Simulation of Fuzzy logic Controller of MPPT Using Cuk Converter Application to PV cell

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Abstract: **This paper proposes a fuzzy logic controller for the maximum power point tracking (MPPT) of a photovoltaic system under various temperature and insolation. This method uses a fuzzy logic controller applied to a dc-dc converter. The main difference between proposed system to existing MPPT system includes elimination of the mathematical calculation and investigation of the effect of simplifying the control circuit. The maximum power point tracking controllers receive solar radiation and photovoltaic cell temperature as inputs, and estimated the optimum duty cycle corresponding to maximum power as output. The new method gives a good maximum power operation of any photovoltaic array under different conditions such as changing solar radiation and PV cell temperature. The different steps of the design of controller are presented above with its simulation results using Simulink/Matlab.**

Keywords: Maximum power point tracking(MPPT), Fuzzy logic controller, Photovoltaic system.

I. INTRODUCTION

Recently, energy generated from clean, efficient, and environmentally friendly sources has become one of the major challenges for engineers and scientists . Among all renewable energy sources, solar power systems attract more attention because they provide excellent opportunity to generate electricity while greenhouse emissions are reduced [1]. It is also gratifying to lose reliance on conventional electricity generated by burning coal and natural gas. Regarding the endless aspect of solar energy, it is worth saying that solar energy is a unique prospective solution for energy crisis. However, 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.

In addressing the poor efficiency of PV systems, some methods are proposed, among which is a new concept called “maximum power point tracking” (MPPT). All MPPT methods follow the same goal which is maximizing the PV array output power by tracking the maximum power on every operating condition.

A. Maximum Power Point Tracking (MPPT)

Maximum Power Point Tracking is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of. MPPT is not a mechanical tracking system that “physically moves” the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power. Under Partial shading conditions it is possible to have multiple local maxima, but overall there is still only one true maximum power point.

B. MPPT Methods

There are large number of algorithms that are able to track MPPs based on their implementation complexity, sensor requirement, speed of convergence, cost, range of operation, popularity, ability to detect multiple local maxima, and their applications[2]. There are two contol methods to track the maximum power from solar panel. They are indirect control methods and direct control method. In indirect control methods the maximum power point can be estimated from voltage, current, irradiance and mathematical expressions of numerical approximations. Some of the indirect control methods are curve fitting method, lookup table method, fractional OC method, fractional SC method.In direct control methods the maximum power point can be estimated from the use of current and voltage information, prior knowledge of PV panel is not required and it is independent of insolation and temperature levels. The most recommended methods are hill climbing and P&O algorithm that were in the centre of consideration because of their simplicity and ease of implementation. Hill climbing is perturbation in the duty ratio of the power converter.

P&O method is perturbation in the operating voltage of the PV array and measures power, if the power increases, further adjustments in the direction and tried until power no longer increases. However, the P&O 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. 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.

Incremental conductance method is based on the slope of the PV array curve, if the power curve is zero at the MPP, which means the maximum point is achieved. The slope of the curve is positive on the left side of the MPP which means that the perturbation should be further preceded to achieve the MPP. On the other hand the slope is negative on the right side of MPP, which means that the perturbation should be done in opposite direction to achieve the MPP.

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 and neural network methods. MPPT fuzzy logic controllers have good performance under varying atmospheric conditions and exhibit better performance than the P&O and incremental conductance method. This method only require It is greatly dependent on how a s the linguistic control rule for maximum power point, the mathematical model is not required and therefore the implementation of this control method is easy to real control system. The disadvantage of the neural network method comes with its reliance on the characteristics of the PV array that change with time, implying that the neural network has to be periodically trained to guarantee accurate MPPs.

II. PV MODULE AND FUZZY LOGIC CONTROL

A. Design of PV module

The basic structural unit of a solar module is the PV cells. A solar cell converts energy in the photons of sunlight into electricity by means of the photoelectric phenomenon found in certain types of semiconductor materials such as silicon and selenium.

A single solar cell can only produce a small amount of power [4]. To increase the output power of a system, solar cells are generally connected in series or parallel to form PV modules. The main equation for the output current of a PV module is

$$I = N_p I_{ph} - N_p I_s \left[\exp\left(\frac{q(V+IR_{SM})}{N_s K T_C}\right) - 1\right] \qquad (1)$$

Where I is the PV module output current, q is an electron charge, K is a Boltzmann's constant, T_C is the cell's working temperature, N_p is number of cells connected in parallel and N_s is number of cells connected in series, I_{ph} is the photocurrent, I_s is the cells saturation current.

