POWER GROUP ELECTRONICS

ЧЕРНІГІВСЬКИЙ ДЕРЖАВНИЙ ТЕХНОЛОГІЧНИЙ УНІВЕРСИТЕТ

1918 TALLINNA TEHNIKAÜLIKOOL
UNIVERSITAS RERUM TECHNICARUM REVALIENSIS

Three-Level Neutral-Point-Clamped Quasi-Z-Source Inverter as a New Solution for Renewable Energy Application

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Dept. of Electrical Drives and Power Electronics

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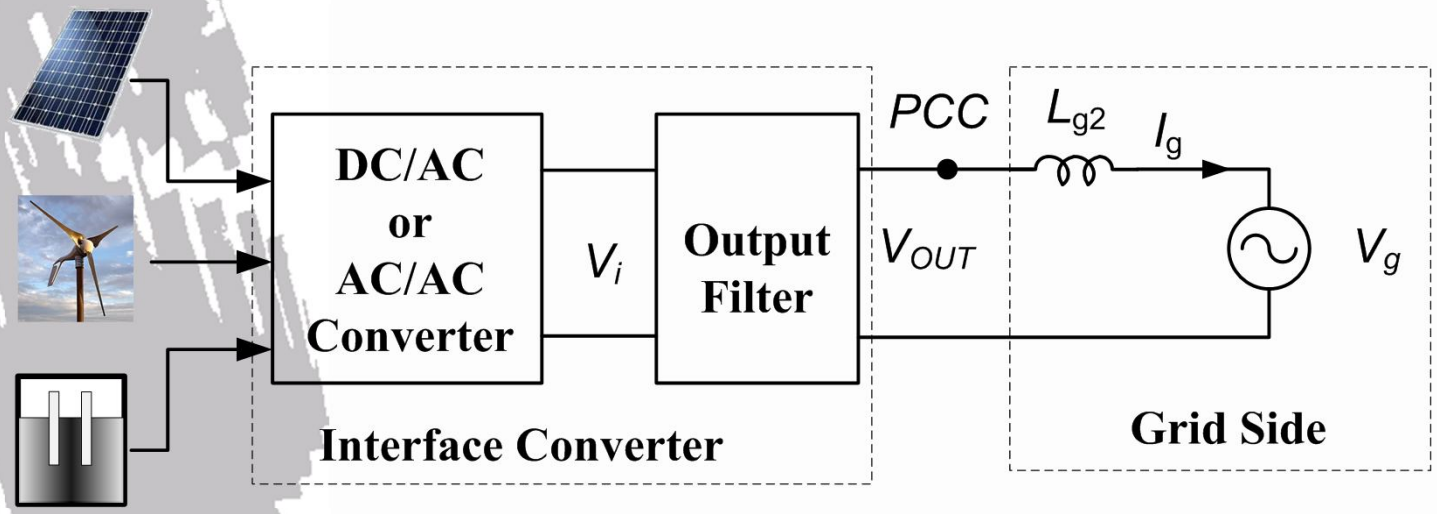
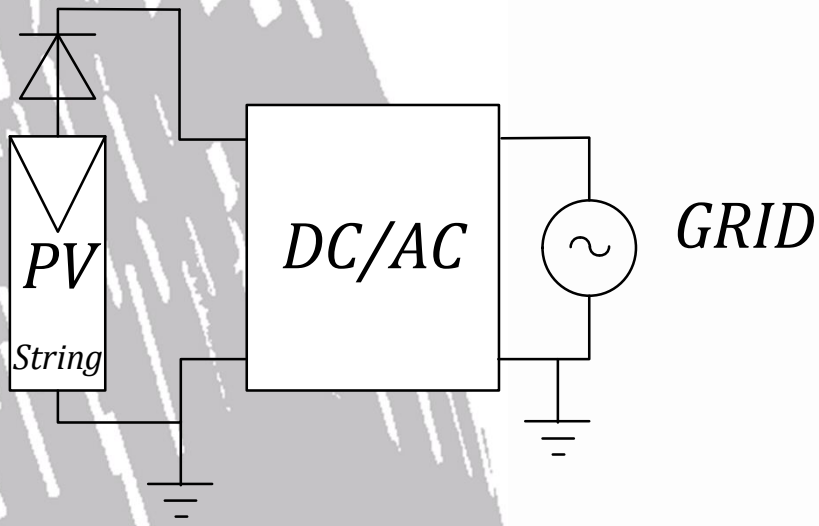
Introduction: renewable energy applications

