# Analysis of High Gain DC-DC Power Electronic Converter for Maximum Power Point Tracking

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**Abstract -** *DC-DC power electronic converter having voltage enhancing potential for MPPT (Maximum Power Point Tracking) with voltage gain cell using Dickson multipliers is the principal objective of this paper. Low ripple content and improved gain with well-balanced capacitor voltages enables the system to easily integrate with load/grid using any type of inverter topology. A 200W solar panel with 20V output voltage is used by the converter to bring about an output voltage of 400V and system can be merged with single phase inverter topology to produce AC voltage. Theoretical study with simulation analysis and results are verified by MATLAB/SIMULINK software.*

***Key Words***: Renewable energy, Voltage gain, Dickson voltage multiplier cell, Photovoltaics, MPPT

## 1. INTRODUCTION

Expeditiously flourishing global energy demand with increased consumption of fossil fuels adversely affects the environment with atmospheric pollution reaching its peak in the impending years. Renewable energy technologies are an effective remedy for worldwide power generation with less outrushes of greenhouse gases [1]. Among different diversities of renewable resources, solar power provides a viable alternative and energy from sun is clean, boundless, and non-polluting [2]. In photovoltaic (PV) technology, solar energy is directly reformed to direct current (DC) electricity by using photovoltaic panels. The amount of energy generated is proportional to the total amount of solar irradiation falling on the shallow of PV panel and cell characteristics [3]. However, energy generated is dependent on atmospheric variations, mainly solar irradiation and temperature, it is quite laborious to extricate maximum power from panel leading to reduced efficiency. To intensify the system efficiency and to extract maximum power from PV panels, Maximum Power Point Tracking (MPPT) algorithms are used. DC-DC power electronic converters regulate the varying power output of solar panels using MPPT techniques with interconnection to a load or power grid [4]. Step-up converters, primarily nonisolated conventional boost converters and its derived topologies [5], isolated converters [6] are used as a power boosting stage to boost the low PV panel voltage which is typically in the range of 15-45V and injecting boosted voltage to AC/DC loads for profuse applications. Using voltage multiplier cell (VMC) with the boost converter topologies increases overall gain [7] with augmentation in performance and converter configurations with these diode capacitor arrangements are extensively used for renewable energy applications. Voltage multiplier power supplies have been used for many years and [8] analysed a hybrid boosting converter for renewable energy applications. The converter has the collective advantages of gain enhancement from voltage multiplier (VM) and voltage supervision capability from boost converter. It offers relatively low value of voltage build-up in comparison to its VM component count. Converter also has a very large input current ripple in proportion to its average. A Dickson based converter topology with voltage boosting technique for maximum power point tracking is discussed in this manuscript which is an extension of the multiport converter proposed in [9] with high voltage gain and unbroken input current for renewable energy applications. The circuit [9] has high voltage stress on its capacitors as the number of voltage multiplier cells is increased. High step up voltage multiplication based current fed converter produces sufficient voltage accretion without a transformer [10] by using capacitor ladder lattice work. Converter topology has equal voltage stress on all capacitors, but in converse to a Dickson based topology, output resistance increases as the number of voltage multiplier stages is increased resulting in reduction of converter performance. An improved converter topology of [11] was designed using interleaving boost stage and Dickson VMC stage. Amended Dickson cells have lower voltage stress on passive semiconductor components, but output capacitor has high voltage stress and converter only operates for odd number of voltage multiplier cell stages. Converter topology in [12] uses Greinacher voltage multiplier cell, suitable for interfacing renewable energy sources, but circuit is not extensible and has reduced efficiency. Dickson based converters discussed above only deals with precise converter study with gain and stress analysis, but not explain how to magnify the power output from solar energy.

In this paper, a DC-DC step-up converter based on a two phase boost stage and voltage gain cells using 180$^{o}$ shifted Dickson topology cascaded with solar panel is designed. MPPT algorithm is investigated to maximize the power obtained from the system.

