A Systematic Approach to Synthesizing Multi-Input DC/DC Converters

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Abstract - **The objective of this paper is to propose a general approach to developing multi-input converters (MICs). The derived MICs can deliver power from all of the input sources to the load either individually or simultaneously, without using coupled transformers. By analyzing the topologies of the six basic pulse-width modulation (PWM) converters, the method for synthesizing an MIC is inspired by adding an extra pulsating voltage or current source to a PWM converter with appropriate connection. As a result, the pulsating voltage source cells (PVSCs) and the pulsating current source cells (PCSCs) are proposed for deriving MICs. According to the presented synthesizing rules, two families of MICs, including quasi-MICs and duplicated MICs, are generated by introducing the PVSCs and the PCSCs into the six basic PWM converters.**

I. INTRODUCTION

Conventionally, a pulse-width modulation (PWM) converter is usually used to draw power from a renewable energy source. In order to combine more than one renewable energy sources to get the regulated output voltage, different circuit topologies of multi-input converters (MICs) have been proposed in recent years [1]-[17]. Different dc sources can be put in series to implement the MIC and the regulated output voltage can be achieved [1]-[3]. Such an MIC can continue to operate even if one of the dc sources has failed. Another approach is to put dc sources in parallel without electrical isolation or with electrical isolation by using the coupled transformer [4]-[10]. Control schemes for those MICs with paralleled dc sources are based on the time-sharing concept because of the clamped voltage. Hence, only one of the dc sources is allowed to transfer power to the load at a time. That is, power of difference dc sources cannot be transferred to the load simultaneously. In addition, various MICs, including one proposed by the author, were developed with no explanation to how they were generated [11]-[17].

The objective of this paper is to propose a systematic approach to unify the generation of MIC topologies without using coupled transformers. Based on this approach, some of the existing MIC topologies and numerous new ones can be systematically generated.

The general form of an MIC consists of several input sources and a single load, as conceptually shown in Fig. 1. Each of the input-to-output port pair can be regarded as an individual PWM converter separately. In general, all of the input sources can deliver power to the load either individually or simultaneously through the MIC. When only one of the input sources feeds the MIC, it will transfer power to the load individually and the MIC will behave identically as a PWM converter operates. On the other hand, when more than one input source are supplied to the MIC, all these input sources will deliver power to the load simultaneously without disturbing each other's operation. Moreover, no power is transferred from one of the input sources to another. For simplicity and convenience, the MICs developed and discussed in this paper are limited to two-input-source MICs. In fact, the MICs with more than two input sources can be also synthesized by the same principle presented in this paper.

In this paper, the topologies of the six basic PWM converters will be first reviewed, from which the method for synthesizing MICs is inspired [18]-[19]. Two basic circuits with different types of sources will be defined as the building cells and used to generate MICs. Then, the principle of synthesizing MICs will be addressed and two families of MICs will be eventually synthesized. Finally, a brief discussion on the developed MICs will be made.

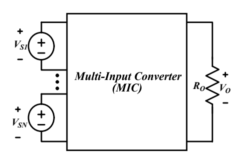


Fig. 1. General form of the multi-input converter.

II. BRIEF REVIEW OF BASIC PWM CONVERTER TOPOLOGIES

The six basic PWM converters, which include buck, boost, buck-boost, Ćuk, zeta and SEPIC converters, are widely utilized in power electronics applications. Topologically, each basic PWM converter can be divided into two or three portions, namely input portion (IP), energy buffer portion (EBP) and output portion (OP), as shown in Fig. 2, where the buck and the boost converters have no energy buffer portions. Topological structures of the six basic PWM converters are shown in Fig. 3 with input portions, energy buffer portions, and output portions marked. In Fig. 3, energy buffer portions, which are depicted by rectangular components, can be implemented by using capacitors or inductors.

From the viewpoint of power flow, the input portion will generate the high-frequency pulsating power with the help of the switch and feed this pulsating power to the energy buffer portion. The energy buffers in the energy buffer portion will faithfully transfer this pulsating power from the input portion to the output portion without hindering it. This pulsating power is then filtered out by the output portion to provide a constant power to the load.

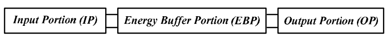


Fig. 2. Three portions of a basic PWM converter.

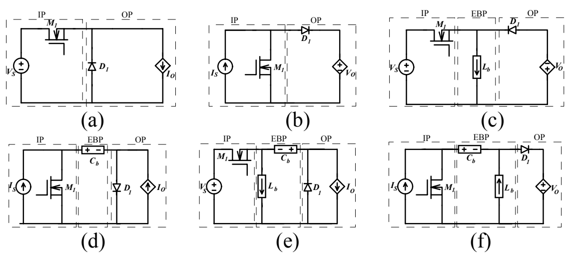


Fig. 3. Topological structures of the six basic PWM converters (a) buck converter (b) boost converter(c) buck-boost converter (d) Ćuk converter (e) zeta converter (f) SEPIC converter.

