Analysis and Design of CUK Converter using PI Controller for PV Application

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Abstract --- Constant and required level of output voltage are important features of DC- DC converters. This paper describes CUK converter using PI controller for PV application. A CUK DC-DC converter is capable of operating in either step-up or step-down mode. Modelling of CUK converter operating in continuous conduction mode using the State-Space Averaging technique. The transfer functions used for feedback control design can be determined from the modelling. Results are presented to verify the accuracy of the obtained model.

Keywords: CUK converter, PI- Proportional Integrator, PV- Photo Voltaic

I. INTRODUCTION

Switched mode DC-DC converters may be thought of as non-linear and time varying dynamical systems. They contain switches that cause the topological structure of the converter to vary with time, energy storage components and diodes with non-linear voltage, current characteristics. CUK converters capable of operating in either step-up or step-down mode are mainly applied to DC power supplies.

The classic CUK converter circuit topology has often been modified for better performance. The research on the CUK converter is concentrated on lowering switching or conduction loss, reducing component size, improve system efficiency, mitigating voltage or current stress, speeding up transient response, etc. PI controller is used to reduce transient response and to improve Steady State response. There are so many methods to find kp and ki values. In this paper Ziegler Nichols method has been used to obtain the kp and ki values.

II. ANALYSIS OF CUK CONVERTER

The CUK converter is capable of providing output voltage that is either greater than or lesser than the input voltage depending on the duty cycle. It has low cost, high efficiency, and low noise. CUK converter is used in automotive, consumer-electronics, and other applications.

It consists of an input voltage source Vs,a MOSFET switch S, an anti-parallel diode D, a capacitor C₁ for transferring energy, a capacitor C₂ for storing energy, two inductors L₁ and L₂, and a load resistor R. Let V₁ and V₂ be the voltages across the capacitors C₁ and C₂, respectively. Let I₁ and I₂ be the currents through the inductors L₁ and L₂, respectively.

When Switch S is ON, the circuit is in charging mode. When Switch S is OPEN, the circuit is in discharging mode. The equations of the CUK converter are as follows:

The average output voltage is

\[ V_o = -\frac{(D/ (1-D))}{E} \] Volts

Where,

\[ E = \text{supply voltage} \]
\[ D = \text{duty ratio} \]

The average load current is

\[ I_o = \frac{V_o}{R} \] Ampere

Where,

\[ R = \text{load resistance} \]

Energy stored in inductor

\[ E = \frac{1}{2} L I^2 \] Joules

The minimum values of inductor for continuous conduction mode is

\[ L_{1_{min}} = \frac{(1-D)^2}{R/2f} H \]
\[ L_{2_{min}} = \frac{(1-D)}{R/2f} H \]

The minimum values of capacitor for continuous conduction mode is

\[ C_{1_{min}} = \frac{D}{2fR} F \]
\[ C_{2_{min}} = \frac{1}{8fR} F \]

The peak-to-peak ripple currents

\[ \Delta I_1 = \frac{(V/L_1)}{DTs} \] Ampere
\[ \Delta I_2 = \frac{(V/L_2)}{DTs} \] Amperes

The peak-to-peak ripple voltages

\[ \Delta V_1 = \frac{(I_2/C_1)}{DTs} \] Volts
\[ \Delta V_2 = \frac{T^2(V_1+V_2)}{8L_2C_2} \]

The dynamic response of this converter has been analyzed by applying Kirchhoff’s voltage law on the loop containing the inductor and Kirchhoff’s current law on the node with the capacitor branch connected to it[3].

There are two modes of operation: mode 1 and mode 2. They are discussed as follows:-

![Fig. 1: Block diagram of the system](image1.png)

![Fig. 2: Basic CUK converter](image2.png)
A. **MODE1: WHEN SWITCH IS OPEN**

![Converter in Mode 1](image1)

When the switch S is open, the inductor currents $I_{L1}$ and $I_{L2}$ flow through the diode. Capacitor $C_1$ is charged through the diode by energy from both the input and $L_1$. Currents $I_{L1}$ decreases, because $V_{C1}$ is lesser than $V_d$. Energy stored in $L_2$ feeds the output. Therefore, $I_{L2}$ also decreases.[4].

**B. MODE2: WHEN SWITCH IS CLOSED**

![Converter in Mode 2](image2)

When switch S is closed, $V_{C1}$ reverse biases the diode. The inductor currents $I_{L1}$ and $I_{L2}$ flow through the switch. Since $V_{C1} > V_o$, $C_1$ discharges through the switch and transferring energy to the output and $L_2$. Therefore, $I_{L2}$ increases. The input feeds energy to $L_1$ causing $I_{L1}$ to increase.

