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Full Length Research Paper

Modeling and fuzzy control of a photovoltaic-assisted watering system

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The effective management of water and soil is crucial for countries with main agricultural activities. Therefore, it is very important to improve practices and irrigation methods to provide suitable and necessary moisture for proper crop development. In this article, we propose first a study of an irrigation system suitable for remote sites and using photovoltaic energy as a power source for pumping. After that, we apply a second fuzzy logic to control the pumping system taking into account the difference between rainfall soil moisture, temperature, and plant transpiration... We treat the case of vine plantations located in the region of Mornag, Tunisia.

Key words: Photovoltaic energy, fuzzy logic, irrigation.

INTRODUCTION

The consumption of energy is a major global concern; therefore, it is essential to use renewable energies which are characterized by their negligible pollution level. The use of these energies from the single form for remote sites (small isolated settlements or large agricultural field), is not supplied by electric power. The use of photovoltaic energy for pumping water is an emerging technology characterized by gradually decreasing cost. Since the first installations in the late 1970's, the solar pumping systems have formed a large part in the implementation of the projects of solar energy, and they belong to the most significant applications of photovoltaic systems. This can be mainly attributed to the fact that it is not economically feasible to connect such remote sites to the grid (Moraes-Duzat, 2000).

A solar pumping system consists of the following main elements: the solar panels and their accessories, electric motor, pump and the distribution system including pipeline and storage. These elements must be designed to have an optimal function of the entire system. The storage of electrical energy with batteries, in this type of application, is rarely used because it is more environmentally useful and easier to store water for periods of less sunshine with a high demand.

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MODELING OF THE PUMPING SYSTEM

Solar panel

The operating principle of the photovoltaic cell uses the properties of solar radiation and semiconductors.

The power supplied by the solar panel can be modified by the action of temperature and solar irradiations. We studied the importance of these two parameters on the control panel located in the Laboratory Research (LACS) and having the characteristics listed in Table 1.

Figure 1 shows that the power delivered by the panel is proportional to the irradiations for a constant temperature T=75°C. Similarly, the figure (Figure 2) illustrates the variation I(V) under the effect of temperature for a constant illumination E = 1000 W / m ^ 2.

Pumping system

Photovoltaic pumping is done through an asynchronous motor that uses either direct or alternate current, leading to a pump that is made adequate to the needs of drinking water supply especially in rural or remote sites or for irrigation as well as watering livestock (Wallace et al. 1998).

Figure 3 represents a model of our photovoltaic irrigation system. This system consists mainly of:

Table 1. Electrical specification.

Photovoltaic Module BP SX 150	
The short circuit current Isc	4.75A
The open circuit voltage	43.5V
The non-ideality factor n	1.62
The number of cells N	72

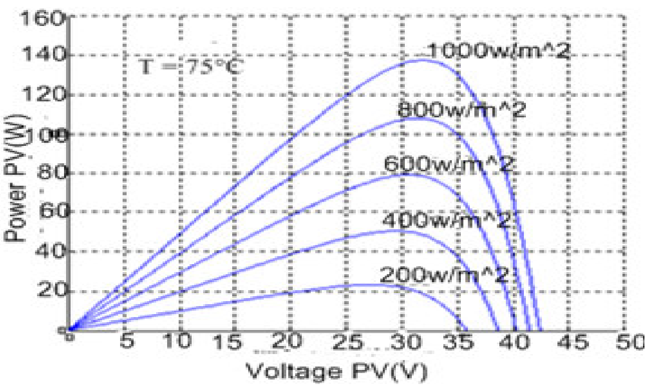

Figure 1. Effect of illumination on the characteristic P (V) at T = constant.

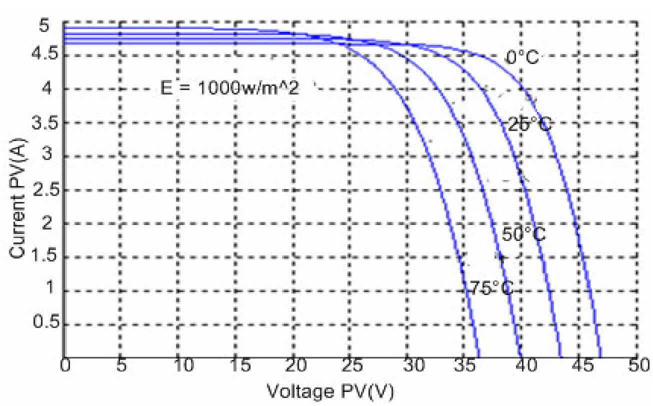

Figure 2. The effect of temperature on the characteristic I (V) at E =constant.

i) **Photovoltaic panels:** to convert any energy from the sunlight into direct electrical energy continues.

ii) **Inverter:** to transfer the power managed by the solar panel from a direct current to an alternative current.

iii) **Motor:** Most pumps are driven by phase electric motors. The choice of the pump drive depends on several factors such as the type of pump, the power, the application of the pump etc.

