Centre of Excellence in Energy Efficiency

TALTECH

PARTIAL POWER ENERGY PROCESSING

A NEW TOOLBOX FOR EFFICIENT DC MICROGRIDS

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Credits

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Jose Cobos, UPM, Spain
Samir Kouro, UTFSM, Chile

ESTONIA

- *Area 45,227 km2*
- *Population about 1.3 million*
- *Capital - Tallinn*
- *Currency: Euro*
- *Estonia has over 1500 islands and 1000 lakes*
- *Over 52% of Estonia is covered with forest*
- *In TOP10 of countries with the cleanest air*
- *The highest point (Suur Munamägi) is 318 m over the sea level*
- *Estonia has most startups per capita in Europe*
  - 1300 startups (100 per capita)
  - 10 unicorns (7.7 per million capita - *Skype, Playtech, Wise, Bolt, Pipedrive, Zego, ID.me, Gelato, Veriff, Glia*)
- *Estonia is a digital society (e-Estonia)*
  - The only country in the world to offer e-residency
  - The first country to adopt online voting
  - E-society: e-tax declaration, e-parking, e-school, etc.

More information: www.visitestonia.com

TALLINN

- *Was founded in 1248*
- *Population about 430 000*
- *Tallinn's old town is a UNESCO World Heritage site*
- *European Capital of Culture 2011 and European Green Capital 2023*
- *Easy connections to everywhere (modern airport, harbour, railway and bus stations)*
- *Since 2013 Tallinn is the first capital in the EU to provide free public transport to its citizens*
- *One of the best public Wi-Fi services in the World*
- Lots of museums, must-see attractions and gourmet restaurants
- *High quality of education and research with 4 public universities, 3 universities of applied sciences and 7 private colleges and universities*
- *More information: https://www.visittallinn.ee/eng*

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POWER ELECTRONICS GROUP OF TALTECH

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ICDCM 2025 IN TALLINN

THE 7TH IEEE INTERNATIONAL CONFERENCE ON DC MICROGRIDS (ICDCM 2025)

You can expect:

- *Highly relevant program on DC microgrids and applications*
- *Over 100 papers to be presented*
- *7 tutorials from world-renown experts*
- *Conference venue next to the Tallinn's Old Town – a UNESCO World Heritage Site*
- *Entertaining social events for attendees, special events for PELS student and WiE members*
- *Lunches and coffee breaks*
- *White nights and mild summer weather*

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ICDCM 2025
The 7th IEEE International Conference on DC Microgrids
June 4 - 6, 2025 – Tallinn, Estonia

International Conference on DC Microgrids

TALLINN
UNESCO WORLD HERITAGE SITE

CALL FOR PAPERS

pels IEEE POWER ELECTRONICS SOCIETY
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IEEE ESTONIA SECTION

ICDCM is a flagship conference of the **IEEE Power Electronics Society (PELS)** devoted to the dissemination of new ideas, research, and work in progress within the rapidly growing fields of **DC microgrids**. It will bring together researchers, engineers, and students from academia, government, and industry to have an interactive discussion on the latest advances in DC Grid Technologies and Applications. This conference is organized by **PELS TC1**: Control and Modeling of Power Electronics. The objectives of the conference are to provide high-quality research and professional interactions between industry and academia for the advancement of science, technology, and fellowship. The **main features** of the conference include Keynote Speeches, Tutorials, Regular and Special Sessions.

TOPICS (include but not limited to)

DC Grid Core Technologies
- Medium voltage power distribution
- Circuit breakers and protection
- Power converters
- Modeling
- Control and stability
- Reliability
- Safety
- Medium voltage engineering

DC Grid Core Applications
- Transportation electrification
- Renewable energy systems
- Energy storage and integration
- Micro-grids and nano-grids
- Telecommunication and data center
- Smart homes and buildings
- Other industrial applications

SPECIAL SESSIONS
The conference will include special sessions on **topics of focused interest** in particular areas, reporting technical trends and breakthroughs within the conference scope. They are organized at the initiative of 1-4 individuals, who must adhere to the procedure published on the conference website.

PAPER SUBMISSION
Prospective authors are invited to submit **2-page digests** in English, following instructions on the website. The conference proceedings will be submitted to IEEE Xplore Digital Library®. **Special Compendium** of the Open Journal of Power Electronics (OJPEL) will be open for full journal articles based on selected contributions accepted at the ICDCM 2025.

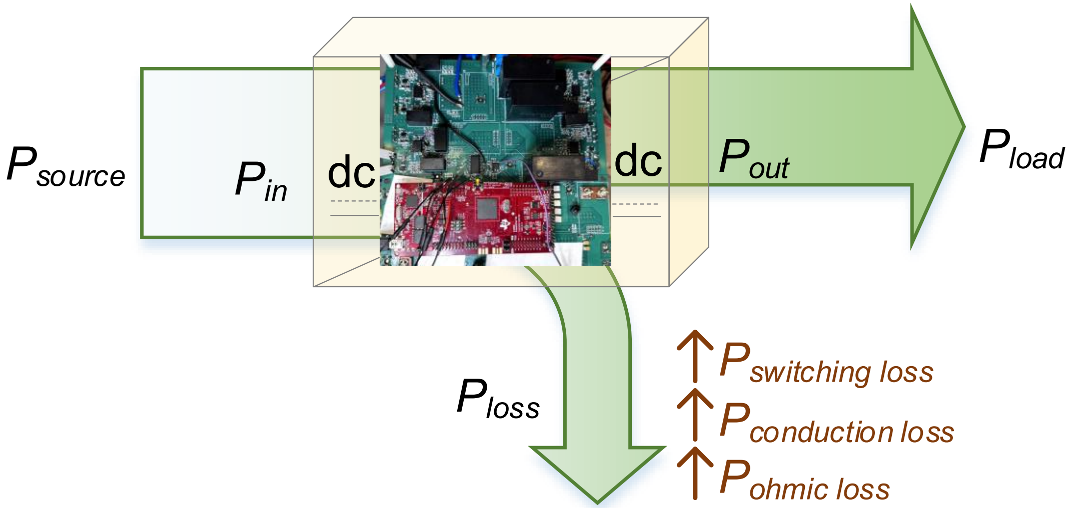
VENUE
The conference will be held at the Original Sokos Hotel Viru.

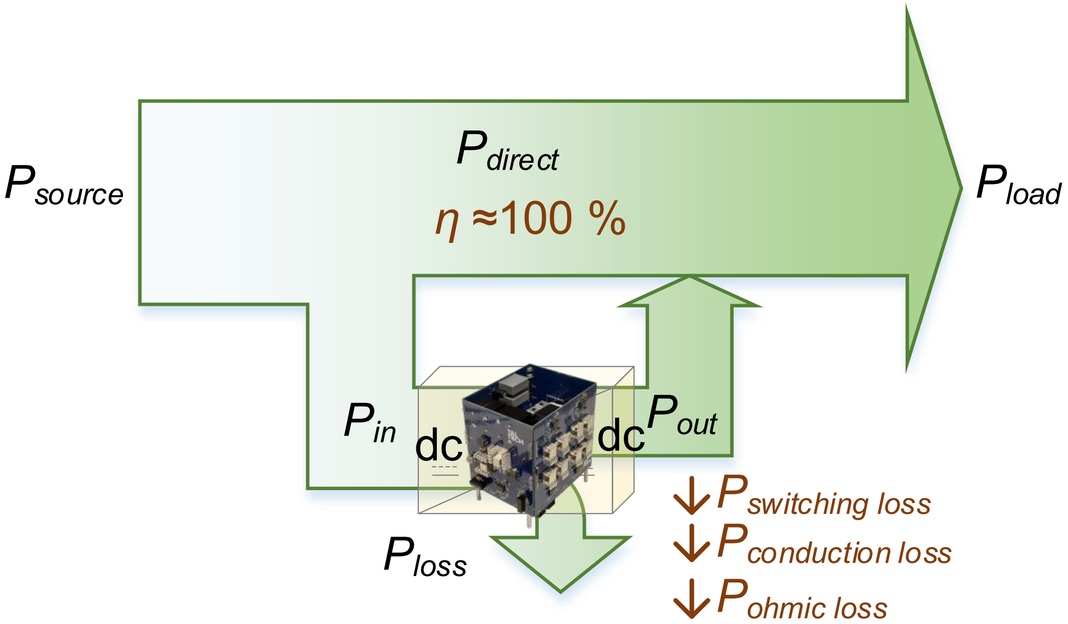
IMPORTANT DATES
Special session proposal deadline 15 Nov. 2024
Tutorial proposal submission deadline 15 Nov. 2024
Digest submission deadline 1 Dec. 2024
Notification of digest/tutorial acceptance 15 Feb. 2025
Final paper/tutorial materials submission 15 Apr. 2025
Early bird fee deadline 20 Apr. 2025

http://icdcm2025.com/ – icdcm2025@taltech.ee

WHAT IS THIS ABOUT?

MAIN CONCEPT





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

- ***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.**

NEW TECHNOLOGY – OLD CONCEPTS

FIRST MENTIONED IN 1966

a) If the output voltage of the network is V_o and the network provides an output current I_o that is greater than the input current I_i, the minimum ac power $P_{ac(min)}$ which must be generated as an intermediate step is

$$P_{ac(min)} = V_o(I_o - I_i). \quad (2)$$

b) If the output current of the network is I_o and the network provides an output voltage V_o that is greater than the input voltage V_i, the minimum amount of ac power that must be generated is

$$P_{ac(min)} = I_o(V_o - V_i). \quad (3)$$

EEE TRANSACTIONS ON MAGNETICS SEPTEMBER, 1966

Basic Considerations for DC to DC Conversion Networks

E. T. MOORE AND T. G. WILSON

Equations (2) and (3) of statement 4 define the minimum amount of ac power that must be generated as an intermediate step by a dc to dc converter network in terms of the direct currents and voltages at its input and output terminals. Accomplishing the desired dc to dc conversion with the minimum amount of intermediate ac power requires the use of a "buck" or "boost" network configuration, i.e., a network in which a portion of the power supplied to the load is supplied by the source directly without being "processed" by the dc to dc conversion network. Given a dc to dc conversion requirement defined in terms of dc input and output voltages and cur-

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E. Moore and T. Wilson, "Basic considerations for DC to DC conversion networks," in IEEE Transactions on Magnetics, vol. 2, no. 3, pp. 620-624, September 1966, doi: 10.1109/TMAG.1966.1065901.

CONFIRMED USING GRAPH THEORY IN 1973

IEEE TRANSACTIONS ON CIRCUIT THEORY, VOL. CT-19, NO. 6, NOVEMBER 1972

Basic Constraints from Graph Theory for DC-to-DC Conversion Networks

DAN H. WOLAVER

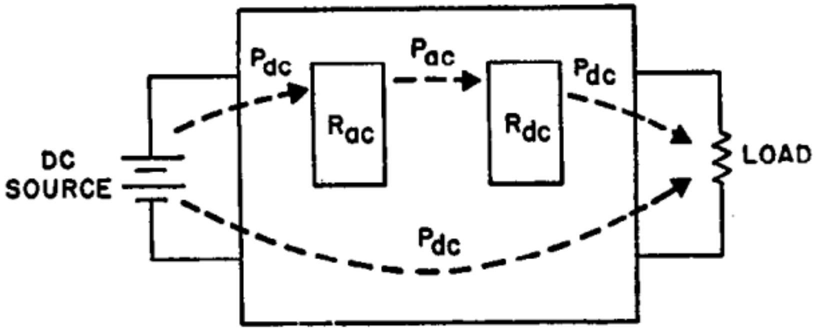

Fig. 2. Model of dc-to-dc conversion process. The sets R_{ac} and R_{dc} are usually switches. A lower bound on the ac power and dc power in the upper path is given by $P_0(G-1)/G$, where P_0 is the output dc power and G is the dc voltage or current gain.

DC power from the dc source at the input of a dc-to-dc conversion network may be transferred to the load at the output through two "paths," as illustrated in Fig. 2. Part may be transferred directly to the load.[5] However, a certain portion of the dc power (given by Theorems 7 and 8) must be converted to ac power by resistors in the ac-active set (Theorem 5). This ac power is converted by resistors in the dc-active set to dc power which is transferred to the load (Theorem 6).

D. Wolaver, "Basic constraints from graph theory for dc-to-dc conversion networks," in IEEE Transactions on Circuit Theory, vol. 19, no. 6, pp. 640-648, November 1972, doi: 10.1109/TCT.1972.1083558.

EARLY EXAMPLES – 1989/1991 – PV APPLICATIONS

IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 6, NO. 1, JANUARY 1991 73

Combined Low-Cost, High-Efficient Inverter, Peak Power Tracker and Regulator for PV Applications

J. H. R. Enslin, *Member, IEEE*, and D. B. Snyman, *Member, IEEE*

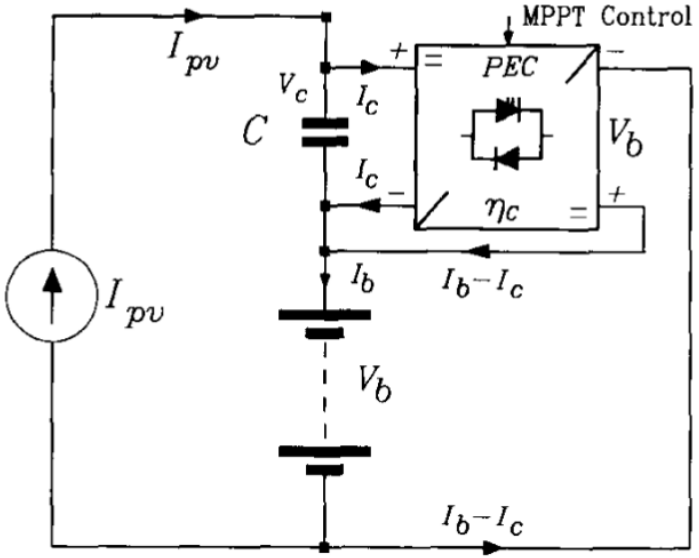

Fig. 2. Novel MPPT, employing capacitor in series with PV array and battery.

The Novel MPPT Topology

A large amount of work has been done on the topic of maximum power point tracking and maximum-power-point-trackers (MPPT's) [1], [5]. A new proposed technique for maximum power point tracking employs a capacitor in series with the PV array and the battery bank. Fig. 2 shows this technique schematically. Most of the time this capacitor C, is the decoupling capacitor at the input of the converter and no extra capacitor is needed. Maximum power point tracking is performed by controlling the converter output voltage to load the PV array in such a manner as to keep the PV output voltage constant [5]. When the capacitor voltge is kept for instance equal to the battery voltage, the power delivered to the battery equals the power delivered to the capacitor. Under this condition, half of the PV power is supplied directly to the battery at an efficiency of nearly 100%, if the conduction losses of the cabling is ignored, while the other half is converted to the battery by means of the power converter.

D. B. Snyman and J. H. R. Enslin, "Combined low-cost, high-efficient inverter, peak power tracker and regulator for PV applications," 20th Annual IEEE PESC, Milwaukee, WI, USA, 1989, pp. 67-74 vol.1, doi: 10.1109/PESC.1989.48474.

J. H. R. Enslin and D. B. Snyman, "Combined low-cost, high-efficient inverter, peak power tracker and regulator for PV applications," in IEEE Transactions on Power Electronics, vol. 6, no. 1, pp. 73-82, Jan. 1991, doi: 10.1109/63.65005.

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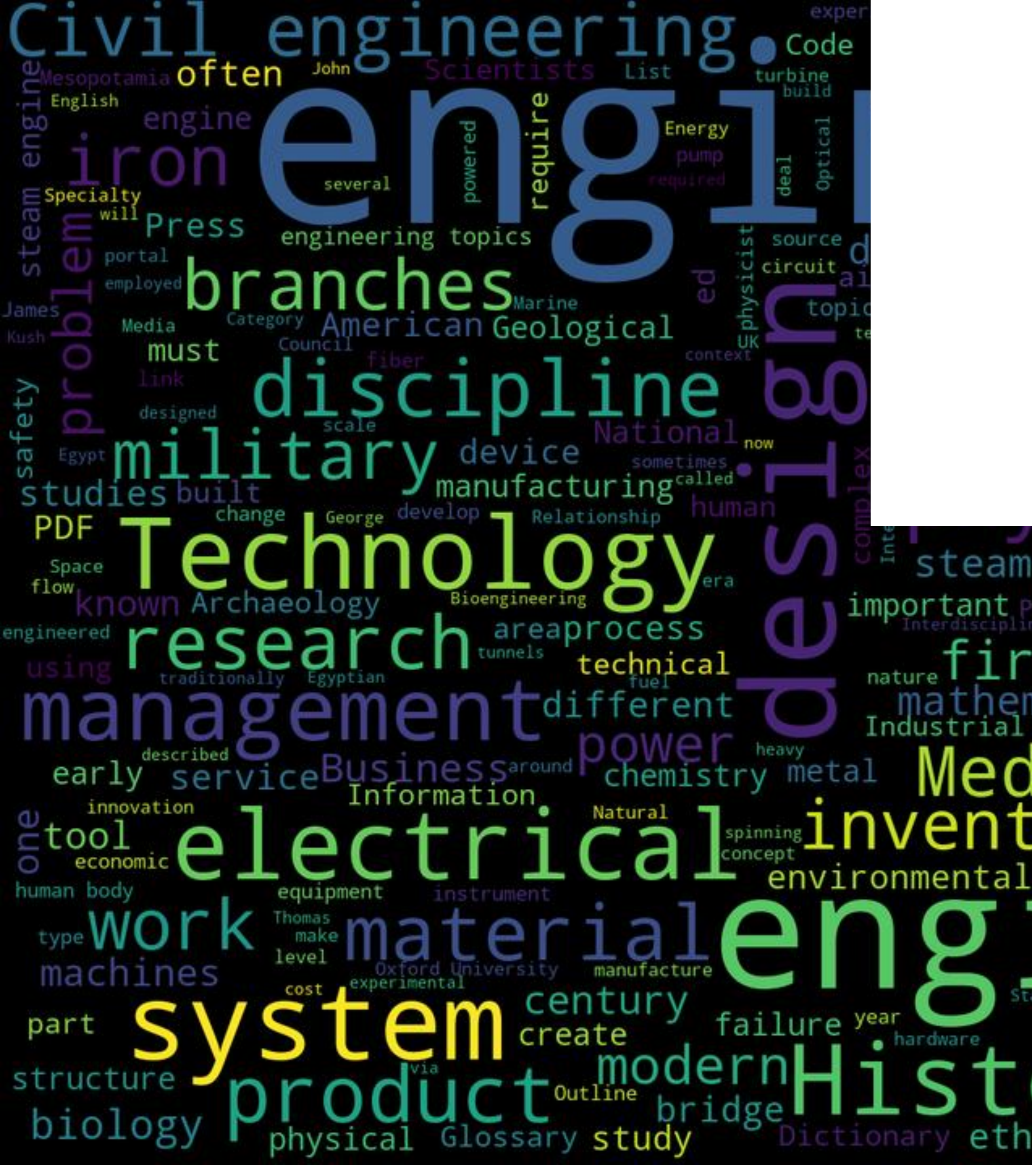
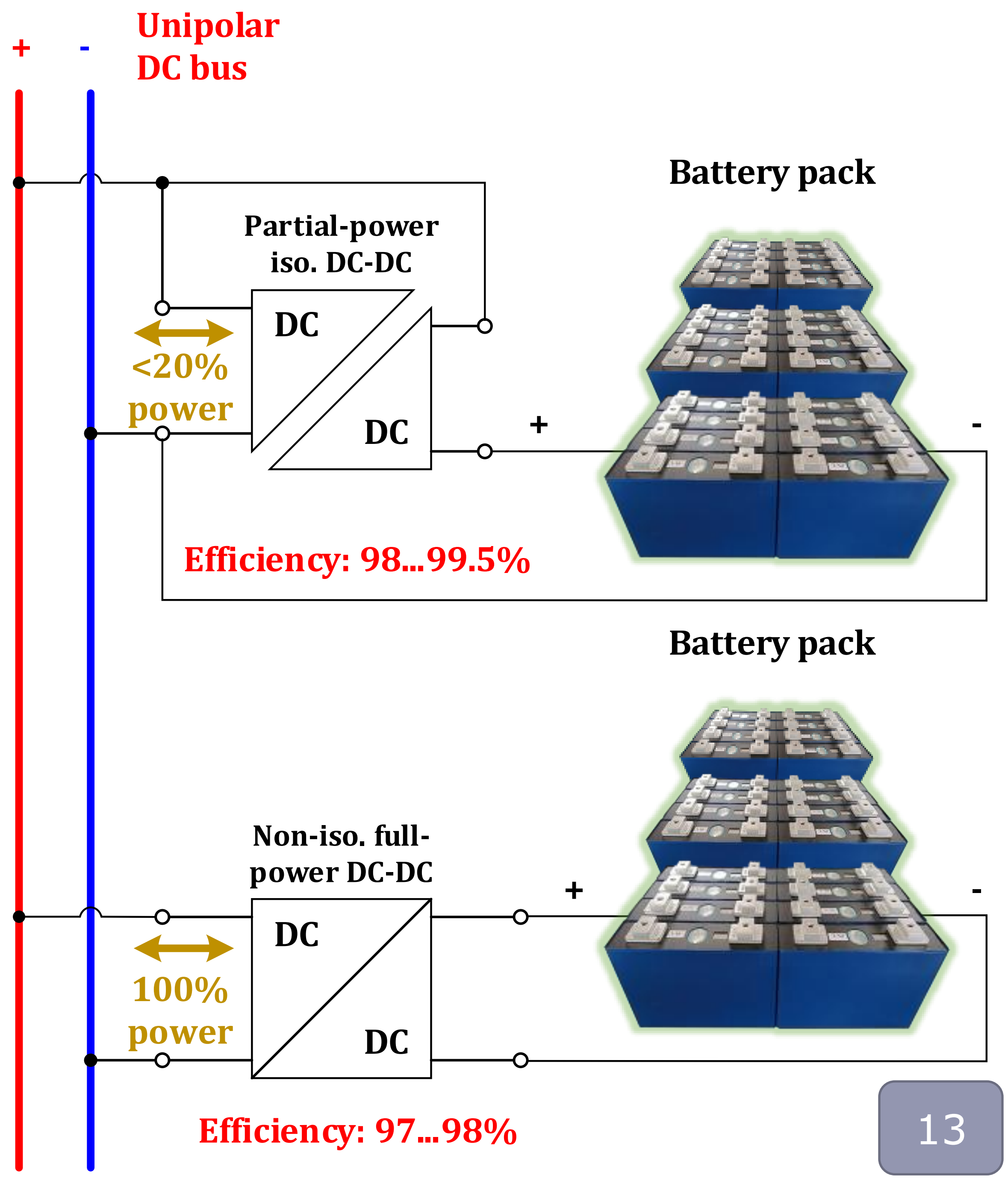


PARTIAL POWER CONVERTERS

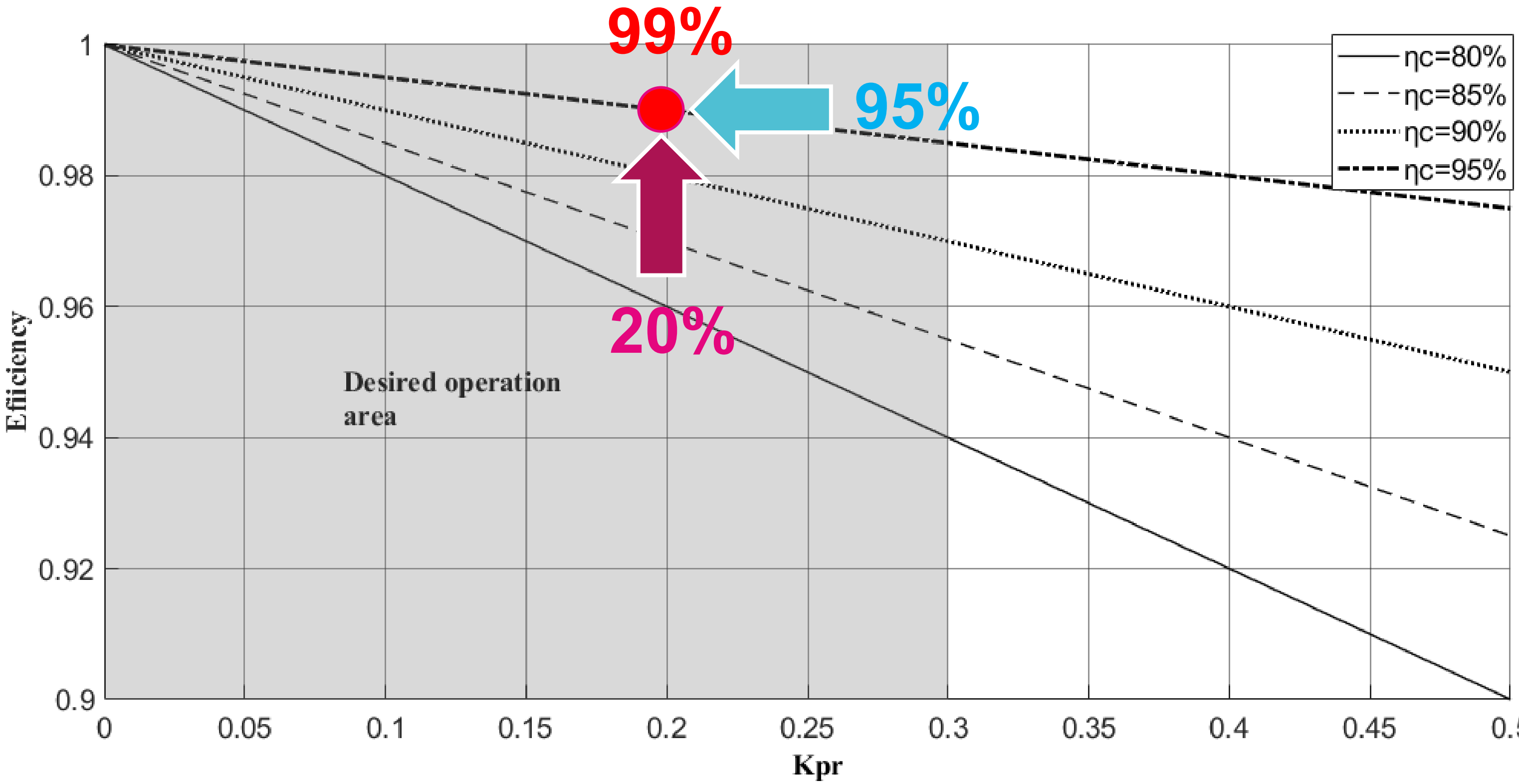
MAIN CONCEPTS AND FEATURES

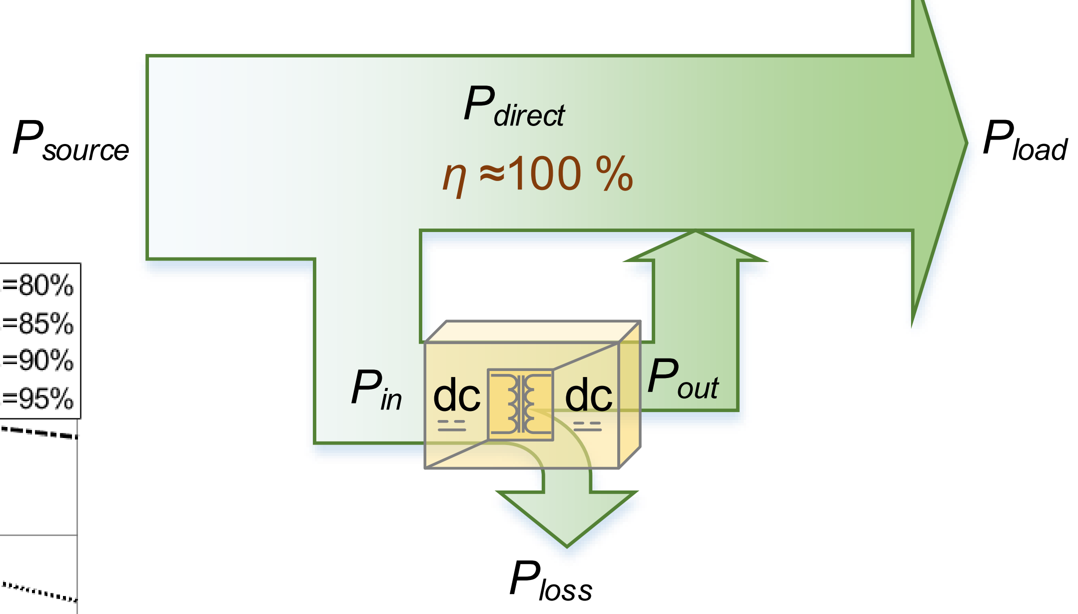
PPC VS. FPC

- ***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 EFFICIENCY

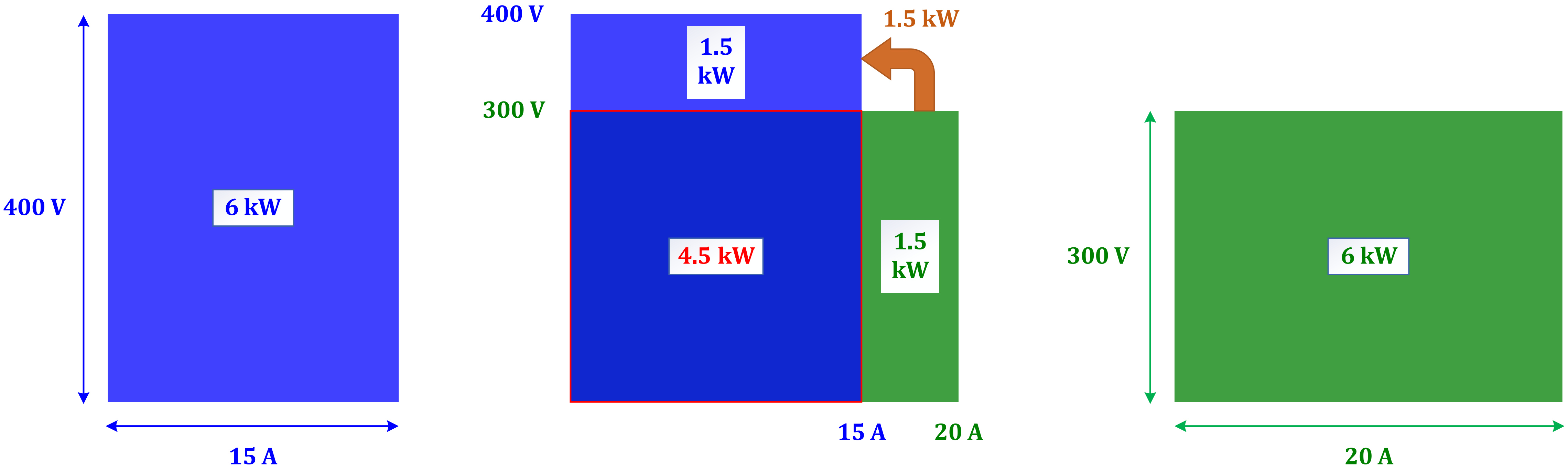




$$\eta_{systemPPC} = \frac{P_{load}}{P_{source}} = 1 - \frac{P_{in}}{P_{source}} \cdot \left(1 - \eta_c\right) = 1 - K_{pr} \cdot \left(1 - \eta_c\right)$$

