Optimization with Adaptive Fuzzy logic controller of Photovoltaic pumping System

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Abstract *: In this paper, an application of adaptive fuzzy logic controller (AFLC) to a photovoltaic pumping system is presented. A comparison of results obtained with AFLC and with those obtained with classical control Perturb & observ. (P&O) is made. For the subsystem pumping, we use the model expresses the water flow output (Q) directly as a function of the electrical power input (P) to the moto-pump, for different total heads. The pumped water is used to satisfy the domestic needs of a family during two different days with an example of profile insolation. The results obtained by simulation using Matlab/Simulink are presented.*

Keywords: *Photovoltaic, Maximum power point tracking, P&O, Adaptive fuzzy logic control, Pumped water.*

1. INTRODUCTION

Solar energy which is free and abundant in most parts of the world has proven to be an economical source of energy in many applications. For optimal management of the energy available at the photovoltaic generator (PV) output, optimization techniques can increase the energy efficiency of the total PV system. Maximum power point tracking (MPPT) are used in photovoltaic systems to maximize the power delivered by the solar panel continuously. In literature, several methods have been developed [1-13].

In this paper, a comparison of two optimization techniques for photovoltaic pumping system is presented. Firstly, we compare conventional method (P&O) with an advanced technique (AFLC). And then, we applied the two methods to a photovoltaic pumping system. Accurate sizing of the overall system is necessary before the system simulation. Finally, an application is made to satisfy the domestic need in water to a family during two consecutive days.. A comparative study between the two methods mentioned above has been developed. Simulation results are obtained under variable weather conditions and show the effectiveness of AFLC method.

2. PHOTOVOLTAIC MODEL

The model is called one diode and the equivalent circuit (Fig 1) consists of a single diode for the cell polarization phenomena and two resistors (series and shunt) for the losses.

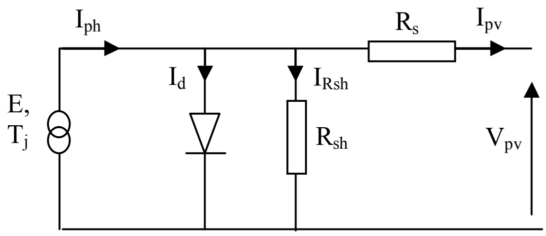

Fig 1.Equivalent circuit of solar cell

$I_{pv}(V_{pv})$ characteristic of this model is given by the following equation [5]:

$$I_{pv} = I_{ph} - I_0\left[e^{q\frac{(V_{pv}+I_{pv}.R_s)}{AkT_j}} - 1\right] - \frac{V_{pv}}{R_{sh}}$$

(1)

The photocurrent, I_{ph}, is directly dependent upon both insolation and panel temperature.

Where*:* *E* insolation in the panel plane (W/m²); I_d is the polarization current of junction PN, T_j : junction temperature of the panels (°K) and R_s, R_{sh} (Ω) resistors (series and shunt).

Table.1.
Parameter of the PV panel SIEMENS SM 110-24

P_{PV}	110W
I_{mpp}	3.15A
V_{mpp}	35V
I_{sc}	3.45A
V_{oc}	43.5V
α_{sc}	1.4mA/°C
β_{oc}	-152mV/°C
P_{mpp}	110W

