Modular Multilevel Submodules for Converters, from the State of the Art to Future Trends

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Modular Multilevel Submodules for Converters, from the State of the Art to Future Trends

- World’s Energy Situation
- Demand for Efficient Energy Distribution and Grid Stability
- Enabling Technology - Modular Multi Level Converters
- State of the Art Submodules
- Design Considerations
- A New Submodule Approach
- Summary
World’s Energy Situation

Today’s situation

- Energy consumption grows worldwide driven by:
  - Population
  - Industry

- Traditional power generation (fossil coal, gas, oil & nuclear)

- Steady growth of renewables (hydro, wind, solar, bio-mass, tidal plant)

picture 1: electrical energy distribution
World’s Energy Situation

Energy consumption grows worldwide

Non-OECD energy consumption by region
quadrillion Btu
[1 Btu ~ 1kJoule]

2018

Asia

Middle East

Africa

Americas

Europe and Eurasia

U.S. Energy Information Administration

picture 2: predicted worldwide energy consumption
source: US Energy Information Administration IEO2017

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MMC Submodules
World’s Energy Situation

Energy consumption growth in China

World’s Energy Situation

Energy generation growth in India

**Sources of electricity generation in India**

- **2010**: Coal = 1000, Natural Gas = 500, Renewables = 150, Liquids = 50, Nuclear = 200
- **2020**: Coal = 1500, Natural Gas = 800, Renewables = 180, Liquids = 60, Nuclear = 240
- **2030**: Coal = 2000, Natural Gas = 1200, Renewables = 240, Liquids = 80, Nuclear = 320
- **2040**: Coal = 2500, Natural Gas = 1600, Renewables = 300, Liquids = 100, Nuclear = 400

**Renewable generation in India**

- **2010**: Other = 200, Solar = 50, Wind = 100, Hydropower = 100
- **2020**: Other = 260, Solar = 60, Wind = 140, Hydropower = 140
- **2030**: Other = 320, Solar = 80, Wind = 180, Hydropower = 180
- **2040**: Other = 380, Solar = 100, Wind = 220, Hydropower = 220

*Source: US Energy Information Administration IEO2017*

- [IEO2017](www.eia.gov/ieo)
World’s Energy Situation
Electrical energy - most dynamic growth

Growth of GDP, power and primary energy

% per annum

- GDP
- Power
- Total primary energy
- Primary energy ex power

Shares of total power generation

- Hydro
- Renewables
- Nuclear
- Gas
- Oil
- Coal

picture 5: Energy outlook, estimated to 2040, source: BP
Demand for Efficient Energy Distribution and Grid Stability

- Worldwide energy consumption grows rapidly. Electrical energy has the highest growth rates.
- With Renewables, the electric grid is fed with more but smaller, decentralized power sources -> fluctuating load-flow directions.
- Irrespective of the primary source of energy (renewable, coal, nuclear) it is desirable to locate power generation away from areas with high population density.

→ Consequences for existing and future power grid

- Need for low loss energy transportation.
- Maximum utilization of existing grids.
- Scalability and modularity to adapt to the size of energy source.
Modular Multi Level Converters

Energy Transportation – traditional HVDC

- 2-level voltage source inverter (2L-VSC)
- poor scalability
- high filter investment

picture 6: High Voltage DC Transmission – basic principles
source: Fraunhofer IISB

AC grid - 1

AC grid - 2

e.g. ± 400kV PWM
Modular Multi Level Converters
Modern HVDC Transmission – MMC [M²C]

-very well scalable
- black-start capable
- very low filter investment

modular converter concept based on submodule „bricks“

source: Fraunhofer IISB / Siemens AG
picture 7: High Voltage DC Transmission – Modular Multi-Level principle
Modular Multi Level Converters
Flexible usage – grid quality applications

Static VAR Compensation
Static Frequency Converter
Active Harmonic Filter

picture 8: grid quality applications; source: Fraunhofer IISB
Modular Multi Level Converters
Flexible usage – other applications

- Very large drives
- Large wind turbines
- MVDC
- Ship drive
- Electrical aircraft

picture 9: gas compressor 61MW ; source: GE  picture 9b: PV field
Modular Multi Level Converters
Flexible usage – other applications

