Modeling and Analysis of PV Fed DC-DC Converters

P. Maithili, J. Kanakaraj, T.Viswanathan

Abstract: ***The renewable energy sources Fuel cell, solar PV has low output voltage characteristics. These energy output voltage should be stepped up with high efficiency to the electrical network standards to connect them into the grid. To regulate the power from renewable sources and to match the load demand and grid requirement in order to improve the dynamic and steady-state characteristics of the system the power electronic converters are used. In this paper, a various DC-DC converter topologies are analyzed mathematically and simulated using MATLAB SIMULINK software. The performance of these converters is analyzed based on the simulation results obtained. Thus, the suitable converter for non-conventional energy source application is identified***

Keywords: Boost, Buck-Boost, Cuk, SEPIC and Zeta Converter, Duty ratio, PV system.

I. INTRODUCTION

Generation of electricity is one of the sources of air pollution. Most of our electricity comes from nuclear, coal, petroleum, natural gas and other non-renewable sources. Carbon is the main element in fossil fuels. Production of energy from these sources leads water, air and land pollution. Renewable energy resources can be used to produce electricity with fewer environmental impacts. Among all renewable energy resources solar energy has been widely accepted in power industry as a result of its cleanness (No carbon dioxide emission) and cost effectiveness. Photovoltaic (PV) is direct transformation of sunlight into electricity. Different materials has been developed to make of a PV modules. But, the common inherent drawback of the source is their intermittent natures that make them unreliable. The main disadvantage of commercially available PV module is low voltage characteristics and the power conversion efficiency is 25-30%. The effective utilization of sustainable energy sources has become a main part of today's research work. The power electronic converter is a fundamental subsystem that interfaces the renewable energy sources to the grid/load. The DC-DC converter is designed such that to obtain the maximum efficiency from PV system.

Design of Cuk converter for PV system with transient analysis is explained by the authors of [1-2]. Similarly, switching conditions in discontinuous mode and MATLAB/Simulink model of SEPIC converter are designed for transient analysis in [3].

In [4-5], the comparison of Cuk, Zeta and Sepic converters was examined and the PV system Performance with Zeta converter has investigated by the author. In [6-8], the recent techniques of DC-DC converter is modeled in MATLAB/Simulink model. The authors in [9-13] investigated power quality improvement of the multi input dc/dc converters and this converter is analyzed for the different applications.

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II. MATHEMATICAL MODEL OF PV SYSTEM

Figure.1 shows the solar cells equivalent circuit. parallel cell Np and Ns Series modules can be represented by:

$$I = nI_{sc} - N_p I_0 (\exp\left[\frac{V_A + I_A R_S}{nN_S V_T}\right] - 1) \quad (1)$$

$$V = N_S\left(\frac{AKT}{q}\right)((N_p I_{SC} - 1 + N_p I_D / N_p I_D) - \frac{N_S}{N_p} IR_S \quad (2)$$

Where I_{sc} is PV module short circuit current (A), I_0 is saturation current of diode (A) , R_s is series resistance (Ω) , n is diode ideal constant, V_T- is PV module thermal potential(V) , k is Boltzmann constant (J/°K) ,q is electron charge (C), V_A is terminal voltage of PV array (V), I is output current of PV array(A), T is temperature (°K) and A is p-n junction material factor.

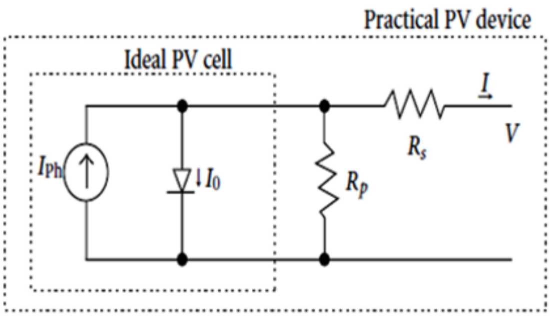

Fig.1 PV Cell Model

The PV cell equivalent circuit is shown in fig. It consists of two parts. Where I0 represents the saturation current of diode, Iph represents the cell photo current, V and I are cell output voltage and cell output current respectively. Rs is series resistance and Rp is parallel (shunt) resistance. They ideal PV module for one diode circuit.

The mathematical model of PV array for single diode circuit can be explained by the following equation.

