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Comparative Study of Cuk, Zeta, Buck-Boost, Boost, Buck Converter in a Standalone PV System

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***Abstract*: -This paper analysis the performance of various DC-DC converters like a Buck converter, Cuk converter, Zeta converter, Buck Boost converter and a Boost converter in a standalone PV system . Where the output values of various converters at the same input are measured at constant irradiation and temperature as input to the PV array. The output of the VSI are also analysed in accordance to their settling time, Steady state and transient period etc. After doing the total analysis of the system the Zeta converter proves to be the best among the five converters discussed in terms of the DC converter output, total ripple factor and settling time.**

Keywords: - SPV Array, MPPT, DC-DC converter, P&O algorithm.

I. INTRODUCTION

The increasing demand of electricity day to day with increasing population and electronic devices has led to the invention of various power sources among which the use of the renewable sources is done mostly due to their various advantages when we talk in terms of environmental aspects.

There are various types of renewable power sources available in literature like solar, Wind, tidal, Geo thermal etc. Among which the use of SPV array is done the most due to its various advantages over other sources. The ease of availability, ease of installation, Low maintenance, and Low capital cost requirement makes its use more prominent in the power industry.

The major limitation of the solar is its low efficiency. This limitation of solar could be eliminated by tracking the Maximum power point continuously for which many MPPT techniques have been designed like Perturb and Observe, Incremental conductance, Fractional short circuit current, Fractional open circuit voltage, Neural networks, Fuzzy logic.etc among which the Perturb and observe technique is implemented in this system due to its simple structure, ease of implementation, etc features with both standalone and grid connected systems.

The use of various types of DC-DC converters is done in this system and analyzed The converters used in this system are a Buck converter, Cuk converter, Zeta converter, Buck Boost converter and a Boost converter.

II SYSTEM DESCRIPTION

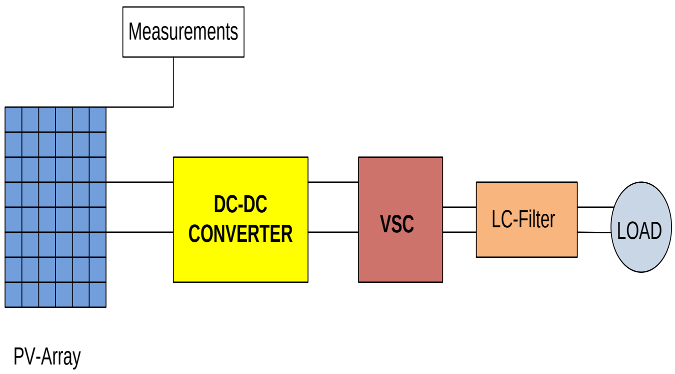

Fig. 1 Block diagram of the system

The system comprises of a PV array, a DC-DC converter, a VSC controller and a filter whose aim is to reduce the ripple content of the output waveform. [1]

a. Solar PV array

The PV array is basically a fabrication of P and N layer semiconductor which converts the sun irradiation into electric energy. By energy from Sun, one can obtain electric current approximate 30Ma/cm2 per PV cell at the sun irradiance 1000W/m2. The equivalent model of the PV cell comprises an ideal current source, series, and parallel resistance and diode as shown below in figure 2.

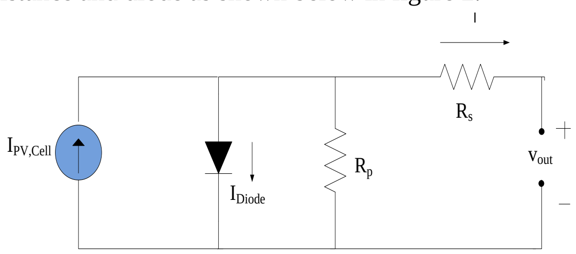

Fig.2 Equivalent model of a SPV cell

The output current of the PV cell is given as

$$I = I_{PV_{cell}} - I_{diode} = I_{pv.cell} - I_{0.CELL}\left[\exp\left(\frac{q*v}{\alpha*K*T}\right)-1\right] \quad -(1)$$

Where

- $I_{PV,\ cell}$ represents the current produced by the irradiation.
- I_{diode} represents the Shockley diode equation.
- $I_{0,\ CELL}$ represents the reverse saturation current of the diode.

