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Assessment of MPPT Controllers (Excite & Monitor and Fuzzy Logic Control) for Detached Photovoltaic Systems

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***Abstract:* - This paper presents a method used to optimize the energy mining in a photovoltaic (PV) power system. The maximum power of a PV module changes with temperature, solar radiation, and load. To increase efficiency, PV systems use a Maximum Power Point Tracker (MPPT) to continuously extract the highest possible power and deliver it to the load. The MPPT finds and maintains operation at the maximum power point using a tracking algorithm. Fuzzy Logic Control (FLC), by dealing naturally with nonlinearities, offers a superior controller for this type of application. In order to change the input resistance of the panel to match the load resistance (by varying the duty cycle), a DC to DC converter is required. The converter used here is boost converter. Finally the performance of the fuzzy based MPPT controller is compared with the MPPT based on Excite and Monitor (E&M) method. MATLAB Simulink is utilized for simulation studies and result comparison.**

***Keywords* - Maximum Power Point (MPP), Maximum Power Point Tracking (MPPT), Excite and Monitor (E&M) method, Photovoltaic (PV).**

INTRODUCTION

Energy has been one of the most important driving forces in our fast growing world. Among all the renewable energy sources, solar power systems attract more attention because they provide excellent opportunity to generate electricity while greenhouse emissions are reduced. Regarding the endless aspect of solar energy, it is worth saying that solar energy is a unique prospective solution for energy crisis [1].

Despite all the aforementioned advantages of solar power systems, they do not present desirable efficiency. The efficiency of solar cells depends on many factors such as temperature, insolation, spectral characteristics of sunlight, dirt, shadow and so on. Changes in insolation on panels due to fast climatic changes such as cloudy weather and increase in ambient temperature can reduce the photovoltaic (PV) array output power. In other words, each PV cell produces energy pertaining to its operational and environmental conditions

The PV array has a particular operating point that can supply the maximum power to the load which is generally called maximum power point (MPP). The maximum power point has a non-linear locus where it varies according to the solar irradiance and the cell temperature [2]. To boost the efficiency of PV system, the MPP has to be tracked followed b regulating the PV panel to operate at MPP operating voltage point, thus optimizing the production of electricity. This process can draw as much power as possible that the PV panel can produce.

There are a large number of algorithms that are able to track MPPs. Having a curious look at the recommended methods, hillclimbing and E&M [6]–[10] are the algorithms that were in the center of consideration because of their simplicity and ease of implementation. The E&M method is perturbation in the operating voltage of the PV array. However, the E&M algorithm cannot compare the array terminal voltage with the actual MPP voltage, since the change in power is only considered to be a result of the array terminal voltage perturbation. As a result, they are not accurate enough because they perform steady-state oscillations, which consequently waste the energy [5]. By minimizing the perturbation step size, oscillation can be reduced, but a smaller perturbation size slows down the speed of tracking MPPs. Thus, there are some disadvantages with these methods, where they fail under rapidly changing atmospheric conditions [11]. On the other hand, some MPPTs are more rapid and accurate and, thus, more impressive, which need special design and familiarity with specific subjects such as fuzzy logic [12] or neural network methods. MPPT fuzzy logic controllers have good performance under varying atmospheric conditions and exhibit better performance than the E&M control method [8].However, the main disadvantage of this method is that its effectiveness is highly dependent on the technical knowledge of the engineer in computing the error and coming up with the rule-based table. It is greatly dependent on how a designer arranges the system that requires skill and experience.

MAXIMUM POWER POINT TRACKING

The power and current characteristics of PV module [3] is extremely nonlinear and under effect of solar irradiance intensity and temperature variation. To overcome these drawbacks the MPP tracker is necessary in order to Fig 3. A DC/DC converter controls the operation point of PV module to transfer maximum power. Most MPPT method are on the basis of power curve [4]. Until now different MPPT algorithms are studied [7], [8], [9]. In this paper Excite and Monitor (E&M) algorithm and FLC introduced and compared with each other.

EXCITE AND MONITOR METHOD

The Excite & Monitor algorithm states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting changes in power ΔP is positive, then going in the direction of MPP and keep on perturbing in the same direction. If ΔP is negative, it going away from the direction of MPP and the sign of perturbation supplied has to be changed.

Fig.1 shows the plot of module output power versus module voltage for a solar panel at a given irradiation. The point marked as MPP is the Maximum Power Point, the theoretical maximum output obtainable from the PV panel.

