

# A New, Alternative Three-Level Topology for Highly Efficient, Single-Phase Solar Applications

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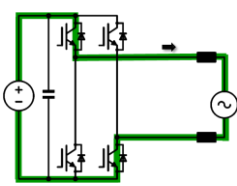
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## 1 Abstract:

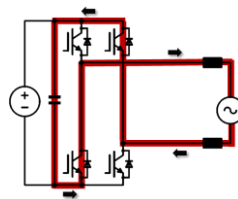
Three-level topologies' most persuasive selling points are high efficiency and reduced filtering effort. Several three-level topologies feature prominently in single-phase solar applications. This paper presents a new alternative that also meets the requirements for reactive power and the need to drive down costs. In the following, this new topology's pro and cons are benchmarked against two established three-level solutions. The discussion concludes with a first look at power modules designed to support this new approach.

## 2 Principle of single phase three-level topologies

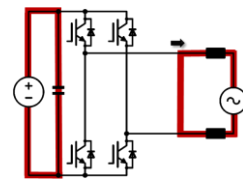
Solar inverters must generate sinusoidal output current to be fed into the public power grid. The simplest way of producing sinusoidal current is to use an H-bridge inverter with pulse width modulation of DC voltage and an output filter. The three-level topology serves to reduce switching losses and the output filter's effort. With two-level modulation, the power semiconductor has to switch at higher voltages, e.g. 400 V. In a single-phase, three-level system the filter's primary output is shorted so that the switched voltage is reduced.



H4-Topology during excitation



Freewheeling



Three-level idea H-bridge is turned off and with shorted output at freewheeling

## 3 Advantage of three-level operation

### 3.1 Elimination of energy fluctuation

In two-level operation will regenerate energy during freewheeling back to the DC-capacitor according:

$$E_{\text{regeneration}} = U_{\text{DC}} * I_{\text{Output}} * t(\text{off})$$

The energy injected into the grid results to:

$$E_{\text{Out}} = E_{\text{Excitation}} - E_{\text{regeneration}} = U_{\text{DC}} * I_{\text{Output}} * t_{\text{ON}} - U_{\text{DC}} * I_{\text{Output}} * t_{\text{off}}$$

$$E_{\text{Out}} = U_{\text{DC}} * I_{\text{Output}} * (t_{\text{on}} - t_{\text{off}})$$

The regenerated energy has to pass the inverter twice (excitation and regeneration) and it will cause additional power dissipation.

### 3.2 Reduced switching losses and output filter effort

With three-level operation is the voltage at a symmetrical output filter changing between  $V_{\text{DC}}$  (e.g. +400 V) and half of the actual output voltage (e.g.: 0.160 V at 230  $V_{\text{AC}}$  grid):

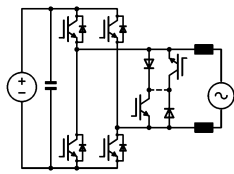
$$V_{\text{SW}} = V_{\text{DC}} - \frac{1}{2} * V_{\text{Out}}(t)$$

The switching losses and the size of the output filter can be minimized using still the same PWM frequency. The excitation works like in standard two-level H-bridge with bipolar switching, but during freewheeling H-bridge turned off and the output shorted.

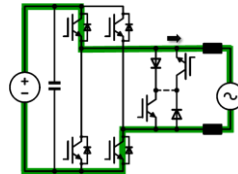
## 4 Single phase – three-level topologies

### 4.1 HERIC Topology™

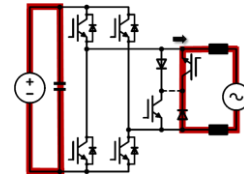
The HERIC™ based inverter circuit is implementing such a dynamic short connection at the output with two set of IGBT and diode in serial. The sets are connected anti-parallel at the output of the H-bridge. For every half wave are 2 different IGBT's of the H-bridge switched with PWM during real power (current and voltage have the same polarity). The IGBT's at the output are turned on / off during the corresponding half-wave.



