Power Electronics' Circuit Topology – the Basic Switching Cells

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Abstract—**In this paper, two basic switching cells, P-cell and N-cell, are presented to investigate the topological nature of power electronics circuits. Both cells consist of a switching device and a diode and are the basic building blocks for almost all power electronics circuits. The mirror relationship of the P-cell and N-cell will be revealed. This paper describes the two basic switching cells and shows how all dc-dc converters, voltage source inverters, current source inverters, and multilevel converters are constituted from the two basic cells. Through these two basic cells, great insights about the topology of all power electronics circuits can be obtained for the construction and decomposition of existing power electronic circuits. New power conversion circuits can now be easily derived and invented.**

Keywords **– basic switching cells, dc-dc converter, inverter, N-cell, P-cell.**

I. Introduction

Power electronic circuits that range from dc-dc, ac-dc, dc-ac, and ac-ac power conversion normally consist of switching devices, diodes, inductors, and capacitors. Many circuits have been invented, proposed, and demonstrated to perform various power conversion uses. However, these circuits have only rarely been examined and investigated in terms of their relationships, topological characteristics, or what are their basic building blocks [1-12].

This paper will attempt to answer the following questions: What are the basic switching cells that are the basic building blocks for construction of all power electronic circuits? How can existing circuits be configured by the basic switching cells? How can existing circuits be evolved from one structure to another? These questions will be addressed and are of great interest in understanding the basics of power electronic circuits and their control.

II. Two Basic Switching Cells

Fig. 1 shows the two basic switching cells defined in this paper. Each cell consists of one switching device and one diode connected to three terminals: (+), (–), and (→) /or (←). The P-cell has the switching device connected to the positive terminal (+) and the common junction of the switching device and diode connected to the positive of a current-source or inductor. On the other hand, the N-cell's switching device is connected to the negative terminal (-) and the common junction of the switching device and diode connected to the negative of a current-source or inductor. The P-cell is the mirror circuit of the N-cell and vice versa.

These circuits are practical implementation of the canonical switching cells found in [13, 14]. This paper extends these cells to dc-dc converters, voltage source and current source inverters, and multilevel converters.

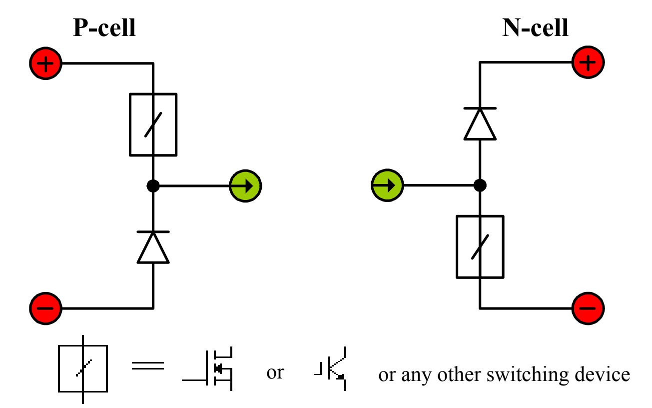


Fig. 1. Two basic switching cells: P-cell and N-cell. Terminal (+) connects to the positive lead of a voltage-source or capacitor, (–) connects to the negative lead of a voltage-source or capacitor, (→) connects to the positive lead of a current-source or inductor, and (←) connects to the negative lead of a current-source or inductor. The switching device can be a MOSFET, IGBT, or other controlled semiconductor switching device.

III. DC-DC Converters Composed from the Basic Cells

Fig. 2 summarizes the four converters and their cell structures. The buck and boost converters can be easily decomposed into a P-cell and N-cell based circuit, respectively. It is not so obvious for the buck-boost and Cuk (boost-buck) converters; however, they are also built from the P-cell. The conventional Cuk converter has an especially unique structure [15]. However, after simplification using P-cells, the two inductors can be equivalently moved to the center rail and consolidated into one inductor as shown in Fig. 3. From Fig. 3, it is obvious that the Cuk converter is quite similar to the buck-boost converter, except for the capacitor across the positive and negative terminals of the P-cell. In practical use, it is necessary to place a decoupling capacitor in the buck-boost converter, which makes the buck-boost converter identical to the Cuk converter.