III. Configuration of PVSCs and PCSCs

The output portion of the PWM converters sees a high-frequency pulse-train voltage or current waveform from the input portion or energy buffer portion. By filtering out this high-frequency pulse-train voltage or current waveform with the output portion, a dc voltage or current can be obtained. From this viewpoint of circuit topology, the method for synthesizing an MIC can be inspired by adding an extra pulsating voltage source or current source to a conventional PWM converter with appropriate connection. In this section, the pulsating voltage source cell (PVSC) and the pulsating current source cell (PCSC), which are formed by a pulsating voltage source along with a diode and a pulsating current source along with a diode, are defined. The principle of synthesizing MICs by combining the PVSCs or the PCSCs with the PWM converters will be addressed in the next section.

A. Configuration of PVSCs

In Fig. 4, the pulsating voltage source as well as the parallel diode are lumped together and named as a PVSC. When a PVSC is introduced into a PWM converter to yield an MIC, it cannot be connected in parallel with any branch of the PWM converter; otherwise, the voltage across the connected branch will be clamped by the introduced PVSC. Hence, a PVSC can be only connected in series with one of the branches of a PWM converter for developing an MIC. In this circuit configuration, the parallel diode in the PVSC is supplemented for circulating the possible current difference between the pulsating voltage source and the connected branch of the PWM converter. According to the topological properties of PWM converters, the pulsating voltage source can be generated by a dc voltage source in series with a switch, a dc current source in parallel with a switch followed by a capacitor, or a dc voltage source in series with a switch followed by an inductor and a capacitor in sequence. Thus, the feasible circuit configurations of the PVSC can be drawn in Fig. 4 (b)-(d), and are named as buck-type, Ćuk-type and zeta-type PVSCs, respectively.

B. Configuration of PCSCs

The conceptual circuit configuration of the PCSC is depicted in Fig. 5(a), in which it consists of a pulsating current source in series with a diode. The only eligible method to insert a PCSC into a PWM converter to develop an MIC is connecting a PCSC in parallel with one of the branches of the PWM converter. This is because the current through the connected branch will be clamped by the pulsating current source if the PCSC is in series connection. The series diode in the PCSC functions to block the possible voltage difference between the voltages imposed on the pulsating current source and the connected branch of the PWM converter. Similar to the generation of the pulsating voltage sources, the pulsating current sources can be generated according to the topological properties of the PWM converters, from which the feasible circuit configurations of the PCSC can be depicted in Fig. 5(b)-(d), and are named as boost-type, buck-boost-type and SEPIC-type PCSCs, respectively.

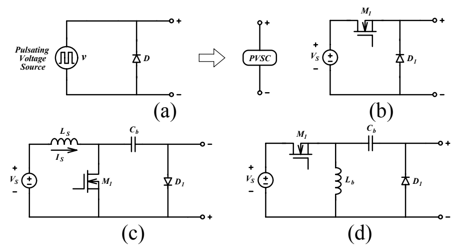


Fig. 4. Circuit configuration of the PVSC (a) conceptual diagram of the PVSC (b) buck-type PVSC (c) Ćuk-type PVSC (d) zeta-type PVSC.

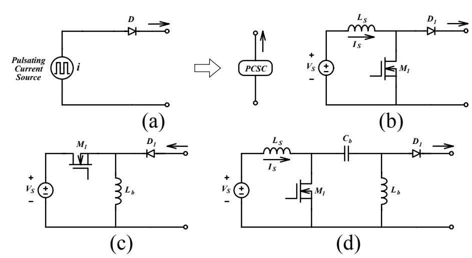


Fig. 5. Circuit configuration of the PCSC (a) conceptual diagram of the PCSC (b) boost-type PCSC (c) buck-boost-type PCSC (d) SEPIC-type PCSC.

IV. Principle of Synthesizing MICs

The MICs can be formed by inserting the PVSCs or the PCSCs into the PWM converters. For convenience of illustration, the PWM converter is referred as the prime PWM converter. After the PVSC or PCSC is inserted into the prime PWM converter, the inserted PVSC or PCSC along with a portion of the prime PWM converter will form another PWM converter, which is called the pulsating-source-derived (PS-derived) converter. In the prime PWM converters, the energy buffer portion and the output portion are the two feasible locations for a PVSC or a PCSC to be inserted into. For different type of the pulsating source cells (the PVSCs or the PCSCs), the rules to synthesizing the MICs are distinct.

