A Comparative Study of Non-Isolated Voltage Balancers Applied to Bipolar DC Microgrids

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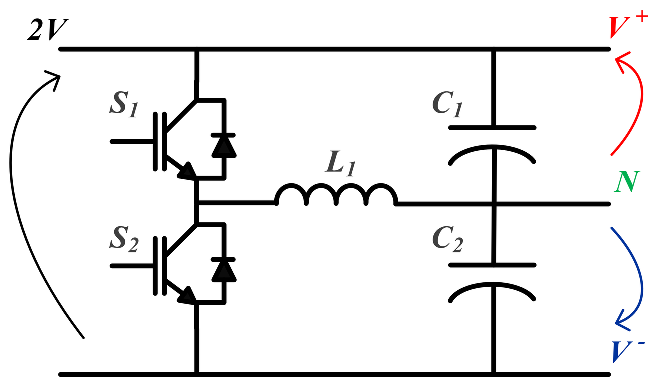
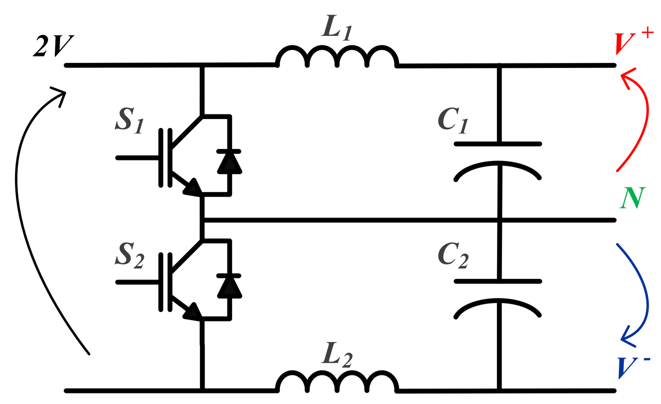
Acknowledgment: The authors gratefully acknowledge the financial support received from CNPq (Process 304707/2021-0 and 304948/2024-1).

Abstract - The imminent expansion of distributed generation by small-scale units associated with renewable sources - such as wind and photovoltaic – combined with the increasing penetration of electric vehicles, highlights the strategic importance of DC microgrids. These systems conventionally adopt two main configurations: unipolar or bipolar. Specifically, in bipolar DC microgrids, converters with multiple voltage levels or voltage balancer converters can be employed. These converters are designed to mitigate the effects between the network terminals, particularly under load imbalance conditions. Hence, this work aims to contribute to a comparative analysis of the main non-isolated voltage balancer topologies, highlighting key aspects such as efficiency, costs, voltage regulation, and current oscillations.

