Modeling and Analysis of PV Fed DC-DC Converters

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Abstract: The renewable energy sources—fuel cell, solar PV—have low output voltage characteristics. These energy outputs 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 requirements, 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 cleanliness (No carbon dioxide emission) and cost effectiveness. Photovoltaic (PV) is direct transformation of sunlight energy into electricity. Different materials have been developed to make a PV module. But, the common inherent drawback of the source is its intermittent nature that makes 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 been 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 different applications.

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:

\[ I = nI_w - N_p I_{ph}(\exp\frac{V_{th} + I_{ph}R_s}{nTV_T}) - 1 \]  
(1)

\[ V = N_p \left(\frac{AKT}{q}\right)(N_p I_{sc} - 1 + N_p I_{ph} / N_s I_{ph}) - \frac{N_p}{N_s} IR_S \]  
(2)

Where \(I_{sc}\) is PV module short circuit current (A), \(I_0\) is saturation current of diode (A), \(A_0\) is diode ideality constant, \(V_T = kT / q\) is PV module thermal potential (V), \(k\) is Boltzmann constant (J/K), \(q\) is electron charge (C), \(V_T\) is terminal voltage of PV array (V), \(I\) is output current of PV array(A), \(T\) is temperature (°K) and \(A\) is junction material factor.

![Fig.1 PV Cell Model](Image)

The PV cell equivalent circuit is shown in fig. It consists of two parts. Where \(I_0\) represents the saturation current of diode, \(I_{ph}\) represents the cell photo current, \(V\) and \(I\) are cell output voltage and cell output current respectively. \(R_s\) is series resistance and \(R_p\) 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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B. Diode Saturation Current ($I_0$):
Saturation current of PV system varies with the cell temperature. It can be calculated by given equation.

$$I_0 = I_{sc} + k1(T_c - T_{ref})\times H \quad (3.1)$$

C. Reverse Saturation Current ($I_{rs}$):
The PV system has Reverse saturation current ($I_{rs}$). It can be determined by the given equation.

$$I_{rs} = \frac{I_{sc}}{[\exp\left(\frac{qV_{oc}}{N_s{kAT}}\right) - 1]} \quad (3.3)$$

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.

$$I_{out} = \frac{N_p \times I_{sc} - N_p \times I_{sc} \exp\left[\frac{qV_{oc}}{N_s{kAT}}\right] - \left[I_p + \frac{I_{sc} \times R_d}{R_d}\right]}{R_d} \quad (3.4)$$

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), $E_{go}$ is band gap energy(1.1eV), $k$ is Boltzmann constant(1.38×10−23 J/K).

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

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

$$\frac{V_o}{V_s} = \frac{D}{1 - D} \quad (5)$$

Duty ratio of the converter is $D$. The inductor values are determined by the following given formula,
\[ L_1 = V_s \Delta I_{L1} / f_s \]
\[ L_2 = V_s \Delta I_{L2} / f_s \]

Where, \( \Delta I_{L1} \) and \( \Delta I_{L2} \) 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

\[ C_1 = \frac{V_s D}{f_s \Delta V_{c1} R} \]  
\[ C_2 = \frac{(1-D) V_s}{F_s^2 \Delta V_{c2} 8L_2} \]  

(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.

\[ V_o = \frac{D}{1-D} V_s \]  

(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, \( \Delta I_{L1} \) and \( \Delta I_{L2} \) is the ripple current of L1 and L2 respectively, \( f_s \) switching frequency, \( V_s \) is the source voltage. The capacitor ripple voltage is expressed as

\[ C_1 = \frac{V_s D}{f_s \Delta V_{c1} R} \]  
\[ C_2 = \frac{(1-D) V_s}{F_s^2 \Delta V_{c2} 8L_2} \]  

(9)

E. Zeta Converter

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

\[ V_o = \frac{D}{1-D} \]  

(10)

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

\[ \Delta I_{L1} = \frac{V_s D}{f_s L_1} = \frac{D}{f_s C_1 V_s} \]  

(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

\[ C_2 = \frac{D}{8F_s \Delta V_{c2}} \]  

(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.

\[ \text{Fig.9 Simulation Result of PV fed Converters} \]

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.
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.

REFERENCES