

Implementation of a dual-input single output synchronous buck-modified SEPIC converter for DC microgrids

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Abstract

An asynchronous dual-input single output (DISO) buck-boost converter is utilized to power DC microgrids (DCMG) with hybrid energy sources, such as solar PV and battery energy harvesting systems. However, the asynchronous buck-boost DISO converter, which produces a continuous output voltage and current at duty ratios above 0.7, can suffer from voltage stress on the power switches at these higher duty ratios. Additionally, this converter provides output current discontinuously at lower duty ratios due to its low resource utilization. A new synchronous buck modified SEPIC converter (MSC) DISO converter is proposed to address these issues. This converter can generate continuous output current and voltage at a duty ratio of 0.3, making it more suitable for integrating PV-battery energy harvesting systems into DCMG. This paper presents a topological analysis of DISO converters using power flow diagrams to establish the foundational principles of the proposed synchronous buck-MSC approach. Comprehensive research and analysis of this synchronous buck-MSC DISO converter are conducted using PSIM software. The simulation results demonstrate the effectiveness of the synchronous buck-MSC DISO converter in meeting the power requirements of DCMG, thereby proving its applicability and efficiency in renewable energy-based DCMG.

Keywords: DISO converters, synchronous buck converters, SEPIC converter, PV systems, battery energy harvesting and DC microgrids.

Introduction

The utilization of renewable energy sources such as wind, fuel cells, and solar energy has significantly increased the demand for power electronic devices [1-6]. These devices serve as electrical interfaces between various energy storage systems, renewable energy sources, and DC loads, facilitating efficient power conversion, effective power conditioning, and

rapid response mechanisms. This paper explores power electronic DC-DC converters for energy harvesting, which are crucial for developing current and future DCMG [7-11].

MISO (multiple inputs single output) converters are ideal for applications requiring a combination of multiple input energy sources to supply a single output. Specifically, DISO (dual input single output) converters are effective for scenarios where two input sources are combined

to control one output, as seen in DC loads and PV systems. In a DISO converter, the input ports can be connected to a voltage source, a current source, or a combination of both in either parallel or series configurations, with the output port connected to a voltage or current load [12]. Various DISO converters are needed for different applications, such as solar PV systems, fuel cell stacks, and wind energy systems [13-15]. Numerous topologies of DISO converters are available to accommodate a variety of input sources and consumer loads [16].

The efficiency of these DISO converters can be enhanced by managing the positions of power switches and sharing power flow [17]. Typically, the input and output ports are unidirectional, but in some cases, they can be bidirectional. Therefore, the design of control strategies and converters significantly impacts the efficiency and performance parameters of the DISO converter [18]. Figure 1 illustrates how energy sources are connected to bidirectional DISO converters to effectively meet the needs of DCMG. In this setup, the primary input sources are solar PV systems and energy storage systems, including batteries, due to their low cost and high-speed operation, ensuring efficient energy supply to the DISO converters [19].

Generally, these DISO converters can effectively utilize the input resources then they can easily and efficiently supply the energy to the DC distribution systems. DCMGs include DC loads, batteries, DC buses and distributed generating sources etc. So here battery can work like sink as well as source also to harvest the energy and supply the energy to these DISO converters [20, 21].

The main aim of this paper is to suggest an efficient technique to analyze entirely DISO converters with possible configurations. This synchronous DISO converter can produce a continuous output current and voltage at a 0.3-duty ratio. The proposed converter demonstrates enhanced performance at low-

duty cycles with improved efficiency. One notable effect of operating at low duty cycles is that it improves the converter's efficiency. This is because, during low-duty cycles, the converter spends more time off-state, resulting in reduced switching losses. Lower switching losses lead to higher overall efficiency, making the converter an efficient choice, especially in applications where minimizing power dissipation is critical. Extended battery life: In battery-powered applications, a low duty cycle can significantly extend the battery life. By spending more time off-state, the converter consumes less power from the source, which is especially advantageous when dealing with limited energy reserves, such as batteries. Reduced voltage stress: Due to lower duty cycles voltage across the switching devices is reduced. This can extend the lifespan of these components and reduce the risk of voltage-related failures. Higher voltage gain: In certain topologies like boost converters, operating at low duty cycles can result in a higher output voltage in comparison with higher-duty cycles. This can be advantageous when you need a higher output voltage.

Traditionally, the asynchronous buck-boost DISO methodology is used to integrate solar PV and energy storage systems and particularly, batteries due to their long lifespan and efficiency. However, asynchronous buck and boost converters have numerous drawbacks, such as high switching and conduction losses associated with their diodes. Additionally, these converters can produce a better output current and voltage at duty ratios above 0.7, but this can increase voltage and current stress on the power switches of both converters. The synchronous buck-MSO DISO converter is proposed to address these issues.

This converter features an efficient configuration and improved switching positions, enhancing energy storage and power distribution for current and future energy needs in modern power conversion systems with

power electronics. The advantages of the synchronous buck converter include its superior performance at low duty ratios and its ability to supply better output current and voltage to DC loads efficiently, even when heavy DC loads are connected. The advantages of MSC are as follows; it drives with single switch which can decrease the difficulty of device circuitry, uninterrupted response current and maximum use of input resources.

The remaining article is organized as follows: Section 1 introduces the DISO converters and their modules. The basic operation of MSC and synchronous converter are deliberated in sections 2 and 3. Section 4 introduces the proposed bidirectional DISO converters with a synchronous buck MSC approach. The power flow diagrams of the proposed bidirectional DISO converters are presented in Section 5. Sections 6 & 7 give information of simulation results and discussions for the proposed bidirectional DISO converter and in the last section the overall work is concluded.

Modified SEPIC converter

The non-isolated modified SEPIC converter (MSC) is designed for high-voltage applications and can seamlessly integrate with a buck converter to form a hybrid DC-DC converter, producing DC output voltage for DC microgrids (DCMG) [11]. MSC containing the single input-output terminals and derived through shifting a conventional SEPIC converter with boost up mode is viewed in Fig. 2 it demonstrates the circuit diagram of the MSC containing three inductors (L_x , L_y and L_z), three diodes (D_x , D_y , and D_z) and three capacitors (C_x , C_y , and C_z). These components are controlled with a single switch S with switching frequency (f_s). The capacitor C_x and inductor L_y are arranged as the voltage-boosting arrangement in adding D_x , D_y diodes in MSC. To assess the steady-state process of the MSC succeeding conventions are deliberated by all components in the MSC reflected as presence model and all capacitors in MSC are large and necessarily to achieve

constant DC voltage. The MSC can operate in two modes individually to fetch the continuous current at the load side.

