Topology exploration and prototype for high voltage, low power, isolated DC-DC converter

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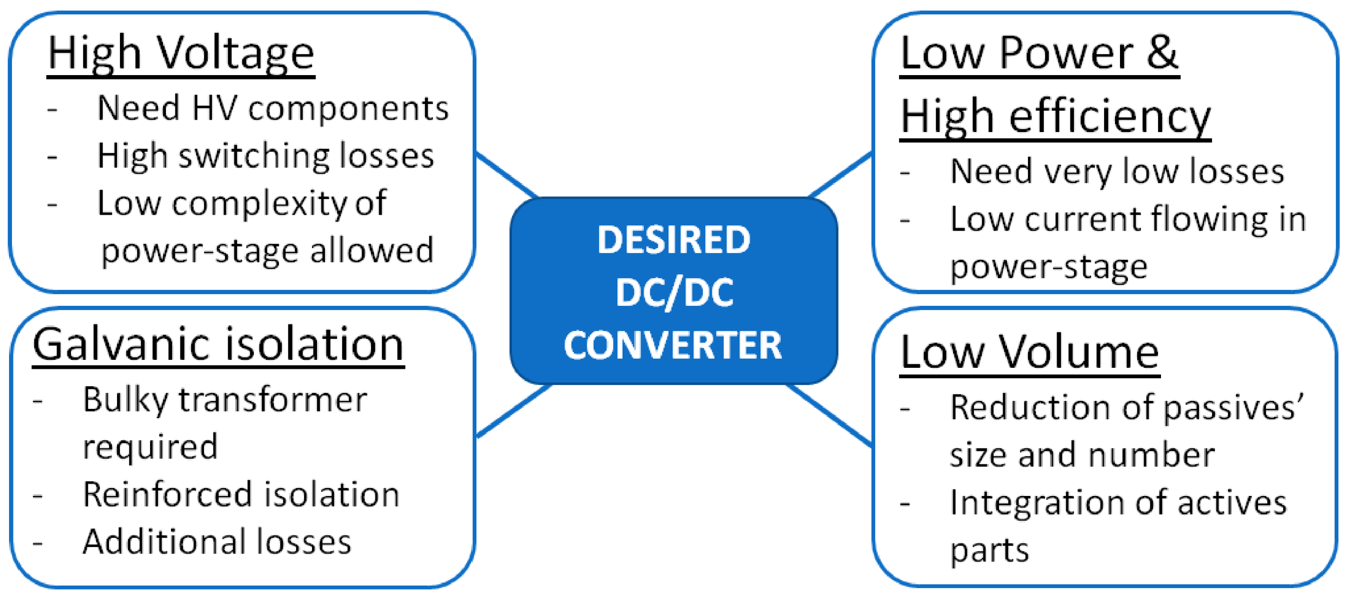
PWR SOC 18
Hsinchu, Taiwan
Oct. 17-19, 2018

Context and objective

- Multiplication of high-voltage DC buses due to electric car multiplication, aircraft electrification, etc. DC voltage that can be as high as **400 V** or even **800 V** in recent or future systems.
- Need to power tiny systems, sensors, etc. **directly from the high-voltage DC bus**, like the Pyroswitch for safety of an electric car battery. Required power is low, around **1 W**.
- As a consequence, a **new type of converter** is required, adapted to this "unconventional" conversion.



- **Topology exploration** was carried out to identify a candidate to operate the conversion and suitable for silicon integration.

Converter general specification	
Input voltage	From 250 V to 1000 V
Output voltage	12 V
Output power	~ 1 W
Isolation	Reinforced isolation
Expected efficency	>85%

Criteria for topology exploration

- Maximum *Volt-second* reduction

Transformer size is a critical aspect to achieve low-volume converter. Maximum volt-second applied to the transformer gives an indication on the **maximum flux density (B_{MAX})**, used to determine core losses. A reduction of volt-second, linked to a reduction of the input voltage or to the reduction of voltage levels applied on the transformer will translate in smaller transformer, if keeping losses at same level.

