Maximum Power Point Tracking of Photovoltaic System Using Intelligent Controller

Swathy C.S[#1], C Agees Kumar*[2] and R Manju[#3]
[#]Dept. of Electronics and Instrumentation, Noorul Islam University, Tamil Nadu, India
[1]swathycsarng@gmail.com
[3]manjurajamony20@yahoo.co.in
[*]Dept. of Electronics and Instrumentation, Noorul Islam University, Tamil Nadu, India
[2]ageesofficials@gmail.com

Abstract- Photovoltaic systems normally use a maximum power point tracking (MPPT) technique to continuously give forth the highest probable power to the load when the temperature and solar irradiation changes occur. This subdues the problem of mismatch between the given load and the solar array. The energy conservation principle is used to obtain small signal model and transfer function. A simulation work handling with MPPT controller, a DC/DC boost converter feeding a load is achieved. PI controller and fuzzy logic controllers were used as the MPPT controller, which controls the dc/dc converter. Simulations and experimental results showed excellent performance and were used for comparing PI controller and fuzzy logic controller.

Index Terms - DC/DC boost converter, fuzzy logic controller, maximum power point tracking, photovoltaic system, PI controller, solar array

I. INTRODUCTION

As conventional sources of energy exhausting quickly and the cost of energy is increasing, solar energy becomes a promising alternative source. The advantages of solar energy are: 1) abundant; 2) pollution free; 3) distributed throughout the earth; and 4) recyclable. But its main disadvantages are its high initial installation cost, and the low energy conversion efficiency. These problems can be overcome by increasing the energy conversion efficiency and by maximizing the output power from the solar array. With the development of technologies, the cost of the photovoltaic or solar array is awaited to reduce continuously in the future, making them useful for residential and industrial applications [2].

Consequently, solar systems must be designed to operate at its maximum output power at any temperature or solar irradiance. Generally if the load is not directly coupled with the PV panel, the operating point and MPP do not coincide. Direct connection of load to the panel may result in the over sizing of the panel and thus increases the cost of the entire system [7]. The solution to this problem is to use a DC/DC boost converter with an automatic duty cycle control which is usually inserted between the solar panel and the load. The MPP computing system will improve the duty cycle and the input impedance of the converter until the system reaches MPP.

The system consists of a DC/DC boost converter and a controller. The controller measures the input voltage and current and reckons the power to control the duty cycle. A capacitor or a battery is used as storage device.

For many years, research has been concentrating on various methods to draw maximum power from solar panel. Several methods of maximum power point tracking have been considered. These methods require intelligent controllers such as fuzzy logic controller and conventional controllers such as PI controller [5]. This paper presents a new maximum power point tracking using various intelligent controllers. The block diagram of the system is shown in Fig.1**.** The converter is used for interfacing the PV output and the load and for tracking the maximum power point of the photovoltaic panel.

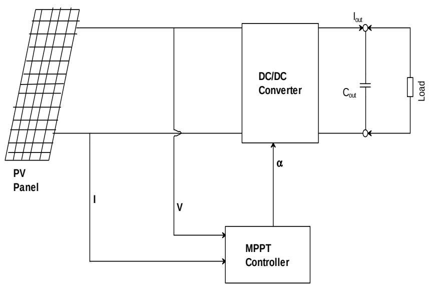


Fig. 1. Block diagram of the PV system

II. PV MODELING

In this section, in order to show the practicability of MPPT using PI and fuzzy logic controller, the photovoltaic system with boost converter is used. The circuit configuration of the system is shown in Fig. 2**.**

A. Circuit Configuration

The cell is fundamentally a large area p-n diode with the junction positioned near to the upper surface. Therefore a perfect photovoltaic cell may be modeled by a current source in parallel with a diode that mathematically describes the V-I characteristics. The relationship between the output voltage V and current I of the solar panel is given by [1] and [3]:

$$I = I_{sol} - \left\{\exp\left[\frac{q}{\gamma kT}(V + R_s I)\right] - 1\right\} - \frac{V+R_s I}{R_{sh}} \qquad (1)$$

Where

$$I_{os} = I_{or}\left(\frac{T}{T_r}\right)^3 \exp\left[\frac{qE_{GO}}{\beta k}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \qquad (2)$$

$$I_{sol} = [I_{sc} + K_I(T - 298.18)]\frac{\lambda}{1000} \qquad (3)$$

Where I, V, I_{os}, T, k, q, K_I, I_{sc}, λ, I_{sol}, E_{GO}, γ(=β), T_r, I_{or}, R_{sh} and R_s are cell output current and voltage, cell reverse saturation current, cell temperature (Kelvin), Boltzmann's constant ($1.381\text{x}10^{-23}$J/K) , electronic charge ($1.602\text{x}10^{-19}$C), short circuit current temperature coefficient at I_{sc}, short-circuit current at 25^0C and 1000W/m^2, solar irradiation in W/m^2, light generated current, band gap for silicon (1.12eV), ideality factor(1.740), reference temperature(298.18 K), cell saturation current at T_r, shunt resistance and series resistance respectively.