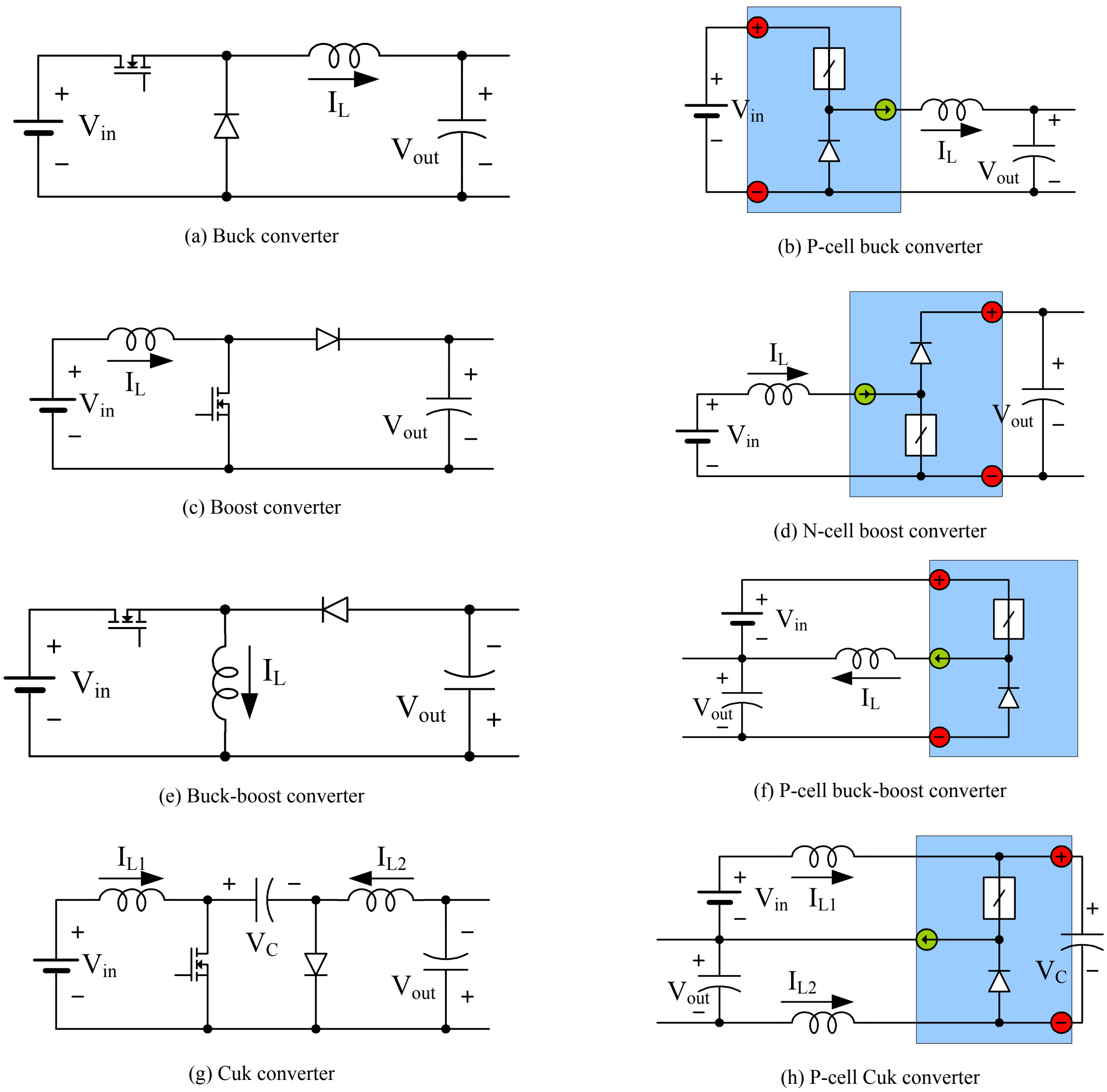


Fig. 2. The dc-dc converters and their construction by the basic cells.

IV. Insights of the Basic Cells and New DC-DC Converters

The brief discussion above reveals some interesting aspects. The buck-boost converter has been deemed as quite a different circuit from the Cuk converter. However, the basic switching cell structures show otherwise. In fact, they are essentially equivalent as shown from the figures. Furthermore, as previously mentioned, the P-cell and N-cell have a mirror relationship. Flipping the P-cell, one gets the N-cell, and vice versa. By the same token, any circuit should have its mirror circuit. For example, as shown in Fig. 2 the traditional buck converter is a P-cell based circuit. Therefore, there should be a mirror circuit; in other words, an N-cell circuit exists. Using the N-cell, an N-cell buck converter circuit can easily be obtained. Similarly, for the other three traditional dc-dc converter circuits, they all should have their mirror circuits. Fig. 4 summarizes the mirror circuits for each of the four traditional dc-dc converter circuits. These circuits are new and will find some interesting applications.

