United Technologies Research Center

WBG Devices in Electrical Motor Drives

NOVEL POWER SYSTEMS ENABLED BY WIDE BAND-GAP SEMICONDUCTORS WORKSHOP

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Figure of Merits, Grand Challenge and Gaps

Performance Indices

Have different weights for different applications, two examples below:

(A) Aerospace and high end drives:

- Power per weight [kW/kg], 10 kW/kg
- Power density [kW/dm^3], 10 kW/dm^3
- Relative cost [kW/$]
- Relative losses [%], <2%
- Life time [Years], >10Y
- EMI – no external filters or shielded cables
- Voltage THD: better than for 3 level inverter

(B) Commercial drives:

Relative losses, <2%

- Life time 5 to 10Y
- No external filters for EMI or dv/dt
- Low grid harmonics (IEEE 519)
- Low cost

Opportunities, Grand Challenge for New Topologies

- Green drive with sinusoidal input and output
- EMI and PWM issues contained within the drive
- Utilization of parasitics to facilitate main functions
- Greater use of semiconductors on the expense of passives
- Active filtering
- Losses reduced by factor of 2
- Size and weight reduced by 2
- Same cost and life time

- The drive topologies we work on today should anticipate device performance and cost we expect in the future based on the performance trends for devices
- Focus on system level benefits

Gaps

Packaging/integration

- Packaging infrastructure for ultra high speed devices missing
  - Take benefits of parasitics
  - 3D packaging
  - Multi physics integration tools
- Life time issues for high temperature operation (thermal cycling, power cycling mostly unknown)

WBG device driven power converter topologies

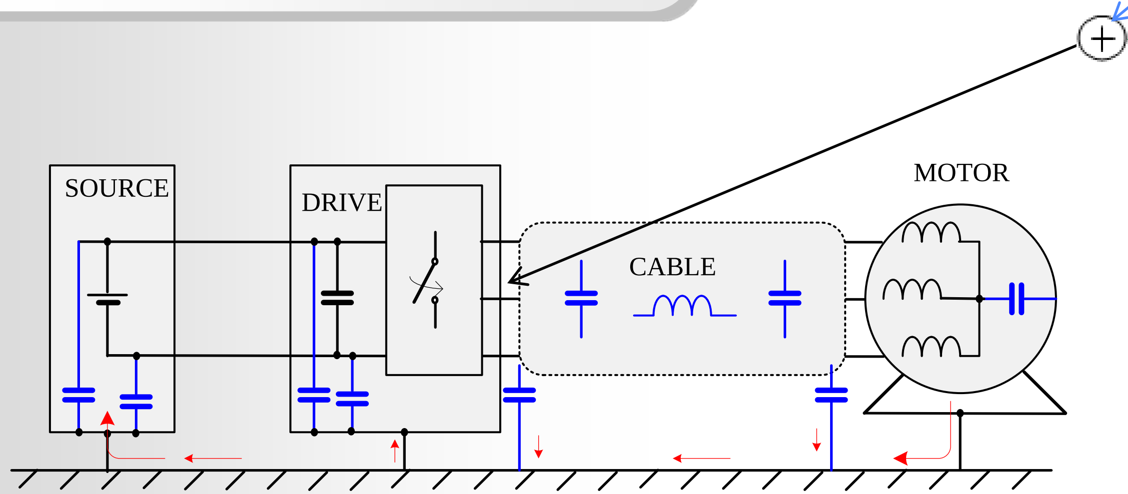
- Low PWM frequency (1 to 20kHz)
- Highly polluted V/I output of the drive

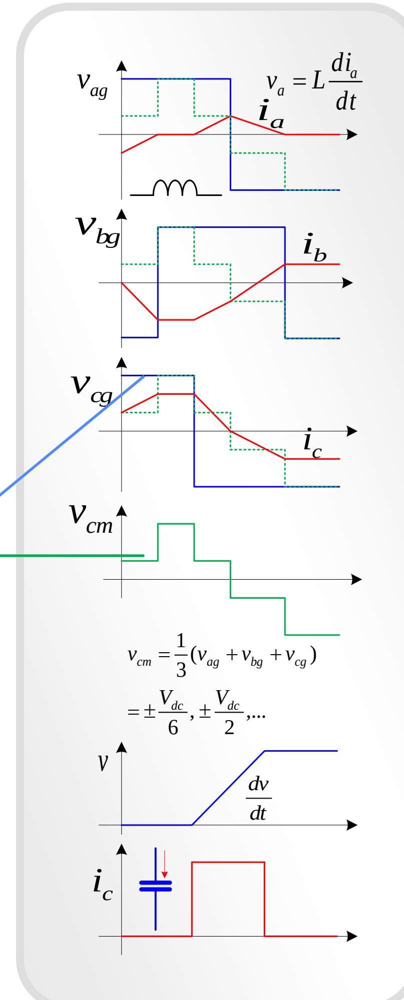
Effects of PWM

High speed switching has negative effects on the motor and the system

System level effects
- EMI conductive and radiated
- Noise in electrical circuits

Effects on the motor
- DM current ripple
    - Additional Cu losses
    - Additional Fe losses
    - Winding overvoltages and partial discharge
- CM currents
    - Bearing current





Drive is a generator of voltage waveforms with sharp transitions between (high) voltage levels

Electromagnetic interference (EMI)

EMI is a *disturbance* generated by an external source that affects the operation of a sensitive electrical circuit.

