FUZZY LOGIC CONTROLLED SEPIC CONVERTER FOR MAXIMUM POWER TRACKING OF PHOTO VOLTAIC SYSTEMS

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Abstract

In this paper, a modified P&O technique that uses fuzzy logic to control the amount of perturbation depending on operating point of PV solar cell is proposed. Fuzzy logic is used to achieve smooth adaptations in duty cycles as well as to control the rate of adaptation. Proposed method helps reducing steady state oscillations and increasing convergence speed. SEPIC (Single Ended Primary Inductor Converter) is employed to realize appropriate output from proposed MPPT control. The limitation of SEPIC to track dynamic variations is overcome by fast operation of control algorithm. The system is simulated and tested in MATLAB/Simulink.

Keywords*—Maximum Power Point Tracking, Photovoltaic Systems, Fuzzy Logic, SEPIC Converter*

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1. INTRODUCTION

Rising concerns about reduction of fossil fuels and environmental aspects has promoted use of renewable energy sources for energy production. Wind, geothermal, tidal etc. are mainly beneficial on large scale at certain locations only; however the only source of energy which can be made available on variety of scales starting from few kW to several MWs as well as on convenient locations even like rooftops is the photovoltaic source utilizing solar power. It is highly recommended and required in developing countries like India, where more than enough solar power is available daily. There are certain technicalities involved however, the solar photovoltaic efficiency being very low as 15 to 20 %. Further, solar power is highly intermittent and it is not available in night. The prediction tools are not that accurate. Our duty is to extract maximum power out of whatever is available at a given point of time, which needs extensive use of power electronics. Maximum power has to be extracted in both variable solar input and variable load cases.

The problem of maximum power point tracking has extensively explored by researchers and several methods have been available for achieving MPPT. Common methods include perturb and observe (P&O) [1]–[5], incremental conductance [6]–[9], optimization based methods [10], several bio-inspired techniques and other heuristic methods [11]–[16]. The most simple and fastest amongst all is P&O. However, this method has a big limitation of continuous perturbation even in steady state, due to fixed amount of perturbation even if maximum power operation is achieved. Further, pre-fixed step at points far away from MPP aids to slower convergence. There are some methods using adaptive perturbation amount, however they do not make smooth variations in duty cycle or reference voltages as they use discrete set of values of reference points calculated from certain formula. When rate of change of power w.r.t. voltage of PV array is very high (e.g. sudden clouds, dynamic load variations and faults), such method fails to properly perturb. In order to have smooth control, fuzzy logic is found to be better [17]–[20]. Also, use of fuzzy look-up table (fuzzy curve in single-input, single-output case) greatly simplifies and speeds up the process. Some authors proposed fuzzy rule base taking error (proportional to difference between reference and actual voltage) and change in error as inputs. However in proposed method, only single input is used for fuzzy controller thereby reducing complexity and increasing decision speed. The input is taken as rate of change of power with respect to voltage of PV module/array, which is the indicator of distance of present operating point from the desired MPP.

The realization of achieving desired operating point of PV system is done through properly selected power electronic circuit, typically a dc-dc converter. Among several available converter types, SEPIC has more advantages such as non-inverted output, more flexibility, availability of more inductance with less core, decoupling of input and output in spite of some limitations like complex fourth order system [21]– [23].

2. PROPOSED SYSTEM

The circuit diagram of considered PV system is shown in Fig. 1. SEPIC converter is fed from PV array, while its switching pulses are controlled from modified Fuzzy logic based adaptive perturb and observe MPPT algorithm. Output of SEPIC is fed to load, which is taken as of variable impedance type. The requirement of MPPT technique is to extract maximum power from PV array and deliver the same to load including losses, as quickly as possible.

