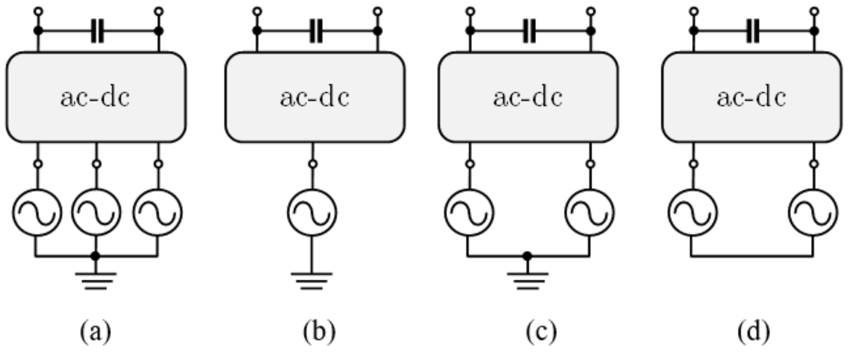
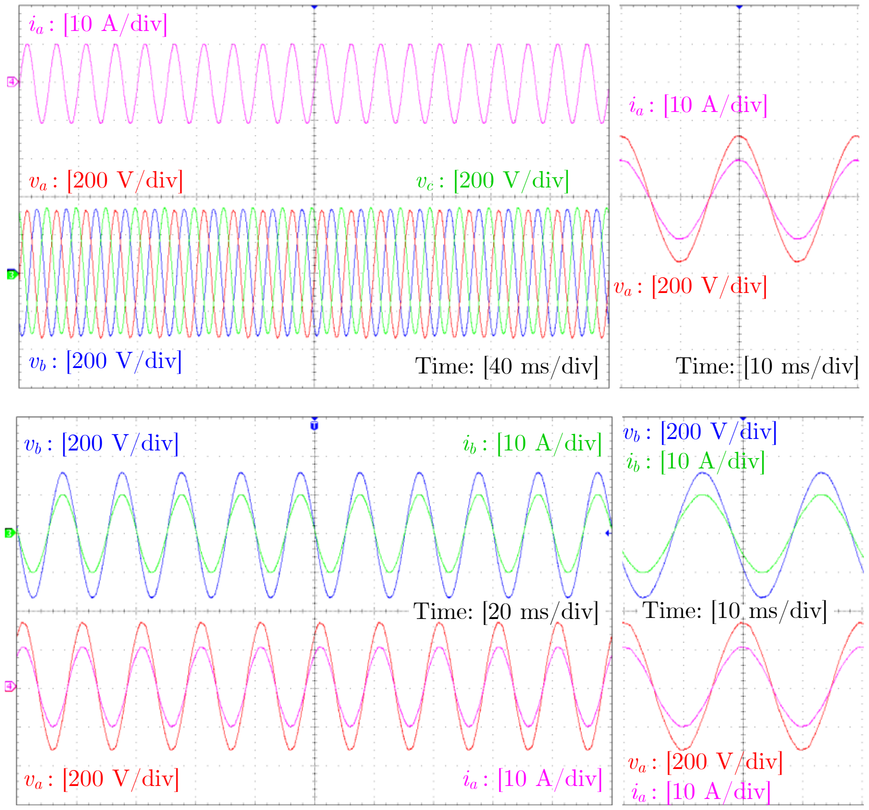


Fig. 2. Possible converter operation modes, according to the ac grid connection, and fault occurrence; (a) Mode I; (b) Mode II; (c) Mode III; and (d) Mode IV.



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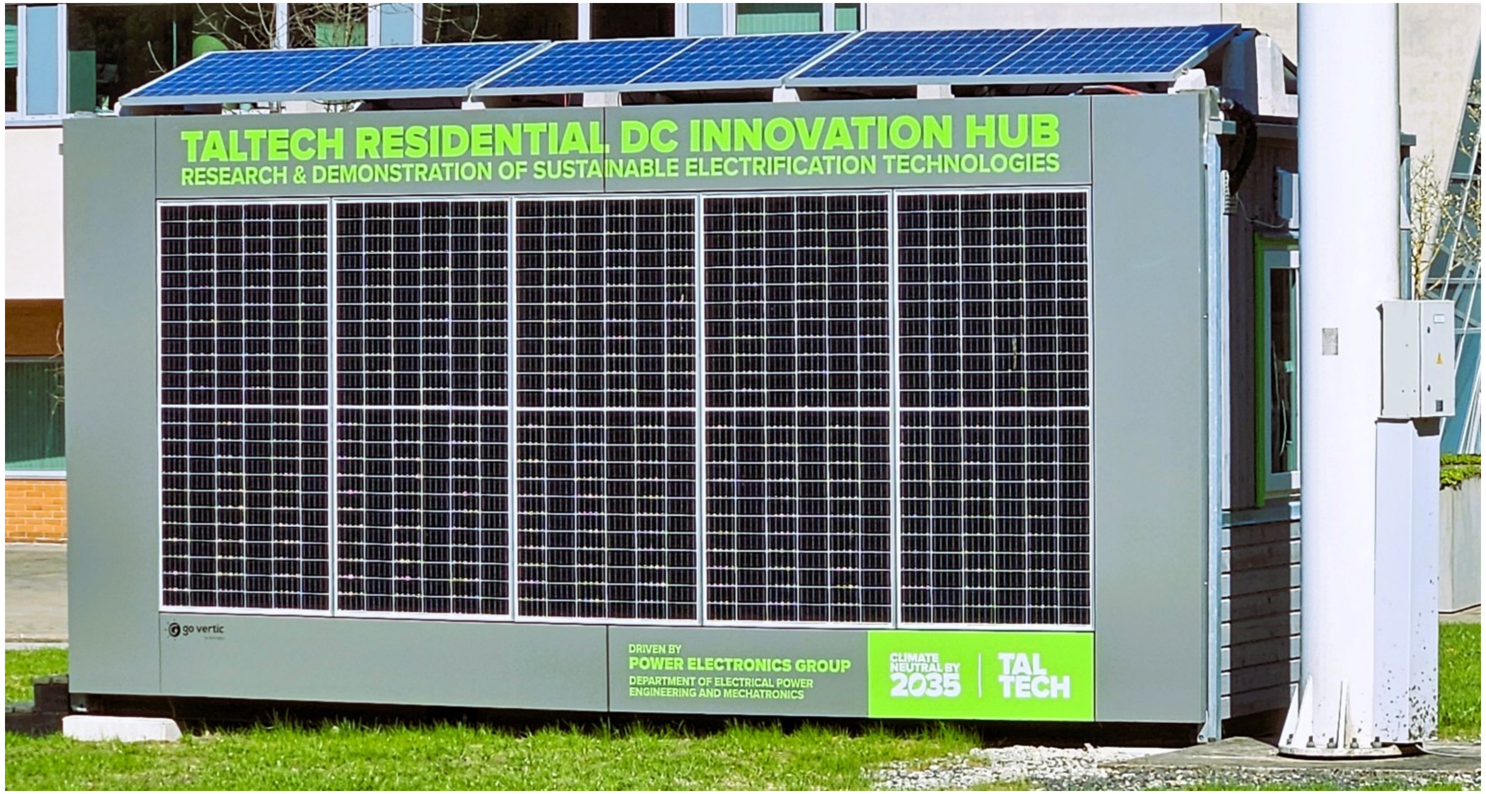
TALTECH RESIDENTIAL DC INNOVATION HUB

The first DC EXPERIENCE CENTER in Northern Europe



- An international open platform for research and demonstration of residential DC power distribution technology
- Validation of net-zero-energy solutions (workplace, space heating and cooling, ventilation, etc.)
- The living lab blends the everyday real-life experiences of pilot users with academic research to develop future-proof, energy-saving technologies
- Data collection for the future design of the energy-neutral TalTech campus

taltech.ee/en/i3dc-initiative

TAL TECH

OVERVIEW OF FULL-POWER CONVERTERS FOR WIDE VOLTAGE RANGE APPLICATIONS

Dr. Sachin Chauhan

TAL TECH

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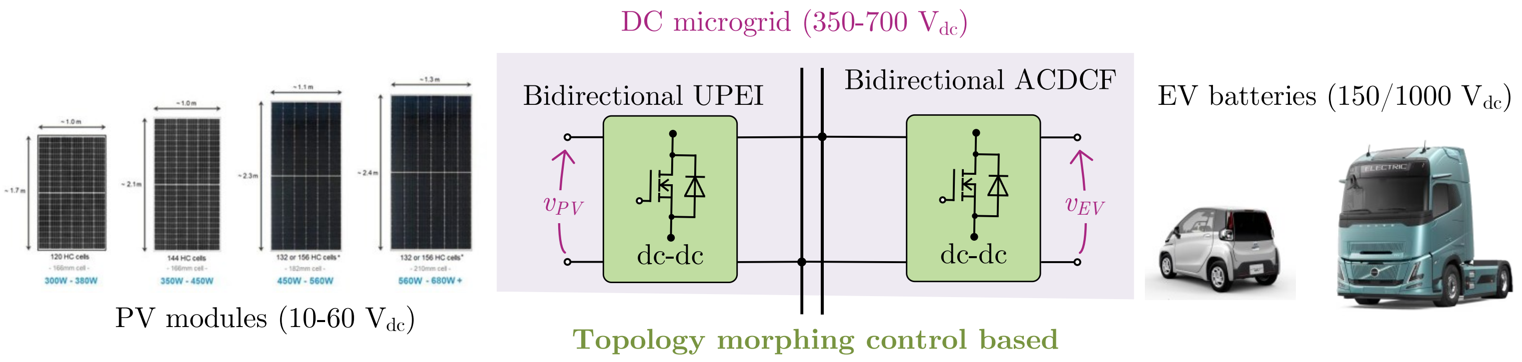
WHY WIDE VOLTAGE RANGE OPERATIONS?

- In Electric Vehicles
  - Battery voltage variation (150 V – 1000 V)
  - Regenerative braking and dynamic load conditions
  - Compatibility with multiple battery chemistries



- In Photo-Voltaic Systems
  - Solar panel voltage variation (e.g., 10-60 V) Per Module :
    - Irradiance/ Temperature/ MPPT

- Supporting Multiple Applications and Standards (350/700 Vdc according to Current/OS)
- Handling input/output voltage variations

Voltage Range	Architecture Type	Chemistry	Examples of Use
200V – 400V	Standard High Voltage	NMC, LFP, NCA	Nissan Leaf, Chevy Bolt, Tesla Model 3/Y (LFP or NCA), BMW i3
400V – 500V	Enhanced High Voltage	NMC, NCA	Tesla Model S/X, Audi e-tron, Hyundai Kona EV
800V – 900V+	Ultra-High Voltage	NMC	Porsche Taycan, Hyundai Ioniq 5, Kia EV6 GT, Lucid Air, Rimac Nevera

- Maximizing Energy Harvest and Efficiency
- Bidirectional capability for batteries

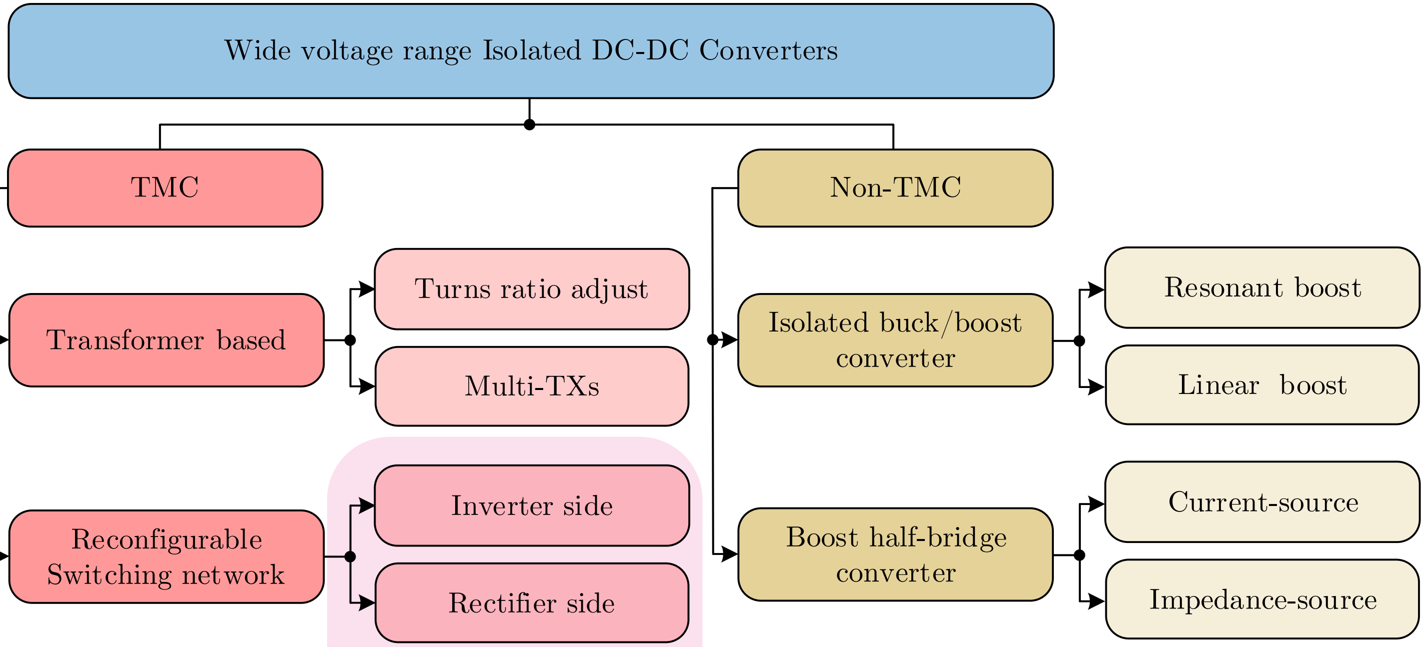
HOW TO ACHIEVE WIDE VOLTAGE RANGE IN DC/DC CONVERTERS?

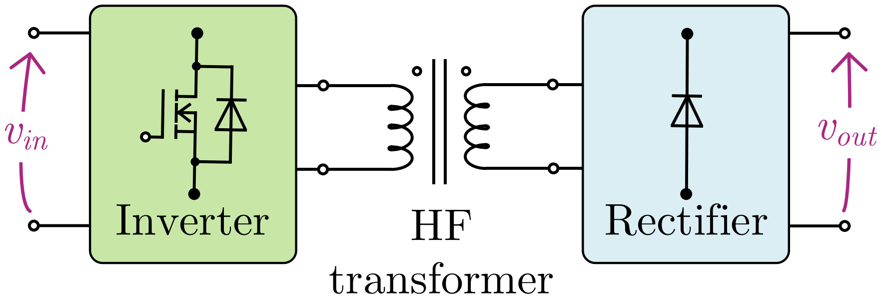
Topology Morphing Control (TMC)

- Dynamic switch control to morph between the different topologies
- Wide Input / Output voltage gain
- Adaptable Gain Relation based on TMC.

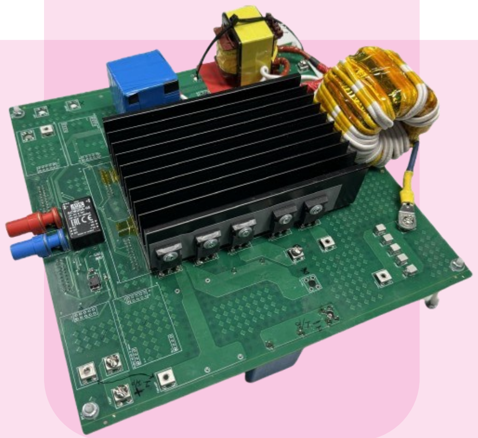
Non-TMC

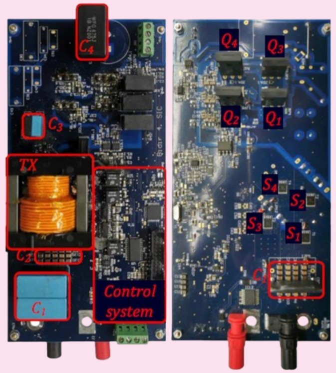
- Gain relation with control is fixed based on the chosen topology.
- Limited gain range.





Overall voltage gain:
Inverter x transformer x rectifier





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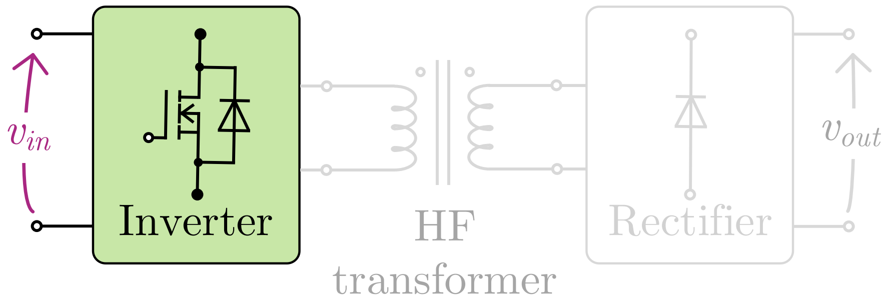
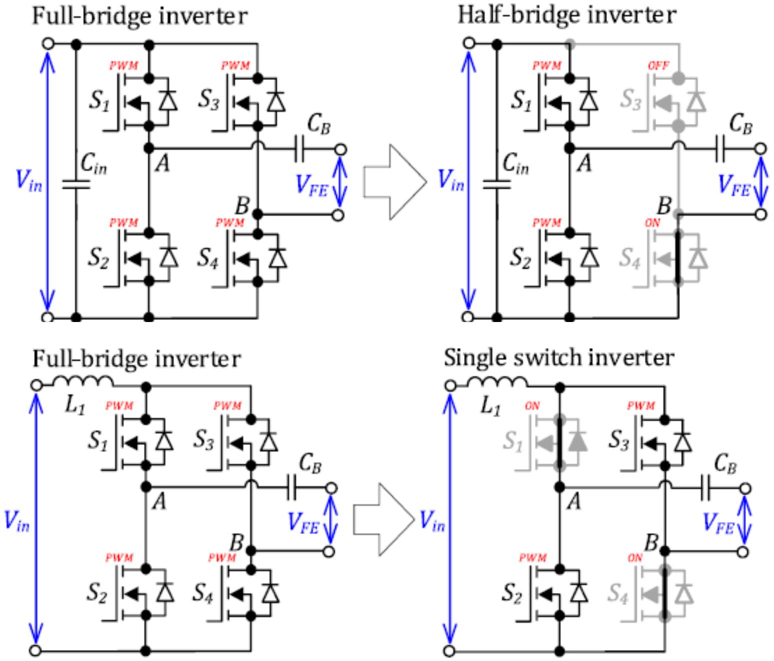
POWER ELECTRONICS GROUP

INVERTER SIDE TMC

- Normalized Voltage Gain Range Achieved (1;0.75;0.5;0.25)





V. Sidirov, A. Chub, D. Vinnikov, and F. Z. Peng, "**SURVEY OF TMC TECHNIQUES FOR PERFORMANCE ENHANCEMENT OF GALVANICALLY ISOLATED DC-DC CONVERTERS**," *in IEEE Open Journal of the Industrial Electronics Society*, vol. 3, pp. 751-777, 2022,

INVERTER SIDE TOPOLOGY MORPHING CONTROL

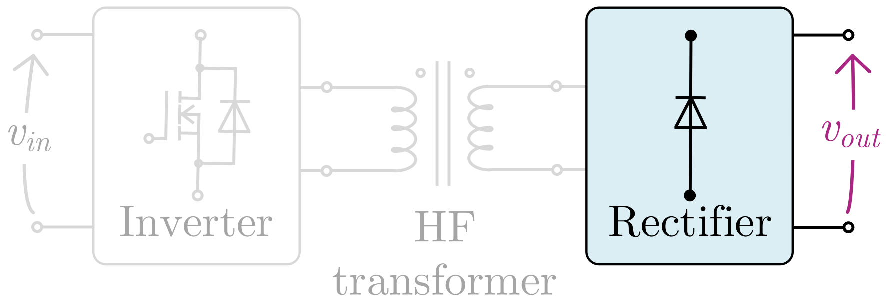
TMC	Gain	S	D	C	Advantage	Disadvantage	Applications Examples		
							Vin, V	Vout, V	Power, W
FBI-HBI	1;0.5	4	0	2	Two-fold gain range extension	Higher Current stress on single switch	150-400	1650	2500[1]
FBI-2T-flyback or forward	1	4	0	1	Light load efficiency improvement (5%)	Higher conduction and reverse losses in body diodes	20-30	200-270	10-100[2]
FBI-SSI	**1**	**4**	**0**	**L=1**	**Light load efficiency improvement (3%)**	**Higher current stress in diagonal switches**	**10-60**	**400**	**25-250[3]**
H-TL FBI to HV FBI, to QBI	1;0.5;0.25	6	2	2	Four times gain range extension	Unequal voltage and current stress in switches	200-400	60	1200[4]
TL FBI to TQBI, to HVFBI, to QBI	1;0.75,0.5;0.25	8	4	4	Six times gain range extension	High number of switches, unequal current stress in switches	200	200-700	3500[5]

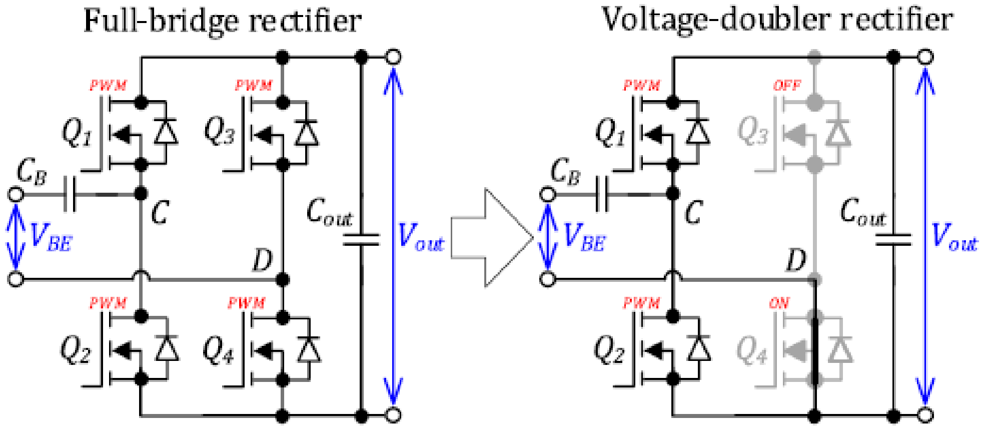
Note: S=Switch, D= Diode, C= capacitor, L= inductor

A. Chub, D. Vinnikov, R. Kosenko, and E. Liivik, "**Wide input voltage range photovoltaic microconverter with reconfigurable buck-boost switching stage**," IEEE Trans. Ind. Electron., vol. 64, no. 7, pp. 5974–5983, Jul. 2017.

RECTIFIER SIDE TOPOLOGY MORPHING CONTROL

- Normalized Voltage Gain Range Achieved (G:1-6)





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V. Sidirov, A. Chub, D. Vinnikov, and F. Z. Peng, "**SURVEY OF TMC TECHNIQUES FOR PERFORMANCE ENHANCEMENT OF GALVANICALLY ISOLATED DC-DC CONVERTERS**," *in IEEE Open Journal of the Industrial Electronics Society*, vol. 3, pp. 751-777, 2022,

RECTIFIER SIDE TOPOLOGY MORPHING CONTROL

TMC	Gain	S	D	C	Advantage	Disadvantage	Applications Examples		
							Vin, V	Vout, V	Power, W
FBR-VDR	1;2	4	0	2	Two fold gain range extension	Higher Current stress on single switch and blocking capacitor	200-950	1650	3300[1]
FBR to SSR	1	4	0	1	Light load efficiency improvement (8%)	Higher conduction and reverse recovery losses in body diodes	20-30	200-270	10-100[2]
VDR-VQR	2;4	1	3	4	Two fold gain range extension	Higher Current stress on single switch and blocking capacitor	150-400	1650	2500[3]
FBR to VDR, to VQR	1;2,4	2	6	4	Four times gain range extension	Higher semiconductors, unequaland high currents stress on diodes and switches	5-110	400	360[4]
VDR to VTR, to VFR	2;3;5	2	7	5	2.5 fold gain range extension	High number of utilized components, unequal current stress in diodes	25-100	500	250[5]
VQR to VFR, to VSR	4;5;6	2	8	6	1.5 fold gain range extension	Higher number of switches, unequal current stress in switches.	25-50	760	300[6]
TL FBR to 1.5xVM, to VDR, to VQR	1;1.5;2;4	8	4	4	Four times gain range extension		200	200-700	3500[7]

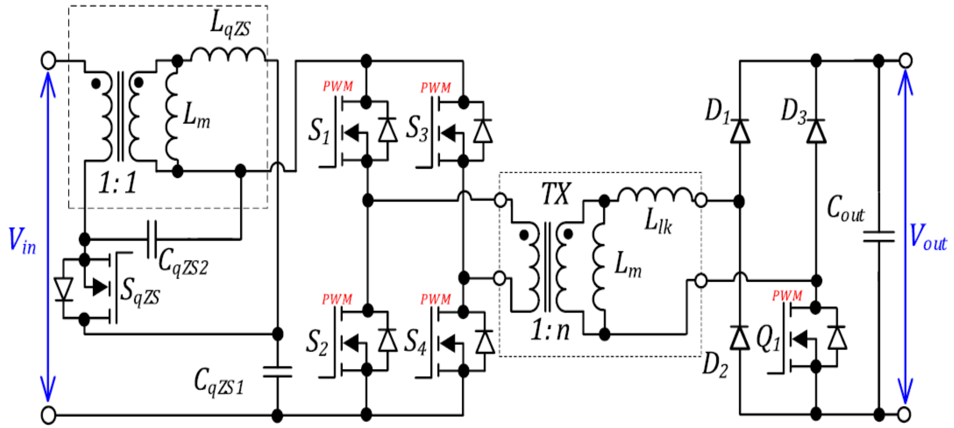
Note: S=Switch, D= Diode, C= capacitor, L= inductor

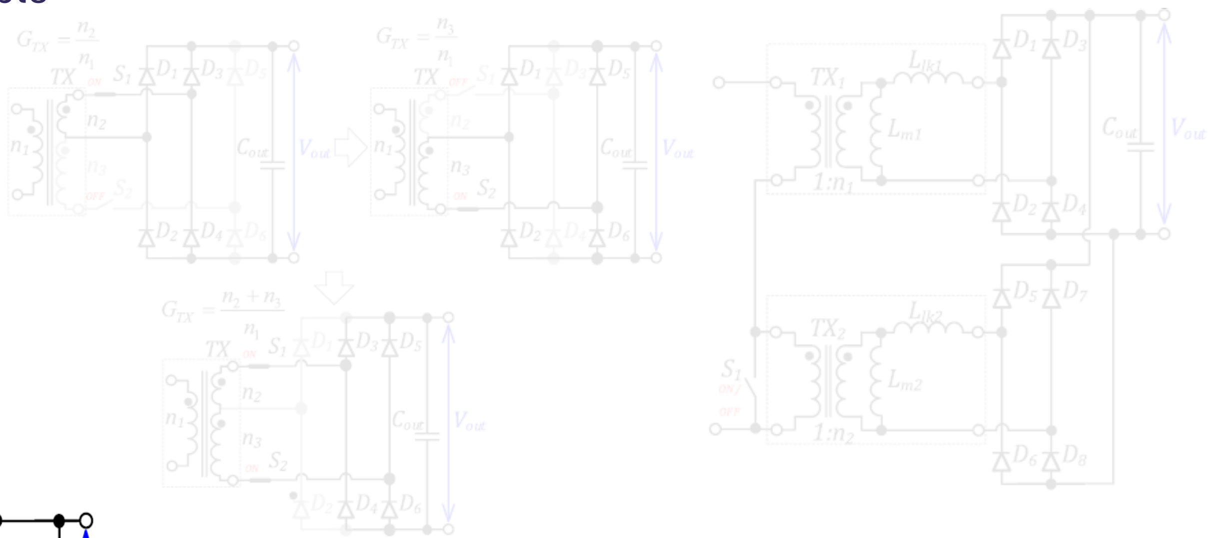
TAL TECH

A. Chub, D. Vinnikov, O. Korkh, M. Malinowski, and S. Kouro, "**Ultrawide voltage gain range microconverter for integration of silicon and thin-film photovoltaic modules in DC microgrids**," IEEE Trans. Power Electron., vol. 36, no. 12, pp. 13763–13778,

ADVANCES IN TOPOLOGY MORPHING CONTROL

- Active rectifier with variable structure
- ACTIVE Three-level Half-bridge Inverter and Rectifier With Variable Structure
- Adjusting Transformer Turns Ratio
- Bypassing Series Transformer
- Double Full-Bridge LLC Converter
- Five-switch reconfigurable inverter
- LLC with auxiliary coupled inductor
- Transformer with fractional turn ratios
- Multitrack Converter Architecture
- Quasi-Z-source



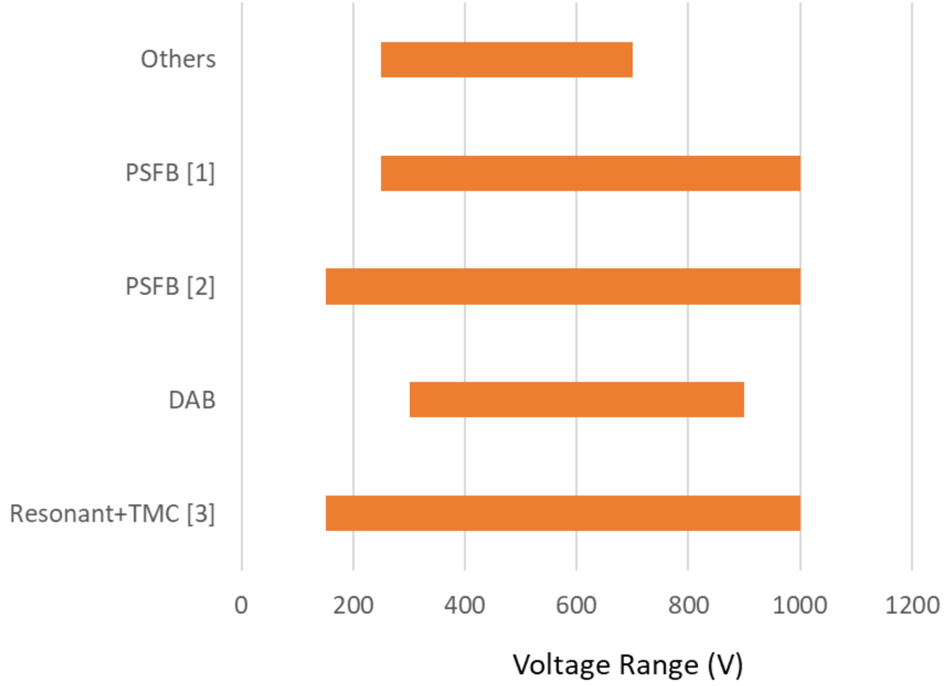


A. Chub, D. Vinnikov, R. Kosenko and E. Liivik, "**Wide Input Voltage Range Photovoltaic Microconverter With Reconfigurable Buck–Boost Switching Stage**," in IEEE Transactions on Industrial Electronics, vol. 64, no. 7, pp. 5974-5983, July 2017.

