# Modular Electronics for Renewable Energy Sources and Grid Storage

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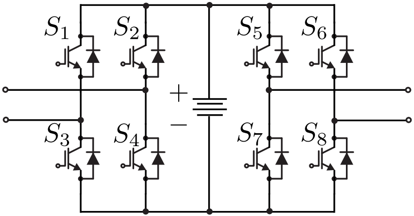
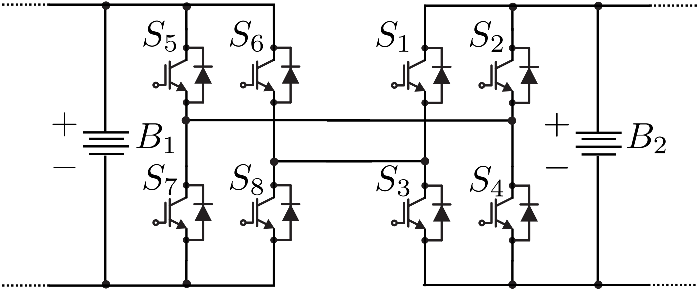
# Summary

# Microtopology



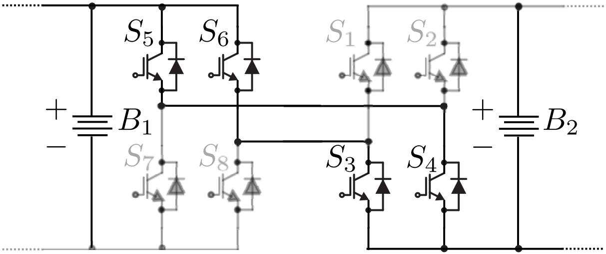

- Each module provides four terminals.
- Every terminal is connected to the module battery (or capacitor) via a half-bridge.
- Every neighbor of a given module has access to both sides of the battery (or capacitor) at the same time for a parallel mode.

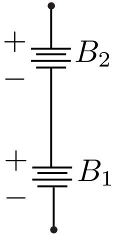
# Possibles states for neighbouring modules.




- The Modular Multilevel Series Parallel Converter (MMSPC) is based on the series connection of the proposed module topology.
- The MMSPC topology is a generalization of the traditional Modular Multilevel Converter (MMC) .

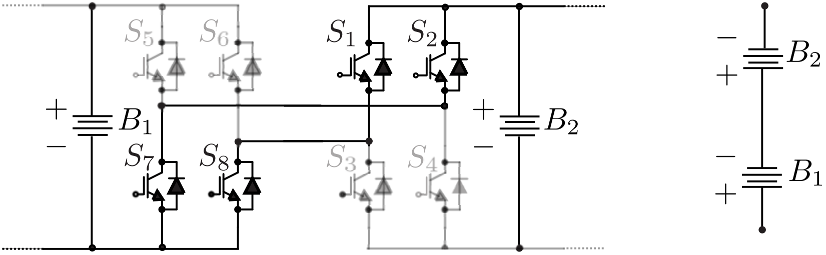
# Possibles states for neighbouring modules.



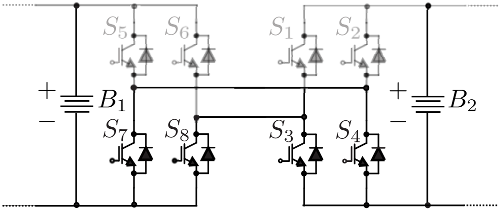

- Series positive state.

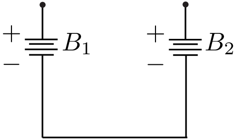
# Possibles states for neighbouring modules.




- Series negative state.

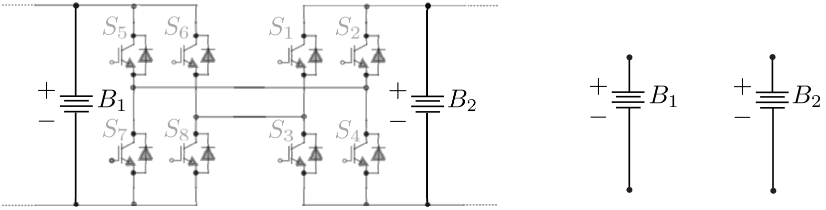
# Possibles states for neighbouring modules.