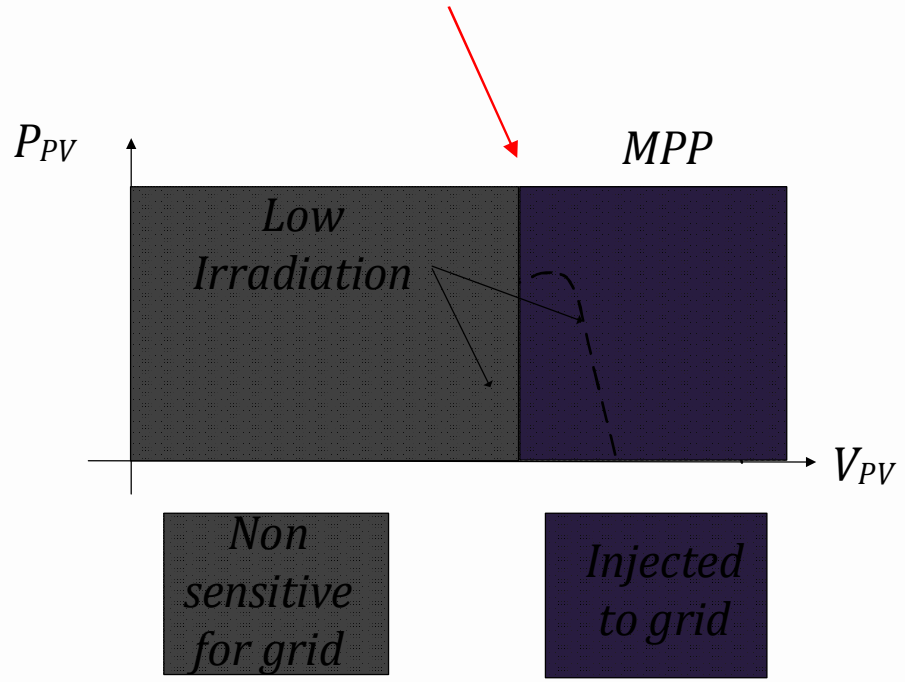


Introduction: traditional solutions

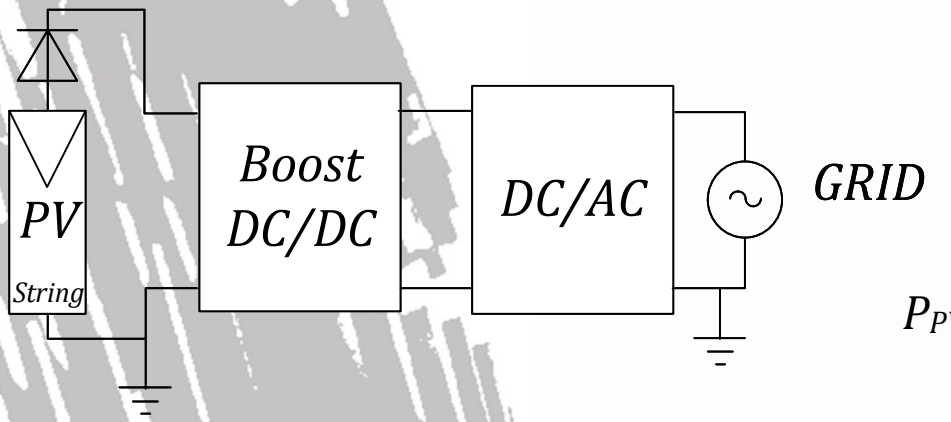


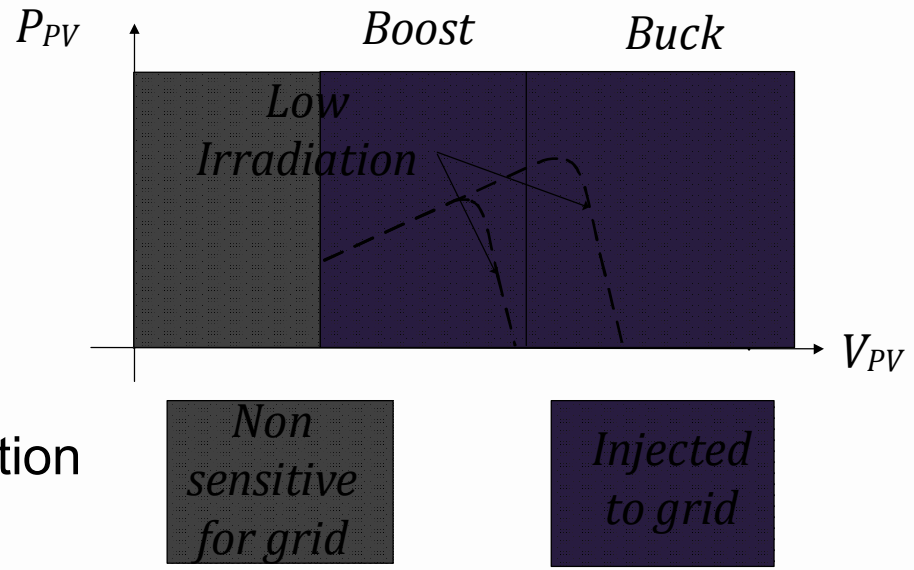
- Simple and cheap solutions
- Narrow range input voltage operation

Maximum Modulation Index



Introduction: traditional solutions



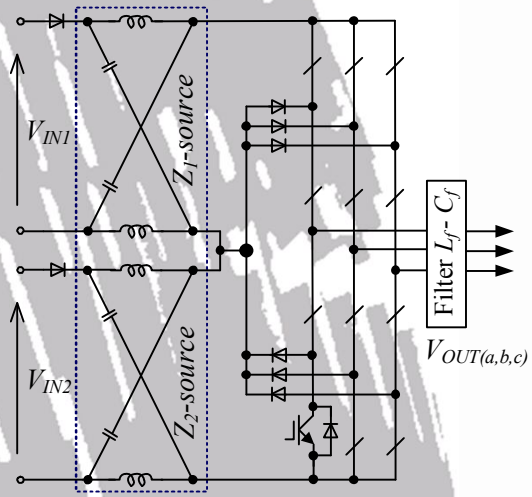


- Two stage conversion solutions
- Wide range input voltage operation

Introduction: new trends in PV inverters

- Wide range input operation;
- Input current continuous operation mode;
- Bidirectional operations (for heating);
- Active filtering function in PCC;
- Multilevel inverters;
- Integrated boost and buck solutions.

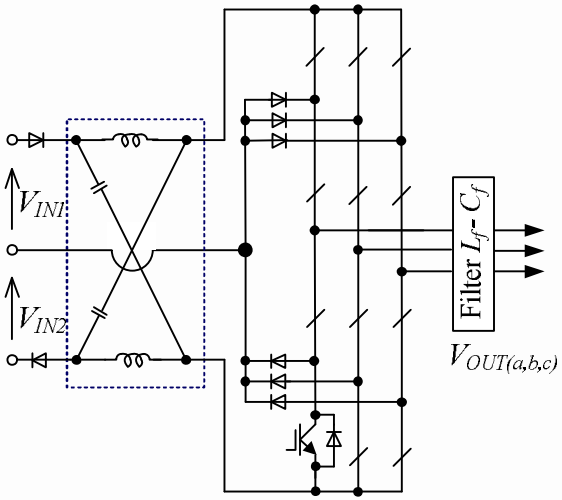
Introduction: new solutions



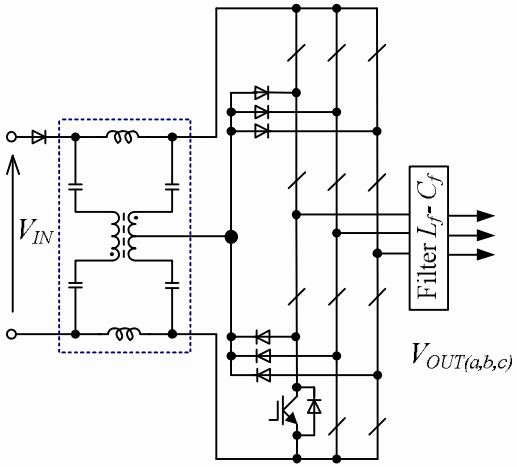
Single-stage buck-boost multilevel inverter with two separate Z-source networks

Poh Chiang Loh; Feng Gao; Blaabjerg, F.; Shi Yun Charmaine Feng; Kong Ngai Jamies Soon, "Pulsewidth-Modulated Z-Source Neutral-Point-Clamped Inverter"

Z-source NPC inverter with single impedance network



Poh Chiang Lo, Sok Wei Lim, Feng Gao, Frede Blaabjerg, "Three-Level Z-Source Inverters Using a Single LC Impedance Network"

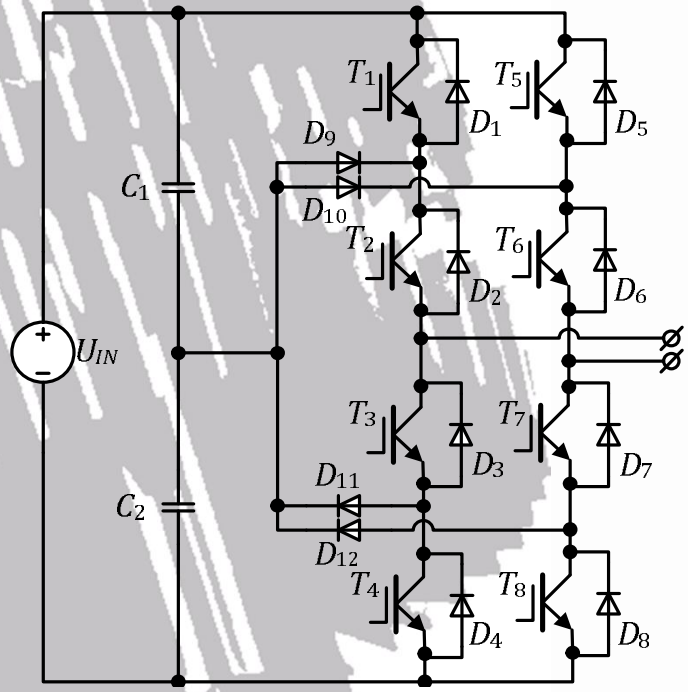


NPC inverter with single impedance network

Strzelecki, R., "Three-Level Z-Source Neutral-Point-Clamped Inverter,"