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

$$I_{ph} = \left[I_{sc} + K_1\left(T_c - T_{Ref}\right)\right]H \qquad (2)$$

Where I_{sc} Cell short-circuit current at a 25 °C and 1kW/m^2,

K_1 Cell short-circuit current temperature coefficient,

T_{Ref} Cell reference temperature, and

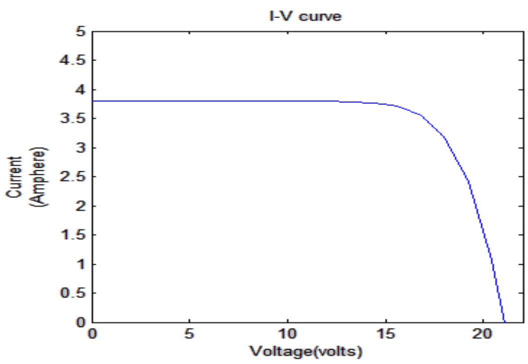
H solar insloation in kW/m^2.
The cell's saturation current varies with the cell temperature, which is described as

$$I_s = I_{RS}\left(\frac{T_c}{T_{Ref}}\right)^3 \exp\left[\frac{qE_G(T_c - T_{Ref})}{T_{Ref}T_c kA}\right] \qquad (3)$$

Where,
E_G is the band gap energy of the semiconductor used in the cell,
A is ideal factor.
For simulation, the electrical parameters of PV module are tabulated in Table I, and the resultant I-V and P-V curve are shown in Fig. 1(a) and (b) for a given insolation and temperature, which provides an idea about open –circuit voltage, short-circuit current and the operating point at which the PV module performs the maximum power.

TABLE I
Electrical Parameters of PV Module

Maximum power (P_{max})	60 W
Voltage at MPP (V_{mpp})	17.1 V
Current at MPP (I_{mpp})	3.5 A
Open circuit voltage (V_{OC})	21.1 V
Short circuit current (I_{SC})	3.8 A



(a)

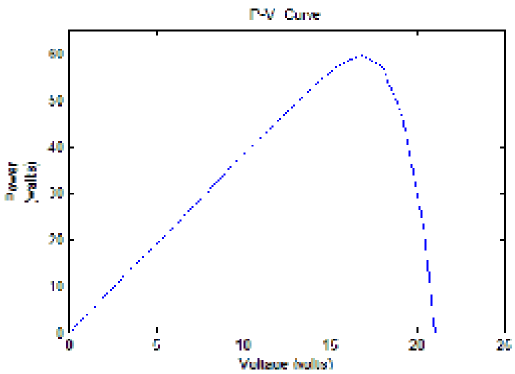

(b)

Fig.1. (a) current-versus-voltage curve of PV module (b) power-versus-voltage curve of PV module

B. Design of Fuzzy logic controller

Fuzzy logic control have made more popular for MPP over the last decade. The fuzzy logic controllers are having a advantage of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity [3],[7].

The fuzzy systems are based on fuzzy set theory and associated techniques pioneered by Lotfi Zadeh. It is a non-linear control method, which attempts to apply the expert knowledge of an experienced user to design of a fuzzy-based controller.

Fuzzy logic control generally consists of three stages: fuzzification, inference system, defuzzification. During fuzzificaion the numerical input variables are converted into linguistic variables based on the membership function. Thus in fuzzification process may involve assigning membership values for a given crisp quantities. In this case, three fuzzy levels are used: Small, Medium, Large. The membership function is sometimes made less symmetric to give importance to specific fuzzy levels. The second stage is inference system, this stage is known as fuzzy rule-based systems. This is a major unit of a fuzzy logic system. The fuzzy inference system formulates suitable rules and based upon the rules the decision is made. This inference system uses "if then" statement and the connector present in the rule statement are "OR" or "AND" to make the necessary decision rules.

The input to the MPPT fuzzy logic controller are temperature T and insolation H. The user has the flexibility of choosing how to compute the temperature T and insolation H. Once the temperature and

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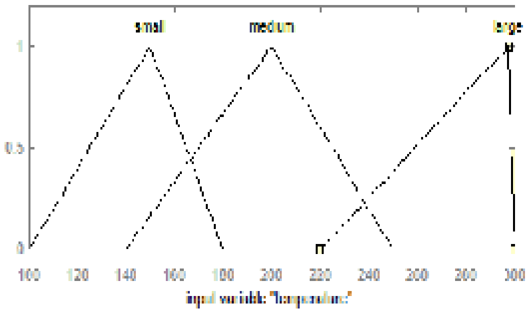
insolation are defined and converted into linguistic variables, the fuzzy logic controller output, which is typically a change in duty cycle ΔD of power converter, which can be looked up in the rule base table II.