EMI standards define the *regulated frequency range* and corresponding *emission limit* for products in various applications. Impact on cost.

In the context of **power electronics**, EMI is the *high frequency* voltage and current components generated by power converters

EMI: Radiated and Conducted

Conducted EMI:

- ***Differential Mode (DM)*-**Only flows on the power leads
- ***Common Mode (CM)*-**Flows to the ground.
- ***CM EMI is very important for qualifications of power electronic converters***
- ***PWM switching frequency, Si Devices***
    - *10 to 20kHz P<5kW*
    - *2 to 10kHz 5kW<P<300kW*
    - *<2kHz P>300kW*
- ***WBG devices fpwm < 50KHz***

Mitigation for CM EMI

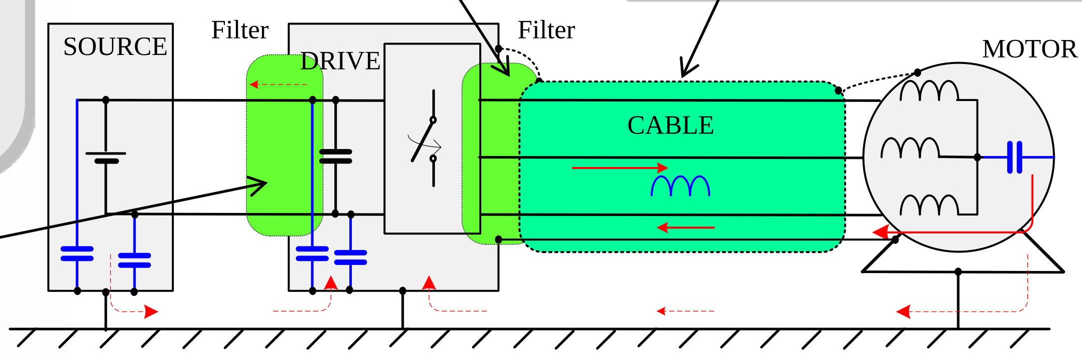
- Shielded cables/conduits between motor and drive
- EMI filters at line side of the drive
- RLC filters at the output of the drive
- Different PWM techniques to reduce CM voltage
- Active CM filter
- Good lay out of the drive
- Conductive/shielding enclosure for radiated EMI
- Integrated motor drive solutions

Output motor filter

- Softens voltage transitions
- Increases HF impedance between motor and drive

Cable

- Shielding for radiated emi
- Low impedance return path for ground currents



Input line filter

- Increases impedance between source and drive

Over-voltages and Bearing Currents

Cause of winding isolation and bearing failures

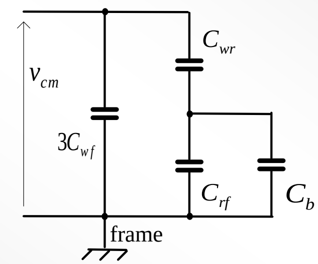
High switching speed with high dV/dt and transmission line effects/overvoltage on the motor terminals, isolation failure

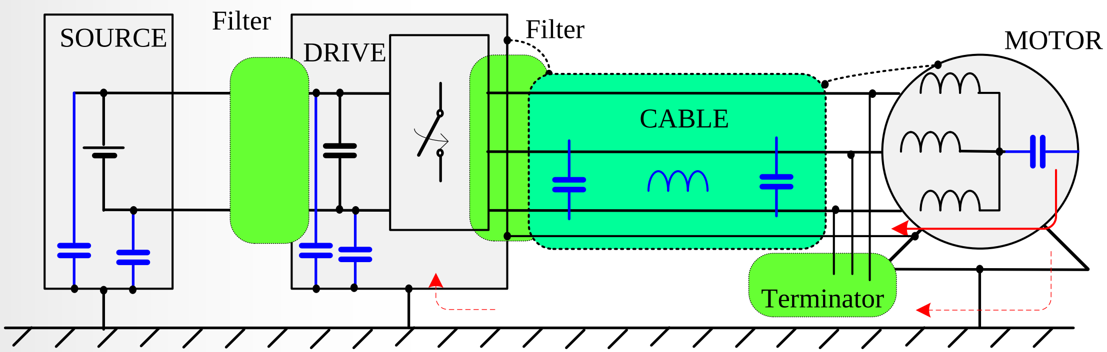
- dv/dt>600V/us acceptable level – bipolar technology,
- **Partial discharge** and motor winding failure, need for inverter grade wire
- For IGBT based technology start to play role for cables >10m, with increased speed of semiconductor switches (x10) shorter distances >1m will start to play critical role
- Mitigation techniques:
  - Output filters (RLC) to slow voltage transition speed, preferred option for smaller power (usually simple filters like just inductor will be sufficient)
  - Motor terminator (to match impedance, close to motor winding, preferred option for larger motors)
  - Reinforced isolation on first turn on the motor winding
  - Slowdown switching devices (fpwm~5kHz)
  - Multi level inverters (reduced voltage steps)

