Wide PV Input High Step-Up Converter

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***Abstract*- Due to wide change in input of solar where converters fail to do proper conversion of power. So there is a need of a converter which works in wide input range with boosted output in high ratio. This paper presents a converter with high boost ratio with voltage multiplier circuit in the output and the boost converter as input with interleaved operation. The performance is analyzed with MATLAB simulation. The open loop prototype is presented in this paper**.

***Keywords*- DC-DC Converter; PV Module; Interleaved Boost operation; High Step-up converter;**

I. INTRODUCTION

There is many advantages of photovoltaic (PV) energy is a high-potential solution for future energy sources. From all renewable energy sources the PV energy is a major contributor in electric power generation. As one of the main components in PV system, several types of power converters are proposed in research literature. Among various ways to interface PV modules with DC-AC inverter, conventionally PV modules are connected in series with the DC-AC inverter through a central DC-DC converter. In order to deal with partial shading effect and the power mismatch problem between PV modules, distributed power management technique is introduced. In this paper, we have presented a novel DC-DC converter to use as a distributed power converter at module level in PV system.

This work mainly focuses to mitigate the partial shading effect and power mismatch problem. A new topology approach is presented to deal with the variations of the output voltage of the PV module more efficiently by increasing input voltage range of the DC-DC converter. This paper proposed a novel structure of non-isolated DC-DC interleaved boost converter of wide voltage gain range. The proposed converter is designed and implemented in MATLAB to explore the performance of the converter and limitations it may impose. This paper propose operation principle of the proposed topology. For further analysis simulation results are also presented.

II. DISTRIBUTED CONVERTER IN PV APPLICATION

In a PV module multiple solar cells are connected in series or in parallel combinations. Similarly many modules are connected to produce large PV power. Due to partial shading and variations of solar irradiation. Output of the PV cells power differs and that results in power mismatch between cells. This power mismatch causes power dissipation in the cells and leads toa significant power loss in the power loss the PV system. To address this problem distributed power conversion at module level has been introduced. Therefore, the maximum available output power of the group of PV cells is utilized and a drop in output power is prevented.

In state of the art research, an approach of distributed power management is presented to deal with the power mismatch problem by adding DC/DC converters at the module level [2]. The paper also compares between different concepts of module level power conversion. Distributed power converters decrease the impact of mismatches by performing maximum power point (MPP) tracking at module level. One of the approaches used a very high gain module integrated DC- DC converter to do MPP control locally [3]. Several high gain high efficiency DC-DC converters have been introduced in prior research and also in the market. Reference [4] presents a high gain high power boost converter based on three state switching cell and voltage multiplier cell. Auto-transformer along with multiplier cells are used for high gain. In a previous attempt, a non-isolated three level hybrid boost converter is proposed [5]. No transformer or coupled inductor is used, rather multiple power switches and diodes are used for high gain. Reference [6] presents a non-isolated high voltage gain boost converter with voltage multiplier cells which are cascaded with the battery bank and the PV panels. This converter operates in soft switching, with ZVS mode. Non- isolated high step-up DC-DC converter with voltage multiplier cells can provide high output voltage without having extreme duty cycle as in [7], [8]. All these converters are capable to have high boost ratio. However, limited studies are available on the high output voltage converters together with wide input voltage range and wide voltage gain range.

In order to handle shading effect and variations of solar irradiance wide input voltage range is to be selected to operate the converter dynamically. The design requirements of an intra- module DC-DC converter have been described in our previous work [10]. According to the design specifications the intra- module converter has been designed and built. The design procedure, prototype of the converter, measurement results and the suitability of the converter in PV application have been discussed in our previous paper [11].

III. BACKGROUND AND SCOPE

Because of the partial shading, PV cells are illuminated with different irradiance level and so each of them has different current-voltage characteristics. In effect, the output power of the cells varies dynamically and causes power mismatch between them. This output power mismatch exists between the cells and also between the modules. Consequently, this phenomenon causes significant power loss which affects the overall efficiency of the PV system. Input voltage of the converter needs to follow from the lowest to the highest point of the MPP tracker. Converter must operate at the low input voltage which is adequate to track the lowest output voltage ofPV module in shading conditions. Maximum input voltage of the converter is to be high enough to address the output of the fully illuminated module when no shading and thus no mismatches are present. Therefore, wide input voltage range and wide voltage gain range of a converter is essential to operate the converter dynamically.