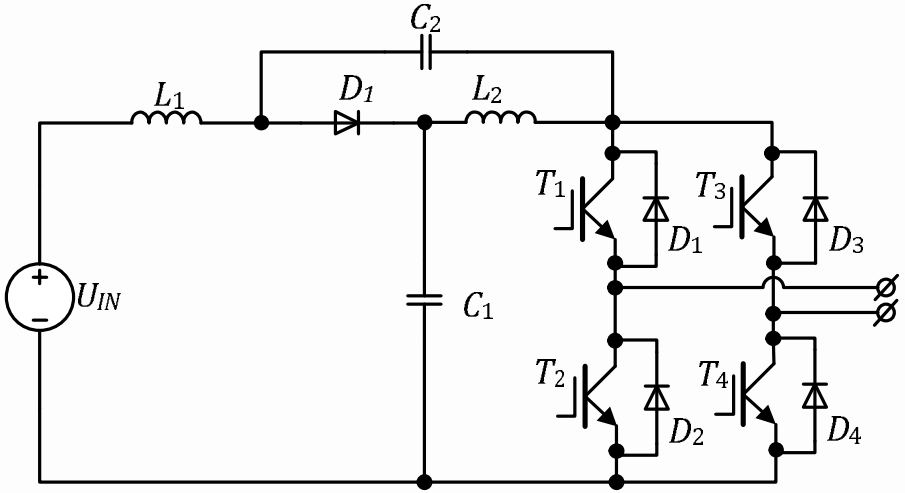
Proposed Topology

3L-NPC



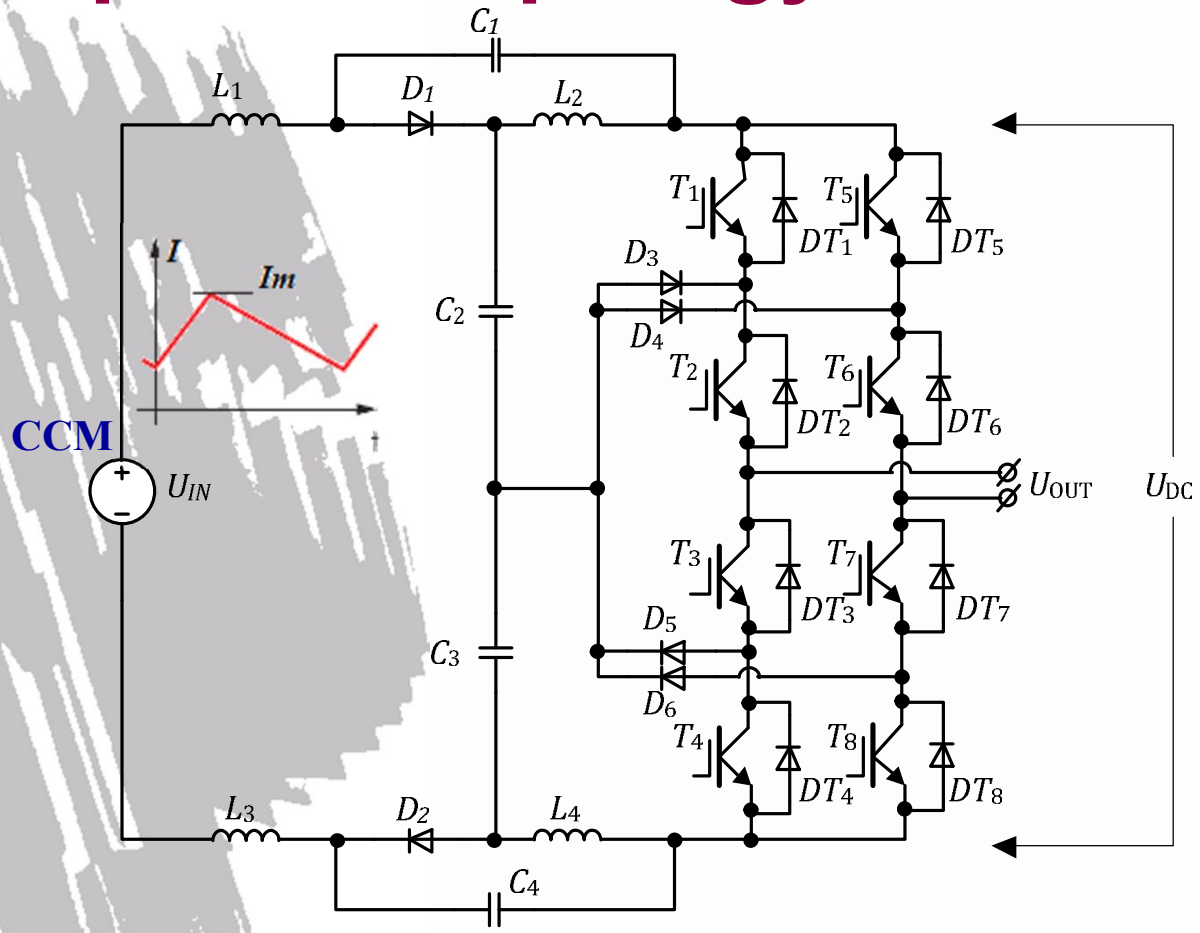
Three-Level Neutral Point Clamped

2L-qZS



Two-Level Quasi-Z-Source Inverter

Proposed Topology 3L-NPC-qZSI

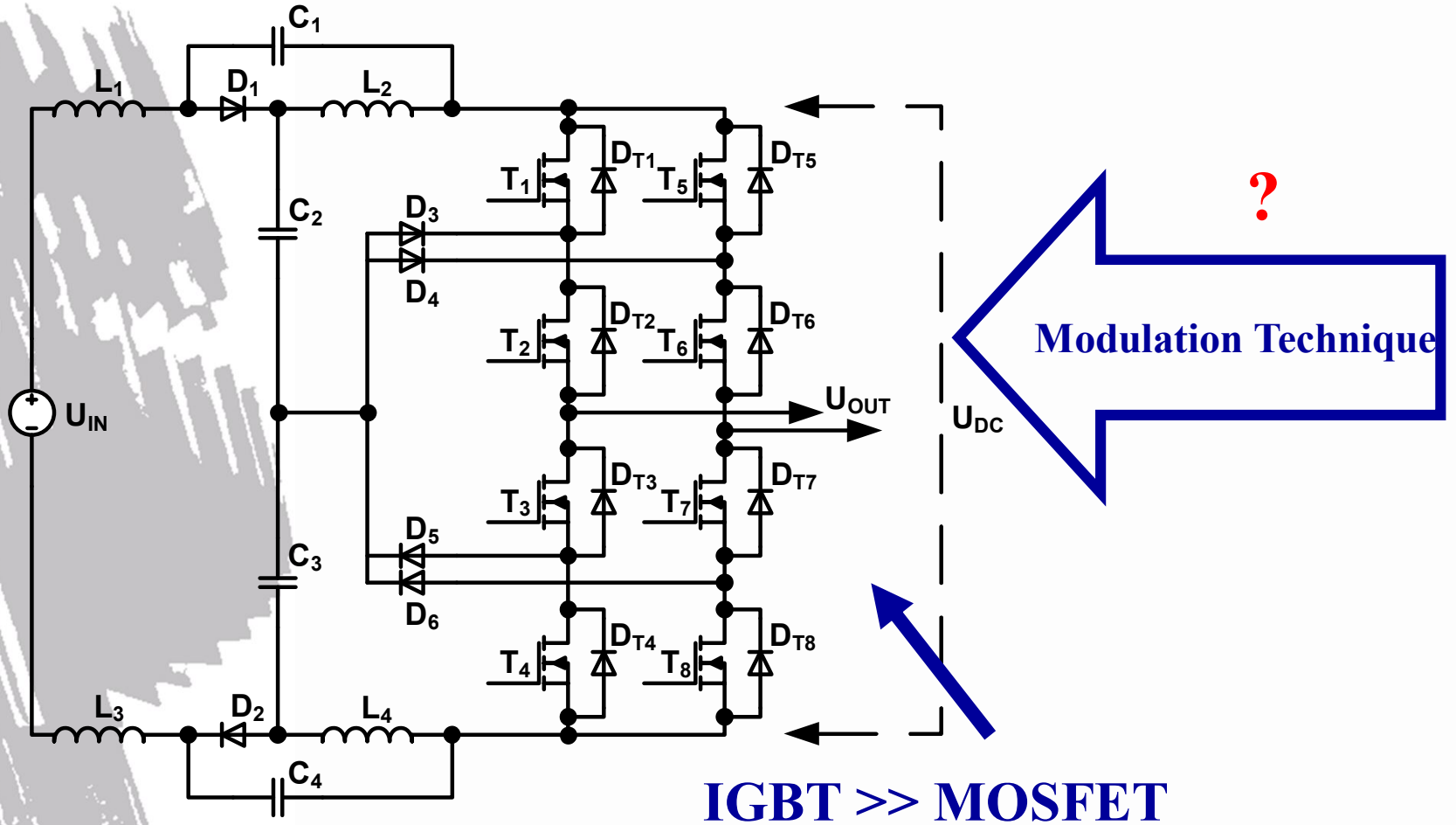


Three-Level Neutral Point Clamped Quasi-Z-Source Inverter