The output power of the panel is P=VI, at maximum point, it is given as:

$$\frac{\partial P}{\partial V} = I + V\frac{\partial I}{\partial V} = 0 \Rightarrow \frac{\partial I}{\partial V} = -\frac{I}{V} \qquad (4)$$

i.e,

$$I = (V - R_s I)\left\{I_{os}[A\exp(V + R_s I)] + \frac{1}{R_{sh}}\right\}$$

Where:

$$A = \frac{q}{\gamma kTN_{cell}}$$

N_{cell} is the number of series cell in the panel.

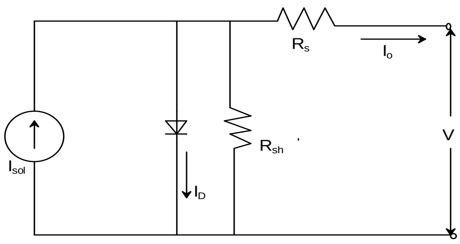


Fig. 2. Circuit configuration of the PV panel

The shunt resistance is measured and the constants are determined in these equations by using manufacturer's ratings under standard test conditions of the Panel.

B. Boost Converter

Value L of the converter shown in Fig. 3. is calculated such that the peak current of the inductor at maximum input power does not exceed the power switch current rating. Hence, L is calculated as [9]:

$$L \geq \frac{V_{om}(1-\alpha_m)\alpha_m}{f_s|\Delta I_{Lm}|} \qquad (5)$$

Where f_s, α_m, ΔIL_m, V_{om} and I_{om} are switching frequency, duty cycle at maximum input power of the converter, peak-to-peak ripple of the inductor current, maximum of DC component of the output voltage and DC component of the output current at maximum output power respectively.

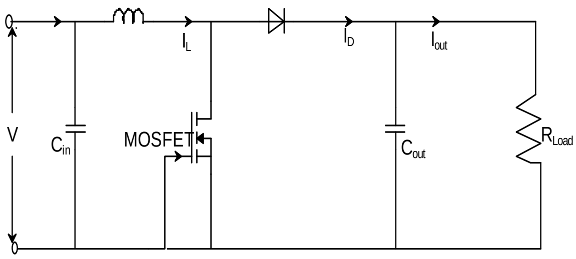


Fig. 3. Boost DC/DC converter

The ripple of the PV output current must be less than 2% of its mean value [3] the capacitor value at the input is given by:

$$C_{in} \geq \frac{I_{om}\alpha_m^2}{0.02(1-\alpha_m)V_{inm}f_s} \quad (6)$$

Where Vinm is the photovoltaic cell's input voltage at the maximum power point.

The input power, input voltage and input current continuously change with atmospheric conditions when the boost converter is used in PV applications. Therefore the conduction mode of the converter could change as it depends on the input power, current and voltage. For tracking maximum power point of the PV panel, the duty cycle also changes continuously. The converter switching frequency and the inductor value choice is a mutual concession between the efficiency, the cost, the power capability and the weight of the converter.

C. Output Capacitor value

The output capacitor value is calculated to give the desired peak-to-peak output voltage ripple and is given by:

$$C_{out} \geq \frac{\alpha_m I_{out}}{rfV_{out}} \quad (7)$$

Where r is the output voltage ripple factor given as:

$$r = \Delta V_{out}/V_{out}$$

and ΔV_{out} is the output voltage peak-to-peak ripple at maximum power.

D. Boost converter model

If the chopping frequency is higher than the system characteristic frequencies, the converter can be replaced with an equivalent model as shown in fig. 3 [8]**.** A voltage source is used for replacing the transistor, having a value equals to its mean value. A current source is used for replacing the diode. Thus:

$$V_T = (1-\alpha)V_{out} \quad (8)$$

$$I_D = (1-\alpha)I_L \quad (9)$$

Where I_L is the mean value of inductor current V_{out} is the output voltage of PV system.