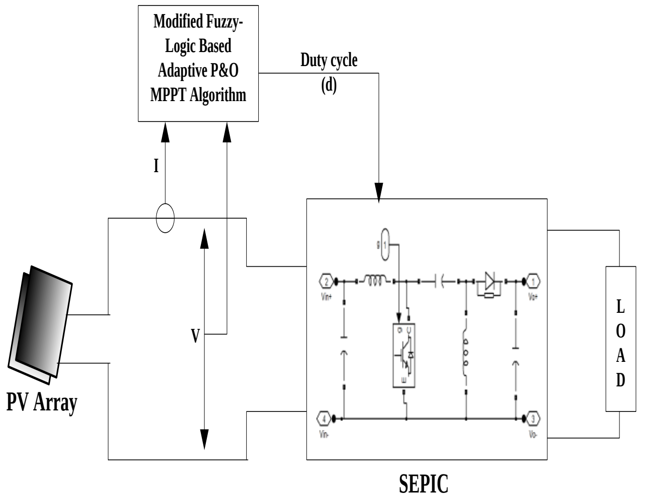


Fig. 1: System Diagram for Proposed MPPT by Fuzzy Controlled SEPIC

2.1 PV Array

Single diode equivalent circuit, as shown in Fig. 2, is generally used for simulation of one PV cell and the PV array is made up of series-parallel connection of such individual PV cells. The equations that define a PV cell are Eqn. (1), (2) and (3), the symbols and their meanings with their values are given in Table I. [24]

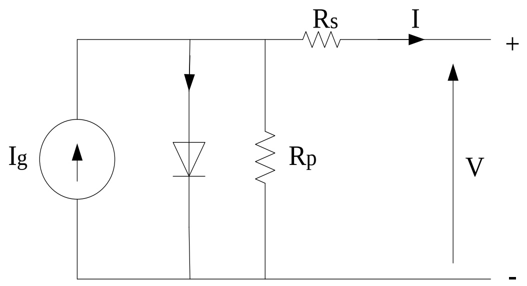


Fig. 2: Single diode equivalent circuit of a PV cell

$$I = N_p I_g - N_p I_o \left[e^{\frac{q}{\eta k T}\left(\frac{V}{N_s}+\frac{IR_s}{N_p}\right)} - 1 \right] - \frac{N_p}{R_p}\left(\frac{V}{N_s}+\frac{IR_s}{N_p}\right) \quad (1)$$

$$I_g = \frac{S}{S_{ref}}\left[I_{g_{ref}} + C_T(T - T_{ref})\right] \quad (2)$$

$$I_o = I_{o_{ref}} \left(\frac{T}{T_{ref}}\right)^3 e^{\frac{qE_g}{\eta k}\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)} \quad (3)$$

Table 1: Symbols and Their Meanings

Symbol	Meaning	Value
I	PV array current	Variable
V	PV array voltage	Variable
I_g	Photon generated current of a PV cell	Variable
$I_{g\ ref}$	Reference I_g of a PV cell	3.35 A
I_o	Saturation current of diode	Variable
$I_{o\ ref}$	I_o at reference conditions	10^{-9} A
S	Solar insolation in W/m^2	Variable
S_{ref}	Reference solar insolation in W/m^2	1000 W/m^2
T	Ambient temperature in Kelvin	Variable
T_{ref}	Reference ambient temperature	300 K
q	Charge of an electron in Coulombs	1.602×10^{-19}
η	Diode ideality factor	2
k	Boltzman's constant (J/K)	1.381×10^{-23}
E_g	Band gap energy of semiconductor	1.237 eV
R_s	Series resistance of a PV cell	0.312 Ω
R_p	Parallel resistance of a PV cell	10^4 Ω
N_s	Number of cells in series	4
N_p	Number of cells in parallel	5
C_T	Temperature coefficient	0.065 %

2.2 SEPIC Converter

Consider a SEPIC converter, if V_o, I_o and V_{in}, I_{in} are output and input voltages and currents respectively and D is the duty cycle, then Eqn. (4) approximately holds (assuming ideal devices),

$$V_o = \frac{D}{1-D} V_{in} \quad \text{and} \quad I_o = \frac{1-D}{D} I_{in} \quad (4)$$

