International Journal of Advances in Electrical Engineering

E-ISSN: 2708-4582
P-ISSN: 2708-4574
IJAEE 2021; 2(1): 01-12

www.electricaltechjournal.com
Received: 03-11-2020
Accepted: 05-12-2020

B Thirumala Rao
PG Scholar, EEE Department, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India

Dr. B Jyothi
EEE Department, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India

P Bhavana
EEE Department, SRKIT, Vijayawada, Andhra Pradesh, India

M Sai Krishna Reddy
EEE Department, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India

Corresponding Author:
B Thirumala Rao
PG Scholar, EEE Department, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India

Implementation of modified SEPIC converter for renewable energy based DC micro grids

B Thirumala Rao, Dr. B Jyothi, P Bhavana and M Sai Krishna Reddy

Abstract
The implementation of PV-driven DC micro grids technology is inexpensive, harmless, simple, flexible, and also energy effective to the end-users. Here the proposed Modified SEPIC converter (MSC) is designed based on the traditional SEPIC with a boost-up module. While related to the conventional or traditional SEPIC converter, the proposed MSC produces higher voltage gain and continuous current to the DC micro grids. Moreover, this MSC is operated with a single controlled switch. Here MSC with PV system-based DC micro grids are implemented to effectively satisfy DC loads requirements and moreover entire this work is carried out in PSIM software.

Keywords: MSC, PV systems, P & O MPPT technique, DC micro grids, half-bridge bidirectional DC-DC converters, DC loads

1. Introduction

In previous days power generation is done by the conventional energy sources and fossil fuels to generate electricity to the end users. But day by day fossil fuels and coal reserves are falling due to the over usage by human beings to fulfil their needs in the area of transport division, electrical energy generation and etc. Here the problem related with these conventional energy sources such as fossil fuels, coal energy, nuclear energy and etc. can generate a harmful gases (SO_2, and NO_2) and carbon emissions (CO and CO_2) in atmosphere, when these energy sources are utilized for electrical energy generation. This SO_2, CO_2 andNO_2 gases are emitted in atmosphere with large quantities can lead to developing a global warming and greenhouse effect in nature [1]. In 2013, Sinopec pipeline blasted in Shandong Area in China, taking away valuable lives of 55 people. The firms of coal, natural gas, and oil are responsible for these severe threats. So, to avoid these serious problems government officials are looking towards for the alternative energy sources [2, 3].
Now-a-days all research persons are looking towards the alternative energy sources to generate electricity without producing any carbon emissions, global warming and etc. Based on the researcher's point of view renewable energy sources are referred as an alternative energy sources to produce electricity to meet the loads without producing any harmful gases. In renewable or non-conventional energy sources like wind and solar energies are the major renewable energy sources for the distributed energy systems due to their availability in nature. While other non-conventional energy sources are biomass, tidal, geothermal energy sources exist in nature in particular regional sectors. But solar and wind energies are abundant in nature and available all regional sectors. Especially, solar and wind energy sources are gives maximum efficiency and reliability when compared with other non-conventional energy sources. More over all research workers are focuses on these two renewable energy sectors integrated to the AC and DC grids.
Normally, in the perception of the micro grid, DC micro grids are implemented easily due to the availability of distributed energy sources like non-conventional energy sources (PV cells, Fuel cells), energy storing devices like batteries, super capacitors and etc. can store electrical energy in the form of DC. So that's the reason nowadays all research people are turning towards the implementation of DC micro grids with PV cells, Batteries and etc. for satisfying the DC load demand.
Another important feature regarding the DC micro grid is one can easily implement a DC micro grid with one or two DC-DC converters but AC micro grids require a larger number of both DC-DC, DC-AC converters. As a result, DC micro grids are required less expensive materials and also these grids provide an improved efficiency compared with the AC micro

grids. Similarly, DC is more efficient due to its simple topology; the absence of frequency, harmonic distortion and reactive power and also DC micro grids don't bother about the grid synchronization with the network. But, in AC micro grids grid synchronization with a network plays a major role. Thus, one can easily design a control structure for DC micro grids over AC micro grids [4, 5, 6].

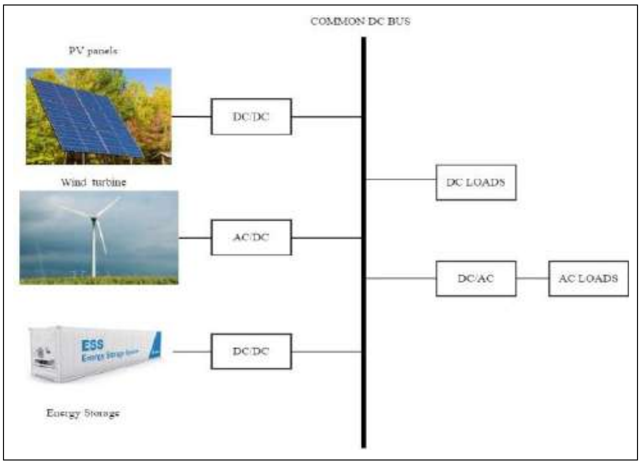

Fig 1: Overview of DC micro grid

Thus, the paper focus on the application of DC micro grids with DC-DC converters for effective driven of the DC loads. So, solar energy is preferred as input resource for DC micro grids. Especially in solar energy, PV panels based solar systems are giving electricity directly from the sun light and these PV systems are requires less space, low cost and gives maximum efficiency to the DC micro grids when compared with the solar thermal collectors. So, most of the research work is carried out with the PV systems based DC micro grids for satisfying the DC load demand.

In general solar PV panels generate low output voltage to the DC micro grids. Then this low DC voltage coming from the PV panels can't properly drive a high voltage DC applications requirement in DC micro grids. Generally, PV cells are connected in parallel and series combination to generate more amount of current and voltage to the PV module. Then several such modules are connected for any application to get preferred volume of voltage and current to the end users. But this is an inefficient way to generate a higher DC voltage and DC current due to the necessity of 2, 3 …N number of series and parallel connected PV panels and also size of this whole system is increased. Due to this reason research towards the integration of DC-DC converters with PV panels based DC micro grids is implemented as up-to-date [2].

Solar PV panels are applicable in the field of a both AC and DC load applications. In DC micro grids, solar PV panels are linked to the DC loads with the help of isolated or non-isolated DC-DC converters to attain high voltage gain and continuous output current to the DC micro grids. Generally DC micro grids are connected to the isolated or non-isolated DC-DC converters with high voltage gain to produces a high voltage on the output side. With the help of a HF transformer by changing its turn ratio one can easily get a boost up voltage at output side in isolated DC-DC converters [7, 8]. But, these isolated DC-DC converters suffering from the problems like that voltage ripples in input current at primary side of high frequency transformer and secondary side of the high-frequency transformer of these converters can produce high voltage stress and leakage currents. Furthermore, very large size high-frequency transformers are placed in these isolated converters to properly produce an output voltage in the boost module etc. [9].

In earlier day's traditional buck-boost, SEPIC, CUK type non-isolated DC-DC converters with maximum duty ratio technique can be used for high voltage applications. But these conventional DC-DC converters are operated at maximum duty ratio [approximately ranges in 0.85 to 0.95] can reduces the efficiency and disturbs the functionality of the converter. In recent times, several DC-DC converters with high voltage gain can be used with the application of passive elements to boost up steps [10, 11].

As a final point, with a compact size, high efficiency, continuous current and etc. are the requirements of economic considerations for DC-DC converters, that is the reason all researchers are utilizing the non-isolated DC-DC converters as unimpeachable key for PV systems, DC micro grids etc. Several voltage-boosting methods as like coupled inductor cascading of converters are attaining high output voltage of non-isolated DC-DC converter are addressed in [12-15].

The non-isolated DC-DC converters with coupled inductors can control the output voltage based on the inductor coil's turn's ratio alteration. This coupled inductor's leakage inductance is inflexible which produces ripples in power switch current, reduces the current spike in coupled inductor and these converters requires a clamping circuit.

In cascaded non-isolated DC-DC converters, the Quadratic Boost Converters (QBC) is an example of series-connected non-isolated DC-DC converters and these produce output voltage with boosting module in a quadratic manner but this QBC produce more voltage stress on the power switch and on the diode also. The high voltage multiplier 2nd order boost non-isolated DC-DC converter is deliberated in [16]. In this converter's output voltage is influenced by the number of voltage multipliers and on-duty ratio. On the other hand, this converter generates an output voltage in less magnitude. However, this converter is equipped with number of voltage multipliers.