- Q represents charge of the electron [1.60217646 * 10e-19 Coulomb].
- K represents the Boltzmann constant value [1.3806503 * 10e-23J/K].
- T {K} represents the temperature of the PN junction.
- ∝ represents the diode ideality constant whose value lies from 1 and 2 for monocrystalline silicon.

III. MODELLING AND WORKING OF CONVERTERS

The DC-DC converters are basically power electronic devices which are used to convert the DC voltage from one level to a different voltage level. Various methods are implemented to perform this conversion like electronic, switched mode capacitive and magnetic. These electronic converters are implemented where a conversion of voltage is required from one level to another level. This could also be termed as SMPS (Switched mode power supply).

a. Boost Converter

The boost converter is a step up converter which generates output DC voltage greater than the input DC voltage. It is a class of SMPS (Switched mode power supply) which consists of two semiconductor switches. A diode and a transistor along with one energy storage element. Filters are also connected to the output of the converters in order to reduce the ripple content in the output side of the converter. [2]

Working of the Boost Converter

The components of the Boost and Buck converter are similar except for the difference in the output voltage produced. The Boost converter starts their voltage conversion with current flowing through the inductor closing all other paths to go than through a diode.

The key principle that drives the Boost converter is the tendency of inductor to resist the changes in current. In Mode I of the Boost converter the inductor acts as a load and absorbs the energy and in Mode II it acts as an energy source. The voltage produced during the discharge phase is directly proportional to the rate of change of current independent of the charging voltage allowing different output and input voltage.

The operation of the Boost converter can be explained in two modes namely.

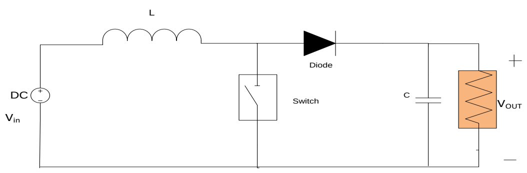

Fig.3 Basic diagram of a boost converter

Mode- I

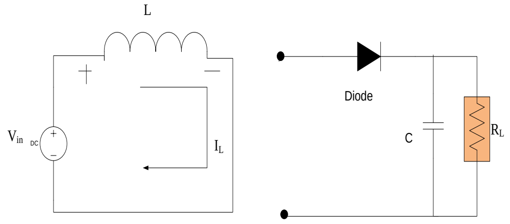

Fig.4 Mode I of boost converter

In this mode the switch is turned on at TON the input current produced starts flowing through the inductor L and switch SW. During this mode the energy gets stored in the inductor.

Mode-II

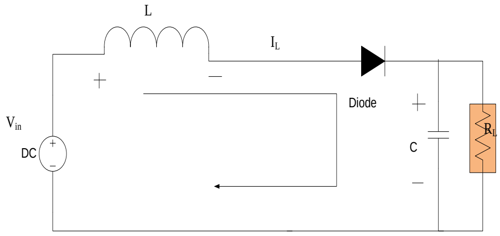

Fig.5 Mode II of boost converter

This mode begins with the turning off the switch at t= TOFF .The current that was earlier flowing through the switch is now flowing through the inductor, capacitor, diode and load R_l. The inductor current fall till the time the switch is turned on again. Energy stored is thus transferred to load.

The output voltage of boost converter is $\mathbf{V_0 = \frac{1}{1-D}}$

The values of L, C, and Vripple are calculated from the pre-determined formulas

$$L_{min} = \frac{(1-D)2 * D * R}{2 * F} \quad - (2)$$

$$C_{min} = \frac{D}{R * F * V} \quad - (3)$$

$$V_{ripple} = \frac{\Delta V}{V} \quad - (4)$$

Where

D= Duty cycle, R= Load, F=Frequency

b. Buck Converter

The DC-DC converter has its applications in the circuits which require a step down of power from one level to another. The main advantage of this converter are its simplicity and low cost. The Fig 6 shows the basic diagram of a Buck converter. [3]

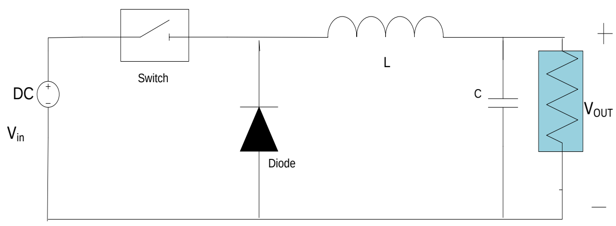

Fig 6 The Buck Converter

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Operating principle

The operation of the Buck converter is quite similar to the Boost converter which could be easily explained by dividing it into two modes.