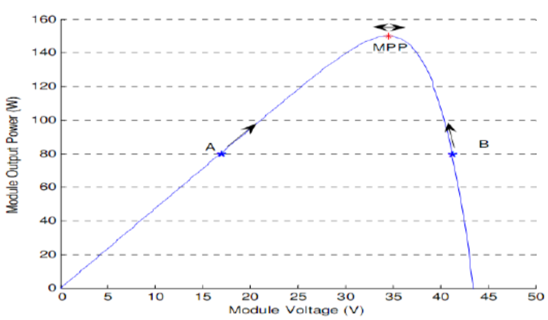

Fig. 1 Solar Panel characteristics showing MPPT

Consider A and B as two operating points. As shown in the figure, the point A is on the left hand side of the MPP. Therefore, move towards the MPP by providing a positive perturbation to the voltage. On the other hand, point B is on the right hand side of the MPP. When the positive perturbation is given, the value of ΔP becomes negative, thus it is imperative to change the direction of perturbation to achieve MPP. So, the duty cycle of the dc converter is changed and the process is repeated until the maximum power point has been reached.

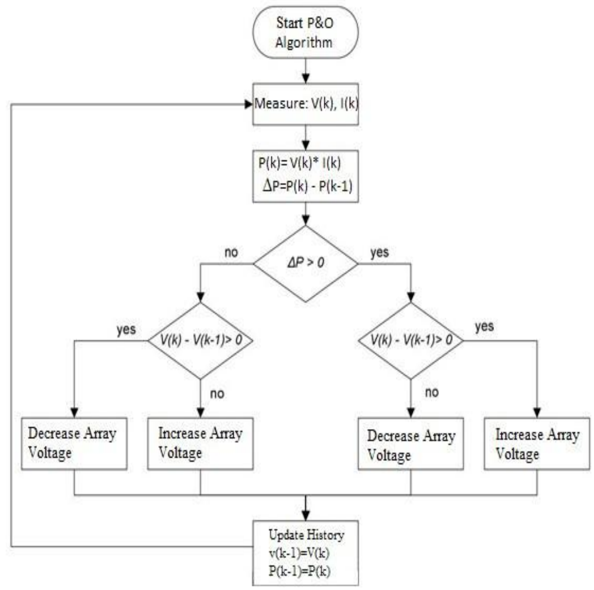

Fig. 2 E&M Algorithm – Flow chart

The panel voltage and current are measured. Change in power is calculated by subtracting the power at the previous instant from the power at the present instant. If this change in power is positive, then it means that going in the direction of MPP and keep on perturbing in the same direction, i.e. if the change in power is due increase in voltage, then the voltage is further increased. On the other hand if the change in power is due to decrease in voltage, then the voltage is further decreased.

If this change in power is negative, then it means we are going away from the direction of MPP and the sign of perturbation supplied has to be changed. i.e. if the change in power is due to increase in voltage, then the voltage is decreased and if the change in power is due to decrease in voltage, then the voltage is increased. If the change in power is zero, then it means that no further perturbation is needed and the corresponding voltage is the reference voltage at which the panel is to be operated.

FUZZY LOGIC MPPT

The general structure of a fuzzy logic controller is presented in Fig 3 and comprises of four principal components such as fuzzification, inference engine, rule base and defuzzification. Fuzzification converts input data into suitable linguistic values using a membership function. Rule Base consists of a database with the necessary linguistic definitions and the control rule set. Inference Engine simulates a human decision making process in order to infer the fuzzy control action from the knowledge of the control rules and the linguistic variable definitions. Defuzzification converts an inferred fuzzy controller output into a non-fuzzy control action. The fuzzy system is represented by a collection of fuzzy IF-THEN rules.

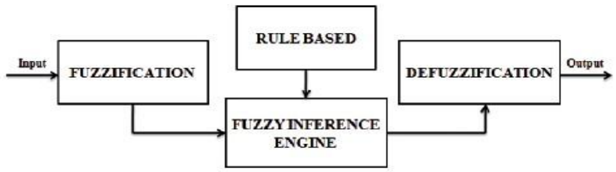

Fig. 3 Basic Structure of a Fuzzy Logic system

The average dynamic model of the photovoltaic system given by Fig 4 can be expressed in continuous conduction by the following equations. By applying KVL to the system,

$$V_L = V_{pv} - V_o \quad (1)$$

where

V_L is voltage across the inductance,

V_{pv} is the voltage generated by PV panel,

V_o is the voltage across the load.