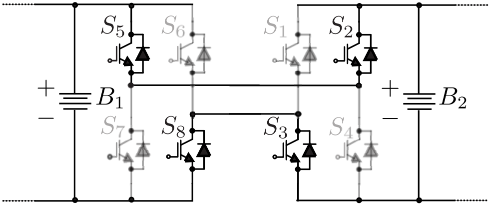

- Bypass state.

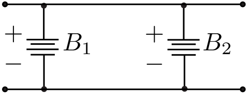
# Possibles states for neighbouring modules.




- Zero state.

# Possibles states for neighbouring modules.



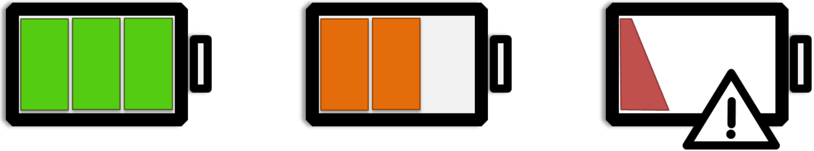

- Parallel state.

# Benefits and advantages of the parallel connection.

- The parallel connection increases the current rating by reducing the internal resistance.
  - This benefit is particularly important for STATCOMs applications, where highest currents occur during low- voltage time intervals.

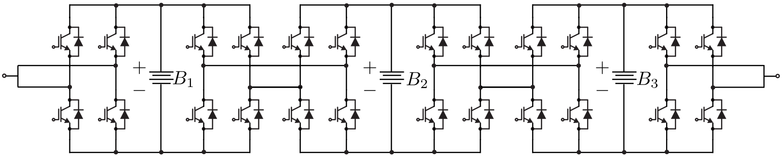
# Benefits and advantages of the parallel connection.

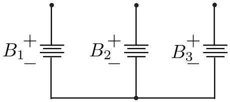
- The parallel connection provides an additional method for balancing the SOCs of the individual modules.
  - The balancing with the parallel connection does not required accurate information of the energy in-flow and out-flow in every module, and it can ensure a balance state even with an open-loop approach.

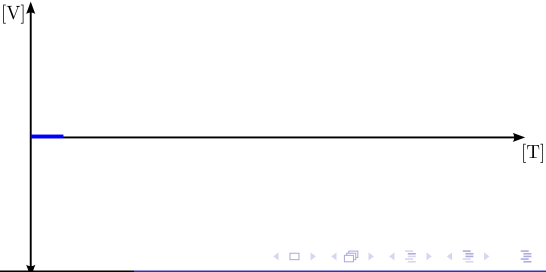


# Macrotopology

- The MMSPC topology can provide the structure for a dynamical reconfiguration of battery cells in series and parallel



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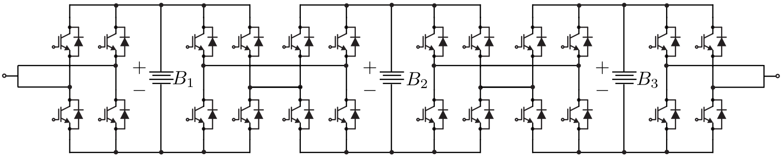


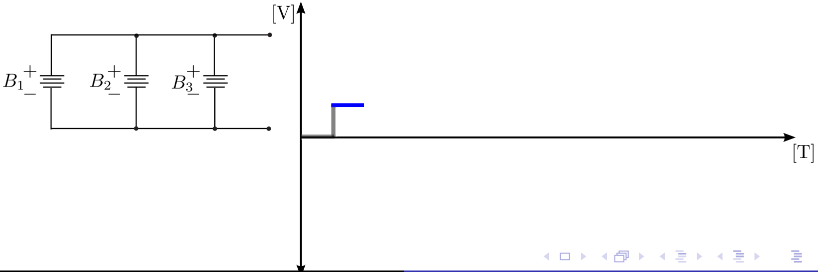

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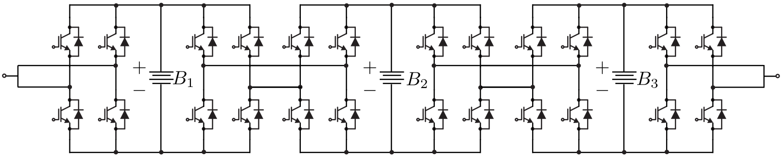