An active network-based switched-capacitor non-isolated DC-DC converter with high gain is presented in [17]. This converter attains high gain with poor regulation. Moreover this converter produces an input current in discontinues way which verifies the least use of the input sources. The [17-20] non-isolated DC-DC converters operate with low voltage stress across diodes and switches. Then low voltage stress across switching mechanisms can be accepted to decrease the conduction loss and cost of the whole system. These converters have a wide regulation series, small component stresses, less significant output ripple, adaptable gain extension, and high-level efficiency. But, these Converters attain high gain with poor regulation and pulsating current. This converter controlled with two switches and those make the difficulty in the controller scheme and disturb the efficiency at the load end.

At this time the proposed MSC [21] can overcome the problems in the non-isolated and isolated DC-DC converters addressed in [7-20]. MSC can't produce any voltage or current ripples even if this converter taking DC voltage with some distortions, because MSC having a resonant elements such as inductor, capacitor across the switch to eliminate switch stress and unwanted disturbances [22]. But MSC overcome all demerits of above non-isolated DC-DC converters. MSC have an extreme utilization of resources when it is connected to input sources. Thus, MSC used as a DC-DC converter in the Photo Voltaic system based DC micro grids to generate a maximum efficiency, high voltage gain, continuous output current to the utility grids.

PV array with MPP is typically an important part of the PV system. Research fellows develop and implement many MPPT techniques used for PV arrays to generate maximum power and transmitting that power to the load to satisfy the load demand [23]. The techniques vary in sensors required, complexity, range of effectiveness, convergence speed and etc.

So many techniques are still exists for the PV system to generate MPP. The DC-DC converter can effectively utilize in transmitting MPP from the PV array to the load. Through regulating the duty cycle of the pulse width modulation control, the DC-DC converter's load voltage differs and obtains the MPP with the input source (PV array) to transmit the maximum power. Utilizing PV panels without any controller that can achieve MPPT will frequently result in unused power. Then to increase the efficiency of the PV system with an effective MPPT controller is necessary to maintain the operating point of the PV array at the maximum power point in all ecological situations.

So to maintain an MPPT of the PV array mandatorily requires a better MPPT controller with less convergence time and less complexity in its controller algorithm. For this solution, researchers develop many MPPT techniques such as Perturb and Observe (P & O) technique, Hill Climbing (HC) technique, Incremental Conductance (IC) technique and etc. But most of the research workers use the P&O MPPT technique is quite easy, a simple algorithm, and less complexity associated with the remaining other MPPT techniques [24].

If in case the PV system can meet the load demand in partially shaded conditions and in rainy days back up should be provided to them DC micro grids through battery with a BDC [Bidirectional DC-DC Converter]. Especially this paper is focus on the half-bridge BDC is the best BDC in its performance (voltage gain, switch stress and etc.) [25]. When compared it with among the [9, 26] BDCs. Here the proposed BDC is a non-isolated DC-DC converter and this proposed BDC requires only two switches with three passive elements (two capacitors, one inductor), moreover this BDCs cost is low when compared with [9, 26] non-isolated DC-DC converters.

When the system with a battery and PV array used as input sources to the DC micro grids can effectively satisfy the DC loads demand. If the PV system fully satisfies the DC micro grid system that time the proposed BDC must work in buck mode to store the DC voltage in a battery. If the PV system can't satisfy the DC loads in DC micro grid necessities, in that time, the proposed BDC can operate in boost mode and makes the battery to supply a DC voltage to the DC loads with their requirements in DC micro grids.

Finally, the remaining paper is organized as follows: section-II, III explains the performance analysis of Conventional SEPIC converter, and MSC. The importance of the half-bridge BDC for the PV system based DC micro grids is addressed in the section IV. Discussion on simulation outcomes of the MSC, the half-bridge BDC, and the PV system based DC micro grid with MSC are viewed in the division of V. At most section-VI concludes this paper.

2. Conventional SEPIC converter

Conventional or traditional SEPIC converter is also termed as a single ended primary inductor converter. In general conventional SEPIC converters normally used in the high-voltage renewable energy applications. But problem associated with this converter is listed as follows:

1. This converter produces less voltage gain.
2. This converter generate ripples at output side (load side) when this converter takes input voltage with some noise signals.
3. This converter does not properly utilize input resources in required manner.

The difficulties related with this conventional SEPIC converter are overcome with the MSC discussed in latter section. Moreover, conventional SEPIC converter needs extreme duty ratio point to operate a converter in a boost mode. So, finally this conventional SEPIC converter is affects the efficiency and functionality of the system when this conventional SEPIC converter is operated at maximum duty ratio. But MSC does not need any maximum duty ratio point and then this converter operate in boost mode in the duty ratio of 0.55 to 1 in efficient manner with producing any unwanted disconcerting signals. The following circuit diagram of the conventional SEPIC converter normally operate like a buck-boost DC-DC converter but this conventional SEPIC converter continuously generate output current in continuous way.

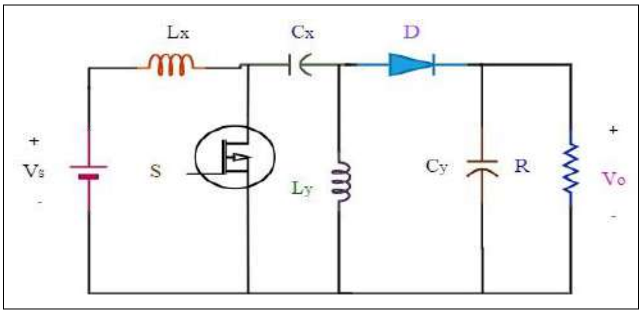

Fig 2: Circuit diagram of a conventional SEPIC converter

3. Modified SEPIC converter

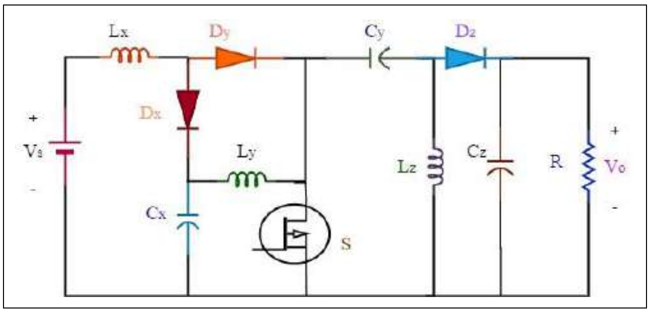

Fig 3: Circuit diagram of a modified SEPIC converter

In this paper non-isolated Modified SEPIC Converter (MSC) is existing for high voltage applications (ex: - renewable energy applications). This MSC containing the single input-output terminals and derivative by changing the conventional SEPIC converter as exposed in Fig. 2. & Fig. 3 demonstrations the circuit diagram of the MSC containing 3 diodes (D_x, D_y and D_z), 3 inductors (L_x, L_y and L_z), and 3 capacitors (C_x, C_y, and C_z), these elements are operated with a single switch S with switching frequency (f_s). The capacitor C_x and inductor L_y attend as the voltage-boosting component in adding with D_x, D_y diodes in MSC. The main advantages of the proposed MSC as follows

1. It works with a single power switch that decreases the difficulty of controller circuitry.
2. This converter produces input current in a continuous way.
3. This converter produces high voltage gain.
4. This converter has been utilizing the input sources in an efficient way.

The above advantages regarding the MSC prove that this converter is suitable for high voltage renewable applications (PV system based DC micro grids). To evaluate the steady-state operation of the MSC following assumptions are considered as all elements in the MSC considered as being ideal and all capacitors in MSC are large and sufficient to attain constant voltage. The Modified SEPIC Converter can operate in 2 modes as mode-1 (t_0 - t_1) and mode-2 (t_1 - t_2) as exposed in Fig.4 and 5 correspondingly to bring the continuous output current.

Mode-1 [t_0 - t_1]

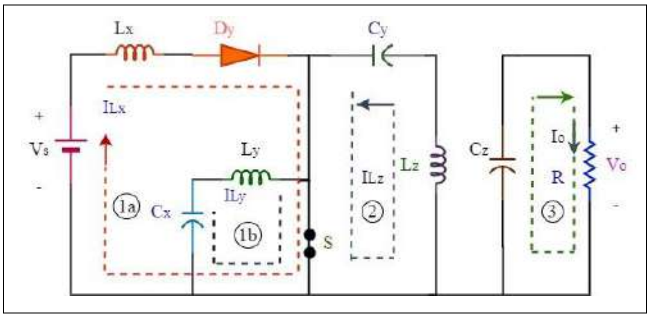

Fig 4: Equivalent circuit diagram of MSC in mode-1

In mode-1, 3 inductors are attaining the following current path when these inductors are magnetized: inductor L_x from input voltage (V_s – VL_x – D_y − S−V_s), inductor L_y from capacitor C_x (VC_x−VL_y −S−VC_x) and inductor L_3 from capacitor C_y (VC_y − S – VL_z − VC_y). On this instant diode D_3 is reverse biased by, capacitor C_3 and transference the energy to the DC load as exposed in Fig. 9.

$$V_{Lx} = V_s \tag{1}$$

$$V_{Ly} = V_{Cx} \tag{2}$$

$$V_{Lz} = V_{Cy} \tag{3}$$

In mode-I (1) VC_x, VC_y is the voltage across capacitor C_x, C_y correspondingly. VL_x, VL_y, VL_z are the voltages across inductor L_x, L_y, L_z correspondingly.