The continuous model equation is deduced as:

$$C_{in}\frac{dv}{dt} = I - I_L \quad (10)$$

$$L\frac{dI_L}{dt} = V - V_T \quad (11)$$

$$C_{out}\frac{dV_{out}}{dt} = I_D - I_{out} \quad (12)$$

$$V_{out} = R_{Load}I_{out} \quad (13)$$

At maximum operating point the equations are given as:

$$\left\{\begin{array}{c} I_m = I_{Lm} \\ V_m = (1-\alpha_m)V_{outm} \\ I_{outm} = (1-\alpha_m)I_{Lm} \\ \alpha_m = 1 - \sqrt{\dfrac{R_m}{R_{Load}}} \end{array}\right\} \quad (14)$$

Where I_m, I_{Lm}, I_{outm}, V_m and α_m are the maximum values of I, I_L, I_{out}, V and α and $R_m = V_m/I_m$ respectively.

The expression of the maximum value of duty cycle **(**$\alpha<1$) show that the maximum value Rm of the output resistance of PV panel must be inferior, at time, that the

$$R_{Load} > R_m \quad (15)$$

E. Small signal model and transfer function

The transfer function of the system open loop for a small variation around an opimal operating point can be determined. The system can be presented as shown in Fig. 4.

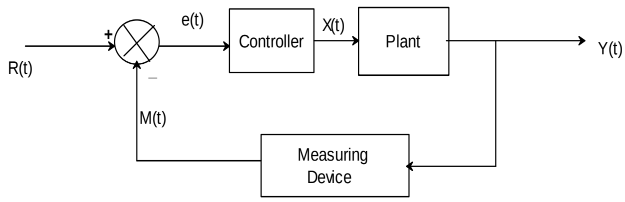


Fig. 4. General block diagram of a closed loop system

Where,

$$G_{a1}(s) = \frac{K_{a1}}{b_2 s^2 + b_1 s + 1} \qquad (16)$$

$$G_{a2}(s) = \frac{K_{a2}(b_2 s^2 + b_1 s + 1)}{a_2 s^2 + a_1 s + 1} \qquad (17)$$

With

$$K_{a1} = \frac{(K_1 G - K_2)(1 + R_s G_m)}{K_1} V_{outm}$$

$$K_{a2} = \frac{K_1}{(1 + R_s G_m)}$$

$$b_2 = a_2 = LC_{in};\ b_1 = \frac{K_2 L}{K_1};\ a_1 = GL$$

$$G = \frac{G_m}{1 + R_s G_m};\ G_m = \frac{1}{R_{dm}} + \frac{1}{R_{sh}}$$

And

$$K_1 = 1 + \frac{AR_s(R_s I_m - V_m)}{R_{dm}(1 + R_s G_m)}$$

$$K_2 = \frac{A(R_s I_m - V_m)}{R_{dm}(1 + R_s G_m)} - G$$

$$R_{dm} = \frac{1}{I_{os} A \exp[A(V_m + R_s I_m)]}$$

K_{a1} and K_{a2} are constants for the given temperature and solar irradiation. R_{dm} and G_m are the maximum dynamic resistance and conductance of the solar panel. If the values of L, C_{in}, V_{outm}, I_m, V, α_m and the parameter values of solar panel are known, then the values of K_{a1}, K_{a2}, K_1, K_2, b_2, b_1, a_1, a_2, G, G_m and R_{dm} can be easily determined. The transfer function of the open loop system is given by:

$$G_0(s) = G_{a1}(s) G_{a2}(s) = \frac{K_{a1} K_{a2}}{a_2 s^2 + a_1 s + 1} \quad (18)$$

III. MAXIMUM POWER POINT TRACKING CONTROLLERS

A. PI controller

PI controller is the co-operation of both propotional and integral action. The analytical expression can be given as:

$P = K_p e + K_p K_i \int e dt + p(0)$

Where,

P= controller output

K_p= proportional gain

K_i= integral constant

e= error input

P(0)= initial value of controller output

The PI controller gain and integral gain obtained by Zeigler Nichols tuning are K_p=0.014 and K_i = 132.85**.** From equation (5), the inductance of the boost converter can be chosen as is L=1mH. From equation (6), the input capacitance of the converter can be chosen as C = 4.7μF, and, from equation (7) the output capacitor is 47μF. The resistance load is R_{Load} = 60 Ω. Fifty kilohertz switching frequency is taken.

B. Fuzzy logic controller

The fuzzy theory based on fuzzy sets and fuzzy algorithms provides a general method of expressing linguistic rules; therefore they may be processed quickly**.** One of the advantages of the fuzzy logic controller is that it does not require any mathematical model of the plant. It is based on knowledge of the plant operator, and it is very easy to apply. Many complex systems deal with complex mathematical model. These complex systems can be controlled without knowing the exact mathematical model of the plant using fuzzy logic control [5]. FLC is capable of improving the tracking performance as compared with other classical methods for linear and nonlinear loads. A FLC has three main components- fuzzification, fuzzy inference and defuzzification.

