Implementation of MPPT for PV Isolated System by P&O, I_C and PSO Methods based on Arduino Technology

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Abstract—Maximum power point tracking (MPPT) algorithms are very essential for the PV systems since they attract the points of maximum power at any conditions of the varying temperature and irradiation and subsequently decrease the PV array cost. This paper submits a heightened MPPT technique for the PV system using particle swarm optimization (PSO) algorithm comparing with the traditional MPPT methods using perturb and observe (P&O) and incremental conductance (I_C). MATLAB simulations are carried out under the same irradiation and temperature and a variation in the load and comparing the performance of the three methods. In Protues 8.3 professional software, a design of the proposed model using Arduino UNO of the three algorithms is achieved. One of the important contributions of this paper is the proposed experimental work which is carried out by the combination of Arduino UNO which is coded by C language and coupled with MATLAB results which obtained by the simulation for the used different optimization methods in this paper. At the end of this paper, there is a comparison in tabular form between the presented 3 optimization methods with their experimental results. It is found that the results obtained by using PSO are more acceptable.

The main advantages of the PSO are as follows: - it reduces the oscillations at the steady state (to approximately zero) once the MPP is located, and its algorithm is very fast comparing to the other two methods.

Index Terms—Maximum Power Point Tracking (M.P.P.T); Photovoltaic system PV; incremental conductance (I_C); Arduino UNO; Perturb & Observe (P&O); particle swarm optimization (PSO)

I. INTRODUCTION

Thinking of the future source of energy, definitely solar energy the most promising source [1]. It can be easily achieving needed electrical power from PV system by coupling the modules in parallel or in series. The most popular technique or algorithm used in PV production system is "Maximum Power Point Tracking" (MPPT). This technique allows getting maximum power that the module can give and track it over time. The MPPT technique can be adapted to improve and optimize the performance of the PV modules. The expected efficiency by using this technique could be improved by 25% [2]. In this paper, the PSO method is introduced and compared with the conventional MPPT methods using I_C and P&O. The proposed model is simulated using MATLAB software [3] and it is designed using Protues 8.3 professional software. The experimental

work is done using a standalone PV Module comprises three identical solar modules coupled in series and it is tested using the three algorithms.

In this paper, the description of the proposed model is discussed in section II after that the Simulation and experimental work results are mentioned in section III.

II. THE DESCRIPTION OF THE PROPOSED MODEL.

In figure. 1, it's shown the circuit diagram of the PV module with The MPPT controller. The main components of the model are: PV panel, current sensor, voltage sensor, buck converter, MOSFET driver, MPPT controller and the load. The full description of each element is provided in details in the following sections.

Fig. 1 Circuit diagram of the proposed system

A. The PV System

B. 1. Mathematical Model of the photovoltaic Module

The PV simple equivalent circuit contains the next basic components; current source, series resistor, diode and shunt resistor as displayed in Fig.2. [4, 5].

Fig. 2. PV cell equivalent circuit.

The load current (I_{pv}) is the difference of the photo-current and the normal diode current obtained by applying Kirchoffs current law as follows:

$$I_{pv} = I_{ph} - I_d - I_p \quad (1)$$

$$I_{pv} = I_{ph} - I_o \left(e^{\frac{v_{pv} + R_s I_{pv}}{v_t Q_d n_s}} - 1 \right) - \frac{v_{pv} + R_s I_{pv}}{R_p} \quad (2)$$

Where:

v_{pv} = module voltage (V),

I_{pv} = module current (A),

I_{ph} = photocurrent (A),

I_o = reverse saturation current (A)

q = the electronic charge

Q_d = diode factor,

n_s = number of cells in series,

R_s = series resistor (Ω),

R_p = shunt resistor (Ω)

K = Boltzmann's constant,

T = absolute temperature (K), and

$v_t = kT/q$ is thermal voltage (V),

The proposed experimental study in this paper includes three identical solar modules which are coupled in series. The used PV module parameters at standard test condition (STC) are tabulated in Table I.

The Matlab software is used to model the used system depending on the previous equations.

The characteristics curves for the used PV array are shown in Fig.3.

TABLE (I): Electrical parameters for a single PV module at STC.

Item	Data
Maximum Power	10 W
Voltage at maximum power	6 V
Current at maximum power	1.66 A
Cells per module	12
Cell Dimension (mm)	30 * 156
Glass Dimension (mm)	244 * 344
Cell Temperature in Kelvin	298

Fig .3. I-V and P-V characteristics of the PV module

B. Current sensor

It is used to measure the PV current and convert it simultaneously to a suitable analog voltage signal between (0-5V). The obtained signal is fed to the analog input (Pin_A0) of the used Arduino Uno ATmega328P (Fig.8). Then it converted to the corresponding decimal number generally between (0-1023bits). The figure of the used current sensor is shown below [6].