Proposed system designed and modified with four stage diode-capacitor voltage gain cell arrangement ensures minimum voltage stress on passive components as the number of stages/ levels is expanded. Equal current sharing is attained with symmetric duty cycle on two phases and converter ensures around 400V output voltage for 20V input voltage using a 200W PV panel. Section II describes the block diagram of the proposed system with a brief review of PV system and MPPT algorithm used. Section III gives the detailed study of converter topology and section IV deals with the simulation analysis. Section V gives the conclusion of the paper.

## 2. PHOTOVOLTAIC INTEGRATION

### 2.1 Proposed Topology for MPPT

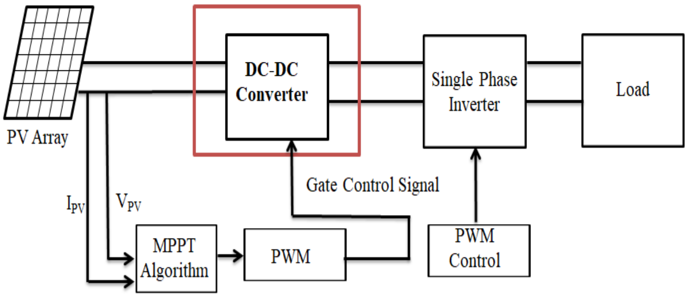


**Fig - 1**: Designed PV system

Fig-1. exhibits the block diagram of the proposed system for PV applications with MPPT. High gain DC-DC converter is the integral component of the system regulated and controlled by MPPT algorithm and PWM (Pulse Width Modulation). Modified Converter with Dickson multiplier arrangement produce high gain and maximum power output is obtained for any accessible solar irradiation. Inverter topology is used to convert DC voltage to AC voltage for load integration.

### 2.2 Photovoltaic Systems and essentials for MPPT

Rising demand for clean energy source with sun's potential as a free energy source, solar photovoltaic systems are widely used and demand for efficient solar cells for conversion of sunlight to electricity are growing faster. The main electrical characteristics of a PV cell are identified from the relationship between voltage and current produced on a typical solar cell V-I characteristics in response to temperature and atmospheric irradiation. The intensity of solar radiation that strikes the cell controls the current, while increase in the temperature of solar cell reduces its voltage.

Fig-2. shows the V-I and P-V characteristics of 200W panel used in this analysis at 1000W/m$^2$ insolation and specified temperature of 25$^o$C. From the P-V curve it is transparent that power is directly proportional to voltage, but with rise in voltage power varies and decreases to zero.

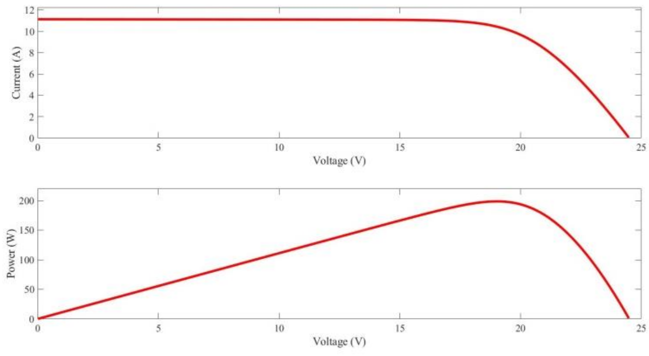


**Fig- 2:** V-I and P-V characteristics of 200W PV panel at 1000W/m$^2$ and 25$^o$C

Due to erratic characteristics of a photovoltaic system, a typical solar panel converts only 30-40% of the incident solar irradiation into electrical energy. In order to extract maximum power from a solar panel and to refine the efficiency of PV panel, maximum power point tracking is used.

### 2.3 MPPT Algorithm

According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit i.e. source impedance matches the load impedance. Hence the problem of tracking the MPP (Maximum Power Point) reduces to an impedance matching problem. Converter topology used in the source side is connected to a solar panel in order to enhance the output voltage for disparate applications. By changing the duty ratio of the converter, source impedance can be matched with the load impedance.

Among different MPPT algorithms, P and O method is used in this paper, because of its ease of implementation and cost of execution is very less. Only one voltage sensor is used in this method and time complexity of algorithm is very less. Maximum power point is tracked based on voltage and current sensing and controller requisite calculation of power and voltage to track maximum power point. If voltage is perturbed in one direction and power continues to increase, then algorithm keeps on perturbing in same direction. If new power is less than previous power, then agitated in opposite direction. When output power reaches maximum power point, there is oscillation around MPP.