CONVERTER TOPOLOGIES FOR WIDE-VOLTAGE RANGE

- Non-Isolated Topologies
  - Buck-Boost (incl. SEPIC, CUK, Zeta)
  - Interleaved design for higher power levels
- Isolated Topologies
  - Full-bridge, Push-Pull, Flyback (up to medium power level)
  - Dual Active Bridge (DAB)
  - Phase-Shift Full Bridge (PSFB)[1,2 (T. U. Delft)]
  - Resonant + Reconfigurable Topologies

Topologies with relatively wider voltage range

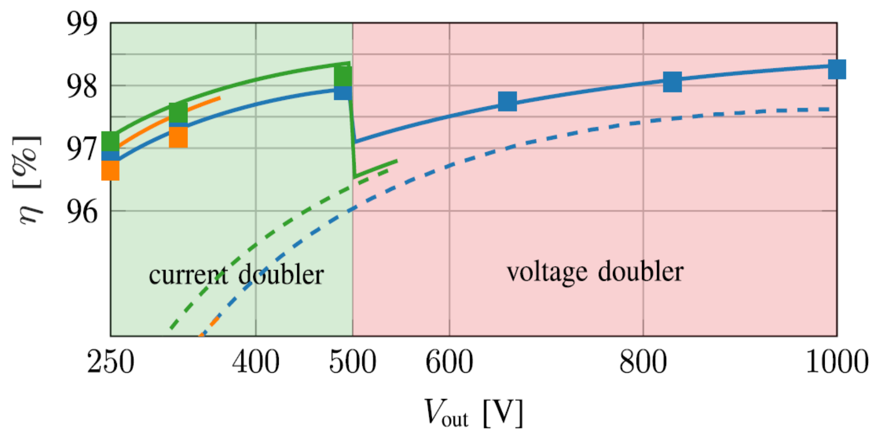


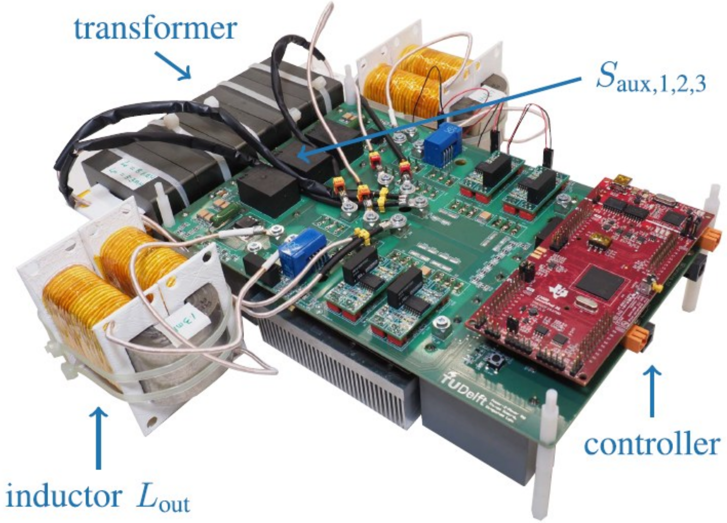
S. Chauhan, A. Blinov, A. Chub and D. Vinnikov, "**Active Clamped Dual Current-Fed Bidirectional DC-DC Converter for Wide Voltage Range Applications**," 2024 IEEE 65th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Riga, Latvia, 2024, pp. 1-7.

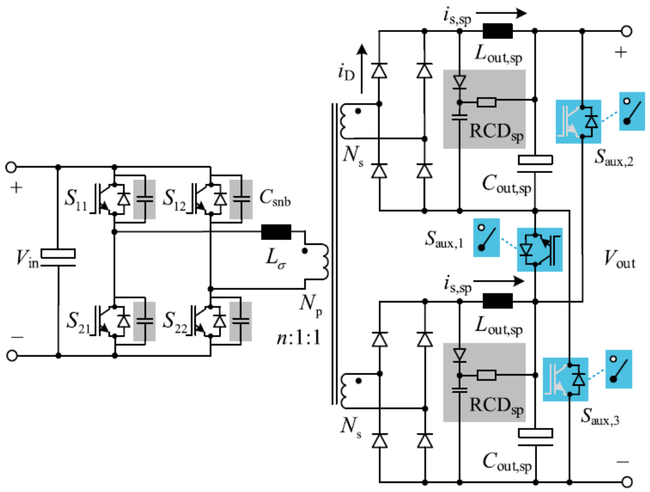
WIDE-VOLTAGE RANGE ISOLATED TOPOLOGIES FOR EVS

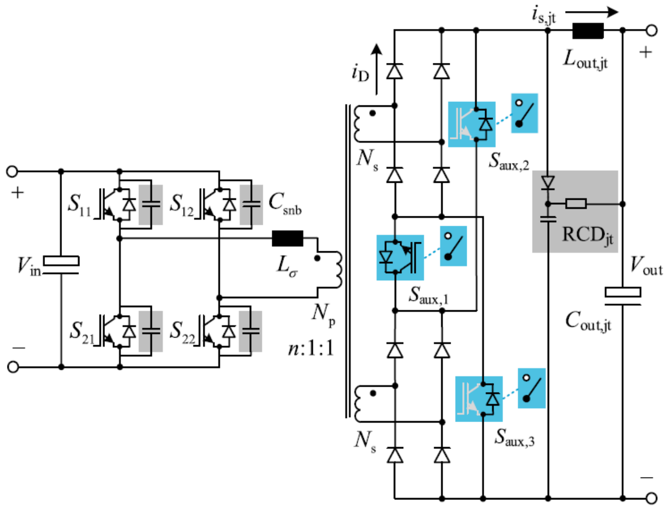
International Conference on DC Microgrids

- Reconfigurable Phase Shift Full-Bridge Converter
  - Vout (250-1000V)
  - Pout 11 kW
  - Full Range Efficiency (>96.5%)
  - Peak. Efficiency (98.3%)









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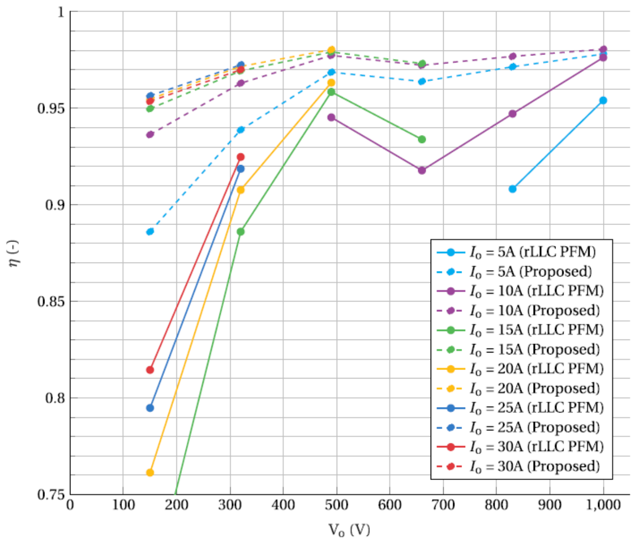
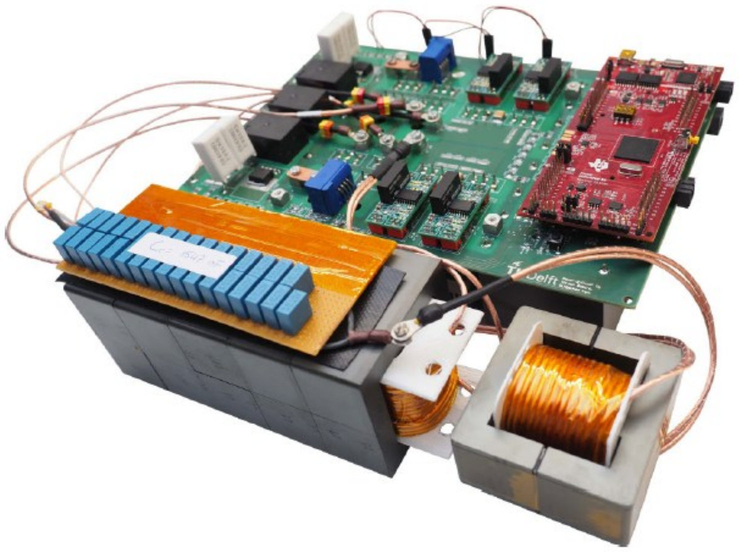
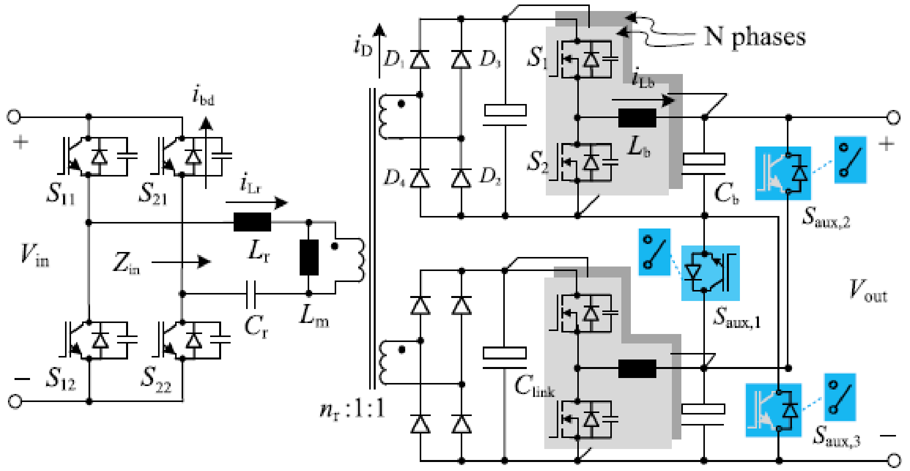
D. Lyu, T. B. Soeiro and P. Bauer, "**Design and Implementation of a Reconfigurable Phase Shift Full-Bridge Converter for Wide Voltage Range EV Charging Application**," in IEEE Transactions on Transportation Electrification, vol. 9, no. 1, pp. 1200-1214, March 2023.

WIDE-OUTPUT VOLTAGE RANGE CONVERTER FOR EVS

- A Reconfigurable Two-Stage 11kW DC-DC Resonant Converter
  - Vout (150-1000V)
  - Pout 11 kW
  - Full Range Efficiency (>95%)
  - Max. Efficiency (97.66%)







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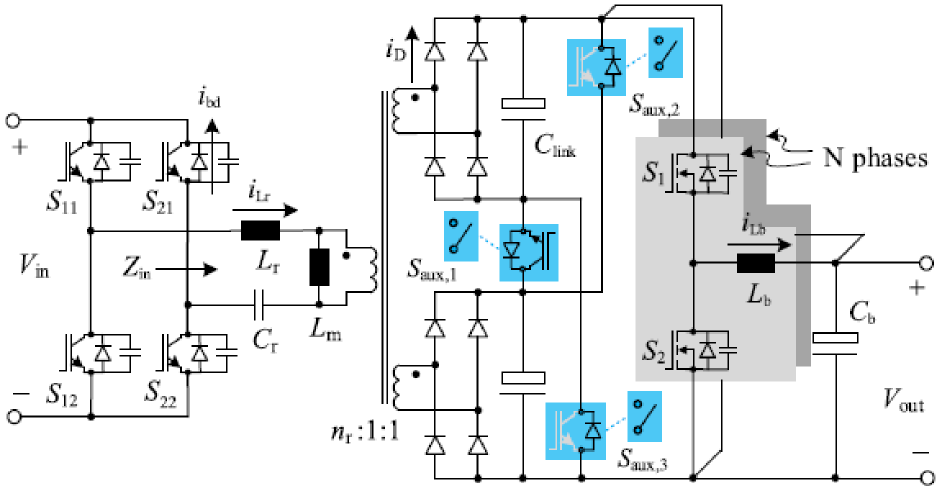


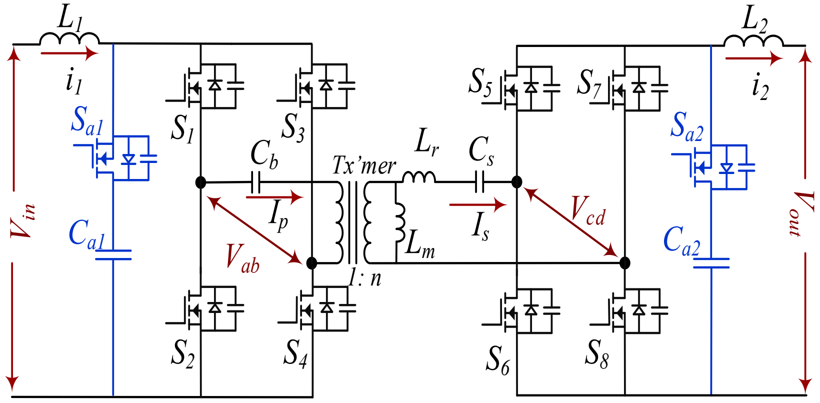
(b)

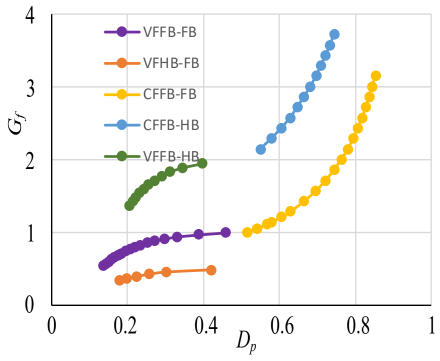
TAL TECH

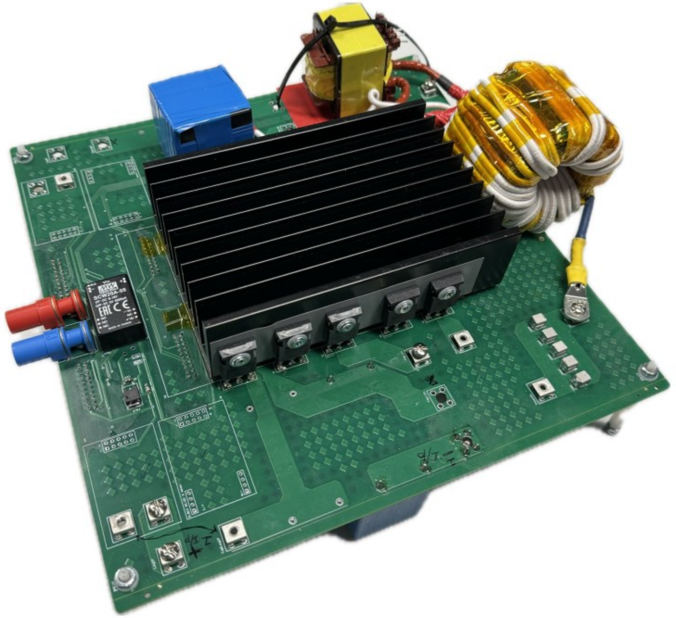
B. O. Aarninkhof, D. Lyu, T. B. Soeiro and P. Bauer, "**A Reconfigurable Two-Stage 11 kW DC–DC Resonant Converter for EV Charging With a 150–1000 V Output Voltage Range**," in IEEE Transactions on Transportation Electrification, vol. 10, no. 1, pp. 509-522, March 2024, doi: 10.1109/TTE.2023.3279211.

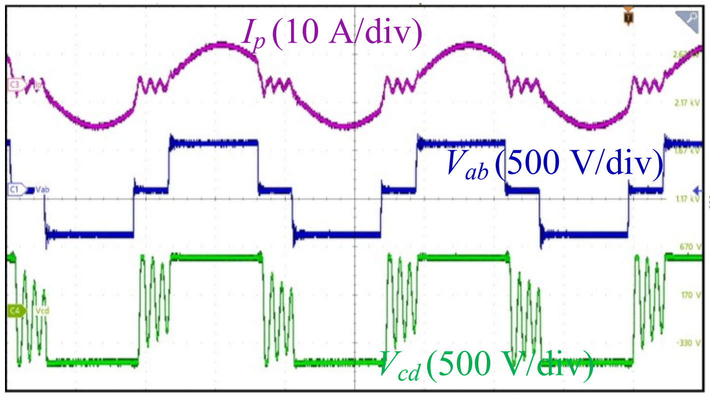
WIDE OUTPUT VOLTAGE RANGE CONVERTER FOR EVS

- Active Clamped Dual Current-Fed Bidirectional Converter
  - Vin (350V) and Vout (150-1000V)
  - 3.1 kW prototype with Max efficiency (97.66%).
  - Full Range Efficiency (>93%)

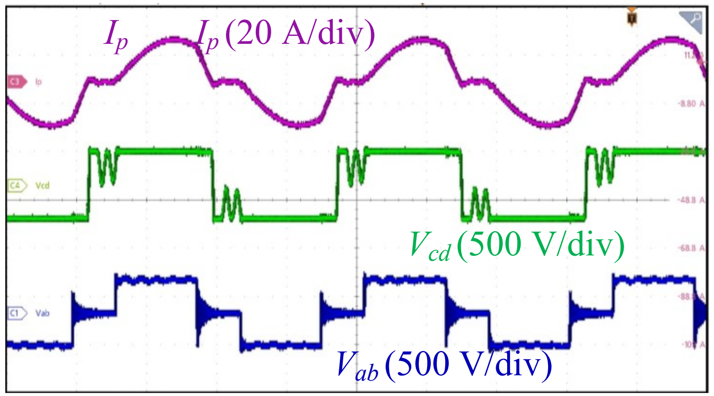








CFFB-FB (Vout=740V, Pout=3.1kW)

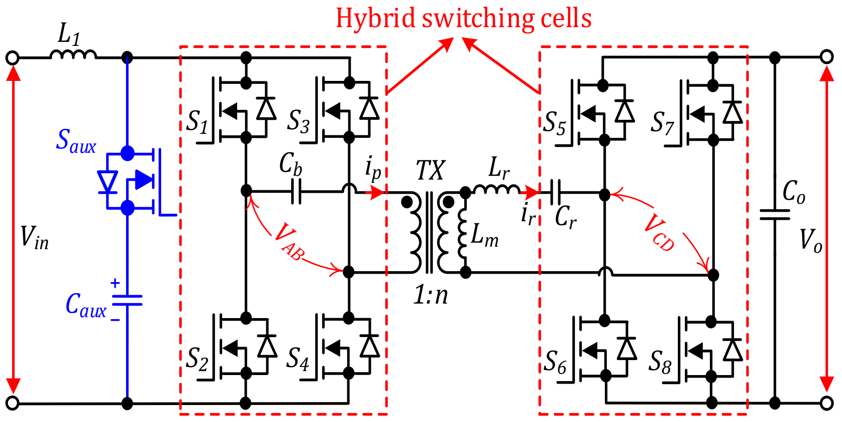


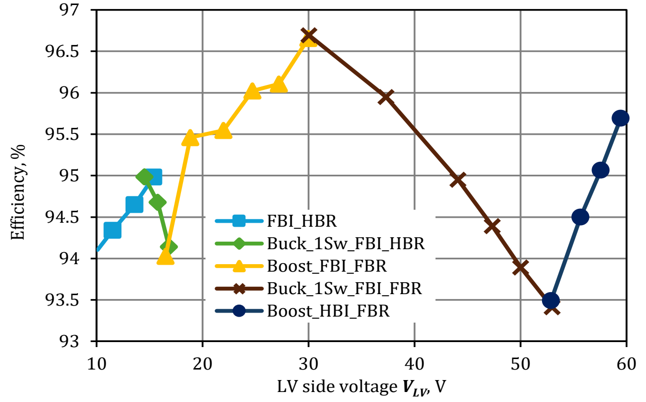
VFFB-FB (Vout=227.73V, Pout=1.8kW)

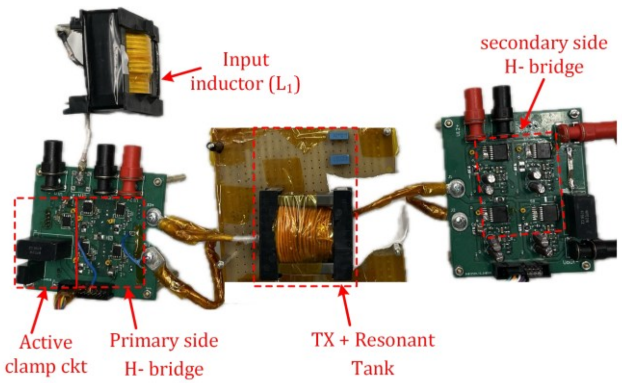
S. Chauhan, A. Blinov, A. Chub and D. Vinnikov, "**Active Clamped Dual Current-Fed Bidirectional DC-DC Converter for Wide Voltage Range Applications**," 2024 IEEE 65th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Riga, Latvia, 2024, pp. 1-7.

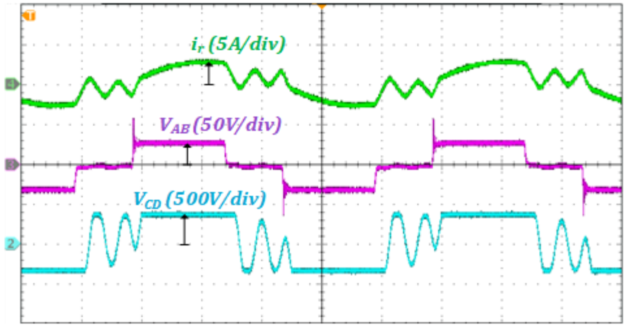
WIDE INPUT VOLTAGE RANGE CONVERTER FOR PV AND DC BUILDING APPLICATIONS

- Current-Fed Isolated Buck-Boost Series-Resonant DC-DC Converter
  - Vin (10-60 V) and Vout 350V.
  - 350W prototype with Max efficiency (>96.6%).
  - Can support both PV and Battery charging
- CF 1sw-FBR mode introduced for better efficiency in buck mode

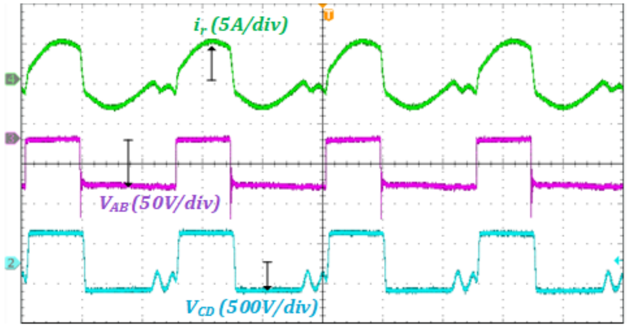








CF FBI-FBR boost mode (Vout=20V, Pout=200W)



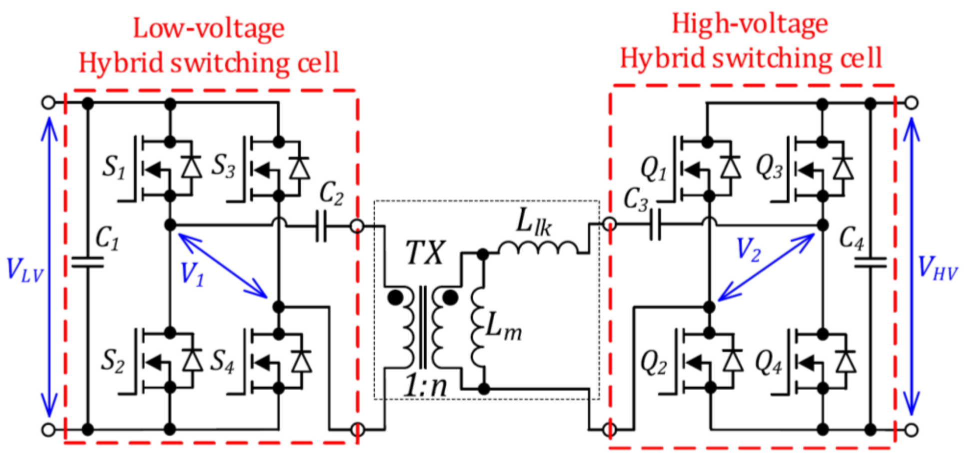
CF 1Sw-FBR buck mode (Vout=740V, Pout=3.1kW)

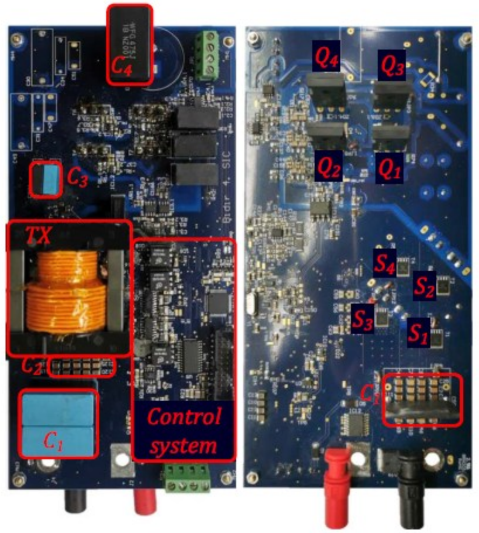
S .Khan, A. Chub, D. Vinnikov, Mathias Kasper, Gerald Deboy and S. Chauhan "**Wide Voltage Gain Current-Fed Isolated Buck-Boost Series-Resonant DC-DC Converter with Active Clamp for DC Microgrid Applications**", ICDCM2025

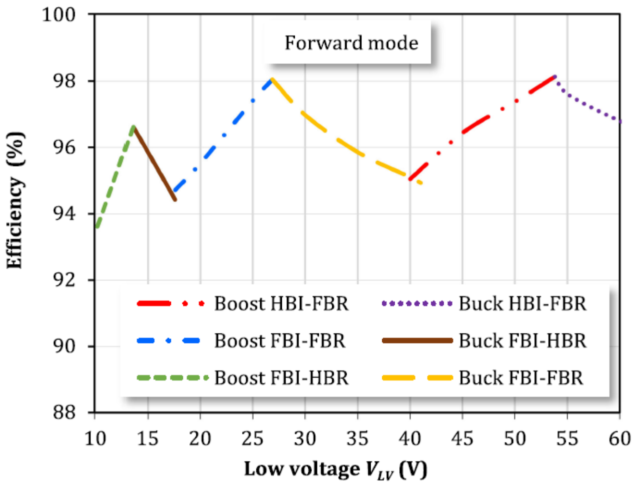
WIDE INPUT VOLTAGE RANGE CONVERTER FOR PV AND DC BUILDING APPLICATIONS

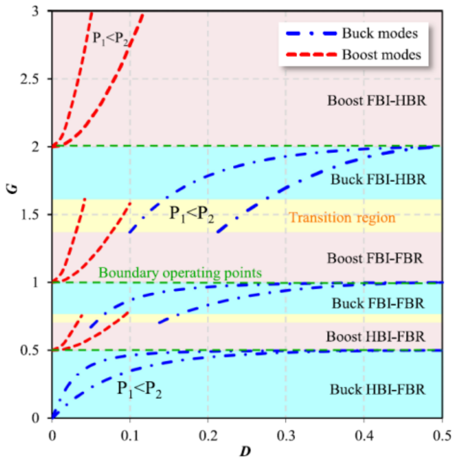
International Conference on DC Microgrids

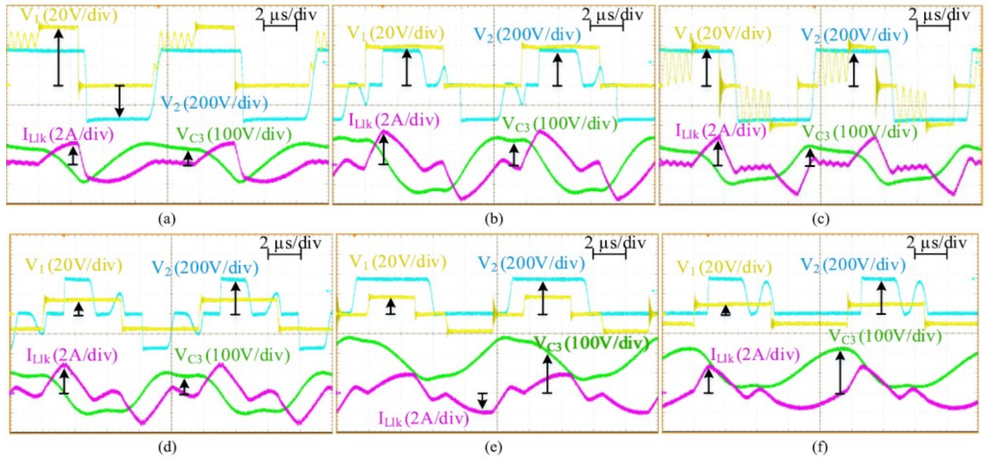
- A Bidirectional Isolated Hexamode DC–DC Converter
  - Vin (10-60 V) and Vout (350/700V).
  - 350W prototype with Max efficiency (>98%).
  - Can support both PV and Battery charging.











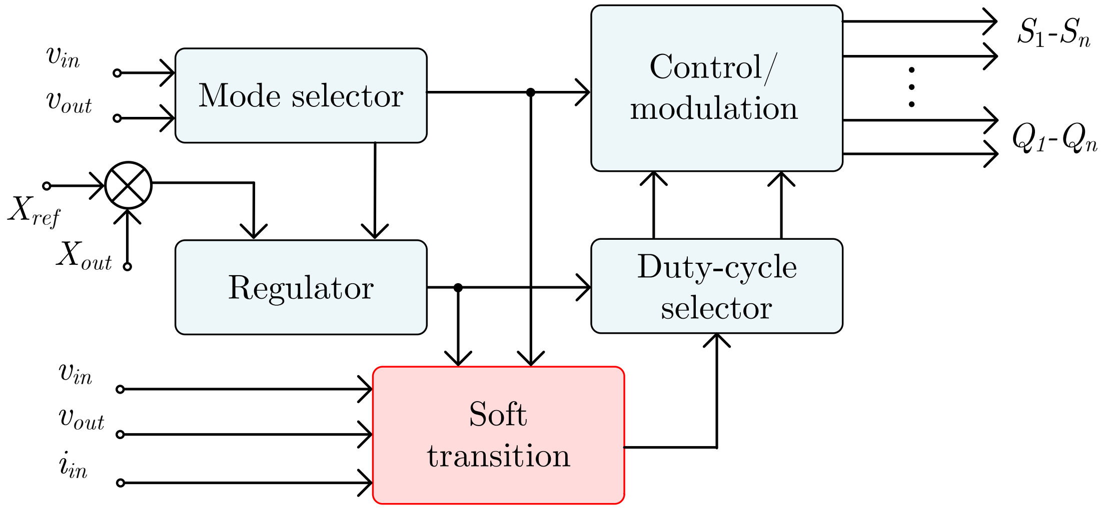
TAL TECH

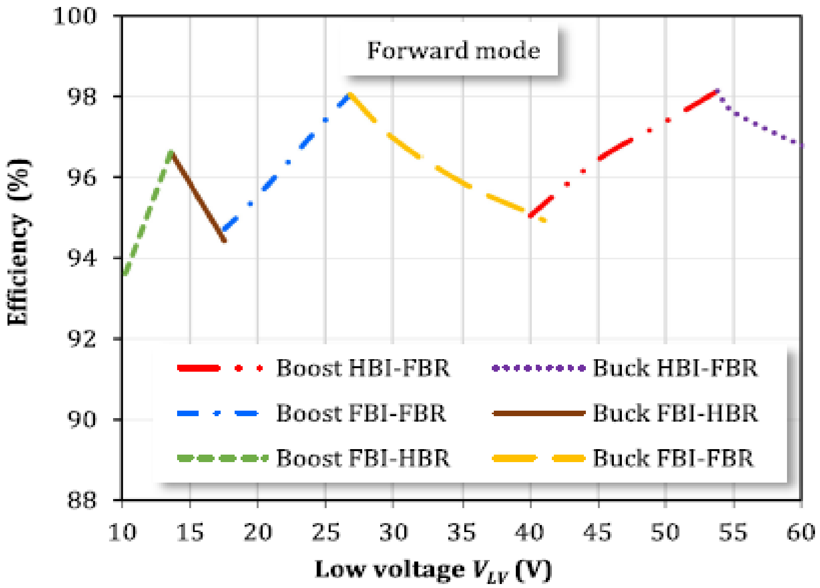
V. Sidorov, A. Chub and D. Vinnikov, "**Bidirectional Isolated Hexa-Mode DC-DC Converter**", IEEE Trans. on Power Electron., vol. 37, no. 10, pp. 12264-12278, Oct. 2022.

