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Water Optimum Management using Fuzzy Logic Controller (FLC) in a PV Water Pumping System

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***Abstract*— in this paper, a new method is proposed to control the water level management of a storage tank. The main purpose is to adapt the variation of the water consumption by an end user, in a stand-alone Photovoltaic Water Pumping System (PVPS). The designed control system is based on the control of water supply from a submersible solar powered pump according to the variation of water demand.**

A Fuzzy Logic Controller (FLC) is developed to achieve this task for the optimal use of ground water in desert areas. The system optimizes water requirements, leading to a continuous abundance in the ground-water flow, satisfying the surplus consumption of water during the hot seasons, when the capacity of the tank is not enough to meet the daily extracted volume of water and increasing the life of submersible pumps and bore wells. Moreover, it reduces water wastage, maintains the water purity and avoids damaging conditions for pump due to muddy water. The system consists of controlling the (ON –OFF) switch of the operating pump to fill up the storage tank in accordance to the water end user demand and the variation of water level in the storage tank. The proposed system has been simulated and validated, for its optimal performances on real water levels of 50 m3 maximum capacity storage tank, by using the Mamdani fuzzy IF – Then rules. The obtained results averred a very high controlling effectiveness of both the water management and the PV pumping system operation.

***Keywords*— Storage, PVPS, FLC, capacity, water level**

I. INTRODUCTION

The extraction and consumption management of water by mean of the Photovoltaic Pumping Systems (PVPS) has approved its effectiveness over the last years. The PV powered pumping provides water with free and clean energy. The management of the water storage assures the protection for the ground water resource flow by auto-operating the pump whenever the water level in the storage tank is decreasing and avoids water wastes. Groundwater is one of the major sources of drinking water and irrigation in both oasis and desert remote areas of Algeria. Beside, Groundwater crisis is not the result of only natural factors; but it has been caused by human actions. During the last decade, the ground water level in several parts of Ghardaia region has been decreasing rapidly due to a random increase of bore wells. Some of the negative effects of ground-water depletion include increased pumping costs, deterioration of water quality, reduction of ground water, land subsidence etc.

It has been found that if the pump, used for pumping ground water, is continuously used for a long time then muddy water starts rising and thus mud and other sediments cause damage to different pumping system parts. This is because the rate of percolation of water inside the ground varies from place to place and the replenishment of the ground water requires some time. Recent researches and studies on water level used the Artificial Neural Networks (ANN) and Fuzzy Logic Controller (FLC) to control the water management [1]. Among the problems faced are the wastage of water due to overflow of tanks and the cumulative water for long time, which has also been investigated [2]. The rule – based Fuzzy Neural Networks are also used in auto-control of pumping operations [3]. The most important objective served by the recent proposed system is that it maintains the extraction rate of ground water at the optimal level sustaining the water resources in the environment as well as meeting the demand of consummator [4]. The current new proposed Fuzzy Logic Controller (FLC) is designed to optimize the supply/demand water operation in a PV pumping system which can maintain the rate of extraction of ground water at an optimal level as per the user's requirement.

The adaptability feature incorporated in this helps to track the rate of water consumption and accordingly adjusts the supply, thus avoiding water stagnation and preventing wastage due to overflow. These constraints have been simulated in the proposed prototype (Figure 1) which includes a fuzzy controlled water supply through a solar powered submersible pump, upon a data base obtained at our PV pumping test facility in Ghardaia.

II. SYSTEM CONFIGURATION

The proposed prototype consists of solar powered submersible pump Grundfos model (900 W), water supply control unit with sensors and storage tank with maximum 50 m^3 capacity as shown in Figure1. There are three sensors positioned at different locations. One sensor is present in the bore well to sense the ground water level. The second sensor, with multi sensing elements at different vertical positions, is put in the tank being used for storing the pumped water. The third sensor is responsible for sending the feedback about load consumption pattern (rate). The (ON-OFF) switch is auto-controlled by the output signal of (FLC). The PV powered submersible pump starts operating in accordance to the level of water in the storage tank and the user requirements which are acting as the inputs of FLC. The time of operation of the pump depends on the water-level in the storage tank and the water consumption.
Thus our system constantly tracks the consumption and intelligently adapts itself to give an optimum performance.