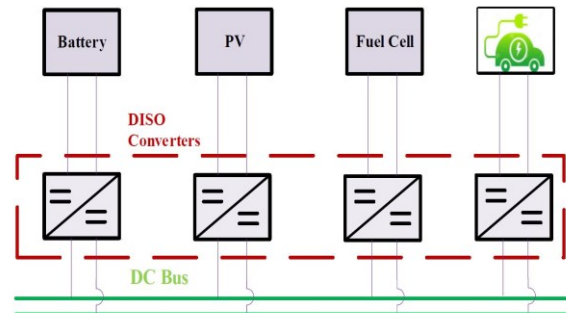


Figure 1: Application of DISO converters in DCMGs.

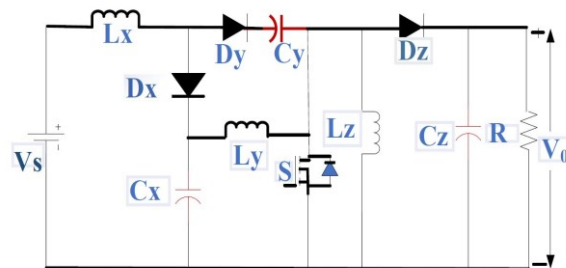


Figure 2: Circuit diagram of a modified SEPIC converter.

Synchronous buck converter

The synchronous buck converter contains two power switches, a capacitor and an inductor [9]. It is required to activate synchronous buck converter in uninterrupted current manner since the MOSFET shall tolerate the current of inductor to reach negative. Inductor current flows regularly in an uninterrupted conduction manner. The switch QA is in on condition and QB is in off condition during first mode. The current passes over the inductor to charge it. The switch QA is in off position, so the current is kept in the inductor, and it will discharge. The inductor's discharging current turns on the QB in second mode of working. Figure 3 represents the circuit diagram of synchronous buck converter.

Proposed two bidirectional DISO converters

This section evaluates the basic information regarding the selection of power flow configuration of the proposed bidirectional DISO converters.

The proposed DISO converter is primarily designed to enhance DC voltage significantly and provide continuous DC current for DC loads in DCMG, operating at a 0.3 duty ratio. What sets this converter apart is its compatibility with high voltage gain converters like MSC, which helps reduce voltage and current stresses, resulting in a well-regulated DC power output [27, 28]. The name "DISO converter"

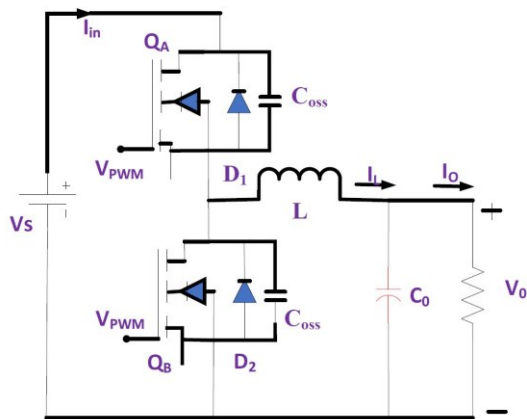


Figure 3: Circuit diagram of synchronous buck converter C_{oss} .

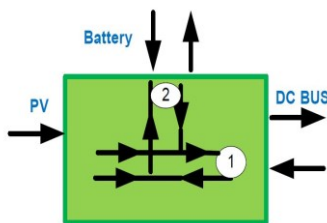


Figure 4: Power flow line diagram of modified bidirectional DISO converters.

itself signifies the requirement for two input resources to drive this converter: PV as the primary source and a battery as the secondary

source. Furthermore, the battery not only acts as a backup but also serves as a sink and harvester, as described in the control strategies proposed in this article. Figure 4 describes the basic block of the bidirectional DISO converter with resources such as PV and battery for DC loads connected via DC bus. Here, two separate converters are needed to control the power flow from the resources.

The efficiency of each converter design is subject to how many power transformation steps are utilized. The benefit of the configuration in the above figure is that PV has a single power conversion point to a battery or DC bus in the DC distribution system. However, it utilizes two power conversions from an energy storage system, including a battery, to a DC bus. That's why this article can rely on this configuration to implement the bidirectional DISO converter efficiently to proficiently feed the DC loads included in the DCMG.

Figure 5 illustrates the circuit configuration of the proposed bidirectional DISO converters with the synchronous buck-MSM approach. This methodology can improve the efficiency of the DC loads in DCMG because it can be implemented using the MSM and synchronous buck converter approach. The introduction section of the article discusses the benefits of these converters. Here, V_{pv} indicates the solar PV voltage, and V_{bat} indicates the battery voltage. The diodes $D1$, $D2$, and $D3$ are additional switches to the proposed DISO converter. The passive elements, including inductors $L1$, $L2$, $L3$, $L4$, and capacitors $C1$, are charged and discharged at particular operations of the proposed DISO converter. This approach can only utilize the three power switches to

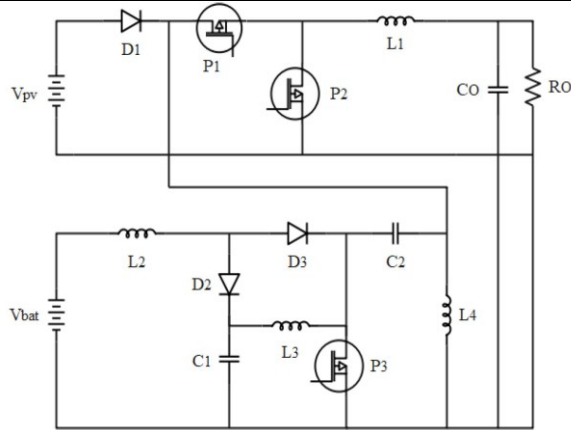


Figure 5: The proposed bidirectional DISO converters with synchronous buck-MSM approach.

accurately handle the power from both the input and output ports without disturbing the DC load functioning. The working operation and power flow diagrams can be effectively explained in the next section.

Moreover, the designing aspects regarding the inductor and capacitor in these proposed bidirectional DISO converters with synchronous buck-MSM approach can follow the design considerations of capacitors and inductors in the article [11] due to the reason of MSM producing negligible current and voltage stress across the switch and being large enough to charge both capacitor and inductor in efficient way. The following equations are followed by the proposed DISO converter mentioned in this paper to generate continuous input and output current for DCMG.

