Simulation of Modular Multilevel Converter System via Analytical Approach

2020 CURENT NSF/DOE Site Visit and Industry Conference
Virtual
Nov. 2020

Xin Xu¹, Yunting Liu¹, Kai Sun¹, Leon Tolbert¹, Suman Debnah²
¹The University of Tennessee
²Oak Ridge National Laboratory
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Background and motivation:

• Modular multilevel converters (MMCs) are widely used in HVDC transmission systems and others.
• Fast and efficient simulation tools would benefit the system planning and analysis.
• An analytical solution will be preferred since the result would be theoretically accurate for relatively longer integration step than the numerical solution.

Technical approach:

• Between any two adjacent switching moments, the MMC system is essentially a set of linear ODEs, the simulation of which can be accelerated by eigenvalue decomposition techniques.

\[ \dot{x}_y = A x + B u \]
\[ x_y = R z \]
\[ \dot{z} = \Lambda z + w \]

• Solve in the mode space and transform back to the state space solution.

\[ x_y(t) = R z(t) \]

Conclusion:

• The proposed approach is shown to be more efficient than the Euler forward method in case studies.
• The analytical approach will be investigated for three-phase large-scale MMC systems with more complex control algorithms.
• How to incorporate MMC system simulation with the transmission system study.
Analytical solution by eigenvalue decomposition

- MMC is a linear system when the switching mode is fixed.

\[ \dot{x}_y = A_y x_y + B_y u \]

- Eigenvalue decomposition.

\[ A_y = R \Lambda L \]

- The ODE of \( z \) is decoupled, and the analytical solution can be easily found.

\[ \dot{x}_y = A_y x_y + B_y u \]
\[ x_y = Rz \]
\[ \dot{z} = \Lambda z + w \]

- Between any two adjacent switching moments, we only need a one-step analytical solution, instead of the time consuming multiple-step numerical integration.

\[ x_y(t) = Rz(t) \]

- The computation burden can also be reduced.
Case studies

• Compare with Euler’s method on a single phase 5-level MMC.

• Accuracy.

• Time consumption.

<table>
<thead>
<tr>
<th>Simulation Method</th>
<th>Computational Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 s</td>
</tr>
<tr>
<td>EM1</td>
<td>5.743 s (87.69 s)</td>
</tr>
<tr>
<td>EM2</td>
<td>1.296 s (11.29 s)</td>
</tr>
<tr>
<td>Analytical Approach</td>
<td>0.88 s</td>
</tr>
</tbody>
</table>
Acknowledgements

The work was supported primarily by the ERC Program of the NSF and U.S. DOE under grant EEC-1041877 and in part by the NSF grant ECCS-1610025.

Other US government and industrial sponsors of CURENT research are also gratefully acknowledged.