A. Scope

A non-isolated high gain DC-DC converter with voltage multiplier cells [9] has been chosen for our application. The schematic diagram of the topology [9] is depicted in Fig. 1. In this topology, capacitorsand diodes formed a multiplier stage which is integrated in boost converter with the possibility to increase several stages to achieve high voltage gain. Two multiplier capacitors (CM1, CM2) are connected with two multiplier diodes (DM1, DM2) to form a multiplier stage (*M*).

Two multiplier stages (*M*=2) are CM3, CM4 and DM3, DM4 are shown in Fig. 1. DS1 and DS2 are two output diodes. Since two power switches (SW1, SW2) are connected in parallel the current stress in all the components is reduced, resulting in lower conduction loss, which helps to increase the efficiency. Because of the configuration, currents of two inductors (L1, L2) are interleaved with each other. The voltage gain of the converter is the function of duty ratio (*D*) and the number of multiplier stage (*M*). The static gain (*Av*) of the converter is shown in equation (1).

$$Av = (M+1)/(D-1) \qquad 1$$

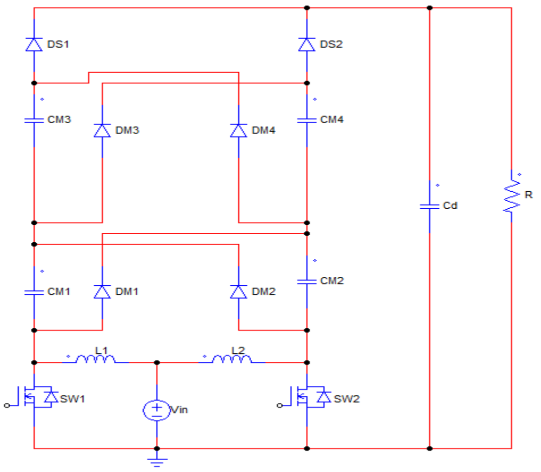

Fig. 1. Selected topology for module level converter. Two multiplier stages are used.

In this topology, high output voltage is achieved without having extreme duty ratio and high voltage stress on power switches. It is possible to get same gain at lower duty cycle by increasing number of multiplier stages. Consequently, duty ratio is directly proportional to the number of multiplier stages for a fixed voltage gain. Moreover, voltage stress across the power switches is proportional to duty ratio at a constant input voltage and inversely proportional to the number of multiplier stages at a constant output voltage. Hence, duty ratio and voltage stress are possible to reduce with the increase of multiplier stages for a particular voltage gain. It entails that voltage stress across the power MOSFETs will be lower for *M*=2 compared to voltage stress for *M*=1 to achieve high voltage gain such as 12. However, increase of multiplier stages will impose the inability to push the lower bound of the voltage gain range to acceptable wide input voltage range for this converter.

For example, it is not feasible to operate the converter with *M*=2 to attain a low voltage gain of 3. In the operating range of duty ratio 0.3 to 0.75, the voltage gain of different multiplier stage is shown in Table I. It is seen that if we operate this topology with M=1 in wide voltage gain range such as 3 to 12 then very high duty ratio will be required to achieve high gain of 12 and so, to operate in wide voltage gain range without compromising the efficiency is a challenge. To address this challenge a novel approach is proposed in this paper.

TABLE 1 VOLTAGE GAIN RANGE OF DIFFERENT MULTIPLIER STAGE

Multiplier Stage (*M*)	**Duty Ratio (*D*)**	**Voltage Gain**
M=1	0.3	2.86
	0.75	8
M=2	0.3	4.3
	0.75	12
M=3	0.3	5.7
	0.75	16

The potential solution of this limitation is to introduce interchangeability between different multiplier stages. Here, we propose a novel structure which can interchange between different multiplier stages dynamically to provide wider voltage gain range. This will facilitate to operate the converter with wide input voltage range in accordance with varying output voltage of PV module.