Since $V_o = V_{c2}$ and it is included when the switch is off,

$$L\frac{dI_L}{dt} = V_{pv} - V_{c2}(1-D) \quad (2)$$

where L is the inductance,

I_L is the current through the inductor, $I_{pv} = I_L$

V_{c2} is the voltage across the capacitor,

D is the duty cycle.

$$\frac{dI_L}{dt} = \frac{1}{L}[V_{pv} - V_{c2}(1-D)] \quad (3)$$

By applying KCL,

$$I_c = I_L - I_o \quad (4)$$

$$C\frac{dV_{c2}}{dt} = I_L(1-D) - \frac{V_o}{R_L} \quad (5)$$

$$\frac{dV_{c2}}{dt} = \frac{1}{C}\left[I_L(1-D) - \frac{V_o}{R_L}\right] \quad (6)$$

The state variables (x) are I_L and V_{c2} .

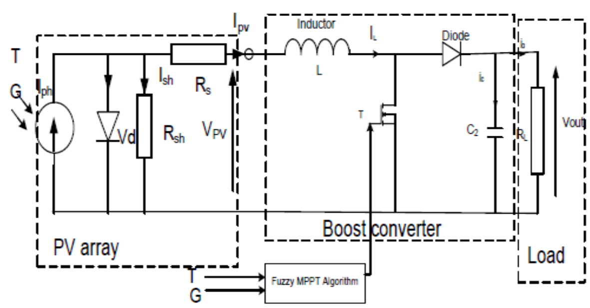

Fig. 4 Circuit Diagram of the FLC System

The input (u) is V_{pv}

$$\dot{x} = \begin{pmatrix} 0 & -\frac{(1-D)}{L} \\ \frac{(1-D)}{C_2} & \frac{-1}{R_L C_2} \end{pmatrix} x + \begin{pmatrix} \frac{1}{L} \\ 0 \end{pmatrix} u \quad (7)$$

Substituting $C_2 = 68\mu F$,

$R_L = 30\ \Omega$,

$$\dot{x} = \begin{pmatrix} 0 & -\frac{(1-D)}{L} \\ \frac{(1-D)}{68*10^{-6}} & \frac{-1}{2.04*10^{-3}} \end{pmatrix} x + \begin{pmatrix} \frac{1}{L} \\ 0 \end{pmatrix} u \quad (8)$$

After getting the V_{mpp} *and* I_{mpp} values, the duty cycle is obtained using the formula,

$$D = 1 - \sqrt{\frac{V_{mpp}}{R_L I_{mpp}}} \quad (9)$$

The inductance value varies with duty cycle,

$$L = \frac{R_L * D * (1-D)^2}{2 * f_s} H \quad (10)$$

where f_s is the switching frequency (10 kHz).

where is the switching frequency (10 kHz).

The optimal duty cycle which allows the converter to transfer maximum power from the PV array panel to the load is given by equation 13. We know that the V_{MPP} and I_{MPP} vary in times according to the variation of temperature and/or irradiation. So the optimal duty cycle is variable in times and does not have a unique value.

In other words, it is necessary to know the optimal corresponding values of voltage and current (V_{MPP}, I_{MPP}) for each pairs of values (G, T), which is extremely difficult or impossible to determine. To overcome this difficulty we use the T-S model. The nonlinearity of the system comes from temperature and irradiation, so we choose them as two premise variables [15]

$$Z(t) = \begin{bmatrix} z_1(t) \\ z_2(t) \end{bmatrix} \quad (11)$$

The membership functions for the input premise variables temperature and insolation are given as [12]

The T-S Fuzzy model of system is defined by the following four fuzzy rules:

Rule 1: IF z_1 is M_{11} and z_2 is M_{22} THEN $V_{mpp} = V_{mpp1}$ and $I_{mpp} = I_{mpp1}$

Rule 2: IF z_1 is M_{12} and z_2 is M_{22} THEN $V_{mpp} = V_{mpp2}$ and $I_{mpp} = I_{mpp2}$

Rule 3: IF z_1 is M_{11} and z_2 is M_{21} THEN $V_{mpp} = V_{mpp3}$ and $I_{mpp} = I_{mpp3}$

Rule 4: IF z_1 is M_{12} and z_2 is M_{21} THEN $V_{mpp} = V_{mpp4}$ and $I_{mpp} = I_{mpp4}$

$$V_{mpp} = \sum_{i=1}^{c} h_i(z(t))V_{mppi} \quad (12)$$

$$I_{mpp} = \sum_{i=1}^{c} h_i(z(t))I_{mppi} \quad (13)$$

SIMULATION RESULTS

The Block diagram of the solar PV panel is shown in Fig.5. The inputs to the solar PV panel are temperature, solar irradiation, number of solar cells in series (N_s) and number of rows of solar cells in parallel (N_p). The temperature and insolation may vary but N_s and N_p are constant for a specific solar panel.

