

P&O or IC for PV Pumping System: what MPPT Algorithm to Improve Performances?

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Abstract— This paper discusses the performance improvement of photovoltaic water pumping system using both P&O and IC MPPT controllers. The efficiency of both proposed MPPT controller has been studied successfully using a DC motor-pump powered by thirty six PV modules fed by DC-DC boost converter controlled using both P&O as well as IC MPPT algorithms. Comparative study results obtained using Matlab/Simulink environment show that the IC outperforms the P&O method in term of convergence speed; while the P&O method presents better performance for the steady state oscillation in case of high level insolation. In case of low level insolation (point C), the steady state oscillations around the MPP point are less in IC compared to those in P&O algorithm.

I. INTRODUCTION

Water is the primary source of life for mankind and one of the most basic necessities for rural development. At the same time, rainfall is decreasing in many arid countries, so surface water is becoming scarce and no longer able to ensure the increasing rural demand for water for crop irrigation and domestic water supplies. Water pumping, which of course requires energy, is a basic need for a large proportion of the world's rural population. Since the majority of this rural population live in the sunny tropics or sub-tropics, to use the sun's energy is an attractive way of providing these vital energy needs [1].

Solar energy can be directly converted into electricity for water pumping applications with either thermoelectricity where the conversion of solar energy to heat can then be used to drive a heat engine direct conversion of solar radiation to electricity using photovoltaic (PV) cells and then conversion of electrical energy to mechanical energy using a motor/pump unit. The latter approach has received widespread attention in research institutions but so far no such systems have proved reliable. Consequently, the most suitable approach used in wide range of applications, from residential rooftop power generation to medium-scale utility-level power generation [2], to feed water pumping systems [3], and Vehicles electrical [4].

In the isolated rural areas where electricity is unavailable, photovoltaic system is necessary to provide electrical energy; this energy is used to supply water pumping utilized for irrigation. These systems usually consist of PV generator, source of water, tank water and DC pump, many studies regarding for this system

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[5-8]. However, the power generated by PV systems is an irregular energy source presents two major problems: low efficiency and the output characteristic is not linear and varies with the conditions atmospheric such as temperature and irradiance [9-10]. Therefore, in order to improve the output power of PV system, maximum power point tracking controller is applying to adapt constantly the generator through the converter used acting as an adaptive impedance to maximize the power transferred to the load [11].

In the last two decades, several MPPT techniques have been proposed, namely: Perturb and Observe [12], Hill Climbing method [13], Incremental Conductance method [14], Fractional short circuit current [15], Fractional open circuit voltage [16], Fuzzy logic [17], Neural networks [18], Genetic algorithm [19], Particle swarm optimization method [20], Ant colony optimization method [21], ...etc. Among several techniques mentioned, the Perturb and Observe (P&O) method and the Incremental Conductance (IC) algorithms are the most commonly applied algorithms.

This paper analyzes the performance of photovoltaic water pumping system using indirect coupling mode using both P&O and IC MPPT controllers. The efficiency of both proposed methods has been studied successfully using a DC motor-pump powered by thirty six PV modules fed by DC-DC boost converter derived using both MPPT algorithms. Comparative study results obtained using Matlab/Simulink environment show that the IC outperforms the P&O method in term of convergence speed. The IC is also slightly better in term of output power. While the P&O method presents better performance for the steady state oscillation in case of high level insolation (points A and B). In case of low level insolation (point C), the steady states oscillation around the MPP point are less in IC than in P&O algorithm. The remainder of the paper is organized as follows. In Section 2, the material and methods used to realize this work are presented. Section 3 presents the simulations results and discussions. While Section 4 draw the main conclusions of this work.

II. MATERIAL AND METHODS

A. PV Modeling

The photovoltaic cell is modeling using the well know one diode equivalent circuit shown in Fig. 1 [22].

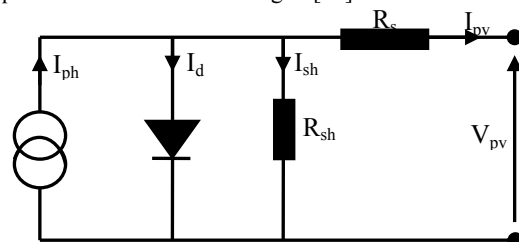


Fig. 2. PV cell model.

