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# PV FED MULTI – INPUT AND SINGLE CASCADED OUTPUT CONVERTER FOR GROUND CURRENT REDUCTION

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**ABSTRACT**

Scalable and power dense configuration is a requisite for high power applications. This paper proposes a Multi-Input and Single Cascaded Output (MISCO) architecture interfacing PV panels at each channel of the multi input structure transacting power to LVDC-μG. The topology offers an extendable and modular solution with minimized common mode and circulating currents with reduced stress over the devices with the flexibility of independent control on current for all the connected panels, thereby improving the reliability. The MISCO converter is simulated in MATLAB/SIMULINK environment.

**Keywords:** Photovoltaic, Common Mode, Multiport

**NONMENCLATURE**

| | |
|---|---|
| *Abbreviations* | |
| LVDC-μG | Low Voltage DC Microgrid |
| PV | Photovoltaic |
| MPPT | Maximum Power Point Tracking |
| MISCO | Multiple Input and Single Cascaded Output |
| *Symbols* | |
| μH | Micro Henry |
| μF | Micro Farad |

## 1. INTRODUCTION

Renewable energy sources such as photovoltaic (PV) offers the best alternatives for energy needs due to the ubiquitous presence of solar energy close to load. PV systems, are dependent on environmental conditions but, with the intervention of power electronic converters and storage systems drawbacks are offsetted.

For the tower mounted PV applications efficient and power dense solutions are a requisite. Furthermore steel tower being open to the sky and also in the conditions where due to high moisture content the structure is vulnerable to rusting and corrosion. The converters mounted for providing boosting of voltage for PV fed applications, the returning path is often properly grounded. This results in high ground currents detoriating the efficiency of the converter at higher duty cycle and may cause shock alongwith accelerated degradation of life cycle. This calls for regular maintenance of the structure which is often a difficult task in remote areas. Generally isolated topologies are researched for providing safety. However, the presence of transformer makes the systems bulky with complex control [1]. For PV specific applications surfeit `literature is presented on the transformerless architectures that provide the advantage of reliability, increased efficiency and cost effectiveness. But, such topologies suffer with the problem of common mode current as the stray capacitance gets formed with the ground, creating unwarranted pathway between the PV and the interfacing converter [2]. The presence of common mode current results in EMI noise, upsurges in losses along with safety issues [2]. It may even result in fluctuations while tracking the maximum power point, thereby resulting in oscillatory response and reduced efficiency of the system [3]. The parasitic capacitance formed between the photovoltaic panel and the interfacing converter due to large voltage differential results in peaky current at high switching frequencies, affecting and the efficiency of the system [2]. To negotiate these common mode current, filters are generally embedded in the circuit [4], at the cost of transient response of the system. Moreover, accurate design and the appropriate tuning of the filter is essential to ensure compensation of the common mode current. Single converter architecture is often not feasible for applications requiring high power due to high voltage and current stresses on devices, thereby putting restriction on the device power ratings which may result in loss of reliability.

To remediate the issues, various parallel configuration on input and output side are presented in the literature [5]. Such multichannel configuration provides improved reliability, efficiency and reduced stresses over the devices. However, parallel architectures suffer due to high circulating currents [5]. Majority of the module integrated converters (MIC) interfaced to PV panels are single input and single output (SISO) converters [6]. Therefore for integrating the multiple PV sources which enhances the reliability using multiple input interface of MIC and than integrating into one output (MISO) offers improved power density while reducing the capital investment [7]. Moreover, the individual control of all the panels using such multiple input interfaces of MIC will provide better solution for maximum power tracking even under the bad weather conditions. However, for the reported converters the problem of common mode current causing EMI noise still remains an issue for exploring the solutions that can reduce their effect.

The paper proposes an even number of multi-input and single cascaded output architecture for tower mounted PV panels based battery charging applications. The topology allows a modular and scalable configuration requisite for high power applications. The interleaved operation of the converter architectures enables reduction in the common mode current and EMI noise. The structure also avoids the condition of inter-converter circulating current. The unidirectional architecture permits easy boosting with improvised power delivery. The individual MPPT control of the PV panels of each channel is also probed under balanced irradiation change and under unbalanced irradiation on the panels. The converter architecture is simulated and examined under MATLAB Simulink environment.

