Standard Modules Supporting Ultra High Motor Speed for Electric Vehicle

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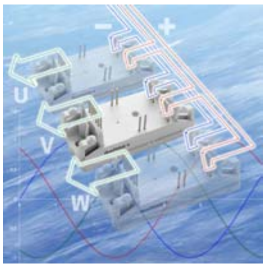
The electrification of vehicle traction generates also new requirements for standard power components. Weight and volume reduction of the system have highest priority, which leads to high motor and switching frequencies. To gain the advantage of high speed drives without the disadvantage of high power losses, resonant switching topologies are required, without becoming too complex and whilst still satisfying the required reliability. The automotive miracle of increased reliability at reduced cost has to become true again to make this vision real. A new standard component which supports an innovative switching topology might be an important step forward.

40kW SoftSwing® inverter with ***soft*****PHASE** modules from Tyco Electronics

The Goal

To increase the reliability and reduce cost in a high volume serial production, it is important to minimize the complexity of the system. Repeating structures can be realized with identical functional blocks. This reduces the development and qualification effort and time. The repeating structure for drives and bi-directional DC-DC converters is the ½ bridge. A module which incorporates this function is a conclusive subsystem for motor drive applications. The combination of a high and low switch in one module makes it easy to minimize the inductive loop in the DC-link by retaining the flexibility to distribute the circuits in the available space. This increases the freedom for the system design and reduces the complexity , which is especially important in the limited space in hybrid car applications. Power modules with ½ bridge topology are available as standard products,
e.g. *flow*PHASE0 (1200V / 150A and 600V / 200A)

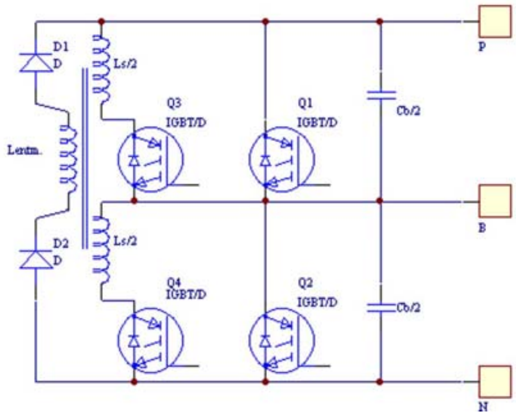


The requirement develop compact but high performance motors lead to high motor speed and high PWM frequencies. Such high switching frequencies will cause unacceptable switching losses in standard hard switched inverter topologies with the usual 3 phase inverter bridges. Special soft switching concepts are required to reduce the max. power dissipation in the semiconductors. The resonant SoftSwing® [1] topology was selected to answer this challenge. But now the standard ½ bridges are obsolete. The modules do not support such an approach sufficiently. The new task is to develop a universal power module for motor drives and DC-DC converters in hybrid and fuel cell vehicles with the following specification:

- Electrical output power: 30kW…100kW.
- DC-voltage: 150V…450V
  and 600V…900V
- The module has to support the special requirements of the SoftSwing® topology at an ultra high motor speed of 100.000rpm (ca. 1700Hz) and a PWM frequency of 24 to 48 kHz.

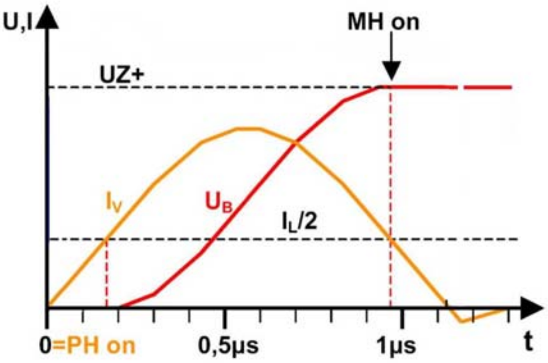
SoftSwing® - description

The bridge point formed by the two main IGBTs is connected to an auxiliary circuitry, consisting of small bridge capacitors and an auxiliary half bridge with small IGBTs and coupled inductors on their drains.



Switching Process and Characteristics

In the case of active switch-on, the external gate stimulus turns on only the auxiliary IGBTs (PH on), which conduct first. Subsequently, the current ramps up flowing into the inductor. Due to the coupling, the same current ramps up in the other inductor through the free wheeling diode of the passive auxiliary switch.



Once the sum of these auxiliary currents reaches the load current level, no load current flows through the main free wheeling diode , which is then about to set the bridge point free. The bridge capacitors and the inductors form an LC-oscillator and the bridge voltage starts to swing around its neutral point, which in this case is the virtual center tap of the DC-link. If the damping is sufficiently low, the bridge voltage nearly reaches the other rail potential where it is trapped by the zero current, zero voltage turn on of the corresponding main IGBT (MH on). From this point on, the auxiliary inductors give off their stored energy as their currents start to ramp down. With the load current is continuously flowing, the main IGBT current must ramp up to compensate for the disappearing auxiliary current.

