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Fuzzy MPPT Based Voltage Regulation on Photovoltaic Power Supply System For Continuously Varying Illumination Condition

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Abstract

Due to scarcity of fossil fuel and increasing demand of power supply we are forced to utilize the renewable energy resources with the shortage of energy and ever increasing of the oil price. Researches on the renewable and green energy sources, especially solar arrays and fuel cells become more and more important. Considering easy availability and vast potential, world has turned to solar photovoltaic energy to meet its ever increasing energy demand. Due to high initial investment on PV systems and non linearity of PV cell output characteristics counteract its wide commercialization. The PV array has an optimum operating point to generate maximum power at some particular point called maximum power point (MPP). To track this maximum power point and to draw maximum power from PV arrays, MPPT controller is required in a stand-alone PV system. Due to the nonlinearity in the output characteristics of PV array, it is very much essential to track the MPPT of the PV array for varying maximum power point due to the insolation variation. In order to track the MPPT intelligent controller like fuzzy logic controller is proposed and simulated. The output of the controller, pulse generated from PWM can switch MOSFET to change the duty cycle of buck DC-DC converter. The result reveals that the maximum power point is tracked satisfactorily for varying insolation condition.

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Photovoltaic, Pulse Width Modulation, Fuzzy Logic Controller.

I. Introduction

Today photovoltaic (PV) systems are becoming more and more popular with increase of energy demand and there is also a great environmental pollution around the world due to fossils and oxides. Solar energy which is free and abundant in most parts of world has proven to be economical source of energy in many applications [1]. The energy that the earth receives from the sun is so enormous and so lasting that the total energy consumed annually by the entire world is supplied in as short a time as half an hour. The sun is a clean and renewable energy source, which produces neither green house effect gas nor toxic waste through its utilization. It can withstand severe weather conditions, including cloudy weather. The watt peak price is decreased since the seventies, this leads to large scale promising areas. It does not have any moving parts and no materials consumed or emitted. Unfortunately, this system has two major disadvantages, which the low conversion efficiency of electric power generation (9 to 16%), especially under low irradiation conditions and the amount of electric power generated by solar array changes continuously with the weather conditions like irradiation and temperature. To overcome this problem, maximum power point tracking (MPPT) technique will be used.

In order to regulate the converter due to non linearity artificial intelligent controller like fuzzy logic controller is proposed and simulated. The tracking algorithm integrated with a solar PV system has been simulated with buck DC-DC converter for the application of battery charging in stand - alone PV system. The proposed MPPT system with buck DC-DC converter is shown in Fig.1.

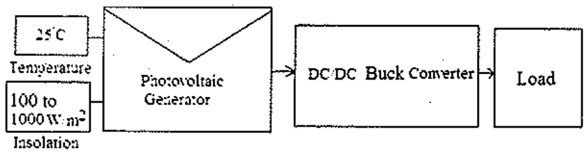


Fig.1. Photovoltaic module with DC-DC buck converter.

II. Photovoltaic cell Modeling

The proposed MPPT is based on the behaviour of the photovoltaic array by means of temperature and irradiation variation [2]. This the mathematical model of PV array is implemented in the form of current source controlled by voltage, sensible to two impact parameters, that is, temperature (°C) and solar irradiation power (w/m²).

An equivalent simplified electric circuit of a photovoltaic cell presented in Fig.2.

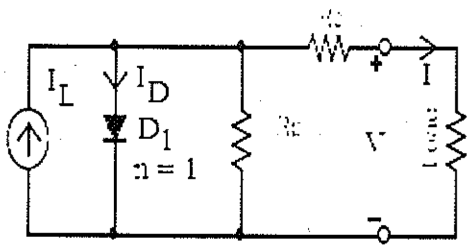


Fig.2. Equivalent circuit of photovoltaic cell.