Fig. 4 ACS-712 Hall Effect current sensor

C. Voltage sensor

On account of Arduino cannot read the value of the voltage greater than 5V, therefore the voltage divider is used to reduce the PV voltage to a lower one between (0 -5 V). The Arduino board receives the analog voltage input from the voltage sensor and then converts it to a digital signal. The circuit of the voltage divider is presented in fig. 5.

Fig.5. Voltage divider circuit

D. Buck converter

It is used to reduce efficiently the voltage value from one value to another. As shown in fig (6), it can be seen that the buck converter comprise MOSFET switches, a diode and an inductor are the elements of the buck converter also there are capacitors at the input and output sides [7]. To filter the input current pulses and the output voltage, the input capacitor and the output capacitor are used. The component values for the buck converter are tabulated in Table II.

Fig (6) Buck DC-DC converter

TABLE II. THE VALUES OF THE COMPONENTS OF THE BUCK CONVERTER

Component	Value
Switching Frequency	31.2 KHZ
Inductor, L	150 H / 5 A
Capacitors. C	$C_{in} = 33\mu F / 50V$ $C_{out} = 100\mu F / 16V$
Diode	1n4148
MOSFET switch	IRF3205(55v/110 A)

E. E. MOSFET driver

The voltage coming from the Arduino microcontroller output (Pin_A10) is not enough to run the MOSFET as its current is inadequate to charge the capacitor in the MOSFET circuit. This is why IR2112 half bridge IC driver is used to enlarge the voltage value from (3.3-5V) to (10.5-12V) [8]. In Fig. 7, the circuit of the IR2112 MOSFET driver is shown.

Fig. 7. Typical connection of MOSFET driver [8]

F. F. Arduino as microcontroller

Based on an ATmega328P microcontroller, the Arduino UNO board is developed and used in this paper [9]. This microcontroller controls all the functions of the tracker, and runs ADCs and DACs that handle the analog section, calculating the power point of the array. This board is very easy to be used as it contains all that is required to sustain the microcontroller USB or power cable with AC to DC adapter or battery can easily start the Arduino board [10].

Fig. 8 Arduino UNO Board

TABLE III SPECIFICATIONS OF ARDUINO UNO BOARD BASED ATMEGA328P [10].

Microcontroller	Value
Operating Voltage	5V
Input Voltage (recommended)	7-12 V
Input Voltage (limit)	6-20 V
Digital I/O Pins	14
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 kB
SRAM	2 kB
EEPROM	1 kB
Clock Speed	16 MHz
LED_BUILTIN	13
Width	53.4 mm
Weight	25 g
Length	68.6 mm

G. G. Maximum power point tracker techniques

In this paper, there are three algorithms that used to get the maximum power from the PV module: P&O which introduced in [11], I_C developed in [12] and PSO presented in [13, 14].

Also, the programmed Arduino UNO Microcontroller is used as a MPPT algorithm and PWM controller which allow us to control the PWM signal which responsible for controlling the buck converter. From the MPPT algorithm, The output PWM signal is a square waveform of maximum amplitude 5 V, constant frequency of 31.2 kHz, and variable duty cycle D (0% - 100%). The Mosfet driver is responsible for transfer the PWM signal to the MOSFET switches of the buck converter.

II. III. SIMULATION AND EXPERIMENTAL RESULTS

A. A. Simulation using MATLAB

The PV module is simulated by MATLAB utilizing the three MPPT methods (P&O, I_C and PSO) under constant irradiation at 1000 W/m², cell temperature at 25 °c and variable load conditions.

B. 1. Simulation results using P&O method

The PV model and the P&O MPPT algorithm are simulated using MATLAB under constant irradiance at 1000 W/m², cell temperature at 25 °c and the resistance of the load is boosted from 5 Ω to 9Ω at time equal 1.3 s. At this moment, the operating point will move to the right direction of the p-v curve fig. 9 and the power will decrease from 24 w to 16 w because of the lowering in current and boosting in voltage as shown in Fig.10. At this moment, the P&O MPPT algorithm try to return the PV module to operate at the MPP by increasing the duty cycle.

Fig. 9. P-V curve for P&O method

Fig. 10. Power, current, voltage and duty cycle under implementation of P&O method.

2. Simulation results using I_C method

The used algorithm in this section is I_C algorithm and as it was done for P&O method, the load is heightened from $5\ \Omega$ to $9\ \Omega$ under constant irradiation at $1000\ \text{W/m}^2$ and cell temperature at $25\ ^\circ\text{C}$.

The P-V curve and (the duty cycle, voltage, current and power) under implementation of I_C method are presented in figs. 11 and 12.

Fig. 11. P-V curve for I_C method

Fig. 12. Power, current, voltage and duty cycle under implementation of I_C method.

C. 3. Simulation results using PSO method

In this section, the PSO algorithm is used to obtain the MPP and the parameters of this algorithm are included in table (IV).

