Reducing the Size and Weight of Filter Inductor for NPC 3-Level Inverter with 240CPWM

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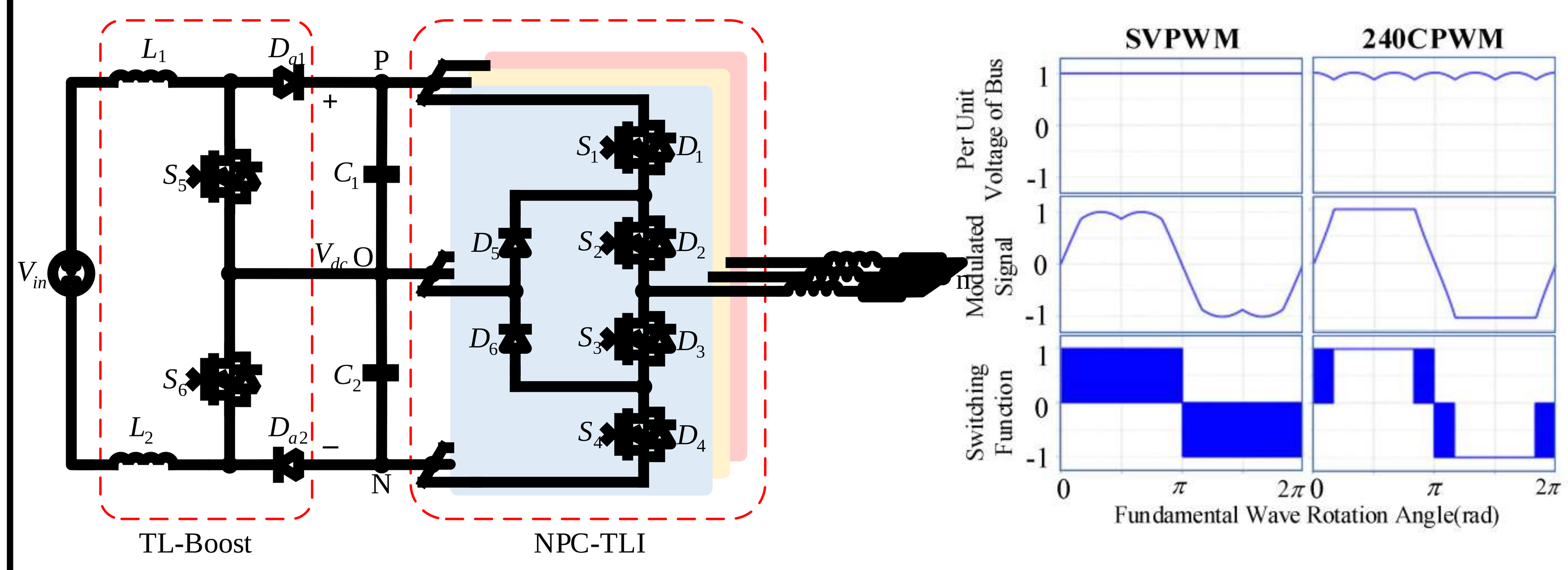
Introduction