Mode I

The operation of the Buck converter starts with the switch that is open (Due to which no current flows in the circuit)

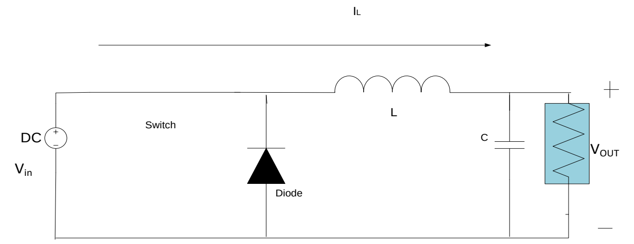

Fig 7 Mode I of Buck Converter

Mode II

When the switch is in off state, The current flows through the inductor in this mode the inductor pulls current through the diode due to which the inductor output is lower than its primary value.

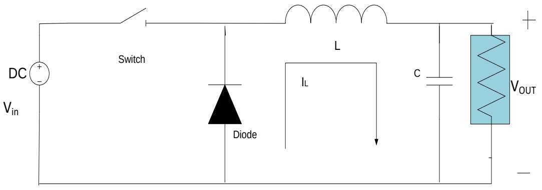

Fig 8 Mode II of Buck converter

This is the very basic operating principle of the buck converter.

c. *Buck Boost Converter*

Buck Boost converter

The Buck-Boost converter is a multipurpose converter which is capable to produce an output voltage either greater than the input voltage or lower than the input voltage depending upon the requirements. [4]

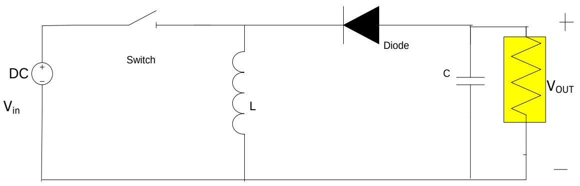

Fig 11 The Buck-Boost converter

The assumptions made for the analysis of this converter are as follows-

- The circuit is in steady state
- The inductor current is continuous
- The output voltage is held constant at V_0
- All the components of the converter are ideal
- The switching period is T

Operating principle

The Buck-Boost converter operation could be explained in two modes namely-

ON Mode

In this Mode the voltage source is connected directly to the inductor. Which results in the accumulation of energy in the inductor. In this mode the load is supplied by the capacitor.

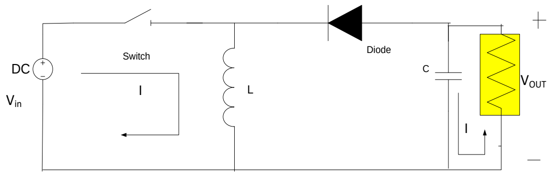

Fig 12 ON Mode of Buck-Boost converter

OFF Mode

In this mode the inductor is connected directly to the output load and capacitor. Hence the load is supplied from L to C and R.

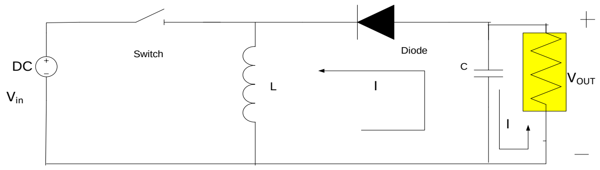

Fig 13 OFF Mode of Buck-Boost converter

The characteristics of the Buck-Boost converter are as follows

The polarity of the input and output voltage are opposite.

The output voltage of the Buck-Boost converter varies from 0 to V_i and V_i to ∞

d. *Cuk Converter*

The Cuk converter is a special type of DC-DC converter which is used to get output voltage with different magnitude and polarity. [5]

It has property to work as both the Buck and Boost converter. The inductor in the converter acts as a filter reducing the large harmonic current problem

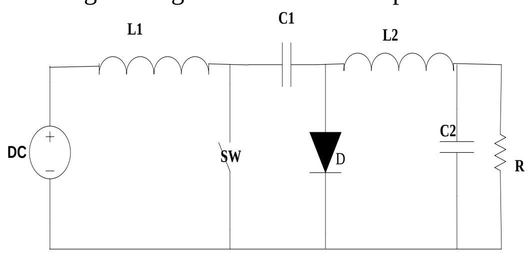

Fig 16 The Cuk converter

Operating principle

The capacitor C is used to transfer energy and connected alternately to the input and to the output converters commuting the transistor and diode.