The engine used is that of the laboratory (LACS) are these characteristics shown in Table 2.

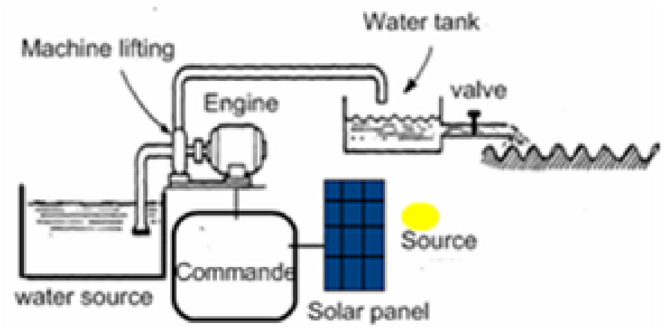

Figure 3. Modeling a photovoltaic irrigation system.

Table 2. Characteristic study of the engine

The nominal output Pn	24.6 kW
The couple useful nominal Cn	90 Nm
Nominal stator current Isn	35.4 A
Nominal rotation speed of the rotor N	2610 rpm
The moment of inertia of the rotor J	0.112kg.m²
The nominal yield η	0.9309

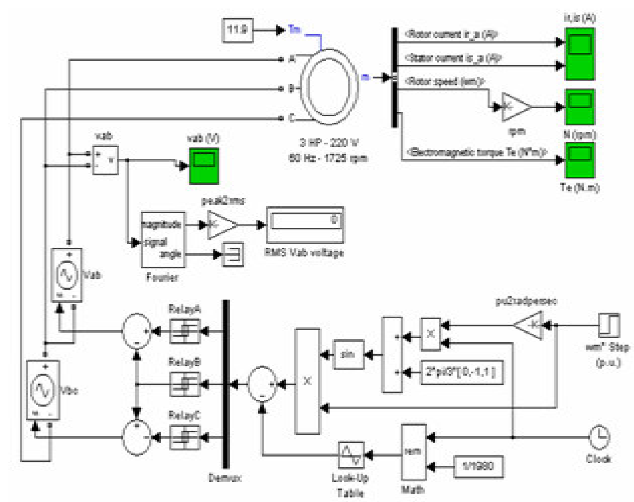

Figure 4. Implementation of the system in MATLAB-SIMULINK.

Simulation of inverter-motor set

Figure 4 represents a simulation model of the machine which is fed by a frequency voltage inverter and an amplitude control. The used inverter is based on PWM modulation.

The simulation results are shown in Figures 5, 6 and 7: Immediately after the start, the current rotor begins to yield a big quantity of waves, hence reaching 60 A. The current starts to decrease from 0.4 s (Figure 6) until it reaches a normal frequency (T=1 s).

The Call for the stator current is very strong as soon as the engine starts (around 80 A). It subsequently stabilizes at a fixed value which equals 15 A.