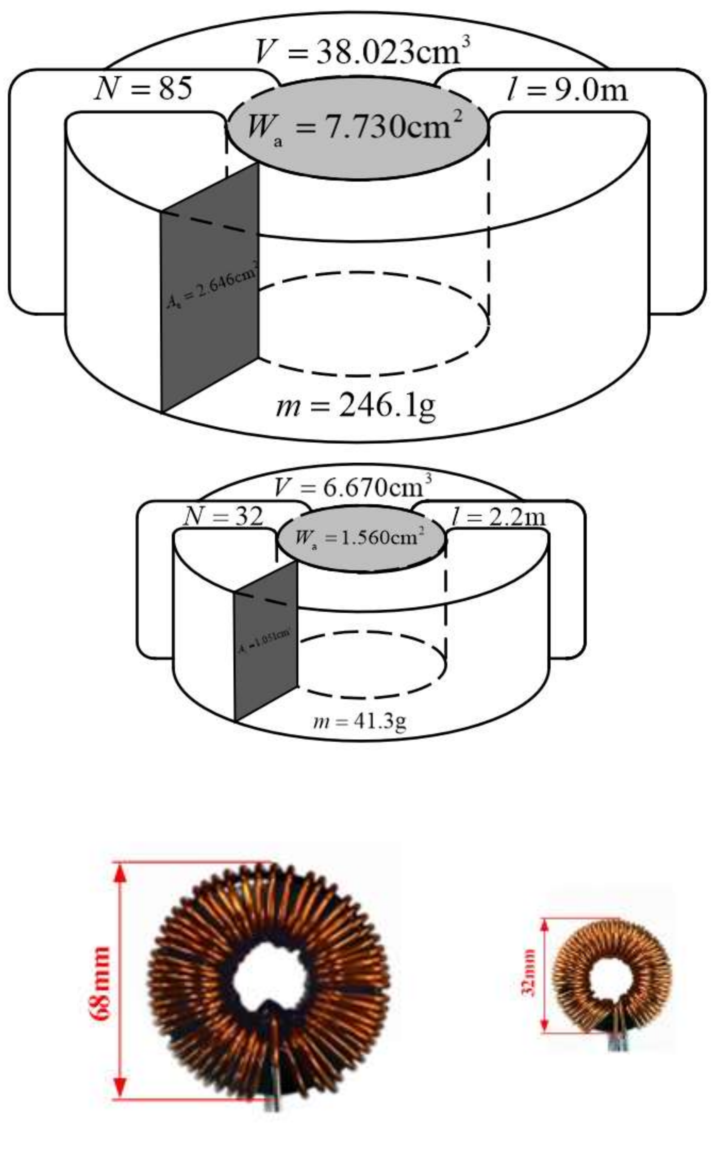
Three-level inverters have emerged as a mainstream topology in high-voltage and high-power applications, leveraging their advantages including low output voltage harmonics and reduced switching losses. Given the need to mitigate the prominent high-frequency harmonics inherent in their PWM waveforms, the design of output filters proves to be of critical importance.



The 240CPWM modulation strategy performs high-frequency switching actions on only one phase at any given moment. Compared with SVPWM, it exhibits nearly identical conduction losses while reducing switching losses by 88%[1]. Replacing SVPWM with 240CPWM allows for increased switching frequencies without compromising THD performance or increasing switching losses—in fact, it improves them. This enables NPC-TLI to maintain low switching losses even at high frequencies, thereby optimizing the design of filter inductors. Higher switching frequencies reduce inductor size, weight, winding turns, and copper losses, which in turn enhances power density, thermal performance, and efficiency in high-voltage, high-power applications.

Results

After increasing the switching frequency, the loss of NPC-TLI with 240CPWM strategy is still significantly lower than the loss value under SVPWM strategy.Meanwhile, with the inductance value reduced,the optimised inductor core reduces the area product by 87.5%, the volume of the core by 82.4% and the core mass by 82.3% compared to the pre-optimisation period.This not only lowers the design requirements for the overall machine size but also improves the system power factor.



