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# Maximum Power Point Tracking For PV Inverter Applications

R.Nithya
Power Electronics and Drives
Sri Venkateswara College of Engineering
Sriperumbudur.
Rnithyaravi89@gmail.com

M.Ranjith kumar
Department of Electrical and Electronics
Sri Venkateswara College of Engineering
Sriperumbedur
mranjith@svce.ac.in

***Abstract*— Solar energy is the abundantly available resource in tropical country. The PV cells are the best mode to collect the solar radiations from the available energy and convert it to electric power. This paper presents a maximum power point tracking (MPPT) scheme for operation of a photo voltaic (PV) system. The CUK converter acts as a DC-DC converter for boosting the voltage level for inverter applications which is present at the load side. The fuzzy logic controller is used as the sliding mode controller for varying weather conditions. For better response of FLC the unsymmetrically or convergent distribution membership functions are used than the symmetrically distributed membership functions. Cuk converter for MPPT is used to produce high precision in current transition and maintain the voltage constant at variable loads. The efficiency of photovoltaic (PV) array is proved with the help of lagging power factor at the output side. In this paper the perturb and observe method of MPPT technique is used. Comparing with the other source of renewable energy solar is most abundantly available in nature. The THD level is reduced to 0.88% from 4.2%. For real-time implementation PIC microcontroller is used.**

***Index Terms*— MPPT algorithm, photovoltaic cells, Fuzzy control, Cuk converter.**

## I. Introduction

The single-ended primary inductor converter acts as a buck-boost DC-DC converter that provides a positive regulated output voltage which varies according to its duty cycle. For maximum power point tracking (MPPT) the selection of DC-DC converter is important. The selection of PV converter depends on the many factors such as cost, flexibility, energy flow and efficiency. The PV model characteristics [1] are simulated using effect of solar intensity and cell temperature. The PV module has nonlinear characteristics and the energy flow is assured with the help of continuous current from the converter. Among many DC-DC converters the buck-boost converters have inverted output voltage [2] and more power loss due to input switching because of discontinuous input current. Due to lack of output voltage flexibility the buck or boost converters are not used. These converters are unable to provide charge continuously for PV system battery charging with MPPT operation.

Based on the irradiation level the power voltage curve changes and the voltage corresponding to the maximum power changes. Comparing with other DC-DC converters the SEPIC have the ability to step up and step down the input voltage [2], with non-inverted output. The main advantage of SEPIC is continuous output current for PV system battery charging. In conventional system MPPT with SEPIC converter is simulated. The disadvantage of this method is use of high capacitor and inductor values and the THD level is 4.2%. To overcome this disadvantage CUK converter can be used instead of SEPIC. The CUK converter have the same characteristics of SEPIC, the difference is the inverted output voltage of CUK. But the value of inductor and capacitor used in this converter is less and the THD level is reduced to 0.88%. Compared with the buck-boost and fly-back converters [3] the CUK have contentious input current and improved efficiency.

The need for MPPT is to obtain the maximum power output [4] under a given temperature and irradiance. PV is increasingly connected to grid. The various MPPT algorithms represents optimal load for PV array. The MPPT is also used find the voltage (VMPP) or current (IMPP) at which a PV array should operate. Comparing with the various MPPT tracking methods Perturb and Observe method [4] is so simple and tracks a new reference signal to the controller. Compared to P&O, incremental conductance and parasitic capacitance methods have increased complexity [5]-[7]. To overcome the disadvantages of PI controllers fuzzy logic controller is used. The maximum power transfer from PV array to inverter side continuously is obtained by integrating FLC with MPPT algorithm.