## 2. SYSTEM CONFIGURATION

The proposed multi input and single cascaded output (MISCO) configuration for LVDC-µG is shown in Fig.1. The paralleling of two channel architecture for a scalable multiport configuration forms a reliable and high power dense solution. The considered system consists of four channels (two port pairs) having

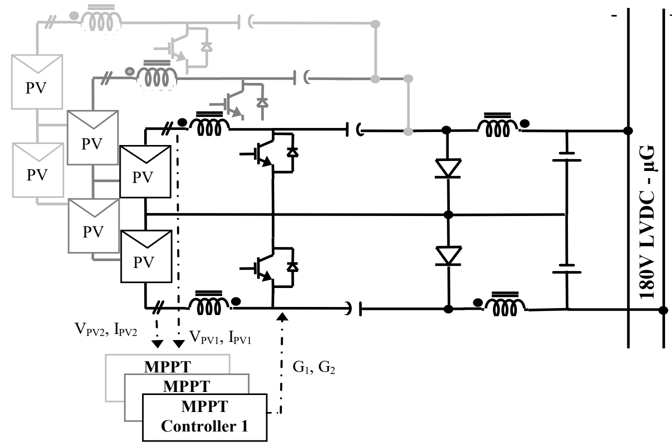


**Fig. 1 System Configuration**

connected at input 300W PV panels at each port with individual MPPT controller. The modular architecture is designed to transact a total power of 1.2 kW and can be augmented with multiple port pairs MIC for catering to higher power applications on the same cascaded output port. The PV panels are independently tracked through Incremental Conductance (InC) algorithm, devising current source and each of them are operating at voltage ($V_{MP}$) of 36V @ 1000W/m$^2$ individually cumulating to 72V on each input side port pair while the LVDC-µG is maintained at 180V. The input side capacitor in every channel serves the purpose of crunching the voltage ripple transacting and maintains operation of the panel near the maximum point. The independently stacked PV panels at each port pair with MPPT control ensure tracking of maximum power ($P_{MPP}$) under varying irradiation condition. The proposed configuration provides a solution to single phase AC distribution grid ready architecture.

## 3. MODES OF OPERATION

The presented MISCO converter is interfaced with a PV panel at each input port transacting power to LVDC-µG maintained at 180V to devise a AC distribution grid ready solution. Since the operating duty of the converters are maintained greater than 50%, and the PWM switching of the lower and the upper channel switches are phase shifted from each other by 180o, the modes of the converter can be subdivided as:-

### *3.1 Mode 1*

As shown in Fig 2a the switches of the upper channel $S_{01}$ and $S_{03}$ of the port pairs of the proposed converters are switched in simultaneously and $S_{02}$ and $S_{04}$ are off. The capacitors $C_1$ and $C_3$ of the upper channels of the port pair discharges to power the output while the capacitors $C_2$ and $C_4$ of the lower

 