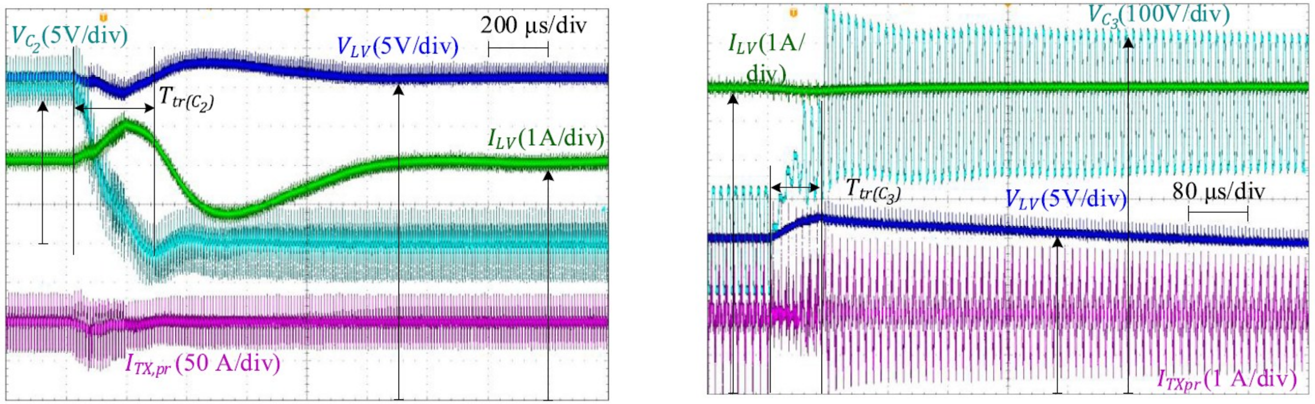
CHALLENGES IN TMC-BASED WIDE-VOLTAGE RANGE TOPOLOGIES

International Conference on DC Microgrids

- Integration of TMC for the control system
- Implementation of transition between topologies
- Step change in efficiency after







(a) (b)

TAL TECH

V. Sidorov, A. Chub and D. Vinnikov, "**Bidirectional Isolated Hexa-Mode DC-DC Converter**", IEEE Trans. on Power Electron., vol. 37, no. 10, pp. 12264-12278, Oct. 2022.

BREAKING LIMITS WITH PARTIAL POWER PROCESSING (PPP)

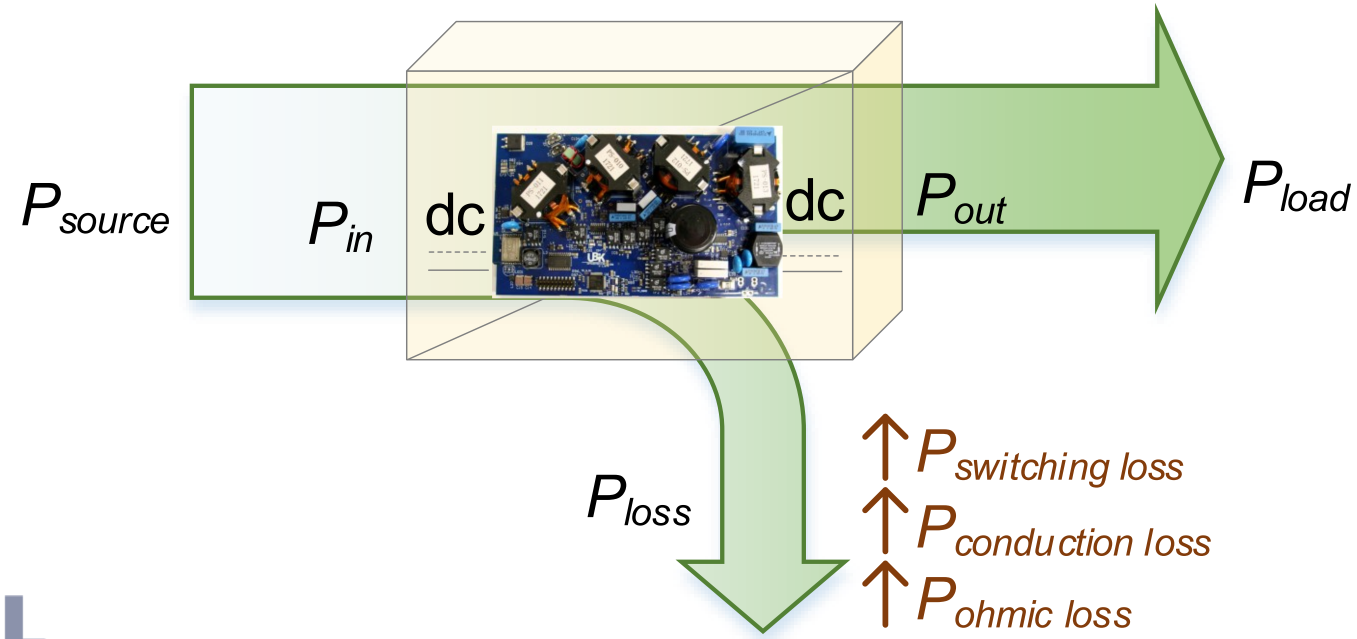
Dr. Neelesh Yadav

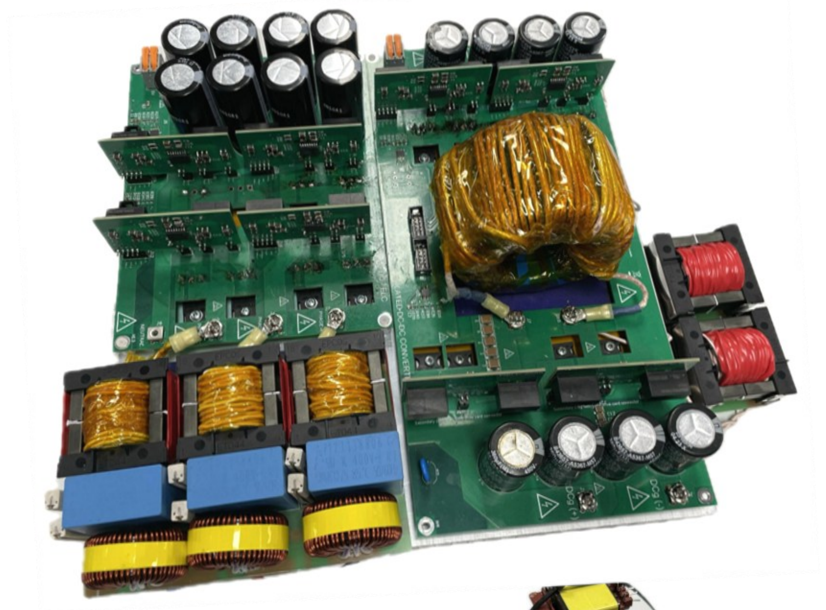
TAL TECH

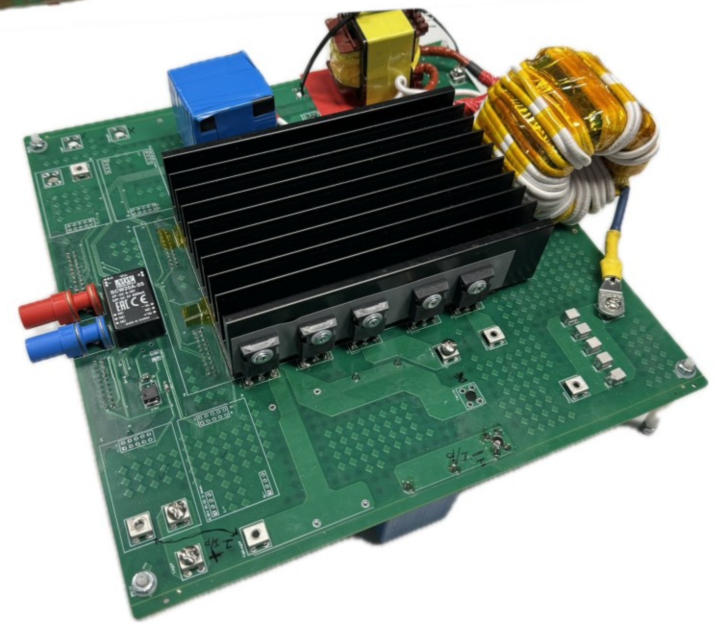
International Conference on DC Microgrids

FULL POWER CONVERTERS

- **Full Power Converter (FPC):**
  all power is processed by a dc-dc converter components. **Losses are a fraction of total power.**





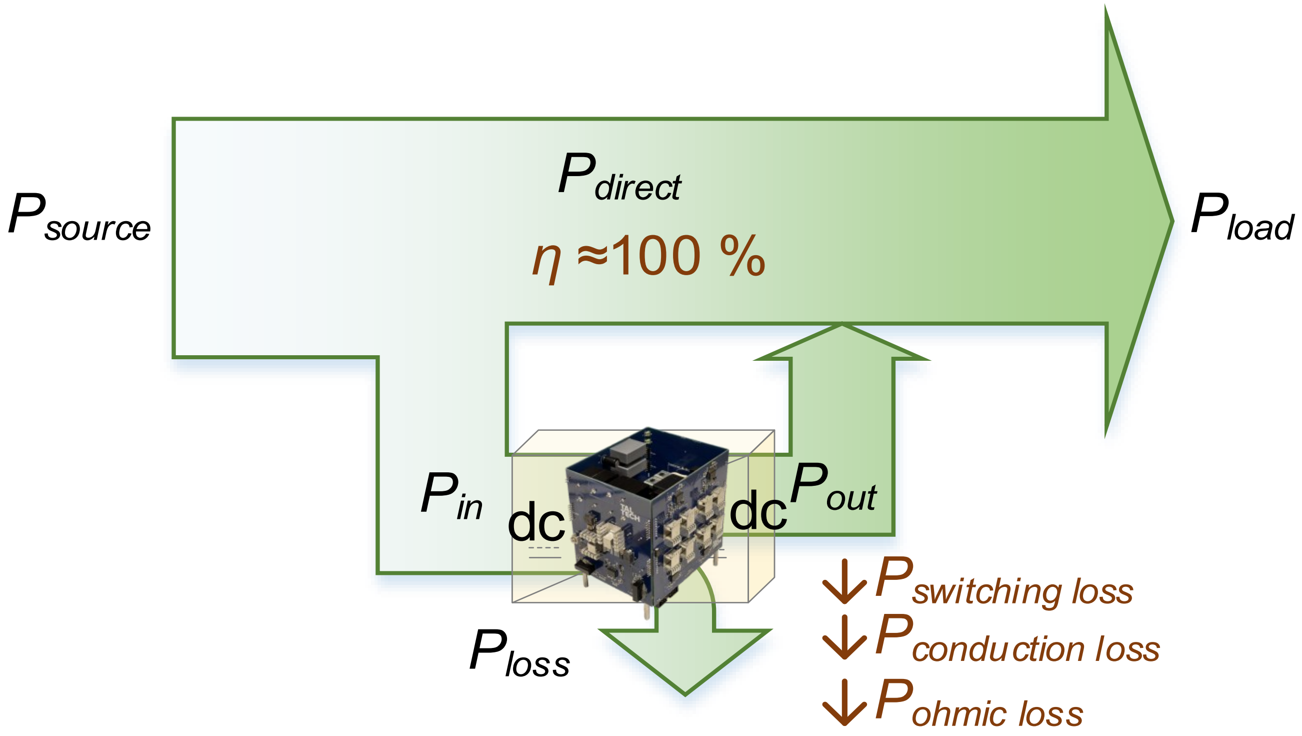


TAL TECH

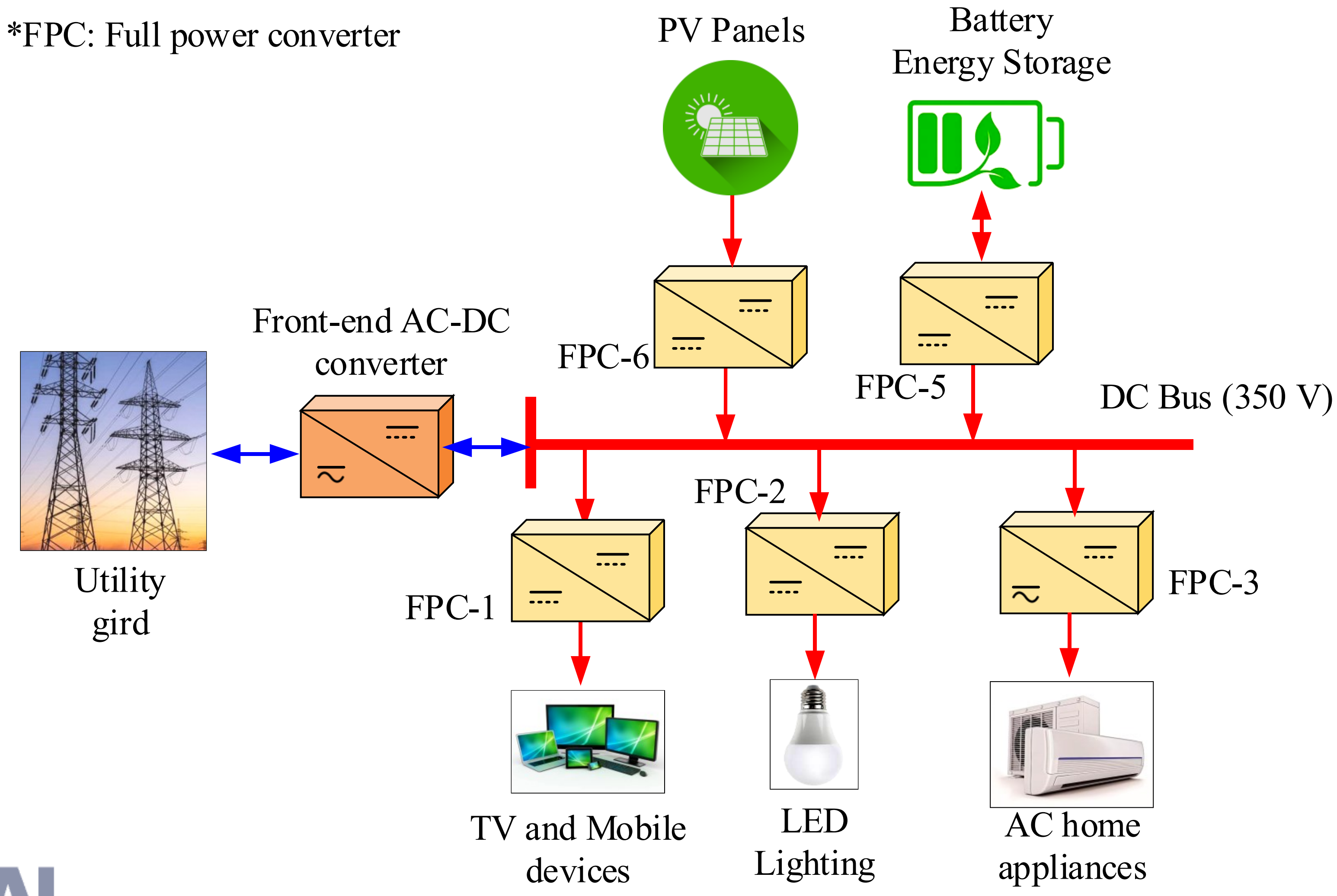
PARTIAL POWER CONVERTER (PPC)

- **Partial Power Converter (PPC):**
  only a fraction of the power is processed by an isolated dc-dc cell. **Losses are a fraction of processed power**

  - Reduced losses
  - Lower component ratings
  - Smaller weight and size
  - Potentially faster dynamics



PPC APPLIED TO DC BUILDINGS

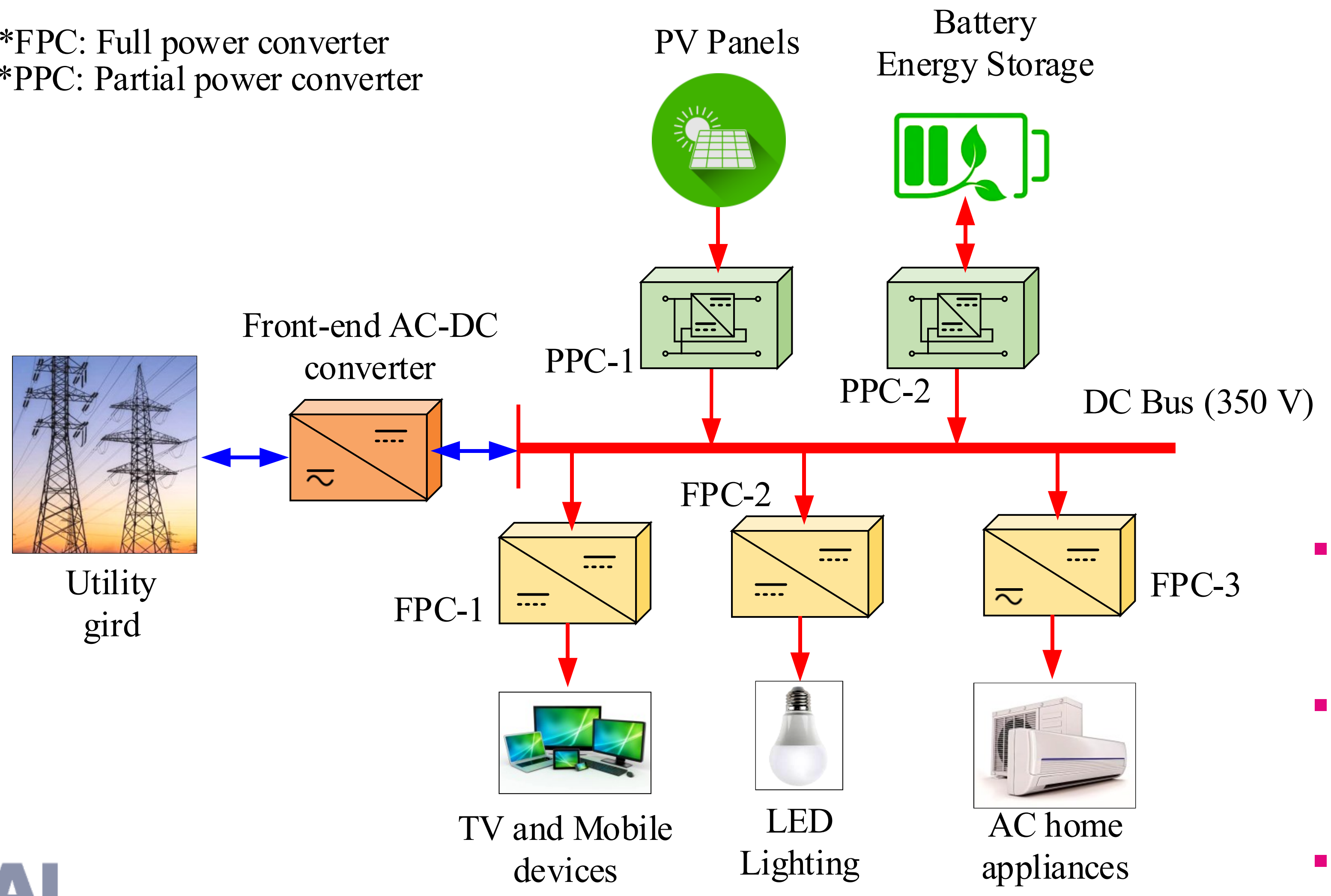


A Typical DC microgrid for a building

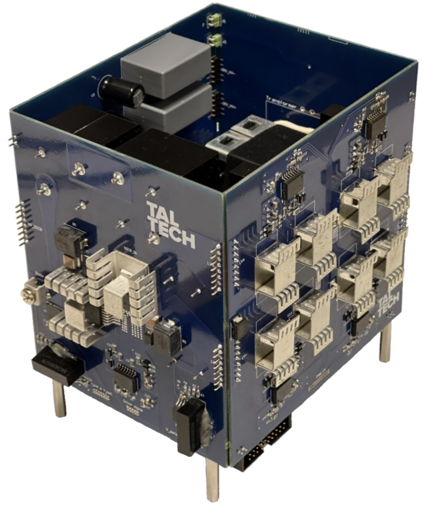
- More losses: Process all power in a wide voltage range, efficiency (97..98%)
- Higher semiconductors cost: Higher current and voltage rating on the converter port
- Cooling required: results in higher cost and volume

PPC APPLIED TO DC BUILDINGS

*FPC: Full power converter
*PPC: Partial power converter



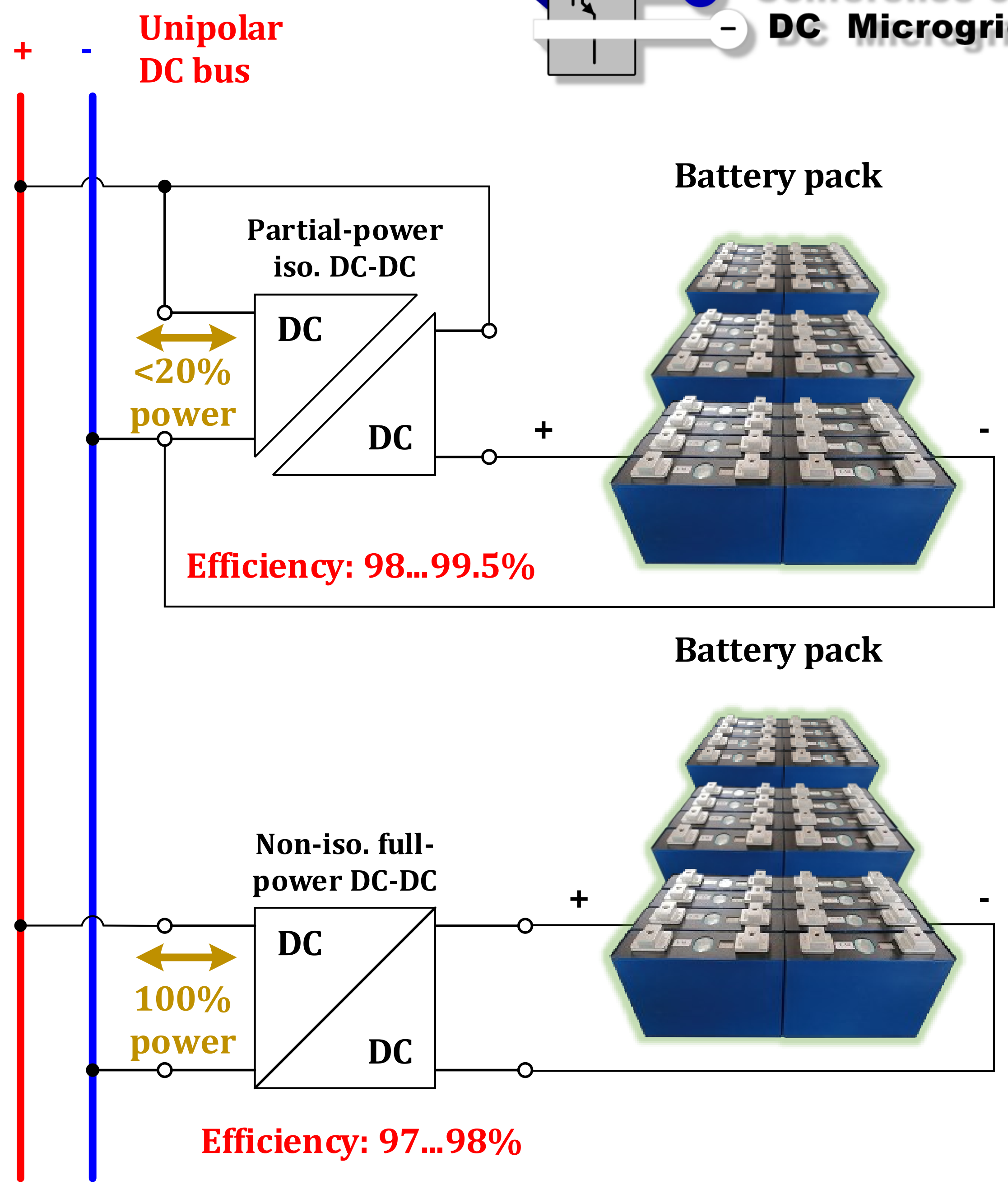
Partial power conveter based DC microgrid for a building



- Reduced losses: Process only a fraction of the power, highly efficient (98...99.5%)
- Low semiconductors cost: Reduced current rating on one converter port, reduced voltage rating on the other
- Reduced cooling requirement: results in higher cost and volume

PPC vs FPC

- Full power converter needs to process all power in a wide voltage range – more losses
- Partial power converter deals with only a fraction of power and thus could be more efficient and low-cost
- Reduced current rating on one converter port, reduced voltage rating on other – reduced semiconductors' cost
- Reduced cooling requirements, resulting in reduced cost and volume
- Higher power density
- Potentially faster dynamics



PPC CLASSIFICATION

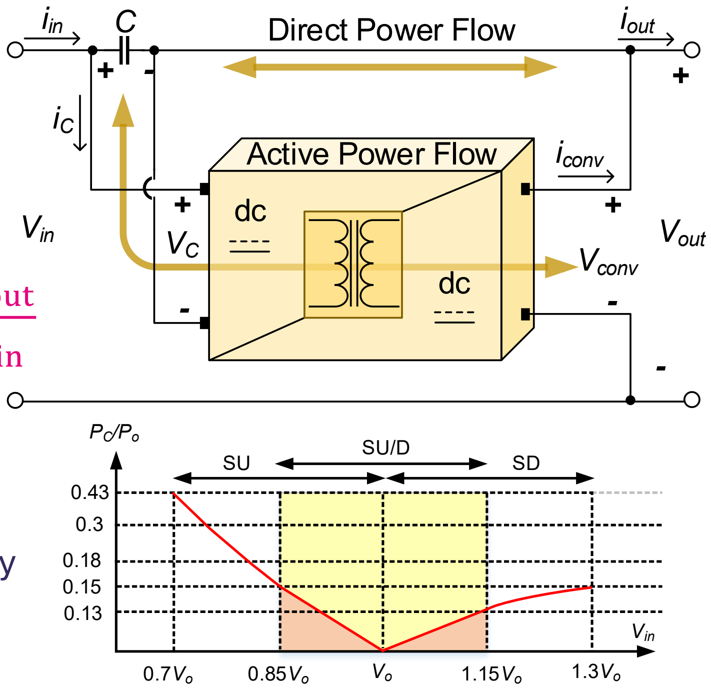
S-PPC

1. DC–DC Stage (M)
   - Step-**up**
   - Step-**down**
   - Step-**up/down**
2. Configuration
   - Type **I**
   - Type **II**
   - *Derived*

All derived configurations exhibit equivalent characteristics as the original configurations

$M = \frac{V_{out}}{V_{in}}$

PPF: Partiality factor

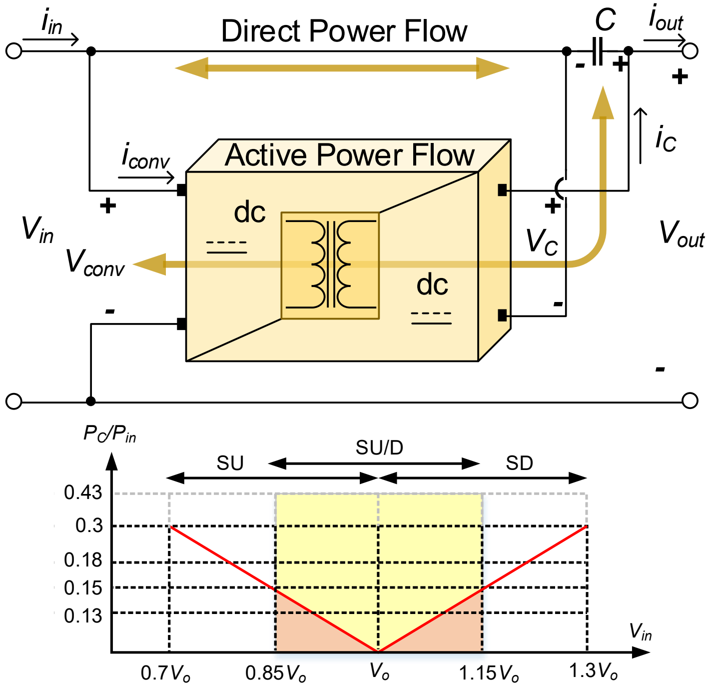


Type II S-PPC:

Series-input–parallel-output (SIPO)

$M = \frac{V_{out}}{V_{in}}$

PPF: Partiality factor



Type I S-PPC:

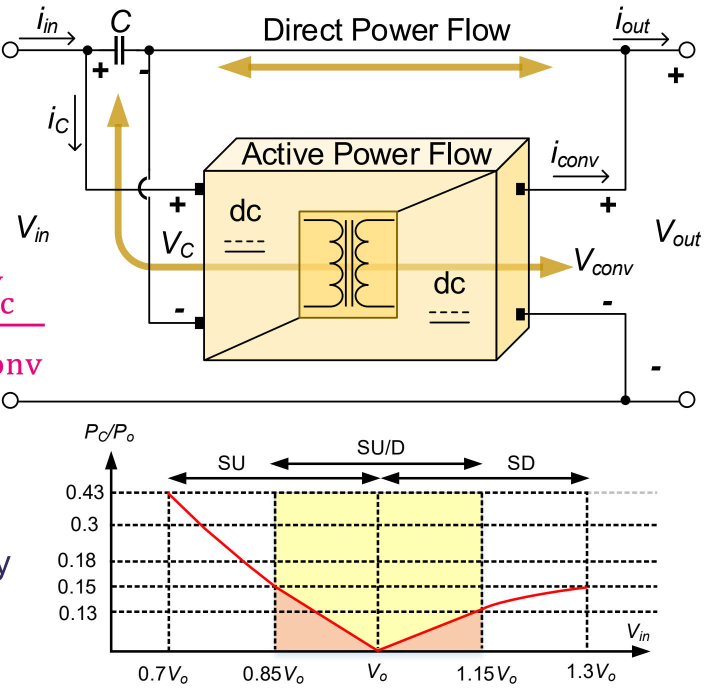
Parallel-input–series-output (PISO)

TAL TECH

A. Chub, "Partial power energy processing – A new toolbox for efficient dc microgrids," presented at the 2024 6th IEEE Int. Conf. on DC Microgrids (ICDCM), Columbia, SC, USA, Aug. 2024.

