August 19, 2019

Switched tank converter with coupled inductors

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ABSTRACT

This disclosure describes modular, low-cost, high-efficiency, high power-density techniques to convert electrical power in a 4n:1 ratio, e.g., 4:1, 8:1, 12:1, etc. The techniques are robust to component non-idealities over a wide range of operating conditions and minimize current stress on components. The switched tank converters find application in data centers, where DC-DC conversion is frequently required, e.g., from a bus voltage of forty-eight volts to a CPU voltage of twelve volts.

KEYWORDS

- Voltage conversion
- Switched tank converter
- DC-DC power converter
- LC resonant tank
- Data center power

BACKGROUND

Recent disclosures [1], [2] have described switched tank converters (STC) for non-isolated DC-DC conversion. As opposed to switched capacitor converters, these STCs use resonant LC tanks to partially replace flying capacitors for the purposes of energy transfer. The STCs thereby achieve soft charging, soft switching, and minimal device voltage stresses under most operating conditions. The number of components required by such STC converters can be high, e.g., up to ten switches and an equivalent number of capacitors. Besides, the design of the current STC converters do not extend immediately, e.g., modularly, to larger power conversion ratios, e.g., 8:1.

DESCRIPTION

This disclosure describes STC techniques with coupled inductors that achieve 4n:1 power conversion ratios with high power density, high efficiency, and low cost. For example, 4:1 conversion requires only four switches, 8:1 conversion requires only eight switches, etc. Further, the coupled inductor windings conduct output current at both operating stages, thereby reducing current stress on the switches and inductors, and further improving efficiency and power density.

