Lecture
Power Electronics

„Multi-Level Inverters“

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MULTILEVEL INVERTERS

- more than 2 voltage levels can be realized at the inverter output

- applications
  
  ➢ (sinusoidal) output voltages can be better realized (less harmonics)
MULTILEVEL INVERTERS

- more than 2 voltage levels can be realized at the inverter output
- applications
  - (sinusoidal) output voltages can be better realized (less harmonics)
  - voltage drop (stress) is less for each power semiconductor device
- 3 main topologies
  - Diode-Clamped Multilevel Inverter (DCMI)
  - Flying Capacitor Multilevel Inverter (FCI)
  - Cascaded Multilevel Inverter (CMI)
Three-Level Inverter

- Finer gradation of the output voltage
- Reduction of the current ripple ...
- Reduction of the pulse frequency
- Halving the voltage stress on the semiconductor switches
- Range of application: approx. 10 MW, 3.3 kV (Siemens, Simovert ML2, Rolling Technology)
- IGCT switches

Origin: Dr.-Ing. Olaf Simon, SEW Eurodrive
Diode Clamped Multilevel Inverter (DCMI)
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Diode Clamped Multilevel Inverter (DCMI)

- the number of semiconductor devices (in series), which are switched on, is always (in each switching state): \((n-1)\)

<table>
<thead>
<tr>
<th>Power device index</th>
<th>Output Phase Voltage ((V_o))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(V_1)</td>
</tr>
<tr>
<td>(S_1)</td>
<td>1</td>
</tr>
<tr>
<td>(S_2)</td>
<td>1</td>
</tr>
<tr>
<td>(S_3)</td>
<td>1</td>
</tr>
<tr>
<td>(S_4)</td>
<td>1</td>
</tr>
<tr>
<td>(S_5)</td>
<td>0</td>
</tr>
<tr>
<td>(S_6)</td>
<td>0</td>
</tr>
<tr>
<td>(S_7)</td>
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</tr>
<tr>
<td>(S_8)</td>
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</tbody>
</table>
Diode Clamped Multilevel Inverter (DCMI)

- widely used special case:

NPC Neutral Point Clamped (3-level) Inverter

Phase voltages at inverter output

Line-to-line voltages at inverter output
Diode Clamped Multilevel Inverter (DCMI)

- widely used special case:
  NPC Neutral Point Clamped (3-level) Inverter

- basic structure
  - DC link voltage is split by several capacitances in series
  - a DCMI providing n different levels in the output voltage needs (n-1) capacitances in series in the DC link

- fundamental behaviour
  - output voltage can achieve each voltage level defined by the DC link capacitances
  - the voltage on each capacitance is $V_{DC}/(n-1)$
  - the line to line output voltage can achieve (2n-1) different voltage levels
Diode Clamped Multilevel Inverter (DCMI)

PWM for Multilevel-Inverters:

- e. g. suboscillation method

→ several triangular signals
Diode Clamped Multilevel Inverter (DCMI)

- In combination with specific PWM schemes, there might occur instabilities in the equal distribution of DC link voltage to the DC link capacitances (balancing)
  - the average current to the inner knots of the DC link might not be 0 within a PWM cycle
  - in case of space vector modulation and inductive load, this problem is of minor importance

- solution of this problem
  - adapted PWM scheme - adapted use of zero vectors ...
  ... for capacitor voltage control (balancing)
Multilevel Inverter (Multi Level)

- Even finer gradation of the output voltage
- Reduction of the current ripple ... or ...
- Reduction of the pulse frequency
- One third of the voltage stress on the semiconductor switches
- Range of application: approx. 2 MW, 6 kV (CONVERTEAM / ALSTOM, SYMPHONY)
- IGBT 4500 V

Origin: Dr.-Ing. Olaf Simon, SEW Eurodrive
Control of Multilevel Inverter

- Switching variations for 2/3 output voltage
- (Dis)charge of the "flying" capacitors
- Balance of capacitors by switching alternatives 1:1:1

Origin: Dr.-Ing. Olaf Simon, SEW Eurodrive
Flying Capacitor Multilevel Inverter (FCI)
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possible space phasors (space vectors)
Flying Capacitor Multilevel Inverter (FCI)

- number of diodes is significantly lower than in a DCMI
- voltage potential of the (“flying”) capacitors is floating with reference to the ground potential
- balanced distribution of DC link voltage to the DC link capacitors (balancing) is not a problem with FCI
Flying Capacitor Multilevel Inverter (FCI)

- applying a sufficient number of levels in combination with a suitable PWM scheme harmonics in the output voltage might be low enough to avoid additional filters

- duty cycles and switching frequencies of power semiconductor devices are different to each other
Flying Capacitor Multilevel Inverter (FCI)

- Appropriate selection with a suitable PWM scheme in combination with a sufficient number of levels might be low enough to avoid additional filters.

- Duty cycles and switching frequencies of power semiconductor devices are different to each other.
Flying Capacitor Multilevel Inverter (FCI)

- applying a sufficient number of levels in combination with a suitable PWM scheme harmonics in the output voltage might be low enough to avoid additional filters

- duty cycles and switching frequencies of power semiconductor devices are different to each other

- additional provisions/strategies are necessary for charging the DC link capacitors
Cascaded Multilevel Inverter (CMI)
Cascaded Multilevel Inverter (CMI)

- also known as Cascaded Multi-Level Inverter with separate DC links or as inverter bridges in series connection

- simple and modular design

- needs lowest number of power semiconductor devices

- needs several DC links isolated against each other
Multi-Level Inverter
comparison of the number of power semiconductor devices
per output phase

(assumption: all power semiconductors are rated to the same voltage,
but not necessarily to the same current)

<table>
<thead>
<tr>
<th>inverter type</th>
<th>DCMI</th>
<th>FCI</th>
<th>CMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>active semiconductors</td>
<td>((n - 1) \times 2)</td>
<td>((n - 1) \times 2)</td>
<td>((n - 1) \times 2)</td>
</tr>
<tr>
<td>power diodes</td>
<td>((n - 1) \times 2)</td>
<td>((n - 1) \times 2)</td>
<td>((n - 1) \times 2)</td>
</tr>
<tr>
<td>„clamping“ diodes</td>
<td>((n - 1) \times (n - 2))</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>DC link capacitors</td>
<td>((n - 1))</td>
<td>((n - 1))</td>
<td>((n - 1) / 2)</td>
</tr>
<tr>
<td>„balancing“ capacitors</td>
<td>0</td>
<td>((n - 1) \times (n - 2) / 2)</td>
<td>0</td>
</tr>
</tbody>
</table>