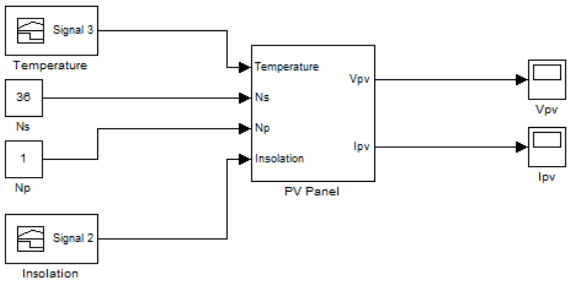

Fig.5 Masked block diagram of solar PV Panel

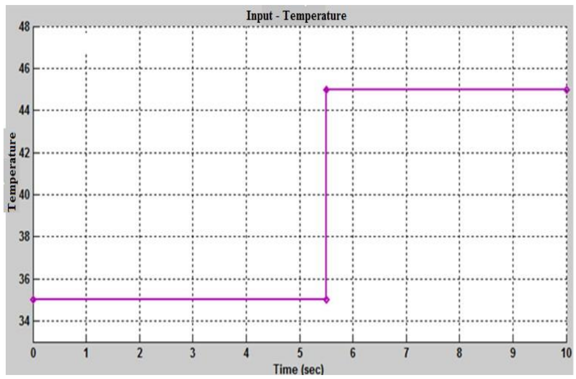

Fig. 6 Input – Temperature (˚ C)

Fig.6 shows the input pattern of temperature(^oC) . Initially the temperature is 35^{o}C , then at time 5.5 s, it raises to 45^{O}C .

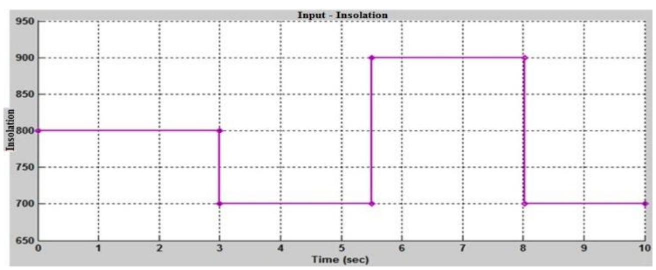

Fig. 7 Input – Insolation (W/m2)

Fig.7 shows the input pattern of insolation (W/m^2) Initially the insolation is 800(W/m^2), then at time 3 s, it changes to 700(W/m^2) At 5.5 s, there is a sudden rise to 900(W/m^2) and at 8 s, it falls to 700(W/m^2).

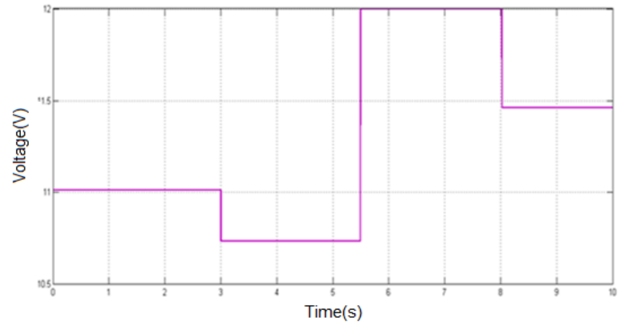

Fig.8 Voltage of the PV Panel

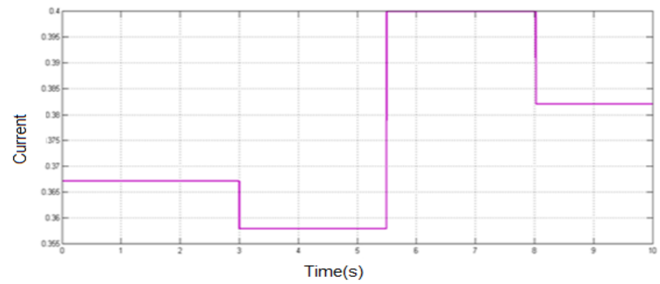

Fig.9 Current of the PV Panel

The Simulink block diagram of the solar PV system employed with boost converter and the E&M MPPT.