Mode-2[t_1 - t_2]

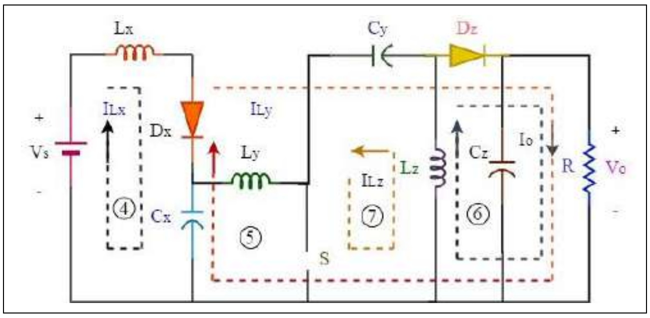

Fig 5: Equivalent circuit diagram of MSC in mode-2

In mode-2, 3 inductors are attained following current path when these inductors are magnetized: L_x with input voltage (V_s) charges the C_x as (V_s – VL_x– D_x – C_x − V_s). The arrangement of L_y and C_x charges to capacitor $C_y$as in path (VC_x – VL_y – VC_y – D_z − V_o – VC_x). Also on this instant, inductor L_z discharges over the DC load with the path (VL_z – D_z − V_o) as exposed in Fig. 2 (d).

$$V_{Lx} = V_s - V_{Cx} \tag{4}$$

$$V_{Ly} = V_s - V_{Lx} - V_{Cy} - V_o \tag{5}$$

$$V_{Ly} = V_{Cx} - V_{Cy} - V_o \tag{6}$$

$$V_{Lz} = V_o \tag{7}$$

Mode-2 here, VC_o is the voltage across capacitor C_z. According to the Inductor Volt Second Balance equation for the inductors L_1, L_2 and L_3,

$$\frac{V_{Cx}}{V_s} = \frac{1}{1-k} \tag{8}$$

$$V_{Cy} = \left(\frac{V_{Cx}}{1-k}\right) - V_o \tag{9}$$

$$\frac{V_o}{V_{Cx}} = \frac{k}{1-k} \tag{10}$$

$$M_{ccm} = \frac{V_o}{V_s} = \frac{k}{(1-k)^2} \tag{11}$$

Table 1: Evaluation of the MSC with conventional non-isolated high gain DC-DC converters

Topologies	No. of Capacitors	No. of Diodes	No. of Inductors	No of Switches	Vcs	M_{ccm}
Switched Capacitor Based Active Network Converter	3	3	2	2	$\frac{V_o}{(2+k)}$	$\frac{(2+k)}{(1-k)}$
New Hybrid Boosting Converter	3	3	1	1	$\frac{V_o}{2}$	$\frac{2}{(1-k)}$
Transformer Less High Gain Boost Converter	3	3	2	2	V_o (1-k)	$\frac{1}{k(1-k)}$
Quadratic Boost Converter	2	3	2	1	V_o	$\frac{1}{k(1-k)^2}$

Modified SEPIC Converter	3	3	3	1	V_o	$\frac{k}{k(1-k)^2}$

From Table 1, comparing performance parameters of MSC with all the other converters, it reduces the voltage stress on switch is almost negligible and moreover generates high voltage gain with a single controlled switch makes this converter is preferable high voltage non-conservative energy applications. Where, V_{cs} is a voltage across the switch, and M_{ccm} is a voltage gain.

From the above table, MSC has a wide range of voltage gain comparing with the other non-isolated DC-DC converters. So, this feature makes the MSC can applicable in DC micro grids.

Table 2: Voltage gain of non-isolated dc-dc converters

Topologies	Voltage gain (M_{ccm}) when K is varied			
	K = 0.6	K = 0.7	K = 0.8	K = 0.9
Switched Capacitor Based Active Network Converter	6.5	9	14	29
New Hybrid Boosting Converter	5	6.67	10	20
Transformer Less High Gain Boost Converter	4.1	4.7	6.25	11.11
Quadratic Boost Converter	6.25	11.11	25	100
Modified SEPIC Converter	3.75	7.78	20	90

From above analysis it leads to conclude that QBC and MSC are almost all similarly produces a maximum voltage gain.

4. Half-bridge BDC

A non-isolated BDC's are essentially understood by the addition of a diode and an anti-parallel diode to the switch of the uni-directional converter is connected with a controllable power switch. Basically, buck, boost, buck-boost, SEPIC, CUK DC-DC converters are makes some non-isolated BDC's when the diode in the above DC-DC converters is interchanged with a controllable power switch. Based on the voltage boosting methods, non-isolated BDC's whereas interleaved multilevel, switched capacitor, etc.

Table 3: Evaluation of the half-bridge BDC with conventional non-isolated BDC'S [6]

Topology in bidirectional DC-DC converters	Voltage conversion ratio in buck mode	Voltage conversion ratio in boost mode	Number of switches	Number of passive components
Half-bridge	D	$\frac{1}{1-D}$	2	3
Inverting bidirectional	$-\frac{D}{1-D}$	$-\frac{D}{1-D}$	2	3
CUK	$-\frac{D}{1-D}$	$-\frac{D}{1-D}$	2	5
SEPIC	$\frac{D}{1-D}$	$\frac{D}{1-D}$	2	5

From the above table [6] half-bridge configuration type non-isolated BDC's are the most capable, high-proficient, robust in configuration and also these BDC's gives the high voltage gain comparing with the other non-isolated BDC's.

The non-isolated half-bridge BDC exposed in Fig. 3a is essentially a combination of a step-down converter and a step-up converter coupled in anti-parallel [6]. Commonly, this BDC can work in both synchronous boost and buck modes for power flow in both forward and reverse directions. The working operation of this BDC can be described in 2 modes as follows. When power switch P is turned on with the help of a required duty ratio control the operation of this BDC viewed in a forward step-down mode. When Q is turned on then P is turns off with the help of a proper controlling duty ratio this BDC can undergo a backward step-up operation.

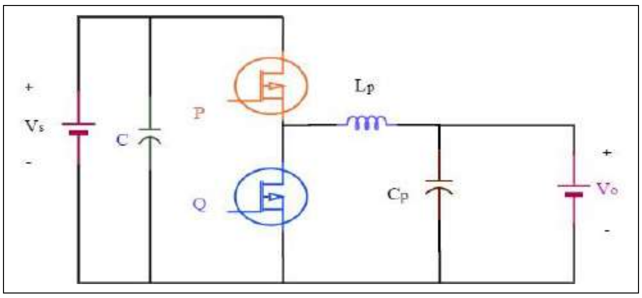

Fig 6: Circuit diagram of the half-bridge BDC

Fig. 6 shows the circuit diagram of the half bridge BDC. This BDC requires only two switches with three passive elements (one inductor and two capacitors). While comparing this BDC with conventional BDC's, this BDC has wide voltage gain especially in boost mode, cost of this BDC is less and also this BDC generate continuous output current without ripples. Generally this converter operates in two modes buck mode and boost mode.

5. Simulation results and Discussion

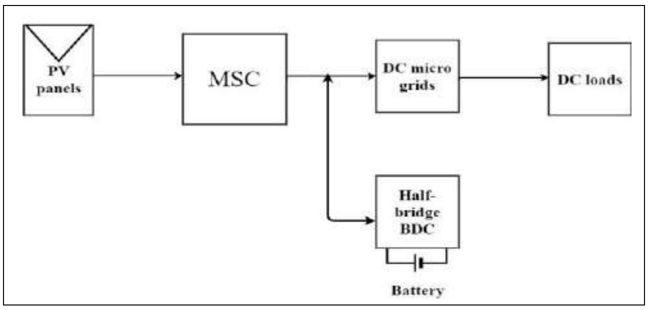

Fig 7: Block diagram of integration of MSC with PV system based DC micro grid

By based on the block diagram of this paper is consisting of two input sources namely as PV source and battery with half bridge BDC, here DC micro grid consists a DC loads. These blocks are connected to the MSC. MSC is probably produces an effective DC voltage and current to the DC loads in DC micro grids from PV source. If in case partially shaded conditions are happened PV panels doesn't supply voltage how much required by the DC micro grid. For back up protection and to balance the supply voltage and currents with load voltage and currents, BDC with battery is required. Here half-bridge BDC is used and supply voltage to the DC loads if in case PV doesn't satisfy the amount of voltage required by the DC loads.