PPC CLASSIFICATION

$$M = \frac{V_C}{V_{conv}}$$



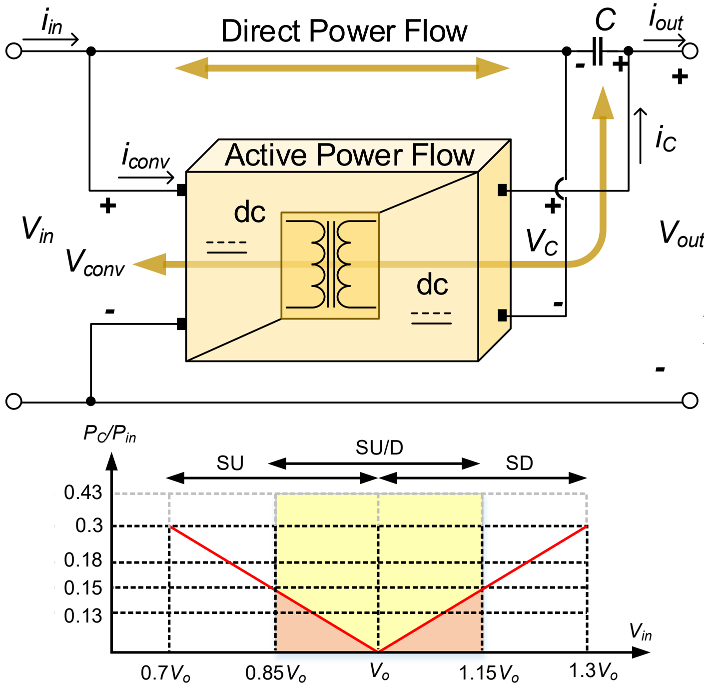
PPF: Partiality factor

Type II S-PPC:

Series-input–parallel-output (SIPO)

DC–DC Converter

1. Topology Ports
   - Current-Fed (**CF**)
   - Voltage-Fed (**VF**)
2. Voltage Gain (M_C)
   - Buck
   - Boost
   - Buck–Boost
3. Isolation
   - Non-Isolated
   - Isolated



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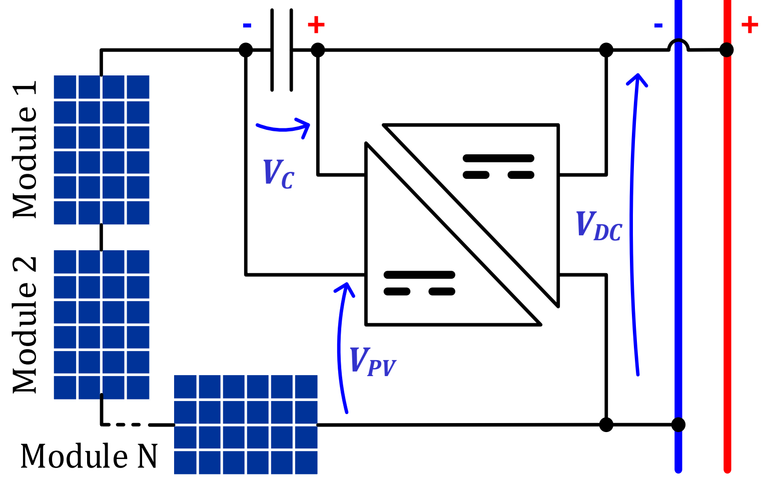
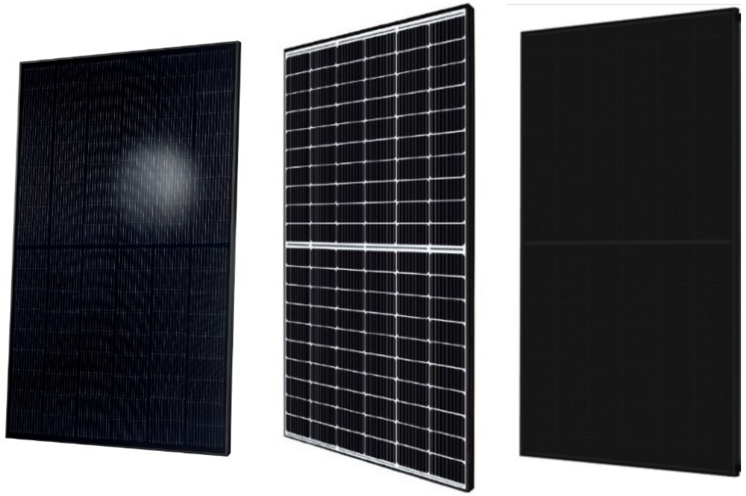
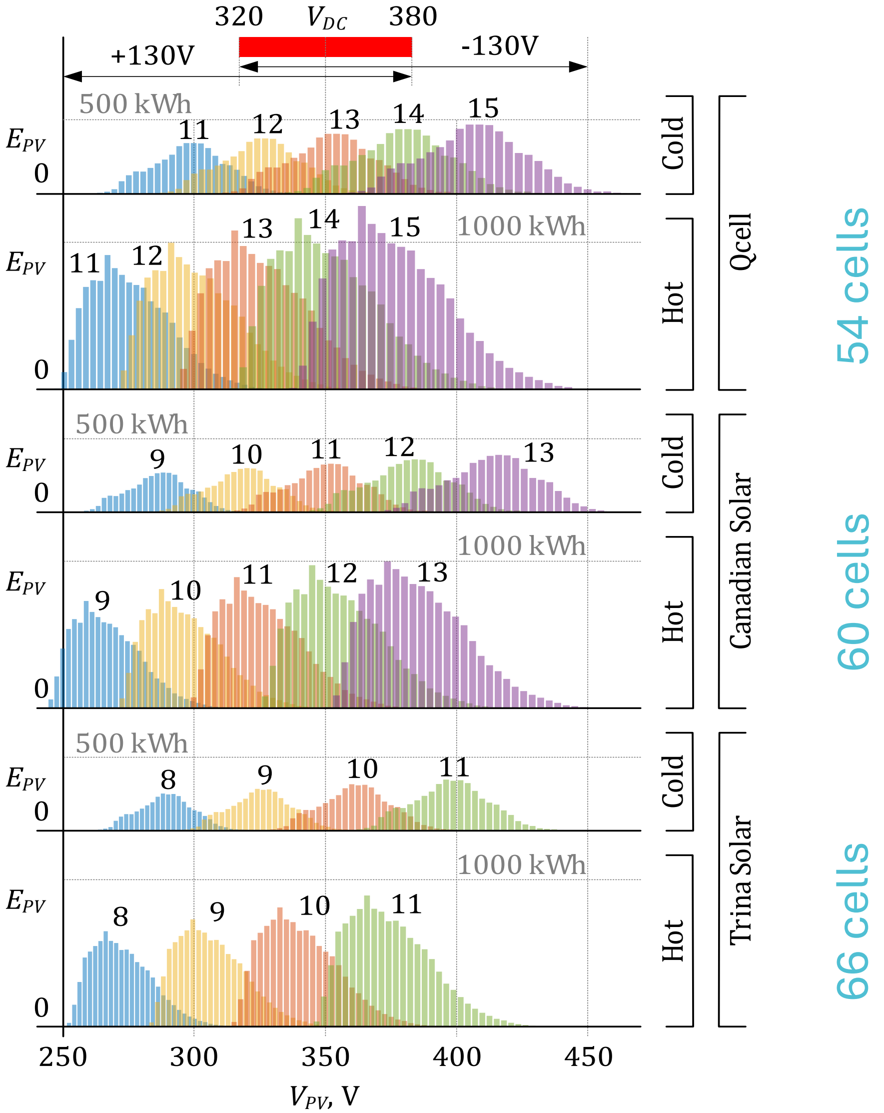
PARTIAL POWER CONVERTERS IN PV APPLICATIONS

- Residential droop-controlled DC microgrid based on Current/OS system can normally very in the range of 350V ± 30V



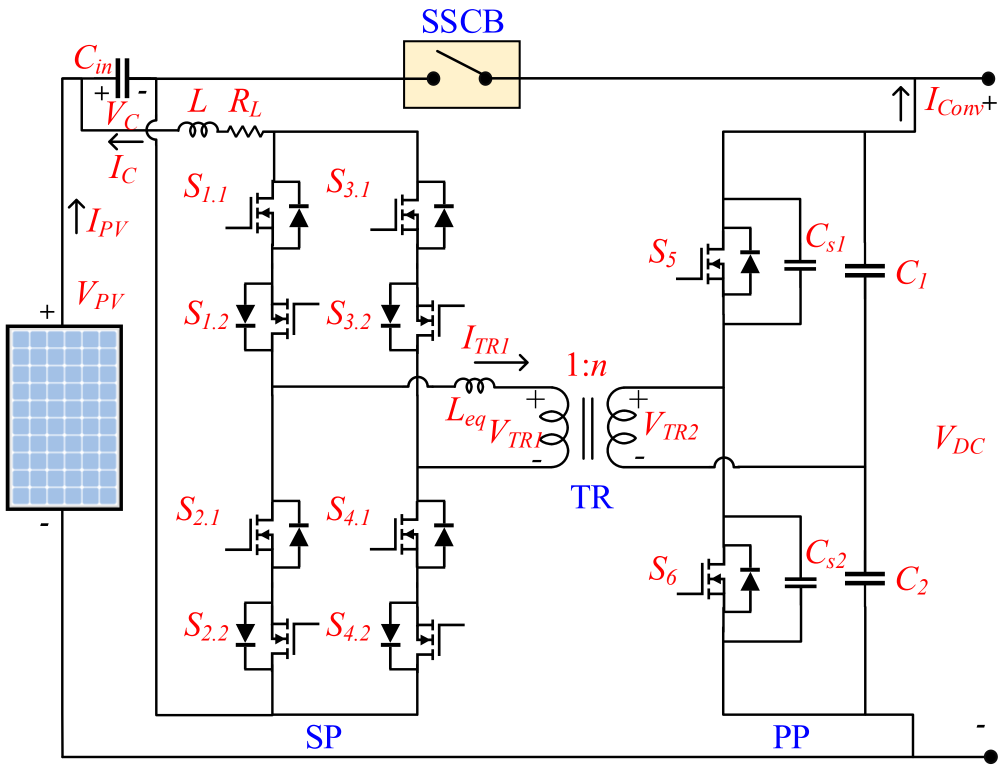


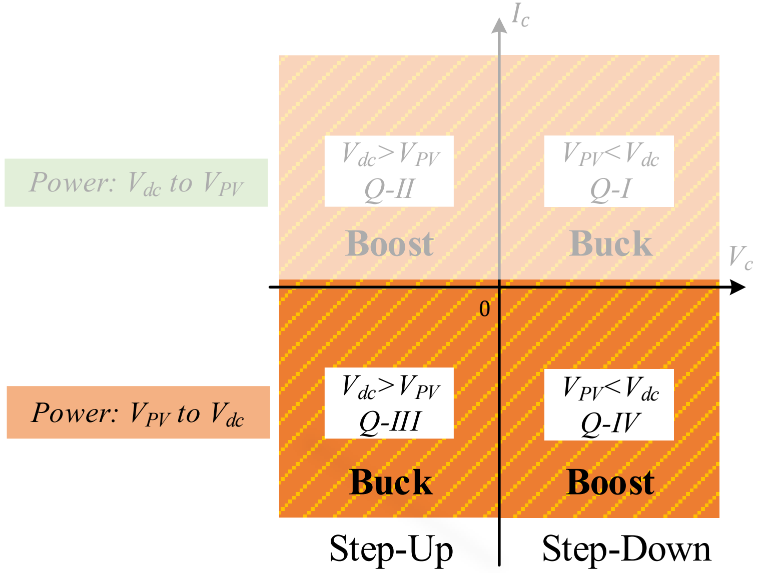


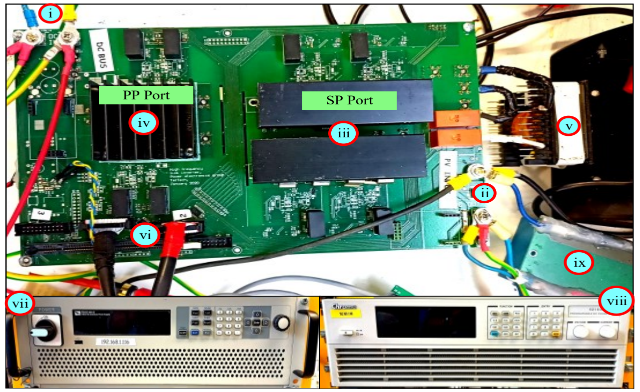
YEARLY MODELING 14 FEASIBLE CASES

TOPOLOGY SIMPLIFICATION

- Current-fed full-bridge converter

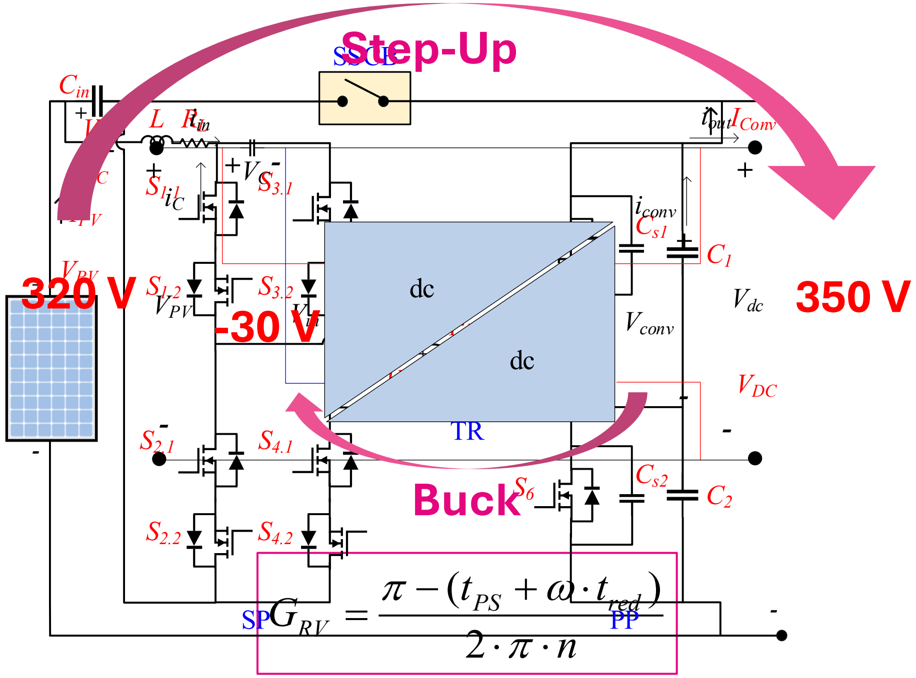


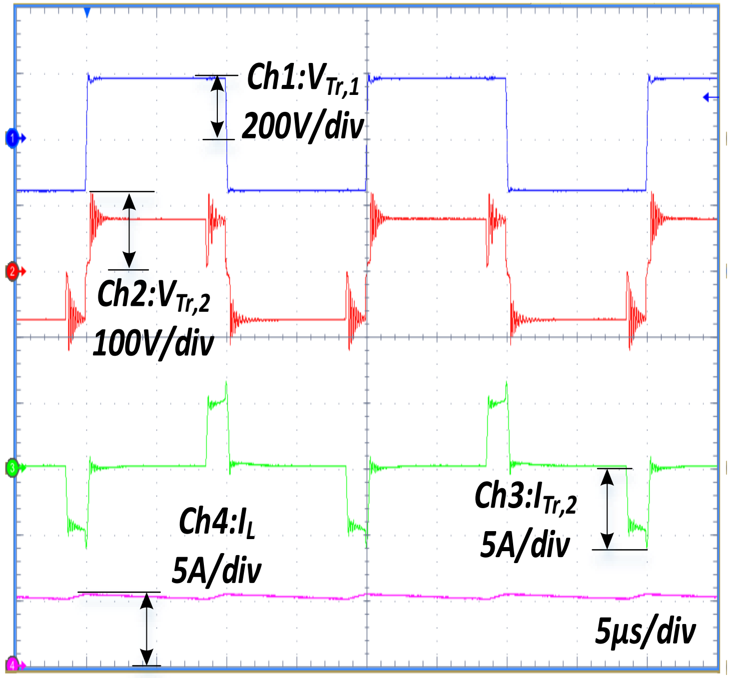




N. Yadav et al., "Performance Evaluation of Step-Up/Down Partial Power Converters Based on Current-Fed DC-DC Topologies," in **IEEE Transactions on Industry Applications**, doi: 10.1109/TIA.2024.3413050.

STEP-UP AND BUCK OPERATION MODE



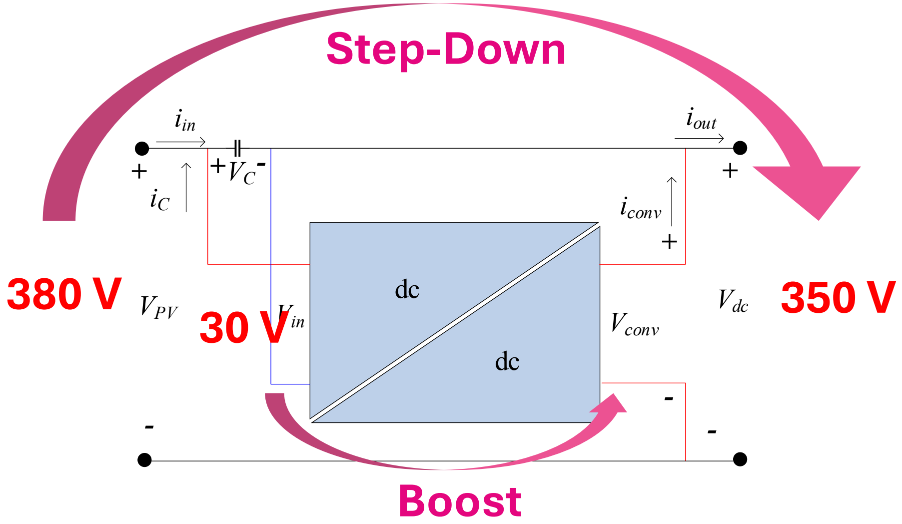


- Power flow from LV to HV
- dc-dc stage gain (G_{RV}) can be reduced to almost zero
- Can regulate near-zero LV port voltage

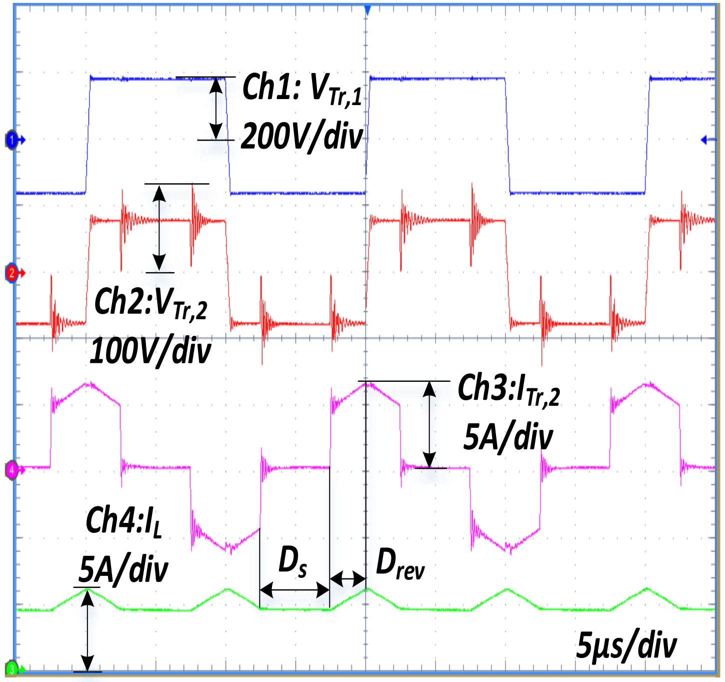
Current-voltage waveforms while working with I_{out}=5 A V_{in}=350 V and V_{out}=350.5 V

N. Hassanpour, A. Chub, A. Blinov and D. Vinnikov, "Operation of the Step-Up/Down Bidirectional Partial Power Converter Near Zero Series Voltage," 2023 IEEE 17th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Tallinn, Estonia, 2023, pp. 1-5.

STEP-DOWN AND BOOST OPERATION MODE



$$G_{FRW} = \frac{2\cdot\pi\cdot n}{1-\frac{2}{T_{SW}}\left(\frac{t_{PS}}{\pi}+\frac{2nL_{eq}(2I_{C(\max)}-I_C)}{V_{DC}}\right)}$$



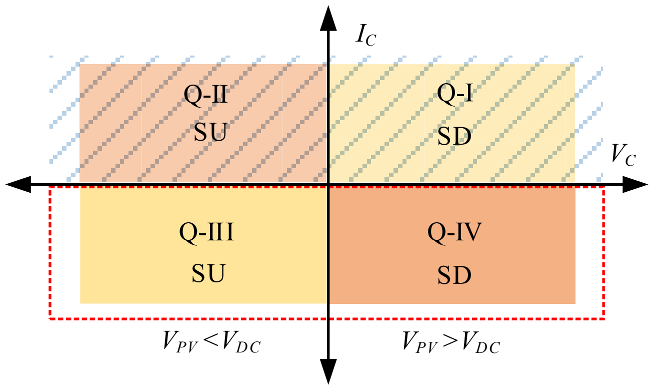
- Power flow from LV to HV
- dc-dc stage gain (G_{RV}) voltage gain depends on the power
- limitations in boosting a very low volatge at the LV port
- This means that the converter can easily handle the zero series port voltage

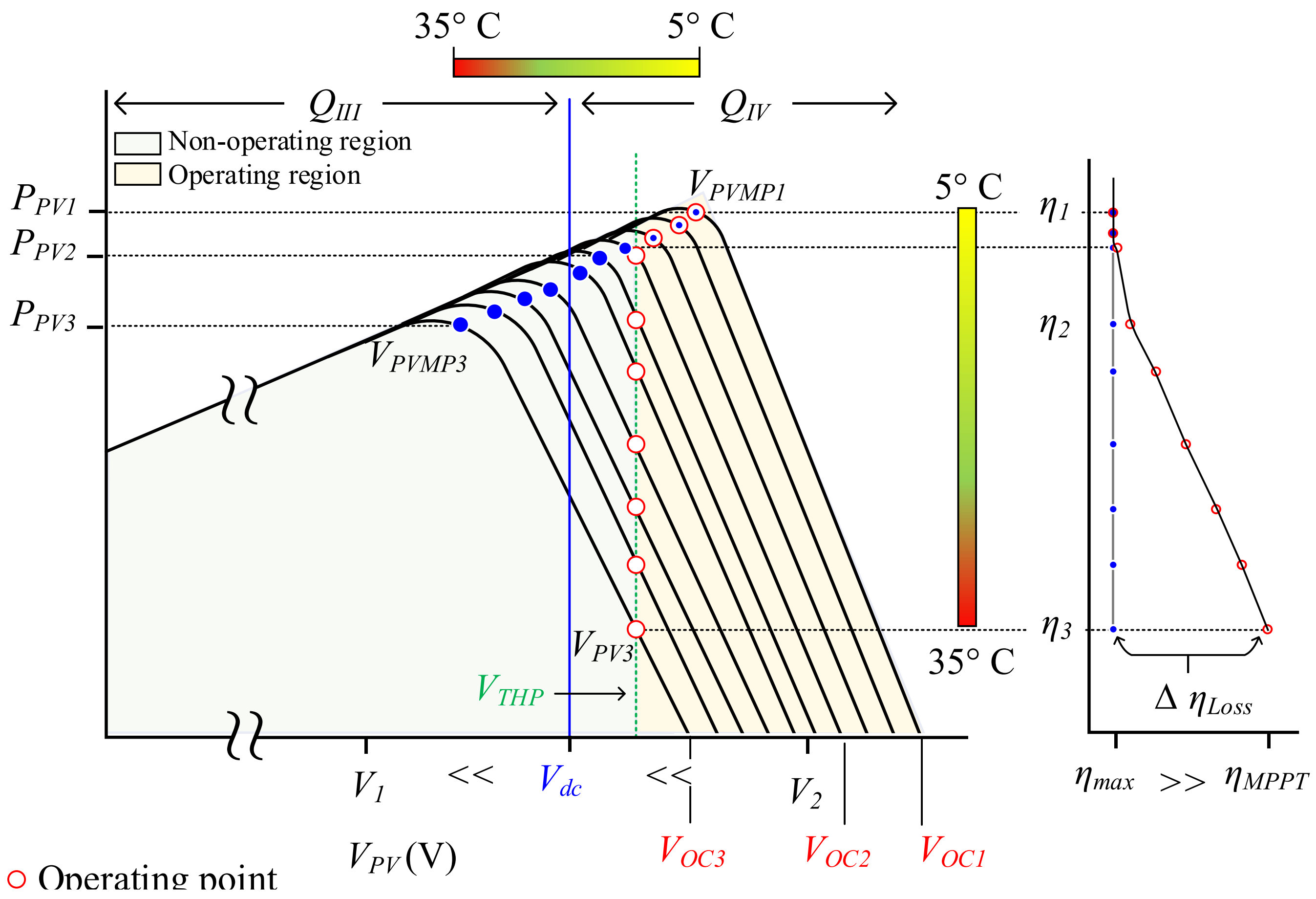
Current-voltage waveforms while working with I_{out}=5 A V_{in}=348 V and V_{out}=350 V

N. Hassanpour, A. Chub, A. Blinov and D. Vinnikov, "Operation of the Step-Up/Down Bidirectional Partial Power Converter Near Zero Series Voltage," 2023 IEEE 17th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Tallinn, Estonia, 2023, pp. 1-5.

MPPT ISSUES IN STEP-UP/DOWN PPC – FORMULATION

- Q-III ↔ Q-IV with change of polarity of V_C Causes MPPT efficiency drop.
- Typical modulations offers few challenges while operating mode at/or near zero partiality (K_{pr}=0) i.e. $V_{PV} \approx V_{dc}$
- PPC does not change its quadrants because capacitor does not have enough charge to transfer energy to inductor at low K_{pr}, which is needed for current control.



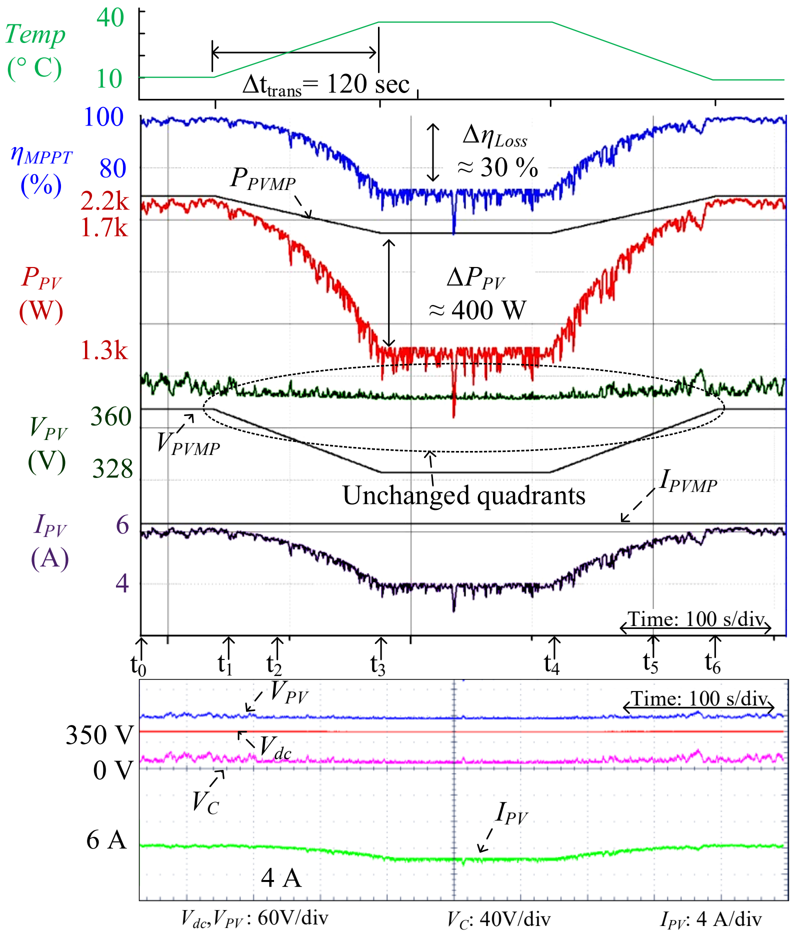


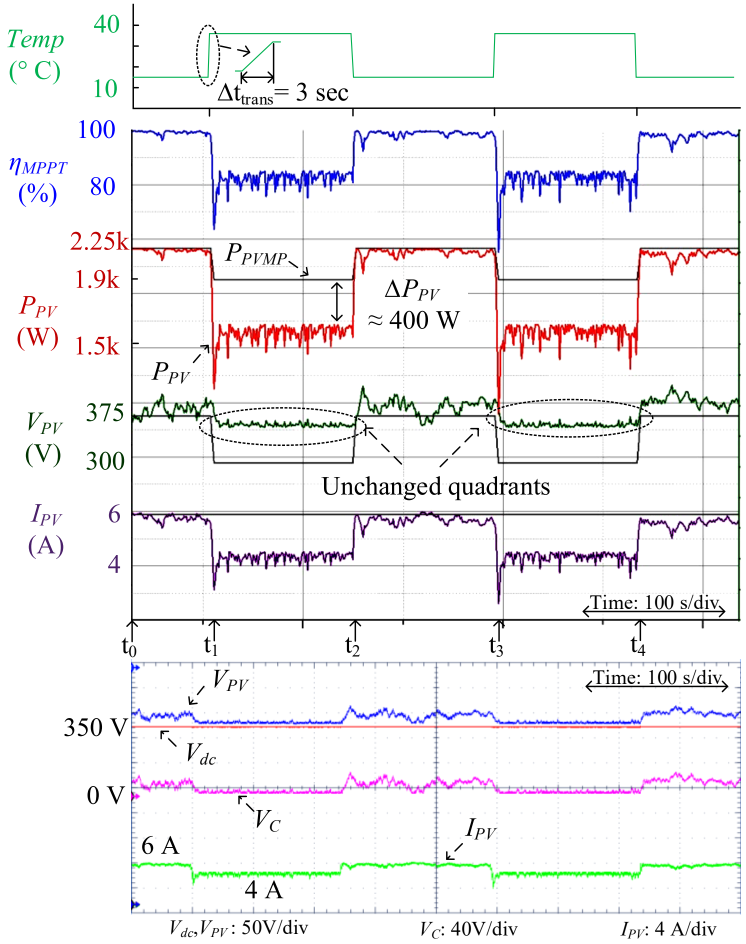
TAL TECH

N. Yadav, at al. "Improved Maximum Power Point Tracking Algorithm for Step-Up/Down Partial Power Converters Operating Around Zero Partiality," in **IEEE J. Emerg. and Sel. Topics in Power Electron.**, vol. 12, no. 2, pp. 1984-1994, April 2024.

MPPT ISSUES IN STEP-UP/DOWN PPC – EXPERIMENTAL

International Conference on DC Microgrids





- At/near zero voltage at the series port converter cannot regulate the current
- Converter gets stuck in one quadrant and MPPT efficiency deteriorate
- In the given experimental example, MPPT efficiency drops by 23.5%

TAL TECH

N. Yadav, at al. "Improved Maximum Power Point Tracking Algorithm for Step-Up/Down Partial Power Converters Operating Around Zero Partiality," in **IEEE J. Emerg. and Sel. Topics in Power Electron.**, vol. 12, no. 2, pp. 1984-1994, April 2024.

