A control method of Boost converter

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Abstract

Within the scope of our investigation, we have resolved the stability issue of the boost converter. The doctoral dissertation of Ouyang Changlian enabled me to recognize the importance of duty ratio in control systems. Finally, this paper was written for patent CN117254710A.

Full Text

A Control Method for Boost Converter

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Abstract—This work addresses the stability problem of boost converters within the scope of our investigation. Ouyang Changlian's doctoral dissertation highlighted the critical importance of duty cycle in control system design.

Index Terms—duty cycle, control system, boost converter

I. Introduction

We introduce several special symbols to represent current instructions more clearly. The expression $i_{ref} = i_{ref} \uparrow + i_{ref} \downarrow = i_k$ indicates that the current instruction gain differs between the inductor current down-stage and up-stage, with i_{ref} emerging as an intrinsic property of the system.

[Figure 0: see original paper] Universal control topology.

Initially, we sought to develop a control method that naturally reflects the duty cycle characteristics, focusing our efforts on the current loop. This approach yields the following formulations:

$$i_{ref} = k_{i0}(k_{i1} i_L + k_{i2} i_c + k_{i3} i_v)$$

$$i_{ref} = k_{i4}(2k_{i5}i_L - k_{i6}i_{MOS})$$

Since $k_{i2} > k_{i3}$, load power feedforward is not required. Additionally, the control method demonstrates effective performance for buck converters as well. From formulas (1) to (3), we derive the following buck converter current references:

$$i_{ref\_buck} = i_L + 3i_{Diode}$$

$$i_{ref\_buck} = i_{DC\_Source} + 4i_{Diode}$$

$$i_{ref\_buck} = -3i_{DC\_Source} + 4i_L$$

$$i_{ref\_FullBridge} = 4i_{Q2} + i_{Q4}$$

where i_{Q2} represents the down-leg current during the inductor current down-stage, and i_{Q4} represents the down-leg current during the inductor current up-stage.

[Figure 1: see original paper] Control topology.
[Figure 2: see original paper] Circuit topology.

II. Discussion 1

Simulink simulations demonstrate that the control method performs effectively. [Figure 3: see original paper] shows the full waveform view, while [Figure 4: see original paper] provides a detailed examination.

The soft-start procedure involves first charging the capacitor to the supply voltage, then linearly increasing V_{ref} to gradually activate the converter. In the test scenario, the system boosts voltage from 200V to 400V at 2 kW inverter power with a switching frequency of 2.7 kHz. Both $G_v(s)$ and $G_d(s)$ employ PI controllers, while $G_s(s)$ uses a notch filter controller. At $t = 50$ ms, the load decreases from 100% to 10%, then returns to 100% at $t = 250$ ms. During partial load shedding, the bus voltage recovery time is only approximately 104 ms, with a maximum bus voltage fluctuation of 10.87 V, demonstrating excellent dynamic response characteristics.

This work builds upon our previously published control method from 2022 [1], with a preprint available in 2024 [2].

III. Discussion 2

For ZVS-Boost converter applications, the current reference formulas require modification:

$$i_{ref1} = i_L + i_c + i_v - i_{ZVS}$$

$$i_{ref2} = 2i_L - i_{MOS} - i_{lr}$$

These equations indicate that the freewheeling/flyback diode branch current i_{ZVS} from the resonant circuit must be subtracted from i_{ref1}, while the resonant inductance current i_{lr} must be subtracted from i_{ref2} when compared to conventional ZVS-Boost converters. The amplitude of the PWM input signal should match the carrier amplitude for proper operation.

IV. Integrated Square Wave Signal

This version incorporates additions made to version 5 on January 30, 2024. The control law now includes square wave injection:

$$i_{ref} = i_L + i_{squarewave}$$

$$i_{ref\_beta} = i_L * \cdot i_{squarewave}$$

The square wave is injected based on the predicted or calculated power factor $cos\varphi$, which determines the timing delays:

$$cos\varphi \Rightarrow T_{on\_delay}, T_{off\_delay} \Rightarrow f_s \leftrightarrow f_r$$

$$T_{on\_delay} \Rightarrow \text{inductive}; \quad T_{off\_delay} \Rightarrow \text{capacitive}$$

The delayed square wave influences switching behavior and subsequently affects interaction with the resonant network. A possible gain curve follows the relationship:

$$y = MT_{dc}(R, Amp_{square}) = MT_{dc}(R, x)$$

where the square wave amplitude can be determined through table lookup according to the boost ratio. This raises an interesting research question: can control systems be designed following principles similar to residual networks?

[Figure 7: see original paper]
[Figure 5: see original paper] Input side signal of PWM generator without i_{ZVS} in transient process.
[Figure 6: see original paper] Input side signal of PWM generator with i_{ZVS} in transient process.

References

[1] Xu Qinghan, Meng Xianhui, Yang Ling, Ye Meiting, He Jianglun. NF+QPR+LPF Dual-Loop Secondary Harmonic Current Suppression Method for Energy Storage System in DC Microgrid. *Transactions of China Electrotechnical Society*, 2022, 37(20):

[2] He Jianglun. A control method of Boost converter [Z]. chinaxiv, 2024.

Note: Figure translations are in progress. See original paper for figures.