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A Review on Multiple-input dc-dc converter topology

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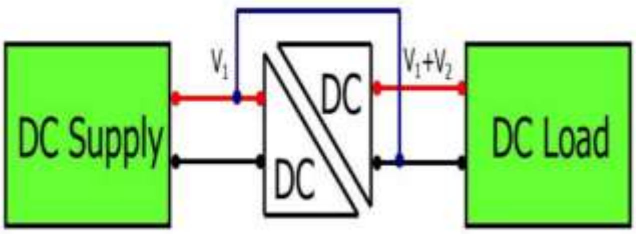
Abstract: **As multiple input converters are gaining importance and the power electronic converters, dc-dc converters find applications in key areas such as dc drives, battery charging, electric traction, and renewable power generation and so on. While many topologies of dc-dc converters are popular, multiple input converters (MICs) have been emerging as practical and efficient means especially for hybrid energy systems.The use of multiple input converters topology enables operation at high switching frequency without sacrificing efficiency. High switching frequency of operation reduces the output filter requirement, which in turn helps in reducing the size of the converters. In this paper review work is done on the basis of analytical study and comparative analysis of different research work.**

Keywords: dc-dc converters, Hybrid Energy System (HES), Multiple input converters (MICs), High switching frequency (HSF), Bidirectional power.

1. Introduction

Multiple-input (MI) dc-dc converters have recently been developed to interface more than one power source with a load. By using modular MI dc-dc converters (MIC), it is possible to diversify the energy sources so that the power system availability can be increased. Furthermore, utilization of renewable and alternative sources can be increased by combining units with different technologies, or by integrating energy storage to provide energy buffer functions or to feed the load when the power sources are unavailable. For example, using MI converters allows for an effective combination of wind and photovoltaic sources, allowing for more options when planning a site location and size [1]. Possible application examples include telecommunication power systems, [2] health care buildings, utilities [3] and sustainable buildings as shown in Fig. 1. Recently, several MICs have been proposed and studied with the objective of effectively combining various power sources and energy storage elements [1]-[15]. However, since each of the topologies proposed in the literature has its own advantages and disadvantages, it is difficult to choose an appropriate topology for specified application. The authors of [4] and [5] reviewed some of the MIC topologies that had been proposed in the past. The reviews are based on topological issues, such as in which circuit point the different inputs are combined. Combination strategies include sharing the output filter capacitor [6],[7], sharing some switches and energy transfer inductor and capacitor [8],[9], and sharing a magnetic core [4],[10]. These input combination methods, mentioned in [4], are shown in Fig. 2. Even though these methods can provide some indications of the MIC characteristics, they are not sufficient to allow a definitive topology selection criterion. A definitive criterion is necessary because it is possible to have different characteristics even when the strategy to couple the inputs is the same. Thus, additional aspects need to be considered in order to realize a reasonable MICs comparison framework. Such a comparison may involve considering different design and operational aspects. Cost and reliability are important characteristics that need to be considered when comparing either single-input or multiple-input converter. However, such a comparison needs to consider additional aspects because of the specific requirements involved in using MICs to combine different alternative power generation units in an effective way. Hence, in this work, two comparison aspects-flexibility and potential modularity-are also considered in addition to cost and reliability. A detailed description of these four comparison aspects is also included in this paper.



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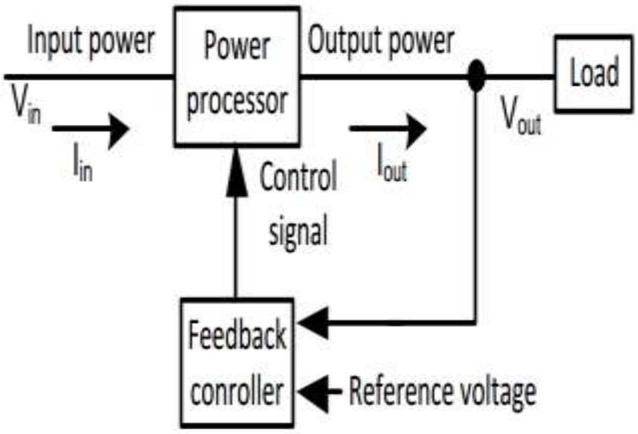
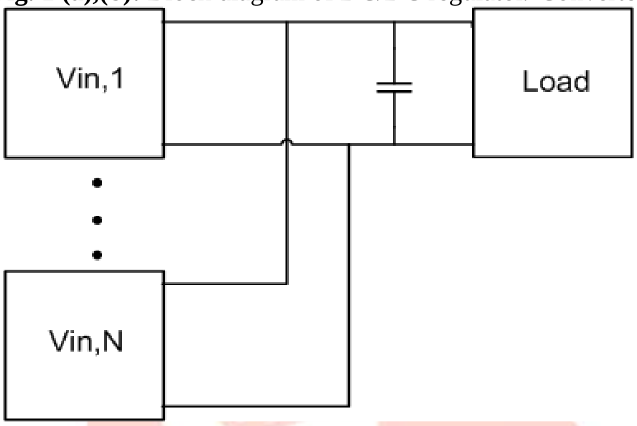