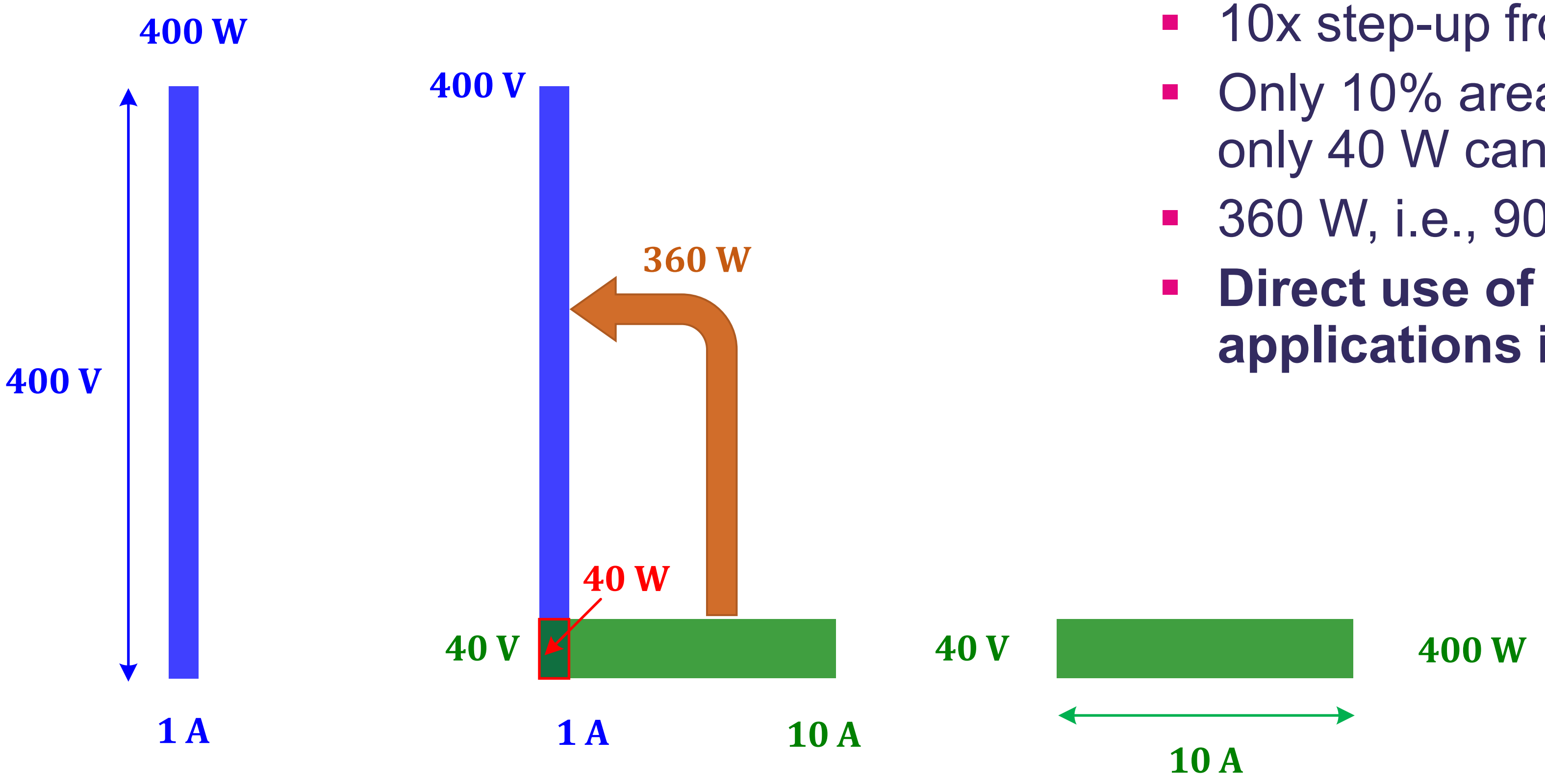
- *The dc-dc converter efficiency (η_C) has less influence on the total efficiency due to the* ***direct power transfer***
- ***Partiality*** *(K_{pr} is a fraction of the processed power) increases this influence*

OVERLAP OF VA AREAS



- Overlapped areas correspond to 4.5 kW of power that can be delivered directly
- The remaining 1.5 kW must be processed by a dc-dc converter, i.e., 25%

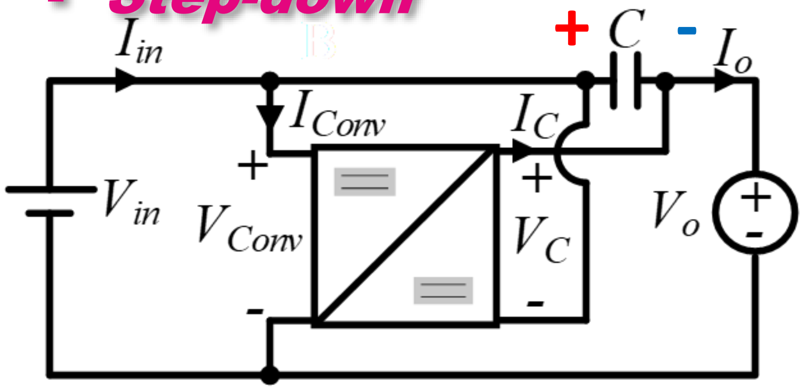
OVERLAP OF VA AREAS – HIGH STEP-UP CASE



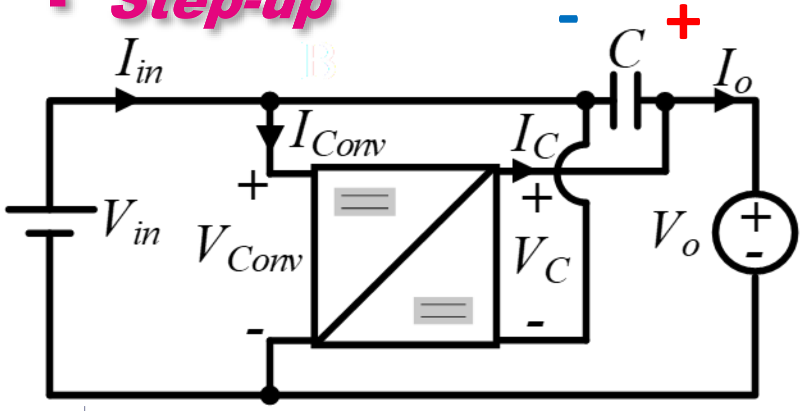
- 10x step-up from 40 V to 400 V
- Only 10% area is overlapped, meaning that only 40 W can be delivered directly
- 360 W, i.e., 90% of power must be processed
- **Direct use of PPCs in high step-up/down applications is not advised**

PPC TYPES

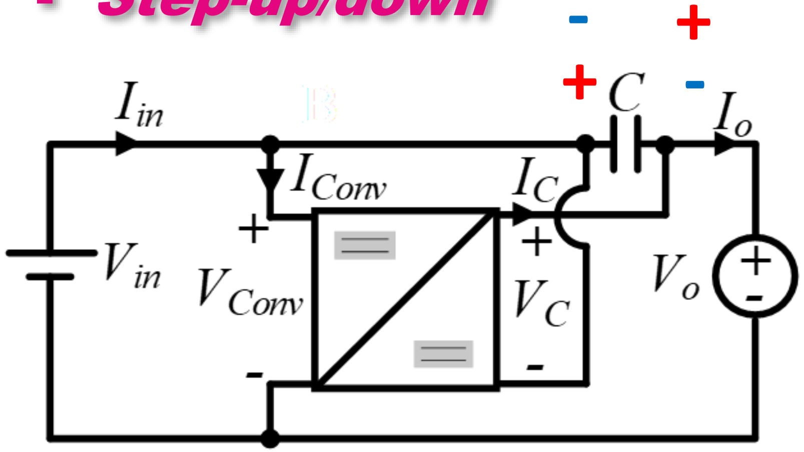
- ***Step-down***



- ***Step-up***



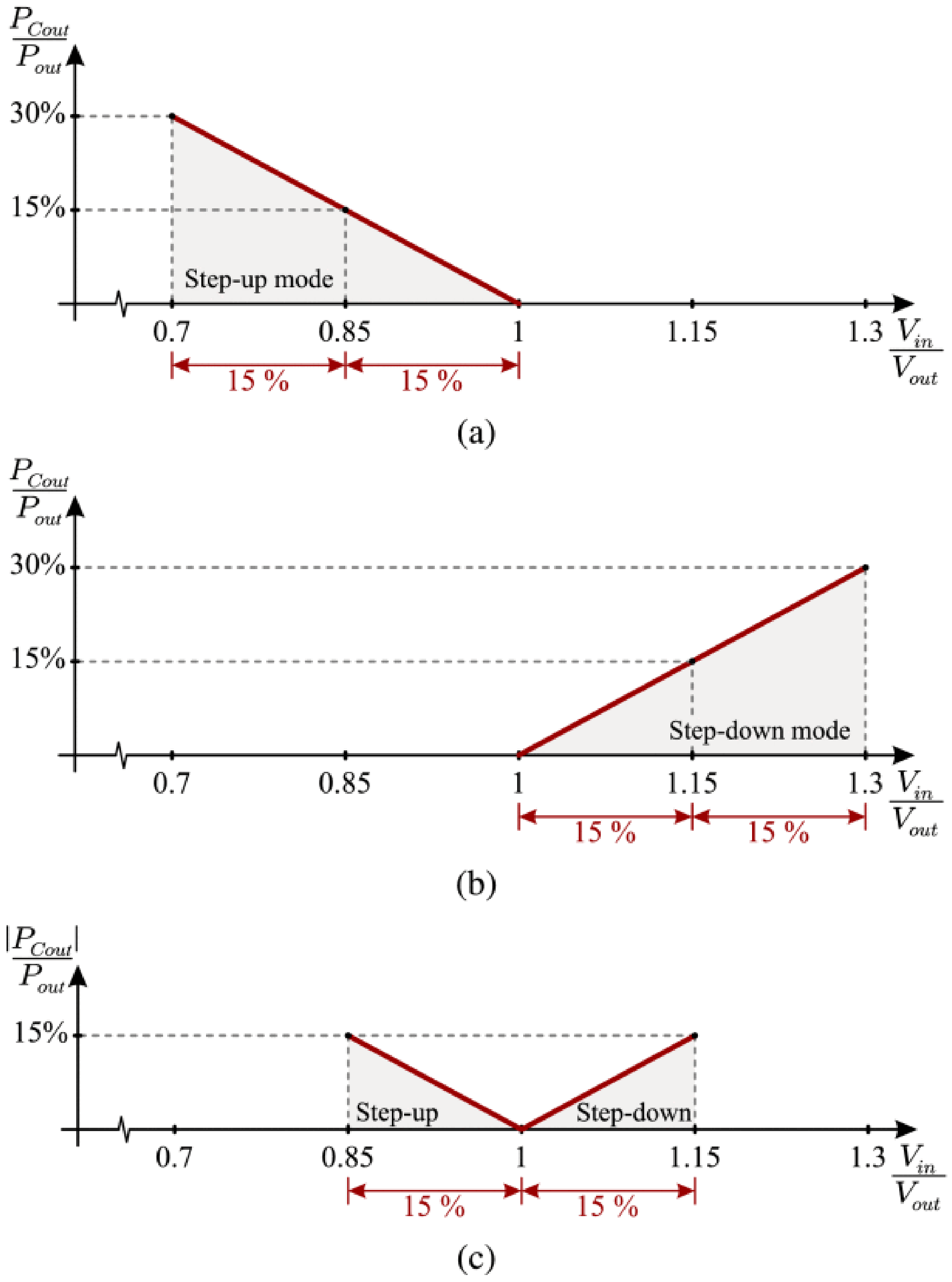
- ***Step-up/down***



COMPARING PPC TYPES

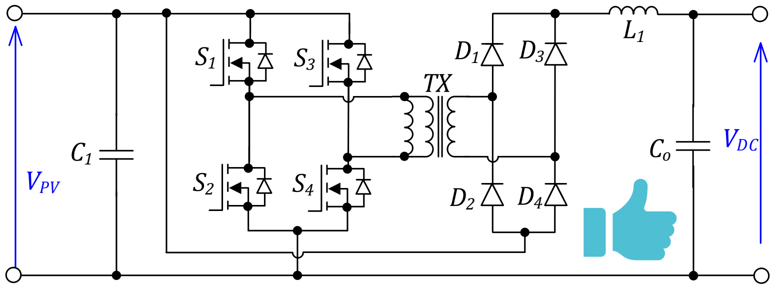
- *Considering the example where Δv=30%, the active power in the PPC is **30%** of P_{out}. This is correct for both step-up and –down PPCs.*
- *Using a step-up/down PPC allows the output voltage of PPC to be reduced by half to maintain the same input voltage range, resulting in a reduction of its active power. It can be seen that the maximum active power is **only 15%** in each operation mode.*
- *Bidirectional step-up/down PPCs require use of **4-quadrant** dc-dc cell*

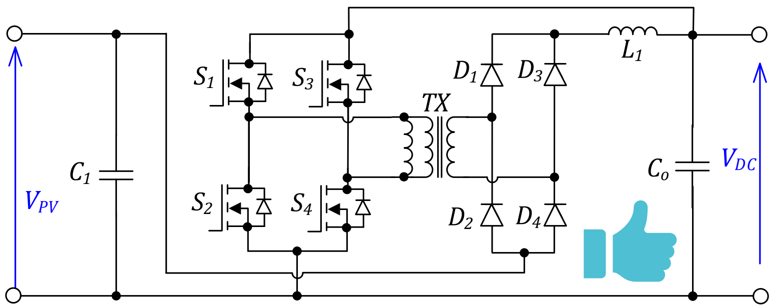
DOI: 10.1109/TPEL.2017.2765928

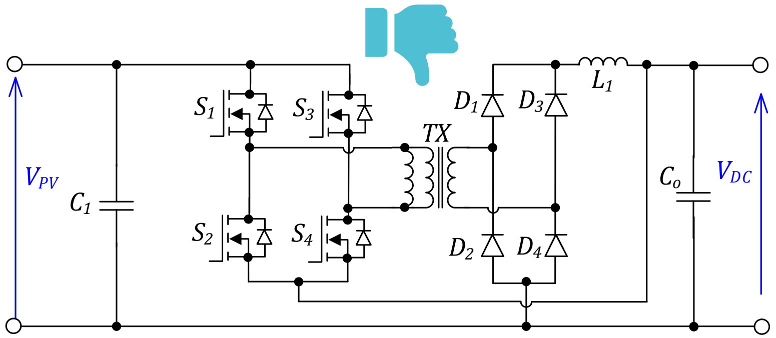


PHOTOVOLTAIC STRING INTEGRATION
TYPICAL APPLICATIONS

EXAMPLES BASED ON PSFB (BUCK) TOPOLOGY





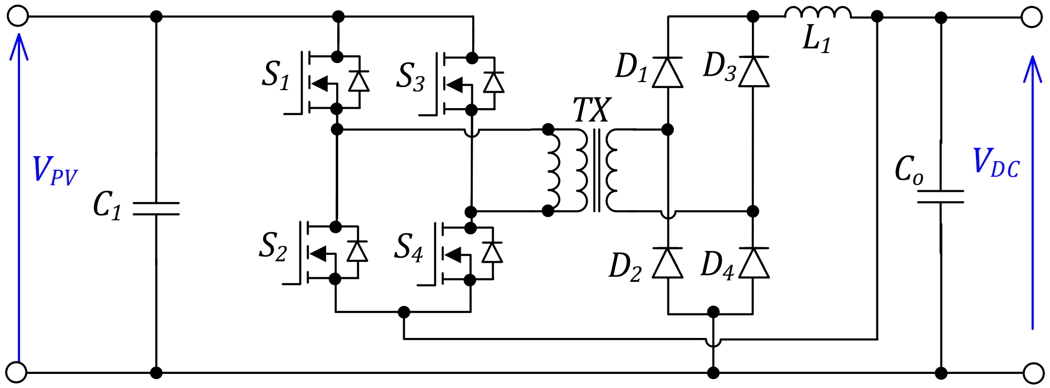


Type	Semic.	V_{PV}	V_{DC}	f_{SW}	P	PPC	η
PISO step-up	Si 300V MOSFETs	450-650 V	650 V	33 kHz	24 kW	78 kW	99.1%
PISO step-up (dc-dc in parallel to output)	MOSFETs*	190.4 V	200 V	75 kHz	821 W	53 W	98.5%
SIPO step-down		182 V	153 V		822 W	110 W	97.5%

O. Abdel-Rahim, A. Chub, D. Vinnikov and A. Blinov, "DC Integration of Residential Photovoltaic Systems: A Survey," in *IEEE Access*, vol. 10, pp. 66974-66991, 2022.

EXAMPLES BASED ON PHASE SHIFTED FULL-BRIDGE

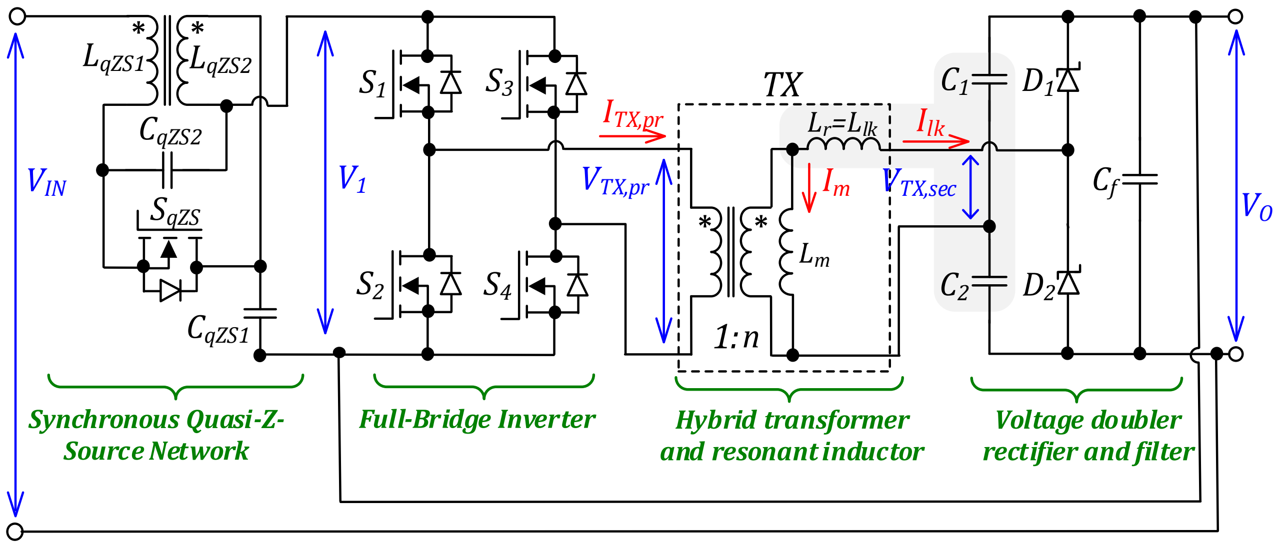
- *Among PPCs based on isolated topologies, PISO topologies show higher performance in PV applications.*
- *The SIPO PPCs are underrepresented in literature. This could be associated with the relatively poor performance of the first demonstrated examples. Poor performance is mainly caused by using voltage-source isolated topologies.*
- *The design of SIPO PPCs becomes unpractical as it requires a very high transformer turns ratio to realize the required regulation range. In addition, it features low efficiency due to the very high voltage step-down requirements when operating at the maximum power, i.e., the maximum series voltage.*



only 97.5%

O. Abdel-Rahim, A. Chub, D. Vinnikov and A. Blinov, "DC Integration of Residential Photovoltaic Systems: A Survey," in *IEEE Access*, vol. 10, pp. 66974-66991, 2022.

BOOST VS. BUCK-BOOST DC-DC IN SIPO PPC

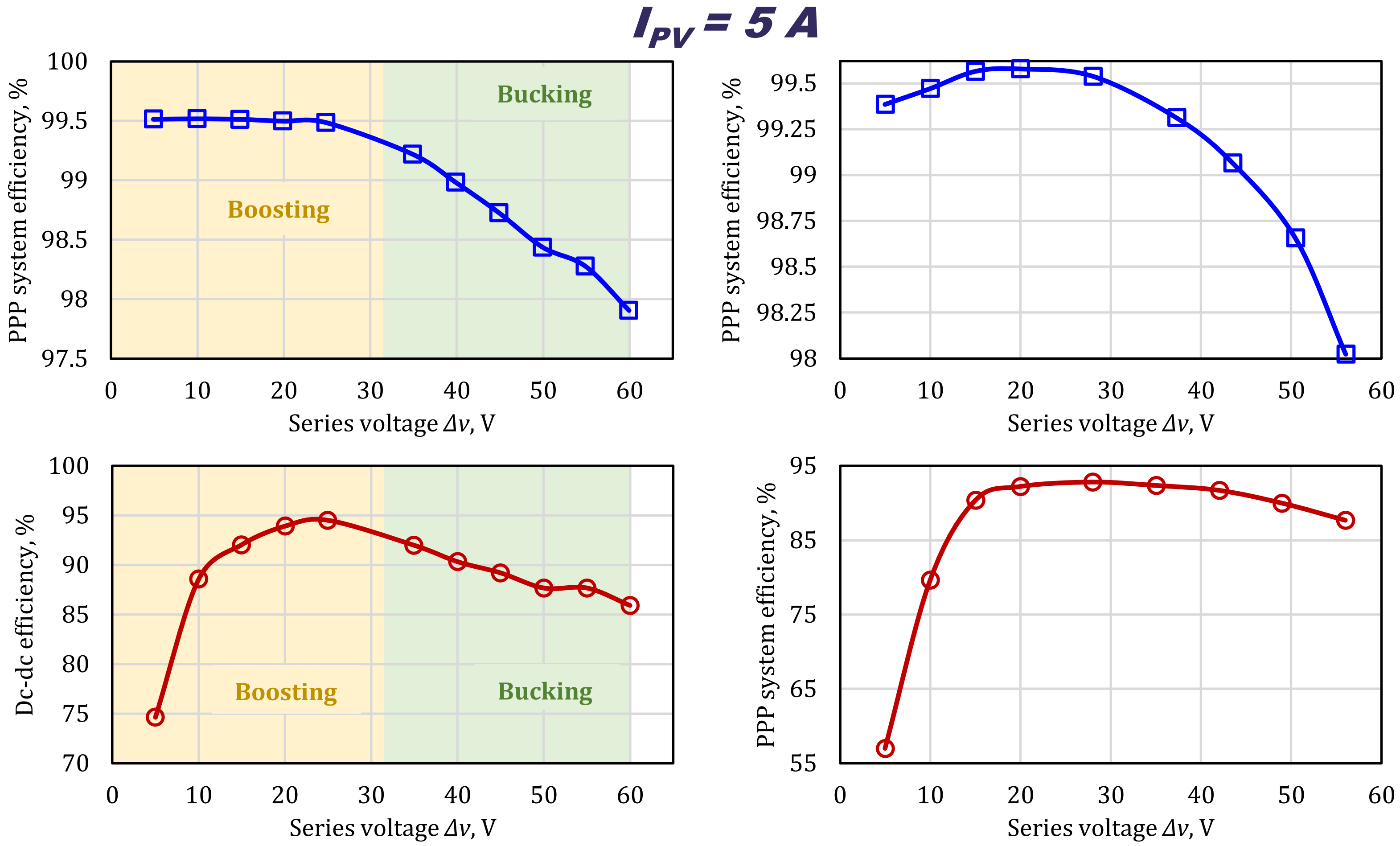


- *Converter can operate as a boost step-up dc-dc with normalized DC gain always over 1 (n=2.9)*
- *Converter can operate as a buck-boost with the normalized DC gain above and below 1 (n=5.6)*
- *Maximum power during the tests =1.75 kW*
- *The PV voltage regulation achieved was 290..350V for 350V fixed DC bus voltage*

Operating parameters		
Parameter	**Symbol**	**Range/Value**
Operating power range	P	0…300 W
Switching frequency	f_{SW}	100 kHz
Load voltage	V_L	350 V
Dc-dc input voltage range	Δv	5...60 V
Transformer turns ratio	$n_{buck\text{-}boost}$	5.6
	n_{boost}	3
Semiconductor components		
S_1…S_4 and S_{qZS}	Fairchild FDMS86180	
Rectifier diodes D_1 and D_2	Cree C3D02060E	

O. Abdel-Rahim, et al., "High-Performance Buck-Boost Partial Power Quasi-Z-Source Series Resonance Converter," in IEEE Access, vol. 10, pp. 130177-130189, 2022, doi: 10.1109/ACCESS.2022.3225751.

BOOST VS. BUCK-BOOST DC-DC – RESULTS



- *SIPO PPCs can provide full efficiency of over 99% in voltage step-down applications*
- *Buck (VF) dc-dc topologies should not be used in SIPO PPCs.*
- *Buck-boost dc-dc converter topologies provide good performance in applications where a PPC operates mainly at low partiality (below 10%).*
- *Boost (CF) dc-dc converter topologies provide balanced performance in the entire regulations range as their efficiency increases with the power processed by a SIPO PPC. They should be used in applications where PPC will operate mainly at partiality >10% or where its operation is equally probable in the entire regulation range.*

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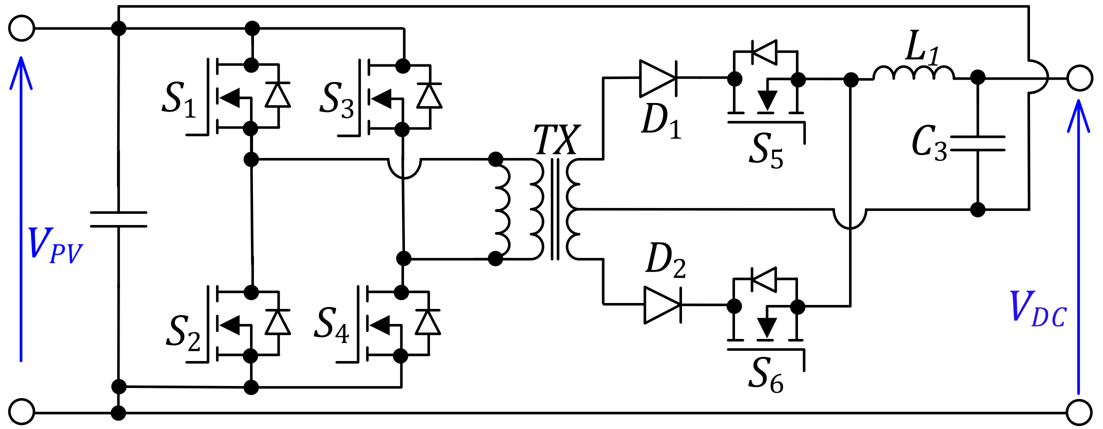
O. Abdel-Rahim, et al., "High-Performance Buck-Boost Partial Power Quasi-Z-Source Series Resonance Converter," in IEEE Access, vol. 10, pp. 130177-130189, 2022, doi: 10.1109/ACCESS.2022.3225751.

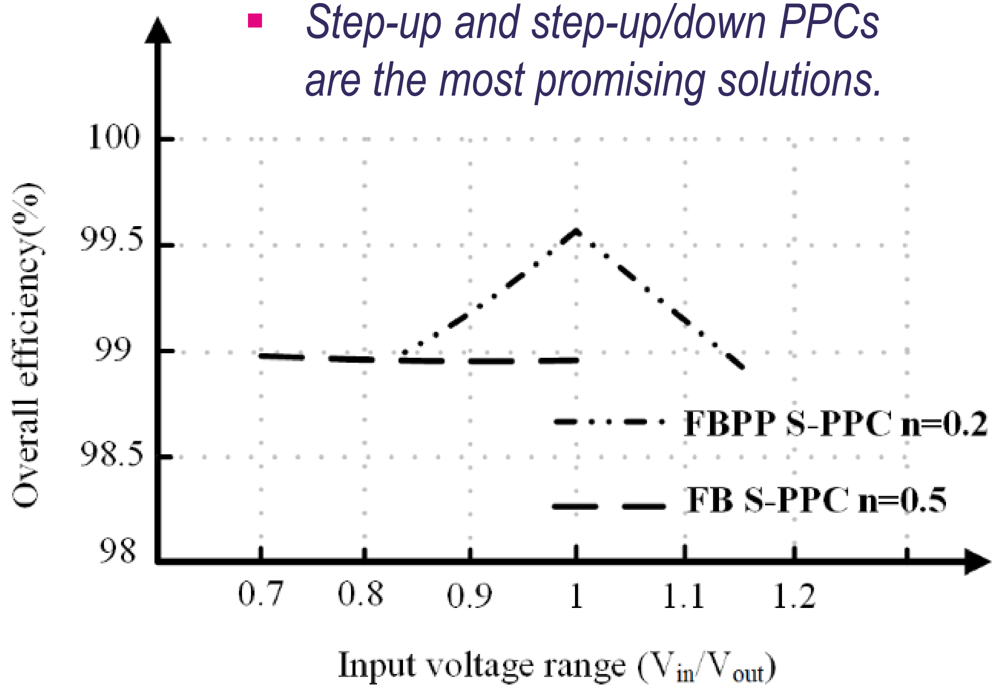
STEP-UP VS. STEP-UP/DOWN



2- quadrant implementation

DOI: 10.1109/TPEL.2017.2765928

- *Step-up and step-up/down PPCs are the most promising solutions.*



Type	Semic.	V_{PV}	V_{DC}	f_{SW}	P	PPC	η
PISO step-up	Si MOSFET	154-220 V	220 V	35 kHz	225 W	750 W	98.9%
PISO step-up/down		187-253 V			113 W		99.6%

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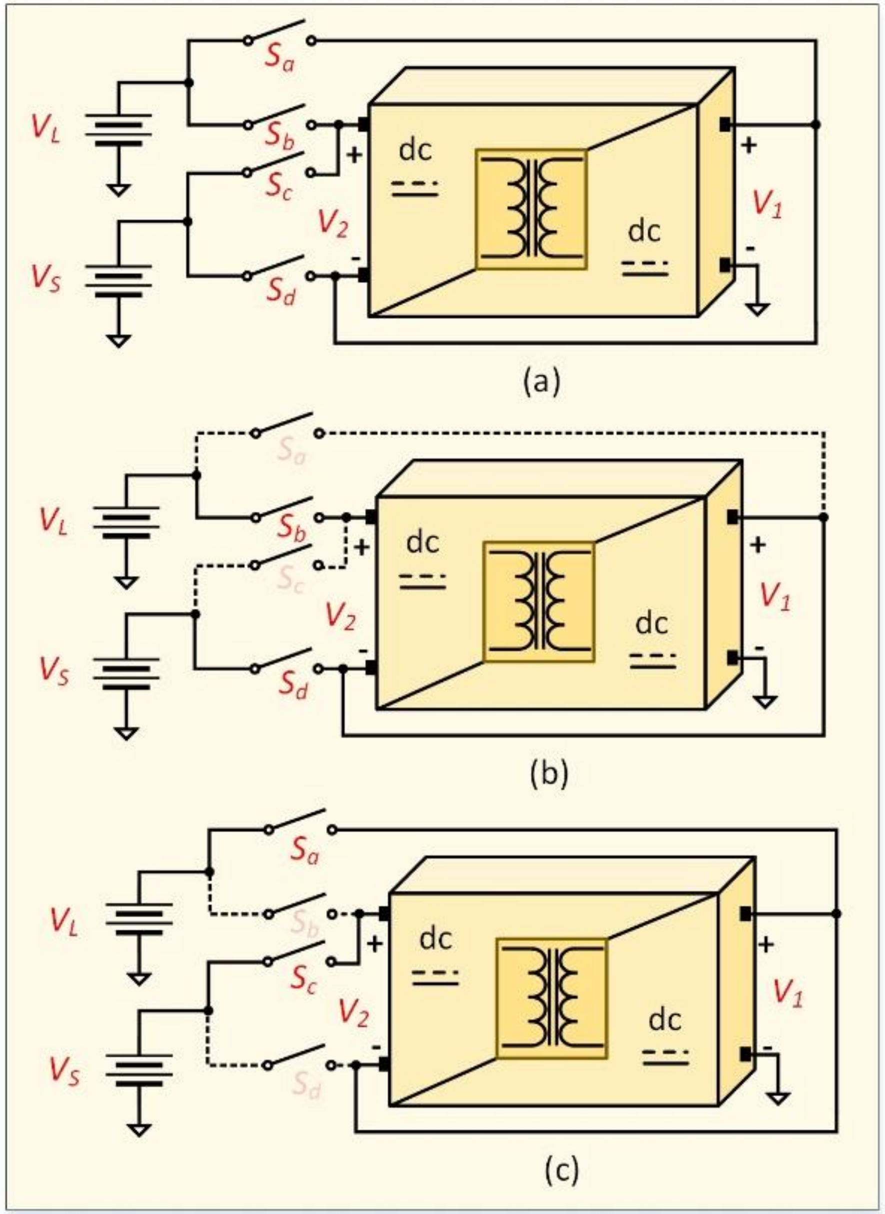
O. Abdel-Rahim, A. Chub, D. Vinnikov and A. Blinov, "DC Integration of Residential Photovoltaic Systems: A Survey," in *IEEE Access*, vol. 10, pp. 66974-66991, 2022.