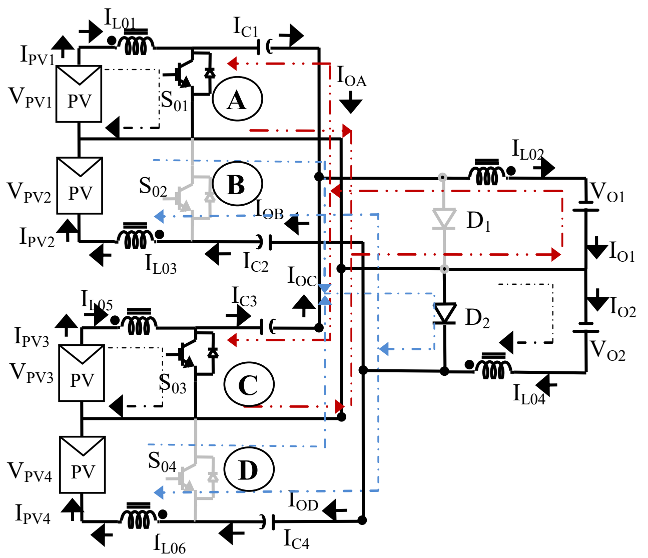


**Fig. 2a Mode I**

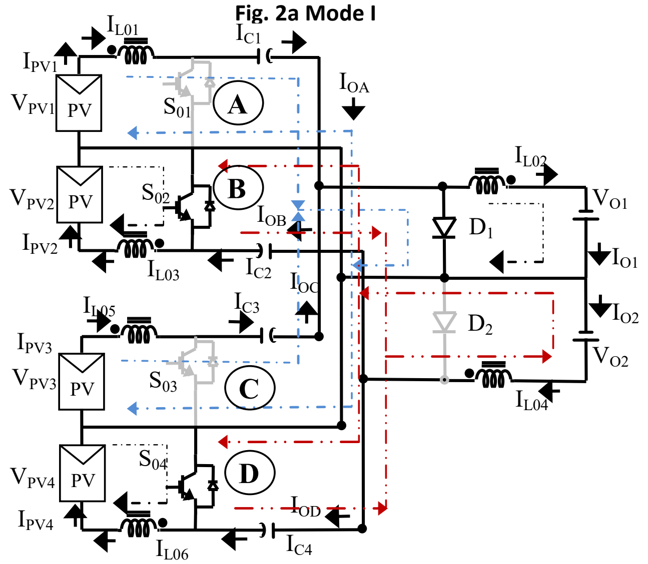


**Fig. 2b Mode II**

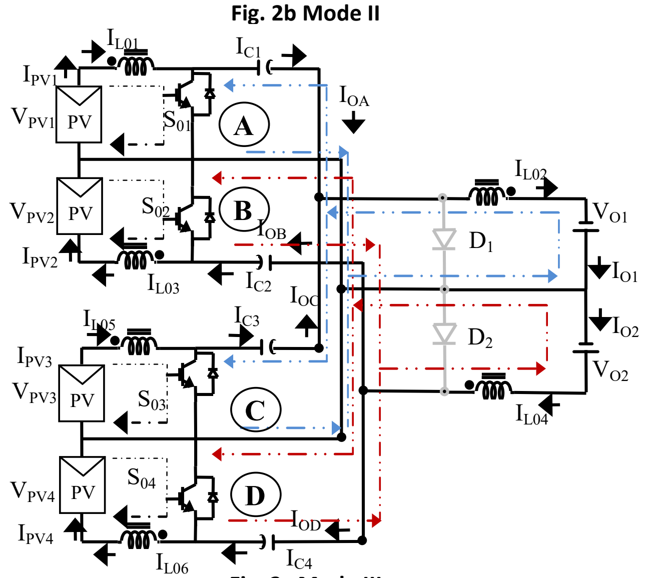


**Fig. 2c Mode III**

channels of the port pairs are charged through input inductors $L_{03}$ and $L_{06}$ separately through diode $D_2$. The output side inductors since are coupled to the input side inductors show identical charging and discharging profile.

### *3.2 Mode 2*

The mode of operation is similar to mode 1 except that instead of the upper channel, the lower channels of the port pairs operates in conjunction with switches $S_{02}$ and $S_{04}$. Now capacitors $C_2$ and $C_4$ are discharged as shown in Fig. 2b

### *3.3 Mode 3*

Since the operating duty is greater than 0.5 there exist a condition where all the switches of the proposed converter operates simultaneously, and accordingly the capacitors of all the channels continue discharging power to the output.

## 4. CONVERTER ANALYSIS

The proposed configuration of MISCO interleaved cuk converter interfaced with the photovoltaic panel acts as a current source, thereby transacting InC tracked maximum power generated from the PV panels to the LVDC- µG. The analysis is carried out for the topology having two input port pairs where each port pair consist of two sub channels (A, B or C, D) respectively for two port pairs as shown in Fig. 2 with output current for each channel is considered to be $I_{OA}$ , $I_{OB}$ , $I_{OC}$, $I_{OD}$. The steady state analysis of the converter is done using Kirchhoff's current law and solving the current second balance across capacitors $C_1$ and $C_2$ for one port pair and similarly for the second across $C_3$ and $C_4$ is carried out as follows. The currents across capacitors $C_1$ and $C_2$ when only $S_1$ is conducting for the duration T/2:

$I_{C1} = I_{L02} = I_{OA}$ and $I_{C2} = I_{L03} = I_{PV2}$ (1)

For S2: $I_{C1} = I_{L01} = I_{PV1}$ and $I_{C2} = I_{L04} = I_{OB}$ (2)

When both $S_1$ and $S_2$ are on for the duration (d-0.5)T the currents across capacitors $C_1$ and $C_2$:

$I_{C1} = I_{L03} = I_{OA}$ and $I_{C2} = I_{L04} = I_{OB}$ (3)

Current second balance for capacitor C1 is given by

$(I_{OA})0.5T + (I_{OA})(d-0.5)T + (I_{PV1})0.5T + (I_{OA})(d - 0.5T = 0$ (4)

On solving: $I_{OA}/I_{PV1} = -1/(4d-1)$ (5)

Similarly, the upper channel capacitor $C_3$ of the other converter is also contributing the current:

$I_{OC}/I_{PV3} = -1/(4d-1)$ (6)

Thereby the total current present at the output node of the upper port pairs for same irradiation conditions such that $I_{PV1} = I_{PV3} = I_{IN1}$ and $I_{OA} + I_{OC} = I_{O1}$ is:

$I_{O1}/I_{IN1} = -2/(4d-1)$ (7)

The current second balance for capacitor $C_2$ is given by

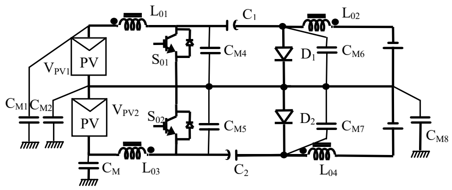

Fig 3a: Equivalent CM circuit for MISCO Converter

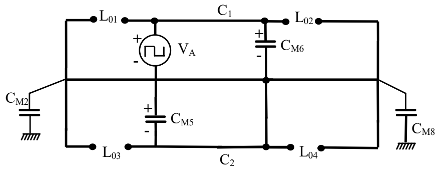

Fig. 3b: When Switch $S_1$ is Operating

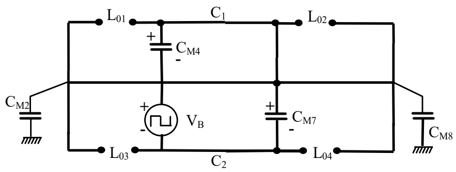

Fig. 3c: When switch $S_2$ is operating

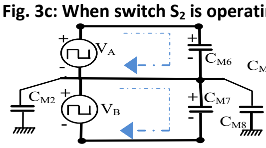

Fig. 3d: Equivalent MISCO circuit for both states

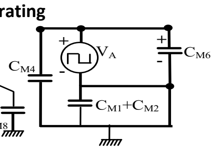

Fig. 3e: Equivalent CUK converter CM circuit

$$(I_{PV2})0.5T + (I_{OB})(d-0.5)T + (I_{OB})0.5T + (I_{OB})(d-0.5)T = 0 \quad (8)$$

On solving: $I_{OB}/I_{PV2} = -1/(4d-1)$ (9)

Similarly, the lower channel capacitor $C_4$ of the other converter is contributing also the current:

$$I_{OD}/I_{PV4} = -1/(4d-1) \quad (10)$$

Thereby the total current present at the output node of the lower port pairs for same irradiation condition when $I_{PV2} = I_{PV4} = I_{IN2}$ and $I_{OB} + I_{OD} = I_{O2}$ is:

$$I_{O2}/I_{IN2} = -2/(4d-1) \quad (11)$$

To analyze and compare the common mode currents in the MISCO with one port pair and CUK Converter the equivalent common mode circuit need to be derived. The stray capacitance formed at various modes of the MISCO converter is shown in Fig. 3a. To simplify the circuit all those components operating with low frequency signals, viz, PV panels following MPPT is considered open circuit, inductors are open circuit for high frequency and bigger capacitors having majority DC components with little ripple as short circuit. A pulsating voltage with the amplitude equivalent to the drain source voltage $V_A$, $V_B$ will appear across the switch in operation. Due to the pulsating voltage the junction capacitance of the switch in other channel will be involved. The stray capacitance will also appear across the open circuited diode in same channel. Accordingly, the equivalent circuit is represented as shown in Fig. 3b, 3c respectively for upper channel and lower channel. The overall common mode equivalent circuit for the MISCO converter with one port pair is shown in Fig 3d. Under the balanced conditions the current flowing through the capacitors in upper and the lower port will be same thus difference voltage imposed on capacitors coupling ground is zero, indicating zero common mode current. While in case of unbalance in currents a differential voltage is created, which would drive the common mode current to the ground current generating in the central limb will flow through the ground. For difference voltage to be lesser the common mode current follows the suit.

For CUK converter the equivalent circuit is represented as Fig 3e, where a large stray capacitance is always present, resulting in large common mode current for any operating condition.

## 5. PERFORMANCE ANALYSIS

The performance of MISCO converter is investigated under same irradiation on each panel with similar irradiation change incident on all panels and with different irradiation condition on panels. Initially with same irradiation (1000W/m$^2$) on each panel, each channel converter carries same amount of current which settles down swiftly at 8.3A without any overshoot as shown in Fig. 3. The PV panels feeding the port pair reach the maximum operating voltage of 35.86V, cumulating to a total of 71.6V at the input port pair with each panel contributing 300W. Series capacitors $C_1$ and $C_2$ assume a voltage of 127V each, affirming balanced operating conditions. The total output current across each of the output side inductors $L_{02}$ and $L_{04}$ is observed as 6.4A. Since the output inductor $L_{03}$ is mutually coupled with input inductors $L_{01}$ and $L_{05}$ while output inductor $L_{04}$ is coupled with input inductors of lower channel $L_{03}$ and $L_{06}$ it offers a power dense solution. The phase shifted current in the input side inductors, of the upper and the lower ports of the port pair (in the zoomed profile) show the interleaved current waveforms.

At t= 0.02s when irradiation transits to 800 W/m$^2$ across all the 4 panels the maximum power generated

TABLE I

| Parameters | Value |
|---|---|
| $V_{MP}$(V) | 35.86V |
| $I_{MP}$(A) | 8.35A |
| $P_{MPP}$(W) | 1200W |
| $f_S$(kHz) | 100kHz |
| L(µH) | 900 µH |
| C(µF) | 10 µF |

