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An ultra-high gain boost converter with reduced switching voltage stress for PV applications integrated with cv control

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Abstract

In this report an ultra-high gain boost converter is proposed with ten times gain achieved at the output with operating loads in the range of 200-400W. The converter is incorporated with two high frequency switching capable MOSFET switches. The converter is included with only one boosting inductor which charges and discharges as per duty cycle of the MOSFET switches. The input to the converter can be lower voltage sources like PV panel or battery which need high voltage gain for operating the loads. The PV panel is considered to be lower voltage source which operates as per the solar irradiation amplitude. As the solar irradiation is unpredictable the voltage and the current of PV array also varies which needs to be stabilized. This is achieved by feedback loop CV control with voltage reference. The CV control stabilizes the output voltage of the converter and maintains at given reference value for variable input voltage source. The graphs and results are generated with different operating conditions using MATLAB Simulink software.

Keywords: Ultra-high gain; MOSFET (“Metal Oxide Semi-conductor Field Effect Transistor”); PV (Photo Voltaic); CV (Constant Voltage); MATLAB Simulink

1. Introduction

DC microgrids will play a crucial role in the next-generation intelligent power distribution system because of their ability to seamlessly include various forms of distributed renewable energy production, energy storage, electric vehicles, and the other electric loads. Recently, “dc-dc converters” have been the subject of much study and implementation due to their central role in enabling energy transmission across the individual components of a dc micro grid . Isolated converters provide both electrical isolation and “high voltage gain” by using transformers with the appropriate turn ratio. In [4], the "isolated boost converter” with soft switching and adjustable gain extension is proposed by combining a snubber that recovers energy with a bipolar voltage multiplier. With a decreased active switch, more passive components, and no snubber circuit, [5] analyzes the “three-switch isolated boost converter” that accepts a “continuous input current”. Non-isolated applications will see an increase in system volume, cost, and weight due to the chosen transformer.

One common dc-dc converter architecture uses a pair of inductors to change the voltage. Two types of the “transformer less boost converters” with reduced ripple are shown in [6] and [7], both of which make use of an interleaved method. The former converter is more dynamically responsive but less efficient, whereas the later has a narrow duty cycle and switches at zero current. In [8], a “three-winding coupled inductor converter” with two hybrid voltage multiplier cells is introduced. In [9], the author examines the effects of combining several switched-capacitor methods with a connected inductor to create a boost converter. In [10], a variety of the "hybrid boost converters” are investigated and examined that are derived from the combination of a boost cells, linked inductor, voltage multiplier, switching capacitors & LC

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filter cells. All of the single-switch converters described in [8]–[10], although additional passive components are required for their construction.

Numerous advanced dc-dc converters are evaluated, all of which make use of the switched-network cell architecture. In [11], a boost converter with tiny input ripple, the "common grounded terminals", and restricted step-up gain is examined by combining a diode-capacitor circuit with a boost and a "single ended primary inductor converter" (SEPIC). A single-switch boost converter with a floating output terminal is shown in [12] by using a "switched-capacitor multiplier" and an integrated LC2D network. Dual-switch boost converters using switched-capacitor cells are examined in detail. The "dual-switch boost converter" described in [13] features a high step-up gain and a single-inductor design with a floating output voltage. While its topological construction is complicated, the "dual-switch boost converter" in [14] achieves substantial voltage gain. Both [15] and [16] examine two types of boost converters that use the "interleaved structure" &"modified Dickson voltage multipliers" to achieve significant voltage gains with low input ripples. These two topologies share nothing except their input and output terminals. Using active-passive inductor cells of two different kinds [17], [18] build boost converters with modular designs. The boost converter is investigated in [19] that use both a switched capacitor and inductor network, respectively, to achieve the desired effect. There is a family of boost converters reported in [20] that combines "switched-capacitor"/"switched-inductor cells" with the conventional switched-boost network. A boost converter is investigated in [21], where it is shown to be depending on the "passive switched-capacitor network" and an "active switched-inductor network". However, converters in [17]-[21] have discontinuous input currents and no common ground between the input and the output terminals. [22] uses a passive switched-network cell to build and improve upon a negative output boost converter. Using two charge pump cells and a switching inductor, [23] describes a boost converter. This converter uses six switches and has three modes of operation to deal with the discontinuous current it receives.