*This comparison is not entirely fair, as different input voltage range typically means a different number of PV modules in a string and, consequently, higher power.

STEP-UP VS. STEP-UP/DOWN
TERMINAL CONVERSION APPROACH BY TU DELFT

- *Allows using a simple off-the-shelf dc-dc converter using various topologies*
- *Requires 4 bidirectional semiconductor or electromechanical switches*
- *Mode transitions could be challenging if must be implemented on-the-fly*
- *The concept is pending patent protection*



Pierpaolo GRANELLO, Thiago Batista Soeiro, Pavol Bauer "A bidirectional partial power processing, ppp, architecture, for converting between a first voltage terminal and a second voltage terminal, as well as a corresponding method", Patent application WO2023101549A1.

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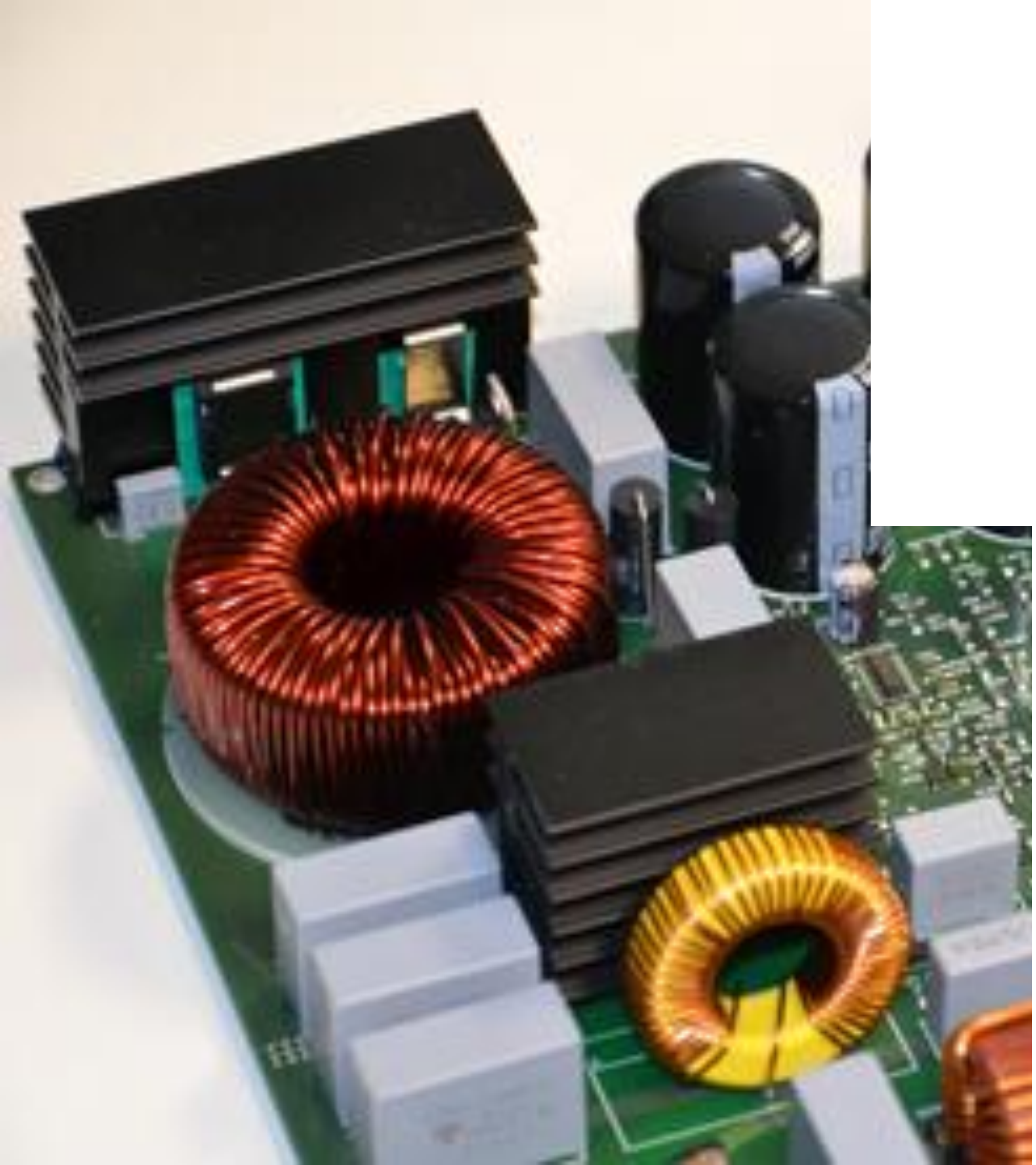
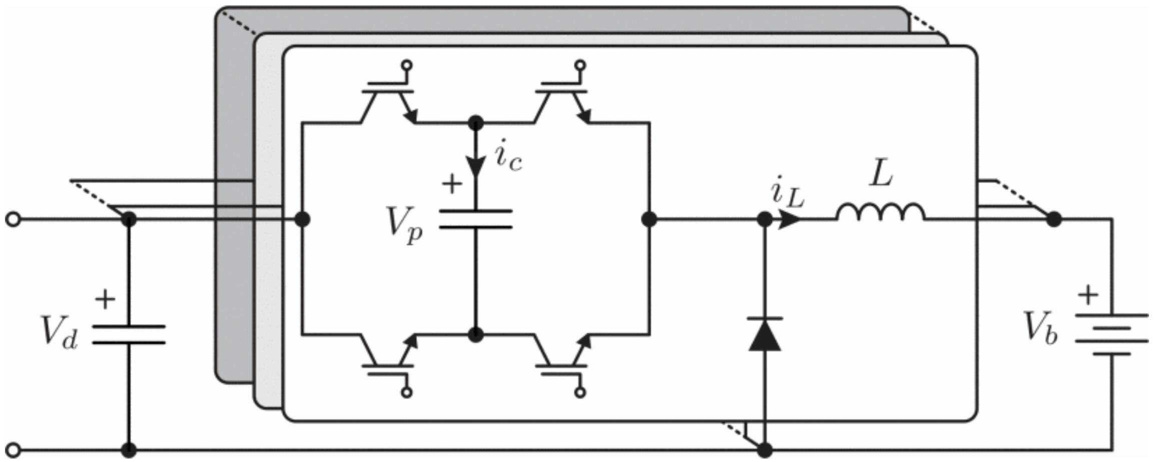
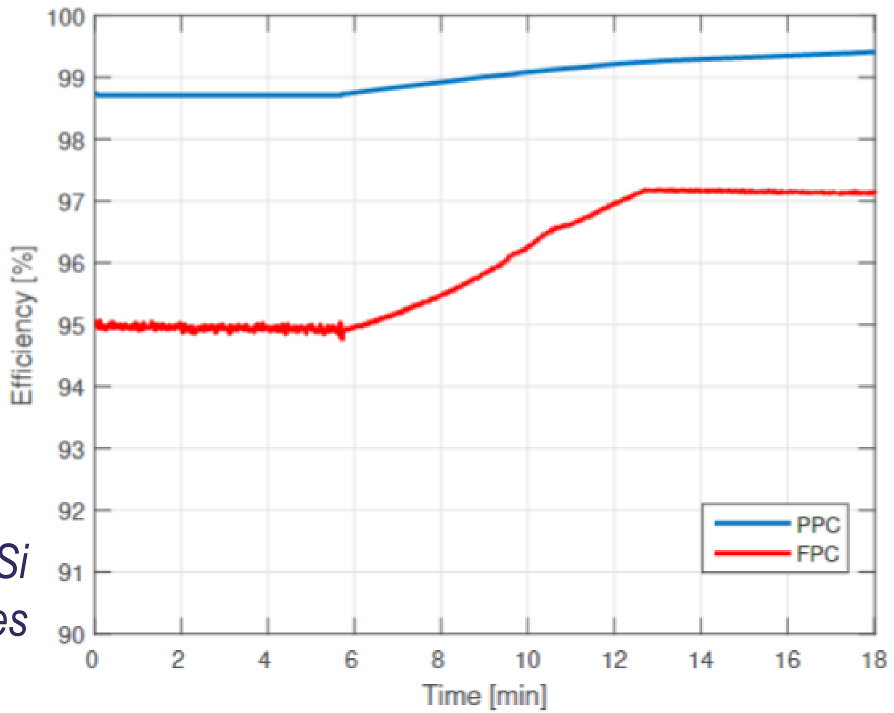


PPC TOPOLOGIES – DO WE NEED GALVANIC ISOLATION?

FLYING CAPACITOR BASED NON-ISO PPC





Simulated efficiency for battery charging, considering Si IGBTs and SiC co-packed Schottky diodes

- *Semiconductors have a lower voltage rating because the flying capacitor voltage (C_3) is lower than the input V_{PV} which is close to V_{DC}*
- *This topology was verified for PV and battery applications, with simulated efficiency between 98.8% and 99.4% for the battery charging.*
- *Asymmetrical PWM of the bridge diagonals is implemented to control current of the inductor.*
- *Voltage control of C_2 must be decoupled from current control of L_1 by making the former regulator much slower.*

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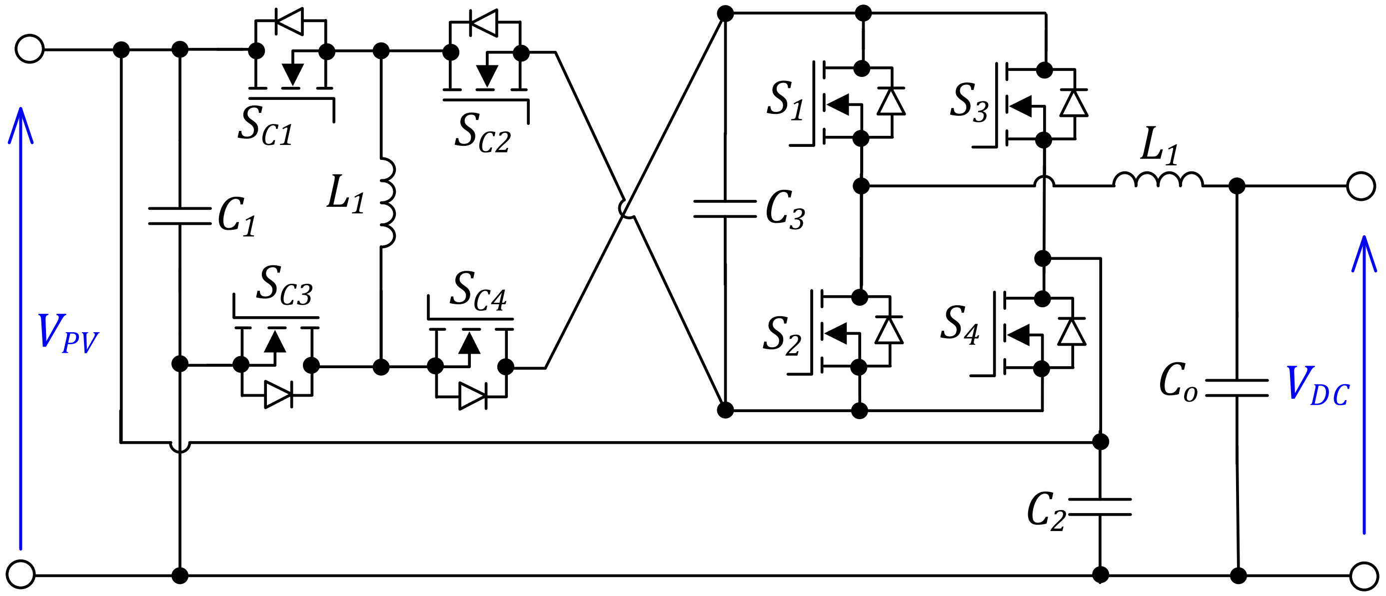
S. Rivera, D. Pesantez, S. Kouro and P. W. Lehn, "Pseudo-Partial-Power Converter without High Frequency Transformer for Electric Vehicle Fast Charging Stations," 2018 IEEE Energy Conversion Congress and Exposition (ECCE), Portland, OR, USA, 2018, pp. 1208-1213, doi: 10.1109/ECCE.2018.8558238.

FLYING INDUCTOR BASED NON-ISO PPC



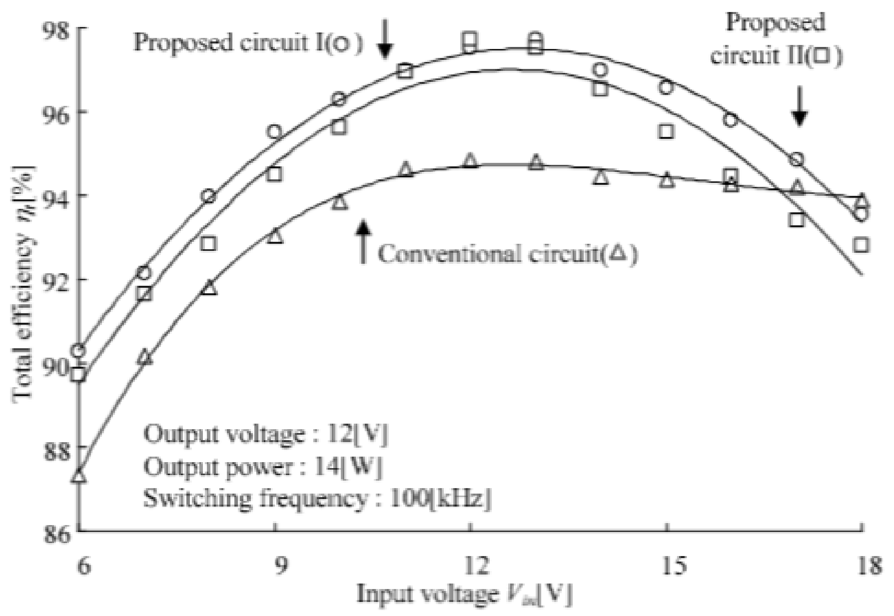
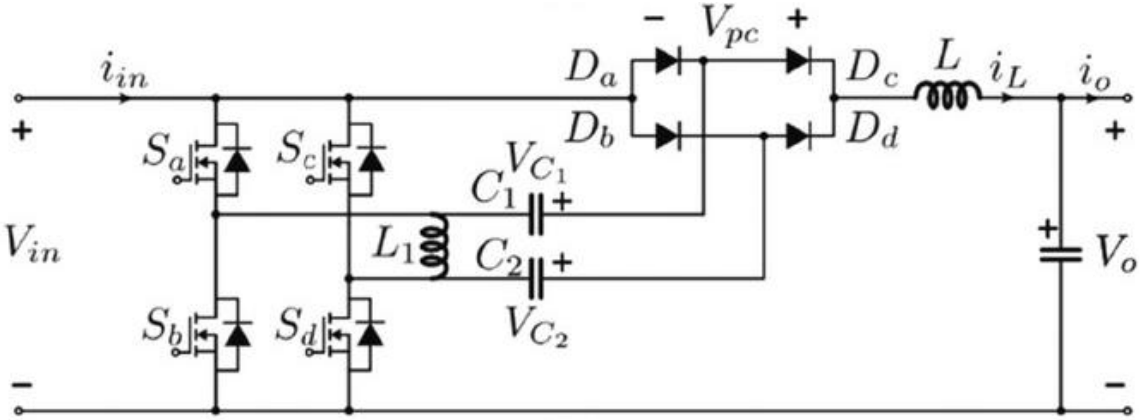


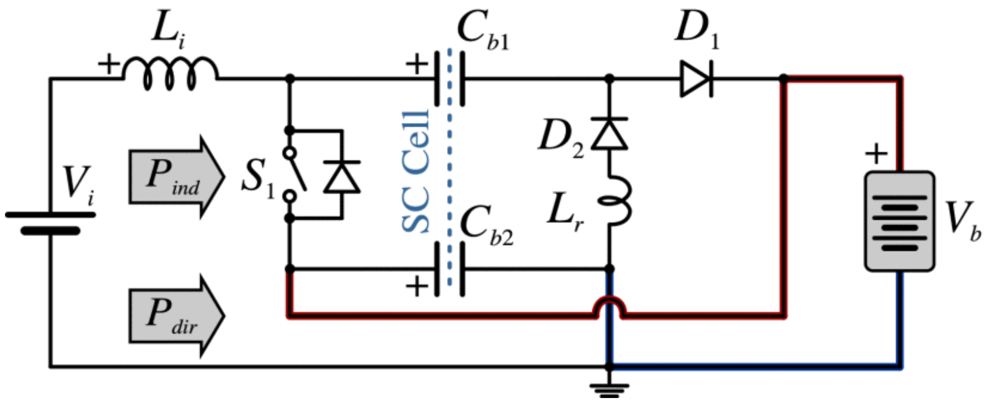
Fig. 14. Input voltage characteristics of efficiency η_t.

- *The capacitor C_1, which determines the output voltage of the series port, stores the energy released by inductance L1.*
- *The unfolding H-bridge (S_1-S_4) can invert the series port's voltage, extending the voltage regulation range of the converter.*
- *This topology is verified with a low input voltage range from 6 V to 8 V while the output voltage is kept as 12 V at 5 W to 30 W power.*
- *The size of the flying inductor L_1 is a limiting factor as It could become prohibitively bulky if the converter scaled up in power.*

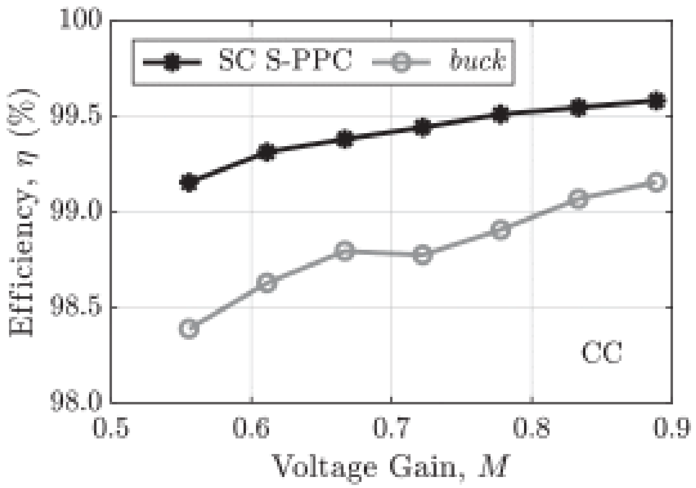
J. -i. Itoh and Takashi Fujii, "A new approach for high efficiency buck-boost DC/DC converters using series compensation," 2008 IEEE Power Electronics Specialists Conference, Rhodes, Greece, 2008, pp. 2109-2114, doi: 10.1109/PESC.2008.4592254.

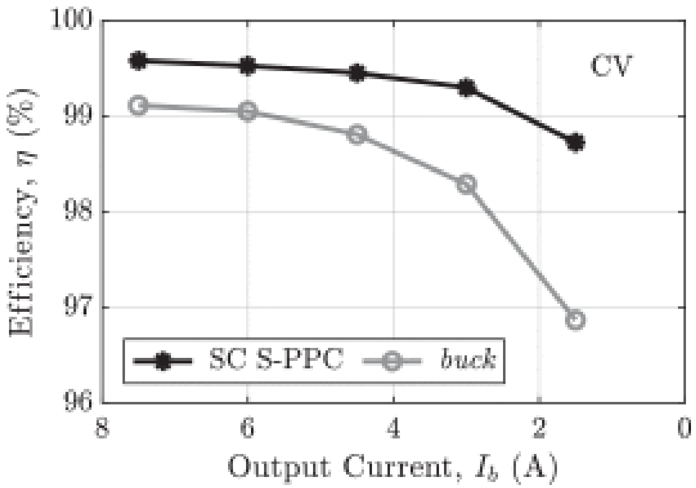
IS IT ALWAYS THE TRANSFORMER?





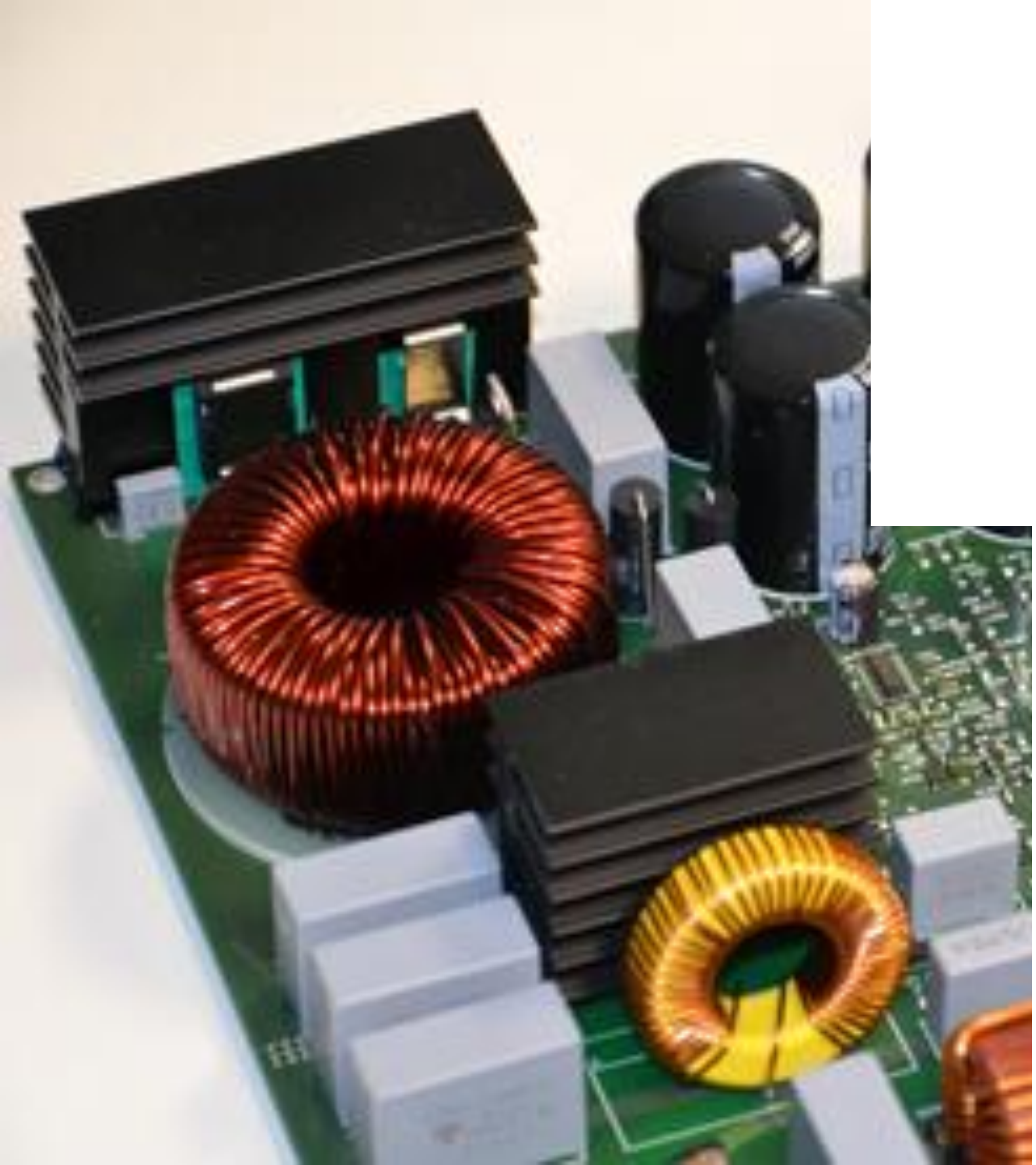
D. Pesantez, et al., “Transformerless partial power converter topology for electric vehicle fast charge,” IET Power Electronics, vol. 17, no. 8, pp. 970–982, Nov. 29, 2023. doi: 10.1049/pel2.12613.





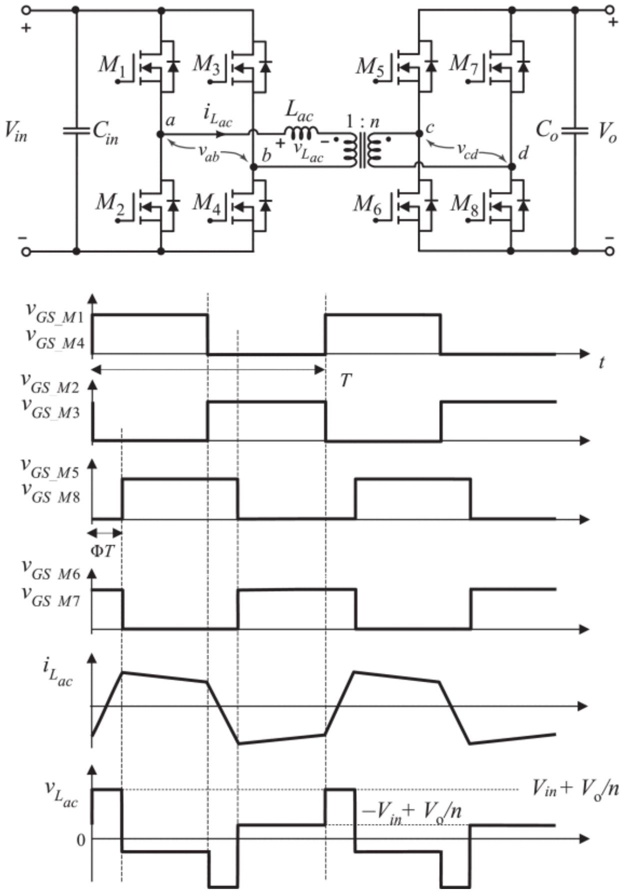
- *Capacitors can replace the magnetic isolation*
- *Y capacitors could be recommended*
- *Long-term reliability needs to be proven*
- *Efficiency is similar to those with transformers*

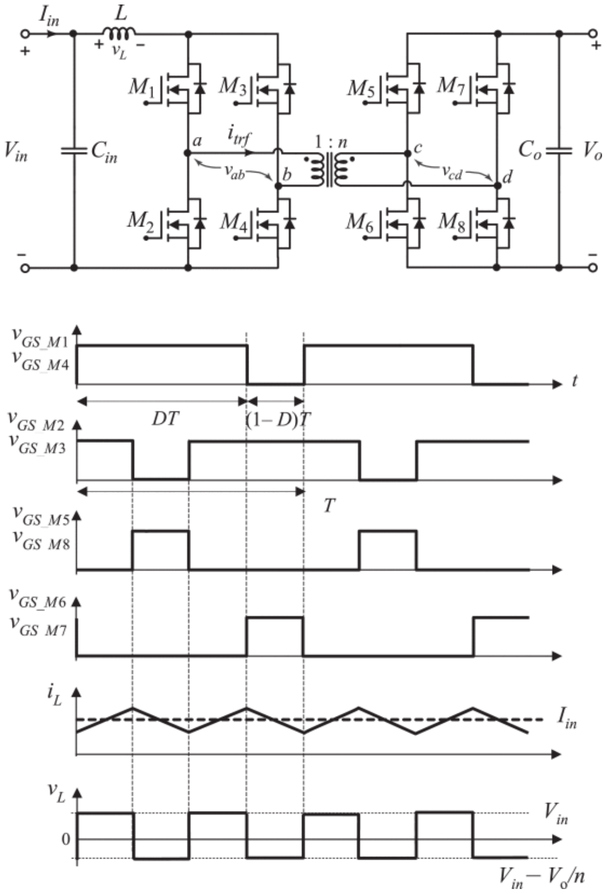
N.G.F. d. Santos, et al., "A High-Efficient Single-Switch Switched-Capacitor Partial Power Converter for On-Board Chargers," in IEEE Transactions on Power Electronics, vol. 39, no. 11, pp. 15269-15280, Nov. 2024, doi: 10.1109/TPEL.2024.3443519.



PPC TOPOLOGIES – ARE THEY THE SAME IN PERFORMANCE?

CURRENT-FED & VOLTAGE-FED DC-DC CELLS



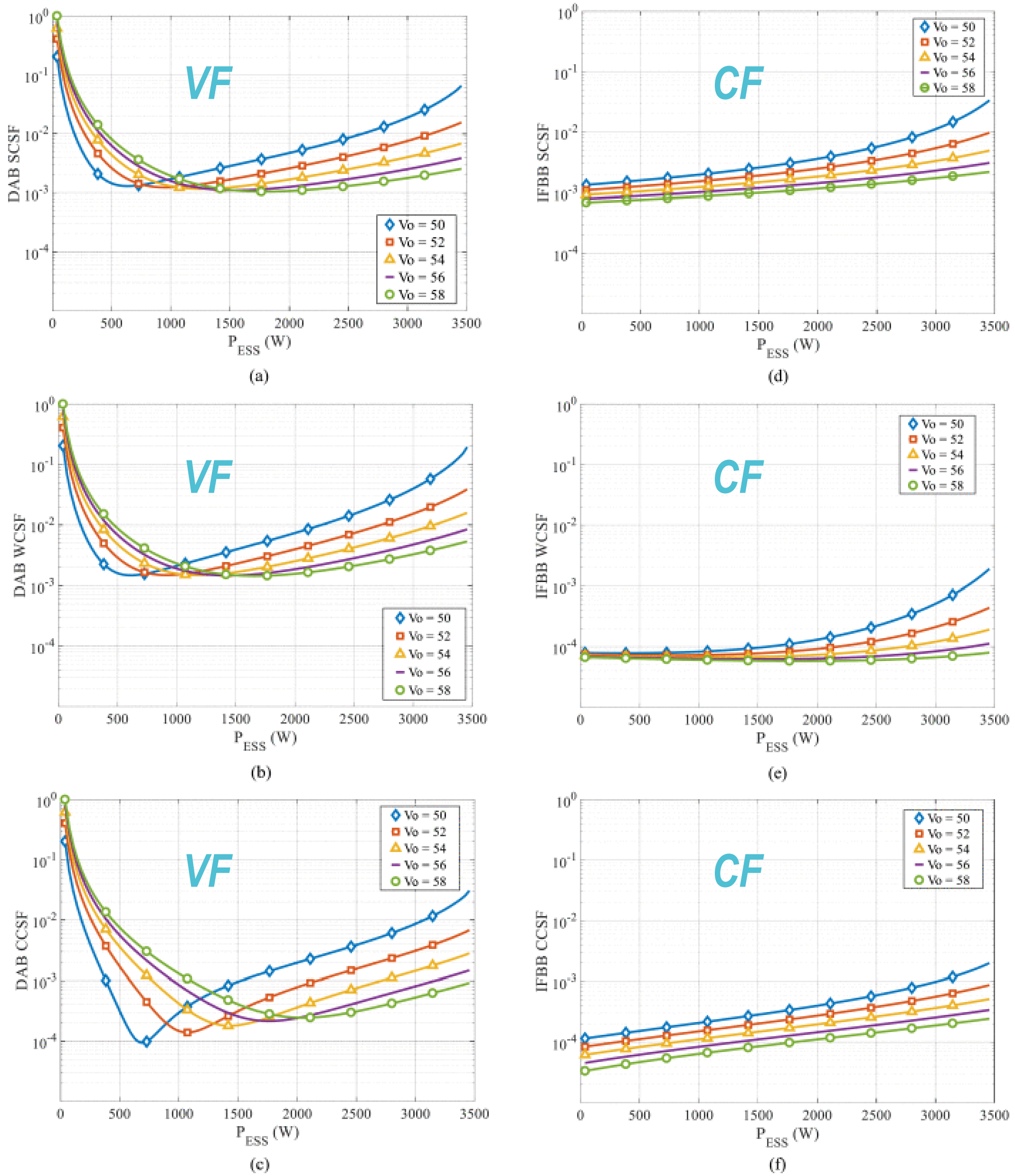


- *DC-DC topology defines the performance of the PPC*
- *Typically, DC-DC cell has turns ratio $n \gg 1$*
- *Voltage- and current-fed full bridge converters are often used in high step-up applications*
- *A study was performed for electrolyzer application, where 750 W converter can control 3.5 kW load*
- *Stress factors of semiconductors, magnetic components, and capacitors were compared*
- *It is important to mention that in other applications VF topologies can have a "sweet spot" as will be shown later*

TAL TECH

M. C. Mira, Z. Zhang, K. L. Jørgensen and M. A. E. Andersen, "Fractional Charging Converter With High Efficiency and Low Cost for Electrochemical Energy Storage Devices," in IEEE Transactions on Industry Applications, vol. 55, no. 6, pp. 7461-7470, Nov.-Dec. 2019, doi: 10.1109/TIA.2019.2921295.