## 3. DESCRIPTION OF CONVERTER TOPOLOGY

The high gain converter topology for maximum power point tracking is the interconnection of two phase boost stage and VMC arrangement with Dickson cells rotated by 180°.

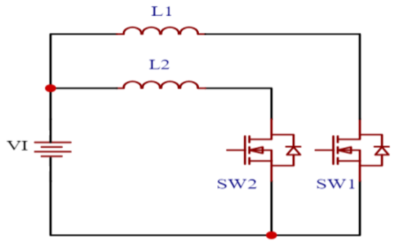


**Fig- 3.** Two phase boost stage

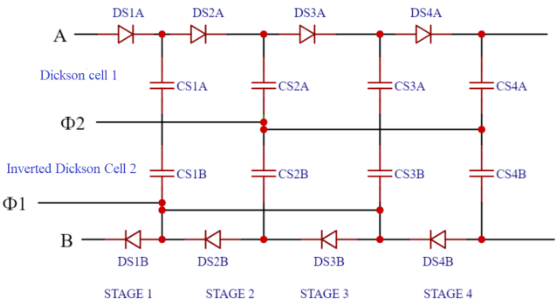


**Fig- 4.** VMC arrangement

Fig- 3. shows the two phase boost stage of the converter topology comprising of two inductors and two switches connected to the input source. This interleaved boost stage decreases the ripple content and ensures equal current sharing to the converter. It stores energy and releases to the Voltage gain cells. Fig- 4. indicates the next phase of the converter topology, 180° inverted Dickson voltage multiplier cells connected to the two phase boost stage. A four stage VMC arrangement is constructed by employing two normal Dickson voltage gain cells and inverting lower cell by 180°. Thereby, phase $\Phi_1$ of the top unit is connected to phase $\Phi_1$ of the lower unit (similar manner for phase $\Phi_2$) and the capacitors of the two stages are connected in a phase shifted manner. This arrangement is recognized as Bi-fold Dickson VMC network [13]. Basic converter topology for PV applications is shown in Fig- 5. with solar panel as input source to the two phase boost stage and VMC stages. A high voltage heaving is produced by the diode-capacitor network with reduced magnetic requirement on account of two phase boost stage. Requisite output voltage with high gain is produced by cutback in voltage stress by capacitors in each stage. Let the number of stages be $S_1$, $S_2$, $S_3$ and $S_4$ for a four stage VMC arrangement constructed by diodes and capacitors. In the circuit representation, $S_{W1}$ and $S_{W2}$ are the two switches of the interleaved stage with inductors $L_1$ and $L_2$. Each stage contains a voltage multiplier cell with capacitors $C_{S1A}$, $C_{S1B}$, $C_{S2A}$, $C_{S2B}$, $C_{S3A}$, $C_{S3B}$, $C_{S4A}$, $C_{S4B}$ and diodes $D_{S1A}$ to $D_{S4B}$. Converter mainly operates in three modes and gate signals with 180° phase change are given to the converter switches with identical duty ratio shown in Fig- 6.