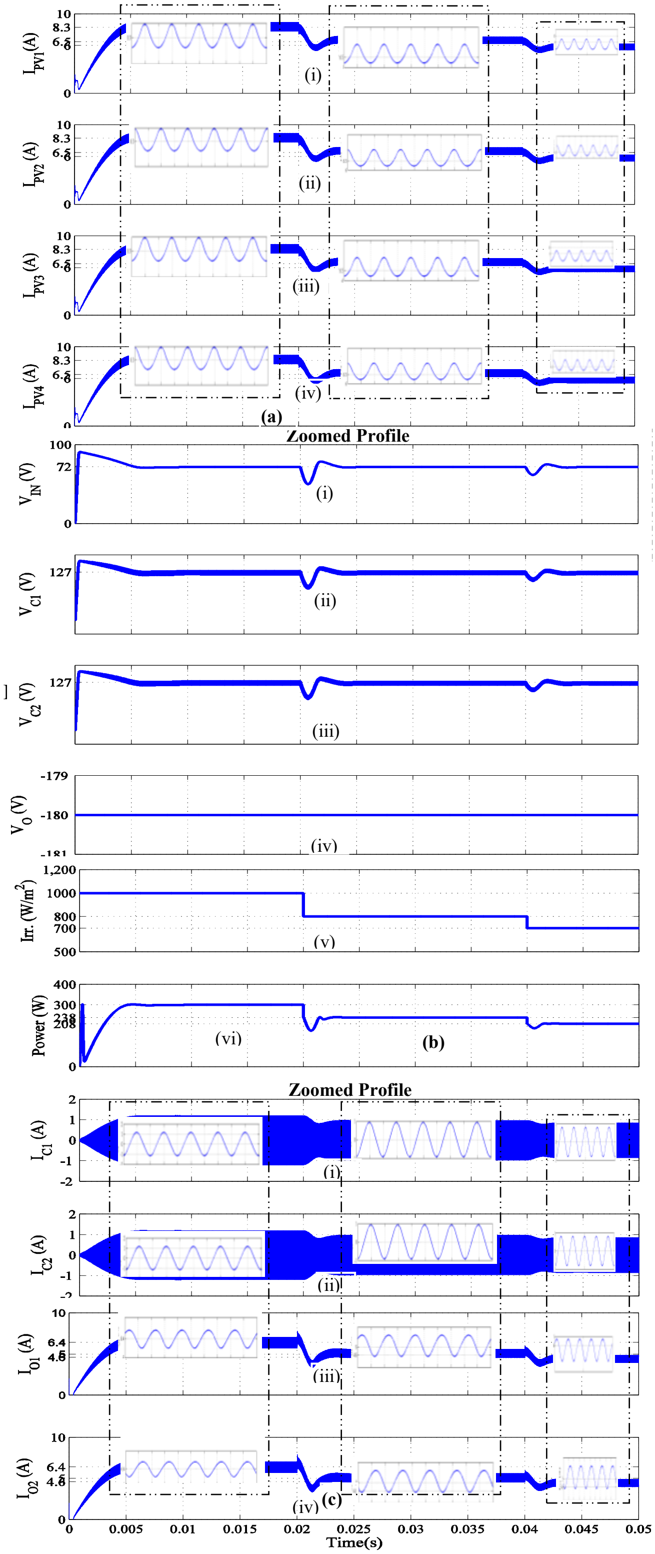


Fig. 4 a,b,c Performance of four channel MISCO converter under similar irradiation on all panels