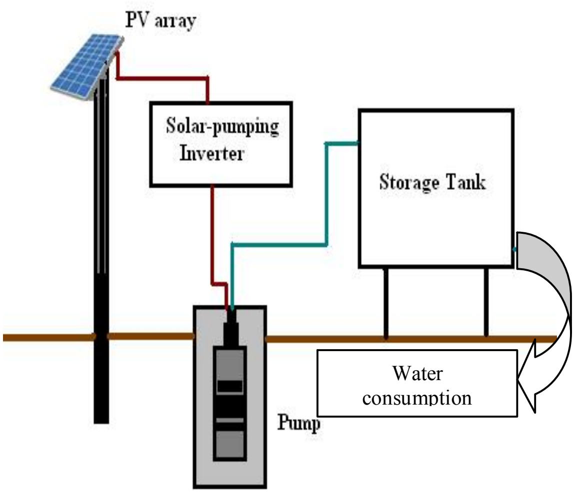


Fig.1. Global PV water pumping system configuration

III. FUZZY LOGIC CONTROLLER (FLC)

Fuzzy Logic is an area of Set of Computing Techniques that enables a computer system to reason with uncertainty. Dealing with humanistic systems, whose behaviour is strongly influenced by human judgment, perception, and decisions, It characterized by its Membership Function (MF).Fuzzy inference systems consist of a set of "if-then" rules defined over fuzzy sets. Fuzzy sets are relations that can be used to model the linguistic variables that human experts use in their domain of expertise. The difference between fuzzy sets and logic (crisp) sets is that the membership function for elements of a fuzzy set can take any value between 0 and 1, however the sets of logic takes only 0 or 1. The fuzzy corresponds to many unambiguous situations where it is difficult to make a decision, if something belongs or not to a specific class. Fuzzy Logic Controllers (FLC) has been applied in many problems of control as diagnosis and classification because they can manage the difficult expert reasoning (Korn, 1995). The main disadvantage with fuzzy systems is that they can't adapt to changing situations. For this reason, many combined methodologies have been used. The adaptability of neural networks (learning and adaptive capabilities) and the flexibility of fuzzy logic (solving complex real world problems) (Yen, Langar & Zadeh, 1995). In this work, a Fuzzy Logic Controller (FLC) is used to control the pump operation in stand-alone PV pumping system installed in a remote desert farm in accordance to the water flowrate consumption and the water level in the storage tank (Fig. 2).

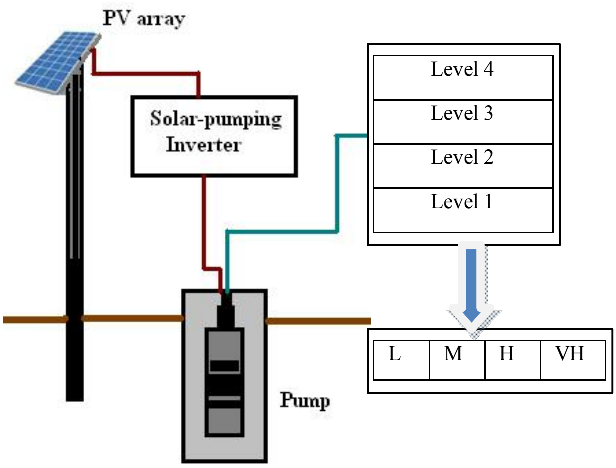


Fig.2. Pumping and storing water in storage tank

The procedures in making the control designs are setting the constraints, assigning the linguistic variables and setting the rules for the controller. The water-consumption and the Level (quantity) of water present in the storage tank are the inputs. The control of ON/OFF switch is the operation-time of the submersible pump, is the output of the system. The synoptic of the design is represented in the following (figure.3),[12].
The basic structure of fuzzy rule-based system involves four principal components: *fuzzification* interface, where the values of inputs are measured, fuzzified and the input range is mapped into the suitable universe of discourse, *knowledge base,* which involves a numeric 'database' section and a fuzzy

(linguistic) rule-base section, *fuzzy inference mechanism or engine*, which constitutes the core of the fuzzy logic control, involves the decision making logic (fuzzy reasoning such as product, max-min composition etc) and *defuzzification* interface, which maps the range of output variables into corresponding universe of discourse and defuzzifies the results of fuzzy inference mechanism,[13].