## II. PROPOSED SYSTEM

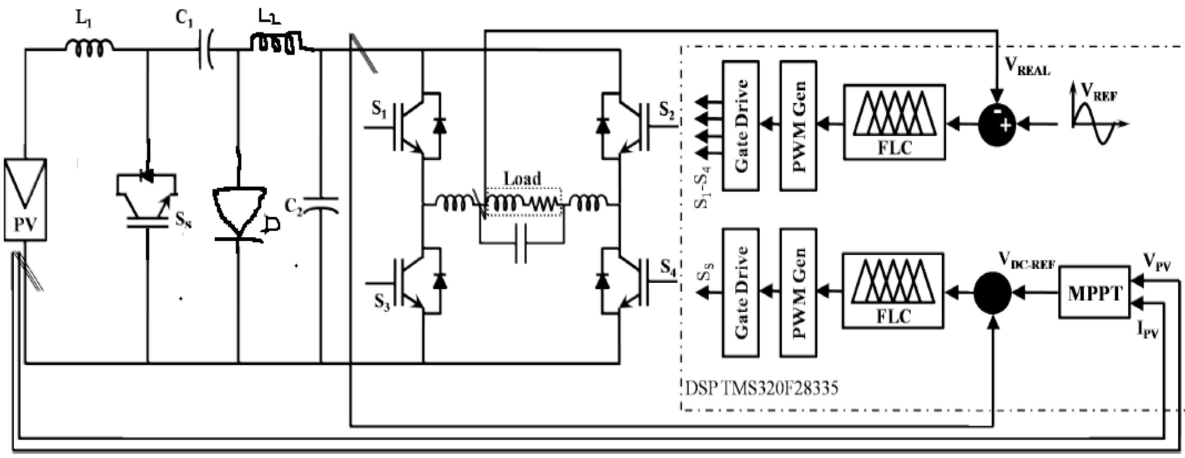


Fig.1 Circuit diagram of overall control scheme

In this paper depending on the maximum power of the PV panel the voltage level changes. The DC-DC converter is used to allow the change in voltage level to the inverter. The reference signal is tracked by the change in duty cycle of the pulse width modulation (PWM) signal, this result in the change in voltage by the controller. The circuit diagram consists of Cuk DC-DC converter with the MPPT and fuzzy controller. The Mamdani method is used for designing the fuzzy controller. The reference signal is obtained from the output signal represented in voltage, current, and power. The PWM changes its duty cycle according to the control signal. Fig.1 shows the overall schematic diagram.

### A. *Cuk converter*

The Cuk converter acts as the boost-buck DC-DC converter. It has an output voltage magnitude that is either greater than or less than the input voltage magnitude. The capacitor is used to couple the energy and it is a energy storage component. Unlike most other types of converters which use an inductor.

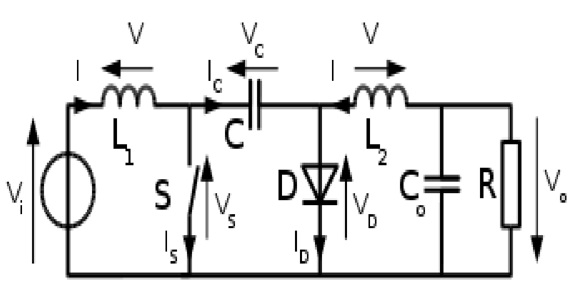


Fig. 2 schematic diagram of Cuk converter.

Fig 2.shows the circuit diagram for Cuk converter. The input and output current are continuous. It uses L-C type filter, so peak-peak ripple current of inductors are less as compared to the Buck-Boost converter.

**Continuous mode**

In steady state, the energy stored in the inductors has to remain the same at the beginning and at the end of a commutation cycle. The energy in an inductor is given by:

$$E=\frac{1}{2}LI^2 \quad (1)$$

This implies that the current through the inductors has to be the same at the beginning and the end of the commutation cycle. As the evolution of the current through an inductor is related to the voltage across it:

$$V_{L}=L\frac{dI}{dt} \quad (2)$$

The converter operates in on-state from t=0 to t=D·T (D is the duty cycle), and in off state from D·T to T (that is, during a period equal to (1-D)·T). The average values of $V_{L1}$ and $V_{L2}$ are therefore:

$$V_{L1}=D.V_i + (1-D) * (V_i-V_C) = (V_i - (1-D) * V_C) \quad (3)$$

$$V_{L2} = D\,(V_o + V_C) + (1-D) * V_o = (V_o + D * V_C) \quad (4)$$

As both average voltage have to be zero to satisfy the steady-state conditions we can write, using the last equation:

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

So the average voltage across $L_1$ becomes:

$$\frac{V_o}{V_i} = \frac{-D}{1-D} \quad (6)$$

It can be seen that this relation is the same as that obtained for the Buck-Boost converter.