- Stress on power switches

Reduction of **voltage stress** on the power switches enable the use of devices with smaller voltage and current ratings, i.e. with **better performances**. It also allows easier **integration**.

- Zero Voltage Switching (ZVS) operation

High-voltage present on switching device might generate very high **switching losses**, as they grow up with the square of the voltage. Zero Voltage Switching helps reducing these losses and allows to operate at higher switching frequencies.

- Start-up and fast transient response

Due to high-voltage input, some phenomena at start-up or during fast transients might create some **additional stress** on components. Some topologies offer capabilities to avoid these issues.

- Complexity

This criterion accounts for aspects of the converter that will be obstacles to **integration** or to fabrication. Number of **active devices**, of which how many floating ones, number of **external passives**… Complexity is also linked to another aspect of converter, as regulation or complexity of components, as the transformer.

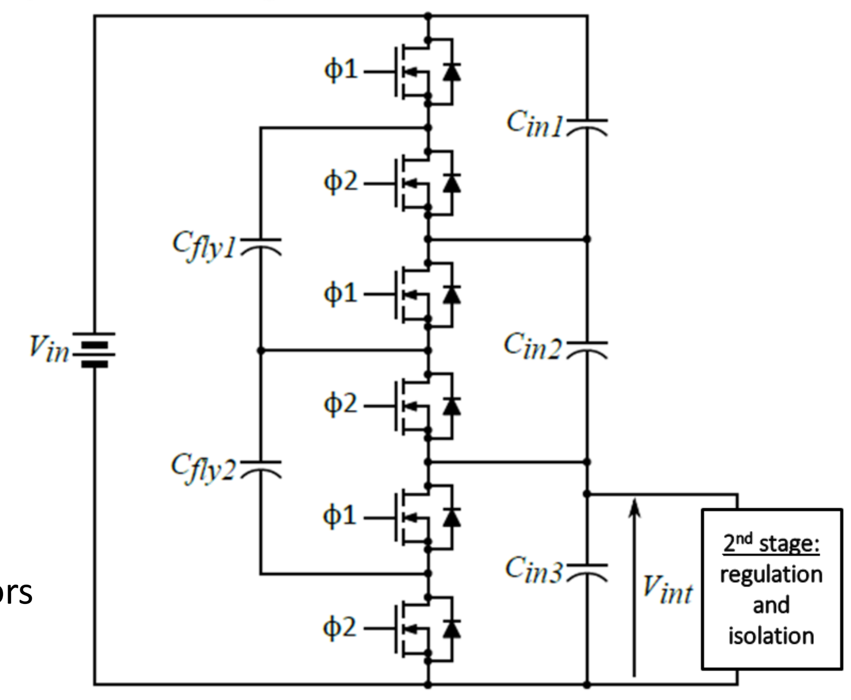
Topologies

Stacked-Up-Capacitor stage

A Switched-Capacitor stage to divide the input voltage:

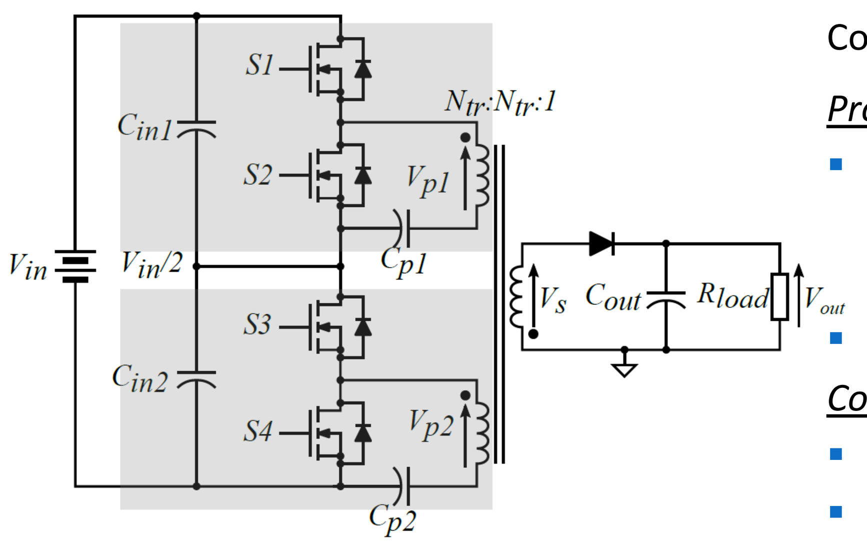
Pros:
- Input voltage of 2nd stage is reduced
  - 2nd stage switch voltage-stress reduced
  - Maximum volt-second is reduced
- Series capacitors share input voltage at start-up
- Reduced voltage-stress on 1st-stage switches