- (1) $L_1 = L_2 = \frac{R(1-D)^4}{2f_s D}$
- (2) $L_3 = \frac{R(1-D)^2}{2f_s D}$
- (3) $L_4 = \frac{R(1-D)}{2f_s}$
- (4) $C_1 = \frac{V_{C1} D}{R \Rightarrow V_{C1} f_s}$
- (5) $C_2 = \frac{V_{C2} D}{R \Rightarrow V_{C2} f_s}$
- (6) $C_o = \frac{V_{C_o} D}{R \Rightarrow V_{C_o} f_s}$

The above six equations can clearly depict that charge and discharge in the presence of duty

ratio operation. Here D indicates the duty ratio, $\Rightarrow V_{C1}, \Rightarrow V_{C2}, \Rightarrow V_{C_o}$ may indicate the change voltage developed by the capacitors C_1, C_2, C_3 in initial conditions before and after switching on and off the power switches. Moreover, f_s can indicate the switching frequency of the power switch, and which is always inversely proportional to time period T. This proposed DISO converter also maintains the frequency range of 50 kHz to avoid the electromagnetic interference and instability conditions [11].

The power flow diagrams of the proposed bidirectional DISO converters

In this section, the power flow graph for the proposed DISO converter can be clearly described with some power flow diagrams. Generally, batteries act like bidirectional elements, which means they can work like a source when a load wants power; otherwise, they can operate like a sink, simply storing the excessive power sent by the load.

In the proposed DISO converter, the solar PV source can be connected to the synchronous buck converter, and the battery is connected to the MSM. Table 1 illustrates the switching operations of the proposed bidirectional DISO converters with a synchronous buck-MSM approach in Mode I to Mode VII. Here, 1 indicates the power switch ON condition, and 0 indicates the power switch OFF condition.

Moreover, the table below clearly illustrates three power switches, P1, P2, and P3, of the proposed DISO converter ON and OFF operations. This table can neatly visualize the switching operations with the help of numerical digits 0 & 1. Thus, it makes it possible to understand any switching operation of any power electronic converter on and off operations with the help of numerical digits 0 & 1. Table 1 represents the switching operations with the voltage and current equation of the proposed bidirectional DISO converter.

Mode I (Solar PV to DC load)

In this Mode I operation the power can transfer only between the solar PV (V_{pv}) to the DC load (R_o) with switching ON the power switch P1 and also diode D1 in forward biased position. Here the inductor L1 can be

in charging mode. The power flow configuration in loop 1 terms the power flow direction as $V_{pv} (+) - P_1 - L_1 - R_o - V_{pv} (-)$. In this mode only PV can act as a input resource to DISO converter.

$$(7) V_{pv} = DV_o$$

Table 1: Switching operations with voltage and current equation of the proposed bidirectional DISO converter

Synchronous buck- converter operations	MSC mode	P ₁	P ₂	P ₃	Voltage equations	Current equations
Mode I		1	0	0	$V_{pv} = D_1 V_o$	$I_o = I_{pv} / D_1$
Mode II		0	1	1	$V_{pv} = D_2 V_o + V_{bat}$	$(I_{pv} - I_{bat}) D_2 = I_o$
Mode III		1	0	0	$V_{pv} + V_{bat} = D_3 V_o$	$(I_{pv} + I_{bat}) D_2 = I_o$
Mode IV		0	0	0	$V_{pv} = V_{bat}$	$I_{pv} = I_{bat}$
Mode V		1	0	0	$V_{bat} = D_4 V_o$	$I_{bat} / D_4 = I_o$
Mode VI		0	1	1	$V_{bat} / D_5 = V_o$	$I_{bat} D_5 = I_o$
Mode VII		0	1	1	$V_{pv} + D_6 V_o = V_{bat}$	$(I_{bat} - I_{pv}) D_6 = I_o$

Equation seven describes that here in this mode of operation the solar PV voltage is simply equal to the D times of output voltage for DCMG. Here D means duty ratio of the power switch P1.

Mode II (PV to battery and DC load)

In this Mode II operation, the power can transfer only between the solar PV (V_{pv}) to the battery and the DC load (R_o) by switching ON the power switches P2 & P3 and also diodes D1 and D3 are in forward biased. Here the inductor L1 can be in discharging Mode Ind L2 & L4 can be in charging mode, capacitor C2 can be in charging and discharging mode. The power flow configuration in loop 2 labels the power flow path as $V_{pv} (+) - D_1 - C_2 - P_3 - V_{bat} - L_2 - D_3 - C_2 - L_4 - R_o - L_1 - P_2 - V_{pv} (-)$. In this mode only PV can act as an input resource to DISO converter and moreover excessive energy generated by the PV can be stored in battery. So, in this Mode II battery can act as a sink to harvest or store the electrical energy.

$$(8) V_{pv} = DV_0 + V_{bat}$$

Equation eight describes that here in this mode of operation the solar PV voltage is simply equal to the D times of output voltage for DCMG, and voltage stored in the battery. Here D means duty ratio of the power switches P2 & P3.

Mode III (PV and battery to DC load)

In this Mode III operation, the power can transfer only between the solar PV (V_{pv}) and the battery to the DC load (R_o) by switching ON the power switch P1 and also diodes D1 and D2 are in forward biased. Here the inductor L1 can be in charging Mode Ind L2 & L4 can be in discharging mode, capacitor C1 can be in charging mode.

The power flow configuration in loop 3 labels the power flow path as $V_{pv} (+) - D_1 - P_1 - L_1 - R_o - V_{pv} (-)$ and $V_{bat} - L_2 - D_3 - C_1 - L_4 - V_{pv} (-)$. In this Mode III both PV and battery can act as an input resources to DISO converter and moreover excessive energy generated in the battery can be fed back to the DC load due to the insufficient energy available at PV. So, in this Mode II

battery can act as a source to deliver the electrical energy to DC load.

$$(9) V_{pv} + V_{bat} = DV_0$$

Equation nine describes that here in this mode of operation the Solar PV voltage and battery voltage is simply equal to the D times of output voltage for DCMG. Here D means duty ratio of the power switch P1.

Mode IV (PV to battery)

In this Mode IV operation the power can transfer only between the solar PV (V_{pv}) to the battery with diodes D1 and D3 being in forward biased. Here the inductor L3, L2 & L4 can be in charging mode, capacitor C1 can be in charging and discharging mode. The power flow configuration in loop 4 makes the power flow path as $V_{pv} (+) - D_1 - C_2 - L_3 - C_1 - V_{bat} - L_2 - D_3 - C_2 - L_4 - V_{pv} (-)$.