Once the load current is completely commuted, the inductors need to be demagnetized, for which the auxiliary IGBT has to be turned off. One solution to perform demagnetization is by using a well coupled demagnetizing winding. Once the auxiliary inductors are completely demagnetized, the half bridge is ready for another active commutation.

Advantages

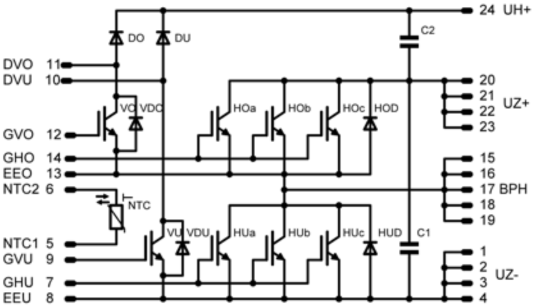
- The reverse recovery charge is not absorbed when the load current commutes from the free wheeling diodes into the IGBT
- The bridge capacitors protect the IGBTs from high voltage as the tail current occurs during turn off.
- Due to the absence of significant switching losses, the IGBTs can be utilized up to their rated DC-capability
- Aging related to periodical thermal expansion of the chip, caused by adiabatic switching loss absorption, is completely avoided.
- The circuit is extremely rugged and tolerant in overload conditions
- At 24kHz, the power dissipation is only half that of conventional hard switched topologies
- Due to the absence of reverse recovery spikes, the circuit generates extremely low disturbance emissions. In particular, DC-link filtering against conducted emissions becomes unnecessary.
- High PWM-frequencies are allowed, leading to sinusoidal motor-currents of up to 2 kHz or more. This allows innovative, high power density motor concepts
- Low du/dt reduces the dielectric stress of the motor insulation and thus enhances the reliability during the expected lifetime of the vehicle

Tradeoffs and Limitations

- The commuting time of course affects the PWM. Generally, the turn on delay, which depends on the current, has to be considered at the control part. In addition, the demagnetizing time limits the minimum turn on time to approximately 3% of the PWM cycle time.
- Standard gate drivers cannot perform well, in particular if they operate with a fixed dead time. Any dead time will increase the turn-on delay and is therefore counterproductive.

Module Definition

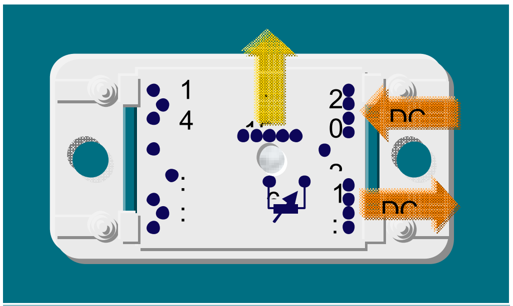
To be developed is a power integrated module with lowest possible inductances, in order to achieve subsystem levels which can be tested, qualified and produced at constant quality levels, using state of the art technologies and fabrication processes.
The repeating structure for drives and bi-directional DC-DC converters is the phase leg topology. To achieve maximum flexibility, the phase leg function with incorporated SoftSwing® topology is integrated into a single module.



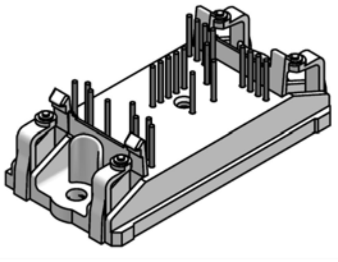
The module is realized on a DBC substrate, which is direct mounted onto the system heat sink. For a better thermal interface to the cooling medium, AlN was chosen as substrate material. For applications with lower power demand, the standard Al_2O_3 DBC can be used .

In order to achieve the required performance levels, the module's main power bridge consists of paralleled high speed IGBTs, designed for fast switching applications, with a given total nominal current of 150A (600V type) and 75A (1200V type). The supporting transistors are single duos, each consisting of one 3rd gen. IGBT and one high efficiency fast recovery diode.

The integrated capacitors are SMD components, specified for the required power and voltage levels. An SMD temperature sensor is integrated as well.



Three such modules represent a complete power kit of 40 kW continuous electrical power. Higher power ratings are possible by paralleling. It is now possible to achieve 40KW, 80kW and 120kW with the same components. The 2 different chip technologies (600V and 1200V) support DC-voltages up to 900V.



Summary

The new ***soft*****PHASE0** modules are easy to use components to design high efficient inverter and DC-DC converter in SoftSwing® resonant topology. The phase leg concept provides the flexibility to distribute the inverter over the available volume in the application. The scaleable power by paralleling multiple modules is a further advantage of the presented solution. The power modules are designed under the maxim of gaining highest power density as well as lowest stray inductances. High switching frequencies enable even special E-motors with extremely low leakage inductance to perform well. This is in particular beneficial for ultra high speed drives or motors with a high pole pair number.

References

[1] SoftSwing® is registered by Brusa Elektronik AG, Switzerland
[2] SoftSwing® Inverter and Customized SoftSwing® Power Module for the Automotive Market and Hybrid Electric Vehicle Applications (Sontheimer, Tyco Electronics and Arno Mathoy, Brusa Elektronik AG, 2006)