### III. STATE SPACE MODEL OF CUK CONVERTER

The CUK converter operating in continuous mode can be described by the following sequence of the state equations. During ON and OFF state of the converter is follows:

\[
A_1 = \begin{bmatrix}
\frac{R_{L1}}{L_1} & 0 & 0 & 0 \\
0 & \frac{R}{L_2} + R_{L2} + R_{C1} & -\frac{1}{L_2} & -\frac{R}{L_2} (R_{C2} + R) \\
0 & \frac{1}{C_1} & 0 & 0 \\
0 & \frac{C_2 (R_{C2} + R)}{R} & 0 & -\frac{1}{C_1} (R_{C2} + R)
\end{bmatrix}, \quad B_1 = \begin{bmatrix}
1 \\
0 \\
0 \\
0
\end{bmatrix}
\]

\[
A_2 = \begin{bmatrix}
\frac{R_{L1} + R_{L2}}{L_1} & 0 & 0 & 0 \\
0 & \frac{R}{L_2} + R_{L2} + R_{C2} & \frac{1}{L_2} & \frac{R}{L_2} (R_{C1} + R) \\
0 & \frac{1}{C_1} & 0 & 0 \\
0 & \frac{R}{C_1 (R_{C1} + R)} & 0 & -\frac{1}{C_1} (R_{C1} + R)
\end{bmatrix}, \quad B_2 = \begin{bmatrix}
1 \\
0 \\
0 \\
0
\end{bmatrix}
\]

**IV. SIMULINK DIAGRAM OF OPEN LOOP CUK CONVERTER:**

![Simulink Diagram](image3)

**V. Open Loop Simulation Results:**

![Simulation Results](image4)

**VI. PI CONTROLLER**

PI controller will eliminate forced oscillations and steady state error. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system[1].

Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future.
This problem can be solved by introducing derivative mode which has the ability to predict what will happen with the error in near future and thus to decrease a response time of the controller.

PI controllers are very often used in industry, especially when speed of the response is not an issue [2]. A control without D mode is used when:

1. Fast response of the system is not required
2. Large disturbances and noise are present during operation of the process
3. There is only one energy storage in this process (capacitive or inductive)
4. There is large transport delay in the system.

VII. PHOTOVOLTAIC ARRAY

Solar cells, which are the foundation of PV system, convert the energy in sunlight directly into electricity. A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Modules are designed to supply electricity at a certain voltage, such as common (12v) system. Multiple modules can be wired together to form an array. In general, the larger the area of a module or array, the more electricity that will be produced. Photovoltaic modules and arrays produce DC current electricity. The current produced is directly on intensity of light strikes the module [5].

VIII. SIMULINK DIAGRAM OF CLOSED LOOP CUK CONVERTER

Fig. 7: Closed loop simulation diagram

IX. SIMULATION RESULTS OF CLOSED LOOP CUK CONVERTER:

There are two different types of solar energy systems that will convert the solar resources into electricity; one method is by collecting solar energy as heat and converting it into electricity using a typical power plant or engine; the other method is by using photovoltaic PV cell to convert solar energy directly into electricity [6].

The solar energy conversion systems can be connected to a large electrical transmission grid, or to the storage or auxiliary energy supply [7]. Auxiliary energy may be supplied either as a heat before the power conversion system, or as electricity after it.

If the photovoltaic route is chosen, extra electricity may be stored, usually in storage batteries, thereby extending the operating time of the system, the (typical 12v) storage batteries are used in the home solar conversion systems to satisfy its operation and maximize power tracking purpose. The objective is to collect the maximum possible power from solar panels at all times, regardless of the load. The DC-DC converter converts DC input voltage to DC output voltage with a magnitude lower or higher than the input voltage.
X. SIMULINK DIAGRAM OF CLOSED LOOP CUK CONVERTER USING PV PANEL AS SOURCE

Fig. 8: Simulation diagram of CUK using source as PV

XI. SIMULATION RESULTS OF CLOSED LOOP CUK CONVERTER USING PV PANEL AS SOURCE:

XII. RESULTS AND DISCUSSION

The open loop CUK converter simulation results having transients in the voltage and current. PI controller has been used to reduce transients. Using Ziegler Nichols method the PI controller has been designed. Replacing battery by PV panel and the simulation results are obtained.

XIII. CONCLUSION

In this paper the modelling, analysis and design of CUK converter of open loop and closed loop system using MATLAB/SIMULINK is shown. The transients occur in the open loop CUK is reduced and steady state output is obtained by using PI controller. The battery is replaced by PV panel and the simulation results are presented. For supporting the above discussion the circuits are designed in MATLAB/SIMULINK and the results are shown.

REFERENCES