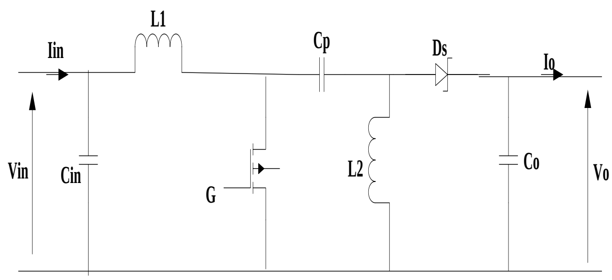


Fig. 3: SEPIC Converter

The load resistance Ro is reflected on input side of SEPIC as a different resistor of value dependent on duty ratio, as evident from Eqn. (5).

$$R_{in} = \frac{V_{in}}{I_{in}} = \left(\frac{1-D}{D}\right)^2 \frac{V_o}{I_o} = \left(\frac{1-D}{D}\right)^2 R_o \quad (5)$$

It is clear from Eqn. (5) that input resistance seen by PV array can be controlled by varying D, irrespective of any load resistance R_o. This provides a great flexibility of operation. It is important to vary input impedance of SEPIC since, at MPP, that must be equal to input impedance seen by PV array, as per maximum power transfer theorem. Eqn. (5) indicates an inverse relationship between R_{in} and D.

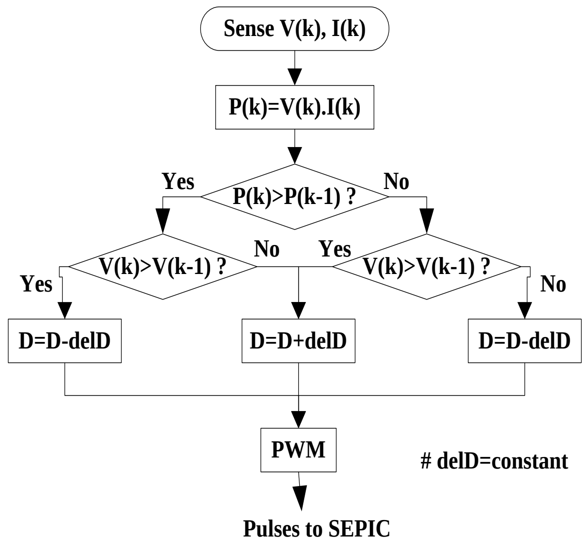
For simulation, the values of elements in SEPIC are taken as, C_{in} = 2 mF, L_1= 5 mH, L_2 = 1 mH, C_p = 470 ^{0}F and C_o = 5 mF.

2.3 Proposed MPPT Algorithm

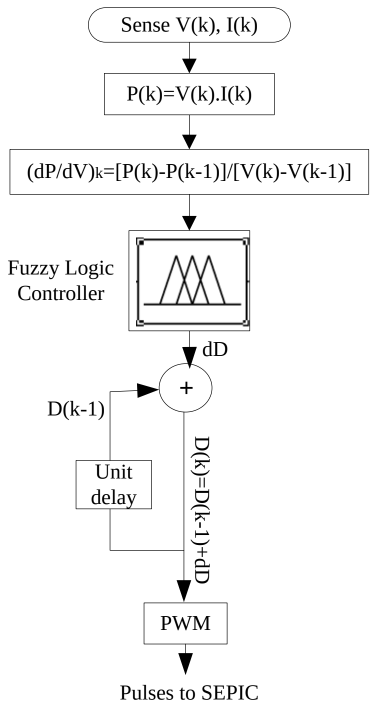
The slope of P-V curve at point of maximum power is zero; it is positive on left side and negative on other side, as evident from Fig. 6 (b). Perturb and Observe method make use of this fact such that, duty cycle (D) is updated each time so as to achieve zero slope of dP/dV. Flow chart of conventional P&O is shown in Fig. 4 (a).

In proposed method, the logic of MPP tracking is kept same as conventional P&O, where each time the perturbation is made, the slope dP/dV is checked and next perturbation is made in a direction to assist that slope towards zero. The difference in proposed method here is that, amount of perturbation in duty cycle is a variable and dependent on position of the operating point relative to MPP. If operating point is far away from MPP, it is obvious that fast and long perturbations are workable. As MPP is get closer, steps can be made smaller and smaller so as to attain fine and accurate position for steady state.

