

Design of Cuk Converter Powered by PV System

¹Patel Jigneshkumar, ²Dattesh krunal

¹PG Student at dept. of Electrical Engineering, Parul Institute of Engineering and Technology

²Asst. prof. At Electrical Engineering, Parul Institute of Engineering & Technology

ABSTRACT- Photovoltaic power systems are becoming increasingly prevalent in distribution and generation systems. Many nations are installing significant solar power capacity in their grids as a supplement or alternative to other power sources. This project presents PV module with CUK converter for electrical applications especially for dc load application. In this paper the cuk converter and PV system is simulated

KEYWORDS- PV module, dc-dc converter, Cuk converter, MPPT, MATLAB

INTRODUCTION

Photovoltaic system is gaining increased importance as a renewablesource because of its advantages such as the absence of fuel cost, little maintenance and no noise and wear due to the absence of moving parts. But there are still two principal barriers to the use of photovoltaic systems: the high installation cost and the low energy conversion efficiency.

A PV panel is a non-linear power source, i.e., its output current and voltage (power) depend on the terminal operating point. The maximum power generated by the PV panel changes with the intensity of the solar radiation and the operating temperature. To increase the ratio of output power/cost of the installation, the PV panel should operate in the maximum output power point.

The main focus of this research is to identify the proper DC-DC converter which uses the adaptive perturbs and observe MPPT algorithm to maximize energy extraction from the solar PV module and to increase the conversion efficiency of MPPT system.

PHOTOVOLTAIC ENERGY SYSTEM

The output of solar PV cell is a Direct Current (DC), where the current is determined by the area of the cell and amount of exposed solar irradiation. The voltage of the individual silicon cell is in the order of 0.5V.

Thereby, the cell has to be connected in a series to constitute modules with reasonable voltage level. The maximum power is delivered at the operating point, where the magnitudes of PV system and load resistance are equal. This is usually performed by an interfacing DC-DC power converter employing certain MPPT technique and algorithm. The operating point is held at MPP by regulating either the current or voltage of the MPPT converter.

PV systems are usually used in three main fields: 1. Satellite applications, where the solar arrays provide power to satellites, 2. Off-grid applications, where solar arrays are used to power remote loads that are not connected to the electric grid, and 3. On-grid, or grid connected applications, in which solar arrays are used to supply energy to local loads as well as to the

Electric grid.

The basic element of the solar PV power conditioning system is the

DC-DC converter. If the purpose is to charge a battery or regulate a DC- bus as in space and telecom applications, the system can be implemented by using only the DC-DC converter as depicted in Figure1

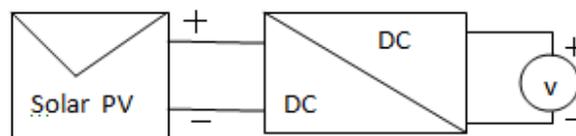


Figure 1 Basic element of power conditioning system

Modelling of Solar PV Module

A simplified equivalent circuit of a solar cell consists of a diode and a current source which are switched in parallel. The photocurrent generated when the sunlight hits the solar panels can be represented with a current source and the p-n

transition area of the solar cell can be represented with a diode. The voltage and current relationship of the simplified solar cell can be derived from Kirchhoff's current law. This simplified equivalent circuit, however, does not give an accurate representation of the electrical process at the solar cell. On real solar cells, voltage losses occur at the boundary and external contacts and leakage currents occur throughout the cell; these losses can be represented with a series resistance and a parallel

resistance. The equivalent circuit of the solar cell showing the series and parallel resistance is shown in Figure 2.

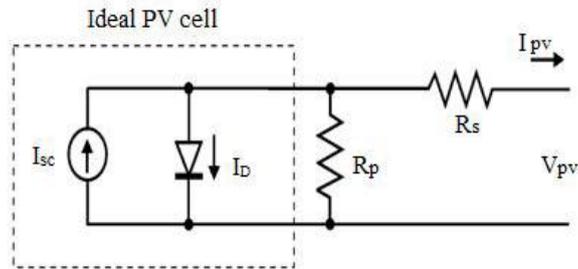


Figure 2 Equivalent circuit of a solar PV module

The current Equation is given by,

$$I_{SC} = I_D + I_{PV} + \left(\frac{V_D}{R_p}\right) \quad (1)$$

$$V_{PV} = V_D - (I_{PV} * R_s) \quad (2)$$

Where diode current is, $I_D = I_o + (e^{\frac{V_D}{V_t}} - 1)$, I_{SC} is the short circuit current, $V_t = N_s K T / q$ is the thermal voltage with N_s cells connected in a series (K is the Boltzmann constant, q is the electron charge and T is the temperature of the PV cells). The short circuit current is directly proportional to the irradiation and slightly proportional to the level of the cell temperature.