**Discontinuous mode:**

Like all DC-DC converters Ćuk converters rely on the ability of the inductors in the circuit to provide continuous current, in much the same way a capacitor in a rectifier filter provides continuous voltage. If this inductor is too small or below the "critical inductance", then the current will be discontinuous. This state of operation is usually not studied in much depth, as it is not used beyond a demonstrating of why the minimum inductance is crucial.

The minimum inductance is given by:

$$L_{1min} = \frac{(1-D)2R}{2Dfs} \quad (7)$$

where $f_s$ is the switching frequency.

B. *FLC algorithm*

In this paper fuzzy logic controller is used to compare the output voltage error and the PV panel voltage to produce duty cycle for the converter. The change in voltage is given to fuzzification block; their rules are formed with knowledge base. The membership functions are formed based on Mamdani fuzzy interference method. Based on decision making the output from rules are obtained and defuzzification process is carried out to produce the gate signal. In fuzzy controller design the membership functions can be designed with symmetrical or unsymmetrical membership function.

The triangular or symmetrical membership functions are used for the FLC for easier computation. A three term fuzzy set, negative (N), zero (Z), positive (P) for the first input and low(L), zero(Z), high (H) for the second input is defined to describe each linguistic variable. The rules of the proposed PV CUK DC-DC converter can be represented in a symmetric form, as shown in Table 1. The member ship functions of the output variables are five-term fuzzy sets with classical triangular shapes, low negative (LN), high negative (HN), zero (Z), low positive (LP), high positive (HP). The Mamdani fuzzy inference method is used for the proposed FLC, where the maximum of minimum composition technique is used for the inference and the center-of-gravity method is used for the defuzzification process. In fuzzy logic controller design the values of each linguistic variable are determined by identifying the main control variables. The input variables of the FLC are the output voltage error, and the PV panel voltage. The output of the FLC is the duty cycle of the PWM signal which regulates the output voltage.

Table 1. Fuzzy rule based matrix

| | **L** | **Z** | **H** |
|---|---|---|---|
| **N** | LN | HN | HN |
| **Z** | Z | Z | Z |
| **P** | LP | LP | HP |

In fuzzy logic algorithm θ represents the factor of asymmetry and its value varies within -50 and +50. Obviously, $\theta = 0$ for symmetrical distribution for membership functions, $\theta > 0$ for convergent distribution and $\theta < 0$ for divergent distribution.

## III. PV ARRAY

The structure of solar cells is made up of P-type semiconductor with a small quantity of boron atoms as the substrate. In the P-n junction, holes and electrons will be rearranged to form a potential barrier in order to prevent the motion of electrical charges. When the p-n structure is irradiated by sunlight, the energy supplied by photons will excite the electrons in the structure to produce hole-electrons pairs. The Fig.1 shows the equivalent circuit of a PV cell which includes a current source, a diode, a series resistance and a shunt resistance. The load current is given in equation 1. The above principle can be understood with the help of Fig.3.

$$I = I_{ph} - I_s\left(exp\frac{q(V+R_sI)}{NKT} - 1\right) - \left(\frac{V+R_s}{R_{sh}}\right) \quad (8)$$

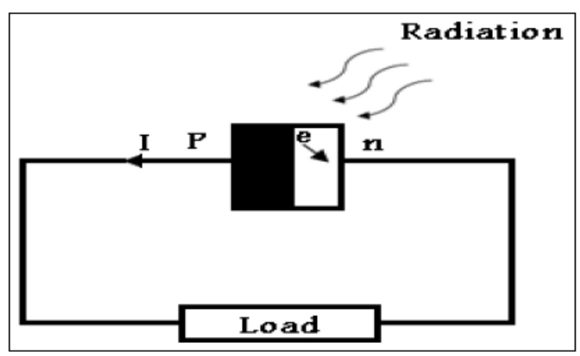


Fig. 3 photovoltaic principle

In the grid connected system, full load condition, or using battery charging in case of standalone system the maximum power point can be achieved. The above equivalent circuit based model is mainly used for the MPPT technologies.