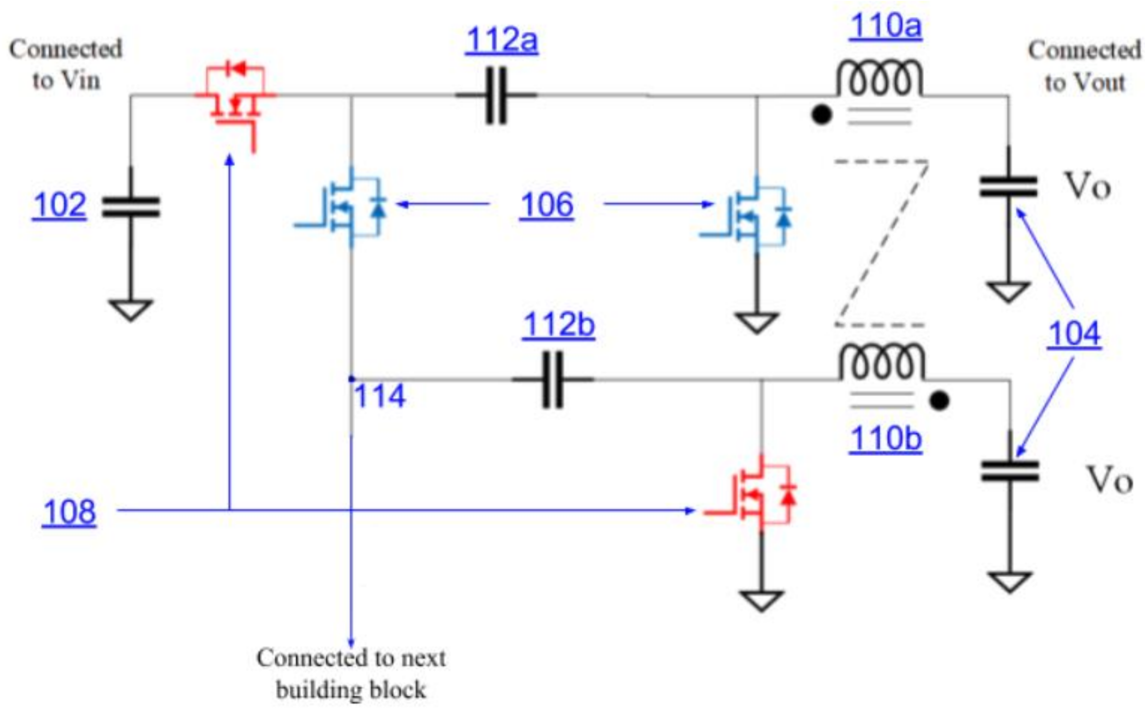

Fig. 1: The building block

Fig. 1 illustrates a modular circuit that can be used as a building block to construct DC-DC power converters of various input-to-output voltage ratios. The input (Vin) is connected across capacitor 102, and the output voltage (Vo) appears across capacitor 104. The circuit has a single input and a single output. The output capacitor 104 is tied to the output voltage Vo. The blue switches (106) and the red switches (108) each have a non-overlapping duty cycle of nearly 50%. In other words, the blue switches are in phase with each other, and are 180 degrees out-of-phase with the red switches. Electromagnetically coupled inductors (110a-b) connect flying capacitors (112a-b) to their outputs. Electromagnetic coupling between inductors is indicated by the dotted-Z shape, and the black circle next to an inductor indicates the polarity of induced voltage. As shown, the point 114 of the building block is connected to the next building block in order to build circuits of various voltage conversion ratios. For example, a single building block achieves a 4:1 voltage conversion ratio; two connected building blocks achieve a 8:1 voltage conversion ratio; three connected building blocks achieve a 12:1 voltage conversion ratio; etc. In the last building block of a connected cascade of building blocks, the capacitor 112b on the lower leg of the building block is shorted.

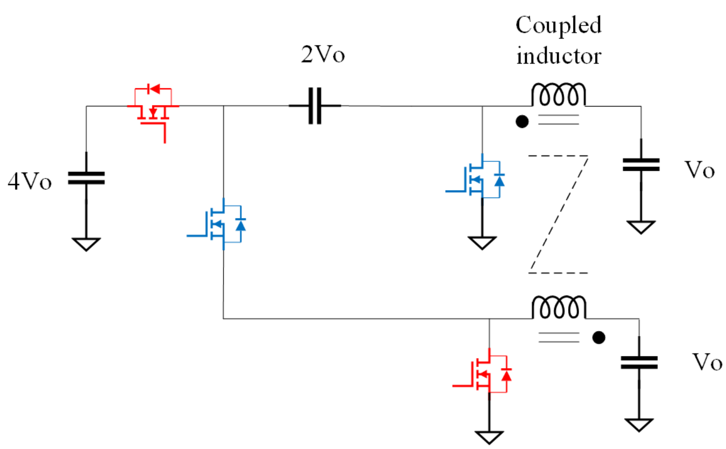

Fig. 2: A 4:1 DC-DC converter

A DC-DC converter with a voltage conversion ratio of 4:1, built with a single building block, is illustrated in Fig. 2. As mentioned earlier, the capacitor on the lower leg of the circuit is shorted.