IV. PROPOSED TOPOLOGY

A. Operating Principle of Proposed Topology

The schematic diagram of our proposed structure is depicted in Fig. 2. Two low frequency voltage controlled switches (S1, S2) are added in the circuit. These switches are inserted to interchange between multiplier stages. The idea is to configure the topology to exchange between the multiplier stages dynamically based on the operating conditions of the PV module. These switches are connected between two multiplier stages as shown in the Fig 2.

As per the voltage gain requirement, the converter will be operated with one or two multiplier stages by controlling these switches at run time. S1 and S2 are always operated simultaneously. The converter is operational with two multiplier stages (i.e. *M*=2) when S1 and S2 both are closed. During this period all the multiplier capacitors CM1, CM2, CM3, and CM4 are working. Inversely, when S1 and S2 are opened then the converter with one multiplier stage (i.e. *M*=1) is in operation. In this case, two multiplier capacitors CM3 and CM4 are functional and other two multiplier capacitors CM1 and CM2 are bypassed completely but DM1 and DM2 are in use as current from input stage is going to output diodes through two multiplier diodes DM3 and DM4.

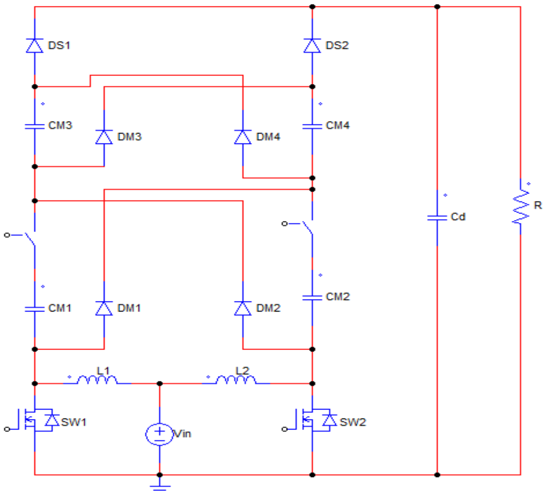

Fig 2. Schematic diagram of proposed topology

If low voltage gain is required then converter with *M*=1 is working and when high voltage gain is needed then converter with *M*=2 is functional. Switches S1 and S2 will be controlled by a controller at run time based on the PV cells output and mismatches present. The overall performances of the converter including conduction loss in the switching devices and voltage stress across power switches also need to be considered in order to determine the number of multiplier stages is in operation for a particular voltage gain.

B. Design Specifications and Suitability of the Proposed Converter

Based on the effectiveness of the proposed converter in PV application following design requirements have been defined. We have designed the converter for 10V-40V input voltage with a maximum of 8A input current and targeted to a fixed output voltage 120V and the rated input power of 80W-320W. This working range is suitable for 60-cell module. In order to address low output voltage from PV cells in shading conditions and to track the lowest point of MPP, minimum input voltage of the converter is set at 10V. The maximum input voltage is 40V which is the operating point of the module when no shading and thus no mismatches are present in the module. Maximum voltage gain is 12 to produce high output voltage as 120V. Switching frequency of this converter is 50 kHz. This topology is suitable to operate in higher and lower than 0.5 duty ratio. The converter also works between 2-8A inputs current. Due to the interleaved technique, low input current ripple and low output voltage ripple is achieved. This technique also helps to reduce current stress in all components. Table II shows the design specifications for our proposed converter.