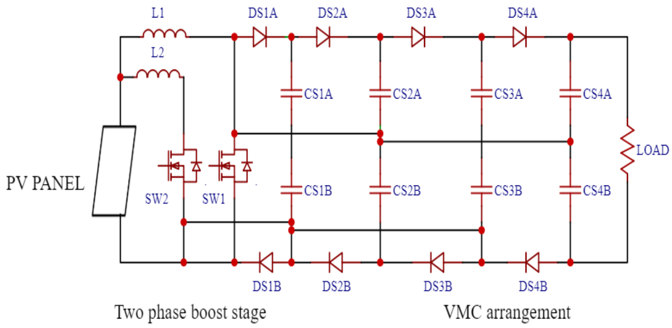


**Fig- 5.** Circuit representation of PV solar converter

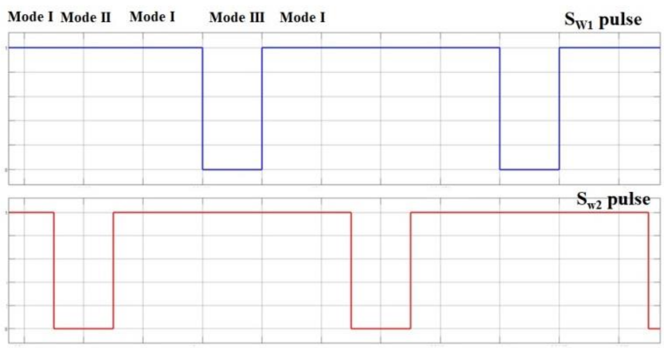


**Fig- 6.** Switching signals

### 3.1 Modes of operation

1) Mode I: - In first mode, $S_{W1}$ and $S_{W2}$ are in operation with input source transferring energy to both inductors $L_1$ and $L_2$. All the diodes in the VMC arrangement are reverse biased and end line capacitors $C_{S4A}$ and $C_{S4B}$ gives the equivalent output voltage across the load, $R_L$. Solar panel is the input source with $V_{PV}$ as panel output voltage.

2) Mode II: - In second mode of operation, $S_{W1}$ is ON and $S_{W2}$ is OFF. $L_1$ is perpetually charged by the input source in this mode and energy in $L_2$ is discharged to the VMC point. Diodes $D_{S1B}$, $D_{S2A}$, $D_{S3B}$ and $D_{S4A}$ are forward biased while other set of diodes are OFF. Capacitors $C_{S1B}$, $C_{S2A}$ and $C_{S3B}$, $C_{S4A}$ are charged by $L_2$ and panel voltage $V_{PV}$. Mode I pursue after mode II operation and then converter swaps to mode III.

3) Mode III: - After mode II operation, $S_{W1}$ is OFF and $S_{W2}$ is still ON in mode III. $L_2$ is charged by the input source in this mode and energy in $L_1$ is discharged to the VMC point. Diodes $D_{S1A}$, $D_{S2B}$, $D_{S3A}$ and $D_{S4B}$ are forward biased while other set of diodes are OFF. Capacitors $C_{S1A}$, $C_{S2B}$ and $C_{S3A}$, $C_{S4B}$ are charged by $L_1$ and $V_{PV}$. Mode III is just the converse of mode II.

### 3.2 Analysis of converter topology

For inductors $L_1$ and $L_2$, the average voltage across the inductors according to volt-sec balance of boost inductors can be noted as

$$< v_{L1} > = < v_{L2} > \quad (1)$$

The capacitor voltages in each VMC stage is given as

$$V_{CSNA} = V_{CSNB} = \frac{S_N \, X \, V_{PV}}{1-D} \quad (2)$$

where, $S_N$ is the no of voltage multiplier stages, with $V_{PV}$ as the panel voltage and D is the duty ratio. From the above equation, first stage capacitor voltage is given by,

$$V_{CS1A} = V_{CS1B} = \frac{V_{PV}}{1-D} \quad (3)$$

The second stage capacitor voltage is expressed as,

$$V_{CS2A} = V_{CS2B} = \frac{2V_{PV}}{1-D} \quad (4)$$

The third stage capacitor voltage is given as,

$$V_{CS3A} = V_{CS3B} = \frac{3V_{PV}}{1-D} \quad (5)$$

Finally, fourth stage capacitor voltage is,

$$V_{CS4A} = V_{CS4B} = \frac{4V_{PV}}{1-D} \quad (6)$$

For a four stage VMC, output voltage is the sum of voltages in the end-line capacitors, i.e.

$$V_O = V_{CS4A} + V_{CS4B} \quad (7)$$

$$V_O = \frac{2 \, X \, S_N \, X \, V_{PV}}{1-D} \quad (8)$$

where, $V_{PV}$ is the panel output voltage and $V_O$ is the output voltage. Hence, the resultant voltage gain of the proposed system with $S_N = 4$ is,

$$\frac{V_O}{V_{PV}} = \frac{2 \, X \, S_N}{1-D} \quad (9)$$

$$\frac{V_O}{V_{PV}} = \frac{2 \, X \, 4}{1-D} = \frac{8}{1-D} \quad (10)$$

From the above equation, it is transpicuous that voltage gain of the system counts on the number of voltage multiplier diodes and capacitors.