A. Simulation results of the MSC

Generally MSC can produce wide voltage gain with continuous output current. Moreover this MSC always uses the resources in maximum level. Then MSC is widely produce voltage gain with better efficiency. Usually, this MSC is effectively operated with a fixed frequency and variable duty ratio technique is widely used PWM technique to effectively generate a gate voltage to the power switch. So, this MSC is effectively simulated in PSIM software and easily generate an output voltage at greater voltage gain with preferred output current required by the DC load. Here this MSC PSIM results are obtained without producing ripple content in its output voltage and current. So, this MSC is well suited for DC micro grids and PV system applications. But conventional non-isolated DC-DC converters produce ripples in the percentage of 0.1-0.5%. But MSC produces ripple content in the percentage of around 0.016. This ripple voltage is a negligible value. That's the reason this converter effectively produce output voltage without producing any ripple content in output voltage and current.

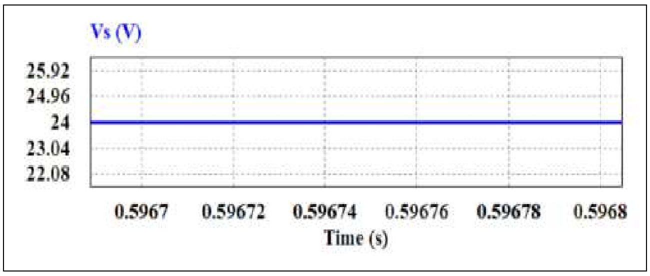

Fig 8: Waveform of a DC supply voltage V_s of MSC

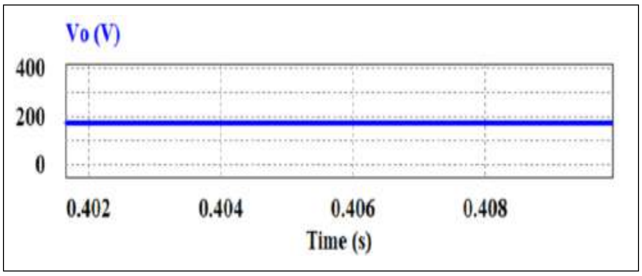

Fig 9: Waveform of a DC output voltage V_O of MSC

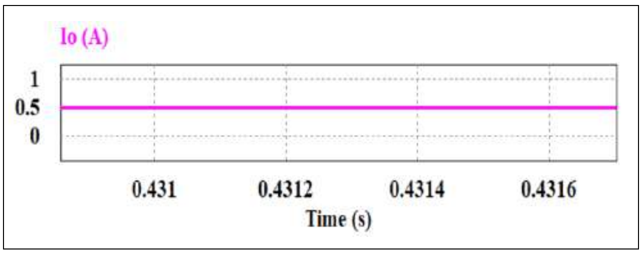

Fig 10: Waveform of a DC output current I_O of MSC

The above figures describe the supply voltage, output voltage and output current simulation result waveforms of the MSC with values of 24V, 186.3V, 0.5A. These three waveforms are periodically DC in nature. Here MSC can't generate any ripple content in the output voltage and current. So that's the reason MSC always generate continuous current to the DC loads.

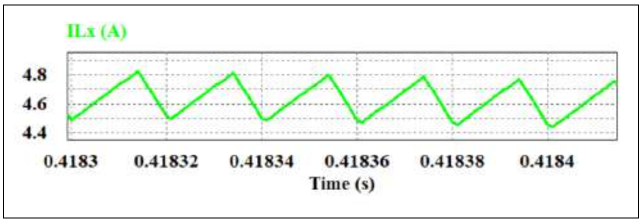

Fig 11: Waveform of a current I_{Lx} flowing in the inductor L_x of MSC

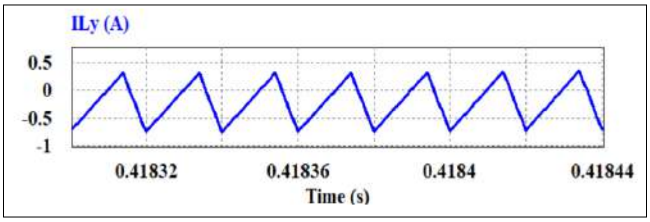

Fig 12: Waveform of a current I_{Ly} flowing in the inductor L_y of MSC

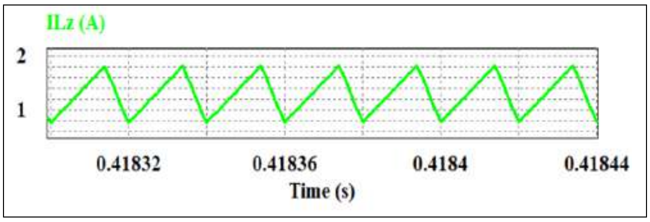

Fig 13: Waveform of a current I_{Lz} flowing in the inductor L_z of MSC

Above figures describes simulation result waveforms of the inductor L_x, L_y and L_z current regarding the MSC with values of 4.2 A, 1.4 A and 0.5 A (average) current. In mode-I, currents flowing in three inductors are increasing with positive slope and vice versa in mode-II operation.

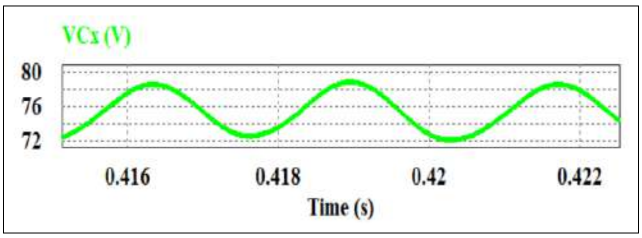

Fig 14: Waveform of a voltage Vcx across the capacitor cx of MSC

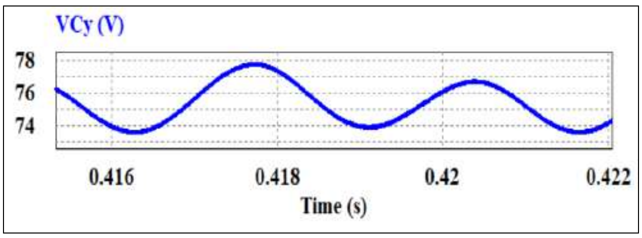

Fig 15: Waveform of a voltage V_{Cy} across the capacitor C_y of MSC

Above figures illustrate the simulation results of capacitor voltages V_{C1} and V_{C2} with values of 78.71V, 76.75V. It is examined that, approximately + 80 V is obtained across the capacitors C_1 and C_2. It is analysed that the characteristic waveforms and this simulation results of capacitor voltages V_{C1} and V_{C2} are matched and steady state in nature.

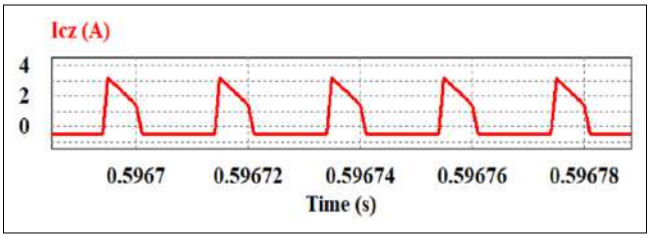

Fig 16: Waveform of a current I_{Cz} flowing in the inductor C_z of MSC

The above figure shows the simulation result waveform of the current flowing in the capacitor C_z with the value of 0.5A [average value]. The average current of this capacitor is exactly equal to the output current flowing in the resistor

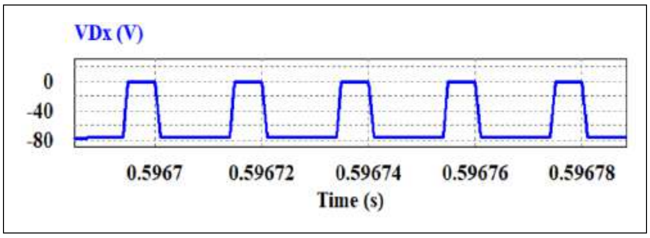

Fig 17: Waveform of a voltage V_{Dx} across the diode D_x of MSC

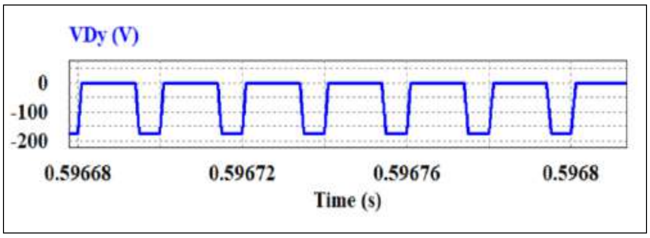

Fig 18: Waveform of a voltage V_{Dy} across the diode D_y of MSC

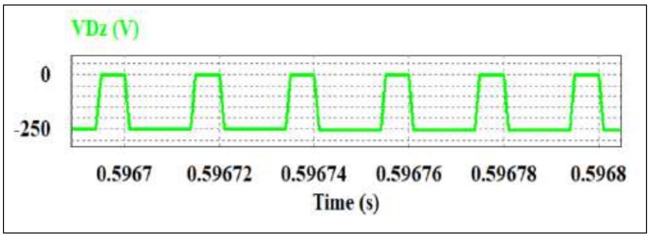

Fig 19: Waveform of a voltage V_{Dz} across the diode D_z of MSC

Above figures demonstrate the diodes D_x, D_y and D_z blocking voltages in reverse bias condition. During mode-I, diodes D_x and D_z are in forward bias condition and these diodes generates Peak Inverse Voltages similar to the capacitors C_x and C_z with values of 76V and 184V. During mode-II, diode D_y is in reverse bias condition and generates Peak Inverse Voltage equal to output voltage (V_o) and equals to 186.3V.

