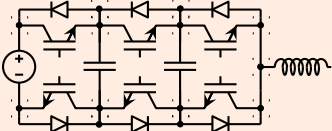


1990's

Medium voltage drive & traction  
CEGELEC, ALSTOM, GEC ALSTHOM



French patent N°31.09582 "Dispositif électronique de conversion d'énergie électrique", 25 July 1991  
T. MEYNARD, H. FOCH

CEGELEC



4.7kV DC bus, liquid-cooled  
3-phase VSI for MV drive  
3-cell, 3.3kV IGBTs

ALSTOM



6kV DC bus, air-cooled  
3-phase VSI for MV drive  
3-cell, 4.5kV IGBTs at 900Hz

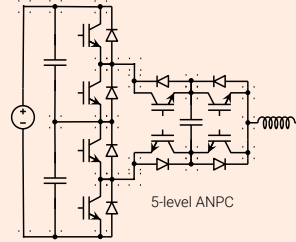
GEC ALSTHOM



3kV DC bus (4.5kV DC max)  
4x 1.5MW DC choppers  
2-cell, 4.5kV GTOs

2000's

Medium voltage drive - ABB



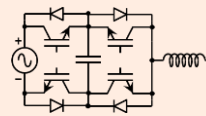
US patent 2007025126 "Converter circuit for connecting a plurality of switching voltage levels"  
P. BARBOSA, J. STEINKE, P. STEIMER, L. MEYSENC, T. MEYNARD

ABB



10kV DC bus, 3-phase VSI for Medium Voltage drive application, 5-level ANPC in each phase

AC/AC chopper - CIRTEM



French patent N°00.11611 "Dispositif de conversion d'énergie électrique à découpage", 12 September 2000  
T. MEYNARD, E. LEFEUVRE

CIRTEM



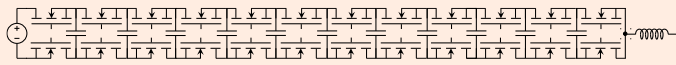
240V AC  
3 & 6kW  
2-cell, 600V IGBTs

2010's

Flywheel high speed drive - CIRTEM

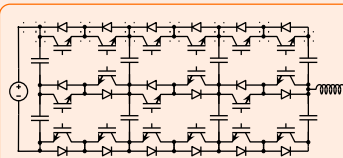


650V DC bus  
6kW,  $\eta > 99.3\%$   
12-cell, 100V MOSFETs



"Development of Multi-Level Converters: a SME's approach", D. FERRER  
ECPE Workshop 'Advanced Multicell / Multilevel Power Converters', 1 - 2 July 2014, Toulouse, France

Medium voltage drive application  
GENERAL ELECTRIC



French patent N°00.06786 "Dispositif de conversion d'énergie multicellulaire", 26 May 2000  
T. MEYNARD, H. FOCH, G. GATEAU

GENERAL ELECTRIC

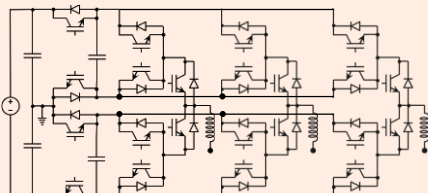


10kV DC bus  
3-phase VSI for MV drive  
2x2-cell (Stacked Multi Cell) each phase

Medium voltage drive application - MEIDENSHA

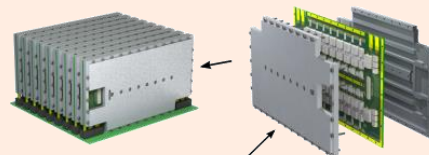


11kV DC bus, 1MVA  
 $\eta > 98\%$  ("industry leader")  
IGBTs, 5-level each phase

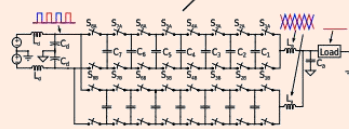
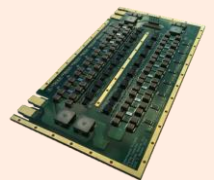


"A multilevel converter topology with common flying capacitors". H. ZHANG, W. YAN, K. OGURA, S. URUSHIBATA.  
In Energy Conversion Congress and Exposition

Embedded application



UNIVERSITY OF ILLINOIS AT  
URBANA-CHAMPAIGN,  
URBANA, ILLINOIS



"Design of a GaN-based, 9-level flying capacitor multilevel inverter with low inductance layout".  
R. C. PILAWA-PODGURSKI et al.