## 4. SIMULATION ANALYSIS AND RESULTS

MATLAB/SIMULINK software environment with Ode23 solver is used to simulate the converter for maximum power point tracking. Simulation parameters are listed in Table -1. Converter operates at a switching frequency of 50 kHz and duty ratio greater than 50% as one of the switches must be ON at any point of time. Literally converter can operate with single and two separate solar panels. Simulation results are validated by using one PV panel as input source.

**Table -1:** Simulation Parameters

| Parameters | Values |
|---|---|
| Input voltage | 20V |
| Output voltage | 400V |
| Ideal duty cycle | 0.6 |
| Switching frequency | 50 kHz |
| Inductors $L_1$ and $L_2$ | 100 µH |
| VM capacitors | 10 µF |
| Load resistance | 800 Ω |

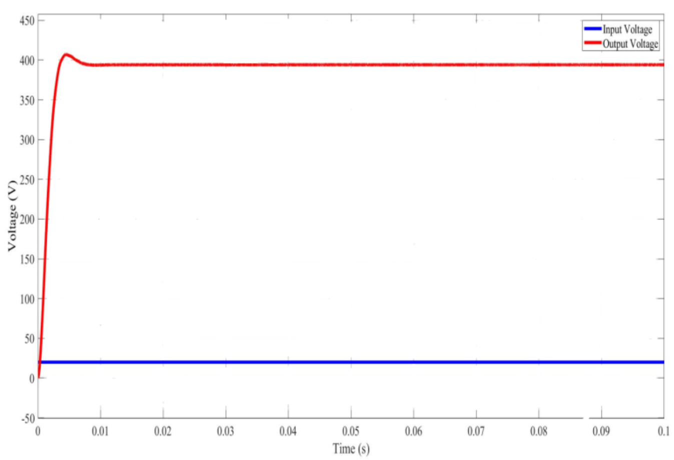


**Fig-7.** Input and output voltage of converter

Fig-7. shows the input and output voltage of the converter topology after open loop simulation. Input voltage is 20V and output voltage level is boosted to 400V. Interleaving technique produces a high output voltage with reduced ripple content. Output current of the converter is about 0.47A and voltage stress across the components used in the circuit are detailed below.

### 4.1 Maximum power point tracking

A 200W solar panel with 20V output voltage is integrated with the converter topology for obtaining maximum output voltage through MPPT. An irradiance of 1000W/m2 and specified temperature of 25°C is selected depending on the irradiance and temperature requirements. Table-2. gives the details of PV panel used for simulation work. Simulation results for PV system after MPPT are detailed below.

**Table -2:** PV panel specifications

| Parameters | Values |
|---|---|
| Solar panel | 200W |
| Open circuit voltage ($V_{oc}$) (V) | 24.5V |
| Voltage at maximum power point($V_{mp}$)(V) | 19.01V |
| Short circuit current($I_{sc}$)(A) | 10.96A |
| Current at maximum power point($I_{mp}$)(A) | 10.52A |
| Irradiance | 1000W/m$^2$ |
| Temperature | 25°C |

