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Adaptive Fuzzy Logic Based Increamental Conductance Maximum Power Point Tracker for PV Array under Partial Shading Condition

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ABSTRACT

The incessant challenges encountered by Photovoltaic generation system emanating from partial shading condition have resulted to low efficiency of the system. Conventional maximum power point tracker techniques failed to give optimum MPP under this condition and as such their optimization took the advantage of their simplicity. Incremental Conductance (IC), one of the conventional MPPT is superior to Perturb and Observe (P&O) MPPT but still gets locked at local maxima. Artificial neural network and particle swarm optimization although are Intelligent Controllers but usually caused complexity in the system. To keep the simplicity of conventional MPPT, this paper presents an improved IC MPPT using Fuzzy Logic Controller for KC200GT PV array under partial shading condition and compares its performance to Adaptive Fuzzy Logic Based P&O MPPT for validation on the same PV and conditions. Simulation and analysis in Mat lab/Simulink environment of these control techniques are presented, and its performances evaluated. The superiority of IC MPPT over P&O MPPT was first established. A model of Fuzzy Logic was used to optimize the two MPPTs for comparison under the same partial shading conditions. The two new models extract more Power than their conventional counterparts with the AFLBIC ahead of the AFLBP&O MPPT.

Key words: maximum power point tracker, optimization, phovoltaic, simulation

INTRODUCTION

Photovoltaic Power Plants use inelectrical energy generation is becoming increasingly important due to its advantages over other sources: incurring no fuel costs, not being polluting, required little maintenance, noise emission free among others.Intelligence Maintenance System (IMS) research predicts 35GW installation capacity of Photovoltaic (PV) generation systems in 2014 [1]. A new era for the use of photovoltaic was established as well as proving that the challenge of using this green energy worldwide not only for transportation but also for other areas has been raised and a new milestone was reached [2]. This cannot hide the fact that the size of this aircraft is the equivalent of a Boeing 747 with 17.000 solar cells necessary to generate the needed energy due to the small photovoltaic cells conversion ratio, (9-17%) efficiency of the converter/inverter and that of the MPPT algorithm [2]. Photovoltaic (PV) generates electrical power by converting solar irradiation into direct current electricity using semiconductors that exhibit Photovoltaic effects. The photovoltaic effect is the creation of current and voltage in the solar cell upon exposure to light. In other to generate more power than delivered by a single cell, cells are electrically connected to form PV modules. Again PV modules are grouped to form PV arrays depending on the demanded power [3-4]. The photovoltaic current-voltage (I-V) characteristic is nonlinear and changes with irradiation and temperature. The knee point of the curve is the optimum operating point of a solar cell where it generates maximum power and is called Maximum Power Point (MPP). To operate the solar cell at this point it is necessary to match the PV source to the load so that the operating point of PV module coincides with maximum power point which correspond to the current values of solar irradiation and cells' module temperature [5]. The state-of-the-art techniques to track the maximum available output powers of PV systems are called the maximum-power point tracking (MPPT). Controlling MPPT for the solar array is essential in a PV system in order to reduce the cost of yielded electrical energy. There are many techniques developed to implement MPPT; these techniques are different in their efficiency, speed, hardware implementation, cost, popularity. Incremental Conductance (IC) and Perturb and Observe (P&O) MPPTs are the most commonly used maximum power point trackers due to their simplicity and ease of implementation. However, while P&O presents drawbacks such as slow response speed, oscillation around the MPP in steady state, and even tracking in wrong way under rapidly changing atmospheric conditions (Partial Shading), IC has high tracking efficiency but got locked at local peak [6-7]. Partial Shading introduces local peaks together with global peak MPP in the PV system and therefore necessitated the use of an improved (Intelligent control) or hybridized MPPT algorithm to achieve an improved PV output performance.The hybrid MPPT has been implemented for fuzzy and P&O MPPT [1]. In this paper, fuzzy logic controller technique is employed to help Incremental conductance and P&O MPPTs to improve their performances under partial shading for KC200GT PV array. Simulation and analysis in Matlab/Simulink environment of these control techniques are presented, and its performances are evaluated. The superiority of IC MPPT over P&O MPPT was first established. A model of Fuzzy Logic was used to Optimize the two MPPTs for comparison under the same partial shading conditions. The two new models extract more Power than their conventional counterparts with the AFLBIC ahead of the AFLBP&O MPPT.