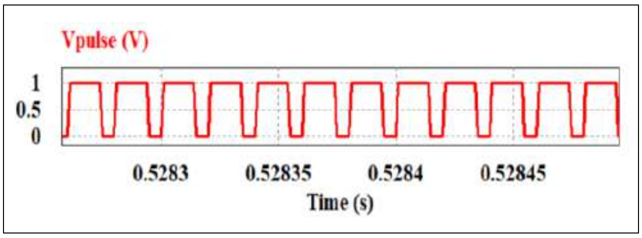

Fig 20: Waveform of a switching pulse voltage V_{pulse} of MSC

The above figure shows the simulation result waveform of a switching pulse voltage V_{pulse} of the MSC. Generally every DC-DC converter is taking pulse voltage from the pulse generator by based on its duty ratio control. Here MSC's power switch also taking pulse voltage from pulse generator with 70% duty ratio.

Table 4: Evaluation of the simulation results of the MSC

Parameters	Values
Supply voltage V_s	24V
Output voltage V_o	186.3V
Output current I_o	0.5A
Inductor currents I_{Lx}, I_{Ly}, I_{Lz}	4.2A, 1.4A, 0.5A
Capacitor voltages V_{Cx}, V_{Cy}	78.71V, 76.75V
I_{Cz} Current flowing in the capacitor C_z	0.5A
Diode currents I_{Dx}, I_{Dy}, I_{Dz}	76V, 172V, 184V
Voltage gain M_{ccm}	7.7
Supply frequency f_s	50kHz

B. Simulation results of the half-bridge BDC

Here V_s is a supply voltage, V_o and V_{o1} are the output voltages of a half-bridge BDC operated in buck or boost modes with values of as V_s is 24V, V_o and V_{o1} are 20V and 48V. By, based on the output voltages produced and shown by the below simulation circuits proves the feasibility of this BDC is effectively well integrated to the DC micro grids and feed DC voltage to the DC loads in reliable manner.

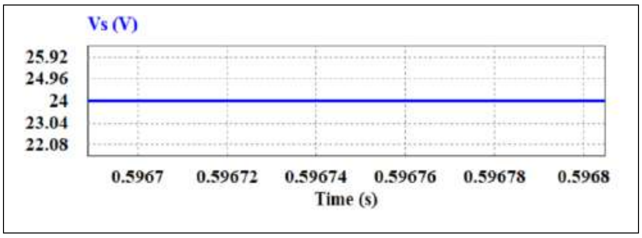

Fig 21: Waveform of a DC supply voltage V_s of half-bridge BDC

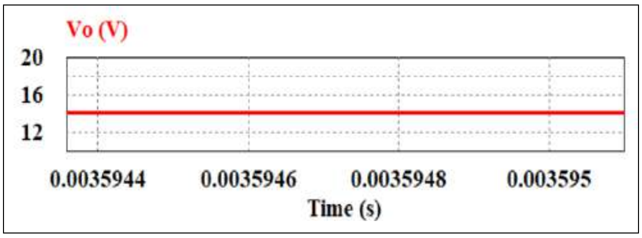

Fig 22: Output voltage V_o waveform of a half-bridge BDC in buck mode

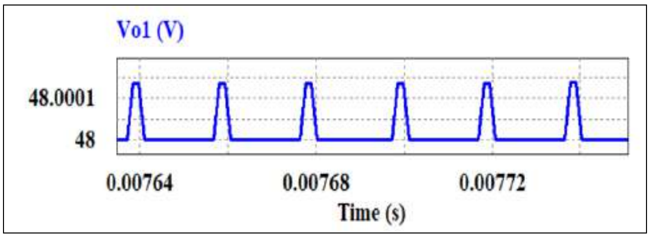

Fig 23: Output voltage V_{o1} waveform of a half-bridge BDC in boost mode

Here half-bridge BDC operated in two modes. The first mode is a buck mode; in this mode this BDC generates the output voltage V_o with the value of 20 V [average value]. The second mode is a boost mode; in this mode this BDC generates an output voltage V_{o1} with the value of 48V. The output voltages of this BDC are determined by the duty ratio of 50%.

C. Simulation results of the PV system based DC micro grid operated with half-bridge BDC in buck mode

In this operation of the PV system based dc micro grid operated with half-bridge BDC in buck mode, one can easily achieve the load demand with the help of the PV system with MSC. Here V_s is a supply voltage of 24V. And $I_s$is supply or input current with 18.6 A. And this supply current is effectively satisfying the three DC loads currents I_{dc1} is 8.1 A, I_{dc2} is 8.1 A, and I_{buck} is 2.4A. So, here $I_s = I_{dc1} + I_{dc2} + I_{buck}$. And V_{dc_bus} DC bus voltage across the DC micro grid with 183.5V when MSC is simply triggered with duty ratio 0.7. Here V_{dc1}, V_{dc2}, and V_{buck} are the DC voltages across the three DC loads with values of 12V, 24V, and 24V. But here the half-bridge BDC simply operated in a buck mode can acts as third DC load. Moreover this DC load will always supplied by the input resource called by the PV system.

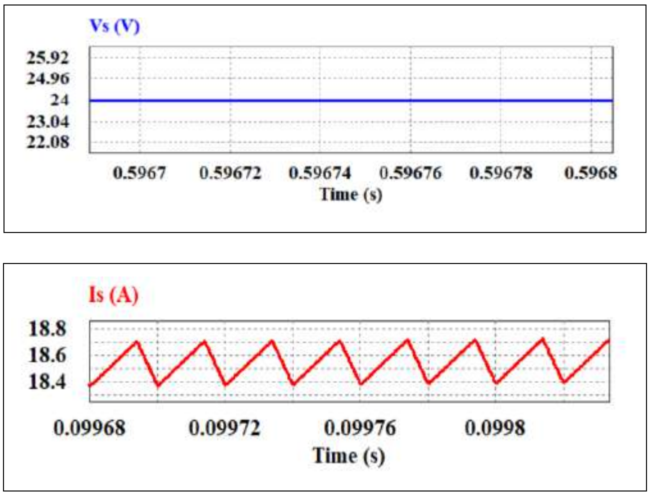

Fig 24: Waveform of a DC supply voltage V_s and current

I_s of the PV system based dc micro grid operated with half-bridge BDC in buck mode.

Here calculate supply current ripple $I_{s\ ripple}$ of a of the PV system based dc micro grid operated with half-bridge BDC in buck mode

$$I_{s\ ripple} = \frac{(I_{s\ max} - I_{s\ min})}{I_{s\ avg}} \quad (12)$$

$$I_{s\ ripple} = 0.0056 \quad (13)$$

Here the negligible ripple in supply current I_s of the PV system based dc micro grid operated with half-bridge BDC in buck mode. And then in this stage the whole system is effectively satisfied the all three DC loads. So, this effective supply voltage and current can reach the three DC loads in effective manner.