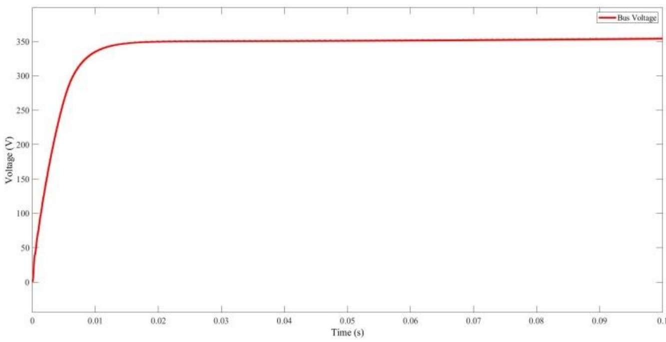


**Fig- 8.** Output voltage after MPPT control

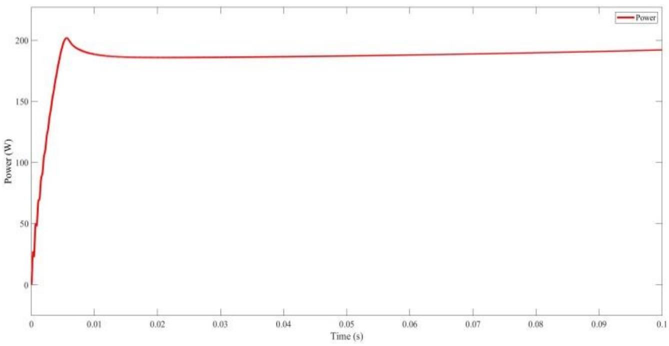


**Fig- 9.** Output power after MPPT control

Fig-8. illustrates the maximum output voltage of the converter topology after connecting it to the MPPT controller circuit. So, it can be inferred that MPPT controller circuit conveniently tracks the maximum voltage and gives it as 350V. Similarly, Fig- 9. outlines the maximum power obtained after MPPT control from the converter and it is approximately anticipated as 200W.

### 4.2 COMPONENT STRESS

This section clearly examines the voltage stress across the passive semiconductor devices used in the circuit.

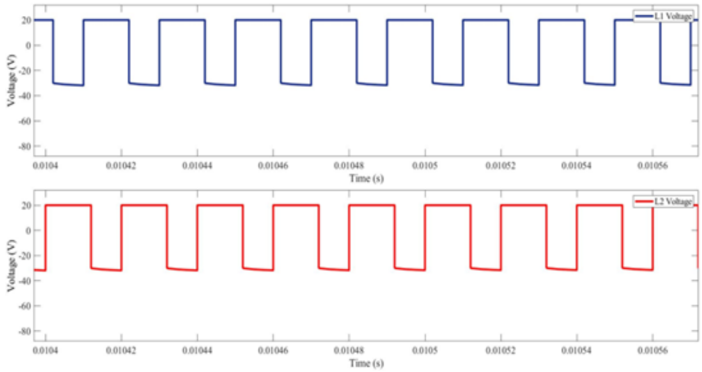


**Fig -10(a).** $L_1$ and $L_2$ voltage stress

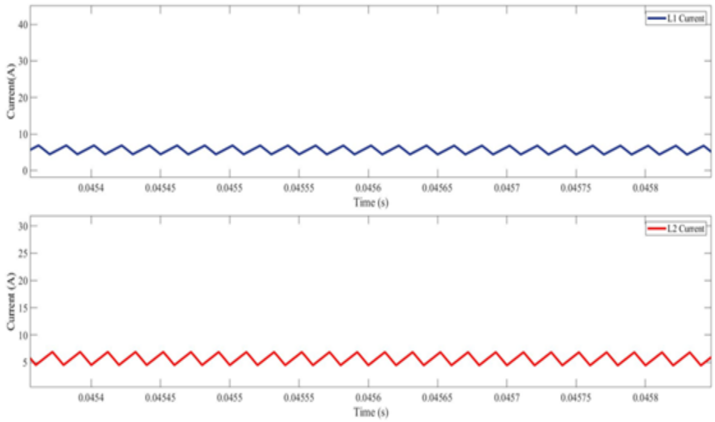


**Fig -10(b).** $L_1$ and $L_2$ current stress

Voltage stress across two inductors is about 50V and $L_1$ and $L_2$ has equal current sharing of 5A, Fig-10(a), (b). Diode voltage stress and capacitor voltage stress of the voltage gain cell arrangement are depicted in Fig-11, 12.