CURRENT-FED VS. VOLTAGE-FED DC-DC CELLS



$$\mathrm{SCSF}_i = \frac{\sum_j W_j}{W_i} \cdot \frac{V_{\mathrm{max}}^2 \cdot I_{\mathrm{rms}}^2}{P_{\mathrm{in}}^2}$$

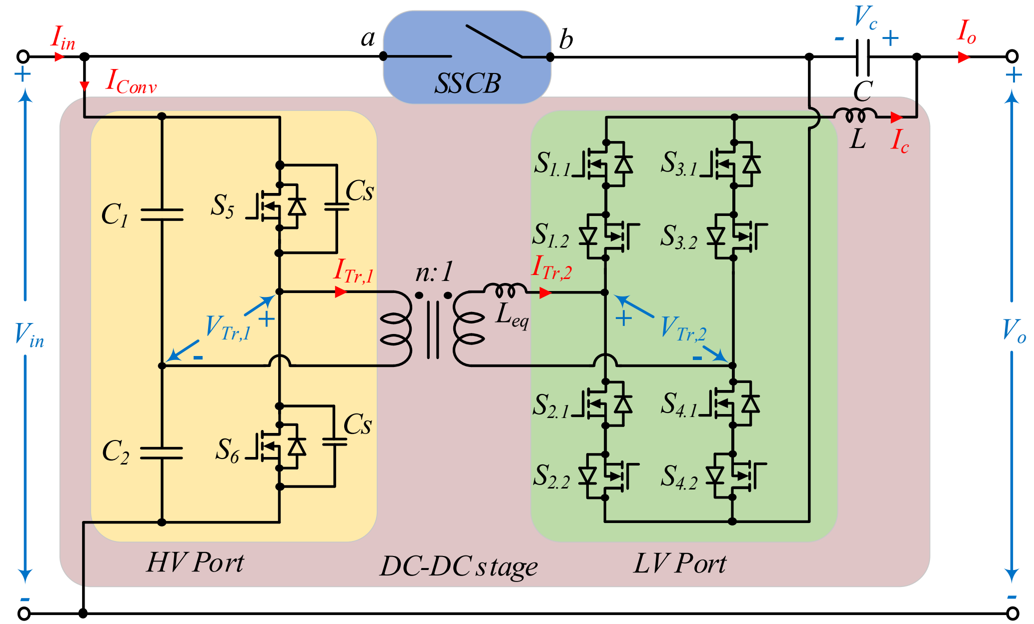
$$\mathrm{WCSF}_i = \frac{\sum_j W_j}{W_i} \cdot \frac{V_{\mathrm{max\_avg}}^2 \cdot I_{\mathrm{rms}}^2}{P_{\mathrm{in}}^2}$$

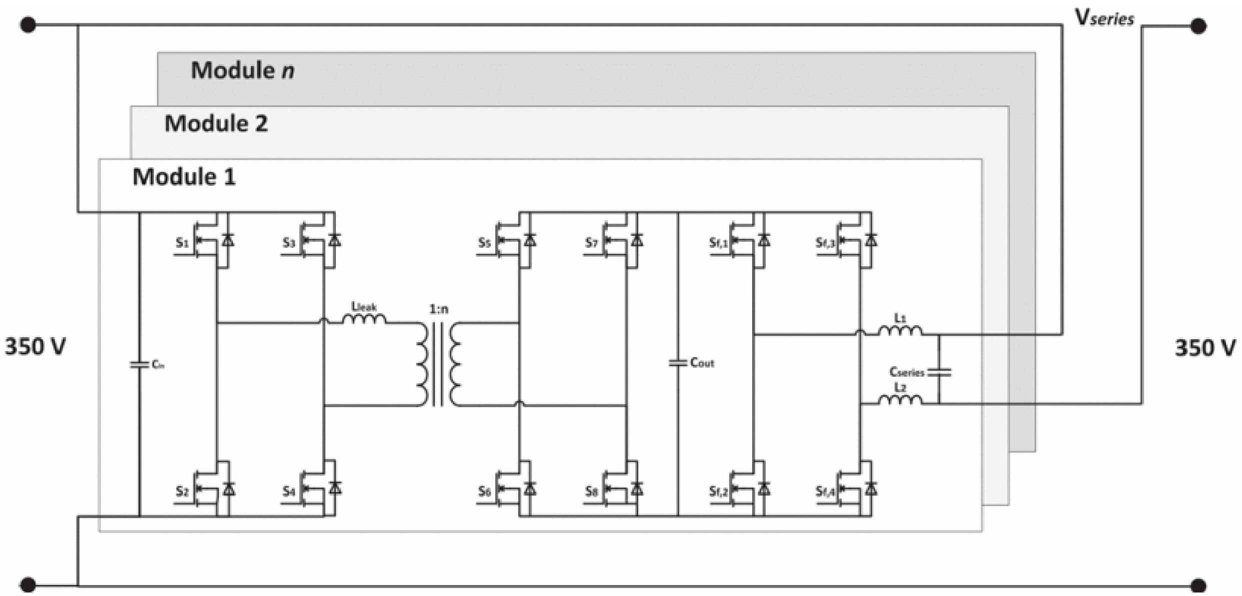
$$\mathrm{CCSF}_i = \frac{\sum_j W_j}{W_i} \cdot \frac{V_{\mathrm{max}}^2 \cdot I_{\mathrm{rms}}^2}{P_{\mathrm{in}}^2}$$

$$\begin{cases} \mathrm{SCSF} = \sum_i \mathrm{SCSF}_i \\ \mathrm{WCSF} = \sum_i \mathrm{WCSF}_i \\ \mathrm{CCSF} = \sum_i \mathrm{SCSF}_i \end{cases}$$

- *At low power levels the VF converter present very high CSFs due to large rms circulating reactive current. As the power of the electrolyzer stack increases, the ratio of the rms current to the processed power is reduced and thus, the CSF.*
- *In the CF converter, the highest CSFs occur at the maximum ESS power (maximum current) and minimum output voltage, which is an expected result from boost-derived topology.*
- *The VF converter shows a reduced SCSF compared to the CF only in a small range of the operating region. WCSF for the VF converter is significantly worse than that of the CF in all the operating range due to the increased voltage stress in the magnetic components*

STEP-UP/DOWN 4-QUADRANT PPC – TOPOLOGIES

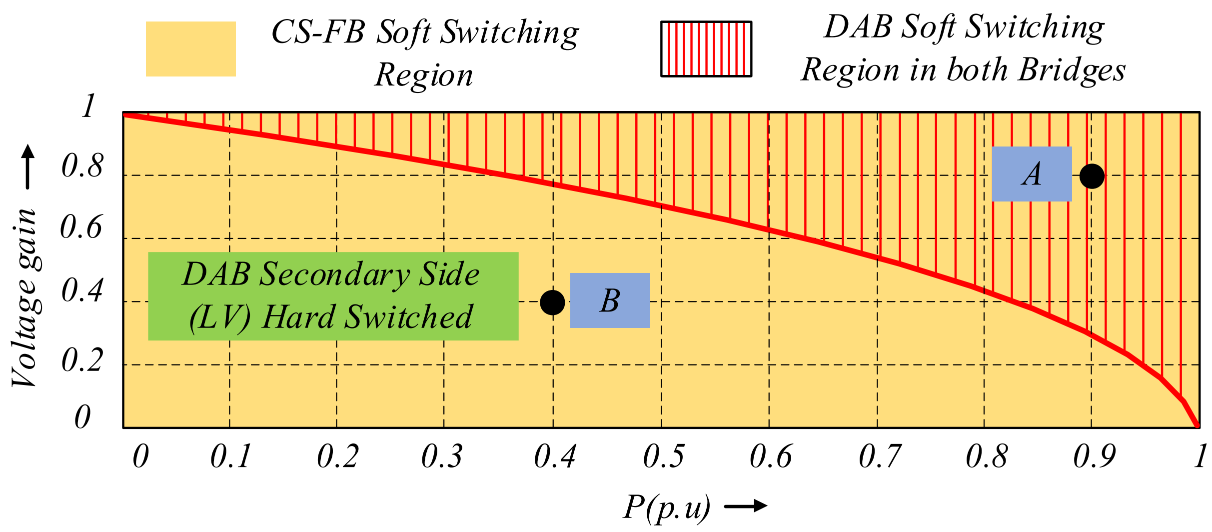




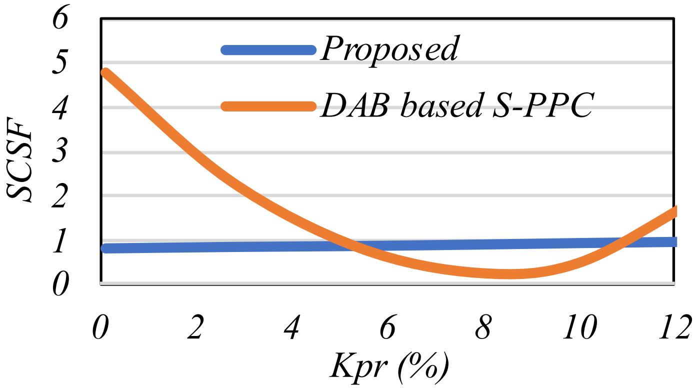
- *4-quadrant S-U/D PPC suits well for battery energy storage systems*
- *4-quadrant operation requires either use 4-quadrant switches or unfolder in the series (low-voltage) port*
- *DC-DC cell must have wide voltage/current regulation range*
- *Current-fed isolated converter was compared vs. solution based on DAB converter and unfolder for 350±30V case*

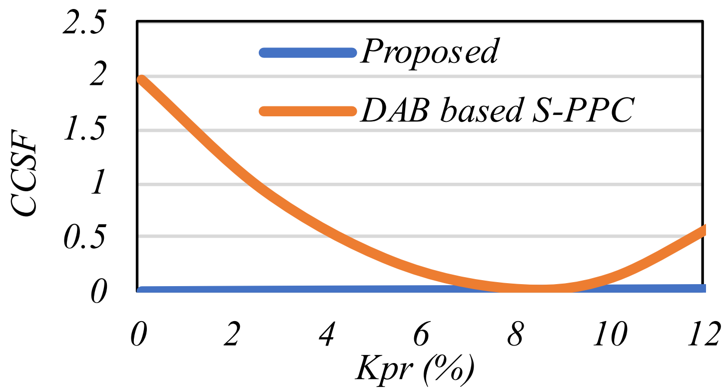
N. Hassanpour, A. Chub, A. Blinov and D. Vinnikov, "Soft-Switching Bidirectional Step-Up/Down Partial Power Converter With Reduced Components Stress," in IEEE Transactions on Power Electronics, vol. 38, no. 11, pp. 14166-14177, Nov. 2023.

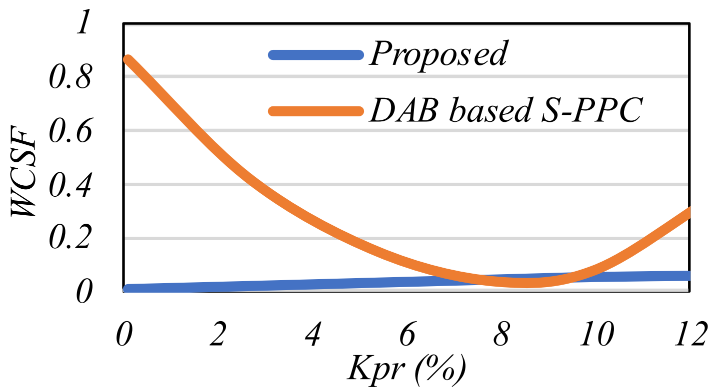
STEP-UP/DOWN 4-QUADRANT PPC – COMPARISON



- *Current-fed converter can achieve soft-switching in the entire operating mode (reverse recovery issue)*
- *DAB converter has a sweet spot in terms of performance, while current-fed topology demonstrate balanced performance in a wide range*
- *Smooth zero-voltage transition and current controllability at zero partiality are not practically feasible for DAB-based PPC and challenging for current-fed topology.*







N. Hassanpour, A. Chub, A. Blinov and D. Vinnikov, "Soft-Switching Bidirectional Step-Up/Down Partial Power Converter With Reduced Components Stress," in IEEE Transactions on Power Electronics, vol. 38, no. 11, pp. 14166-14177, Nov. 2023.

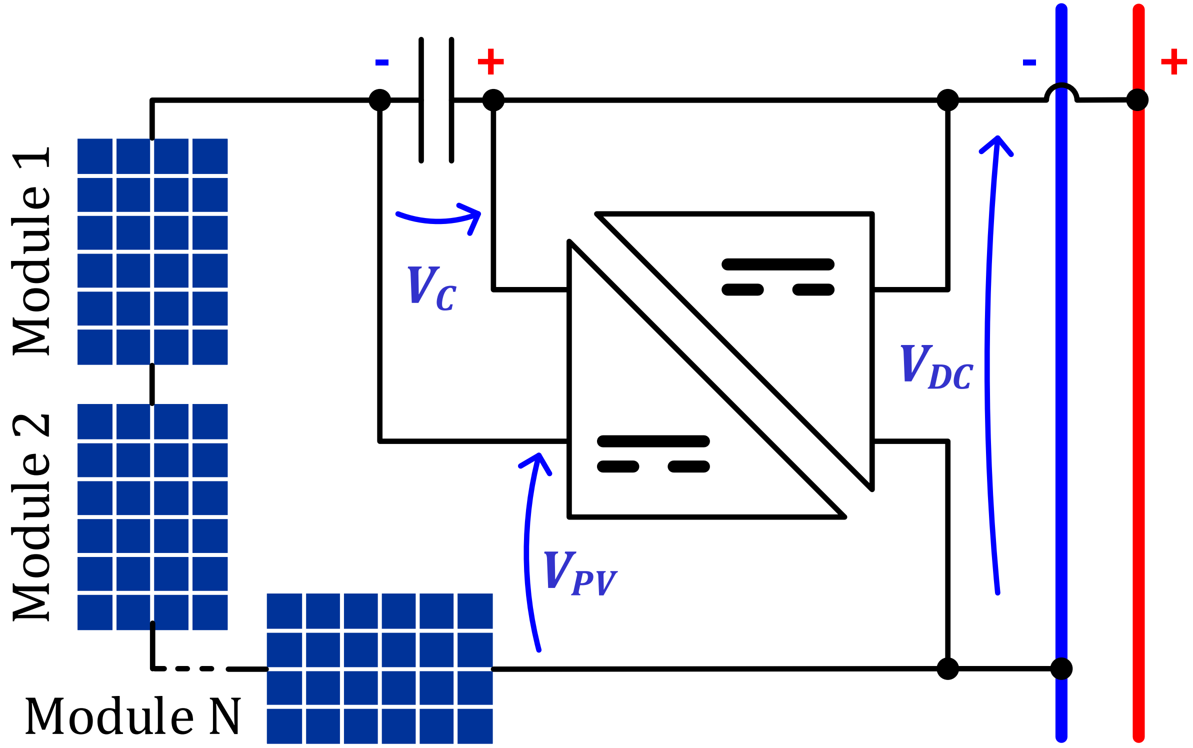
PHOTOVOLTAIC STRING DC INTEGRATION PRACTICAL LIMITS

FEASIBILITY STUDY

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

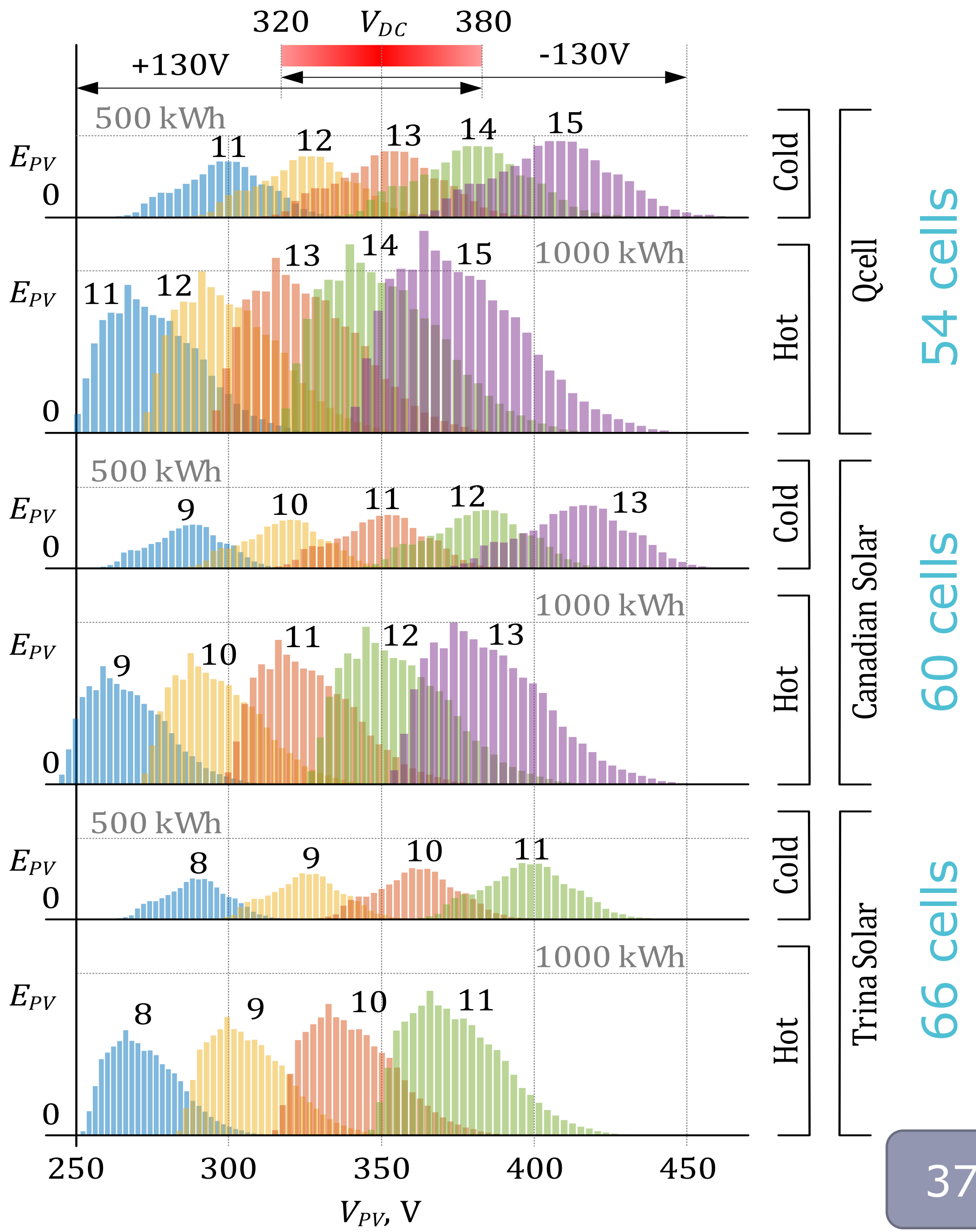
CurrentOS

- *Considering availability of 200V Si and GaN switches with good parameter, the PPC series voltage can be limited at* ***± 130V***
- *Typical residential 54-, 60-, and 66-cell PV modules were considered to demonstrate typical module types available on the market*



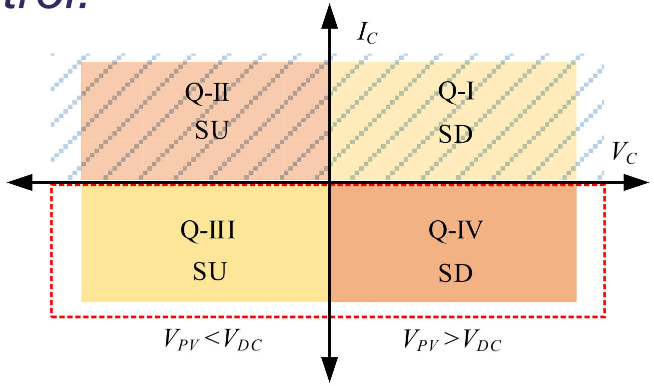
YEARLY MODELING
14 FEASIBLE CASES

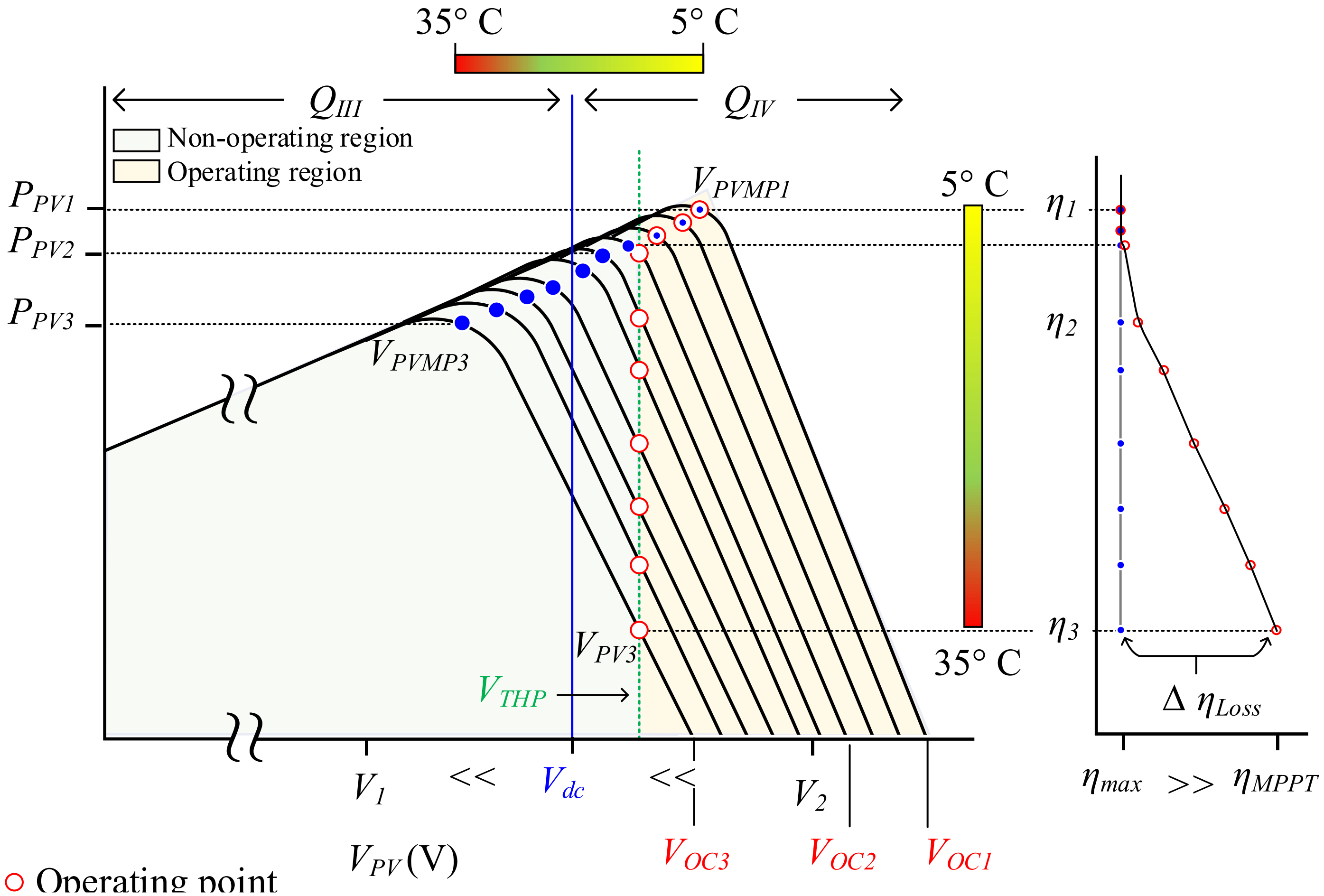
- ***54-cell PV module:*** *PV strings of **11 to 15** modules are feasible with power ratings between 4.4 kW and 6 kW for the roof installation area between 21 m² and 29 m².*
- ***60-cell PV module:*** *PV strings of **9 to 13** modules are feasible with power ratings between 3.3 kW and 4.8 kW for the roof installation area between 17 m² and 24 m².*
- ***66-cell PV module:*** *PV strings of **8 to 11** modules are feasible with power ratings between 3 kW and 4.2 kW for the roof installation area between 15 m² and 21 m².*
- ***Feasible roof installations*** *are between 3 kW and 6 kW for the roof installation area between 15 m² and 29 m².*



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.*

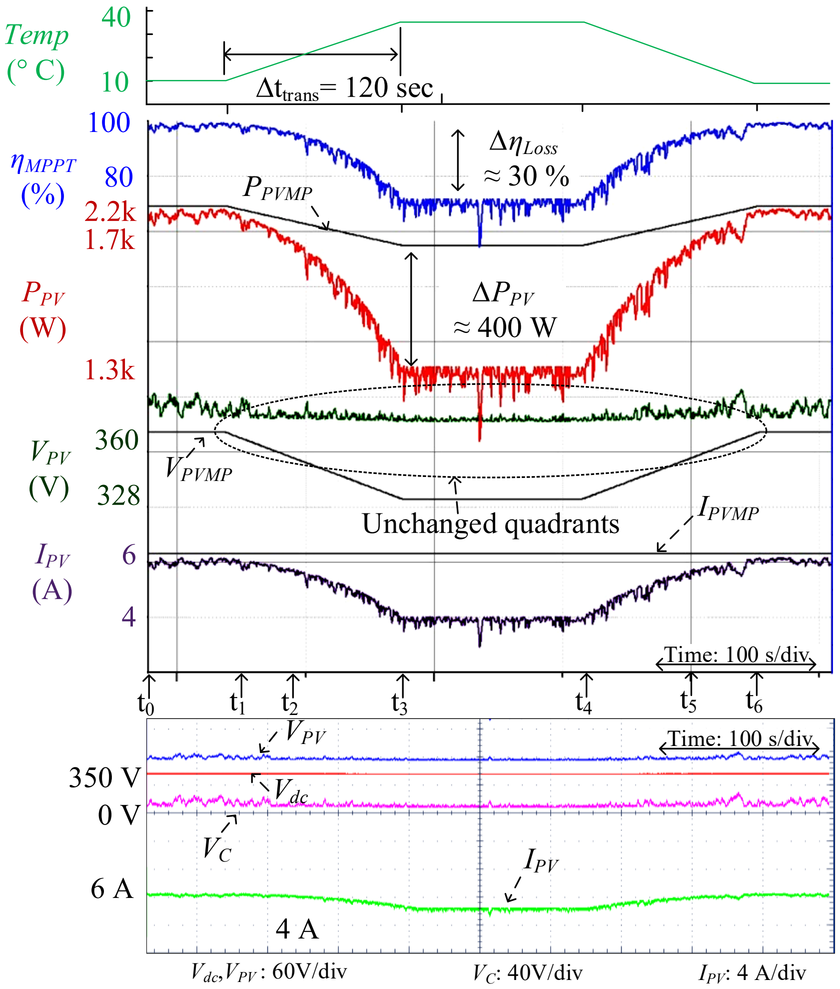


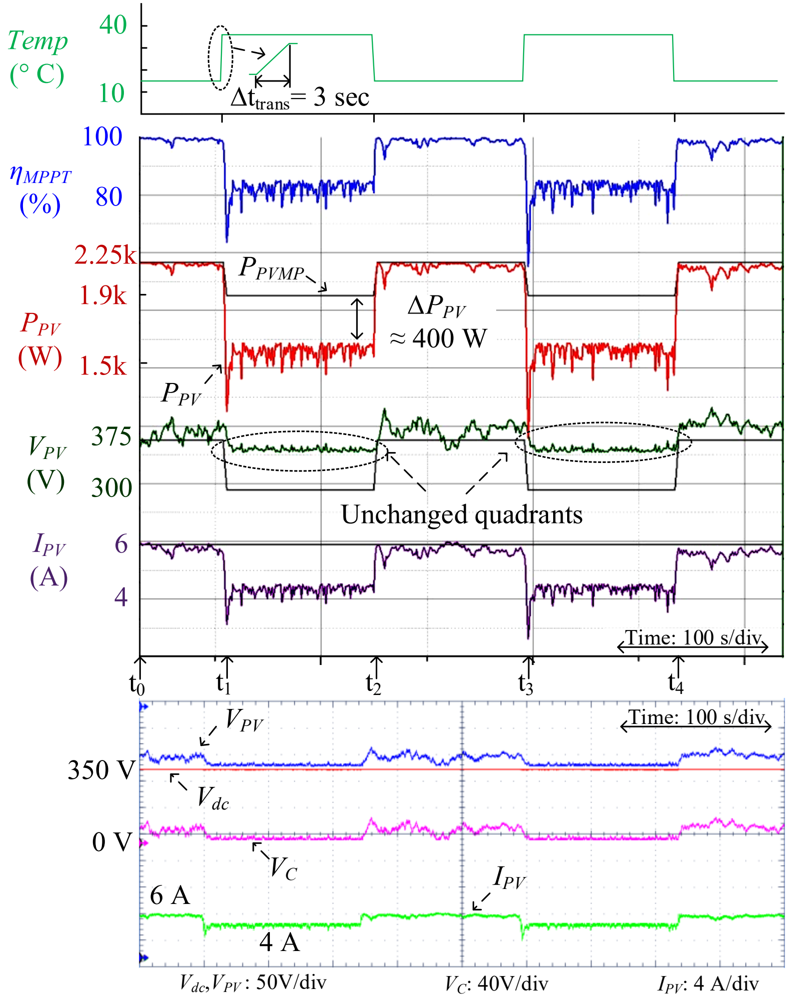


TAL TECH

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





- *Temperature variations result in MPP voltage variations*
- *At zero voltage at the series port and power flowing to that 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%*