The model mathematical is expressed by:

$$I_{pv} = I_{ph} - I_s \left(\exp[\lambda(V_{pv} + I_{pv}R_s)] - 1 \right) - \frac{V_{pv} + I_{pv}R_s}{R_{sh}} \quad (1)$$

$$I_s = I_{s,ref} \left(\frac{T}{T_{ref}} \right)^3 \exp \left(\frac{qE_g \left(\frac{1}{T_{ref}} - \frac{1}{T} \right)}{kA} \right) \quad (2)$$

where q is coulomb constant ($1.602e^{-19}$ C), k is the Boltzman's constant ($1.381e^{-23}$ J/K), A is ideality factor, R_s is the PV series resistor, R_{sh} is the PV parallel resistor, γ is the real solar radiation (W/m^2), γ_{ref} is solar radiation in standard test condition (W/m^2), $I_{ph,ref}$ is photocurrent is solar radiation in standard test condition (A), \aleph is temperature coefficient (A/K), T is the temperature of cell (K), T_{ref} is cell absolute temperature is solar radiation in standard test condition (A), E_g is the band-gap energy of the cell (eV) and $I_{s,ref}$ is the diode saturation current in standard test condition

B. DC Motor Modeling

The equivalent electrical circuit of DC motor is illustrated in Fig. 2 [23-24].

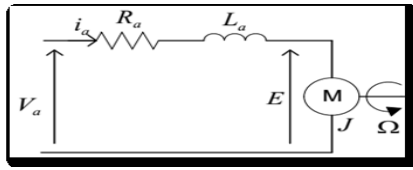


Fig. 2. DC motor equivalent circuit.

1) Electric Equation

The armature voltage is given by:

$$u_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + e_m(t) \quad (3)$$

where u_a is armature applied voltage (V), i_a is armature current (A), e_m is back electromotive force, R_a is the armature resistance (Ω) and L_a is the armature inductance (H).

2) Electromagnetic Equation

The back electromotive force can be written as:

$$e_m(t) = k_e \omega(t) \quad (4)$$

where k_e is the electromotive force constant (V/rad/s), ω is the rotational speed of motor (rad/s).

The motor torque T_{em} is related to the armature current I_a by a motor torque constant k_t (Nm/A).

$$T_{em}(t) = k_t I_a \quad (5)$$

3) Mechanic equation

The mechanic equation is given by:

$$J_t \frac{d\omega}{dt} = T_{em}(t) - \beta_m \omega(t) - T_r - T_f \quad (6)$$

where J_t is the moment of inertia of the rotor (Kgm^2), β_m is the motor viscous friction constant (Nms), T_r is the resistant torque (Nm) and T_f is the friction torque (Nm).

The state-space form is given by choosing the rotating speed and electric current as the state variables and the voltage as an input. The output is the rotating speed.

$$[X^\circ] = [A][X] + [B][U] \quad (7)$$

$$[Y] = [C][X] \quad (8)$$

C. MPPT Algorithms

The output PV power has a maximum dependent on the atmospheric conditions. To convert the energy available with the best performance, it is essential to work around an optimal operating point corresponding to the maximum power delivered by the PV generator. This is possible by adapting constantly the generator through the converter used for the indirect coupling mode that acts as an adaptive impedance. The Perturb and Observe (P&O) and the Incremental Conductance (IC) MPPTs are the most used algorithms for their simplicity and easy implementation [25-26].

1) P&O MPPT

Perturb and Observe MPPT involves perturbation of the operating voltage or the duty cycle based on a comparison of the generated power to ensures maximum power point. The principle is very simple: in the ascending phase of the P-V curve and considering a positive change of the voltage, the tracker generates a positive voltage increasing as a consequence the delivered PV power and change of the operating point. In this case, the PV voltage and power increase up to a new point. Similar steps with opposite direction can be done in the case of a decrease in the PV power; the instantaneous PV voltage follows the maximum power point according to a predetermined PV voltage and power values. Under these conditions, the tracker seeks the MPP permanently. At specified PV voltage, the desired power is the solution of the nonlinear equation given by ($dP/dV = 0$) as shown in Fig. 3 [27].