IMPROVED MPPT OMITTING DEAD ZONE- CONCEPT

When V_{PV} decreases into the DZ

↓

PPC controller saturation

Critical Dead Zone (CDZ)

↓

Change of quadrant forcefully

↓

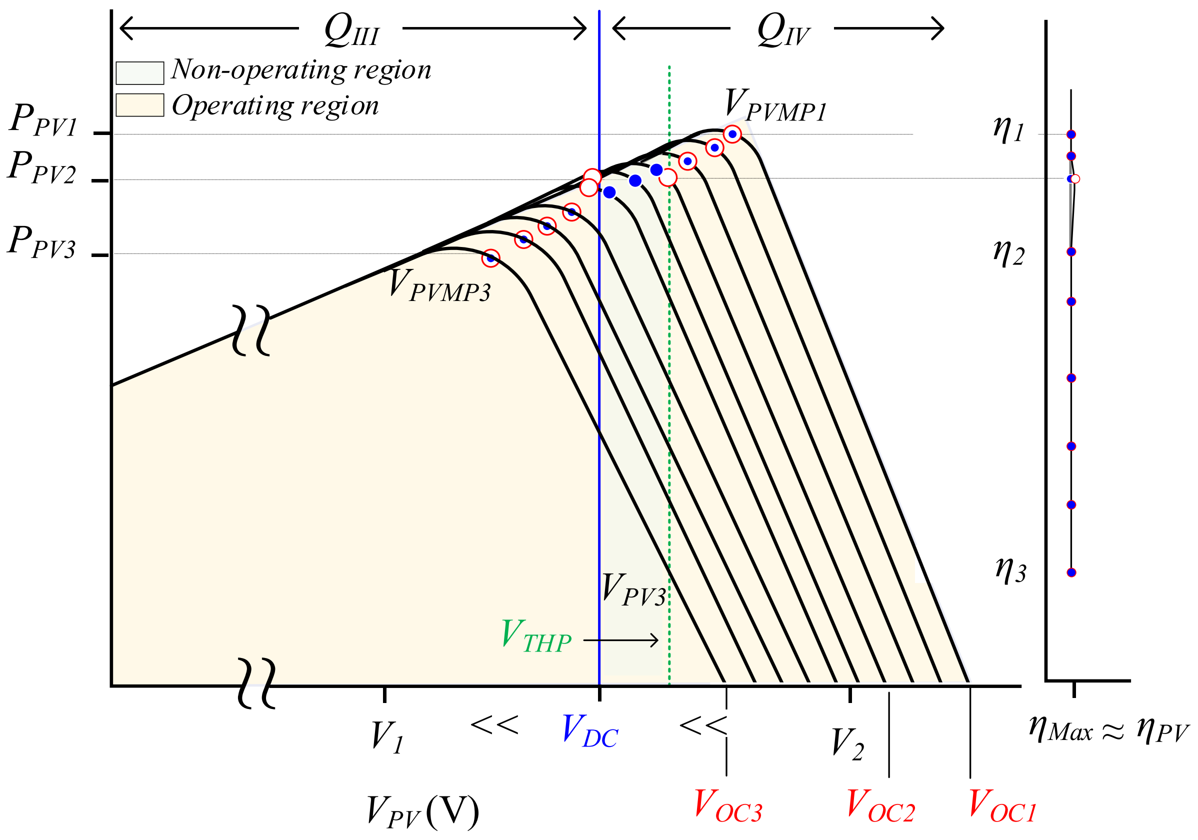
Proposed control algorithm pushes the operating point

↓

PPC changes its operating quadrants

(Q-IV→Q-III) and (SD→SU)

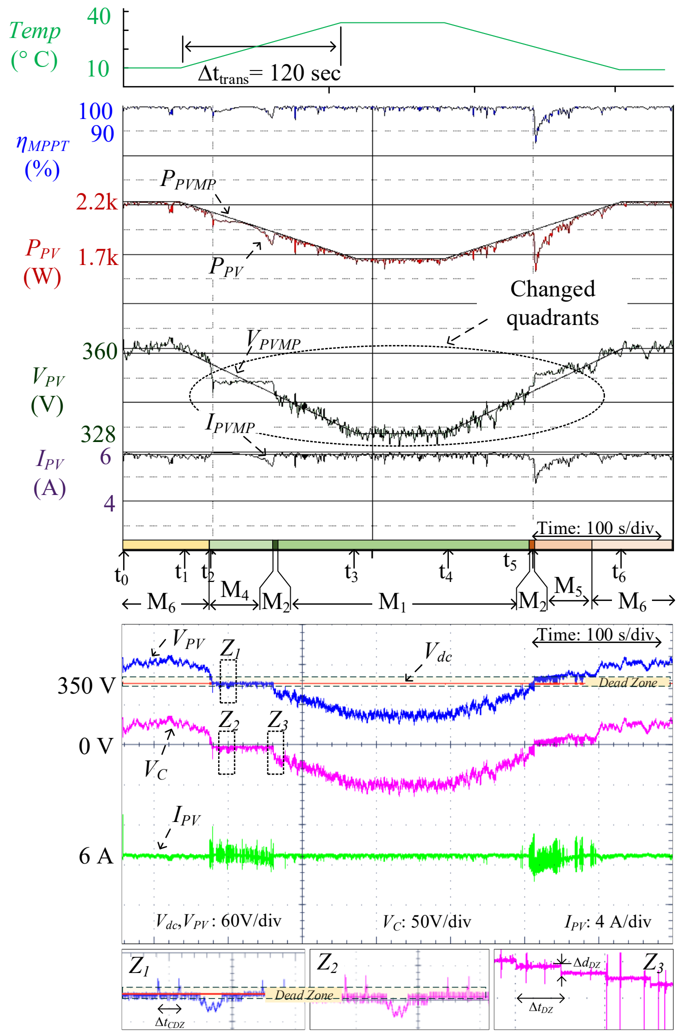
- The proposed algorithm avoids the saturation of the controller
- Gets a new operation point to enhance the MPPT efficiency.

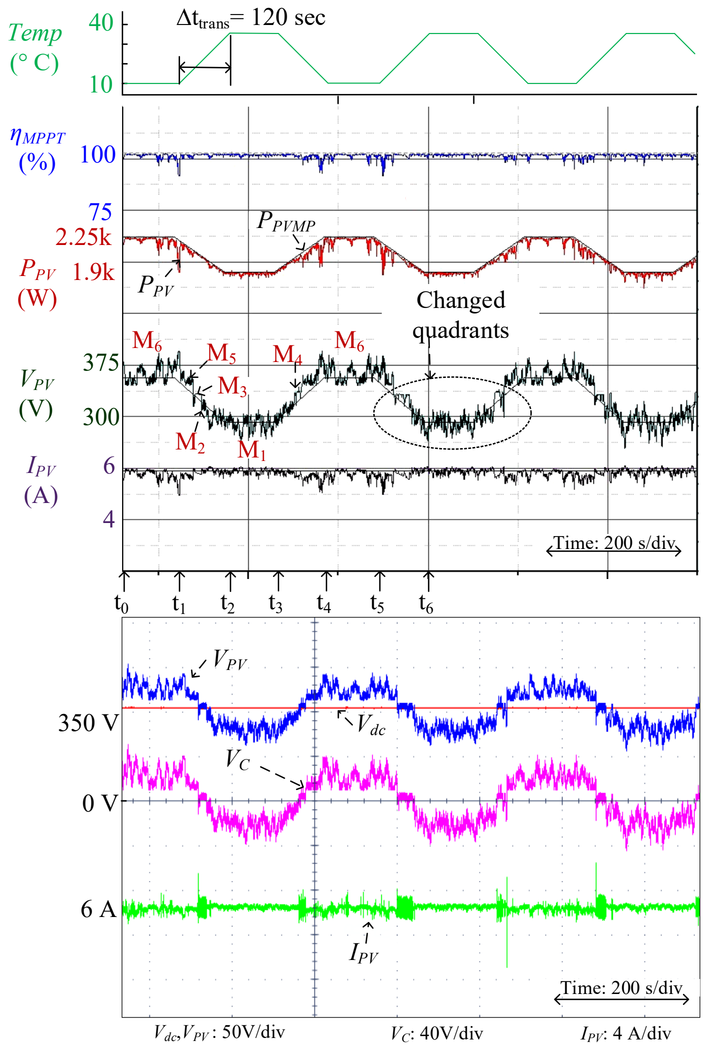


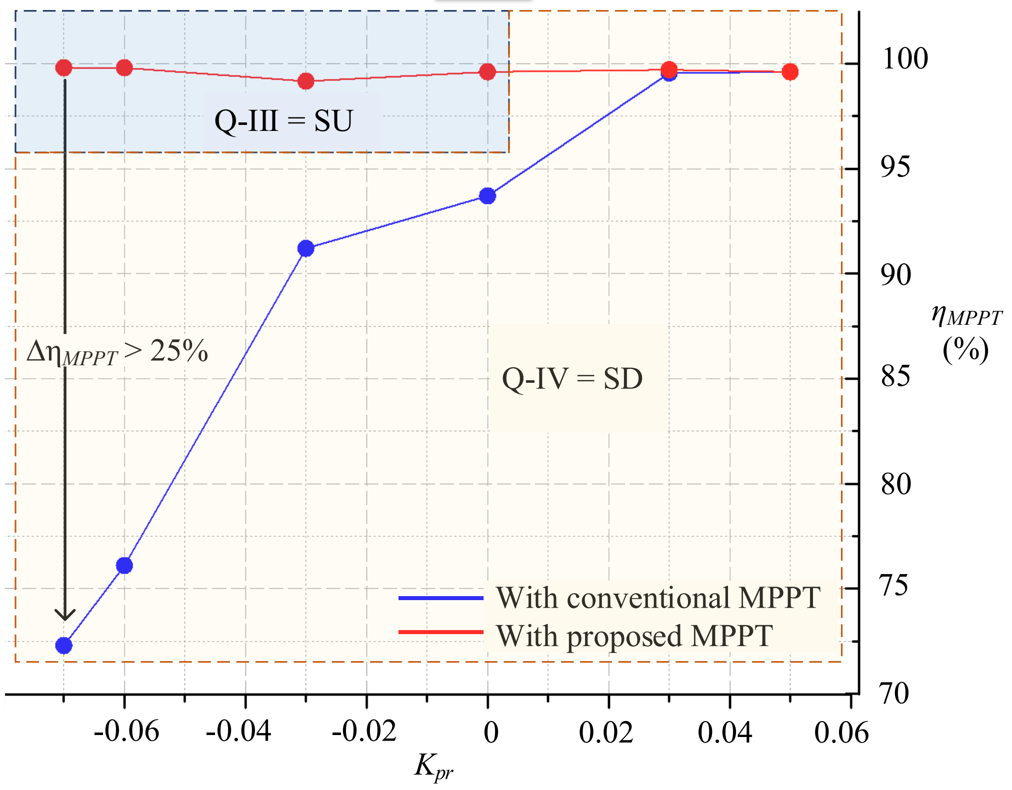
TALTECH

N. Yadav, at al. "Improved Maximum Power Point Tracking Algorithm for Step-Up/Down Partial Power Converters Operating Around Zero Partiality," in **IEEE J. Emerg. and Sel. Topics in Power Electron.**, vol. 12, no. 2, pp. 1984-1994, April 2024.

IMPROVED MPPT IMPLEMENTATION



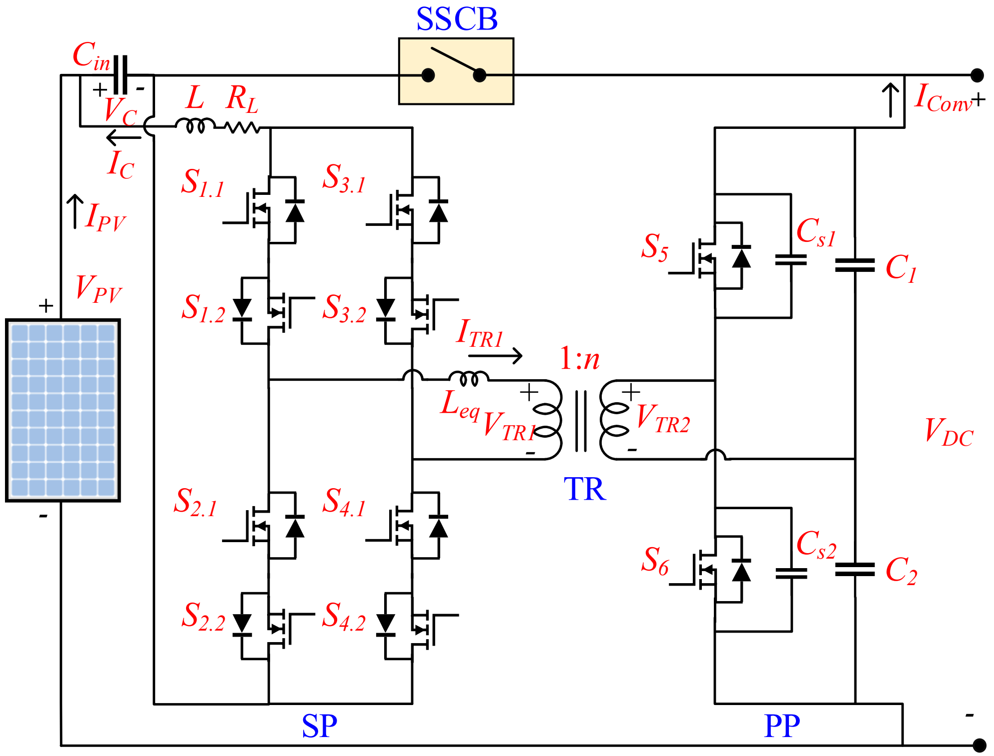


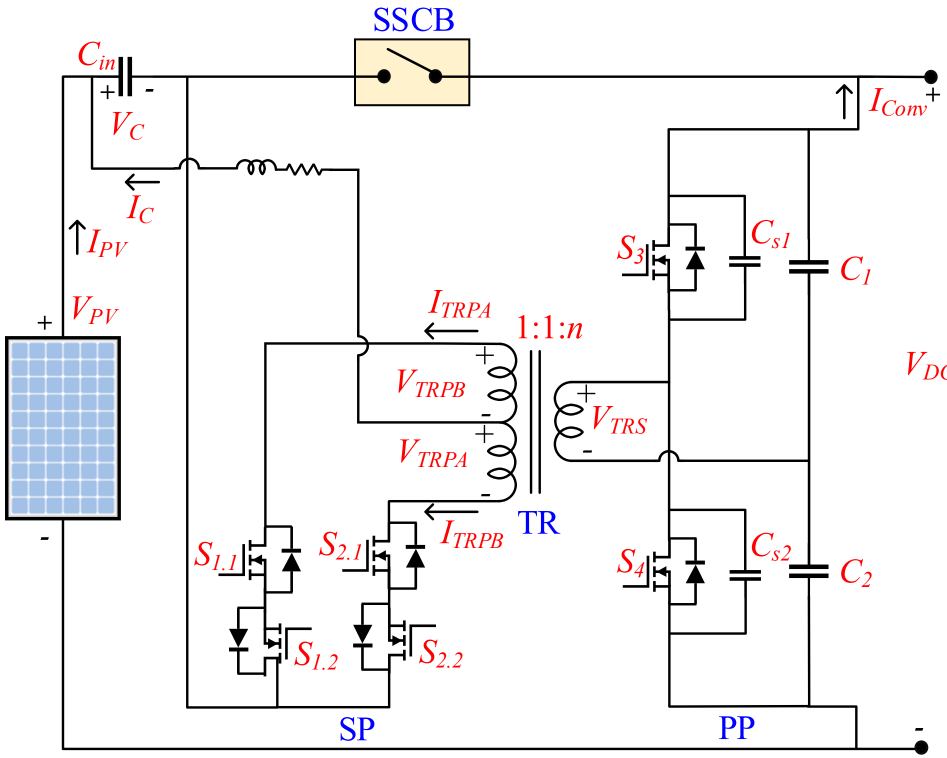


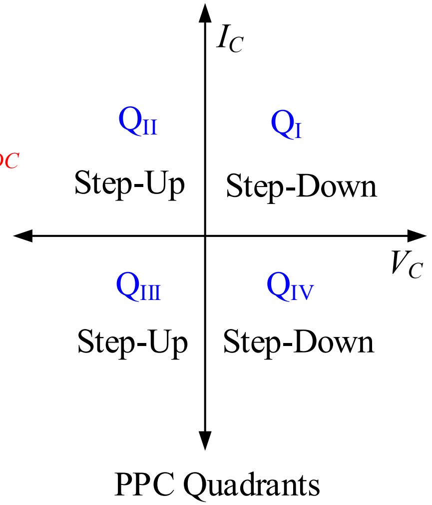
- Quadrant switching results in significant transients, but allows to improve MPPT overall
- A better solution is needed if PV string is likely to operate near the dead zone

PUSH-PULL TOPOLOGIES REDUCING THE NUMBER OF 4-QUADRANT SWITCHES

- Current-fed full-bridge converter can be replaced with the current-fed push-pull topology







N. Yadav et al., "Performance Evaluation of Step-Up/Down Partial Power Converters Based on Current-Fed DC-DC Topologies," in **IEEE Transactions on Industry Applications**, doi: 10.1109/TIA.2024.3413050.

COMPARISON OF IMPLEMENTATIONS

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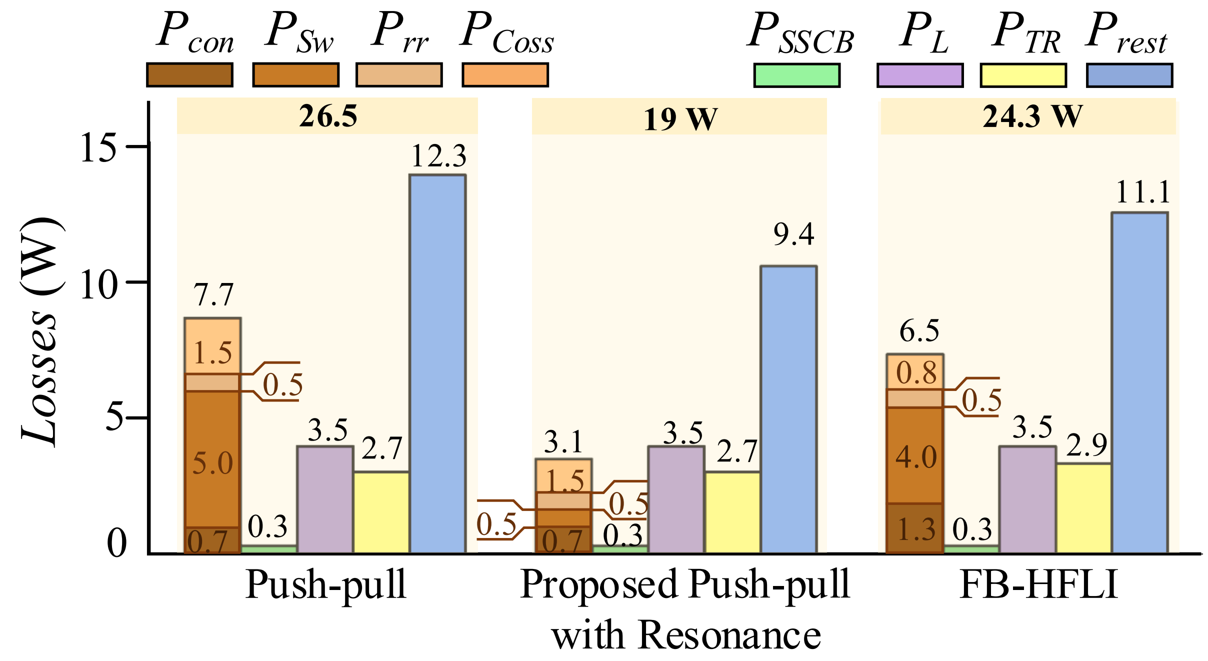
- Power losses at 2.5kW/350V/30V considering best possible implementation
- The CF push-pull with resonant switching can outperform FB topology with resonant switching as well

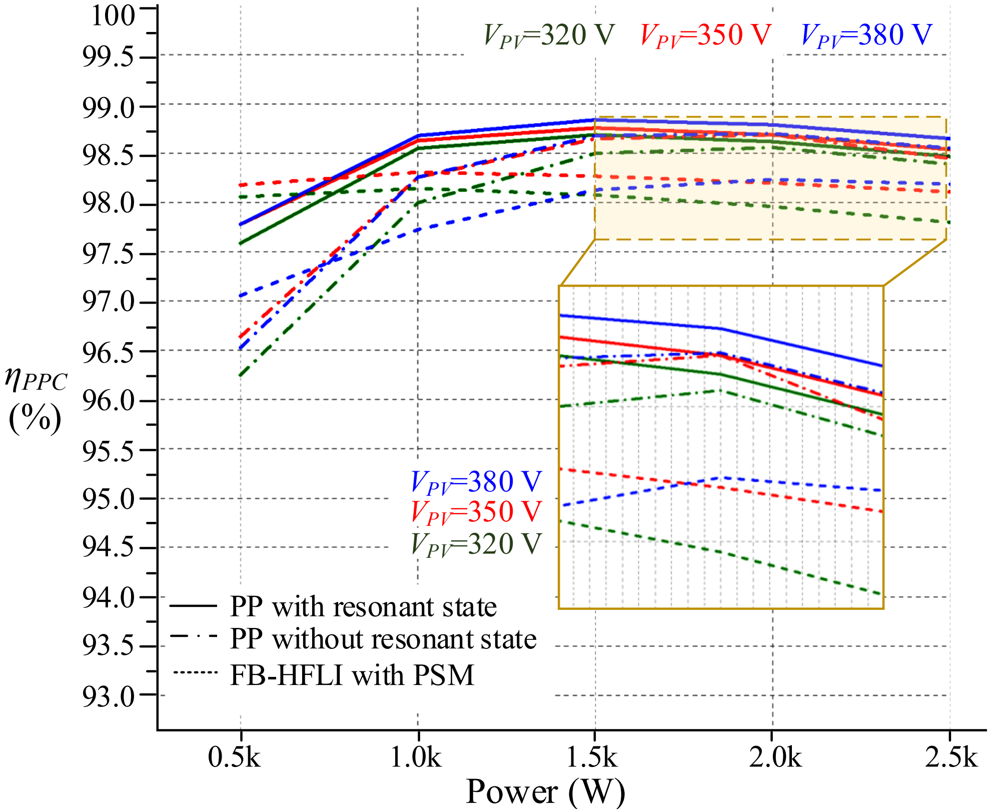


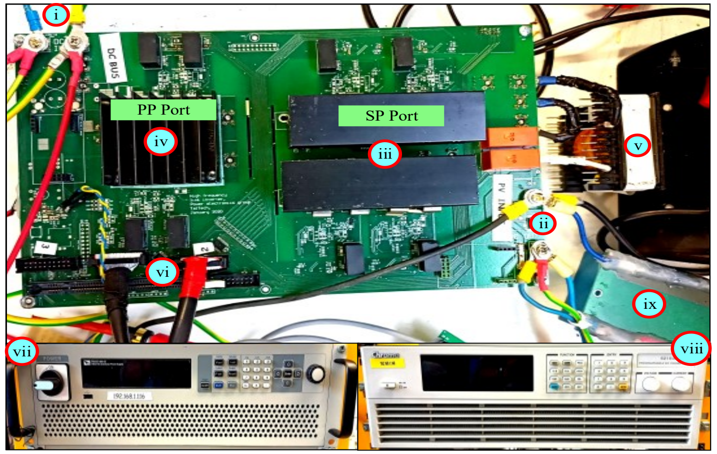
At 2kW, V_{PV}=320 V, V_{DC}=350 V			
Topology	Low Voltage side Switch stress		Price, p.u.
	Voltage (V)		
	V_S	$V_{S,max}$	
FB-HFLI	75	85	1.4
Push-pull	**220**	**339**	1.0
Proposed push-pull	**192**	**328**	1.0

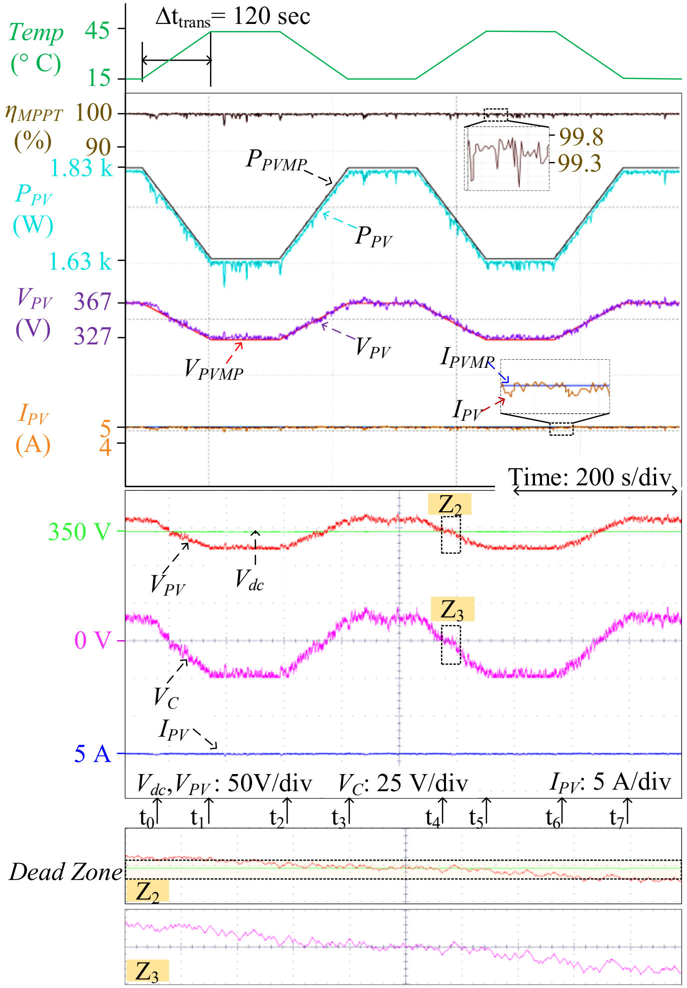
TAL TECH

N. Yadav et al., "Performance Evaluation of Step-Up/Down Partial Power Converters Based on Current-Fed DC-DC Topologies," **in IEEE Transactions on Industry Applications**, doi: 10.1109/TIA.2024.3413050.

OPERATION WITH PV STRING







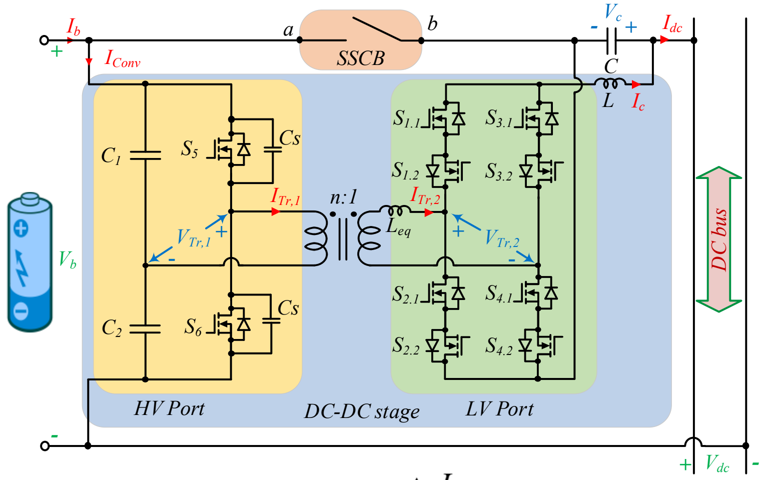
- This topology can be recommended for application with narrow voltage regulation range, i.e., low partiality

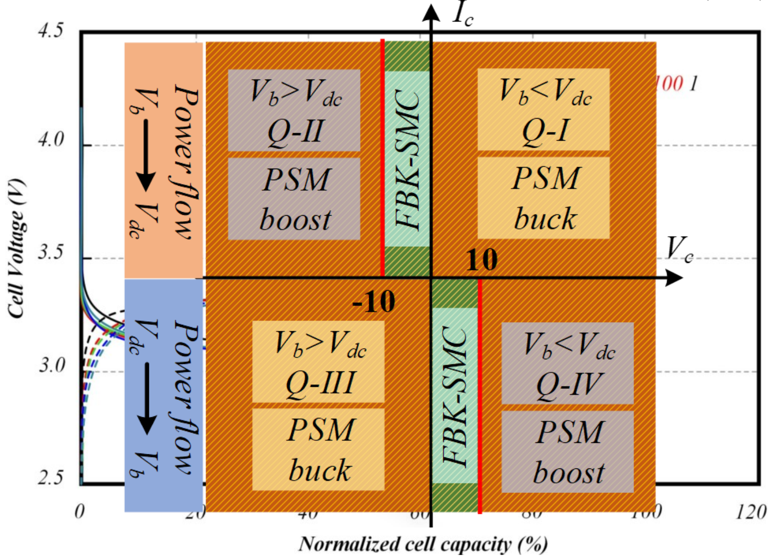
N. Yadav et al., "Performance Evaluation of Step-Up/Down Partial Power Converters Based on Current-Fed DC-DC Topologies," in **IEEE Transactions on Industry Applications**, doi: 10.1109/TIA.2024.3413050.

DC BUILDING APPLICATIONS SECOND LIFE BATTERY ENERGY STORAGE INTEGRATION

International Conference on DC Microgrids

- Current-fed implementation limits current stress on components
- Can manage current control at zero ser. voltage
- RMS current of capacitor is constrained
- Series port utilizes bidirectional switches for 4-quadrant operation and full soft switching
- Half-bridge implementation of the parallel port improves efficiency of the isolation transformer
- Low-cost power semiconductors
- Embedded solid-state circuit breaker





Bat. voltage	V_b	350 V(± 30V)
DC µG voltage	V_{dc}	350 V(± 30V)
Rated power	P_{reated}	4 kW
Rated power of dc-dc cell	P_{Conv}	750 W
Switching frequency	f_{SW}	75 kHz

- $V_{battery\_nominal}$: **350 V** [LiFePo$_4$: 109 cell]
- **At SoC = 90 %** 109 × 3.2 V ≈ 380 V
- **At SoC = 10 %** 109 × 2.9 V ≈ 320 V
- **V_{dc} = 320 V to 380 V**
- **I_{dc} = 10 A to -10 A**

TAL TECH

N. Hassanpour, et al. "High-Efficiency Partial Power Converter for Integration of Second-Life Battery Energy Storage Systems in DC Microgrids," in **IEEE Open Journal of the Industrial Electronics Society**, doi: 10.1109/OJIES.2024.3389466.

KEY FEATURES

- **Highest Efficiency:**

  Achieves up to 99.45% efficiency, cutting energy losses and operational costs.

- **Embedded Protection:**

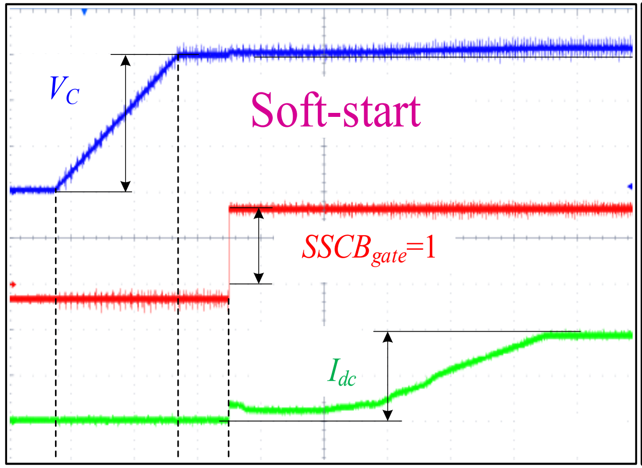
  Built-in short- and open-circuit protection ensures long-term system reliability.