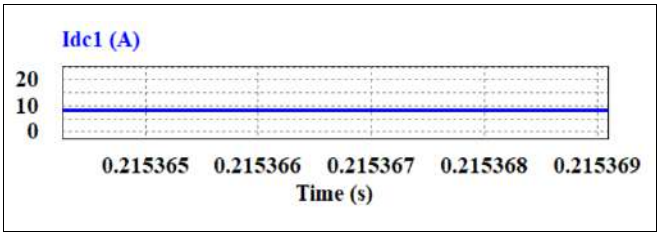

Fig 25: Waveform of a DC current I_{dc1} of the PV system based DC micro grid operated with half-bridge BDC in buck mode

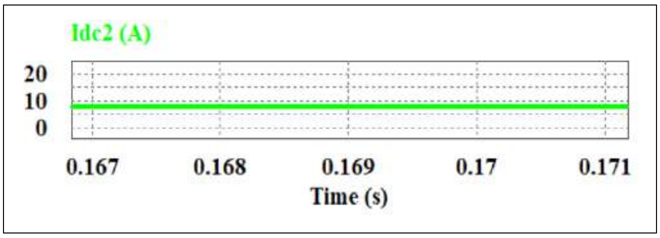

Fig 26: Waveform of a DC current I_{dc2} of the PV system based DC micro grid operated with half-bridge BDC in buck mode

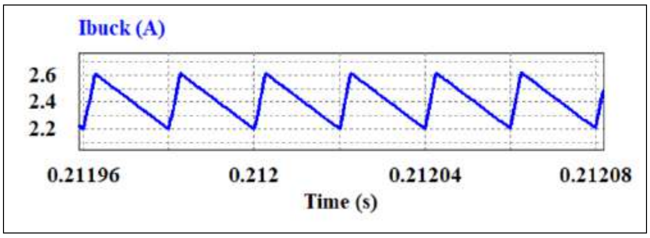

Fig 27: Waveform of an I_{buck} of the PV system based dc micro grid operated with half-bridge BDC in buck mode

The above figures 25-27 shows the simulation result waveforms of the dc currents I_{dc1}, I_{dc2} and current flowing in the half-bridge BDC in buck mode I_{buck} of the PV system based dc micro grid operated with half-bridge BDC in buck mode with the values of 7.55A, 7.3A, and 3.1 A. Here these three currents are feeding the DC load ends which are connected to the DC micro grid.

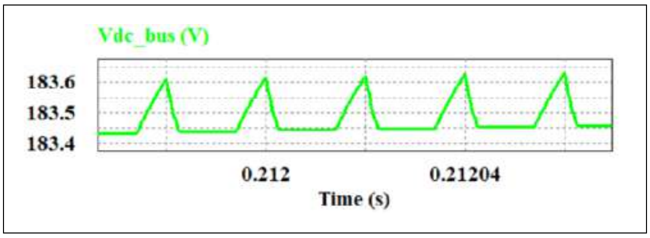

Fig 28: Waveform of a dc bus voltage V_{dc_bus} of the PV system based dc micro grid operated with half-bridge BDC in buck mode

Here calculate dc bus voltage ripple $V_{dc\_bus\_ripple}$ of a of the PV system based dc micro grid operated with half-bridge BDC in buck mode

$$V_{dc\_bus\ ripple} = \frac{(V_{dc\_bus\_max} - V_{dc\_bus\_min})}{V_{dc\_bus\_avg}} \quad (14)$$

$$V_{dc\_bus\ ripple} = 0.00042 \quad (15)$$

Here the negligible voltage ripple in dc bus voltage V_{dc_bus} of the PV system based dc micro grid operated with half-bridge BDC in buck mode. And then in this stage the whole system is effectively satisfied the all three DC loads. So, this effective supply voltage and current can reach the three DC loads in effective manner.

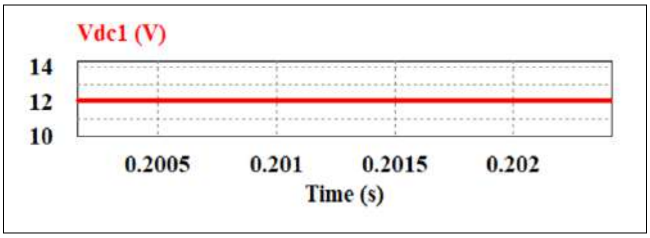

Fig 29: Waveform of a DC voltage V_{dc1} of the PV system based DC micro grid operated with half-bridge BDC in buck mode

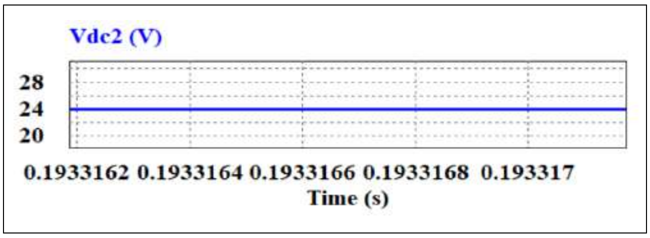

Fig 30: Waveform of a DC voltage V_{dc2} of the PV system based DC micro grid operated with half-bridge BDC in buck mode

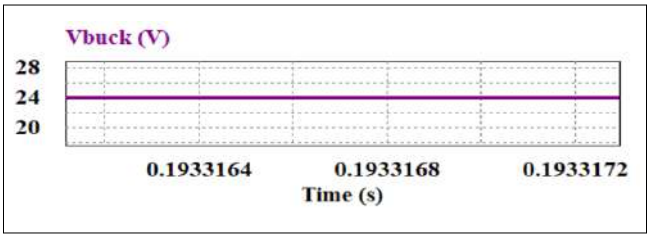

Fig 31: Waveform of a V_{buck} of the PV system based dc micro grid operated with half-bridge BDC in buck mode

The above figures 29-31 shows the simulation result waveforms of the dc voltages V_{dc1}, V_{dc2} and voltage of the half-bridge BDC in buck mode V_{buck} of the PV system based dc micro grid operated with half-bridge BDC in buck mode with the values of 12V, 24V, and 24V. Here these three voltages are appearing as an output voltages of the DC load ends which are connected to the DC micro grid. Here one thing to be noticed that with the help of MSC, PV system effectively serve the dc loads which are connected in a DC micro grid without generating any current or voltage ripples in the mode of the PV system based dc micro grid operated with half-bridge BDC in buck mode. The input power P_{in} supplied by the PV system with the help of the MSC effectively satisfy the all three dc loads output power P_{out} connected in DC micro grid in this PV system based dc micro grid operated with half-bridge BDC in buck mode. In this mode 12V to 24V DC loads are effectively utilized the output power produced from the integration of PV system with MSC.

Table 5: Evaluation of the simulation results of the PV system based DC micro grid operated with half-bridge BDC in buck mode

Parameters	Values
Supply voltage V_s	24V
DC bus voltage V_{dc_bus}	183.5V
Voltage of the half-bridge BDC in buck mode V_{buck}	24V
DC voltage for the DC load-1 V_{dc1}	12V
DC voltage for the DC load-2 V_{dc2}	24V
Supply current I_s	18.6A
Current flowing in the half-bridge BDC in buck mode I_{buck}	2.4A
DC current for the DC load-1 I_{dc1}	8.1A
DC current for the DC load-2 I_{dc2}	8.1A

Neglecting the losses [Switch and diode power losses]

$$P_{in} > P_{out} \quad (16)$$

$$V_{in} I_{in} > V_{out} I_{out} \quad (17)$$

$$V_s I_s > V_{dc1} I_{dc1} + V_{dc2} I_{dc2} + V_{buck} I_{buck} \quad (18)$$

From the table three substituting values of the parameters specified in above equation are

$$V_s I_s = 428.4\ W \quad (19)$$

$$V_{dc1} I_{dc1} + V_{dc2} I_{dc2} + V_{buck} I_{buck} = 340.2\ W \quad (20)$$

By based on above numerical analysis regarding this PV system based dc micro grid operated with half-bridge BDC in buck mode with the application of MSC can generate the input power more than the load requirement without generating any fluctuations in output power.

D. Simulation Results of the PV System Based DC Micro Grid operated with half-bridge BDC in Boost Mode: In this operation of the PV system based dc micro grid operated with half-bridge BDC in boost mode, one can easily achieve the load demand with the help of the PV system and half bridge BDC operated in boost mode with MSC. Here V_{s1} and V_{boost} are supply voltages with value of 24V and 40V. And I_{s1} and I_{boost} are supply or input currents with values of 2.4A and 16.6A. And these supply currents are effectively satisfying the two DC loads currents I_{dc4} is 8.4A andI_{dc5} is 8.2A. So, here $I_{s1} + I_{boost} \geq I_{dc3} + I_{dc4}$ And V_{dc_bus} DC bus voltage across the DC micro grid with 183.76V when MSC is simply triggered with duty ratio 0.7. Here $V_{dc4}$and V_{dc5} is the DC voltages across the three DC loads with values of 12V and 24V. But here the half-bridge BDC simply operated in a boost mode can acts as supply system with battery source. Moreover these DC loads are always supplied by the input resources called by the PV system and battery with half-bridge BDC operated in boost mode.