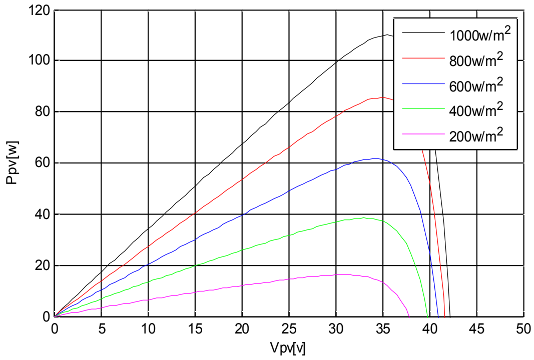

Fig. 2.Characteristic P_{pv}-I_{pv}- Effects of solar irradiation changing

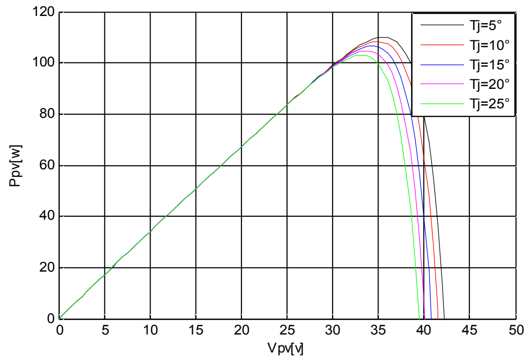

Fig. 3.Characteristic P_{pv}-I_{pv}- Effects of temperature changing

3. MPPT CONTROLLERS

3.1. Perturb& Observ method

This is the most widely used method [2-12]. A feedback loop and few measures are needed. The panel voltage is deliberately perturbed then the power is compared to the power obtained before to disturbance. Specifically, if the power panel is increased due to the disturbance, the following disturbance will be made in the same direction. And if the power decreases, the new perturbation is made in the opposite direction. The advantages of this method can be summarized as follows: knowledge of the characteristics of the photovoltaic generator is not required, it is relatively simple. Nevertheless, in steady state, the operating point oscillates around the MPP, which causes energy losses. The MPPT is necessary to draw the maximum amount of power from the PV module [8-11].

3.2. Adaptive Fuzzy logic controller

The AFLC is improved from scaling Fuzzy logic controller (FLC), and it's mainly to adjust the duty-cycle of the defuzzification of FLC for facing many kinds of external. Voltage V_{PV} and current I_{PV} of PV module are combined with the previous V_{PV} and I_{PV} for the averaged value:

The error (e) and the variation error (Ce) of the system and of the modifier based learning are used to modify the fuzzy parameters to optimize system operation. The controller MAMDANI type with seven classes' membership functions is represented in Table.3. The errors are given by [13-14]:

$$e(k) = \frac{P_{pv}(k+1) - P_{pv}(k)}{V_{pv}(k+1) - V_{pv}(k)} \quad (2)$$

And the error variation CE (K) is

$$Ce(k) = e(k+1) - e(k) \quad (3)$$

The fuzzy parameters can be adjusted using the following condition:

Si $e\langle\varepsilon$ (limit value), then the modifier based learning will be selected.

Table.3.
Modified Fuzzy Rules table

Error(e)	Variation error(Ce)						
	NB	NM	NS	ZE	PS	PM	PM
NB	NB	NB	NM	ZE	ZE	ZE	ZE
NM	NB	NM	NM	ZE	NM	PS	PS
NS	NB	NB	NB	NB	PM	PS	PM
ZE	NB	NB	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	PB	PB	PB	PB	PB	PB
PB	ZE	PB	PB	PB	PB	PB	PB

The AFLC method is composed of two parts: The fuzzy logic control and adaptive mechanism. The FLC is one part of AFLC, which is composed of three units: fuzzification, fuzzy rules and defuzzification [14-16].

Fig.5. shows the membership function of AFLC method.

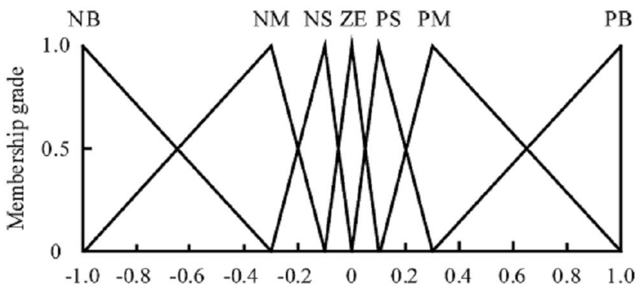

Fig. 4. Membership functions of AFLC method

4. MODELLING SUBSYSTEM PUMPING

Many different varieties of p4umps are used with PV-pumping system. In our case, we use the model expresses the water flow output (Q) directly as a function of the electrical power input (P) to the motor-pump, for different total heads. A polynomial fit of the third order expresses the relationship between the flow rate and power input, as described by the following equation [6, 7]:

$$P(Q,h) = a(h)Q^3 + b(h)Q^2 + c(h)Q + d(h) \quad (6)$$

Where P is the electrical power input of the motor-pump, h is the total head and a(h), b(h), c(h), d(h) are the coefficients corresponding to the working total head.