Using Equations 1 and 2, the solar PV module is modeled in MATLAB/Simulink as shown in Figure 8 and used to enhance the understanding and predict the I-V and P-V characteristics and to analyze the effect of temperature and irradiation variation. If irradiance increases, the fluctuation of the open-circuit voltage is very small. But the short circuit current has sharp fluctuations with respect to irradiance. However, for a rising operating temperature, the open-circuit voltage is decreased in a non-linear fashion.

Parameter	Values
Open circuit voltage (V_{oc})	21 V
Short circuit current (I_{sc})	2.5A
Voltage at MPP (V_{max})	16.4V
Current at MPP (I_{max})	2.25A
Power rating (P_{max})	37W
Size (mm)	645*530*16
Weight (kg)	5

Table 1 Specification of a solar PV module under test

APPLICATION-BASED SELECTION OF MPPT ALGORITHM

The main aspects for selection of the MPPT techniques are essentially:

- The ease of implementation is an important factor in deciding which MPPT technique to use. Some techniques require analogue circuitry and others digital circuitry, even if that may require the use of software and programming
- The number of sensors required to implement MPPT also affects the selection process. It is easier and more reliable to measure voltage than current. Moreover, current sensors are usually expensive and bulky. It is also uncommon to find sensors that measure irradiance levels, as needed in the linear current controls and

the maximum power point current (IMPP) and maximum power point voltage (VMPP) computation methods.

- The occurrence of multiple local maxima due to partial shading of the PV array can be a real hindrance to the proper functioning of an MPP tracker. Considerable power loss can be incurred if a local maximum is tracked instead of the real MPP.
- It is hard to mention the monetary costs of every single MPPT technique unless it is built and implemented. A good cost comparison can be made by knowing whether the technique is analogue or digital, whether it requires software and programming, and the number of sensors. Analogue implementation is generally cheaper than digital, which normally involves a microcontroller that needs to be programmed.