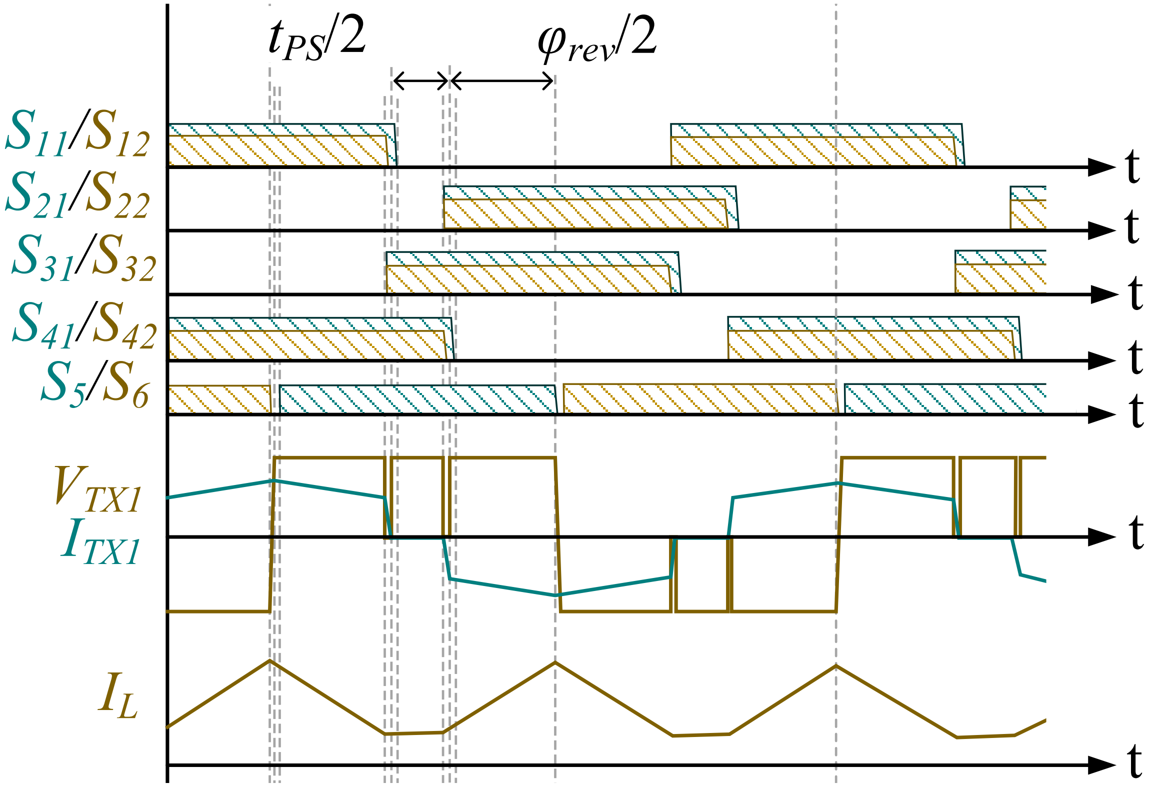
TAL TECH

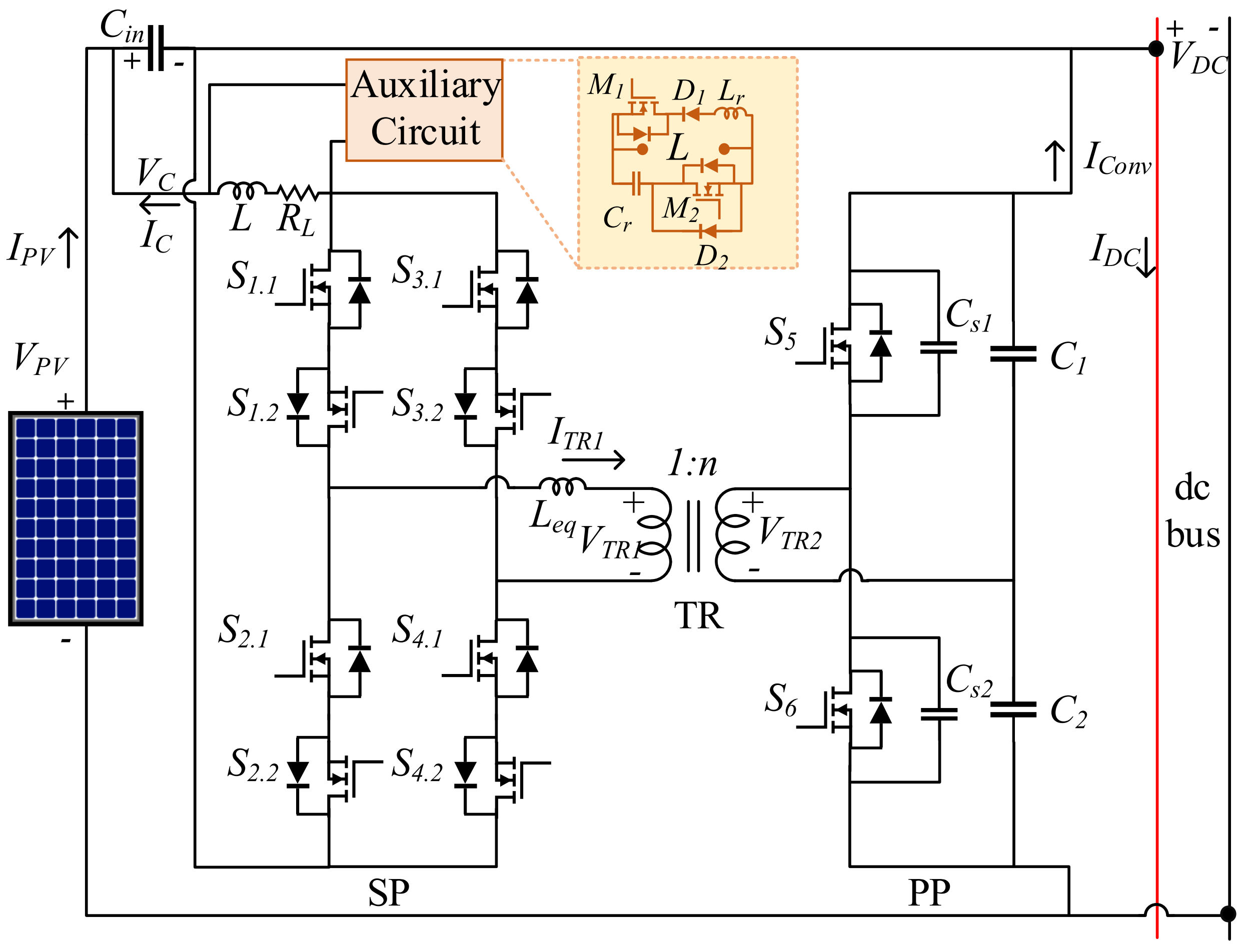
N. Yadav, at al. "Improved Maximum Power Point Tracking Algorithm for Step-Up/Down Partial Power Converters Operating Around Zero Partiality," in IEEE J. Emerg. and Sel. Topics in Power Electron., vol. 12, no. 2, pp. 1984-1994, April 2024.

ENHANCED MPPT WITH HYBRID MODULATION

CONCEPT

- *Close to the control dead zone, a new modulation must be applied*
- *Circulating energy can be used to control the inductor current near zero average value*

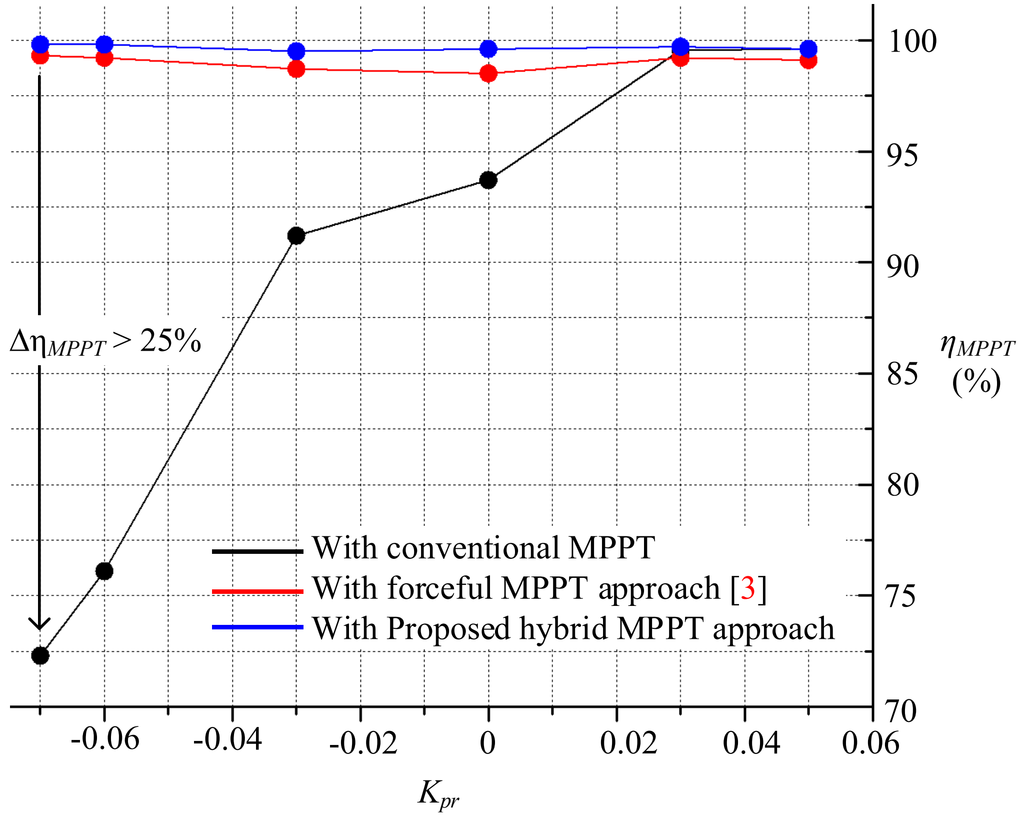


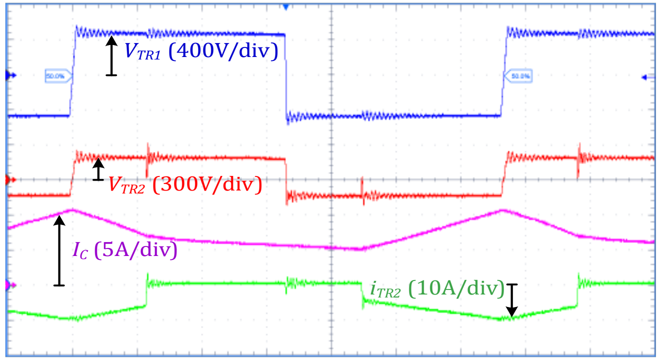


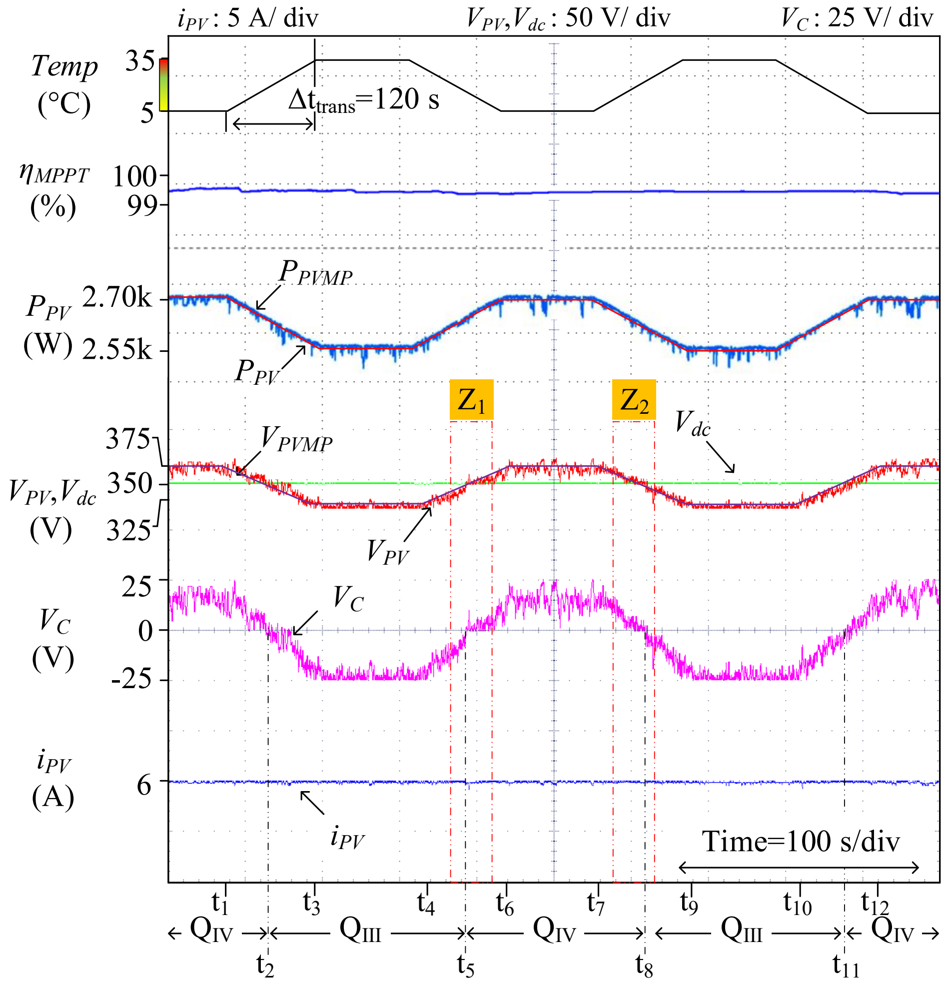
Accepted to IEEE TIA, doi pending

ENHANCED MPPT VALIDATION

- *Smooth transition through deadzone*
- *Increased conduction losses in the deadzone*
- *Improved MPPT efficiency vs. the forceful quadrant switching*







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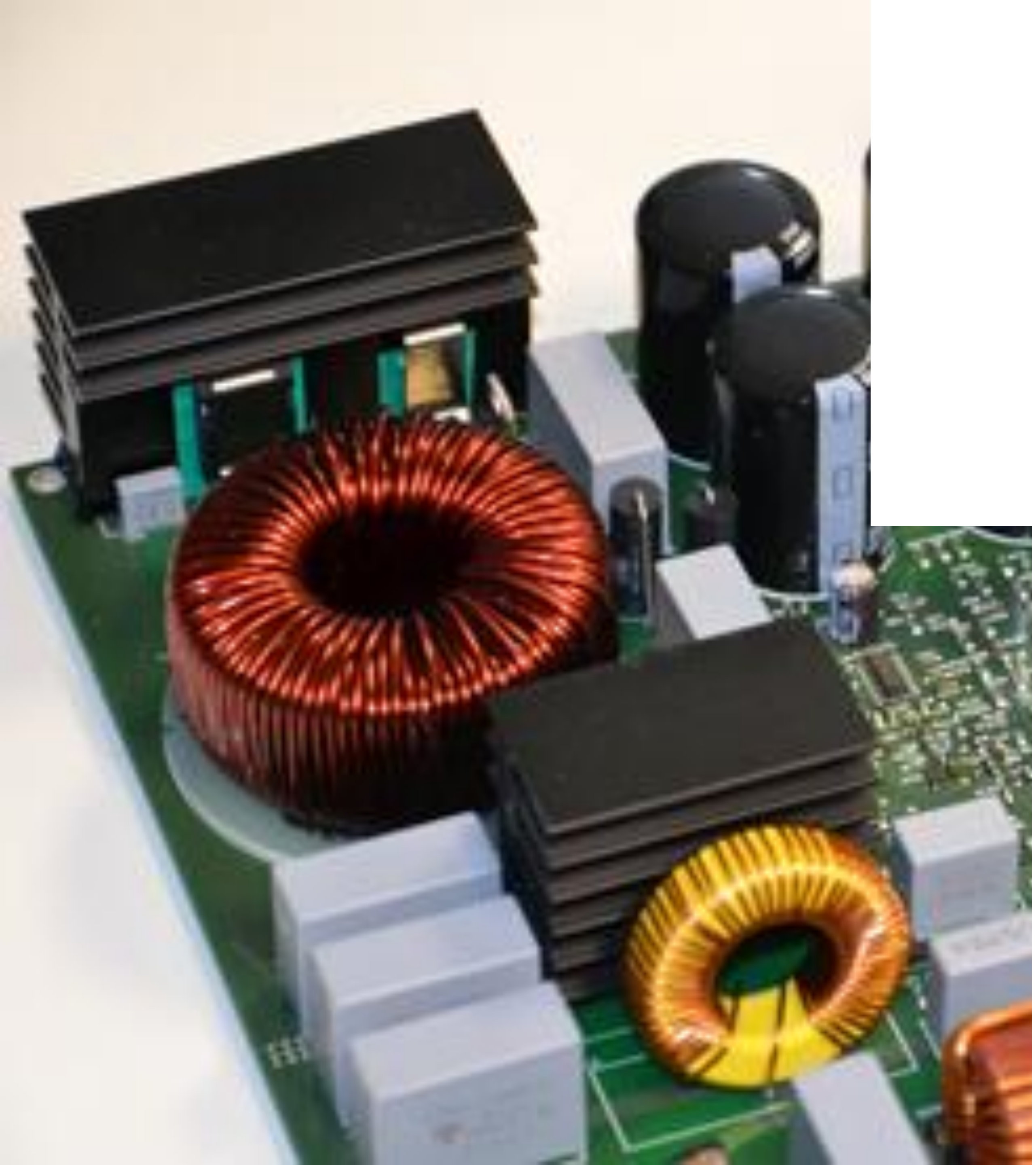
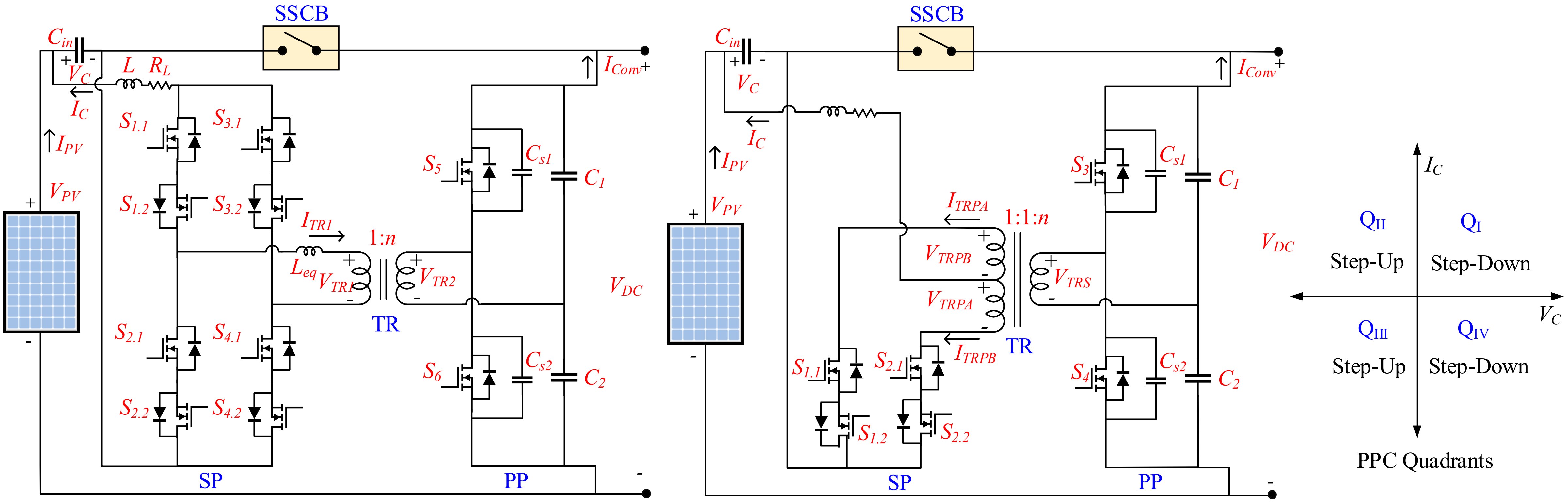


PUSH-PULL TOPOLOGIES REDUCING THE NUMBER OF 4-QUADRANT SWITCHES

TOPOLOGY SIMPLIFICATION

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



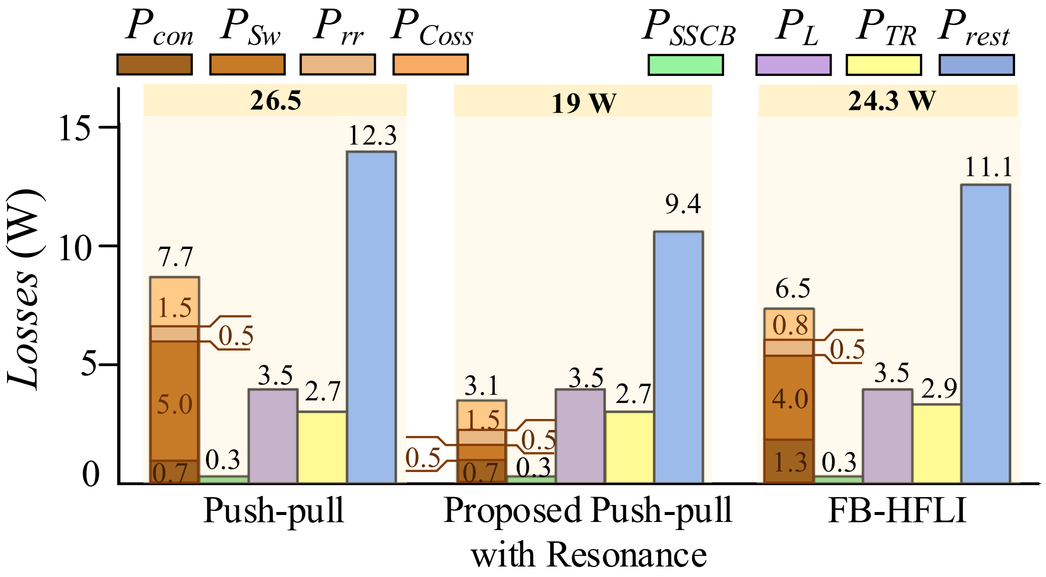
N. Yadav et al., "Performance Evaluation of Step-Up/Down Partial Power Converters Based on Current-Fed DC-DC Topologies," in IEEE Transactions on Industry Applications, doi: 10.1109/TIA.2024.3413050.

TAL TECH

COMPARISON OF IMPLEMENTATIONS

- *Current and voltage stresses can be compared*

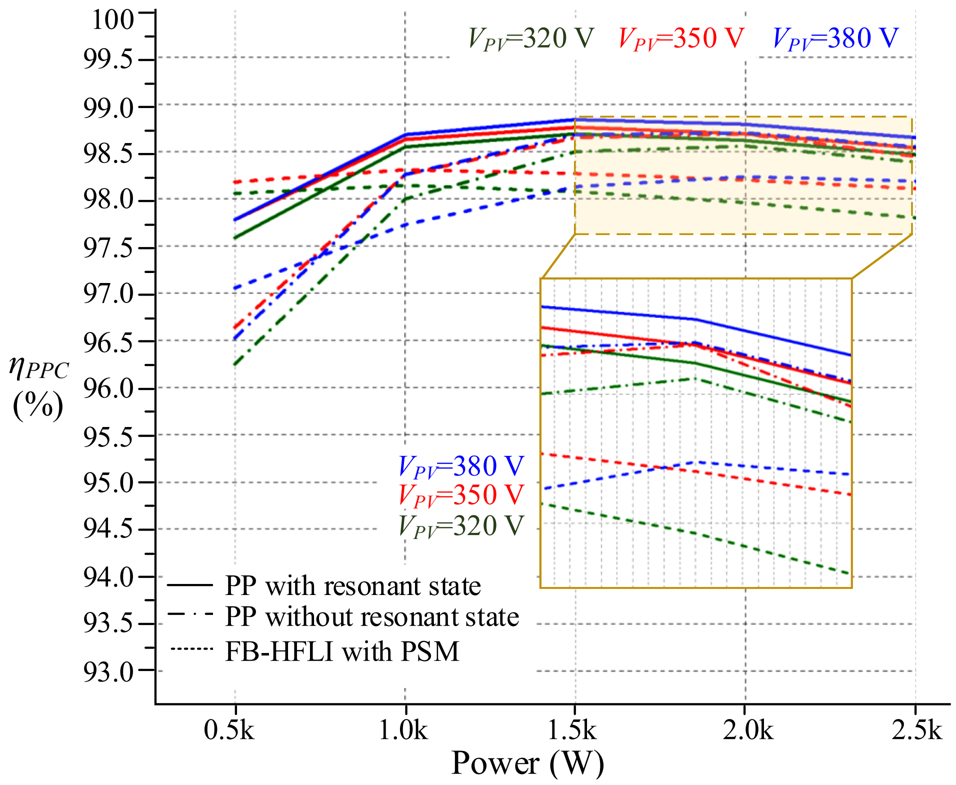
At 2kW, V_{PV}=320 V, V_{DC}=350 V										
Topology	PP Switch stress				SP Switch stress				Price, p.u.	Power density
	Voltage (V)		Current (A)		Voltage (V)		Current (A)			
	V_S	$V_{S,max}$	I_S	$I_{S,max}$	V_S	$V_{S,max}$	I_S	$I_{S,max}$		
FB-HFLI	350	380	2.4	24	75	85	3.5	5.5	1.4	4.3 kW/l
Push-pull	350	391	2.8	11.2	**220**	**339**	4.9	11.2	1.0	
Proposed push-pull (PP)	350	391	2	5	**192**	**328**	4.9	11.2	1.0	

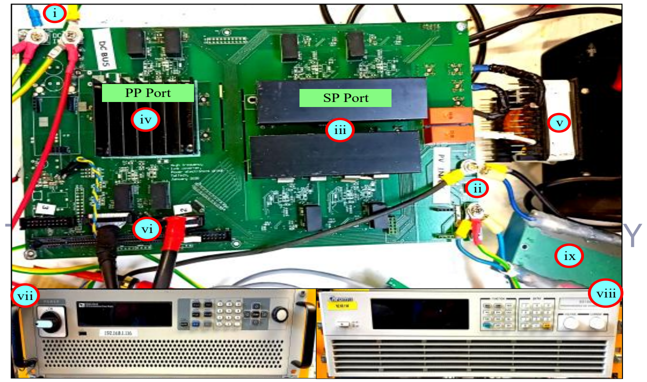


- *Power losses at 2.5kW/350V/30V considering best possible implementation*
- *The CF push-pull with resonant switching can outperform FB topology with resonant switching as well*
- *High stresses like in flyback-based PPC*

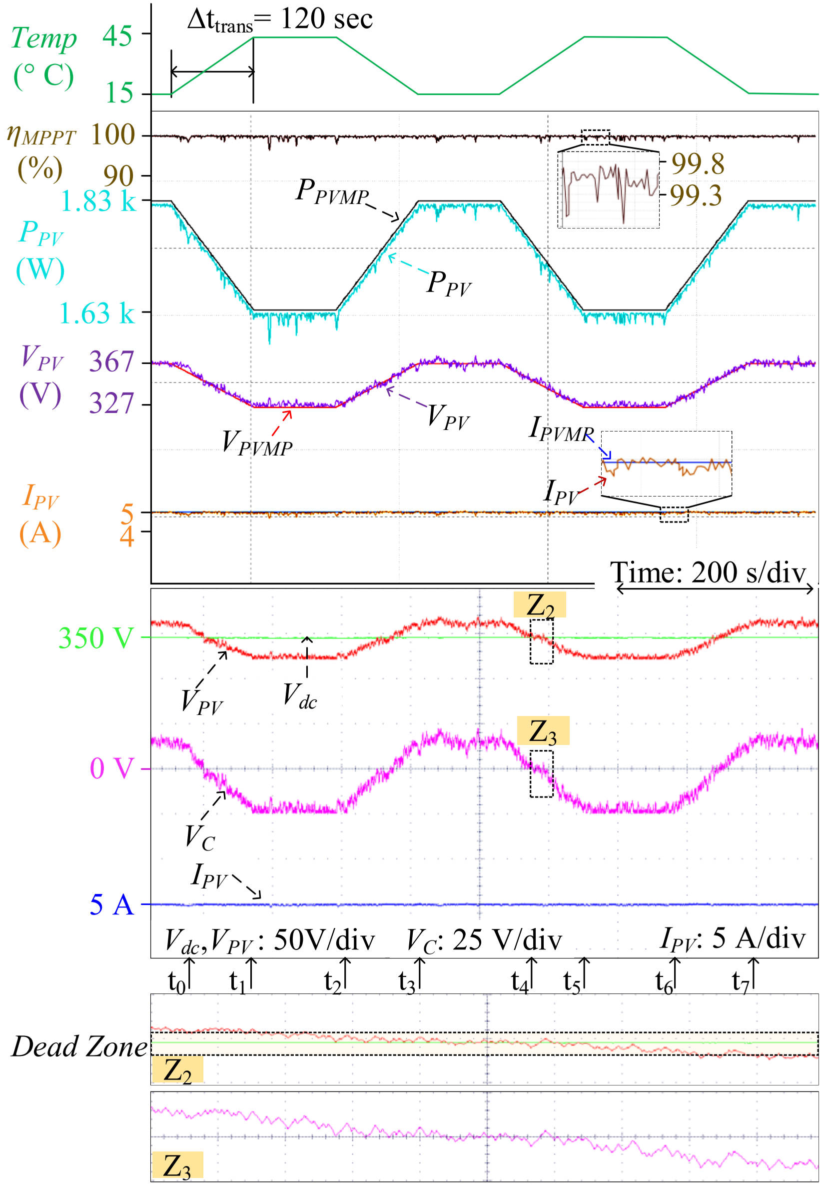
doi: 10.1109/TIA.2024.3413050

OPERATION WITH PV STRING





- *Having sizable amount of circulating energy, the PP converter implements smooth MPPT with zero voltage transitions*
- *Efficiency comparison is not entirely fair as it uses the same switches*
- *Cost optimized converter could have lower efficiency than FB, but it is justified*
- ***This topology can be recommended for application with narrow voltage regulation range, i.e., low partiality***

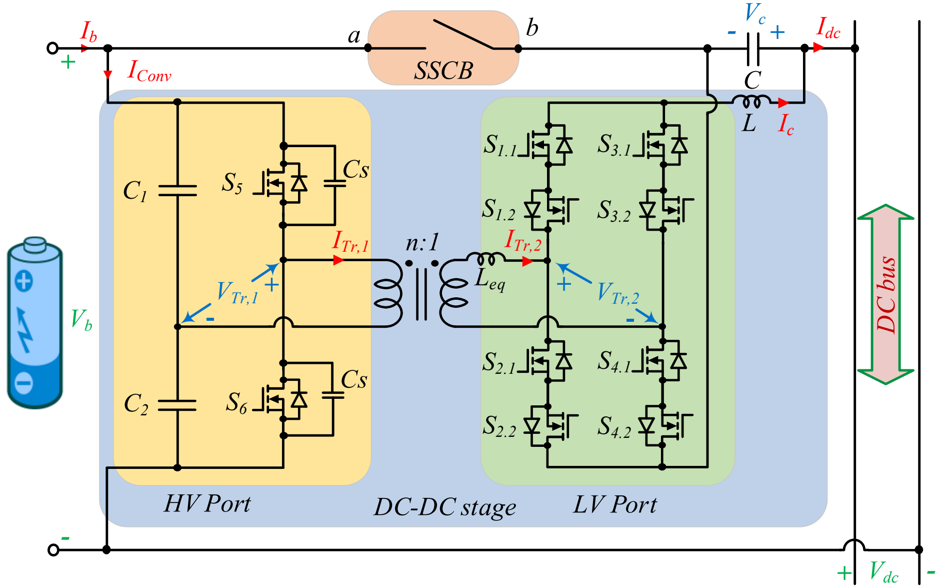


doi: 10.1109/TIA.2024.3413050

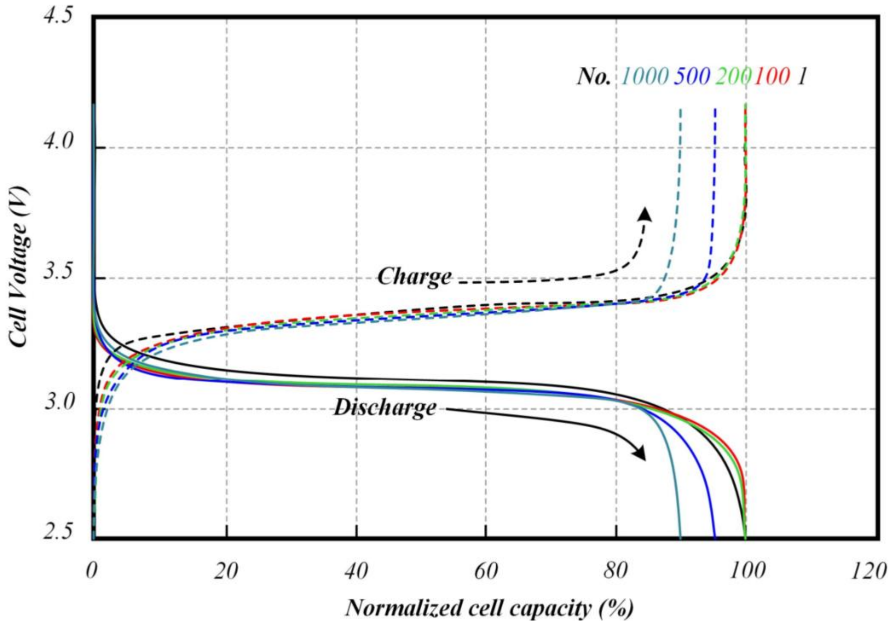
DC MICROGRID APPLICATIONS SECOND LIFE BATTERY ENERGY STORAGE INTEGRATION

OUR SOLUTION

- ***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



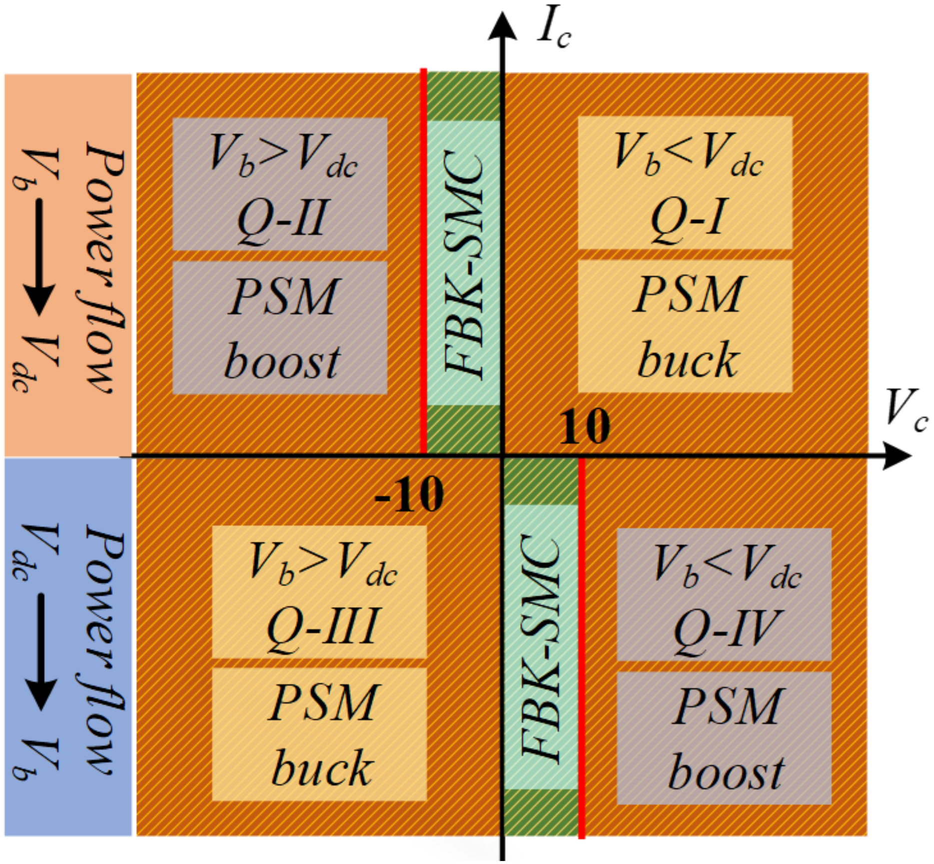
- $V_{battery\_nominal}$: **350 V** [$LiFePo_4$: 109 cell]
- **At SoC = 90 %** 109 × 3.2 V ≈ 380 V
- **At SoC = 10 %** 109 × 2.9 V ≈ 320 V
- V_{dc} **= 320 V to 380 V**
- I_{dc} **= 10 A to -10 A**