The load current with shunt resistance and current is given as

$$I = I_{ph} - I_s\left(exp\frac{q(V+I\boldsymbol{R_s})}{\boldsymbol{K}T_C A} - \mathbf{1}\right) - \frac{\boldsymbol{V+IR_s}}{\boldsymbol{R_{sh}}} \quad (9)$$

The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as

$$I_{ph} = [I_{SC} + K_I(T_C - T_{Ref})]H \quad (10)$$

PV array is a group of several PV cells which are electrically connected in series and parallel circuits to generate the required current and voltage. The equivalent circuit for the solar module with shunt and series resistances, diode is shown in Fig. 4.

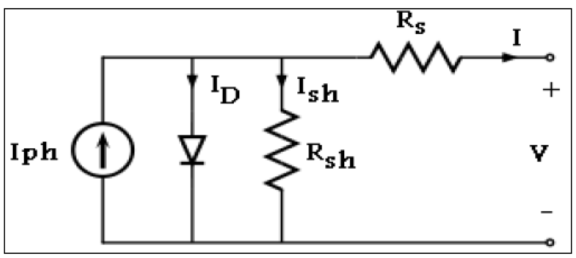


Fig. 4 Equivalent circuit of solar cell

The shunt resistance $R_{sh}$ is inversely related with shunt leakage current to the ground. The load current for solar array is given as

$$I = N_p I_{ph} - N_p I_s\left[\exp\left(\frac{q(V+I\boldsymbol{R_{SM}})}{\boldsymbol{N_{SK}\,T_{cA}}}\right) - 1\right] \quad (11)$$

$$R_{SM} = \frac{\boldsymbol{N_s R_s}}{\boldsymbol{N_p}} \quad (12)$$

An array of 19 series solar module is used to generate 330V DC voltage. The module rated voltage is 30V. The solar module used in this paper is PV-AE125MF5N. The rated values for the solar array are given in Table.2. With increase of solar insolation, the short-circuit current of the PV module increases, and the maximum power output increases as well. The reason is the open-circuit voltage is logarithmically dependent on the solar irradiance, yet the short-circuit current is directly proportional to the radiant intensity.

Table.2 PV module parameters

| **PARAMETERS** | **VALUE** |
|---|---|
| Maximum Power | 124W |
| Warranted Power | 116W |
| Rated Current | 4.1A |
| Rated voltage | 30V |
| Short Circuit Current | 3.8A |
| Open Circuit Voltage | 21.1V |

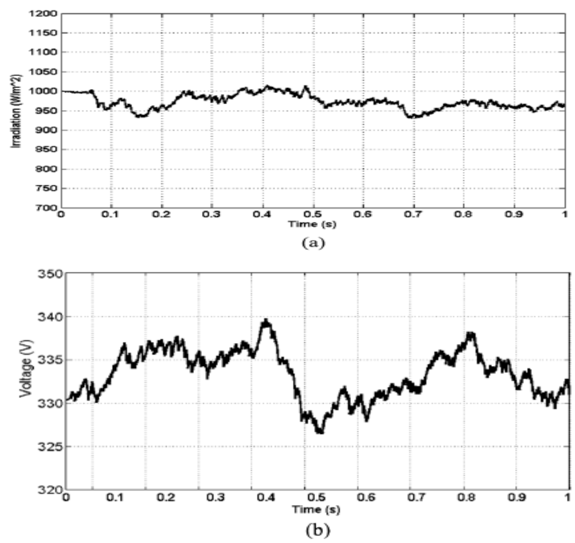


Fig.5 (a) The irradiation ($W$=$m$2), (b) Reference voltage.

IV. MAXIMUM POWER POINT TRACKING

The MPPT method is used to track the maximum power from the PV array and it is applied to the Fuzzy logic controller which produces the duty cycle to the CUK converter. The new duty cycle δ(k) of the CUK converter switch will be adjusted either by adding or subtracting the previous duty cycle δ(k-1) with the duty-cycles perturbation step-size.

$$\delta(k) = \delta(k-1) \pm \Delta\delta \quad (13)$$

Equation (13) presents the relation between the present and the previous duty cycles; where Δ δ is the change in duty cycle, resulting from the change of reference signal.