Constructing converters using "Z-source" or "quasi-Z-source structures" is also an efficient way to get better features. Two distinct types of Z-source boost converters with grounded input and output terminals are described in [24, 25]. These two converters have a few drawbacks, including low voltage gain and a "discontinuous input current". By recombining classic Z-source networks in novel ways, [26] introduces a series of hybrid "Z-source boost converters". Despite the complexity of their topological topologies, these converters are able to reach high conversion ratios in low duty cycle regions. In [27], a boost converter using the "switched-capacitor" and the "quasi-Z-source topology" is proposed. In [28], two types of boost converters are shown that combine the Z-network with the switched-capacitor approach. Despite having similar ground connections, voltage gains in converters in [27] and [28] are insufficient. Analysis of the "quasi-Z-source boost converter" using a switched-capacitor/switched-inductor hybrid topology yields better step-up gain without a common node between the input and output terminals [29]. Improved quasi-Z-source converter using a switched inductor is shown in [30]. Although its duty cycle range is small, this boost converter shares a grounded design and has a strong step-up gain.

Using the "Sheppard-Taylor structure" [31] and the "switched-capacitor approach", a "single-inductor boost converter" (SLBC) is described and investigated in this work. The SLBC's primary benefits lie in its "ultrahigh voltage boosting capability", reduced voltage stress on the switches, and intrinsically low duty cycle, all of which serve to boost the system's efficiency. Additionally, the SLBC's single-inductor structure allows for a consistent input current and the high power density, and its grounded terminals help to eliminate du/dt issues and ensure reliable output

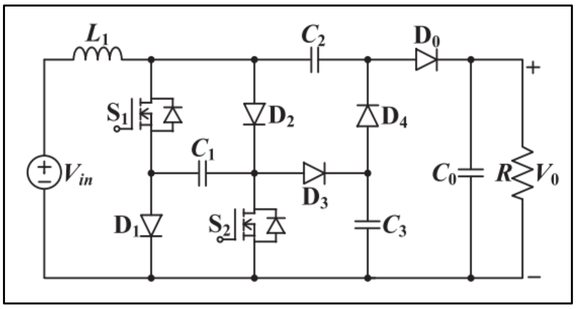


Figure 1 Topological structure of the SLBC

1.1. Proposed high gain converter

As can be seen in Fig. 1, the SLBC has a fifth-order structure with one input inductor L1, three intermediate capacitors C1 through C3, & one output capacitor C0. Two synchronously controlled switches, S1 & S2, four intermediate diodes, D1 through D4, and one output diode, D0, make up the SLBC's semiconducting components. Figures 2 and 3 show the analogous circuits and time-domain waveforms for the SLBC's two states in CCM, which are based on the control actions (ON-OFF) of the switches.

1.2. A. Operational Principles: State 1

Figure 2(a) depicts a time period during which the two synchronously controlled switches S1 and S2 and the