A. Photo Current (I_{ph}):

I_{ph} depends on the solar irradiation. It depends on cell's operating temperature.

The photo current(I_{ph}) derived according to the equation given below

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$$Iph = [Isc + k1(Tc - Tref)] * H \quad (3.1)$$

B. Diode Saturation Current (I_0):

Saturation current of PV system varies with the cell temperature. It can be calculated by given equation.

$$I_0 = I_{rs} * \left[\frac{T}{TR}\right]^3 * exp\left[\left(\frac{q * E_{go}}{A * K}\right) * \left(\left(\frac{1}{T_r} - \left(\frac{1}{T}\right)\right)\right)\right] \quad (3.2)$$

C. Reverse Saturation Current (Irs):

The PV system has Reverse saturation current (Irs). It can be determined by the given equation.

$$Irs = Isc/[\exp\left(\frac{qVoc}{NskAT}\right) - 1] \quad (3.3)$$

D. output current (I):

The Figure 1 presents the PV system of single diode model. The equation for output current is presented by the given equation,

$$Ipv = Np * Iph - Np * Io * \exp\left[\frac{q*(Vpv+Ipv*Rs*Rsh)}{(Ns*A*K*T)} - 1\right] - (Vpv + (Ipv * Rs))/Rsh \quad (3.4)$$

From the above equations, T_c is the operating temperature(°C), N_p is number of parallel connection of cell(1), H is solar isolation (kW/m2), I_{sc} is cell's short circuit current(A),K is the temperature coefficient(0.0017A/K), T_{ref} is the reference temperature(°C), V_{oc} is open circuit voltage(V), N_s is number of cells connected in series(36), q is charge of electron (1.6×10-19C), A is ideal factor(1.6), Ego is band gap energy(1.1eV),k is Boltzmann constant(1.38×10-23 J/K).

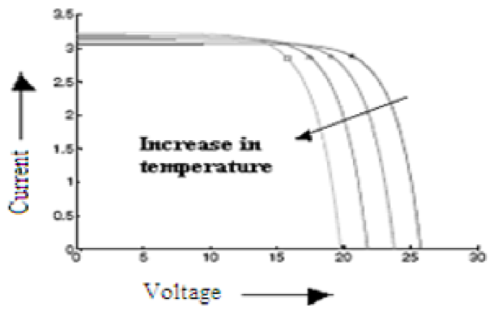

Fig.2 Current vs. Voltage curve of PV Cell Model

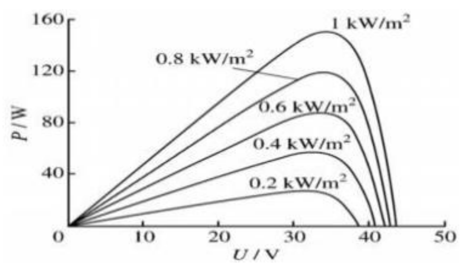

Fig.3 Power vs. Voltage curve of PV Cell Model

III. MATHEMATICAL AND SIMULINK MODEL OF DC-DC CONVERTERS

A. Boost Converter

The Figure 4 shows the switching circuit of the Boost converter. The operation of the converter is in continuous conduction mode.

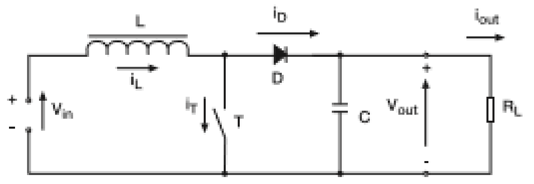

Fig.4 Switching Circuit of Boost Converter

The switching circuit consists of one capacitor, one inductor, a switch, diode and R_L load. The transfer function of the converter voltage is,

$$\frac{Vo}{Vs} = \frac{1}{1-D} \quad (4)$$

B. Buck-Boost Converter

Figure 5 shows the switching circuit of the Buck-Boost DC-DC converter. The converter operates in CCM mode.

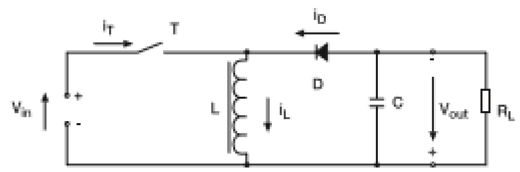

Fig.5 Switching circuit of Buck-Boost converter

The converter consists of one capacitor, one inductor, a switch, resistive load and diode. This converter can operate in both buck and boost mode of operation. The transfer function of the converter voltage is,

$$\frac{Vo}{Vs} = \frac{D}{1-D} \quad (5)$$

C. Cuk Converter

The simulation circuit of the Cuk converter in continuous conduction mode is shown in figure.6.