Proposed Topology: expected benefits

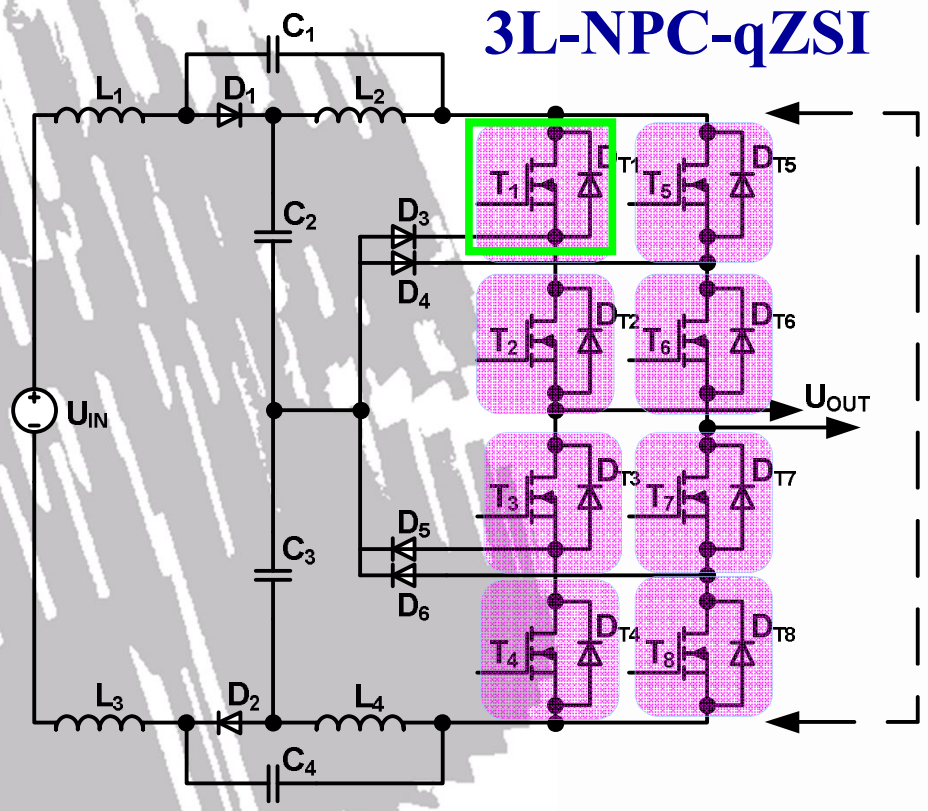
- One stage energy conversion topology;
- Short circuit immunity;
- Low voltage stress on the semiconductors;
- Bidirectional operations (for heating);
- Improved injected current quality;
- Active filtering functions in PCC.