The two inductors L1 and L2 convert the input and output voltage sources into current sources. This conversion is required because if the capacitor is connected directly to the voltage source, The current is limited by the resistances, resulting in high energy sources.

Unlike other converters (buck converter, boost converter, buck-boost converter) the Ćuk converter can either operate

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in continuous or discontinuous current mode. However, unlike these converters, it can also operate in discontinuous voltage mode.

e. Zeta Converter

A Zeta converter is a DC/DC converter. This is capable to convert the input voltage to either a higher voltage level or lower voltage level. The function of a Zeta converter is similar to a Buck-Boost converters. [6]

The ideal switch-based diagram of a Zeta converter is shown in Fig.17

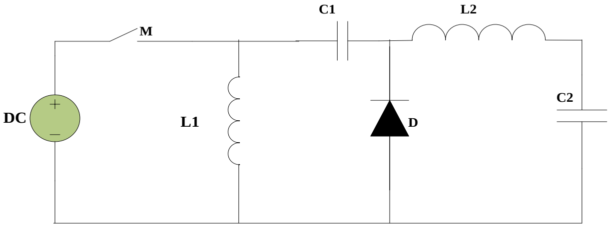

Fig.17. Diagram of a Zeta converter

The operation of this converter could be depicted in various modes. In this system, continuous inductor current method is adopted with the current I_L.

The conditions that are taken for the Zeta converter simulation are.

- All the Switches used in this converter are considered to be ideal.
- The operation is performed by taking inductor current to be continuous.
- The ripple factor is considered to be negligible.

The working of this converter is explained in two modes.

Mode-I In the First mode. The switch is considered to be in OFF condition. In this Mode, the current flows through the inductors L_1 and L_2. This mode is considered to be the charging mode.

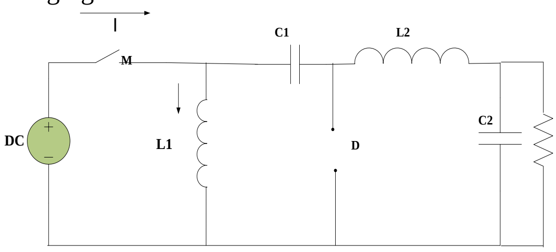

Fig. 18 Mode-I of Zeta converter

Mode-II In the second mode the switch is considered to be in OFF state and the diode to be in ON state which is just opposite to the first Mode. This mode of operation could also be considered as the discharging mode. Since the energy stored in the inductor L_2 is released across the load resistance.