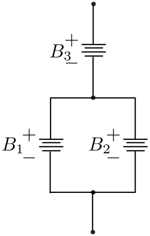


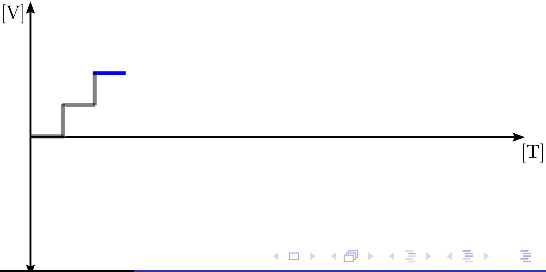

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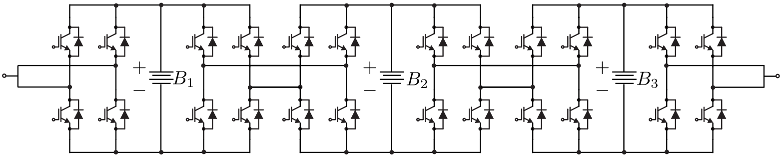


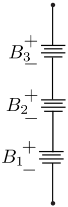


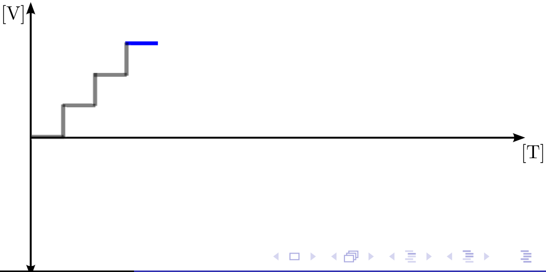

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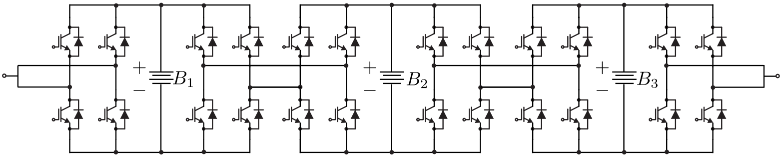


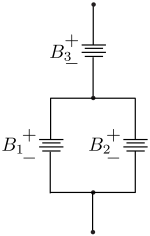


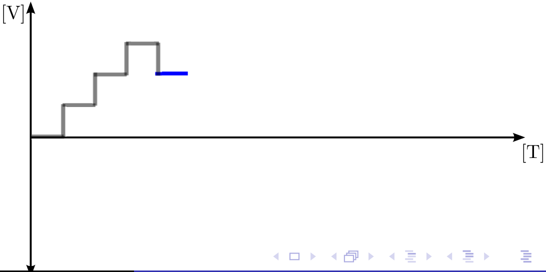

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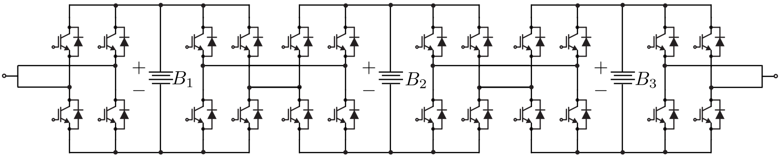


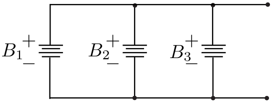


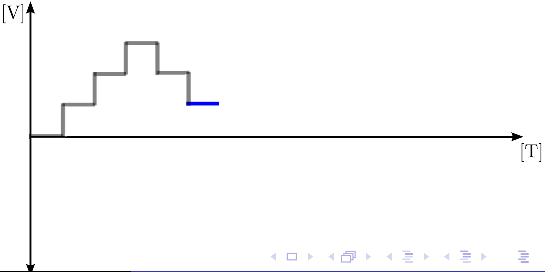

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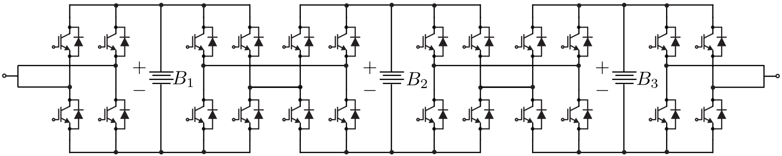