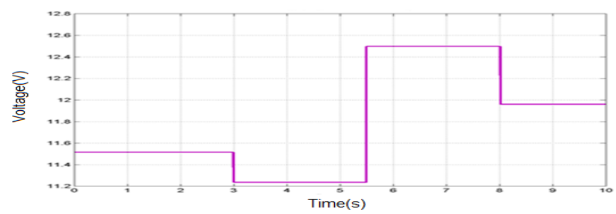

Fig.10 Output Voltage of E&M MPP Tracker

The simulation is carried for 10 seconds. The E&M algorithm is written in M- file and used in the Simulink block. Fig 10 shows the reference voltage at which the panel is to be operated so that maximum power transfer from panel to load is possible. Its variation with temperature and insolation can be realized.

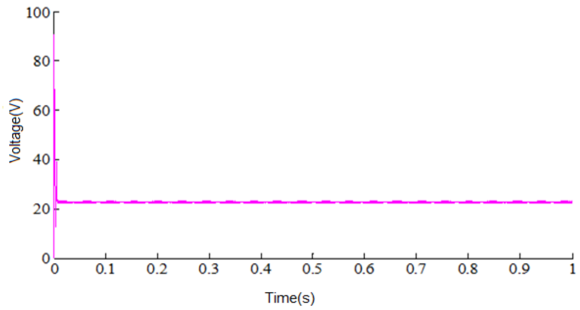

Fig 11.Output Voltage across load of E&M MPPT

The block diagram of the solar panel with Fuzzy MPP was developed. The simulation is carried out under varying temperature and insolation.

Fig.10 shows the maximum voltage corresponding to maximum power at which the panel is to be operated. The variation of the operating point with the variation in insolation and temperature can be seen in the Fig.11.

This value of maximum voltage is found by fuzzy rules and it is used to calculate the optimal duty cycle.

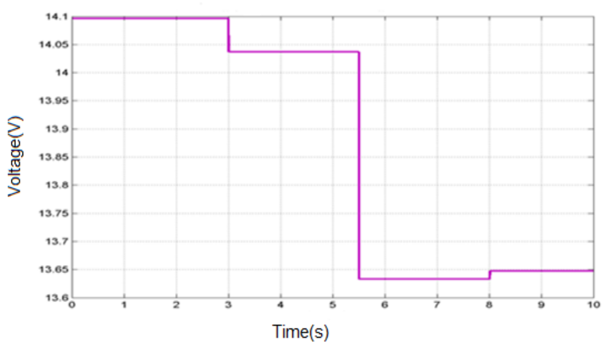

Fig.12 Output Voltage of Fuzzy MPP Tracker

The following output shows the improved voltage across load of Fuzzy MPPT compared to E&M MPPT.

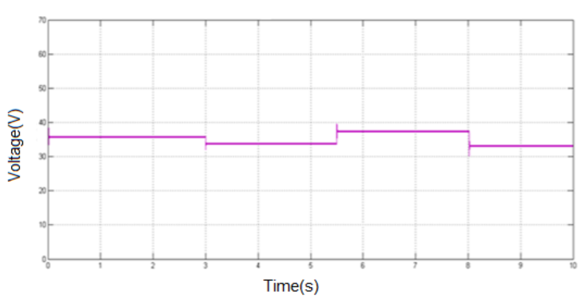

Fig.13 Output Voltage across load of Fuzzy MPPT

Fig.13 shows the variation of output voltage according to the change in insolation and temperature.

Using fuzzy rules, the PV panel reference voltage and current can be obtained. The fuzzy system is represented by a collection of fuzzy IF-THEN rules. For each rule, a weight $w_i(z(t))$ is attributed which depends on the grade of membership function of the premise variables $z_j(t)$ in the fuzzy sets. So, the membership functions for the input premise variables temperature and insolation.

From the simulation results, it can be seen that when TS fuzzy logic based MPPT algorithm is used for maximum power transfer, the ripples in the output voltage across the load and in the power delivered to the load are minimum when compared to the conventional technique E&M method.

CONCLUSION

The Excite and Monitor method based MPPT technique and fuzzy logic based MPPT techniques are employed in this work. The system is simulated in MATLAB SIMULINK.. From the results acquired during simulations, it is confirmed that with properly designed converter and MPPT algorithm, achieving maximum power transfer from solar PV panel to load is possible. The results also show that the MPPT technique based on Fuzzy Logic approach is more efficient when compared to the conventional MPPT technique excite and monitor method based algorithm. The system completes maximum power point tracking successfully without much fluctuation. It can also be observed that the system continues to track the maximum power point in spite of the sudden environmental changes.

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