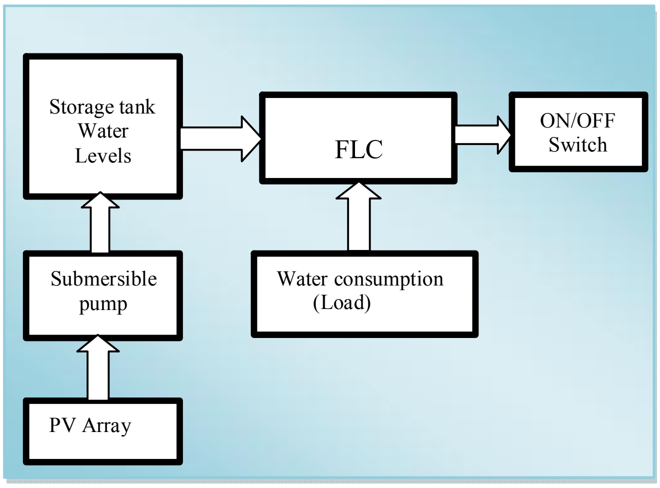


Fig.3. Synoptic of the control water management

The proposed FLC design (Figure 4) has to generate an output signal to control the ON/OFF switch of the pump in accordance of the water levels in the storage tank and the water requirement rate, represented by the input variables ST and Load, respectively. The FLC design is characterized by the main following sections:

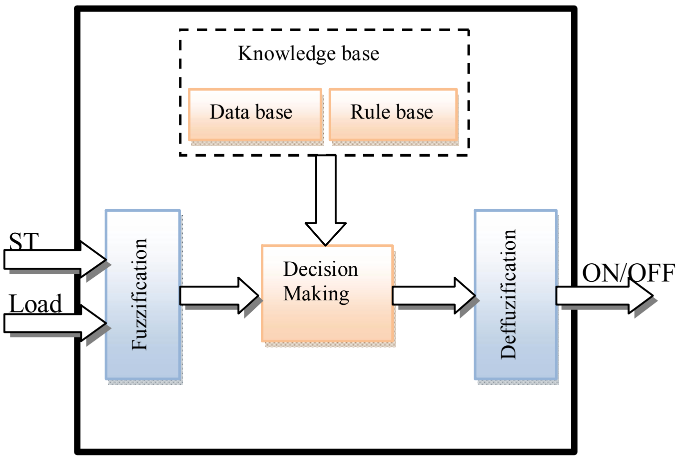


Fig.4. Fuzzy Logic Controller Design

A. Fuzzification

The Load (water consumption) and ST (storage tank) represented by the membership functions shown in (Fig.5) which are the inputs to the fuzzy logic controller, into a normalized fuzzy subset consisting of a subset (interval) for the range of the input values and a normalized membership function describing the degree of confidence of the input belonging to this range. In the fuzzification module, the input is a crisp physical signal of the real process and the ON/OFF switch output is a fuzzy subset consisting of intervals and membership functions. This output will be the input to the next module, the fuzzy logic IF-THEN rule base for the control, which requires fuzzy-subset inputs in order to be compatible with the fuzzy logic rules.

B. Interpretation of IF-Then-Rules

Knowledge based decisions, according to the input conditions of storage tank (water level) and load (water consumption), have been formulated as a fuzzy rule base as shown in (Table 1). The output result controls of the ON/OFF switch which regulates the operating period of the pump. The simulated results of a case study on a typical day are shown below. The rules that explain the working principle of our system based on Mamdani fuzzy inference system are represented in (Table 2). Since these input parameters represented by membership Functions (MFs) are to be fuzzified, Depending on the actual membership degree values, µST(a) and µLoad(b), where a and b represent the current conditions of both the storage tank (current level of water) and the load (water quantity required), The Min-Max method of fuzzification is used to set the fuzzy rules of the controller according to the equation (1),