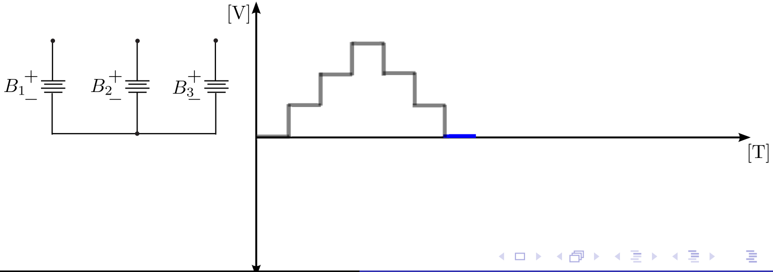

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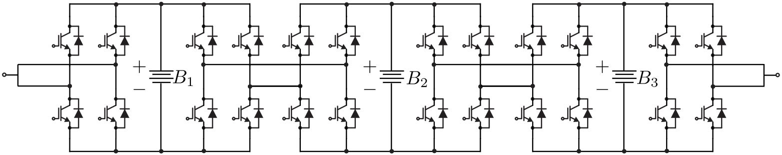


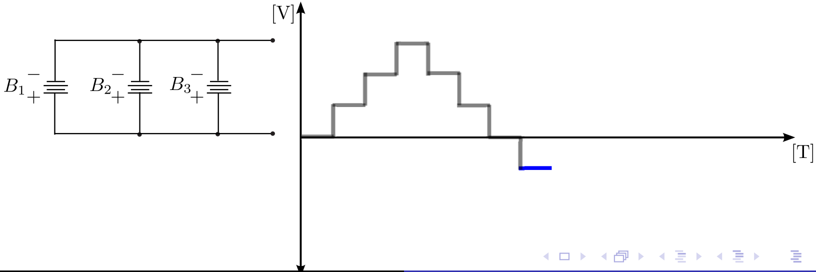

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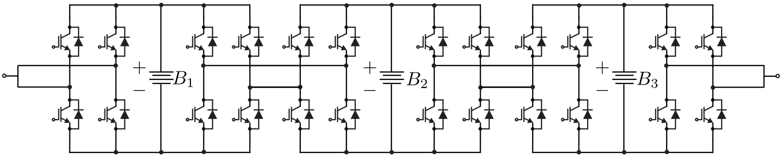


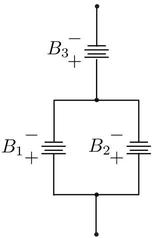


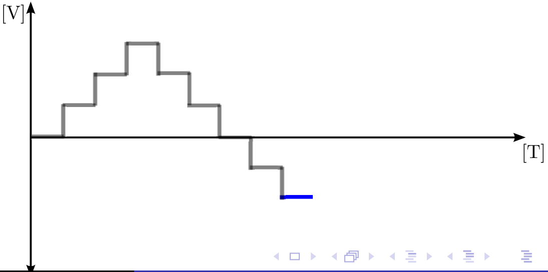

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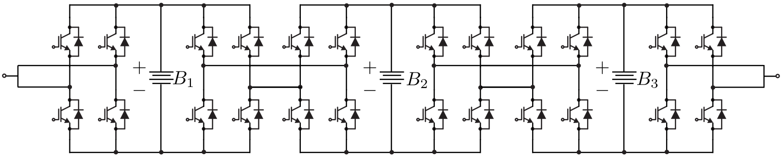
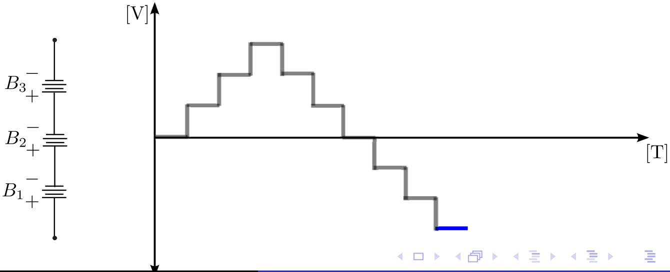
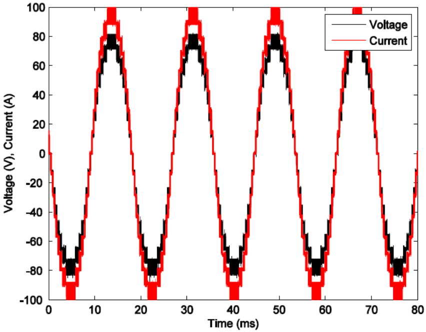


# Experimental results

- MMSPC prototype based on 8 modules.