The expressions obtained from fig.2. are given below. The load current I_L is obtained is given in equation (1) as,

$$I = I_L - I_o\left[\exp\left(\frac{q(V + IR_s)}{\gamma k T_c}\right) - 1\right] \quad (1)$$

I_L is the photo electric current related to the given irradiation condition given by equation (2),

$$I_L = \left(\frac{G}{G_{REF}}\right)\left[I_{L,REF} + \mu_{tsc}\left(T_C - T_{C,REF}\right)\right] \quad (2)$$

The diode saturation current (I_o) is given by the equation (3),

$$I_o = I_{o,REF}\left(\frac{T_C}{T_{C,REF}}\right)^3 \exp\left[\left(\frac{qEg}{k\gamma}\right)\left(\frac{1}{T_{C,REF}} - \frac{1}{T_C}\right)\right] \quad (3)$$

where - I_D is the diode current; I_L - is the photoelectric current related to a given condition of radiation and temperature; V is the output voltage [V]; I_o is the saturation diode current [A]; γ is the form factor which represents an index of the cell failing; R_s is the series resistance of the cell [Ω]; q is the electric charge ($1.602*10^{-19}$C); k is the Boltzmann's constant ($1.381*10^{-23}$K); T_c is the module temperature [K]. E_g is the energy gap of the material with which the cell is made (for the silicon it is 1.12 eV); G is the radiation [W/m²]; GREF is the radiation under standard conditions [W/m²] $I_{L,REF}$ is the photoelectric current under standard conditions [A]; $T_{C,REF}$ is the module temperature under standard conditions [K]; μ_{tsc} is the temperature coefficient of the short circuit current [A/K], given by the manufacturer according to CEI EN 60891 standard [3-4].

Fig. 3. shows the simulated P-V characteristics for varying irradiation and temperature in MATLAB/SIMULINK environment.

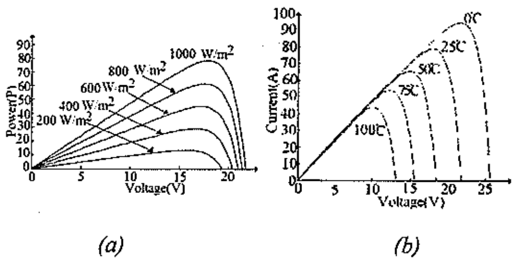


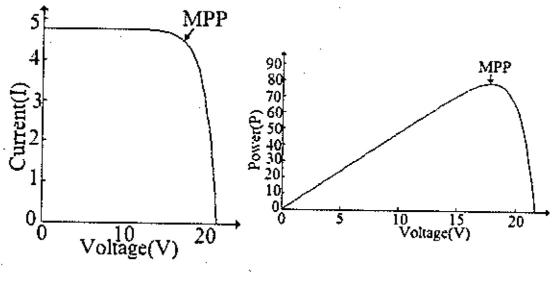
Fig.3. Simulated waveforms showing the effect of (a) radiation and (b) temperature on P-V characteristics.

It can be observed from simulated results as shown in Fig. 3(a), the photo current is directly proportional to irradiation. It is noted from Fig. 3(b) that the terminal voltage increases with decreasing temperature.

The manufacturers data at standard conditions are given as P_{max} = 80W, I_{max} = 4.515 A and V_{max} = 21.6V. The simulation results obtained were: P_{max} = 78.51W, I_{max} = 4.515 A and V_{max} = 21.65V. It is seen that the simulation model showed excellent correspondence to manufacturer's data and therefore this model was considered sufficient for the purpose of further study [4-8].

Simulated I-V, P-V characteristics for the maximum power point tracking (MPPT) is shown in figure.4.

At this Maximum Power Point (MPP), the solar array is matched to its load and when operated at this point the array will yield the maximum power output. From Fig. 4 (a) & (b), it is observed that the power output has an almost linear relationship with array voltage unit, hence the MPP is attained. Any further increase in voltage results in power reduction [5].



(a) *(b)*

Fig.4. PV array simulated curves (a) I-V curve (25°C) and (b) P-V curve (1000w/m²).

III. Designing of Buck converter

A. Circuit diagram of buck converter.

Fig. (5) shows the schematic diagram of buck converter with varying irradiation, which consists of DC supply voltage V_s, as PV generator controlled switch S, diode D, buck inductor L, filter capacitor C and load resistance R. The current and voltage waveforms of the converter in CCM are presented in fig.6.

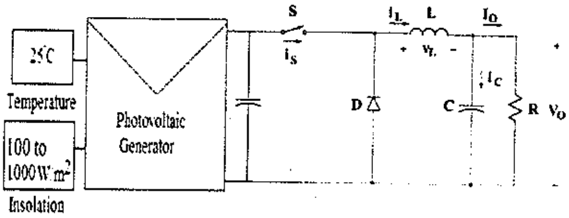


Fig.5. Circuit diagram of buck converter with PV module.