- **Soft-Start and Soft-Stop:**

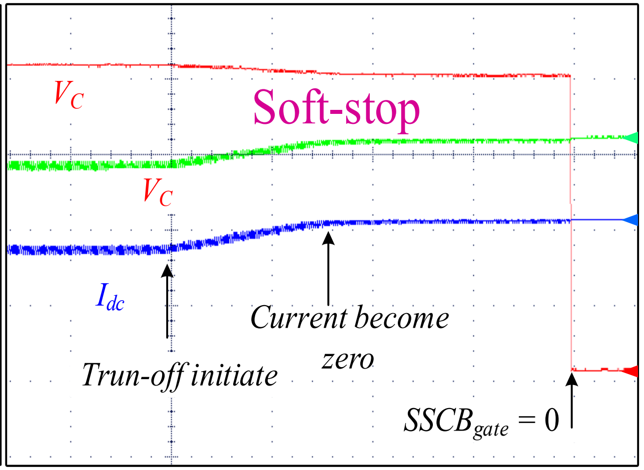
  Meets soft turn-on/off requirements to prevent false triggers of solid-state protection and reduce component wear-out.

TAL TECH

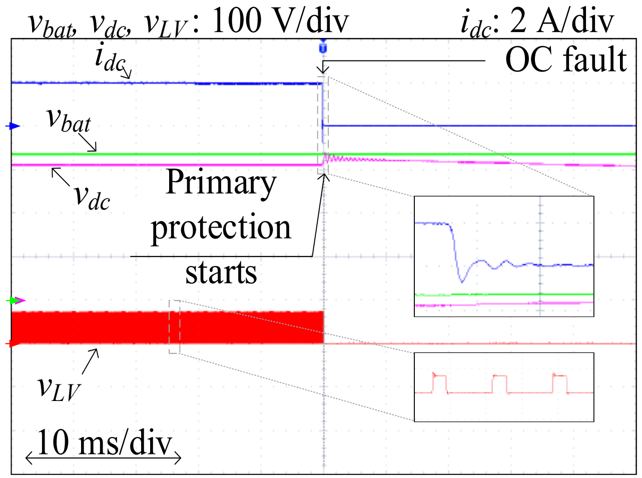
- **Soft-start**



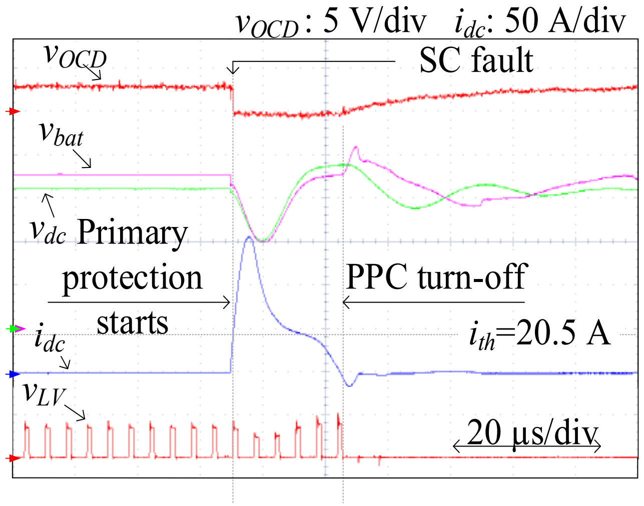
- **Short-stop**



- **Open-circuit protection**

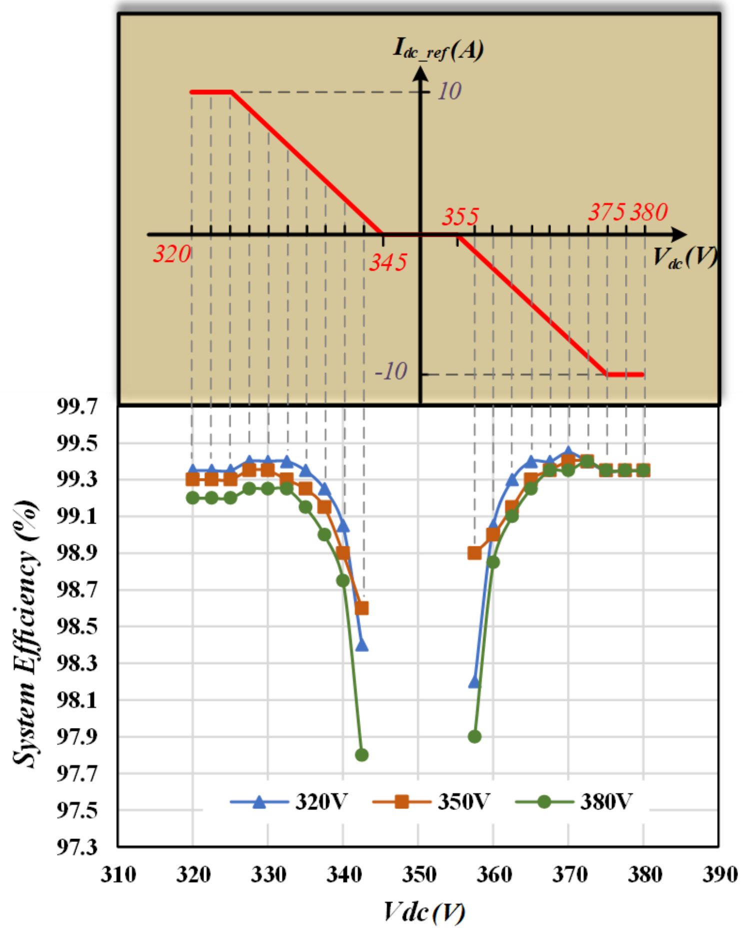


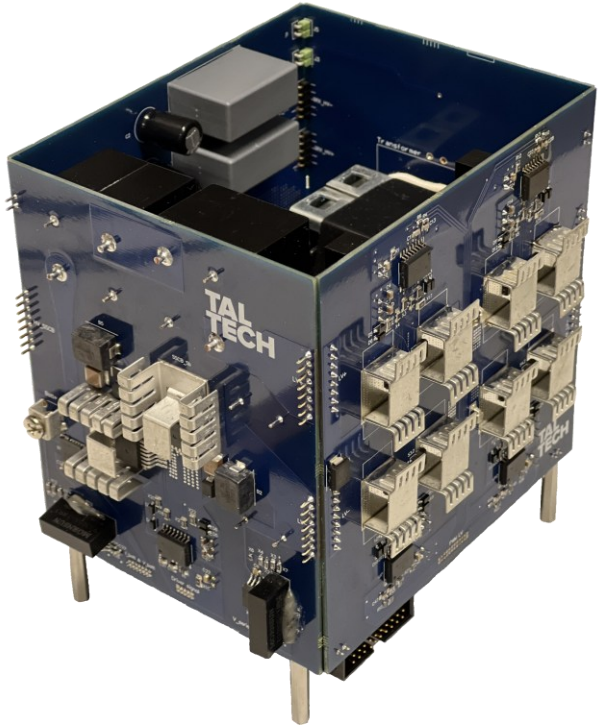
- **Short-circuit protection**

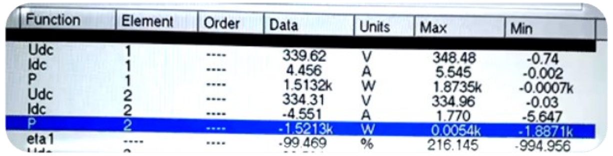


EXPERIMENTAL PROTOTYPE

International Conference on DC Microgrids







Function	Element	Order	Data	Units	Max	Min
Udc	1	----	339.62	V	348.48	-0.74
Idc	1	----	4.456	A	5.545	-0.002
P	1	----	1.5132k	W	1.8735k	-0.0007k
Udc	2	----	334.31	V	334.96	-0.03
Idc	2	----	-4.551	A	1.770	-5.647
P	2	----	-1.5213k	W	0.0054k	-1.8871k
eta1	----	----	-99.469	%	216.145	-994.956

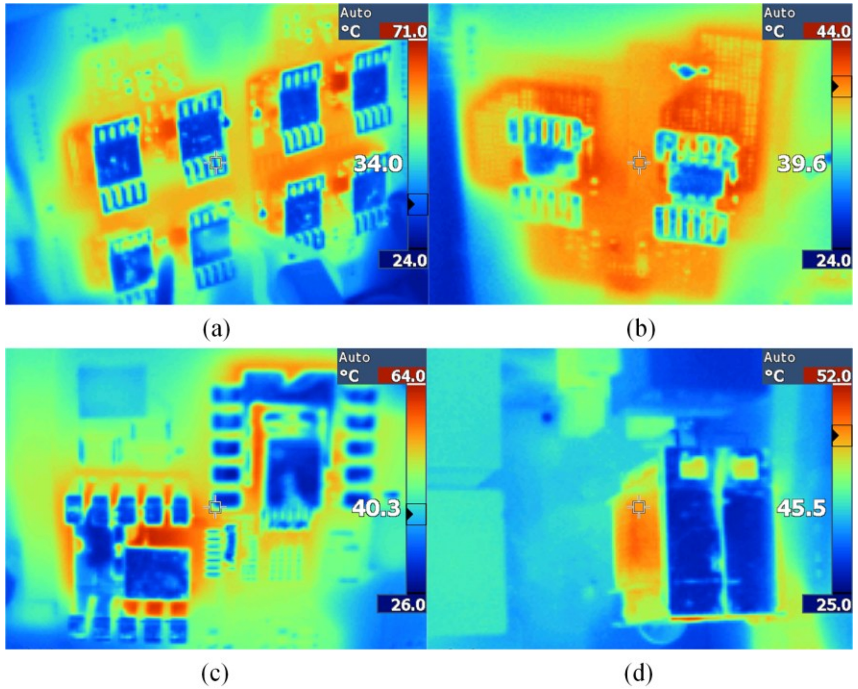
Parameters	Value/Type
LV port (Output) switches	BSC0403NSATMA1
HV port (Input) switches	G3R60MT07J
SSCB switches	UF3SC065030B7S
LV port inductor	164 μH (CPER3231-820MC)
Transformer turns ratio	2.4:1 (EILP32 core)
HV port capacitors	20 μF (R60IR51005040K)
Series capacitor	60 μF (DCP4G056007GD4KSSD)
Switching frequency	75 kHz
Microcontroller	STM32G474

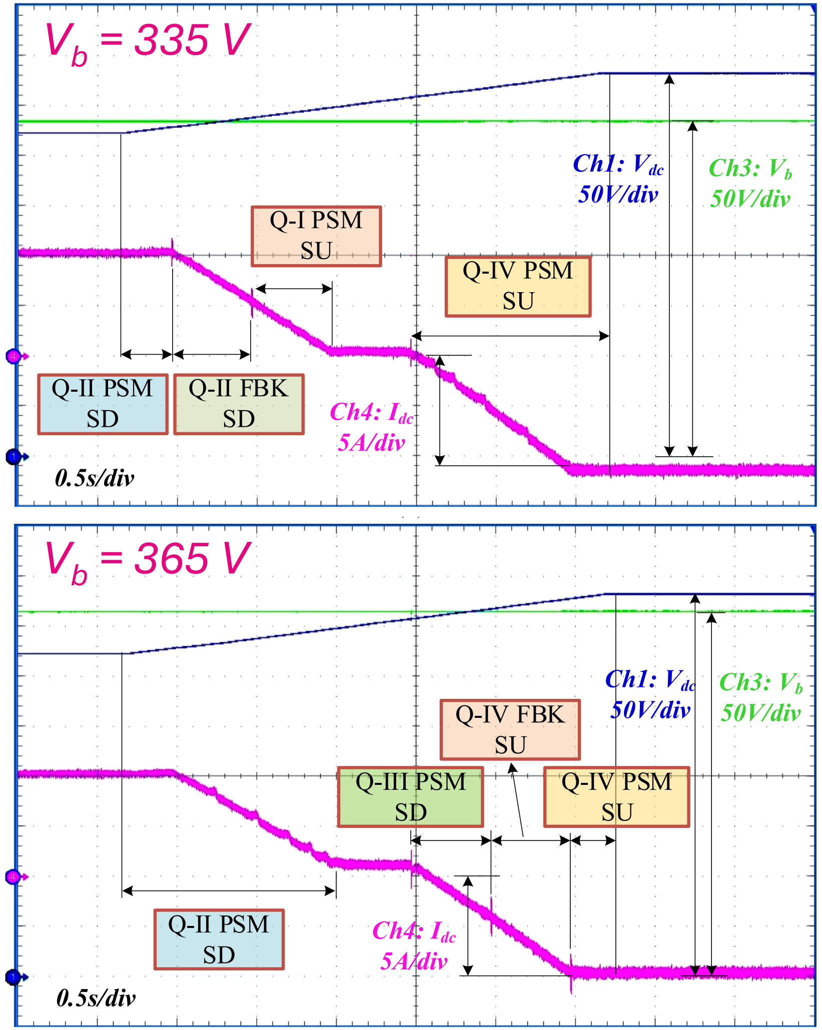
TAL TECH

N. Hassanpour, et al. "High-Efficiency Partial Power Converter for Integration of Second-Life Battery Energy Storage Systems in DC Microgrids," in **IEEE Open Journal of the Industrial Electronics Society**, doi: 10.1109/OJIES.2024.3389466.

EXPERIMENTAL VALIDATION

- Topology morphing control enables smooth transition between modes
- PCB-soldered heatsinks are sufficient for thermal management (SSCB is the hottest part)
- Control considers variations in both DC and battery voltage





TAL TECH

N. Hassanpour, et al. "High-Efficiency Partial Power Converter for Integration of Second-Life Battery Energy Storage Systems in DC Microgrids," in **IEEE Open Journal of the Industrial Electronics Society**, doi: 10.1109/OJIES.2024.3389466.

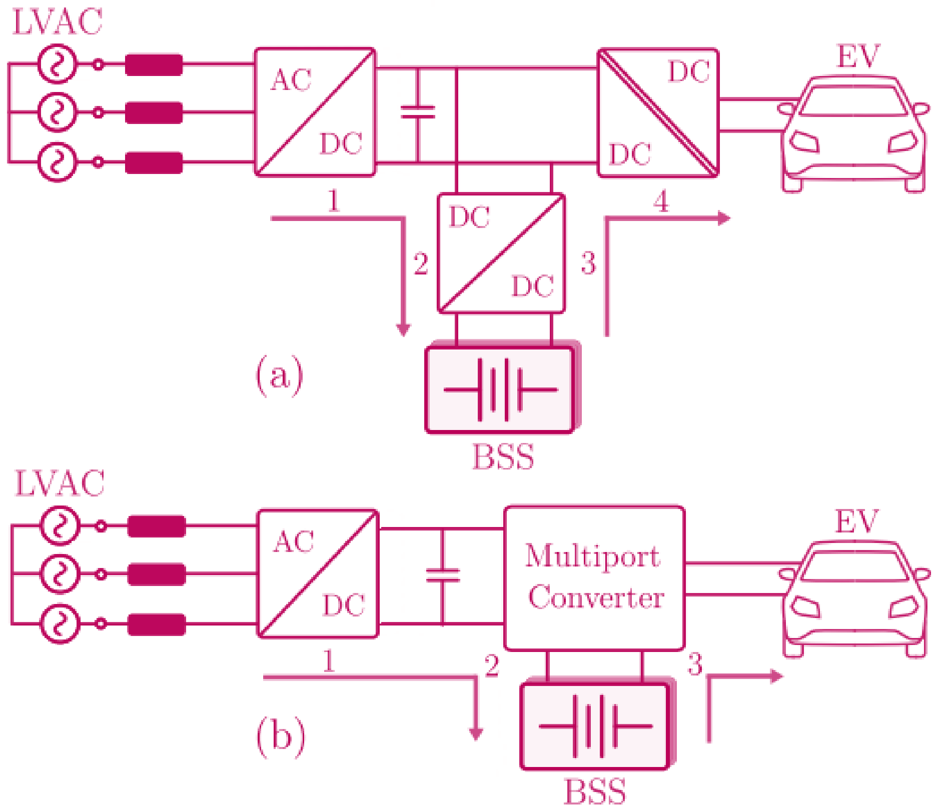
MULTIPORT CONVERTER

- Integration of battery storage systems (BSS) is becoming of particular interest because of the peak power reduction during the charging process.

MPC features:

- Reduces the number of conversions,
- High conversion efficiency and
- High power density.

- State-of-the-art PPC architectures that two-port applications are the primary emphasis of present PPC technology.
- Work to be done on the PPC approach's application to multiport networks.



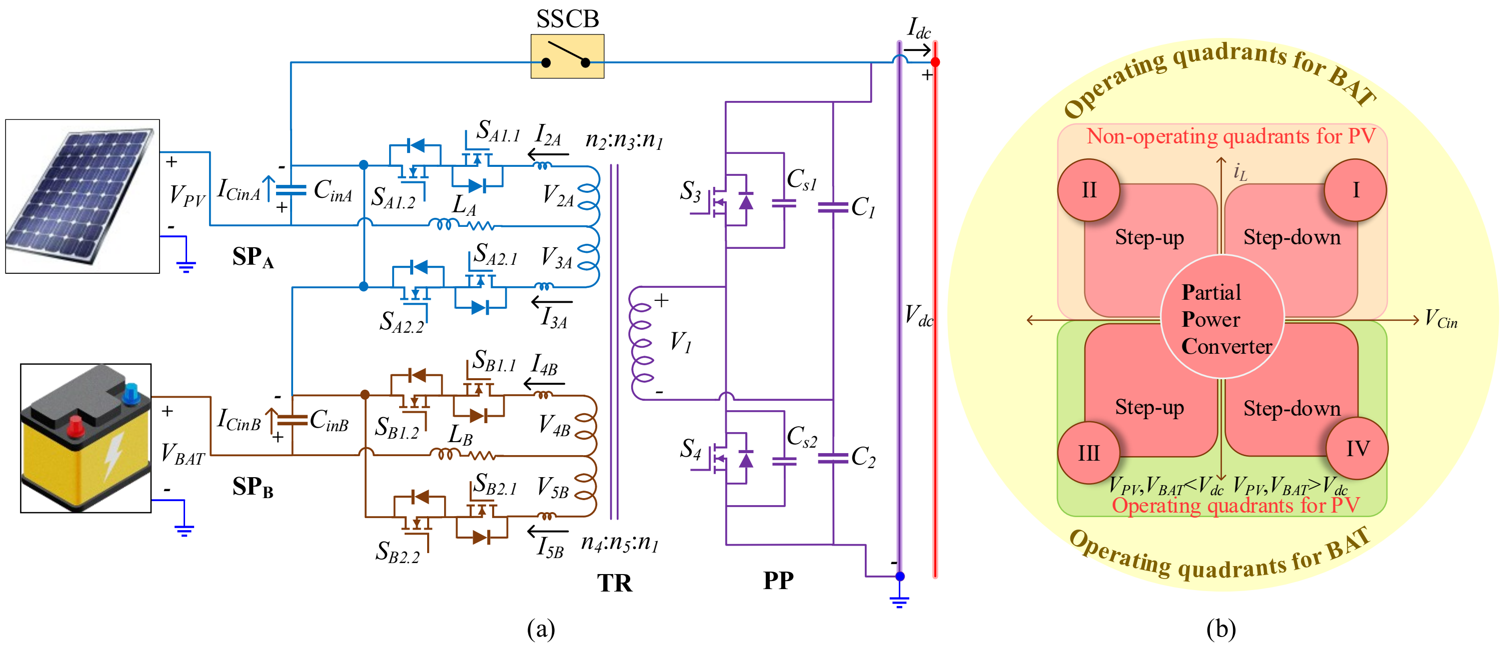
(a) BSS integration in DC link, (b) BSS integration with multiport converter

F. Hoffmann, J. Person, M. Andresen, M. Liserre, F. D. Freijedo and T. Wijekoon, "A Multiport Partial Power Processing Converter With Energy Storage Integration for EV Stationary Charging," in **IEEE Journal of Emerging and Selected Topics in Power Electronics**, vol. 10, no. 6, pp. 7950-7962, Dec. 2022, doi: 10.1109/JESTPE.2021.3102180.

DUAL-INPUT SINGLE OUTPUT MULTIPORT CONFIGURATION

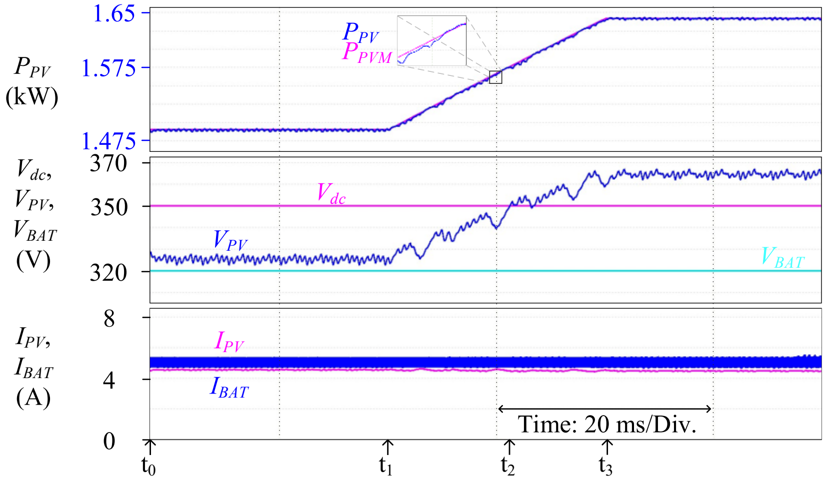
Main features

- Utilizes a soft-switching current-fed push-pull topology, which reduces the number of switches and the implementation cost.
- Fully decoupled control loops
- Wide voltage regulation range with min. partiality
- A short resonant state is introduced into the modulation to enable complete soft switching and reduce switching losses.
- Embedded protection enables soft start-up and safe operation of the system

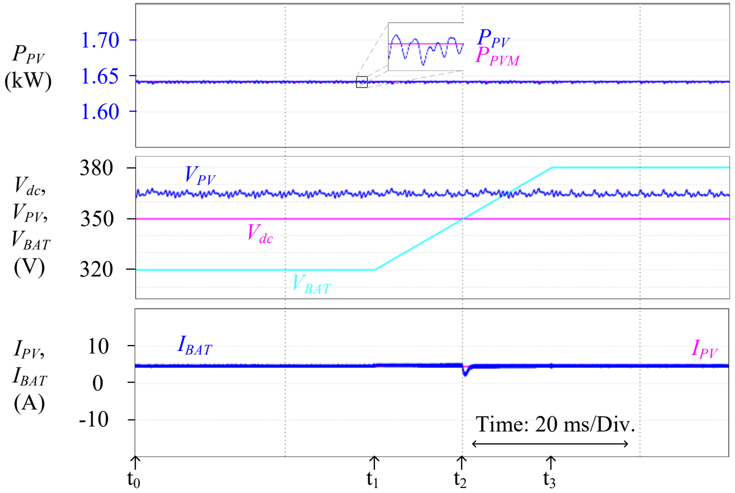


N. Yadav, A. Chub and L. Kütt, "Three-Port Current Fed Push/Pull Partial Power Converter for Integration of PV/Battery Systems in DC Microgrids," 2024 19th Biennial Baltic Electronics Conference (BEC), Tallinn, Estonia, 2024, pp. 1-6, doi: 10.1109/BEC61458.2024.10737934.

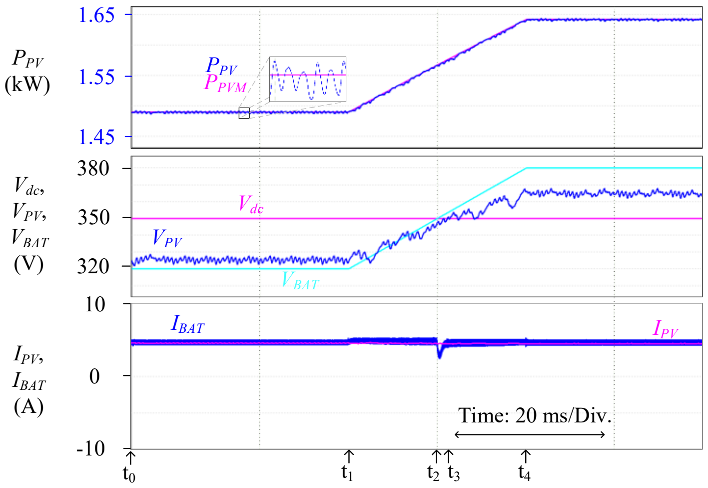
DUAL-INPUT SINGLE OUTPUT MULTIPORT: RESULTS



PPC performance for varying V_{PV} (325 to 365 V) while keeping constant V_{BAT} = 320 V and V_{dc} = 350 V.



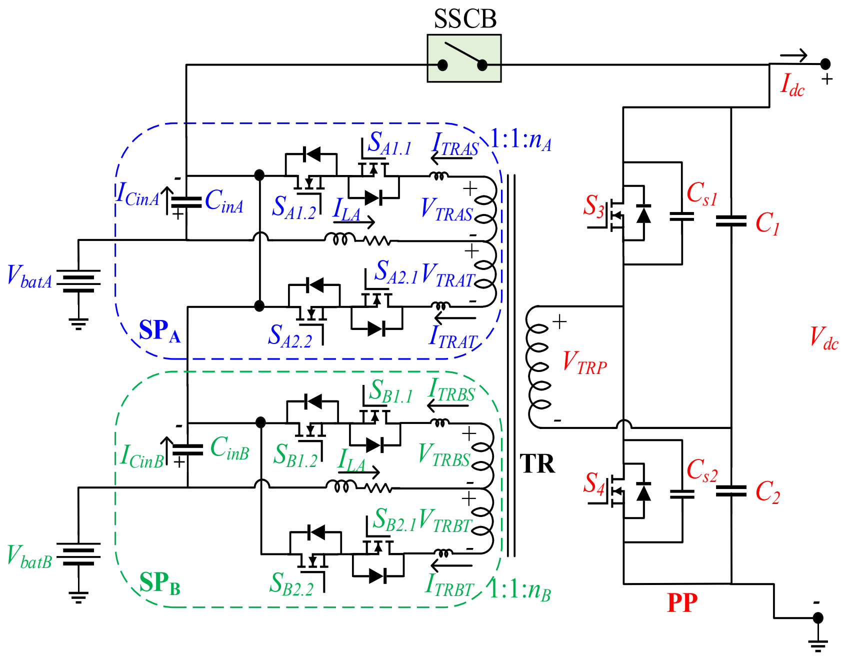
PPC performance for varying V_{BAT} (320 to 380 V) while keeping constant V_{PV} = 365 V and V_{dc} = 350 V.



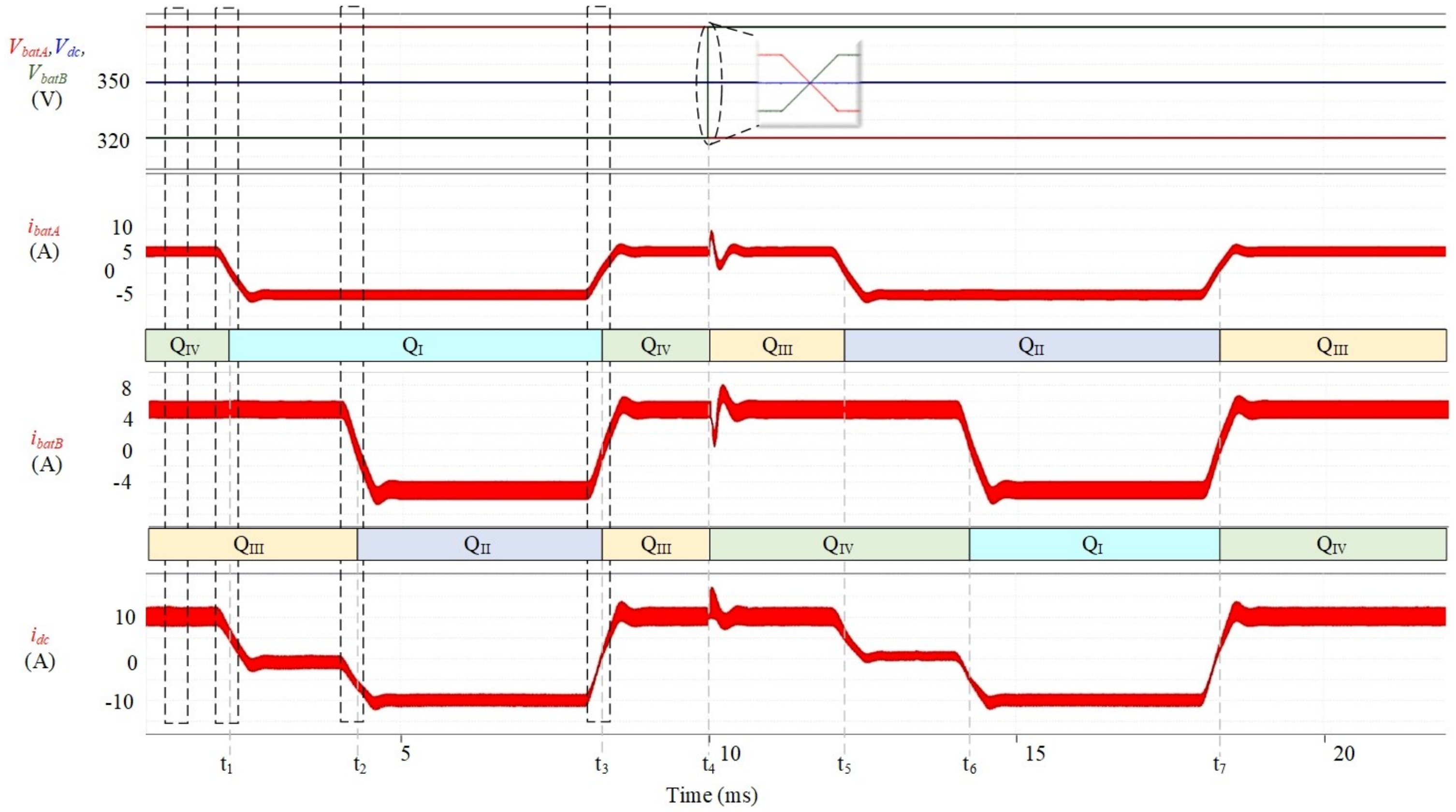
PPC performance for varying V_{PV} (325 to 365 V) and varying V_{BAT} (320 to 380 V) while keeping constant V_{dc} = 350 V.

N. Yadav, A. Chub and L. Kütt, "Three-Port Current Fed Push/Pull Partial Power Converter for Integration of PV/Battery Systems in DC Microgrids," 2024 19th Biennial Baltic Electronics Conference (BEC), Tallinn, Estonia, 2024, pp. 1-6, doi: 10.1109/BEC61458.2024.10737934.

FOUR QUADRANT OPERATION OF MULTIPORT PPC



Multiport partial power converter structure



TAL TECH

N. Yadav and A. Chub, "Multiport Current Fed Push/Pull Partial Power Converter for Battery Integration in DC Microgrid," 2024 IEEE 18th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Gdynia, Poland, 2024, pp. 1-6, doi: 10.1109/CPE-POWERENG60842.2024.10604406.