There are many different methods of MPPT technique, among them P&O is the simplest and most extensively used MPPT system for few parameter requirements. In this we use only one sensor that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less. Incrementing the voltage increases the power when operating on the left of the MPP and decreases the power when on the right of the MPP. It involves a perturbation in the duty ratio. P&O is the perturbation in the operating voltage of the PV array. The direction of the voltage and power are determined from the Figure.6 and the sign is obtained from the Table 3. The P&O method tracks the power curve of the PV array; it compares the voltage of the present cycle and previous cycle, if the voltage in the present cycle is greater, then the next perturbation is in positive direction, otherwise it is opposite direction.

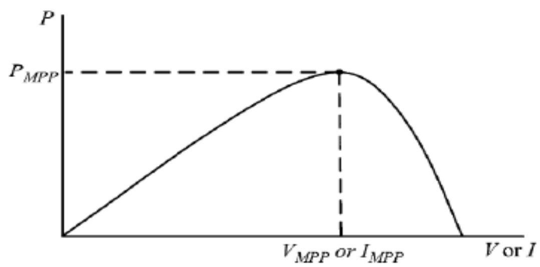


Fig 6. Power Vs voltage, current curve

Table 3. Determination of perturbation

| Perturbation | Change in power | Next Perturbation |
|---|---|---|
| Positive | Positive | Positive |
| Positive | Negative | Negative |
| Negative | Positive | Negative |
| Negative | Negative | Positive |

The step-size of the P&O method affects two parameters: accuracy and speed. Accuracy increases when the step-size decreases. However, accuracy leads to slow response when the environmental conditions change rapidly. Larger step-size mean higher speed for the MPPT operation, but this will lead to inaccuracy and larger intrinsic oscillations around the maximum power point in steady state. Step sizes should, thus, be chosen well to achieve high speed and accuracy. The step-size rate for the voltage reference signal in this work is0.5V/ms.

V. SIMULATION CIRCUIT AND RESULTS

Two types of simulations for the MPPT converter were done using MATLAB/Simulink. The first simulation used the characteristic equations of the PV array while the second one used the solar-panel module given in Simulink. The MPPT algorithm was built via (.m) file and linked with Simulink. The SEPIC circuit was built via SimPower toolbox. Fig 8. Shows the simulation circuit for the proposed FLC based MPPT scheme for Cuk converter. For the design of PV array the characteristic equations are used.