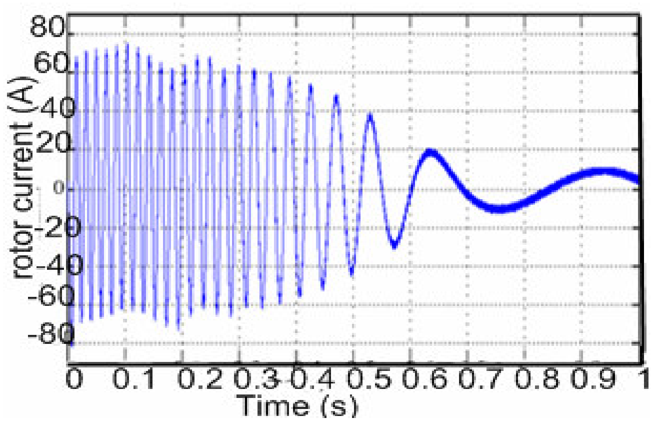

Figure 5. Rotor current

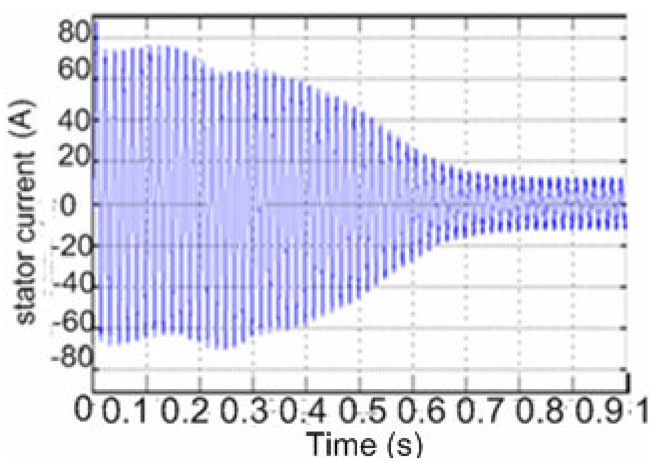

Figure 6. Stator current.

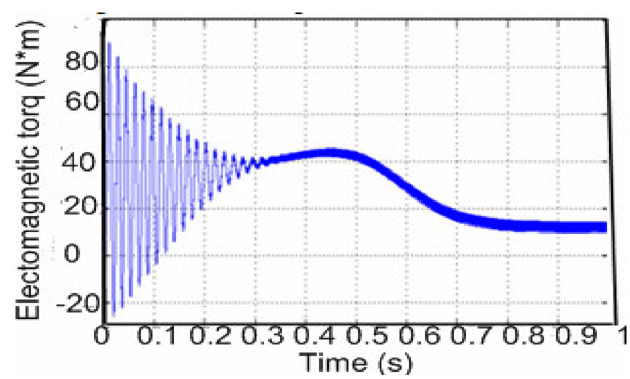

Figure 7. Electromagnetic torque.

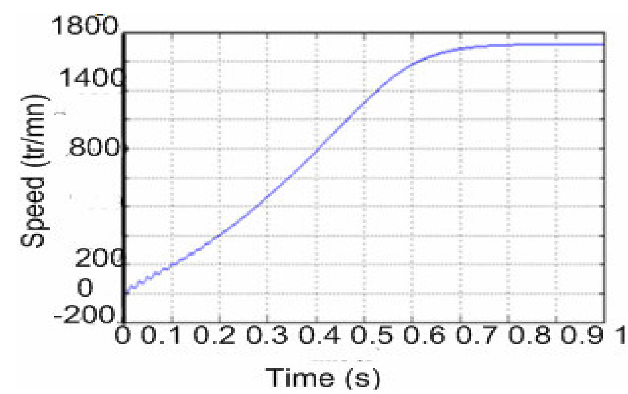

Figure 8. Engine speed.

The following figure represents the electromagnetic torque: The figure shows strong oscillations in the power inverter. These oscillations are due to the PWM modulation; they are often very high. The couple is stable for T = 0.7 s, with a value in a range of 15 nm. The following figure shows the variation of velocity with time:

According to the figure, the speed starts to increase until reaching a stable value of T= 0.7 s. The value of stability is around 1750 rpm. We note that the nominal speed is able to run the pump but the optimal retrieval of water supply is not yet achieved. Therefore, it is very important for the control system to use the MPPT technique.

Operation strategy of irrigation system by photovoltaic control

The simulation results show that Figure 1 requires a command module for structured irrigation system with a command module for fuzzy logic to improve and optimize the entire system. There are two orders: the MPPT and control by fuzzy logic.

MPPT Method (maximum power point tracking) For this method, the nominal values are in Table 2 which provides a good system fit. In order to improve the performance of photovoltaic (PV) and maximize the power delivered to the load terminals connected to the generator, several criteria to optimize the efficiency of the photovoltaic system was applied (Glasner, 1996; Mujadi, 2000), and techniques were followed for a good adaptation and high yields. Among these techniques is the technique of "pursuit of maximum power point" or "maximum power point tracker, MPPT" (Mujadi, 1997; Bose, 1985) technology to find points of optimum power without temperature compensation and with temperature compensation (Hua, 1998;Altas and al,1996)It is well known that the load of the inverter is the infinite, so to adapt well and maintain the system without problems or motor breakdown, the goal of this method is to adapt at each instant the charge level of the solar panel to get the most power out of it. This adaptation is achieved by controlling the voltage of the motor through the inverter voltage. Controlling the voltage with the inverter adjusts the demand for power compared to the one available while adjusting the output and playing on the voltage / frequency (Figure 8). If, for example, there is an increase in sunshine, the