THE ROLE OF PPC IN INTEGRATING ELECTRIC VEHICLE AND DC BUILDING TECHNOLOGIES

Dr. Niwton Gabriel Feliciani dos Santos

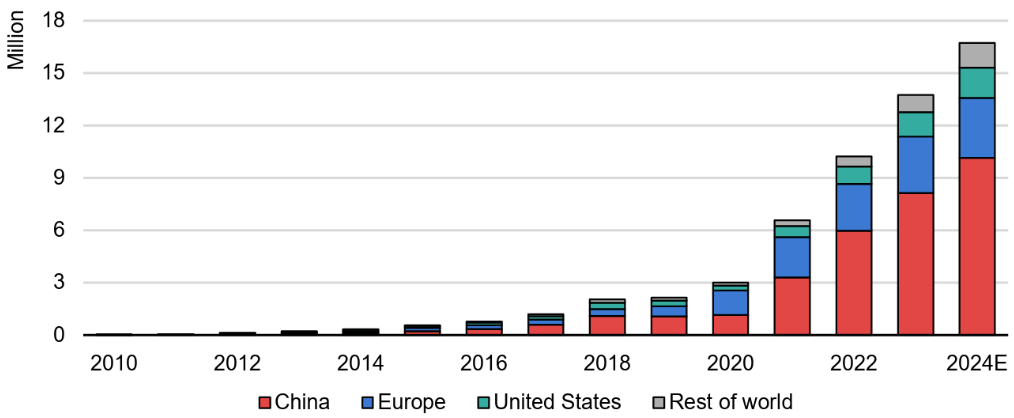
International Conference on DC Microgrids

TRENDS IN ELECTRIC VEHICLES (EVs)

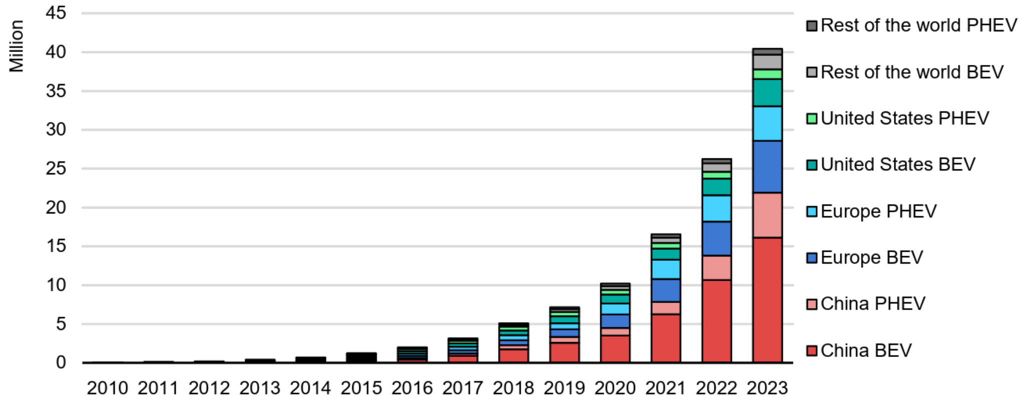
International Conference on DC Microgrids

- **EVs** continue to make progress toward becoming a mass-market product in an increasing number of countries.
- In **2023**, most sales occurred in China (**60%**), Europe (**25%**), and the United States (**10%**).
- In India, **EVs** hold a **2% market share**, supported by government incentives and domestic manufacturing efforts.
- In Brazil (**3% share**), the adoption of **EVs** is being driven by the availability of cheaper models, primarily from **Chinese brands**.

Electric car sales, 2010-2024



Global electric car stock trends, 2010-2023

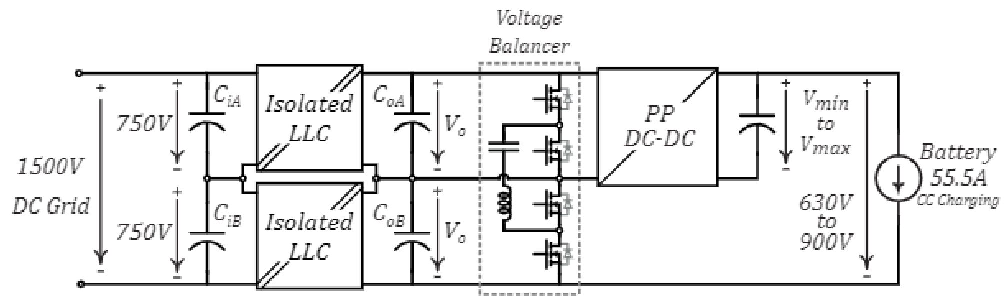


TAL TECH

Global EV Outlook 2024: Moving Towards Increased Affordability, International Energy Agency, Paris, France, 2024. [Online]. Available: https://www.iea.org/reports/global-ev-outlook-2024

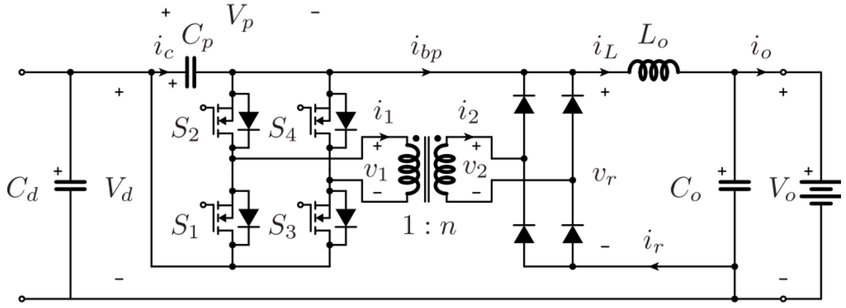
SOLUTIONS FOR EVS

Two-stage PPC for **fast charging**



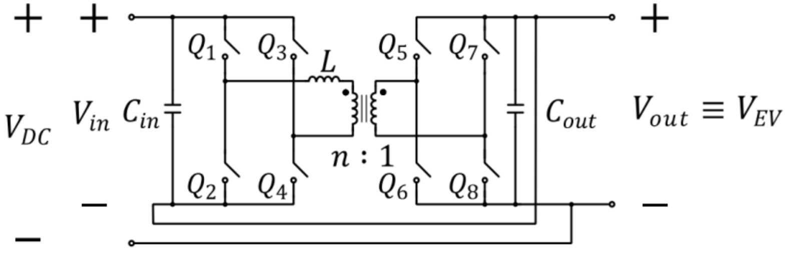
A. Stanojević, Y. E. Bouvier, and P. J. Grbović, "Comparison of 2-stage isolated converters for fast EV charger, using partial power," in *Proc. IECON 2022 – 48th Annu. Conf. IEEE Ind. Electron. Soc.*, Brussels, Belgium, 2022.

Type II S-PPC for **fast charging**



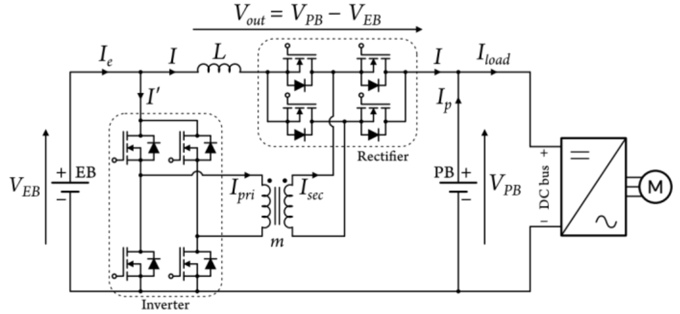
S. Rivera *et al.*, "Partial-power converter topology of type II for efficient electric vehicle fast charging," *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 10, no. 6, pp. 7839–7848, Dec. 2022.

DAB-PPC for an **on-board charger**



J. Anzola, S. Sharma, I. Aizpuru, S. Bhattacharya, and J. S. Artal-Sevil, "Performance improvement of a silicon partial power converter over a silicon carbide full power converter," *IEEE Trans. Transp. Electrific.*, vol. 10, no. 1, pp. 1680–1691, Mar. 2024.

PISO S-PPC for **HESS** and **EV traction**

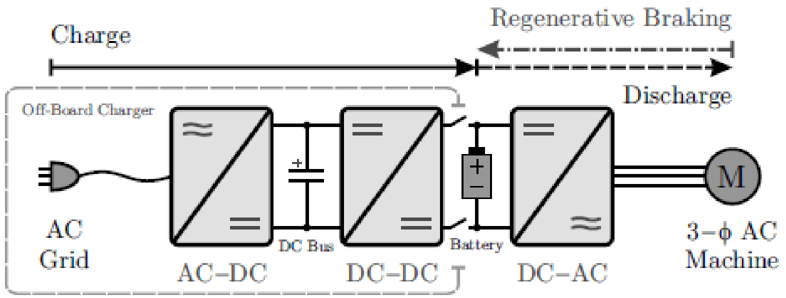


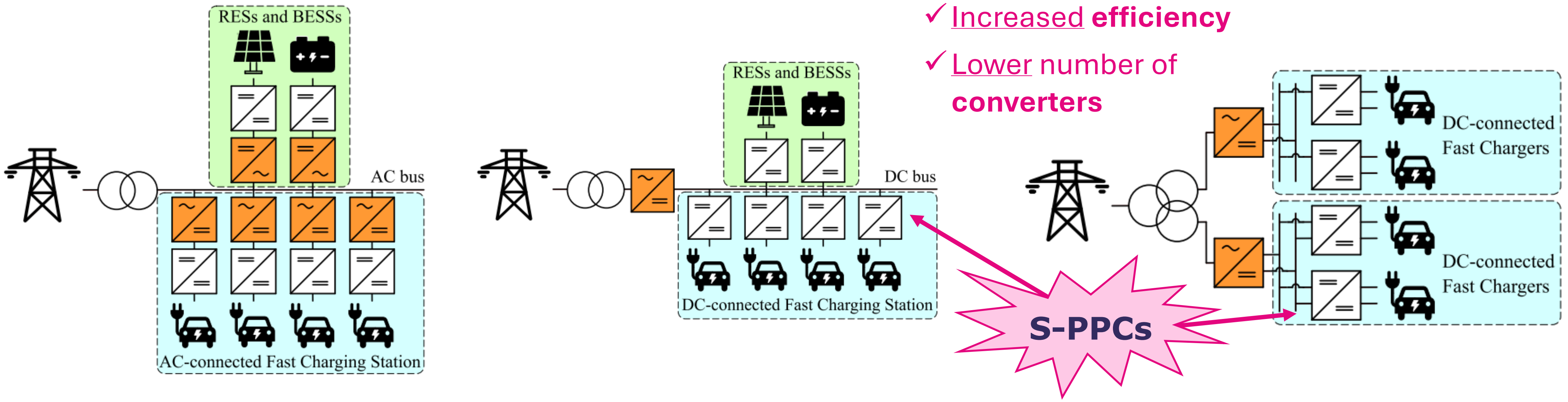
C. A. F. de Freitas, P. Bartholomeus, X. Margueron, and P. Le Moigne, "Partial power converter for electric vehicle hybrid energy storage system using a controlled current source cascade architecture," *IEEE Access*, vol. 12, pp. 150898–150913, 2024.

EVS AND DC BUILDINGS INTEGRATION

International Conference on DC Microgrids

- Ideas for **Smarter Energy Use**:
  - **AC-connected** fast charging stations (**FCSs**) are still more common.
  - **DC-connected FCSs** are on track to become the main **fast-charging** solution in the growing world of DC-powered buildings.





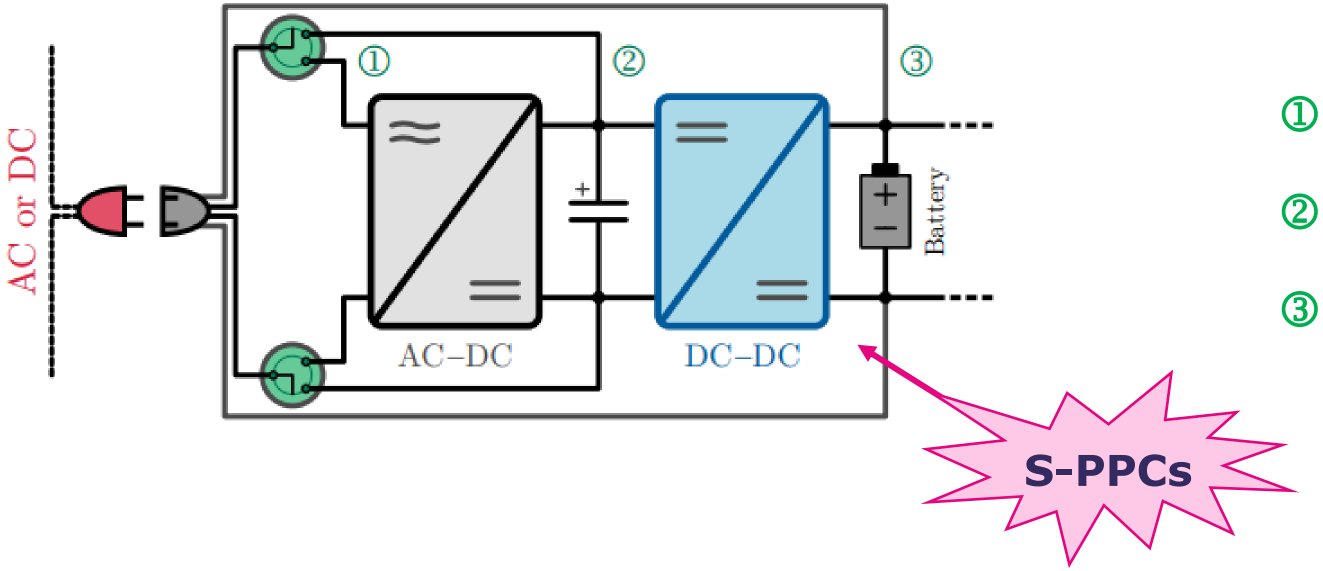
TAL TECH

G. Arena, A. Chub, M. Lukianov, R. Strzelecki, D. Vinnikov, and G. De Carne, “A comprehensive review on DC fast charging stations for electric vehicles: Standards, power conversion technologies, architectures, energy management, and cybersecurity,” *IEEE Open J. Power Electron.*, vol. 5, pp. 1573–1611, 2024.

EVS AND DC BUILDINGS INTEGRATION

International Conference on DC Microgrids

- Ideas for **Smarter Energy Use**:
  - For the on-board chargers (**OBCs**), one idea is to allow <u>switching</u> between **slow AC charging** and integration with **DC buildings**, without needing an external converter.



① **Slow** charging from the ac grid (**OBC**)

② **Integration** with dc buildings (**OBC**)

③ **Fast** or **semi-fast** charging (**FCS**)

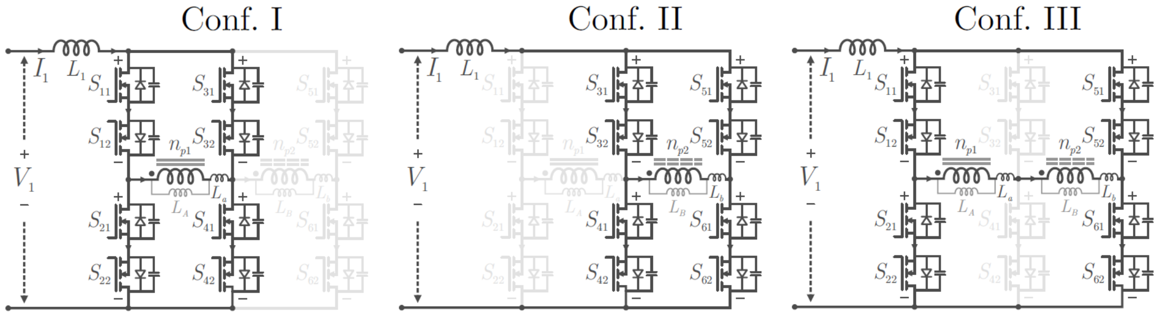
TAL TECH

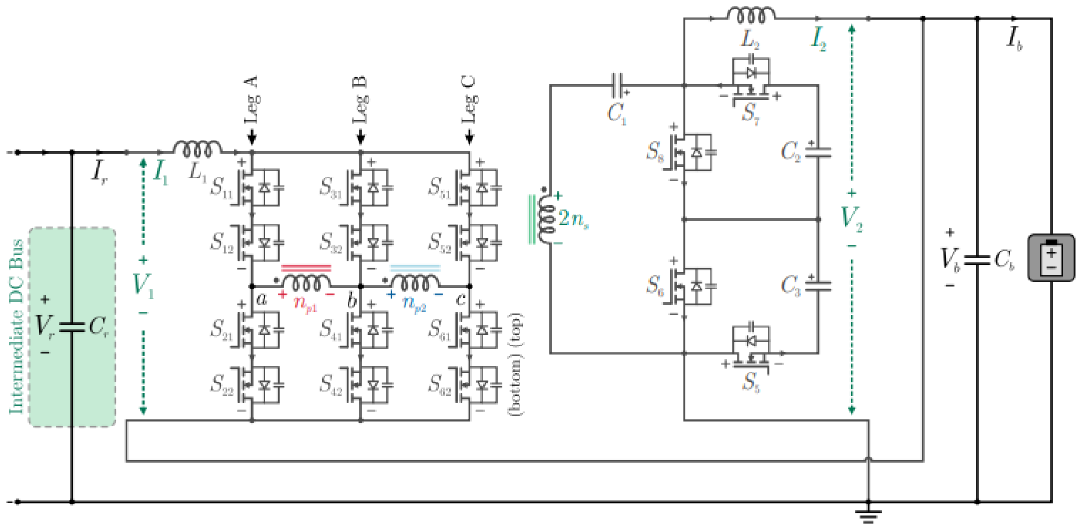
N. G. F. dos Santos, A. Chub, and M. L. S. Martins, “A topology morphing partial power converter with variable turns ratio for integration of on-board battery chargers with DC buildings,” in *Proc. 2025 IEEE 7th Int. Conf. DC Microgrids (ICDCM)*, Tallinn, Estonia, 2025, pp. 1–5.

RECONFIGURABLE S-PPCs (OBC)

International Conference on DC Microgrids

- **Advanced Topologies** for PPCs:
  - Reconfigurable PPCs
    - Achieve an optimal balance between power processing, performance, and voltage regulation range
    - Step-up/down **SIPO S-PPC**
    - Adjustable transformer turns ratio
    - PWM strategies (fixed-frequency)
    - Full-range soft-switching
    - **Bidirectional** current-fed (CF) ports
    - Snubberless **without** voltage spikes





TAL TECH

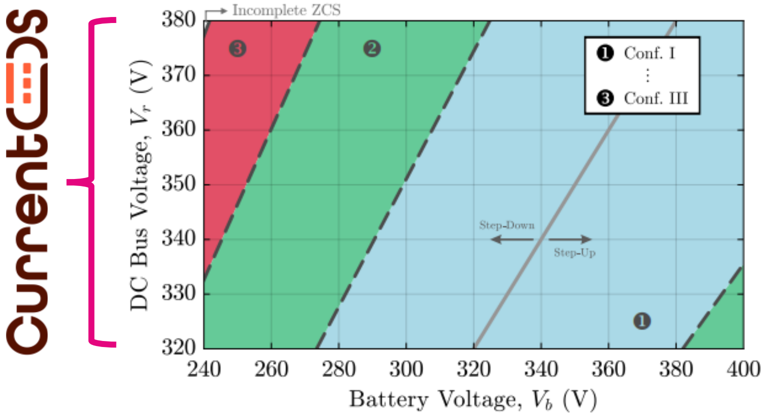
N. G. F. dos Santos, A. Chub, and M. L. S. Martins, “A topology morphing partial power converter with variable turns ratio for integration of on-board battery chargers with DC buildings,” in *Proc. 2025 IEEE 7th Int. Conf. DC Microgrids (ICDCM)*, Tallinn, Estonia, 2025, pp. 1–5.

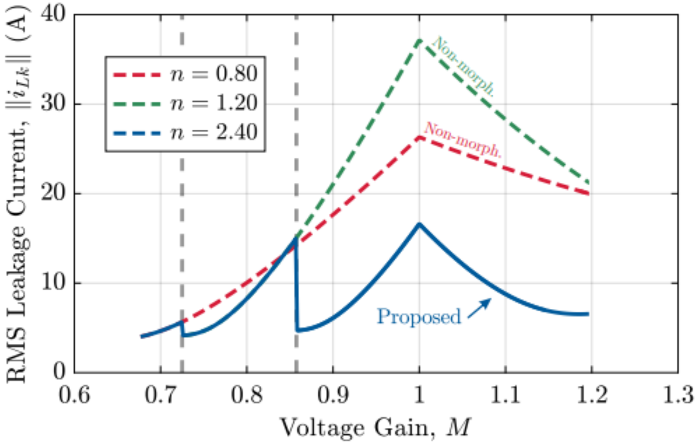
RECONFIGURABLE S-PPCs (OBC)

International Conference on DC Microgrids

- **Advanced Topologies** for PPCs:
  - Reconfigurable PPCs
    - Achieve an optimal balance between power processing, performance, and voltage regulation range
    - The **soft-switching** absorbs all the energy stored in the leakage inductance
    - The **S-PPC** operates predominantly within a range where the turns ratio is higher (**Conf. I**), which reduces conduction losses by minimizing the circulating currents

Nissan LEAF®





TAL TECH

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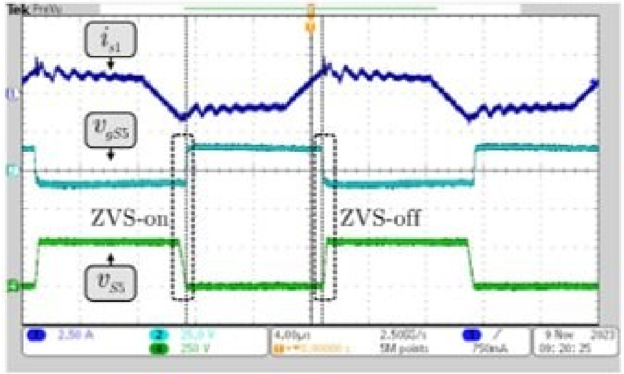
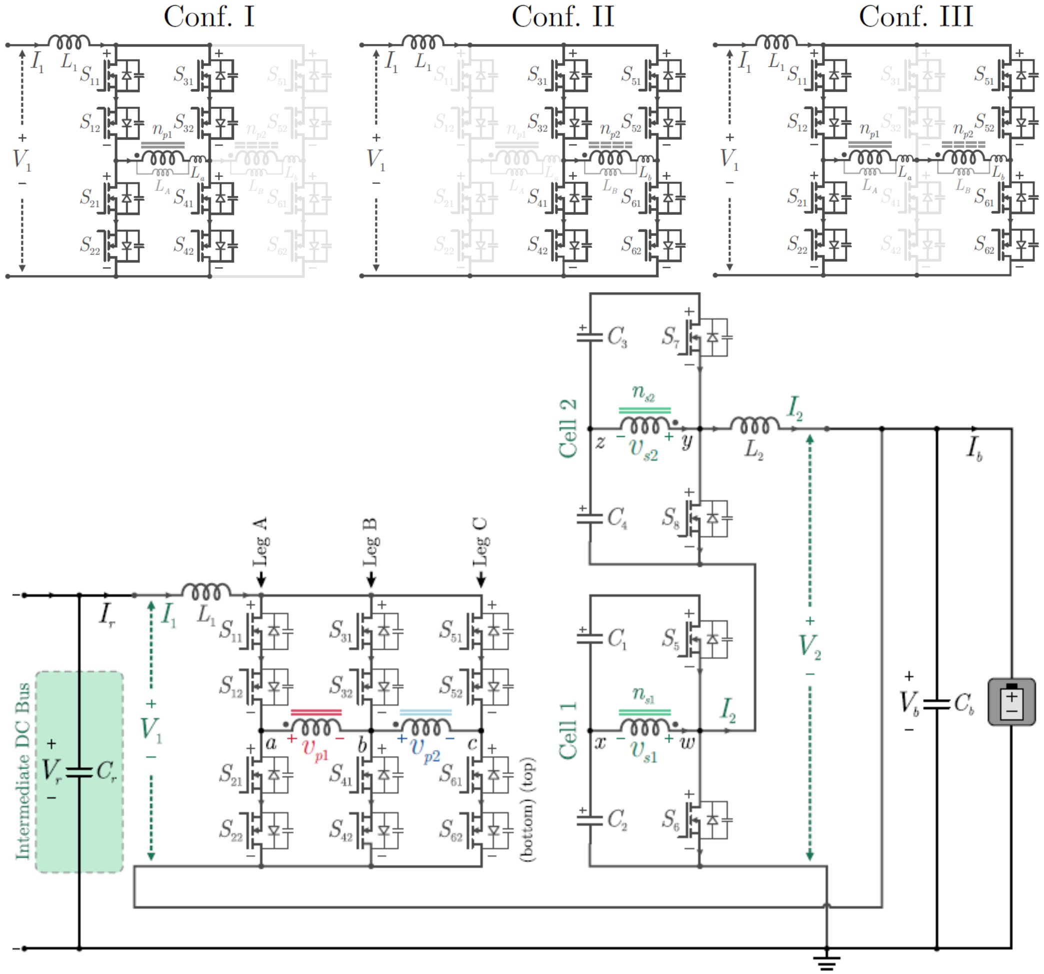
RECONFIGURABLE S-PPCs (OBC)

- **Advanced Topologies** for PPCs:
  - Reconfigurable PPCs: **Option 2**
    - Wide voltage regulation range
    - Adjustable transformer turns ratio
    - **Bidirectional** current-fed (CF) ports
    - *LC* resonance



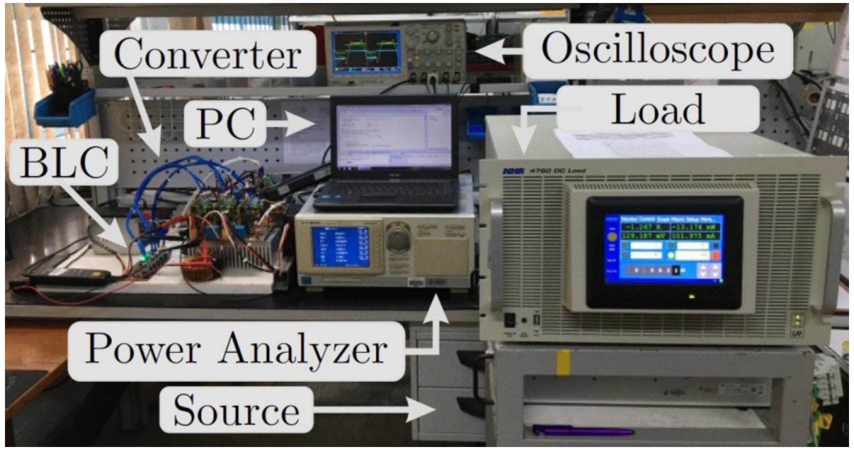


N. G. F. dos Santos, J. R. R. Zientarski, and M. L. S. Martins, “A ZCS/ZVS DC–DC partial power converter with reconfigurable H-bridge and variable turns ratio for an integrated on-board charger,” ***IEEE Trans. Power Electron.***, vol. 39, no. 10, pp. 13916–13933, Oct. 2024.

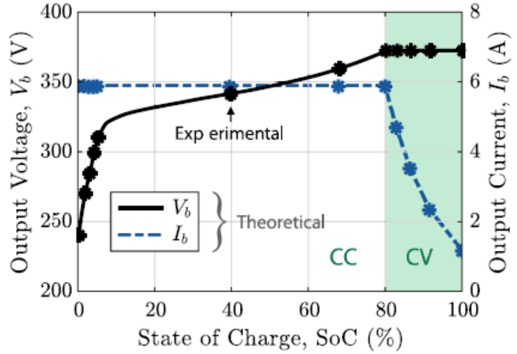
RECONFIGURABLE S-PPCs

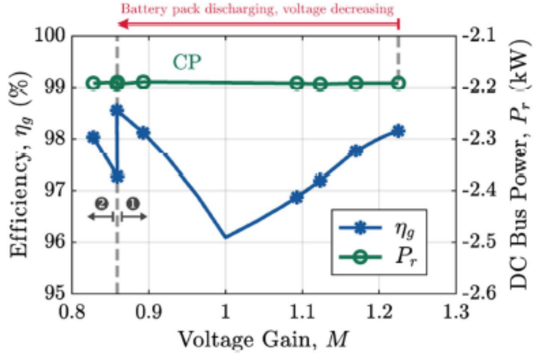
International Conference on DC Microgrids

- **Advanced Topologies** for PPCs:
  - Reconfigurable PPCs: **Option 2**
    - **Optimized turns ratio** ensures a good compromise between power processing, efficiency, and voltage range **(LEAF®)**.

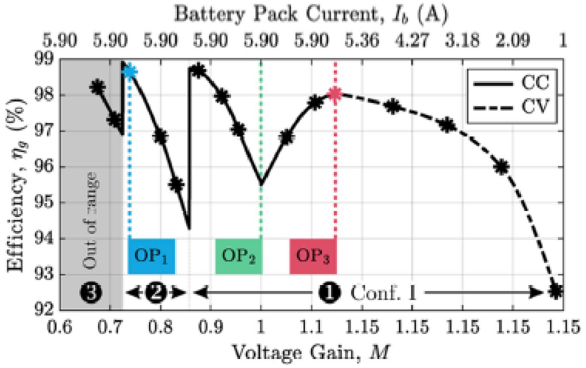


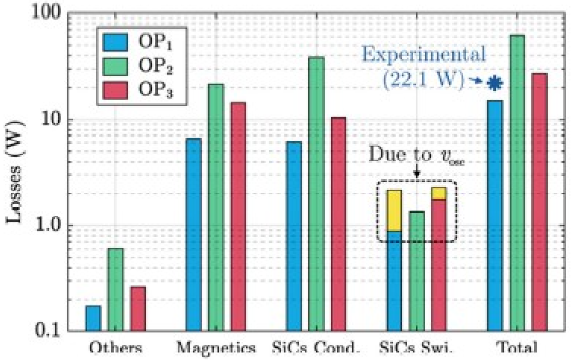
CC/CV method and **discharging mode** (2.2 kW)





Peak global efficiency of 98.7%



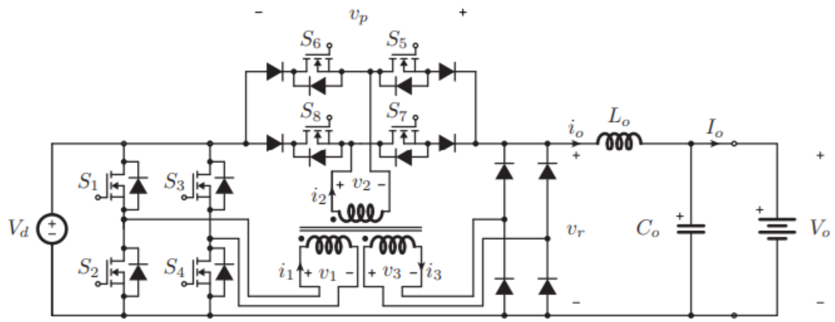


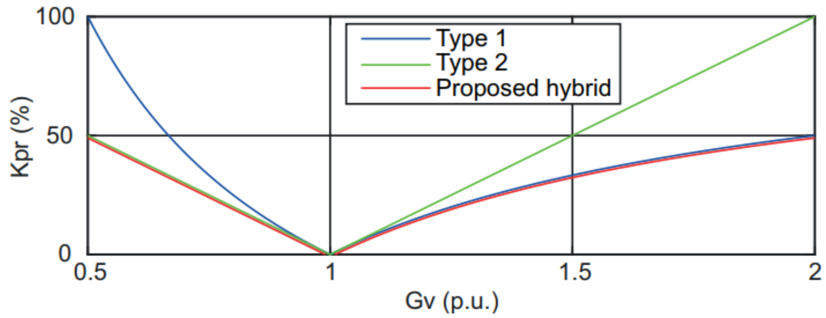
TAL TECH

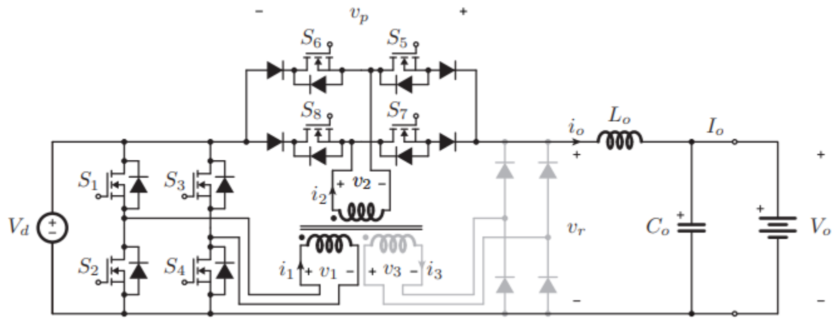
N. G. F. dos Santos, J. R. R. Zientarski, and M. L. S. Martins, “A ZCS/ZVS DC–DC partial power converter with reconfigurable H-bridge and variable turns ratio for an integrated on-board charger,” ***IEEE Trans. Power Electron.***, vol. 39, no. 10, pp. 13916–13933, Oct. 2024.