HERIC topology™



Excitation (positive half-wave)



Freewheeling

Pros:

Low static losses in the 3<sup>rd</sup> level operation:

- Voltage drop at real power during ON: 2x IGBT
- Voltage drop at real power during OFF and freewheeling: 2x IGBT + 2x diode
- Voltage drop at reactive power during OFF and freewheeling: 2x diode

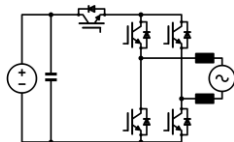
Cons:

Complex structure:

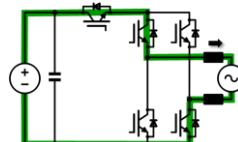
- 6 IGBT's (4x ultrafast switching) and 6 fast diodes required

### 4.2 H5-Topology

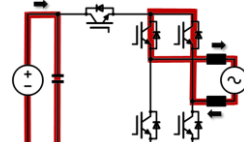
A different solution for the same approach is the H5-topology. The additional IGBT is switched with PWM together with the low side IGBT's, the high side IGBT are turned on/off during the complete corresponding half-wave at real power.



H5-topology



Excitation (positive half-wave)



Freewheeling

Pros:

Less components required:

- 5 IGBT's and 5 fast diodes required
- Only 3 of the 5 IGBT have to be ultra fast switching (if real power efficiency is in the focus)

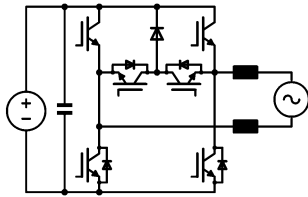
Cons:

High static losses:

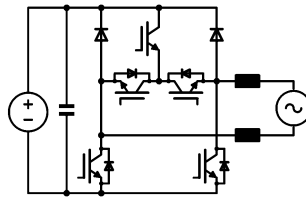
- Voltage drop at real power during ON: 3x IGBT
- Voltage drop at real power during OFF and freewheeling: 1x IGBT + 1x diode
- Voltage drop at reactive power during OFF and freewheeling: 3x diode
- The 5<sup>th</sup> switch requires an extra power supply for its gate drive.

## 5 New H6.5 and 5.6 Topology

In the following are the new H6.5 and H5.6 topologies introduced.



New H6.5 topology

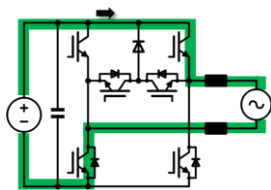


New H5.6 topology

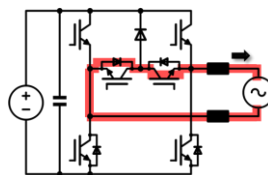
### 5.1 Function of the new H6.5 Topology:

The new H6.5 topology uses also 6 IGBT's as the HERIC topology™ but only 5 diodes are required.

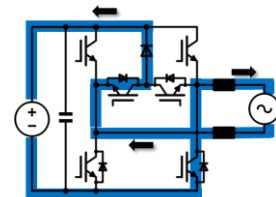
#### positive half-wave



Real power - On

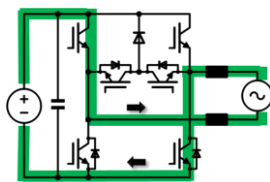


Real power - Off-Freewheeling /  
On-Reactive Power

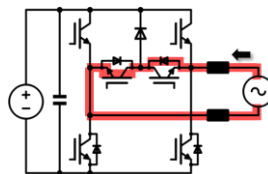


Reactive power - Off-  
Freewheeling

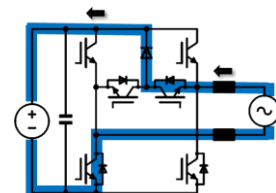
#### negative half-wave



Real power - On



Real power - Off-Freewheeling /  
On-Reactive Power



Reactive power - Off-  
Freewheeling

### 5.2 Performance

The new H6.5 topology is showing the identical real power performance as the HERIC topology™. The reduction of the number of diodes from 6 to 5 has to be paid with one additional junction at freewheeling during reactive power but this is of minor importance in solar applications.