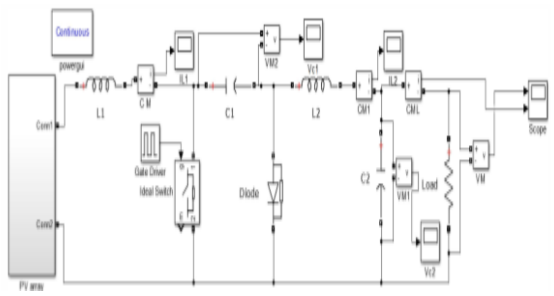

Fig.6 Simulation Diagram of Cuk Converter

The switching circuit consists of two inductors, resistive load, a switch, two capacitors and diode. The voltage transfer function of the converter is,

$$\frac{Vo}{Vs} = \frac{D}{1-D} \quad (5)$$

Duty ratio of the converter is D, The inductor values are determined by the following given formula,

$L_1 = V_s D / f_s \Delta I_{L1}$

$L_2 = V_s D / f_s \Delta I_{L2}$

Where, ΔI_{L1} and ΔI_{L2} is the ripple current of L1 and L2 respectively, f_s is switching frequency. V_s is the source voltage. The ripple voltage of the C_1, C_2 is given as

$$C_1 = \frac{V_o D}{F_s \Delta V_{c1} R}$$
$$C_2 = \frac{(1-D)V_o}{F_s^2 \Delta V_o 8L_2} \quad (7)$$

D. Sepic Converter

The SEPIC converter has the positive output voltage. This converter has the following components such as resistive load, two capacitors (C1C2), two inductors (L1L2), a diode and switch. The converter Simulink diagram is shown in figure.7.

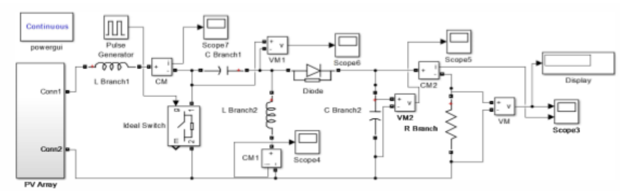

Fig.7 Simulation diagram of SEPIC converter

Transfer function of the converter voltage is,

$$\frac{Vo}{Vs} = \frac{D}{1-D} \quad (8)$$

The converter Duty ratio is D, The value of inductors are determined by the following expression,

$L_1 = V_s D / f_s \Delta I_{L1}$

$L_2 = V_s D / f_s \Delta I_{L2}$

Where, ΔI_{L1} and ΔI_{L2} is the ripple current of L_1 and L_2 respectively, fs-switching frequency, Vs is the source voltage. The capacitor ripple voltage is expressed as

$$C_1 = \frac{V_o D}{F_s \Delta V_{c1} R}$$
$$C_2 = \frac{(1-D)V_o}{F_s^2 \Delta V_o 8L_2} \quad (9)$$

E. Zeta Converter

The ZETA converter is nonlinear converter. The Simulink model diagram of this converter is shown in figure.8

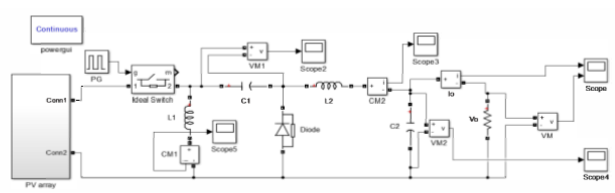

Fig.8 Simulation Circuit of ZETA converter

It has the following components such as two capacitors (C1C2), a switch, two inductors (L1L2) and resistive load. The converter voltage transfer function is,

$$\frac{Vo}{Vs} = \frac{D}{1-D} \quad (10)$$

Duty ratio of the converter is D, the inductor ripple current values are calculated by the given expression,

$$\Delta I_{L1} = \frac{V_s D}{F_s L_1} = \frac{D}{F_s C_1 V_s} \quad (11)$$

The ripple current in first inductor is depends on duty ratio, switching frequency, source voltage and the value of first capacitor. The output capacitor values are determined by the following expression

$$C_2 = \frac{D}{8F_s \Delta V_{c2}} \quad (12)$$

IV. SIMULATION RESULTS

The PV fed various DC-DC converter voltage, current and power is analyzed through simulation results. The steady state analysis of PV system simulated and the simulation result are observed. MATLAB R2017a software was used for simulation.