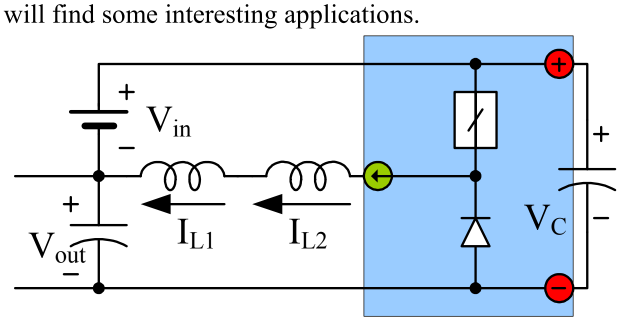
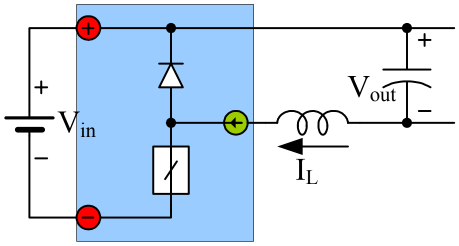
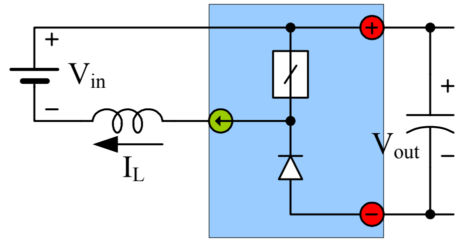


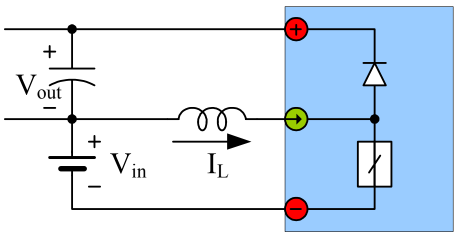
Fig. 3. Moving the two inductors of the P-cell Cuk converter (Fig. 2h) to the center rail and combining them into one.