A. Rules to Synthesizing MICs with PVSCs

As mentioned previously, a PVSC which is composed of a pulsating voltage source and a parallel diode can be inserted into a prime PWM converter to yield an MIC. If the PVSC is connected in parallel with one of the branches of the prime PWM converter, the voltage across the connected branch will be clamped by the pulsating voltage source. Thus, the PVSC and the branch of the prime PWM converter must be connected in series to avoid this situation taking place.

When a PVSC is introduced into the energy buffer portion of a prime PWM converter to form an MIC, it can be connected in series only with a current buffer, as conceptually illustrated in Fig. 6(a). In addition, it should be noted that the orientation of a PVSC must have the uni-directional current flow of the connected current buffer flowing out the positive end of the PVSC, so that the diode in the PVSC would not prohibit the uni-directional current of the current buffer from flowing. That is, the current buffer shown in Fig. 6(a) will never be open-circuited.

In the case of inserting a PVSC into the output portion of a prime PWM converter, the PVSC must be connected in series with the current sink rather than the voltage sink, as depicted in Fig. 6(b). Similarly, to circulate the current flow of the current sink, the PVSC and the current sink are connected in series with the current flow of the current sink flowing out the positive end of the PVSC.

Furthermore, each of the input-to-output port pair of an MIC can be regarded as an individual PWM converter separately and all of the input sources can deliver power to the load either individually or simultaneously through the MIC. That is, the prime PWM converter and the PS-derived converter can operate individually or simultaneously. To meet this requirement, a PVSC and an output sink of a prime PWM converter must form a mesh when a PVSC is introduced into a prime PWM converter.

According to the above discussion, the rules to synthesizing MICs with PVSCs can be summarized as follows.

Rule 1: When a PVSC is introduced into the energy buffer portion of a prime PWM converter, it must be connected in series with a current buffer and have the current flow of the connected current buffer flowing out its positive end.

Rule 2: When a PVSC is inserted into the output portion of a prime PWM converter, it must be connected in series with a current sink and have the current flow of the connected current sink flowing out its positive end.

Rule 3: A PVSC must form a mesh with an output sink.

B. Rules to Synthesizing MICs with PCSCs

A PCSC should be connected in parallel with a voltage buffer when it is inserted into the energy buffer portion of a prime PWM converter to yield an MIC, as depicted in Fig. 7(a). The feasible orientation of a PCSC can be found to possess the outgoing current terminal of the PCSC tied to the positive end of the voltage buffer. Fig. 7(b) conceptually shows the feasible circuit configuration of a PCSC connecting to the output portion of a prime PWM converter.

According to the definition of an MIC described in the Introduction section, both the input sources of the prime PWM converter and the PS-derived converter should be able to deliver power to the load either individually or simultaneously. To fulfill this capability, a PCSC must form a mesh with an output sink of a prime PWM converter when it is inserted into a prime PWM converter.

Based on the previous discussion, the rules to synthesizing MICs with PCSCs can be summarized as follows.

Rule 1: When a PCSC is introduced into the energy buffer portion of a prime PWM converter, it must be connected in parallel with a voltage buffer and its outgoing current terminal must tie to the positive end of the voltage buffer.

Rule 2: When a PCSC is inserted into the output portion of a prime PWM converter, it must be connected across a voltage sink with its outgoing current terminal tied to the positive end of the voltage sink.

Rule 3: A PCSC must form a mesh with an output sink.

(a) (b)

Fig. 6. Feasible circuit configuration of a PVSC connecting to a prime PWM converter (a) the energy buffer portion connection (b) the output portion connection.

(a) (b)

Fig. 7. Feasible circuit configuration of a PCSC connecting to a prime PWM converter(a) the energy buffer portion connection (b) the output portion connection.

V. SYNTHESIS OF MICS

An MIC can be developed by introducing a PVSC or a PCSC into a prime PWM converter. For different type of the pulsating source cells (the PVSCs and the PCSCs), the synthesis procedures of the MICs are distinct from each other. In this section, two families of the MICs classified by the PVSCs and the PCSCs will be developed.

A. Generation of MICs with PVSCs

Based on the rules listed in section IV, part A, the synthesis process of the MICs with PVSCs is summarized as:

Step 1: Choose one of the PVSCs shown in Fig. 4.

Step 2: Select one of the six basic PWM converters as the prime PWM converter which contains the current buffers or the current sink.

Step 3: Insert the chosen PVSC into the selected prime PWM converter according to the rules 1 and 2 listed in section IV, part A.

Step 4: Verify whether the inserted PVSC obeys the rule 3 listed in section IV part A. The final version of an MIC can be then obtained.