It can be seen from the circuit that when the switch S is commanded to the on state, the Diode D is reverse biased. When the switch S is off, the diode conducts to support an uninterrupted current in the inductor through the output RC circuit using faradays law for the buck inductor as given in (4)

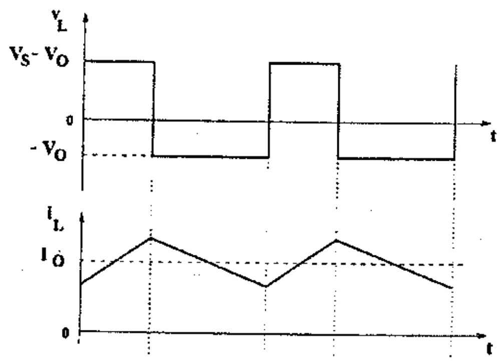


Fig.6. Theoretical voltage and current waveforms of buck converter.

$$(V_s - V_o)DT = (-V_o)(1 - D)T \quad (4)$$

The DC voltage transfer function turns out to be,

$$M_V = \frac{V_o}{V_s} = D \qquad (5)$$

The buck converter operates in the CCM for L>Lb. The calculated value of inductance L=15μH. To limit the ripples in the output side, larger filter capacitor is required. The filter capacitor must provide the output dc current to the load when diode D is off. The minimum value of filter capacitance calculated that results in the voltage ripple V_r is given by C_{min} =12.675uF.

Thus the buck converter is designed in the open loop for the supply voltage of 21.7V DC, which is generated by the Photovoltaic panel for 1000w/m² and 25°C. Fig.7 shows the simulated voltage and current waveforms of buck converter. It is seen that these waveforms are agreed closely with theoretical waveforms as shown in fig.6.

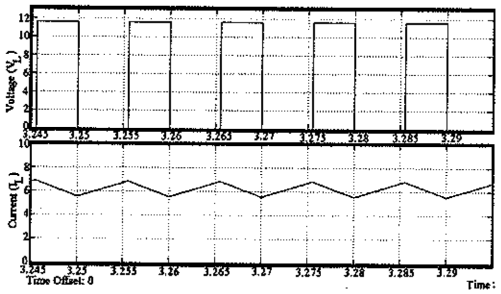


Fig.7. Simulated waveforms showing the voltage and current of buck converter.

IV. MPPT with Intelligent Fuzzy Method

The block diagram of closed loop simulation with fuzzy logic controller is shown in fig.8. To regulate the output voltage V_o, the switching frequency of the PWM pulses are varied depends on error.

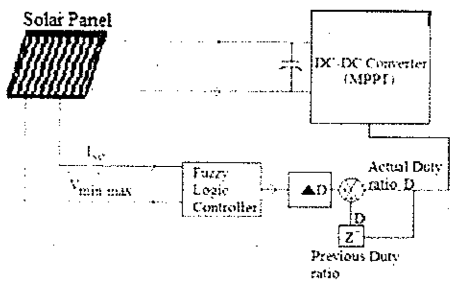


Fig. 8. Block diagram of the proposed fuzzy based MPPT scheme.

A. MPPT with the Intelligent Fuzzy Method

To track and extract maximum power from the PV arrays for a varying insolation level and at a given cell temperature, a novel fuzzy logic controller is proposed based on the intelligent fuzzy logic method.

It consists of three parts: fuzzification, inference engine and defuzzification [9-11].

An error function (E) and change of error (ΔE) are calculated from (6) and (7) and created during fuzzificaion. These variables are then compared to a set of pre-designed values during inference method in order to determine the appropriate response.

Defuzzification is for converting the fuzzy subset of control from inference back to crisp values [12-15].

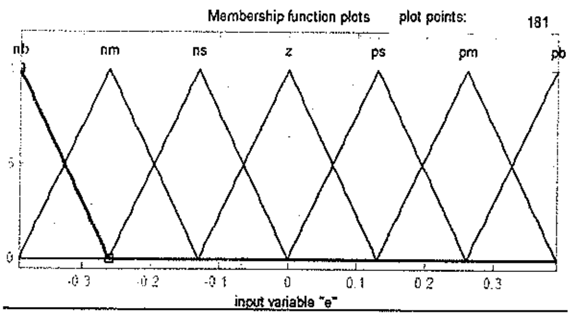
$$E = \frac{P_{ph}(k) - P_{ph}(k-1)}{V_{ph}(k) - V_{ph}(k-1)} \qquad (6)$$

$$\Delta E = E(k) - E(k-1) \qquad (7)$$

The E and ΔE function is compared to the graph of Fig. 9. to obtain a variable NB or ZE, then this parameter will be used to locate the respective output function (u) from the fuzzy rule table I.