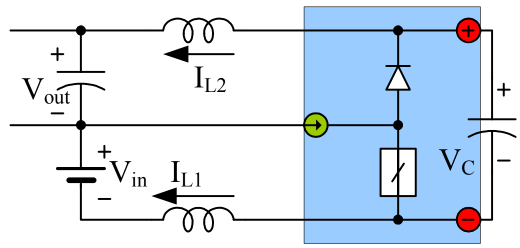
(a) N-cell buck converter



(b) P-cell boost converter

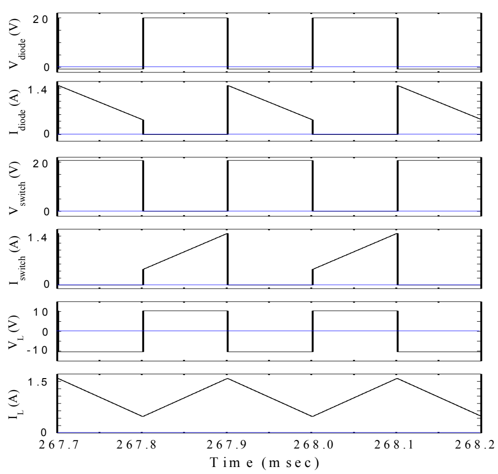


(c) N-cell buck-boost converter

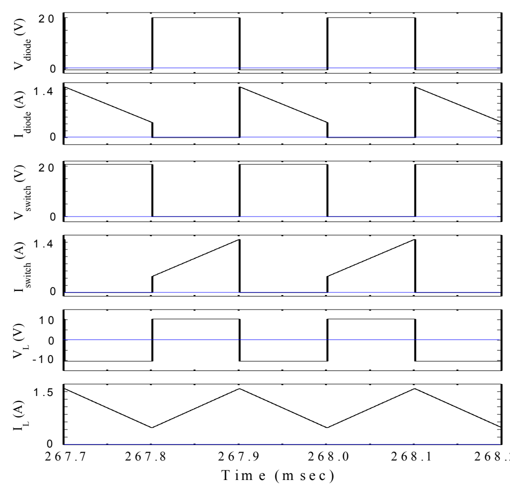


(d) N-cell Cuk converter

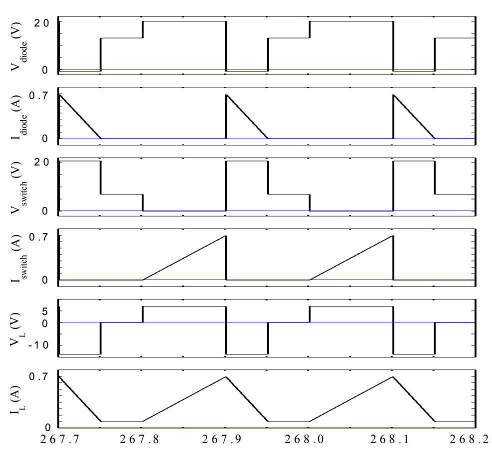
Fig. 4. The mirror circuits of the traditional dc-dc converters.



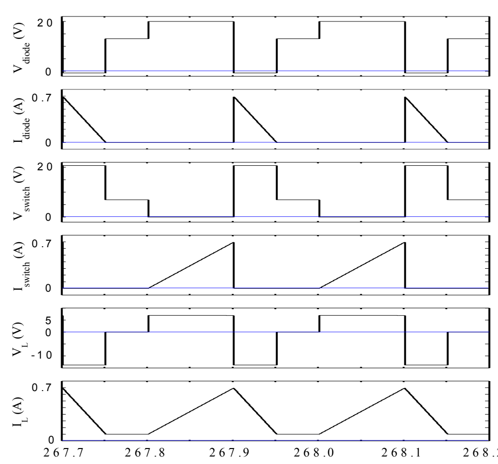
(a)



(b)



(c)



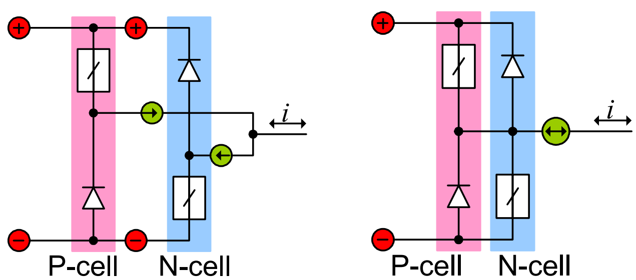
(d)

Fig. 5. Simulation results of (a) N-cell buck converter with continuous conduction, (b) P-cell buck converter with continuous conduction, (c) N-cell buck converter with discontinuous conduction, (d) P-cell buck converter with discontinuous conduction.

A buck converter was constructed in PSIM (a power electronic circuit simulation software) and simulated in continuous and discontinuous conduction mode. Fig. 5(a) shows the different voltages and currents in an N-cell buck converter for continuous operation, whereas Fig. 5(b) shows the same parameters for a P-cell structure. The simulation shows that the characteristics of a P-cell structure are identical to that of an N-cell, and their structures are interchangeable. These structures were also simulated in discontinuous conduction mode, and the simulation results are shown in Fig. 5(c) and (d).

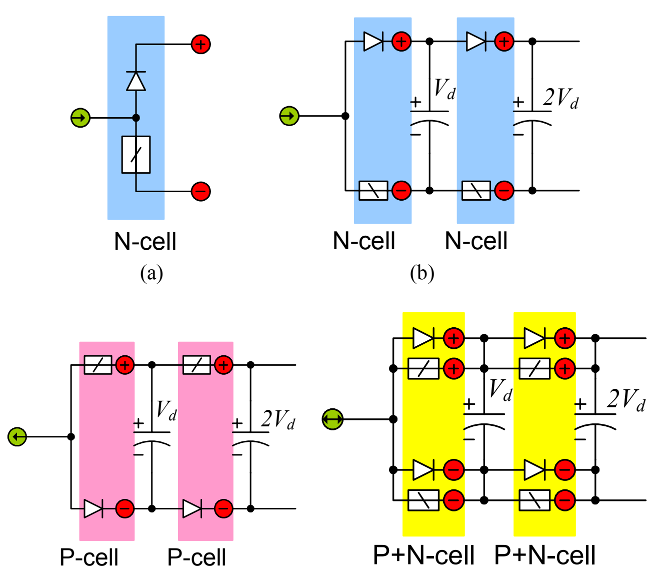
V. CONSTRUCTING INVERTERS BY THE BASIC CELLS

All inverters can be similarly constructed by the basic cells. Fig. 6 shows that the parallel combination of the P- and N-cells form a phase leg providing bi-directional current flow. Therefore, a (single phase or three phase) voltage-source inverter can be constructed. This combination suggests that the traditional switching modules such as switching device IGBT with anti-parallel diode are not best suited for inverter operation and parasitic inductance minimization. IGBT-diode modules configured as the P- and N-cell are better suited for inverter operation and minimizing parasitic inductance, because at any instant of time, the load current only goes through the P-cell during the positive half cycle and through the N-cell during the negative half cycle of the current. The P- and N-cell IGBT-diode modules also minimize or eliminate the dead-time requirement, thus improving reliability.