To illustrate the synthesis procedure, an MIC which is derived from introducing the buck-type PVSC into the buck-boost converter is demonstrated and shown in Fig. 8. The buck-boost converter is selected as the prime PWM converter since it contains a current buffer. Fig. 8(a) shows the topological circuit diagram of a buck-type PVSC and a buck-boost converter with the inserting location marked. According to the rule 1 listed in section IV part A, the buck-type PVSC should be connected in series with the current buffer of the buck-boost converter with appropriate orientation where the current through the current buffer must flow out from PVSC's positive end. The conceptual circuit diagram of the buck-boost prime converter with the inserted buck-type PVSC is shown in Fig. 8(b). In this figure, the buck-type PVSC and the output sink of the buck-boost prime converter form a mesh. This can ensure that the PS-derived converter can operate individually. The detailed circuit diagram of Fig. 8(b) is drawn in Fig. 8(c). By properly rearranging the overall circuit configuration, the MIC which is derived from combining the buck-type PVSC and the buck-boost converter is obtained and depicted in Fig. 8(d). This MIC circuitry had been published by the authors and used for the renewable energy applications. Details of the operation principle and control strategy can be found in [17].

Another synthesis example of the MIC is illustrated in Fig. 9 where the buck-type PVSC and the zeta converter are selected as a PVSC and a prime PWM converter, respectively. In Fig. 9(a), the zeta converter possesses a current buffer and a current sink so that it has two feasible positions for the buck-type PVSC to be inserted into. When the buck-type PVSC is inserted into the output portion of the zeta converter, as shown in Fig. 9(b), it must be connected in series with the current sink of the zeta converter according to the rule 2 listed in section IV, part A. By properly re-configuring the circuit, the MIC which is derived from combining the buck-type PVSC and the zeta converter can be obtained and depicted in Fig. 9(c). On the other hand, Fig. 9(d) shows the case of introducing the buck-type PVSC into the energy buffer portion of the zeta converter. With proper relocation, the final version of the converter is depicted in Fig. 9(e).

Investigation of Fig. 9(d) reveals that the buck-type PVSC doesn't form a mesh with the output sink of the zeta converter so that the PS-derived converter cannot operate individually. That is, the buck-type PVSC can deliver power to the load only when the zeta converter operates. This kind of MIC is defined as a quasi-MIC because it lacks the property of transferring power individually. The further investigation of quasi-MIC will be addressed latter.

By following the same synthesis procedure, the rest of the MICs with buck-type, Ćuk-type and zeta-type PVSCs can be also generated, and shown in Figs. 10, 11, and 12, respectively.

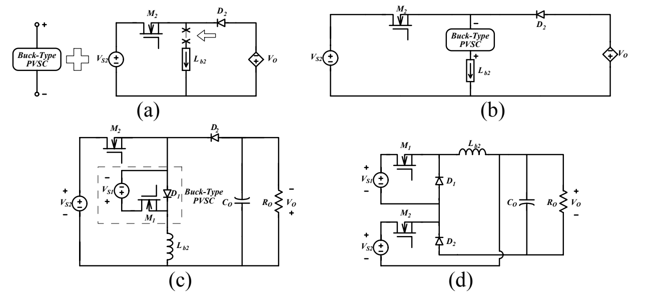


Fig. 8. Illustration of the MIC derived from the buck-type PVSC and the buck-boost converter (a) the buck-type PVSC and the buck-boost prime converter (b) the PVSC is inserted into the prime converter (c) circuit diagram of the synthesized MIC (d) the synthesized MIC with appropriate circuit configuration.

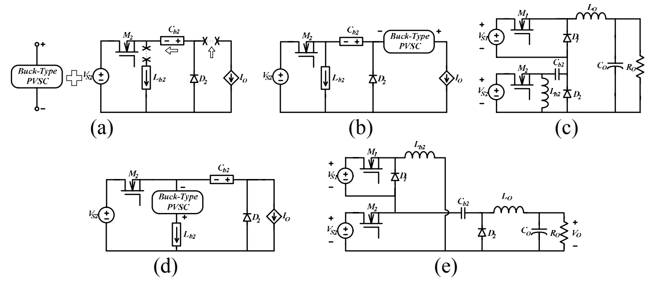


Fig. 9. Illustration of the MIC derived from the buck-type PVSC and the zeta converter (a) the buck-type PVSC and the zeta prime converter (b) the PVSC is inserted into the output sink of the prime converter (c) the synthesized MIC with appropriate circuit configuration (d) the PVSC is inserted into the current buffer of the prime converter (e) the synthesize MIC with appropriate circuit configuration.

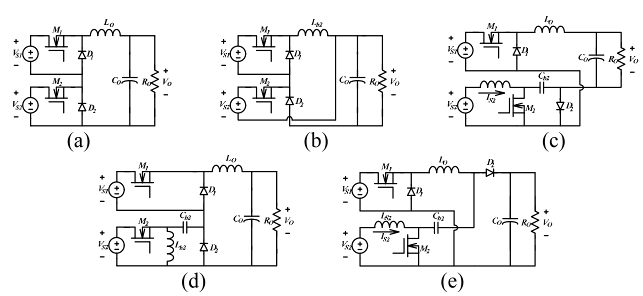


Fig. 10. MICs synthesized by the buck-type PVSC with different prime converters (a) with buck converter (b) with buck-boost converter (c) with Ćuk converter(d) with zeta converter (e) with SEPIC converter.