(b)

Fig. 1 (a),(b): Block diagram of DC/DC regulator/ Converter



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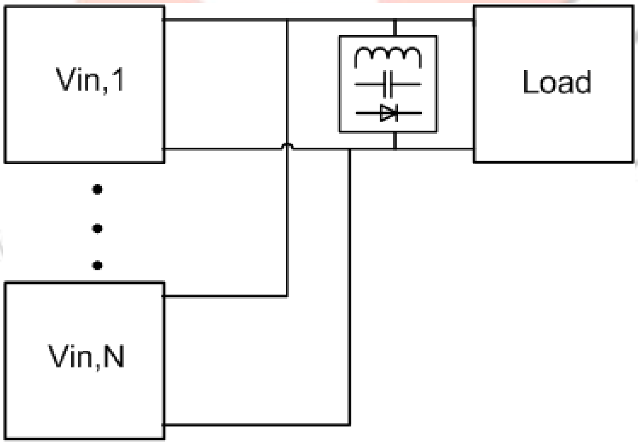

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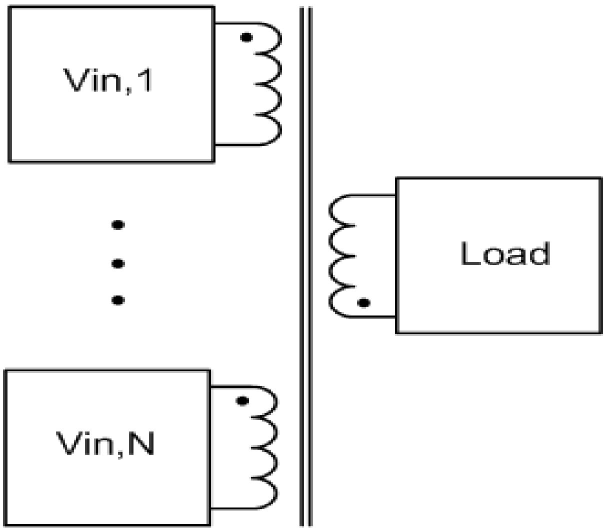

(c)

Fig. 2: Combining methods of MI dc-dc converter **(a)** sharing the output filter capacitor **(b)** sharing the switch, inductor and/or capacitor **(c)** sharing the magnetic core

This paper is organized in the following manner: In the next section (Section II), three new MIC topologies are suggested. The comparison among ten different topologies is performed in Section III. Section IV includes a brief discussion of the observations made through the comparison. Finally, the paper summarizes some conclusions in Section V.

2. Mi Dc-Dc Converters Comparison

This section compares ten MICs, including the three proposed in Section II. This ten MIC topologies, indicated in Table I, where selected because they all present relatively significant differences both in their topologies and operation.