(a) (b)

Fig. 6. A phase leg with bidirectional current flow by paralleling the P- and N-cells.



(a) (b) (c) (d)

Fig. 7. A phase leg with bidirectional current flow by paralleling the P- and N-cells.

Fig. 7 shows that the series connection of the P- and N-cells form a three-level (flying capacitor) converter and inverter. Similarly, the diode clamped multilevel inverter and the generalized multilevel inverter structure [16] can be constructed. In Fig. 7, the series connection uses the same voltage polarity, thus adding voltage to a higher level.

Again it is obvious from these circuits that IGBT-diode modules should be assembled and built according to the P- and N-cell structures. The P- and N-cell structures have advantages over the traditional IGBT module with an anti-parallel diode.

VI. CURRENT SOURCE INVERTER FROM BASIC SWITCHING CELLS

A current source inverter (CSI) has several key applications in industry. A conventional CSI differs from a VSI from the point of input DC source. Fig. 8 shows a conventional CSI where the load is a series connection of a resistor and an inductor. Four switches S1, S2, S3, and S4 are operated in pairs so that an alternating current can flow through the load. To get the alternating current, S1 and S4 are operated during the positive half cycle of the current, whereas, S2 and S3 are switched on during the negative half cycle or vice-versa.

To form a VSI, a P-cell and an N-cell are connected in parallel to build a block, and two blocks in parallel form the entire VSI. However, the mirror structure of this VSI construction is followed to build the series combination of a P-cell and an N-cell, and thus a new type of CSI can be formed. This is shown in Fig. 9(a), where two N-cells form an ac voltage port from a current source. Fig. 9(b) shows the series combination of two P-cells to obtain a current source from an ac voltage input.

If we connect the two blocks depicted in Fig. 9 together, a new single phase current-source inverter can be constructed as shown in Fig. 10. By eliminating the two middle capacitors (v_d) of Fig. 10, the traditional current-source inverter can be obtained as shown in Fig. 8. As a well-known fact, the traditional current-source inverter has trouble with voltage over-shoot at turn-off and a current commutation problem that requires over-lap time from one phase leg to another. However, the new current-source inverter in Fig. 10 has no voltage overshoot and no current commutation problem. The capacitor (v_d) with the two diodes form a lossless snubber providing voltage clamping to the switching device and a

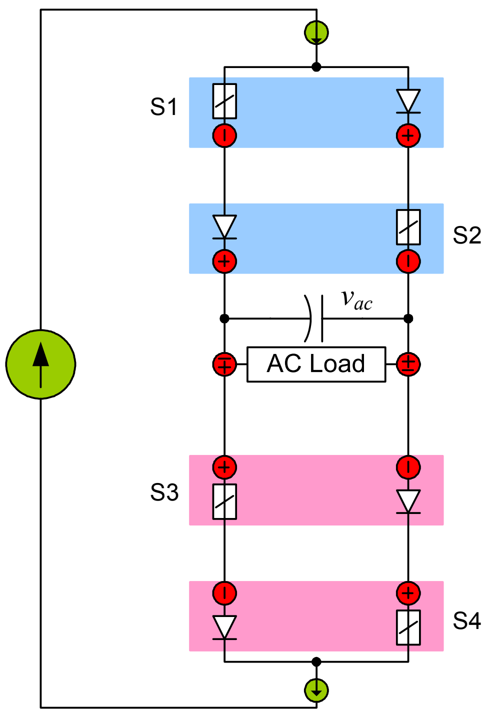


Fig. 8. Conventional current source inverter.