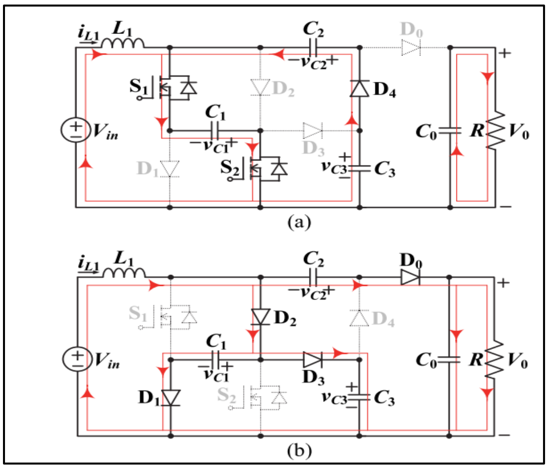


Figure 2 Equivalent circuits of the SLBC. (a) State 1. (b) State 2

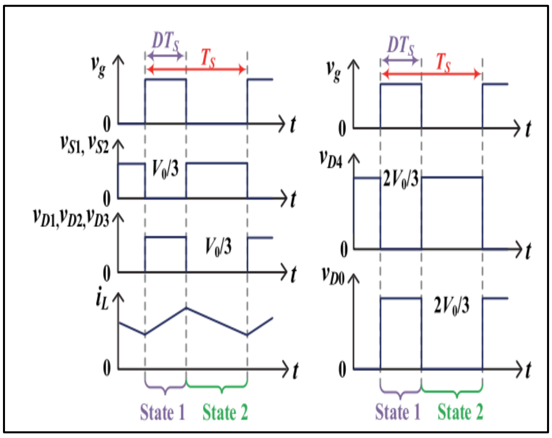


Figure 3 The waveforms of SLBC in CCM

intermediate diode D4 are all ON while the other diodes are OFF. In state 1, the SLBC uses three circuit loops: Magnetizing L1 is Vin and C1 via switches S1 and S2, mid-capacitors C1 and C3 releasing energy for C2 through switches S1, S2, and D4, and the last capacitor C0 releasing energy for the resistive load R.

1.3. State 2

As can be seen in Fig. 2(b), at this time just the output diode D0 and the intermediate diodes D1 through D3 are ON, while the other switches and diodes are OFF. In state 2, the SLBC has three circuit loops: Vin and L1 provide energy to C1 through D1 and D2; Vin and L2 send energy to C2 via D1 and D2.L1 provides power to C3 via D2 & D3; Vin, L1, and C2 provide power to C0 and R through D0.

Once these parameters have been accounted for in the model of the converter, the duty ratio controller is constructed to regulate the MOSFET switch. Below in fig.2 you can see an example of a voltage-oriented control system using a PI controller.

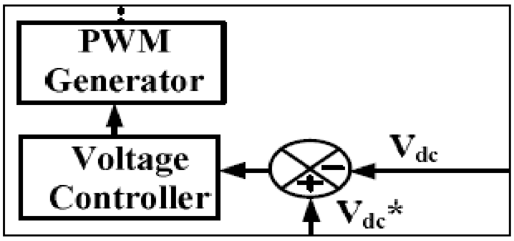


Figure 4 Voltage oriented control

For optimal converter functioning, the voltage controller in a traditional system is often assumed to be a PI (Proportional Integral) gain controller. The difference between the nominal DC voltage and the actual DC voltage is used as input to the voltage controller, which in turn produces the duty ratio.

Pulses for a MOSFET may be formed by comparing the duty ratio (which is dynamic with regard to change in measured voltage) to a saw tooth or triangular waveform. When the duty ratio is raised, more current flows through the MOSFET, leading to a higher output voltage; lowering the duty ratio has the opposite effect.

PI stands for "proportional integral" and is a hybrid of the P and I controllers. Block diagrammatic representation of the PI control system is shown in Figure 9. “PI controlling system” is composed of the control signal, $U(s)$, error signal, $E(s)$, reference signal, $R(s)$, disturbing signal, $D(s)$, output response signal, $C(s)$, and transferring signal of a system $G_p(s)$ and $G_c(s)$. In theory, the PI controller performs as shown in the following equation:

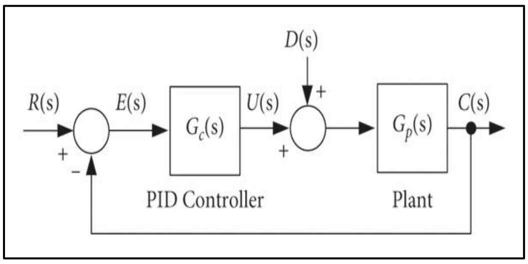


Figure 5 Operation diagram of the PI controller.

The PI controlling system is shown in Figure. The output response of the “four-phase interleaved boost converter system” is quick, but it is not stable. The PI controller is preferable because of its reduced error stability and quicker reaction times. This system would benefit greatly from the implementation of a PI controller.

As can be seen in Figure 10, PI controller design makes use of PSO search to regulate the voltage of the “four-phase interleaved boost converter” to determine its optimal value.