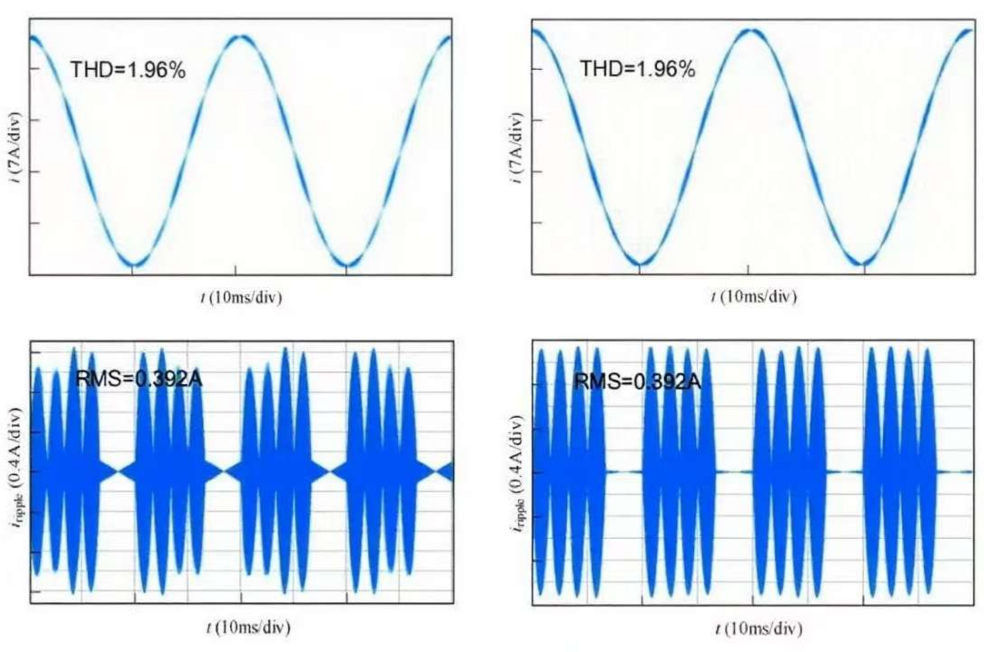
(a)1030μH (b)128μH

Parameter	Before	After	Comparison
Switching Frequency f/kHz	20	160	
Inductance Value L/μH	1030	128	
Area Product A_P/cm^4	12.61	1.57	-87.5%
Effective Core Cross - sectional Area A_e/cm^2	2.646	1.051	-60.2%
Effective Window Area W_a/cm^2	7.730	1.560	-79.8%
Core Volume V/cm^3	38.023	6.670	-82.4%
Core Mass m/g	246.1	41.3	-83.2%
Number of Winding Turns N	85	32	-62.3%
Winding Length l_w/mm	9019	2218	-75.4%
Core Loss P_{Fe}/W	1.4	4.2	+2.8
Copper Loss P_{cu}/W	8.5	3.4	-5.1
Total Loss P_L/W	9.9	7.6	-2.3

Methodology

Increasing the switching frequency reduces the filter inductance value.However, the following constraints need to be satisfied after boosting the switching frequency:

- THD of the output current remains constant;
- The switching loss does not exceed the loss level when SVPWM is used.



(afs=20kHz) (bfs=160kHz)

TLI are commonly used in scenarios such as high-power photovoltaic power plants, where the actual power factor is close to the unit power factor, so the maximum frequency can be increased up to 8 times.This constraint specifies the key boundary conditions for high-frequency design.

Conclusion

Design Methodology and Object

- An inductor design approach rooted in the area product method[2] is introduced.Taking a 10 kVA NPC-TLI as the design target, core selection and winding parameter design are accomplished.
- Leveraging the minimum switching loss feature of the 240CPWM strategy under unity power factor, with the constraint of keeping the output current THD unchanged:The system switching frequency is increased to 8 times the original value.The filter inductance value is reduced to 1/8 of the original design.

Optimization Outcomes

- Volume and Mass: The core volume is decreased by 82.4%, and the mass is reduced by 83.2%, significantly alleviating the pressure on the overall size and the heat dissipation system.
- Loss and Energy Efficiency: The inductor loss is cut by 2.3 W. While enhancing the power density, the energy efficiency of the system is optimized.

[1] D. Wu, H. Qamar, H. Qamar and R. Ayyanar, "Comprehensive Analysis and Experimental Validation of 240°-Clamped Space Vector PWM Technique Eliminating Zero States for EV Traction Inverters With Dynamic DC Link," in IEEE Transactions on Power Electronics, vol. 35, no. 12, pp. 13295-13307, Dec. 2020.
[2] J. J. Shea, "Transformer and Inductor Design Handbook, 3rd Ed. [Book Review]," in IEEE Electrical Insulation Magazine, vol. 21, no. 1, pp. 61-61, Jan.-Feb. 2005.