ADAPTIVE PERTURB AND OBSERVER MPPT

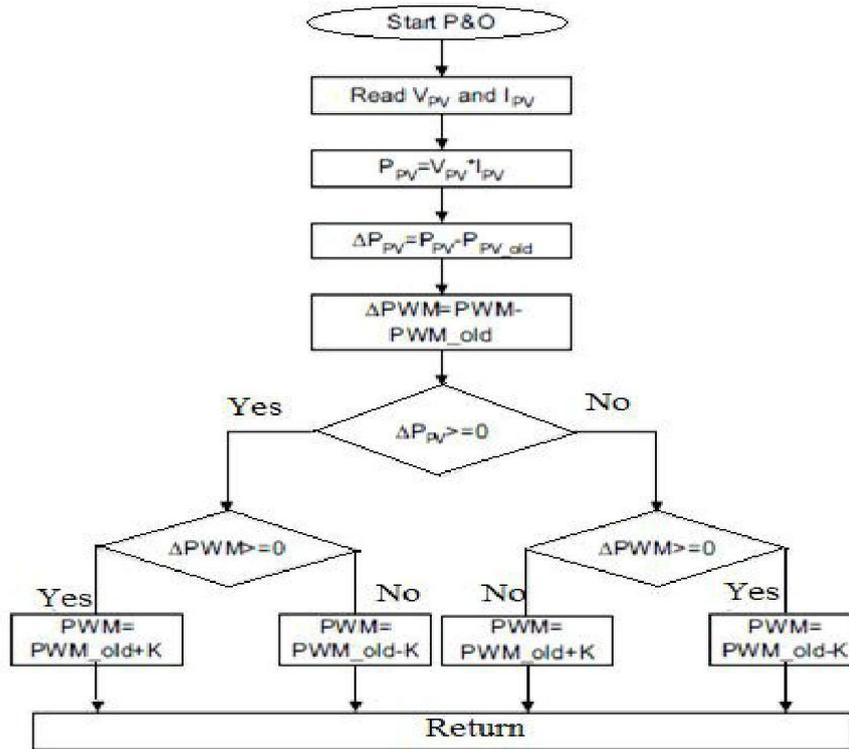


Figure 3 Flow chart of Adaptive perturb and observer algorithm

In the PAO algorithm, the operating voltage of the PV array is perturbed by a small increment, and the resulting change in power, ΔP , is measured. If ΔP is positive, the perturbation of the operating voltage moves the PV array's operating point closer to the MPP. Thus, further voltage perturbations in the same direction (that is, with the same algebraic sign) should move the operating point towards the MPP. If ΔP is negative, the system operating point moves from the MPP, and the algebraic sign of the perturbation should be reversed towards the MPP. Though PAO algorithm is simple and easy to implement, it fails when the atmospheric conditions change rapidly. To overcome this problem, the adaptive PAO algorithm improves the dynamic response without affecting stability. In this algorithm, high perturbation is selected when the operating point is far away from MPP and low perturbation is selected when the operating point is closer to MPP. The adaptive PAO algorithm has been implemented in ATMEGA16 micro-controller to generate gate pulse which can be given to the switches of DC-DC converter.

The flow chart of the adaptive perturbs and observer MPPT algorithm is illustrated in Figure 3. The parameter K is the step given to the PWM signal. This parameter can vary depending on the working point of the DC-DC converter. To get a faster convergence, high value of K is selected to avoid big oscillations near to the MPPT. The PAO MPPT control algorithm is implemented in a micro-controller (ATMEGA16) that has ten 10-bits analogue-to-digital converter (ADC) and two fast PWM mode signals with 10-bits of resolution. The control circuit compares the PV output power before and after a change in the duty-cycle of the DC-DC converter control signal and acts in conformity. The PWM old is the sample of the PWM signal in the previous iteration of the algorithm and ΔP_{PV} is the variation of the delivered power to the load.

Cuk Converter

The basic circuit configuration used in Cuk converter is shown in Figure 4 Cuk converter has two modes of operation. The first mode of operation is when the switch (MOSFET) is closed (ON) and it is conducting as a short circuit as shown in Figure 5 In this mode, the current through inductor L_1 rises. At the same time, the voltage of capacitor C_1 reverse biases the diode D and turns it off. The capacitor (C_1) releases its stored energy to the load. The second operating mode is when the switch (S) is open (OFF), diode (D) is forward biased and conducting energy to the output as shown in Figure 6 Capacitor C_1 is charging from input supply and the energy stored in the inductor L_2 is transferred to the load. The diode D and switch (S) provide a synchronous switching action The relation between input and output currents and voltage is given by

$$\frac{V_o}{V_{IN}} = -\frac{d}{(1-d)} \quad (3)$$

$$\frac{I_{IN}}{I_o} = -\frac{d}{(1-d)} \quad (4)$$

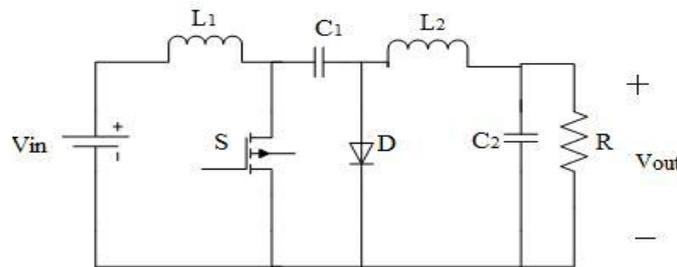


Figure 4 Cuk converter

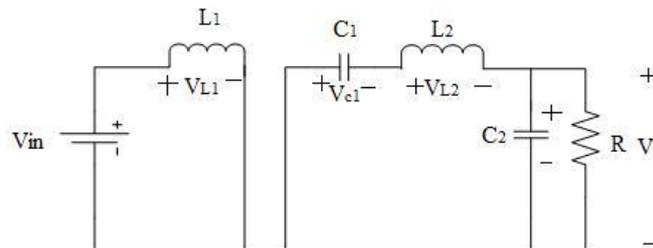


Figure 5 Mode 1: Switch S is ON

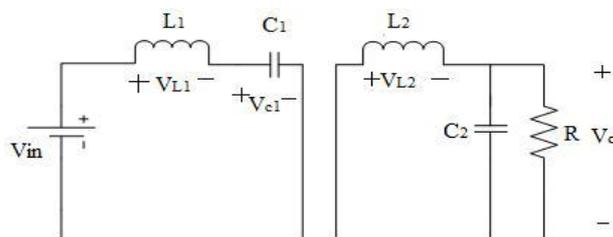


Figure6 Mode 2: switch S is OFF

The input resistance of Cuk converter during the continuous conduction mode is given by

$$R_i(CCM) = \frac{2L_{eq}f_s}{d^2} \quad (5)$$

Where $L_{eq} = L_1//L_2$ and f_s switching frequency

The input resistance R_i during the discontinuous conduction mode is given by

$$R_i = \frac{KR}{d^2} \quad (6)$$

Therefore, the Cuk converter is capable of sweeping the whole I-V curve of a solar PV module in CCM from open circuit voltage (V_{oc}) to short circuit current (I_{sc}) condition. Due to the input and output inductor in Cuk converter, the input

current is non-pulsating. Therefore, the sweep of the I-V curve is carried out in a more reliable and less noisy way. So Cuk converter is more suitable in MPP tracking circuits. The Cuk converter is preferred in power conditioning process of solar PV system since Cuk converter works based on the energy transfer of the capacitor.

