

Selective Phase-shifting Control of Secondary Rectifiers in Resonant Converters with Matrix Transformers

Many applications, such as datacenters, aerospace, automotive, etc., require high-efficiency dc-dc converters that provide isolation to the load, for which resonant converters (especially LLC converters) are great candidates. However, some applications, such as datacenters, also typically require these converters to operate at a high gain (>1) during hold-up time when the input voltage drops. The conventional method to achieve high gains is to operate at a frequency (f_s) less than the series resonant frequency (f_0). However, a large resonant inductor is required to attain the required gain level, resulting in lower nominal operating efficiencies.

The resonant converter's gain is increased by boosting the resonant tank energy, whose voltage $V_{tank} = V_{in,eq} - V_{tr,eq}$, where $V_{in,eq}$ is the equivalent tank input voltage, and $V_{tr,eq}$ is the equivalent transformer voltage. Prior experiments have implemented phase-shifting the secondary rectifiers (SRs) (one half-bridge in case of full-bridge rectifiers) with respect to the primary inverter devices to effectively reduce $V_{tr,eq}$ and boost the resonant tank gain. High controllability can be achieved with full-bridge (FB) rectifiers, where three distinct levels for $V_{tr,eq}$ (0 , $+nV_o$ and $-nV_o$) can be achieved. However, this method results in poor controllability with center-tap (CT) rectifiers, since only two voltage levels for $V_{tr,eq}$ ($+nV_o$ and $-nV_o$) can be obtained.

To address this, this paper proposes a selective SR phase-shift control method that utilizes matrix transformers to achieve a higher number of voltage levels for $V_{tr,eq}$, thereby improving controllability. Fig. 1 explains the method with a matrix of 4 identical transformers, where the SR devices of one elemental transformer (shown in Fig. 1 (a)) are phase-shifted with respect to the others. During the phase-shifted period (shown in Fig. 1 (b)), the transformer voltages of the first two transformers are equal and opposite, thereby effectively "shorting" part of the complete transformer, resulting in a "0V" level in V_{tr1} . Hence, 4 distinct voltage levels for the total transformer voltage V_{tr} can be obtained, thereby increasing the resonant tank voltage. Moreover the duration of phase-shifting, coupled with the number of elemental transformers phase-shifted, results in multiple degrees of freedom to improve the converter's gain controllability.

Finally, this control method is demonstrated on a 1.6 kW, 400V/12V LLC converter for datacenters, where the selective SR phase-shifting control is implemented during hold-up time to boost the gain of the converter without compromising nominal efficiency.

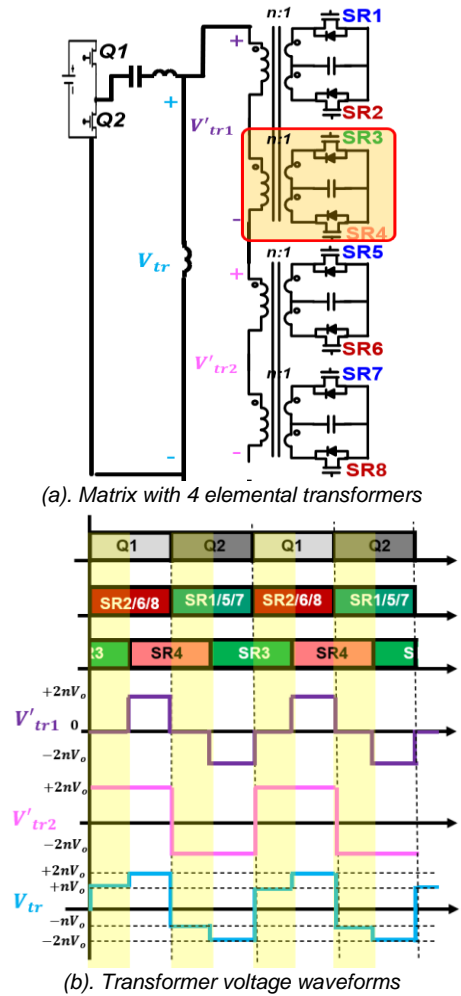


Fig. 1. Selective phase-shifting of one elemental transformer in a matrix transformer