$$a(h) = a_0 + a_1h^1 + a_2h^2 + a_3h^3 \quad (7)$$
$$b(h) = b_0 + b_1h^1 + b_2h^2 + b_3h^3 \quad (8)$$
$$c(h) = c_0 + c_1h^1 + c_2h^2 + c_3h^3 \quad (9)$$
$$d(h) = d_0 + d_1h^1 + d_2h^2 + d_3h^3 \quad (10)$$

With: a_i, b_i, and d_i constants which depend on the type of sub-solar pumping system.

The calculation of the instantaneous flow in terms of power is calculated using Newton-Raphson method. Thus at the k[th] iteration, the flow Q is given by the following equation:

For d – Pa (Q)> 0:

$$Q_k = Q_{k-1} - \frac{F(Q_{k-1})}{F'(Q_{k-1})} \quad (11)$$

With:

$$F(Q_{k-1}) = aQ^3_{k-1} + bQ^2_{k-1} + cQ_{k-1} + d - P_a(Q_{k-1}) \quad (12)$$

$F'(Q_{k-1})$ is the derivative of the function $F(Q_{k-1})$

We use an induction motor which is modeled using voltage and flux equations referred in a general frame:

$$\begin{cases} V_{Sd} = R_S I_{Sd} + \dfrac{d\Phi_{Sd}}{dt} \\ V_{Sq} = R_S I_{Sq} + \dfrac{d\Phi_{Sq}}{dt} \end{cases} \quad (13)$$

Where: $(I_{sd}\ I_{sq})$, (V_{sd}, V_{sq}) and (Φ_{sd}, Φ_{sq}) are the (d,q) components of the stator current, voltage and flux, R_s is the stator resistance.

$$\begin{cases} 0 = V_{Rd} = R_R I_{Rd} + \dfrac{d\Phi_{Rd}}{dt} + \dfrac{d\theta}{dt}\Phi_{Rq} \\ 0 = V_{Rq} = R_R I_{Rq} + \dfrac{d\Phi_{Rq}}{dt} - \dfrac{d\theta}{dt}\Phi_{Rd} \end{cases} \quad (14)$$

Where: I_{Rd}, I_{Rq} are (d,q) rotor current, Φ_{Rd}, Φ_{Rq} are (d,q) rotor flux, R_r is the rotor resistance.
We obtain the follow mathematical model:

$$\begin{bmatrix} \dfrac{di_{ds}}{dt} \\ \dfrac{di_{qs}}{dt} \\ \dfrac{di_{dr}}{dt} \\ \dfrac{di_{qr}}{dt} \end{bmatrix} = \frac{1}{\sigma}\begin{bmatrix} -\dfrac{R_s}{L_s} & \dfrac{P\cdot\omega_r\cdot L_m^2}{L_s\cdot L_r} & \dfrac{L_m.R_r}{L_s\cdot L_r} & \dfrac{P\cdot\omega_r\cdot L_m}{L_s} \\ -\dfrac{P\cdot\omega_r\cdot L_m^2}{L_s\cdot L_r} & -\dfrac{R_s}{L_s} & \dfrac{P\cdot\omega_r\cdot L_m}{L_s} & \dfrac{L_m.R_r}{L_s\cdot L_r} \\ \dfrac{L_m.R_s}{L_s\cdot L_r} & -\dfrac{P\cdot\omega_r\cdot L_m}{L_r} & -\dfrac{R_r}{L_r} & -P.\omega_r \\ \dfrac{P\cdot\omega_r\cdot L_m}{L_r} & \dfrac{L_m.R_s}{L_s\cdot L_r} & P.\omega_r & -\dfrac{R_r}{L_r} \end{bmatrix}\begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} + \frac{1}{\sigma}\begin{bmatrix} \dfrac{1}{L_s} & 0 \\ 0 & \dfrac{1}{L_s} \\ -\dfrac{L_m}{L_s.L_r} & 0 \\ 0 & -\dfrac{L_m}{L_s.L_r} \end{bmatrix}\begin{bmatrix} v_{ds} \\ v_{qs} \end{bmatrix} \quad (15)$$