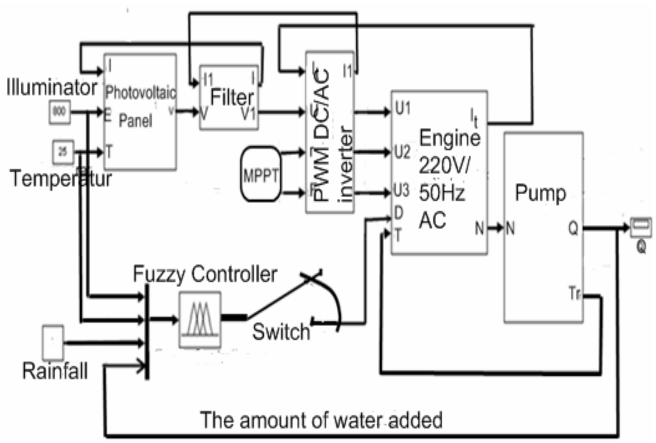

Figure 9. Control of an irrigation system by fuzzy logic.

inverter frequency increases until the application of engine power is equal to that provided by the generator. A decrease in sunlight leads to a reduction in frequency until a new balance of power is established. The second entrance of the flow controller is managed by the centrifugal pump.

Fuzzy logic control

Fuzzy logic (Buhler, 2004; Zadeh, 1996) is a modeling method that is more effective than most traditional methods, especially for complex systems: systems controlled by human experts, systems with several, inputs / outputs and non-linear answers systems, where human observation is the source of input or control rules, systems where uncertainty persists, especially economics, natural sciences and humanities (Zimmermann, 1987; Stopper, 1999; Fustier, 2000; Wang and Tyan, 1994).

The inputs of a fuzzy controller in the system as they are represented in Figure 9 are: light, temperature, rainfall and the added amount of water (irrigation).

The parameters representing the fuzzy controller are fuzzification using a database of climatic conditions in the region of Mornag and calculation method that determines the water requirements of a plant vine throughout the year, according to the weather conditions (temperature, rainfall).

To improve an irrigation system so that it responds according to the need for water. We propose the technique of control by fuzzy logic. This method allows the system to function independently.

Figure 9 introduces the principle of control in this system. The previous assembly represents the full model of a sprinkler system controlled by fuzzy logic with a solar panel, allowing converting any energy from the sun to electricity. Note that LC filter type has been introduced to eliminate the parasites from the output voltage of the photovoltaic generator. The output voltage V provided by the photovoltaic generator is the voltage of the inverter; it can convert the output voltage V1 of the filter to another alternative form of the phase (U1, U2, U3) to feed the engine. This latter transforms the voltage at its terminals into a rotational speed N electromagnetic torque depends on the resistance imposed by the pump shaft, hence, converts the torque resistant current.

The pump is in operation only if the speed N is maintaining nominal (presented in Table 2), the pump raises the water relatively to the latter.

The engine's start button D is linked directly by a switch, which is the output of fuzzy controller.

Fuzzification parameters

Illumination: is the amount of light received by the solar panel to implement, a power capable to pump water. It is a parameter of engine protection in case the lighting is insufficient even though we need to raise the amount of water. In this case the controller prevents the engine to start. The variation of the illumination varies from 0 W / m ^ 2 and 1000 w / m ^ 2. The range of variation was divided to two membership functions.

Temperature: it is the heat supplied by the sun. This is efficient to determine the amount of water that must be added to ensure a good growth of the plant. The ambient temperature varies between 0 and 50°C. Membership function of this parameter contains 4 intervals (Figure 11).

Rainfall: is the amount of rain in mm / day recorded in the city of Mornag also operates its value in equation (1) Riou.

Quantity of added water: Riou's formula to calculate the amount of water needed for a plant water in a given ambient conditions.

For the calculation, we fixed the range of variation of the added amount of water between 0 and 20mm. Represents four membership functions (Figure 13).

System Output: It has two Boolean values (either 0 or 1), directly linked to a switch connected directly to the engine. Two actions have either 0 or 1 (Figure 14).