Fuzzy logic is used to generate a smooth curve establishing relationship between the slope dP=dV and the step in duty ratio to be taken i.e. dD. The fuzzy membership functions are defined (Table III) by seven groups for both input and output. The rule base (Table II) is defined considering principal of hill-climbing and inverse relation of duty ratio with voltage [Eqn. (4)].



(a) Flow Chart of Conventional P&O Method

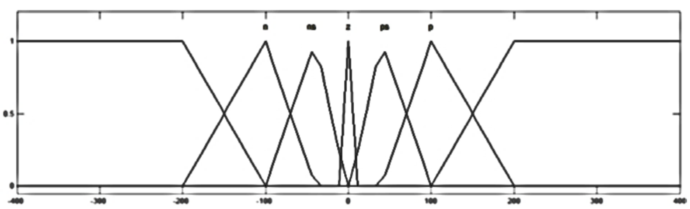


(b) Flow Chart of Proposed Fuzzy Logic based Modified MPPT Algorithm

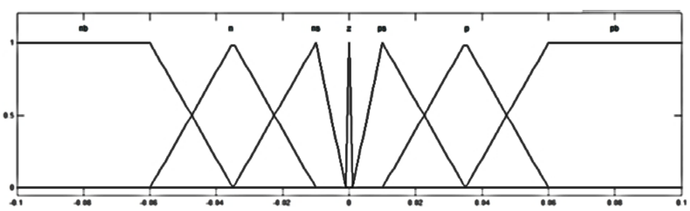
Fig. 4: Conventional Vs. Modified P&O MPPT Methods

The flow chart of proposed algorithm, fuzzy membership functions and fuzzy look-up curve is depicted in Fig. 4 (b) and 5 respectively.

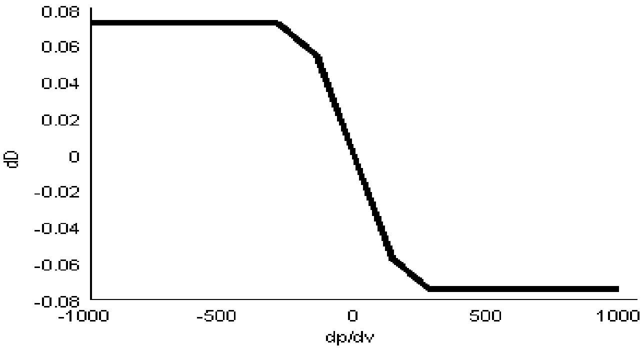
The membership functions have unequal shapes, the area assigned to part nearer to zero is gradually decreasing. This is to ensure the adaptive step-size to be taken at every hill-climbing step. Trapezoidal membership functions are chosen for values far away from zero since a big step with constant amplitude can be taken for such a vast range. Values for output dD i.e. change in duty cycle are chosen within range of [-0.1, 0.1], whereas that of dP/dV are chosen with high ranges (theoretically the range should be $(-\infty, \infty)$). The value of membership function at origin is zero indicating the operation at MPP itself.



(a) Membership function of input dP/dV



(b) Membership function of output dD



(c) Fuzzy Curve

Fig. 5: Membership Functions and their Relation

Table 2: Fuzzy Rule-Base

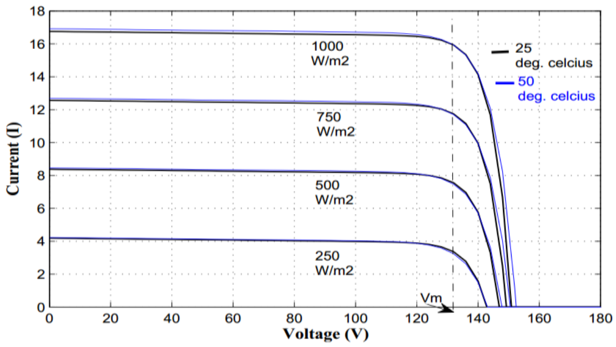
If dP/dV	NB	N	NS	Z	PS	P	PB
Then dD	PB	P	PS	Z	NS	N	NB