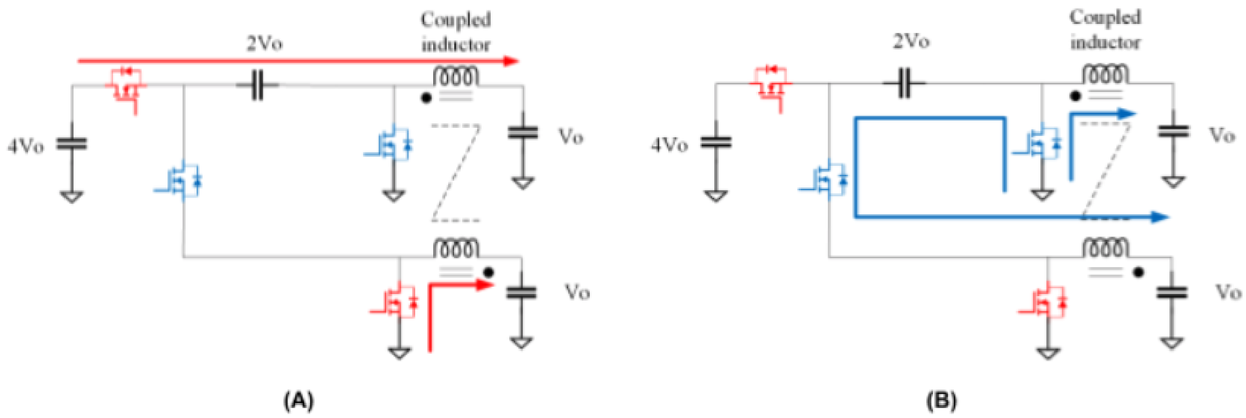

Fig. 3: Operating stages of a 4:1 DC-DC converter (A) Stage-1 - the red switches are closed and the blue switches are open (B) Stage-2 - the red switches are open and the blue switches are closed.

Fig. 3 illustrates the operating stages of a 4:1 DC-DC converter. In stage-1 (Fig. 3A), the red switches conduct current while the blue ones are open. The red arrows indicate the direction of current flow. In stage-2 (Fig. 3B), the blue switches conduct current while the red ones are open. The blue arrows indicate the direction of current flow. In stage-1, the flying capacitor is charged by the input voltage, while a lead of the lower inductor is tied to ground, so that a 4:1 input-to-output voltage conversion ratio is achieved. In stage-2, a lead of the upper inductor is tied to ground, while the flying capacitor discharges, so that again a 4:1 input-to-output voltage conversion ratio is achieved. Stages 1 and 2 alternate in time to produce a 4:1 DC-DC voltage conversion through all time. As is seen from Fig. 3, the coupled inductor windings conduct current at both stages, thereby reducing the current stress on switches and inductors, and achieving high efficiencies and power densities.

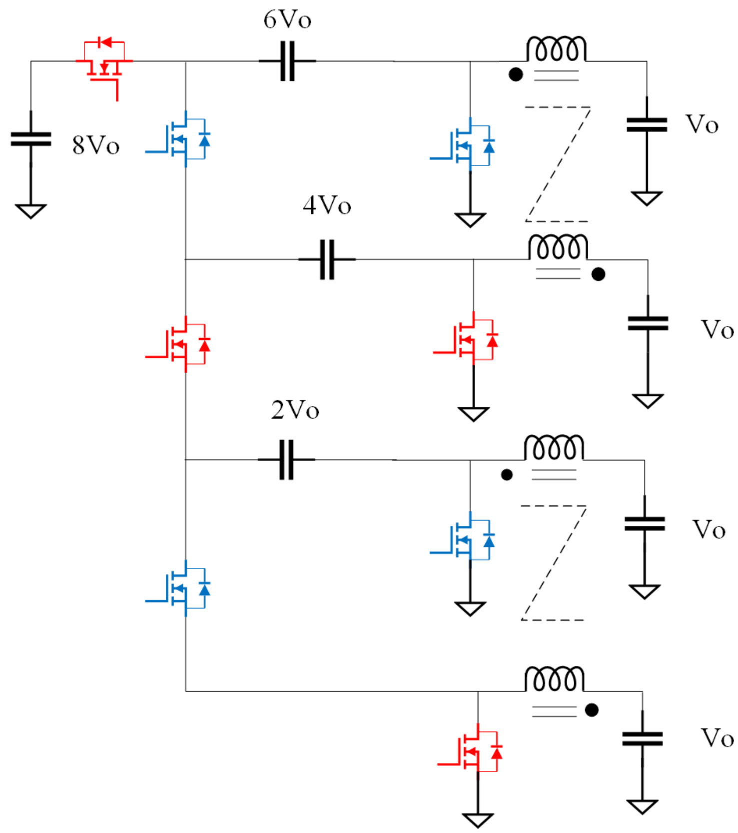

Fig. 4: An 8:1 DC-DC converter

Fig. 4 illustrates a DC-DC converter with a voltage conversion ratio of 8:1, built with two building blocks.