TABLE IV PARAMETERS USED FOR PSO ALGORITHM

PARAMETERS	VALUE
NO OF PARTICLES (N)	100
NO OF DIMENSIONS (D)	1
MAXIMUM VELOCITY (V_{max})	4
NO OF ITERATIONS ($Iter_{max}$)	250
ACCELERATION CONSTANT 1 (c_1)	1.2
ACCELERATION CONSTANT 2 (c_2)	1.8
INITIAL INERTIA WEIGHT (w_1)	0.5
FINAL INERTIA WEIGHT (w_2)	0.7

Fig. 13. P-V curve for PSO method

Fig. 14. Power, current, voltage and duty cycle under implementation of PSO method.

It's cleared from figure (15) that the power delivered from the model that uses PSO controller is larger than the power from the same model using I_C and P&O controller. It is also observed that PSO is faster than other two methods and more stable in the steady state.

Fig. 15. Power, current, voltage and duty cycle for the three methods (1)PSO, (2)I_C and (3) P&O.

D. B. Simulation with Proteus

The first step of using Proteus for implementation the three methods is to model a PV module in Proteus tool as shown in Fig. 16.

Figs. 17, 18 present the I-V and P-V characteristics for PV panel by using Proteus.

Fig. 16. The PV panel model under Proteus

Fig. 17. P-V characteristics for PV panel by using Proteus

Fig. 18. I-V and P-V characteristics for PV panel by using Proteus

Fig. 20. The results for P&O method using Proteus

Fig. 21. The results for I_C method using Proteus

Fig. 19. The proposed model Using Arduino and Proteus

As shown in fig. 19, the proposed model comprises a PV panel, DC-DC buck converter, current sensor, voltage sensor, Arduino board and load. The voltage and current of the module taken from voltage and current sensors are required for Arduino board to calculate PV power. And then, the PV voltage, current, power and duty cycle are displayed on the LCD screen.

E. 2.1 Results from Proteus

The duty cycle, current, voltage and extracted power from PV module for the used methods (P&O, I_C and PSO) are shown in figs. 20, 21 and 22.

Fig. 22. The results for PSO method using Proteus

F. C. Experimental work

The Arduino microcontroller is the programmed board used to implement the entire system using the algorithms of P&O, I_C and PSO methods. In figs. 23, 24 and 25, the implement breadboard, the printed circuit board and the proposed model are presented.

Fig. (23) breadboard configuration.

Fig. 24 the printed circuit board

Fig. 25 the proposed model.

1. experimental results for the three methods

After preparing the Arduino UNO board by uploading the used MPPT codes on it (one at a time), with the resistive load varies from $5\ \Omega$ to $9\ \Omega$ at 1.3s and the duty cycle varies from (0 to 100%).

Fig. 26 the duty cycle, PV voltage, current and PV power for the P&O method.

When the load is increased at time 1.3 s, the PV power will decrease due to the lowering in current and the boosting in voltage and the MPPT algorithm tries to return the PV module to operate at the MPP by increasing the duty cycle. The duty cycle, PV voltage, current and PV power for the P&O, I_C and PSO methods are presented in Figs. 26, 27 and 28.

Fig. 27. the duty cycle, PV voltage, current and PV power for the I_C

Fig. 28. the duty cycle, PV voltage, current and PV power for the PSO

G. 2. Comparison between experimental results

As it cleared from fig. 29, that PSO algorithm is faster than I_C and P&O to obtain the MPP, the steady state oscillations are almost zero when using PSO. For the P&O method, the oscillations are high and as a result, there will be more power losses than I_C and PSO.

Fig. 29. The duty cycle, PV voltage, current and PV power for the three methods (1)PSO, (2)I_C and (3) P&O

The table V totalizes the performance comparison between the three methods through several factors: the tracked power, power losses, time taken to obtain MPP and efficiency. The time taken to reach MPP is commensurate with the tracking speed.

The MPPT efficiency is calculated by using this equation.

$$\text{MPPT efficiency(\%)} = \frac{p_{\text{out (tracked)}}}{p_{\text{max (rated)}}} * 100\% \quad (3)$$

TABLE V. COMPARISON BETWEEN PSO, I_C AND P&O ALGORITHMS

Parameter	Method		
	PSO	I_C	P&O
Tracked power (w)	23.1	22.5	22
Process time to reach MPP (s)	0.5	0.8	0.89
Power loss (w)	1	1.6	2.1
MPPT efficiency (%)	95.85	93.36	91.28

It is spotted that PSO has the highest efficiency, least power losses and the highest precision than P&O and I_C. Plus, PSO has larger tracking speed than I_C and P&O with the least time in between the other two methods (the tracking speed is proportional to the time taken to get the MPP).

III. VI. CONCLUSION

The three techniques P&O, I_C and PSO are used to simulate and model a PV system relied on MPPT. The algorithms are simulated and tested using MATLAB software and Proteus tool. This paper presents an experimental work to model a PV system anchored in MPPT using the three algorithms and a comparison between the experimental results based on the tracked power, tracking speed, power loss and efficiency.

The comparison showed that PSO has higher tracked power, higher tracking speed, lower power loss and higher efficiency than the two other methods.

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