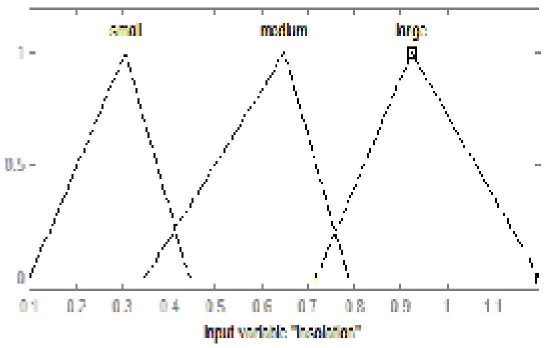
The linguistic variable assigned to ΔD for the different combinations of T and H are based on the power converter being used and also the knowledge of the user. Table II is based on Cuk converter. For example if the temperature is large and insolation is small we want to increase the duty cycle that is the duty cycle should be large to reach the maximum power.

TABLE II
Fuzzy Rule Base Table

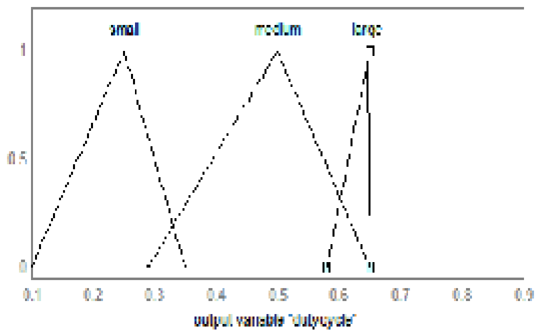
TEMPERATURE	**INSOLATION**		
	Small	**Medium**	**Large**
Small	Small	Medium	Large
Medium	Large	Medium	Small
Large	Large	Medium	Large



(a)



(b)



(c)

Fig. 2 (a) and (b) are Membership function for inputs Temperature and Insolation. (c) is the membership function for output duty cycle.

In the defuzzification stage, the fuzzy logic controller output is converted from a linguistic variable to a numerical variable still using a membership function as shown in Fig.2. This provide an analog signal that will control the power converter.

III. Selection Of Power Converter

When proposing an MPP tracker, the major work is to choose a highly efficient converter, which should operate as a main part of maximum power point tracking. The efficiency of switch-mode dc-dc converters is widely discussed in [1]. Most of the switching-mode power supplies are designed properly to function with high efficiency.

Among all the topologies, the buck boost and Cuk converter will provide either higher or lower output voltage compared with the input voltage. Though the buck boost converter is cheaper than Cuk converter some disadvantages are discontinuous input current, high peak currents in power components and poor transient response which makes it less efficient. The Cuk converter has low switching losses and the highest efficiency among non isolated dc-dc converters. It can also provide a better output-current characteristic due to the inductor on the output stage. Thus the Cuk converter is a proper converter which is used in designing of the MPPT[5].

Fig. 3 and 4 shows a Cuk converter and its operating modes, which is used as a power stage interface between the PV module and the load. The Cuk converter has two modes of operation. The first mode of operation is when the switch is closed (ON), and it is conducting as a short circuit. In this mode, the capacitor releases energy to the output. The equations for the switch conduction mode are follows:

$$v_{L1} = v_g \quad (4)$$

$v_{L2} = -v_1 - v_2$ (5)

$i_{c1} = i_2$ (6)

$i_{c2} = i_2 - \frac{v_2}{R}$ (7)

In second operating mode when the switch is open(OFF), the diode is forward-biased and conducting energy to the output. Capacitor C1 is charging from the input. The equations for this mode of operation are as follows:

$v_{L1} = v_g - v_1$ (8)

$v_{L2} = -v_2$ (9)

$i_{c1} = i_1$ (10)

$i_{c2} = i_2 - \frac{v_2}{R}$ (11)

The relations between output and input currents and voltage are given below, some analysis of converter is provided in[6].