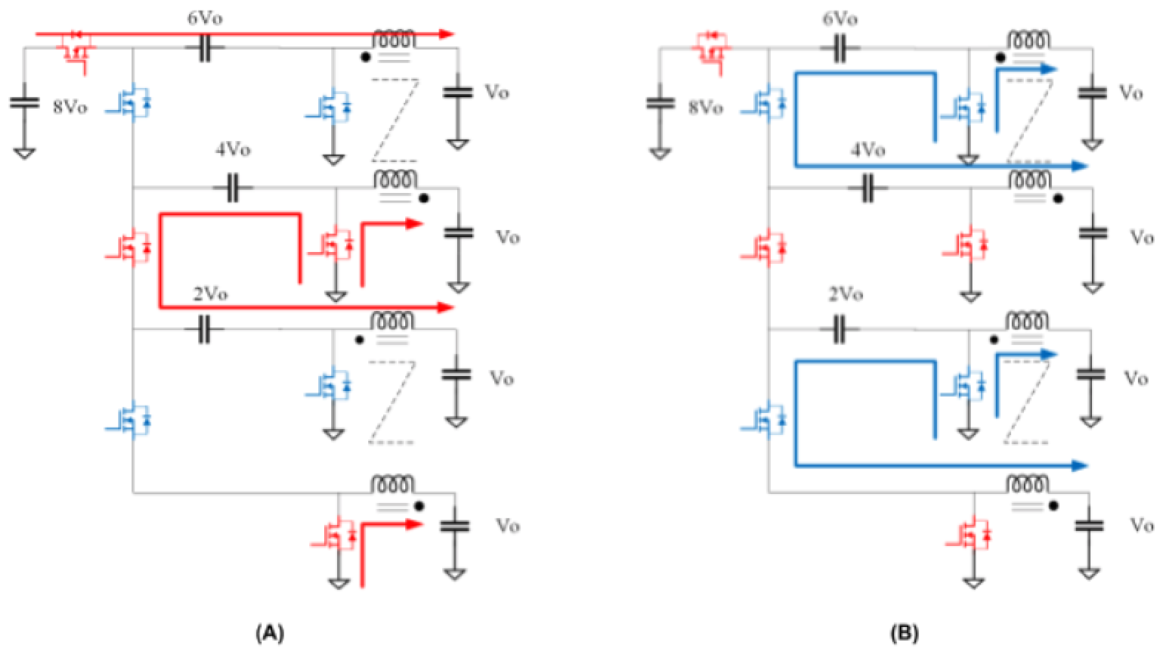

Fig. 5: The operating stages of an 8:1 DC-DC converter (A) Stage-1 (B) Stage-2

Fig. 5 illustrates the operating stages of an 8:1 DC-DC converter. As in the case of the 4:1 DC-DC converter, in stage-1 (Fig. 5A), the red switches conduct current while the blue ones are open. The red arrows indicate the direction of current flow. In stage-2 (Fig. 5B), the blue switches conduct current while the red ones are open. The blue arrows indicate the direction of current flow. Stages 1 and 2 alternate in time to produce an 8:1 DC-DC voltage conversion. All coupled inductor windings conduct current at both stages, thereby reducing the current stress on switches and inductors, and achieving high efficiencies and power densities.