Here designing parameters from duty ratio of 0.34-0.75 are 40v and 10v inputs. From the duty ratio designing the inductors and capacitors values. Equations are bellows.

$$L = (1-D)^2 \times R/2f \qquad 2$$

$$C = \frac{D \times Vout}{Vr \times R \times f} \qquad 3$$

TABLE II. DESIGN SPECIFICATIONS OF THE CONVERTER

Design Parameters	**values**
Input voltage range (V)	10-40
Max input current (A)	8
Power range (W)	80-320
Operating Frequency (kHz)	50
Output voltage (V)	120
Max voltage gain	12

This converter is able to deal with the low output voltage from shaded cells and also to track the high output voltage from fully illuminated cells. By implementing this approach, high output voltage is attained without transformer and together with wide input range. In addition, all the passive components are always not in use. Because when module is fully illuminated then lower voltage gain is required, thus one multiplier stage is in operation andCM1 and CM2 are not in use. Extra voltage controller switches may impose power loss in the circuit but that can be reduced by using efficient low loss switches. It may impose additional cost in the converter due to some extra switches but low frequency voltage controlled switches are economical to use. Thefrequency of the added switches (S1, S2) will be low as the frequency of irradiation variation is also low.

The converter can also be designed in different input, output voltage range such as for large PV module, 96-cell module or 128-cell module. For instance, it can be designed for 16V - 78V input range and 260V output voltage which is fitted for 96-cell and also 128-cell module. This approach can also be applied in different multiplier stages based on the requirement.

V. EXPERIMENTAL RESULTS

The proposed converter is designed and implemented in MATLAB Simulink. Real commercial model of MOSFETs and diodes have been used for all these simulations. The converter operation is in continuous conduction mode and operating frequency of the converter is 50 kHz. Input current is set at 8A and frequency of S1, S2 is considered as 100Hz for all the simulations.

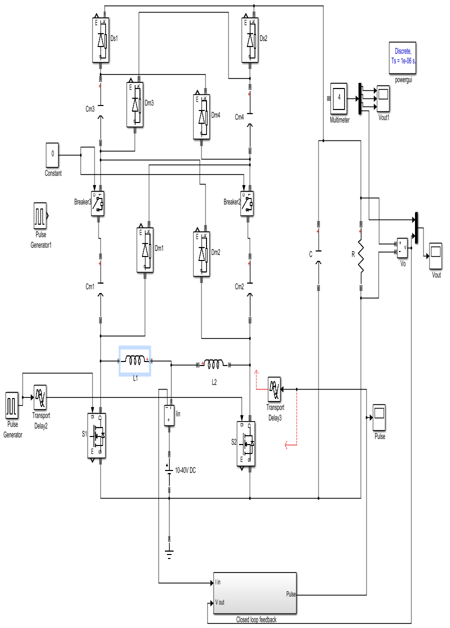

Fig 3. Open loop simulation of proposed converter.

A. Current Waveform

The simulated current waveforms of this converter are depicted in Fig. 4 to verify the functionality of the converter. Input voltage and duty cycle are kept same as 10V and 0.78 respectively for this simulation as well. Switching signal of S1 (VS1), current of both inductors (IL1, IL2) and current of multiplier capacitor (ICM3) are shown here. Both power switches SW1, SW2 are operated at 50 kHz and is not shown in this figure. It is seen that both inductor currents follow the interchangeability between the multiplier stages. Current through the multiplier capacitor ICM3 becomes zero when S1, S2 are opened (VS1=0V) which signifies CM3, CM4 are bypassed completely and *M*=1 is in operation. When both low frequency switches S1, S2 are closed then converter is operational with two multiplier stages (i.e. *M*=2) and so, multiplier capacitors CM3, CM4 are working in this duration, which is displayed in Fig. 4. The frequency of ICM3 is same as the frequency of SW1 that is 50 kHz. As the signal of ICM3 is plotted with the signal of S1, which is switching at 100Hz and is significantly lower than the frequency of SW1 so, invariably ICM3 signal is pictorially compressed and looks oscillating.