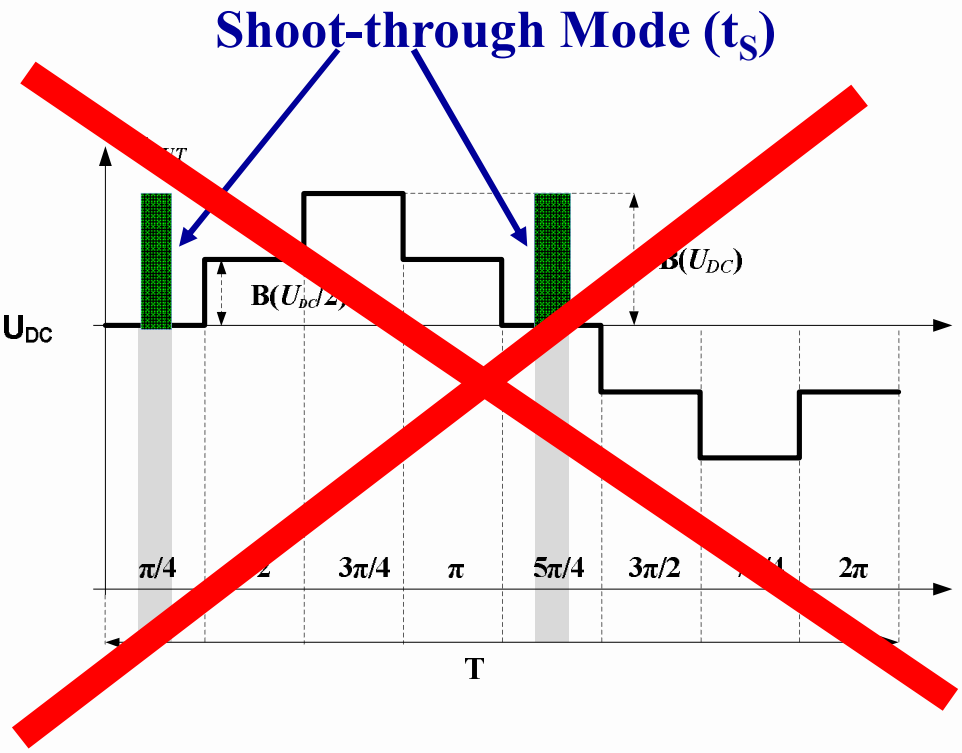
Proposed Topology 3L-NPC-qZSI



Modulation Technique

3L-NPC-qZSI



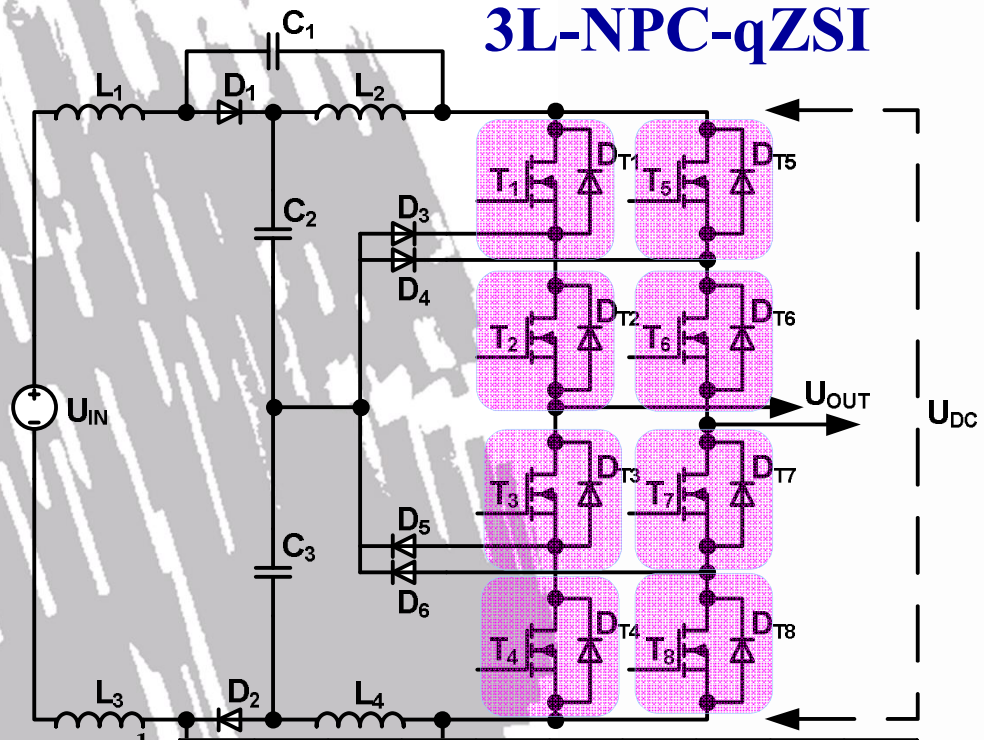


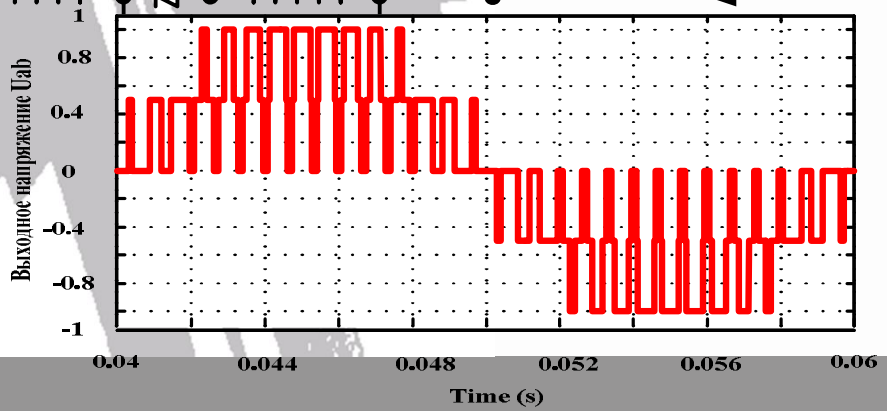
$$B = \frac{U_{DC}}{U_{IN}}$$

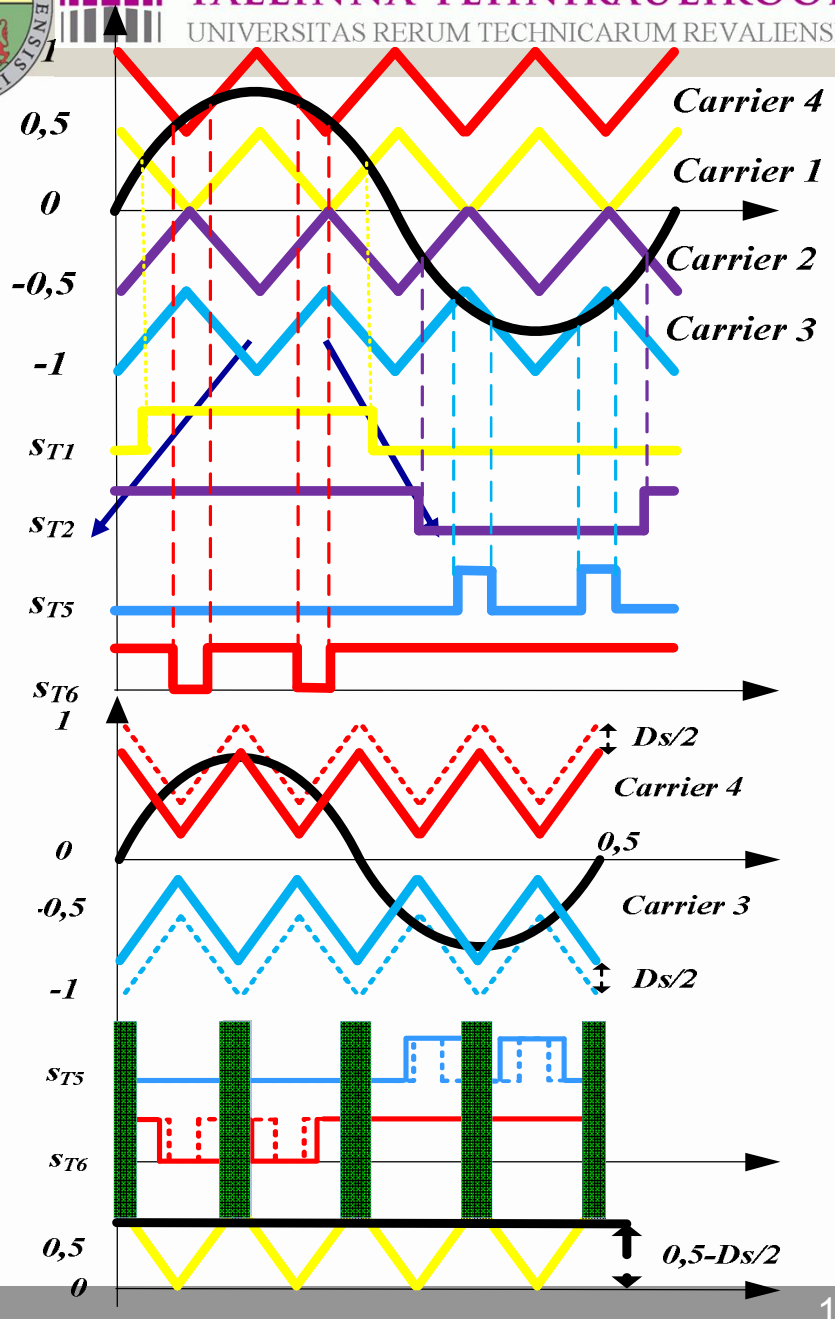
$$\frac{t_N}{T} + \frac{t_S}{T} = D_N + D_S = 1$$