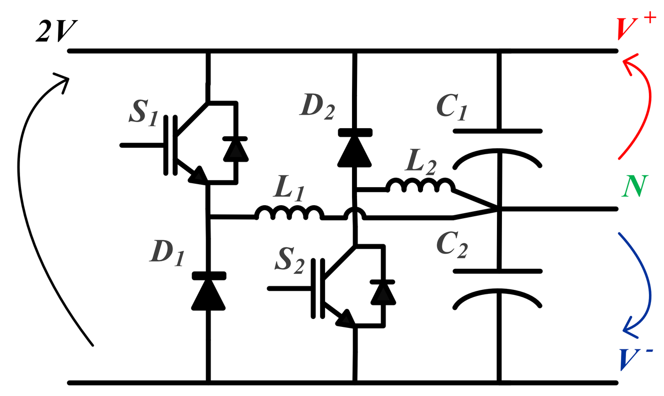
Methodology



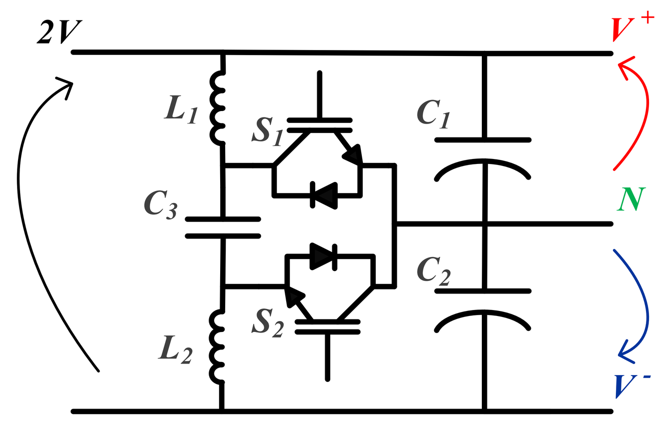
1: Buck-Boost



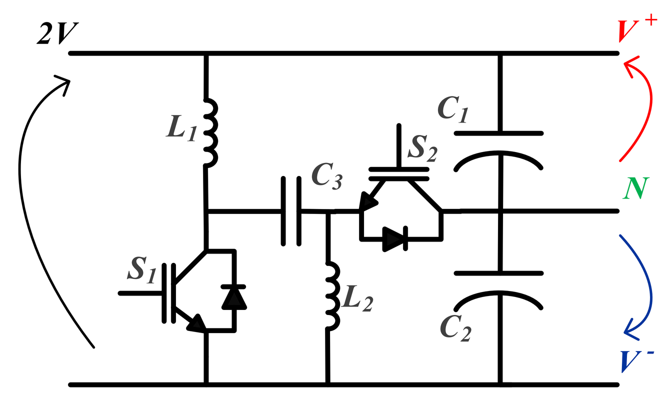
2: Type 2



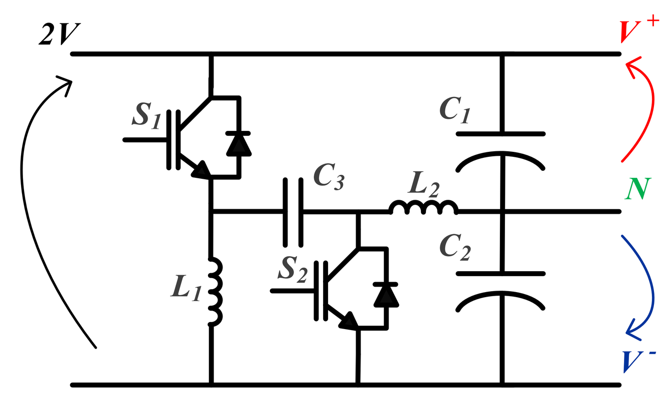
3: Dual-Buck Half-Bridge



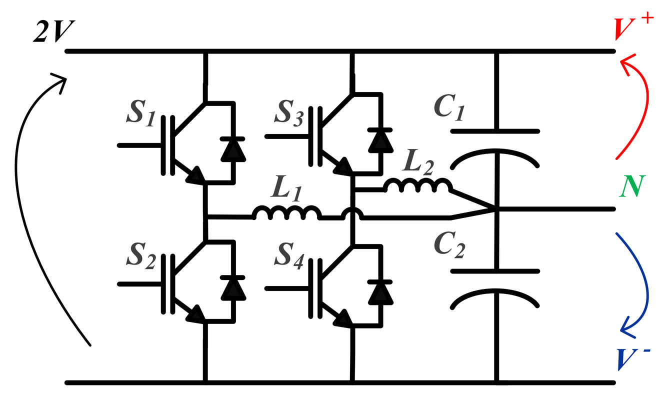
4: Ćuk



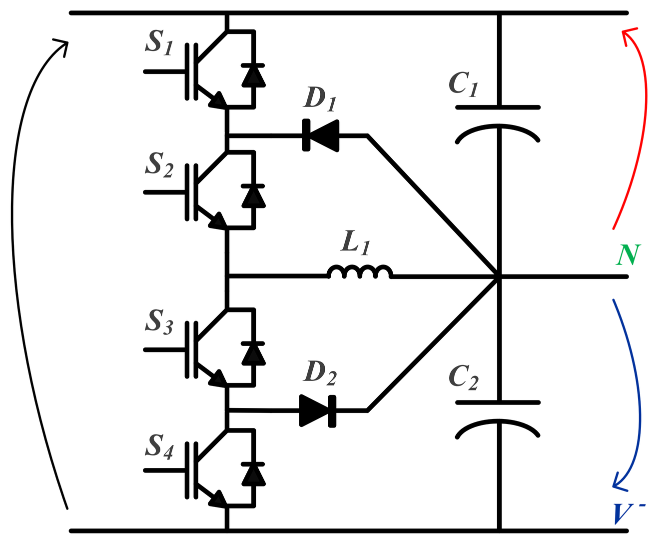
5: Super SEPIC