$$\frac{V_o}{V_{in}} = -\left(\frac{D}{1-D}\right) \quad (12)$$

$$\frac{I_o}{I_{in}} = -\left(\frac{D}{1-D}\right) \quad (13)$$

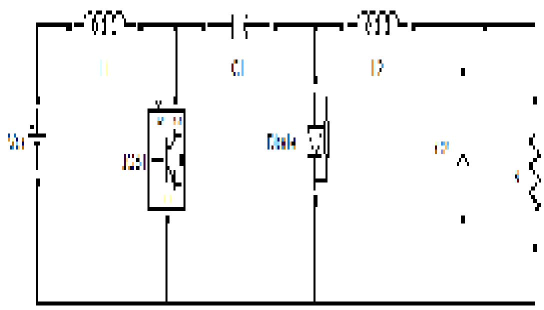
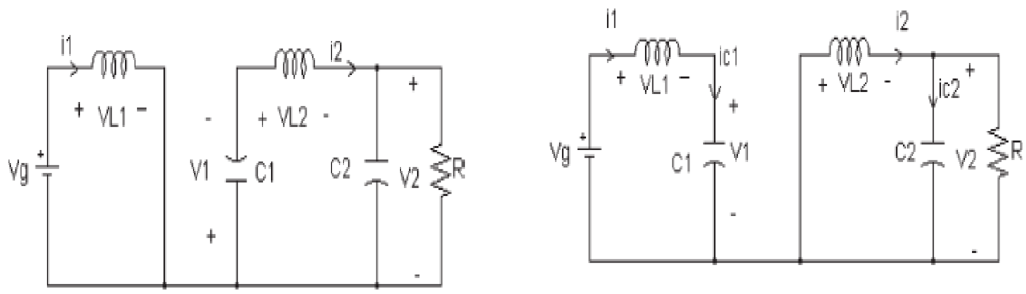


Fig. 3. Electrical circuit of Cuk converter used as the PV power stage interface.



(a) (b)

Fig. 4 Cuk converter with (a) switch ON and (b) switch OFF

IV. Simulation Results

The simulation diagram is designed in MATLAB and Simulink and shown in Fig. 5, which includes the PV module electrical circuit, the Cuk converter and the MPPT algorithm. The PV module is modeled using electrical characteristics which provide current as output, but the current provided by the PV is not directly given to the power converter, the output current of PV module is given to a controlled voltage source which converts the equivalent simulink input into equivalent voltage which is fed as input to the converter. The output current of a single PV module is less, the PV modules are connected in parallel to increase the output current.

Case (i). The temperature 298K and insolation 1000 watts, are inputs to the PV array. The fuzzy logic controller sense the change in the input side of the PV array and provide the duty cycle to the converter circuit, based on the rules. The membership function for temperature 298K and insolation 1000 watts are assumed as Large. According to the fuzzy rules framed by us, if the temperature and insoaltion are large then duty cycle is large. For large, the duty cycle is greater than 0.5, so the output voltage of the Cuk converter is greater than input voltage. For the given value of temperature and insolation the voltage provided to the converter is 15.2V and the output voltage obtained for the given input is 60V which is shown in Fig.6 (a).

Fig.5. Simulation diagram of fuzzy logic control based MPPT method.

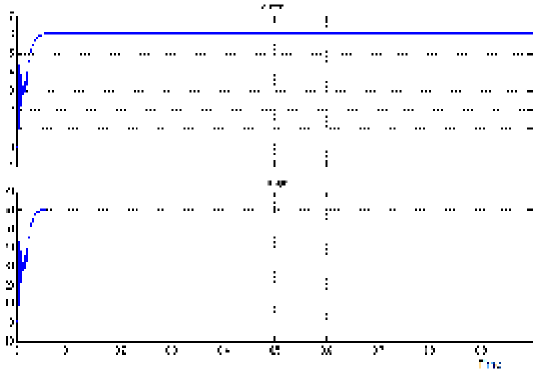


Fig.6(a)

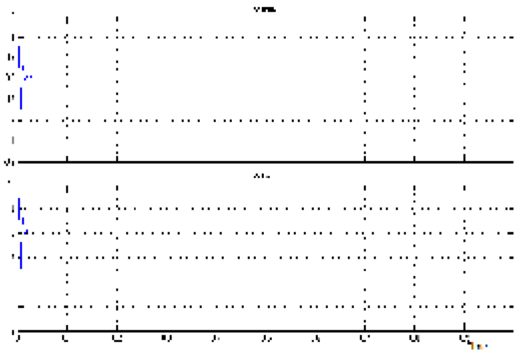


Fig.6(b)

Fig.6. (a) and (b) shows the output voltage and current waveform of proposed method.

Case(ii) The temperature 220K and insolation 600 watts the voltage provided by the PV array to the converter is 8V, the rules framed for this condition is if temperature is medium and insolation is medium then the duty ratio is also minimum, the duty ratio assigned for minimum is less than 0.5 so the output voltage provided by the converter is less than that of input voltage which is shown in Fig. 6 (b).

V. CONCLUSION

The new MPPT method based on the fuzzy logic controller is simulated in MATLAB. This proposed algorithm in fuzzy logic, commands a Cuk converter to obtain the MPPT directly from the climate data such as solar insolation and PV array temperature. In these MPPT gives a simplified system for implementation. Further the obtained DC voltage from converter is converted into AC by adding an inverter and it is used for various applications. The results also indicate that the proposed control system is capable of tracking the PV array maximum power and thus improves the efficiency of the PV system and reduces low power loss and system cost.

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