2) IC MPPT

The Incremental Conductance focuses directly on power variations. The output current and voltage of the photovoltaic panel are used to calculate the conductance and the incremental conductance. The basic equations of this method are as follows [28-32]:

$$\frac{dP}{dV} = 0 \quad (9)$$

Equation (9) can be rewritten as:

$$\frac{dP}{dV} = \frac{d(I.V)}{dV} = I + V \frac{dI}{dV} = 0 \quad (10)$$

$$\frac{dI}{dV} = -\frac{I}{V} \text{ at MPP} \quad (11)$$

$$\frac{dl}{dV} > -\frac{l}{V} \text{ at the left of MPP} \quad (12)$$

$$\frac{dl}{dV} < -\frac{l}{V} \text{ at the right of MPP} \quad (13)$$

The flowchart of the Incremental Conductance method is illustrated in Fig. 4.

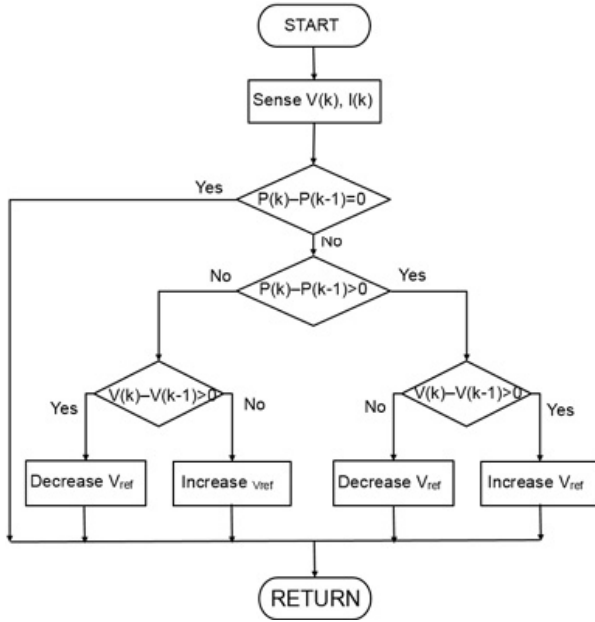


Fig. 3. P&O flowchart.

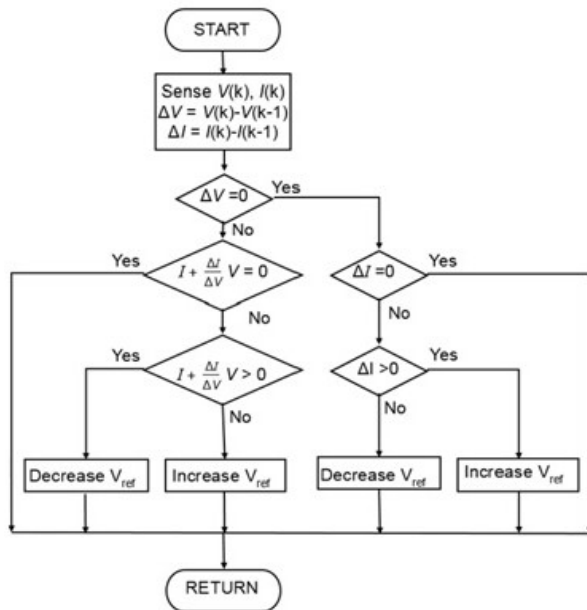


Fig. 4. IC algorithm flowchart.

III. RESULTS AND DISCUSSIONS

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The comparative study of the indirect coupling mode of the proposed PV pumping system is investigated by implementing the model of the entire system using Matlab/Simulink software, composed of 36 Solarex MSX-60W PV panel operating at variable atmospheric conditions (Table I) and DC-DC boost converter driven using both P&O and IC MPPT controllers. The load is a motor-pump DC motor (Table II).

Fig. 5 shows the output power using both MPPT controllers. While Fig. 6.gives the corresponding duty cycle.

Table III. summarizes the obtained results.

Table I. Electrical Characteristics of Solarex MSX -60[33].