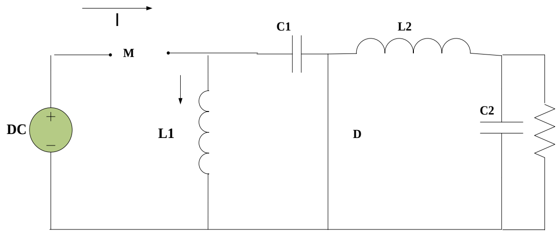

Fig.19 Mode-II of Zeta converter

IV SIMULATION RESULTS

Simulation results of Boost converter

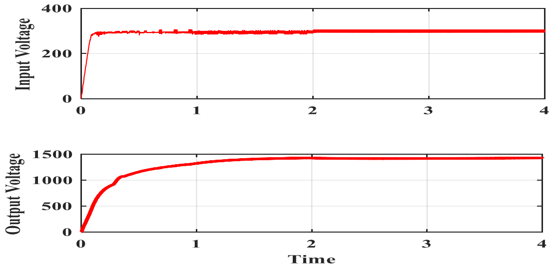

Fig 20 Simulation results of Boost converter

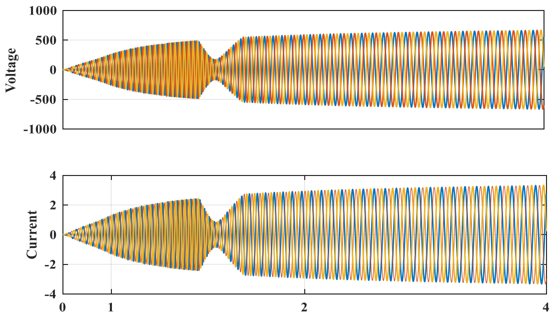

Fig 21 Simulation results of Voltage source converter

Simulation results of Buck converter

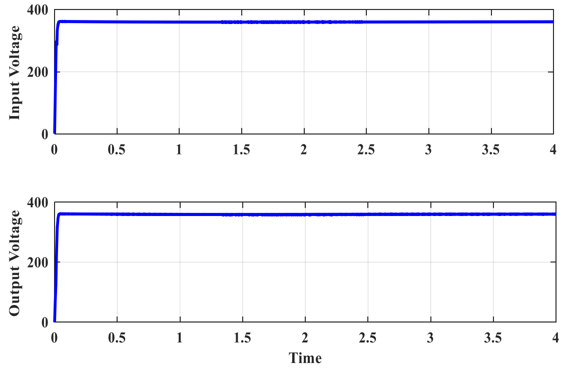

Fig 22 Simulation results of Buck converter

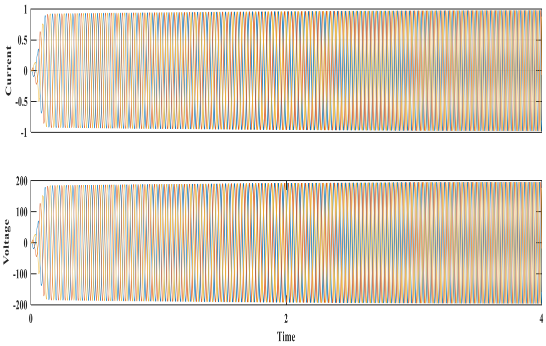

Fig 23 Simulation results of Voltage source converter

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Simulation results of Buck-Boost converter