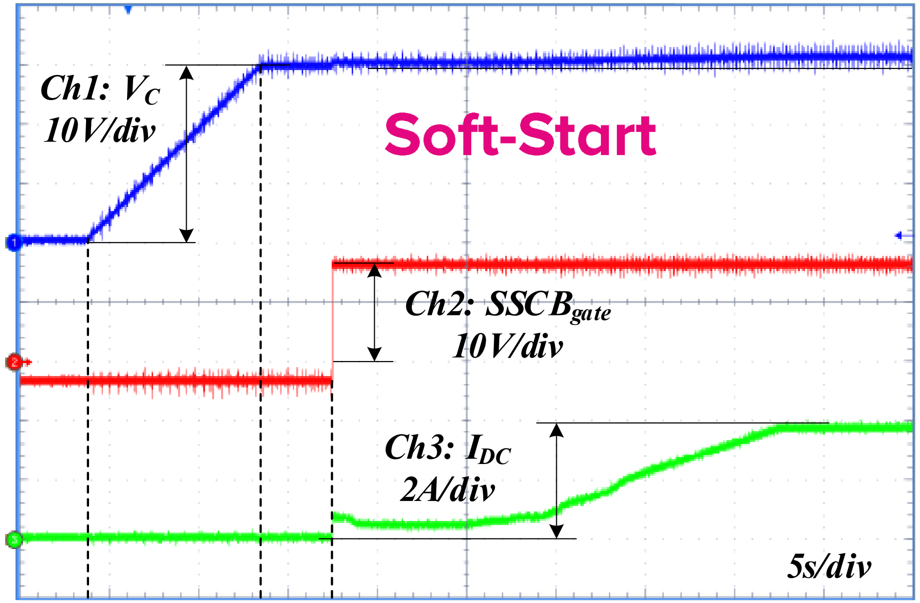
TAL TECH

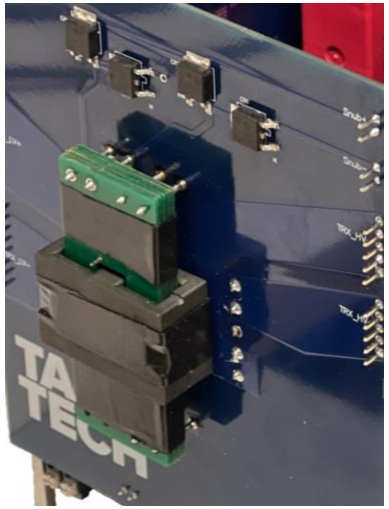
N. Hassanpour, et al. "High-Efficiency Partial Power Converter for Integration of Second-Life Battery Energy Storage Systems in DC Microgrids," in IEEE Open Journal of the Industrial Electronics Society, doi: 10.1109/OJIES.2024.3389466.

4-QUADRANT OPERATION

- *Three basic modulations are implemented to achieve current controllability in all operating points, where FBK-SMC is the modulation with circulating energy*
- *Presence of the SSCB allow to pre-charge the series capacitor, and initiate soft-start with gradual increase of the battery current up to the set point*
- *Also, a planar snubber transformer was implemented to alleviate parasitic resonances caused by reverse recovery*

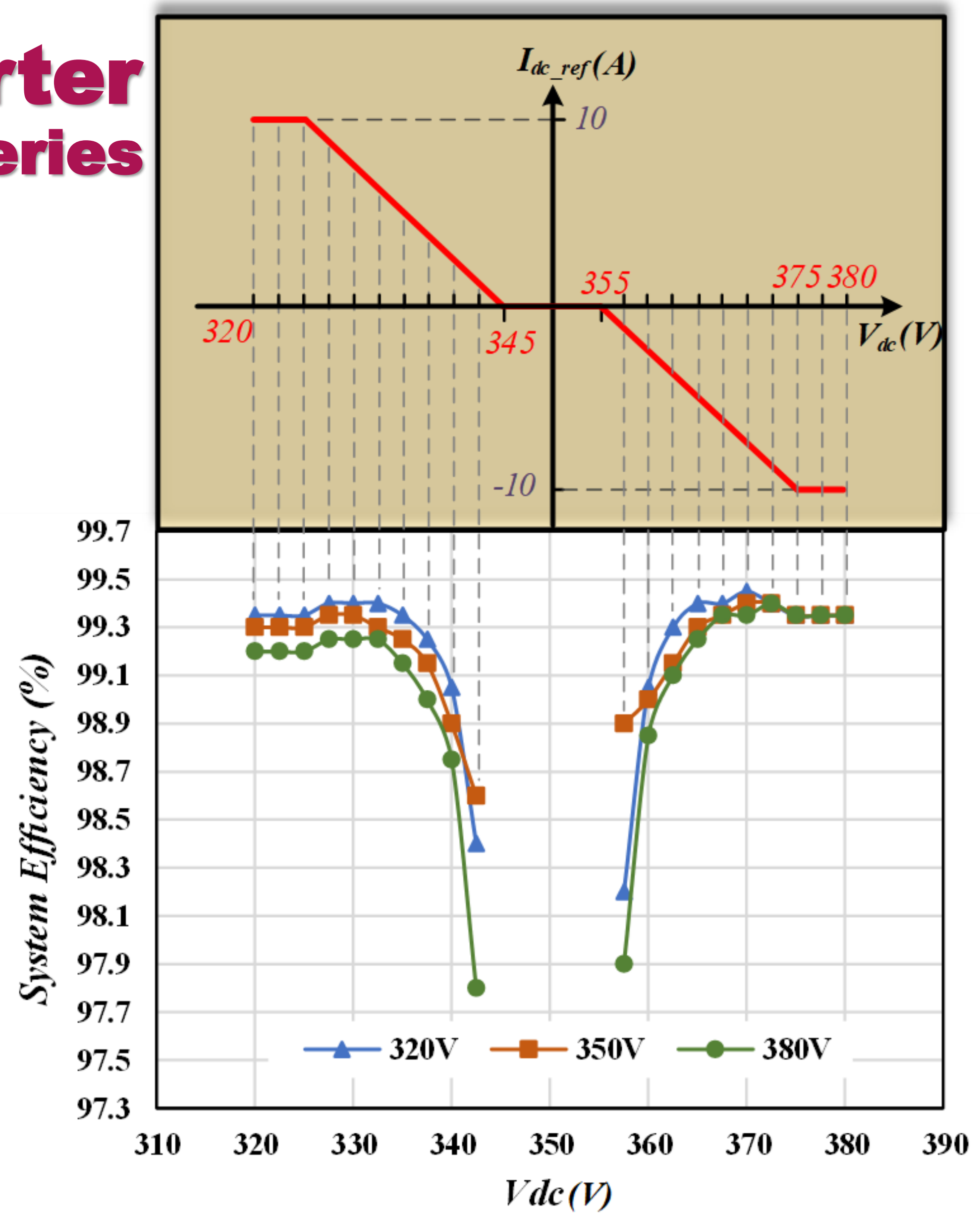






FORCE – Fractional pOweR ConvErter
For efficient integration of high-voltage batteries

- *Ultra-efficient* ***>99%***
- *Optimized for* ***350±30V*** *DC bus*
- *Designed for* ***second-life*** *LFP battery stack of 109 cells, ~8 kWh*
- ***Patented control*** *with soft-switching in the entire range*
- ***Soft-start*** *and embedded solid-state* ***protection*** *for compatibility with* ***CurrentOS*** *system*
- ***Low stress*** *on components, passive PCB-mounted cooling*
- *Ready for bidirectional* ***monolithic GaN switches*** *(Infineon)*
- ***4 kW/l*** *power density*

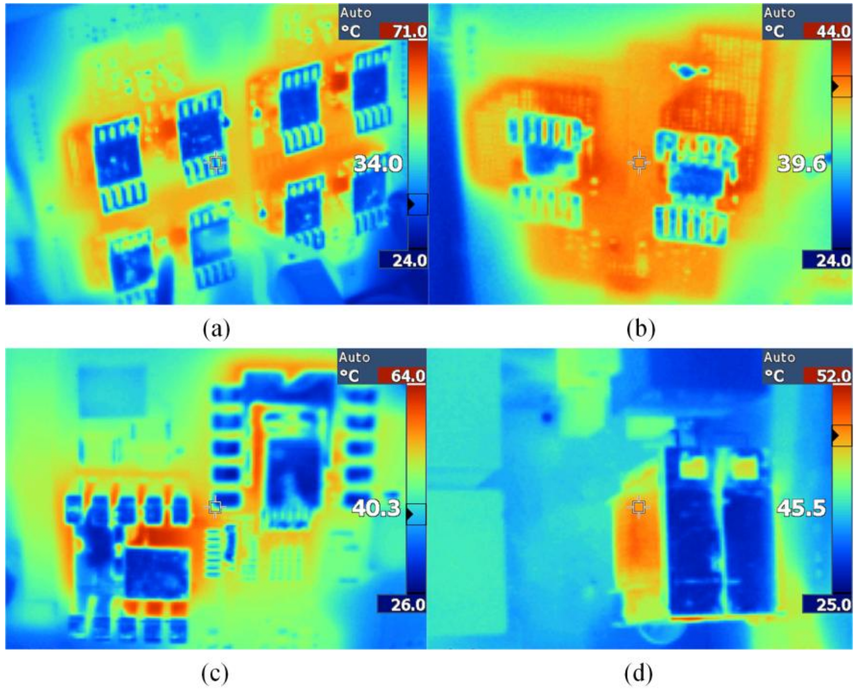


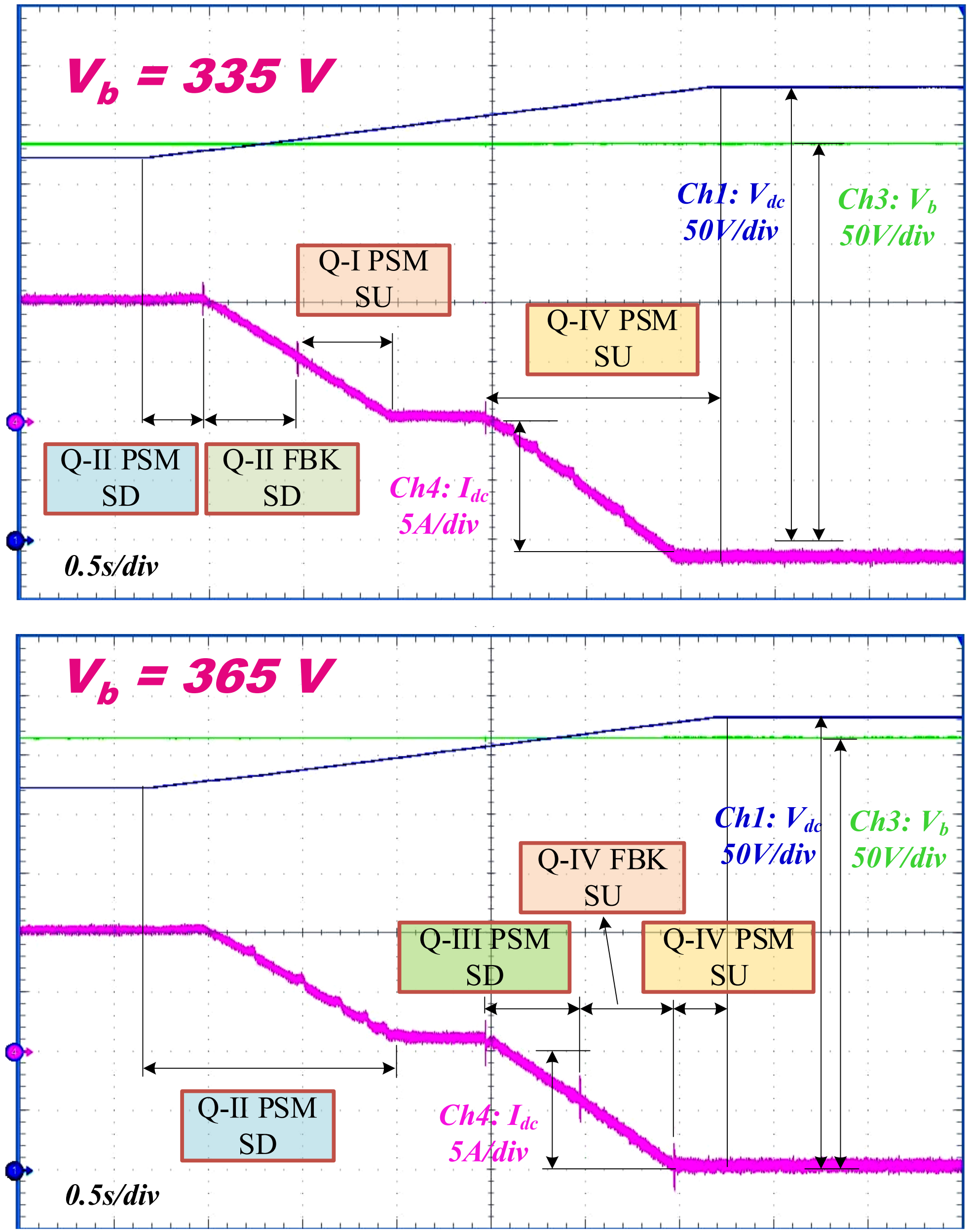
TALTECH
TALLINN UNIVERSITY OF TECHNOLOGY

doi: 10.1109/OJIES.2024.3389466

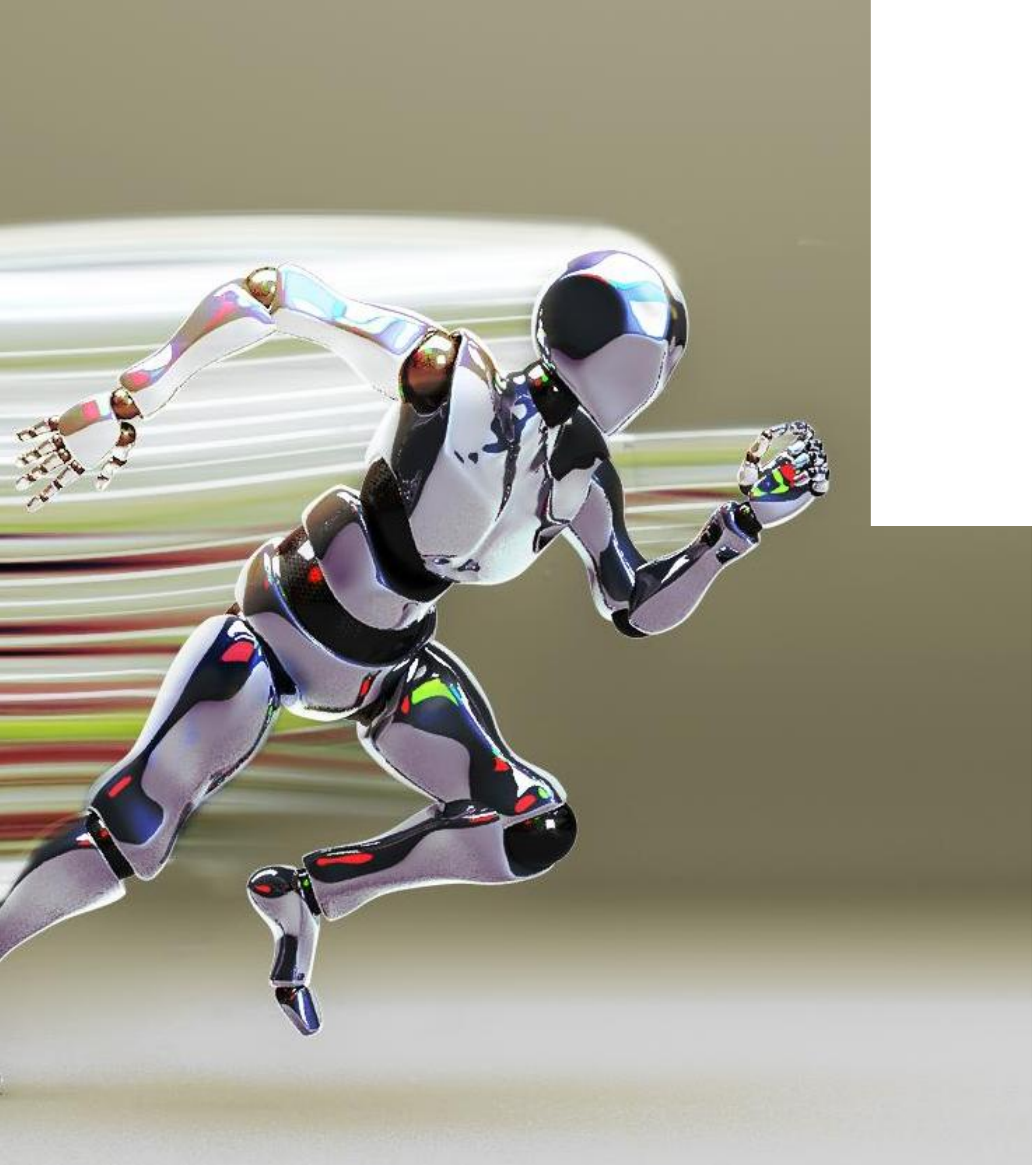
VALIDATION

- ***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*



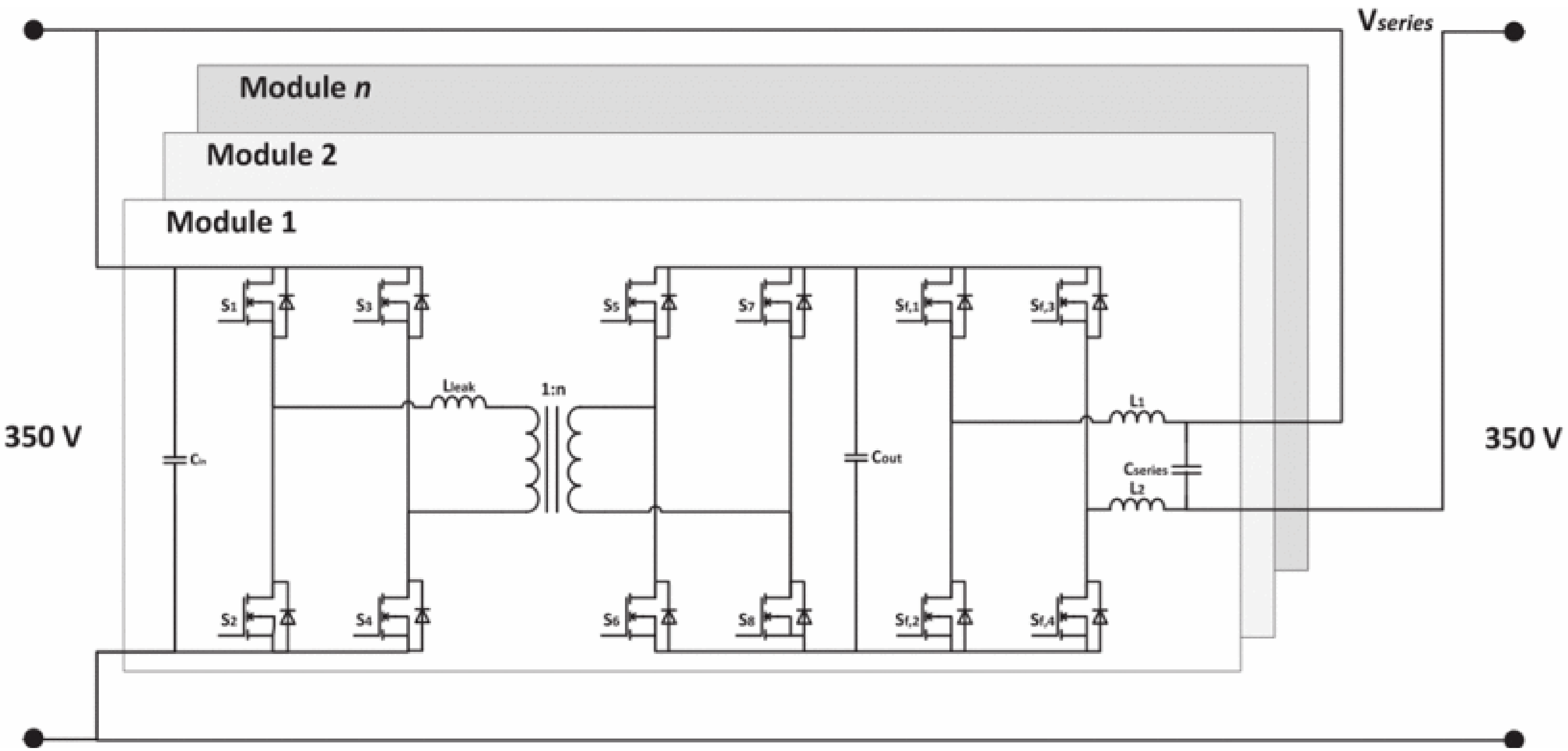


doi: 10.1109/OJIES.2024.3389466



EMERGING CONCEPTS MOVING FORWARD WITH TECHNOLOGY

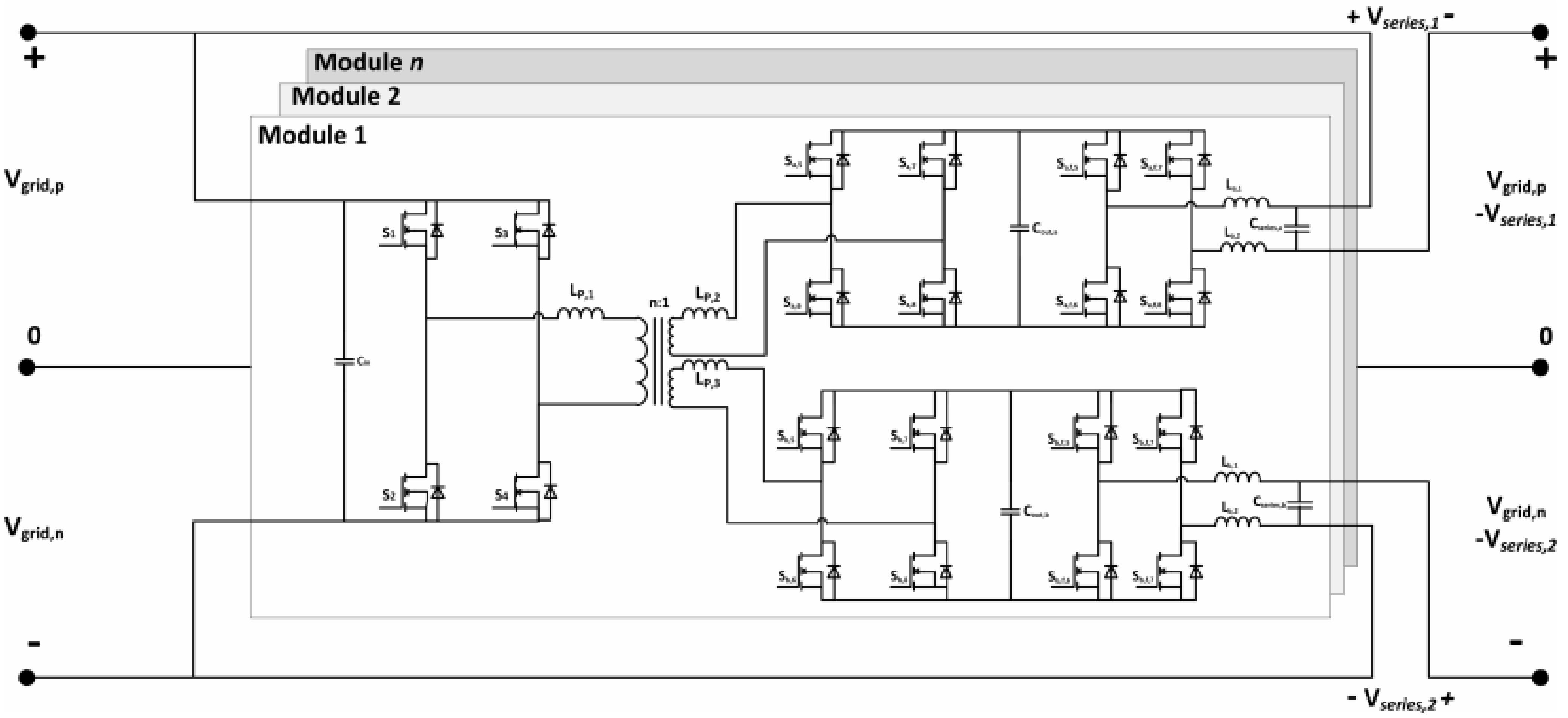
POWER FLOW CONTROL CONVERTER – UNIPOLAR



- ***Unproven** performance near zero partiality*

P. Purgat, R. A. Prakoso, L. Mackay, Z. Qin, L. Ramirez-Elizondo and P. Bauer, "A partially rated DC-DC converter for power flow control in meshed LVDC distribution grids," 2018 IEEE APEC, San Antonio, TX, USA, 2018, pp. 1591-1596, doi: 10.1109/APEC.2018.8341229.

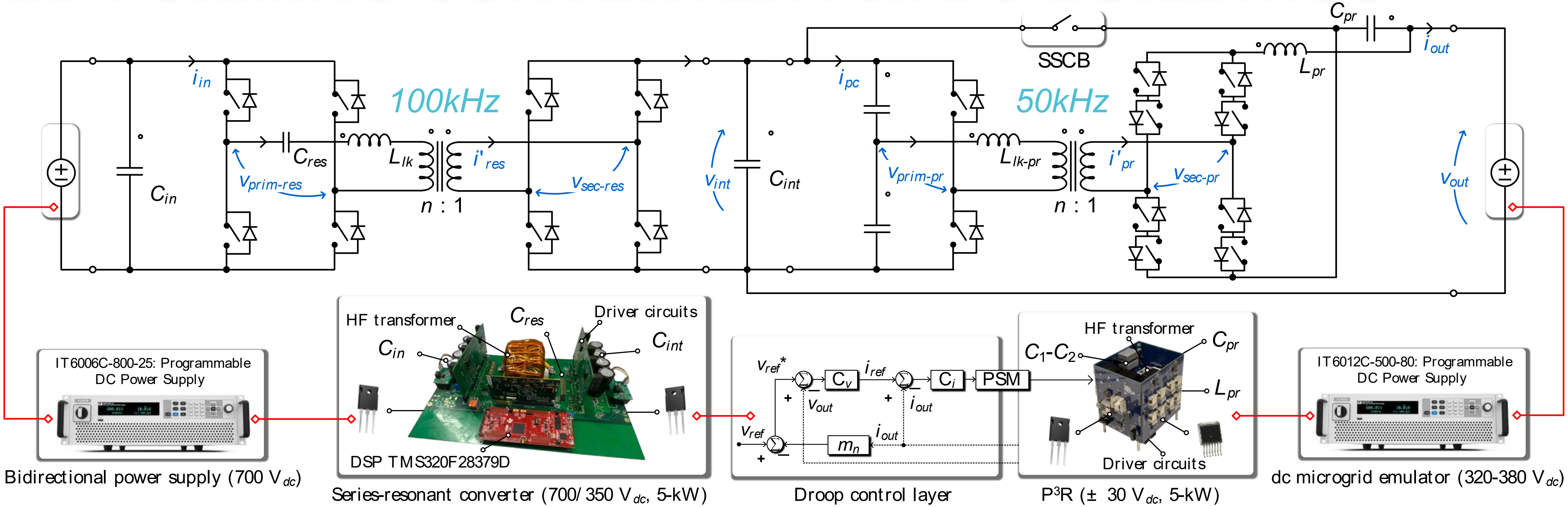
POWER FLOW CONTROL CONVERTER – BIPOLAR



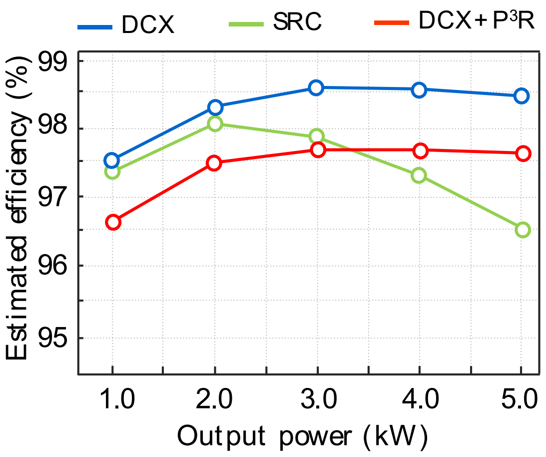
P. Purgat et al., "Design of a Power Flow Control Converter for Bipolar Meshed LVDC Distribution Grids," 2018 IEEE 18th International Power Electronics and Motion Control Conference (PEMC), Budapest, Hungary, 2018, pp. 1073-1078, doi: 10.1109/EPEPEMC.2018.8521853.