CUK CONVERTER-BASED MPPT FOR SOLAR PV SYSTEM

Figure 7 shows a Cuk converter-based MPPT system consisting of solar PV module, Cuk converter (DC-DC) and load. Cuk converter is capable of sweeping the I-V curve of solar PV module in CCM from open circuit voltage to short-circuit current condition and, hence, Cuk converter is suitable to be employed in designing the MPPT circuits.

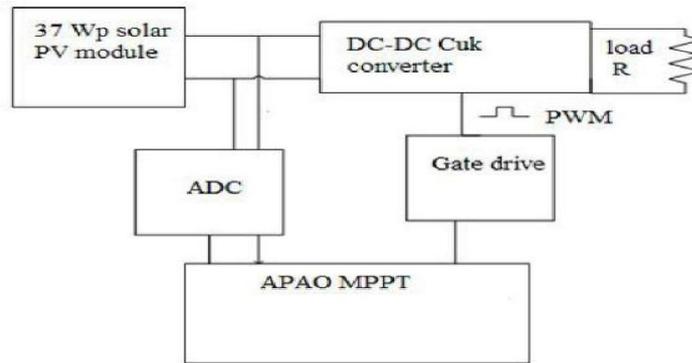


Figure 7 Cuk converter-based MPPT system

The closed loop control is obtained by implementing the MPPT algorithm using micro-controller. In the PAO algorithm, the operating voltage of the PV array is perturbed by a small increment, and the resulting change in power, ΔP , is measured. If ΔP is positive, the perturbation of the operating voltage moves the PV array's operating point closer to the MPP. Thus, further voltage perturbations in the same direction (that is, with the same algebraic sign) should move the operating point towards the MPP. If ΔP is negative, the system operating point moves from the MPP, and the algebraic sign of the perturbation should be reversed towards the MPP. To improve the dynamic response without affecting stability the Adaptive Perturb and Observer algorithm (APAO) is used. In APAO algorithm, high perturbation is selected when the operating point is far away from MPP and low perturbation is selected when the operating point is closer to MPP.

DESIGN CONSIDERATION OF CUK CONVERTER

The relation between input and output currents and voltage is given in Equations 1 and 2
The duty cycle of the Cuk converter under continuous conduction mode is given by

$$d = \frac{V_{out} + V_D}{V_{in} + V_{out} + V_D} \quad (7)$$

V_D is the forward voltage drop across the diode (D). The maximum duty cycle is given by Equation (2)

$$d_{max} = \frac{V_{out} + V_D}{V_{in(min)} + V_{out} + V_D} \quad (8)$$

The value of inductor is selected based on following equation

$$L_1 = L_2 = L = \frac{V_{in(min)} * d_{max}}{\Delta I_L * f_s} \quad (9)$$

ΔI_L is the peak-to-peak ripple current at the minimum input voltage and f_s -switching frequency. The value of C_1 depends on RMS current which is given by

$$I_{C1(rms)} = I_{out} * \sqrt{\frac{V_{out} + V_D}{V_{in(min)}}} \quad (10)$$

The voltage rating of capacitor C_1 must be greater than the input voltage. The ripple voltage on C_1 is given by

$$\Delta V_{C1} = \frac{I_{out} * d_{max}}{C_1 * f_s} \quad (11)$$

The parameters governing the selection of the MOSFET are the minimum threshold voltage $V_{th(min)}$, the on-resistance $R_{DS(on)}$, gate-drain charge Q_{GD} , and the maximum drain to source voltage, $V_{DS(max)}$. The peak switch voltage is equal to $V_{in} + V_{out}$. The peak switch current is given by

$$I_{Q1(rms)} = I_{L1(peak)} + I_{L2(peak)} \quad (12)$$

The RMS current is given by

$$I_{Q1(rms)} = I_{out} \sqrt{(V_{out} + V_{in(min)}) * \frac{V_{out}}{V_{in(min)}^2}} \quad (13)$$