PROPOSED SYSTEM

Fig.1 below shows the block diagram of the system. It consists of PV array, DC-DC boost converter and MPPTs.

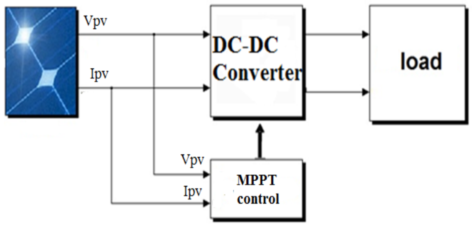

Fig. 1 Block diagram of the proposed system

The PV array as adopted from [1] has the characteristic for one module given in table 1 below. Three of the modules are connected in series to form the Arrays.

Table -1 Parameters of the KC200GT solar array at 25 ◦C

Parameter	**Value**	**Unit**
Imp	7.61	A
Vmp	26.3	V
Pmax, e	200.143	W
Isc	8.21	A
Voc	32.9	V
K_V	-0.1230	V/K
K_I	0.0032	A/K
Ns	36	-

1% of deviation from the optimum power transfer condition can cause a loss of output power in normal operation of solar cells [8]. For increasing efficiency of PV, tracking MPP is a necessity.

Maximum power point tracking (MPPT) scheme obtained by varying the duty ratio for DC/DC boost converter was successful. Boost converters was used in Photovoltaic in order to keep voltage at a value that has maximum power.

MODEL OF BOOST CONVERTER

DC-DC converters can be used as switching mode regulators to convert an unregulated dc voltage to a regulated dc output voltage [12].

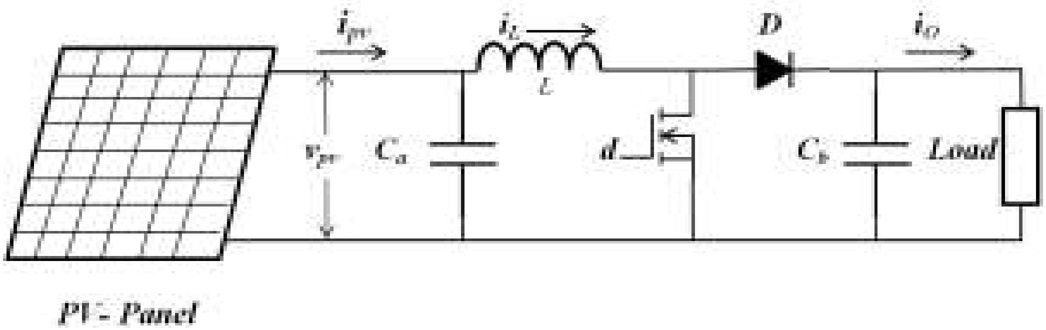

Fig. 2 PV array and Boost Converter

The regulation is normally achieved by PWM at a fixed frequency and the switching device is generally BJT, MOSFET or IGBT. The minimum oscillator frequency should be about 100 times longer than the transistor switching time to maximize efficiency. This limitation is due to the switching loss in the transistor. The transistor switching loss increases with the switching frequency and thereby, the efficiency decreases. The topology of the boost converter interface with PV array is shown in fig. 2 below:

The boost converter parameter can be calculated from the following equations

$$V_o = \frac{V_{in}}{(1-D)} \quad \text{...1}$$

Vo is the output voltage of the converter,
Vin is the input voltage and
D is the duty cycle.