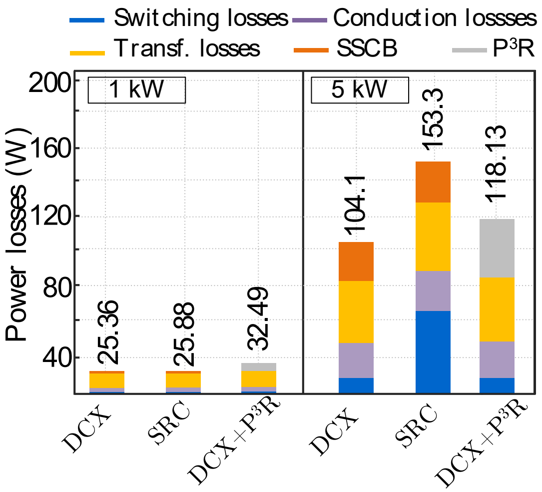
TAL TECH

GRID FORMING CONVERTER FOR DC BUILDINGS



- ***Voltage-matching DCX is uncontrolled, while PPC regulates 350V±30V DC grid voltage***

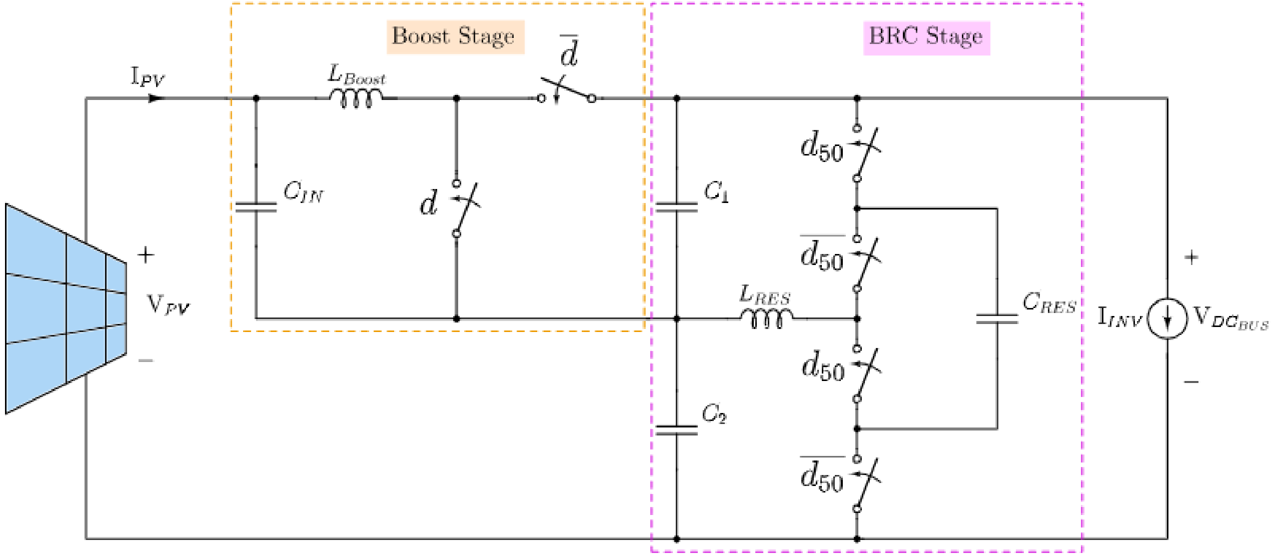


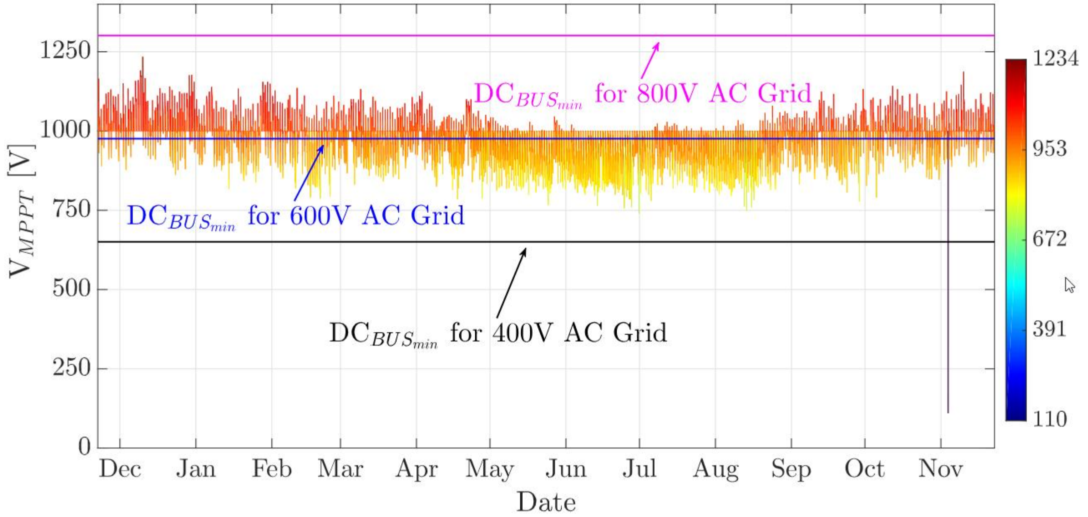


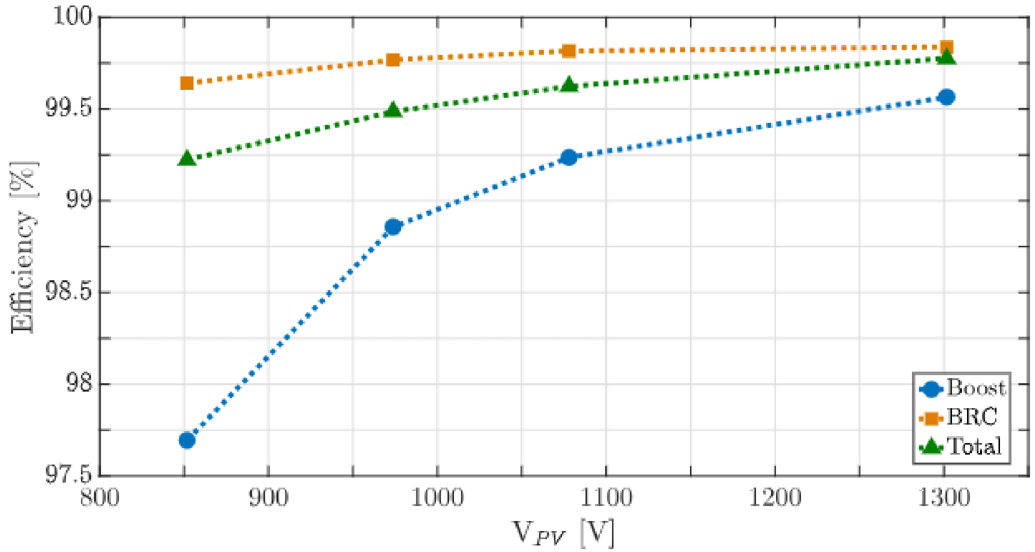
E. L. Carvalho, et al., "P3R: Partial Power Postregulated Grid-Forming Converter for Prosumer DC Buildings," in IEEE Transactions on Industrial Electronics, doi: 10.1109/TIE.2024.3423358.

TAL TECH

QUASI-2-STAGE PPC FOR PV STRING APPLICATIONS





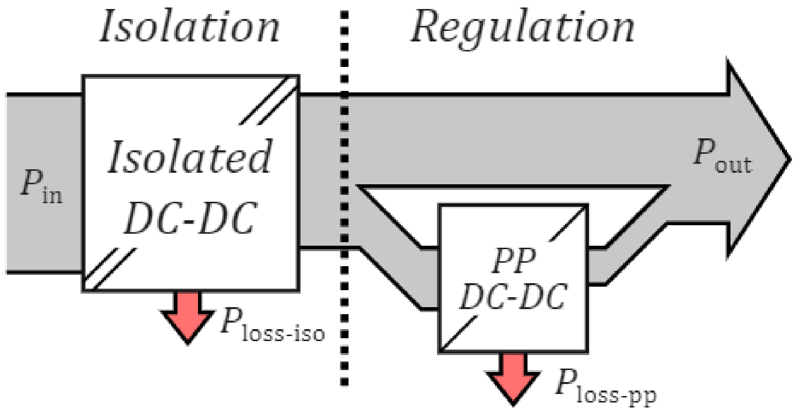


- *Resonant cell balances voltage of capacitors, allowing the boost converter to operate at half the voltage (only 900V MOSFETs used for 1500V PV string)*
- *This solution allows retrofitting existing PV plants*
- *DC-side resonant inductor extends soft-switching range*

TAL TECH

B. Stevanović, et al. "Highly Efficient, Full ZVS, Hybrid, Multilevel DC/DC Topology for Two-Stage Grid-Connected 1500-V PV System With Employed 900-V SiC Devices," in IEEE J. of Emerging and Selected Topics in Power Electronics, vol. 7, no. 2, pp. 811-832, June 2019, doi: 10.1109/JESTPE.2019.2893106.

2-STAGE PP CONVERSION FOR EV CHARGING



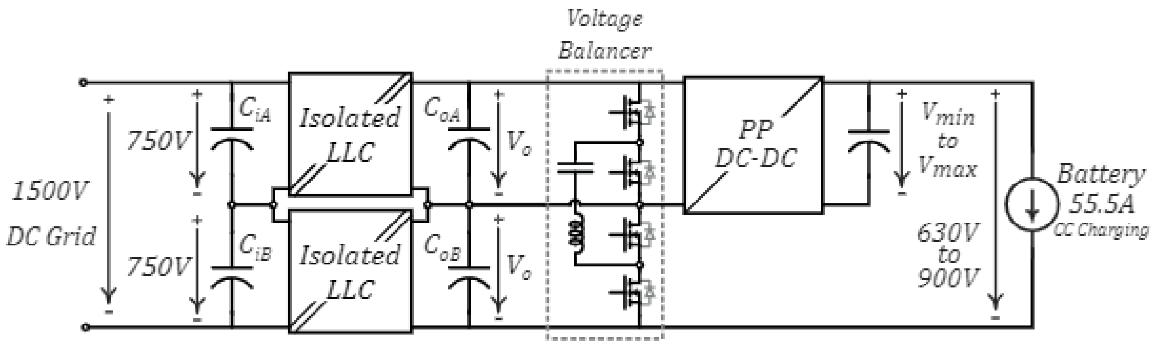


Fig. 2. 2-Level Topology

- *2-level can be implemented with SiC, while Si can be used in 3-level for connection to 1500 V DC microgrid*
- *The full ZVS condition was employed for all switches, except for ZCS in the balancer switches*
- *2-level topology shows 60% lower RMS current stress on the inductor and switches of PP converter*
- *20% lower RMS current of the 2-level voltage balancer switches*
- *The RMS current of isolated LLC is the same for both solutions*

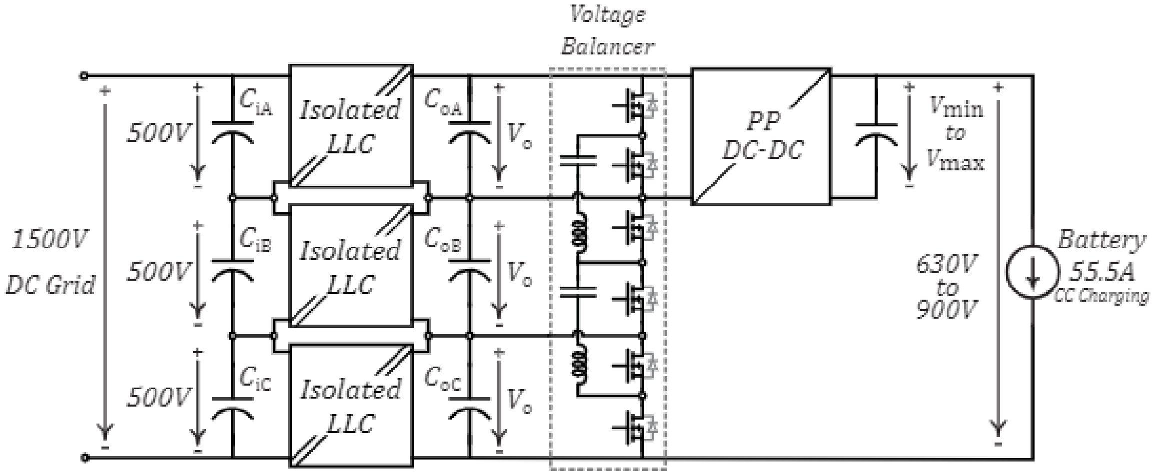


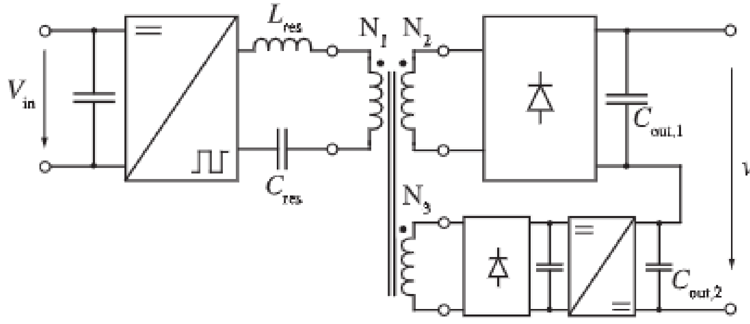
Fig. 3. 3-Level Topology

TAL TECH

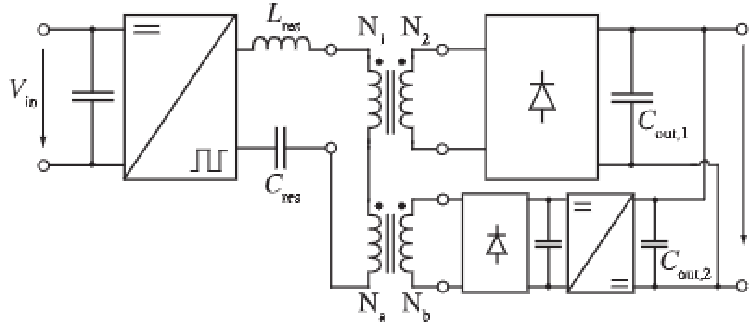
A. Stanojević, Y. E. Bouvier and P. J. Grbović, "Comparison of 2-stage isolated converters for fast EV charger, using partial power," IECON 2022 – 48th Annual Conference of the IEEE Industrial Electronics Society, Brussels, Belgium, 2022, pp. 1-6, doi: 10.1109/IECON49645.2022.9968597.

ISOLATION + PPC REGULATION CONCEPTS

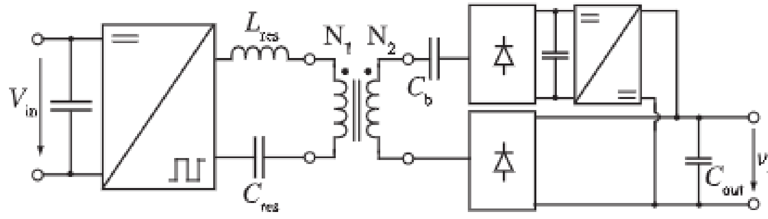
- *Series connection of integrated post-regulator allows for adjusting the output voltage in a narrow range.*
- *Parallel connection of the post-regulator requires using of two separate transformers to regulate voltage applied to the primary winding of the main transformer.*
- *Voltage can be also adjusted only in one of the legs of inverter or rectifier to provide DC gain regulation*
- *The fourth approach demonstrated could be referred to as filter-less, pre-regulation. In this case high-frequency voltage is applied to the main intverter's DC link to regulate the DC gain of the entire converter.*



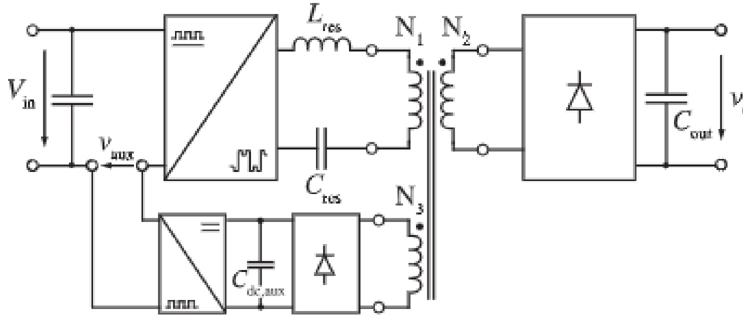
(a)



(b)



(c)

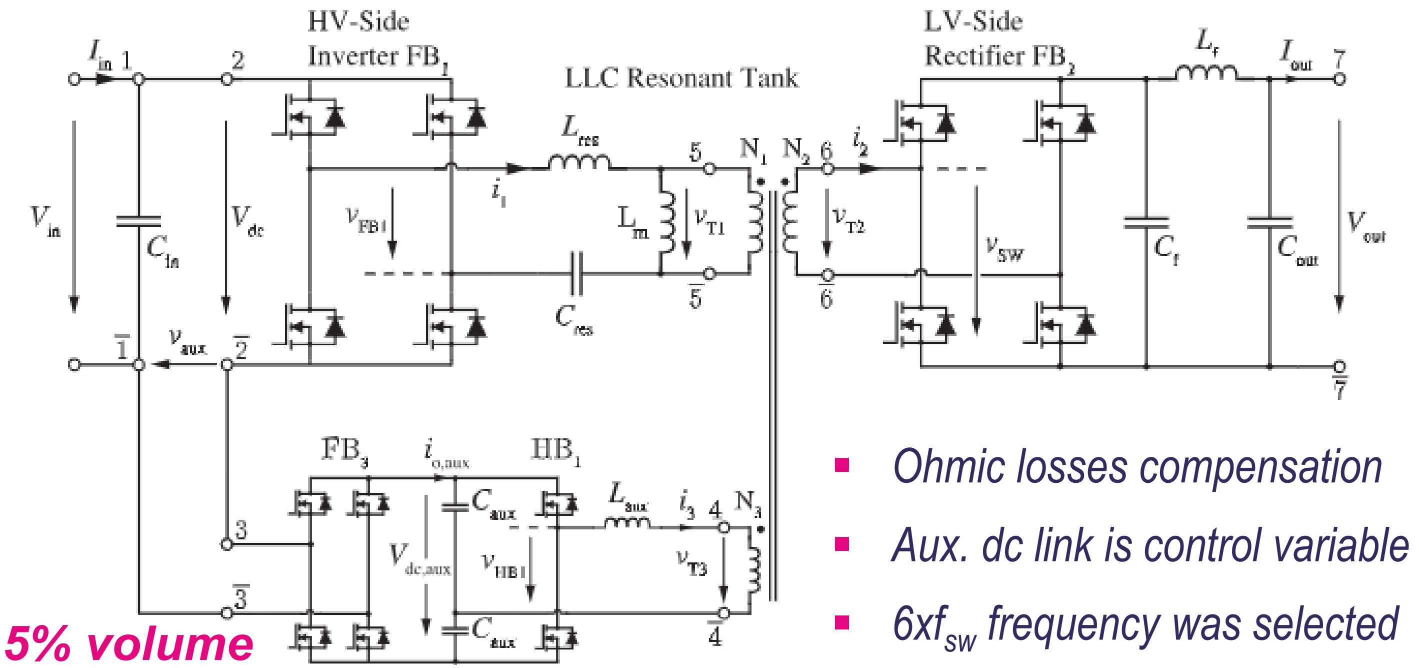


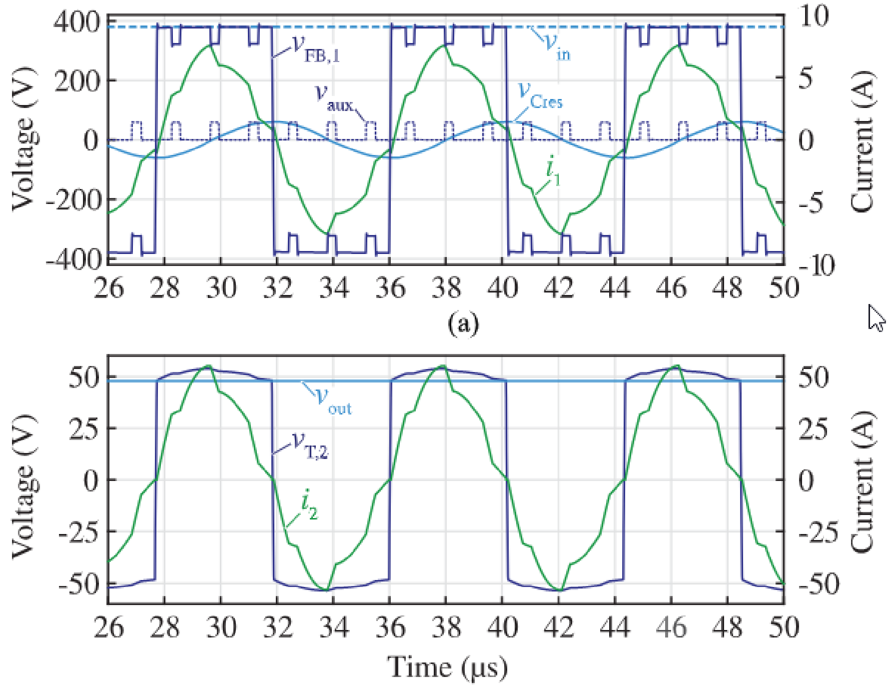
(d)

TALTECH

D. Neumayr, M. Vöhringer, N. Chrysogelos, G. Deboy and J. W. Kolar, "P³DCT—Partial-Power Pre-Regulated DC Transformer," in IEEE Transactions on Power Electronics, vol. 34, no. 7, pp. 6036-6047, July 2019, doi: 10.1109/TPEL.2018.2879064.

HF-AC-BASED PRE-REGULATION FOR TELECOM

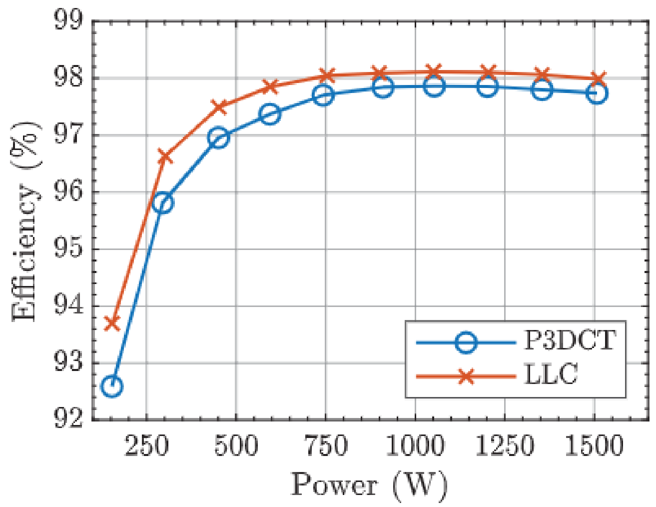


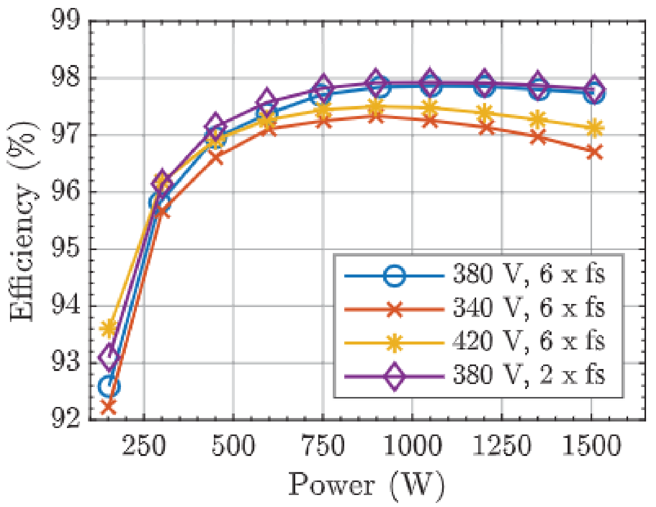


15% volume
7% partiality

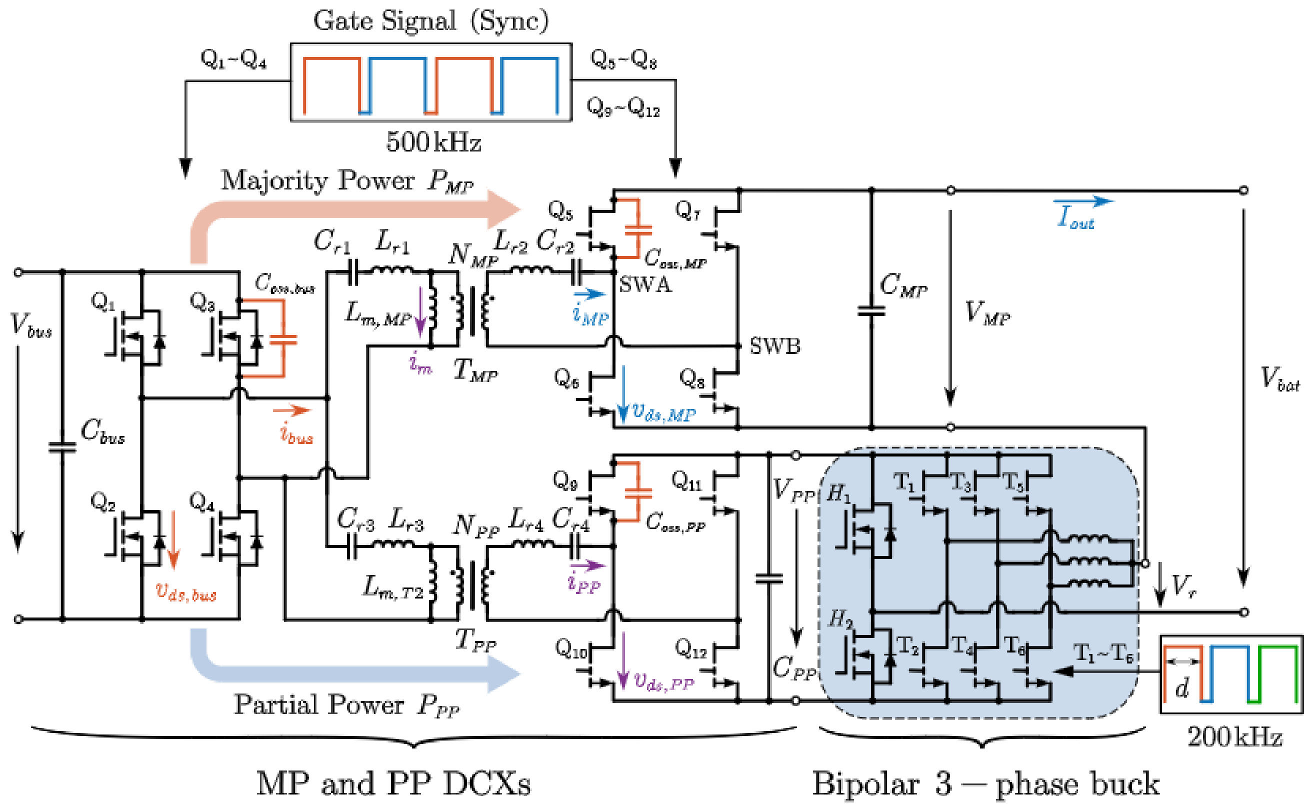
- *Ohmic losses compensation*
- *Aux. dc link is control variable*
- *6xf$_{sw}$ frequency was selected*

D. Neumayr, M. Vöhringer, N. Chrysogelos, G. Deboy and J. W. Kolar, "P³DCT—Partial-Power Pre-Regulated DC Transformer," in IEEE Transactions on Power Electronics, vol. 34, no. 7, pp. 6036-6047, July 2019, doi: 10.1109/TPEL.2018.2879064.



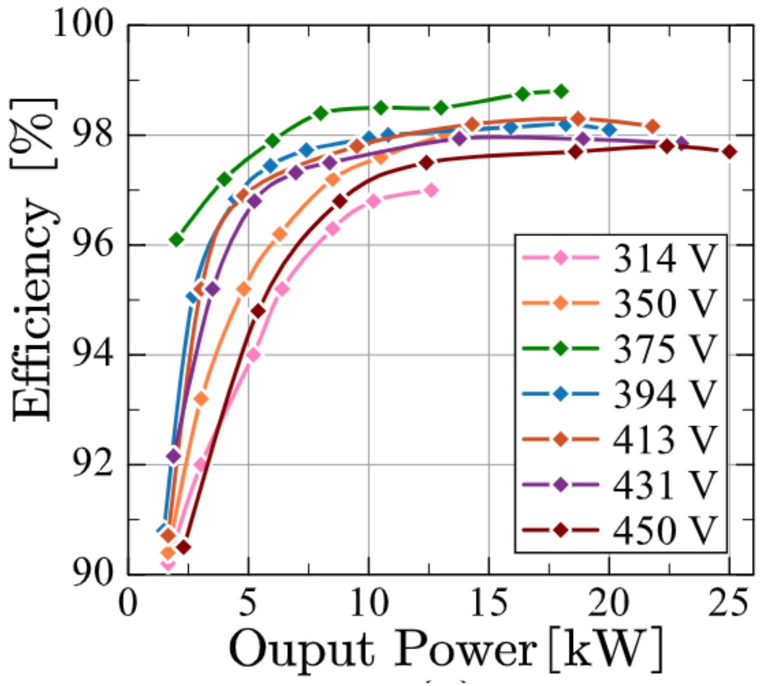


IPOS DCX + S-U/D PPC FOR BATTERY CHARGING APPL.



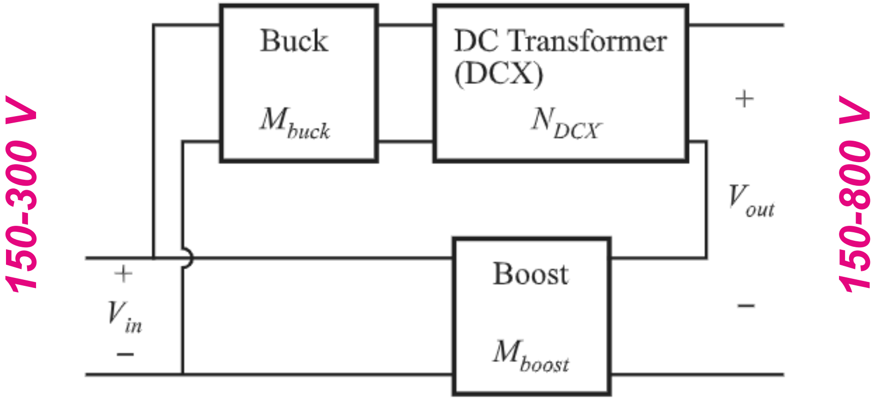
- *Interfaces 750 V bus with 315-450 V battery (375 V nominal)*
- *Delivers 18 kW (25 kW peak) at 500 kHz*
- *Max. partiality: ~17%*
- *3-phase buck provides the best loss/cost ratio*
- *Peak efficiency of 98.8% achieved @ nom. voltage*

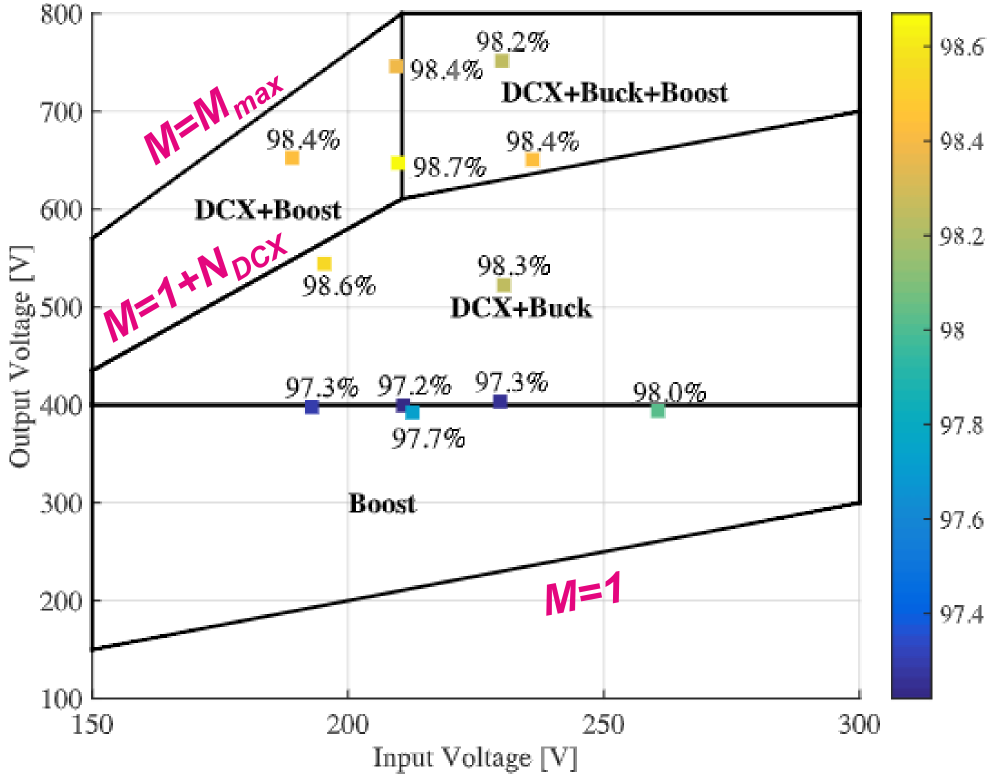
	Device	C_{oss}	Description	Parallel No.
MP DCX	C3M0016120	418 pF	1.2 kV (17 mΩ)	2
	GS66526T	276 pF	650 V (25 mΩ)	4
PP DCX	EPC2033	900 pF	150 V (15 mΩ)	2



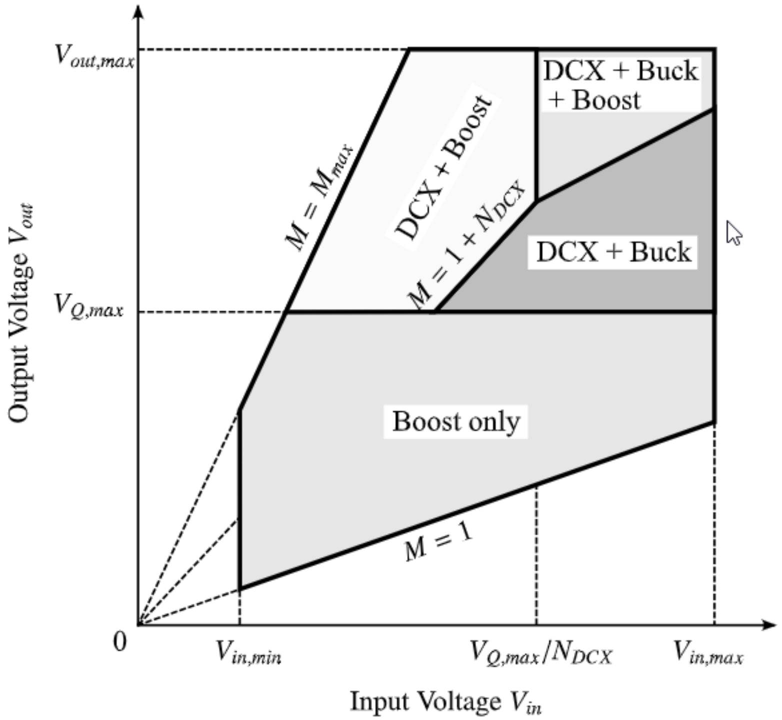
Y. Cao, M. Ngo, N. Yan, D. Dong, R. Burgos and A. Ismail, "Design and Implementation of an 18-kW 500-kHz 98.8% Efficiency High-Density Battery Charger With Partial Power Processing," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 10, no. 6, pp. 7963-7975, Dec. 2022, doi: 10.1109/JESTPE.2021.3108717.