- AC voltage and current.
- Absorbent-glass-mat lead-acid battery (nominal 12V, 7 Ah, Enersys Genesis NP7-12, Reading, PA)

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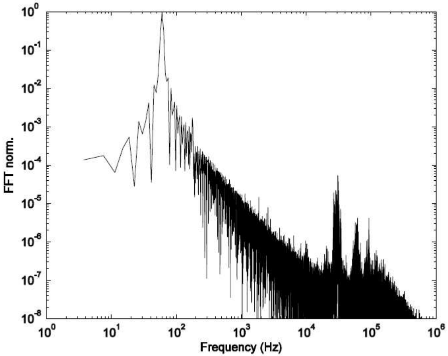
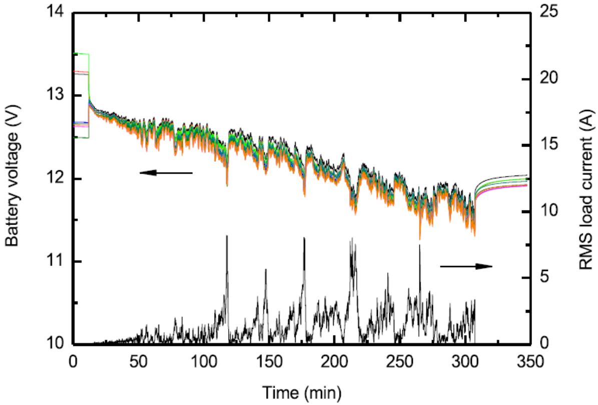
- MMSPC prototype based on 8 modules.




- FFT of the AC voltage.
- Absorbent-glass-mat lead-acid battery (nominal 12V, 7 Ah, Enersys Genesis NP7-12, Reading, PA)

# Module balancing performance

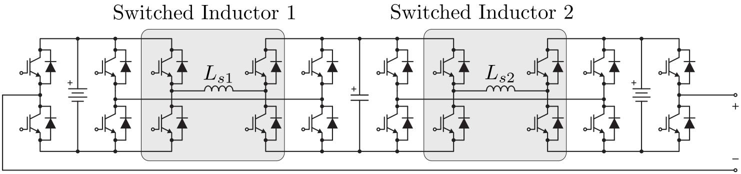



The standard deviation of the individual module voltages is reduced by a factor of eight (from 0.367 to 0.045 V)

# Summary

1. Topology Description
2. Topology Generalization
3. Conclusions

# Switched-Inductor Energy Transfer Between Modules




The switched-inductor voltage conversion feature allows controllable and efficient transfer of energy between modules with nonnegligible voltage difference, providing both step-down and boost functionalities.

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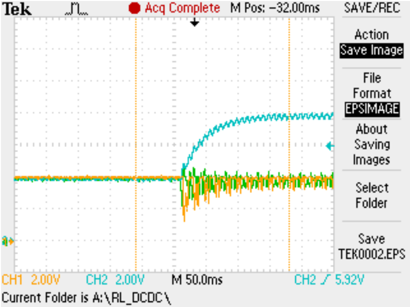


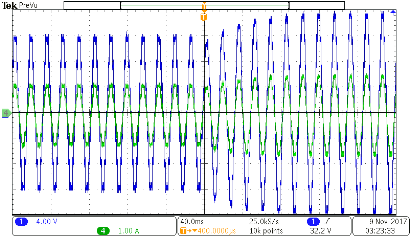


Results of a change in the voltage ratio from 1:1:1 to 1:2:1.