With: σ is the leakage coefficient

- Mechanical equation:

$$T_{em} - T_{Load} = J.\frac{d\omega_r}{dt} \quad (16)$$

With: ω_r is the AC motor velocity angular, J the inertia of the AC motor.

The electromagnetic torque can be written as:

$$T_{em} = P.(\phi_{sd} i_{sq} - \phi_{sq} i_{sd}) \quad (17)$$

5. SIMULATIONS RESULTS

In order to prove the robustness of the proposed MPPT using AFLC, we compare it with conventional MPPT using P&O algorithm in terms of tracking of the PPM at different tests conditions. The first test we make at standard conditions (1000 W/m^2, T=25°C).

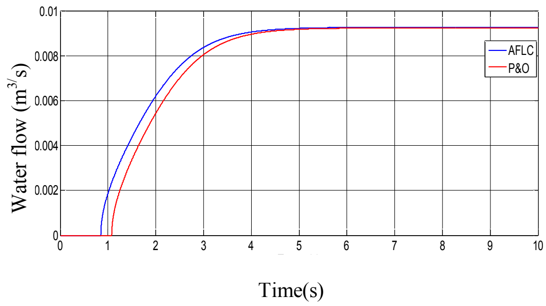

Fig.5. Pump flow at standard conditions

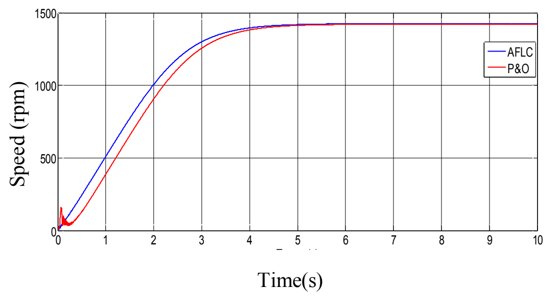

Fig.6. Speed variations at standard conditions

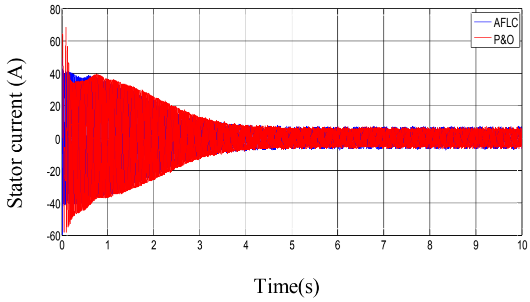

Fig.7. Stator current at standard conditions

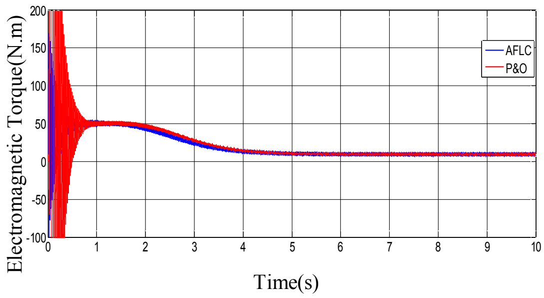

Fig.8. Electromagnetic torque at standard conditions

The second test is made for medium solar radiation(600 W/m^2, T=25°C).

