넓은 출력 전압제어범위를 갖는 3레벨 단상 단일전력단 AC/DC 컨버터

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THREE LEVEL SINGLE-PHASE SINGLE STAGE AC/DC RESONANT CONVERTER WITH A WIDE OUTPUT OPERATING VOLTAGE RANGE

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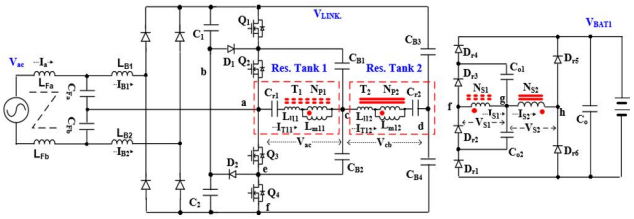
1. Abstract

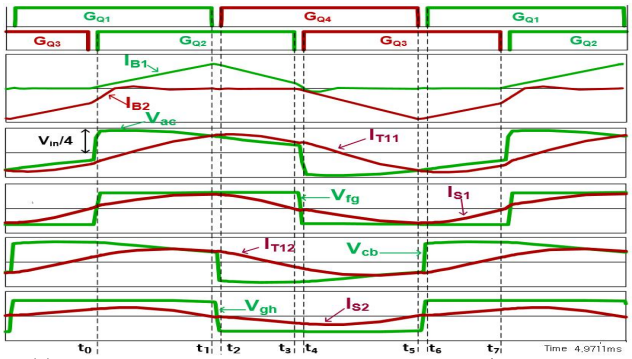
In this paper, a single phase single stage three level AC/DC converter with a wide controllable output voltage is presented. It integrates a PFC converter and a three level DC/DC converter into one. The proposed converter operates at a fixed frequency and provides a wide controllable output voltage ($200V_{dc}$ $430V_{dc}$) with high efficiencies over a wide load range. In addition, the input boost inductors operate in a discontinuous mode to improve the input power factor. Moreover, all the switching devices operate with ZVS, and the converter's THD is small especially at full load. The feasibility of the proposed converter is verified with experimental results of a 1.5kW prototype.

2. The Proposed Three-Phase Single-Stage Three Level AC/DC Converter

Figure.1 (a) shows the circuit diagram of the proposed single phase single stage three level AC/DC LLC resonant converter. It is powered by a single phase AC source (V_{RMS}: 220 V_{ac}) and comprise of input filters (L_{Fa}~L_{Fb}, C_{Fa}~C_{Fb}), boost inductors (L_{B1}~L_{B2}), an input rectifier and a three level LLC resonant converter for DC voltage regulation. The filter capacitors (C_{Fa}~C_{Fb}) and filter inductors (L_{Fa}~L_{Fb}) are connected to the single phase input source to filter the input currents. The neutral point of the filter capacitors (C_{Fa}~C_{Fb}) is connected between the source of switch Q_2 and the drain of switch Q_3. The boost inductors (L_{B1}~L_{B2}) are connected to the input rectifiers and each pairs of the switching devices (Q_1 and Q_4) and (Q_2 and Q_3) in the primary side is alternately switched on and off with a fixed duty ratio of 50%. During the interval t_0 t_1 (Q_1 & Q_2 are switched on) or t_4 t_5 (Q_3 & Q_4 are switched on), the boost inductors (L_{B1}, L_{B2}) are energized according to the phase shift modulation of the three level converter. When the switching device Q_1 (or Q_4) is switched off during the interval t_2 t_3 (or t_6 t_7), the boost inductors (L_{B1}, L_{B2}) transfers the previously stored energy to the link capacitors C_1 and C_2 and their currents begin to reduce. The proposed converter has two transformers (T_1, T_2) whose primary windings are connected in parallel and the secondary windings are connected in series to ensure proper load sharing within the two transformers. The resonant circuits (Res. Tank 1, Res. Tank 2) operates with a constant switching frequency of Q_1 and Q_4 (Q_2 and Q_3), which alternately operate with a 50% duty