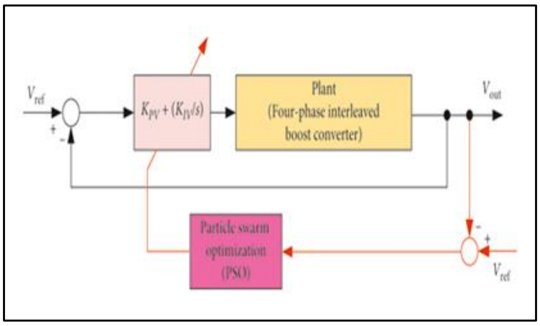


Figure 6 The schematic depicts the PSO search being used as part of the PI controller design to regulate the voltage in a four-phase interleaved boost converter circuit

Photovoltaic Cell: One way that light may be converted into electricity is via the use of a special kind of diode called a "photovoltaic cell." The normal operating state for them is one of reverse bias. It is comparable to a solar cell in that they share certain fundamental operating principles but are otherwise somewhat different

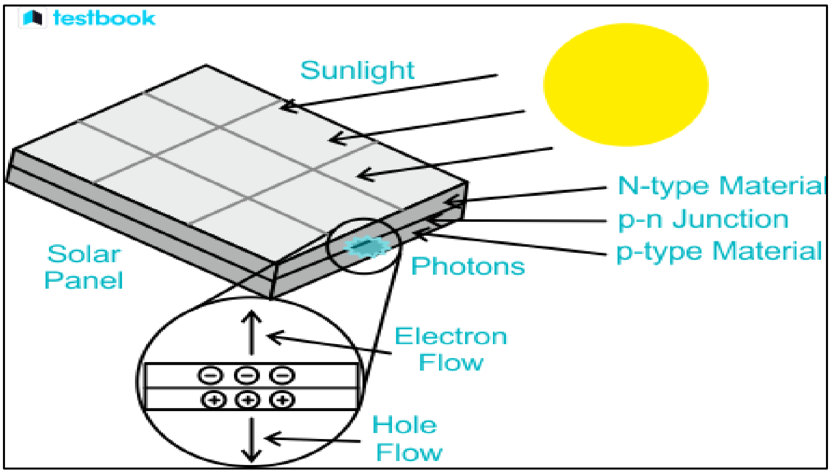


Figure 7 Solar cell working

An example of a photovoltaic cell, such as those used in solar panels, is seen in cross section above. The cell has a P-type material, an N-type material, and a PN junction diode. This layer stores the sun's rays until they can be transformed into usable power. The N-type layer is the initial layer of a semiconductor device and is also called the emitter layer.

PN junction diodes consist of a P-type base layer and an N-type upper layer. The cell's surface is coated with an anti-reflective substance that absorbs light and prevents it from escaping the cell. The substance from which the conductor is constructed may entirely cover the bottom layer, the final one.

1.4. Photovoltaic Cell Working Principle

A photovoltaic cell is similar to a diode in that it only generates forward bias current when an electric current is allowed to flow in one direction and is blocked when it attempts to reverse itself.

When photons from an external light source strike a cell's surface, the semiconductor absorbs them and releases electron-hole pairs, creating a DC voltage.

The primary goal of a solar cell is power production, whereas the primary goal of a photovoltaic cell is electricity generation, hence the solar cell's junction area is significantly larger.

This electron-hole pair generation occurs in the depletion zone of a diode if the incoming energy (hv) is larger than the energy gap of that semiconductor material.

When this photon of radiation from the outside world strikes the diode, the neutrality of the conductor is broken up because of the presence of these electron-hole pairs. Electrons moving from the P-side to the N-side, thanks to the presence of an external current channel, create a DC current, the strength of which is proportional to the intensity of the incoming radiation.

This is the working of a photovoltaic cell.

1.5. Advantages and Disadvantages of Photovoltaic Cell

The Advantages and Disadvantages of using a photovoltaic cell are listed below.

1.5.1. Advantages

They are environmentally friendly since they provide renewable energy.

- Reasonable servicing prices.
- It's a sustainable kind of energy that's readily accessible.
- They are more durable and less likely to lose efficiency over time.
- Reduces or eliminates ambient noise.
- As long as there is adequate sunshine, they can produce power in any location.