- Very large drives
- Large wind turbines
- MVDC
- Ship drive
- Electrical aircraft

picture 9c: popular science monthly, 1933
Modular Multi Level Converters
HVDC links - Germany

Offshore links in test phase or under construction

picture 10: planned high voltage transmission – off shore and Germany
Modular Multi Level Converters

HVDC links – China & Russia

Planned Future HVDC Projects by 2020 in China

(The year means project in operation)

picture 11: HVDC projects
source: ABB 2013
Modular Multi Level Converters
HVDC & STATCOM

HVDC - Transbay Cable Link (2008-2010)
- electrical: ± 200 kV, 400 MW (±300 MVA)
- under water cable: 88 km

SVC PLUS
- grid quality
- grid stability

Submodules arranged like “brick in a wall”
Modular Multi Level Converters
Intermediate Summary

- The modular multi-level converter (MMC / M²C) technology fits perfectly to satisfy future high voltage energy transportation and grid quality demands.

- Very good scalability, versatile usage for various MV & HV applications.

- Modular Multi-level converters are successfully in service for several years, provided by a few big players worldwide.

- The heart of the modular multi-level converters are so called sub-modules, today designed differently in detail by each player, with very similar appearance.

- These submodules are one of the technical core pieces, but not the mayor cost aspect of such projects.
Modular Multi Level Converters
HVDC - Different System Suppliers

- Similar style
- Different Submodules „bricks“

picture 15: HVDC-LGHT converter hall with sub-modules
source: ABB

picture 16: HVDC-PLUS converter hall with sub-modules
source: Siemens AG
Modular Multi Level Converters

Submodules

- Today Modular Multi-Level Converters are an acknowledged and mature technology.

- Up to several thousand of such sub-modules are interconnected per converter, similar to bricks in a wall.

- As everybody builds a similar kind of “wall”

- Why not use same kind of „bricks“?

- The next consequent step:

  → Provide a standardized Platform for Modular Multi-Level Submodules
State of the Art Submodules
Principle & Interfaces

MMC submodule

2x power
2x signal
2x cooling
mechanical fixation zones

Basic Half Bridge:

Basic Full Bridge:

voltage levels: 3.3kV / 4.5kV / 6.5kV
current ranges: < 1kA ... > 2kA

switched capacitors

picture 17: MMC submodule interfaces
State of the Art Submodules
Principle & Interfaces

picture 18: Traditional MMC submodule - simplified block diagram
State of the Art Submodules
Selection of today’s submodules

picture 19: Hyosung; source: Hyosung

picture 20: Mitsubishi; source: Mitsubishi

picture 21: GE; source: GE

picture 22a/b: ABB; source: ABB
State of the Art Submodules
Selection of today’s submodules

picture 23: Siemens Submodules - Half- & Full-Bridges
source: Siemens AG, Fraunhofer IISB
State of the Art Submodules

Today’s Mechanical Design

- Today’s Submodules appear similar [besides single source semiconductor usage]

- Functional blocks appear in same order [Bypass – Switches – Capacitor]

- Upright capacitor
  - Form factor / aspect ratio challenging with respect to installation space (depth).
  - High balance point of modules.
  - Service on site difficult (accessibility, exchange of modules)
  - Enlarging family power range will increase unfavorable form-factor

picture 24: state of the art submodule design – top view
Standardization – MMC Submodules

Future Trend – Technical Considerations

- Remember lessons learned
- Provide a platform for a family of submodules [topology, voltage level, current rating]
- Do not use single source components
- Use state of the art components, apply conservative rating
- Allow variants in key components for various customers & applications [switch, capacitor]
- ALWAYS respect interfacing system demands
- Provide a sustainable, backward compatible concept for exchange & maintenance
Standardization – MMC Submodules  
Future Trend – Economic Aspects

- Provide standardized submodules for multiple users.
- Enable new business fields for smaller and medium size players.
- Manufacturers focus on their core-competence: System design and integration.
- Provide unique selling points by customizing options (component & controller)
- Design, testing, quality control and reliability validation of the sub-modules are ensured by large-number statistics generated by all platform-users, not only by one single system supplier.