FLC has two inputs: error and the change in error. The triangular shaped membership function is used due to the resulting best control performance and simplicity. The range of each membership function is settled by the previous knowledge of the suggested scheme parameters. The inputs of the FLC are expressed seven linguistic variables [4]. The linguistic variables are:

NB: Negative Big

NM: Negative Medium

NS: Negative Small

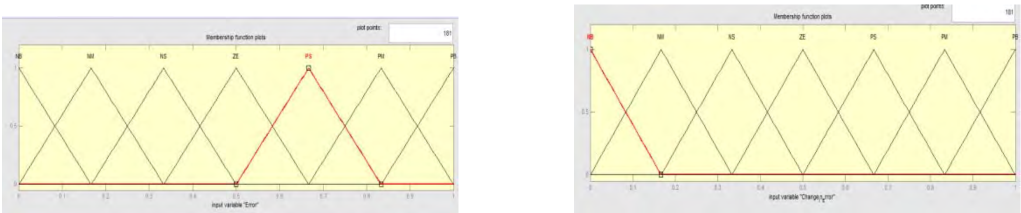
Z: Zero

PB: Positive Big

PM: Positive Medium

PS: Positive Small

Fig. 5 (a) and (b) show the fuzzy set of error input (E) and change in error (CE) with seven triangular membership functions**.**



(a) (b)

Fig. 5. (a) Fuzzy set of error input (E) (b) Fuzzy set of change in error input (CE)

Fig. 6. shows the surface of the base rules used FLC.

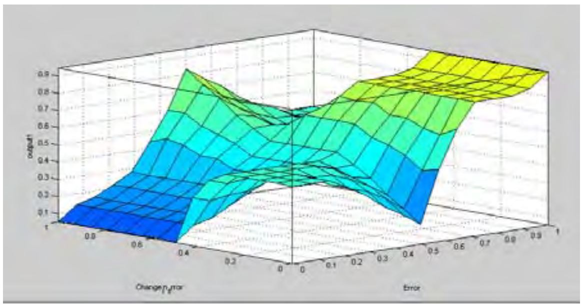


Fig.6. Rule surface of FLC.

Inference engine of the fuzzy logic controller mainly consists of Fuzzy rule base and fuzzy implication sub blocks. The inputs that are fuzzified are fed to the inference engine and then the rule base is applied. The output fuzzy sets are then identified using fuzzy implication sub-blocks.

Once the fuzzification is over, fuzzy range of output is located. Since at this stage a non-fuzzy value of control is available, therefore a defuzzification stage is needed. Centroid defuzzification method [8] is used in this proposed scheme.

IV. SIMULATIONS AND EXPERIMENTAL RESULTS

In order to show clearly the effectiveness of these methods, some simulations were carried out. A MATLAB based modeling and simulation scheme along with MPPT PI controller and fuzzy logic controller are proposed which are suitable for studying the *I-V* and*P-V* characteristics of a PV array under a non-uniform irradiation and different temperature. The fuzzy logic controller based results are compared with the conventional the PI controlling methods which validate its merits.

A. PI controller Simulation

Fig. 7. shows the simulink model of MPPT using PI controller.

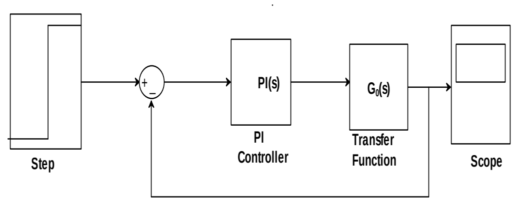


Fig. 7. Simulink model of MPPT using PI controller

B. Fuzzy Logic Controller Simulation

Fig**.** 8**.** shows the simulink model of MPPT using fuzzy logic controller.

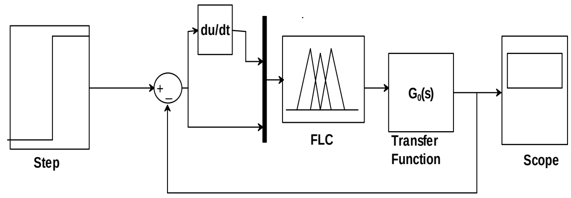


Fig . 8. Simulink model of MPPT using fuzzy logic controller.