Cons:
- No ZVS operation for 1st-stage MOSFETs
- At start-up, high inrush current in series capacitors and flying capacitors charging
- Imbalance issues between voltages levels



3-Stacked-Up-Capacitors + 2nd stage topology

ISOP arrangements of several converters



ISOP arrangement of two Fly-Buck

Converters with Inputs in Series and Outputs in Parallel

Pros:
- Series converters share input voltage
  - Reduced voltage switch-stress
  - Sharing is effective also during start-up
- ZVS possible for all power MOSFETs

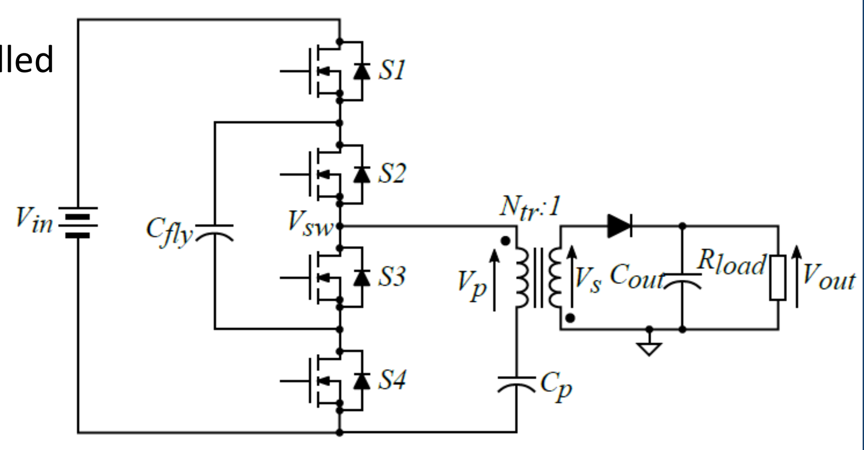
Cons:
- Transformer with multiple windings required
- Synchronization is required between the control signals to enable the use of a unique transformer
- No reduction of the maximum volt-second

Multi-Level Flying-Capacitor Fly-Buck

- Isolated version of multi-level buck
- Fly-Buck topology: isolated output voltage controlled by top-switches duty-cycle (S1/S2)

Pros:
- Reduced voltage excursion of primary voltage
- Reduced voltage switch-stress
- ZVS is possible for all power MOSFETs

Cons:
- Additional control to regulate flying capacitor voltage
- Charging of the flying capacitor at start-up