In this mode only PV can act as an input resource to DISO converter and moreover excessive energy generated in the PV can fed back to the battery due to the more sufficient energy available at PV. So, in this Mode IV battery can act as a sink to store the electrical energy for DC load. In this mode the diodes D1 and D3 are responsible for transfer the electrical energy from PV to battery in accurate manner with biasing condition.

$$(10) V_{pv} = V_{bat}$$

Equation ten describes that here in this mode of operation the solar PV voltage is simply equal to the voltage stored in the battery. Here the diodes D1 and D3 are responsible for transmitting the electrical energy from PV to the battery storage system when the diodes are in ON condition.

Mode V (battery to DC load)

In this Mode V operation, the power can transfer only between the battery to the DC load with switching ON the power switch P1 with diodes D2 in forward biased. Here the inductor L1 can be

in discharging Mode V and L_2 , L_3 & L_4 can be in discharging mode, capacitor C_1 can be in discharging mode. The power flow configuration in loop 5 creates the power flow path as $V_{bat}(+) - L_2 - D_2 - C_1 - L_3 - L_4 - P_1 - L_1 - R_o - V_{bat}(-)$.

In this mode only battery can act as an input resource to DISO converter and moreover excessive energy generated in the battery can be fed back to the DC load due to the absence of energy

available at PV. So, in this Mode V battery can act as a source to deliver the electrical energy to DC load.

$$(11) V_{bat} = DV_0$$

Mode VI (DC load to battery)

In this Mode VI operation, the power can transfer only between the DC load to the battery by switching ON the power switches P_2 & P_3 with diodes D_3 being in forward biased. Here the inductors and L_1 & L_2 can be in charging mode. The power flow configuration in loop 6 forms the power flow route as $R_o(+) - L_1 - P_2 - V_{bat} - L_2 - D_3 - P_3 - R_o(-)$. In this mode only DC load can act as an input resource to DISO converter and moreover, excessive energy stored in the DC bus can be fed back via DC load to the battery. So, in this mode VI battery can act as a sink to store the electrical energy for DC load.

$$(12) \frac{V_{bat}}{D} = V_0$$

Equation twelve describes that here in this mode of operation, the ratio of battery voltage to D is equal to output voltage for DCMG. Here D means duty ratio of the power switch P_2 & P_3 .

Mode VII (PV and DC load to battery)

In this Mode VII operation, the power can transfer only between the PV and DC load to battery while switching ON the power switches P_2 & P_3 with diodes D_1 & D_3 being in forward biased. Here the inductors and L_1 , can be in

discharging Mode Ind L_2 & L_4 can be in charging mode. The power flow configuration in loop 7 forms the power flow track as $V_{pv}(+) - D_1 - R_o - L_1 - P_2 - V_{bat} - L_2 - D_3 - P_3 - L_4 - V_{pv}(-)$. In this Mode VII both PV and DC load can act as an input resources to DISO converter and moreover excessive energy stored in the DC bus and PV can be fed back to battery. So, in this Mode VII battery can act as a sink to store the electrical energy for DC load.

$$(13) V_{pv} + DV_0 = V_{bat}$$

Equation thirteen describes that here in this mode of operation the solar PV voltage and output voltage for DCMG is simply equal to the battery voltage. Here D means duty ratio of the power switches P_2 & P_3 .

In all modes of operation, it is confined that each operation has its controlling capability on electrical energy transmission from one input resource to DC load, DC load to one input resource, two input resources to DC load, and at most, DC load to two input resources. Each mode's energy consumption and delivery depend on the passive elements called inductors and capacitors. Quick response is shown in modes of operation circuit diagrams. In each operational mode, there are consistently two energy sources in play. For instance, PV is a source while the battery is a sink. In another scenario, both PV and the battery function as input energy sources. Similarly, in each operational mode, two current directions are always present, with their specific orientations determined by the mode of operation.

In every mode, the switching operation is continuously done by either power switches or diodes without interrupting the DC loads in DCMG. In every mode, the energy consumption and energy delivered by the battery are quick, avoiding switching losses and conduction losses with the help of the synchronous buck-MSM approach's resource handling capability. In each case, energy consumption and utilization are equal due to the negligible losses created by the



passive elements in this bidirectional DISO converter.

That's why this approach is very familiar and suitable for accurately satisfying the DC loads in DCMG. Moreover, this approach can offer better reliability and efficiency to the bidirectional

DISO converter with hybrid PV-battery energy harvesting systems. Figure 6 shows the Mode I to Mode VII power flow diagrams of the proposed bidirectional DISO converter.