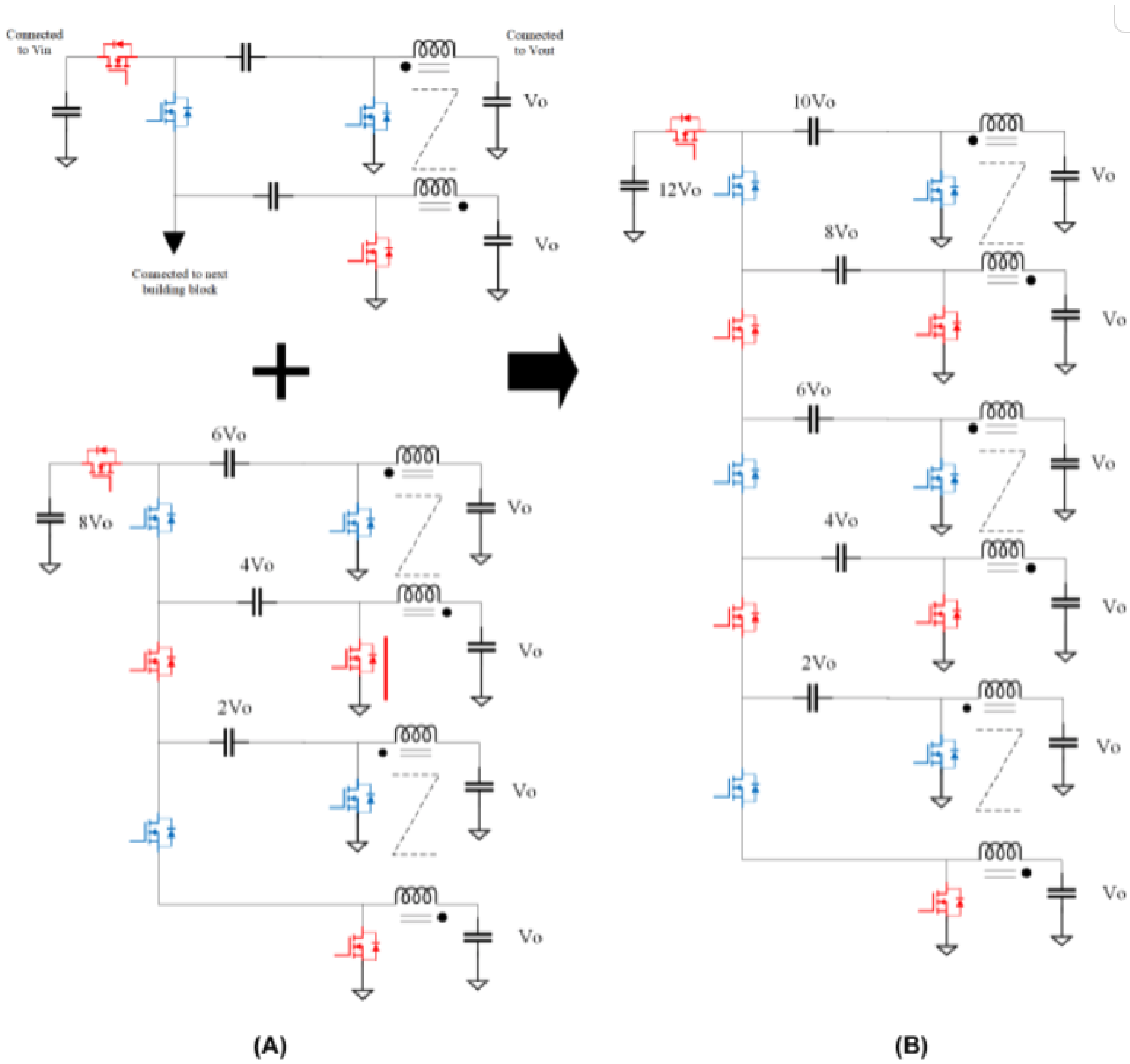

Fig. 6: A 12:1 DC-DC converter (A) Construction from modular building blocks (B) A 12:1 DC-DC converter

Fig. 6 illustrates a 12:1 DC-DC converter (Fig. 12B) including its construction from the union of the modular building block and an 8:1 DC-DC converter (Fig. 12A).

CONCLUSION

This disclosure describes modular, low-cost, high-efficiency, high power-density techniques to convert electrical power in a 4n:1 ratio, e.g., 4:1, 8:1, 12:1, etc. The techniques are robust to component non-idealities over a wide range of operating conditions and minimize current stress on components. The switched tank converters find application in data centers, where DC-DC conversion is frequently required, e.g., from a bus voltage of forty-eight volts to a CPU voltage of twelve volts.

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