Pros:

Low static losses at real power operation:

- Voltage drop at real power during ON: 2x IGBT
- Voltage drop at real power during OFF and freewheeling: 2x IGBT + 2x diode

Cons:

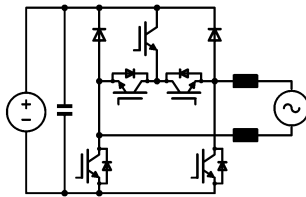
Complex structure:

- 6 IGBT's (4x ultrafast switching) and 5 fast diodes required
- Voltage drop at reactive power during OFF and freewheeling: 3x diode

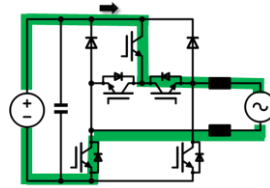
### 5.3 Function of the new H5.6 Topology:

A 2<sup>nd</sup> new alternative topology is the H5.6 Topology. The new topology uses also 5 IGBT's but only 6 diodes are required. The 5<sup>th</sup> switch can be placed in the high-side or low-side of the circuit.

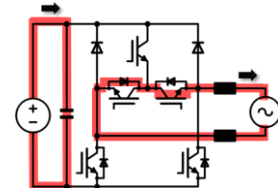
H5.6-1



5<sup>th</sup> switch in the high-side

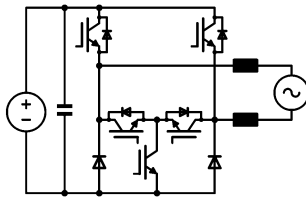


Real power – On



Real power - Off-Freewheeling /  
On-Reactive Power

H5.6-2



5<sup>th</sup> switch in the low-side

### 5.4 Performance

The new topology is showing the same performance as H5. The efficiency during real power is identical with H5 but the freewheeling at reactive power is same as HERIC<sup>TM</sup>.

Pros:

- Reduced complexity, 5 IGBT's required
- Voltage drop at real power during OFF and freewheeling: 1x IGBT + 1x diode
- Voltage drop at reactive power during OFF and freewheeling: 2x diode
- The 5<sup>th</sup> switch requires an extra power supply for its gate drive.

Cons:

- Voltage drop at real power during ON: 3x IGBT
- 6 diodes required
- The 5<sup>th</sup> switch requires an extra power supply for its gate drive.

## 6 Power module concepts supporting the new topology

The requirements into a power module for a integration of the semiconductors<sup>TM</sup> are the following:

- 2 independent boost stages for MPP (maximum power point) tracking
- Incorporation of the new H6.5-Topology
- High switching frequency e.g.: 40kHz
- Low inductance, integration of DC-capacitors
- Integration of all components of the commutation circle, also at reactive power
- Temperature sensor
- Good thermal interface

The new topology can be implemented with common collector or common emitter (see Figure 1) for the freewheeling path. The usage of common collector of the IGBT's in the freewheeling path is generating the advantage that no additional power supply is required as the emitter is here common with the high-side IGBT's of the H-bridge.

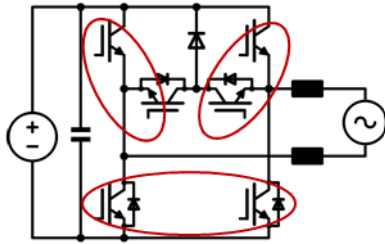


Figure 1: H6.5 Topology with common collector in the freewheeling path with 3 voltage potentials for the gate drive circuit