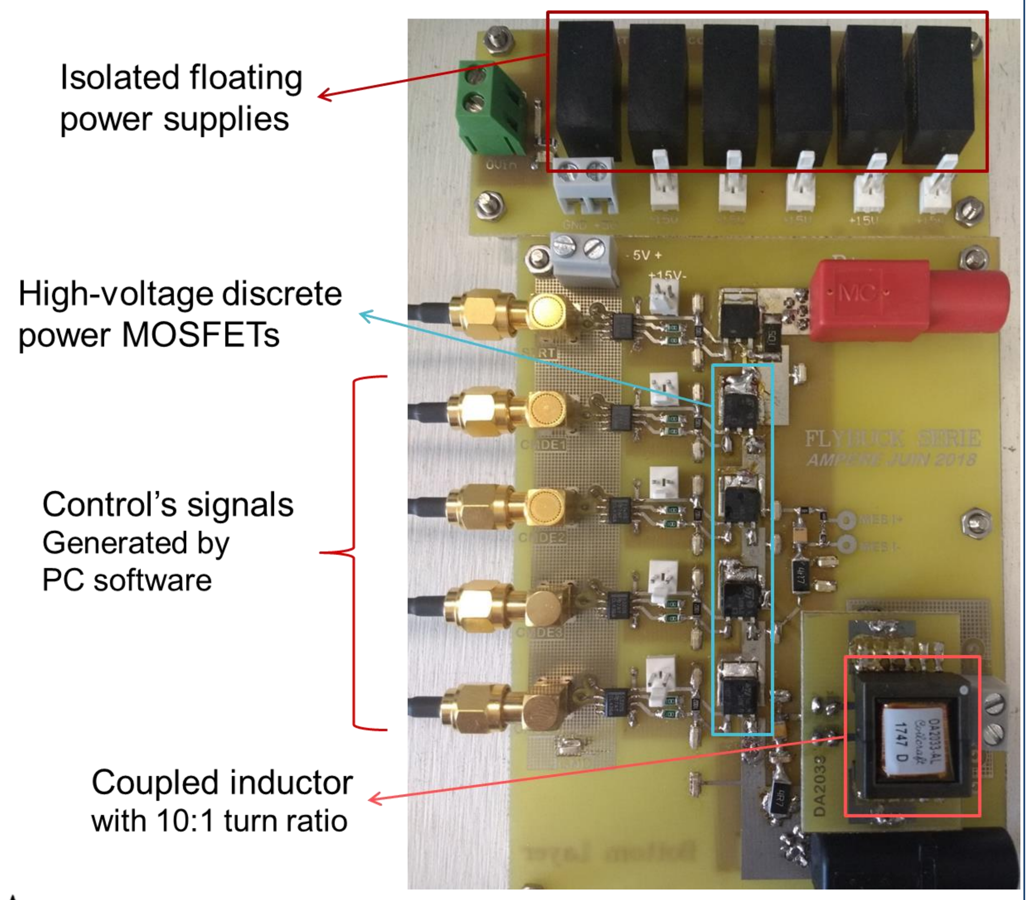


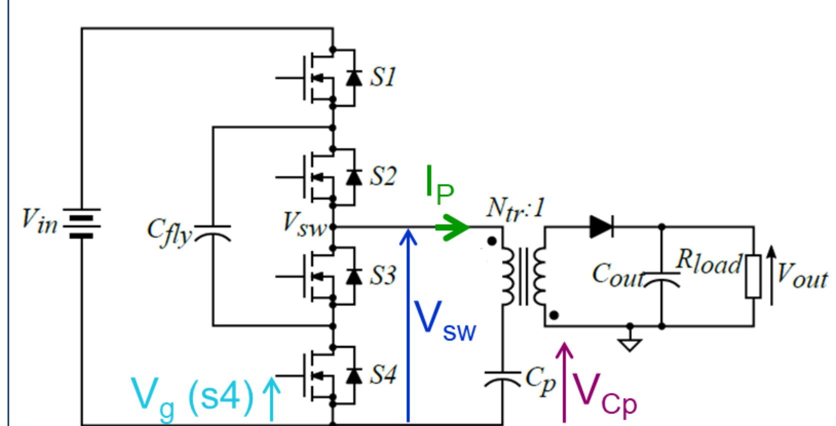
3-Level FC Fly-Buck power-stage

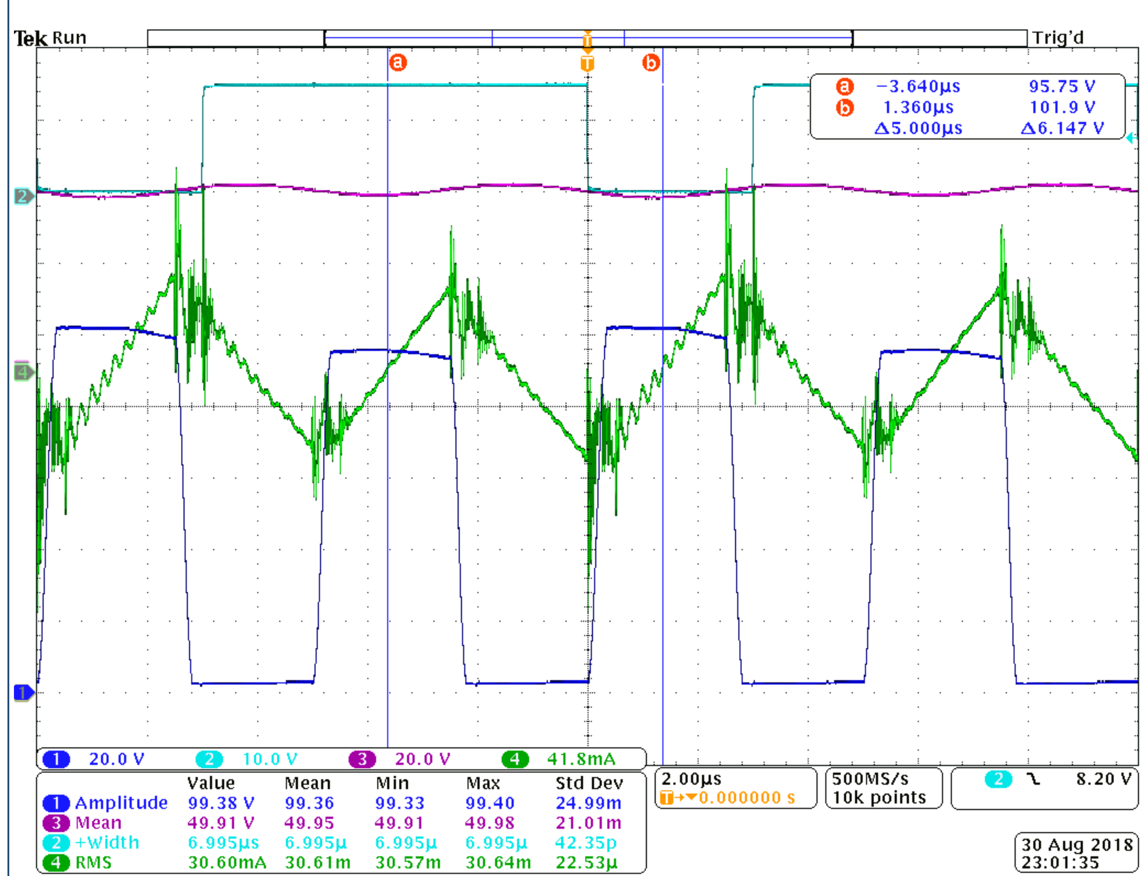
PCB prototype of 3-level FC Fly-Buck

- Topology chosen for its simplicity, compactness and good reduction of switch-stress and of maximum volt-second
- PCB prototype with discrete components is built to validate simulation waveforms

Parameters:
- Input voltage: 200 V
- Switching frequency: 100 kHz
- Output load: ≈ 150 Ω
- Magnetizing inductance: 1 mH
- Transformer turn ratio: 10:1
- Duty-cycle: 25%
- Dead-time ~ 400 ns







Measurement outcome:
- Validation of ZVS operation
- Underlining stability issues of flying capacitor voltage
- Validation of output voltage estimation
- Reduced voltage stress on switches and transformer in steady-state mode
- Validation of low conduction losses and low transformer losses for Vin = 200 V
- Detection of expect flying capacitor's voltage stability issue

Key contributions

- ✓ **Important criteria identified**
- ✓ **Different topologies evaluated**
- ✓ **Comparison of unconventional topologies**
- ✓ **PCB prototype of the Multi-Level Flying-Capacitor Fly-Buck topology**
- ✓ **Next step: Silicon integration of the selected power-stage in a test-chip**

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