$$\mu = (\alpha 1 \wedge \mu 1) \vee (\alpha 2 \wedge \mu 2) \quad (1)$$

C Defuzzification

The defuzzification module is in a sense the reverse of the fuzzification module: it converts all the fuzzy terms created by the rule base of the controller to crisp terms (numerical values) and then sends them to the physical system (process), so as to execute the control of the system,[14]. The defuzzification module performs the following functions similarly; since the ON/OFF switch of pump operating control unit cannot respond directly to the fuzzy controls, [8] the fuzzy control sets generated by the fuzzy algorithm have to be converted to crisp values by using the method of defuzzification. Subsequently, the approximate centre of gravity (COG) method, supposed to be the most accurate method to get a crisp value is used for the defuzzification, as shown in equation (2)

$$\mu_{ON/OFF} = COG = (\sum w_i \ \mu(i))/\sum\mu_i \qquad (2)$$

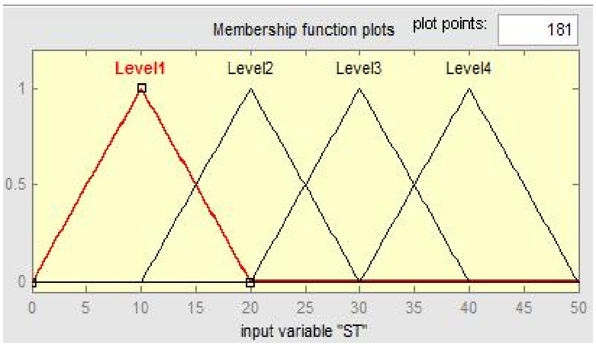
Where, µi = action dictated by the ith rule
µ(i)= truth value of rule

V. METHODOLOGY

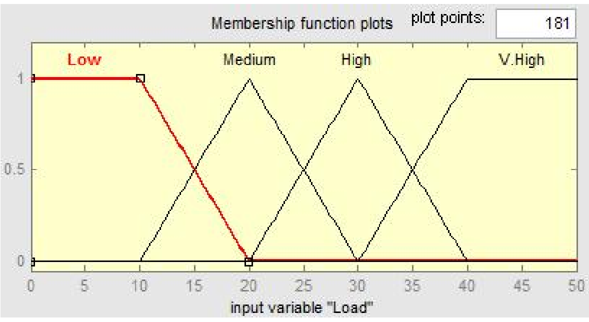
A. *Data base of Input/output variables*

A1. Input variables:

First input variable "ST level"
-Name: Storage water levels
-Universe of discourse: [0 50m^3]
-Fuzzy sub set linguistic variables:
{Level1[0 20],Level2[10 30],level3[20 40],Level4[30 50]}
-Membership Functions:



Second input variable "Load"
-Name: Water rate requirement
-Universe of discourse: [0 50m^3]
-Fuzzy sub set linguistic variables:
{Low[0 20],Medium[10 30],High[20 40],V.high[30 50]}
-Membership Functions:



A2. Output variable:
-Output variable "ON/OFF switch"
-Name: ON/OFF switch of operating the pump
-Universe of discourse: [0 1]
-Fuzzy sub set linguistic variables:
{ON[0 0.7],OFF[0.5 1]}
-Membership Functions:

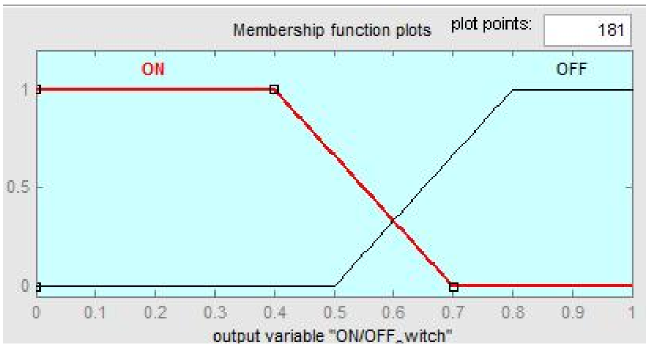


Fig.4.Membership functions for (a) storage tank, (b) load (water consumption), (c) output i.e. control of ON/OFF switch of the pump