To determine the amount of water the plant needs a full study of all parameters that are strongly linked in the calculation of the needs of a plant is necessary. In our case the plants studied are "vine plants."

Here's some rule that explains the working principle of our system based on the fuzzy, it is represented as follows:

i) If (E is INSF) then (S is Z)
ii) If (T is TF) then (S is Z)
iii) If (T is TF) and (P is TF) and (Q is TF) then (S is P)
iv) If (T is TF) and (P is TF) and (Q is F) then (S is P)

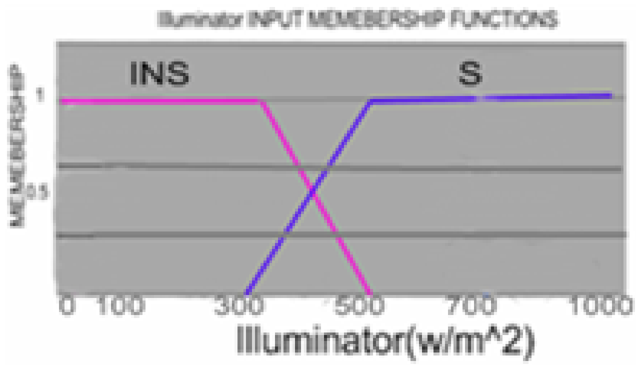

Figure 10. Fuzzification of the illumination.

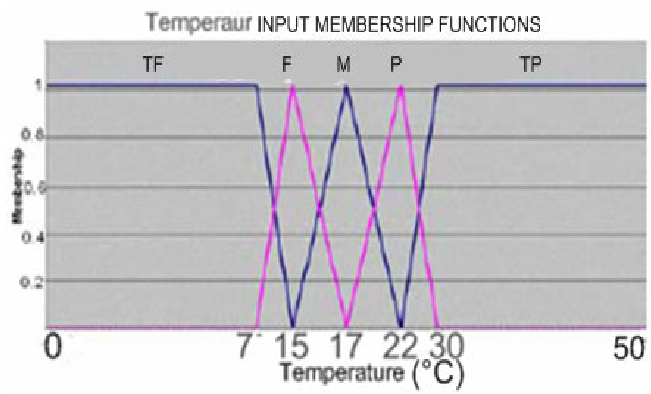

Figure 11. Fuzzification of the temperature.

Table 3. The operating principle of the fuzzy controller.

E	T	P	Q	S
300	*	*	*	0
<450	*	*	*	0
500	14	*	*	0
>450	<15	*	*	
>450	22	1	0.51	1
>450	>22	<1.6	<1	1
>450	22	<1.6	≥1	0
>450	35	0	0	1
>450	35	<1	3	1
>450	35	<1	5.5	0

E: irradiance **(w/m^2)**, T: temperature **(℃)**, P: rainfall **(mm)**, Q: quantity of water added **(mm)**, S: action.

v) If (T is TF) and (P is TF) and (Q is MF) then (S is P)
vi) If (T is TF) and (P is TF) and (Q is P) then (S is P)
vii) If (T is TF) and (P is TF) and (Q is TP) then (S is Z)
viii) If (P is TP) then (S is Z)

The meanings of the labels designating the names of linguistic values, are:

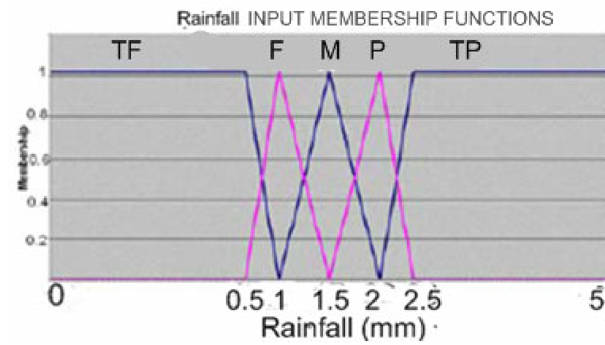

Figure 12. Fuzzification of rainfall.