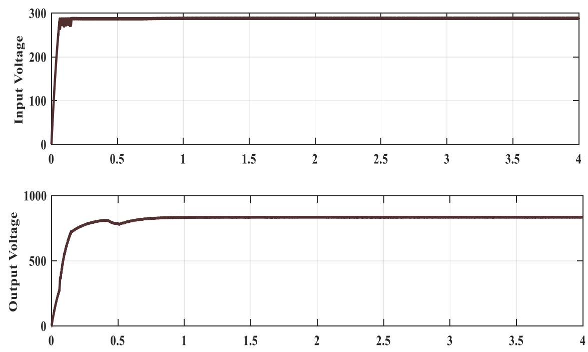

Fig 24 Simulation results of Buck-Boost converter

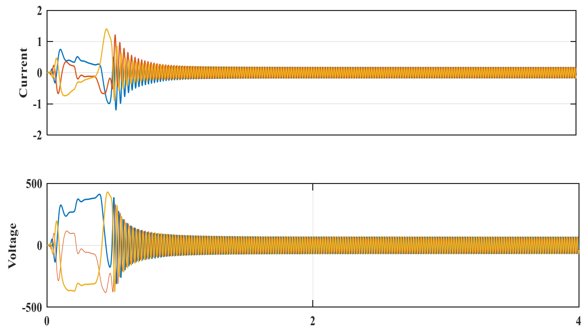

Fig 25 Simulation results of Voltage source converter

Simulation results of Cuk converter

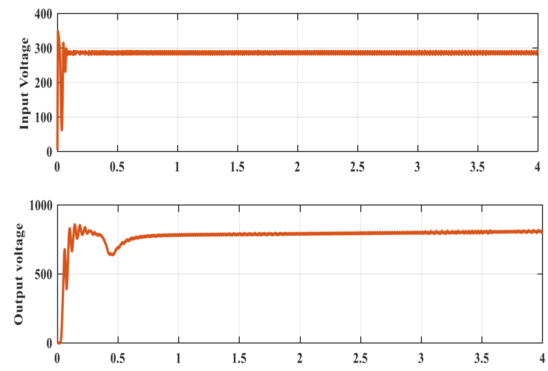

Fig 26 Simulation results of Cuk converter

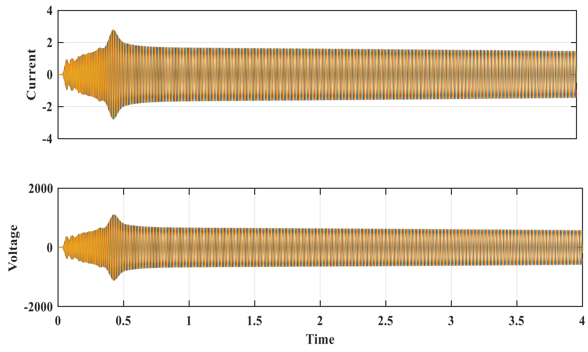

Fig 27 Simulation results of Voltage source converter

Simulation results of Zeta converter

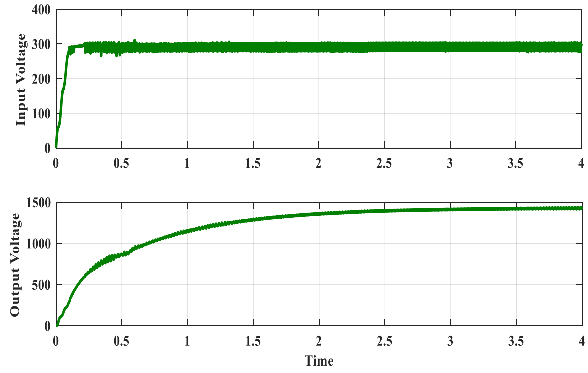

Fig 28 Simulation results of Zeta converter

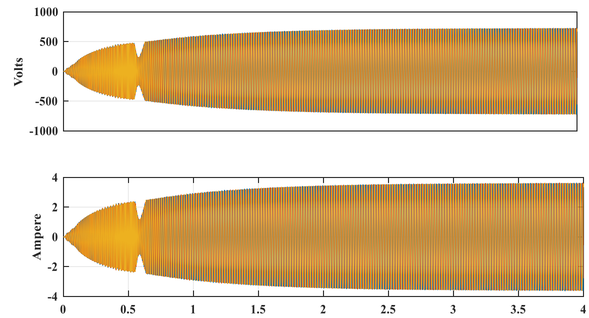

Fig 29 Simulation results of Voltage source converter

Simulation of the solar PV system is done by measuring the output power and viewing the output signal. For the simulation analysis, the parameters that are inspected are the input power of the PV module and output of various DC-DC converter at the equal load for all the converters. This section of the thesis shows the simulation results of various types of DC-DC converter with the P &O MPPT algorithm.

The consequence of PV array output with MPPT algorithm for every DC-DC converter like Buck, Boost, Buck-Boost, Cuk, and Zeta can be explored that the resultant power of the Buck-Boost and Zeta converter have the identic polarity with i/p voltage, whereas Cuk converter has the inverse polarity.

In Buck-Boost converter intense ripple signal take place on behalf of output voltage and as well output current. At the time of the steady-state period approximate 0.06 ms, the input current and voltage haven't too high ripple level. Whereas the Cuk converter has the low ripple signal at the input side while the steady-state period comes about after 0.06 ms. The power signal at the i/p side and o/p side of both converter have similitude isolation, the ripple output voltage and current are not so much as compared to that of other DC-DC converter. On the subject of a circuit, Cuk converter entails more components as regards with the Buck-Boost converter.

CONCLUSION

The following are the major contribution of this work-

This work provides deep study of the mostly used DC-DC converters.

The analysis of power quality is done by using various DC-DC converters. Provides user with the detailed characteristics of the converters so that one of them could be chosen by them accordingly to the application. The power source of the DC-DC converters is taken as SPV array which has it's numerous of advantages over other DC sources. The power sources of the DC-DC converters are taken as SPV array which has it's numerous of advantages over the other DC sources. The novelty of this work is that after making all other values a constant i.e the source and the load analysis of DC-DC converters is done out of which the performance of the zeta converter is found to be the most efficient and reliable as it has inferior ripple content as compared to the other four converters at the time period steady state about 0.06ms, recognising the small ripple level to be excellent in the procedure of tracking the MPP of the solar PV system. When the ripple output voltage and current are small at that time the zeta converter has the best tracking power point.

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