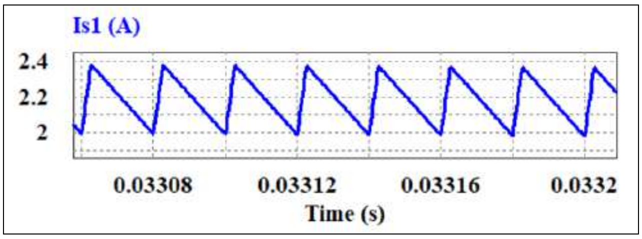

Fig 32: Waveform of a DC supply current I_{s1} of the PV system based DC micro grid operated with half-bridge BDC in boost mode

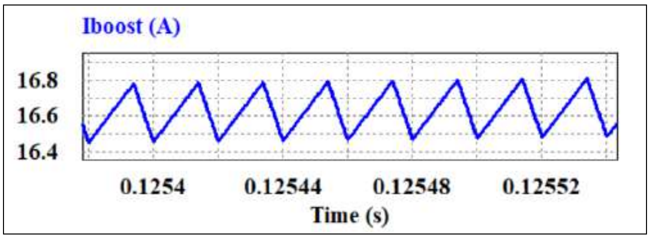

Fig 33: Waveform of an I_{boost} of the PV system based dc micro grid operated with half-bridge BDC in boost mode

The above figures 32 and 33 shows the simulation result waveforms of the dc supply currents I_{s1} and current flowing in the half-bridge BDC in boost mode I_{boost} of the PV system based dc micro grid operated with half-bridge BDC in boost mode with the values of 3.4A and23A. Here these two currents are supply currents to the PV system based dc micro grid operated with half-bridge BDC in boost mode.

Here calculate current ripple I_{boost_ripple} of the half-bridge BDC in boost mode is given as

$$I_{boost\_ripple} = \frac{(I_{boost\_max} - I_{boost\_min})}{I_{boost\_avg}} \quad (21)$$

$$I_{boost\_ripple} = 0.034 \quad (22)$$

Here the negligible ripple in current I_{boost} of the PV system based dc micro grid operated with half-bridge BDC in boost mode. And then in this stage the whole system is effectively satisfied the all two DC loads. So, this effective supply voltage and current can reach the three DC loads in effective manner.

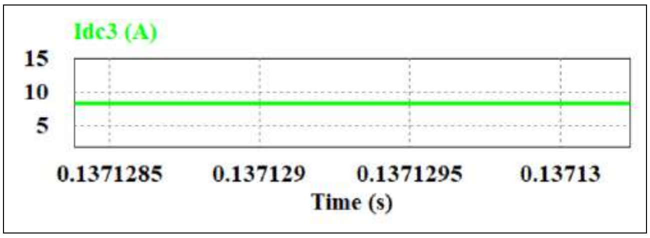

Fig. 34: Waveform of a DC current I_{dc3} of the PV system based DC micro grid operated with half-bridge BDC in boost mode

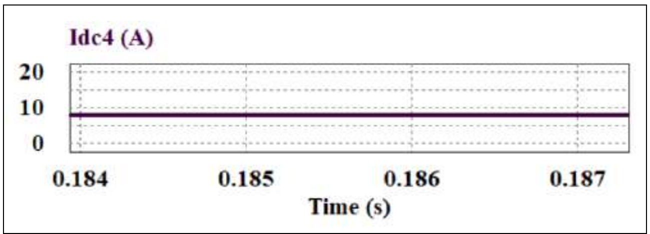

Fig 35: Waveform of a DC current I_{dc4} of the PV system based DC micro grid operated with half-bridge BDC in boost mode

The above figures 33 and 34 shows the simulation result waveforms of the dc currents I_{dc3}, I_{dc4} of the PV system based dc micro grid operated with half-bridge BDC in boost mode with the values of 13.2A and13.2A. Here these two currents are feeding the dc loads which are connected to the DC micro grid.

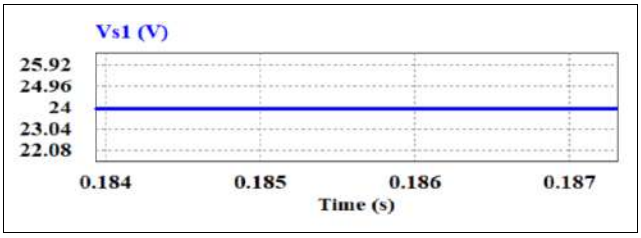

Fig 36: Waveform of a DC supply voltage V_{s1} of the PV system based DC micro grid operated with half-bridge BDC in boost mode

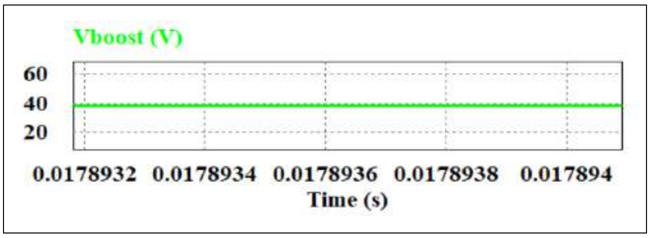

Fig 37: Waveform of V_{boost} of the PV system based dc micro grid operated with half-bridge BDC in boost mode

The above figures 36 and 37 shows the simulation result waveforms of the supply voltage V_{s1} and voltage of the half-bridge BDC in boost mode V_{boost} of the PV system based dc micro grid operated with half-bridge BDC in boost mode with the values of 24V and 40V. Here these two voltages are appearing as a supply voltages of the PV system based dc micro grid operated with half-bridge BDC in boost mode.

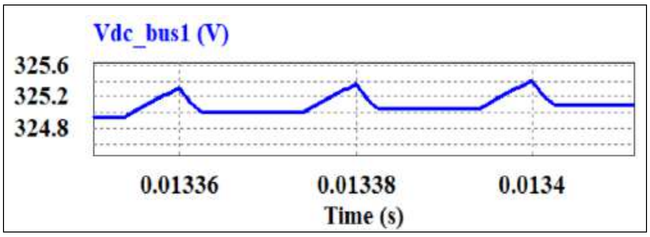

Fig 38: Waveform of a DC bus voltage V_{dc_bus1} of the PV system based DC micro grid operated with half-bridge BDC in boost mode

Here calculate dc bus voltage ripple $V_{dc\_bus1\_ripple}$ of a of the PV system based dc micro grid operated with half-bridge BDC in boost mode

$$V_{dc\_bus1\_ripple} = \frac{(V_{dc\_bus1\_max} - V_{dc\_bus1\_min})}{V_{dc\_bus1\_avg}} \quad (23)$$

$$V_{dc\_bus1\_ripple} = 0.00065 \quad (24)$$

Here the negligible ripple in dc bus voltage V_{dc_bus} of the PV system based dc micro grid operated with half-bridge BDC in boost mode. And then in this stage the whole system is effectively satisfied the all two DC loads. So, this effective supply voltage and current can reach the two DC loads in effective manner.

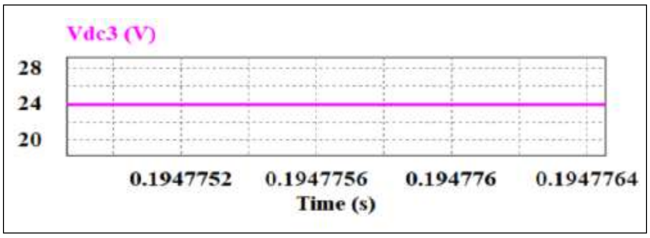

Fig 39: Waveform of a DC voltage V_{dc3} of the PV system based DC micro grid operated with half-bridge BDC in boost mode

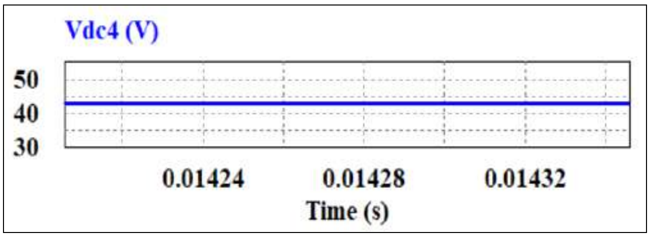

Fig 40: Waveform of a DC voltage V_{dc4} of the PV system based DC micro grid operated with half-bridge BDC in boost mode

The above figures 39 and 40 shows the simulation result waveforms of the dc voltages V_{dc3} andV_{dc4} of the PV system based dc micro grid operated with half-bridge BDC in boost mode with the values of 24V and 48V. Here these two voltages are appearing as an output voltages to the dc loads which are connected DC micro grids. Here one thing notice that with the help of MSC, PV system and energy storage element connected with the help of a half-bridge BDC can effectively serve the dc loads which are connected in a DC micro grid without generating any current or voltage ripples in the mode of the PV system based dc micro grid operated with half-bridge BDC in boost mode. The input power P_{in} supplied by the PV system and energy storage element connected with the help of a half-bridge BDC with the help of the MSC is effectively satisfy the two dc loads output power P_{out} connected in DC micro grid in this PV system based dc micro grid operated with half-bridge BDC in boost mode. In this mode 24V to 48V DC loads are effectively utilized the output power produced from the integration of PV system with MSC.