COMPOSITE CONVERTER – WIDE-RANGE EV CHARGING



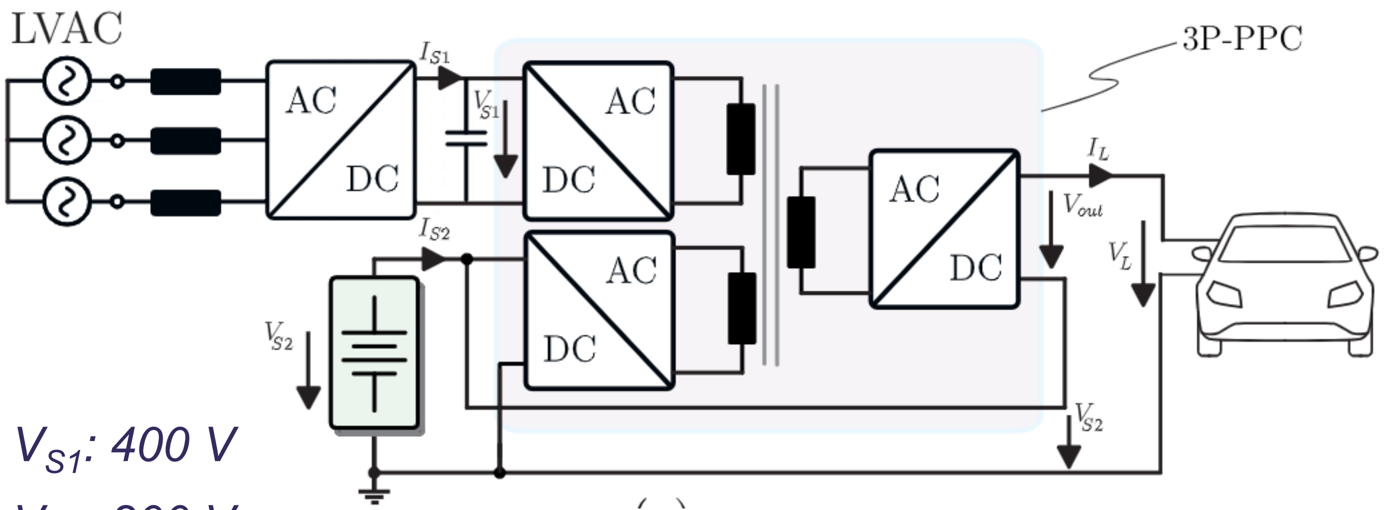


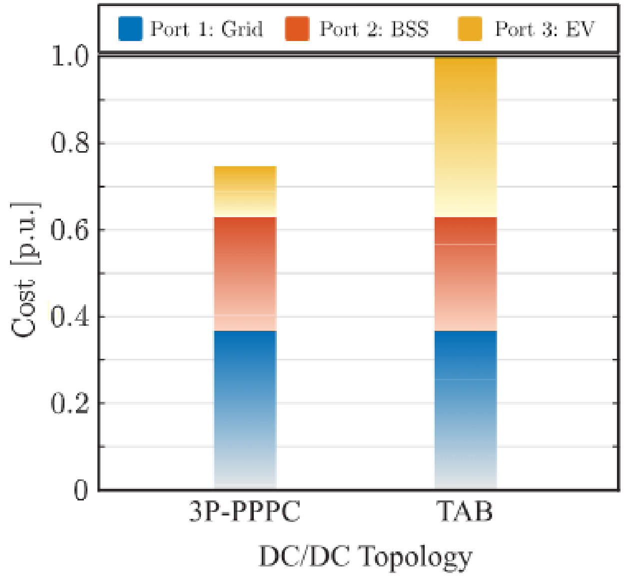
- *It is desired to maximize the boost+DCX operating area to achieve lower DCX primary side transformer current and lower inductor current.*
- *Since the lowest conversion ratio the boost+DCX mode can achieve is $M = N_{DCX} + 1$, maximizing boost+DCX operating area requires minimization of N_{DCX}.*
- *Minimizing N_{DCX} also minimizes the operating area where the buck and boost modules operate simultaneously. Hence, switching loss is reduced as well.*
- *Therefore, the minimum value $N_{DCX} = 1.9$ is chosen.*



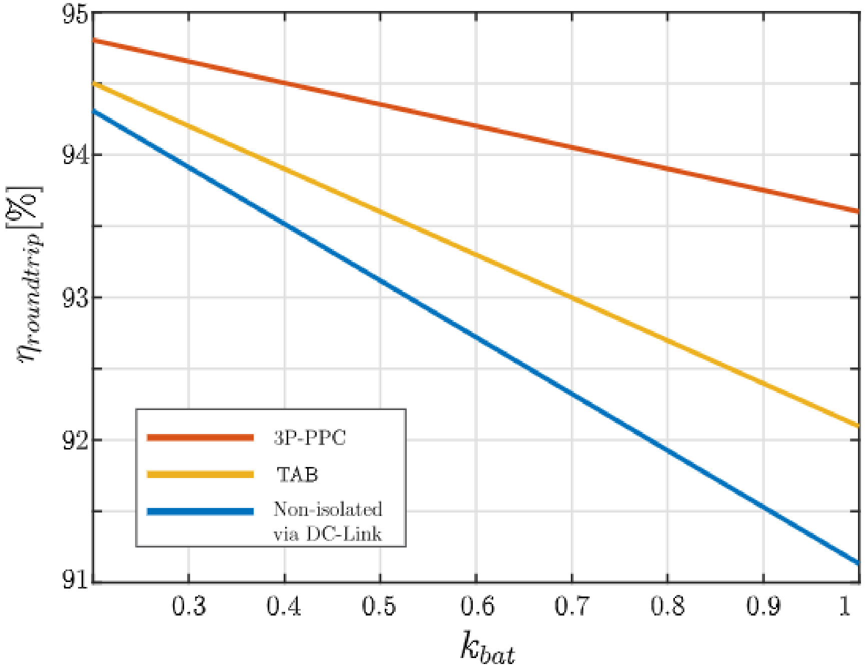
H. Chen, K. Sabi, H. Kim, T. Harada, R. Erickson and D. Maksimovic, "A 98.7% Efficient Composite Converter Architecture With Application-Tailored Efficiency Characteristic," in IEEE Transactions on Power Electronics, vol. 31, no. 1, pp. 101-110, Jan. 2016, doi: 10.1109/TPEL.2015.2398429.

3-PORT CONVERTER WITH PPC PORT – EV CHARGING





- V_{S1}: 400 V
- V_{S2}: 200 V
- V_L: 260-340 V
- V_{out}: 60-140 V (reduced due to PPC port)
- TX freq.: 20 kHz

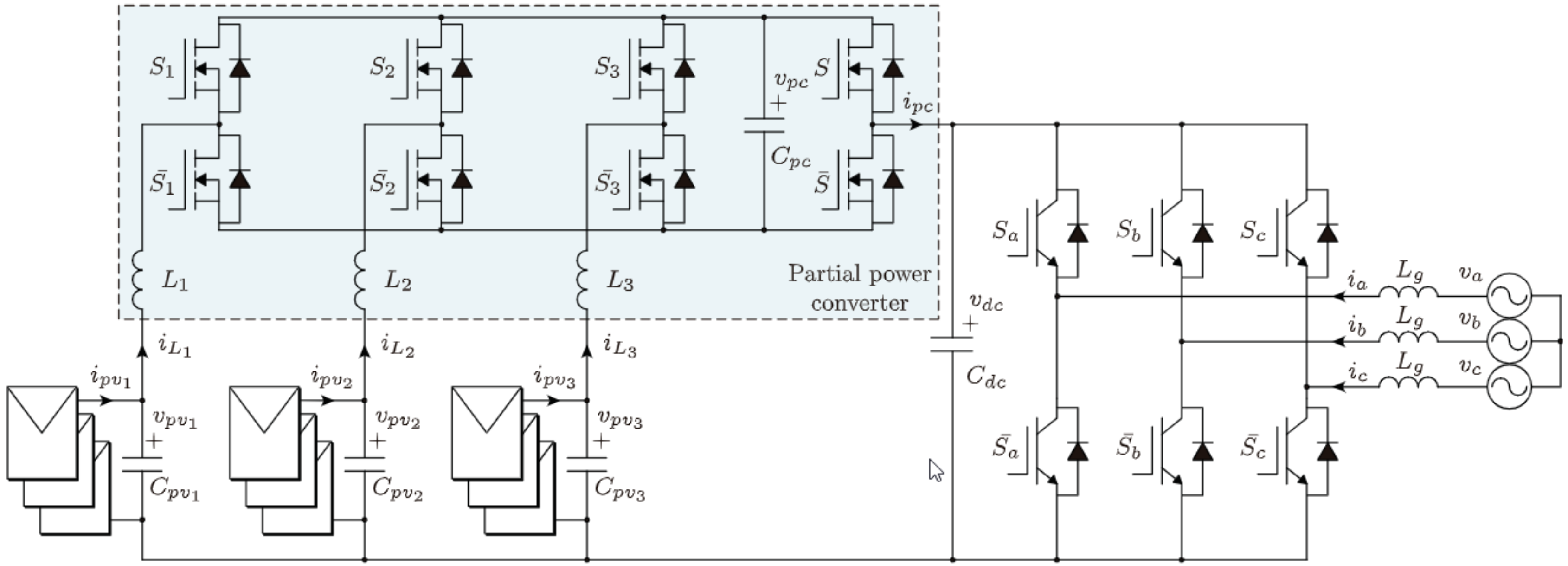


F. Hoffmann, et al. "A Multiport Partial Power Processing Converter With Energy Storage Integration for EV Stationary Charging," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 10, no. 6, pp. 7950-7962, Dec. 2022, doi: 10.1109/JESTPE.2021.3102180.

TAL TECH

MULTIPORT TRANSFORMERLESS PPC – PV STRINGS

- *The main topology is the same as in the quasi-PPC presented before*
- *The peak efficiency is estimated to be over 99%*
- *Controllability is limited as v_{pc} dynamics is coupled with the dynamics of individual inductors*

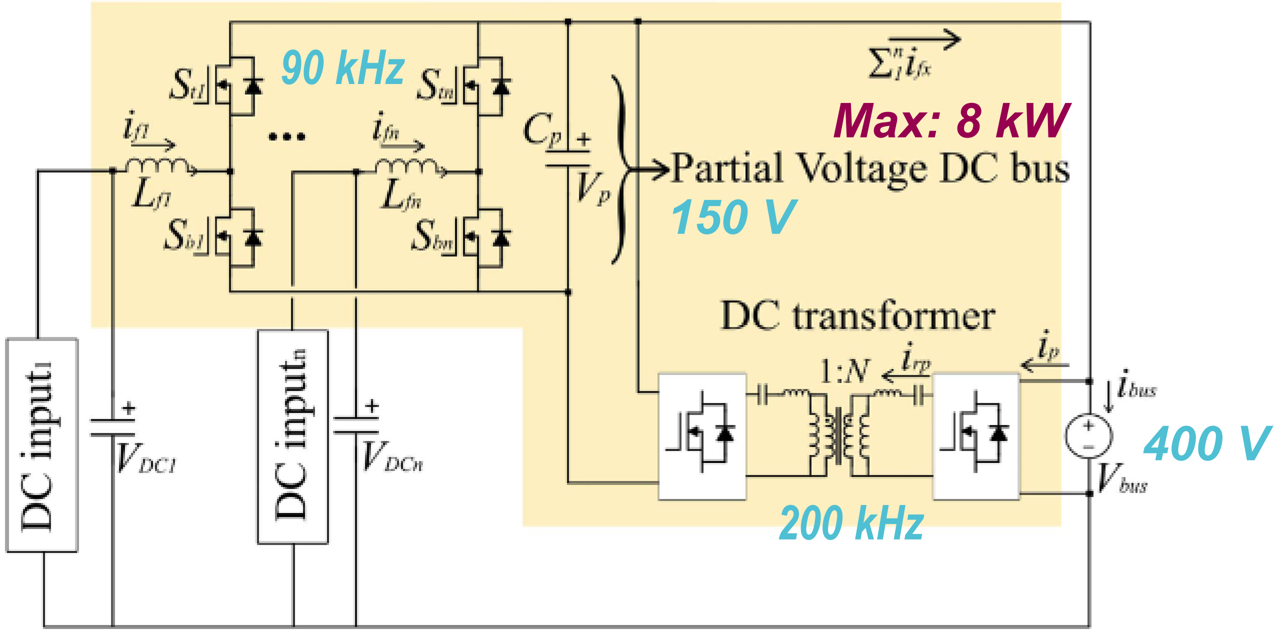


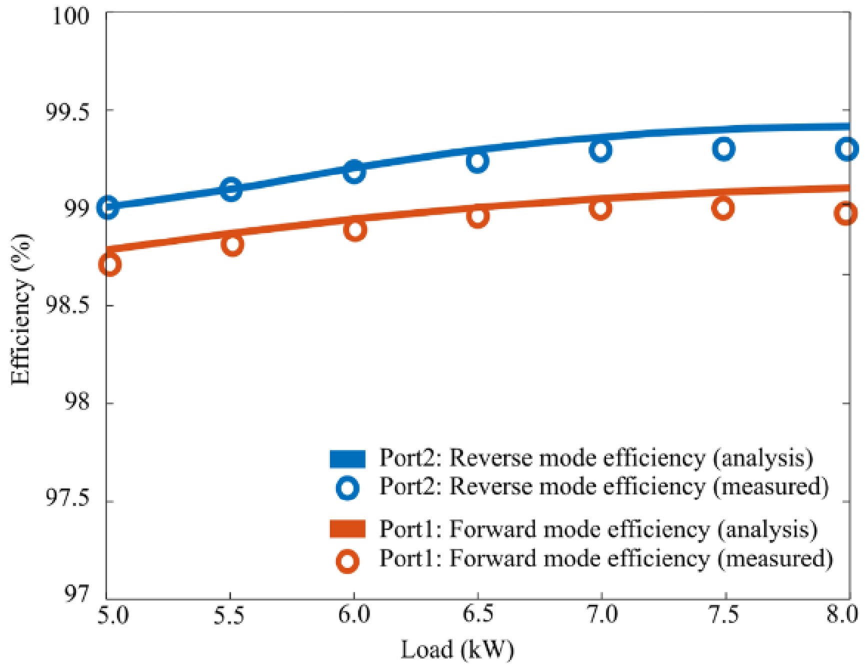
- *Suitable for utility-scale PV installations*
- *Each PV string has individual MPPT PPC*
- *PV strings are highly standardized, little variations of MPP voltage*
- *Scalability is limited due to share leg coupled to DC link*

J. W. Zapata, T. A. Meynard and S. Kouro, "Partial power DC-DC converter for large-scale photovoltaic systems," 2016 IEEE 2nd Annual Southern Power Electronics Conference (SPEC), Auckland, New Zealand, 2016, pp. 1-6, doi: 10.1109/SPEC.2016.7846077.

MULTI-INPUT PPC – RESIDENTIAL PV APPLICATIONS

- *This concept can only step-up PV string voltage, hence applicability is limited to small (home) PV systems*
- *Each channel's half-bridge controls current independently, which can be bidirectional*
- *PPC peak efficiency reaches 99.2%, while resonant DC-DC within reaches 97.4%*
- *PPC is rated for 3 kW to be capable of delivering 8kW of total power with two half-bridges*

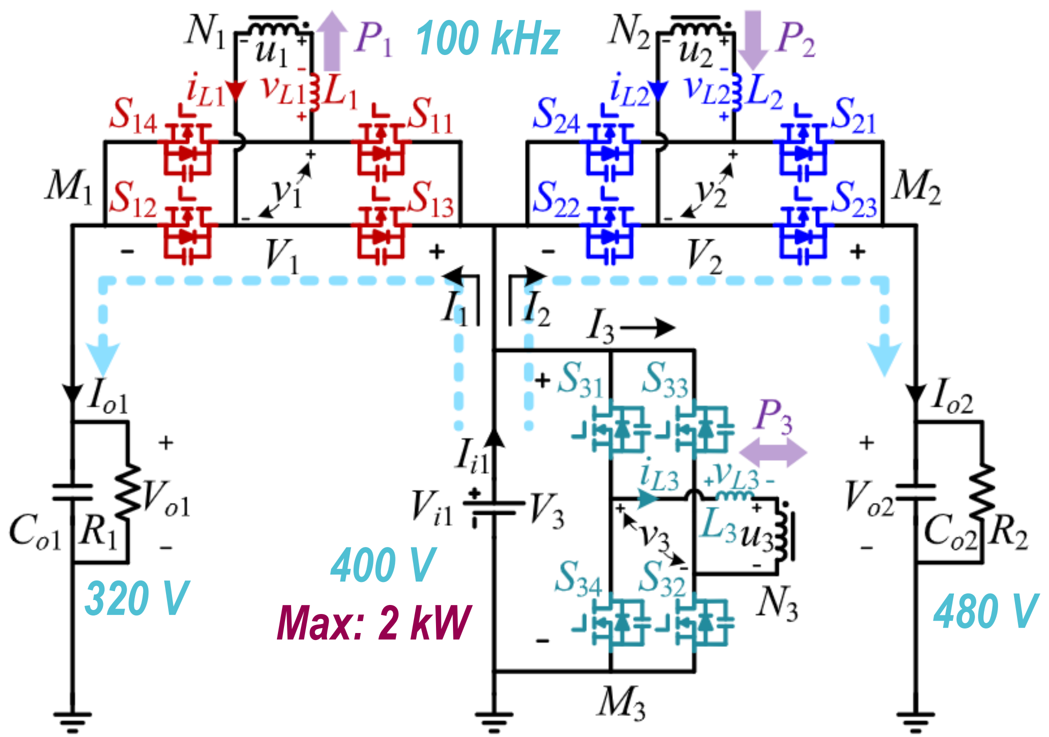


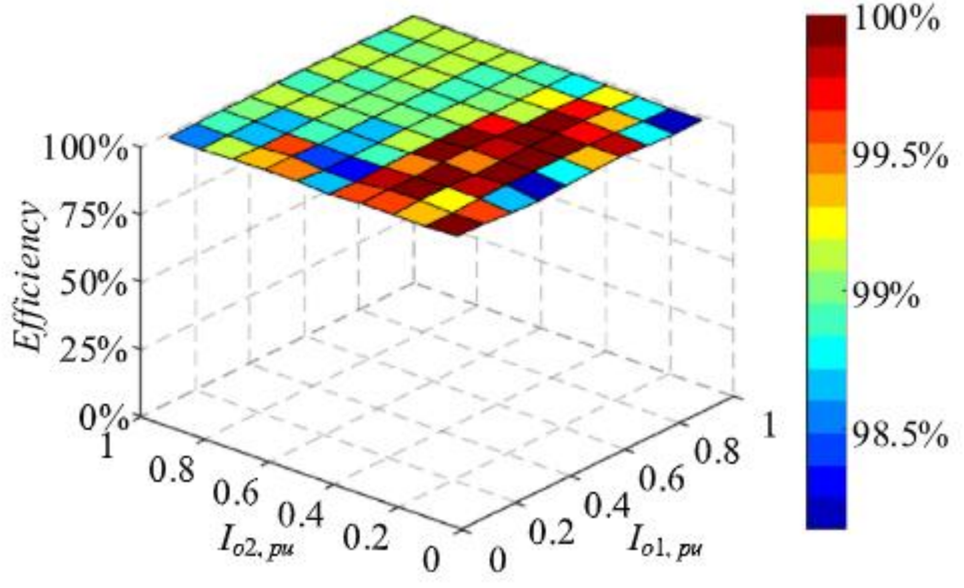


TAL TECH

Y. D. Kwon, F. D. Freijedo, T. Wijekoon and M. Liserre, "A Multiport Partial Power Converter for Smart Home Applications," in IEEE Transactions on Power Electronics, vol. 39, no. 7, pp. 8824-8833, July 2024, doi: 10.1109/TPEL.2024.3388322.

RADIAL MULTIPORT STEP-UP PPC



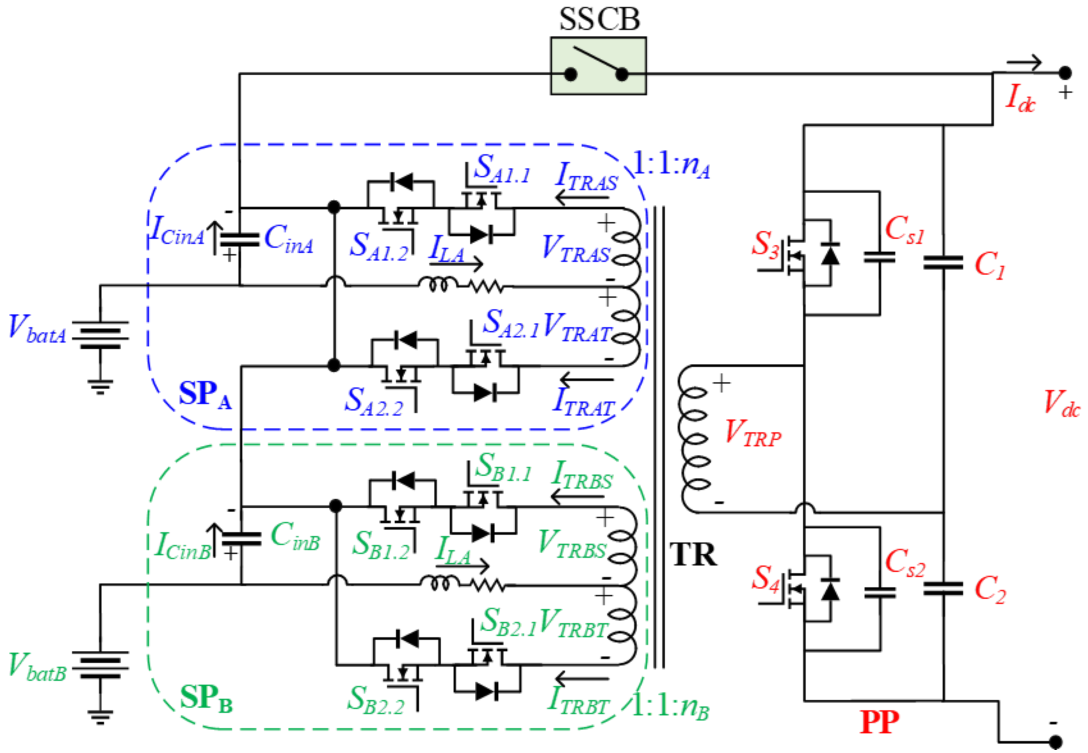


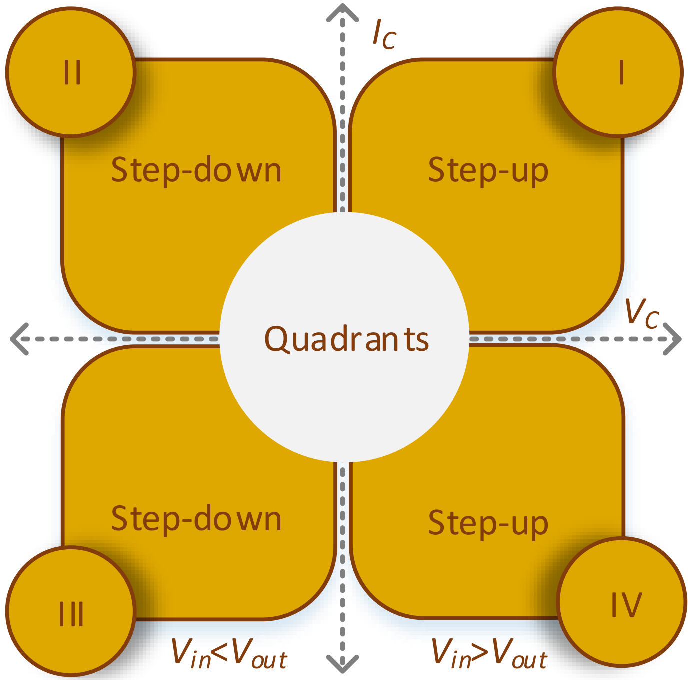
- *Hard to control due to coupling between ports*
- *Limited voltage regulation range*
- *Limited soft-switching range*
- *Could suffer from high circulating current (losses)*
- *Startup process could be challenging when outputs needs to be charged first*

TAL TECH

Y. Liu, Y. Hu, G. Chen and H. Wen, "Partial Power Processing Multiport DC–DC Converter With Radial Module Connections," in IEEE Transactions on Power Electronics, vol. 37, no. 11, pp. 13398-13412, Nov. 2022, doi: 10.1109/TPEL.2022.3181025.

MULTIPORT STEP-UP/DOWN PPC – CONCEPT

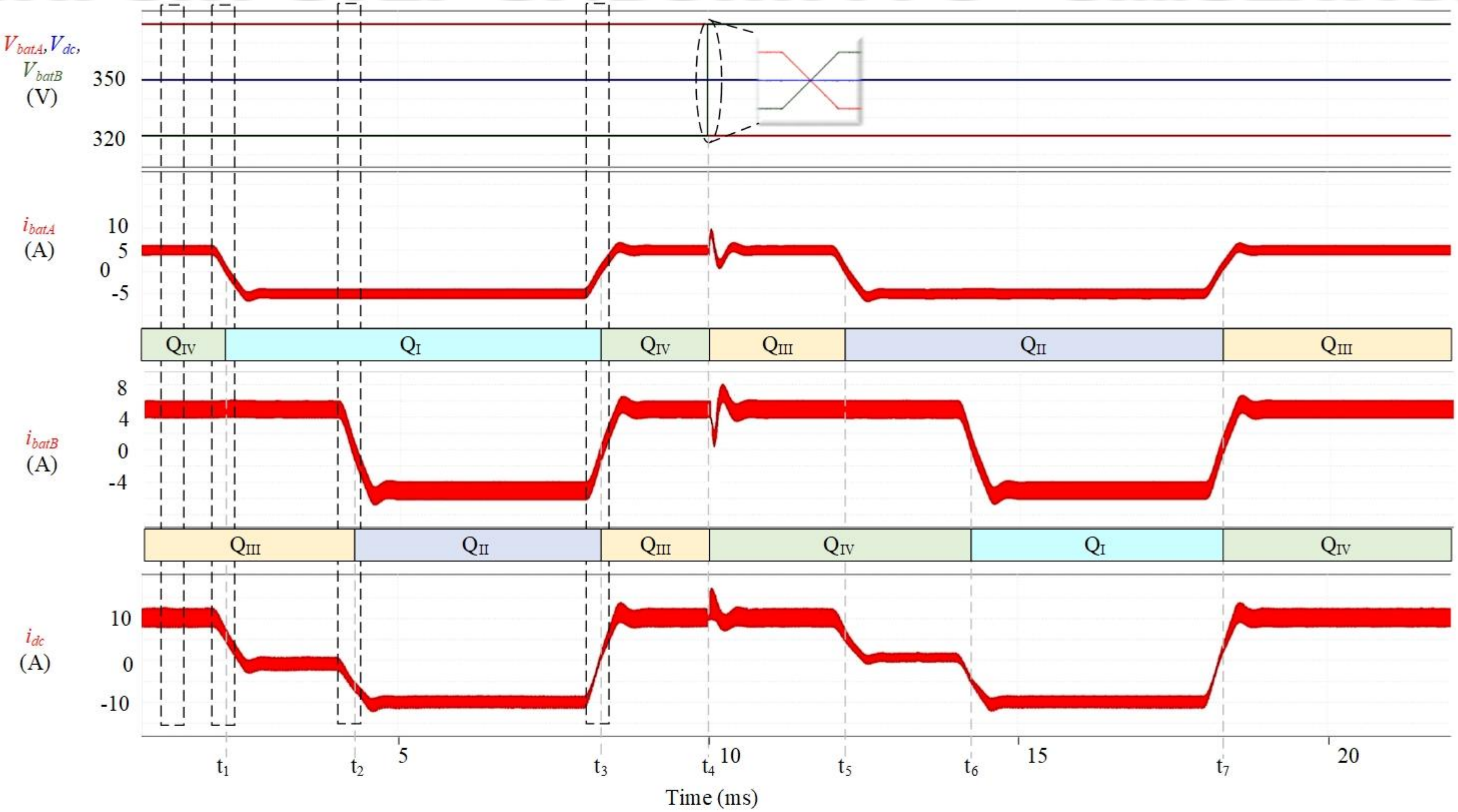




- *Fully decoupled control loops*
- *Wide voltage regulation range with min. partiality*
- *Wide soft-switching range*
- *Balanced VA stresses of components*
- *Embedded protection enables soft start-up and safe operation of the system*

N. Yadav and A. Chub, "Multiport Current Fed Push/Pull Partial Power Converter for Battery Integration in DC Microgrid," IEEE CPE-POWERENG 2024, Gdynia, Poland, 2024, pp. 1-6.

MULTIPORT STEP-UP/DOWN PPC – SIMULATIONS



N. Yadav and A. Chub, "Three-Port Current Fed Push/Pull Partial Power Converter for Integration of PV/Battery Systems in DC Microgrids, IEEE CPE-POWERENG2024, presented, pending submission to IEEEXplore.

THANK YOU FOR YOUR TIME
QUESTIONS?

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