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软开关技术

移相控制的LLC变换器轻载增益研究

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Research on Light-load Gain of Phase-shift Controlled LLC Converter

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摘要

传统的LLC谐振变换器为适应负载宽范围变化常采用变频控制策略，但存在调频范围过宽、限制感性元件设计、造成了额外的损耗等问题。因此采用变频移相控制方法以缩小调频范围，能够较好地实现原边开关管零电压开关ZVS（zero-voltage switching）及副边整流二极管零电流开关ZCS（zero-current switching），但由于滞后臂与超前臂的出现，在轻载工况下额外增加了死区时间T_d内实现ZVS分析的难度。通过对电路工作波形的分析，继承了传统分析方法中对电路工作波形优化处理的思想，在满足ZVS实现的前提下，结合时域分析法进行了死区时间对输出电压增益影响规律的相关研究。通过对电路工作波形进行理想化处理，考虑开关管寄生电容参与的充放电过程，结合死区时间内ZVS临界实现条件，建立了增益G受移相占空比D、死区时间T_d以及开关频率f_s等参数的影响函数关系，最终划定出既考虑死区时间影响，又满足给定增益要求下的最优移相占空比与死区时间。通过设计额定输入200 V、额定输出160 V、输出5%额定负载的仿真样机与实验样机，验证了所提研究方法的有效性。

Abstract

To adapt to the wide range of load variation, the conventional LLC resonant converter adopts a frequency conversion control strategy. However, the range of frequency modulation is too wide, which limits the design of inductive components, and further causes problems such as additional loss. Therefore, the frequency conversion combined with phase shift(FC-PS) control is usually adopted to reduce the frequency modulation range, and it can better realize zero-voltage switching(ZVS) of a switching tube on the primary side and zero-current switching(ZCS) of a rectifier diode on the secondary side. But the difficulty in achieving ZVS within dead time T_d increases additionally due to the lagging and leading arms under light load. In this paper, through the analysis of the working waveforms of the circuit, the idea of optimal processing the circuit's working waveforms by the traditional analysis method is inherited, and the time-domain analysis method is combined. Under the premise of satisfying the realization of ZVS, the effect of dead-time on the gain of output voltage is studied. By idealizing the circuit's working waveforms and considering the charging/discharging process with the participation of parasitic capacitance of switch, the function of gain G over parameters such as phase shift duty ratio D, dead time T_d, and switching frequency f_s is established with the combination of the critical realization condition for ZVS in dead time. Finally, the optimal phase-shift duty ratio and dead time are derived with both the consideration of dead time and the satisfaction of requirement for a given gain. The effectiveness of the proposed method was verified by designing a simulated prototype and an experimental prototype with rated input of 200 V, rated output of 160 V, and output rated load of 5%.

关键词

LLC谐振变换器;轻载;变频移相控制;增益研究;死区时间;时域分析法

Key words

LLC resonant converter;light-load;frequency conversion combined with phase-shift(FC-PS) control;research of gain;dead time;time-domain analysis method

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