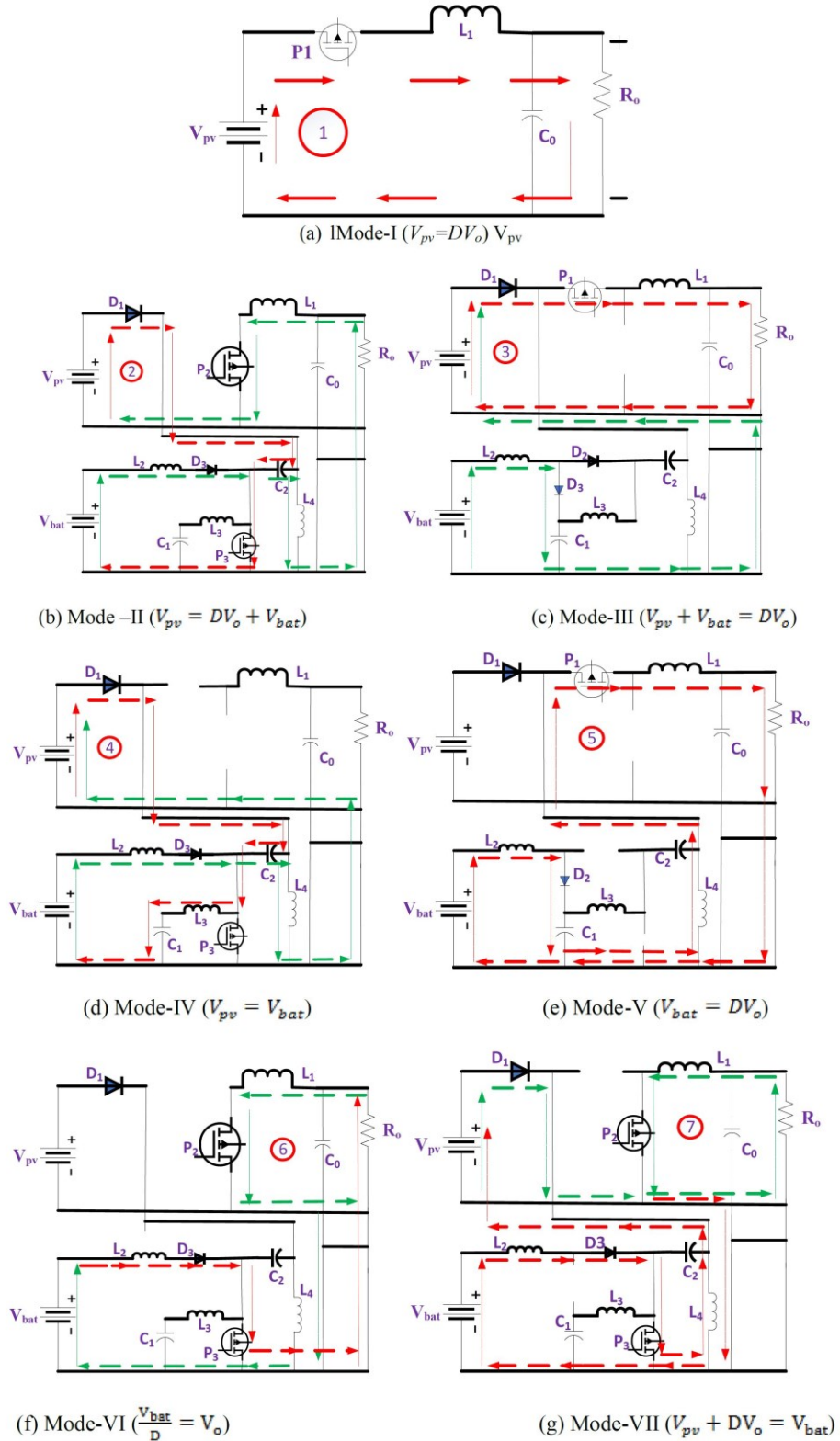


Figure 6: Mode I to Mode VII power flow diagrams of the proposed bidirectional DISO converter.

Control strategy of the proposed DISO converter

Dual-input single-output (DISO) converter that operates without a battery, allocating input power from the two sources to the output load is a fundamental consideration in the design process. Additionally, the nature of the load itself plays a pivotal role in determining the necessary control specifications. Specifically, the design incorporates a voltage control loop for voltage-type loads to maintain and regulate the output voltage. In contrast, a dedicated current control loop is established for current type loads to program and regulate the output current. Consequently, the primary control objectives for a DISO converter typically revolve around the regulation of either the output voltage or current and the attainment of a specific power distribution between the two input sources. The control strategies for DISO converters are formulated in alignment with these core objectives, and these strategies are elaborated upon in the subsequent subsections.

When addressing voltage loads, which necessitate a consistent regulated voltage supply, the initial requirement is the implementation of a voltage control loop. This loop upholds the output voltage stability, mainly when the input sources exhibit potential fluctuations. Following this, an additional control loop, whether current or voltage-based, is essential to establish the desired power distribution. This secondary loop's specific design depends on the characteristics of the input sources. For applications involving current loads, where a consistent regulated current is required, the primary control objective is establishing a current control loop to regulate the output current. Subsequently, a secondary control loop, either current-based or voltage-based, is introduced to govern the power flow distribution. The choice between these secondary control loop types is contingent on the characteristics of the input sources, as explained earlier.

It is essential to underscore that this control strategy, comprising two distinct control loops, is a generic approach. This arises from the fundamental concept that a single power converter, in theory, can exclusively perform one specific control function by adjusting its power flow, typically with the duty cycle as the control variable. Consequently, the outcomes derived from employing this control method are generally applicable. For specialized applications demanding more intricate control strategies, such as double-loop or multiple-loop control, these can be devised to achieve more complex control objectives, as outlined in existing literature [8, 23].

In cases where one of the input sources is a voltage source, employing a current loop to regulate the input power from that source is imperative. Similarly, a voltage loop is deployed to control the input power if one of the input sources is a current source. This design choice is rooted in the fundamental principle that the input power of a voltage source can only be manipulated by regulating the input current. In contrast, for a current source, the input voltage must be controlled. Once the input power from one of the sources is determined, the allocation of input power from the other source becomes automatic, as the total output power has already been defined by the initial control loop, which manages the output voltage or current. The voltage stress and efficiency across the power switch comparisons of different DISO converters are shown in Table 2.

Simulation results and discussion

Simulation results and discussions In this section the simulation results regarding the proposed bidirectional DISO converter can be clearly deliberated with the help of numerical simulation with Power SIM (PSIM) software. The advantage of PSIM is that it can easily simulate the integrated and power electronic circuits in accurate manner with less response time comparing with any other software like MATLAB, PSPICE etc. The simulation results for

the proposed bidirectional DISO converter are available here with graphical representations. Here the supply voltage given by the both solar PV and battery maintained as 24V and also maintaining the duty ratio for power switches P_1 and P_3 as D ($D = 0.3$), for power switch P_2 as $1-D$. The passive elements like inductors (L_1, L_2, L_3 , and L_4) & capacitors (C_1, C_2, C_0) values are considered as a 1Mh and 154Uf from [11]. The exact output current and voltage of 1A & 12V is getting form the proposed bidirectional DISO converter with hybrid PV-battery input for DC loads in DCMG [29-31].

Table 2: Switching operations with voltage and current equation of the proposed bidirectional DISO converter

DISO CONVERTER TYPE	VOLTAGE STRESS ACROSS	EFFICIENCY
	POWER SWITCH	(OUTPUT POWER / INPUT POWER for 5000W loads)
	$V_{pv} = 24V, V_{bat} = 24V, V_{grid} = 24$	
Converter in [24]	$2(V_{pv} + V_{bat}) = V_s$	90%
Converter in [25]	$V_{pv} + V_{bat} = V_s$	93%
Converter in [26] (PV-BAT)	$V_{pv} = V_{bat} = V_s$	95%
Converter in [26] (GRID-BAT)	$V_{grid} = V_{bat} = V_s$	95%
Converter in [26] (PV-GRID)	$V_{grid} = V_{pv} = V_s$	93%
Converter in [26] (BAT-GRID)	$V_{bat} = V_{grid} = V_s$	95%
Proposed Converter	$V_{pv} = V_{bat} = 2V_s$	98%

The simulation results are viewed in the Figures below with a time range below 0.01 seconds. Moreover, here every simulation result can clearly express every parameter configuration in detailed view with supporting the maximum

utilization of input resources in maximum way due to the converters of MSC and synchronous buck converter. Figure 7 depicts the solar PV voltage (V_{pv}) and battery voltage (V_{bat}) as the value of 24V.