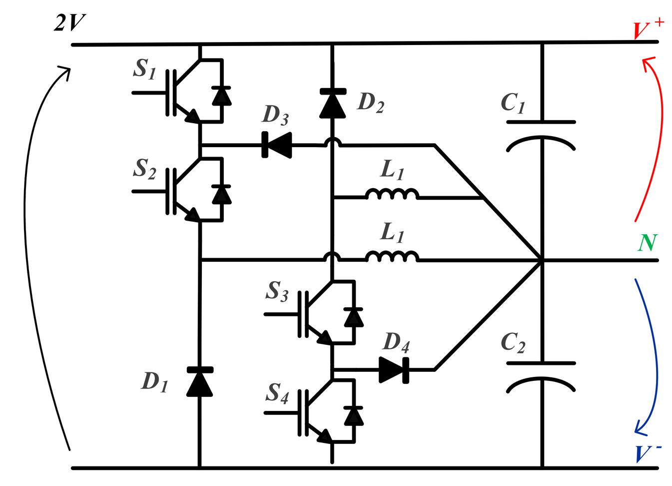
6: Super Zeta



7: Interleaved Buck-Boost



8: Three Level Converter

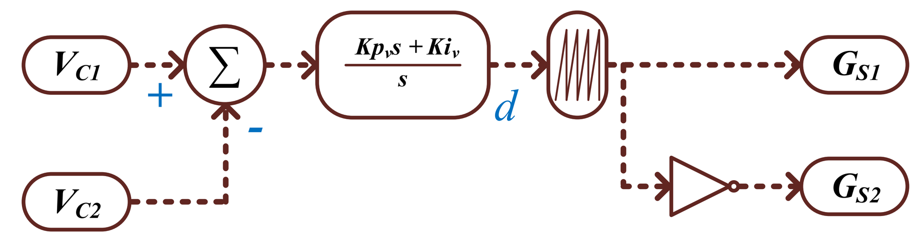


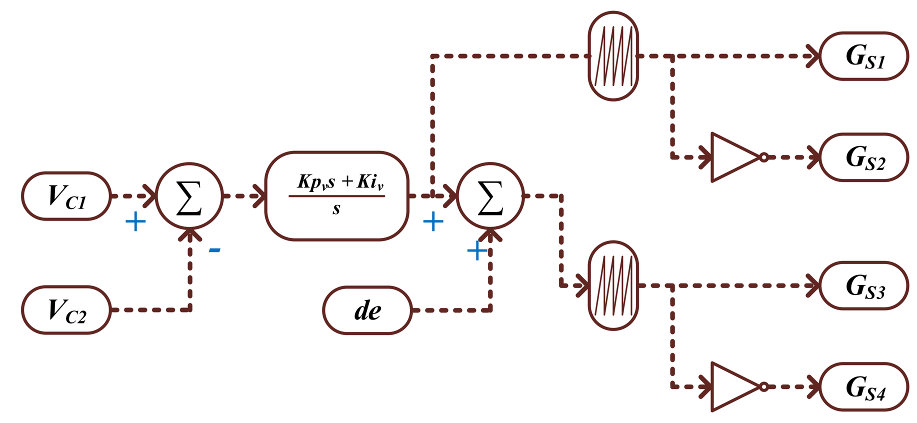
9: Three Level Dual Buck-Boost

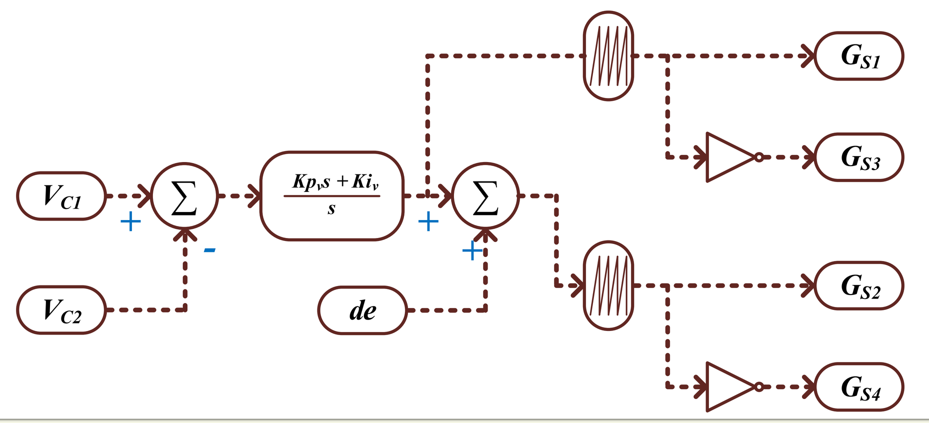
$$I_{L_1} = \frac{V_{C_1}}{R_1} - \frac{V_{C_2}}{R_2} \qquad L_1 = \frac{V_{in}D}{f_s \Delta I_{L_1} I_{L_1}}$$