Modulation Technique

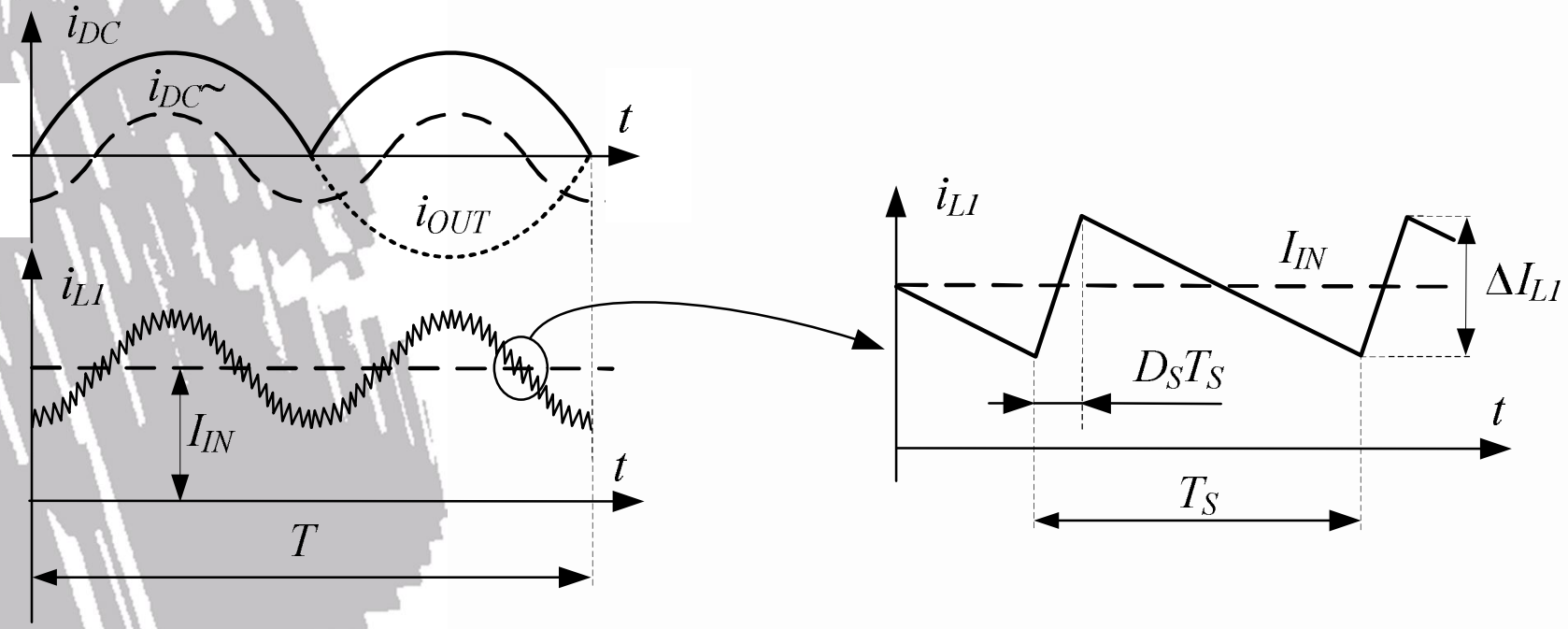
3L-NPC-qZSI







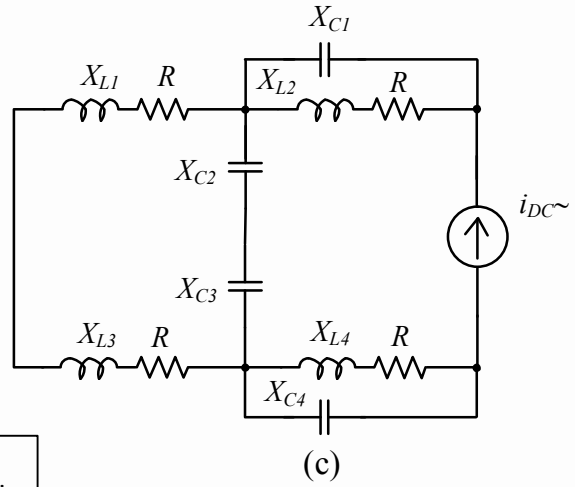
Steady State Analyses. CCM conditions



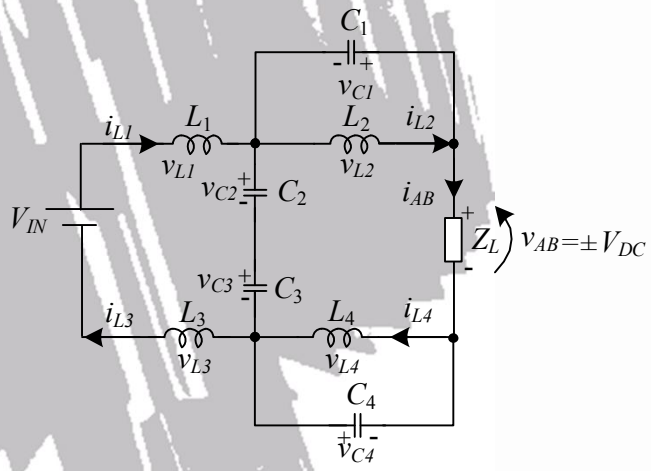
There are two components of current ripple: high switching frequency ripple and 100 Hz (single phase) ripple

Steady State Analyses. Equivalent circuits

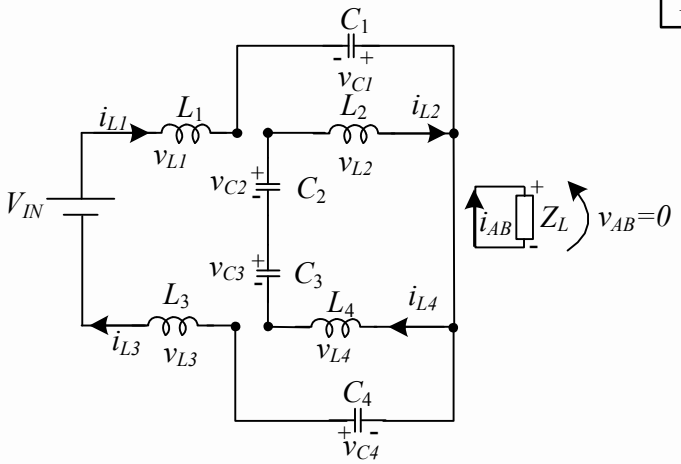
Equivalent circuit for 100 Hz (single phase) ripple



(c)



Non shoot through



Shoot through

Equivalent circuits for switching ripple

Steady State Analyses. Analytical equations

Boost Factor: $$V_{OUT\_MAX} = V_{IN} \cdot \frac{1 - D_S}{(1 - 2 \cdot D_S)}.$$

$$V_{C2} = V_{C3} = \frac{V_{IN} \cdot (D_S - 1)}{4 \cdot D_S - 2}$$

$$V_{C1} = V_{C4} = \frac{D_S \cdot V_{IN}}{2 - 4 \cdot D_S}$$

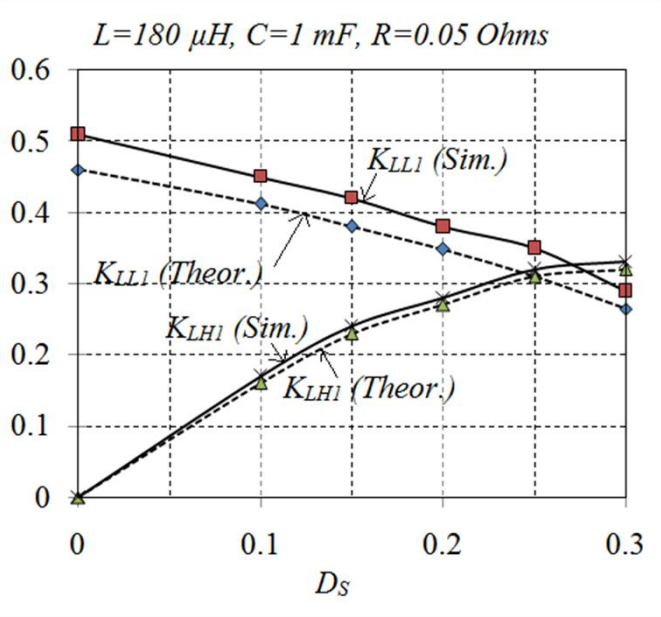
Capacitors:

$$K_{CL1} = \frac{v_{C1\sim}}{V_{C1}} = \frac{4}{3 \cdot \pi^2} \cdot \frac{P_{OUT} \cdot (1 - D_S) \cdot T^3}{V_{OUT}^2 \cdot D_S \cdot \left| 16\pi^2 \cdot C_1^2 \cdot L_2 - T^2 \cdot C_1 \right|}.$$

Inductances:

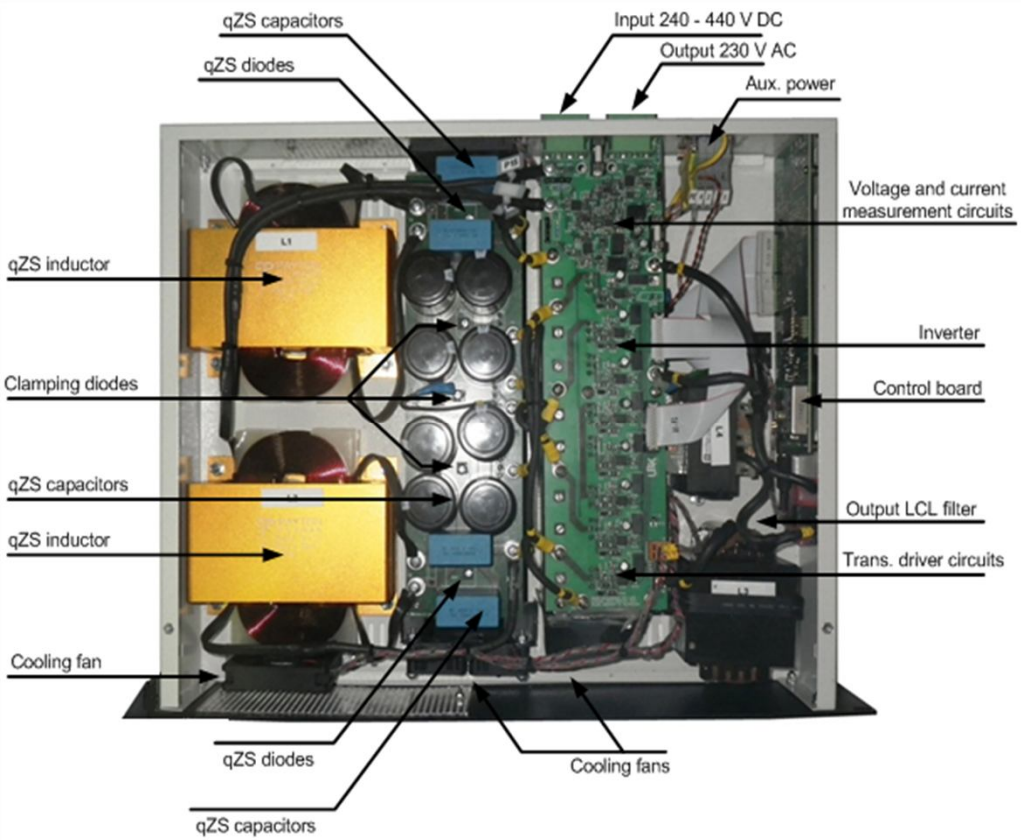
$$K_{LL1} = \frac{i_{L1\sim}}{I_{IN}} = \frac{i_{L1\sim} \cdot V_{IN}}{P_{OUT}} = \frac{8}{3 \cdot \pi} \frac{(1 - 2 \cdot D_S) \cdot T^2}{(1 - D_S)(16\pi^2 \cdot C_2 \cdot L_1 - T^2)}.$$

$$K_{LH1} = \frac{\Delta I_{L1}}{2 \cdot I_{IN}} = \frac{V^2_{OUT} \cdot (1 - 2 \cdot D_S)}{2 \cdot (1 - D_S) \cdot L_1 \cdot P_{OUT}} T_S \cdot D_S$$

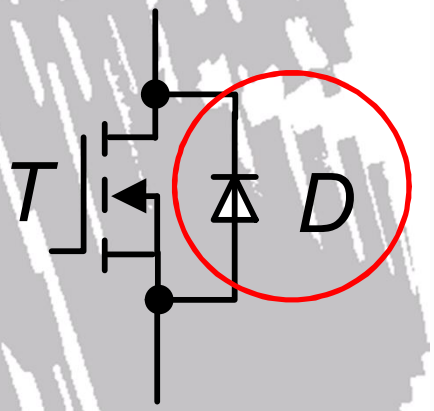


Experimental Prototype

Control Unit (FPGA)	Cyclone IV EP4CE15E22C8
Input DC voltage U_N	220-440 V
Output power	2800 W
Nominal output AC voltage U_{OUT}	230 V
Capacitance value of the capacitors C_1,C_4	4000uF
Capacitance value of the capacitors C_2, C_3	1000 uF
Inductance value of the inductors L_1... L_4	145uH
Inductance of the inverter filter inductor L_{f1}	560uH
Inductance of the grid filter inductor L_{f2}	200 uH
Capacitance of the filter capacitor C_f	0,47uF
Switching frequency	100 kHz
PV panels	LDK 185D



Selected Components: transistors



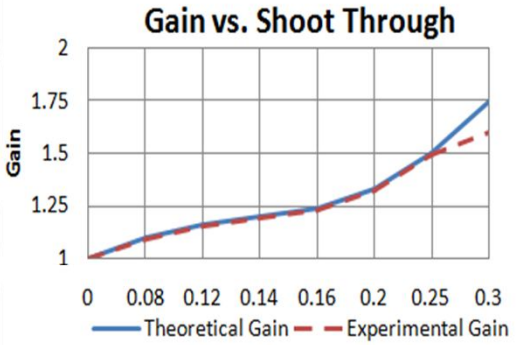
- **FCH47N60NF** (FAIRCHILD)
- $R_{DS}(on)$ = 57.5mΩ, I_D = 23.5A
-
- Total Gate Charge 121 nC
- dv/dt =50 V/ns
- Reverse Recovery Time 169 ns
- Reverse Recovery Charge 1.3 µC

- **IPW65R080CFD** (Infineon)

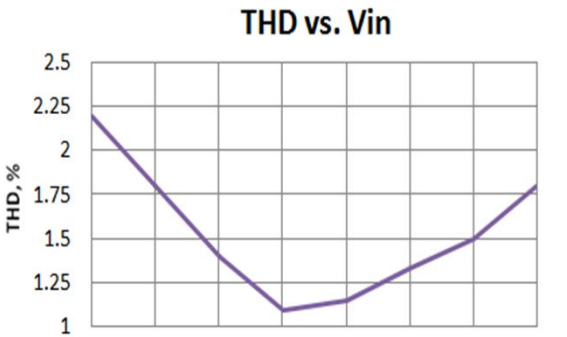
Selected Components: qZS and clamped diodes

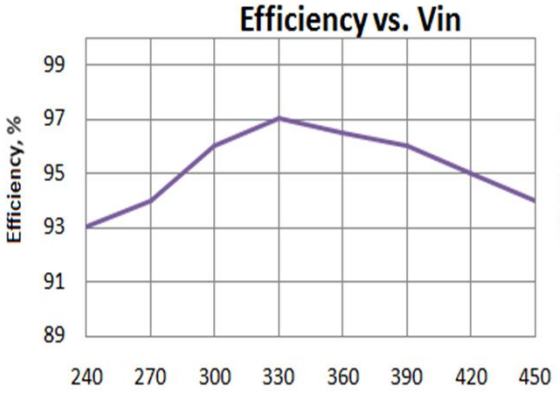
- **C3D20060D (Cree)**
- Repetitive Peak Reverse Voltage V600V
- Continuous Forward Current 28 A
- Total Capacitive Charge 20 nC

Experimental results

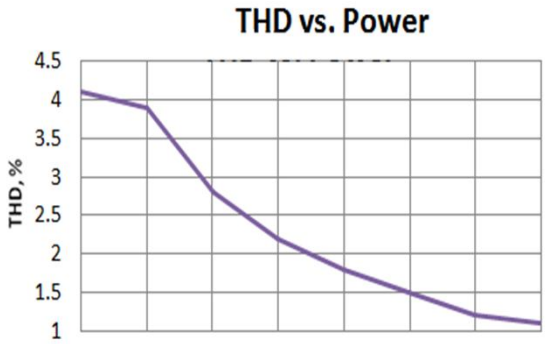


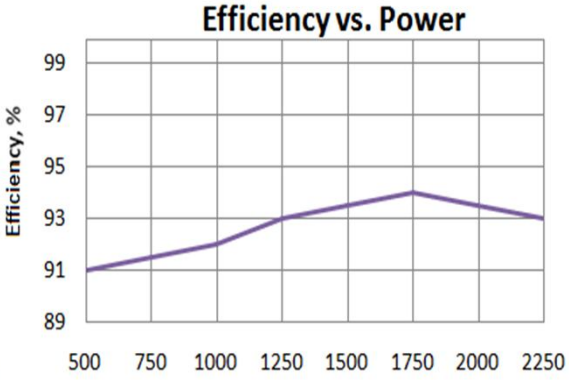
(a)