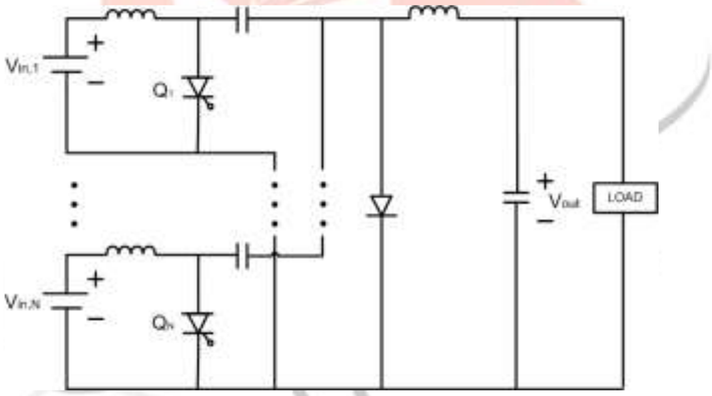

Fig. 3:MICUK converter

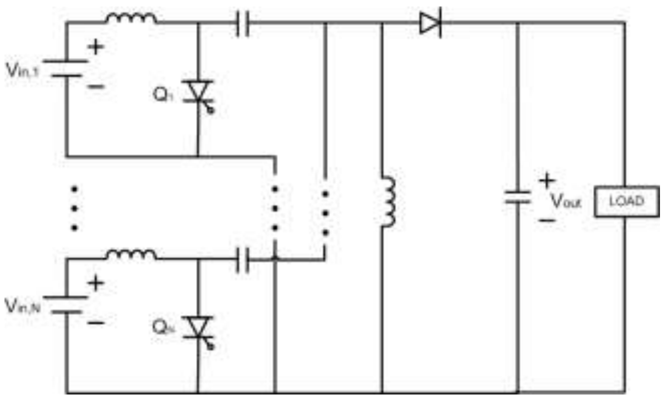

Fig. 4: MISEPIC converter

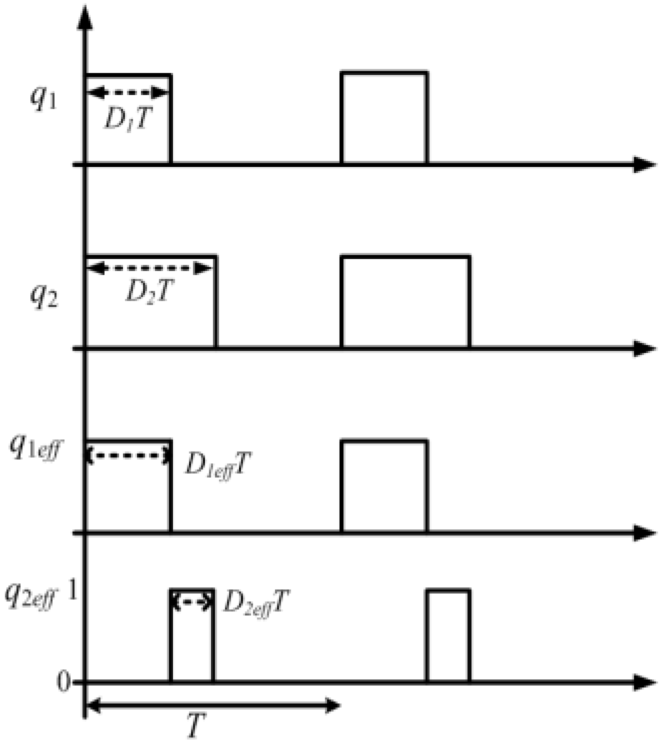

Fig. 5: Switching Strategy for MICUK, MISEPIC and MIG1

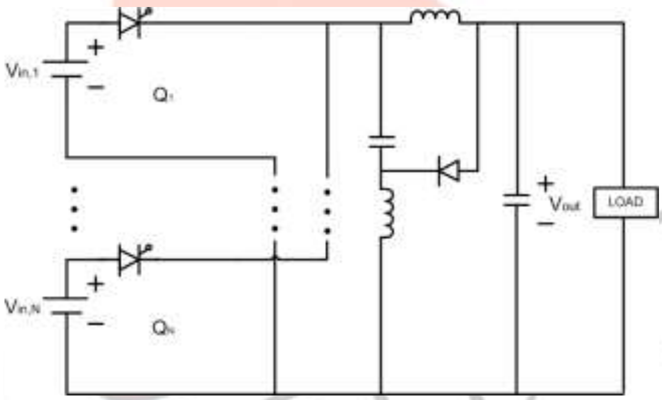

Fig. 6: MIG1 converter

This section compares ten MICs, including the three proposed in Section II. This ten MIC topologies, indicated in Table I, where selected because they all present relatively significant differences both in their topologies and operation. The objective is to provide a simple, but reasonable way to identify the most suitable topology in a given application involving the integration of alternative energy sources. The converters in Table I are treated in their simplest form. That is to say, control parts, additional stages to provide a given functionality, such as zero-voltage switching, or filters to provide a modified input or output interface, are not considered in this section. Especially important is the avoidance of current source interfaces in converters that have a switch input current characteristic, to make them more suitable to integrate some alternative power sources, such as fuel cells. The reason is that such an inclusion would affect the basis for a reasonable comparison among topologies. The most prominent advantage of using MICs over single input dc-dc counterparts is to provide a cost-effective solution and an improved availability system through the implementation of modular components. In addition, reliability and flexibility should also be considered when selecting the appropriate topology for a desired application. These four comparison categories are shown in Table II. These categories are selected because they provide important features to integrate alternative energy sources in an economical and technically sound way. The results are summarized in Table II based on relative evaluation of the topologies under considerations. The results can be interpreted in the following way: '*' in a given converter indicates that it has better attribute than '-'or '0' in other converters in the same category. Similarly, '0' represents better attribute than '-'. Hence, '****' should not be interpreted as four times better than '*' but should be interpreted as merely better than "***'. To avoid this kind of confusion, the scaling by numbers such as 1, 2, 3… are not used for the comparisons.