The inference mechanism is implemented with mamdani algorithm and the centre of gravity method is used for defuzzification.

The error function E



The change of error function ΔE

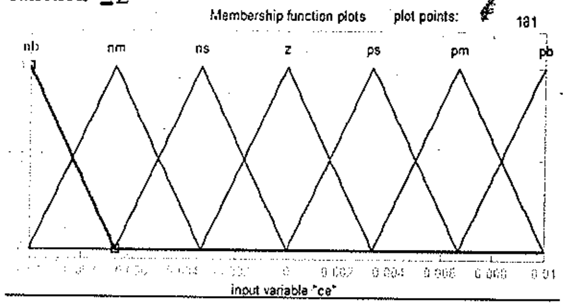


Fig No. 9, Fuzzy Logic membership function

The output function u

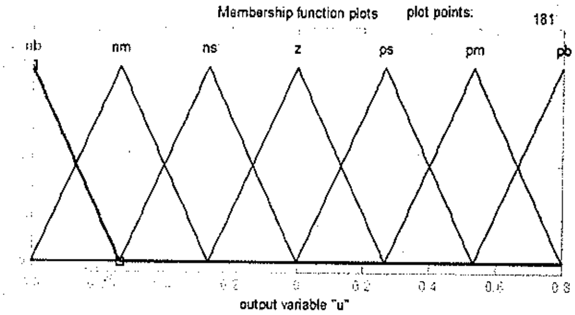
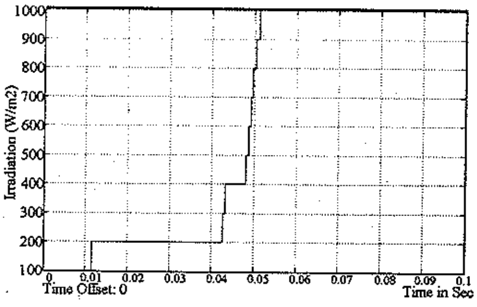
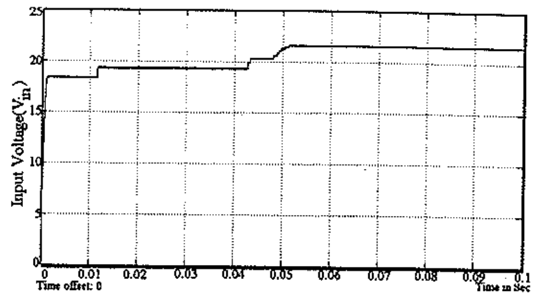


TABLE I
FUZZY RULE TABLE

ΔE \ E	NB	NM	NS	Z	PS	PM	PB
NB	Z	NM	NS	NB	NS	PB	PB
NM	NM	Z	Z	NB	PM	Z	NB
NS	PM	NB	Z	NS	Z	PM	NS
Z	NB	NB	Z	Z	Z	Z	PS
PS	NM	PM	NS	Z	Z	NB	Z
PM	PM	NS	NS	NB	Z	Z	NB
PB	NB	PB	PM	Z	NS	NS	Z

The insolation variation from 100 w/m² to 1000 w/m², input voltage (V_{in}) and output voltage (V_o) are shown in Fig.10.





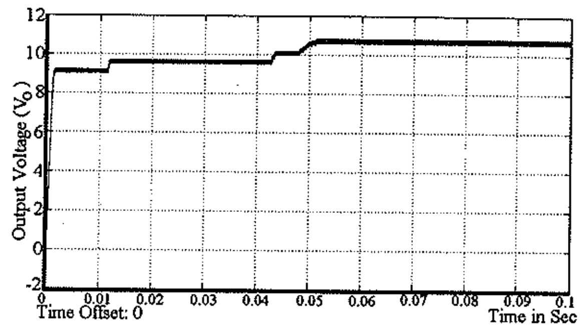


Fig.10. Simulation results depicting the change of insolation from 100 to 1000w/m2, input voltage (V_{in}) and output voltage (V_o).

V. CONCLUSION

An intelligent fuzzy method for MPPT of Photovoltaic array is presented in this paper on the base of fuzzy logic control algorithm. The simulation results show that the fuzzy controller has the merits such as simplicity fast response, low over-tuning, high control, precision and easy implementation.

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