The total power dissipation for MOSFET includes conduction loss (as shown in the first term of the above equation) and switching loss as shown in the second term. I_G is the gate drive current. The $R_{DS(ON)}$ value should be selected at maximum operating junction temperature and is typically given in the MOSFET datasheet.

$$P_{switc h} = (I_{Q1(rms)} * R_{DS(ON)} * d_{max}) + (V_{in(min)} + V_{out}) * I_{Q1(peak)} * \frac{Q_{GD} f_s}{I_G} \quad (14)$$

The output diode must be selected to handle the peak current and the reverse voltage. In a Cuk converter, the diode peak current is the same as the switch peak current $I_{Q1(peak)}$. The minimum peak reverse voltage that the diode must withstand is

$$V_{RD} = V_{in(max)} + V_{out(max)} \quad (15)$$

Similar to the boost converter, the average diode current is equal to the output current. The power dissipation of the diode is equal to the output current multiplied by the forward voltage drop of the diode. Schottky diodes are recommended in order to minimize the efficiency loss.

MATLAB Simulation of PV Module

The P-V and I-V characteristics are validated in MATLAB software for the L1235-37Wp (Watt peak) solar module. Table .1 shows the technical specification of L1235-37Wp solar panel under test which is shown in Figure. The I-V characteristic is obtained based on experimental results under irradiation =1000 W/m², temperature =25 °C

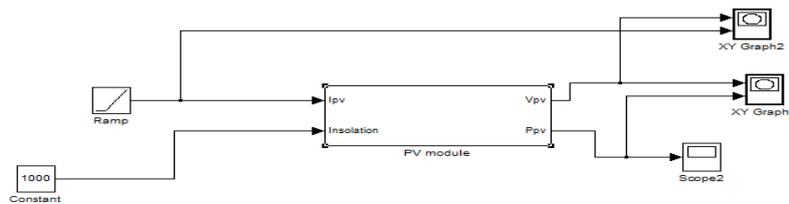


Figure 8 MATLAB model for PV module

I-V waveform of PV module

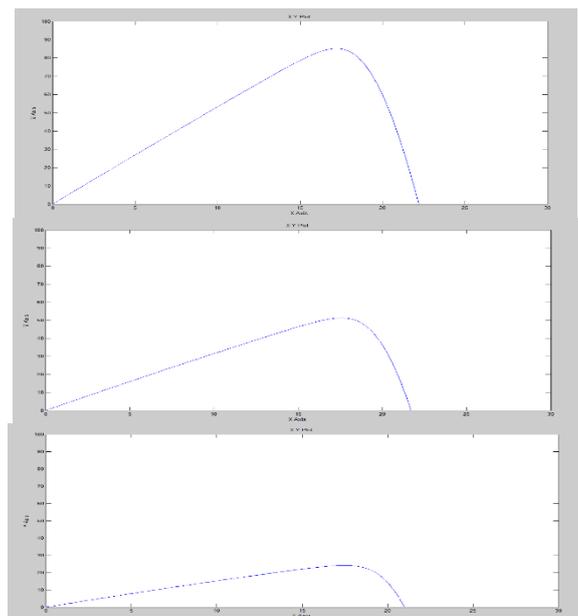


Figure 9 P-V Characteristics of solar PV module at irradiation (1000/600/300 $\frac{W}{m^2}$)

Conclusion

A brief survey of the techniques and methods available in the literature for effective implementation of design and analysis of Cuk converter circuits has been discussed. Also simulate PV module under different irradiation levels and study about MPPT.

References

- Analysis and Design of ZVS-PWM Active Clamping DC-to-DC Cuk Converter Based PV Generation System by Mutta Krishna Murthy, Sandeep. N, Student Member, IEEE, and P.S. Kulkarni
- Analysis and Design of a Solar Charge Controller Using Cuk Converter D.C. Riawan and C.V. Nayar, Senior Member, IEEE Department of Electrical and Computer Engineering Curtin University of Technology, Perth, WA 6845, Australia
- Cascaded Control System Design for a Cuk Converter via Singular Perturbation Approach Efim A.Aksenov, Valery D.Yurkevich, Member, IEEE Novosibirsk State Technical University, Novosibirsk, Russia
- Design and Simulation of Incremental Conductance MPPT Using Self Lift Cuk Converter by M.LathaDevi, Mr.M.Chilambarasan at 2013 International Conference on Renewable Energy and Sustainable Energy [ICRESE'13]
- Analysis and Design of DC- DC/AC Non Isolated Cuk Converter using Sliding Mode Controller by 2015 International Conference on Circuit, Power and Computing Technologies [ICCPCT] by Dr.B.Meenakshi Professor, Department Of EEE,