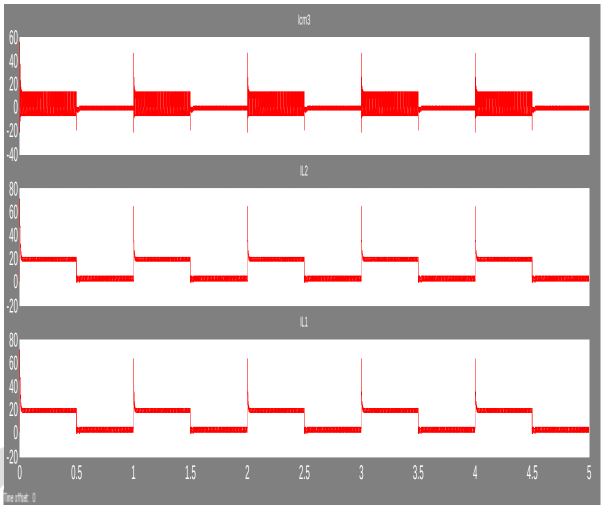

Fig. 4. Current waveform of inductors current and multiplier capacitor current

B. Output Voltage at Minimum & Maximum Input

Fig. 5 and Fig. 6 present the converter output voltage waveform when input voltage at its minimum and maximum respectively. Input voltage Vin and output voltage Vout of the converter are shown in these figures. In Fig. 5, output voltage is 114V at 10V input voltage. Here, converter is working with two multiplier stages (*M*=2) at 0.78 duty ratio as high voltage gain is required. It is seen that output voltage is 121V at its maximum input voltage of 40V in Fig. 6. In this case, converter is working with one multiplier stage (*M*=1) at 0.46 duty ratio. As the voltage gain is 3 here, instead of two multiplier stages one multiplier stage is in operation. It shows the expected functionality of the converter.