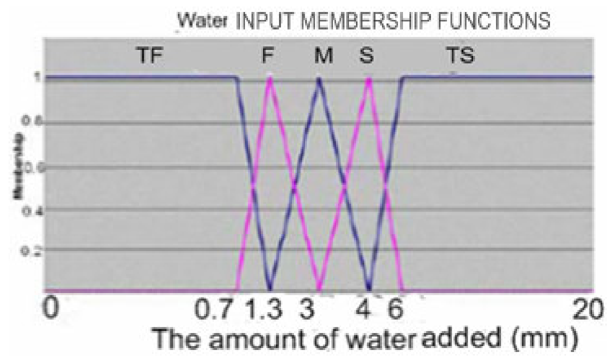

Figure 13. Fuzzification of the amount added.

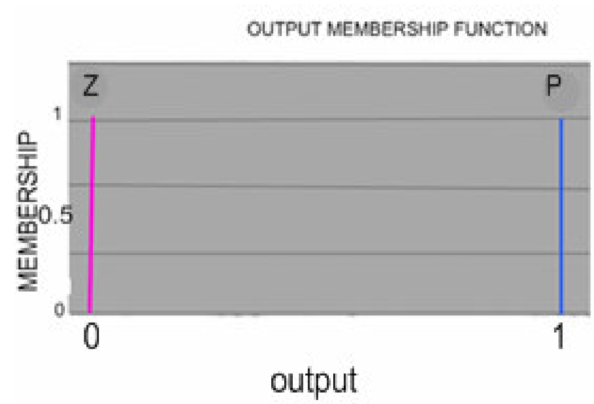

Figure 14. Fuzzification of the output to the switch.

TF: Very low, F: low, M medium, P: powerful, TP: very strong, S: sufficient, TS: very sufficient, INS: Insufficient, Z: zero, P: positive

This stage involves the development of rules to define the operating principle of the irrigation system on these intrinsic parameters: illumination (E), temperature (T), rainfall (P) and quantity of water added (Q); Output is a switch allows you to activate the motor. Combinations for the input parameters, an action on the output variables it is associated. The table (Table 3) of fuzzy rules following

Table 4. Meteorological data and results of calculation of water needs.

Month	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kc	*	*	0.65	0.65	0.7	0.75	0.75	.075	0.7	0.6	*	*
Temperature max(^oC)	14	1505	18	22.5	22.5	22.5	35	34	30.5	25.6	19.5	15
Rainfall-Avg (mm/day)	1.9	2.44	1.62	1.58	0.74	0.4	0.1	0.32	1.53	1.92	1.75	1.61
Gross need (mm/day)	0	0	0.93	1.03	3.35	5.1	5.4	4.58	2.2	0.85	0	0

explains the origin of real values of our system.

Defuzzification method

Once the definition of the functions of ownership and implementation of rules defining the behavior of the fuzzy controller has been made, we move on to the stage of a method for defuzzification. This step allows transforming the values of input and output in the form in another language of physical fitness.

In this work, we used the bisector method; this choice was made after various simulations with different methods leading to the conclusion that it was the best for our system.

Case study: Planting of vines in the region Mornag

The goal of our system is to control the speed and torque of the motor together and thereafter to ensure good performance. These pumping systems and solar-electric driven motors at variable speeds are used more than any others. In future studies, different methods of command as the command or fuzzy genetics can be used... For the good of the systems ordered, it is necessary to determine the needs of the plant in water, taking into account the climatic conditions and the nature of this plant (water needs).

In what follows, we explore the culture of the vine plantings in the region of Mornag to identify these additional needs in water and model a command to the planting in this climate (Mornag).

Mornag is a city of Tunisia located southeast of Tunis. It is the capital of a delegation of the governorate of Ben Arous and the seat of a municipality of 26,406 inhabitants (2006). Mornag is mainly known for its agricultural plain dedicated to the vine and the olive tree. It is the largest and the richest plain of Tunisia, which covers 36 812 of which 19 900 hectares of farmland. It is dominated by a peak, the Jebel Ressas (805 meters), and is crossed by Milian and Wadi El Hamma and the channel Medjerda-Cap Bon. For wine, the AOC Mornag and Grand Cru wines are among the most famous of the country (Mornag - Wikipédia.htm)

Evaporation reference ET_0

It is the loss of water by a combination of soil evaporation and transpiration of a culture of uniform height grass holding the soil in full development of water supply on a non-restrictive and under no the influence of any factor.