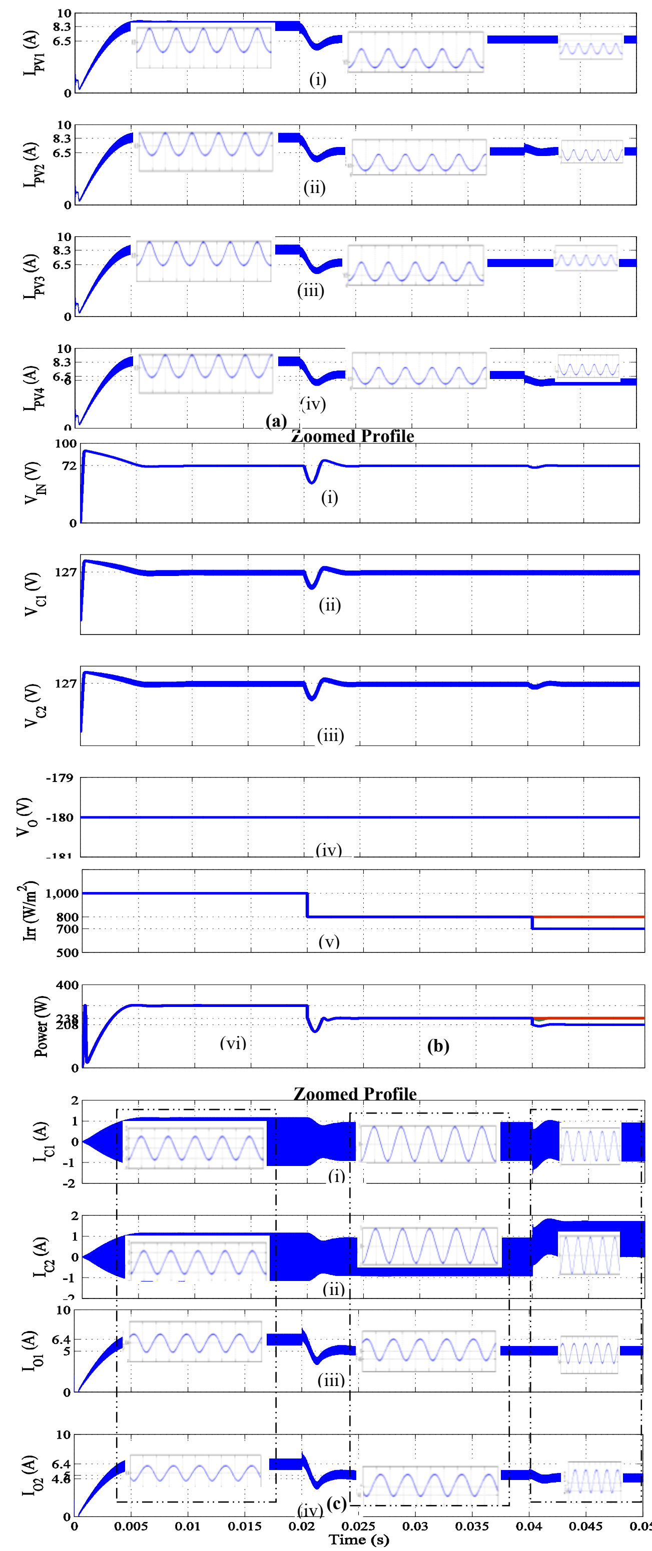


Fig. 5 a,b,c Performance of four channel MISCO converter under similar irradiation on three panels and different irradiance on fourth panel

by individual panel reduces to 238W with a current of 6.6A and the converter feeding 5A to the grid. At t=0.04s when irradiation further droops to 700W/m$^2$ across all the panels, the input current accordingly drops to 5.85A with the contribution of power from individual panel dropping to 208W, 4.6A fed to the grid. Minimal changes are observed in both the input voltage

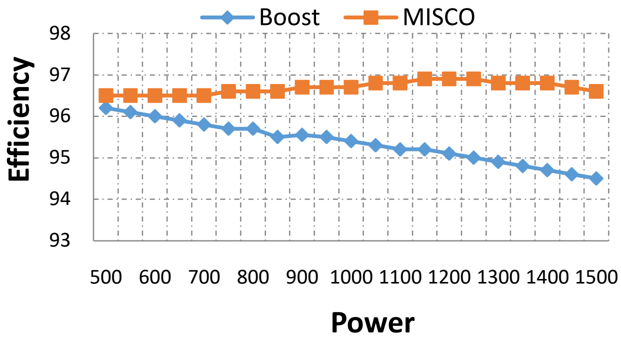


Fig.6 Efficiency v/s Power

and the series capacitors $C_1$ and $C_2$ during irradiation changes.

The performance of the proposed parallel architecture is further tested for insolation change only in one panel depicting unbalance irradiation condition. At t=0.04 secs in Fig.4 when the insolation of three panels are maintained at 800 W/m$^2$ while of the lower port of lower channel panel droops to 700 W/m$^2$. Under this condition the power of all three panels stays at 238W while the fourth moves to and 208W with the input current of 6.6A and 5.85A respectively. The output currents in the lower and upper channels corresponds to at 5A and 4.6A respectively as observed in Fig.5. A unbalance in current with non zero DC current is also seen in the central limb of 2nd channel (Fig.5 (ii)) Since the panels are mounted in close proximation to each other so deviation in the irradiation level will be very less. Hence the MISCO converter exhibits an impeccable solution avoiding the leakage and common mode current suitable for steel mounting structures.

A comparative study is done to highlight the merits of MISCO converter over boost converter. MISCO converter exhibits approximately constant efficiency for wide range of output power while for the same range of operation the efficiency of boost converter decreases as shown in Fig. 6. The comparative study clearly demonstrates the edge of proposed converter over boost converter.

## 6. CONCLUSION

The results demonstrate the proficiency of the proposed architecture while transacting power from source to LVDC-μG. The circuit is tested under sudden irradiation change with symmetrical and asymmetrical irradiation on the channel assuring minimized common mode current within the converter with almost nil inter circulating current. The presence of the sinusoidal ripple current affirms reduction in the EMI noise posing a good solution for battery charging applications. The scalable and modular architecture with mutually coupled input and output inductors of upper channel and lower channel offers an efficient and a power dense solution. The multiport architecture allows higher degree of freedom for interfacing PV panel with each channel ensuring improved reliability.

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