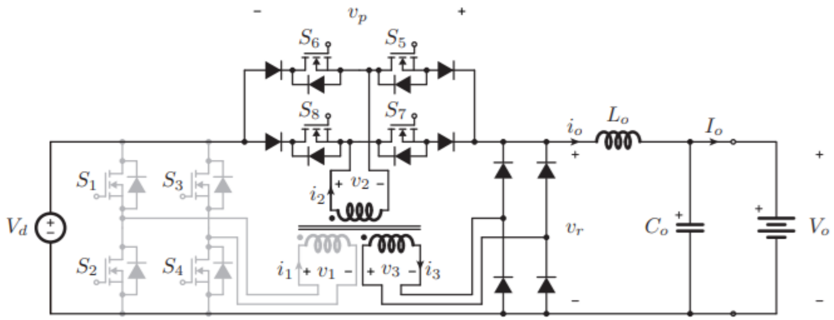
RECONFIGURABLE S-PPCs (FAST CHARGING)

- **Advanced Topologies** for PPCs:
  - <u>Reconfigurable</u> PPCs: The S-PPC can be reconfigured as **Type I** <u>or</u> **Type II**.





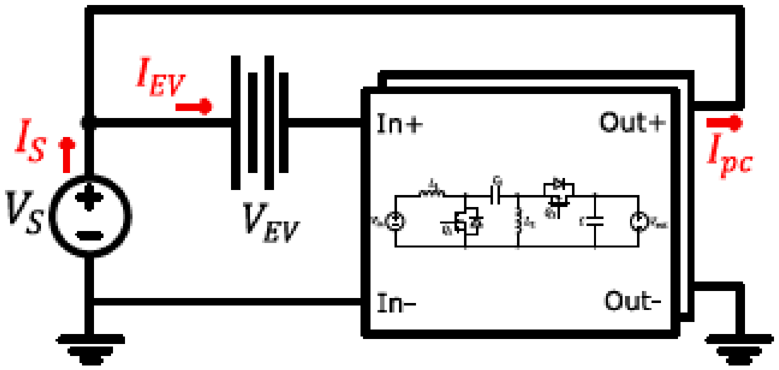




S. Rivera, F. Flores-Bahamonde, H. Renaudineau, T. Dragicevic, and S. Kouro, “A buck-boost series partial power converter using a three-port structure for electric vehicle charging stations,” in *Proc. 2021 IEEE 12th Energy Convers. Congr. Expo. – Asia (ECCE-Asia)*, Singapore, 2021.

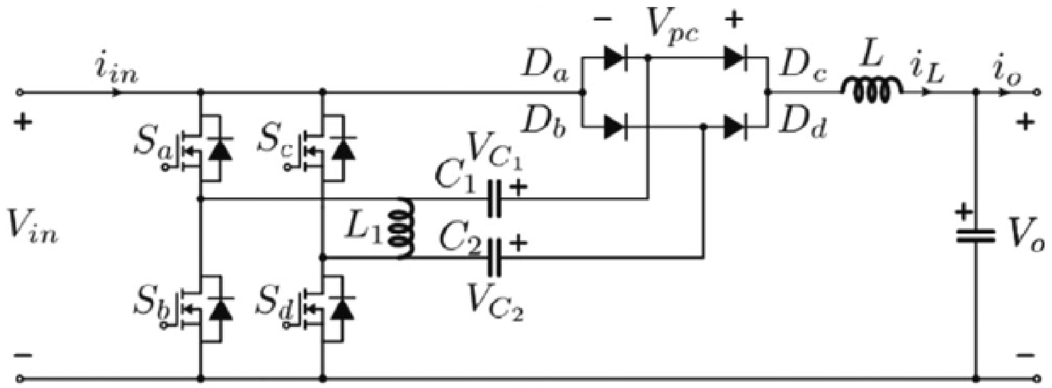
TRANSFORMERLESS S-PPCs (FAST CHARGING)

- **Advanced Topologies** for PPCs:
  - <u>Transformerless</u> PPCs: The idea is to avoid transformers due to their **losses**, **size**, **cost**, **slow response**, and **EMI issues**.



SIPO S-PPC:

Non-isolated DC–DC converter with a non-grounded battery pack **[1]**.



PISO S-PPC:

Capacitively isolated DC–DC converter with a grounded battery pack **[2]**.

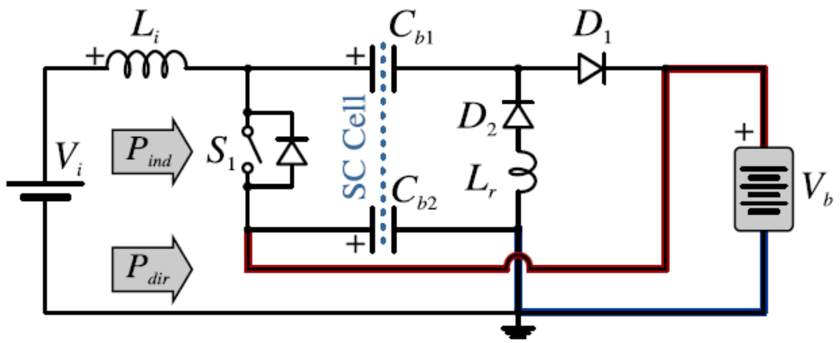
[1] J. Anzola, I. Aizpuru, and A. Arruti, "Non-isolated partial power converter for electric vehicle fast charging stations," in *Proc. 2020 IEEE 11th Int. Symp. Power Electron. Distrib. Gener. Syst. (PEDG)*, Dubrovnik, Croatia, 2020.

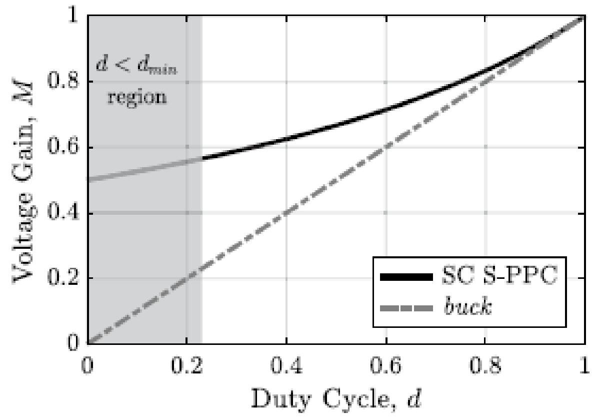
[2] D. Pesantez, H. Renaudineau, S. Rivera, A. Peralta, A. M. Alcaide, and S. Kouro, "Transformerless partial power converter topology for electric vehicle fast charge," *IET Power Electron.*, vol. 17, pp. 970–982, 2024.

TRANSFORMERLESS S-PPCs (OBC)

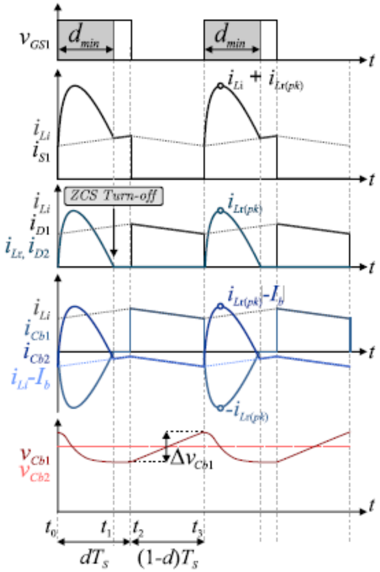
International Conference on DC Microgrids

- **Advanced Topologies** for PPCs:
  - Transformerless PPCs
    - ✓ Switched-capacitor (capacitive isolation)
    - ✓ **Single-Switch** step-down **SIPO S-PPC**
    - ✓ Only **three** operating stages
    - ✓ PWM strategy (fixed-frequency)
    - ✓ Nearly full-range ZCS-off for D_2
    - × Unidirectional
    - × *LC* resonance stage
    - × **NO** turns ratio to minimize *N*





$$T_r = 2\pi\sqrt{L_r C_{eq}}, \quad d_{min} = T_r/(2T_S)$$



TAL TECH

N. G. F. dos Santos, A. Toebe, P. H. B. Löbler, L. Schuch, M. L. d. S. Martins, and C. Rech, “A high-efficient single-switch switched-capacitor partial power converter for on-board chargers,” ***IEEE Trans. Power Electron.***, vol. 39, no. 11, pp. 15269–15280, Nov. 2024.

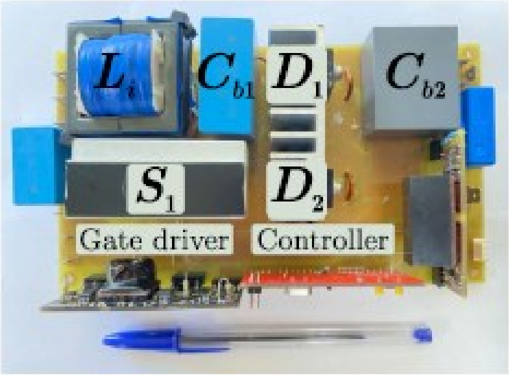
TRANSFORMERLESS S-PPCs

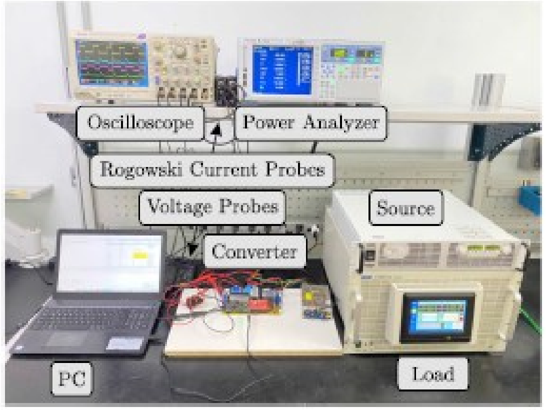
- **Advanced Topologies** for PPCs:
  - Transformerless PPCs
    - Low **complexity**, **losses**, **volume**, and **cost**.

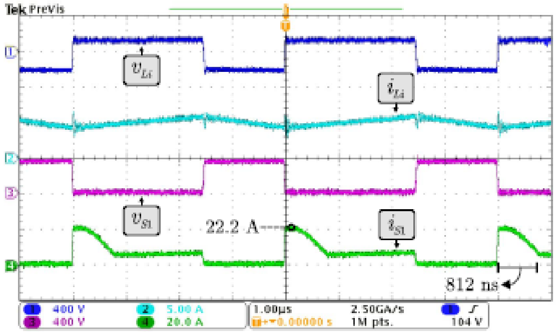
$$P_{ind} = \text{PPF} \times V_b \times I_b = 0.44 \times 250 \times 7.5 = 825\ \text{W},$$

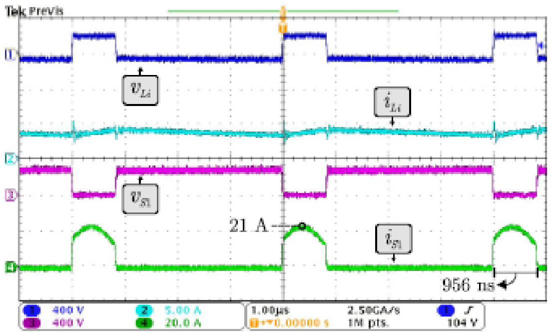
Parameter	Part	Parameter	Part
Controller	TMS320F280037	P_b	up to 3 kW
V_i	450 V	V_b	250–400 V
f_S	250 kHz	L_i	220 μH
L_i turns	27 (250×37 AWG)	L_i core	NEE-42/21/20
C_{b1}	1 μF (1000 V) B32656A0105	C_{b2}	36 μF (500 V) C4AQLLW5360A36K
S_1	UJ4C075023K4S 23 mΩ (750 V)	Diodes	FFSH2065A 1.5 V (650 V)
C_{eq}	973 nF	L_r *	95 nH◇
d_{min}	≈ 0.23◇	d	0.2–0.875

* Comprises the inductance of both the printed circuit board (PCB) tracks and the circuit devices terminals in the loop.
◇ Measured at 0% SoC, for $V_b = 250$ V and $I_b = 7.5$ A.









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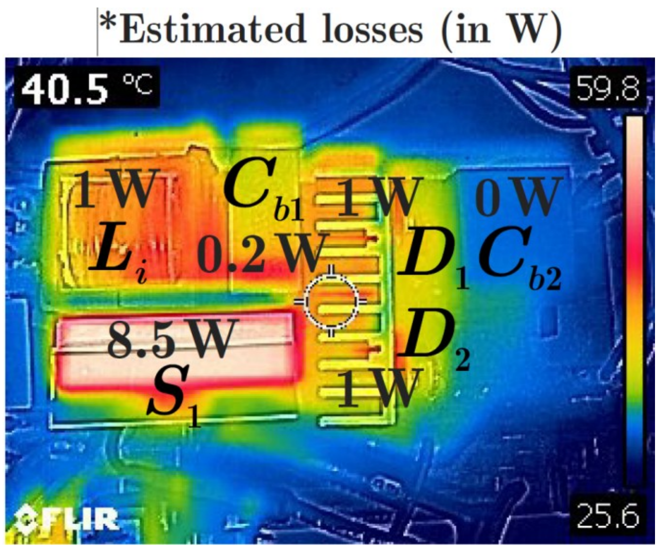
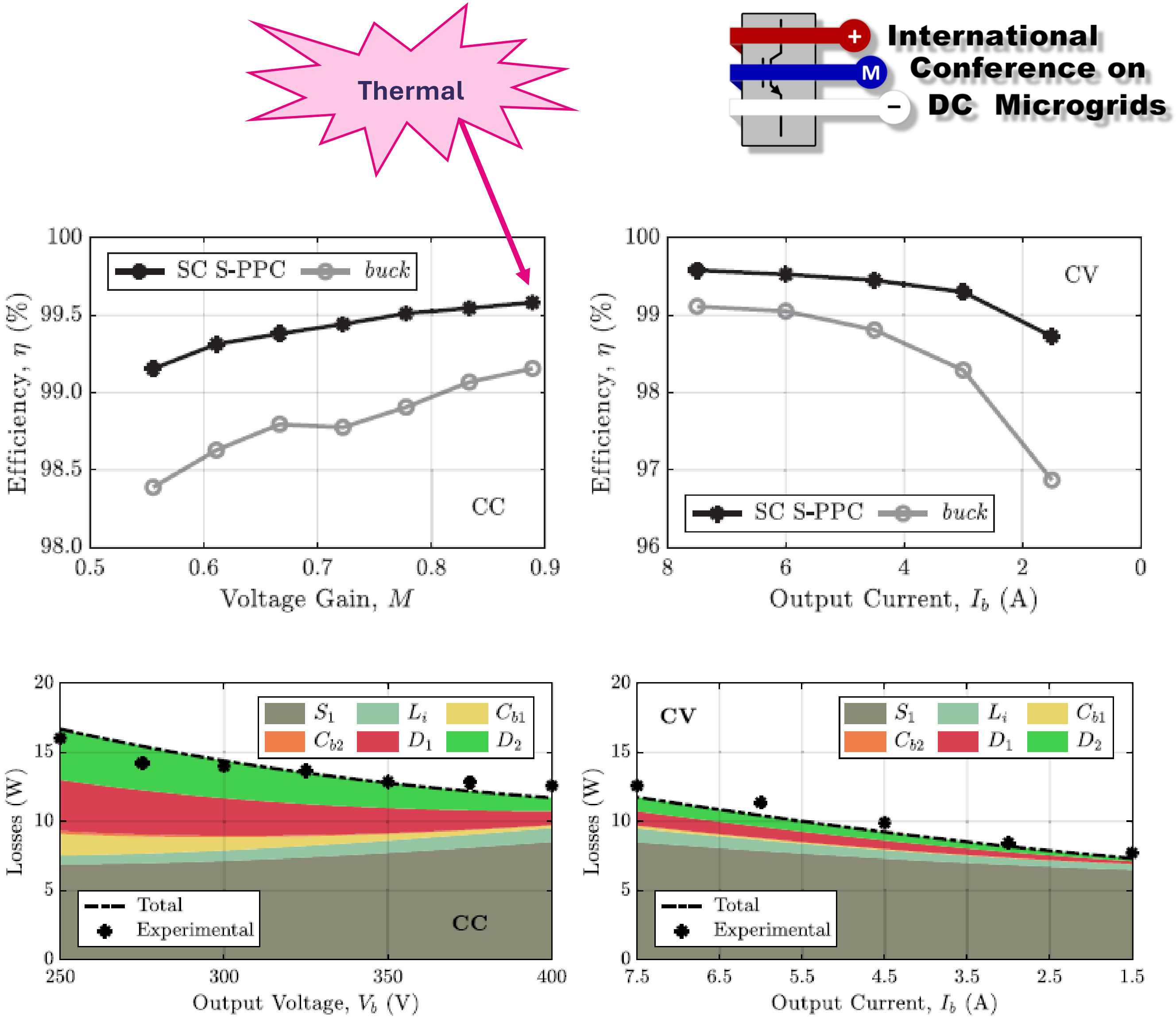
TRANSFORMERLESS S-PPCs

- **Advanced Topologies** for PPCs:
  - Transformerless PPCs
    - Minimum and maximum **efficiencies** around **98.7%** and **99.6%**.

3 kW

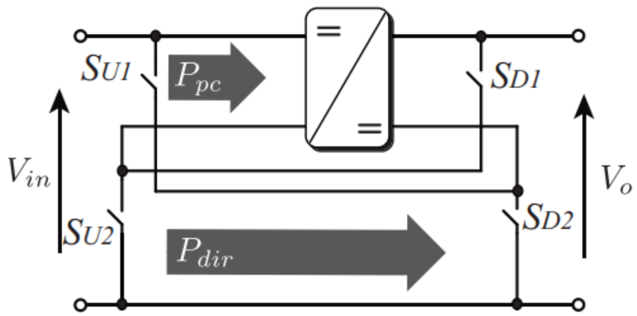


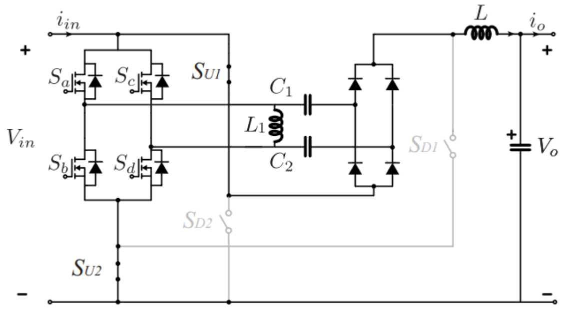


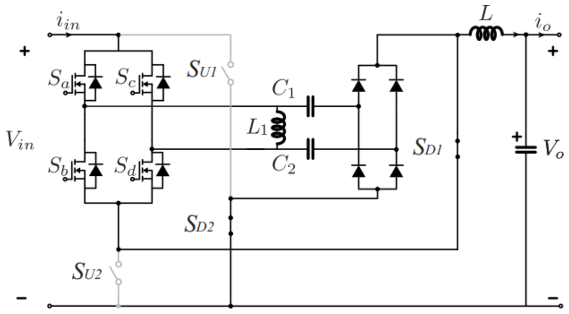
N. G. F. dos Santos, A. Toebe, P. H. B. Löbler, L. Schuch, M. L. d. S. Martins, and C. Rech, "A high-efficient single-switch switched-capacitor partial power converter for on-board chargers," ***IEEE Trans. Power Electron.***, vol. 39, no. 11, pp. 15269–15280, Nov. 2024.

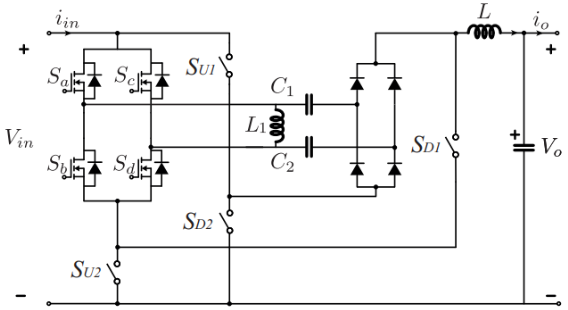
TRANSFORMERLESS S-PPCs (FAST CHARGING)

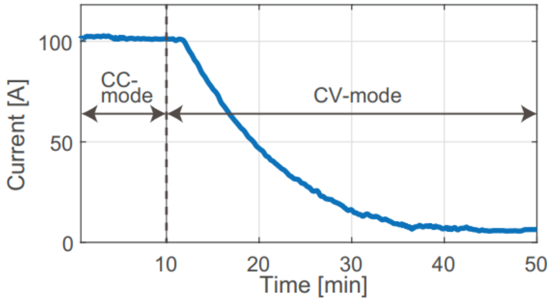
- **Advanced Topologies** for PPCs:
  - The **transformerless** S-PPC can be **reconfigured** as **Type I** or **Type II**.

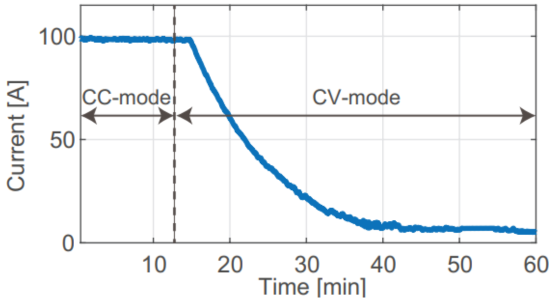








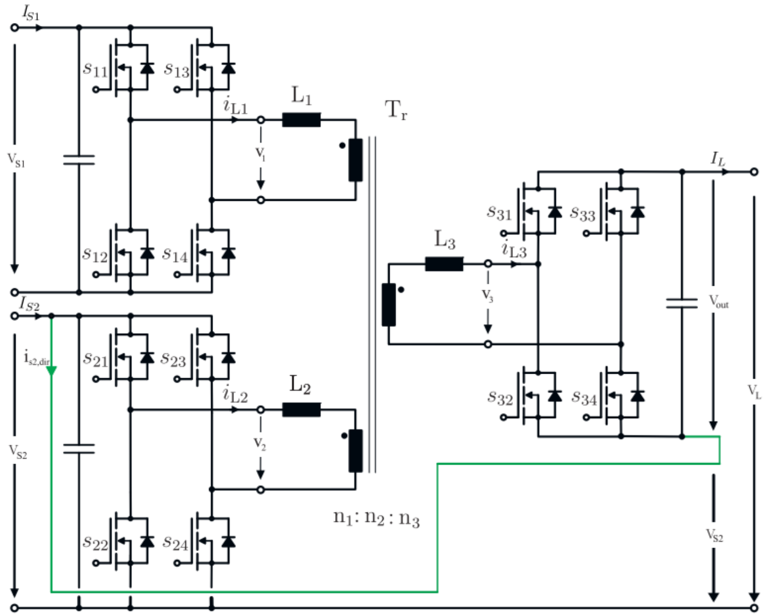


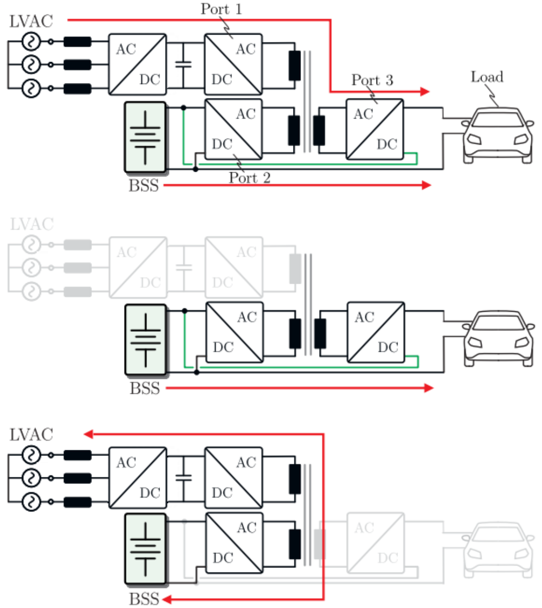


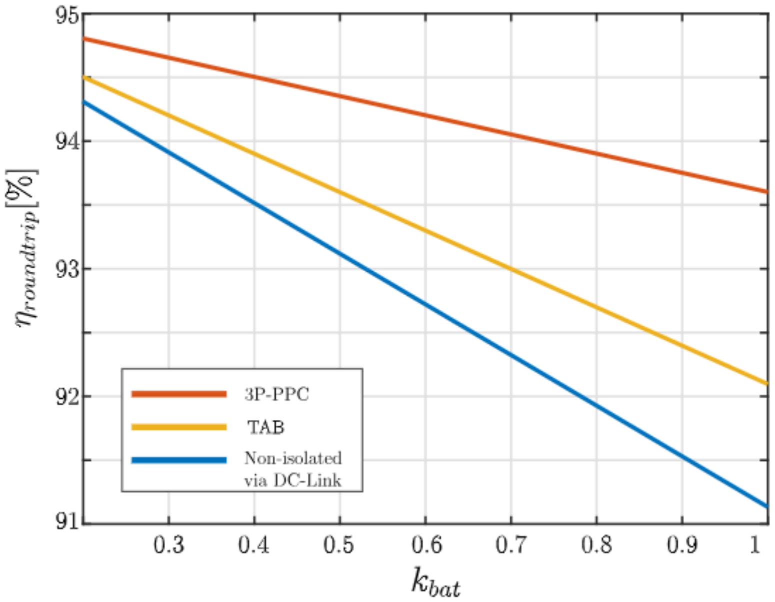
D. Pesantez, H. Renaudineau, S. Kouro, S. Rivera, and J. Rodriguez, "Reconfigurable Type I and Type II buck-boost partial power converter for EV fast chargers," in *Proc. 2024 IEEE Int. Conf. Power Electron., Drives Energy Syst. (PEDES)*, Mangalore, India, 2024, pp. 1–6.

ADVANCED TOPOLOGIES FOR FAST CHARGING

- **Advanced Topologies** for PPCs:
  - Multi-Port PPCs: The architecture allows the **integration** of a battery storage system in fast charging stations, which can also be used for **DC buildings**.





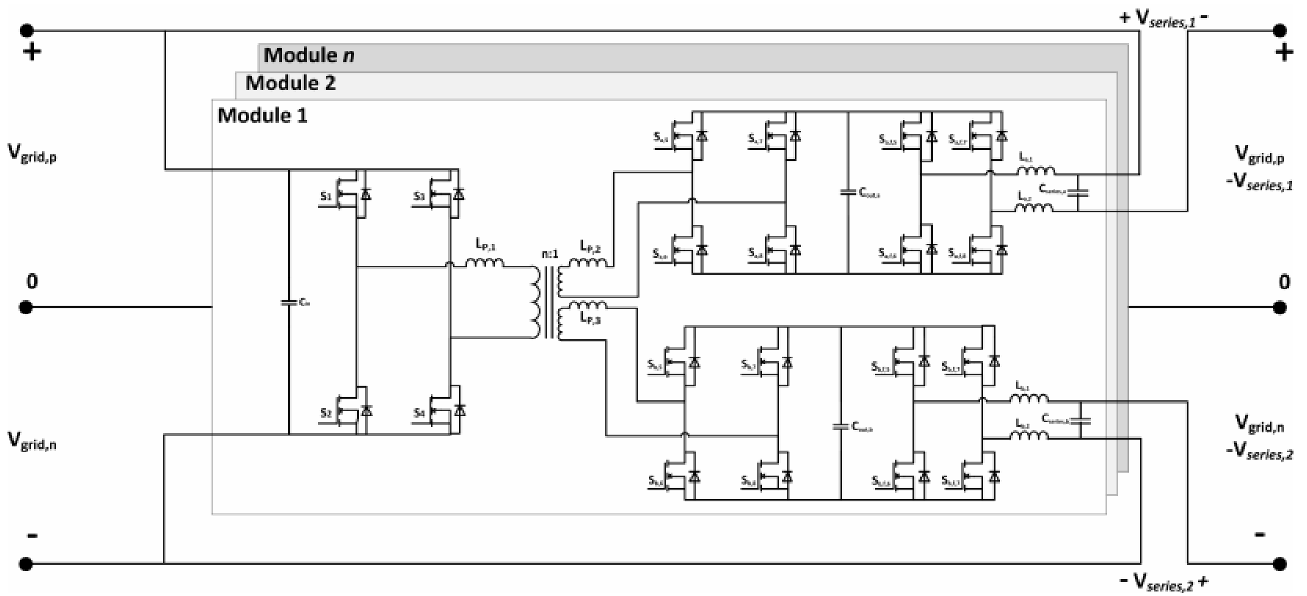


F. Hoffmann, J. Person, M. Andresen, M. Liserre, F. D. Freijedo, and T. Wijekoon, "A multiport partial power processing converter with energy storage integration for EV stationary charging," ***IEEE J. Emerg. Sel. Topics Power Electron.***, vol. 10, no. 6, pp. 7950–7962, Dec. 2022.

ADVANCED TOPOLOGIES

- **Emerging Features** in PPCs: *Moving forward with technology*

1. **Bipolar DC distribution grid (concept)**
   - This concept can be used to implement a bipolar DC distribution grid using S-PPCs, enabling the **charging of either 400 V or 800 V EVs**.



P. Purgat *et al.*, "Design of a power flow control converter for bipolar meshed LVDC distribution grids," in *Proc. 2018 IEEE 18th Int. Power Electron. Motion Control Conf. (PEMC)*, Budapest, Hungary, 2018, pp. 1073–1078.

GENERAL REMARKS

- **AC-grid integration**
  - AC grid integration is still needed
  - AC-DC converter should provide services for both, AC and DC grids
  - Standartization is a challenge
- **Wide voltage range power converters**
  - Topoly morphing control (TMC) based
  - Semless integration with ELVDC applications
  - Full compatible with different types of DC grids (350/700 Vdc)
- **Breaking Limits with Partial Power Processing**
  - Higher efficiency for non-isolated applications (99.5%)
  - Aplied for 2nd life battery
  - SC/OC Protection
- **Partial Power Processing for EVs Integration**
  - Emerging application for V2B
  - Easily integrated with DC buildings
  - Advanced topologies can cover a wide range of application

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Accelerates Energy Transition

EMERGING POWER CONVERTERS TOPOLOGIES
FOR DC BUILDINGS APPLICATION

Tutorial 3

International Conference on DC Microgrids