$$C_1 = C_2 = \frac{V_{in}D}{8{f_s}^2 \Delta V_{C_1} I_{L_1} L_1}$$

$$C_3 = \frac{V_{in}}{f_s \Delta V_{C_3}(R_1 + R_3)}$$



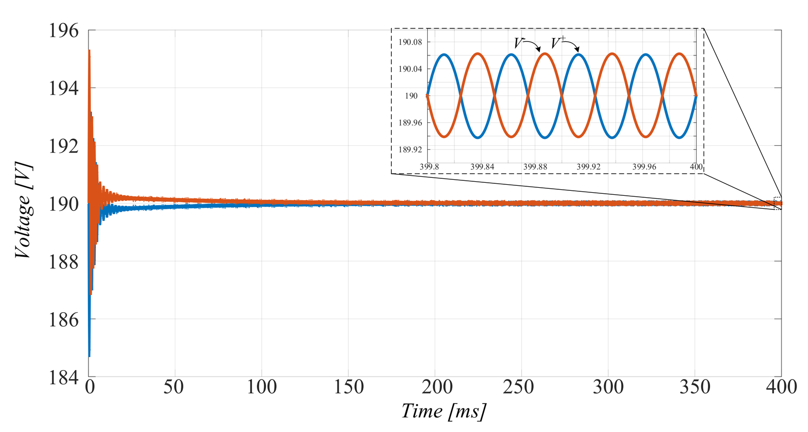




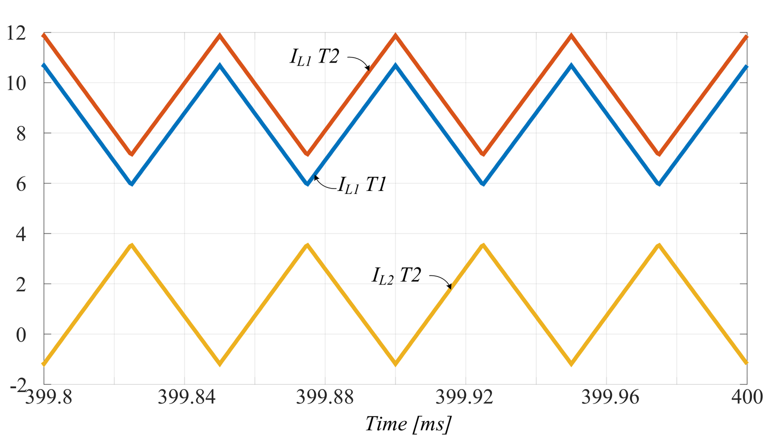
Simulation Results

This work employed a load imbalance of eight times to compare the topologies. Thus, the negative pole supplies a load of 226 W, using 160 Ω resistance, while the positive pole supplies a load of 1805 W, employing a 20 Ω resistance, totalizing a 2031 W system.

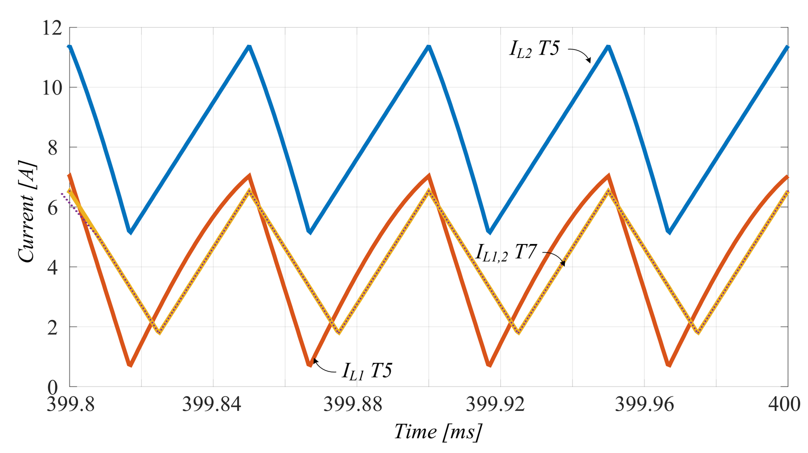
The proportional and integral gains of the PI controllers are tunned based on the frequency response of the transfer function. Choosing a crossover frequency at 12 Hz and a phase margin at 88º, the PI controllers' gains are obtained by Kp = 0.000103 and Ki = 0.1977. The obtained gains are employed in all topologies, independently of the control schematic utilized.