- Has the potential to end the global energy problem.

1.5.2. Disadvantages

- Large-scale installation of solar cells lacks the necessary supporting infrastructure.
- Setting up is more costly, but the maintenance expenses are quite modest.
- Photovoltaic cells can only power low-power, low-energy devices at the moment, therefore they aren't practical for widespread use.
- Transmission over long distances with photo voltaic is challenging.
- They are simple to damage and delicate.

1.5.3. Application of Photovoltaic Cell

Some main applications of photovoltaic cells are as follows.

- It can be used to construct solar farms, which in turn might produce several gigawatts of power.
- Photovoltaic cells would be a more efficient source of power delivery in areas with challenging topography.
- Adaptable to various meters and other self-contained devices.
- Primary energy source for space missions and experiments because of its portability.
- Instruments to help in navigation.

2. Simulation results and outputs

The proposed ultra-high gain converter is modeled in Simulink environment using block from Simulink library power system block set. The circuit is modeled using passive elements from 'elements' block set and MOSFETs used from power electronic block set. The input conventional DC source of the converter is replaced with PV array block representing solar panel source. The parameters of the converter are given in table below.

Table 1 Circuit parameters

Name of the parameter	**Value**
Input voltage: Vin	30 V
Output voltage: V0	300 V
Output power: P0	250 W
Switching frequency: fS	30 kHz
duty cycle D	0.35
resistive load R	360 Ω

As per the given parameters the circuit is updated accordingly with PV panel at the input using the below parameters.

The modeling of the proposed circuit with the given parameters is shown in figure below.

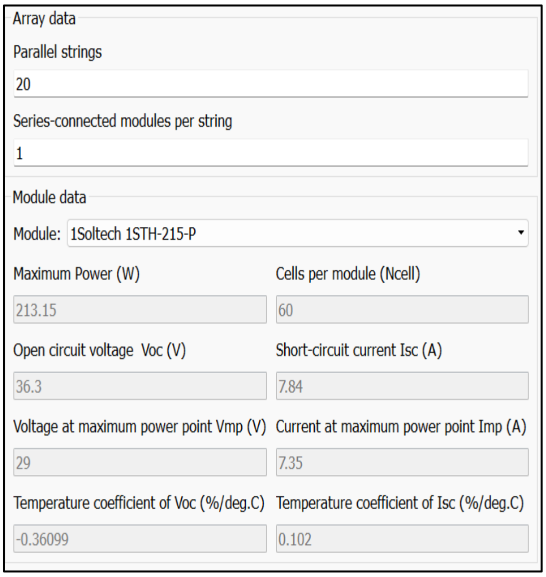


Figure 8 PV array parameters

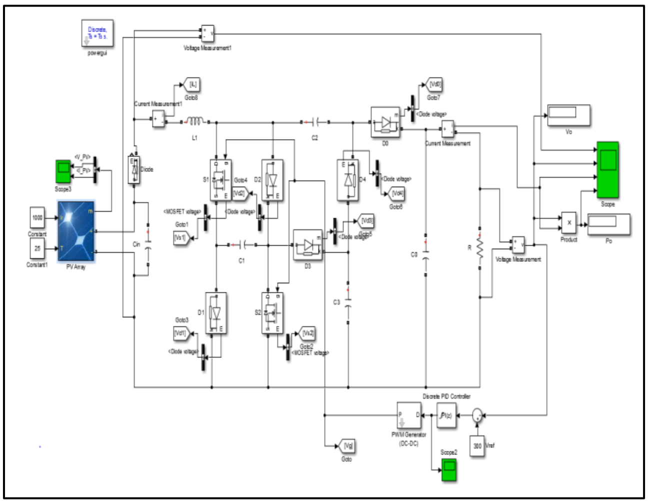


Figure 9 Ultra-high gain converter modeling with PV array input source

The modeling is run for a time of 1sec and the results of the passive elements, source, load and the controller are shown for different operating conditions. Initially the solar irradiation is considered to be optimum and stable at 1000W/mt2 and the other condition is variable solar irradiation with respect to time.