The relationship between the input and output current is:

$$I_o = (1-D)I_{in} \quad \text{...2}$$

The capacitance C of a boost converter is given by:

$$C = \frac{D}{f \times R_o \times \left[\frac{\Delta V_o}{V_o}\right]} \quad \text{...3}$$

The inductance L is:

$$L = \frac{V_{in} \times D}{f \times \Delta I_o} \quad \text{...4}$$

According to [13] the steady-state equation of boost converter under ideal condition in terms of load resistance and internal resistance can be expressed as:

$$R_{in} = \frac{V_{in}}{I_{in}} = (1-D)^2 R_o \quad \text{...5}$$

The range of duty ratio is from 0 to 1 and

$$R_o \geq R_{in} \quad \text{...6}$$

IEC harmonics standard recommends current and voltage ripple percentages (CRP) and (CVP) be bounded within 40% and 2% respectively. Using equations (1) - (5) the parameters of the boost converter are:
Vo = 136V, Vin = 78.9V, L = 0.0011H, C =30µF f = 20KH_Z.

PERTURB AND OBSERVE MPPT

The P&O algorithm finds the maximum power point (MPP) of PV modules by iteratively perturbing the array voltage V, observing and comparing the power generated by the PV modules $P(n)$ at any instant with the previous power $(n-1)$. The voltage perturbation is achieved through the change in the duty cycle D. The increment or decrement of the duty cycle D in every sampling period is determined by the comparison of the power at present time and previous time. If $\Delta P = P(n) - P(n-1) > 0$, the duty cycle is increased and if $\Delta P > 0$, the duty cycle is then reduced.
The duty cycle perturbation is stopped when $\Delta P = 0$ or practically equal to a small preset value [14]. Fig. 3 shows the flowchart of the P&O algorithm with duty cycle perturbation [1]

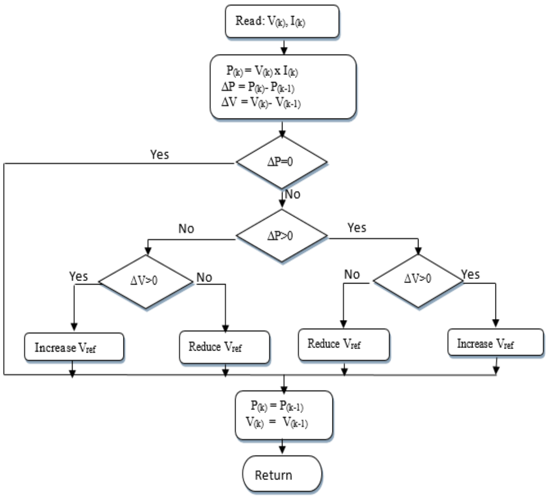

Fig. 3 P&O MPPT algorithms

INCREMENTAL CONDUCTANCE MPPT

Among the most widely used conventional maximum power point trackers Incremental Conductance has high tracking speed and better efficiency [7]. The technique focuses directly on power variations. The incremental conductance algorithms use the fact the PV panel power curve derivative (slope) with respect to voltage is zero at MPP, positive on the left side and negative on the right side of MPP. The basic equations describing this method is as follows:

At MPP

$\frac{dP}{dV} = 0$……………………………………………………………………………...............................1

At Left of MPP

$\frac{dP}{dV} > 0$ …………………………...2

At right of MPP

$\frac{dP}{dV} < 0$ ……………………………………………………………………………………………3

Base on equation (1)

$\frac{dP}{dV} = \frac{d(IV)}{dV} = \frac{IdV}{dV} + \frac{VdI}{dV} = I + V\frac{dI}{dV} = 0$ ………………………………...4

$I + V\frac{dI}{dV} = I + V\frac{\Delta I}{\Delta V}$ …………………………………………………………………………………5

Thus

$\frac{\Delta I}{\Delta V} = -\frac{I}{V}$ at MPP

$\frac{\Delta I}{\Delta V} > -\frac{I}{V}$ at left side MPP

$\frac{\Delta I}{\Delta V} < -\frac{I}{V}$ at right side of MPP

This shows that the tracker operates by comparing the incremental conductance $\left(\frac{\Delta I}{\Delta V}\right)$ to the instantaneous conductance $\left(\frac{I}{V}\right)$ and depending on the result the panel operating voltage is either increased or decreased to reach MPP. Unlike P&O algorithm that naturally oscillate at MPP, incremental conductance algorithm stops modifying the operating voltage when the correct value is reached. The flowchart of the IC is shown in fig. 4:

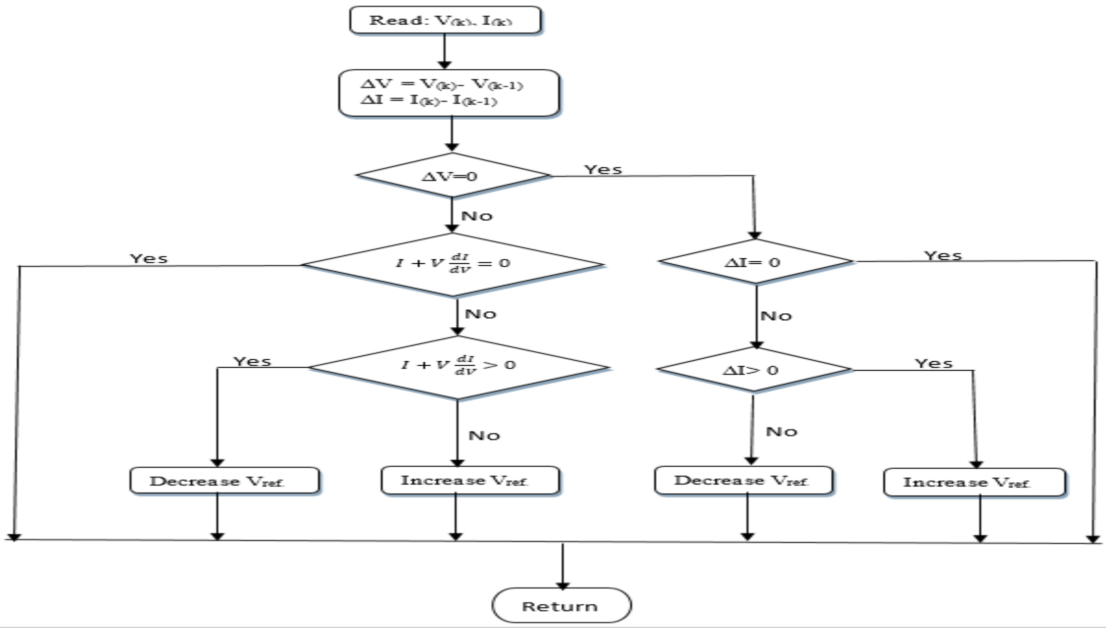

Fig. 4 Incremental Conductance Algorithm

FUZZY LOGIC CONTROLLER

Fuzzy Logic Controller is one of the most successful applications of fuzzy set theory, introduced by Zadeh in 1965 [8]. For the MPPT controller with fuzzy logic, the inputs are taken as a change in power and voltage as well. Fuzzy logic controllers have the advantages of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity. Fuzzy logic control generally consists of three stages: fuzzification, rule base table lookup, and defuzzification. During fuzzification, numerical input variables are converted into linguistic variables based on a membership function similar to Fig. 6 below. In this case, five fuzzy levels are used: NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small), and PB (Positive Big).

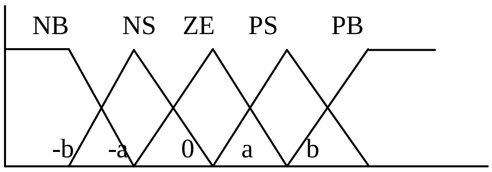

Fig. 6 Membership function for input and output of fuzzy logic controller.

The membership function is sometimes made less symmetric to give more importance to specific fuzzy levels. The inputs to a MPPT fuzzy logic controller are usually an error E and a change in error ΔE. The user has the flexibility of choosing how to compute E and ΔE. Since dP/dV or dP/dI vanishes at the MPP, approximation can be applied as follows,

$$\text{Error}, E = \frac{P(t) - P(t-1)}{Ipv(t) - Ipv(t-1)}$$

$$\text{Change in error}, \Delta E = E(t) - E(t-1)$$

Once E and ΔE are calculated and converted to the linguistic variables, the fuzzy logic controller output, which is typically a change in duty ratio ΔD of the power converter, can be looked up in a rule base table such as Table 2 below. The linguistic variables assigned to ΔD for the different combinations of E and ΔE is based on the power converter being used and also on the knowledge of the user for the boost converter. If for example, the operating point is far to the left of the MPP, that is E is PB, and ΔE is ZE, then we want to increase the duty ratio largely, that is ΔD should be PB to reach the MPP. 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. 6. This provides an analog signal that will control the power converter to the MPP [1].