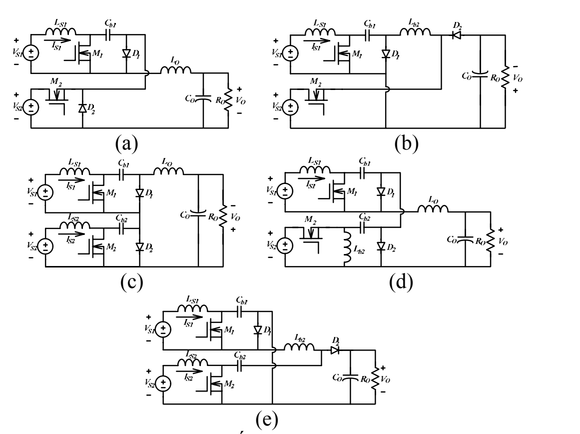


Fig. 11. MICs synthesized by the Ćuk-type PVSC with different prime converters (a) with buck converter (b) with buck-boost converter (c) with Ćuk converter (d) with zeta converter (e) with SEPIC converter.

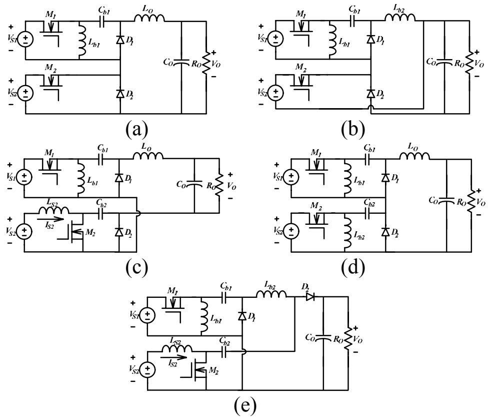


Fig. 12. MICs synthesized by the zeta-type PVSC with different prime converters (a) with buck converter (b) with buck-boost converter (c) with Ćuk converter (d) with zeta converter(e) with SEPIC converter.

B. Generation of MICs with PCSCs

Similarly, the synthesis procedure of the MICs with PCSCs can be summarized by the following steps:

Step 1: Choose one of the PCSCs shown in Fig. 5.

Step 2: Select one of the six basic PWM converters as the prime PWM converter which contains the voltage buffers or the voltage sink.

Step 3: Insert the chosen PCSC into the selected prime PWM converter according to the rules 1 and 2 listed in section IV, part B.

Step 4: Verify whether the inserted PCSC obeys the rule 3 listed in section IV, part B. The final version of an MIC can be then obtained.

An example is demonstrated to describe the synthesis procedure of the MICs with PCSCs. Derivation of this MIC is illustrated in Fig. 13 where the SEPIC converter is selected as the prime PWM converter for the boost-type PCSC to be inserted into. For convenience of derivation, the boost-type PCSC is lumped into an element and the SEPIC converter is redrawn to a topological structure form, as shown in Fig. 13(a). In this figure, it can be seen that the SEPIC converter has two feasible positions, the voltage buffer and the voltage sink, for the boost-type PCSC to be introduced into. According to the rule 2 listed in section IV part B, the boost-type PCSC is connected in parallel with the voltage sink of the SEPIC converter, as depicted in Fig. 13(b). By rearranging the overall circuit, the MIC shown in Fig. 13(c) can be obtained. Although the schematic diagram shown in Fig. 13(c) seems to be trivial and can be generated just by connecting the outputs of the boost and the SEPIC converters in parallel, it is indeed an MIC which is developed by following the synthesis procedure described previously in this sub-section.

On the other hand, Fig. 13(d) shows that a PCSC is connected in parallel with the voltage buffer of the SEPIC converter when it is inserted into the energy buffer portion of the SEPIC converter. In Fig. 13(d), it can be seen that the boost-type PCSC does not form a mesh with the output sink of the SEPIC converter. This will result that the boost-type PCSC converter cannot operated individually which makes the derived converter become a quasi-MIC. By properly relocating the overall circuit, the final version of the quasi-MIC is depicted in Fig. 13(e).

By following the same synthesis procedure, the rest of the MICs with boost-type, buck-boost-type and SEPIC-type PCSCs can be also generated, and shown in Figs. 14, 15, and 16, respectively. It is worth mentioning that the circuit topology shown in Fig. 14(a) is the multiple input DC/DC power converter for hybrid vehicles proposed in [11]-[15].