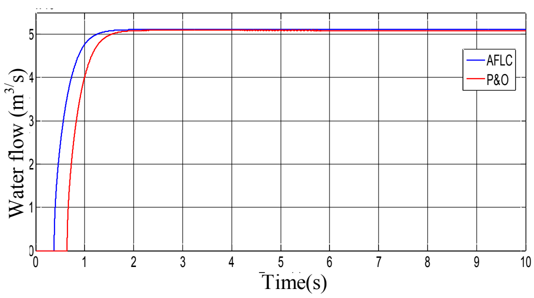

Fig.9. Pump flow at medium solar radiation

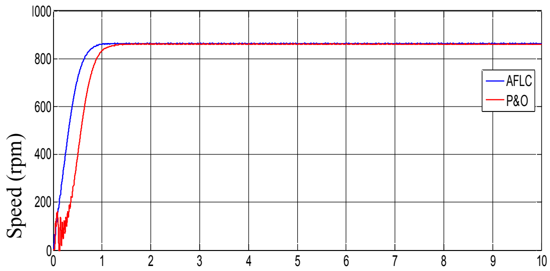

Fig.10. Speed variations at medium solar radiation

Time(s)

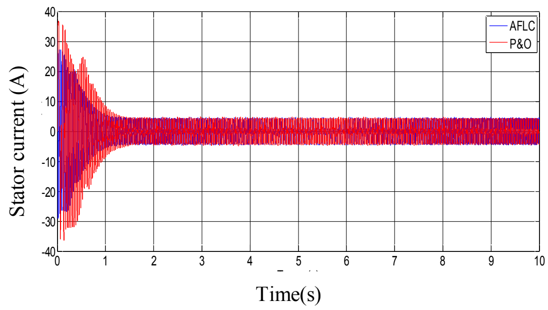

Fig. 11.Stator current at medium solar radiation

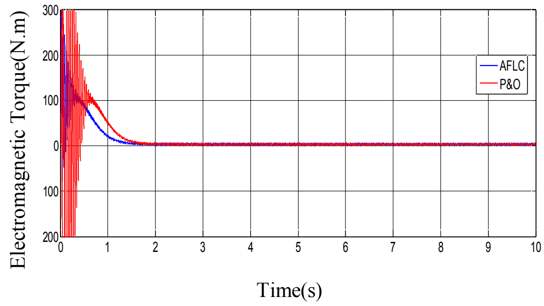

Fig.12. Electromagnetic torque at medium solar radiation

The third test is made under low insolation (E_s=300W/m^2, T=25°C).

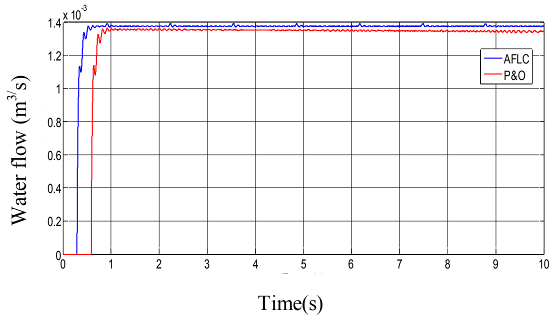

Fig.13. Pump flow at low solar radiation

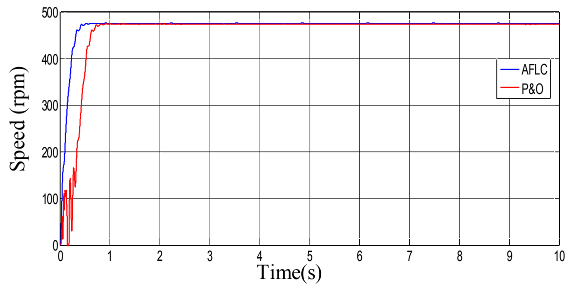

Fig.14. Speed variations at low solar radiation

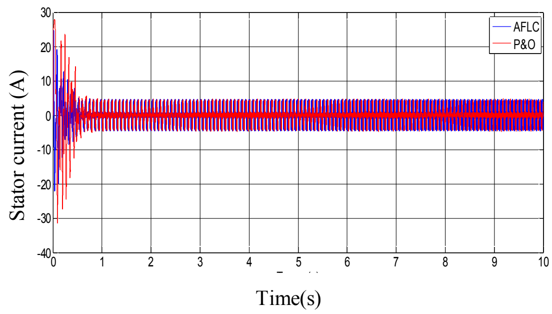

Fig.15. Stator current at low solar radiation

6. APPLICATION OF AFLC TO PUMPING SYSTEM

We make a sizing of the various components of the studied system which consists of a water tank of 100m^3 to satisfy the domestic needs of a family. The dynamic level head is about 10 m and the nominal flow rate is of 34m^3/h. We obtain the following scheme (Fig.17).