Table 2: Fuzzy rule base

E \ ΔE	NB	NS	ZE	PS	PB
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

The structure of fuzzy logic controller is shown in fig. 7:

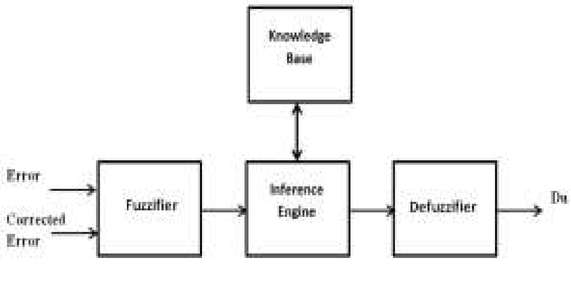

Fig. 7 Structure of Fuzzy Logic Controller

THE PROPOSED SCHEME

Adopting the method of Fuzzy Logic Controller (FLC) in [1], the proposed scheme comprises of following components:

Fuzzification interface, where predefined fuzzy subsets determine the input crisp values.

Fuzzy rule base, which provides the set of "*if then*" statements to define the controller behavior.

Inference engine, which processes output from input set of fuzzy values using the fuzzy rule base.

Defuzzification interface is where crisp values of output fuzzy set are obtained. The output of FLC is a change in the duty cycle of the DC-DC converter. The process of defuzzification converts linguistic value of output into a crisp output value. The input to defuzzification process is an aggregated output fuzzy set and the output is a single number. Many defuzzification techniques have been proposed in the literature. The most commonly used method is the Center of Gravity (COG) or centroid defuzzification method. In this method, the defuzzifier determines the center of gravity (centroid) and uses that value as the output of FLC. For a continuous aggregated fuzzy set, the centroid is given by:

$$U_f = \frac{\sum_{i=1}^{n} w_i V_{fi}}{\sum_{i=1}^{n} w_i}$$

For the purpose of this thesis the output duty cycle U_F of the FLC is use to further increase the next perturbation step size voltage output of IC before feeding it to control the converter duty cycle, D. The output of the FLBIC MPPT is given by:

$$V_{FLBIC} = \frac{\sum_{i=1}^{n} w_i V_{fi}}{\sum_{i=1}^{n} w_i} + V_{IC}$$

The flowchart of the proposed Adaptive Fuzzy Logic Controller Based Incremental Conductance MPPT is shown in the fig. 8 below.

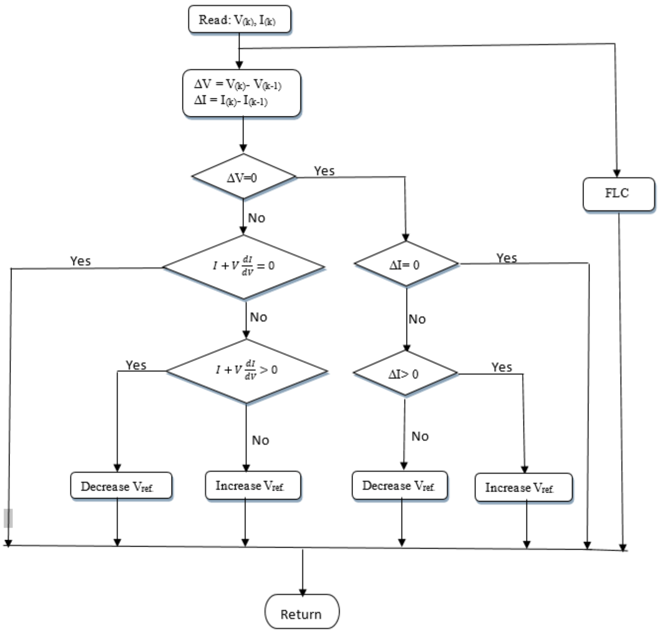

Fig. 8 Flowchart of the proposed scheme

The scale factors K_1, K_2 and K_3 are adjusted base on [14].