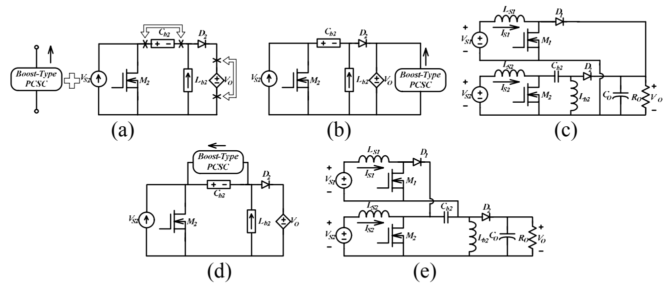


Fig. 13. Illustration of the MIC derived from the boost-type PCSC and the SEPIC converter (a) the boost-type PCSC and the SEPIC prime converter (b) the PCSC is inserted into the voltage buffer of the prime converter (c) the synthesized MIC with appropriate circuit configuration (d) the PCSC is inserted into the voltage buffer of the prime converter (e) the synthesized MIC with appropriate circuit configuration.

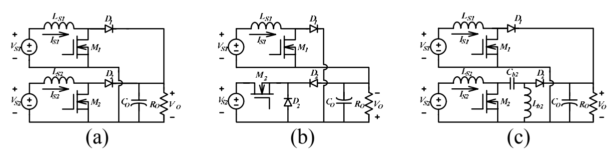


Fig. 14. MICs synthesized by the boost-type PCSC with different prime converters (a) with boost converter (b) with buck-boost converter(c)with SEPIC converter.

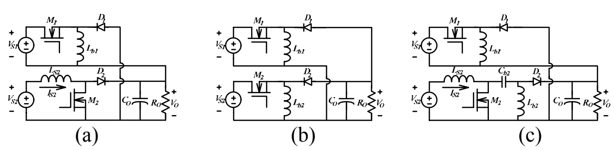


Fig. 15. MICs synthesized by the buck-boost-type PCSC with different prime converters (a) with boost converter (b) with buck-boost converter (c) with SEPIC converter.

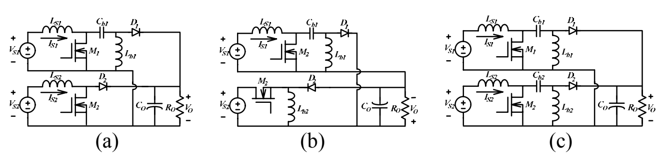


Fig. 16. MICs synthesized by the SEPIC-type PCSC with different prime converters (a) with boost converter (b) with buck-boost converter (c) with SEPIC converter.

C. Quasi-Multi-Input Converters

As described previously, the MICs possess the feature of that all of their input sources can deliver power to the load either individually or simultaneously. When the PVSCs or the PCSCs are introduced into the output portions of the prime PWM converters, the derived converters will have this feature and become MICs. However, when the PVSCs or the PCSCs are inserted into the energy buffer portions of the prime PWM converters, not all of the derived converters can be identified as the MICs. For instance, when the buck-type PVSC is connected in series with the current buffer of the zeta converter, as shown in Fig. 9(d), it doesn't form a mesh with the output sink of the zeta converter. This will result that the input source of the buck-type PVSC cannot deliver power directly to the load but only to the energy buffer. In other words, it can only deliver power to the load when the input source of the prime PWM converter delivers power to the load simultaneously. Therefore, the derived converter shown in Fig. 9(e) will be classified as a quasi-MIC. The quasi-MICs synthesized with different types of the PVSCs and the PCSCs are shown in Fig. 17 through Fig. 22.

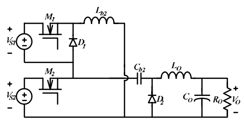


Fig. 17. A quasi-MIC derived from the buck-type PVSC and the zeta converter.

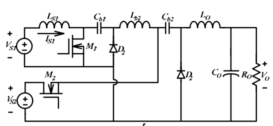


Fig. 18. A quasi-MIC derived from the Ćuk-type PVSC and the zeta converter.

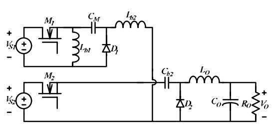
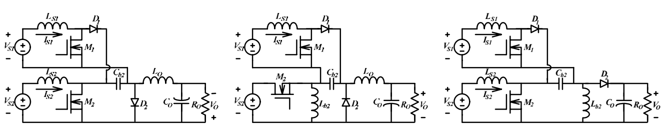
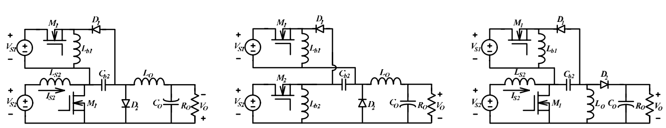


Fig. 19. A quasi-MIC derived from the zeta-type PVSC and the zeta converter.