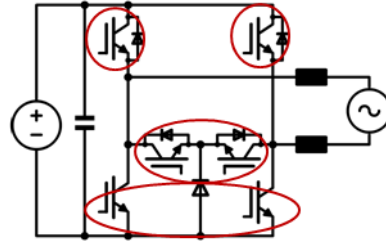
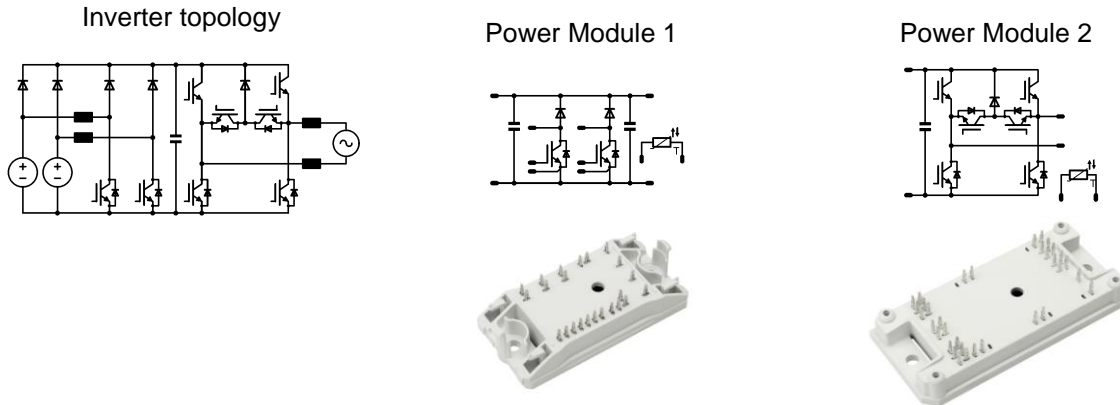


Figure 2: H6.5 Topology with common emitter in the freewheeling path with 4 voltage potentials for the gate drive circuit

This facts leading to the following 2 module concepts:

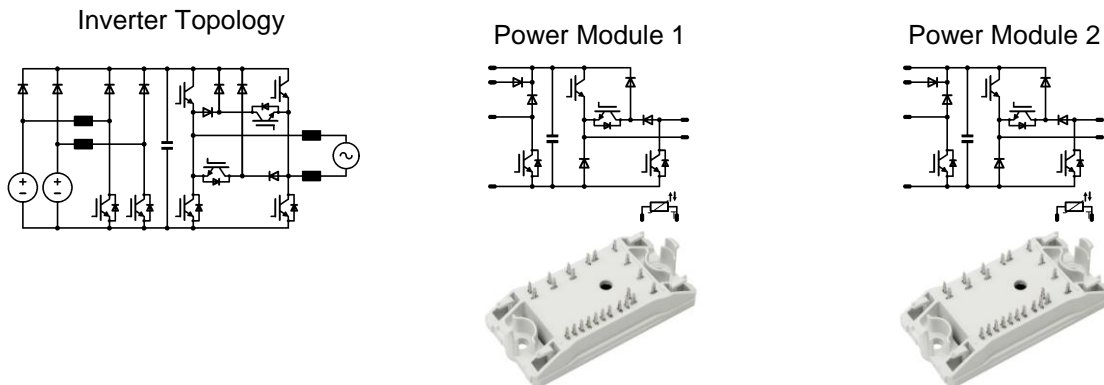
### 6.1 2x Boost + H6.5 Inverter Concept

This concept uses a standard 2x booster module and implement the new topology in a 2<sup>nd</sup> module based on the Vincotech flow 1 power module housing. This structure is supporting also designs were the MPP-tracker and the inverter are on different locations on the PCB.



### 6.2 2x [Boost + Half-wave Inverter] – Concept

Here is one boost stage and the inverter components for one half-wave combined In one module. The advantage is a identical power dissipation of the 2 modules, independent of the input voltage. Two identical modules are able to build the power electronics core of the inverter. The corresponding IGBT of the switching device is on the other module which makes this solution extremely robust against X-conduction at fast turn on.



Both concepts incorporating all components of the commutation circle inside one module, in case of distribution between 2 modules will the inductance of the electrical interface of both modules cause overvoltage at turn off an reduce the utilization of fast components.

## 7 Conclusion

A new three-level topology for single phase solar inverter is extending the available solutions as Heric™ or H5-topology. The new topology is able to be used in real power and reactive power modus. Two different power module concepts are available.

## 8 References

- [1] Efficiency and grid compatibility of photovoltaic inverters – state-of-the-art and future trends, Dipl. Ing. Andreas Falk, Dr. Ing. Mike Meinhardt, Dipl. Ing. Volker Wachenfeld, SMA Solar Technology AG, Germany, Proceedings PCIM Europe 2009 Conference
- [2] Dr.-Ing. Bruno Burger, Seminar ECPE, ETG, FhG-IISB, „Energieeinsparung und rationelle Energienutzung durch Leistungselektronik“, Erlangen, den 13. Oktober 2005

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