Description	MSX-60
Maximum Power (P_{MPP})	60W
Voltage P_{max} (V_{MPP})	17.1V
Current at P_{max} (I_{MPP})	3.5A
Short Circuit current (I_{sc})	3.8A
Open Circuit voltage (V_{oc})	21.1V
Temperature coeff of V_{oc}	$-(80 \pm 10)mV/^{\circ}C$
Temperature co-eff of I_{sc}	$(0.065 \pm 0.01)\%/^{\circ}C$
Temperature co-eff of power	$(-0.5 \ 0.05)\%/^{\circ}C$
NOCT	$47 \ 2^{\circ}C$

Table II. DC motor parameters[34].

DCMotor Parameters	Value	UN
Nominal Armature Voltage	24	Volt
Armature Nominal Current	12	Amp
Nominal Speed	3750	rpm
Moment of inertia of the rotor	0.000476	Kgm ²
Armature resistance	1.072	Ω
Armature inductance	0.055	H
Electromotive force constant	0.0317	V/rad/s
Friction	0.0008814	Nms

Table III. Summarized results.

	Response time (ms)		Steady State Osc. (W)		Avg. Final value (W)	
	P&O	IC	P&O	IC	P&O	IC
Point A	225	16	51	71	1453.5	1453.5
Point B	136	15	31.9	39.2	864.5	964.9
Point C	134	8	41	27	1159.5	1160.5

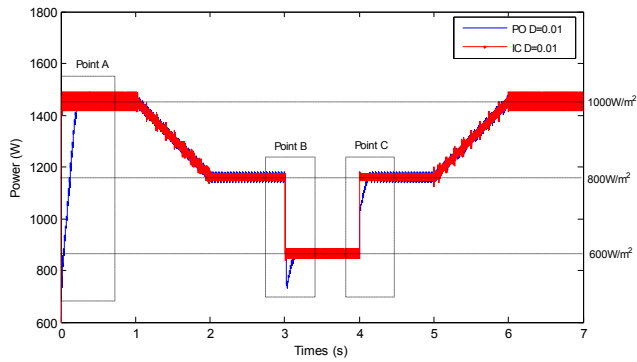


Fig. 5. Output power.

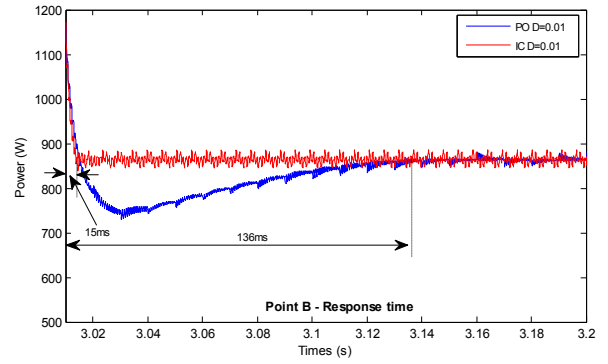


Fig. 9. Point B: response time.

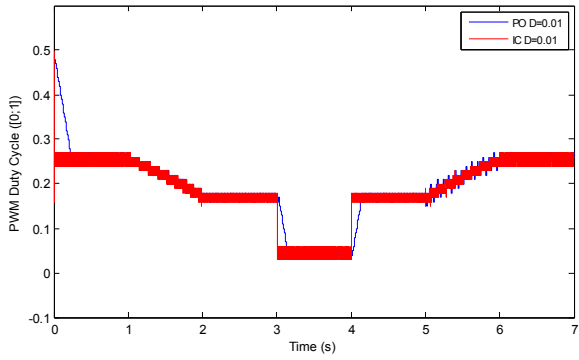


Fig. 6. Output power.

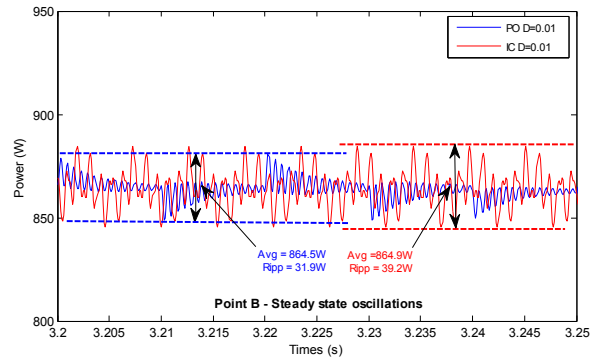


Fig. 10. Point B: steady state oscillations.