Table 6: Evaluation of the simulation results of the PV system based DC micro grid operated with half-bridge BDC in boost mode

Parameters	Values
Supply voltage V_{s1}	24V
DC bus voltage V_{dc_bus1}	325.2V
Voltage of the half-bridge BDC in boost mode V_{boost}	40V
DC voltage for the DC load-3 V_{dc3}	24V
DC voltage for the DC load-4 V_{dc4}	48V
Supply current I_{s1}	2.4A
Current flowing in the half-bridge BDC in boost mode I_{boost}	16.6A
DC current for the DC load-3 I_{dc3}	9.5A
DC current for the DC load-4 I_{dc4}	9.5A

By based on above numerical analysis regarding this PV system based dc micro grid operated with half-bridge BDC in boost mode with the application of MSC can generate the input power more than the load requirement without generating any fluctuations in output power.

6. Conclusion

The MSC topology for PV system based DC micro grids is discussed and simulated using PSIM software. Moreover advantages of using MSC in this topology are addressed in the section of simulation results and discussion. So, PV system with a MSC configuration has continuously generates output current without producing any ripples. This configuration gives the output voltage with high gain and also deliver required amount of power supply demanded by the DC loads. That's the reason this configuration is most probably well integrated with the DC micro grids to deliver a reliable power supply to the DC loads. Especially this topology well suited for domestic applications. Now a day's most of the houses are equipped with DC LED lamps, BLDCM based ceiling fans and etc. These applications require DC supply. So, domestic appliances which are operated by the DC supply definitely satisfy their load demand when they are using this topology addressed in this paper work.

7. Data availability

The data available in this paper regarding the MSC is under the reference of this citation https://ieeexplore.ieee.org/abstract/document/8750785.

8. References

1. Umair Shahzad. "The Need for Renewable Energy Sources'' International Journal of Information Technology and Electrical Engineering 2017.
2. Mclamb E. "Fossil fuels vs. renewable energy resources" 2011. [Online], Available at http://www.ecology.com/2011/09/06/fossil-fuelsrenewable-energy-resources/, [Accessed 20th April 2015].
3. Anders CJ. "Greatest fossil fuels disasters in human history" 2010. [Online], Available at http://io9.com/5526826/greatest-fossil-fuel-disasters-inhuman-history, [Accessed 20th April 2015].
4. Kumar D, Zare F, Ghosh A. "Dc microgrid technology: System architectures, ac grid interfaces, grounding schemes, power quality, communication networks, applications, and standardizations aspects," Ieee 2017;5, 12 230–12 256.
5. Dragiˇcevi´c T, Lu X, Vasquez JC, Guerrero JM. "Dc microgrids—part i: A review of control strategies and stabilization techniques," IEEE Transactions on power electronics 2016;31(7):4876–4891.
6. Yang N, Nahid-Mobarakeh B, Gao F, Paire D, Miraoui A, Liu W. "Modeling and stability analysis of multi-time scale dc microgrid, " Electric Power Systems Research 2016;140:906–916.
7. Nymand M, Andersen MAE. ''High-efficiency isolated boost DC–DC converter for high-power low-voltage fuel-cell applications,'' IEEE Trans. Ind. Electron 2010;57(2):505–514.
8. Hwu KI, Jiang WZ. ''Isolated step-up converter based on flyback converter and charge pumps,'' IET Power Electron 2014;7(9):2250–2257.
9. Tank SB, Manavar K, Adroja N. "Non-Isolated Bi-directional DCDC Converters for Plug-In Hybrid Electric Vehicle Charge Station Application, " in Proc. of Emerging Trends in Computer & Electrical Engineering (ETC. EE 2015) 2015.
10. Lakshmi M, Hemamalini S. ''Non-isolated high gain

DC–DC converter for DC microgrids, ’’ IEEE Trans. Ind. Electron 2018;65(2):1205–1212.
11. Li W, He X. ‘‘Review of non-isolated high-step-up DC/DC converters in photovoltaic grid-connected applications,’’ IEEE Trans. Ind. Electron 2011;58(4):1239–1250.
12. Cao Y, Samavatian V, Kaskani K, Eshraghi H. A novel non-isolated ultra-high-voltage-gain DC–DC converter with low voltage stress,’’ IEEE Trans. Ind. Electron 2017;64(4):2809–2819.
13. Yu D, Yang J, Xu R, Xia Z, C Iu HH, Fernando T. ‘‘A family of module-integrated high step-up converters with dual coupled inductors,’’ IEEE Access 2018;6:16256–16266.
14. Zhang M, Xing Y, Wu H, Hu H, Ma X. ‘‘A dual coupled inductors based high step-up/step-down bidirectional DC-DC converter for energy storage system,’’ in Proc. IEEE Appl. Power Electron. Conf. Expo. (APEC), Tampa, FL, USA 2017, 2958–2963.
15. Nilanjan M, Dani S. ‘‘Control of cascaded DC–DC converter-based hybrid battery energy storage systems—Part I: Stability issue, ’’ IEEE Trans. Ind. Electron 2016;63(4):2340–2349.
16. Rosas-Caro JC, Mancilla-David F, Mayo-Maldonado JC, Gonzalez-Lopez JM, Torres-Espinosa HL, Valdez-Resendiz JE, ‘‘A transformer-less high-gain boost converter with input current ripple cancelation at a selectable duty cycle, ’’ IEEE Trans. Ind. Electron 2013;60(10):4492–4499.
17. Yu Tang, Member IEEE, Ting Wang, Yaohua A. Switched-Capacitor-Based Active-Network Converter With High Voltage Gain H IEEE Transactions On Power Electronics 2014;29(6):2959.
18. Wu B, Li S, Liu Y, Smedley KM. ‘‘A new hybrid boosting converter for renewable energy applications,’’ IEEE Trans. Power Electron 2016;31(2):1203–1215.
19. Rosas-Caro JC, Mancilla-David F, Mayo-Maldonado JC, Gonzalez-Lopez JM, Torres-Espinosa HL, Valdez-Resendiz JE. ‘‘A transformer-less high-gain boost converter with input current ripple cancelation at a selectable duty cycle, ’’ IEEE Trans. Ind. Electron 2013;60(10):4492–4499.
20. Beena1 KH, Anish Benny. 2 PG Student, Dept. of EEE, AmalJyothi College of Engineering, Kottayam, Kerala India1 Assistant Professor, Dept. of EEE, AmalJyothi College of Engineering, Kottayam, Kerala IndiaAnalysis and Implementation of Quadratic Boost Converter for Nanogrid Applications 2015;4(7). Copyright to IJAREEIE DOI: 10.15662/ijareeie.2015.0407030 6043.
21. Pandav Kiran Maroti, (Member, IEEE), Sanjeevi Kumar Padmanaban, (Senior Member, IEEE), Jens Bo Holm-Nielsen, Mahajan Sagar Bhaskar, (Member, IEEE), Mohammad Meraj, (Student Member, IEEE), Atif Iqbal, (Senior Member, IEEE). “A New Structure of High Voltage Gain SEPIC Converter for Renewable Energy Applications” 2019. Digital Object Identifier 10.1109/ACCESS.2019.
22. Wuhua Li, Member IEEE, Xiangning He. Fellow Review of Non-isolated High-Step-Up DC/DC Converters in Photovoltaic Grid-Connected Applications, IEEE IEEE Transactions on Industrial Electronics 2011;58(4):1239.
23. “Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques”, Trishan Esram, Student Member Patrick L. Chapman, Member. National Science Foundation ECS-01-34208 2011.
24. “Maximum Power Point Tracker for Photovoltaic Systems with Resistive Load”. G. De Cesar, D. Captuo and A. Nascetti, Solar Energy 2006;80:982-988.
25. Caricchi F, Crescimbini F, Noia G, Pirolo D. "Experimental study of a bidirectional DC-DC converter for the DC link voltage control and the regenerative braking in PM motor drives devoted to electrical vehicles," in Proc. of 9th Annual Applied Power Electronics Conference and Exposition (APEC 1994), Orlando 1994.
26. Denny DC, Shahin M. "Analysis of bidirectional SEPIC/Zeta converter with coupled inductor, "In Proc. of International Conference on Advancements in Power and Energy (TAP Energy 2015), Kollam 2015.