Bearing currents

- Cause of bearings failure
- Mitigation: filters, ceramic bearings, shaft grounding, closed winding slots

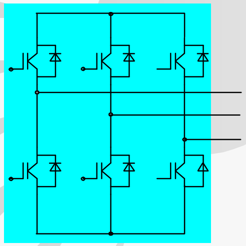
High frequency equivalent circuit with main capacitances important for bearing currents



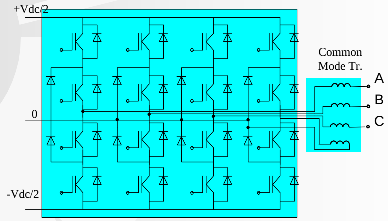


Existing drive topologies – comparison

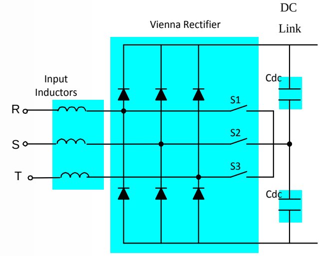
Present topologies are dominated by hard switching voltage source variants without considerations for PWM and EMI issues



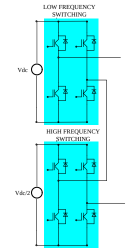
2 level



3 level 4 leg NC

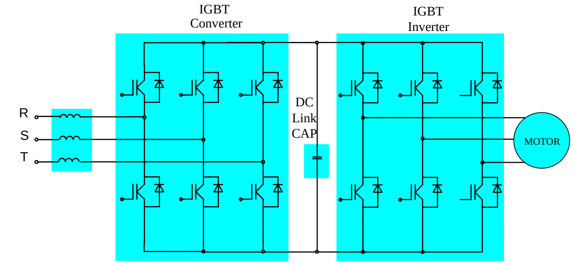


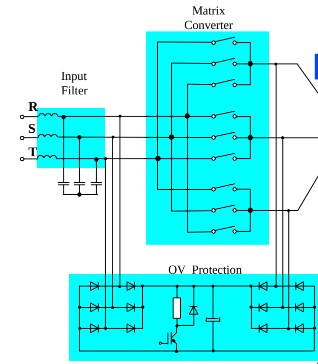
Vienna



Cascaded

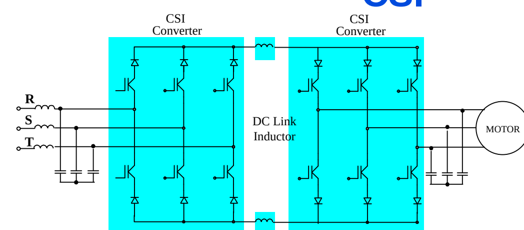
Back to Back VSC

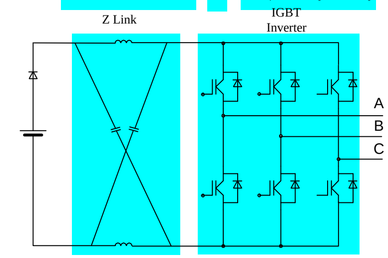




MxC

CSI





"Z" source

	Resonant	2 Level	Multi Level	Multi level cascaded	Vienna	Back to Back VSC	CSI	Mxc	Z
Overall Complexity									
# of Power components									
Revers blocking devices									
Additionala passive components to meet EMI									
Gate driving									
Power input complexity									
Control Complexity									
dv/dt and dI/dt									
Conduction losses									
Switching losses									
Extra Voltage or Current stress									
THD									
Regeneration									

Wide Band Gap Power Devices

Devices and applications – historic perspective

Transition from BJT to IGBT technology

Fast transition

- 1988/89 IGBT lab samples available
- 1991 – Drives with IGBTs available

Packaging/integration

- Packaging infrastructure was available (all Si based)
- Life time issues (thermal cycling, power cycling mostly unknown)

Device driven power converter topologies

- Low voltage 6 step (VSI vs CSI)
- Multi level inverters
- Cascaded inverters

Transition from Si to SiC /GaN technology

Slow transition

- Cost of active/switching devices
- Need for new packaging infrastructure to support high temperature operation
- Thermal/power cycling
- High temperature passive devices and control

Packaging/integration

- Need for material and test data to guarantee long life time
- Multi physics integration tools

New power converter topologies

- Integrated filters (green drives/inverters) with sinusoidal outputs, HF – enabler)
- Broader application of multi level, cascaded and CSI inverters (enabled by low conduction losses and HF)
- Reduced size and weight, simplified cooling