Given the meteorological data available a method of calculating ET_0 is chosen: the formula of equation (1) of Riou, (1994)

$$ET_0 = 0.31 * ((\theta_n{}^2 * \theta_{n+1}) / 3)-b \qquad (1)$$

With:

θ_n: average maximum temperature of the month n

θ_{n+1}: average maximum temperature of the month (n +1)

b: 7,1-0,1 * β with β : Latitude = 38°

Cultures need

The need for water or the amount of water added is given by equation (2).

$$B_n = ET_0 * K_C\text{-}PU \qquad (2)$$

With:

B_n: need net crop Riou in (mm / day)

ET_0: Reference evaporation

K_c: cultural factor which takes into account the vegetative stage of crops.

B_b is needed is the raw plant vine with what the amount consumed by the plant, is different depending on the type of irrigation. In our case, it is assumed that $B_b = 0.8 * B_n$.

According to Table 4, we chose intervals fuzzification represented in Figures 10, 11, 12, 13 and 14). The operating principle of the controller is to know at each moment of climate change the amount of water needed and then acting on the switch to enable or disable the engine. The following example explains the approach and the resonance of the fuzzy rules.

In the case where the temperature is 35℃ in the universe of discourse very powerful (TP), rainfall in the area quite low (TF), the engine must start by closing the switch (output Boolean is equal to 1, to close the switch) to the sensor for measuring the amount of water displays 6 mm in this case the engine automatically stops its operation (Boolean output is equal to 0, allows to open the switch). The engine can not function in any case for a light at 400 w / m ^ 2, insufficient quantity (INS) for the solar panel power supply capable of maintaining the engine.

Conclusion

In this paper, we have modeled an irrigation system operated by solar energy as the only source of energy. This free and renewable energy is the only available in these sites.

In the next section, we calculated the water requirements of a plant with the formula Riou; we applied this method on a case study of grape plantation located in Mornag. We determined from this study, the time of year where irrigation is necessary to compensate for the lack of water. We proposed a simple model of an irrigation system with and without command module. We propose in future work, control algorithms based on fuzzy logic and neural network to better optimize the operation of irrigation system powered hybrid photovoltaic-wind power taking into account the different climatic parameters (rainfall, sunshine , humidity, ...) and cultural (nature of the plant, sun, water requirements ...)

REFERENCES

Altas IH, Al (1996). A Novel On Line MPP Search Algorithm For PV Arrays, IEEE trans. on E.C. 11(4): 748-754.

Bose BK (1985). Microcomputer Control Of A Residential Photovoltaic Power Conditioning System, IEEE Trans. I.A. IA-21(5) : 1182-1191.

Buhler H (2004). Adjustment by fuzzy logic, polytechnic and university presses Romandes.

Fustier B (2000). Evaluation, decision making and fuzzy logic, Applied Economics. (1)

Glasner I (1996). Advantage Of Boost Vs. Buck Topology For Maximum Power Point Tracker In Photovoltaic Systems, Tel-Aviv University, Faculty of Engi, Dept. of Electrical Eng. Israel, IEEE.1996, pp: 355-358.

Hua C (1998). Implementation Of A DSP- Controlled Photovoltaic System With Peak Power Tracking, IEEE trans. on I.E. 45(1): 99-107.

Moraes-Duzat R (2000). Analytical and experimental investigation of photovoltaic pumping systems, Thesis of "Doktors der Naturwissenschaften", University of Oldenburg – Germany.

Mornag - Wikipédia.htm

Mujadi E (1997). PV Water Pumping With A Peck-Power Tracker Using A Simple Six Step Square-Wave Inverter, IEEE trans. on I. A .33(3): 714-721.

Mujadi E (2000). ANN Based Peak Power Tracking for PV Supplied DC Motors, Solar Energy. 69(4): 343-354.

Riou C (1994). Le déterminisme climatique de la maturation du raisin : application au zonage de la teneur en sucre dans la Communauté Européenne, Edition.

Stopper MB (1999). Fuzzy logic, Presses Universitaires de France, Paris.

Wallace WL, Jingming LI, shangbin G (1998). The Use of photovoltaic for rural Electrification in Northwestern China, Preceded at the 2nd Word Conference and Exhibition on Photovoltaic Solar Energy conversion;6-10 July 1998; Vienna; Austria.

Wang PP, Tyan CY (1994). Fuzzy Dynamic System and Fuzzy Linguistic Controller Classification, Automatica. 30(11) :1769-1774.

Zadeh L (1996). Fuzzy logic: computing with words, IEEE transactions on fuzzy systems, 103-111.

Zimmermann HJ (1987). Fuzzy sets and its applications, Kluwer Nighoff.