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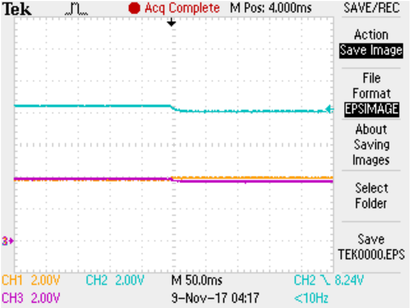
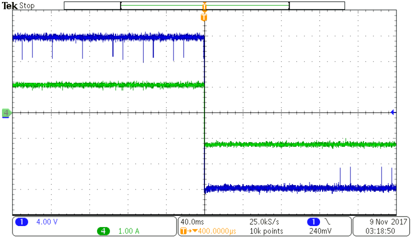
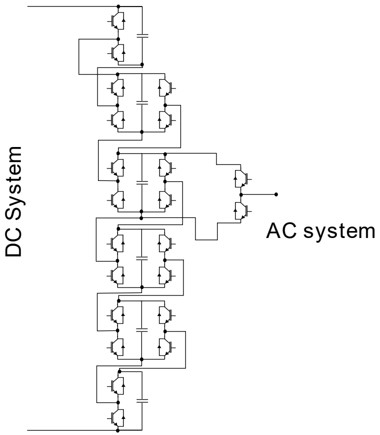


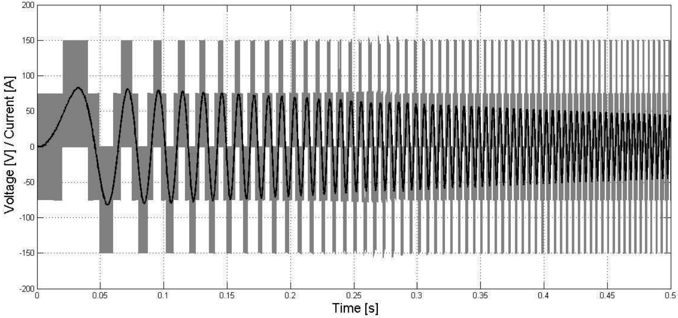

Results of proposed topology with a dc output voltage.

# MMSPC for HVDC applications




- The parallel interconnection among the modules of the same phase allows to obtain an improved balance (Open loop strategy).
- For closed loop control, only requires the measurement of one module capacitor voltage per phase.
- It is possible to extend the application of the MMSPC for low frequency operation.

# MMSPC for HVDC applications




Waveforms for MMSPC for a wide range of frequency: AC voltage and current

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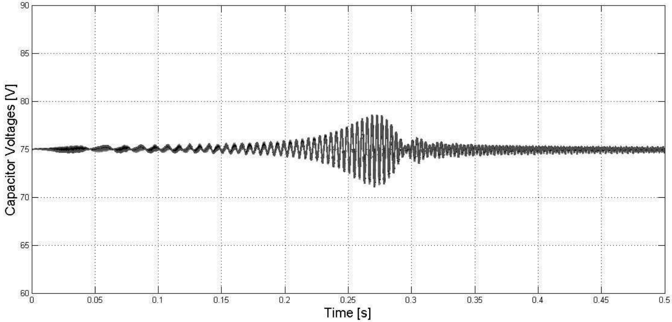
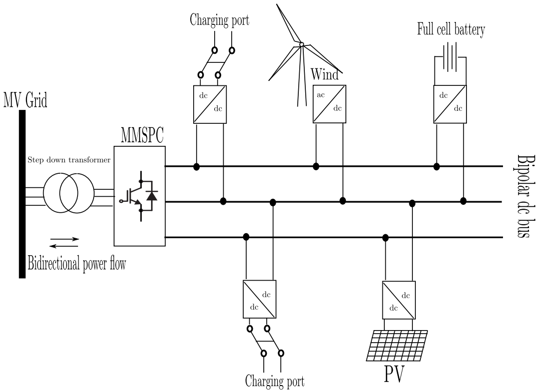



Waveforms for MMSPC for a wide range of frequency: modules capacitor voltages.

# Bipolar DC systems based on MMSPC




The parallel interconnection have to ensure the energy distribution among the modules and the control strategy have to ensure enough energy for keep the complete system balanced.