Constant optimum solar irradiation at 1000W/mt2. The below are the graphs of PV array characteristics with respect to time for the given parameters

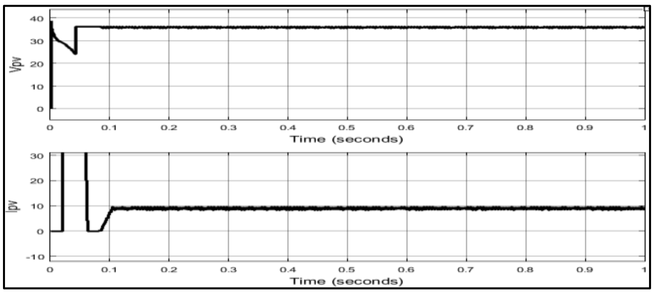


Figure 10 PV array characteristics with constant optimum solar irradiation

As observed in the above graph the PV voltage is recorded at 35V and current at 9A. The total power PV injected to the converter is calculated as

Ppv = 35V * 9A = 315W

The below are the graphs of the voltages and currents of the active and passive elements of the converter with input voltage 35V from PV array.

The above graphs are gate pulse to MOSFET switches (Vg), Voltage across the MOSFET switches (Vs1 Vs2), Voltages across the diodes (Vd1 Vd2 Vd3 Vd4 Vd0), Inductor current (iL). The voltage across the switches doesn't have any voltage overshoots and doesn't create any voltage stress on the switches. The inductor current is continuous which charges and discharges as per the duty ratio of the MOSFET switches.

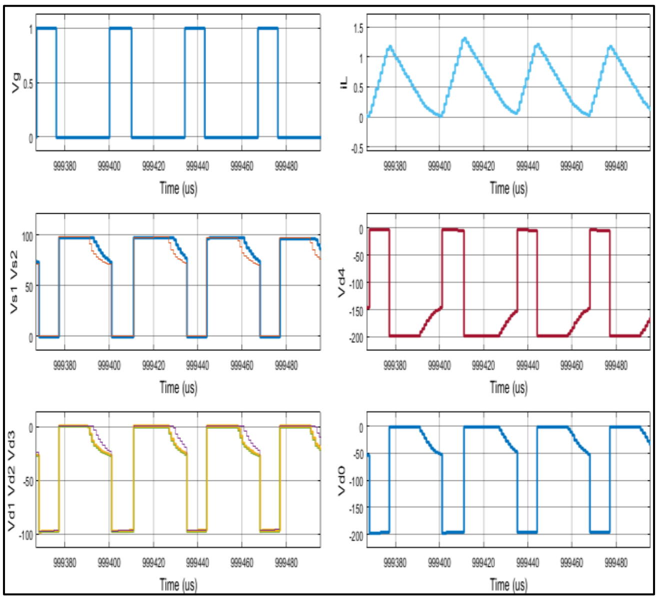


Figure 11 Voltages and current of active and passive elements with constant optimum solar irradiation

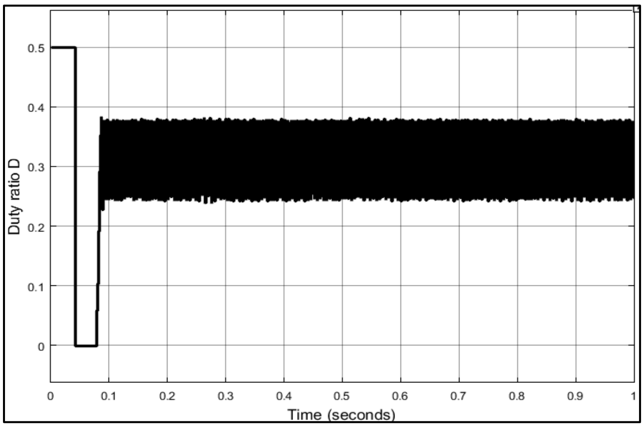


Figure 12 Duty ratio of the MOSFET switches with constant optimum solar irradiation

The above graph is the dynamic duty ratio of the MOSFET switches generated by CV control with output voltage feedback and PI controller. The duty oscillates between 0.25 and 0.38 maintaining the output voltage at given reference value 300V.