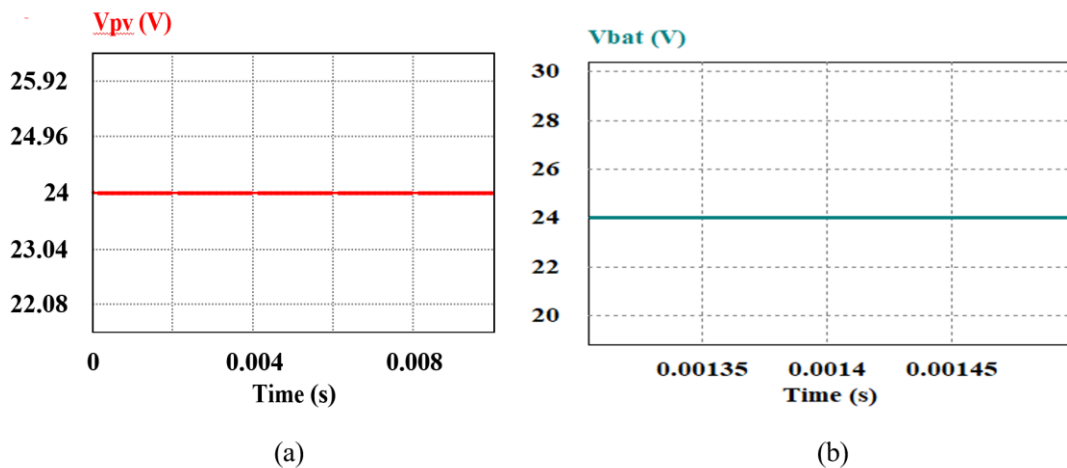


Figure 7: Mode I to Mode VII power flow diagrams of the proposed Bidirectional DISO Converter.

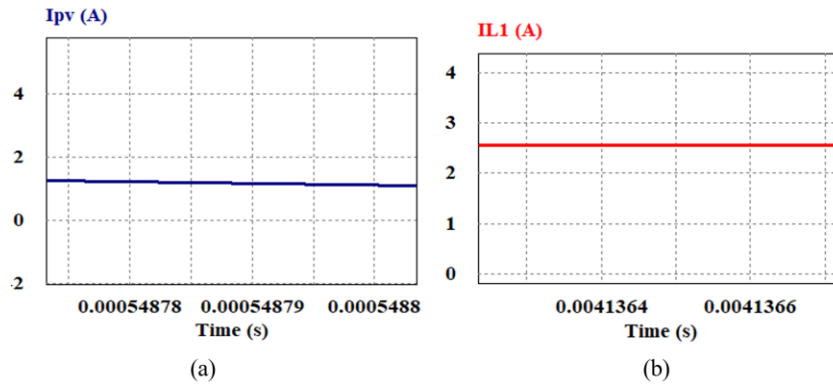


Figure 8: (a) Input current waveforms of (a) Solar PV, and (b) Battery.

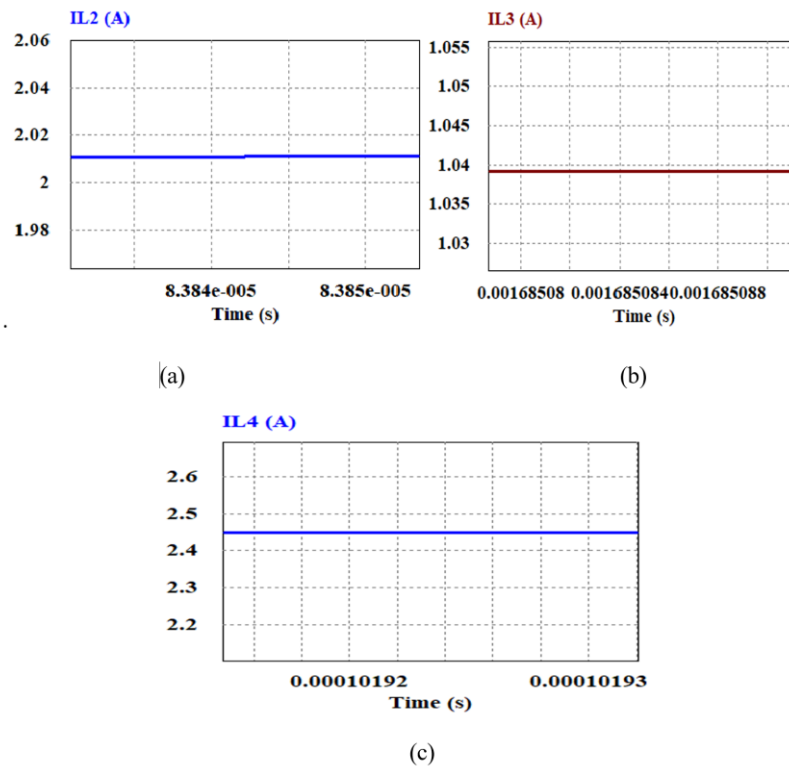


Figure 9. Inductor current waveforms of Proposed Bidirectional DISO converters (a) inductor current (IL_2), (b) inductor current (IL_3), and (c) inductor current (IL_4).

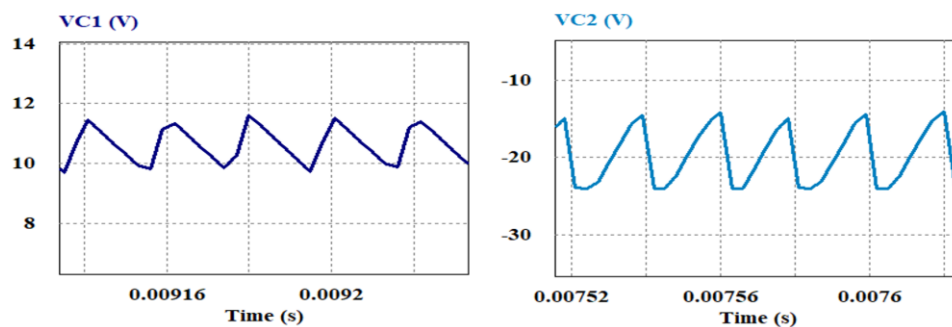


Figure 10: Capacitor voltage waveforms of Proposed Bidirectional DISO converters (a) capacitor voltage (VC_1), and (b) capacitor voltage (VC_2).

are considered as continuously feeding the DISO converter in continuous mode without interrupting the DC loads in DCMG. Figure 8 can depict the solar PV current I_{pv} and battery current I_{L1} as the values of 1A and 2.5A

In this process input currents of these sources are considered as continuously feeding the DISO converter in continuous mode without interrupting the DC loads in DCMG.