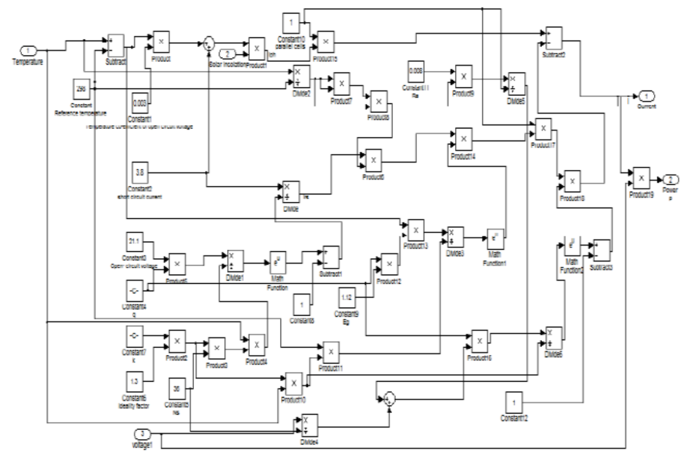

Fig.7 Sub-system of PV array

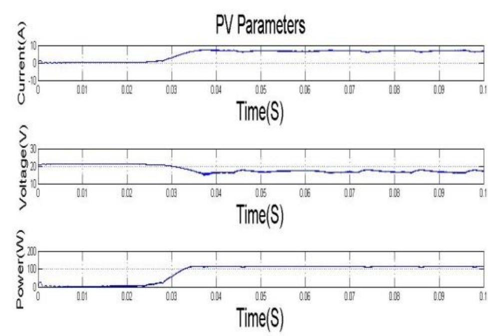


Fig.8. PV- Current, Voltage, Power

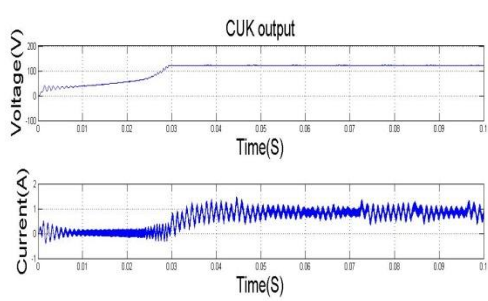


Fig.9. Converter Output

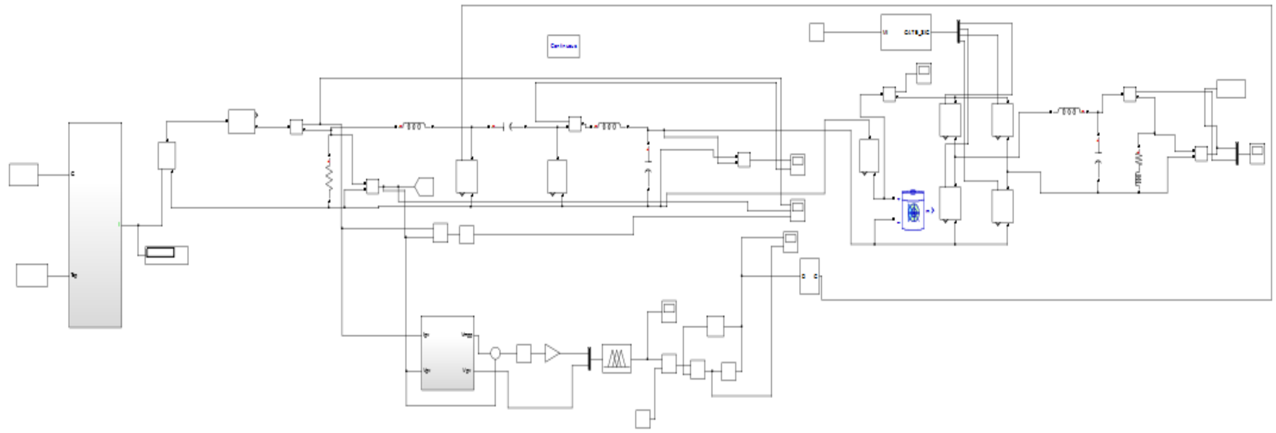

Fig.10.Simulation circuit of MPPT for PV inverter applications

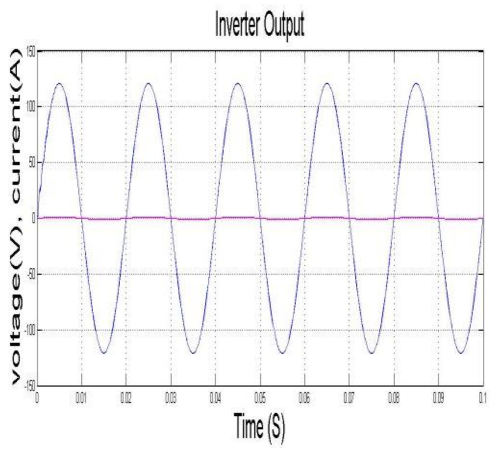


Fig.11. Inverter output

The Figs.8, 9, 11, shows the waveform of PV array, Cuk converter and inverter outputs respectively. The rated power from the PV system is 124W, 30V and 3.8A, but obtained level of power is 116W. The values of L1 and L2 are 5mH and 2.5mH respectively. The values of capacitor C1 and C2 are 10μF and 5μF respectively. The single phase AC voltage is obtained for unity power factor.

## VI. CONCLUSION

The Maximum Power Point Tracking algorithm is carried out with the help of PV array, Cuk converter and FLC systems. Because of continuous output and input current of the Cuk converter this method is found to be better than the use of SEPIC as DC-DC converter. The THD level of the circuit is reduced to 0.88% from 4.2%. This scheme is used in PV inverter applications.

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