The different parameter values taken for simulation from SM55 solar array data sheet:

Solar module temperature (T): 28^0C

No: of cells in series (N_s): 36

No: of cells in parallel (N_p): 1

Open-circuit voltage (V_{oc}): 21.7V

Short-circuit current (I_{sc}): 3.45A

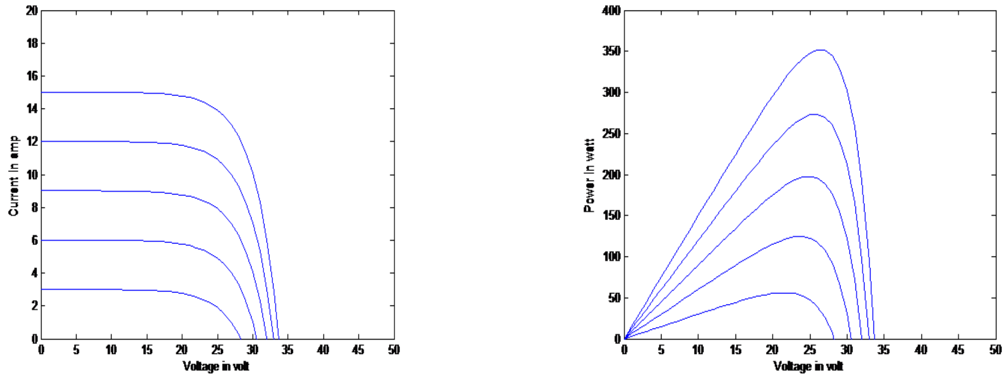
Maximum power current (I_m): 3.15A

Maximum power voltage (V_m): 17.4V

Maximum power (P_m): 55W

C. Experimental Results

Fig. 9 (a) and (b) show the I-V and P-V characteristics of the solar panel before adding controller. It is found that the set of P-V and I-V characteristics are highly nonlinear and depends on solar irradiance of the solar array. The combination of V and I maximizing the output depends on solar irradiation and is also affected by the temperature.

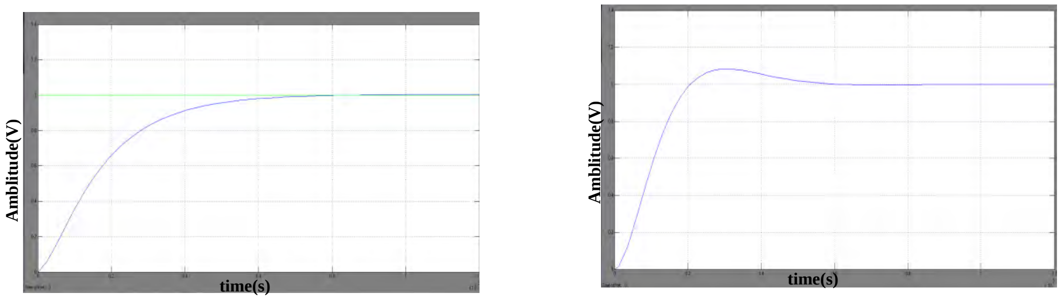


(a) (b)

Fig. 9. (a) I-V characteristics (b) P-V characteristics

From I-V characteristics it was observed that as the cell temperature remain constant, the PV output voltage remains nearly constant while the PV output current increases with increasing solar intensity.

Fig. 10 (a) and (b) show the result for PI and fuzzy controlled MPPT for PV system.



(a) (b)

Fig. 10. (a) PI controlled MPPT for PV system. (b) Fuzzy controlled MPPT for PV system.

V. COMPARISON OF FLC AND CONVENTIONAL PI CONTROLLER

The results of applying the FLC on PV system to track the maximum power point is compared with the conventional PI controller applied on the same system. Figure shows the effect of the PI controller and FLC controller on the same PV power. The response of FLC is better than the response of the PI controller since it take more settling time. Therefore the fuzzy control algorithm is capable of improving the tracking performance as compared with the conventional PI controller.

VI. CONCLUSION

The purpose of maximum power tracking is to extract the highest possible power to the load from the solar arrays. In this paper, the principle of energy conservation has been used to derive the system transfer function. Both the controllers used in this paper improve the efficiency. The proposed method is by implementing a maximum power point tracker controlled by fuzzy logic controller and PI controller using boost DC/DC converter to keep the PV output power at the maximum point all the time. These controllers are tested using Matlab/Simulink program, and the results were compared. The comparison between PI controller and FLC shows that the fuzzy logic controller is better in response and don't depend on knowing any parameter of PV panel.

ACKNOWLEDGMENT

The authors thank the authorities of Noorul Islam University for the facilities provided.

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