(a) Proposed 3 level AC / DC converter



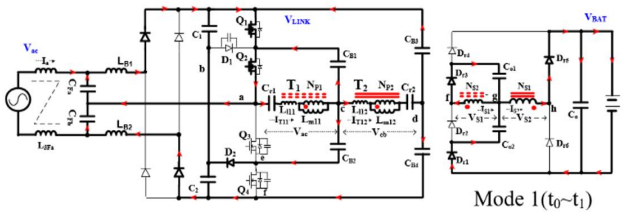
(b) Operating waveforms of the proposed 3 level AC/DC converter

Figure 1. The proposed single stage 3 level AC/DC converter 2 and its operating waveforms

When the switching device Q_1 (or Q_4) is switched off during the interval t_1 t_2 (or t_6 t_7), the boost inductor currents are shared between the two resonant circuits. 1/4 of the link voltage (V_{LINK}) is applied across the primary windings of each transformers and a voltage according to the gain characteristic of the converter is reflected to the secondary windings connected in series across the output diodes (D_1~D_6). In addition, since the proposed single phase single stage three level AC/DC converters operate with a fixed frequency, the magnetic inductances of the transformers (L_m) are designed to be considerably bigger than those in conventional LLC resonant converters operating with variable frequency control mechanism and as a result, limits conduction losses.

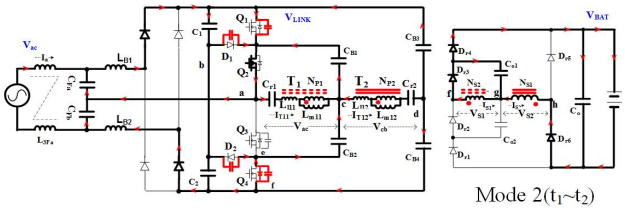
Mode 1(t_0~t_1) : In mode 1, the switching devices Q_1 and Q_2 are turn on. The filter capacitor voltage (V_{CFa}) is applied across the input boost inductor (L_{B1}) and current flows from C_{Fa} through L_{B1}, the input rectifier diodes, Q_1 & Q_2 and returns to C_{Fa}.. The boost inductor (L_{B1}) is energized while 1/4 of the link voltage ($1/4V_{LINK}$) is applied across the

primary terminals of the resonate circuits (Res. Tank 1, Res. Tank 2) and power is transfers to the secondary terminals. In addition, the boost inductor L_{B2} resets to zero.



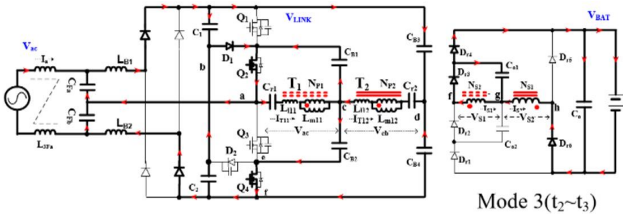
Mode 1(t_0~t_1)

Mode 2(t_2~t_3) : At t1, Q_1 is switched off and its parasitic capacitor is charged while that of Q_4 is discharged. This mode ends when the voltage across the parasitic capacitor of Q_1 is clamped to half of the link voltage (V_{C1}) and when the voltage across the parasitic capacitor of Q_4 decreases to zero.



Mode 2(t_1~t_2)

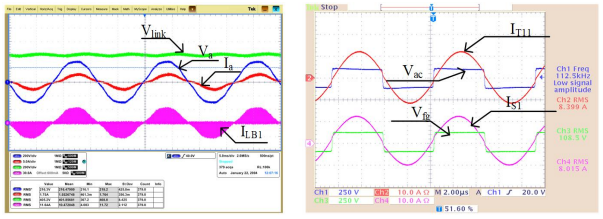
Mode 3(t_4~t_5) : This is a freewheeling stage; the switching device Q_1 is switched off and Q_4 is switched on with ZVS. In addition, Q_2 remains on and the energy previously stored in the boost inductors is transferred to the link capacitors.