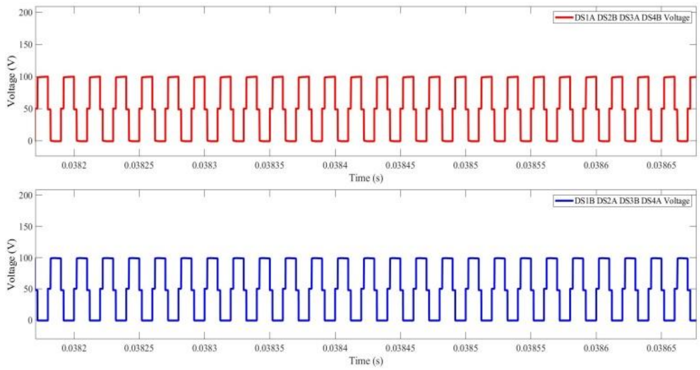


**Fig-11.** Diode voltage stress of each VMC stage

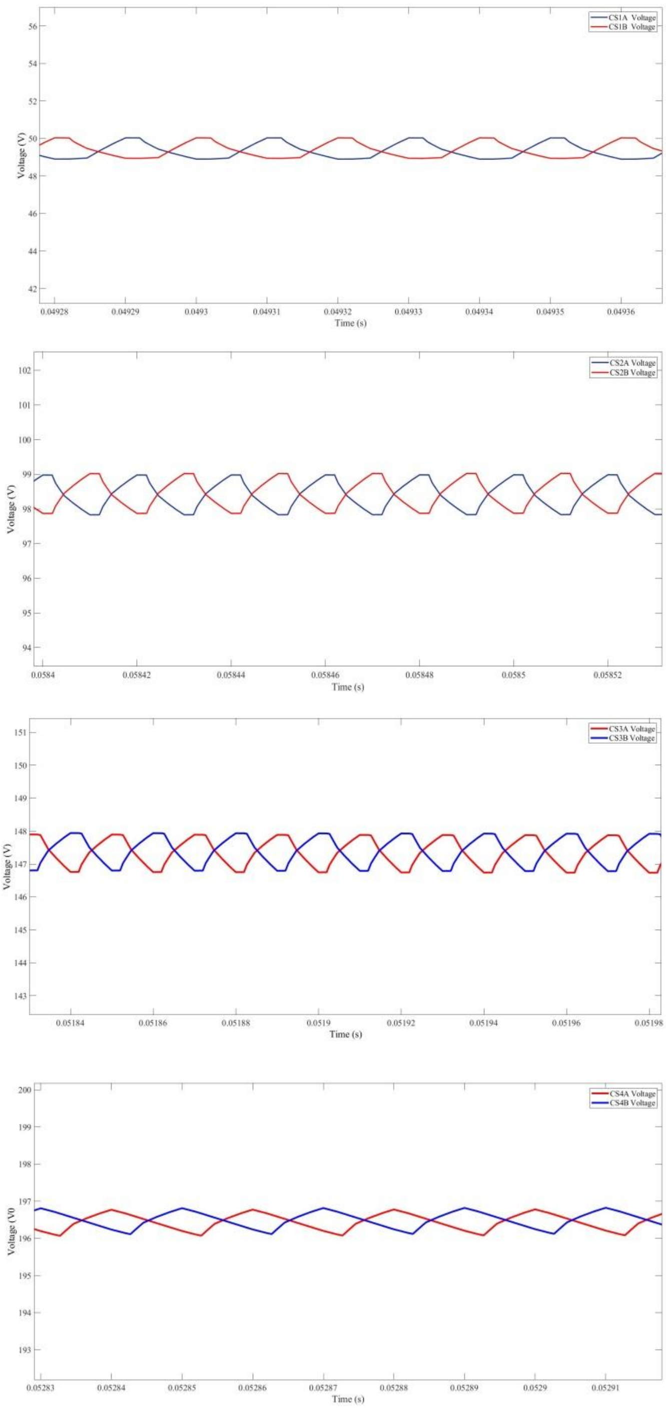


**Fig-12.** Capacitor voltage stress of each VMC stage

## 5. CONCLUSION

In this paper, a high voltage gain DC-DC converter with 180° inverted Dickson topology for photovoltaic applications is presented. Voltage stress across the passive components and diode-capacitor network decreases as the number of gain cells is increased with ripple retraction in each stage. Therefore, converter does not entail a filter and high gain is achieved with a four stage converter. Maximum power point tracking is perfectly achieved by the converter. Converter is effectively used in unification of solar panels to the 400V distribution bus in telecom centers, power data centers, super computers, micro grids etc. with maximum power extraction. The system integrating with inverter topology can be used for AC applications as well.

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