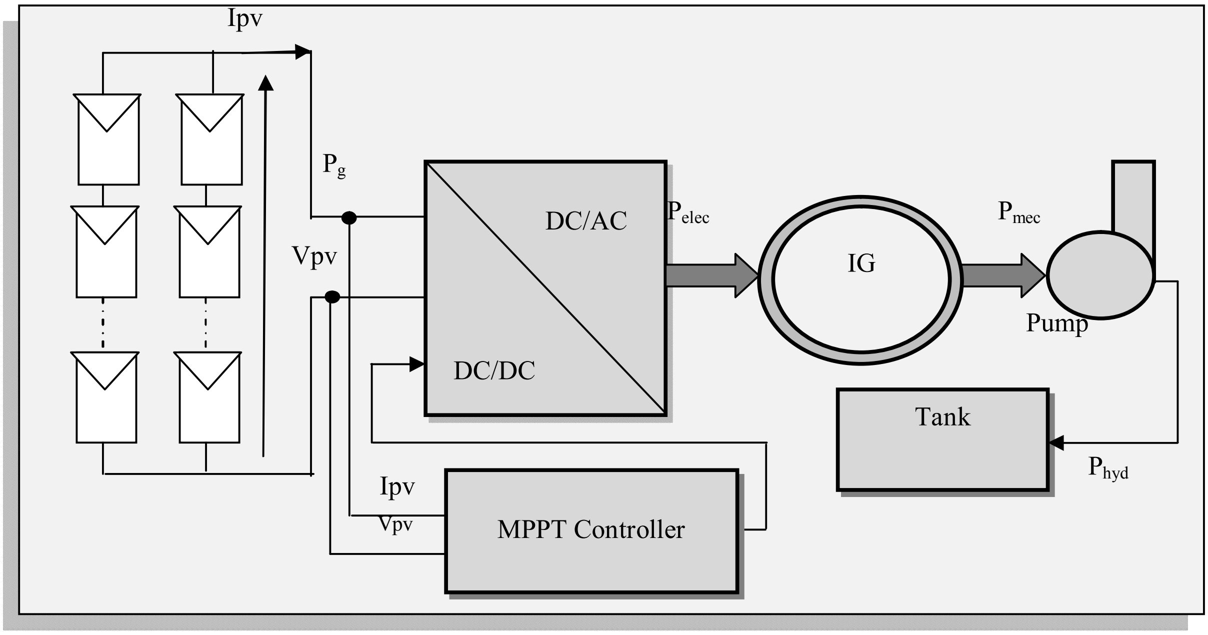

Fig. 16.Diagram power for the studied system

We represent the flow pump with AFLC and without MPPT (Fig.18). It is clear that the system pumping operation is improved by using the method AFLC especially in low variations of insolation, the power extracted is more important, the speed increases and thus the pumped flow increases.

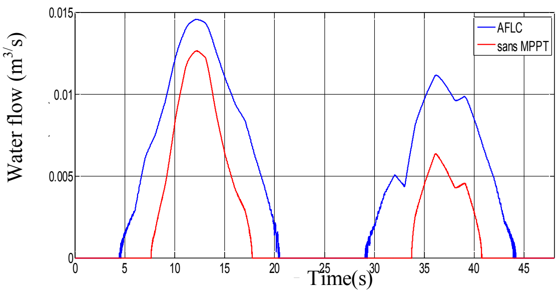

Fig. 17.Flow pump with and without MPPT

7. Conclusion

In this paper, we have compared between two MPPT methods (P&O and AFLC) applied to a photovoltaic pumping system. An application is made to satisfy water needs of a family. The simulation results show that the control with AFLC method is more efficient in terms of stability, precision and speed to reach the maximum power point

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