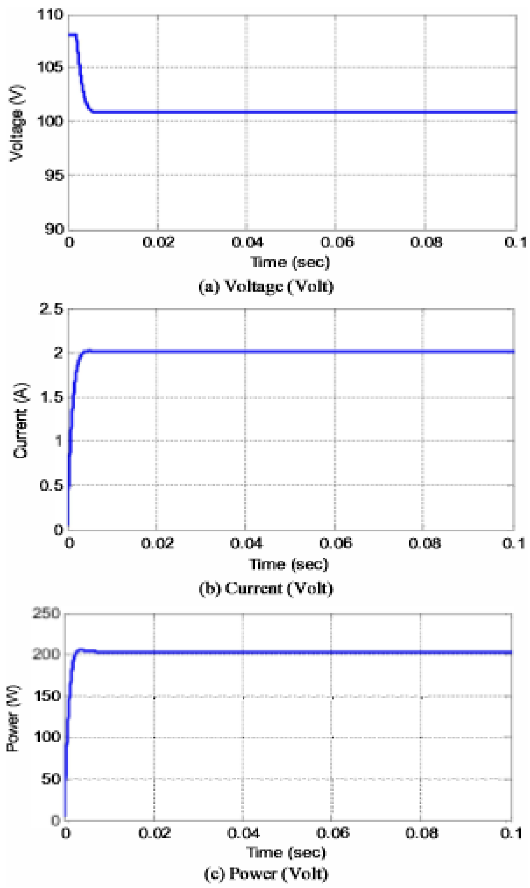

Fig.9 Simulation Result of PV fed Converters

The transient analysis of PV system is simulated and simulation results are observed. It is seen from the figure.10. The Zeta converter results are better than the other converters.

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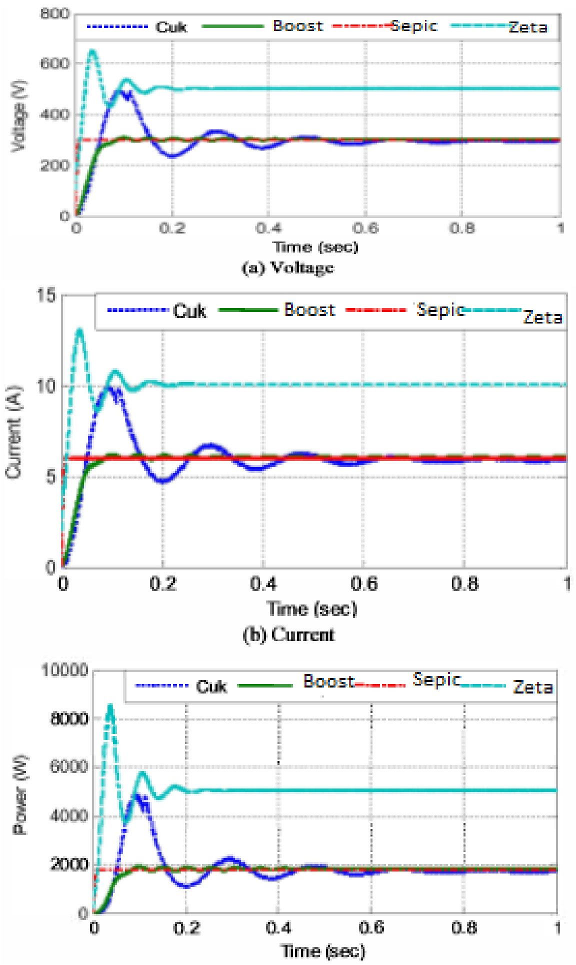

Fig.10 Comparison of various DC-DC converters

V. CONCLUSION

The mathematical and simulation analysis of PV fed Boost, Buck-Boost, Cuk, SEPIC and ZETA converter was done in this paper. The simulation carried out for a resistive load of 50Ω with 75% duty cycle of the dc-dc converter. It is shown that the Zeta converter has better performance than other DC-DC converters from the above obtained results.

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