Table 3: Membership Functions and Their Distribution

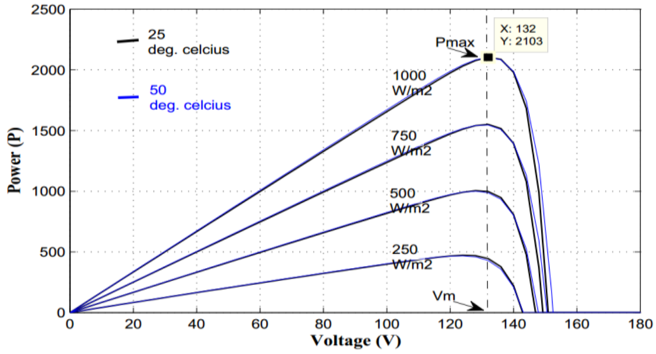
	dP/dV	dD
NB	[-20000 -20000 -200 -100]	[-0.1 -0.1 -0.06 -0.035]
N	[-200 -100 -40]	[-0.06 -0.035 -0.01]
NS	[-100 -40 -2]	[-0.035 -0.01 -0.001]
Z	[-10 0 10]	[-0.001 0 0.001]
PS	[2 40 100]	[0.001 0.01 0.035]
P	[40 100 200]	[0.01 0.035 0.06]
PB	[100 200 20000 20000]	[0.035 0.06 0.1 0.1]

3. SIMULATION RESULTS AND DISCUSSIONS

The I-V and P-V characteristics of simulated photovoltaic array are shown in Fig. 6 for various temperatures and solar insolation values. It can be observed that, under standard test conditions with S = 1000 W/m^2 and T = 300 K, the maximum power of P_{max} = 2100 W is achieved at a voltage of around V_m = 132 V. Also, impact of temperature variation on operating characteristics of PV array is not much as compared to impact of solar insolation variation. In practice, ambient temperature does not vary so much, whereas solar insolation greatly fluctuates as per climatic conditions, clouds and other distractions causing shadows.



(a) I-V Characteristics



(b) P-V Characteristics

Fig. 6: Characteristics of Simulated PV Module

The system of Fig. 1 is simulated with S = 500 W/m^2 and T = 300 K. The results of input and output powers are compared with conventional P&O algorithm. The maximum power of Pmax = 1000 W (refer Fig. 6 (b)) is effectively tracked by proposed method within less time and with least oscillations in steady state output.

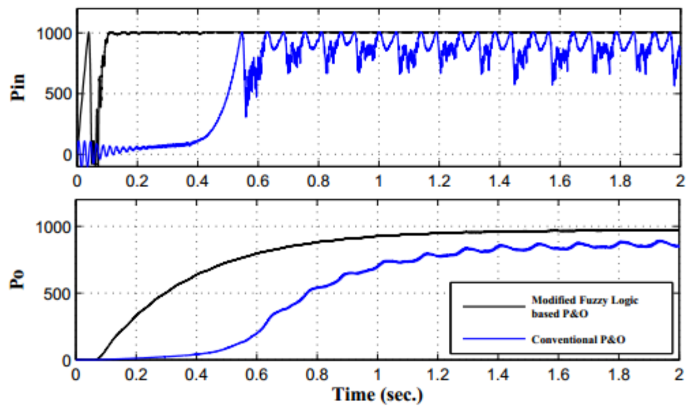
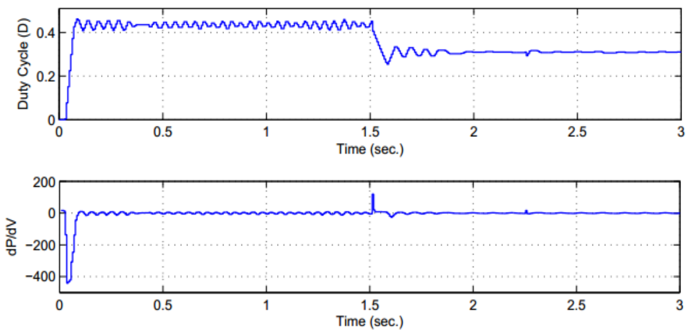
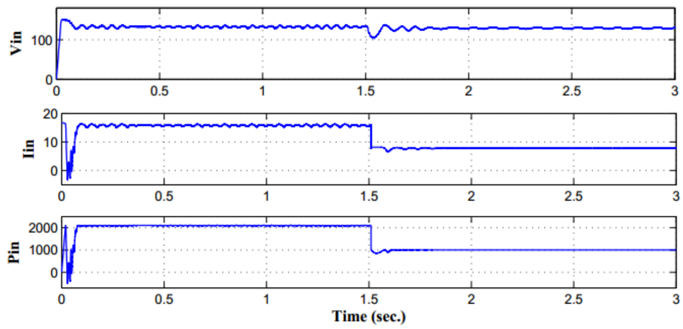