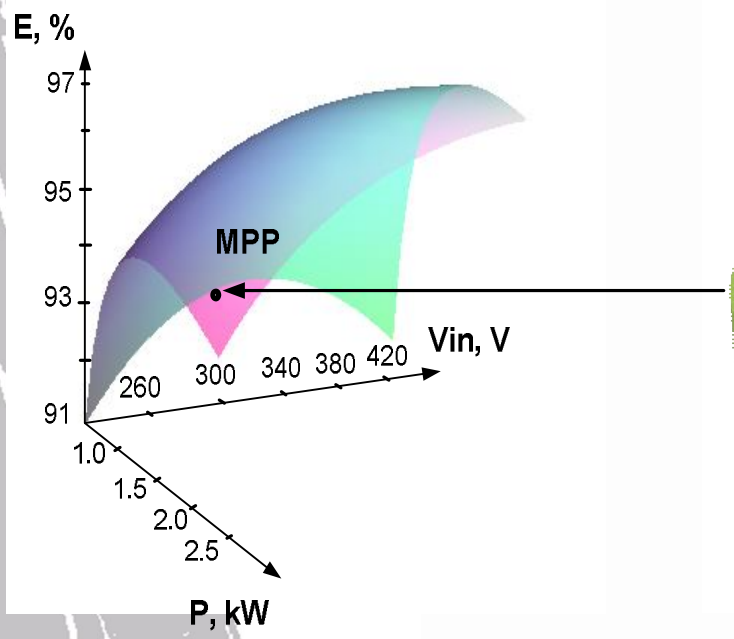
(b)



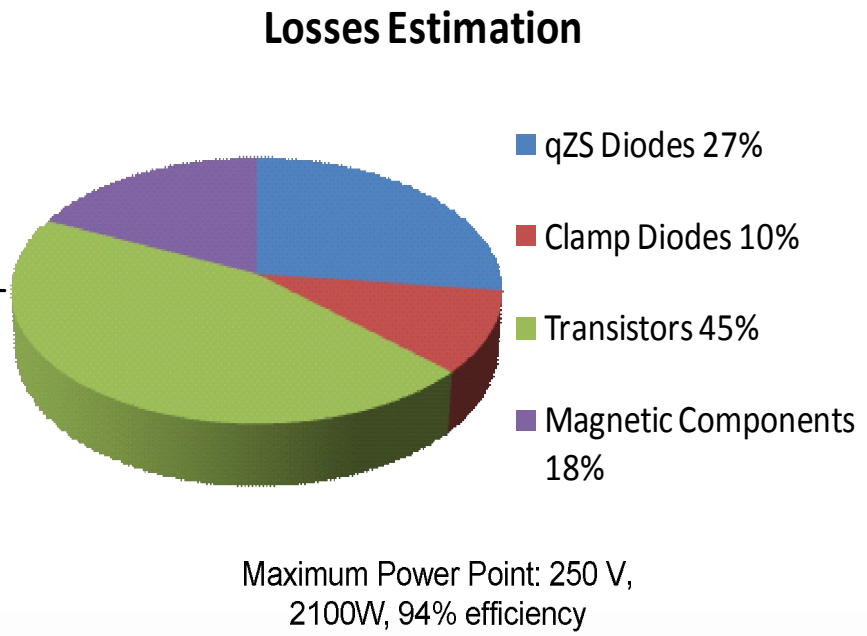


(c)

Experimental results. Losses distribution.



(a)

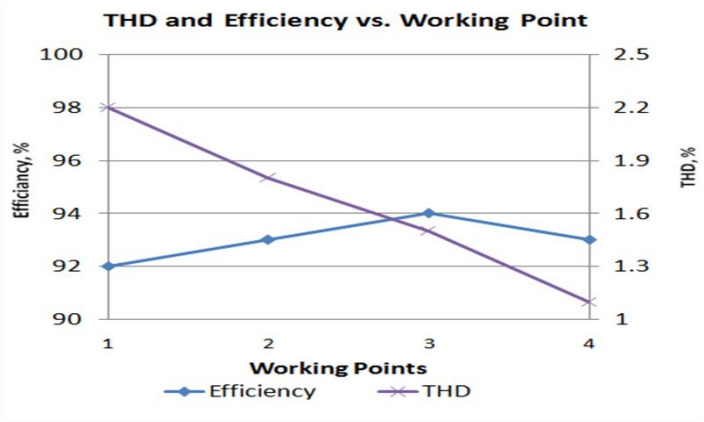


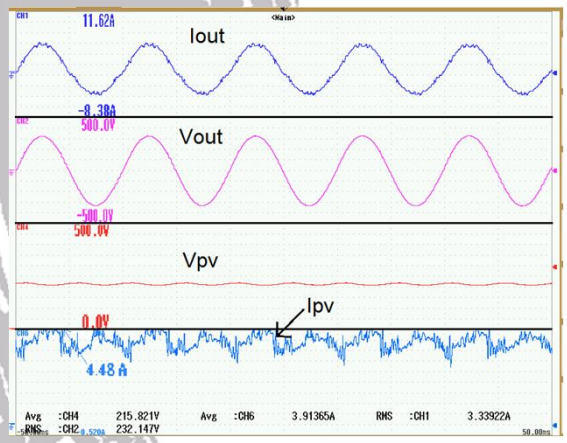
Maximum Power Point: 250 V, 2100W, 94% efficiency

(b)

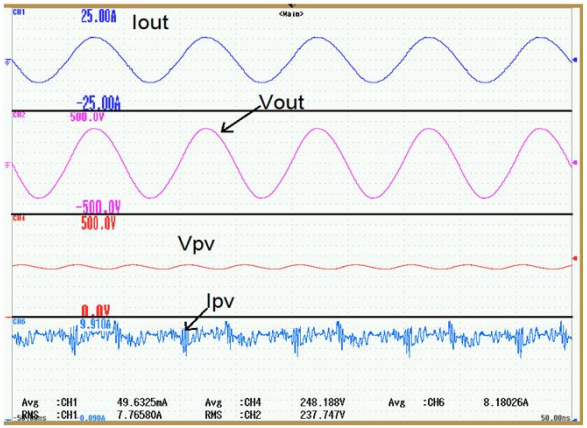
Experimental Results in Spain with PV panels

Working Point	1	2	3	4
Vpv, V	227	234	241	249
Power, W	1200	1500	1800	2100
THD, %	2.2	1.8	1.5	1.1
Efficiency, %	92	93	94	93





7 serial panels



7x2 serial panels

Conclusions:

- 3L-NPC qZS single phase inverter was proposed and designed (3kW).
- Features: wide input voltage range (220V - 450V), CCM of the input current (20% ripple).
- A sufficiently high converter efficiency (94-97%) was achieved through the use of modern electronic components, such as Schottky diodes based on silicon carbide and power switches with low gate charge and barrier capacitance reverse.

Further Research Activity

ECPE Competence Centre

3 kW 3-phase 3L NPC qZSI project financed by ECPE!

Thank you for attention!

Questions?