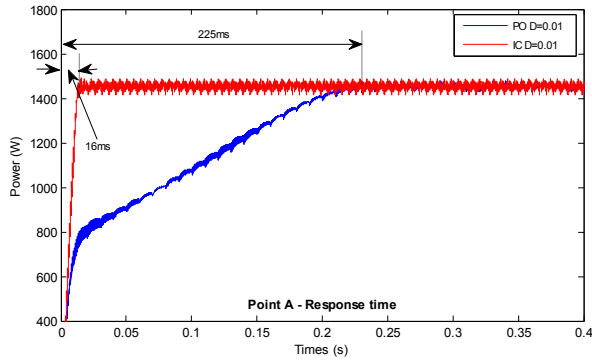


Fig. 7. Point A: response time.

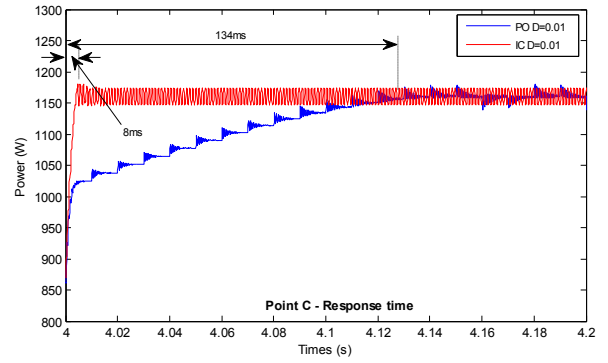


Fig. 11. Point C: response time.

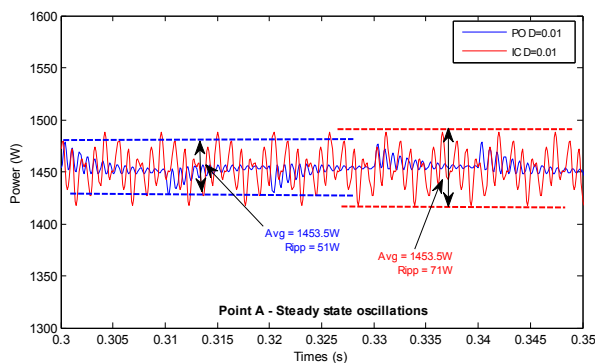


Fig. 8. Point A: steady state oscillations.

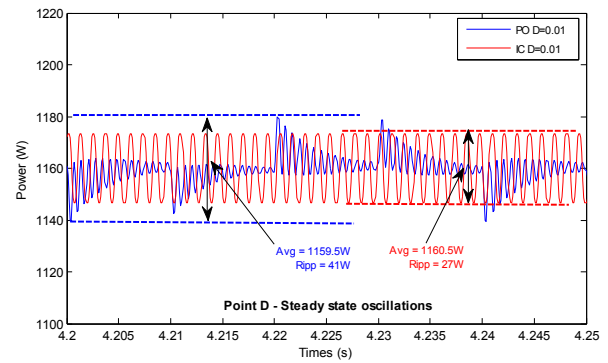


Fig. 12. Point C: steady state oscillations.

From figures 5 to 12 and summarized results in Table III, we can clearly see that the IC outperforms the P&O method in term of convergence speed. The IC is also slightly better in term of output power. While the P&O method presents better performance for the steady state oscillation in case of high level insolation (points A and B). In case of low level insolation (point C), the steady states oscillation around the MPP point are less in IC than in P&O algorithm.

IV. CONCLUSION

In this paper, the performance of photovoltaic water pumping system using indirect coupling has been investigated using both P&O and IC MPPT controller. The efficiency of both proposed methods has been studied successfully using a DC motor-pump powered by thirty six PV modules fed by DC-DC boost converter derived using both MPPT algorithms. Comparative study results obtained using Matlab/Simulink environment show that the IC outperforms the P&O method in term of convergence speed. The IC is also slightly better in term of output power. While the P&O method presents better performance for the steady state oscillation in case of high level insolation (points A and B). In case of low level insolation (point C), the steady states oscillation around the MPP point are less in IC than in P&O algorithm.

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