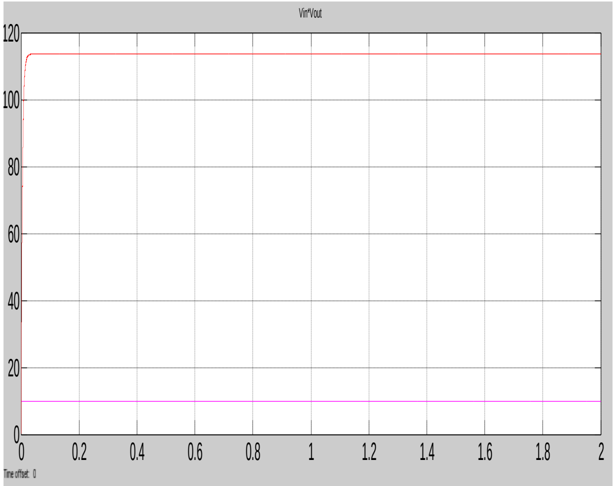

Fig. 5. Output voltage waveform at minimum input voltage

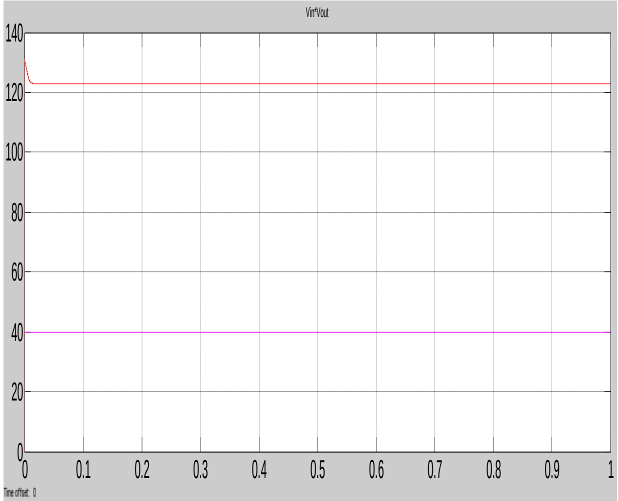

Fig. 6. Output voltage waveform at maximum input voltage

Closed loop simulation

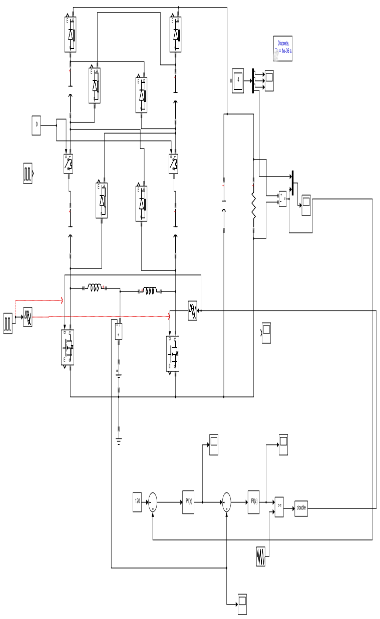

Fig. 7. Closed loop Simulation of High Step-up Converter

In an open loop system it is required to obtain constant output voltage but it’s varying so it is necessary to go for closed loop system where the output voltage is maintained constant by adjusting the switching using PI controller in the feedback. In closed loop system the output voltage is compared to that of the reference voltage using the comparator. The error signal is generated by the comparator, this generated signal is fed to the PI controller which generates the control signal. The control signal is compared to input current in order to regulate the current. The output from the comparison is fed to the PI controller which generates the control signal. This control signal is compared to the repeating sequence. Whenever the repeating signal is greater than or equal to the control signal the gating signals are generated, these gating signals are given to the switches in order to regulate the output voltage. For varying input voltage the output voltage will be constant.

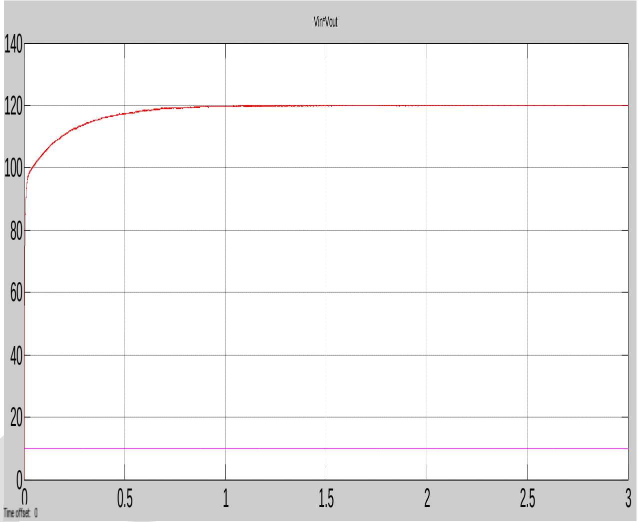

Fig. 8. Output voltage waveform at minimum input voltage.

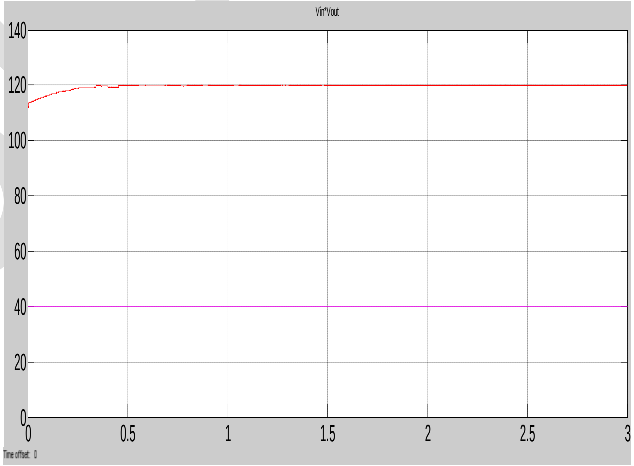

Fig. 9. Output voltage waveform at maximum input voltage

In the above fig 7. Shows that closed loop circuit of high step-up converter. And fig 8, fig 9. Shows that output voltage waveforms of minimum and maximum input voltages.

VI. CONCLUSION

This high step-up converter is able to interchange between multiplier stages and eventually make voltage gain range wider. This topology of DC-DC converter is useful to operate the converter in wide input voltage range and also to operate in wide output voltage range whenever is necessary.From our work, it is concluded that the proposed converter is useful to use as a distributed converter in PV application and it is beneficial in terms of overall performance improvement of the

PV system. All the waveforms demonstrate the viability of the proposed converter.

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