TABLE I ABBREVIATED IDENTIFICATION OF MI TOPOLOGIES

Abbreviation	Description
MISEPIC	multiple input SEPIC
MICUK	multiple input CUK
MIbB	multiple input buck-boost
MIB	multiple input boost
MIb	multiple input buck
MIFB	multiple input full-bridge
MIHB	multiple input half-bridge
MIF	multiple input flyback
MIBbB	multiple input boost/buck-boost
MIG1(1)	multiple input G1(1)

A. Expected Cost

Expected cost is compared based on the assumption that each MIC has four input legs, each of them with the same power rating. In the MIBbB case, cost is estimated assuming that the four input legs are equally divided between boost inputs and buck-boost inputs. When compared to equivalent system configurations using single input converters, cost savings in MICs are achieved by maximizing the number of components in their common stage. Hence, cost tends to be reduced as the number of common components is increased. Consequently, input legs connection at the output filter capacitor (Fig. 2 (a)) tends to provide few cost savings because the only common component is the common output capacitor. Since transformers tend to be relatively costly to produce, input legs connection at a common magnetic core (Fig. 2 (c)) can be even more expensive. Thus, MIFB converter cost tends to be the higher because it not only has a transformer to interconnect the inputs, but also has more switches in the input legs.

B. Modularity Potential

Modularity potential considers how easy it is to develop each of the converters in a modular way. Because a modular converter can improve availability by reducing the off-line time, modularity potential should be an important factor choosing a MIC topology. In order to compare the modularity potential, input combining methods (Fig. 2), and number and type of devices needed for each input module are considered. Among the methods, output filter capacitor sharing is considered to be the simplest way to make a module. On the contrary, interconnection through a magnetic core is considered as the most complex method in terms of creating modules. The reason is that when the design requires an specific winding for each input that needs to be pre-wired into the core. Configurations in which the common stage includes at least one switch (e.g. a diode) tend to be slightly more difficult to modularize than configurations in which only the output capacitor is shared, because mechanical and thermal requirements are added, such as the need to mount the diode and the switch on different heat sinks.

C. Reliability

MICs' reliability can be lower than that of parallel connection of equivalent single-input dc-dc converter configurations. The reason is that MICs share some components, which may act as a single point of failures. Thus, reliability decreases as the number of common components increases. Another factor to consider when evaluating reliability is the reliability of each individual part being shared and how much stress each part is receiving. For example, sharing electrolytic capacitors is worse than sharing inductors. Also switches tend to have a higher failure rate when the reverse blocking voltage is higher. Hence Table II
consider three aspects when comparing reliability: number of common components, type of common components and voltage stress across the switch. Current stress is not considered because same power rating is assumed. Likewise, since every component is considered ideal, stress from current and voltage spikes are ignored. Table II shows that both the MIFB converter is the least reliable of all MI converters because the voltage stress on the input switches is higher than that on other converters with large number of components, such as the MIHB.

TABLE II MI DC-DC CONVERTERS COMPARISON

Topology	Expected Cost	Modularity Potential	Reliability	Flexibility
MISEPIC	0	0	0	**
MICUK	0	0	0	**
MIbB	*	0	*	0
MIB	0	*	**	*
MIb	*	0	*	-
MIFB	-	--	---	0
MIHB	-	0	--	****
MIF	*	0	0	0
MIBbB	0	-	*	***
MIG1(1)	0	0	-	*

D. Flexibility

Flexibility in MIC means that the topology is compatible with different kinds of input sources. To compare the flexibility in Table II, two factors are considered. First, the type of input interface is considered, namely, current source converter (CSC) or voltage source converter (VSC). Since one of the main goals of using MICs is to combine different input sources, it is important to consider each topology input interface so that different source technologies can be integrated. Besides, having different sources increases overall availability by diversifying the input. In particular, some input sources such as fuel-cell require a low ripple current present in CSC. Other sources, such as photovoltaic modules also require CSC to implement some maximum power racking controls. Second, the conversion ratio is considered.