The below are the graphs recorded for the given input voltage of 35V from PV array. As seen the output voltage of the converter is maintained at 300V with power consumption of 250W by 360Ω resistive load. The output current is recorded at 0.83A which is the consumed current by the resistance load.

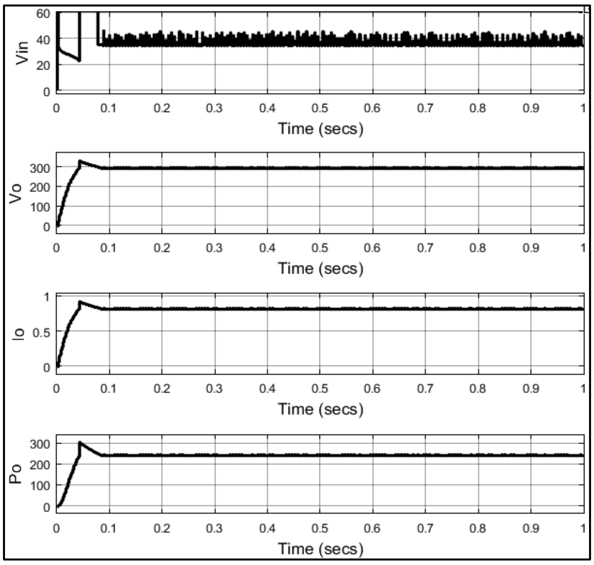


Figure 13 Input voltage, Output voltage, Output current and Output power of the circuit with constant optimum solar irradiation

The efficiency of the converter with PV array input can be calculated as

Efficiency = (Po/Pin)*100% = (250W/315W)*100 ≅**80%**

Variable Solar irradiation with respect to time

In this mode the solar irradiation is varied with respect to time at multiple intervals. During initial time 0sec the solar irradiation is at 1000W/mt2 and later dropped to 100W/mt2 at 0.3sec maintained till 0.6sec. At 0.6sec the solar irradiation is raised to 500W/mt2 maintained at this level till 1sec. The below are the graphs of PV array voltage and current with variable solar irradiation with respect to time.

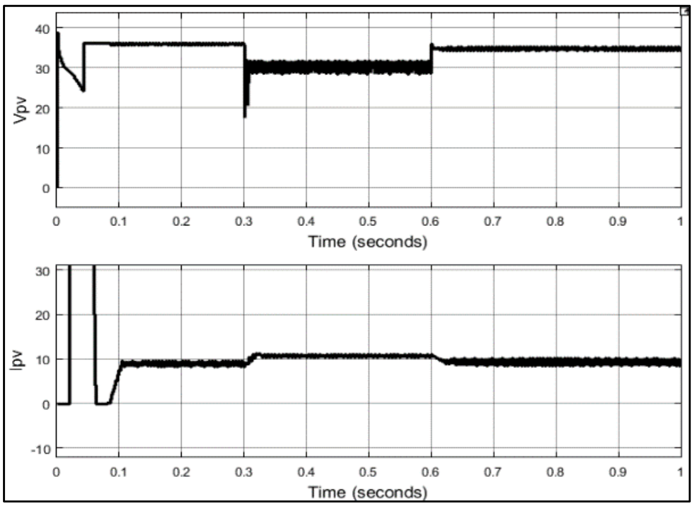


Figure 14 PV array characteristics with variable solar irradiation

In any given condition the voltage of PV is maintained between 30 to 35V and the current is changed from 9A to 10.5A as per the given solar irradiation. For the same the below are the graphs of active and passive elements voltages and currents with variable solar irradiation.