B. *Fuzzy rules*

……..ST Load	Level1	Level2	Level3	Level4
Low	ON (R1)	OFF (R5)	OFF (R9)	OFF (R13)
Medium	ON (R2)	ON (R6)	OFF (R10)	OFF (R14)
High	ON (R3)	ON (R7)	ON (R11)	OFF (R15)
V.High	ON (R4)	ON (R8)	ON (R12)	ON (R16)

TABLE 1.Output fuzzy rule (FLC output)

R1	If ST is Level1 And Load is Low Then Switch is ON
R2	If ST is Level1 And Load is Medium Then Switch is ON
R3	If ST is Level1 And Load is High Then Switch is ON
R4	If ST is Level1 And Load is Very High Then Switch is ON
R5	If ST is Level2 And Load is Low Then Switch is OFF
R6	If ST is Level2 And Load is Medium Then Switch is ON
R7	If ST is Level2 And Load is High Then Switch is OFF
R8	If ST is Level2 And Load is Very High Then Switch is ON
R9	If ST is Level3 And Load is Low Then Switch is OFF
R10	If ST is Level3 And Load is Medium Then Switch is OFF
R11	If ST is Level3 And Load is High Then Switch is ON
R12	If ST is Level3 And Load is Very High Then Switch is ON
R13	If ST is Level4 And Load is Low Then Switch is OFF
R14	If ST is Level4 And Load is Medium Then Switch is OFF
R15	If ST is Level4 And Load is High Then Switch is OFF
R16	If ST is Level4 And Load is Very High Then Switch is ON

TABLE 2. If Then inference rules

C. *Simulation Results:*

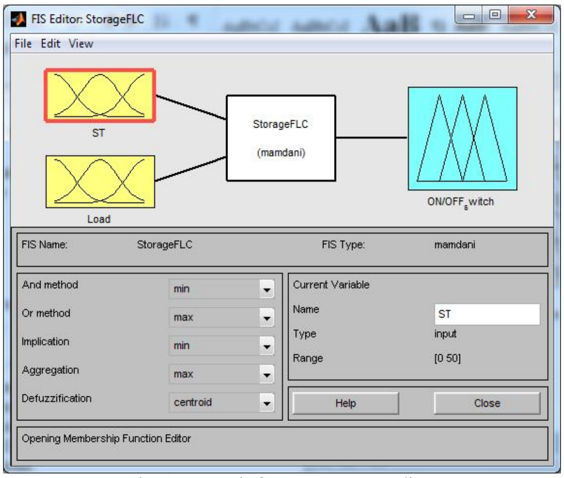


Fig.6. Fuzzy inference system editor

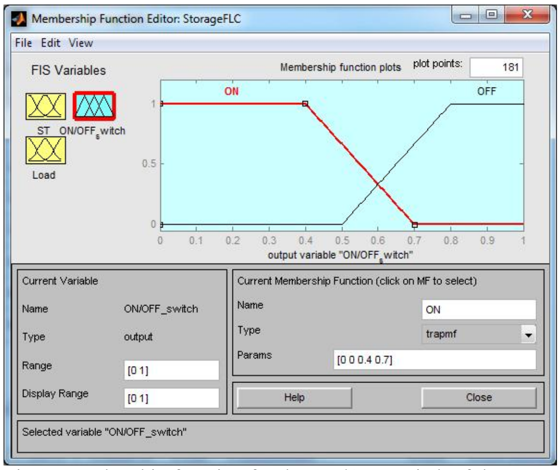


Fig.9. Membership function for the ON/OFF switch of the pump

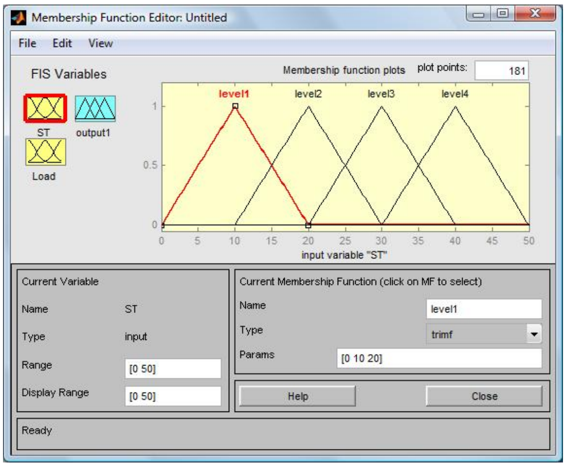


Fig.7. Membership function for the storage levels (ST)