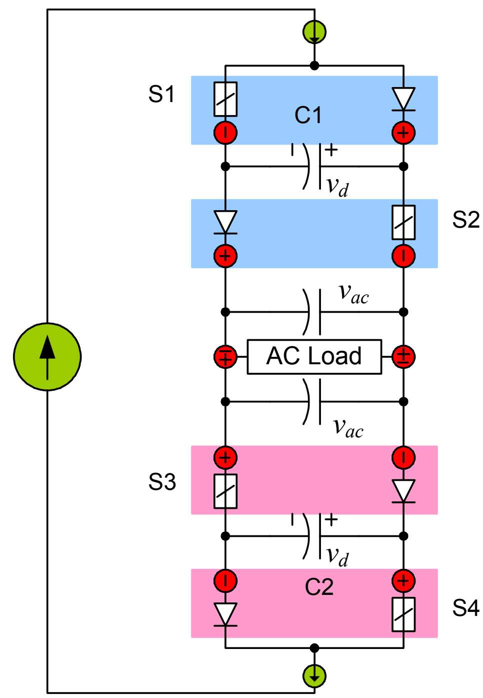
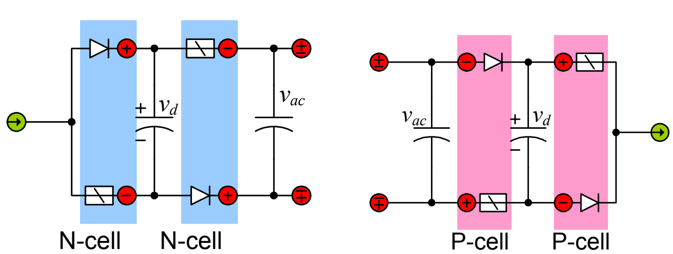


Fig. 10. Current source inverter constructed from series combination of P-cell and N-cell shown in Fig. 9.

current path to the current source, thus improving reliability. The required capacitance should be very small for voltage clamping and current commutation. The three-phase version of Fig. 10 is obvious.

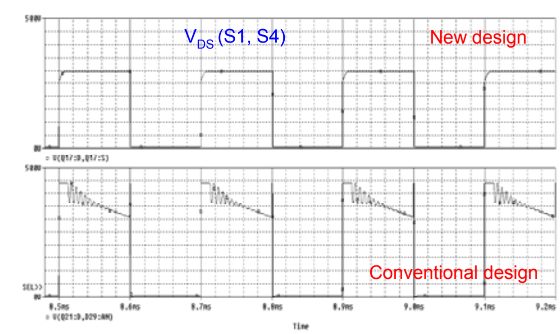
To get a clear picture of the superiority of the new topology, a current source inverter was designed and simulated using the basic cells. The new circuit has no voltage overshoot as compared to the traditional CSI (illustrated in Fig. 11(a)) and has less output power ripple (shown in Fig. 11(b)). A 1000 W load was used for the simulation of both converter types.

The new topology can be implemented in several different inverter types. Multilevel inverters with voltage balancing features can be constructed using these basic switching cells, and thus it becomes easier to analyze the entire circuit.

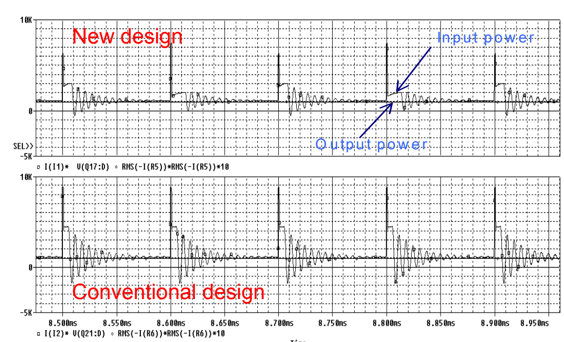


(a) (b)

Fig. 9. Series connection of the N-cells and P-cells to form an ac voltage port.



(a)



(b)

Fig. 11. Comparison of voltage across switch and output power ripple for a traditional CSI and the new topology. (a) voltage across switches S1 and S4 for both topologies, (b) output power ripple for both topologies.

VII. Conclusion and Future Work

This paper has defined the two basic switching cells: P-cell and N-cell. It has been shown that the traditional buck, boost, buck-boost, and Cuk dc-dc converters are composed of these basic cells. The two cells are the foundation and basic building blocks of all power electronic circuits. The two cells have a mirror relationship that helps in the analysis of circuits as well as the derivation of new circuit topologies.

This paper has focused on how traditional dc-dc conversion circuits, inverters, and multilevel converters can be formed from the basic switching cells. IGBT-diode modules configured as the P- and N-cell are more suited for inverter operation and minimizing parasitic inductance. Thus, the design of various kinds of inverters using the P-cell and/or N-cell can be accomplished. These basic cells will lead to some new topologies for dc-dc converters and for inverters.

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