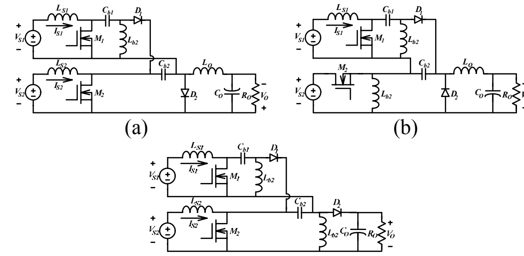
(a) (b) (c)

Fig. 20. Quasi-MICs synthesized by the boost-type PCSC with different prime converters (a) with Ćuk converter (b) with zeta converter (c) with SEPIC converter.



(a) (b) (c)

Fig. 21. Quasi-MICs synthesized by the buck-boost-type PCSC with different prime converters (a) with Ćuk converter (b) with zeta converter (c) with SEPIC converter.



(a) (b) (c)

Fig. 22. Quasi-MICs synthesized by the SEPIC-type PCSC with different prime converters (a) with Ćuk converter (b) with zeta converter (c) with SEPIC converter.

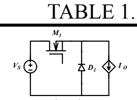
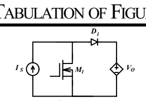
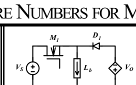
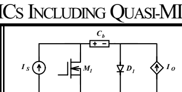
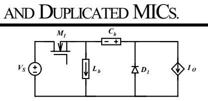
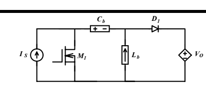
VI. Discussion

For clarity, the MICs and the quasi-MICs generated in this paper are tabulated in Table 1. In the table, the figure number denotes the schematic diagram of the MIC or the quasi-MIC developed from the corresponding pulsating source cell along with prime PWM converter. The non-underlined figure numbers denote that the derived converters are MICs, while the underlined ones designate that they are quasi-MICs. For the PVSCs, they must be connected in series only with the current buffers or the current sinks so that no MICs or quasi-MICs can be generated when they are introduced into the boost converter. Similarly, no MICs or quasi-MICs can be developed when the PCSCs are inserted into the buck converter, since the buck converter doesn't possess any voltage buffer or voltage sink.

In Table 1, some schematic diagrams of MICs are found to be duplicated. In the case of inserting one of the PVSCs into a prime PWM converter, the duplicated circuit diagrams might be recognized when the prime PWM converter is the one among the buck, Ćuk, and zeta converters.

In general, a PVSC-derived MIC can be considered as the combination of the prime PWM converter and the PS-derived converter which are any two of the three converters (buck, Ćuk, and zeta converters). Three duplicated MICs can be found when the circuit diagrams of the prime PWM converter and PS-derived converter are exchanged. By applying the same principle to the PCSC-derived MICs, three more duplicated MICs can be also obtained. In Table 1, the duplicated MICs are marked by the same symbol. For example, Fig. 14(b) and Fig. 15(a) are identical.

TABLE 1. Tabulation of Figure Numbers for MICs Including Quasi-MICs and Duplicated MICs.

Pulsating Source Cell \ Prime PWM Converter		 buck	 boost	 buck-boost	 Ćuk	 zeta	 SEPIC
PVSC	buck-type PVSC	Fig. 10(a)	N/A	Fig. 10(b)	Fig. 10(c)♣	Fig. 10(d)♦ Fig. 17	Fig. 10(e)
	Ćuk-type PVSC	Fig. 11(a)♣	N/A	Fig. 11(b)	Fig. 11(c)	Fig. 11(d)♥ Fig. 18	Fig. 11(e)
	zeta-type PVSC	Fig. 12(a)♦	N/A	Fig. 12(b)	Fig. 12(c)♥	Fig. 12(d) Fig. 19	Fig. 12(e)
PCSC	boost-type PCSC	N/A	Fig. 14(a)	Fig. 14(b)♠	Fig. 20(a)	Fig. 20(b)	Fig. 14(c)■ Fig. 20(c)
	buck-boost-type PCSC	N/A	Fig. 15(a)♠	Fig. 15(b)	Fig. 21(a)	Fig. 21(b)	Fig. 15(c)• Fig. 21(c)
	SEPIC-type PCSC	N/A	Fig. 16(a)■	Fig. 16(b)•	Fig. 22(a)	Fig. 22(b)	Fig. 16(c) Fig. 22(c)

VII. Conclusion

In this paper, the pulsating voltage source along with the parallel-connected diode and the pulsating current source along with the series-connected diode are defined as the PVSC and PCSC, respectively. From these circuit configurations, two families of pulsating source cells can be derived. According to the circuit characteristics of the PVSCs and PCSCs, rules to synthesizing MICs with PVSCs and PCSCs are presented. In addition, to ensure all of the input sources can deliver power to the load either individually or simultaneously, a PVSC or PCSC must form a mesh with the output sink of a prime PWM converter. By using the presented rules, two families of MICs have been generated.