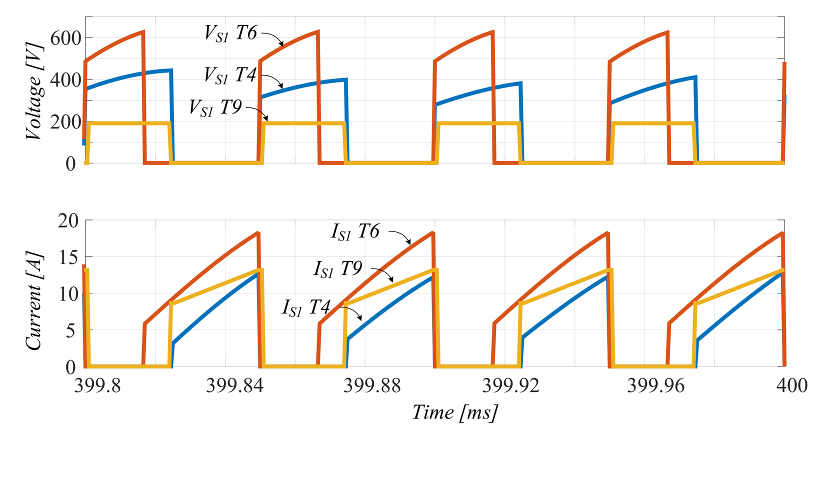
Positive and negative pole voltage for topology 3



Currents through inductors in topologies 1 and 2



Currents through inductors in topologies 5 and 7



Voltage and current for power switches in topologies 4, 6, and 9.

The main results for each voltage balancer

Top		V_{Smax} [V]	S_Loss [W]		V_{dmax} [V]	D_Loss [W]		I_{Lmed} [A]	I_{Lef} [A]	L_Loss [W]	T_Loss [W]	Effi [%]	Cost [pu]
1	S_1	380	5.39				L_1	8.31	8.42	0.85	21.47	98.95	1.00
	S_2	380	15.23										
2	S_1	380	5.7				L_1	9.50	9.60	1.11	22.50	98.90	1.31
	S_2	380	16.18				L_2	1.18	1.81	0.04			
3	S_1	380	8.16	D_1	380	1.23	L_1	2.32	2.69	0.09	36.23	98.25	1.45
	S_2	380	17.83	D_2	380	7.54	L_2	10.63	10.72	1.38			
4	S_1	380	15.4				L_1	4.13	4.42	0.23	21.06	98.97	1.43
	S_2	380	5.19				L_2	4.18	4.47	0.24			
5	S_1	570	29.23				L_1	4.11	4.52	0.25	36.96	98.21	1.43
	S_2	570	6.62				L_2	8.31	8.51	0.87			
6	S_1	570	29.45				L_1	4.01	11.24	1.52	41.84	97.98	1.43
	S_2	570	9.65				L_2	8.33	10.11	1.23			
7	S_1	380	2.16				L_1	4.16	4.38	0.23	27.88	98.65	1.74
	S_2	380	11.55										
	S_3	380	11.55				L_2	4.16	4.38	0.23			
	S_4	380	2.16										
8	S_1	190	5.14	D_1	190	0.48	L_1	8.75	8.86	0.94	36.32	98.24	1.57
	S_2	190	10.76										
	S_3	190	8.67	D_2	190	0.00							
	S_4	190	10.33										
9	S_1	190	5.48	D_1	380	0.64	L_1	10.92	11.00	1.45	45.81	97.79	2.03
	S_2	190	12.84	D_2	380	0.10							
	S_3	190	4.31	D_3	190	1.10	L_2	2.17	2.56	0.08			
	S_4	190	12.3	D_4	190	7.51							

Conclusions - This paper presented an extensive comparative analysis of the most relevant non-isolated voltage balancer topologies, evaluating nine different structures that can be employed in bipolar DC microgrids to mitigate voltage imbalance issues. All topologies exhibited high efficiency under imbalanced load conditions. Notably, the Ćuk voltage balancer achieved the highest efficiency and provided equalized currents through the inductors. Additionally, this topology is not susceptible to shoot-through problems due to its structure. The Buck-Boost topology stands out for its simplicity, low implementation cost, and good overall efficiency.