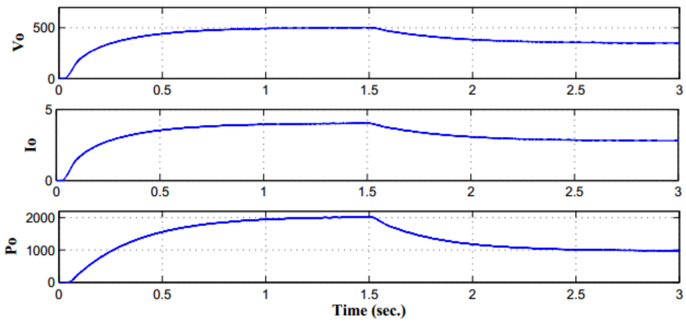
Fig. 7: Comparison of Proposed MPPT Method with Conventional Fixed Perturbation P&O



(a) Input and Output of Fuzzy Logic Controller



(b) Input of SEPIC



(c) Output of SEPIC

Fig. 8: Performance of Proposed MPPT Method

To validate the performance of proposed method with dynamic variations on environmental side as well as electrical load side, two disturbances are created. One at 1.5 sec., where solar insolation suddenly reduces from 1000 W=m^2 to 500 W=m^2. Secondly, at 2.25 sec., electrical load is varied from 5 to 50. The simulation results are shown in Fig. 8.

It can be observed that, solar irradiation has great impact on output power since P-V characteristics is completely changed. The algorithm quickly senses this change and varies its duty ratio to desired value where a new maximum power is tracked.

The oscillations in duty cycle die out after few milliseconds, so those in the input and output voltages and currents. The input power to SEPIC is almost instantaneously changed. Output power varies slowly due to time delay caused by SEPIC converter.

Load resistance variation has little impact, since very little change in duty ratio is needed and same maximum power point is continuing. Also, change in the slope i.e. dP/dV is very negligible. It can be noted that, maximum power point is characteristics of PV array and not that of load. In this case, duty ratio is changed to ensure impedance matching as per maximum power transfer theorem.

The method seems to work robust under drifting phenomenon. When P-V characteristics are dynamically changing, there is possibility in conventional P&O method to track in wrong direction since dP/dV may have wrong sign in a direction. However, in proposed method, both left and right sides of MPP are not equally climbed. The left side having comparatively little absolute slope w.r.t. right side of MPP, is climbed slower. If drifting causes MPP to shift towards right, method will see a negative slope dP/dV and speedily go away the MPP. Thus, phenomenon can be quickly recovered once the new characteristics become steady. Here, drifting cannot be avoided however it can be suffered through very quickly by the proposed method.

4. CONCLUSION

A new MPPT method for photovoltaic systems is proposed. Fuzzy logic based controller is used to optimally adapt step size and perturbation amount in the conventional P&O method. SEPIC converter is used to realize the control method. The proposed method seems to achieve fastness and steady-state accuracy compared to conventional method. Proposed technique is simple to implement and will be implemented in future in the form of real-time hardware.

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