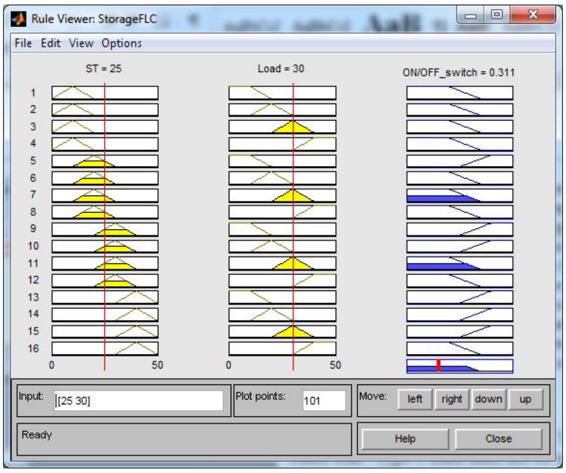


Fig.10. Rule viewer

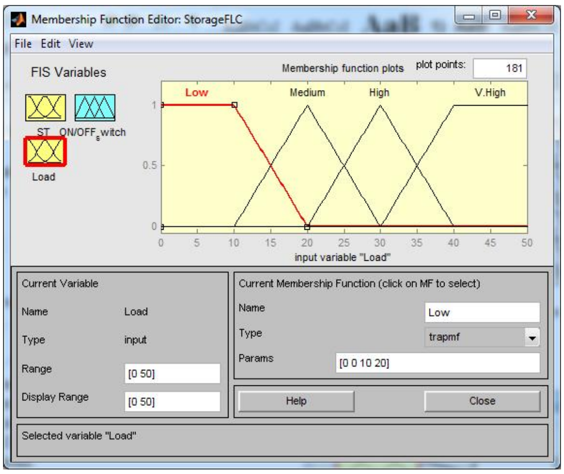


Fig.8. Membership function for the load (Load)

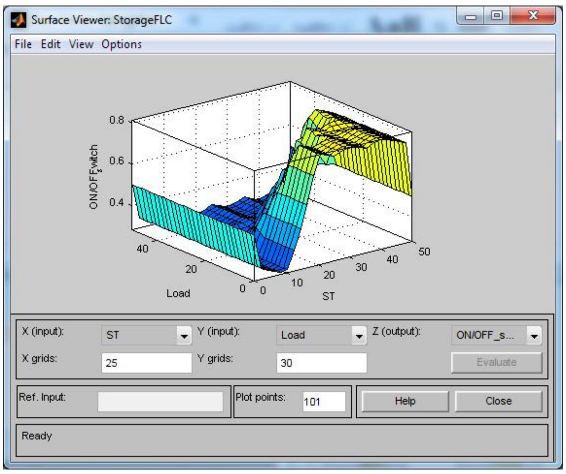


Fig.11. Surface viewer

VI. CONCLUSION

The Fuzzy Logic Controller (FLC) was successfully applied for reproducing optimal control management for water levels of storage tank and water requirement, in a PV pumping system. The purpose is to operate the pump whenever is needed to extract the water upon the user's requirement. The main consequence is to maintain the ground water level. As the rate of ground water extraction is more than its replenishment, the ground level of water may be decreasing, and then it causes a damage of the pump. The storage tank is previously filled. But in circumstances when water in reservoir is either not available or it is insufficient to meet the demand for water at any instant, the submersible pump is operated automatically to fill water in the storage tank as per the user's requirement. In this way, we are conserving the water with no wastage of water, maintaining the ground water table, preventing damage to pump and also saving more energy. The advantages of intelligent controllers are in their robustness and ability to reproduce the centralized behavior of control actions by using the easily measurable local information.

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