The figure 9 can illustrates the Inductor currents I_{L2} , I_{L3} , I_{L4} as the values of 1.5A, 1A & 1.5A . These inductors are fully controlled by the input currents produced by the hybrid PV and Battery.

The figure 10 can represents the Capacitor voltages V_{C1} , V_{C2} as the values of 12V & -14V. In this process capacitors are in continuous Mode Ind large enough to chare and discharge in

accurate manner. These capacitors are fully controlled by the input voltages produced by the hybrid PV and Battery.

The figure 11 can illustrate the peak inverse voltage of the diodes D_1 , D_2 & D_3 with the values of -4V, -6V & 0.02V. These diodes are switch ON and OFF continuously without producing the voltage stress. Figure 11 gives the waveforms of diode peak inverse voltages and these waveforms describe that there is a negligible voltage stress across the each and every diode.

Because all these diodes are in MSC, so that's the reason these diodes are not producing the voltage stress.

Figure 12 illustrates the gating pulse taken by the three power switches P_1 , P_2 & P_3 in the manner of duty ratio D for power switches P_1 , P_2 and duty ratio 1-D for power switch P_3 .

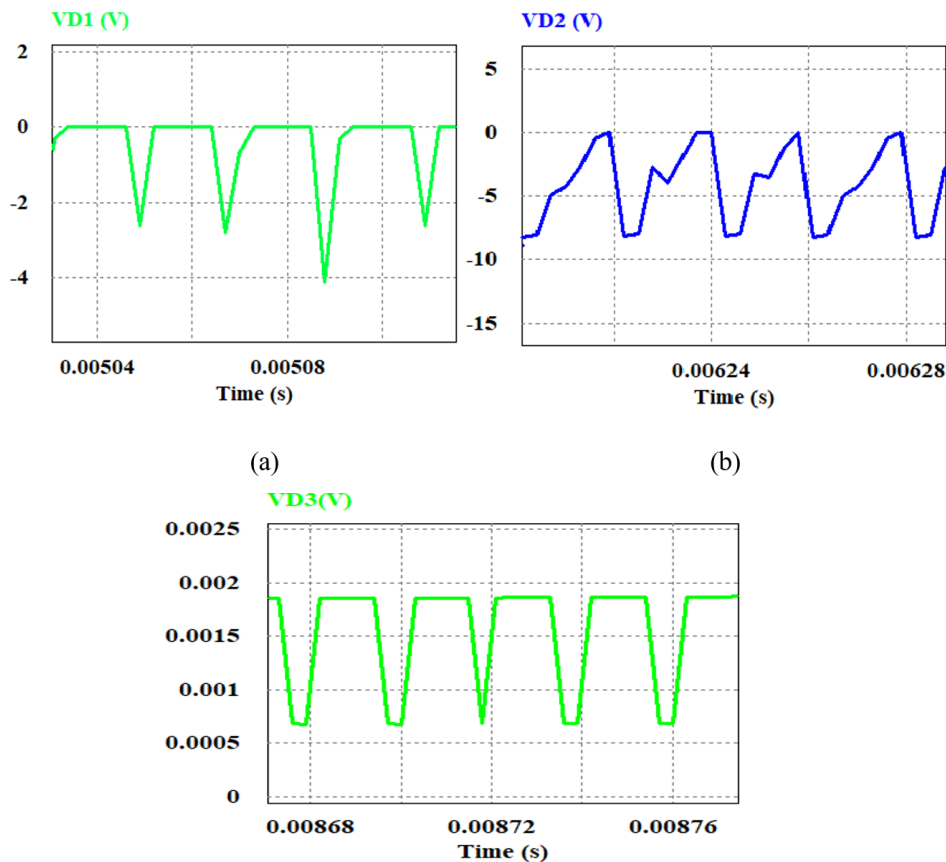


Figure 11: Diode peak inverse voltage waveforms of Proposed Bidirectional DISO converters (a) VD_1 (V), (b) VD_2 (V), and (c) VD_3 (V).