SIMULATION RESULTS AND DISCUSSION

Interfacing the PV array with boost converter without MPPT and with MPPT for simulation, the following results are obtained:

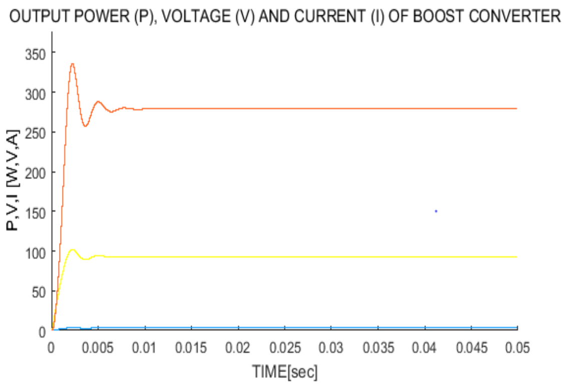

Fig. 9 Output Power, Voltage and Current versus time of the converter interface with PV module without MPPT

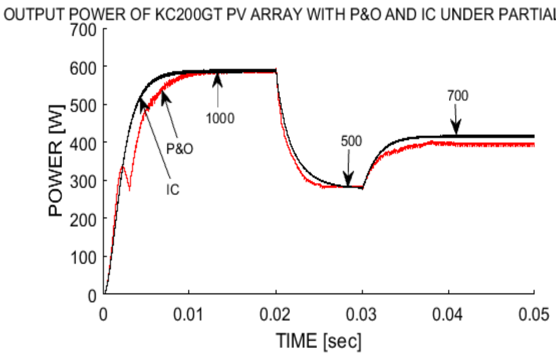

Fig. 10 Output Power versus time of the converter interface with PV module, P&O and IC MPPTs

The fig. 10 shows the IC reaching MPP ahead of P&O at 0.08sec and 0.13sec respectively and extract more power under partial shading as analyzed in table 3:

Table -3 Comparison between P&O and IC MPPT output power of KC200GT PV array

Case No	Irradiance Level (Watt/m^2)	Output Power (Watt) with P&O MPPT	Output Power (Watt) with IC MPPT	% Increase
1	1000	598	600	0.34%
2	700	400	420	5%
3	500	298	299	0.34%

The hybrid MPPTs output are also shown in fig. 11.

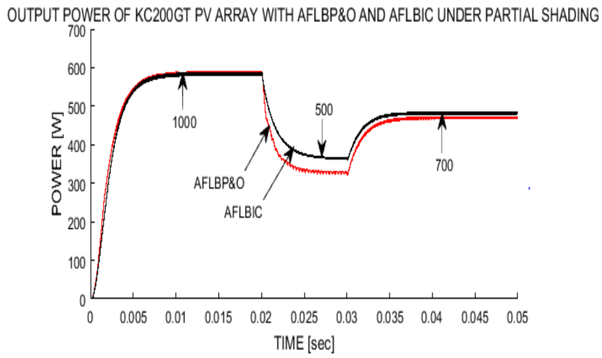

Fig. 11 Output Power versus time of the converter interface with PV array, AFLBP&O and AFLBIC MPPT at irradiance variation from 1000 W/m^2, 500 W/m^2 and 700 W/m^2 respectively.

Base on fig. 11, the output is summarized in table for comparison.

Table -4 Comparison between AFLBP&O and AFLBIC MPPT output power of KC200GT PV array

Case No	Irradiance Level (Watt/m^2)	Output Power (Watt) with AFLBP&O MPPT	Output Power (Watt) with AFLBIC MPPT	%Increase
1	1000	600	600	0%
2	700	438	459	4.79%
3	500	329	360	9.4%

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