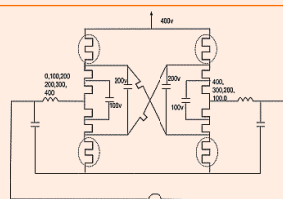
1000V DC bus  
20kW,  $\eta > 99\%$   
2x8-cell, 200V GaN FETs

PV inverter - SOLAREEDGE

SOLAREEDGE



400V DC - 240V AC  
3 to 7.6kVA,  $\eta_{max} = 99.5\%$   
(first ever to reach 99% CEC efficiency rating)  
Si MOSFETs, 4-level each phase



UPS - APC by Schneider

APC BY SCHNEIDER



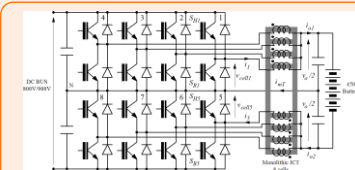
800V DC bus  
137kW  
8-cell coupled interleaved

2020's

Smartphone



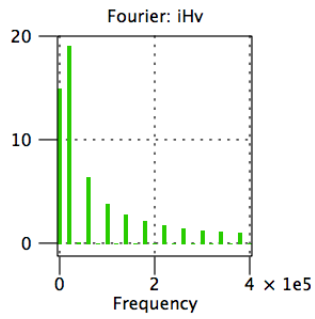
3-5V DC, 2-5W & 6-9V, 10-20W  
2- or 3-cell, 5V or 2.5V MOSFETs  
Market ~50.10<sup>9</sup> chips/year



"Design and characterization of an eight-phase-137-kW intercell transformer dedicated to multicell DC-DC stages in a modular UPS".  
F. FOREST, T. MEYNARD, J. HUSELSTEIN, D. FLUMIAN, C. RIZET, A. LACARNOY.

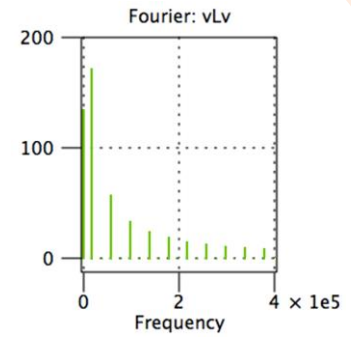
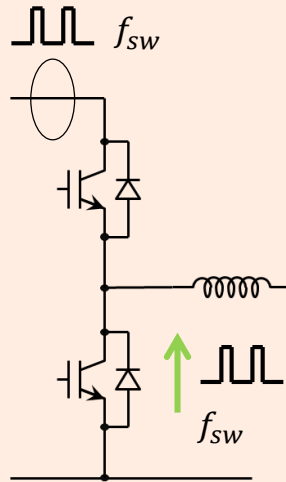
# Series parallel multilevel converters: influence on filters (DC-DC example)

## 2-level



$$A_1 = \frac{2I_{LV}}{\pi} \sin(\pi D)$$

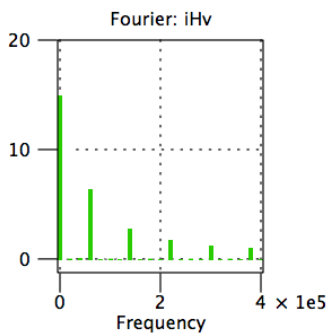
@  $f_{sw}$



$$A_1 = \frac{2V_{HV}}{\pi} \sin(\pi D)$$

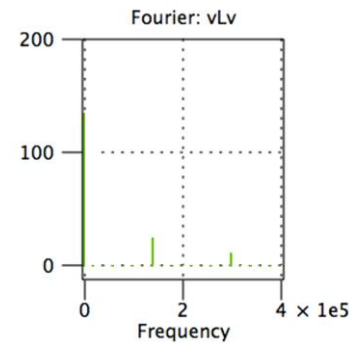
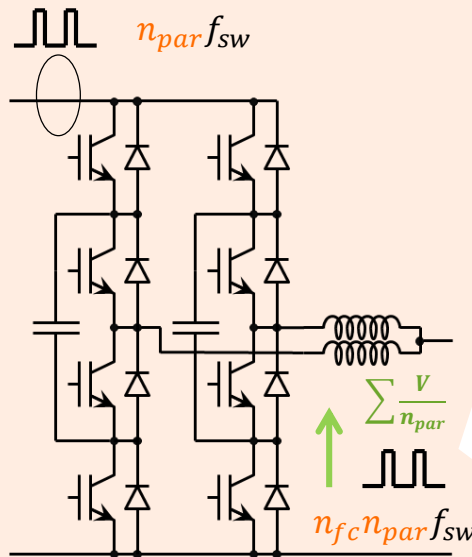
@  $f_{sw}$

## Multilevel



$$A_1 = \frac{2V_{HV}}{n_{par}\pi} \sin(\pi D)$$

@  $n_{par} f_{sw}$



$$A_1 = \frac{2V_{HV}}{n_{fc} n_{par} \pi} \sin(\pi D)$$

@  $n_{fc} n_{par} f_{sw}$

Increased apparent switching frequencies

Reduced amplitudes of voltage and current harmonic