Mode 3(t_2~t_3)

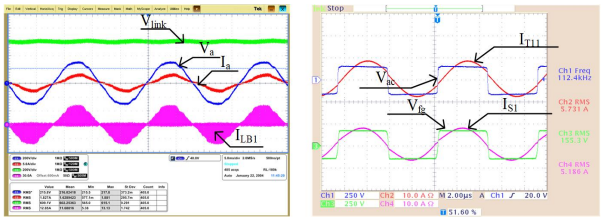
3. Experimental Results and Conclusion

Experimental results shows that the highest efficiencies are obtained with an output operating voltage of 200V. However, the converter's efficiency decrease as the output voltage(V_o) increases due to the increase in input and boost inductor currents. A maximum efficiency of 91.75% was recorded with a 1kW/200V experiment while a minimum efficiency of 80.41% was registered with a 500W/430V experiment.



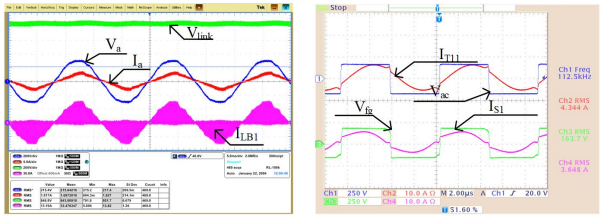
(a) Ch1:200V/div, Ch2:5A/div, [Ch3:200V/div, Ch4:30A/div, 5ms/div (b) Ch1:250V/div, Ch2:10A/div, Ch3:250V/div, Ch4:10A/div, 2us/div.]

Figure 2: Experimental waveforms (a) the PFC Circuit (b) the current/ voltage across the transformer's primary and secondary [200V/1.5kW]



(a) Ch1: 200V/div, Ch2: 5A/div, Ch3:200V/div, Ch4:30A/div, 5ms/div (b) Ch1: 250V/div, Ch2: 10A/div, Ch3:250V/div, Ch4:10A/div, 2us/div.

Figure 3: Experimental wave form (a) the PFC Circuit (b) the current/ voltage across the transformer's primary and secondary [300V/1.5kW]



(a) Ch1:200V/div, Ch2:5A/div, Ch3:200V/div, Ch4:30A/div, 5ms/div (b) Ch1:250V/div, Ch2:10A/div, Ch3:250V/div, Ch4:10A/div, 2us/div.

Figure 4: Experimental wave form (a) the PFC Circuit (b) the current/ voltage across the transformer's primary and secondary [430V/1.5kW]

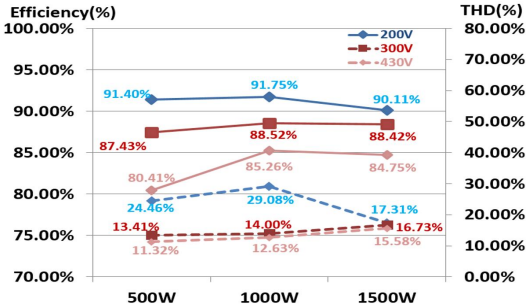


Figure 5: Efficiency and THD of the proposed Single phase single stage AC/DC converter

Further research is required to improve the efficiency of the proposed single phase, single stage three level AC/DC converter. The circuits on Figure 6 (a) and (b) with a different secondary topology could be used to improve the efficiency of the proposed single phase single stage three level converter.[1] [2]

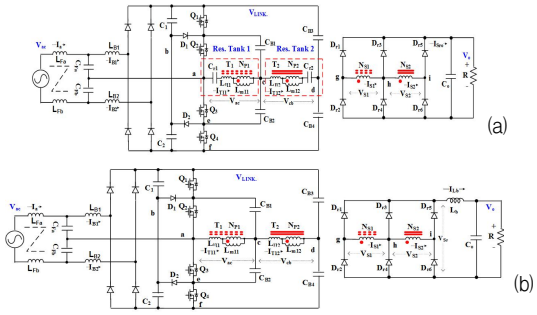


Figure 6: Application circuits

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Reference

[1] P. M. Barbosa, F. Canales, J. M. Burdio, F. C. Lee, "A Three Level Converter and Its Application to Power Factor Correction," IEEE Transactions on Power Electronics, Vol. 20, no.6, pp.1319-1327, November 2005.
[2] Eun-Soo Kim, "Single stage AC/DC Converter", Patent pending, 2018. 06.