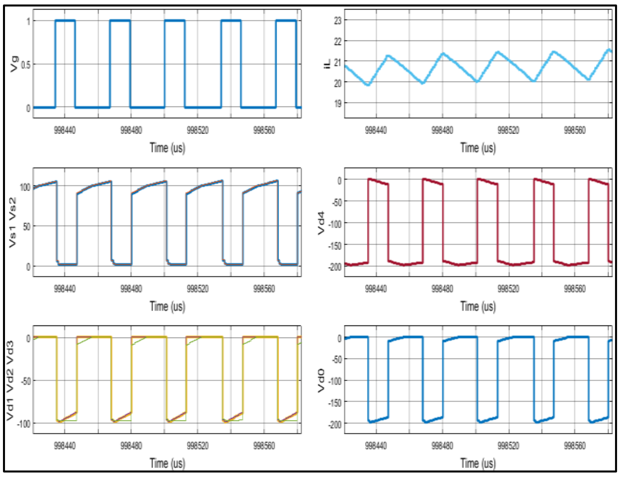
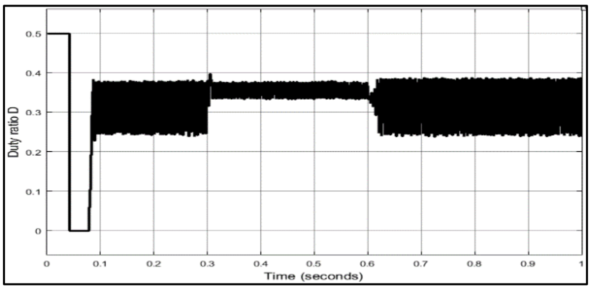


Figure 15 Voltages and current of active and passive elements with variable solar irradiation

As per the change in solar irradiation the below is the dynamic duty ratio developed by CV controller controlling the ON and OFF time of the MOSFET switches.



Figure`16 Duty ratio of the MOSFET switches with variable solar irradiation

As observed in above graph the duty ratio (D) is increased at 0.3sec when the solar irradiation is dropped to 100W/mt2. This increase in duty ratio maintains the output voltage of the converter at the given reference value of 300V even during drastic drop in solar irradiation.

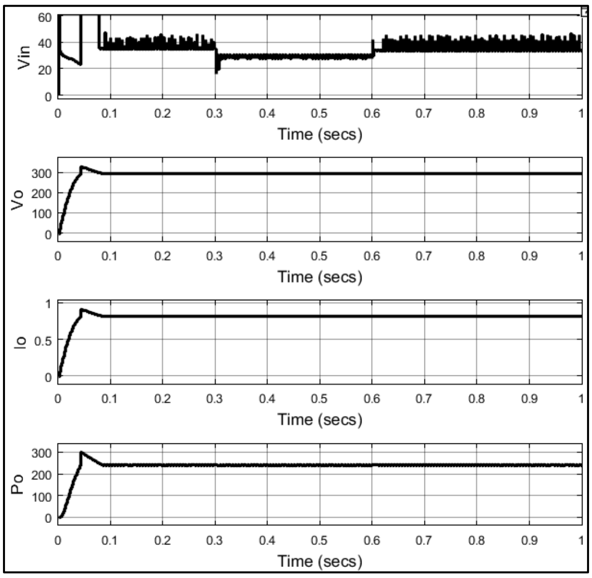


Figure 17 Voltages, Current and power of the circuit with variable solar irradiation

The above graphs are the Input voltage Vin, Output voltage Vo, Output current Io and Output power Po of the circuit with variable solar irradiation. As observed in any given solar irradiation condition the output voltage Vo is maintained at 300V and the power consumed by the 360Ω load is 250W.

3. Conclusion

The modeling of proposed ultra-high gain boost converter with renewable source PV array input is done using MATLAB Simulink block sets for analysis the circuit topology. The circuit output voltage is controlled by varying the duty ratio of the MOSFET switches which controls the charge stored in the inductor. The duty ratio of the MOSFET switches is controlled by feedback CV controller with reference voltage value given as per user requirement. The reference is set at 300V in the controller where the PI controller varies the duty ratio as per the input voltage for controlling the output voltage of the converter. For validating the robustness of the converter the input voltage is varied by changing the solar irradiation of the PV array which impacts the PV voltage and current. With respect to change in PV voltage and current the CV controlled adjusts the duty ratio of the MOSFET switches to ensure development of required reference voltage of 300V. For any given condition the efficiency of the converter is at 80% during full load condition and is maintained same for variable solar irradiations.

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