- Centralized perfective maintenance (rapidly changing HV IGBT generations, handling of obsolete components)

- Choose an independent provider – not one of today’s key component or system suppliers
Standardization – MMC Submodules

Future Trend – Required Functionality

- Latest IGBT modules
- Fast semiconductor Bypass [~10µsec]

**options:**
- Control interface
- Various topologies
- 3.3kV / 4.5kV / 6.5 kV
- Scalable current
- RCDC, SiC
- IHM modules

Slide 27
Markus Billmann
Application Group / Energy Electronic Department, June, 7th, 2018
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MMC Submodules
A New Approach – MMC Submodules
One Small Step – Many Benefits

picture 27: one main design step

Cross section for electronic mounting space today
A New Approach – MMC Submodules
One Small Step – Many Benefits

- Flip over brick
- No more fall over
- Much more than double flat space
- Low balance point
- Cross section for electronic mounting space

picture 27: one main design step
A New Approach – MMC Submodules

Future Trend – Horizontal Design Concept

- upright capacitor today
A New Approach – MMC Submodules
Future Trend – Horizontal Design Concept

- Water-cooled capacitor
- Low balance point

picture 28: simplified sketch
A New Approach – MMC Submodules
Future Trend – Horizontal Design Concept

- Water-cooled capacitor
- Very large rectangular flat space for electronics
- Low balance point
- Integrated cooler acts as support surface
- Good form factor (total depth determined by capacitor)
- Capacitor and power module form a simple structured unit

picture 28: simplified sketch
A New Approach – MMC Submodules
Future Trend - Horizontal Design Concept

Family options:
- Cooler as reference point
- Decoupled electronic mounting space

picture 29: decoupling capacitor & switches
A New Approach – MMC Submodules

Future Trend - Horizontal Design Concept

Family options:
- Cooler as reference point
- Decoupled capacitor length & depth

picture 29: decoupling capacitor & switches
A New Approach – MMC Submodules
Future Trend - Horizontal Design Concept

Family options:

- Cooler as reference point
- Decoupled capacitor length & depth

picture 29: decoupling capacitor & switches
A New Approach – MMC Submodules

Future Trend - Horizontal Design Concept

Family options:

- Cooler as reference point
- Decoupled capacitor length & depth
- Decoupled electronic mounting space
- Space for various sensors

picture 29: decoupling capacitor & switches
A New Approach – MMC Submodules

Future Trend - Horizontal Design Concept

- Standardized shape
- Compact design
- All functional blocks inside
- Standardized interfaces
- Front access
- Various topologies in same outline

picture 30: standardized submodule – design
A New Approach – MMC Submodules
Future Trend – Horizontal Design Concept

- Designed for 3k3 / 4k5 / 6k5 clearance & creepage
- Conductor cross section up to 1000mm²

picture 31: standardized submodule – rear view
A New Approach – MMC Submodules
Future Trend - Horizontal Design Concept

Same mechanical family outline – various topologies, currents & voltages
→ only one rack design for all options

picture 33: standardized submodule – front view
A New Approach – MMC Submodules

Future Trend – System Rack Concept Design

- Simple construction
- **one rack for all family members**
- VERY compact
- Minimum peripheral conductors
- Expandable to 6-8-10(?) levels
- No exchange tool stay inside rack
- Submodule exchange time < 5min

picture 34: rack mounting
A New Approach – MMC Submodules
Future Trend – Submodule Exchange Concept

- Insert tool
- Easy lift up
- Roll-out

picture 35: insert tools

picture 36: exchange mechanism
A New Approach – MMC Submodules
Future Trend – No Longer a Vision

picture 37: new submodules mounted in demonstrator rack

picture 38: demonstrator rack with 3 submodule levels installed
Modular Multilevel Submodules for Converters, from the State of the Art to Future Trends

Summary

- Worldwide energy demands call for Modular Multi-Level Converters
- Today MMC [M²C] is a well proven and mature technology
- Providing a standardized Platform for Modular Multi-Level Submodules is the next consequent step
- New design approach for family of submodules
- First family member is realized [full-bridge 3.3kV]
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Thank You for Your Attention!

see hardware

further information: multilevelcube@miba.com
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