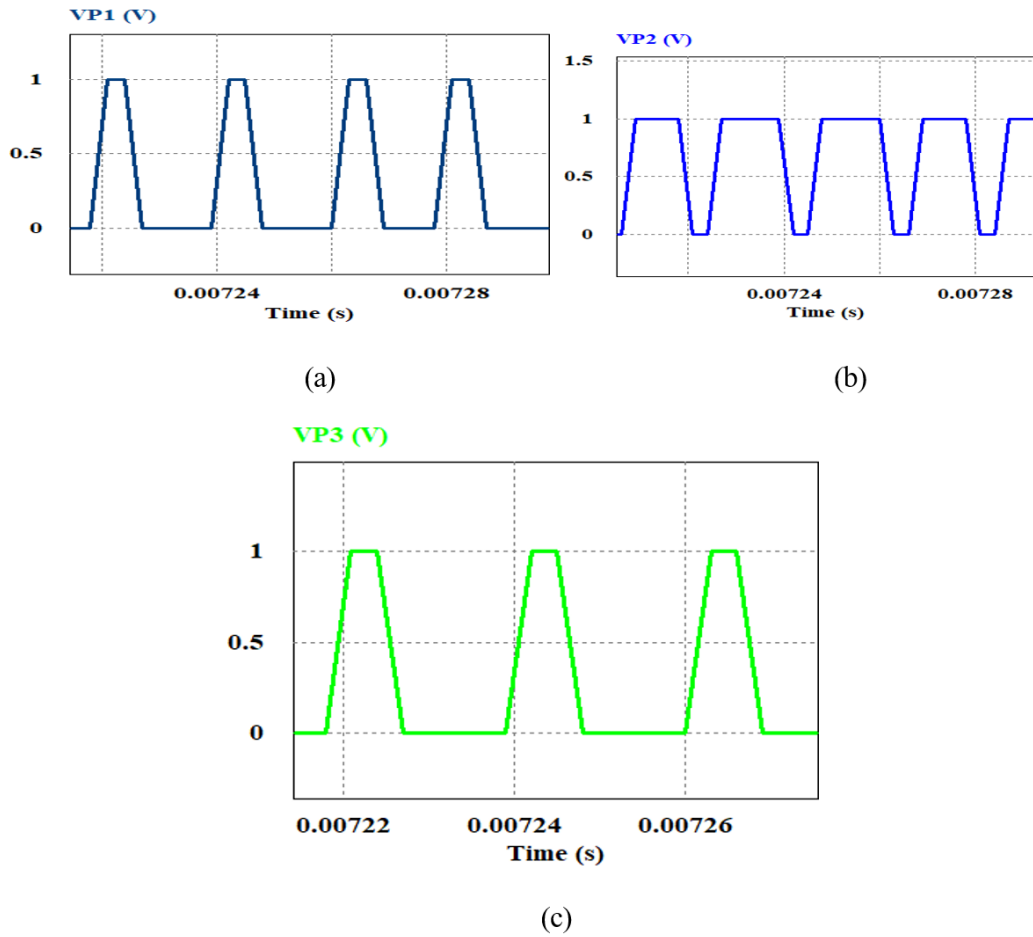


Figure 12: Gating pulses of power switches (a) VP_1 , (b) VP_2 and (c) VP_3

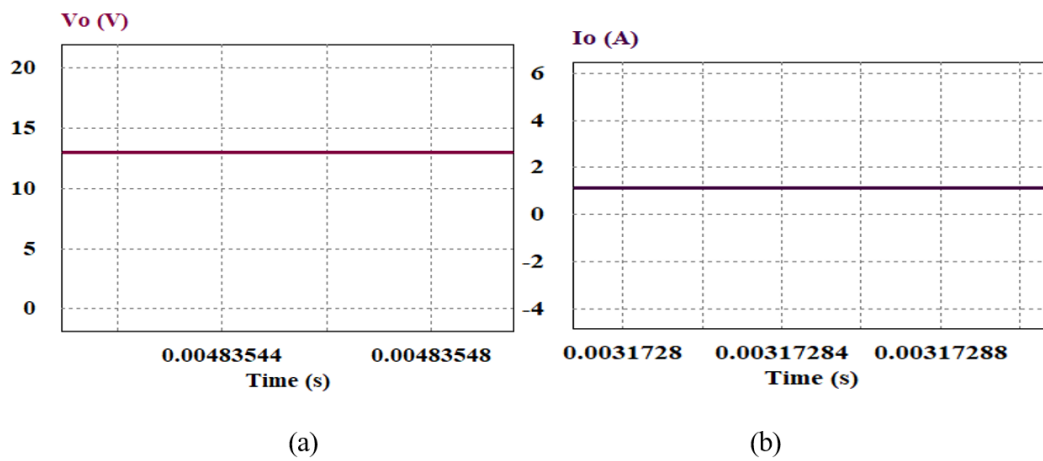


Figure 13: Output voltage & current waveforms for DCMG (a) output voltage (b) output current.

of power switches. These pulsating signals are accurately driving the power switches at 0.3 duty ratio. The gating pulses are precisely generated by the pulse generator. When these power switches produce gating pulses with a low duty ratio, it results in a negligible current and voltage stress. In this context, the bidirectional DISO converter employs the MSC approach. The entire article aims to consistently achieve optimal results for supplying DC loads in DCMG. The methodology used in this bidirectional DISO converter closely resembles the synchronous buck-MSM converter approach, with a low duty ratio, effectively improving the overall efficiency of the bidirectional DISO converter by reducing conduction and switching losses.

The figure 13 describes the output voltage V_o and output current I_o and as the values of 12V and 1A. Here the output current produced by hybrid PV and battery resources is in continuous mode with Bidirectional DISO converter for feeding the DC loads in DCMG. Table 3 represent the evaluation of simulation results of Synchronous buck-MSM Bidirectional DISO converter.

Table3: Evaluation of simulation results of Synchronous buck-MSM Bidirectional DISO converter.

Parameters	Numerical values
Vbat	24V
Vpv	24V
Ipv	1.5A
IL1	2.5A
Vo	12V
Io	1A
IL2	1.5A
IL3	1A
IL4	1.5A
VC1	12V
VC2	-14V

VD1	-4V
VD2	-6V
VD3	0.02V

Table 3 also gives information regarding whatever parameters might be visualized in numerical simulation with their corresponding values. One thing that should be highlighted for this converter is that it can obtain 12V as output while taking input as 24V from PV or Battery or a hybrid source at a duty ratio of 0.3. This is beneficial for the DCMG in accurately operating the DC loads below the 12V. In most cases, this type of converter can easily handle LED Drivers, Computers, Mobiles, and more electronic gadgets, which can operate by the below 12V in a superior way.

This bidirectional DISO converter type applies to DC micro grids, electrical vehicles, DC energy harvesting systems, renewable energy applications, and Fuel cell technologies. So, this type of efficient bidirectional DISO converter can satisfy any DC load with a rating below 12V and can easily be handled and controlled by this converter with low-duty ratio operation efficiently.

Nowadays, so many advanced technologies in power electronics are gradually increasing to satisfy the power loads in a decentralized way with the integrations of DC microgrids, primarily to satisfy the DC load requirements. In DC micro grids, efficient power electronic bidirectional DISO converters are needed to meet the DC loads from two input resources. So, based on the requirement of DC micro grids, it is satisfied with this bidirectional DISO converter.

Conclusions

This paper presented a bidirectional DISO (double input single output) converter using a synchronous buck-MSM (modified SEPIC converter) approach, accompanied by power flow diagrams. The study offers a topological analysis, utilizing power flow illustrations, to explore the fundamental principles of DISO

converters and their potential configurations when employing the proposed synchronous buck-MSM approach.

Utilizing power flow diagrams for the proposed DISO converter reduced the number of power electronic converters and created a practical design. Moreover, this proposed DISO converter can function with a low duty ratio of 0.3,

effectively reducing the current and voltage stress on the diodes and power switches. The correlation between the low duty ratio and voltage stress remains relatively consistent across various DC-DC converters. Additionally, this approach efficiently maximizes the utilization of input resources, effectively meeting the power demands of DC loads in DCMG.

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