References

[1] L. Solero, F. Caricchi, F. Crescimbini, O. Honorati, and F. Mezzetti, "Performance of a 10 kW power electronic interface for combined wind/PV isolated generating systems," in *Proc. IEEE PESC96*, 1996, pp. 1027–1032.

[2] F. Caricchi, F. Crescimbini, A. D. Napoli, O. Honorati, and E. Santini, "Testing of a new DC-DC converter topology for integrated wind-photovoltaic generating systems," in *Proc. European Conf. on Power Electronics and Applications*, 1993, pp. 83–88.

[3] F. Crescimbini, F. Carricchi, L. Solero, B. J. Chalmers, E. Spooner, and Wu Wei, "Electrical equipment for a combined wind/PV isolated generating system," in *Proc. IEE Opportunities and Advances in International Electric Power Generation*, 1996, pp. 59–64.

[4] B. G. Dobbs and P. L. Chapman, "A multiple-input DC-DC converter topology," *IEEE Power Electron. Letters*, vol. 1, pp. 6–9, Mar. 2003.

[5] N. D. Benavides and P. L. Chapman, "Power budgeting of a multiple-input buck-boost converter," *IEEE Trans. Power Electron*., vol. 20, pp. 1303–1309, Nov. 2005.

[6] H. Matsuo, T. Shigemizu, F. Kurokawa, and N. Watanabe, "Characteristics of the multiple-input DC-DC converter," in *Proc. IEEE PESC93*, 1993, pp. 115–120.

[7] H. Matsuo, K. Kobayashi, Y. Sekine, M. Asano, and L. Wenzhong, "Novel solar cell power supply system using the multiple-input DC-DC converter," in *Proc. IEEE INTELEC98*, 1998, pp. 797–802.

[8] H. Matsuo, F. Kurokawa, B. Lee, and K. Akise, "Suppression of the input current harmonics and output voltage ripple using the novel multiple-input AC-DC converter," in *Proc. IEEE INTELEC97*, 1997, pp. 710–714.

[9] H. Matsuo, W. Lin, F. Kurokawa, T. Shigemizu, and N. Watanabe, "Characteristics of the multiple-input DC-DC converter," *IEEE Trans. Ind. Electron.*, vol. 51, pp. 625–631, June 2004.

[10] K. Kobayashi, H. Matsuo, and Y. Sekine, "Novel solar-cell power supply system using a multiple-input DC-DC converter," *IEEE Trans. Ind. Electron*., vol. 53, pp. 281–286, Feb. 2006.

[11] A. Di Napoli, F. Crescimbini, F. Giulii Capponi, and L. Solero, "Control strategy for multiple input DC-DC power converters devoted to hybrid vehicle propulsion systems," in *Proc. IEEE ISIE02*, 2002, pp. 1036–1041.

[12] A. Di Napoli, F. Crescimbini, S. Rodo, and L. Solero, "Multiple input DC-DC power converter for fuel-cell powered hybrid vehicles," in *Proc. IEEE PESC02*, 2002, pp. 1685–1690.

[13] A. Di Napoli, F. Crescimbini, L. Solero, F. Caricchi, and F. Giulii Capponi, "Multiple-input DC-DC power converter for power-flow management in hybrid vehicles," in *Conf. Rec. IEEE IAS02*, 2002, pp. 1578–1585.

[14] A. Lidozzi and L. Solero, "Power balance control of multiple-input DC-DC power converter for hybrid vehicles," in *Proc. IEEE ISIE04*, 2004, pp. 1467–1472.

[15] L. Solero, A. Lidozzi, and J. A. Pomilio, "Design of multiple-input power converter for hybrid vehicles," *IEEE Trans. Power Electron.*, vol. 20, pp. 1007–1016, Sept. 2005.

[16] H.-J. Chiu, H.-M. Huang, L.-W. Lin, and M.-H.Tseng, "A multiple-input DC/DC converter for renewable energy systems," in *Proc. IEEE ICIT05*, 2005, pp. 1304–1308.

[17] Y.-M. Chen, Y.-C. Liu, and S.-H. Lin, "Double input PWM DC/DC converter for high-/low- voltage sources," *IEEE Trans. Ind. Electron*., vol. 53, pp. 1538–1545, Oct. 2006.

[18] K.-H. Liu and F. C. Lee, "Topological constraints on basic PWM converters," in *Proc. IEEE PESC88*, 1988, pp. 164–172.

[19] R. W. Erickson, "Synthesis of switched-mode converters," in *Proc. IEEE PESC83*, 1983, pp. 9–22.