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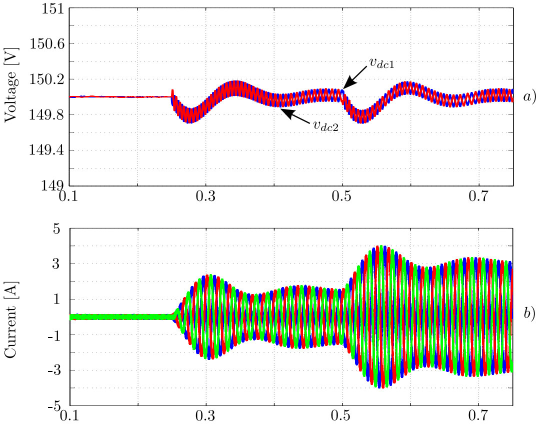


In $t = 0{,}25[s]$ a load is connected to dc system 1. In $t = 0{,}5[s]$ a load is connected to dc system 2.

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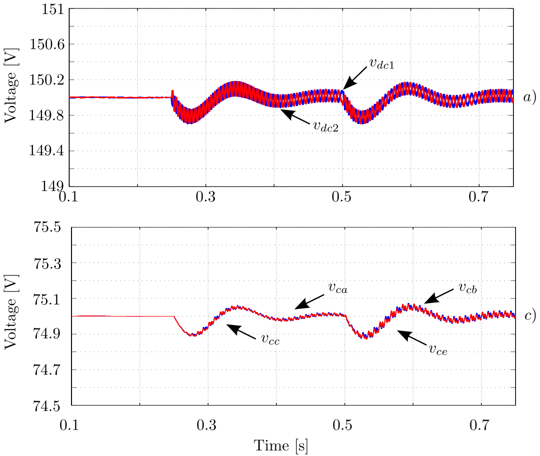


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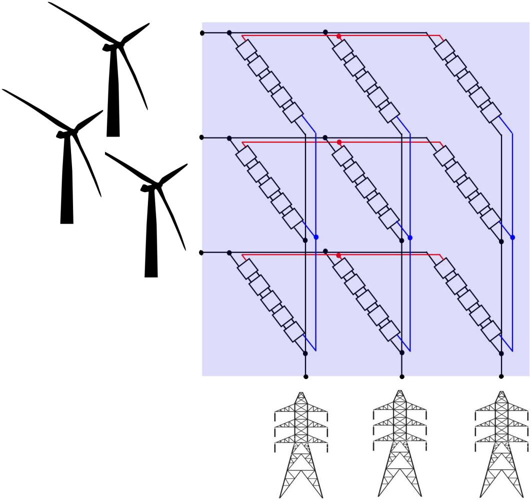
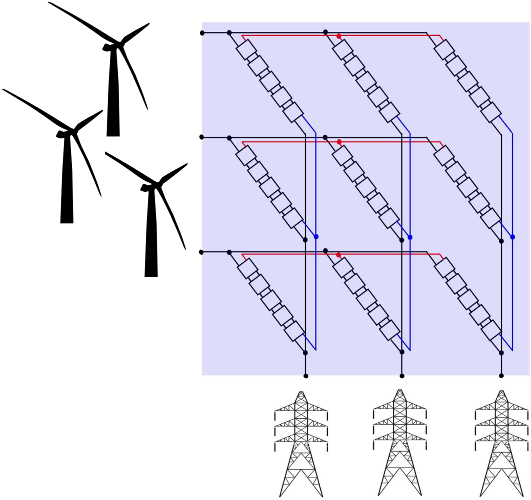
# Matrix configuration based on MMSPC



The matrix configuration of the MMSPC brings the opportunity to create parallel states among the modules of each arm, plus the parallel state among the arms of the converter.

# Matrix configuration based on MMSPC



This configuration brings the opportunity to interconnect asynchronous systems, without a central DC link.

# Summary

# Conclusions

The MMSPC is a novel topology with the capability for parallel connectivity between modules.

The MMSPC parallel state reduces the source impedance and hence conduction losses

The switched-capacitor-type energy transfer enables a simple, sensorless control approach that balances the module voltages by parallelization.

# Conclusions

The switched-inductor voltage conversion feature allows controllable and efficient transfer of energy between modules with nonnegligible voltage difference, providing both step-down and boost functionalities.

The topology extension, using capacitors in each module, allows the implementation of the MMSPC in a wide range of applications like HVDC systems, Bipolar type DC microgrids and grid connection for renewable energy sources.

Thank you for your attention!