In MICs, it is desirable that a given topology provides a wide input and output voltage ranges. That is, only step-up or stepdown conversion converter is less flexible than the converter that can do both step-up and step-down function. In that sense, the existence of a transformer can be beneficial because it may provide a large input-to-output voltage ratio. Hence, Table II indicates that the MIHB has the highest flexibility since it is a CSC and has a transformer. The MIBbB also has a high flexibility in that it is a CSC and it is possible to do step-up and down conversion.

Among the new proposed topologies MICUK and MISEPIC tend to provide a high degree of flexibility because they are CSC and the output voltage can be stepped up and down. Although the MIG1(6) converter can also step up or step down the input voltage, it does not have a same degree of flexibility since it is a VSC. Output voltage profile of this converter has an additional interesting characteristic: as the duty cycle tends to 0.5, the output voltage tends to become several times that of the input. Hence, MIG1(6) can be useful when transformer-less implementation of high step-up conversion, such as achieving 400 V output with a 48 V input, is desired.

E. MI CUK and MISEPIC

Usually, buck, boost, buck-boost, CUK, and SEPIC converters are considered to be the five basic topologies. This section introduces an alternative to the MI CUK (MICUK) and MI SEPIC (MISEPIC) presented in [11]. Contrary to [11], the topologies suggested here supply power to the load at different intervals during the switching period. Both of the topologies shown here in Figs. 3 and 4 combine the input sources by sharing the energy transfer inductor, the output filter capacitor and the diode, with the method shown in Fig. 2. (b). For the sake of the analytical convenience, it is assumed that all duty cycles are realized with the same carrier signal so that the leading edges of all switching signals occur simultaneously, as shown in Fig. 5 [8]. Because of the time sharing concept, i.e., no two input sources deliver power simultaneously, there exists an effective duty cycle which differ from the commanded duty cycle in all input legs in which there exists at least one source in another leg with a higher voltage [9]. Hence, the effective duty cycle Deff is the portion of the switching period when the switch conducts current [4].

F. MIG1

In this section, another possible MIC is proposed. The topology is derived from the single input version, called G1(6) in Table II in [14]. When both inductors are coupled, the single input converter G1(6) is similar to an inverse Watkins-Johnson converter. To simplify the analysis, this paper consider that the inductors are uncoupled, leaving a more detailed analysis of the circuit, including the inverse Watkins-Johnson version for future work. The proposed schematic of the MIG1(6) converter is shown in Fig. 6. As in the MICUK and the MISEPIC suggested in part B of this section, the input to output voltage relationship is also a function of Deff.

3. Discussion

The Table II can be used for choosing the appropriate MIC topology in a given application. In a simple example, when low cost is the driving design goal, then either one of MIb, MIbB and MIF can be a good topology. If flexibility and modularity are what matters, then the MIBbB can be a good choice or if the flexibility is the most important factor then the MIHB can be an appropriate topology. If having only step-up conversion ratio is not a design issue, then MIB might be the chosen topology. As shown in Table II, there are five topologies that do not have negative evaluations: MIB, MIbB, MICUK, MISEPIC, and FB. Among them, the MIB is the only one that only has three positive evaluations in the four categories. Hence, if voltage-step down function is not needed, MIB seems to provide a good trade-off option for many applications. Since MIBbB is the only topology which integrates different inputs, it could obtain relatively high flexibility without negatively affecting in any other category. Hence, MIBbB could also be a good general purpose topology. MISEPIC and MICUK converters provide very good flexibility. However, their use in a variety of application might be affected by neutral scores in all other categories.

4. Conclusion

In this paper work, ten MI dc-dc converter topologies are compared. To simplify the analysis and provide a direct way of selecting the most suitable option for a given application, the comparison includes four characteristics that are considered to be the most significant ones: modularity, potential, cost, flexibility, and reliability. As part of the assessment, focus is given to how appropriate each topology is for integration of a variety of alternative energy sources Future work on MI dc-dc converter comparison could consider the option of having bi-directional ports as part of the flexibility category, and alternative control methods in the modularity potential and the flexibility categories. In addition, control of soft switching techniques and isolation problems could also be considered in future analysis within the reliability category.

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